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PERFORMANCE ANALYSIS OF EAHE FOR DIFFERENT PIPE GEOMETRIES AND PIPE MATERIALS USING CFD

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ABSTRACT

The study investigates the thermal performance of Earth air Heat Exchanger (EAHE) for heating and cooling modes under Indian climatic conditions. A 3-dimensional, double precision computational fluid dynamics (CFD) model is developed in Ansys FLUENT v15.0 under steady conditions for three different pipe materials and four different pipe geometries. The pipe geometries considered for the study are round; square; triangle and triangular-corrugated and the pipe materials considered are Aluminium and Steel. This paper aims to find the appropriate pipe geometry and pipe material to obtain optimum temperature variation for thermal comfort. The impact of ambient temperature, mass flow rate, Reynolds Number, Prandtl number and Nussult number were studied. Results show that as the length of the pipe increases the temperature at the outlet decreases during cooling mode and vice versa. The maximum temperature drop observed is 12.05K during cooling mode and 16.65K during heating mode for triangular-corrugated pipe. This was observed by varying the mass flow rate and without considering the pipe material. Whereas Reynolds number decreases with increases in the temperature drop for corrugated pipe irrespective of the modes and pipe material. The maximum temperature drops around 13.62K at Reynolds number 38.664. Furthermore, out of the two different pipe materials the maximum temperature drop was observed for corrugated pipe in case of aluminum pipe material when compared with steel at 2m/s. It can be concluded that corrugated aluminum pipes can be used to get optimum temperature drop for better thermal comfort. Moreover, as the mass flow rate increases, the outlet temperature increases during cooling modes and vice versa during heating mode irrespective of the pipe materials and pipe cross sections.

KEYWORDS: EAHE, CFD Simulations, Corrugated Geometry, Pipe Materials, Heat Transfer, Temperature Variation.

Minimization of high grade energy and promoting renewable energy has become an important aspect in today's world. The Renewable Energy Source (RES) supply only 14% out of the total energy used in the world [Panwar et. al., 2011], [UNDP, 2000]. In developing countries such as Russia, USA etc. has already introduced many RES technologies to minimize the use conventional high grade energies. One such RES technology is the EAHE technology which uses earth's energy captured beneath the ground which is known as geothermal energy. This technology has its found applications in space heating/cooling, green houses and also can be used domestically in residential buildings. Heating/cooling of air with EAHE is a passive way to reduce the heat losses due to ventilation and thermal comfort in buildings. EAHE is a non-conventional technology that utilizes the underground soil temperature which remains constant at a depth of 2.5– 3m [Ozgener, 2011],[Peretti et. al., 2013]. In the history the use of wind towers and underground air tunnels has been found that were used for cooling and heating by the Iranian architects in 3000 B.C. [Ozgener, 2011]. The principle of EAHE is that it captures/ dissipates the heat from the ground. A network of pipes is buried into the ground at a depth of 2.5– 3 m with one end acting as inlet. The air travels through the pipes and exchanges heat by conduction and convection. The heat is conducted to the surrounding through the pipe thickness and convected through the internal surface [Peretti et. al., 2013]. The schematic diagram of EAHE system is shown in figure 1. During summers the outside temperature is higher vice versa during winters but the underground soil temperature remains constant for both seasons [Kumar et. al., 2015].

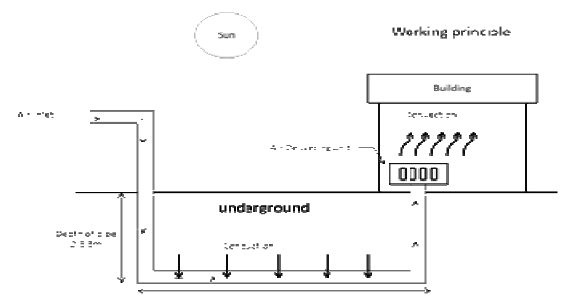

Figure 1: Schematic diagram of EAHE

The EAHX system has been designed on the basis of three configurations. The three configurations are the open loop system, the closed loop system and the hybrid system [Dhruw et. al., 2015],[Chaturvedi and Bartaria, 2015]. The basic principle for all the systems is similar. The schematic diagram of open loop in closed loop system is shown in figure 2 and 3. Researchers like Sikarwar, 2014 investigated the performance of EAHE system by coupling it with air conditioner. The results indicated that under extreme summer and winter seasons, EAHE was feasible with an air conditioner as it reduces the power consumption. Jakhar et al., 2015 evaluate the heating potential of

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EAHE with or without solar air heating duct. The results of the experiment conclude that at a depth of 3.7 m and length of 34 m, optimum outlet temperature can be achieved. Thus, the hybrid systems are beneficial to use in order to achieve better efficiency and reduce energy consumptions.

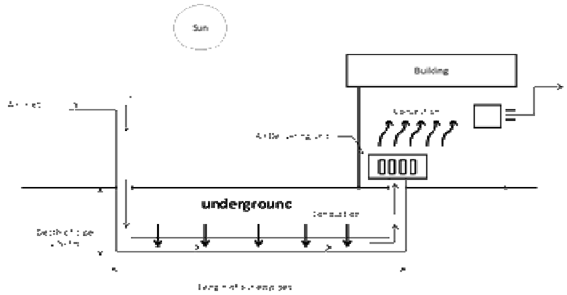


Figure 2: Schematic Diagram for Open Loop EAHE system

The EAHE performance depends on the length of pipe, diameter of the pipe, soil characteristics, moisture content, temperature difference between earth and ambient air etc. [Ozgener, 2011], [Kumar et. al., 2015], [Bisoniya et. al., 2015]. The pipe materials should have high thermal conductivity like mild steel, concrete pipes, Polyvinylchloride (PVC) pipes, High Density Polyethylene (HDPE) pipes etc. depending on the soil characteristics [Sobti and Singh, 2015]. The soil temperature beneath the ground depends on the soil characteristics and climatic condition of a certain place [Florides and Kalogirou, 2007]. The EAHE systems have several advantages over the conventional system. In the EAHE systems air is generally as the working fluid. No refrigerants or compressors are used only natural fluids such as air, water etc. are used thus causing less harm to the environment. This passive technique consumes lesser power than conventional system. It has been observed from literature that EAHE save about 50% more energy than Air conditioner (AC). Since it is a renewable source of energy it requires less maintenance. From designing point of view the design is very simple thus can be adapted in residential house for thermal comfort without the use of AC. The main disadvantage of EAHE is that the installation cost is high but it is durable for more than 20 years. As the outside air is directly pumped into the underground pipes, condensation occurs inside the pipes and also leads to growth of microorganisms inside the pipes. The condensation problem can be overcome by installing small submersible pumps that pumps the condensed water from the pipes. A ventilation system generally used with EAHE system. The EAHE system undergoes conduction as well as convection. In some cases, for the delivery of the air (convection) fans are used, these fans produce high sound which affects the occupants in the space.

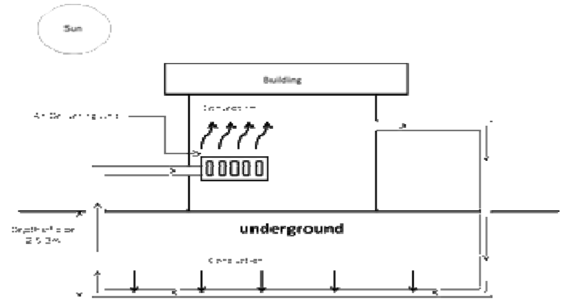


Figure 3: Schematic Diagram for Closed Loop EAHE system

To design an EAHX system, selection of the correct model, determination of the accurate soil characteristics, depth of the water table and rock bed, moisture content, geographical availability of a certain place is very essential. The design parameters are to be considered very precisely to get the optimum efficiency in EAHE systems.

LITERATURE REVIEW

The air conditioning systems are generally used in building, offices; etc. to maintain thermal comfort during different seasons. This system consumes a large amount of energy and also releases CFCs which depletes the ozone layer of the earth. The United Nations Framework Convention on Climate Change (UNFCCC) introduced the Kyoto Protocol that aims to reduce the greenhouse gases emissions [Mongkon et. al., 2013], [De Paepe and Janssens, 2003]. Nowadays passive techniques are introduced to reduce the energy consumption rate, one such passive technique is EAHE system. The usage of EAHE system has been seen in different climates such as moderate climate of India, tropical climate of Brazil, Mediterranean climate, hot and humid climate of Sahara, cold climate of Australia. It has been observed that several analytical and experimental research are in progress in order to identify influence of design parameters on the EAHE systems. These researches aim in obtaining the optimum configuration for the EAHE system so that it can be an alternative to conventional air conditioning systems in the years to come. This literature includes some of the analytical and experimental researches that considered the influence of pipe material, pipe geometry, mass flow rate, seasons etc. to enhance the performance of EAHE systems. Researchers like Serageldin et al., 2016 studied the soil temperature distribution for Egyptian weather conditions. The results indicate that the inlet temperature depends on ambient temperature and outlet temperature as the convective heat transfer has less influence than conductive heat transfer. Also, it was found that when the pipe length was increased, the temperature inside the pipe along the length increases but decreases at the outlet due to heat losses to the surrounding. The CFD simulation results show that the temperature increases with depth during winters and vice versa. The results from the parametric study show that as the pipe diameter was increased the air temperature decreases, thus decreasing the convective heat transfer. The outlet temperature variation for 3 different pipe materials shows that the outlet temperatures for all materials were almost similar. Thus, the pipe material has very less effect on the performance of EAHE.

Aziah et al., 2014 investigated different pipe materials to find the appropriate pipe material to obtain the optimum air temperature for achieving thermal comfort. The performances of three pipe materials system such as single pipe material, hybrid pipes and insulated hybrid pipes system were investigated. The test 1 was performed to standardise the factors for the 3 simulations. In Test 2, the 4 different pipe materials were evaluated as the pipes for clay and concrete were not available, they were eliminated. The results from the study indicate polyethylene pipes can be used to obtain optimum temperature drop in EAHE system. The results of test 3 indicate that combination of metal and non-metal materials shows better reduction in temperature. The results of test 4 indicate that metal+non-metal shows better results but using non-metal+non-metal pipe such as (Polyethylene + Polyethylene) (PE + PE) can also be an alternative pipe material as they are more durable and cheaper. The simulation results of 4B show, this combination provides better air flow and temperature difference.

Kumar et al., 2003 studied the numerical techniques to investigate the performance of EAHE system. The results were validated against the experimental data of a similar tunnel in Mathura (India). The results of the study indicate that when the length and flow rate was decreased the outlet temperature increases and decreases respectively. Also, when the radius of the pipe was increased, the outlet temperature was increased but convective heat transfer coefficient was lowered. Thus, can be concluded that longer tunnel length is efficient for more cooling energy saving. Thus, it was concluded that by using larger diameter pipe large outlet temperature can be achieved.

Jakhar et al., 2016 used TRNSYS v17.0 to investigate the operating temperature of Photovoltaic panels (PV). In the study three types of pipes materials were considered. On taking the pipe material into consideration there was a temperature variation of +1.61°C between the three materials. Thus, the pipe material does not affect the performance of EAHE. But when the mass flow rate was increased the outlet temperature, Reynolds number and Nussult number was increased. Thus, mass flow rate affects the outlet temperature, Reynolds number and Nussult number.

Singh, 2015 determined the heating and cooling loads of a classroom by designing a metallic EAHE system. The ducts had a combination of round cross section PVC pipes and square cross section Iron pipes. The results show that there was a change in the temperature profile at the outlet of the metallic section. The air in the central portion was warmer than the air near the boundary layer by 2°C as the inner part gets less convected. The prototype showed that the Coefficient of Performance [COP] was summer season which was more than in winter season. Thus, it can be concluded that the EAHE is more useful during summer season than in winter season for the climate of Punjab.

Abbaspour-Fard et al., 2011 aims to evaluate the effect of parameters such as burial depth, pipe length, air velocity, pipe material. Results show that 3.8°C (heating mode) and 36.5°C (cooling mode). It was also seen that the differential temperature of galvanised pipe is more than PVC because the heat transfer coefficient of galvanised pipe is more than PVC when pipe material was taken into consideration. There is no significant affect seen in case of material of the pipe as pipe material does not vary the temperature.

Hatraf et al., estimate the depth of the pipe by studying the soil ground temperature profile. A comparison was made between the simulated and experimental results by considering different flow rates at 100, 150 and 200m3/s. The results show that the air flow affects the performance. The results also indicate that the Nussult number increases with the increase in Reynolds number. Thus, the Nussult number is a function of Reynolds number.

Dubey and Bhagoria, 2013 parallel connected 3 horizontal pipes in an open loop EAHE system to find cooling rate during summer season. The pipes were in parallel connection has a common intake and exhaust manifold of air passage. The results show that there was decrease in the temperature and COP of the system as the velocity was increased. Thus, it can be concluded that the velocity of air flow affects the performance of the system.

Choudhury and Mishra, 2014 investigated an experimental study in Arunachal Pradesh of open loop EAHE system. The design was made using low cost material like Bamboos and hydra form plaster to reduce energy consumption. The study mainly focuses on the use of locally available materials. The thermal conductivity of bamboo was increased by using hydra form plaster. The results show that the maximum humidity recorded was 98% on using this pipe material. The variation of outlet temperature with air flow velocity was also observed. It was seen that using of bamboo with hydra form plaster in the tunnel, reduces the outlet temperature by 10-15°C thus reducing the electricity consumption. Thus, this type of tunnel configuration is very effective for agricultural and residential buildings. Thus, from the literature it can be clearly noted that the parameters such as velocity of pipe, length of the pipe, material of the pipe, pipe geometries etc. are responsible in increasing/decreasing the outlet temperature in order to achieve thermal comfort. It has also been observed that CFD is a very productive tool for predicting the thermal performance of EAHE.

MODELLING THE EAHE FOR CFD SIMULATION

The CFD software Ansys FLUENT v15.0 is used to investigate the airflow within the pipe in the EAHE system. Ansys FLUENT is computational fluid dynamics software used to solve turbulence, flow models, heat transfer etc. This software provides the user a continuous stream of data which in turn helps the user to depict accurate results for the analysis. This study considers four different pipe geometries and three different pipe materials to evaluate the appropriate pipe geometry and material in order to obtain optimum thermal comfort. In this study, the CFD simulations have been employed to study the temperature contours to fulfill the above-mentioned objective.

Pipe geometries and Pipe Materials

The geometries and pipe materials considered are discussed in details for better understanding of the study.

Pipe Geometries

- Circular geometry: The most conventional pipe geometry generally found in the market is of circular cross section.

Thus, considering the geometry as base geometry. Most of the in-ground heat exchangers possess circular cross section pipes. All the CFD simulations are done for 1m long pipe having same hydraulic diameter.

- Square geometry: The square geometry is considered to analyze the performance of the pipes as earth tube. But this geometry is recommended for earth tube heat exchangers.
- Triangular geometry: The triangular geometry provides high ratio of heat transfer area to overall volume. Thus, this geometry is important when compactness is required. But this provides less heat transfer rate. Thus, this geometry can be used to minimize the heat transfer rate.
- Triangular corrugated geometry: This is a special type of pipe geometry which is generally used by civil engineers which are generally installed at constricted areas. This pipe geometry provides more heat transfer rates than conventional pipe geometries. These corrugations are introduced on the inner surface along the length of the pipe to increases the heat transfer. These corrugations also help in the formation of eddy. As air flows along the length of the pipe the velocity at the center of each corrugation varies with the velocity of the remaining sections. This variation was observed because of eddy formation at each corrugation which enhances the heat transfer. The pipe geometries are shown in figure 4.

Pipe Materials

The study considers three different pipe materials to evaluate the affect the temperature variations. In the CFD simulations air is used as the operating fluid. The thermo physical properties of the materials used in simulations are stated in table 1.

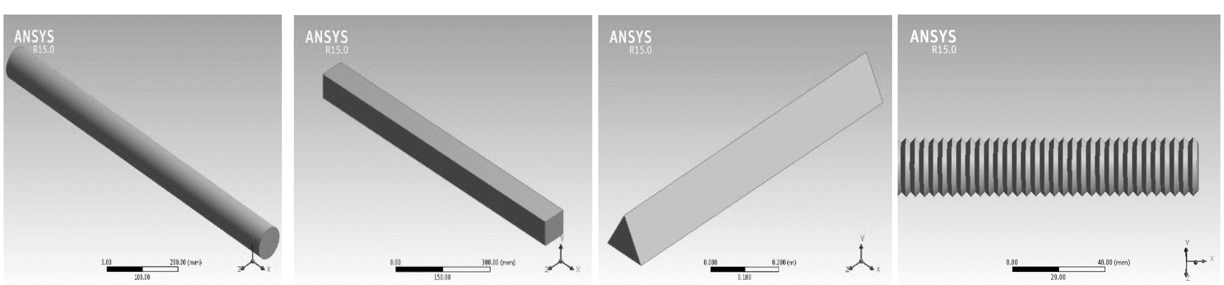


Figure 4: Pipe geometries considered for the simulation (a) Circular; (b) Square; (c) Triangular; (d) Triangular-corrugated

Table 1: Thermo-physical properties of material used in simulation

Material	Density (Kg/m^3)	Specific Heat Capacity (J/Kg K)	Thermal Conductivity (W/m K)
Air	1.225	1006	0.024
Aluminium	2719	871	202.4
Steel	7833	465	54

Assumptions

In the present study, the following assumptions are considered:

- The air is incompressible.
- The soil properties are homogenous in nature.
- The soil temperature /wall surface temperature of the pipe are 300K.
- The soil temperature is constant throughout the length.
- Hydraulic diameter and length of pipe is equal for all geometries.

Creation of geometry

A 3-dimensional model of all four geometries is created in Ansys design modeller and meshing is done using Ansys ICEM CFD. The parameters considered for the analysis are states in table 2. The aim behind creating these geometries is to maintain a constant hydraulic diameter of 80mm for all four geometries. The pipe length considered for the study is 1000 mm. The CFD model is generally connected together by a large number of points in the form of numerical grid or mesh. These grids are formed to get the values in large number points. The mesh elements can be different shapes like tetrahedral, pyramid, hexahedral etc. For the post processing of the simulation, the results were executed considering steady state, pressure based and turbulence model enabling the energy equation. The most commonly used turbulence model in the K-epsilon model. The turbulence model is selected for thermal modelling of flow having Reynolds number ranges from 4900-13000.

Boundary Conditions

The boundary conditions considered for the CFD simulations are discussed below. The boundary conditions are applied for inlet and wall to investigate the variation in the temperature at outlet. At the inlet, subsonic flow regime and medium turbulence was considered for the simulations. The uniform inlet velocity range varies between 2- 5 m/s and the inlet temperature considered was 45°C and 5°C during cooling and heating modes. The upper and lower walls of the pipe are assumed isothermal walls. The wall surface temperature considered is 27°C. For coupled heat transfer to take place the wall thickness considered is 0.001m. At the outlet of the flow regime zero-gauge pressure is considered. The fundamental fluid and heat flow equations is used in this analysis. The objective of the CFD simulation is to investigate the effect of different pipe geometries and pipe material on varying the inlet conditions for 1m length pipe.

Table 2: Table showing design and mesh information

Design Information

Geometry	Circular		Square		Triangular		Triangular-Corrugated	
Mode	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating
Inlet temperature	318K	278 K	318K	278 K	318K	278 K	318K	278 K
Hydraulic Diameter	0.08m		0.08m		0.08m		0.08m	
Length of pipe	1m		1m		1m		1m	

Mesh Information

Nodes	4212	2484	249	29559
Elements	3280	1700	160	24000
Element type	Hexahedral	Hexahedral	Hexahedral	Hexahedral

RESULTS AND DISCUSSION

The simulations results were carried out for two modes (heating and cooling) and each mode is divided into 2 phases. Phase I studied the temperature contours at different mass flow rate on different pipe geometries without the consideration of the pipe material. Phase II studied the temperature contours at different air flow rate on different pipe geometries by considering the different pipe materials.

Cooling mode

The cooling mode refers to summer season and the study carried out for Indian climatic conditions the outside temperature/ inlet for the EAHE system is

45°C (318K). Based on the literature the results excepted at the outlet of the pipe should be less than the inlet temperature. The results for phase I were evaluated by varying the mass flow rate from 2-5m/s along the length of 1m. This was done to find the appropriate pipe geometry that gives maximum temperature drop. The temperature variation along the length at different the velocities for all the pipe geometries were studied. Simulation results indicates a drop-in outlet temperature with increase in velocity as shown in table 3. The maximum temperature drop was 305.994K observed for triangular-corrugated pipes at 5m/s. From figure 5(a) it was observed that at mass flow rate 0.000757 kg/s, the maximum temperature drop observed was 12.06K for triangular corrugated geometry. Thus, corrugated geometry pipes can be used in buildings to achieve thermal comfort in summer season.

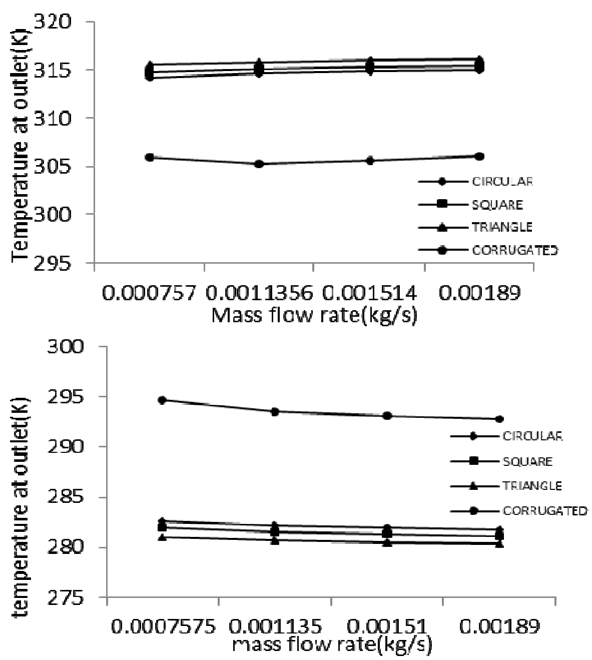


Figure 5: Temperature drop verses Mass flow rate (a) Cooling mode (b) Heating mode

In Phase II, the evaluation was done for all pipe geometries considering the pipe materials by varying the velocity for 2-5m/s. The maximum temperature at the outlet was 304.376 K observed for aluminium triangular corrugated pipe at 2m/s. Whereas on considering the two pipe materials the temperature drops ranges between 0.02-0.03 for round, 0.0015-0.002 for square, 0.0007-0.001 for triangular, 0.003-0.007 for triangular corrugated when the velocity was increased from 2-5m/s. Thus, the pipe material has very less impact on the temperature variation. It has also been observed that the Reynolds number varies with the change in temperature. It has been seen from the figure 6(a) that the Reynolds number increases as the temperature drop decreases. Thus, the Reynolds number is a function of the outlet temperature irrespective of the pipe materials. Moreover, Nussult number is a function of Reynolds number and Prandtl number but it has been observed that the Nussult number increases with increase in velocity. However, for circular geometry pipe the Nussult number was increased from -527.64 to -1054 with increase in the velocity from 2 to 3m/s, same variation pattern has been observed for the remaining geometries. Also at 5m/s the Nussult number for Aluminium pipe material was -1054 and for Steel pipe material was 1051.36, the Nussult number for Steel is less than Aluminium. Hence the Nussult number is a function of velocity and pipe material. From figure 6(b) it is observed that as the Prandtl number increases the Nussult number also increases. For both the pipe material the maximum variation of the Prandtl number and Nussult number was observed for triangular pipe geometry.

In cooling mode, the maximum temperature difference was for triangular corrugated pipe geometry and in case of the pipe materials both the materials have very small temperature difference on comparing with one another. Thus, the pipe materials do not affect the temperature variation to a large extent.

Table 3: Temperature variation for Phase I in cooling mode

Geometry	Inlet	2 m/s	3 m/s	4 m/s	5 m/s
Circular	318K	314.223	314.5824	314.8078	314.9688
Square		314.7822	315.0979	315.296	315.439
Triangular		315.55	315.804	315.964	316.0778
Triangular-corrugated		305.9403	305.298	305.6409	305.994

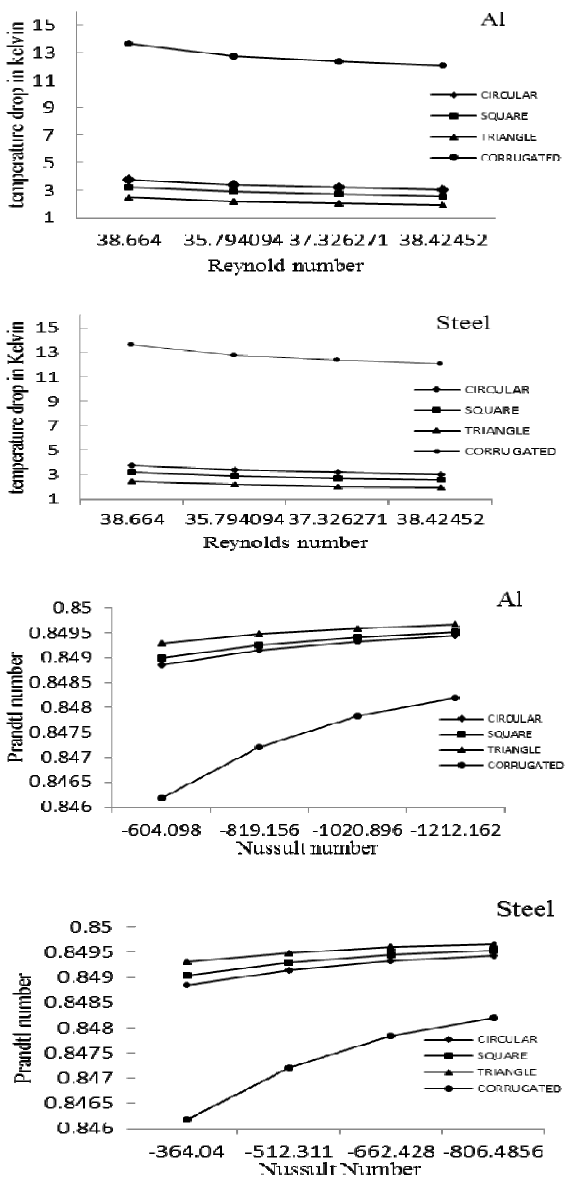
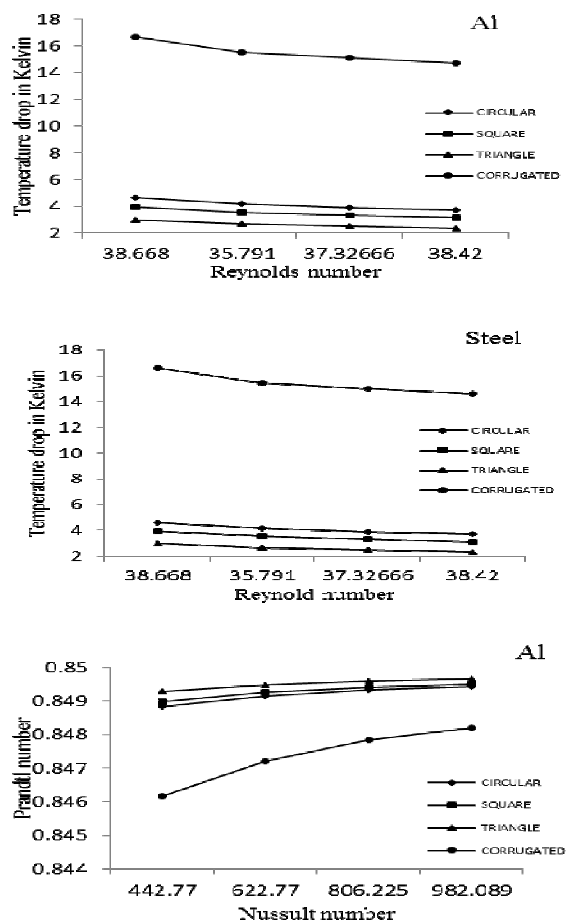


Figure 6: Temperature variation in cooling mode (a) Temperature drop and Reynolds Number, (b) Prandtl Number and Nussult Number

Heating Mode

The heating mode refers to winter season. The inlet temperature considered is 5°C (278K) and the temperature variation is evaluated by varying the velocity from 2-5m/s. The results for Phase I was obtained by varying the velocity for 2-5m/s as in cooling mode. The outlet temperature decreases with increase in velocity as shown in table 4. The maximum temperature observed was 294.65K at 2m/s which completely adverse of the cooling mode. The variation of mass flow rate with temperature drop was also studied. From figure 5(b) it was observed that for maximum temperature drop was 16.652 K at a mass flow rate of 0.0007575 kg/s for triangular corrugated pipe. For Phase II, the results were evaluated for all the pipe geometries considering the pipe material. At different velocities temperature at outlet is evaluated for the two materials and Aluminium Corrugated pipes resulted in maximum outlet temperature of 294.648K at 2m/s. The outlet temperature was higher than the inlet temperature by 16.648K. Thus, lower velocities result in higher temperature drop during heating mode. When temperature drop between the two pipe materials were compared there was about 0.0016-0.011K for circular, 0.002-0.003K for square, 0.001-0.002K for triangular, 0.043-0.096K for triangular-corrugated were obtained. Hence the pipe material does not show significant difference in the temperature variation. As stated earlier Reynolds Number is a function of outlet temperature, in heating mode the variation of Reynolds number increases with decrease in the outlet temperature. In figure 7(a) shows that as the temperature drop decreases the Reynolds number increases irrespective of the pipe material. Whereas Nussult number vary in the same manner as that in cooling mode as shown in figure 7(b). Thus, pipe material does not significant effect on the temperature variation during heating mode.



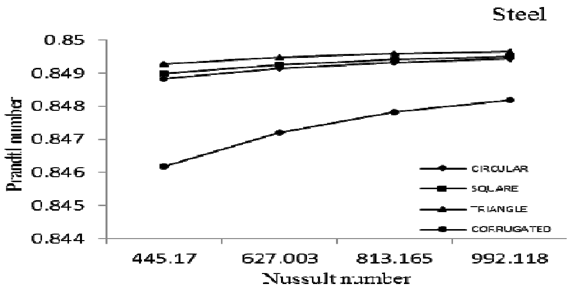


Figure 7: Temperature variation in heating mode (a) Temperature drop and Reynolds Number, (b) Prandtl Number and Nussult Number

Out of the two pipe materials the aluminium pipe material with triangular-corrugated pipe geometry provides more temperature drop than the steel pipe materials. This is because the aluminium pipe material has higher ability to conduct heat as it has high thermal conductivity than steel. When the outlet temperature was observed precisely for different velocities, it was found that the temperature at outlet did not vary to a large extend for both the materials. Thus, on establishing an experimental setup for EAHE, cheaper pipe materials can be used.

Table 4: Temperature variation for Phase I in Heating Mode

Geometry	Inlet	2 m/s	3 m/s	4 m/s	5 m/s
Circular	278 K	282.6162	282.175	281.901	281.7
Square		281.932	281.547	281.3042	281.13
Triangular		280.9945	280.6839	280.4884	280.3494
Triangular-corrugated		294.6521	293.524	293.1056	292.734

CONCLUSION

There are various passive cooling techniques and strategies that are nowadays integrated in buildings to reduce energy consumption. There are various passive techniques like solar heater, wind tower etc. that are already been utilized in the last decade but not much has been explored in EAHE system. This paper intends to study the temperature reduction for the two modes. This paper was commenced to investigate the optimum pipe geometry and pipe material to be used for future experimental setups. The use of most commonly used computational software Ansys FLUENT for the simulations to investigate the variations. Four different pipe geometry and two different pipe materials were considered. The outcome reveals that there was not much difference in terms of temperature variation between two materials. However, a meaningful difference was observed in case of pipe geometries.

Based on the results obtained from the CFD simulations we can establish that the pipe geometry affects the temperature variation whereas pipe material does not show any significant effect on the temperature variation. In Phase I the maximum temperature at outlet was 305.94K (32.94°C) observed during cooling mode and 294.65K (21.65°C) during heating mode for triangular-corrugated pipe geometry. Again, in Phase II the maximum temperature drop was observed for aluminium material having corrugated geometry during both the modes. On analysing the results, it was found the outlet temperature increases with increase in the velocity. Also affirms that the outlet temperature also depends on the pipe geometry and pipe materials have very less significance in temperature variation. This study thus reasserts the objective that for obtaining the optimum temperature variation aluminium corrugated pipes can be used. For future experimental studies, cheaper pipe materials with corrugations can help the researchers in establishing relation with the other parameters.

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