A COMPUTATIONAL STUDY ON THE PERFORMANCE OF EARTH AIR HEAT EXCHANGER (EAHE) USING DIFFERENT DUCT GEOMETRIES AND MATERIAL COMBINATIONS

Dissertation-II

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MECHANICAL ENGINEERING

By

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CERTIFICATE

I hereby certify that the work being presented in the dissertation entitled ***"A computational study on the performance of Earth Air heat exchanger (EAHE) using different duct geometries and material combination"*** in partial fulfilment of the requirement of the award of the Degree of master of technology and submitted to the Department of Mechanical Engineering of Lovely Professional University, Phagwara, is an authentic record of my own work carried out under the supervision of ***(Aashish Sharma, Assistant Professor)*** Department of Mechanical Engineering, Lovely Professional University. The matter embodied in this dissertation has not been submitted in part or full to any other University or Institute for the award of any degree.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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______The external viva-voce examination of the student was held on successfully __________

Signature of Examiner

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ABSTRACT

The implementation of passive technology in buildings for space heating and cooling to reduce the energy consumption is relatively new in Indian climatic conditions. This technology is known as Earth Air Heat Exchanger (EAHE) system. Although, various studies have been conducted in India of EAHE but minimum studies have been conducted considering the cross-sectional geometry of the pipe. Studies of the researchers in India were limited to the investigation of the potential and variable affecting the performance of EAHE. This study aims in investigating the appropriate pipe geometry that will anticipate the optimum temperature reduction through Computational Fluid Dynamics (CFD) for achieving thermal comfort. For the investigation of four different pipe geometries and four pipe materials this paper utilizes Ansys FLUENT v15.0. software. Through thorough investigation of the study it was found that the triangular-corrugated pipe showed best temperature reduction during summers as well as winter season. Further enumeration also results that EAHE system is beneficial to use during both the seasons in Indian climatic conditions.

TERMINOLOGY

Nomenclature

EAHE	Earth Air Heat Exchanger
HETS/HEAHE	Horizontal Earth Air Heat Exchanger System
ATEHE	Air-to-Earth Heat Exchanger
RES	Renewable Energy Sources
MOE	Ministry of Environment
CFC	Chlorofluorocarbon
HVAC	Heating, Ventilation and Air conditioning
SAHD	Solar Air Heating Duct
PV	Photovoltaic
PID	Proportional Integral Derivative
CFD	Computational Fluid Dynamics
FVM	Finite Volume Method
COP	Coefficient of Performance
FFT	Fast Fourier Transform
EPBT	Energy Payback time
EER	Energy Efficiency Ratio
PVC	Polyvinyl Chloride
HDPE	High Density Polyethylene
MS	Mild Steel

Units

m	meter
°C	Celsius
K	Kelvin
m/s	velocity

Subscripts

l	length
d	diameter
r	radius
i	inlet
o	outlet

1. INTRODUCTION

Energy is one of the major inputs in the economic growth of a country but energy saving is one of the major challenges in today's world. Our concern is to minimize the use of high grade energy and to promote the use of renewable energy. Out of the world's total energy demand, Renewable Energy Sources (RES) supply up to 14%[1], [2]. Renewable energy includes biomass, geothermal energy, hydropower etc.[1]. In developing countries energy sector is considered as a crucial sector, the demand for consumption is increasing than its production. India consumes more energy in residential, commercial and agricultural sectors than China, Japan, Russia etc. [3]

The consumption of energy in buildings has significantly increased in the last decade. In order to improve the energy conservation in building it has been recommended to use energy audit in buildings while construction. The governments of developing countries have initiated campaigns and amended strict laws against the consumption of energy. European countries has pledged to reduce the annual consumption of primary energy by 20% by 2020 [4]. The Japanese MOE launched a campaign that encourages the people to wear lighter clothes and for companies to set their air conditioner at 28°C [5]. In India, the government in 1977 created a body Petroleum Conservation Research Association, the motto of the body was to reduce the country's dependency on oil and gas products and to promote the conservation of Petroleum products [6]. According to the research conducted by United States department of energy, RES can be a good alternative to the non-renewable sources. Sources like solar energy, wind energy, geothermal energy and Ocean energy can be envisaged in the years. These sources have enormous potential to replace the prevailing sources if used in correct way.

The energy usage depends on temperature, humidity as its changes affect the demand of space heating or cooling. In summers, generally in commercial buildings air conditioning system are used. These systems improve the efficiency by using heat sink and are cooler than the standard air. Heating / cooling of air with Earth Air Heat Exchanger (EAHE) is a passive way to reduce the heat losses due to ventilation and thermal comfort in buildings. This system uses geothermal energy by burying a network of pipes of different combination installed in open spaces or beneath the building at a certain depth [7].

1.1 Earth Air Heat Exchanger (EAHE)

Depending on the current scenario, energy saving has become one of the important element for the economic growth countries like US, Russia, India etc. have been taking initiatives to save energy. EAHE is a new passive technology efficient to save energy which has been used by many countries for achieving thermal comfort in buildings. EAHE is a non-conventional technique that has found applications in residential buildings with air conditioning system, greenhouses, commercial buildings etc. which utilizes the underground soil temperature of earth.

In ancient times, wind towers and underground air tunnels were used for cooling and heating buildings by the Iranian architects in 3000 B.C [8]. During industrial revolution, these natural techniques faded with time. As the energy reservoir of the world is depleting fast, governments of different countries are taking initiatives to promote green energy techniques and EAHE is one such techniques.

EAHE system depends on the ambient temperature of any location [9] which can be used for both cooling and heating during summers and winter seasons. During winters the temperature underground is higher than the ambient temperature and vice versa during summers [10]. Researchers found that the underground soil temperature also known as earths undisturbed temperature remains constant at a depth of 2.5 –3m [8]. EAHE uses a network of pipes buried in ground at depth of 2.5– 3 m with one end acting as inlet for the ambient air and other as outlet. Earth is used as heat sink or source. Air enters from the inlet and continuously flows through the buried pipes. This then passes through the stable soil temperature. The temperature is either increased or decreased by conduction with underground soil. This is then delivered to the outlet maintaining a temperature difference with the ambient temperature.

In summers, the ambient temperature is around approximately 39- 45°C [11] depending on the location. The hot air flows through the buried pipes; the stable temperature of the soil cools down the temperature of the air and delivers it to the outlet. The air flowing in the building is cool air thus maintaining lower temperature inside the building than the outside temperature as shown in figure 1.

In winters, the ambient temperature is approximately 4- 9°C [11] depending on the location, the same process helps in heating the air thus maintaining a higher temperature inside the building keeping the inside environment warmer than the outside. The heat dissipated /

generated by the soil is transferred to the pipes by conduction which causes the temperature to increases / decrease inside the buried pipes [7]. For the continuous flow of air through the inlet certain mechanical devices such as fans, blowers etc. or passive systems are installed to create adequate pressure difference.

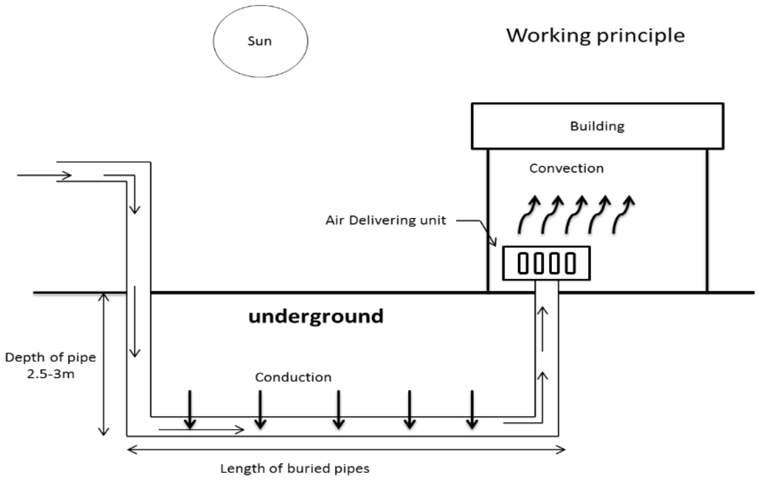

Figure 1: Working Principle of EAHE

The performance of EAHE depends on the pipe material, diameter of the pipe, length of pipe, soil characteristics, moisture content, temperature difference between earth and ambient air etc. [7], [8], [12]. The material of the pipe should have high thermal conductivity like mild steel, PVC pipes, cemented pipes etc. depending on the soil characteristics [13]. The underground soil temperature is mainly affected by the climatic condition and soil characteristics of a certain location [14].

In order to determine the undisturbed temperature of earth the soil characteristics has to be determined of any location. The effectiveness of EAHE depends on depth of the pipe installed, thermal diffusivity of the soil, length and diameter of the pipe, Ambient Temperature of a certain location, thermal conductivity of the pipe and air flow velocity[13], [9], [16], [17], [18]. It is generally seen that the effectiveness of these systems is quite high as compared to conventional HVAC system [19]. Nowadays researches have been using EAHE of configurations to study the performance and to save energy. Results showed that EAHE is an energy efficient system that can be used in lieu of our prevailing conventional system used for thermal comfort. Some researches that proved this systems compatibility with conventional systems are discussed here.

Sodha et al. [20] determined the annual cooling potential of an underground air pipe system considering the effect of length, radius and mass flow rate. The analysis was done for hot dry composite climate of Jodhpur and Delhi. Mihalakakou et al. [21] predicted the soil and air temperature below the surface considering the heat and moisture gradient in the soil. Results proposed that difference between the inlet and outlet temperature as the energy potential of the EAHE system. Ascion et al. [22] showed that in wet and humid soil having a pipe length of 50 m buried to a depth of 3 m, the best performance of a EAHE system can be achieved. Lee et al. [23] used Energyplus software and created a mathematical model form EAHE. A detailed algorithm was used to calculate the variation in the soil temperature variation for each pipe for every time step of the simulation. Thiers et al. [24] laid several pipes in parallel at the same depth. Finite volume method with limited number of meshes was used. Two concentric cylindrical meshes were used for each pipe to study the interaction between several parallel pipes laid at the same depth. One year later Tittelein et al. [25] developed a new numerical method for EAHE. It showed that heat flux entering the pipe is functions of the temperature of air flowing through the pipe. To find the outlet temperature, a heat balance equation is applied. The problem faced using the above-mentioned model was that it took longer time to calculate the behaviour of the heat exchanger accurately due to the type of mesh required. Bisoniya et al. [19] examined the EAHE system in different seasons and found that at lower air velocities there is high temperature drop irrespective of the seasons. The same was validated using a simulation model developed on Computational fluid Dynamics (CFD). Ralegaonkar et al. [26] in Nagpur India compared EAHE system with conventional system and concluded that EAHE system saves energy up to 90% as compared to conventional systems. Chaudhary et al. [27] in place of using PVC pipes or mild steel pipe he used bamboo and a plaster of soil-cement mixture. It was seen that it reduced humidity by 30-40 % and reduced outlet temperature by 30-35%. Thus, all design parameters (pipe material, diameter of the pipe, length of pipe, soil characteristics, moisture content, temperature difference between earth and ambient air etc.) contributes to the performance and to save energy.

1.2 Classification of EAHE

The EAHE systems are design on the basis of three configurations: open loop system and closed loop system and hybrid system [28], [29].

Open loop System: The ambient air is passed through the buried pipes for pre-heating or pre-cooling of air as shown in figure 2. Then the air passes through a conventional system to cool down or get warm up before entering the space. The air is then passes away through the ventilation. Woodson et al. [30] used open loop EAHE design with PVC pipes having length of 25m, diameter 125mm buried at a depth of 1.5m. The pipes were laid in serpentine pattern. It was seen the air drawn from outside reduces temperature by more than 7.5°C. The outdoor temperature varied from 25°C to 43°C and the soil temperature of 30.4°C remained the same at a depth of 1.5m.

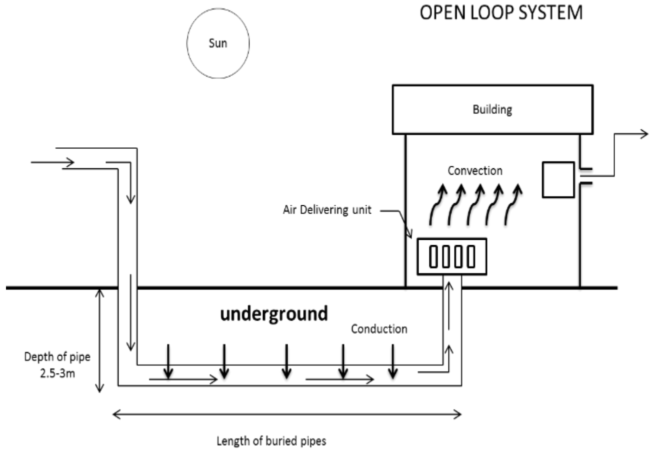

Figure 2: Open Loop System

Closed loop system: Closed loop systems are also known as earth coupled system as shown in figure 3. Air sucked from inlet travels through a loop of pipes buried underground and extracts the heat from ground [29]. The ground loops are arranged either vertically or horizontally. The vertical loops are more expensive than horizontal loop. Closed loop are efficient than open loop system. Closed loop system reduces the problem of humidity.

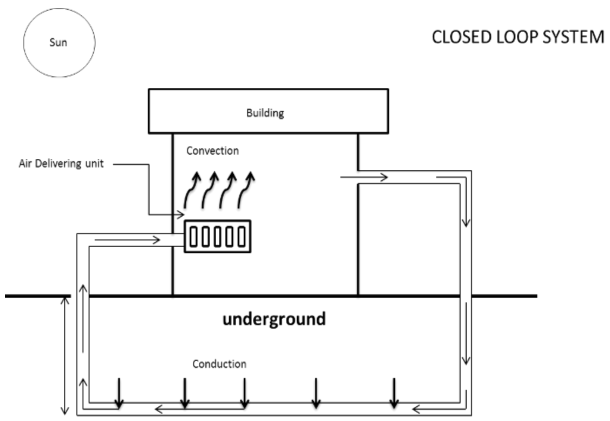

Figure 3: Closed loop System

Hybrid Systems: The EAHE is coupled with other heating/cooling devices such as air conditioner, heaters, solar chimney, solar air heaters etc. These devices improve the comfort and efficiency of the EAHE systems. Researches like Jakhar et al. [31] coupled the Earth to air heat exchanger with a solar air heating duct. The aim was to evaluate the heating potential of EAHE with or without solar air heating duct. TRNSYS 17 was used as the simulation tool. Results were validated with an experimental setup in Ajmer, India. Evaluation was done for inlet flow at different inlet temperature. The experiment was concluded that at a depth of 3.7m and length of 34m, optimum outlet temperature can be achieved. Sikarwar et al. [32] made a conjunction of the EAHE system with air conditioner to reduce the energy consumption and to improve the COP. Results showed that under extreme summer and winter seasons, ground coupled condenser is seen feasible with air conditioner. Chlela et al. [33] made a conjunction of EAHE with heat recovery balanced ventilation system to investigate the energy consumption and thermal comfort. It was found that the EAHE system reduce the energy consumption and control the CO_2 emissions and to ensure good thermal comfort. Nowadays hybrid EAHE has become one of the prominent technologies to increase the efficiency of the system.

The EAHE are also classified on the basis of pipe layout in the ground and according to mode of arrangement [9].

On the basis of pipe layout, the EAHE classified as:

- Horizontal / straight Loop
- Vertical Looped
- Slinky / spiral Looped
- Pond / Helical Looped

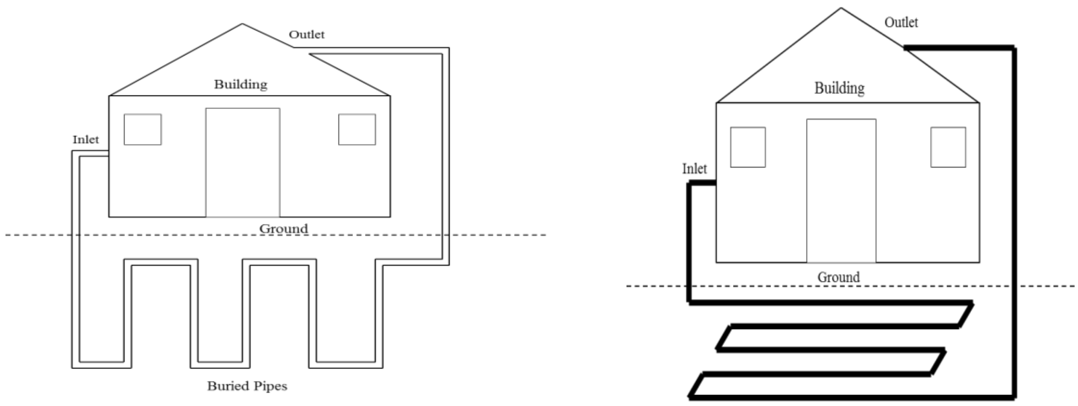

Figure 4: Horizontal Loop and Vertical Loop System

On the basis of mode of arrangement EAHE are classified as:

- One tube system

- Parallel tube system

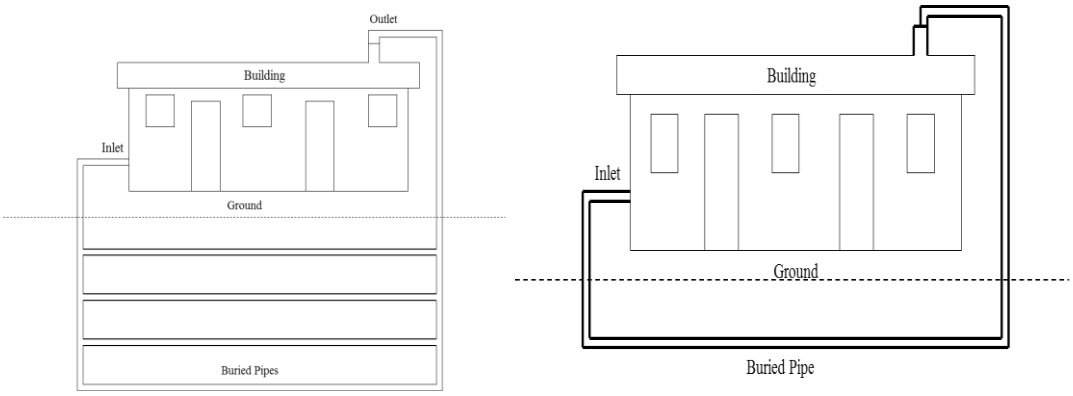

Figure 5: Parallel Tube and One Tube System

One tube system is not appropriate to meet the requirements of an air conditioning system in a building. This is because the tube is too large for the use in generation. Parallel tube systems are used as it reduces the pressure drop and increases the thermal performance of the system.

1.3 Advantages and Disadvantages of EAHE

The EAHE systems have several advantages over the conventional system. They are:[8]

1. Air is used as working fluid.
2. It consumes less energy as compared to prevailing conventional systems.
3. Design is simple hence requires less maintenance and low cost.
4. Pollution is minimized as no refrigerant or compressors are used in this system.

The disadvantages are:

1. The cost for installation is high.
2. Condensation occurs in the pipes. The condensed water can be pumped out by using a small submersible pump.
3. Convection occurs in the pipes; no uniform temperature is achieved.
4. As the refrigerant used is air, growth of microorganisms can become one of the causes to use ventilating system coupled to the system. This causes decrease in quality of air.

Thus, installation of EAHE with appropriate design parameters can be a perfect alternative to the conventional systems.

2. SCOPE OF THE STUDY

EAHE technology is an emerging technology and has many advantages over conventional systems. EAHE technology finds its application specially in space heating / cooling, greenhouses, snow melting etc. This technology can also be adapted for energy saving as it saves around 50% more energy than conventional system. Nowadays, hybrid EAHE are also used for increasing the efficiency of these systems.

Research Gap: It has been already noted that the effectiveness of EAHE depends on depth of the pipe installed, thermal diffusivity of the soil, length and diameter of the pipe, ambient temperature of a certain location, thermal conductivity of the pipe and air flow velocity. Adequate studies have already been conducted on EAHE considering the above-mentioned parameters. But least studies have been conducted considering the pipe geometry and materials. This research work focuses on the variation of temperature for different duct geometries and different pipe material.

In the literature, none of the studies suggest the variation of pipe geometry and pipe material as pipe material do not affect the performance to large extend. The pipe material does not have much effect on temperature variation as seen in literature survey. This study is a computational approach that investigates the temperature variation for different pipe material along with different duct geometries. This study may give an approximation about the appropriate duct geometries and materials that can be used in EAHE for optimum temperature reduction which can be practicable in the future experiments.

This is a new technology and not much work has been explored. Based on the energy scenario today, green energy is encouraged in developed and developing countries like USA, Russia, Germany, India etc. This EAHE technology can be a future green technology that used a sustainable source of energy like solar energy. The research is still limited in this field considering different soil parameters, different working fluids etc. One application of EAHE technology is snow melting, thus, studies can be conducted in cold areas for melting of snow and to furnish warm water during winters. Research of EAHE technology is still in budding stage, a large scope for improvement this technology is still usable for research.

3. OBJECTIVE OF THE STUDY

The objectives laid out in reference to the contention above are as:

- To study the cooling and heating potential of EAHE by utilizing four different pipe geometries and materials by virtue of temperature reduction.
- To investigate and assess the best pipe geometry and material for EAHE in Indian climatic condition by employing CFD.
- The prediction of temperature reduction and recommendation of optimum pipe geometry and pipe materials under Indian climatic conditions.
- To understand the variation of pressure (ΔP), Reynolds number (Re), Prandtl number (Pr) and Nussult number (Nu) for different pipe geometries and materials.

4. LITERATURE REVIEW

The most commonly used systems to obtain comfort in residential buildings, offices, etc. is the conventional air conditioning system. The working principle of air conditioning system is to condition the air, transport it and introduce it to conditioned space. Air conditioning system uses a large amount of energy and also causing depletion of ozone layer due to the emission of CFCs. The Kyoto Protocol given by United Nations Framework Convention on Climate Change (UNFCCC) emphasizes on the reduction the greenhouse gases emission.[34], [35]. In order to reduce the consumption of energy passive techniques are introduced in HVAC installations. One such passive technique is EAHE that uses earth as the heat sink. Air is the transfer medium for summer cooling and winter heating. When air flows through the pipes heat exchange between air and earth takes place. This concludes that the temperature at outlet is higher/lower than the ambient temperature [8].

Many ancient Greeks, Persians and Iranian Architects have used this technology indirectly [21]. Wilkinson in the 19th century designed a Barn; in order to cool the barn during summer time he buried a 500ft underground passage [36]. As mentioned earlier Iranian architects also used underground air tunnels and wind towers for passive cooling. For many decades EAHE system has been used as a conjunction with solar chimneys or with air conditioning system. EAHE system is probably the most growing alternative renewable energy in the world. With increasing demand for energy savings, places like Europe, Germany have grown its market widely in the recent years [37]. A 10% increase has been seen in installations in about 30 countries over the last 10 years. Places like South Algeria where four fifth of the land is desert which has a dry desert climate, where during summer maximum temperature rises to 45°C and during winter temperature lower below 1°C, the EAHE system cannot be used all alone [38]. Under this condition EAHE system is made conjunction with air conditioning system.

4.1 Research conducted in the other parts of the world:

Several researchers around the globe had investigated the performance of EAHE using various numerical and computational methods. The parameters for the experiments are tabulated in table 1 and 2. Fard et al. [39] in North east of Iran made a system that comprises of 2 parallel horizontal pipes. The aim of the project was to evaluate the effect of parameters such as burial depth, pipe length, air velocity, pipe material. The simulations were based on factorial design. Results show that the average relative humidity was 67% with average temperature of 3.8°C (heating mode) and average relative humidity is 14% with average temperature was 36.5°C (cooling mode). Also, the soil temperature, length of pipe increases with increases in depth for both heating and cooling mode. It was also observed that the differential temperature of galvanised pipe is more than PVC because the heat transfer coefficient of galvanised pipe is more than PVC. There is no significant affect seen in case of material of the pipe as pipe material do not vary the temperature variation.

Ozegener et al. [8] made an experimental setup with ambient temperature 18.67°C and relative humidity 48.16%. It was found that the average temperature for greenhouse was 21.5°C and relative humidity 40%. Results showed that average heating capacity obtained from the setup was 7.67 kW. Thus, concluded that an effective use of EAHE with a suitable technology is beneficial to the climate of Turkey.

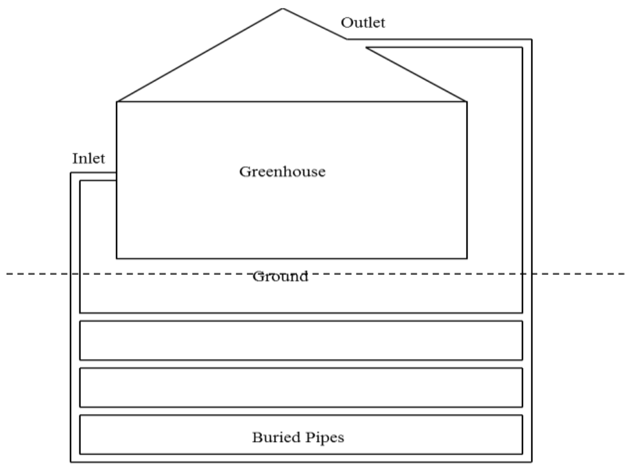

Figure 6: Schematic diagram of EAHE coupled with Greenhouse

Mongkon et al. [34] considered three seasons; winter, summer and monsoon in Chaing Mai for HETS cooling in tropical climate of Thailand. The cooling performance and condensation in pipes were evaluated. The experiment was concluded with a series of pipes placed in serpentine manner considering fully developed turbulent flow as shown in figure 6. The temperature difference between inlet and outlet is studied by regression analysis. A high temperature difference during summer season was observed. In condensation analysis, it was found that saturated temperature decreases due to the dew point temperature. The results also indicate that maximum COP was obtained during summers in comparison with other two seasons.

Table 1: Summary of analytical results studied around the world

Author	Place/Year	Season	Material	Length of pipe[m]	Diameter of pipe[m]	Depth of pipe[m]	Temperature range [°C]	Velocity range [m/s]	Temperature rise/fall [°C]	Variable	Others
Mihalakakou et al.[21]	1994	Summers	Plastic	14.8	0.15	1.1	-	10.5	17-33.5	Burial Depth	-
Santamouris et al.[46]	Athens, Greece, 1995	-	-	50	0.2	1.5	37-42.3	8	23-36	Diameter of Pipe	-
Bojic et al.[36]	Athens, Greece, 1996	Winter	PVC	50	0.15	2.4	8	-	20	Length of pipe	-
		Summer					16				-
Vaz et al.[41]	Viamas, Brazil, 2011	Summer and Winter	PVC	A:0.11		2	30	-	20	-	-
				B: 0.11		2				-	-
				C: 0.10		5	16	-	19	-	-
Su et al. [43]	2012	-	-	900	-	-	19	-	17.6	Error analysis	-
Silva et al. [42]	2013	Winter	PVC	25.77	0.11	1.0-5.0	-	-	2	Burial Depth	increase
		Summer							8		decrease
Vaz et al.[51]	Viamas, Brazil, 2014	Summer	PVC	A:0.11	-	1.6	18.8	-	12	Burial Depth	-
		Winter		B: 0.11		0.6				-	-
				C: 0.10		0.5				-	-
Ahmed et al.[52]	Queensland, Australia, 2014	-	PVC	8	0.021	-	21.01	3.4	24.61	Configuration	VEPC
									24.58	Configuration	HEPC
									23.05	Configuration	VEPC
									23.85	Configuration	HEPC
Ariffin et al. [53]	Malaysia, 2014	Summer	PVC	30	0.076	1	36.46	0.5	30.345	Material of pipe	-
			PE						30.231	Material of pipe	-
			Steel						30.248	Material of pipe	-
			Copper						30.25	Material of pipe	-
Benhammou et al.[54]	2014	Summer	PVC	-	-	2	45	-	44.991	Crossectional area	-
									44.46	Height of tower	-
Xamána et al. [55]	Mexico, 2014	Winter	-	5	0.15	10	-	-	0.5	Configuration	Mexico City
									5.8	Configuration	Marida City
									3.3	Configuration	Juarez City
Carlucci et al. [56]	2014	-	-	-	-	-	-	-	no monitored results	-	-
Mendez et al.[57]	Mexico, 2014	-	-	-	-	-	-	-	-	-	-

Author	Place/Year	Season	Material	Length of pipe[m]	Diameter of pipe[m]	Depth of pipe[m]	Temperature range [°C]	Velocity range [m/s]	Temperature rise/fall [°C]	Variable	Others
Sansui et al. [58]	Malaysia, 2014	-	-	-	-	-	21.9-34.8	-	27.2 - 30.5	Burial Depth	-
Gan et al.[59]	UK, 2015	-	HDPE	-	0.2	1.5	10	2	17.6	-	-
Xaman et al. [60]	Mexico, 2015	Winter	-	-	-	10	-	-	6.3	Reynolds number[Re=100]	Juarez City
									12.5	Reynolds number[Re=100]	Merida
									10.2	Reynolds number[Re=100]	Mexico City
		Summer	-	-	-		-		8.8	Reynolds number[Re=100]	Juarez City
									10.2	Reynolds number[Re=100]	Merida
									6.3	Reynolds number[Re=100]	Mexico City
Rodriguez et al.[51]	Viamao, Brazil 2015	-	PVC	26	-	-	-	-	-	-	-
Ahmed et al.[52]	Rockhamton, Australia, 2015	-	-	-	-	-	22.4-26.4	-	22.61-25.32	Configuration	HEAHE
									23.48-26.3	Configuration	VEAHE
Niu et al.[61]	USA,2015	-	Steel	57	0.45	3	30	-	16	Soil Temperature	-
Niu et al.[62]	USA,2015	-	-	57	0.45	3	26-34	-	15	Surface temperature	-
									13	Diameter of Pipe	-
Serageldin et al. [48]	2016	Winter	Steel and Copper(Cu)	5.5	0.0508	2	14.7	1.0-3.9	18.7	Diameter of Pipe	-
									19.9	Length of pipe	-
									19.2	Velocity of pipe	-
			PVC						19.7	Material of Pipe	-
			Steel						19.88	Material of Pipe	-
			Copper(Cu)						19.8	Material of Pipe	-
Barakat et al.[49]	2016	-	-	24.7	0.3	7	40	1.5	29	Length of pipe	-
									35.4	Diameter of Pipe	-
									30.5	Velocity of pipe	-
Ascione et al.[63]	Italy, 2016	Summer	-	50	0.3	4		-	-	-	energy demand
		Winter							-	-	

Goswami et al. [40] used plastic corrugated pipe for the experimental setup conducted in Floridas. The experiment was conducted considering the soil having high moisture content. The operating time for the EAHE system was 8-12 hours/day. A heat pump was used that circulates the air at outlet. It was observed that if air was spread uniformly throughout the tunnel COP was improved by 8%. The open loop tunnel used 14kWh of electricity during cooling period and 52kWh during heating period. Thus, indicates that the EAHE consumes less energy than conventional AC. The author also recommends the EAHE for agricultural buildings. It was also seen that the payback period was approximately 20 years. Thus, the use of multi pipe system that instead of using single pipe is more cost effective.

Vaz et al. [41] considered an experimental and numerical simulation to reduce the consumption of conventional energy. The experiment was set up in Viamas, Brazil. The numerical solution considered was solved based on FVM and turbulence and was solved with Reynolds stress model. The computational modelling was done using GAMBIT and FLUENT. The numerical solutions were validated against experimental results. The temperature variation of 3 ducts show that on moving along the length the magnitude of air temperature decreases in the same soil temperature. There was a difference of 15% with numerical model proposed during validation. Also, it was found that if the depth is more than 2m, the operating potential for heating and cooling was higher by than 8°C and 4°C respectively.

Bojic et al. [36] investigated the performance of ATEHE for summer and winter season in Athens, Greece. The space was heated by using a heater during winters and cooled by using an air conditioning system during summers. At ambient temperature of 20°C results indicate that with increase in length of pipe, the energy use ratio for building increases. It was also observed that the energy use ratio in summer days was higher than winters. In summers the expenditure for energy was 11d/MJ-s with 10 m long pipe and lowest was 7d/MJ-s on application of 2 pipes for ATEHE. The author suggests that when length of pipe L< 17m it is better to use 4 pipes instead of 2, thus making the ATEHE cheaper. The temperature at outlet was found 3 times higher in summer than winters. This clearly shows that the ATEHE is more energy saving and cheaper in summers than winters.

Mihalakakou et al. [21] predicted the thermal performance inside the tube. The model was developed within TRANSYS. The influence of temperature due to ground surface temperature at any point of the pipe was analysed. The proposed model was validated against the experimental data and was predicted the temperature of the circulated air and temperature distribution contributes to the performance of EAHE.

Silva et al. [42] modelled a computational model to predict the thermal behaviour of EAHE. The results were checked for every time step for 2 years. The soil average temperature considered was 29.1°C for the entire computation simulation and the temperature variations were checked at every point from 1-5m and was plotted at outlet. The results indicate that an increase in depth causes decrease in temperature amplitude variation because the temperature becomes constant at 3m depth. Thus, this configuration causes a decrease of 8°C in summers and increase by 2°C in winters.

Su et al. [43] developed a computational model with 1D implicit transient convection diffusion model for air temperature and humidity and 1D explicit heat conduction sub model for the rock temperature. The mass transfer coefficient is large h_d =1-5X10^{-4} kg/m^2s. On studying the results, it was found that the difference of outer temperature and humidity between 2 simulations is very small.

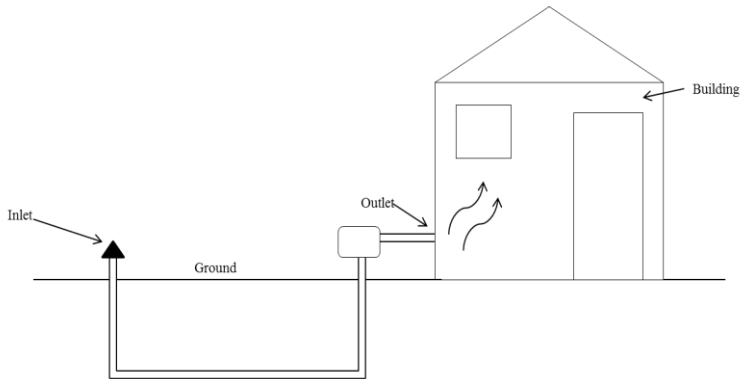

Figure 7: Schematic diagram for EAHE coupled to a building

Benhammou et al. [44] studied the thermal performance in steady state and transient condition in Algerian Sahara during July. The experimental setup shown figure 7. A new term DF was introduced by the author which is a function of length of the buried pipe. The results indicate that as the length increases, DF decreases thus temperature at the outlet increases. The study states that the outlet temperature is a function of diameter of the buried pipe. Again, as the length is increased, the mean efficiency also increases but COP is decreases. Also on studying the influence of pipe diameter, as the pipe diameter increases, COP decreases. This increase in pipe diameter reduces the pressure losses in turn increases the thermal potential but the cooling potential was reduced resulting in decrease of COP.

DF is proportional to the pipe diameter. Thus, EAHE with larger pipe diameter has more heat transfer than smaller diameter pipes.

Yang et al. [45] predicted the performance EAHE subjected to Harmonic thermal environments. The experiment was conducted in Changqing, China considering cylindrical coordinate system. Total time for the numerical simulation was t=1000s. It was found that with increase in depth the outlet temperature decreases. It was observed that the annual fluctuating amplitude decreases with depth and attains a certain value when depth exceeds 7m. Results show that the outlet temperature initially decreases then increases with increase in radius. The cooling and heating capacity are a function of outlet temperature and air flow rate. As the flow rate increases the cooling /heating capacity increases.

Santamouris et al. [46] performed a parametric analysis performed on glass greenhouse of $1000m^2$ area having 4 buried pipes in Athens, Greece. TRNSYS software was used simulation tool. A relationship between change in pipe length and outlet temperature was observed. The results show that the outlet temperature increases more during July and August but the greenhouse temperature in August was higher due to the time lag of the underground temperature which delay the temperature variation at different depths. Also, an increase in radius of pipe causes high indoor temperature and high outlet temperature because of high convective heat transfer coefficient. It was observed that the indoor temperature increases with increase in depth of the pipe but the cooling capacity increases with increase in depth. The indoor temperature also increases with increase in velocity of air. Thus, due to increase in mass flow rate, thus the outlet temperature increases.

Yassine et al. [47] coupled EAHE with mechanical ventilation system for thermal comfort of a typical house conducted in Lebanon. The study aimed the use of regional materials such as strawboard for insulation and Hempcrete to decrease buildings embodied and operational energy. The author used PID (Proportional Integral derivation) for controlling the amount of ventilation air. The house was divided into 2 thermal zones: Living Zone and Bedroom Zone. The lower limit of air flow rate was 7.5 ACH (air change/hour) and upper limit flow rate was 25ACH as recommended by ASHRAE. In winters, during occupancy PID controller was activated where $T_{room} < T_{winter}$, so T_{out} of EAHE can moderate indoor temperature as $T_{out} > T_{room.}$ In summers, controller was activated when $T_{room} > T_{summer}$ so that outer temperature can moderate indoor temperature. The energy and mass balance equation were solved numerically to predict the indoor air temperature for each zone. The program was developed using MATLAB and the numerical model was validated against TRNSYS (2009). It was seen that space temperature obtained numerically and space temperature predicted by TRNSYS showed a difference of $\pm 4\%$.

Serageldin et al. [48] conducted an experiment for Egyptian weather condition where the soil temperature distribution was studied. An unsteady, 1D quasi mathematical model was developed for energy equation using MATLAB. A CFD analysis was done to estimate the air and soil temperature. The mathematical and simulation results were validated against experimental results. Also, a mathematical model was developed to predict the temperature profile along the length and time. Explicit finite difference method was used to solve the governing equation. The results show that the inlet temperature depends on ambient temperature and outlet temperature thus the convective heat transfer has less influence than conductive heat transfer. Thus, the soil temperature increases with increase in the outlet temperature. Also as 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 simulations indicate that the temperature increases with depth during winters and vice versa. Also, a parametric study was conducted to study the design parameters considered in simulation. The results for the study show that as the pipe diameter was increased the air temperature decreases, thus decreasing the convection heat transfer. The effect of outlet temperature variation for 3 different pipe materials was also considered. It showed that the outlet temperatures for all 3-pipe materials were similar. Thus, the pipe material has less affect in the performance of EAHE.

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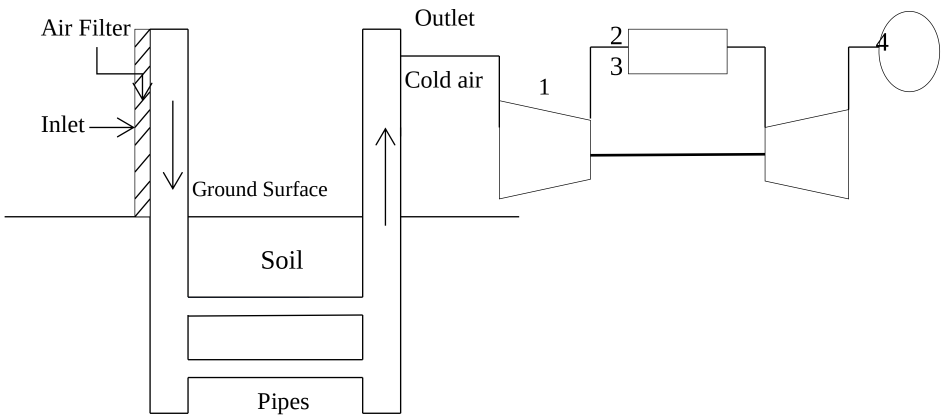


Figure 8: Schematic diagram of EAHE installed in gas turbine plant

Table 2: Summary of the Experimental results studied around the world

Author	**Place/ Year**	**Season**	**material**	**Length of pipe[m]**	**Diameter of pipe[m]**	**Depth of pipe[m]**	**Temperature range [°C]**	**Velocity range[m/s]**	**Temperature variation [°C]**	**Variable**	**Others**	**COP**
Goswami et al.[40]	Florida, 1993	-	-	30.48	0.3048	3.6576	23.89-33.05	-	26.67-28.33	Inlet temperature	-	5.8
Li et al.[66]	Harbin, China,2006	Summer	HDPE	-	0.0325	47.6	-	-	0.75°C	Ground Temperature	-	-
Fard et al.[39]	North east of Iran, 2011	Winter	PVC and galvanised mild steel	20	-	4	35-43	0.4-30	-	Material of Pipe	-	3.5
		Summer								Soil Temperature	-	5.5
Vaz et al.[41]	Viamas, Brazil, 2011	Summer	PVC	A: 0.11	-	2	30	-	25	-	-	-
		Winter	-	B: 0.11	-	2	12.8	-	19	-	-	-
		-	-	C: 0.10	-	5	-	-	-	-	-	-
Ozegener et al.[8]	Turkey, 2011	-	-	47	-	3	18.67	-	21..5	-	greenhouse temperature	-
Mongkon et al.[34]	Thailand, 2013	Winter	Iron	38.5	0.08	1	24.5	9	20.88	-	-	2.04
		Summer					28.8		21.37	-	-	3.56
		Monsoon					28.6		26.8	-	-	0.77
Benhammou et al.[44]	Algerian Sahara,2013	Summer	PVC	23.42	0.10-0.30	-	29	2.0-5.0	22.3-23	Diameter of pipe	-	0.98-0.67
									24	Length of pipe		
						-	-	-	27.8	Velocity of pipe	-	-
Yassine et al.[47]	Lebanon, 2013	summer	-	-	-	-	28	-	26.88	Mass flow rate	-	-
		winter	-	-	-	-	16	-	16.64		-	-
Chiesa et al.[67]	Imola, Italy, 2014	Summer	PE	2240	0.25	-	-	-	-	-	-	19.7
Sansui et al.[68]	Malaysia, 2014	-	-	-	-	-	-	-	21.5 - 34.1	Soil type	-	-
Vaz et al.[51]	Viamas, Brazil, 2014	Summer	PVC	A:0.110	-	1.6	18.8	-	12	Burial Depth	-	-
		Winter		B : 0.11		0.6		-		-	-	-
				C: 0.10		0.5		-		-	-	-
Yu et al.[61]	Omaha, USA 2014	Winter	Culvert Steel	57	0.45	3	12.78	-	21-24	Configuration	Passive	-
								-	20–27.5	Configuration	Active	-
Hatraf et al.[69]	2014	Summer	PVC	60	0.11	-	-	-	-	Mass flow rate	-	-

Author	Place/ Year	Season	material	Length of pipe[m]	Diameter of pipe[m]	Depth of pipe[m]	Temperature range [°C]	Velocity range[m/s]	Temperature variation [°C]	Variable	Others	COP
Li et al. [70]	2014	-	Culvert steel	57	0.45	3	-	-	14.6	Burial Depth	-	-
Yang et al.[71]	Changqing, China, 2015		-	-	-	-	20	0.5	1.4	Diameter of pipe	small change diameter from 0.05 to 1 m	-
									15	Length of pipe		-
		-							13	Mass flow rate		-
Mohamed et al. [65]	Marrakech, 2015	Winter	PVC	72	0.15	2.2-3.2	4.2-11	-	16.7-21.2	Time	-	-
		Summer					44.6		24.8	Time	-	-
Jassim et al. [71]	Baghdad, Iraq, 2015	Summer	-	-	-	-	-	-	25.3-28.2	Burial Depth		3.43-5.24
Serageldin et al.[48]	2016	Winter	PVC	5.5	0.0508	2	14.7	1-3.9	22	Burial Depth	-	-
									15.8	Velocity of pipe		-
Uddin et al.[50]	Bangladesh, 2016	Winter	PVC	14.3256	0.0381	2.43884	11	-	21.3	Time	-	-
		summer					34		20.5	Time	-	-
							-		23–24	-	-	-
Chela et al.[33]	France,2016	Winter	-	-	-	-	5	-	-	Configuration	Nancy	-
							8			Configuration	La Rochelle	-
							10			Configuration	Nice	-

Barakat et al. [49] studied the application of EAHE as inlet of a gas turbine as shown in figure 8. The thermal performance of EAHE was studied using transient 1D model developed using MATLAB. A mathematical model was validated against an experiment study conducted in Damietta Power Plant, North Carolina. Results show that the outlet temperature decreases with the decrease in length. Thus, longer pipe length provides more heat exchange. It was also seen that as the pipe diameter and velocity increases the outlet temperature also increases and decreases respectively. The fuel consumption was evaluated which showed a drop of 4.4% on using EAHE as inlet to gas turbine. Thus, longer tube, smaller diameter, placed deep and low inlet air velocity give lower outlet temperature using EAHE increases the power output.

Uddin et al. [50] investigated the performance of EAHE to maintain thermal comfort in Bangladesh. Life cycle energy and GHG emission analysis done using cradle to grave assessment. The experiment was conducted in an office for 2 seasons, winter (11°C, 91% RH) and summer (34°C, 77% RH) with an AC of 1 TR was already present in the room. A small fan of 30W was place to ensure flow of air through the coil. For the cradle to grave analysis 4 stages was considered. Stage I: extraction of raw material, Stage II: manufacturing of heat exchanger material (PVC and MS). Stage III: installation and use and Stage IV: disposal at the end of life. The thermal performance was estimated for both the seasons and results showed that the outlet temperature was around 23-24°C for both seasons. But the outlet humidity during winters was 45-50% and during summers RH was 30-70%. In life cycle assessment, the total life cycle energy for PVC= 307 MJ and for MS= 96.4 MJ. Thus, MS pipe can be used as pipe material from life cycle energy point of view as MS generated lesser energy than PVC. In the GHG analysis was it was observed that the magnitude of emission in MS is lower than PVC. Also, the Co_2 emission for PVC and MS was 86kgs and 20 kg respectively. Thus, MS is preferred over PVC for the cases. As specified before 1TR of AC consumes 9.6 kWh of energy per day. When EAHE is coupled to AC it saves up to 288 kWh per month during both seasons. Thus, using AC with EAHE saves more energy than single AC.

Gan et al. [51] formulated a model in FORTRAN to study the thermal performance of EAHE. To study the heat and moisture transfer 3D mass and energy equation, 2 interfaces were considered; between earth and atmosphere between heat exchanger and supply air. The simulation of the present study was run on FLUENT for 2 modes continuous and intermittent modes. In continuous mode, the heat is transferred from the soil to air at any given time. In intermittent mode, this occurs for a specific time period when the air is preheated only then heat transfer takes place. Simulations were done at different lengths (10 to 40 m). There was a rise in temperature from 5- 6.6°C for ambient air. It was seen that the heat transfer rate decreases day by day with decrease in soil temperature. Thus, with increase in the length the rate of heat transfer and temperature rise decreases but overall heat gain increases. Also, the author found that the thermal and moisture interaction between heat exchanger atmosphere and soil has significant effect on the rate of heat transfer.

Xaman et al. [52] aims to study the transient thermal behaviour of EAHE in 3 cities of Mexico. A mathematical model was formulated considering conduction heat transfer in the soil, between pipe and soil and flow is laminar in the pipe. The governing equations were solved using finite volume method. The convective terms were discritised by hybrid scheme and diffusive terms were discritised by central difference scheme for the mathematical model. For the analysis 3 cities of Mexico are considered (Juarez City, Mexico City and Merida) and four Reynolds number are considered (100, 500, 1000 and 1500). It was concluded that the EAHE has high heating potential for all the Reynolds number in the cities Juarez and Merida as the cities exhibits very low temperature during winters. Whereas, EAHE system for Mexico exhibits a good heating as well as cooling potential for only Reynolds number 100.

Mohamed et al. [53] investigated the thermal performance of EAHE in Marrakech. The EAHE consist of 3 parallel pipes each connected with a fan of 44-90 W. The spacing between the pipes was 14cm and the vertical parts of the pipe were insulated with 4cm thick polystyrene. During the operation, only one pipe was monitored and fans of non-monitored pipes were kept off. A numerical model was developed using TRNSYS, which was validated against the data obtained from the experimental setup. Results were estimated by taking time as variable. During summer season the temperature drop was nearly 19.8°C which was more than the winter season. Thus, EAHE system is more efficient during summer season.

Rodrigues et al. [54] employed constructional design for EAHE to obtain the highest thermal potential. The numerical simulation was performed using Ansys FLUENT. The computational domains were developed in FLUENT and discretised in Gambit. The numerical simulation was done as a function of time. The validation was done against an experimental setup constructed in 2007. The constructional design was created by Adrain Bejaan in 1997. In this experiment, 5 different configurations of EAHE were evaluated. This design was applied by means of volume fraction parameters to find the optimal installation. For installation I, high thermal potential was reached during December. In Installation 2, a stable behaviour of thermal potential were seen. In this installation, the horizontal spacing of pipe was increased so thermal potential was also increased. In installation 3, the concept of volume fraction was considered. The highest value of thermal potential was seen in May, June, July, October, November and December. There was no significant change in thermal potential seen during January and February. In installation 4, Thermal potential has an intermediate value. Installation 5 showed the superior performance in heating and cooling. Thus, by increasing the number of ducts and reducing the duct diameter, constant air volume fraction can be maintained.

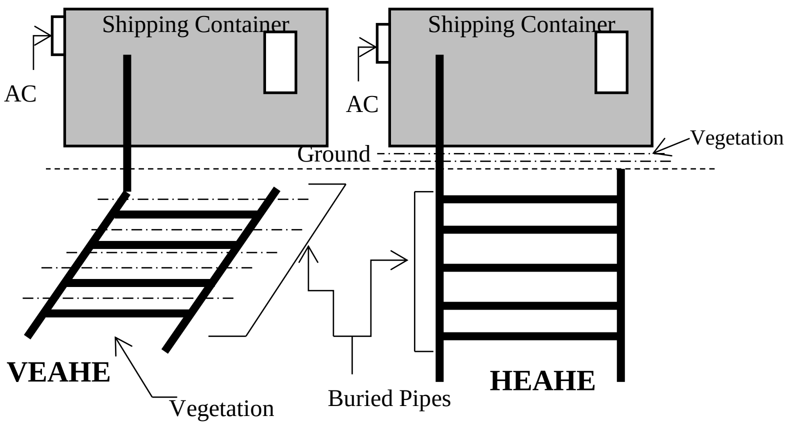


Figure 9: Schematic diagram of VEAHE and HEAHE

Ahmed et al. [55] investigated of the thermal potential of EAHE by conducting experiment in Rockhamton, Australia. Using two shipping containers, one connected with Vertical EAHE [VEAHE] and other with horizontal EAHE [HEAHE] as shown in figure 9. Fans were installed to suck the air inside the pipe inlet. 20 PVC corrugated pipes for each configuration. To increase the cooling effect small trees were planted to cover the underground pipe. The schematic diagram of the setup is given in figure 7. A CFD model was formulated considering the flow inside the corrugated pipe to be turbulent. The discritization was done using PRESTO scheme. The soil temperature analysis was done for different depths and showed that on a summer day the soil temperature increases with decrease in depth. For the measure of the performance of HEAHE, the VEAHE was turned off and vice versa. Simulation results show the average room temperature for HEAHE was slightly larger than VEAHE. Thus, concluded that VEAHE provides more reduction in temperature drop than the HEAHE. So VEAHE is preferable to use for Australian weather.

Chiesa et al. [56] aims to study the results of EAHE in a school building of Imola, Italy during winter and summer seasons. A solar wall air collector made of Polyethylene was connected to the EAHE. The energy performance of EAHE system was evaluated by using GAEA software (Graphische Auslegung von Erdwärme Austauschern). The effectiveness of EAHE was found by using Parson and Koehler's expression. This expression was used to validate the collected data neglecting the outlet temperature. A Psychometric analysis was performed to predict the inlet, outlet temperature and relative and absolute humidity. It was seen that during summer there was a significant decrease in the temperature with increase in the relative humidity. The absolute humidity increases when the dew point temperature is reached in the tubes. During winters, there was remarkable increase in temperature, so outlet air requires treatment to reach it to indoor conditions. An energy balance was considered to calculate the rate of heat transfer. The COP of the EAHE was also calculated by considering the pressure loss of the system. The monitored results were compared with the results already present in literature. It was found that EAHE is an effective system which depends on the design parameters.

Sansui et al. [57] studied the capacity of Malaysian soil for the application of EAHE. This research aims to predict the soil temperature for different soil surface condition. The experiment was set up at Gombak campus of International Islamic University, Malaysia. Three different soil surface conditions were considered. The soil condition was; Bare and short grass; Sheltered by layers of recycled timber palette and Insulated by layers of used tyres. A parametric analysis estimate the soil temperature at an optimum depth was done to find the appropriate soil surface condition. The simulations for the study was conducted in Energy Plus software. The soil temperature was investigated and it was observed that soil temperature ranges between 21.5- 34.1°C. For soil shaded with timber palette and insulated with used tyres had the coolest soil temperature of all three types. On running the simulation for all 3-soil surface condition by considering the solar radiation, soil shaded with timber palette and insulated with used tyres shows best results. Thus, low soil temperature gives better heat exchange and more cooling temperature. Hence the EAHE cooling is feasible in Malaysia climate.

Vaz et al. [58] investigated the transient behaviour of the temperature fields for the external air soil and buried ducts. The experimental set up was implemented in Casa Ventura. Temperature and humidity was also monitored for soil, air and water. This research involves the fluid and heat flow. The thermal properties of Udult soil having density of 1800 kg/m^3 was studied. The variation of soil temperature was investigated at different depths. Results show that the temperature increases with increase in depth.

Ahmed et al. [55] focused on the comparison made on the two different pipe system of earth pipe cooling .The thermal performance was estimated using Ansys FLUENT. The experiment was conducted in Queensland, Australia. Two containers were considered as modelled room where one was connected to Vertical Earth pipe cooling system (VEPC) and other was connected to Horizontal Earth pipe cooling system (HEPC). There were 20 corrugated PVC pipe connected to each arrangement. For estimating the performance of VEPC, the HEPC was turned off and vice-versa. The 2D thermal model was generated in Ansys FLUENT 13.0. The simulated results show that room temperature for VEPC system was 23.05°C and HEPC 23.85°C. When comparison was made with the predicted temperature, it was found that VEPC system has 1.82°C less and HEPC system has 1.03°C less than the measured value. Thus, VEPC gives better performance than HEPC system. On studying the thermal performance for VEPC and HEPC system on the climate of Australia, it was seen that VEPC system shows better performance than HEPC system. The simulated results were validated with the measured data at the pipe inlet at different points.

Yu et al. [59] investigated a coupled geothermal system with earth tube and solar chimney in Omaha, USA. Three experimental tests were conducted in a sequence (passive, active, and passive). In this experiment analysis of indoor air condition, cooling capacity, and soil temperature was carried out. The design for cooling load was done using software TRACE 700. A solar collector was constructed with a solar chimney. This hybrid system was constructed to provide cooling and ventilation for solar energy research test facility. The experiment was monitored both natural (Passive) and forced cooling modes. During the passive cooling modes, the air flow rate varied from 0 m^3/h to 500 m^3/h. Thus, solar collector coupled with solar chimney is capable to provide sufficient cooling force for coupled geothermal system. For the forced cooling modes, the air flow rate was constant with a value of 2750 m^3/h. For the thermal comfort analysis Predicted Mean Vote (PMV) and Predicted Percent of Dissatisfied people (PPD) was evaluated. The results show that the indoor air condition under passive air flow condition is more comfortable than forced air flow condition. For the underground soil temperature analysis, the temperature profile of the soil at different depth was studied and was observed that during the forced air flow condition the soil temperature increases regardless of the depth. Thus, the indoor condition was more stable for passive cooling modes than active cooling modes.

Ariffin et al. [60] investigated the appropriate pipe materials to predict the optimum air temperature to achieve thermal comfort. The study uses Energy Plus for environmental simulation program. The pipe materials considered for the study were: Polyethylene (PE), PVC (polyvinyl chloride), Steel, clay, concrete and Copper. The performances of three pipe materials system: single pipe material, hybrid pipes and insulated hybrid pipes system was investigated. The study uses 3 polyethylene pipes buried at different depths. Using Energy Plus software a parametric study was carried of 6 different pipe material; PVC (polyvinyl chloride), PE (polyethylene), steel, clay, concrete and copper. The simulated results were validated with the results of an experiment conducted in 2012. In the study four types of test were conducted which are stated as follows. Test 1: primary test, Test 2: simulation of individual material, Test 3: hybrid material (simulations of 2 different materials), Test 4: hybrid material and insulation (Simulation of combination of 2 materials and insulation). Test 1 was performed to standardise the factors for the 3 simulations. Test 2: The 6 different pipe materials were evaluated. The pipe diameter of 50mm was not available in Malaysian market for the pipe material clay and concrete so these were eliminated from the study. The results indicated that the PE (polyethylene) has the maximum temperature reduction of 6.23°C in comparison to other three. Test 3: The simulation was run for 2 pipe one inside the other. Results indicated that combination of metal and non-metal shows better reduction of temperature. Test 4: In this test 2 types of simulation were done 4A: hybrid system + water and 4B: hybrid system + Rockwool insulation were evaluated. Results show that the best water-hybrid system is the combination of Steel and PE (ST+PE). The metal+ non-metal combination shows better results but non-metal+non-metal can also be an alternative. Thus, PE + PE pipe is recommended for the selection since they are more durable and cheaper. Simulation results of 4B show, the temperature reduction ranges between 6.03-6.23°C. Thus, this combination also provides better temperature difference.

Hatraf et al. [61] studied the soil ground temperature profile to estimate the depth of the pipe. The physical characteristics of the soil were studied and a mathematical model was formulated. A comparison was made between the simulated and experimental results by considering different flow rates at 100, 150 and 200 m^3/s. The air flow affects the performance. The Nusselt number increases with the increase in Reynolds number. Thus, the soil properties have large impact on the performance. The depth of the pipe depends on the diffusivity of the pipe.

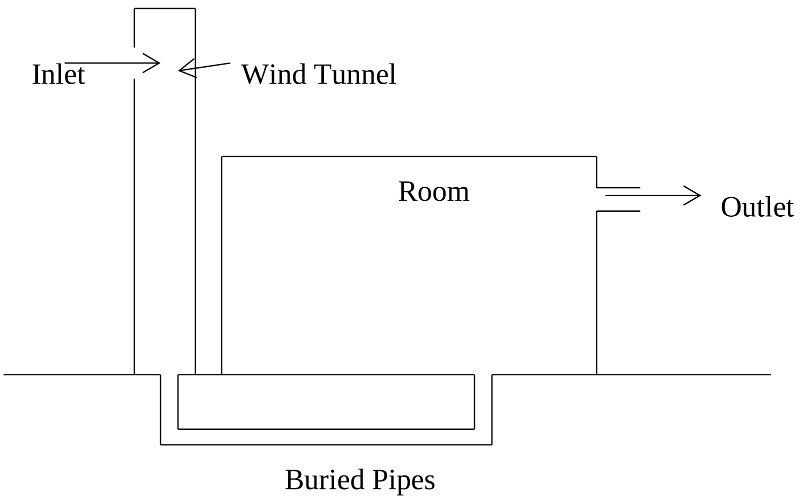


Figure 10: Schematic diagram of EAHE coupled to wind tunnel

Benhammou et al. [62] made an analytical design model to investigate the influence of design parameters on the performance of EAHE. The outlet of the EAHE is placed inside the building and the inlet is connected to a wind tower considering that the wind direction was unidirectional. The schematic diagram of the setup is given in figure 10. A mathematical model was developed for the thermal analysis of EAHE. The model was validated against the experimental data collected by Dhaliwal and Goswami [63]. The soil temperature of the burial depth was 18.89°C. The variation of the air velocity inside the pipe was studied and results show that with the increase in the pipe diameter there is increase in the air velocity. When diameter was increased the air- velocity was increased, the air velocity decreases as length of the pipe increases. The influence of wind tower cross sectional area was also discussed. When the cross section increased by a very small difference there was a change of 0.009°C in temperature. Again, when the tower height was increased, air velocity was increased and temperature was decreased. Thus, the cross section has no effect on the performance of the system. The cooling effectiveness of the system was also evaluated. Results show that the air temperature is lower for the system coupled with wind tower in comparison with the air temperature of wind tower in wet surface. This comparison was done considering a similar work done by Bouchahm et al.

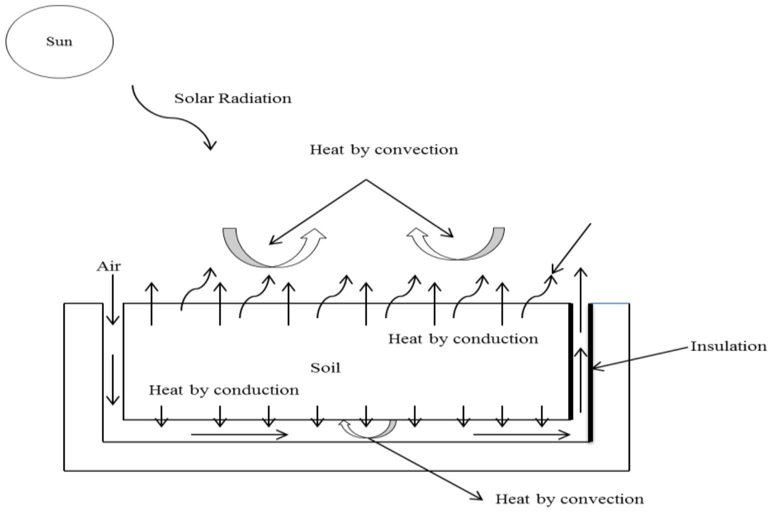


Figure 11: Schematic of EAHE with thermal Insulation

Xamána et al. [64] predicted the thermal performance of EAHE for the 3 cities of Mexico. The effect of thermal insulation at outlet was investigated. This study considers two different configurations of the EAHE system. The configurations were: EAHE without insulation and EAHE with thermal insulation (polystyrene) at the outlet. The schematic diagram of the setup is given in figure 11. The results were obtained for Re=1500 for 3 cities of Mexico (México City, Mérida and Cd. Juarez) with soil condition of silt, clay and sand soil. Thus, showed on adding insulation to EAHE system, EAHE for México and Mérida city was profitable during summer season and for Cd. Juarez city the thermal insulation was useful during winter season.

Carlucci. et al. [65] considered a EAHE coupled with HVAC system and coupled system to estimate the thermal potential of the system. The pipes were laid on L-shaped pattern. The selection of soil has also been monitored. To investigate the temperature profiles many sensors were installed at different depths. For the installation of EAHE the first phase is the excavation up to a depth of 0.3m. The pipe bed was fill by FSC soil. The EAHE consist of 3 pipes that are connected to the inside of the tower and other end was connected to conveyor box. A planned monitoring system was also installed to monitor the results whether the non-zero objective is reached or not. In this study only the systems were installed, the results were not monitored. Three types of soil have been used to cover the pipes: a mixture of fine sand and clay, scoriaceous lava and topsoil.

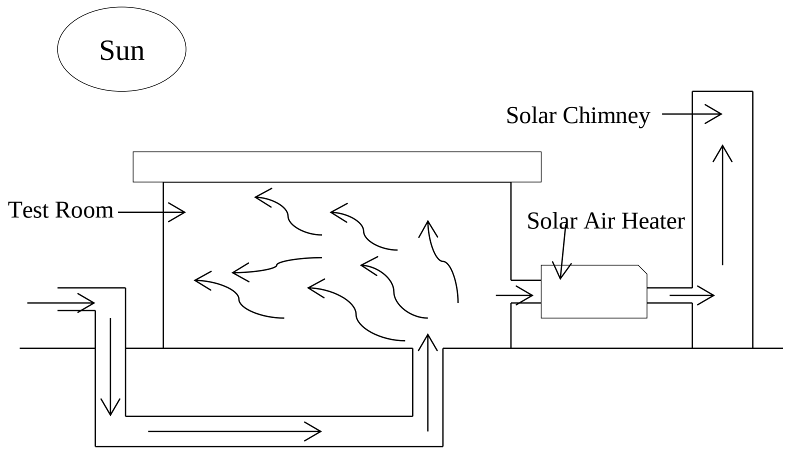


Figure 12: Schematic diagram of EAHE coupled to solar chimney

Li et al. [66] studied a hybrid EAHE coupled with solar chimney. The solar collector is used to connect the solar chimney to the building. The system consists of an EAHE pipe with one end exposed to outside and the other end to inner side. The experimental setup was made on a testing facility of University of Nebraska. The solar chimney was designed in such a way that the pressure losses from EAHE were compensated. The schematic diagram of the setup is given in figure 12. The parameters examined are time and date, the indoor relative humidity (%), outdoor relative humidity (%), supply air relative humidity (%), supply airflow rate (m^3/s), solar collector airflow rate (m^3/s), average indoor temperature (°C), supply air temperature (°C), and outdoor air temperature (°C). The underground soil temperature was monitored at different depths. It was seen that less temperature fluctuations were observed for deeper depth. The maximum temperature difference was observed at 2.9m depth.

Mendez et al. [67] studied the uses of PID controller, which is generally used for thermal processes. This study shows the usage of PID in improving the performance of EAHE than conventional heat exchange. The simulations of PID were created in LabVIEW. The results show that PID controllers show better control of temperature in comparison with the conventional controller. The PID controller reduces energy consumptions after a steady temperature is achieved. The average energy consumption on energy consumption was 0.017kWh. There was about 87% energy saved in comparison to conventional controllers. A simulation run on PID controller, results show that energy consumption can be reduced if a PID controller is applied. It not only increases the efficiency but also the sustainability of EAHE system and has lower emission in comparison to conventional systems.

Sansui et al. [68] investigated the soil temperature at different depth up to 5m to estimate the potential of EAHE in Malaysia. The site location for the experiment was International Islamic University campus in Malaysia which was generally exposed to solar radiation. The soil type is sandy and covered with short grass. The study was carried out in 2 phase: in the first phase temperature measured up to 5m and other the second phase focuses more on temperature at shallow depths. It was seen that there was a little change in temperature for shallow depths. The results indicate that on application of EAHE in building is possible only if the air temperature increases beyond 34°C. Also, the optimum temperature for the undisturbed soil temperature was at a depth of 1m.

Niu et al. [69] studied 2D heat transfer mechanism through transient control volume method. The computational domain was divided into control units and thermal balance was applied. A self-recovery temperature analysis was done using continuous and intermittent modes. The data was validated against an experimental set up already present in Omaha, USA. The measurements were done to record the cooling capacity of the system. The simulations were done using MATLAB 8. Results indicate that the outlet temperature increases when soil air temperature was increased. It was observed that there was a good agreement with the experimental results during validation. It was observed that the soil temperature near the tube fluctuated more the far one. Thus, the temperature difference between soil and air is higher than the outlet. To recover the lost energy, night time is the time for recovery. Two modes were considered to analyse the recovery analysis: continuous modes and intermittent mode. In intermittent mode, the soil temperature was recovered during non-working time. The recovery ability decreases with time and distance. In continuous mode as the supply air temperature increases the recovery temperature varies between 19.5- 21.7°C.

Niu et al. [70] predicted the cooling capacity of EAHE using regression analysis. The study considers both heat and mass transfer between tube and air. A mathematical model was formulated to estimate the underground soil temperature. The results were validated with results already present in a test facility. For the heat transfer analysis, sensible and latent heat transfer were considered. A simulation model was developed in MATLAB 8. The data was validated with the experimental data already present in a test facility at Omaha, USA. The results when compared show a good agreement with the present data. Thus, the formulated equation for soil temperature can be used. For the EAHE, there was rise in outlet temperature. To predict the soil temperature, temperature profiles were checked along the length. The results indicate that as the surface temperature increases, the outlet temperature increases. Also as the tube diameter increases there is decrease in the outlet temperature. Cooling capacity for the system was also investigated. The cooling capacity increases with increase in the inlet air temperature. On calculating the cooling capacity sensible cooling capacity was 0.31 kW/°C and latent cooling capacity was 0.7 kW/°C. Thus, the total cooling capacity was 1.1 kW/°C.

Jassim et al. [71] investigated the performance of wind catcher in EAHE to reduce the energy consumption in hot dry areas like Iraq. Wind Catcher is a device designed for pulling and expelling the air. Generally, wind catcher towers are connected to a building to cool the building. The thermal performance was studied in two phases. Phase 1: The temperature was measured using data loggers. Phase 2: Simulation done using CFD. The model was a 2-storied building with a wind catcher of $2m^2$ area. A CFD model was formulated and was validated against the experimental setup. Results indicate that a higher fluctuation in temperature was seen in August. But these fluctuations were decreased in June, but the relative humidity was increased. This result also indicate that the soil temperature also depends on the soil type and water table. It was observed that if the wind catcher space was increased in phase 1, the thermal comfort was not achieved. But in phase 2 if space is increased the temperature is reduced by 18°C. It was also observed that when the velocity was increased, the COP was increased to 5.24. Thus, this new design for self-cooling reduces energy consumption.

Li et al. [72] constructed an experiment in Harbin area of an air conditioned system for cold areas which directly supplies the cold energy stored in ground. The operation time was in summer in 2006. Performance parameters such as cooling seasonal performance factor (CSPF) and the average heat rejection rate unit depth of borehole were investigated. The system consists of ground heat exchanger and indoor fan coil. The circulating fluid considered was water. To reduce the thermal influence of the building on the ground, the borehole was made 7m exterior to the walls. The heat rejection rate per unit depth of borehole ranged between 40-100 W/m. The cooling characteristics are divided into seasonal cooling characteristics and daily cooling characteristics. On daily basis, maximum cooling capacity occurred on 2^{nd} day. The ground temperature rises rapidly initially but become stable at a later stage. There was an increase of cooling 0.75°C on last 45 days. On hourly basis, maximum cooling capacity occurred on 1st hour and minimum cooling capacity occurred on tenth hour having a ratio 0.81. Thus, the increase in ground temperature in initially low at different depth and gradually becomes faster.

Chlela et al. [33] carried out a numerical study to evaluate energy performance of two different ventilation system and earth air heat exchanger for three French climates. The building considered is a dwelling called "Mozart" having floor area 101m^2. The simulations were carried out for three French cities: Nancy [5°C], La Rochelle [8°C] and Nice [10°C]. Two ventilation systems were considered: mechanical extract ventilation system and balanced ventilation system. The soil type proposed was clay. The thermal behaviour of the building was carried out using SIMBAD. The results were validated with other building data [El Khouryet et al., 2005]. Yearly simulations were done to evaluate the thermal performance of EAHE and balanced ventilation system for all three cities. The heating demands of the ventilation system for the three cities were evaluated and there was reduction in heating demand. The results of Nice were very interesting. The heating demand for the house in Nice was 13.2 kWh/m^2, which was almost equal with the annual heating demand. There was a decrease in heating demand for EAHE with mechanical extract ventilation system. Thus, the balanced ventilation with heat recovery unit is more efficient than EAHE. During summer season the heat exchanger of the balanced system was bypassed. The cooling potential for the 3 cities three modes were evaluated on 3 modes. Thus, EAHE has a good potential for cooling.

Ascione et al. [73] studies the Net Zero Energy buildings[NZEB], the main strategy to reduce energy consumption and CO_2 emission in buildings. It analyses a case of a two-storied building in Palero, Italy having an area of 520m^2. The NZEB is a new concept introduced by European Directive 31/2010/UE. This concept came from nearly Zero Energy Building [nZEB], which implies that the non-renewable energy demand is equal to 0 kWh/m^2 annually. For the analysis, the computational software used is EnergyPlus. The results obtained were validated with the climate data available at International Weather for Energy Calculation. A PV system made of monocrystalline silicon panels titled to an angle of 15° [essential to obtain NZEB]. A mechanical ventilation system [MVS] was considered to estimate the thermal performance. Energy Plus was used to evaluate the heating, cooling potential considering 2 modes. Results show the primary energy use per floor [PE] for summer [PE_c] and for winter [PE_h]. Thus, during summers PE_c reduces with increase in airflow and vice-versa in winters. The annual electricity demand for MVS was 35455 kWh and for EAHE+MVS, the demand was 31200kWh. But the PV panels produced only

31300kWh. Thus, more PV panels are to be installed to satisfy the demand. Thus, NZEB is possible using renewable energy is possible. The electrical demand in the case of only MV is more so a higher number of PV must be used to compensate the demand than the other case.

Table 3: Thermo-physical Properties of Materials used in literature

Material	Density (Kg/m^3)	Specific Heat Capacity (J/Kg K)	Thermal Conductivity (W/m K)
PVC [76]	1380	900	0.161
Copper*	8933	385	401
Aluminium*	2702	903	237
Galvanised Iron[GI] [75]	-	-	-
Steel* [AISI304]	7900	477	14.9
Galvanised steel [76]	-	-	-
Mild Steel[MS]*	7854	434	60.5
Galvanised mild steel [40]	-	-	-
Polyethylene [PE]**	-	2000	0.45
High density Polyethylene (HDPE)**	940	2000	0.45
Iron*	7870	447	80.2
Plastic [76]	-	-	-
Culvert steel [67], [60]	-	-	-
Reinforced concrete [74]	-	-	-
Bamboo + Cement Plaster [27]	-	-	3.14
Air*	1.225	1006	0.024
Water*	1000	4190	0.55

*Thermo-physical properties of Materials at 300K [77] , **Thermo-physical properties of Material at 296K

4.2 Research conducted in India

The climate of India ranges from tropical in the south and temperate in the north. The climate of India is influenced by The Himalaya and Thar Desert. With the help of geothermal energy about 6.5% of electricity generation are achieved [37], but India is at nascent stage for power generation using geothermal energy. The Geological Survey of India reported that there are about 340 geothermal hot springs [37] that conserve geothermal energy in India. The Indian market has not been much influenced by EAHE.

Many Indian researches have been initiated to study the potential of buried pipes. The parameters for the studies are given in table 4 and 5. Ghosal et al. [11] conducted an analytical study in New Delhi, India. The pipes were arranged in serpentine manner with mass flow rate 100 kg/h. The performance was evaluated on the basis length of pipe, air temperature inside the greenhouse for both the seasons. The results indicate that with increase in length of the buried pipes the air temperature inside greenhouse increases in winters and decreases in summers. Thus, concluded that performance of the EAHE is a function of length and temperature of the greenhouse.

Bansal et al. [74] developed a model in FLUENT to reduce heating loads in a building. A transient and implicit model based on CFD was developed and was validated against a setup in Ajmer (winters). Two type of materials were considered Mild steel and PVC. CFD simulations were performed in FLUENT 6.3. Results show that as the air velocity increases the outlet temperature decreases due to increase in heat transfer coefficient of the materials. On keeping the same input conditions for both the materials it was seen that there was a small temperature difference at the outlet of the pipe due to high coefficient of friction. It can be concluded that convective heat transfer plays an important role than conductive heat transfer. It can also be concluded that the performance of EAHE does not depend on material of the pipe. Results show that EAHE saves 38% of electricity in comparison to an electric heater having efficiency of 95%. Thus, the material of the pipe is not of much concern so a cheaper material can be used.

Bansal et al. [15] conducted the same experiment for summer season considering the same input parameters. When comparison was made, there was a variation of 0- 11.4% with the experimental results. It was seen that as the air velocity increases the outlet temperature increases. For both the materials a very small temperature difference at the outlet of the pipe. The maximum hourly energy gain was 3.1 MWh, observed at 5 m/s, in the same velocity range the COP obtained was 1.9- 2.9. Thus, the material of pipe does not influence the performance of EAHE.

Chel et al. [75] formulated a thermal model of vault roof building coupled with EAHE solved by Ranga Kutta approach. The adobe house has a room air temperature higher than ambient air in winters and lowers than ambient temperature in summers by 5-15°C which increases the energy saving potential. The analysis of the adobe house was done under 3 conditions (Before renovation, after renovation, with EAHE for 6 rooms). The total energy saving potential obtained between 4183-10321 kWh/year for all three cases and the CO_2 emission ranged between 7-16 tonnes/year. The average seasonal energy efficient ratio for heating was 1.8 and for winters were 2.9. Thus, it can be concluded that EAHE is more efficient for heating than for cooling.

Bisoniya et al. [19] investigated the cooling demand in a building for hot and dry climate of Bhopal considering quasi steady state model, developed in CFX 12.0. The simulated results were validated against an experimental set up in Bhopal. The observations were made for different flow velocities assuming $T_{surface}= T_{ambient}= T_{inlet}$ to evaluate the total hourly energy gain. Results indicate that the temperature drop was faster at initial length of the pipe and became moderate for rest of the length. Also, a comparison was made with experimental data and simulated data at different velocities; there was a deviation of 0-8.86% of the experimental results. It was observed that the maximum hourly cooling energy gain was 1.8 MWh at 5m/s. Thus, it was concluded that EAHE can be used efficiently to reduce cooling load of the building in hot and dry summer in comparison with AC.

Dubey et al. [76] considered an open loop EAHE having 3 horizontal pipes connected in parallel to the find cooling rate during summer season. The pipes were in parallel connection with a common intake and exhaust manifold of air passage. Results indicate that there was decrease in the temperature and COP of the system as the velocity was increased. Thus, the velocity of air flow affects the performance of the system.

Chaturvedi et al. [29] investigated the performance of EAHE in Bhopal having multiple pipes in parallel during summer season. It was seen that material of the pipe has no effect on the output. Results show that the temperature difference at inlet and outlet is less if the length of the pipe is small and blower voltage is high. Thus, it can be concluded that material of pipe does not affect the performance of the system.

Kumar et al. [77] studied the numerical techniques of finite difference method and FFT (MATLAB) model. The results were validated against the experimental data of a similar tunnel in Mathura (India). It was observed 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 is lowered. Thus, can be concluded that longer tunnel length is efficient for more cooling energy saving. Results indicate that the cooling potential for the setup was 456kWh. By increasing the pipe radius above a critical value, the outlet temperature can be increased which affects the heating / cooling potential. Thus, it was concluded that by using larger diameter pipe large outlet temperature can be achieved.

Singh et al. [78] designs a metallic EAHE to determine the heating and cooling loads of a classroom. The ducts were laid in zigzag pattern having a combination of PVC and Iron, square cross section for the metallic pipe and round cross section for PVC. The cooling load was found using CLTD method. Main duct was divided into 3 parts; inlet and outlet was made of PVC and remaining sections were made of galvanised iron. The simulations were run in ANSYS. Results show that there was a change in the temperature profile at the outlet of metallic section. The air in the central portion is warmer than the air near the boundary layer by 2°C as the inner part gets less convected. After all the variables were taken into account, final layout of the earth-air tunnel was made through CATIA software.

Prototype was run in different seasons. Prototype showed a maximum C.O.P of 3.9 in summer season which was more than COP of 2.1 in winter season. It was seen that the maximum cooling effect of the prototype was 2.6 kW. Thus, it can be concluded that the EAHE is more useful during summer season than in winter season for the climate of Punjab. Thakur et al. [79] developed a model in Pro–e to study the effect of finned model of EAHE. This was compared with a finless model of EAHE. Meshing tool used was ANSYS Workbench, complex heat transfer and air flow process studied using FLUENT. The computational model validated against an experimental study conducted by Misra [80]. The simulations were run at different pipe inlet velocities. On comparing the data with the existing experimental data, it was seen that there was a variation of 7.64%. The simulation results for finned and finless EAHE system were studied. From the results, it was concluded that on addition of fins, the system to work efficiently even if the soil has poor thermal conductivity. Also, concluded that smaller length of pipes can perform satisfactorily thus lowering the initial cost.

Soni et al. [81] conducted an experiment to reduce the power consumption of a 1.5TR air conditioner coupled to EAHE. For the experiment three different arrangements were considered. The economic analysis techniques such as simple payback period, discounted payback period etc. were also evaluated. From the arrangements, it was observed that in arrangement II, the condenser tube temperature was reduced by 10% than the arrangement III condenser tube temperature. The power consumption in all 3 arrangements was also calculated and a comparison was with the base mode. The results indicate that the arrangement III was useful in terms of power reduction during summer days. At a velocity range between 5- 7 m/s, EAHE arrangement gave optimum results. For the energy matrices, the EPBT for arrangement II is 604.3 days and arrangement III is 362.6 days and the CO_2 emissions for arrangement II are 5425.92 kg and arrangement III is 9043.2 kg. Thus, arrangement II is profitable to use in order to reduce the CO_2 emissions.

Jakhar et al. [82] estimated the performance of EAHE with and without Solar air heating duct (SAHD) during winter season and was formulated using TRNSYS 17. The results were validated against an experimental setup in Ajmer, India. For the solar air heating purpose, galvanised iron ducts were used. In the study three cases were considered to investigate the performance of EAHE. The results show that EAHE coupled with SAHD increases the outlet by 6- 9°C when the air velocity was varied. Also, it was observed that the heating capacity of EAHE was improved when coupled with solar air heating duct. In the error analysis, it was observed that there was an error of 3.9%.

Table 4: Summary of analytical results studied in India

Author	Place/Year	Season	Material	Length of pipe[m]	Diameter of pipe[m]	Depth of pipe[m]	Temperature range [°C]	Velocity range [m/s]	Temperature rise/fall [°C]	Variable	Others
Kumar et al.[79]	Mathura, India, 2003	-	-	80	-	-	23.8-27.9	4.9	20.2	Length of pipe	-
									2.15°C	Mass flow rate	-
									25.3	Radius of Pipe	-
Ghosal et al. [11]	New Delhi, India, 2003	Summers	PVC	39	0.06	≤ 4	39-45	-	34-39	Length of pipe	-
		Winter					4.0-9.0		7.0-8.0	Length of pipe	-
Bansal et al.[76]	Ajmer, India, 2009	Winter	Mild steel	23.42	0.15	2.7	8.0-12.7	2.0-5.0	12.8	Velocity of pipe	-
			PVC						12.5	Velocity of pipe	-
Bansal et al.[15]	Ajmer, India, 2009	Summer	Mild steel	23.42	0.15	2.7	8.0-12.7	2.0-5.0	12.7	Velocity of pipe	-
			PVC						10.3	Velocity of pipe	-
Bisoniya et al. [19]	Bhopal, India, 2014	Summer	PVC	9.114	0.1016	2	25-40	0.4-25	12.9-11.3	Velocity of pipe	-
Bisoniya et al. [80]	Bhopal, India, 2014	Summer	-	-	-	-	-	-	-	No results monitored	-
							-	-	-	No results monitored	-
Mathur et al.[81]	Jaipur, India, 2014		HDPE	40	0.1		27	5	46.7-28.8	Soil Type	Soil J
									46.2- 28.8	Soil Type	Soil F
									46.2- 28.8	Soil Type	Soil A
Chaturvedi et al.[29]	Bhopal, India, 2015	Summer	GI	9	0.05	2.0-3.0	-	-	-	Material of Pipe	-
Thakur et al.[82]	India, 2015	Summer	Aluminium	60	0.1	-	46	3.0-9.0	25.5	Configuration	finned
		Summer							28.3	Configuration	unfinned
Singh et al.[83]	Punjab, India 2015	Winter	Galvanised Iron	-	0.1524	3.048	-	16.7	29.3	Crossectional area	-
		Summer							-	-	-
Khandelwal et al.[84]	Jaipur, India, 2015	-	PVC	-	0.1524	4	-	4	11.5	-	mathematical model
Mathur et al.[85]	Jaipur, India, 2015	-	HDPE	-	-	-	26.39	-	27.27	Burial Depth	-

Author	Place/Year	Season	Material	Length of pipe[m]	Diameter of pipe[m]	Depth of pipe[m]	Temperature range[°C]	Velocity range [m/s]	Temperature rise/fall[°C]	Variable	Others
Singh et al.[13]	Chandigarh, India, 2015	-	-	-	-	-	-	-	-	-	-
Kaushal et al. [86]	India, 2015	-	-	3	0.1m	-	7	1.0-3.0	21-24	Configuration	Hybrid EAHE
									12	Configuration	EAHE
Jakhar et al.[87]	Rajasthan, India, 2016	-	HDPE	90	0.025	-	90	-	±1.61	Material of pipe	-
			GI							Material of pipe	-
			Steel							Material of pipe	-
			HDPE						22.5-27.7	Burial Depth	-
									31.9	Length of pipe	-
									31.8	Diameter of Pipe	-

Table 5: Summary of Experimental results studied in India

Author	Place/ Year	Season	material	Length of pipe[m]	Diameter of pipe[m]	Depth of pipe[m]	Temperature range [°C]	Velocity range[m/s]	Temperature variation [°C]	Variable	Others	COP
Chel et al. [78]	New Delhi, India 2009	Winter	PVC	78	0.06	1.5	-	13	-	-	Before renovation, after renovation, EAHX for 6 rooms	2.9
		Summer					-		-			1.8
Dubey et al. [88]	India, 2013	-	GI	17	0.064	1.5	-	4.1-11.6	12.7-15.7	Velocity of pipe	-	6.4-3.6
Choudhury et al. [27]	Arunachal Pradesh, India, 2013	-	Bamboo +Hydra form Plaster			-	35-42		25.8	Velocity of pipe		-
								-	25-26	-		-
Misra et al. [92]	India, 2014	Summer	PVC	-	-	3	34°-44	-	20-22	Time	-	-
Jakhar et al. [31]	Ajmer, India 2015	Winter	PVC	60	0.1	3.7	15-18	5	17.7°-21.1	Configuration	Mode I	-
									17.5-22.3	Configuration	Mode II	1.54
									17.6-24.1	Configuration	Mode III	4.57
Soni et al. [90]	Bhopal, India, 2016	Rainy	galvanised steel	11	0.05	2	37.5-46	-	35.5-42	Burial Depth	-	-
		Summer									-	-
Jakhar et al. [91]	Ajmer, India, 2016	Winter	PVC	60	0.1	3.7	13.9- 20.4	2.5,3.5,5	24.3-24.7	Velocity of pipe	-	2.8-3.1
									24.3-32.5	Velocity of pipe	-	

Jakhar et al. [83] investigated the operating temperature of Photovoltaic panels (PV) which was responsible for life span and performance using TRNSYS v17.0. Water was used as operating fluid. The simulated system was compared with the existing ones in the literature for a given cooling setup of Concentrating Photovoltaic (CPV). In the study three types of pipes material considered for the study. The temperatures along the depth for all 3 pipes were evaluated keeping the pipe length, flow rate, diameter constant. On taking the pipe material into consideration it was observed that there was a temperature variation $\pm$1.61°C. For the analysis, HDPE was considered as it cheaper. It was observed that as the depth increases the average temperature also increases. Thus, it was concluded that at 3.5m was considered as optimum depth for further simulation. Also, concluded that 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 affect the outlet temperature.

Mathur et al. [84] focuses on the thermal saturation of soil and self-recovery ability of the soil between different (continuous and intermittent) modes of EAHE system which was set up in MNIT Jaipur, India. The numerical simulations were performed using Ansys FLUENT v14.5. It was seen that there was a good agreement between the measured and simulated results. After the validation of the CFD model, a comprehensive analysis was done to analyses the impact the soil temperature on EAHE. Results indicate that the soil temperature along the length decreases. Thus, ambient air temperature is also an important factor with soil temperature. For the study of heat penetrating the soil, the temperature profile in radial direction was simulated. Results showed that the soil temperature decreases as it moves away from the EAHE surface but the soil temperature around the pipe varies with ambient air temperature. This effect is analysed by considering the continuous and intermittent operation modes. In continuous operation, ambient temperature goes down and cools the heated sub soil which helps to recover its cooling ability. In intermittent operation mode through the heat conduction among the soil layers the soil temp can be recovered during non-working hours. The self-recovery temperature for continuous operation was more than intermittent operation mode.

Jakhar et al. [31] predicted the thermal performance of EAHE when coupled with solar air heating duct in Ajmer where the temperature ranges from 15-18 °C in winters. The inlet of solar air heating duct is connected to the outlet of the EAHE. In this study three modes were considered to estimate the thermal performance. The three modes were evaluated in four periods 14-16 January, 26-28 January, 1-3 February and 13-15 February. The results show that by using EAHE with solar heating duct increases temperature 1.1- 3.5°C inside the room. The heating capacity and COP for mode II was 665.52 kW and 1.54, for mode III heating capacity was increased to 1976.02 kW and COP 4.57. Thus, it was concluded that solar heating duct increases the heating capacity as well as the COP of the system for same power consumption.

Singh et al. [13] studied Chandigarh city for the installation of EAHE. Chandigarh is situated at latitude 30.74°N, longitude 76.79°E and at an altitude of 321 m. It receives a rainfall of 1110.7 mm. The cooling period is from April to October and heating period is from November to March. The soil type is sandy soil type in Chandigarh up to a depth of 3m with a water table of 5-15 m. The electricity demand in summers and winters is 350 MW but available is only 324 MW. The soil diffusivity varies from 0.084 to 0.14 m^2/day. Thus, Chandigarh city is suitable for the installation of EAHE.

Khandelwal et al. [85] studied heating and cooling load of a Library of MNIT, Jaipur. A simple excel model was developed. The library consists of 4 rooms conditioned with split AC to which EAHE was connected. For the cooling load estimation, total sensible and latent heat was considered including infiltration load. On survey, it was found the comfort temperature was 28.6°C. Results show the maximum temperature drop was 11.5°C and length of the pipe was 72 m. Cost analysis results Rs. 1149380 was estimated for its installation. The cooling load was 77 kW including ventilation load and the cooling capacity of EAHE was 60781 kW.

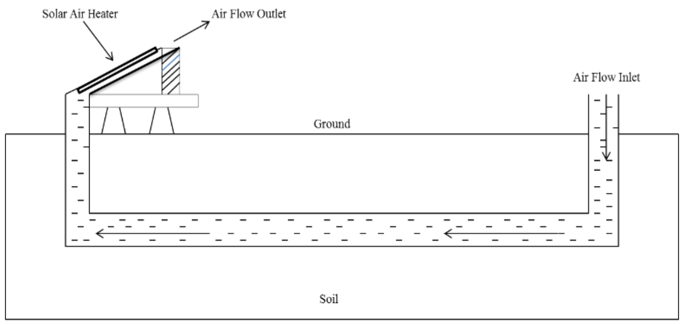


Figure 13: Schematic diagram of EAHE with SAHD

Kaushal et al. [86] used FVM to investigate the thermal potential of hybrid EAHE. This study also used response surface method is used to optimise the process parameters using Ansys Fluent. The numerical results are compared to individual EAHE. The EAHE is made hybrid by coupling it with a solar air heater. The schematic diagram of the setup is given in figure 14. The temperature contours along the length were studied which shows that temperature increases with increase in length. The results of only EAHE was validated against the data reported by Bansal [74]. The results of HEAHE were validated against the experiment set up. Response surface methodology uses f-test and ANOVA technique to estimate the factors affecting the input variables. Results show that the potential or solar heat gain decreases with increase in temperature. Results show that for hybrid EAHE shows maximum temperature drop. Thus, HEAHE shows good performance than EAHE.

Misra et al. [87] emphasises on the use of low cost material like PVC to the cooling potential .This focuses on the design of the duct system. The experimental setup was made as a prototype model where the base of the model was a metal tray. As noted earlier the performance of EAHE depends on the air velocity and on the material of the pipe. Thus, a cheaper material can be used for the analysis. It was observed that the minimum EER for the system was 3.78 which were almost equal to an energy star5 rating. Thus, EAHE also consume less energy than convention systems. This study suggest that the prototype model can be used in small houses which can maintain the room temperature lower than outside temperature during summer season. The author recommends the EAHE to use domestically in houses to achieve thermal comfort. Thus, EAHE is an energy efficient system when compared with energy star rating system.

Bisoniya et al. [88] developed a model to study the different design parameters pipe length, radius, depth of burial and air flow rate to estimate the thermal potential of EAHE. For one dimensional model a relation was derived between inlet and outlet temperature by giving a description of pipe. This shows that performance of EAHE as steady state 1D model. 2D models are used to calculate the ground temperature at surface at 5 different depths. Finite element methods are used to solve the conduction problems. 3-D models are developed to analyse the performance analysis also provides room for all types of grid geometry. For solving 3D heat transfer and energy equation CFD is used. For complex fluid flow and heat transfer process in any heat exchanger CFD software alike Ansys FLUENT, STAR CD, CFX, FIDAP, CFD2000, PHOENICS, ADINA can be used.

Choudhury et al. [27] investigated an experimental study of EAHE design using low cost material like Bamboos and hydra form to reduce energy consumption. An open loop EAHE system was used to predict the potential of EAHE. The experiment was conducted in Arunachal Pradesh. The study mainly focuses on the use of locally available materials. Out of all locally available materials bamboo was selected for the pipe material. The thermal conductivity of bamboo was increased by using hydra form plaster. PVC pipes were used to install sensors for the measure of temperature gradient. The inlet and outlet was formed using PVC pipes and bricks. Results show the maximum humidity recorded was 98%. Irrespective of the inlet temperature, outlet temperature range between 25- 26°C. Results also show variation of outlet temperature with air flow velocity. It was seen that using of bamboo with hydra form plaster in the tunnel, reduces the outlet temperature by 10-15°C which reduces the electricity consumption. Thus, this type of tunnel configuration is very effective for agricultural and residential buildings. EAHE supplies fresh air ventilation and is save for environment. It also reduces the CO_2 emission which helps in environment management.

Mathur et al. [89] studied the thermo-physical properties of soil on the performance of EAHE. The study was validated using 3D transient numerical model for 3 different soil type. A CFD model was formulated and solved using Ansys FLUENT 6.3. For the creation of geometry Gambit 3.3 was used. The model was validated against the numerical model developed by Mishra,2013[80]. The three soil types selected for the study are: Soil J, F and A. The results also imply that there was more heat penetration in the surrounding soil for J and F soil type as they have high thermal conductivity than soil type A. Thus, the performance of soil type J and F were similar because soil with high thermal conductivity have high rate of heat transfer

From the literature survey, it can be concluded that the performance of EAHE system depends on the material type of the pipe, length of the pipe, diameter of the pipe, pattern of the pipes laid on the ground, underground soil temperature, soil properties, soil thermal conductivity, inlet flow velocity, geographical and climatic conditions. For the computational formulation selection of suitable software like FLUENT, TRNSYS, EnergyPlus, REHAU. The performance parameter that are affected are the pressure drop, temperature drop at the inlet and outlet, convective heat transfer coefficient, Reynolds Number, Friction factor, overall heat transfer coefficient, heat capacity and total heat generated by the system. In case of coupled EAHE system the coefficient of performance is greatly affected. The significance of Boundary layer formation inside the pipes has not been brought into focus. It has been observed in the literature that least studies have been conducted considering the pipe geometry and also effect of pipe material on EAHE is not significant. Thus, an attempt can be made by comparing different duct geometries with different duct material considering the boundary layer formation inside the pipes. Computational software such as ANSYS Fluent, STAR CD, EnergyPlus, Comsol etc. can be used as the simulation tool to evaluate the performance of EAHE.

5. RESEARCH METHODOLOGY

The study intends to computationally find the best pipe geometry and material for EAHE suitable for Indian climatic conditions. For the study four different pipe geometries such as circular, square and triangular-corrugated and circular-corrugated and four different pipe materials such as Aluminium (Al), Steel (St), Copper (Cu) and Polyvinylchloride (PVC) were considered. The Computational Fluid Dynamics analysis was run using Ansys FLUENT v15.0. Ansys FLUENT is computational fluid dynamics (CFD) software generally 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. In this study, this software was used to evaluate the functioning of different types of pipe geometries and materials to obtain favorable outlet temperature. The expected results will be in the form of temperature difference between the inlet and outlet of the EAHE system.

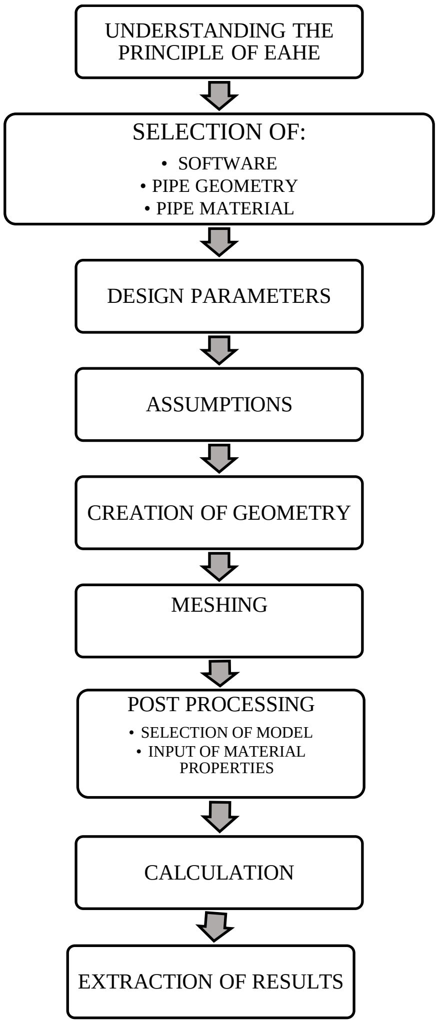


Figure 14: Flowchart of the methodology

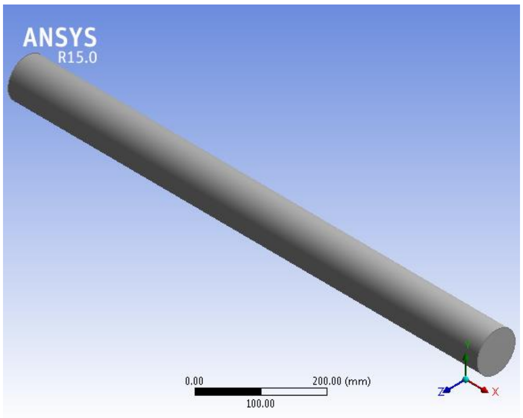
5.1 Selection of Pipe geometries and pipe materials

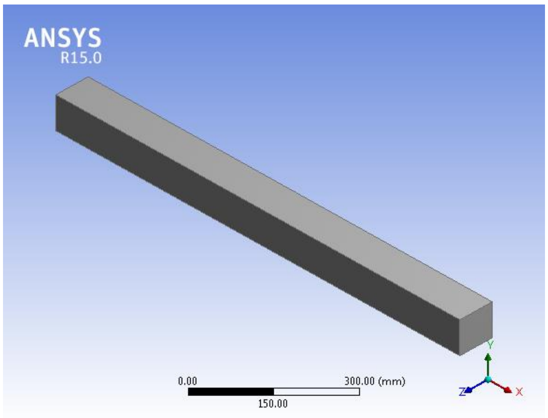
The geometries and pipe materials considered are discussed in details for better understanding of the study.

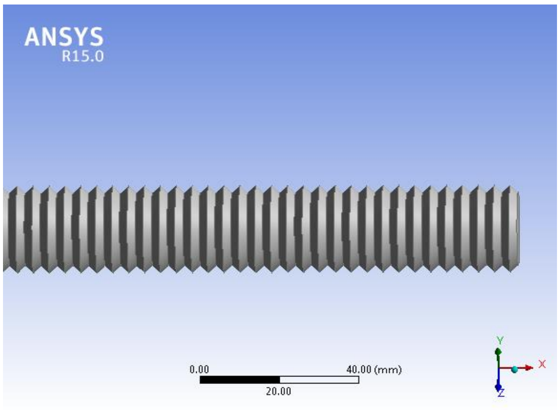
5.1.1 Pipe Geometries

- 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.
- Corrugated geometries: 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 considered for the simulations are shown in figure 15.







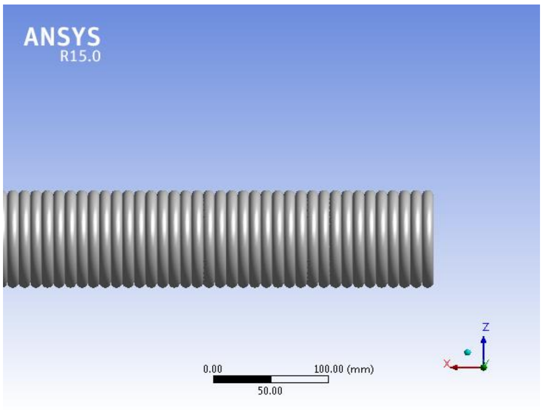


Figure 15: Different pipe geometries considered for simulation (a) Circular; (b) Square; (c) Triangular-corrugated; (d) Circular-corrugated

5.1.2 Pipe Materials

The study considers four different pipe materials to evaluate the affect the temperature variations. Thermal conductivity is an important property in heat transfer which may be defined as the ability of a material to conduct heat. Thus, selection of material was done on the basis of the thermal conductivity. 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 6.

Table 6: Thermo-physical properties of materials considered for simulation

Material	**Density (Kg/m^3)**	**Specific Heat Capacity (J/Kg K)**	**Thermal Conductivity (W/m K)**
PVC	1380	900	0.161
Copper	8978	381	387.6
Aluminium	2719	871	202.4
Steel	7833	465	54
Air	1.225	1006	0.024

5.2 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.

- The wall thickness on consideration of pipe material is 0.001m for all the pipe geometries.

5.3 Design Parameters

Table 7: Design parameters considered for simulation

Design Information								
Geometry	Circular		Square		Triangular-Corrugated		Circular-Corrugated	
Mode	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Inlet temperature	318K	278 K	318K	318K	318K	278 K	318K	278 K
Hydraulic Diameter	0.08m		0.08m		0.08m		0.08m	
Length of pipe	1m		1m		1m		1m	

5.4 Creation of Geometry and Meshing

A 3-dimensional model of all four geometries is created in Ansys design modeller and meshing is done using Ansys ICEM CFD. 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 of different shapes like tetrahedral, pyramid, hexahedral etc. In the study a general meshing was considered without undergoing any mesh independence test for all the pipe geometries. The mesh information for all the pipe geometries are given in the table 8.

Table 8: Mesh Information of the geometries considered

Mesh Information				
Geometry	Circular	Square	Triangular-Corrugated	Circular-Corrugated
Nodes	4212	2484	29559	2351349
Elements	3280	1700	24000	2271000
Element type	Hexahedral	Hexahedral	Hexahedral	Hexahedral

5.5 Post-processing

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 model for turbulence are K-epsilon, K-omega, Spart - allaras etc. model. Generally, K-epsilon model includes three models Standard, RNG and realizable model is used for viscous heating, buoyancy effect etc. The RNG models can be used for differential viscosity model where low Reynolds number is included under turbulence viscosity. The turbulence model is selected for thermal modelling of flow having Reynolds number greater than 4000. In the present study, K-epsilon model with standard wall treatment is considered.

5.5.1. Selection of model and materials

i. Steady State
ii. Pressure based
iii. Energy Equation
iv. K-epsilon Model
v. Fluid medium: Air
vi. Solid Medium: Aluminium, Steel, Copper, PVC

5.5.2 Boundary Conditions

Inlet Condition:

Velocity magnitude: 2-5m/s

Inlet Temperature: 318K (summer), 278K (winter)

Wall Condition:

Wall Thickness: 0.001m

5.6 Extraction of Results

The results of the CFD simulation were extracted for two seasons (summer and winter) by varying the velocities from 2-5m/s for all the considered geometries and materials. The results were in the form of temperature reduction. The variable considered were:

i. The variation of temperature along the length.
ii. The behaviour of Pressure drop and Reynolds number.
iii. Variation of Nussult number over Prandtl number.

6. RESULTS AND DISCUSSSIONS

In this paper, the simulations results were carried out for two seasons (summer and winter). For the study of temperature reduction, the parameters such as velocity, length, Pressure drop, Reynolds number and Nussult number were examined for the all four geometries by taking the four-pipe material into account. The slope of each graph presented in this paper indicates different pipe geometries such as orange indicates round geometry, blue indicates the square geometry, grey indicates triangular-corrugated geometry and yellow indicates circular-corrugated geometry.

6.1 Variation of Temperature along the length at different velocities for all pipe geometries and materials.

The temperature variation for the four pipe geometries were investigated at different velocities ranging between 2-5m/s for both the seasons. The velocity range chosen was quite low keeping in mind the design dimensions as well as suggested in literature. Based on Indian climatic conditions, during summer season the inlet temperature considered was 318K. In order to study the temperature reduction for the four pipe geometries, the temperature variation from inlet to outlet along the length was considered. The simulation results indicate that there was decrease in temperature at the outlet in reference to the inlet temperature at 2m/s as shown in figure 16 (a). For the same pipe material such as PVC, the triangular-corrugated pipe resulted a drop of 13.24 K in comparison to the other three geometries. Also, on comparing both the corrugated geometry pipe, triangular-corrugated pipe geometry resulted a maximum drop. While varying the velocities from 2-5m/s a similar trend was observed for all the pipe geometries. It was concluded that on varying the velocities from 2-5m/s the outlet temperature increases with increase in the inlet velocities. Thus, the inlet velocities are a direct function of outlet temperature during summer season.

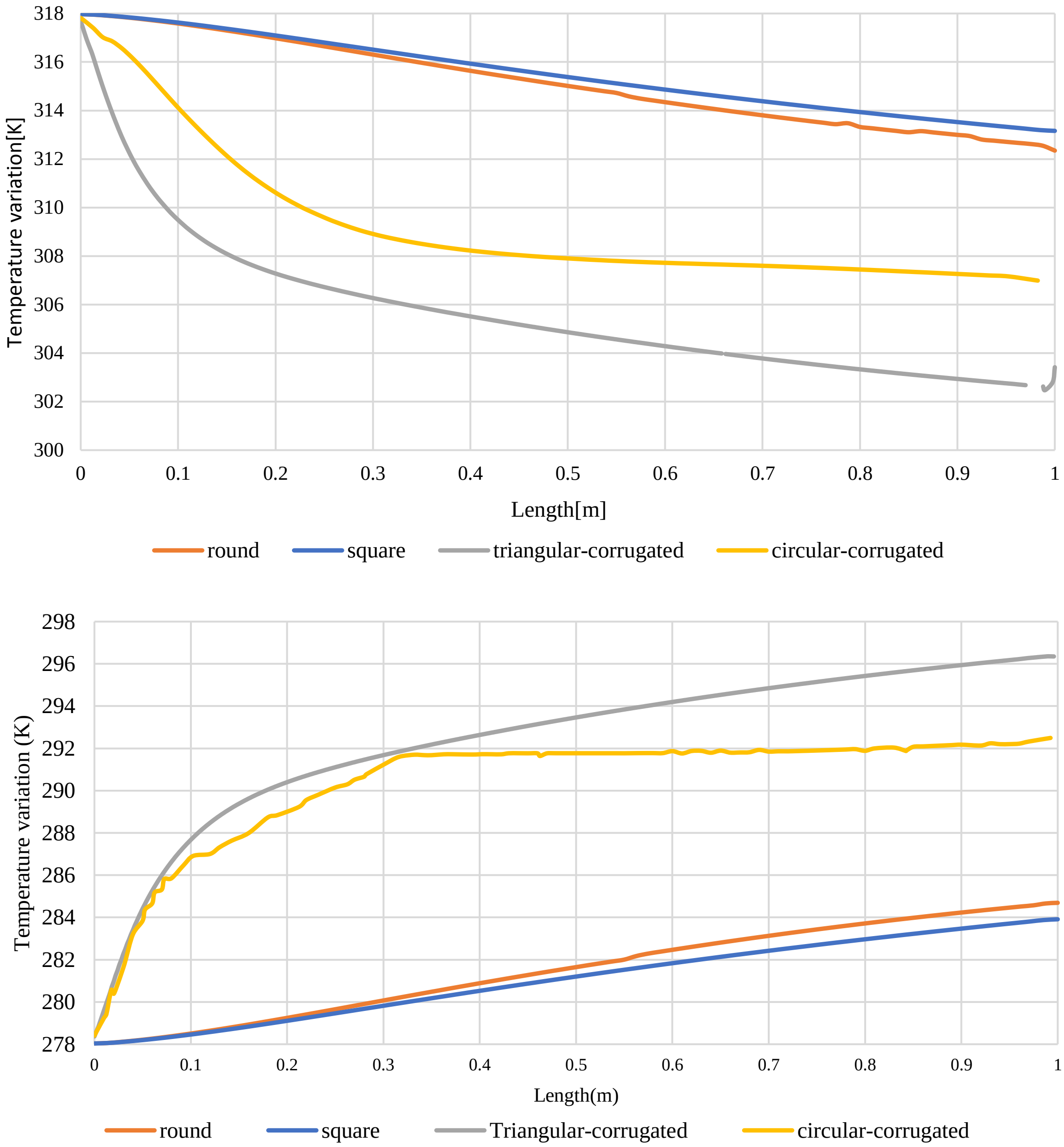


Figure 16: Temperature variation along the length for all pipe geometries at 2m/s (a) Summer season; (b) Winter Season

Again, during winter season the inlet temperature considered was 278 K. The simulation results suggest that at 2m/s there was rise in outlet temperature in reference to the inlet temperature as shown in figure 16 (b). Again, keeping the pipe material constant as in summer season the triangular- corrugated pipe resulted a drop of 16.81 K at inlet velocity of 2m/s in comparison to the other three pipe geometries. Also, on comparing both the corrugated pipe geometries triangular-corrugated pipe indicates maximum temperature drop. Moreover, on varying the velocities from 2-5m/s, a similar trend of variation was observed for all the geometries. However, on varying the velocities from 2-5m/s, the outlet temperature decreases with increase in the inlet velocity. Thus, the inlet velocity is an inverse function of outlet temperature during winter season. The results for both the seasons shows a good agreement with the literature stated above in reference to temperature variation. Thus, the results infer that in order to obtain optimum temperature variation for both the season, triangular- corrugated geometry pipe is the most appropriate pipe geometry amongst the four irrespective of the pipe material. It can also be concluded from the results that the EAHE system is beneficial to use during summer as well as winter season in Indian climatic conditions.

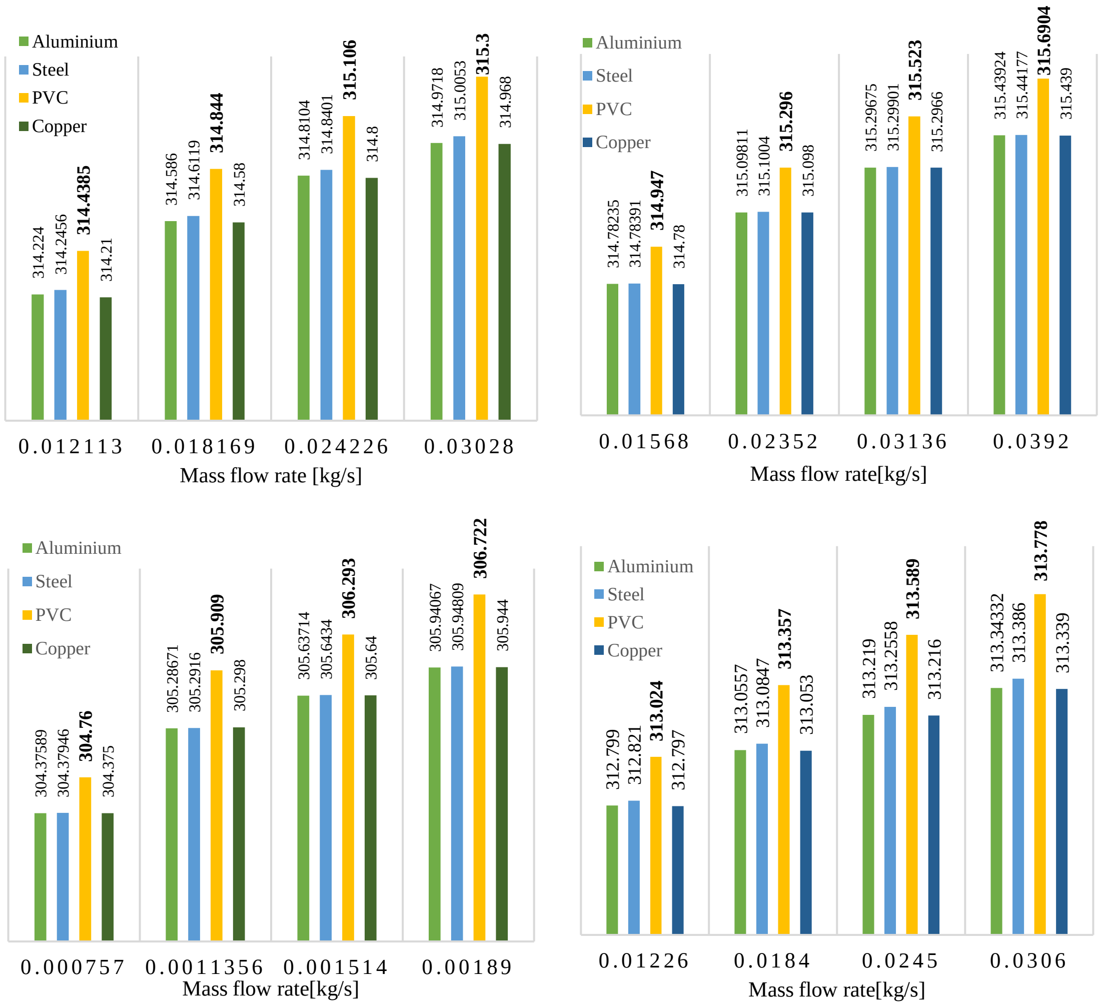


Figure 17: Variation of outlet temperature at different mass flow rates considering four- pipe material for all pipe geometries (a) Circular; (b) Square; (c) Triangular-corrugated; (d) Circular-corrugated during summer season

On considering the different pipe materials for all the pipe geometries for both the seasons, it can be clearly noted that there rise in outlet temperature during summer season and decrease in outlet temperature during winter season for all four materials as shown in figure 17 and 18. It can be observed from figure 17 and 18 that there almost similar variation of temperature for Aluminium, Steel and Copper pipe materials. PVC also does not show significant difference in temperature for all the pipe geometries during both the seasons.

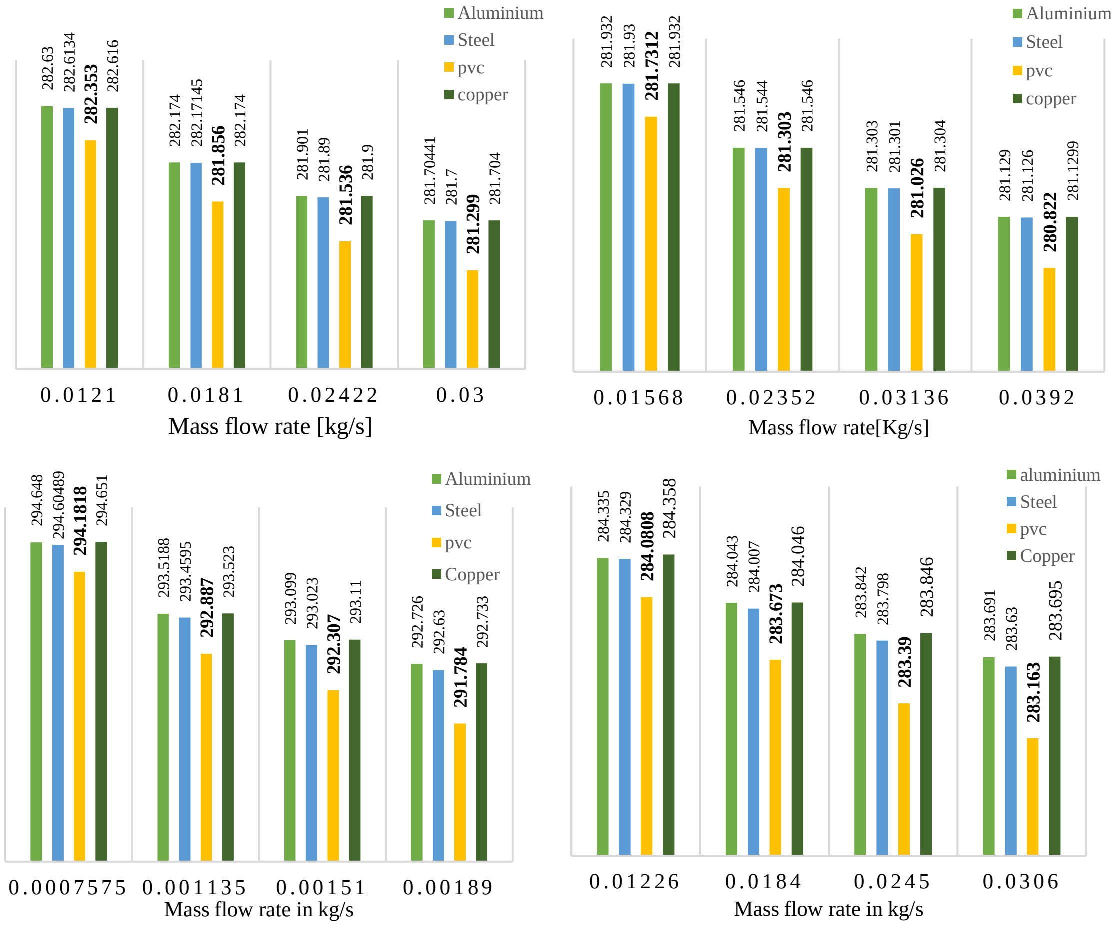


Figure 18: Variation of outlet temperature at different mass flow rates considering four- pipe material for all pipe geometries (a) Circular; (b) Square; (c) Triangular-corrugated; (d) Circular-corrugated during winter season

Thus, it can be clearly concluded from the figures above that irrespective of the pipe geometry the pipe materials do not have significant variation in outlet temperature that might affect the performance of EAHX. The above statement is in good agreement with the literature. Hence, cheaper pipe materials can be used for the reduction of the capital cost.

6.2 Behaviour of Pressure drop and Reynolds number for all pipe geometries.

Generally, pressure drop may be defined as the variation between inlet and outlet section of a pipe flow. Pressure drop is developed in a pipe considering the frictional forces acting on the fluid. Liquids and gases flow in the direction of low pressure. The pressure drop in a pipe is affected by various factors such as surface roughness, tube convergence, pipe fittings, pipes materials etc. Low velocities results in low pressure drop. Ordinarily, the pressure drop is calculated using Reynolds number and relative roughness of the pipe. However, Reynold number provides the information about the flow (laminar or turbulent). Reynolds number may be defined as the ratio of the inertial forces and viscous forces. In this study, the flow results in low Reynolds number where the viscous forces are dominated.

The variation of Pressure drop over Reynolds number on varying the inlet velocity from 2-5m/s is shown in figure 19 (a), (b). The figure clearly indicates that as the Reynolds number increases the pressure also increase irrespective of the seasons. Also, it can be observed that the triangular-corrugated pipe resulted in maximum pressure drop as compared to the other three geometries. Thus, the pressure drop and Reynold number of a pipe is in direct variation with the inlet velocity.

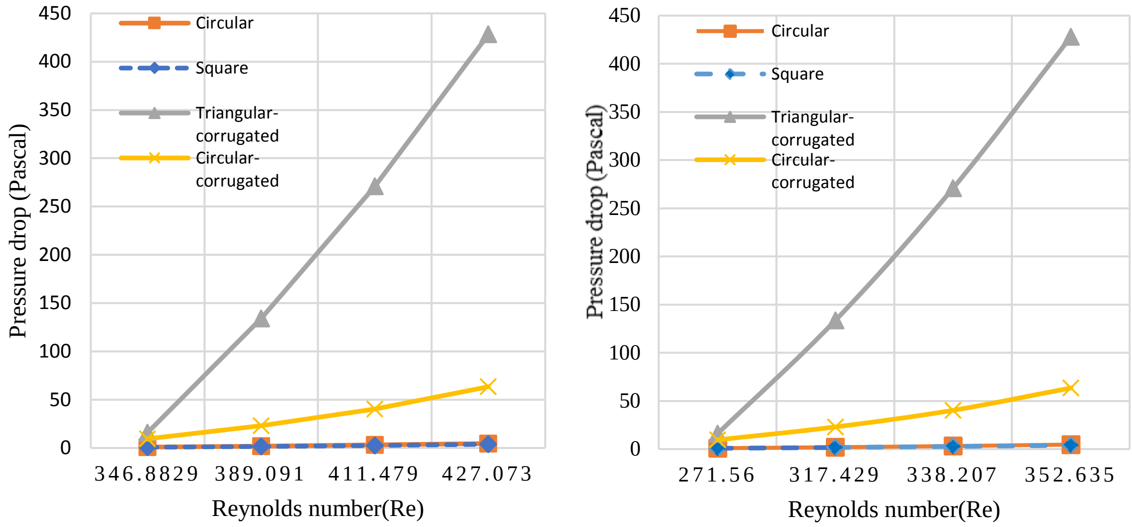


Figure 19: Variation of Pressure drop and Reynolds number for two seasons (a) Summer; (b) Winter

6.3 Effect of Prandtl number over Nussult number for all the pipe geometries and materials.

In heat transfer studies the dimensionless quantities such as Prandtl number and Nussult number are generally considered. The Nussult number is a function of Prandtl number and Reynolds number. The Nussult number is considered to make a comparison between the conductive heat transfer and convective heat transfer whereas Prandtl number is considered to study about the type of fluid (information about thermal thickness and hydrodynamic boundary layer). In this study, the variation of Nussult number over Prandtl number at different inlet velocities for all four-pipe geometry and four-pipe material are investigated.

The variation of Nussult number over Prandtl number for velocities ranging betweeen 2-5m/s as shown in figure 20 and 21. It can be clearly observed that the triangular-corrugated pipe have the lowest Nussult number in both the cases irrespective of the pipe materials. Also**,** from the figure 20 and 21 it can be clearly stated that the Nussult number value increases with the increase in Prandtl number during both the seasons for varible inlet velocities thus confirming that Nussult number is a function of Prandtl number.

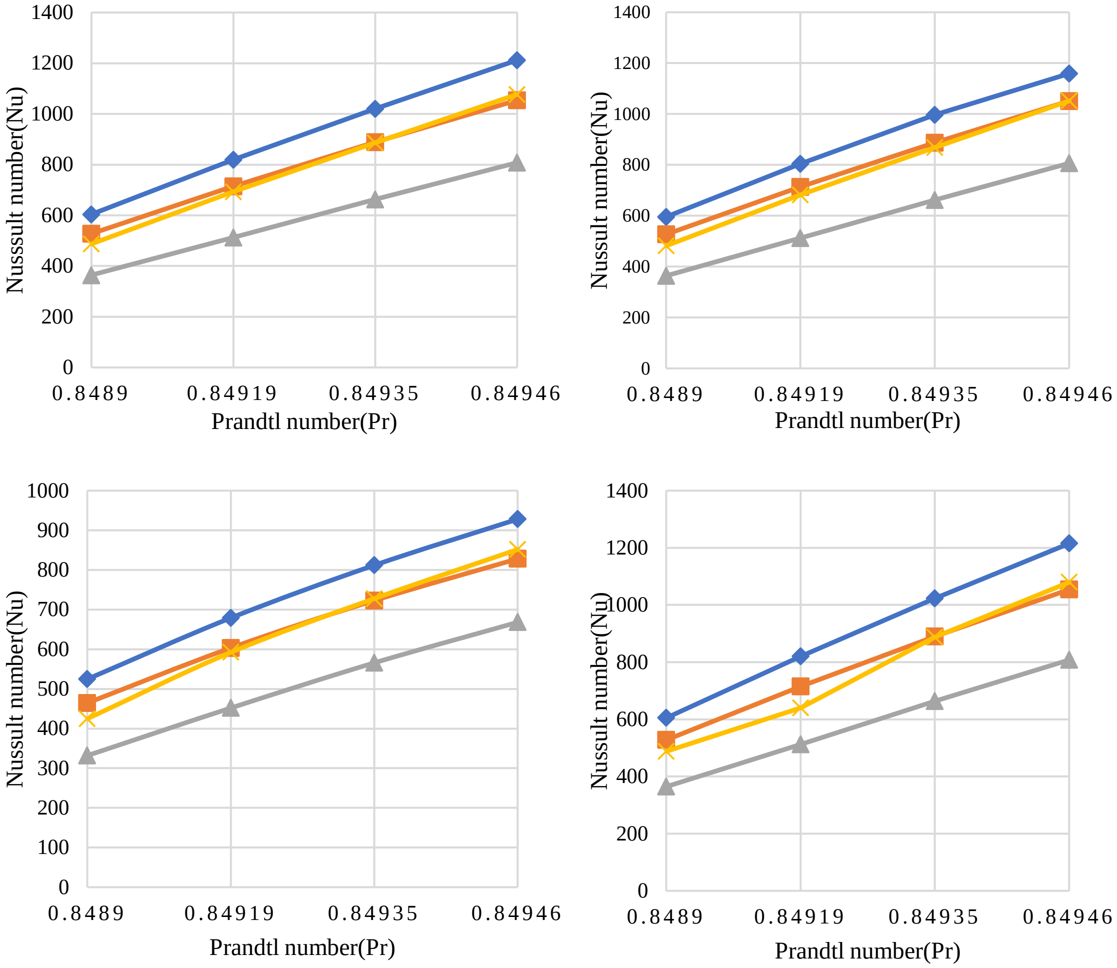
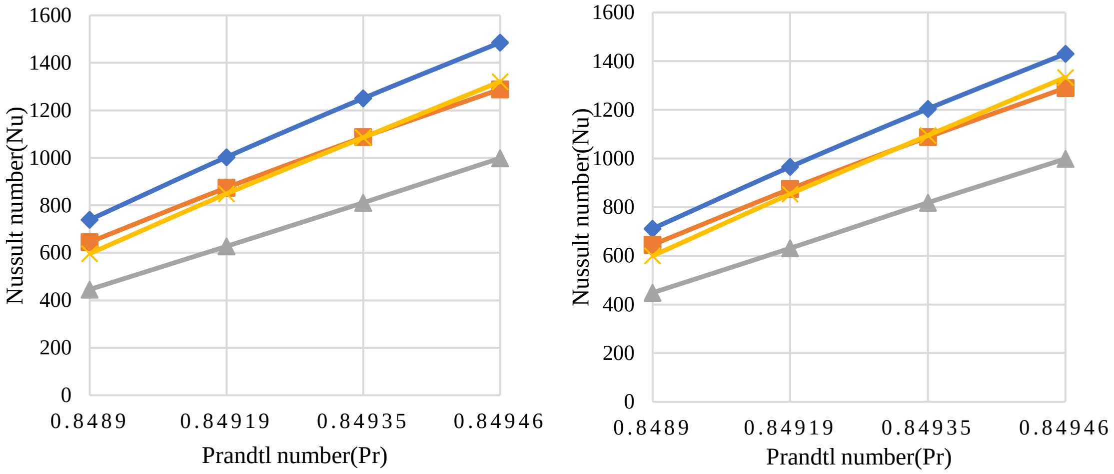


Figure 20: Variation of Nussult number over Prandtl Number for different pipe materials during summer season (a) Aluminium; (b) Steel; (c) PVC; (d) Copper



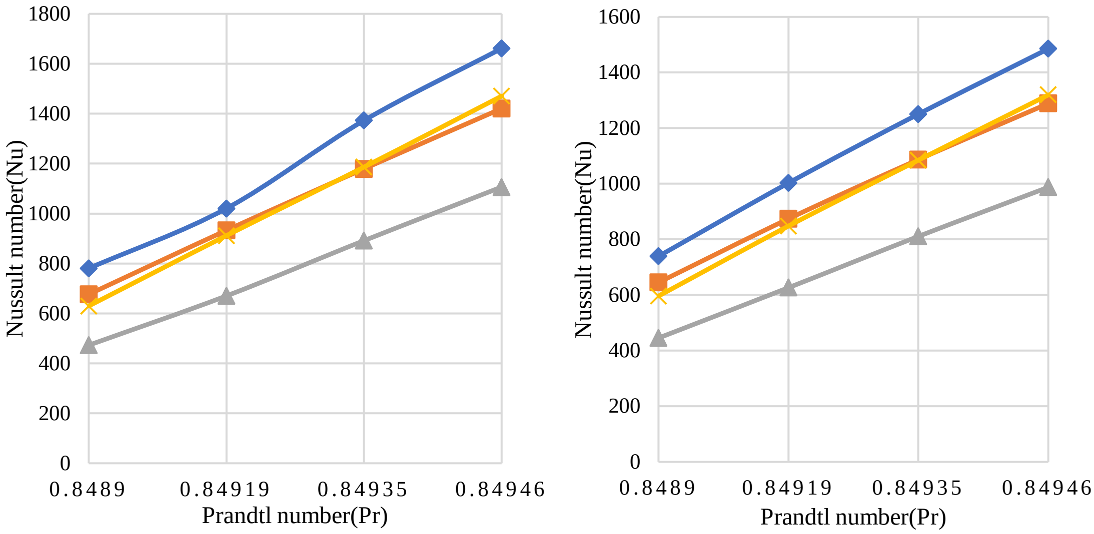


Figure 21: Variation of Nussult number over Prandtl Number for different pipe materials during winter season (a) Aluminium; (b) Steel; (c) PVC; (d) Copper

7. CONCLUSION

Energy consumption in building for thermal comfort a quite high thus numerous passive heating and cooling techniques and strategies are introduced to save energy. One such passive technique is EAHE that uses geothermal energy. This paper aims in studying the cooling and heating potential of EAHE system. Also, approaches to find the appropriate pipe geometry to obtain optimum temperature drop using CFD that will help the occupants for thermal comfort. The CFD simulations were carried out using Ansys FLUENT. In the study four different pipe geometries such as circular, square and triangular-corrugated, circular-corrugated geometry and four- pipe materials such as Aluminium, Steel, PVC and Copper of 0.001m thickness was considered. The simulations were carried out for two seasons (summer and winter). The results reveal that there was appreciable temperature variation while comparing the four geometries. As suggested in the literature the pipe material was not taken into much importance.

Based the result of the CFD simulations it can be established that the pipe geometries can have large impact on the performance of EAHE system. During summer season the maximum drop in temperature was 13.24 K and 16.18 K during winter season at 2 m/s. Thus, EAHE system is beneficial for Indian climatic conditions. Again, in case of pressure drop and Reynolds number, both the variables are direct function of inlet velocity for all the four-pipe geometry. Also, for both the seasons there was similar trend of variation was observed irrespective of the pipe material. In the variation of Nussult number over Prandtl number, the results indicate that the Nussult number is a function of Prandtl number. But during summer season there was a negative variation of Nussult number was observed and vice versa during winter season. This kind of variation was observed for inlet velocities ranging between 2-5 m/s. Thus, the inlet velocity and pipe geometries plays an important role in estimating the performance of EAHE system. This study confirms the objective that the appropriate pipe geometry is the corrugated pipe geometry for optimum temperature variation. Also, reasserts that the EAHE system can be used for space heating as well as cooling in Indian climatic conditions. In order to obtain maximum temperature reduction corrugated pipes can be laid underground for further experimentation in this field.

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