Parametric Investigation on Various Earth-Air Heat Exchanger (EAHX) Models Using Computational Fluid Dynamics

DISSERTATION

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By

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CERTIFICATE

I hereby certify that the work which is being presented in the Dissertation entitled **"Parametric Investigation on Various Earth-Air Heat Exchanger (EAHX) Models Using Computational Fluid Dynamics"** in partial fulfillment of the requirement for the award of degree of **Master of Technology** and submitted in Department of Mechanical Engineering, Lovely Professional University, Punjab is an authentic record of my own work carried out during period of Dissertation under the supervision of **Mr. Aashish Sharma**, **Assistant Professor**, Department of Mechanical Engineering, Lovely Professional University, Punjab.

The matter presented in this dissertation has not been submitted by me anywhere for the award of any other degree or to any other institute.

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Date: **(Arpit Thakur)**

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

Date: **(Mr. Aashish Sharma)**

Supervisor

Acknowledgement

This Dissertation was a welcome and challenging experience for me as it took a great deal of hard work and dedication for its successful completion. It's my pleasure to take this opportunity to thank all those who help me directly or indirectly in preparation of this report.

I would also like to offer very sincere thanks to my guide "Mr. Aashish Sharma" who supported me technically as well as morally in every stage. Without his guidance and support, this would not have seen light of the day.

It gives me an immense pleasure in expressing a deep sense of gratitude and sincere thanks to Lovely Professional University.

There are times in such projects when clock beats you again and again and you run out of energy and you want to finish it once and forever. Last but not the least I would like to thank family and friends for their boost and support in every sphere. Their vital push infused a sense of insurgency in me.

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Abstract

In view of present day sources of producing energy and their depletion rate, there is a large shift of attention on using non-convention sources of energy so that the conventional one's can be sustained. Similarly, space heating or cooling systems requires larger power input in order to achieve human comfort for its conditioning. Hence there is a need to concentrate on effective utilization of energy available naturally.

This work is an attempt in minimizing the power consumed for space heating or cooling by conventional appliances like AC or heat pumps. This system can utilize ground as heat source for winter conditions and heat sink for summer conditions. An effort is made by installing pipes buried at sufficient depth in ground and blowing air inside the section of pipe by a blower so that air can accept or reject its heat from or to the ground. Since the temperature of ground after sufficient depth become independent of variable climatic conditions, hence this system can be proved very prolific in full or partial heating or cooling of our homes, offices, schools etc. This work advocates about the changes a finned pipe can cause in the output of the system and how different parameters can be varied to obtain optimized result and hence a comparison can be drawn on the output behavior of a finned and finless EAHX.

1. Introduction

Energy scenario these days majorly deals with carbon and its many forms which come under conventional sources of energy, from lightening up of homes to operating heavy machinery or several other applications require a large quantity of such fuels. Availability and utilization of these fuels comes under one of the most important factors which decides economic growth and influence of a nation, hence the need of conservation and efficient management of these fuels have become an utmost priority. India's major sources of power generation are coal (59%), hydraulic energy (17%), renewable energy (12%), natural gas (9%), oil (1%), and nuclear energy (2%).

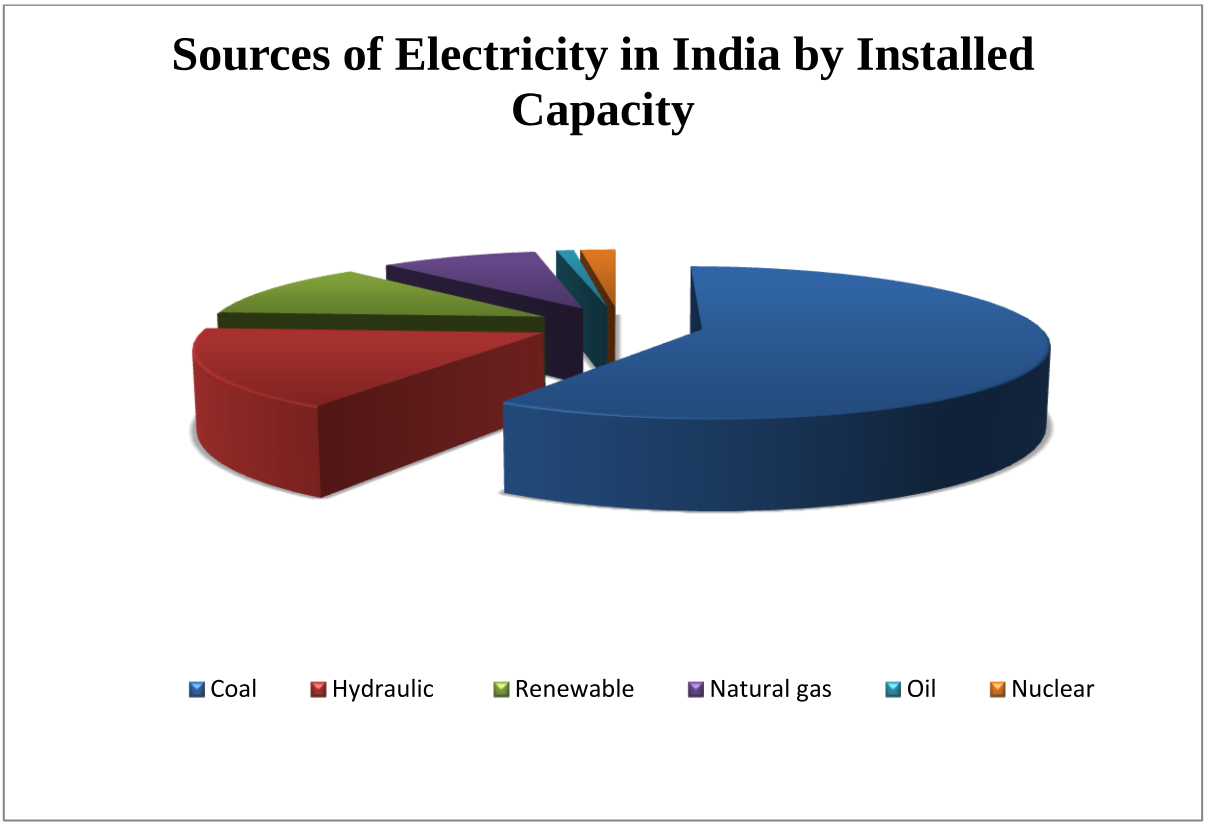

Figure 1.1 Sources of electricity in India by Installed Capacity Reference: Power Sector at a Glance "ALL INDIA"

At the end of September, 2014 India achieved the installed capability of 254.049 GW (Coordination Division of CEA, Government Of India, 2014) which is world's third largest producer of electricity after Japan and Russia. But after rigorous study and surveys it is estimated that India's demand for electricity will cross 300 GW shortly, thus to meet this demand 400 GW installed (according to "Powering India: The Road to 2017")capacity is required.

A large part of power plant's production is supplied for the domestic purposes like lightening, cooling, entertainment appliances etc. In countries like India, people use to spend a great portion of their pockets for space cooling and heating.

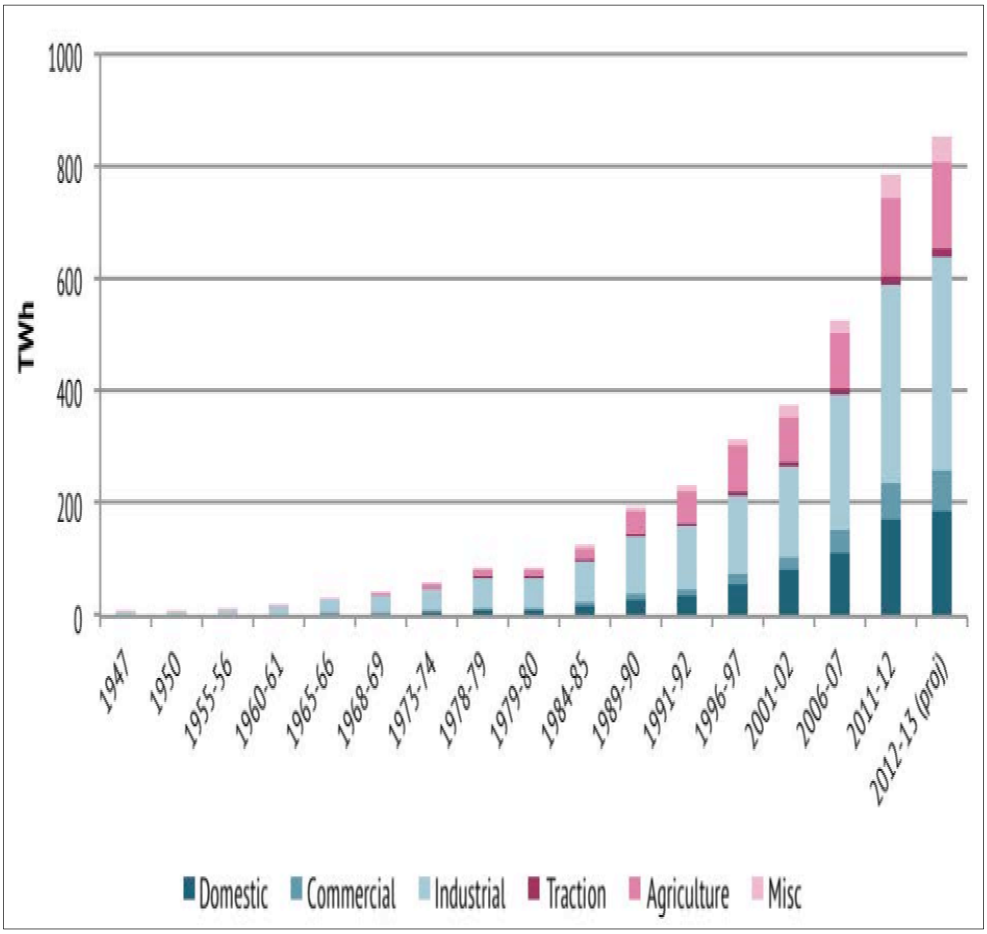

Figure 1.2 Rises in the Consumption of Electricity in India as Reported by Planning Commission, 2011

In a research of Issac and Van Vuuen (2009) they projected that at the end of 21st century, energy required for domestic conditioning multiplies 40 times of what we need today. According to the studies of Sivak (2009) present condition is 87% homes of U.S. have air conditioning, while in India, only 2% of homes have air conditioning, by 2030 India will catch up with the USA in the number of air conditioning units used within the country. Therefore we can estimate how tremendously the need of energy for space conditioning will increase.

Above data and information are bit alarming as the reserves of coal and most of the other fuels are diminishing promptly. Hence the necessity of finding alternatives of these conventional sources of fuels has been stressed.

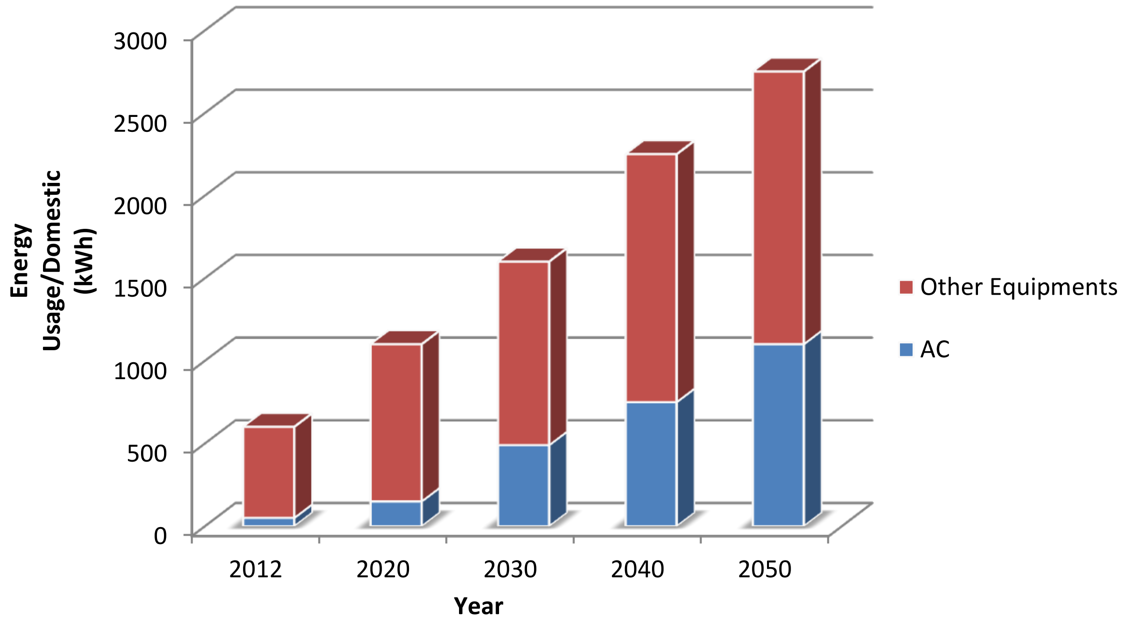

Figure 1.3 Domestic Energy Usage Source: Residential Buildings in India: Energy Use Projections and Savings Potentials, GBPN, 2014

A number of non-conventional sources of energy nowadays are being took into the consideration for producing energy and same methodologies are practiced to devise appliances which provide an option over devices which use electricity, for example solar water heaters.

1.1. Sources of Energy

1 **Solar Energy**: Radiation produced by the sun because of nuclear fusion reactions is termed as Solar Energy. It is transferred to earth via space in bundle of energy termed photons that interacts with the earth surface. The intensity of solar radiation at the outer atmosphere when the earth taken at its average distance from sun is referred as solar constant, the average value of solar constant is 1.37×10^6 ergs/cm^2 which is about 2 calories/ (min×cm$^{2)}$. Earth collects about 1.5×10^{21} W-h of solar radiation yearly, out of the energy transferred from the Sun. This massive amount of energy is greater than 23,000 times to that which is used by the human population on earth, but it is merely about two-billionth fraction of the Sun's enormous outburst about 3.9×10^{20} MW.

Solar radiation is weakened before arriving earth's surface by an atmosphere that eliminates or adjusts part of the incident energy by scattering, reflection and absorption. In particular, approximately all ultraviolet radiation and some wavelengths in the infrared region are eliminated. The total solar radiation which incidents on earth surface per year is greater than 10K times world's current energy usage. Radiation dispersed by striking water vapor, gas molecules, or dust particles is called as diffuse radiation. Clouds are a predominantly important reflecting and scattering agent, proficient of decreasing direct radiation upto 90**%.** The radiation coming at ground straight from the Sun is called direct or beam radiation. Global radiation is solar radiation arriving on the surface, including diffuse and direct. Development of solar research & technology aims at discovering most efficient ways to capture low density solar energy and devising a system to transform captured energy for beneficial purposes. Solar energy can be transformed to useful heat or work using a collector to absorb solar radiation, allowing much of the Sun's radiant energy to be converted to heat. Solar heat is directly used in agricultural, residential and industrial, which is converted to electrical or mechanical power, utilized in chemical reactions for production of chemicals and fuels [5].

2 **Wind Energy**: Large turbines are installed at long pillars so capture the energy of wind blowing at high velocity so that this energy can help to operate turbine whose work can be used in power house to generate electricity. Energy of wind can be in stand-alone applications or can be produced centrally and supplied to different electric grids. Energy of wind is an indirect form of solar energy; wind circulates due to uneven heating of land and water. This occurs at local, regional and global scales. Winds which flow near earth's surface are slowed down due to friction, which causes gusting and turbulence. As you go higher above the ground, the faster is the wind's speed due to lesser resistance.

There are large varieties of configuration of wind plants or turbines with various outputs are available. Usually, these plants produce either DC (direct current) or AC (alternating current) electricity. Direct Current wind plants are used to charge DC storage systems like batteries or to produce heat and electricity without storing it. Alternative Current wind plants are used for the production of electricity for supplying energy to a utility grid or for direct use. Another type of wind energy application is water pumping wind energy, which is used to pump water by mechanical energy obtained from wind, typically for agricultural applications. There are various systems used, few plants have vertical axis wind turbines (VAWT) while others have a horizontal axis (HAWT) most common ones. VAWT may look little like an eggbeater. Several wind plant use belt, gearboxes, or direct drives while designing. Various have rotor blades that change pitch to decrease speed and loads in high winds, while some have fixed pitch blades. Some HAWT designs face upwind and have tails while other face downwind without tails [5].

3 **Ocean Energy**: OTEC (Ocean Thermal Energy Conversion) is a tool to produce power using temperature variation of sea water of different layers at different depth. In this method cold water is pumped from ocean depth, nearly 1 km from surface and extruding energy from flow of warm surface water and cool water from the depth of ocean. OTEC make use of

temperature difference which exists between shallow and deep waters within 21°C of the equator in tropics to run a heat engine. Since the oceans are constantly heated by the sun and cover about 70% of Earth surface, that temperature difference carries a massive amount of solar energy that could possibly be tapped for our use. Some of the energy problems can be resolved if this type of extraction can be achieved economically and on larger scale. Ocean thermal energy is nearly two times higher than other available energy from ocean like wave power, because of its small temperature difference, extracting energy is costly and problematic. Hence, prevailing OTEC systems have a total efficiency of only 1 to 4%.

The idea of a heat engine is quite common in engineering. Typical heat engine includes a device which operates between a source at high temperature and a sink at low temperature. As heat flow from source to sink, a portion of heat is extracted by heat engine to convert it into mechanical work. Similar general principle is used in internal combustion engines and steam turbines, while refrigerators consumes a form of energy it can be heat or work to reverse the transfer of heat i.e. from cool body to heated body. In place of utilizing heat energy by the burning the fuel, OTEC draw power due to temperature differences induced by the sun's heating of the ocean surface [5].

4 **Nuclear Energy**: Utilization of energy present in nucleus of an atom by the process of fission, fusion etc. comes under nuclear energy. According to $E= mc^2$, E is energy, m is mass and c is velocity of light, in this process a mass is transformed into energy. The most terrible problems to be concerned about nuclear energy is the possibility of any mishap at fuel plant or nuclear reactor, like those of which occurred at Chernobyl of Russia (1986), Three Mile Island of USA (1979) and Takaimura of Japan (1999) and the probable threat to the continual existence on the human race stood by nuclear arms [5].

5 **Bio Mass**: Biomasses are organic materials obtained from animals and plants. Biomass composed of stored energy of sun. Absorption of sun light by the plants to make food in a process called photosynthesis. The chemical energy in plants gets passed on to animals and people when we eat them. Biomass is a renewable source of energy because we can always grow more crops, grass, trees and waste will always exist. Some examples of biomass fuels are crops, manure, woods and some garbage. When burned, the chemical energy in biomass is released as heat. Garbage or Wood waste is burned to produces steam which is used for generating electricity, or to provide heat to industries and homes. Apart from burning biomass there are other ways to release its energy. Biomass can be converted to other usable forms of energy like transportation fuels like ethanol, methane and bio-diesel. Methane gas is the main ingredient of natural gas. Smelly stuff like decaying garbage, human and agricultural release methane gas also called “biogas” or “landfill gas.” Crops like sugar cane

and corn can be fermented to produce the transportation fuel, ethanol, Biodiesel, another conveyance fuel that is produced from discarded food products like animal fats and vegetable oils. Biomass fuels provide about 3% of the energy used in the United States. People in the United States are trying to develop ways to burn more biomass and less fossil fuel. Using biomass for energy can reduce waste and support agricultural products that have grown in the U.S. Biomass fuels also have numerous environmental benefits [5].

6 **Geothermal Energy**: Earth can be a huge thermal reservoir as its core has a temperature of about 6000^{o}C. Heat is continuously transferred in different layers of soil by conduction from earth's interior and heat is transferred by means of convection from molten mantle under earth crust.

Geothermal energy is produced from the internal heat of earth. Heat further rises above towards earth surface heating volumes of water within few 100's and nearly 3k meters below. "Geothermal deposits" are these volumes of hot water which can be used to deliver heat or electricity according to their temperature. A lower energy deposit such as water within 274K to 304K at lesser depth can be used to heat swimming pools, greenhouses, and at times buildings (example the Maison de la Radio in Paris). Water within 304K and 363K at a depth ranging between 1,550 at 2,100 meters can be used to supply district heating (Paris is the largest deposit region in France). Energy deposits in medium range i.e. water within 363K to 423K at a depth ranging between 2,100 and 2,600 meters are used to supply electricity in some countries (two small deposits are there in France). In high energy deposits turbines are operated directly & supply electricity, high pressure steam/water at temperature of 423K to 623K (Guadeloupe is one of such facility in France) [5].

1.2. Earth-Air Heat Exchanger

It is one of the most promising techniques to minimize ill effects caused by burning fossil fuels to generate electricity in addition to the depiction of energy consumption displayed in the earlier section.

It is seen that temperature of ground at a depth of about 3 m to 4 m remains constant around the year and is equal to the annual average temperature of a particular locality. This constant temperature (earth's undisturbed temperature) remains lower than ambient temperature in summer season and vice-versa in winter. The EAHX is basically a series of concrete, metallic or plastic pipes buried underground at a particular depth through which the fresh atmospheric air flows and gets cooled in summer and vice versa in winter. This technology can utilizes heat capacity of earth effectively; hence this makes an earth-air heat exchanger as a storage type heat exchanger.

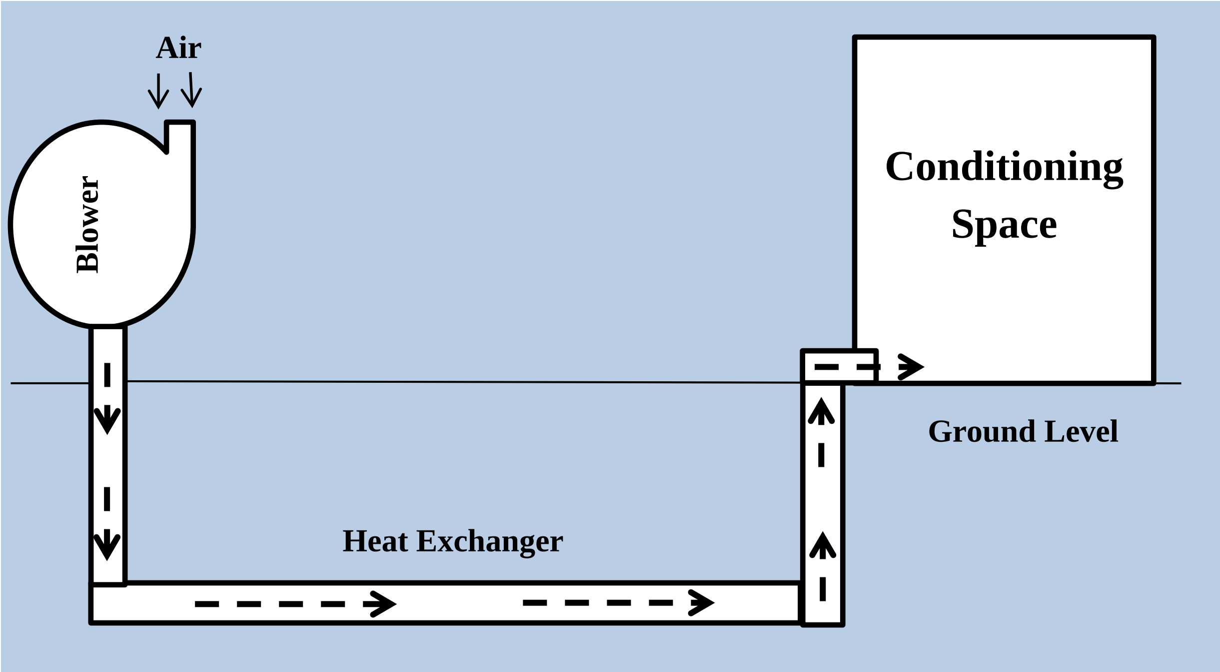

Figure 1.4 Working of Earth-air heat exchanger

The ground at the burial depth of pipe of EAHX acts as heat source in winter and as sink in summer for air which is used as heat transfer medium in the system. The EAHX system can effectively meet the heating/cooling requirement of the building if the temperature of air at outlet of the system is sufficiently high/low. Otherwise, additional heating/cooling of the outlet air may be achieved by passing it through the conventional air conditioners of lower capacity. The EAHX used in either way can result in reduction of high grade energy depletion. Numerous researchers have denoted that the earth-air thermal heat exchangers (EAHXs) connected with buildings are effective and passive energy source for space conditioning of buildings. The behavior of an EAHX system is mainly affected by surface conditions, temperature, and moisture distribution in the ground.

1.3. Classification

The classification of site for installation of EAHXs was done on the basis of geological properties of particular location. The information of thermal and physical properties of soil (thermal conductivity, density, diffusivity, etc.), depth of water, depth of bedrock, and type of soil helps designer in choosing correct type of EAHX system and in the design of the system.

The EAHX systems were mainly classified as open loop EAHX and closed loop EAHX system.

1. Open loop EAHX: In an open loop EAHX system, fresh air from atmosphere is drawn in buried pipes that gets conditioned to the earth’s undisturbed temperature and at

last it is supplied to the building to acquire the cooling/heating necessity of the building.

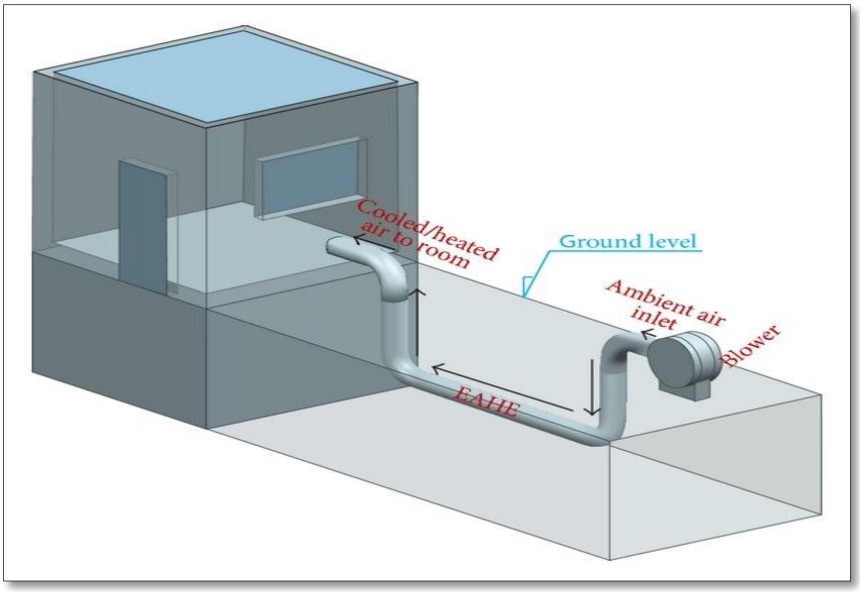

Figure 1.5 Open Loop EAHX Source: Bisoniya et al.

2. Closed Loop EAHX: In a closed loop EAHX system recirculation of the air drawn from building by the buried pipes is done. Air from inside the home is blown through a tube by the help of a blower it is conditioned to near earth temperature before resending it back, to be distributed through duct throughout the home or building.

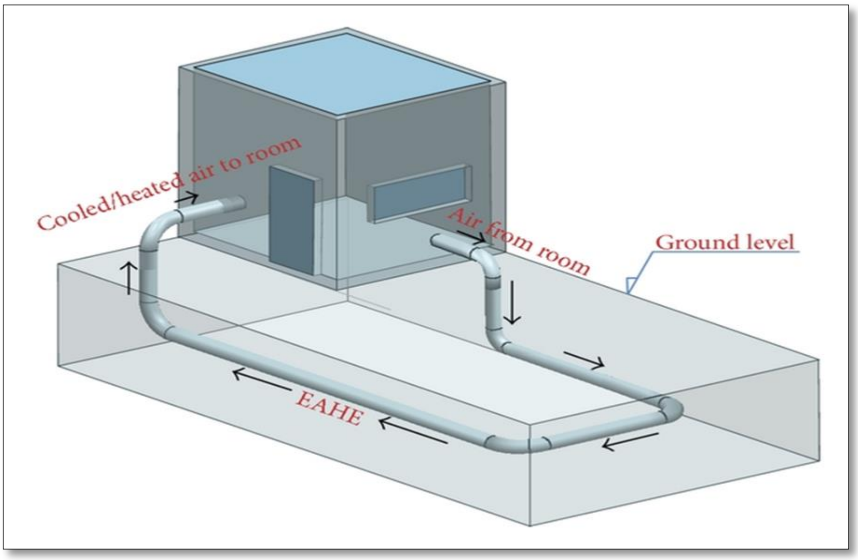

Figure 1.6 Closed Loop EAHX Source: Bisoniya et al.

1.4. Historical Background

In ground heat exchanger concept is not new it was first introduced in Zoelly, 1912 a Swiss patent. As the conventional theory of conduction of heat in pipe-ground developed, in 1948

Ingersoll & Plass bring back the concept of using ground like a heat reservoir. During the end of 40's & beginning of 50's a substantial effort in United States and European countries to encouraged development of heat pumps on commercial stage, however due to availability of cheaper energy this system was not economically challenging. Interests reduced and ultimately limit it to researches only, which is emphasized only on calculating heat extraction rates for installation.

At the distance of 2 meters in English moist condition of soil Griffith reported that for a copper pipe, heat is been extracted at the rate of 35-61 W/m in 1952, he concluded for a pipe material which is having higher thermal conductivity the rate of heat extraction is nearly independent to the diameter of pipe of ranging from 18 to 24 mm.

In 1954, rate of heat extraction ranging from 21-51 W/m for copper pipes of diameter 26 mm placed 1.5 m below the earth surface is published by Penrod. Fluker & Vestal, in 1956 showed that for copper pipes of 14 and 26 mm in diameter placed as deep as 1.5 m in Texas, rate of heat extraction found was upto 105 W/m is obtained from diameter of copper pipe as large as 51 mm.

In 1959 likewise results were published by Whitlow, Freund in 1959, Sumner in 1976 and Smith in 1956 similarly Ledbetter, Partin and Bose in 1979. In 1978 Fearon & Goulburn published analysis for vertical as well as horizontal configuration of ground heat exchanger, a het extraction rate of 32 W/m per heat tube is achieved for horizontally placed tubes while 35-45 W/m per tube is observed for vertically placed tubes.

With progression of availability of different piping material such as plastics and other polymerized pipes are being used due to its cost as compared with the conventional metallic pipes, but due to extremely poor thermal conductivity of plastics there is a significant drop in the heat extraction rate as Bose, Ledbetter and Partin in 1979 achieve heat extraction rate upto 20-50 Wm^{-1} for a polyethylene pipe of diameter 101.6 mm buried 1.2 m deep.

In Germany & Sweden there are a quite huge amount such heat pumps which uses ground's heat as source is installed. Since there is not a limit in the list of this thus all cannot be cited here in order of ranking. So many projects are enlisted on ground heat pumps in Nordic Symposium as mentioned by Hellstrom in 1979 and Rosenbald in 1979; Rouvel in 1975, Rudolf in 1979, Reiman in 1980 and Mostofizadeh & Schinke in 1981 have described about few installations in Germany. In these studies and installation majorly a horizontally placed pipe system is used with a pipe material as polyethylene of higher density, but a number of studies are also carried out on vertically placed systems which have a U-shaped return pipe that depicts about the shift of interest toward vertically configured system [10].

Recently Defense Research and Development Organization (DRDO) have successfully developed and installed India's first geothermal space heating system at Snow and Avalanche Study Establishment (SASE), Manali. Presently, it is working with output load capacity of approximately 115 kW, which is one third of the actual design capacity. According to scientists, the system requires input power supply of only 35 kW and saves about 69 kW with no carbon emission. It increased the room temperature up to 30-32^{o}C on mountains. The tested cooling temperature was 18-19^{o}C. With this unit in operation, it is estimated that annual reduction in carbon emission will be 14.2 tonnes with a payback period of only five to six years.

2. Terminology

Computational Fluid Dynamics: It is an approach to solve many physical problems as it is a comparable technique as pure theory and pure experimental approach for the solution and analysis of fluid problems. As a research tool it is used to solve complex heat transfer and flow problems.

Heat Exchanger: It's a device use in which heat gets transferred between two fluids at different temperature or between one fluid and another higher heat carrying capacity material. A heat exchanger can be classified in many ways but in general there are three types of heat exchangers, namely:

1. Transfer type HEs
2. Storage type HEs
3. Direct contact type HEs

Storage Type Heat Exchanger: A storage type heat exchanger is also known as regenerators. In this type of heat exchanger, heat is transferred from fluid or to fluid from a high heat capacity material like earth.

Earth-Air Heat Exchanger: An earth-air heat exchanger (EAHX) is a type of heat exchanger in which air is sent into pipe with the help of a blower or compressor which is buried deep inside the ground. This system makes use of the property of massive heat carrying capacity of earth so if, summer cooling is required than hot air will transfer heat to the ground or ground will extract heat from the air and cool it for further space conditioning and if winter heating is required than air will take heat from the ground and can be used for space conditioning hence it is an storage type heat exchanger.

Thermal Resistance: It is the obstruction offered in heat flow in a solid or fluid medium. It is the ratio of temperature difference to the heat flux. On the basis of mode of heat transfer thermal resistance is classified as conductive resistance and convective resistance. Its SI unit is W/m-K.

Nusselt Number: It is a dimensionless form of heat transfer coefficient which is the ratio of rate of heat transfer to the rate heat is conducted in the fluid for temperature gradient $\Delta T/l$.

$$Nu = \frac{hL}{K} = \frac{q}{\Delta T} \times \frac{L}{k} = \frac{q}{\frac{\Delta T}{L} k}$$

3. Objective of Study

Since studying factors that influence the performance of underground heat exchanger which has significant effect are dimensions of pipe like length and diameter, pipe material, fluid flow velocity. Thus studying an EAHX model revolves around these factors only.

1. Study is carried out for summer cooling conditions in which atmospheric air is required to be cooled efficiently with optimized design parameters and operating conditions.
2. To study the performance of EAHX model, by importing the model designed in Pro-E to ANSYS Workbench and fulfilling the necessary requirements like meshing the geometry imposing boundary conditions and interpreting the results displayed in FLUENT 14, study includes changes in the outlet temperature of air for given inlet condition at different sections of pipe and to find rate of heat added or extracted.
3. Applying circular fins over the length of the pipe.
4. Finding the optimum pitch length for the fins for maximizing the heat flux between air and ground to obtain the desired result.
5. Analyzing the changes in the output which can be obtained by the application of fins over the entire length of pipe with respect to the outlet temperature and heat flux relative to inlet conditions of air.
6. Executing a comparison between a finned and finless model. Combining the results of both models of EAHX, i.e. finned and finless models by plotting the output temperature of both models at different lengths of pipe and similar plot of heat flux.

Above steps will be done so as to find how this finned model can help in achieving better results as compared to those models which are normally analyzed and used.

4. Review of Literature

Svec et. al. [10] emphasized on important considerations while designing an in-ground heat exchangers. It is based on study conducted in laboratory to analyze the heat flow pattern of fluid transporting in plastic pipes placed in clay type soil. For different configurations an estimate of contact resistance and measurement of heat flow is studied. After analyzing several configurations of numerical models for transient, steady state and cyclical behavior it is observed that for plastic pipe heat flow reduces quite substantially. The resulting analysis is based on:

$$T_f - T_s(r) = \frac{Q}{2\pi}\left|\frac{1}{h_f r_o} + \frac{1}{k_p} ln\frac{r_1}{r_o} + \frac{1}{k_s} ln\frac{r}{r_1} + \frac{R}{r_1}\right|$$

5 systems considered that were kept at center of box.

(a) Solitary arrangement of pipes of PVC material with inner diameter of 4.75 cm and wall thickness of 0.25 cm and thermal conductivity to be 0.14 W/m-K.

(b) Similar to (a) but this one is bounded by saturated sand's ring with outer diameter of 0.1 m.

(c) Polyethylene pipe of inner diameter of 1.45 cm and wall thickness of 0.15 cm with thermal conductivity of 0.25 W/m-K.

(d) Liner PVC tube of outer diameter of 0.05 m and thickness of wall 9 mm with thermal conductivity of 0.10 W/m-K.

(e) Couples of tubes similar to (c) but 0.15 m apart.

Their analysis reflected that the operation of such system vastly depends on:

a) Contact thermal resistance present at the soil-pipe interface.
b) thermal properties of the soil.
c) HTC of wall i.e. operational wall heat transfer constant in pipe & fluid.
d) thermal resistance due to pipe wall

Results obtained:

1. Due to the low thermal conductive property of plastics hence the heat transfer between plastic pipes and soil is inefficient. Whereas, the steel which is having a comparatively high value of thermal conductivity have a increased heat flux of near about 35% as compared with PVC for steady state analysis. For cyclic thermal loading shifting from steel to PVC heat flux attenuated by 74% near the periphery of the pipe while 80% at 7 cm apart from the pipe.
2. Considering the effect of contact thermal resistance 16 % decrease was observed in heat flux.

Sodha et. al.[9] investigated that for an underground air pipe system the effect of length, radius of pipe and air mass flow rate on the seasonal cooling potential. Investigation of most optimized combination of radius, length, number of pipes and air mass flow rate for maximum cooling potential, corresponding to a given mass of material of the pipe was carried out.

Results obtained:

1. Showed the effect of length, radius of pipe and air mass flow rate on the seasonal cooling potential of an underground air pipe system. Thus give the most effective combination of the above parameters for which the TCP was found maximum.
2. The most cost effective combination of pipes for the Jodhpur climate, for which TCP/UM = 1920 kWh/m^2 is the highest, is R = 0.05 L = 12.5 $\dot{m}$ = 2400 m^3/h and m = 16(no. of pipes).
3. The most cost effective combination for the Delhi climate is found to be for R = 0.05 m, L = 12.5 m, $\dot{m}$ = 2400 m^3/h and m = 16, for which TCP/UM = 1280 kWh/m^2 is the highest.

Krarti et. al.[8] developed an analytical model to determine the energy performance of an underground air tunnel. The model based on the assumption that the air tunnel-ground system reaches periodic and quasi-steady state behavior after some days of operation. Therefore, all the variations are periodic functions of time. This model can predict the air temperature variation along the air tunnel for any hour of the day.

Results obtained:

1. Effect of pipe diameter: Increasing the diameter results in a higher outlet air temperature. And increased amount of mass flow rate of fluid required which leads to higher capacity fan.
2. Effect of air velocity: Increase of the air mass flow rate through the pipe, results in an increase of the outlet temperature, since the air has a shorter residence time in contact with the soil

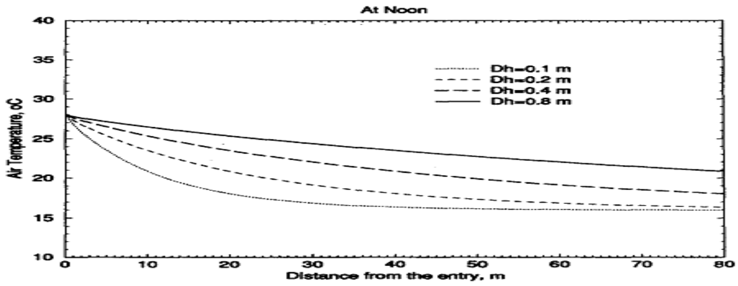

Figure 4.1 Effect of Air Velocity

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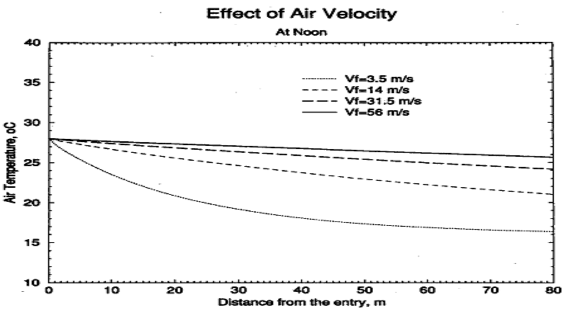


Figure 4.2 Effect of Length

Deglin et. al.[4] established a three-dimensional non-steady-state heat flow in order to simulate the heat transfer between the air circulating in the tubes and the surrounding ground and studied influence of various parameters, such as the type of ground and the air speed, as well as the characteristics of the pipes (diameter, length, depth and spacing), on the efficiency of heat exchange.

Results obtained:

1. Soil type: The higher the soil moisture, the higher is the thermal conductivity and the latent heat transfer in winter.
2. Depth below the ground level: The greater the depth, the smaller is the effect of a variation in the outside climate on the soil.
3. Pipe diameter: Small pipes are thermally more efficient but cause greater pressure losses and require larger installations.
4. Air speed: Its diminution causes an increase of thermal efficiency and a diminution of pressure losses.
5. Pipe length: The length determines the thermal efficiency of the installation but the maximum length of pipe is limited by cost and pressure losses. A thermal efficiency of 100% requires a pipe of infinite length.

F. Al-Ajmi et al [6] considered a conceptual model for EAHX, model is developed to forecast the exit temperature of air and potential of cooling of such systems in dry & hot climatic conditions of Kuwait. Simulation has proved by the results that an EAHX can enable 1700 W reduction in peak cooling power requirement, a decrease of 2.8 K in temperature inside the room is provided by EAHX during peak hours in summers which is half past of July.

Assumptions:

1. Soil which bounds the pipe in ground is isotropic properties with uniform thermal conductivity in soil domain.

2. As the difference of pipe's inner & outer diameter is very small therefore, thermal resistance due to pipe material is neglected.

3. Temperature of air at the inlet of pipe is taken equal to the temperature of ground surface which is approximately equals to atmospheric temperature of air.

4. The pipes are considered of having uniform circular cross-section.

5. At a distance of r from the exterior pipe surface, which is the radius of pipe soil have insignificant thermal effect on pipe.

Results Obtained:

1. A decrease of 2.8 K is observed in interior room temperature using an EAHX system having length of pipe 60 m and diameter of pipe as 250 mm while the mass flow rate of air is taken to be 110 kg/h during the peak times of middle of July. Temperature inside a building resides under 301 K to 305 K which has an EAHX system for conditioning.

2. Power requirement for removing heat from the air by the air conditioner can be reduced upto 1701 W with the use of an EAHX system installed in the building, this conclusion has been made after a 2771 hours of study with the help of TRNSYS simulation on EAHX for a duration between May to September.

3. Nearly 421 kWh of energy can be saved using an EAHX system with an air conditioning system for domestic cooling. Seasonal cooling need is reduced by 31 % using this system is possible.

4. An EAHX system can't be used as a stand-alone system to maintain desirable cooling condition and thermal comfort which ranges from 21 to 27^{o}C but this system can be used to reduce the power required by air conditioning system when used in combination with one of such systems.

Badescue [3] developed a simple and accurate ground heat exchanger model and a numerical transient bi-dimensional approach that allows to computing the ground temperature at the surface and at various depths. Outcome of the analysis is the energy delivered by the ground heat exchanger depends significantly on different design parameters like pipe's depth, diameter and material. A simple model analyzed in this paper.

The two dimensional approach used is given by:

$$(\rho c)_i \frac{\partial T_i}{\partial t} = \frac{\partial}{\partial x_i}\left(\lambda_i \frac{\partial T_i}{\partial x_i}\right) + \frac{\partial}{\partial y_i}\left(\lambda_i \frac{\partial T_i}{\partial y_i}\right) + q_{i,z} + q_{i,p}$$

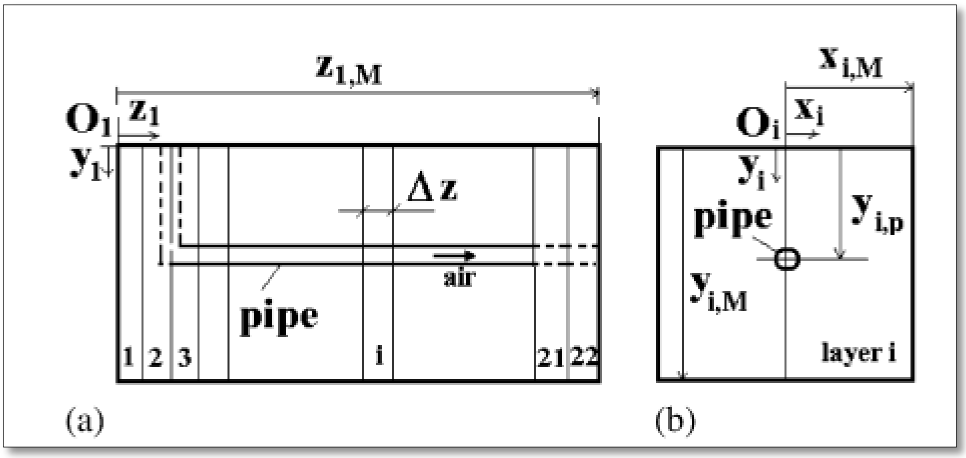


Figure 4.3 Ground Heat Exchanger Model

Where, ρ, c and ƛ are soil mass density, specific heat and thermal conductibility $q_{i,z}$ and $q_{i,p}$ are heat source density respectively.

Boundary Conditions:

1. The ground temperature distribution is not influenced by the air-flow at large enough distance from the pipe.

$$-ƛ_i \frac{\partial T_i}{\partial x_i} = 0, \quad (x_i = x_{i,m}), (i = 1,2 \dots \dots ,22)$$

$$-ƛ_i \frac{\partial T_i}{\partial y_i} = 0, \quad (y_i = y_{i,m}), (i = 1.2, \dots \dots . ,22)$$

2. Temperature gradient with depth is given by:

$$-ƛ_i \frac{\partial T_i}{\partial y_i} = CE - LR + SR - LE, \quad (y_i = 0), (i = 1,2, \dots \dots ,22)$$

Where, CE is the convective energy flux exchanged between atmospheric air and ground surface, LR the long-wave radiation flux emitted from the ground surface, SR the solar irradiance absorbed from the ground surface and LE the latent heat flux due to evaporation

Results obtained:

1. Yearly heating and cooling thermal energy provided by the GHE (q_{GHT+} and q_{GHT-} respectively) increase by increasing the depth $y_{i,M}$ where the pipe is buried.
2. The heat stored by the ground is higher in case of vegetation-covered soils and q_{GHT+} is higher while q_{GHT-} is smaller
3. Increasing the pipe external radius r_{ext} makes the air speed inside the pipe to decrease. Consequently, both the convection heat transfer coefficient $h_{conv,I}$ entering and the overall heat transfer coefficient $U_{air-\ soil,i}$ decrease. This finally yields the decrease of both the heating energy q_{GHT+} and the cooling energy q_{GHT-}.

Bansal et al. [16] studied deterioration in thermal performance of Earth-air Tunnel Heat Exchanger (EATHE) under transient operating conditions in predominantly hot and dry climate of Ajmer (India) is evaluated in terms of a new term '*Derating Factor'* using experimental and computational fluid dynamics modeling with FLUENT software. For the model of pipe of length 100 m, pipe diameter of 0.05 m, 0.1 m, 0.15 m and 0.2 m depth is 3.7 m.

Results obtained:

1. Maximum air temperature drop obtained using steady state approach for EATHE of pipe length100 m, pipe diameter 0.2 m and at air velocity of 5 m/s is 18.4°C, 18.7°C and 18.4°C for soil thermal conductivity of 0.52, 2.0 and 4.0 W/mK
2. Maximum air temperature drop obtained using transient approach during 24 h of operation vary between 18.3°C and 14.0°C, 18.3°C and 17.2°C and 18.6°C and 18.0°C for soil thermal conductivity of 0.52, 2.0 and 4.0 W/mK
3. The derating factor is found to be a function of thermal conductivity of soil, duration of continuous operation of EATHE and length of pipe.

$$DF_{l,t} = 1 - \frac{(T_i - T_o)transient}{(T_i - T_o)steady}$$

4. The analyzed cases have shown the range of derating to be as minimal as 0.2% to as high as 68%, which if ignored while designing may lead to poor performance of earth-air heat exchangers.

Misra et al. [11], [12], [13] conducted an exhaustive parametric analysis to study the transient behavior of Earth-air heat exchanger (EATHE) for extreme climatic conditions i.e. for winters and summers using experimental and Computational Fluid Dynamics modeling. Effects of time duration of continuous operation and flow velocity on thermal performance of EATHE under transient conditions have been analyzed. After the analysis for the aforementioned conditions and parameters EATHE's performance is related with the magnitude of its derating factor value i.e. higher the value of derating factor there will be more deterioration in performance of EATHE.

Results obtained:

For summer conditions:

1. The increase in flow velocity leads to deterioration in thermal performance of EATHE system.
2. Under steady state condition, drop of 18.8°C in air temperature is obtained, whereas under transient conditions cooling of air reduces from 18.7°C to 16.6°C for soil thermal

conductivity of 0.52 W/mK after 24 h of continuous operation for EATHE having 0.1 m diameter and 60 m length, at 5 m/s flow velocity.

3. The transient analysis shows that for soil having thermal conductivity of 0.52W/mK, the cooling of air reduces from 18.7°C to 16.6°C, after 24 hours of continuous operation for soil thermal conductivity of 2.0 W/mK and 4.0W/mK, reduced from 18.8°C to 18.5°C and 18.8°C to 18.7°C.

For winter conditions:

1. Under steady state condition, a rise of 19.6°C is obtained in air passing through EATHE having 0.1m diameter and 60m length, at 5m/s flow velocity.
2. The transient analysis shows that for soil having thermal conductivity of 0.52W/mK, the heating of air reduces from 19.4°C to 17.2°C, after 24 hours of continuous operation for soil thermal conductivity of 2.0 W/mK and 4.0W/mK, reduced from 19.6°C to 19.2°C and 19.6°C to 19.5°C.

Brum et al. [14] devised a new computational modeling to predict the thermal behavior of EAHX. This new numerical model has the advantage of needing a lower computational effort, allowing the study about the influence of operational and constructive parameters, as well as, the application of geometric optimization methods in EAHX.

For finding the temperature of ground at any depth following expression will be used,

$$T_S(up,\ t) = T_S(0.6,\ t) = 291.70 - 4.89 \sin(200.00 \times 10^{-9}t - 2.31)$$

$$T_S(low,\ t) = T_S(2.6,\ t) = 291.70 + 2.25 \sin(200.00 \times 10^{-9}t + 0.02)$$

using the least-squares method, a nonlinear regression technique

$$T_A(depth,\ t) = T_A(1.6,\ t) = 293.49 + 5.66 \sin(200.00 \times 10^{-9}t - 5.30)$$

Results obtained:

1. Installation depths of 1.0 m, 2.0 m, 3.0 m, 4.0 m and 5.0 m were analyzed increase in the depth installation causes a decrease in the temperature amplitude variation. However, for depths higher than 3.0 m there is no significant gain in the EAHX thermal potential.
2. A depth installation of 1.0 m the EAHX can be used only for cooling of buildings, decreasing around 6.0◦C in November and December. There already exists a thermal potential for heating when depths reach the values of 3.0 m and 5.0 m, respectively, but the cooling potential remains superior. However, there is no meaningful difference in the thermal potential between these two depths. Therefore, considering the higher

complexity for deeper installations, the recommendation is to install the EAHX up to 3.0 m.

Tudor et al. [2] examined the influence of several design parameters of a system on its performance. The following parameters were taken into account: the length and diameter of the pipe, the depth where the exchanger is placed. This paper analyzes for the first time the appropriateness of this solution in the climate of South-Eastern Europe.

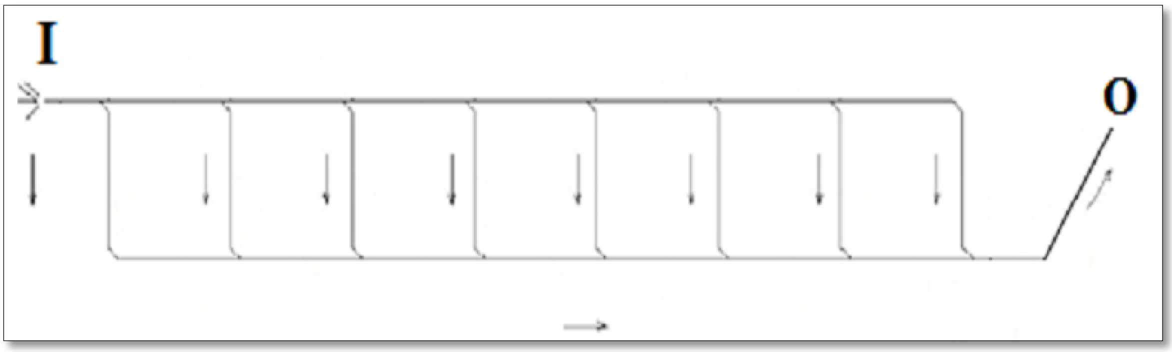


Figure 4.4 Airflow from the air intake through the earth-to-air heat exchanger; I – fresh air intake, O – output from earth-to-air heat exchanger [12]

Dimensions: Diameter 200 mm, Length of pipe 5, 10, 17 m, Number of parallel pipe 8, Spacing between pipes 4.34 m, Depth 3.5 m.

Results obtained:

1. The influence of pipe length: The maximum difference in temperature in every case was found in case of pipe having length 17 m in each month of the year as this can be seen in the below plot.
2. The influence of pipe depth: According to the conducted simulation, in most cases, the depth at which obtained the best performance for heat input was 2.5 m. the heat loss, in most cases, the depth at which the best performance obtained for the cooling intake was 2.5 m. The highest values for cooling energy intake were recorded for Belgrade, 987 kWh.

   Generally better performance at greater burial depths (2.5m and 3.5m instead of 1.5m), increasing the depth from 1m to 2m resulted in an increase by 24.31% of heat gain and 47.57% of heat loss.
3. Influence of pipe diameter: For all 5 cities the diameter of 100mm relatively to 200mm is most beneficial for heat gain, it was observed something similar. In that paper, the heat capacity of the system was reduced when the pipe diameter was increased from 100 to 150mm.

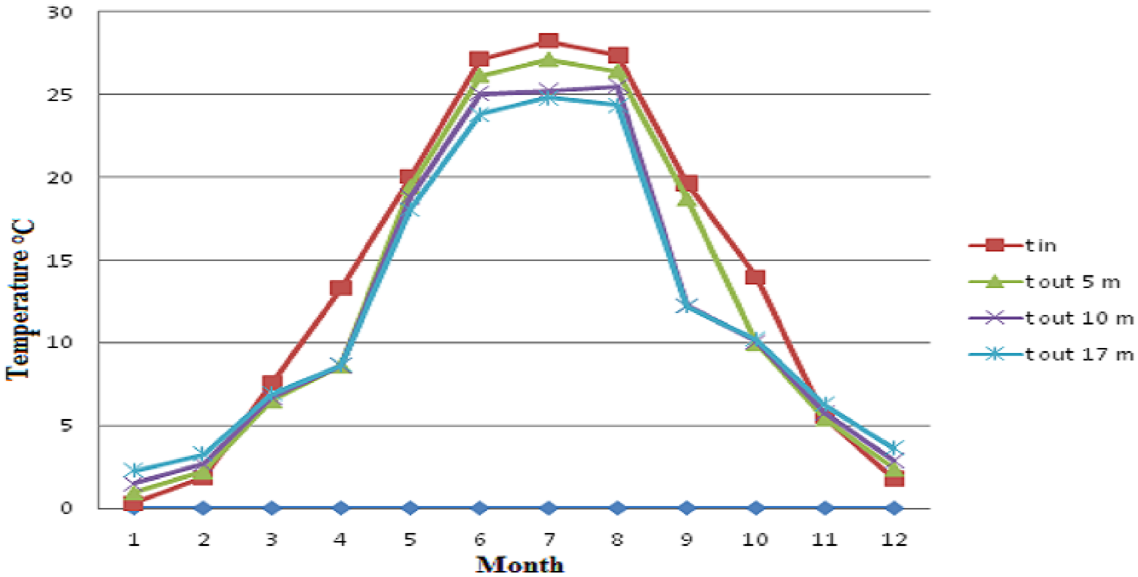


Figure 4.5 Air temperature at the exit from EAHX at Bucharest; annual values for different values of pipeline length: 5; 10; 17m [12]

Ramirez et al. [7] devised a CFD model of EAHX based on FVM is developed and simulated. Simulations have been conducted for sand, silt and clay soil textures for the cities of Cd. Juárez, México city and Mérida, respectively. Also, for different Reynolds numbers, Re = 100, 500, 1000, 1500 through one year.

Assumptions:

(a) Energy transfer is bi-dimensional.

(b) Temperature in soil remains constant after 10 m depth and reaches the outdoors annual average temperature

(c) Evaporation of water is only considered in the surface of the ground.

(d) Pipe's circular cross section is modeled as a square cross section. Also, the thermal influence of the pipe is disregarded due to its thickness; it is so small that it is negligible.

(e) Condensation and evaporation inside of the pipe are not taken into account.

(f) The dominant heat transfer mechanism is convection.

(g) The air is in a laminar flow regime.

Boundary Condition:

i) North Boundary: For the ground surface

$$-\lambda\frac{\partial T}{\partial y} = CE - LR + SR - LE,\ \ (y = 0)$$

Where, CE is the convective energy flux exchanged between atmospheric air and ground surface, LR the long-wave radiation flux emitted from the ground surface, SR the solar irradiance absorbed from the ground surface and LE the latent heat flux due to evaporation.

ii) South Boundary: Ground temperature remains constant beyond 10 m depth, which approaches the annual average air temperature, therefore

$$\frac{\partial T}{\partial y} = 0, \quad (y = Hy)$$

where Hy = depth of soil.

iii) East & West Boundary: Adiabatic conditions are used for this boundary since any thermal influence coming from these boundaries is ignored, therefore

$$\frac{\partial T}{\partial x} = 0, \quad (x = 0 \; and \; x = Hx)$$

where Hx = diameter of pipe.

Results obtained:

1. Effect of Reynolds Number: It is observed comparing the T_{out}^{ave} obtained for Re = 100 and Re = 1500 during winter season, an average difference of 19% was obtained, which tends to increase along with Re. This is because a higher velocity in the flow reduces the interaction with the cold soil near the surface, decreasing the energy loss.
2. Thermal evaluation: An increase of 26.63% in the incident radiation on the soil surface can increase the T_{out}^{ave} in 13.98%. Therefore, in order to avoid undesirable gain or loss of heat, it is recommended to insulate the vertical section of the outlet pipe.
3. Depth: The higher temperature variations are located within the first 2 m depth in the soil, therefore, it is not necessary to bury the pipe to greater depths.

Agnieszka et al. [1] investigated a ground source heat exchanger operating at a cold climate for a passive house ventilation system by numerical simulations. An open type under-ground heat exchanger pipe is buried at the depth of 1.5 m The three 15.85 m long pipes of a diameter 125 mm are connected in parallel along with a manifold and returning pipes of a diameter 200 mm and total length of 9.19 m is simulated using CFD (Computational Fluid Dynamics) simulations in ANSYS's Fluent are reported for February (cold climate) at Poland.

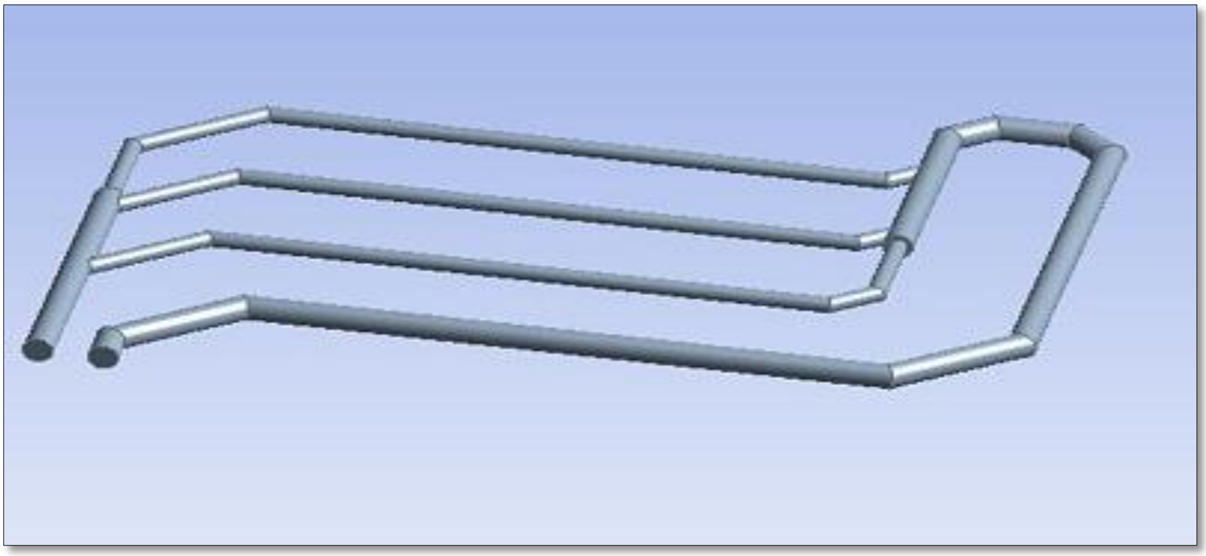


Figure 4.6 A ground source heat exchanger coupled with a ventilation system of the Passive House [14]

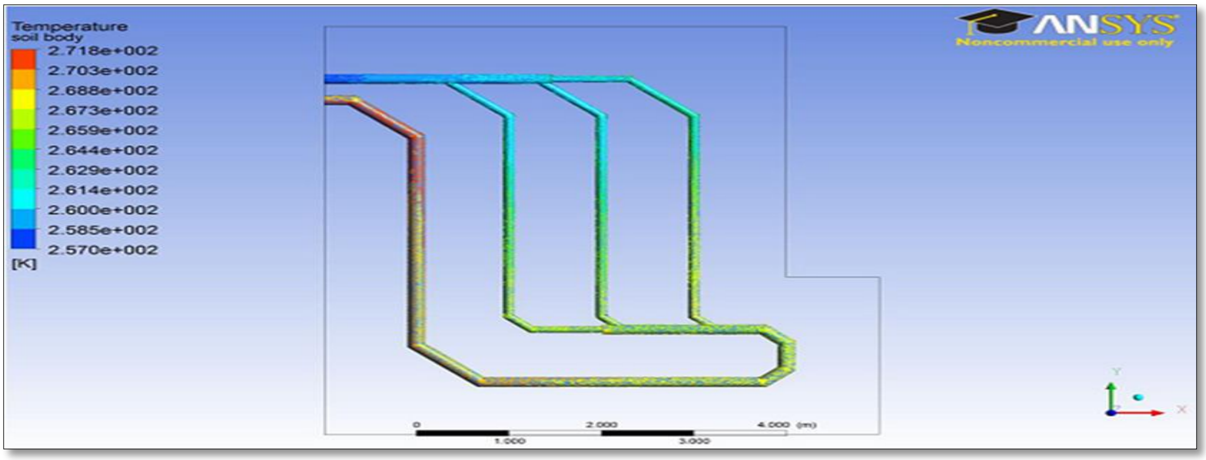


Figure 4.7 Ground source heat exchanger 3D pipe temperature distribution. [14]

Liu et al. [17] presented a numerical model taking condensation phenomenon inside the pipe into account to give a description of transfer of heat between ground tunnel and air simultaneously.

Assumptions:

i. The transfer of heat across Δz i.e. thickness is insignificant as compared with radial direction i.e. r, hence the variation in temperature along Δz is assumed to be constant in contrast with temperature variation in radial direction. Since r has an extreme value of 10000 mm variation along this direction is significantly large.

ii. If the variation in temperature along the radial direction is minor than temperature distribution in angular coordinates or azimuthal coordinates are taken as constant.

iii. Field measurements were obtained at underground tunnels service the Hydropower Stations in China. These tunnels are at an average underground depth of 50 m and 70 m respectively. Therefore the influence of the surface

The heat conduction occurring radially through each thin soil section is given by:

$$\frac{\partial T}{\partial t} = \frac{k}{\rho C_p}\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right)$$

Boundary condition: The transfer of heat among surface of tunnel & air is pronounced by convective heat transfer equation, which is

$$\dot{Q}_c = -k\left(\frac{\partial T}{\partial r}\right)surface$$

Result obtained:

For the complete year during the simulation, peak and average temperature drop of air stream for summer cooling condition was found to be 8.92 K and 2.34 K, respectively, while for the winter heating condition peak and average temperature rise in air is found to be 6.3 K and 2.2 K.

Bisnoiya et al. [15] tried to evaluate yearly performance of EAHX system having length of buried pipe, 19.228m, diameter of pipe, 0.1016m and depth of burial, 2 m study is conducted in dry and summer climatic conditions of Bhopal a region in Central India. A quasi-steady state, 3-D model based on computational fluid dynamics (CFD) was developed to evaluate the heating/cooling potential of EAHX system. The energy metrics namely energy payback time (EPBT) and seasonal energy efficiency ratio (SEER) for EAHX system were evaluated on the basis of energy analysis of simulation results.

Assumptions:

1 The surface temperature of the ground can be taken equal to the ambient air temperature, which equals the inlet air temperature.

2 Earth's undisturbed temperature can be approximated to yearly average temperature of the location (Bhopal—India).

3 The PVC pipe used in EAHX is of uniform cross section.

4 The thickness of pipe used in EAHX is very small hence thermal resistance of pipe material is negligible.

5 The temperature on the surface of pipe is uniform in the axial direction because the temperature of soil surrounding the pipe is assumed constant

Boundary conditions:

1 Inlet: The normal speed of air flow was definned such as 2, 3.5, 5 m/s. The static temperature of air at inlet was definned such as 40.4, 38.8, 39.9 °C for summer season.

2 Outlet: The relative pressure at outlet of EHE pipe was taken equal to zero atm.

3 Wall: The temperature on the surface of pipe (wall) was uniform in axial direction and was taken equal to earth's undisturbed temperature at Bhopal city (25.2^{o}C). No slip condition with smooth wall was taken at inner surface of the pipe.

Results obtained:

5. Embodied energy of EAHX system: The total energy requirement for individual components and their manufacturing energy. Embodied energy of 0.1016 m diameter PVC pipe = 104.15 MJ/kg = 5988.62 MJ = 1663.5 kWh (length of PVC pipe = 19.228 m and weight of 19.228 m long pipe = 57.5 kg) Embodied energy of 0.5 hp blower = 373 W = 0.38 kWh.

Total embodied energy of EAHX system becomes,

E_{emb}= 1663.5 kWh + 0.38 kWh = 1663.88 kWh

6. Energy payback time (EPBT): The number of years required to recover energy invested, i.e. in manufacturing, transportation, installation, operation and maintenance of the system while in use is called EPBT.

$E_{epb} = E_{emb} / (Q_u)_{yearly}$ 1663.5/ 1290.53 = 1.29 years

7. Seasonal energy efficiency ratio (SEER):

SEER = monthly heat gain or loss in kWh /monthly electrical energy consumed EAHX in kWh

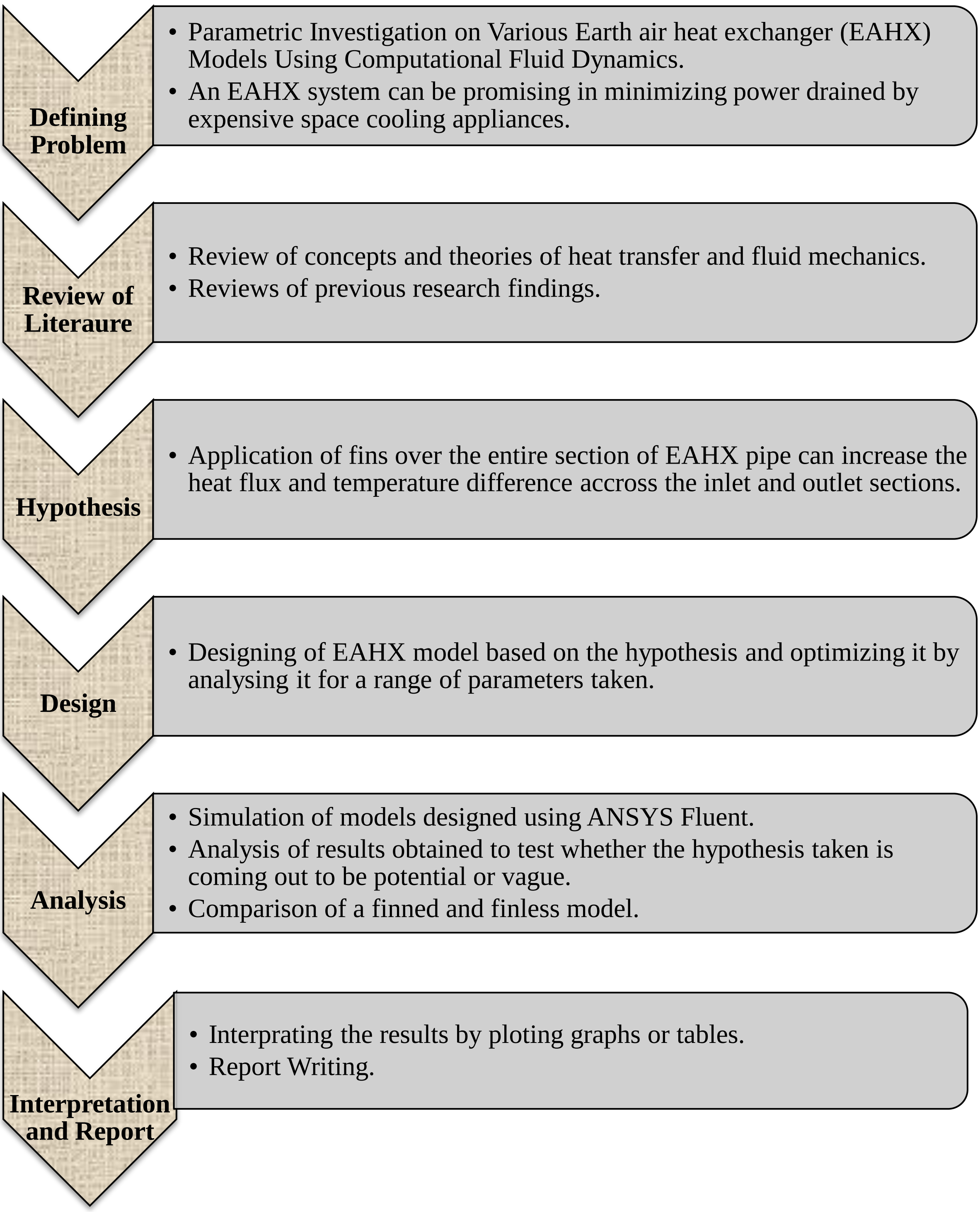
For summer SEER = 247.25/185.01 = 1.34

For winters SEER = 101.87/92.5 = 1.10

All the above mentioned works and several other motivated me to conduct a study on an earth to air heat exchanging system which can focus on effects of several parameters on the working and output of an EAHX and how some method can be implemented so that their dominance can be attenuated.

5. Methodology

5.1. Research Methodology



5.2. Analytical Model of EAHX system

Since in an EAHX system there are two heat transfer mechanism are in operation, namely convection and conduction. Heat is transferred by means of convection between air and inner pipe surface while it is transferred by mean of conduction between outer and inner pipe

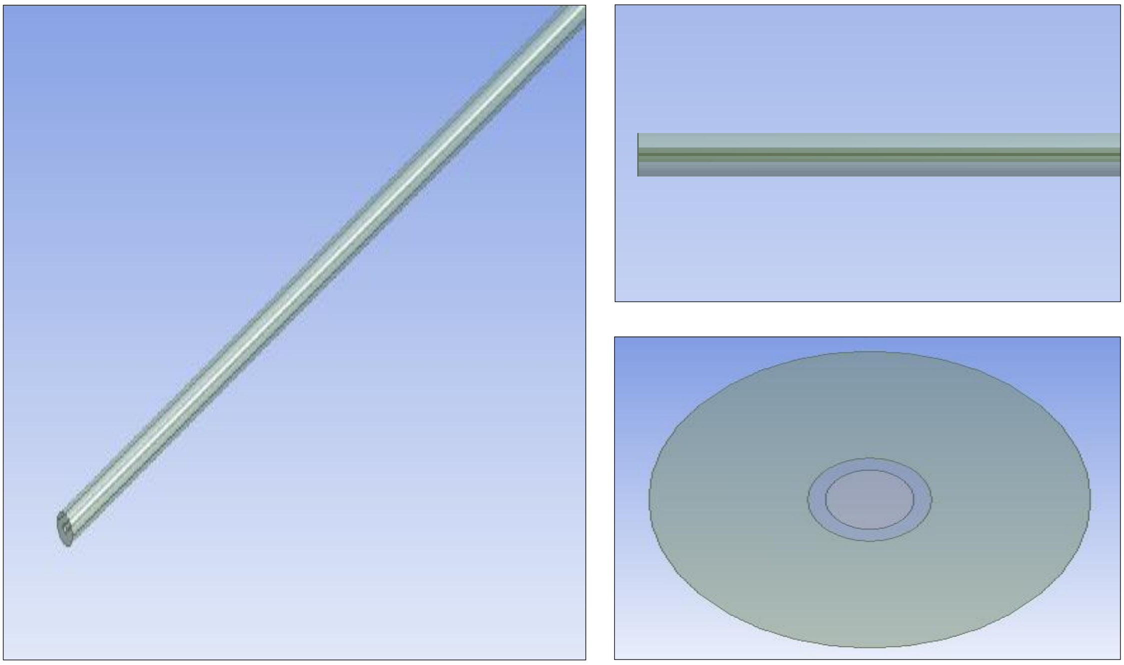


Figure 5.1 (a) Isometric view (b) Side view (c) Front view of EAHX system

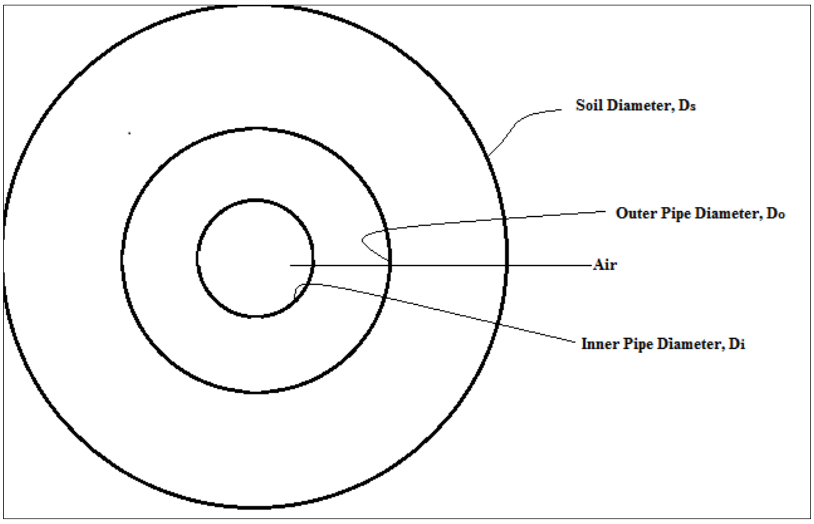


Figure 5.2 Cross section of EAHX in soil layer is shown

surfaces and also the heat is transferred by conduction by means of conduction between pipe's outer surface and layers of soil.

Pipe and soil environment is modeled as two concentric cylinders as shown in the Figure15. Thermal resistances which will be acting are provided by soil pipe and in air. Following are the assumptions considered while developing this system:

1. The soil environment is considered to be isotropic, i.e. its conductivity is considered uniform everywhere in its domain.
2. Temperature of air at pipe's inlet is taken equal to atmospheric temperature.
3. Pipe has a uniform cross section.

4. Moisture diffusion is taken to be negligible in air from soil.
5. Thermal conductivity is assumed to be constant for pipe and soil.

As already mentioned the thermal resistance (R_s) due to soil surrounding will be:

$$R_s = \frac{ln\frac{r_s}{r_o}}{2\pi k_s \Delta l}$$

Thermal resistance (R_p) due to pipe material i.e. between outer and inner surfaces:

$$R_p = \frac{ln\frac{r_o}{r_i}}{2\pi k_p \Delta l}$$

Thermal resistance (R_a) because of convection between air and inner pipe surface is:

$$R_a = \frac{1}{2\pi r_i h \Delta l}$$

Where,

r_s & r_o is radius of soil cylinder & outer radius of pipe respectively,

r_i is inner radius of pipe,

Δl is length of discretized grid,

k_s and k_p are thermal conductivity of soil and pipe respectively,

h is convective heat transfer coefficient between air and inner pipe surface

Here h can be derived as:

$$h = \frac{Nu\ k_{air}}{d}$$

since convective heat transfer coefficient is a function of Nusselt number and Reynolds number hence,

Reynolds number Re is:

$$Re = \frac{\rho_{air} V d}{\mu_{air}}$$

For a laminar flow inside a pipe Nusselt number is given by,

$$Nu = 4.36 \text{ if } Re < 2300$$

For turbulent flow in cylindrical pipe for the ranges of Prandtl number (Pr) is $0.5 < Pr < 2000$ and Reynolds number $2300 < Re < 5 \times 10^6$, Nusselt number is given by

$$Nu = \frac{\left(f/8\right)(Re - 1000)Pr}{1 + 12.7\left(f/8\right)^{\frac{1}{2}}\left(Pr^{\frac{2}{3}} - 1\right)}$$

Here f is coefficient of friction in smooth pipes and Pr is Prandtl number; these are definned by following relations:

$$f = (0.79\ \ln Re - 1.64)^{-2}$$

$$P_r = \mu_{air} C_p / k_{air}$$

Since the thermal resistance between soil surrounding pipe and air is in series hence total thermal resistance can be given by:

$$R_{total} = R_s + R_p + R_a$$

$$R_{total} = \frac{ln\frac{r_s}{r_o}}{2\pi k_s \Delta l} + \frac{ln\frac{r_o}{r_i}}{2\pi k_p \Delta l} + \frac{1}{2\pi r_i h \Delta l}$$

Since the model is discretized in n number of grids than heat transfer between soil and air modeled as surrounded by soil as a cylinder with internal convection and external conduction from a grid is calculated using following equation:

$$Q = \frac{2\pi(T_{soil} - T_i)}{R_{total}}$$

Where T_i is the temperature of air at inlet of a particular grid

Now the temperature of air at the outlet of that particular grid can be computed using the following equation:

$$T_{out} = T_i - \frac{Q}{mC}$$

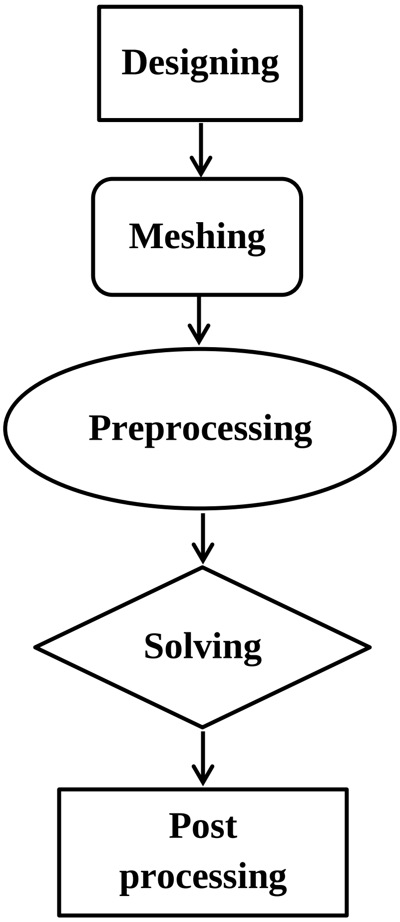
5.3. CFD model of EAHX system

A CFD model and analysis of a system mail based on finite volume approach which begins with designing of the system which includes fabricating each and every part followed by meshing in which the whole designed system i.e. every part is discretized into number of smaller volumes. A general procedure followed in a CFD study is described with the help of a flow chart.

Designing: Since this study is based on observing the effects of several design parameters on the performance of the entire system. It has been done in Pro E 5.0. A number of parts for different parameters have been developed in the software for air, pipe and soil cylinder parts are modeled as concentric cylinders in finless model, while fins are applied on the surface of pipe.

Table 1 Dimensions of the parts modeled

Parts	Length	Diameter
Air	30 m & 60 m	0.1 m, 0.15 m, 0.2 m, 0.3 m
Pipe	30 m & 60 m	0.1 m, 0.15 m, 0.2 m, 0.3 m
Soil	30 m & 60 m	1 m



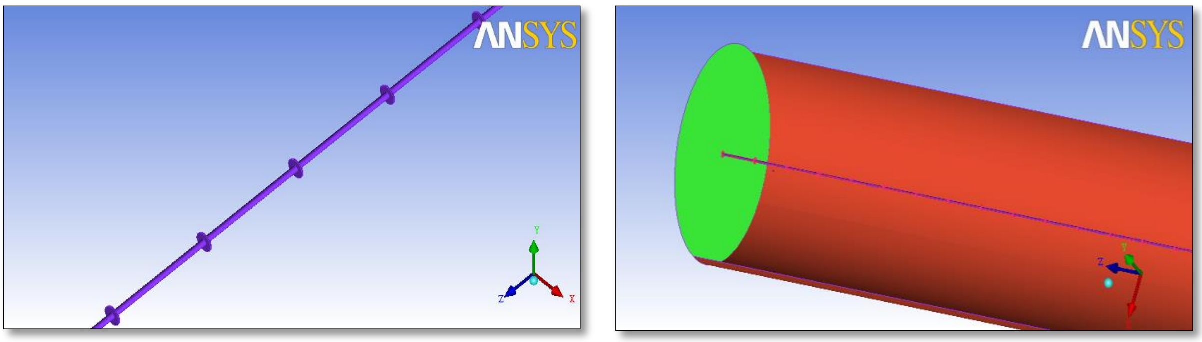


Figure 5.3 (a) Design of finned pipe (b) Pipe buried in soil domain

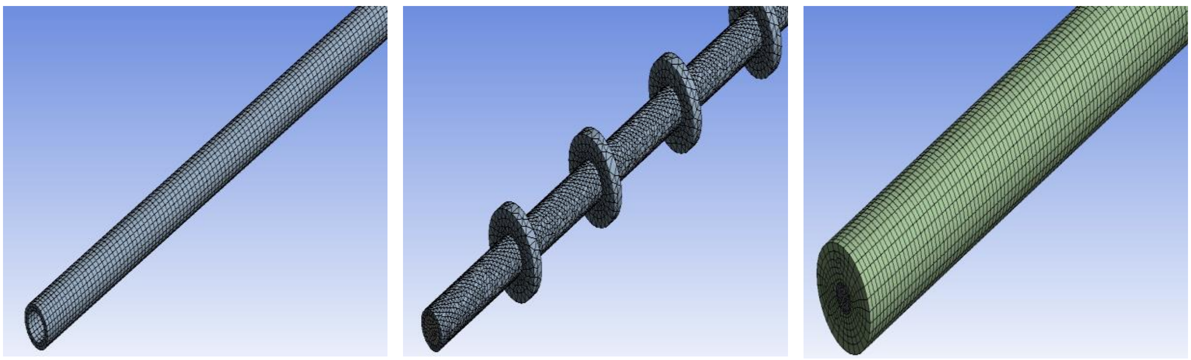


Figure 5.4 Meshed parts (a) Simple pipe (b) Finned pipe (c) Pipe in soil

Meshing: Parts are discretized in smaller elements. Meshing of the parts designed and assembled in Pro E is done in ANSYS Workbench 14.0's meshing tool. Mesh is created in meters using fine relevance center in sizing and successive refinement for pipe surface parts. Following table shows the details of mesh for all domains.

Table 2 Mesh information of different domains for designed model

Domain	Nodes	Elements
Air	82280	65670
Pipe	93984	65458
Soil	184500	163618
All Domains	360764	294856

Preprocessing: The mesh file generated is exported to Fluent 14.0 for assigning material and their properties to different domains. Selection of suitable model as per the requirements and posing necessary boundary conditions, following table shows the materials and their properties for the study.

Table 3 Material and its properties

Domain	Material	State	Thermal Conductivity (W/m-K)	Density (Kg/m^3)	Specific Heat (J/Kg-K)
Air	Air	Fluid	0.0242	1.225	1006.3
	Aluminum		202.4	2719	871
Pipe	Steel	Solid	16.27	8030	502.48
	PVC		1.16	1380	900
Soil	Soil	Solid	4	2050	1840

Boundary Conditions: Following are the boundary conditions used to solve current problem:

1. At Inlet the velocity of air is taken as 5, 10, 15 and 20 m/s simultaneously for different studies along the axis of pipe with inlet temperature of air similar to assumed temperature as prevailing in atmosphere and for turbulence specification, its intensity is taken 5% and hydraulic diameter as selected value for the parameter under study.
2. At inlet and exit faces boundaries are taken as wall and heat flux is zero.

3. At interface coupled heat transfer condition is implemented and slip condition for the velocity is chosen with no diffusion in between zones.
4. At far boundary of soil temperature is taken similar as earth's undisturbed temperature.

Solution & post processing: Solution of the problem is done in pressure based velocity type solver adopting simple scheme and an upwind spatial discretization for solving governing equations. Criteria for convergence of solution are taken as 10^{-6}.

Solution generally solve following governing equations by iterative methods:

Continuity equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

x-Momentum equation:

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + v\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right]$$

y-Momentum equation:

$$u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = -\frac{1}{\rho}\frac{\partial P}{\partial y} + v\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right]$$

z-Momentum equation:

$$u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{\partial P}{\partial z} + v\left[\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right]$$

The result of solution is exported to CFD-Post for result compilation through charts, temperature contours, vector plots, streamline plots and tables.

6. Results and Discussion

6.1. Validation of Result

Results are calculated on the basis of both analytical model and simulated model.

6.1.1. Result for Analytical Model

Thermal resistances due to aforementioned causes:

Resistance due to soil, pipe and convection in air and inner pipe surface

$$R_s = \frac{ln\frac{0.5}{0.07}}{2\pi 4\Delta l} \quad R_p = \frac{ln\frac{0.07}{0.05}}{2\pi\ 202.4\ \Delta l} \quad R_a = \frac{1}{2\pi 0.05 h\Delta l}$$

Reynolds number

$$Re = \frac{1.225 \times 5 \times 0.05}{1.7894 \times 10^{-5}} = 34229.3$$

Hence friction coefficient f is 0.022899,

Thus Nusselt number is Nu = 80.7449 and since h = Nu×k_a/d, heat transfer coefficient is h = 19.54 W/m^2K

Using these values calculating the value of R_{total} and then Q i.e. heat transfer in each grid, temperature at the outlet of that grid can be calculated and is tabulated in table 4.

Table 4 Temperature of air at outlet as calculated

Axial Distance From inlet (m)	Temperature at grid inlet (K)	Temperature at outlet (K)
Inlet-5	319.00	310.90
5-10	310.90	306.00
10-15	306.00	302.90
15-20	302.90	301.00
20-30	301.00	299.14
30-40	299.14	298.43
40-50	298.43	298.16
50-Outlet	298.16	298.10

6.1.2. Result for Simulated Model

Designed model with parameter similar to the one for which the results are calculated analytically in previous section is simulated in fluent 14.0 implementing boundary conditions as mentioned in section 4.3. Results of the simulation came is in close agreement to the calculated results as shown in the table below. Hence the simulation approach to study the effects of parameters on EAHX models is suitable.

Table 5 Comparison for simulated and calculated results

Axial Distance From inlet (m)	**Temperature at outlet from simulation (K)**	**Temperature at outlet from calculation (K)**	**Percentage difference in both results**
5	313.6	310.9	0.86
10	309.2	306.0	1.04
15	306.8	302.9	1.27
20	304.1	301.0	1.02
30	302.4	299.14	1.08
40	301.9	298.43	1.15
50	301.6	298.16	1.14
Outlet	301.3	298.10	1.66

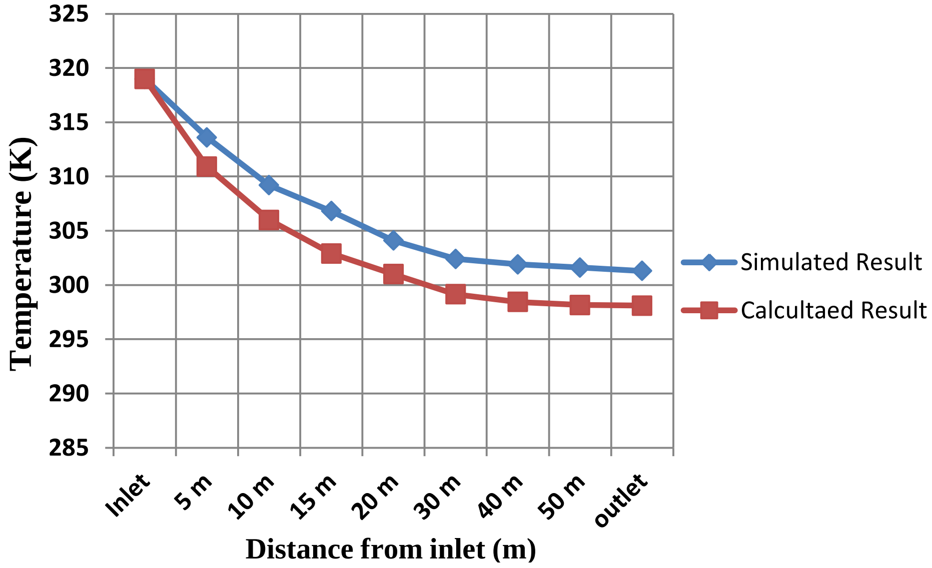


Figure 6.1 Comparison for simulated and calculated results

6.2. Effect of Pipe's Diameter

To study the effect of pipe's diameter on thermal performance i.e. temperature at the exit of pipe there are 4 models designed each with internal diameter of 0.1 m, 0.15 m, 0.2 m, 0.3 m while pipe thickness is taken as 0.02 m and length of pipe to be 30 m for the inlet air velocity of 5 m/s.

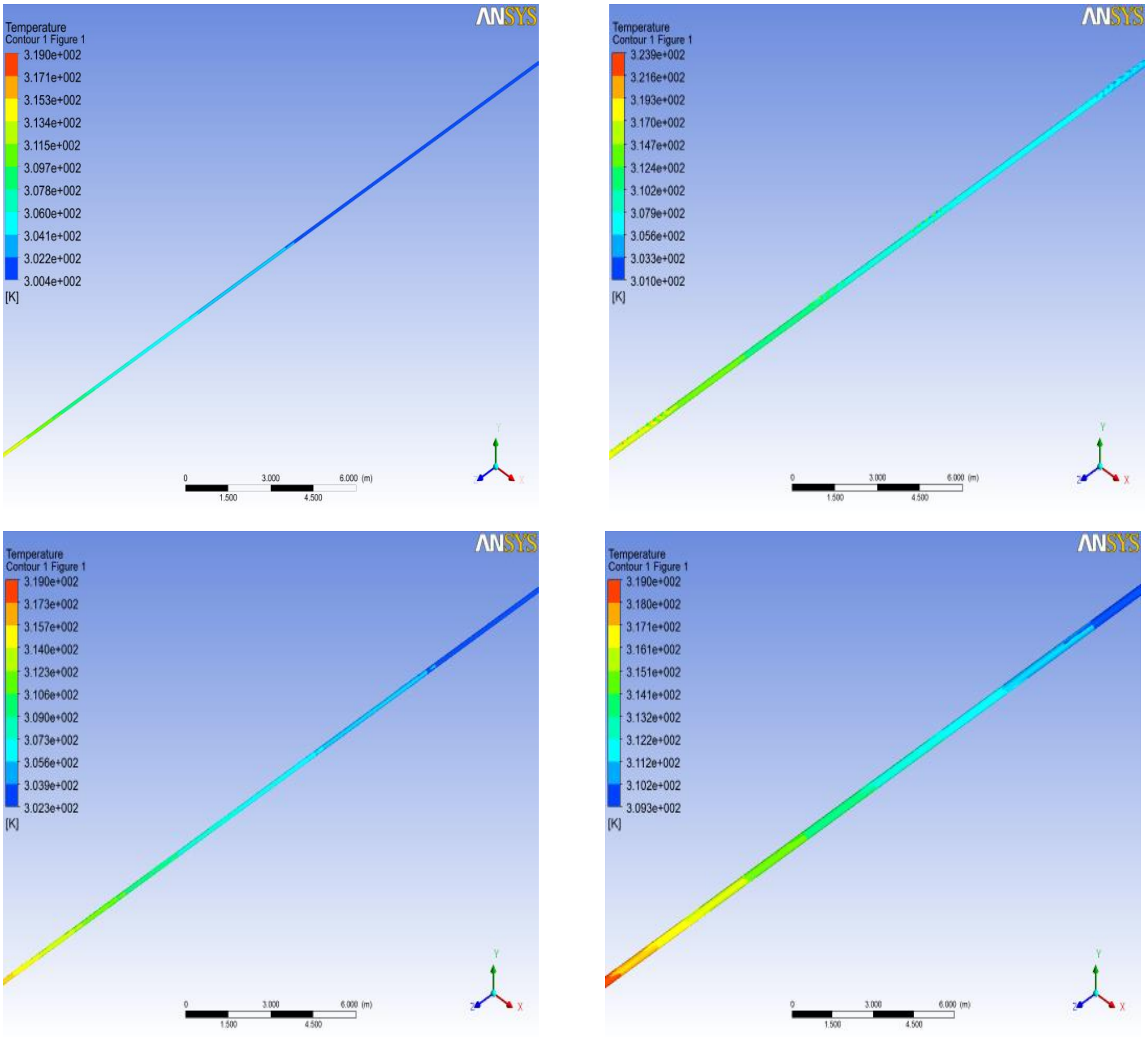


Figure 6.2 Temperature contour of pipe diameter (a) 0.10 m (b) 0.15 m (c) 0.20 m (d) 0.30 m

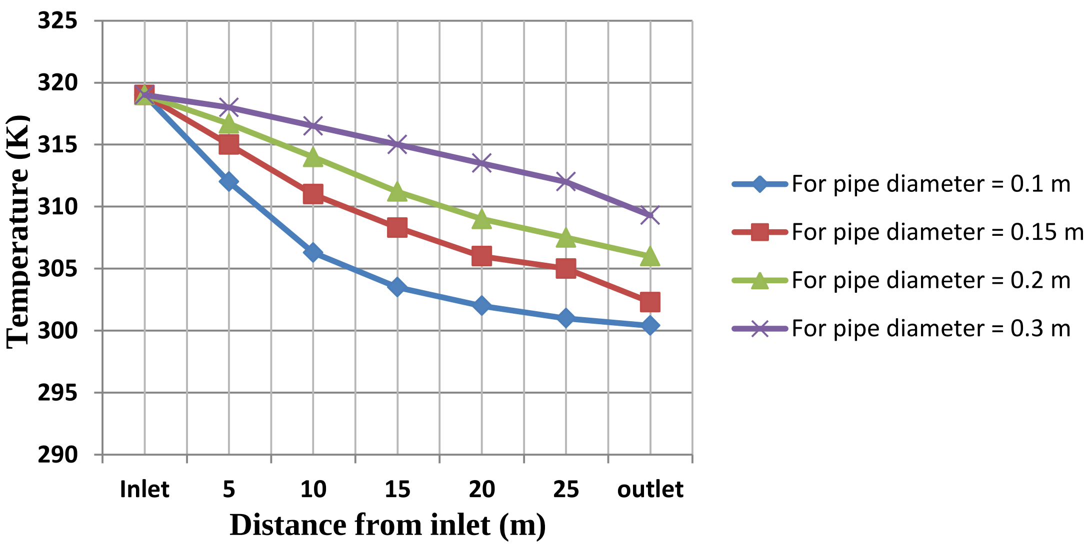


Figure 6.3 Comparison of all models to show the effect of pipe's diameter

Since the results shows a decreasing trend in temperature drop of air through the given pipe length, hence pipe of smaller diameter will be desirable for setting up such space conditioning system. This is may be due to increasing diameter of pipe air velocity inside the pipe will reduce results in lower Reynolds number hence this will tend to reduce the value of Nusselt number which ultimately affect the heat transfer rate or the large diameter pipe have lesser turbulence so there will be a lower heat transfer.

6.3. Effect of Flow Velocity

To study the effect of air flow velocity, velocity of air at inlet is given 5 m/s, 10 m/s, 15 m/s and 20 m/s simultaneously for different simulations of a given pipe length and diameter.

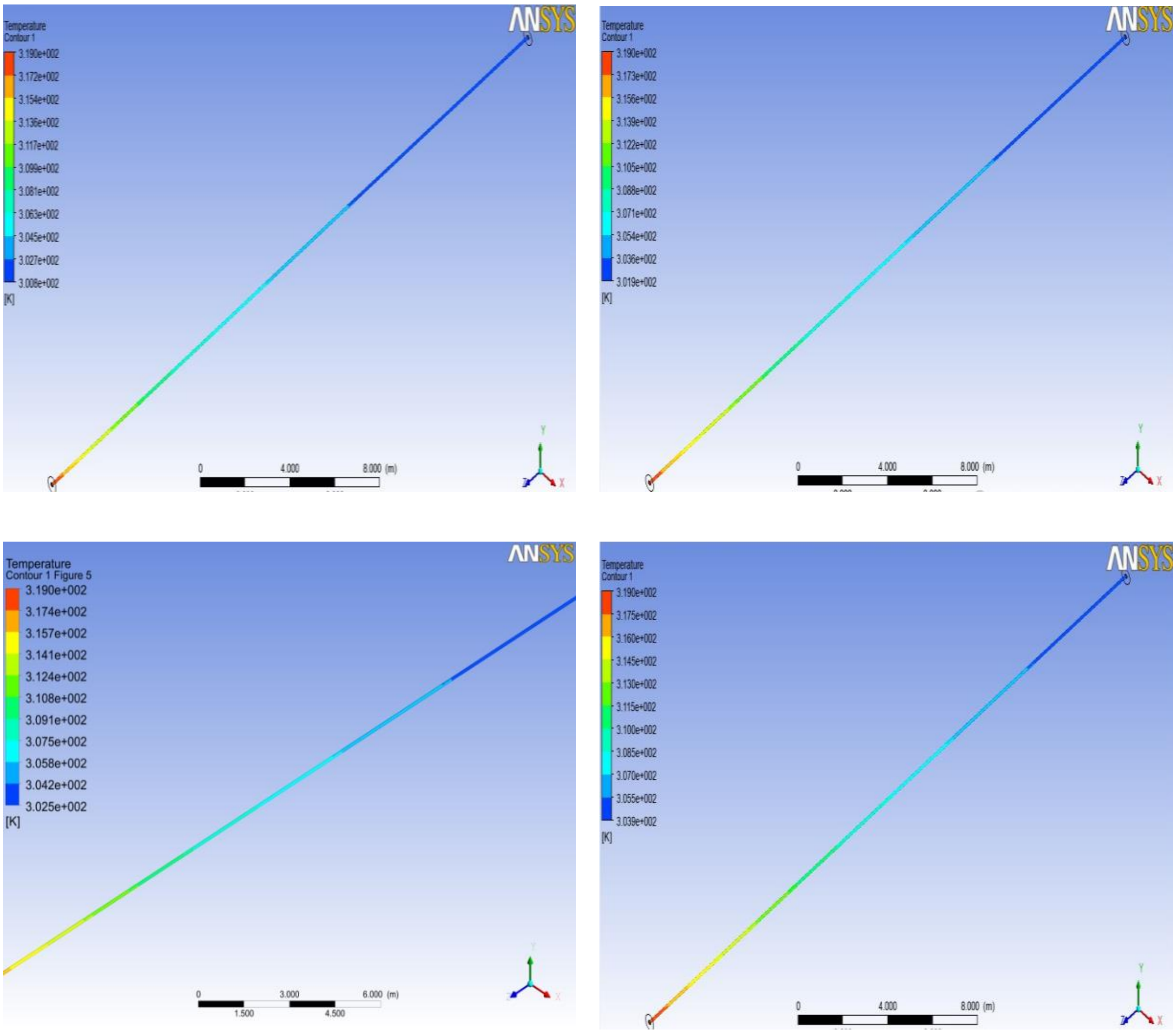


Figure 6.4 Temperature contour for inlet air velocity (a) 5 m/s (b) 10 m/s (c) 15 m/s (d) 20 m/s

Hence the results show a trend of decrease in temperature drop of air at the outlet of pipe, hence from these results it is better to send air at lower velocity, this is may be because at higher velocity due lower residence time of air in pipe, there will be an in inadequate heat transfer between ground and air. Figure below shows a comparison of air outlet temperature for different velocities it is clearly shown in the chart that for velocity of air at 5 m/s has the best thermal performance in contrast with other results at higher velocities

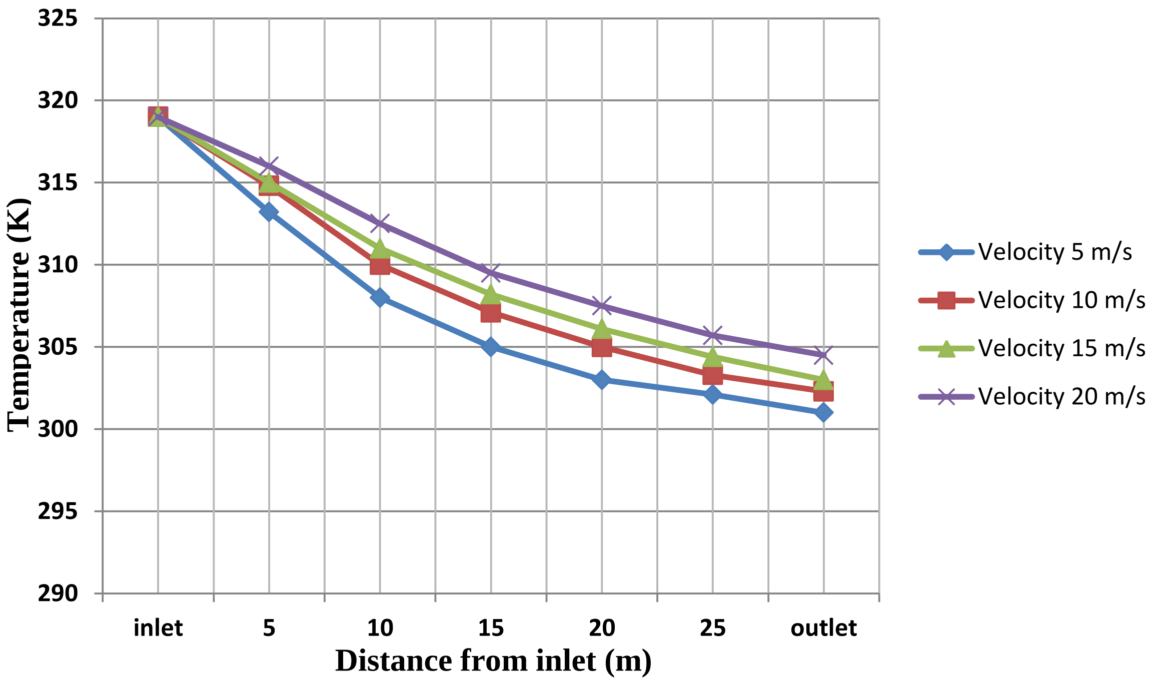


Figure 6.5 Comparison of air outlet temperature for different air velocities

6.4. Effect of Pipe Material

To study the effect of pipe material on the thermal performance of EAHX, in this study three types of materials has been considered, namely aluminum, steel and pvc. Simulations are done on a model of length 30 m and internal diameter of 0.1 m.

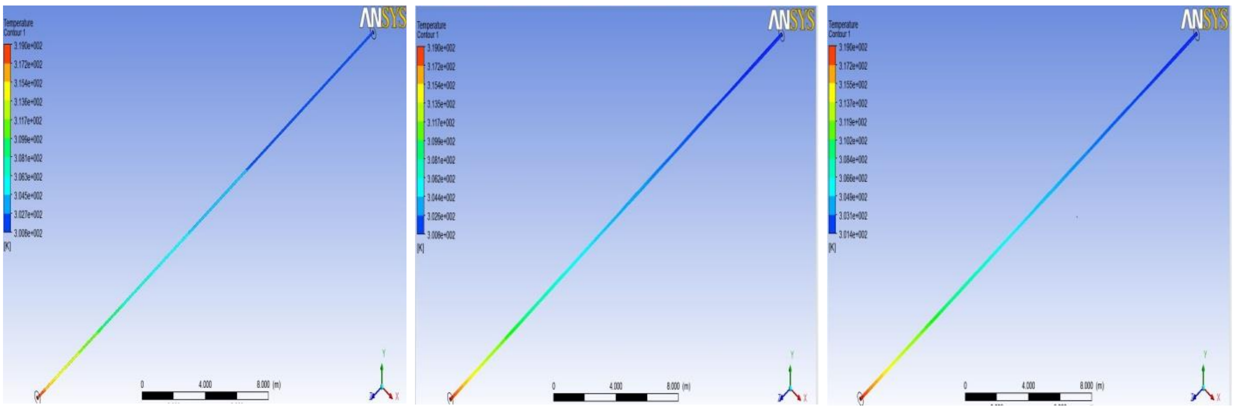


Figure 6.6 Temperature contour for pipe material (a) Aluminum (b) Steel (c) PVC

As the results from figure 6.6 have shown that there is not much of a variation in the thermal performance of EAHX on using pipe of three different materials having significantly different thermal properties i.e. aluminum which has a thermal conductivity of 202.4 W/m-k while pvc which having 1.16 W/m-k thermal conductivity hence it can be established that pipe material have almost negligible effect on thermal performance of such system, this is may be because of negligible thermal resistance due to conduction offered by pipe as pipe thickness is very small as compared with soil domain i.e. $R_{pipe} \propto \ln r_o - \ln r_i$ which came out as a very low value.

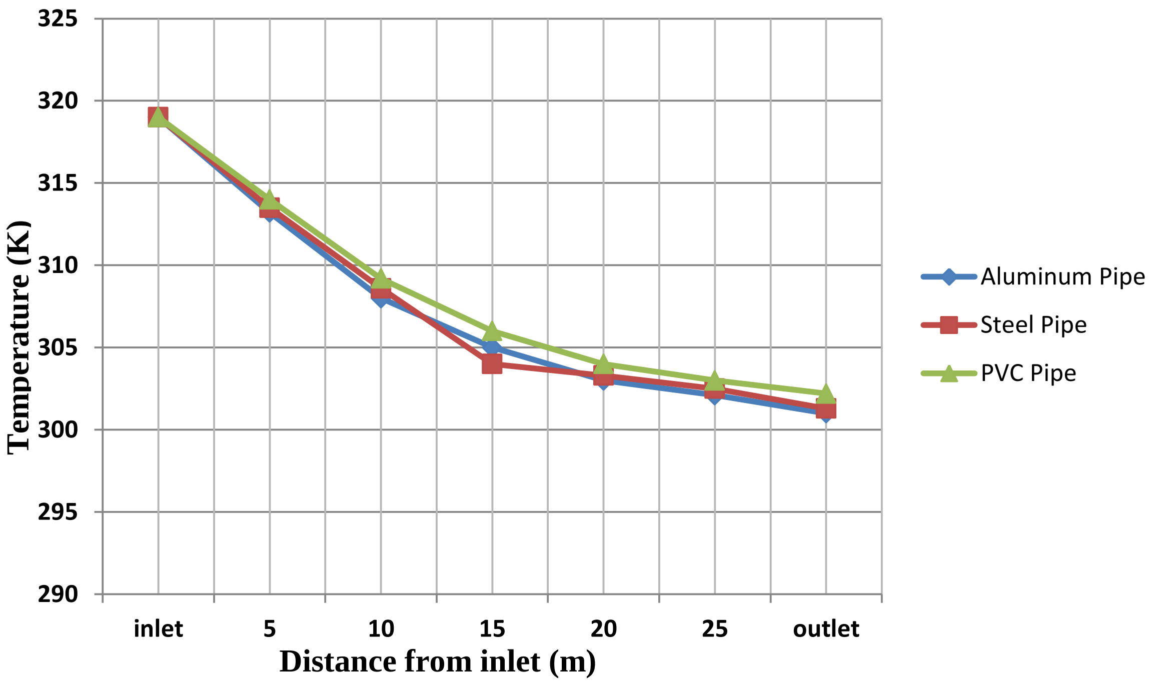


Figure 6.7 Comparison of air outlet temperature for different pipe materials

6.5. Effect of Length & Application of Fins

To study the effect of length and applying fins over the entire length of the pipe two different models are designed in Pro E one with inner diameter of pipe as 0.1 m, pipe length 60 m, air velocity of 5 m/s and other having 120 fins over entire pipe surface. Temperature variation of air in both finned and finless model is shown with the help of temperature contours as shown in figure 6.8.

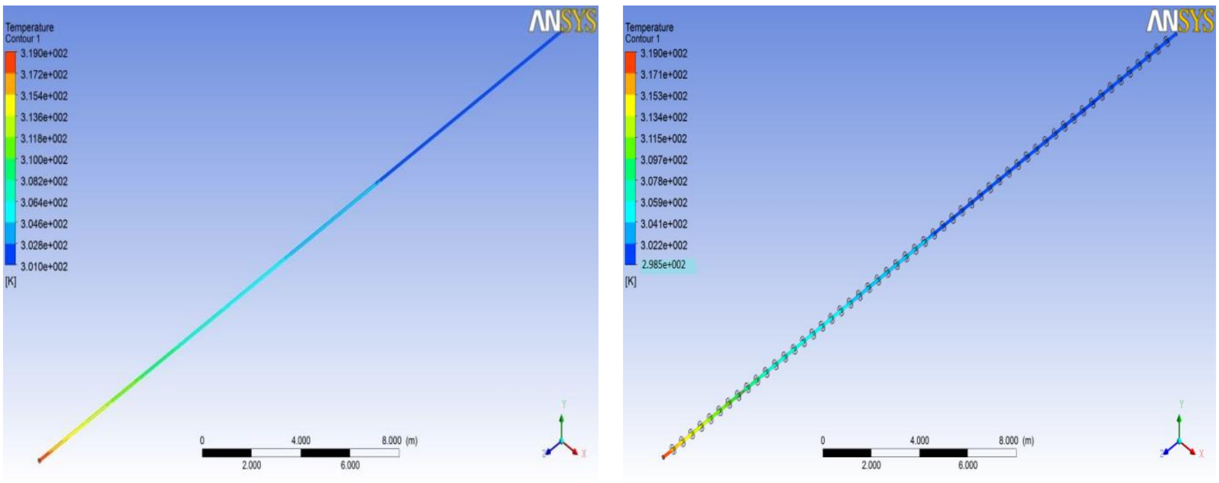


Figure 6.8 Temperature contour for (a) Finless Model (b) Finned Model

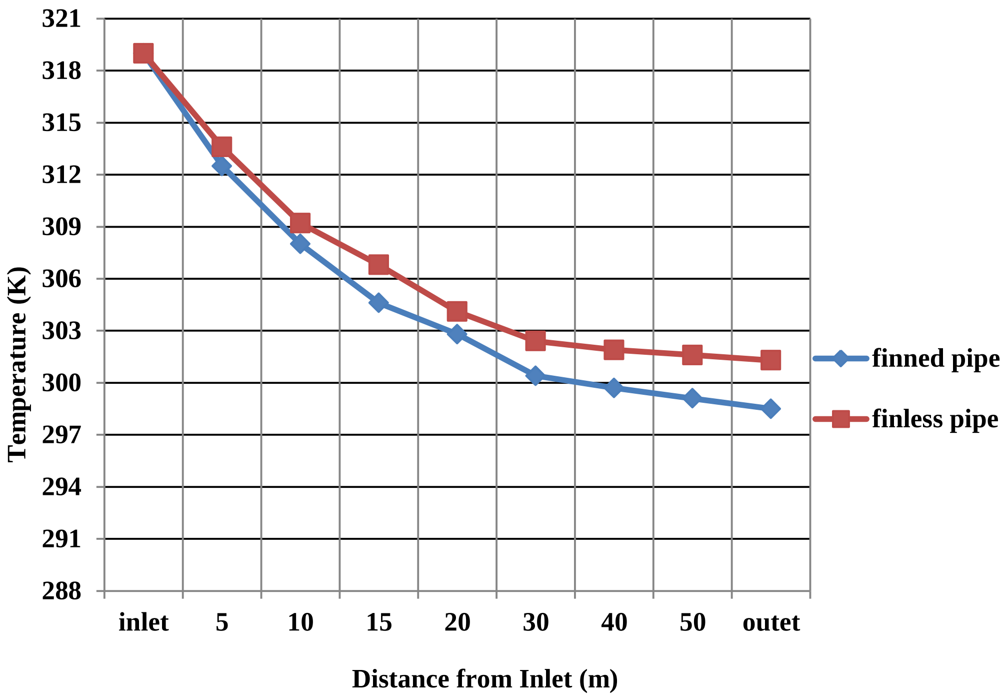


Figure 6.9 Comparison of a finless & finned model

Above results doesn't show much of a temperature difference in the condition of air at pipe's outlet i.e. for a finless model outlet temperature is found to be 301 K while for finned model it is found to be 298.5 K. But the significance of fins can be seen in figure 6.9 which is a plot of temperature at different pipe section from the inlet of pipe. It is clear that the result that the state of air which has been achieved on a 60 m pipe in finless model is accomplished in 30 m finned pipe hence it will help to cut the initial set up cost.

7. Conclusion

This work reports about the thermal performance of EAHX system by the results which are formulated by software simulation and are theoretically validated, a simulated investigation has been carried out to analyze the effect of pipe's geometric parameters like diameter and length, air flow velocity, pipe material and application of fins on the thermal performance of EAHX.

Four diameter viz. 0.10 m, 0.15 m, 0.20 m and 0.30 m have been designed to examine the effect of pipe's diameter on output of EAHX keeping length of pipe fixed which is equal to 30 m and velocity of air flow as 5 m/s. Thermal performance of EAHX system gets reduced in large diameter pipes may be due to insufficient heat transfer because of lower turbulence. A model of pipe length of 60 m is designed and simulated and it can be seen that temperature keeps on decreasing in pipe sections away from inlet hence we need to select an optimized length of pipe to keep a check on cost of setup.

Three different materials viz. aluminum, steel and pvc are considered to check the effect of pipe material on temperature drop of air, results have proved that pipe material is not having sufficient effect on the output may be due to very smaller value of thermal resistance of pipe irrespective of pipe material because of negligible pipe thickness. Air is blown at 4 different velocities inside the pipe to study its effect it has been found that as the flow velocity is raised temperature at the outlet gets decreased which is so may be because of limited time available to exchange heat with ground at higher velocities.

Application of fins leads the outlet air temperature to the value of 298.5 K while a finless model has temperature of 301.3 K which shows that there is no radical difference in the results but from figure 26 it can be analyzed that in a finned model at 30 m from the pipe's inlet temperature of air is 302 K which very close to the result observed at 60 m in finless pipe hence a half-length finned pipe can substitute a full length finless pipe.

This study advocated about the conditioning ability and its dependence several parameters of an EAHX system which is the need of hour in such energy as discussed in section 1 thus there is a huge need of optimizing these parameters and bringing out such techniques so that the dominance of these parameters can be minimized on the ability of EAHX system.

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