DESIGN OF EARTH-AIR HEAT EXCHANGER FOR A COMMERCIAL BUILDING WITH COMPARISON TO CONVENTIONAL HVAC

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CERTIFICATE

This is to certify that the work contained in this thesis titled **"DESIGN OF EARTH TO AIR HEAT EXCHANGER FOR A COMMERCIAL BUILDING AND COMPARISON TO CONVENTIONAL HVAC"** has been carried out by **SRIDHAR VIJAYAN** under my/our supervision.

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Abstract

Geothermal energy is one of the renewable sources that can generate electricity and heat with a minimum impact on the environment. Most primary energy consumed, is used for heating and cooling of buildings. The energy demand for buildings is driven by population growth and climatic conditions. For these reasons, geothermal cooling and heating has proved to be very efficient. This thesis presents the design of an earth to air heat exchangers with different pipe configuration which is installed to preheat and cool the ventilation air for commercial and industrial building and comparison with conventional HVAC. The high grade heat is used for power generation and whereas the low grade heat is used for space heating and cooling the building. The energy consumption when using the geothermal cooling system will partly be reduced than the conventional one as per the calculations generated. The system is space constraint and more efficient than the conventional. The earth air heat exchanger or earth tube or earth soil heat exchanger or earth tunneling systems design is calculated manually with variation in underground temperature for the heat transfer from ambient air condition to underground temperature. The ground acts as a heat sink in summer and as a heat source in winter. As the increase in annual energy consumption will mitigate the CO_2 emission, correspondingly increase the carbon credit. The Earth tube heat exchanger is designed for the particular site for the pre-cooling purpose which leads to energy savings than using the conventional HVAC.

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Nomenclature

$\dot{m}_{air}$ – Mass flow rate of air in kg/s

C_p – Specific heat capacity in J/kg.K

ρ – Density of air in kg/m^3

λ – Thermal conductivity of air in W/m.K

μ – Dynamic viscosity of air in kg/m.s

ϑ – Kinematic viscosity of air in m^2/s

$\dot{Q}$ – Volumetric Flow Rate in m^3/hr

v_{air} – Velocity of air in m/s

A – Area of the pipe in m^2

Q – Total heat transfer in Watts (W)

q – Convective heat transfer in watts (W)

h_a – Convective heat transfer Coefficient in W/m^2.K

ΔT – Logarithmic mean temperature in °C

NTU – Number of transfer units

ε – Effectiveness of heat exchanger

Re – Reynolds Number

Pr – Prandtl Number

Nu – Nusselt Number

D – Diameter of the pipe in m

L – Length of the pipe in m

ΔP – Pressure drop in Pascals (Pa)

ξ – Friction factor

SH – Sensible Heat load in Btu/Hr

LH – Latent Heat Load in Btu/Hr

T_{inlet} – Inlet air temperature in °C

T_{outlet} – Outlet air temperature in °C

ω – Specific Humidity in kg/kg of dry air

DBT – Dry Bulb Temperature in °C

RH – Relative Humidity (%)

Chapter 1

Introduction

1.1 Overview:

Geothermal energy, a renewable resource, should be utilized in order to sustain the demand for energy. Renewable energy should be used as there is increasing threat of global warming and increase in energy prices. This energy can be extracted and rejected through geothermal heat pumps (GHPs) connected to a series of ground loops which exchange energy with the earth by conduction and convection. During the winter season, the heat pump will extract heat from the earth while in the summer season; it will deposit the unwanted heat below the earth. Therefore in hot or semiarid climate, the system produces more heat than it extracts, creating heat around the ground loops which will drastically reduce the efficiency and performance of the system. This ability of the earth to trap the heat over time is referred to as the "thermal sink" capacity.

1.2 Geothermal Energy:

It is obtained due to the difference in temperature gradient above and below sea level. There will be an increase of 10 °C for every 10 feet depth. As deeper the ground level, the temperature will be around 200°C. These heats can be classified into low grade heat and high grade heat, based on their grade and quality they can be used for power generation or space heating and cooling. The upper portion of the earth surface i.e. from ground till 15 feet depth has relatively constant temperature in all seasons.

Geothermal heating and cooling Systems provide space conditioning -- heating, cooling, and humidity control. They can also provide water heating -- either to supplement or replace conventional water heaters are the applications of geothermal cooling systems. Geothermal heating and cooling systems work by winding the heat, rather than by converting it from chemical energy to heat like in a furnace.

1.3 Current Energy Demands and Goals for the Future:

Due to the increase in population, demand for energy tends to increase and we should find ways to utilize the energy in most efficient way. Combustible renewables and waste constitute about one fourth of Indian energy mix. Firewood and dung are the other biomass resource of share about 24% in Indian fuel mix, which are used by many households for cooking and other domestic purpose. Renewables such as wind, geothermal, solar, and hydroelectricity represent of two percent share in the Indian fuel mix. Nuclear holds a one percent share.

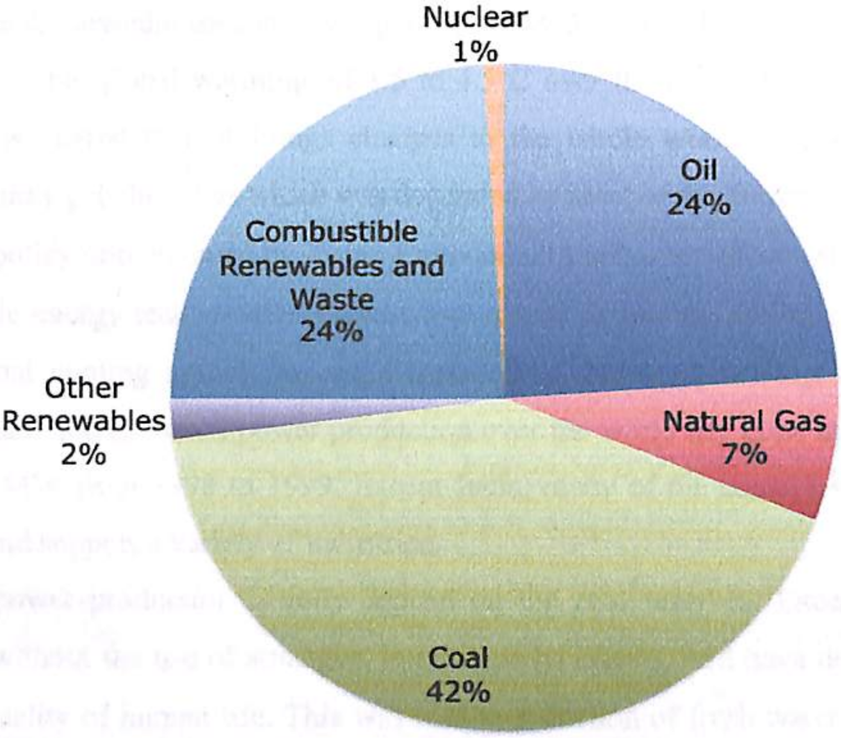


Figure 1 Percentage of energy resources in India

The largest source of energy to fill 42% gap is coal. Increase in carbon footprint by the usage of coal and the problem is been avoided, as increased its demands rather than implementing a solution. Therefore with rise in demand of the coal resources, global warming is calling for policies to be implemented to reduce the negative impact in energy production on our environment. In India there is no significant of power generation through geothermal power plants. At present situation there is a upcoming geothermal plant in Chattisgarh. "In 1997, 'Kyoto protocol' says that industrialized countries will reduce emission of Green House Gases (GHGs) by at least 5% compared to 1990 levels by the period extending from 2008 to 2012." Green House Gases are the most important gases which acts like a blanket around the earth. Without these natural blanketing surface the earth temperature will be 30°C less than the present level. These layer gets thicker by human activities. "For example, when we burn coal, oil, and natural gas we spew huge amounts of carbon dioxide into the atmosphere." If Green House Gases emission continues to increase in the current trend, the atmospheric levels of carbon dioxide will be doubled from pre- industrial levels during the next year. If no actions are taken to minimize the greenhouse gas it will get tripled by the year 2100. "The most direct result is likely to be 'global warming' of 1.5 to 4.5 C over the next 100 years". If the global climate is altered then it brings changes to the whole world. The wind and rainfall patterns may get altered as which was depended by most of the humans.

From a policy implemented by Kyoto Protocol, all the industries are establishing the new renewable energy technologies. Geothermal energy is gaining its importance as the first geothermal cooling system has been installed in the Appolo Hospital in Hyderabad. Geothermal energy based power production over the world has gone up from 5800 MW to 8400 MW from 1998 to 1999. Except India, many of the countries uses geothermal energy and support a variety of industries.

India's power production is fully depend on the coal reserves. Excessive use of this source, without the use of strategies to mitigate its effects, will have deteriorating effect on the quality of human life. This will lead to reduction of fresh water to the point may lead to severe droughts, especially in developing countries like India, where there are major threats to public health.

Though India has been excluded from joining the Kyoto protocol, in future it has to reduce the carbon dioxide emission - which means reduction in usage of coal and other fossil fuels. This is the time for India to launch its geothermal energy resources program in a big way to implement clean development mechanism (CDM). The country has enormous resources, which are lying untapped. The country should use the technology to trap the heat and to produce energy. Future for development of geothermal energy fits in very well under the above described Kyoto-FCCC. World funding organizations and developed countries, which are using extensively geothermal energy, are keen to promote this energy sources to reduce GHGs by India. This clearly displays the lack of awareness and underutilization of geothermal energy. According to the Department of Energy, geothermal heat pumps can reduce electricity consumption by up to 72% compared to a home using electric resistance heating and standard air conditioning (DOE Alternative, 2009).

New Energy goals can be seen at every level of government to produce "zero energy" industrial and residential buildings. The term zero energy means the building consumes no more energy than it produces.

There is no doubt that the cost of electricity produced from coal is far less expensive compared with other fuels. The present day cost of one unit of power is less than a rupee in the case of coal based power while liquid fuel based power costs about Rs. 2 per unit and hydro power costs about Rs.1.50. But the expenditure spent to meet the consequences (like disposal of fly ash; treating the coal with high ash content etc.) is high which automatically increases one rupee a unit to a several rupee unit. Nearly 400 low to medium enthalpy thermal springs exists in India. These are distributed in seven geothermal provinces. The surface temperatures of these thermal springs vary from 47 to 98°C. They are also the best sites for "Direct" application technologies. Direct application technologies are those where the heat energy is utilized directly by a variety of small scale industries.

1.4 Using Geothermal Applications to Meet Energy Goals

Zero energy can be produced by the renewable resource like Solar, Wind and geothermal. However there are drawbacks with the first two. Solar energy or photovoltaic systems can only be used during periods of sunlight and according to scientists photovoltaic technology reaches a maximum efficiency of 45% (Solar, 2009). While on the other hand wind is primarily available in the evening and entirely dependent on weather fronts. Also in suburban and urban environments the size of a necessary wind turbine can be a very unattractive option. Geothermal resources on the other hand operate 24 hours a day, out of sight. They come in a variety of configurations and can be buried underground.

Also if resources permit, they can be placed in a pond or lake. Geothermal heat pumps pump a liquid, generally water for safety concerns, through a series of tubes called ground loops. In cold conditions, the cold liquid is pumped underground through the loops obtaining the natural heat in the earth in order to increase the efficiency of hot water heaters and provide heat for homes. In hot conditions like Chennai, the water is pumped from underground or in surface water loops in order to expel heat from the environment using the cool liquid in systems such as swamp coolers.

1.5 Geothermal Heat Pumps:

The most common usage of geothermal heat is by geothermal heat pumps for space heating and cooling and hot water. The geothermal heat pump is a closed package in a single cabinet, and includes the components like compressor, loop-to-refrigerant heat exchanger, and controls. Systems that distribute heat using ducted air also contain the air handler, duct fan, filter, refrigerant-to-air heat exchanger, and condensate removal system for air conditioning.

For residential installations, the geothermal heat pump cabinet is usually located in a basement.

For commercial buildings, it is placed on the top of the ceiling or installed as a self-contained console.

Every Geothermal Heating and Cooling Systems has three major subsystems or parts: a geothermal heat pump to evacuate the heat between the building and the fluid in the earth connection, an earth connection i.e. ground loop for transferring heat between its fluid and the earth, and a distribution subsystem for delivering heating or cooling to the building. Each system may also have a de-superheater to supplement the building's water heater, or a full-demand water heater to meet all of the building's hot water needs.

1.5.1 Types of Geothermal Heat Pumps:

1. Ground coupled heat exchanger
2. Ground water heat exchanger
3. Surface water heat exchanger

4. Earth air heat exchanger- an energy efficient technologies accredited by Griha

These geothermal heat pumps are classified according to the loop configuration which is placed underground. The ground coupled heat exchanger uses the closed loop, the ground water heat exchanger (GWHX) and Surface water heat exchanger (SWHX) uses the open loop configuration.

1.5.2 Geothermal Loop Configuration Types:

Open and Closed Loops:

There are two basic types of loops open and closed loop configuration. Open loop is the common and simplest when the site is facilitated with water body near it. Ground water from the aquifer passes through the ground water heat exchanger and transfers the heat and is discharged to the same aquifer through a second well. Normally, two to three gallons per minute per ton of capacity are necessary for effective heat exchange. The temperature of ground water is constant all the year; Open loop has some in evident challenges.

It depends upon the chemical components in the water which will lead to the fouling of heat exchangers. In these situations carbon dioxide and other gases should be filled in the water. Using cupronickel material for designing the heat exchanger which will permit the water with more chemicals. This will not affect the heat exchanger. It should get approved by the local officials and should comply the discharge method with the environment.

Closed systems are the common loop configuration. For proper installation, it will be economical, efficient, and reliable. Water or antifreeze solution is circulated through a continuous buried pipe which is the closed loop. The closed loop is environmental friendly as it does not have any hazardous by the refrigerant.

The length of loop piping has other depending parameters on ground temperature, thermal conductivity of the ground, soil moisture, and system design.

Horizontal Loops:

The horizontal one closed the buckle installations generally are the most profitable ones for the small installations, notably for the new construction where the sector of sufficient earth is available. These installations imply burying the pipe in the dug trenches with the excavators or chain. Until six pipes, of ordinary one in the parallel connections, are buried in every trench, with the separations minimum of a foot between the pipes and ten to fifteen feet between the trenches. .

Vertical Loops:

The vertical closed loops are preferred in a lot of positions. Most of big buildings and the commercial schools use vertical loops because the sector of demanded earth for the horizontal buckles would be prohibitive. The vertical loops also are used where the ground is too not very deep for trenching. The vertical buckles minimize also the disturbance to exist installation. For the vertical closed buckle systems, a u-tube (more rarely, two u-tubes) is installed in an induced good 100 to 400 feet depth. Because the conditions in the ground can vary strongly, the buckle lengths can spread of 130 to 300 feet by the ton of exchange of heat. The multiple holes of exercise are demanded for most of the installations, where the pipes generally are participated the configurations of analogy or collection analogy. The pipes that are buried under earth that contains liquid (the solution of water or antifreeze) the go through the pipes that absorb the heat of the building during the summer and transfers the heat under earth, to cool operation the heat of earth is absorbed by the liquid and emits the heat in the construction space. The pumps of heat can be installed anywhere in the world as the sufficient heat is stored in the earth. Theoretically the geothermal heat pumps of heat can save energy until 80 percent.

The geothermal technology to be implemented in the site APPOLO TYES, CHENNAI is used to control temperature inside buildings (Pre-cooling). This project accounts for not more than 500 feet below the surface as it is not used for power generation. Most geothermal climate systems do not go below this depth, although they shouldn't be less than three feet below the surface either. These systems are so installed to reduce the need for conventional cooling and heating.

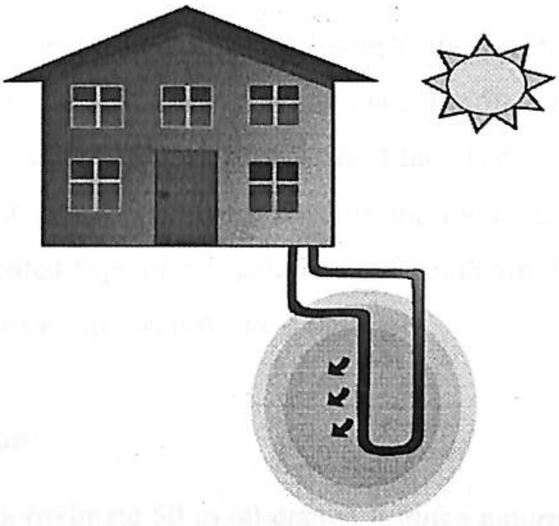


Figure 2 Working of Earth - air heat exchangers in summer days (Cooling Operation)

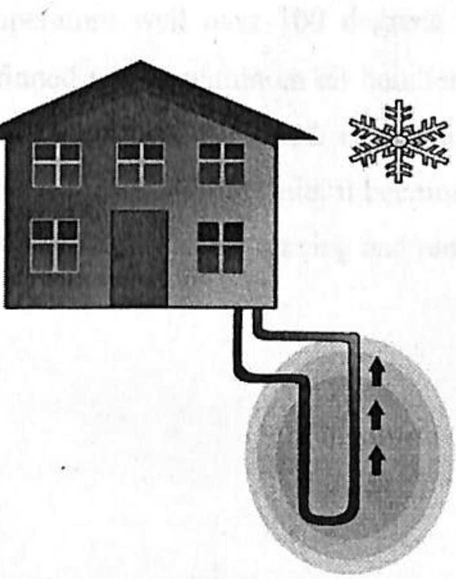


Figure 3 Working of Earth - air heat exchanger in winter days (Heating Operation)

Basically, geothermal heating/cooling systems operate via sub-surface conductive heat transfer, using the naturally renewable temperature of the earth's crust as a heat source in the winter, and as a heat sink in the summer.

1.5.3 Cooling Operation:

In the cooling method, the refrigerating hot (more than 100 degrees F) going out the compressor of ETA directly is sent in the approximate one 50 to 60 ranges of F of degree to the deep earth, that absorbs now and takes the heat far. The cooled liquid of refrigerate then is circulated by the air agent where it absorbs and removes the superfluous heat of the internal air. The heated trips of refrigerate to the geothermal heat pump the unity of compressor of the system where the process is repeated.

1.5.4 Heating Operation:

In the heating mode, approximate 50 to 60 degree F range naturally occurring heat from deep within the earth travels to, and is absorbed by, a much colder refrigerant fluid that is circulated within the copper tubing inside a deep well/borehole. Such naturally occurring heat is transported by the refrigerant fluid to the system's compressor where the fluid is compressed, thereby raising its pressure and temperature, transforming the 55 degree F temperature into a temperature well over 100 degrees F. The hot refrigerant is then circulated through the finned tubing within an air handler, where the cold return interior air absorbs the heat. The heated air is supplied, via a fan, to the interior air space. With the heat now removed from the refrigerant fluid, it becomes very cold and is re-circulated into the ground to absorb more naturally occurring and renewable heat.

Chapter 2

Literature Survey

Sodha et al. have carried out rigorous experimental studies with a large earth-to-air heat exchanger system situated at Mathura, India. These models were based on several assumptions such as axially symmetric flow, constant pipe wall temperature, negligible humidity variations etc. Moreover, earth- to-air heat exchanger in these studies was analyzed independent of the effects of variations in ground temperature. One of the important aspects in concern of EAHEs is categorization of the site in terms of geology availability. The knowledge of soil thermal and physical properties (thermal conductivity, density, diffusivity etc.), depth of bedrock, depth to water and the nature of soil is required. This information guides the designer in the selection of the type of EAHE system to be used and in the design of the system]. Two major types exist: 'open-loop' (i.e., drawing outside air through the pipes to ventilate the house) or 'closed-loop' (i.e., re-circulating the air from the building through the earth tubes). The second kind seems to have fallen out of favor, probably because it is insufficient to provide heating to the building by itself, and because it does not help meet the building's fresh air requirements. The EAHE systems gained some popularity about three decades before but they were not used commonly by people either because of poor performance or because of certain disadvantages related to them like higher initial cost, decrease in air quality with increase in time of use, growth of fatal micro-organisms, transfer of fan noise through pipes to living space etc. The present requirement of use of renewable and sustainable energy technologies has again generated interest of researchers and scientists in the concept of EAHEs.

Viorel Badescu, Dragos Isvoranu Developed an analytical pneumatic and thermal design procedure is proposed for earth-to-air heat exchangers (EAHEs) of registry type. The procedure allows to choosing between different EAHE geometrical configurations and between the two usual air circulation paths inside the EAHE (i.e. the Z- and P-paths, respectively). The implementation of the design procedure is made for the EAHE of a large passive house (PH) built near Bucharest, Romania (AMVIC PH). A time-dependent simulation of EAHE's operation is performed. It allows to computing the soil temperature profile at the surface and at various depths and the air temperature distribution inside the EAHE. This simulation is validated by comparison with experimental results. The EAHE heating and cooling potential during the year is investigated. The energy delivered by the EAHE depends significantly on its geometrical configuration. A computer fluid dynamics (CFD) analysis is also performed. This analysis is validated by comparison with experimental results. There is good agreement between the results predicted by the design procedure and the CFD analysis concerning the air pressure drops in the EAHE. From a thermal point of view the Z-path should be preferred to the P-path. The CFD analysis results confirm the conclusions stressed out from the simple analytic design procedure and the time-dependent simulation

A thermal model has been developed to investigate the potential of using the stored thermal energy of the ground for greenhouse heating and cooling with the help of an earth to air heat exchanger (EAHE) system integrated with the greenhouse located in the premises of IIT, Delhi, India. Experiments were conducted extensively throughout the year 2003, but the developed model was validated against typical clear and sunny days experiments. Parametric studies performed for the EAHE coupled with the greenhouse illustrate the effects of buried pipe length, pipe diameter, mass flow rate of air, depth of ground and types of soil on the greenhouse air temperatures. The temperatures of the greenhouse air, with the experimental parameters of the EAHE, were found to be, on average 7– 9°C higher in the winter and 5–6 °C lower in the summer than those of the same greenhouse without the EAHE. The greenhouse air temperatures increase in the winter and decrease in the summer with increasing pipe length, decreasing pipe diameter, decreasing mass flow rate of flowing air inside buried pipe and increasing depth of ground up to 4 m. The predicted and measured values of the greenhouse air temperatures that were verified, in terms of root mean square percent deviation and correlation coefficient, exhibited fair agreement

Chapter 3

Theoretical Development

3.1 Building Cooling loads:

These building cooling loads are calculated according to the specific location weather data (Appolo Tyres Chennai) which helps to find the capacity of the conventional HVAC to cool the building in tons of refrigeration or in kW. The main difference of using earth air heat exchanger over conventional HVAC is that it pre-cools the building and there will never be higher power consumption than the conventional systems.

Heating and cooling loads are calculated from the software (Hourly Analysis Program software developed by Carrier). Before selecting the conventional equipment and its capacity the building's cooling and heating loads should be identified manually or by using software. It can be determined by assigning the parameters like zone, space and other requirement the heat gain by the occupant schedule, equipment and the outlet ambient air condition mentioned by the building description.

Cooling load calculations may be used to accomplish one or more of the following objectives:

a) It gives information for system design, system sizing, and equipment

b) It gives data for evaluating the optimum possibilities for load reduction.

c) Permit analysis of partial loads as required for system design, operation and control.

There are set of rules followed in the calculation of cooling loads i.e. the building should be divided into space-is either a volume or a site without a partition or a partitioned room or group of rooms, room- is an enclosed or partitioned space that is usually treated as single load. Or into zones- is a space or group of spaces within a building with heating and/or cooling requirements sufficiently similar so that comfort conditions can be maintained throughout by a single controlling device.

The heat gain or heat loss through a building depends on:

a. The temperature difference between outside temperature and our desired temperature.
b. The type of construction and the amount of insulation in the ceiling and walls that influence the air conditioner sizing.
c. The surface area of the walls. The larger the surface area ,more heat can lose, or gain through it.
d. Infiltration plays a part in determining the air conditioner sizing.
e. The occupants presence in the living space.
f. Activities and other equipment within a building.
h. Amount of lighting in the room. High efficiency lighting fixtures generate less heat.

The heat gains in the building are classified into two types. 1. Sensible heat load, 2. Latent heat load

3.1.1 Sensible Heat Loads:

Heat which a substance absorbs, and while its temperature increases, the substance does not change state. Sensible heat gain is directly added to the conditioned space by conduction, convection, and/or radiation. The sensible heat gain entering the conditioned space does not equal the sensible cooling load during the same time interval because of the stored heat in the building envelope. Only the convective heat becomes cooling load instantaneously. Sensible heat load is total of

a. Heat transmitted through floors, ceilings, walls
b. Occupant's body heat
c. Appliance & Light heat
d. Solar Heat gain through glass
e. Infiltration of outside air
f. Air introduced by Ventilation

3.1.2 Latent Heat Loads:

Latent heat gain occurs when moisture is added to the space either from internal sources (e.g. vapor emitted by occupants and equipment) or from outdoor air as a result of infiltration or ventilation to maintain proper indoor air quality. Latent heat load is total of

a. Moisture-laden outside air form Infiltration & Ventilation

b. Occupant Respiration & Activities

c. Moisture from Equipment & Appliances

To maintain a constant humidity ratio, water vapor must condense on cooling apparatus at a rate equal to its rate of addition into the space. This process is called dehumidification and is very energy intensive, for instance, removing 1 kg of humidity requires approximately 0.7 kWh of energy.

Building Description:

Type of Building	Area in (m^2)	Number of stories to be air conditioned	Total Kw of air conditioned or total tonnage (TR)	Number of Air handling Unit	Total Cost of the equipment
Commercial Building	8299.5	2	120 TR – Variable refrigerant Flow (Conventional Air conditioning)	2	RS10,2500/-

Table 1 Building description of Appolo Tyres Chennai

The APPOLO TYRES CHENNAI is a two storey building with a area of 8299.5 Square meter. The rooms are divided into number of zones and its cooling load is calculated by assigning the ASHAE 90.1 for the occupant schedule, lighting schedule, equipment, wall resistance, roof resistance etc. The area summary and the schedules are mentioned for the site APPOLO TYRES, CHENNAI in the appendix.

The cooling load estimates that it requires 120 TR of capacity (as it has the heat gain of 15,236 Btu/hr to cool the building. The conventional HVAC equipment which is selected according to the tonnage is Variable Refrigerant Flow. In short the Variable refrigerant Flow consists of one out door unit i.e. Condenser and 5 indoor units for the Auditorium, Conference hall and etc and an Air Handling Unit of 60 TR each. The advantage of using VRF over DX cooling systems is that it controls the capacity by regulating the refrigerant flow in the particular space if occupants are not present. The ventilated air quantity estimated in the two storey building is given below

Floors	Calculated ventilation Air quantity
Ground Floor	4200 CMH
1st Floor	5300 CMH
2nd Floor	2102 CMH

Table 2 Ventilation air quantity for each floor

3.2 Theory of Heat Exchangers:

Importance of energy should be given to the environment, and it is very much required to find a alternate energy source to replace the conventional systems or at least reduce its consumption and its consequent impact on the environment. Alternative energy does not only give a energy efficient option, but it is synonymous of clean and renewable energy. These type of energy are in exhaustible can be well adversely found available and exploited in the earth. Air conditioning was widely used in the industrial buildings in recent times and also for the comfort of occupants as mentioned by ASHRAE (American Society of Heating, Refrigeration and Air conditioning). The air conditioning system can be achieved by the known vapor compression cycle, as it has a drawback of depleting the ozone layer, global warming takes places and in order to reduce maximum energy consumption; many techniques were explored. One such method is the earth to air heat exchanger systems. EAHX system uses the underground soil temperature and uses it as a heat sink in summer i.e. for cooling. Warm ambient outdoor air is sent into the earth-to-air heat exchangers. When air flows in the earth–air heat exchangers, heat is transferred from the air to the earth. As a result, the air temperature at the outlet of the earth to air pipes will be much lower than that of the ambient. The outlet air from the earth–air–pipes can be directly used for space cooling if its temperature is low enough. If it does not meet the total cooling requirement, the outlet air from the earth air heat exchanger may be cooled further by associated air conditioning machines. These alternative methods of using earth–air pipes can contribute to reduction in energy consumption.

Many researches have been done to describe the earth-to-air heat exchangers (EAHE) coupled with buildings as an effective passive energy source for building space conditioning. These earth air heat exchanger systems can meet the building's cooling load, and its performance is fully based on the parameters like periodically varying air inlet temperature, and the pipe wall temperature which further depends on the ground temperature. The performance of an EAHE system depends upon the temperature and moisture distribution in the ground, as well as on the surface conditions.

The earth-tube heat exchanger (ETHE) can be designed for use in green house in arid areas like Chennai. The basic process taking place in the earth air heat exchanger is the due to the pipes placed underground. The ambient air transfers the heat through the pipe surface walls with the surrounding earth. At the outlet of the earth air heat exchanger system the air enters the ventilation system of a building and is usually conditioned for heating or cooling. This report is basically dealing with the design of EAHX with the thermal heat transfer mechanism and the fluid dynamics.

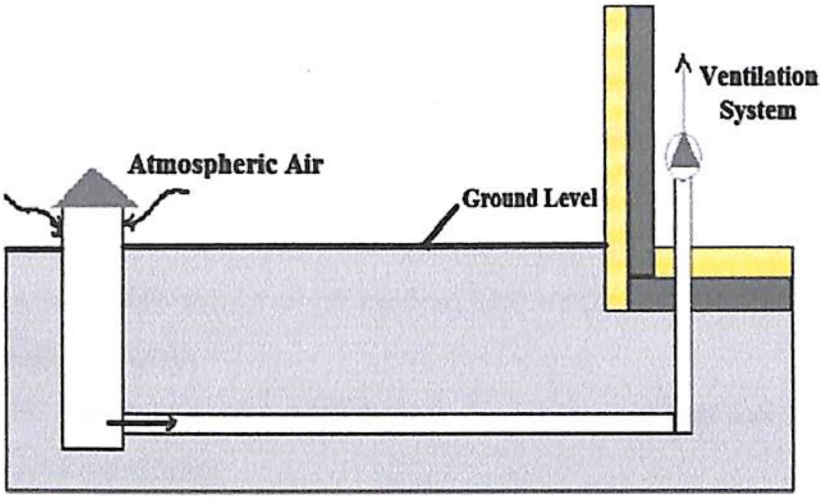


Figure 4 Earth to air heat exchanger

The approximately constant temperatures of the soil at a certain depth are much lower in summer and higher in winter than the temperatures of unconditioned greenhouse air. By allowing the air to flow in buried pipes of plastic, steel or concrete, there occurs an energy exchange between the flowing air and the underground soil depending on the difference of temperatures between them. This exchange of thermal energy induces variations in the temperatures of the moving air and the soil around the pipe. The inlet (suction) and outlet (delivery) ends of the circulating air are positioned at the opposite sides of the enclosure for uniform mixing in the space to be conditioned. During the operation, the blower sucks air from the greenhouse and circulates it through the pipes of the earth coupled heat exchanger. In summer, the warm air from the greenhouse, sucked through the suction pipe, gives up its heat content to the buried pipe by convection, which is then dissipated to the earth by conduction. The cool air from the heat exchanger is then entered into the greenhouse. In winter, when cold air from inside the greenhouse is circulated through the buried pipes, there occurs a transfer of heat from the earth to the air stream, resulting in the increase of the delivery air temperature. In the mid period, when the indoor temperature is higher than the required level during the daytime, the excess heat content of the flowing air is transferred to the earth to reduce the undesirable rise of temperature in the enclosure. Thus, the enclosed air of the greenhouse gets cooled during summer and heated in winter by utilizing the stable thermal content of the ground with the help of the earth air heat exchanger.

3.2.1 Thermal Energy Storage of Ground:

It is flexible cooling technique to store or dampen the diurnal or fluctuating heat source under-ground to effective utilization in the buildings. From all the thermal energy storage medium the ground is the most convenient and simple medium for the buildings to store and utilize the heat due to its huge capacity and availability. There is stability in the ground temperature which makes the ground as heat source, and sinks which can be an energy conservation measure.

Ground medium thermal storage applications for space heating and cooling can be classified into three categories:

1) The direct method, which cools or heat the indoor air by the direct contact of the ground to the buildings;

2) The indirect method, that precools the ambient air or air from the ventilation and send it to the tunneling underground, and

3) The isolated method, which uses a heat exchange medium, such as ground water or antifreeze refrigerant or coolant, to exchange energy between the ground and the indoor environment.

3.2.2 Design Parameters of Earth Cooling Tubes:

The earth air heat exchanger is to be designed according to the design requirements i.e. by the site layout (Space consideration) and energy efficient measures. The air leaving the heat exchanger should fully or partly satisfy the building cooling requirement at the design summer day. These design requirements are achieved by the ventilation air from the building is cooled by passing it underground where the heat transfer from the ambient air to the ground temperature.

The sizing parameters are the air mass flow rate, air inlet temperature, air outlet temperature from the heat exchanger to the building, and the ground temperature which is shown above on the particular location (Chennai). The mass flow rate, air inlet temperature and the ground temperature are to be set by the design requirement, based on the climatic condition of the location. Optimal depths are between 2 to 4 m. The ground temperature fluctuates with time but the amplitude diminishes with increasing depth of the tubes as it is low enthalpy heat it can be possessed by the depth of 3 m.

Earth to Air heat Exchangers are long metallic, concrete or PVC pipes buried in the ground connected to the air intake of the building that is the ventilation of the building. It serves for pre-cooling purpose in that commercial building which is represented below with layout drawings. The air quantity in that building is calculated and those are compared with conventional HVAC systems. From a known literature [1] the economics of earth air heat exchanger are marginal, particularly for cooling purpose. This report summarize the proposed design, sizing and basic construction of the earth air heat exchanger that is designed to be has economical with current technology and its prices. The design parameters are listed down based on their performance and their economic feasibility

1. Tube material

Tube material gain an importance in the thermal performance of the design of the earth air heat exchanger, as the conductivity of the soil surrounding the pipe is the limiting factor. PVC, concrete or metallic tube can also be used. The concrete pipes have the stability to withstand crushing when the pipe is buried underground. If PVC pipes are used there should be Corrugation (as in corrugated PVC) gives a maximum structural strength and has a disadvantage of storing the water in those traps and finally the pipes will be corroded and even the moisture inside pipe will be increased. As the water cannot penetrate through the pipes. In this proposed design the reinforced concrete pipes of class 4 as per the ASTM C76 standards are used as their thermal conductivity is more than the PVC and metallic tubes.

2. Length

The length of the pipe can be typically be in a range of 20 – 100 m for a single pipes based upon the building cooling requirement (as per the ventilation air quantity in CFM). Longer pipes will make the system efficient and most expensive. The drawback of using longer pipes is that which increase the capacity of the blower. The blower consumes more power to send the air to the building.

3. Diameter

By the thermal design consideration smaller diameter are preferred, but they also account (at equal flow rate) to maximum friction losses, so it becomes a challenging step to balance between increasing heat transfer and lowering fan power, by selecting the optimum diameters as per the building requirement. Typical diameters can vary between 10 cm to 30 cm for residential buildings and can be as large as up to 1 m for commercial buildings.

4. Spacing

Spacing should be more enough as it is thermally independent, typically at least 1 m apart. Tubes can also be placed in a radial pattern. This proposed design was made to fit the pipes in parallel pattern so has to increase the heat transfer area to achieve more cooling abilities. The serpentine flow is tuned in the parallel pipes which makes a turbulent flow for the continuous smooth pipes.

5. Number of tubes

The number of tubes is selected as per the air flow requirements, the length of the tubes and the required thermal performance.

6. Soil type

Wet soil is preferred than the dry soil as it has a maximum thermal conductivity which conducts heat inside the soil. Many authors suggested that the clay types will be having good thermal contact between the pipes and the earth.

7. Depth

As deeper the pipes are placed it yields to a maximum performance. The optimal depth have been studied and it was found to be in 2 – 4 m in depth, the pipes can be placed under the building or apart in the open space available near the location. These systems will be space constraint and the horizontal pipes can be laid only when there is enough space. The vertical will be preferred only if the site has limited space.

8. Flow rate:

Minimum flow rates are employed so as to achieve higher or lower temperature which accounts for the fan energy consumption. The flow rate depends upon the diameter and flow rate to the system.

9. Controls

The system should be bypassed when the outside temperature is typically between 27 and 29 °C (one can also take the earth temperature into account to decide when to turn the system off). Windows need to be closed for the system to contribute properly to the heating or air conditioning of the building.

10. Economics

The economics of installing the earth air heat exchange systems are positive for cooling applications, because in some climates earth tubes enable the user to dispense with a dedicated air-conditioning system. The economics are not as good for heating applications because earth tubes by themselves are not sufficient to significantly heat a building and therefore a heating system is still required. In other words, the small heating gain does not justify the additional cost of the earth tubes. However, if earth tubes are used for cooling in the summer, an added benefit is to use them for preheating ventilation air in the winter, either directly or by preheating the inlet air of a heat recovery ventilator (HRV).

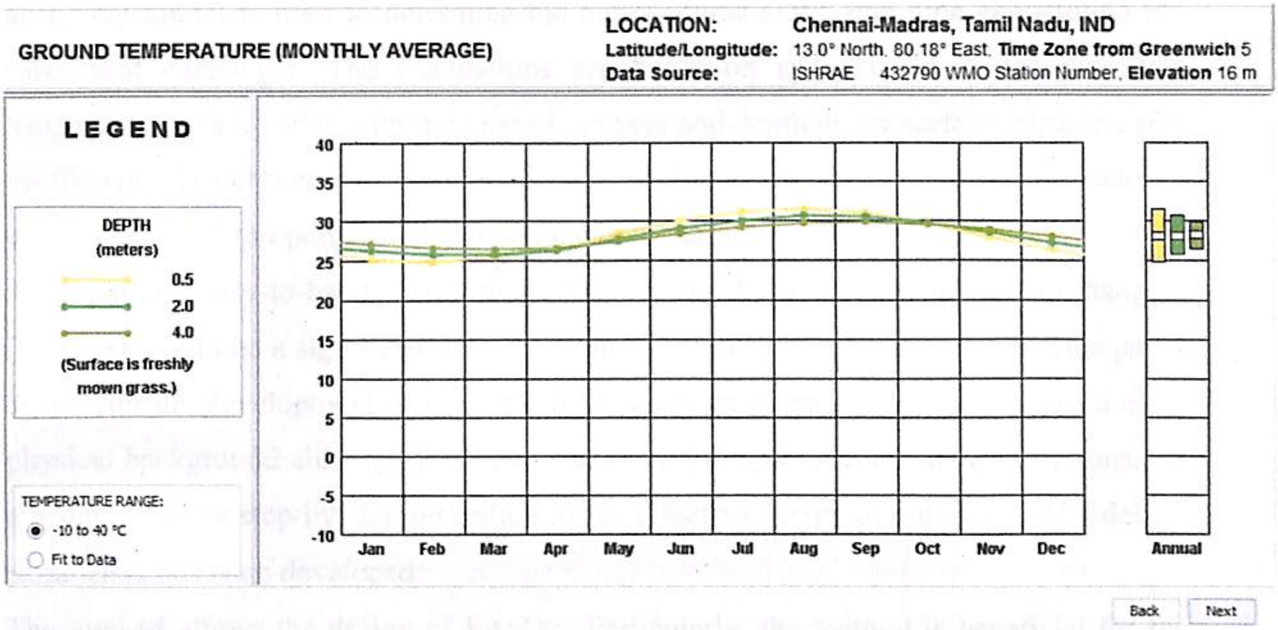
3.2.3 Design Procedure for EAHX:

The first criteria in designing the earth air heat exchange is to know whether the ground has the ability to act as a heat sink for summer season, so the deep soil temperature regime in Chennai was studied, The strata of the soil temperature underground will be stable and the regime will be suitable for installation of Earth air tunneling or heat exchanger system. The temperature in this stratum shown by the climate consultant software displays no diurnal fluctuation. The annual fluctuation will be present, but the amplitude is small. Average temperature in this stratum is 27°C. The second criterion is to design the earth air system and analyzed.

Heat Transfer in the Earth:

From the ground to 100 feet depth the heat transfer takes place in different forms. Short/long wave radiation, convection and evapotranspiration, are the modes of heat transfer that takes place in the ground. The majority of heat transfer takes place by conduction except for the regions with water movements. Although another forms of heat transfer also take place (such as latent heat which is transferred through evaporation and condensation, and sensible heat transferred by moisture), the soil's conductivity is taken into consideration. Geothermal energy which can be obtained from the crust (the mantle and core) which will be a constant heat source flow and it is negligible when the heat flow is analyzed in the shallow region. (Rybach and Sanner 2000).

Earth temperature at the wall of the pipe depends firstly on the heat transfer from earth surface to deeper layers. Secondly when the earth heat exchanger is used the air in the pipe itself influences the earth temperature at the pipe wall. There are many numerical calculations for the ground temperature by some influencing parameters like soil diffusivity, density, the type of soil; conductivity test and the moisture absorbance level are analyzed by the soil testing Centre. Once the soil is good to conduct the heat the project can be implemented. The ground temperature can be calculated using the software Climate Consultant. The weather file of Chennai in .epw format is imported to the software and the ground temperatures are shown as in fig 5


GROUND TEMPERATURE (MONTHLY AVERAGE)

LOCATION: **Chennai-Madras, Tamil Nadu, IND**
Latitude/Longitude: 13.0° North, 80.18° East, **Time Zone from Greenwich** 5
Data Source: ISHRAE 432790 WMO Station Number, **Elevation** 16 m

TEMPERATURE RANGE:
● -10 to 40 °C
○ Fit to Data

Figure 5 Ground Temperature profile by ISHRAE

As the software shows the ground temperature fluctuation of 27°C - 29°C which is based on the soil condition. The .epw file consists of dry bulb and wet bulb temperature for 8760 hours.

This thesis shows the proposed design and experimental set up of the earth air heat exchanger systems. Theoretical Performance data has been calculated for May and January as it is considered as the design summer and design winter day discussed in detail. May month is the hottest part of summer, January the coolest part of winter in Chennai region.

3.3 Design of earth air heat Exchanger:

There were many numerical simulation calculations of one dimensional heat transfer models based on earth air heat exchanger was calculated as it was difficult to get the accurate result. This earth air heat exchanger is designed by the basic heat transfer formula (Thermal Design). The authors designed GAEA (Software) according to well-known models of heat and mass transfer. As the software is so expensive, manual calculation has been done for the dimensioning the earth air heat exchanger. An analytical model is used to determine the temperatures along one pipe constituting the earth heat exchanger. The calculations are based on approximations for the earth temperature which varies with the time of the year and depth under surface. Heat transfer coefficients for the heat flow between air, pipe wall and earth are estimated from material coefficients, flow properties and geometric parameters.

A simple and easy-to-handle method for the design of the earth-to-air heat exchangers (EAHXs) would be a significant improvement to the practical design process. This paper deals with the development of a simple EAHX design method. The method has a clear physical background although it is based on several simplifications and assumptions. As a result, a simple step-by-step procedure for an effective design of optimal EAHX design parameters has been developed.

The method allows the design of EAHXs. Particularly, the method is beneficial for the preliminary design phase when conceptual variants of building ventilation and cooling are prepared.

Pipe length, diameter, and the number of pipes are the main design parameters of EAHX. It has to be decided whether it is more advantageous to lengthen the pipe and/or to add another pipe (the reduction of air flow rate through one pipe). Generally, an EAHX improvement should be balanced against reasonable investment costs.

If a constant internal pipe surface temperature is considered as t_S °C along the length of EAHX the outlet air temperature t_{out} °C can be described with this formula:

$$t_{out} = t_{\text{Surface wall}} + (\, t_{inlet\ air} - t_{\text{Surface wall}}\,) \times EXP^{-\left(\frac{h \times A}{\dot{m}_{air} \times Cp_{Air}}\right)}$$

Where **NTU** (number of transfer unit) is a dimensionless parameter:

$$\text{NTU} = \frac{h_a \times \pi \times D \times L}{\dot{m}_{air} \times C_{p_{air}}}$$

Where $\dot{m}_{air}$ is the air flow rate in (kg/s]), $C_{p_{air}}$ is the specific thermal capacity of the air (J/kg.K), h_a is the air-to-pipe convective heat transfer coefficient (W/m^2.K) D is the internal diameter of pipe (m), L (m) is pipe length, and $t_{inlet\,air}$ is the inlet air temperature °C.

EAHX efficiency represents how much the outlet air temperature comes close to the internal pipe surface temperature.

$$\eta_{EAHX} = 1 - exp^{-NTU}$$

Theoretically, we should increase ***NTU*** as much as possible to increase the exchanger efficiency. It would lead to a combination of minimal airflow rate and a very long pipe. However, when a certain value of ***NTU*** (2.0 – 2.5) is reached, there is only a minor gain in efficiency. Therefore, ***NTU*** should be higher than 1.2, but it should not exceed 2.5. Such a range leads to efficiency from 70 % to 92 %.

Pressure loss [Pa] in a straight pipe with a smooth surface can be calculated as:

$$\Delta p_{Friction} = \xi \times \frac{L}{D} \times \rho_{Air} \times \frac{Velocity_{Air}^2}{2}$$

Where, ξ is the friction factor, the friction factor can be calculated based on the flow inside the tube i.e. turbulent or laminar and it can be selected in the graph according to the l/d ration on the heat and mass transfer data book.

ρ (kg/m3)- density of air, and v_a (m/s) is the mean air velocity inside the pipe.

Heat flow Q (W) extracted from or delivered to soil is not equal to EAHX cooling power $Q_{Cooling}$ (W). Despite air-cooling in EAHX, when the temperature of the internal air is lower than the outlet air temperature from EAHX, a building cannot be cooled down. The heat flow Q (W) is defined as:

$$Q_{Cooling} = \dot{m} \times C_{p_{Air}}(t_{outlet} - t_{inlet})$$

Where t_{inlet} is the temperature of internal air in a cooled building. Generally, lower pipe diameter leads to higher NTU; higher NTU leads to higher exchanger efficiency. The increase of the airflow rate does not reduce NTU considerably. The increase of the airflow rate or the decrease in pipe diameter leads to a higher value of the convective heat transfer coefficient, and this characteristic compensates the disadvantage of the higher airflow rate, to some extent. However, the pressure loss increases with the increase of the airflow rate and/or with the decrease in pipe diameter. Therefore, it is rather suitable to split the total airflow rate into more pipes with as low a diameter as possible, which will ensure reasonable high efficiency and still acceptable pressure loss. On the contrary, many long pipes are in conflict with financial restrictions and often with building site possibilities, as well.

Although there are some differences among the models based on their respective assumptions, their principles are fundamentally the same. They all use below equation to calculate convective heat flux between the duct surfaces and the air.

$$q'' = h(T_{air} - T_{wall})$$

The h, convective heat transfer coefficient (CHTC) is a complex function of air velocity and temperature differences between the air and the duct surfaces. The heating or cooling capacity of ETAHE is determined by integrating the heat flux over the total internal duct surface area. Therefore, CHTC determination is critical to the prediction of the system's capacity. Since analytical solutions of the air velocity and the air temperature profiles are usually not available, except for some very simple scenarios, most CHTC in ETAHE are obtained experimentally. In the existing ETAHE models, a few empirical correlations have been adopted and they are all applicable for fully developed turbulent flow in smooth circular ducts.

3.4 Experimental Set-up

3.4.1 Site

The installation is on an open field at APPOLO TYRES, Chennai. Soil at the site was tested at C.Tech Environmental Lab, Chennai. The site is found to be sandy-silt (sand 48%, silt 41%, clay 11%). Moisture content at the time of excavation was 12.61% (d b). Proposed design set-up consists of an ETHE, fan house, temperature sensors and back-up risers. A schematic diagram of the set-up is shown in

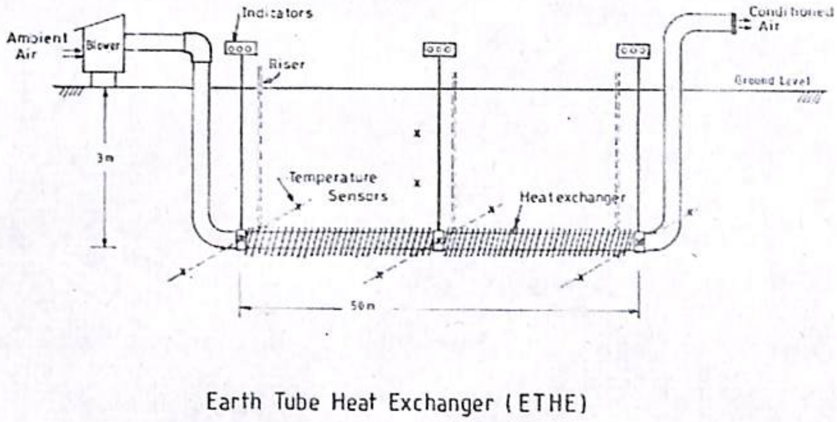


Figure 6 Proposed Earth air heat exchangers with thermistors and sensors

Revit drawing Layout of the site Appolo Tyres in 3D view

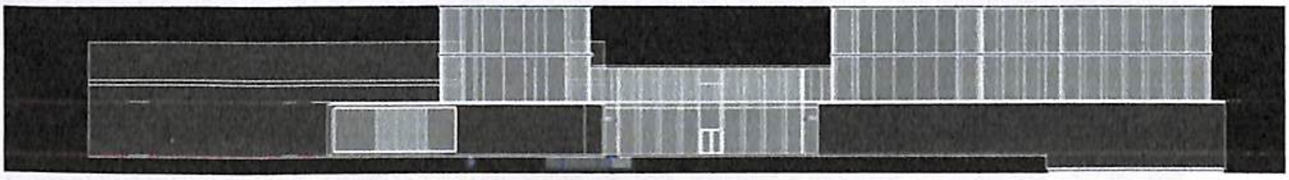


Figure 7 3D View of Appolo Tyres Chennai in revet software

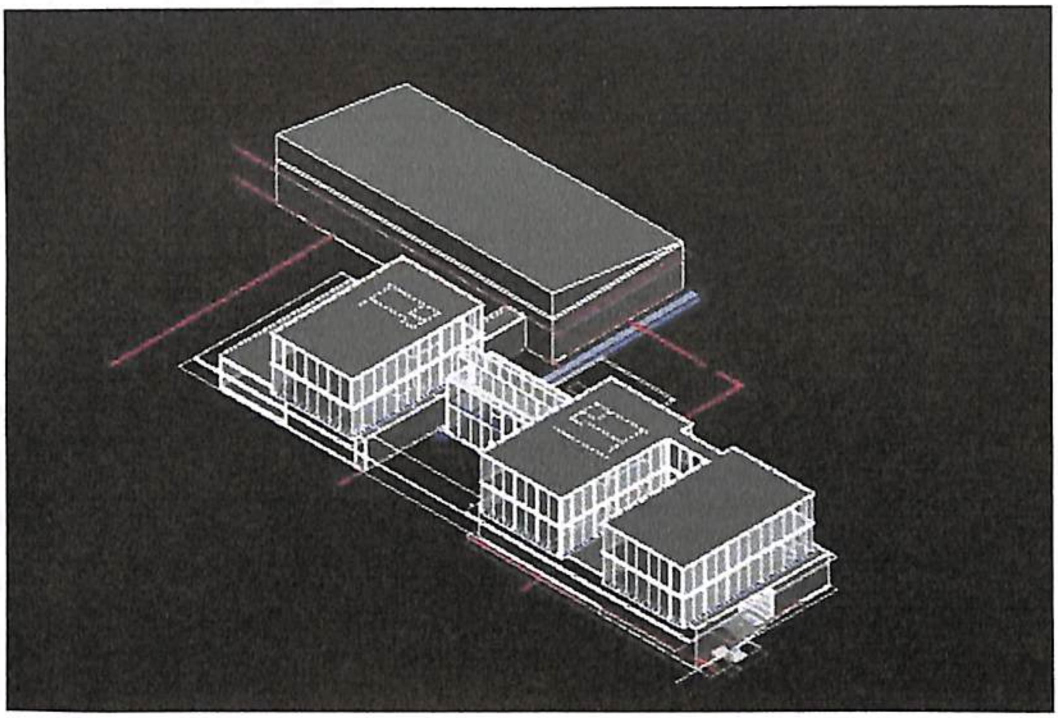


Figure 8 3D Elevation Cross view

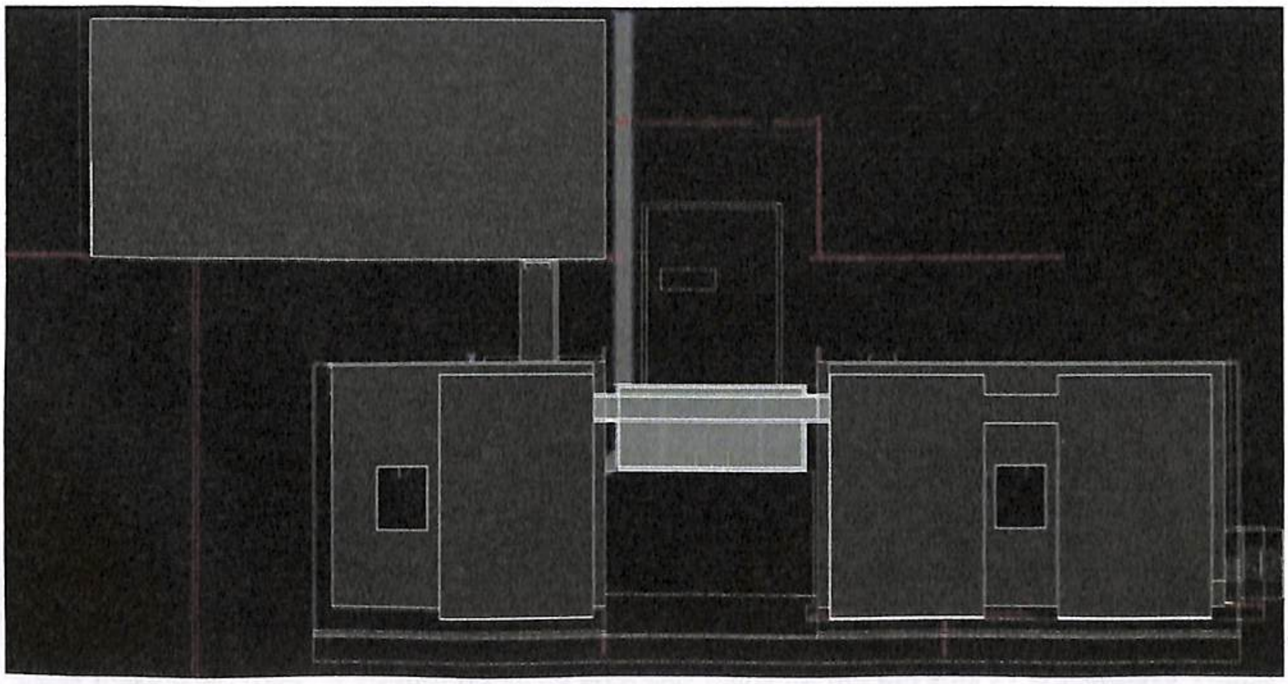


Figure 9 3D Top Elevation View

3.4.2 Earth-Tube Heat Exchanger

ETHE consists of a 44 m long 0.6 m diameter of concrete pipe with wall thickness of 0.23 m. Concrete is the good conductor of heat as it has been proposed for this site. These depend upon the thermal conductivity of the material to absorb the heat. If metallic tubes are used, fins can be attached are attached to the total length of the pipe so as to absorb the heat in the soil. The fins are made up of galvanized iron. A long trench is first excavated by a bucket excavator. Trench floor is properly leveled and a 15 cm thick bed of sand placed on it. ETHE is placed and covered with sand up to about 15 cm above it. Then the trench is back-filled with the original soil. The inlet and outlet of the ETHE rise 0.5 m above ground. Inlet is connected to the delivery end of blower and outlet is open to atmosphere. A 90 elbow at the end makes the outlet.

The concrete tube has a thicker wall but one with higher thermal conductivity and increased surface roughness, which results in a slightly higher overalls *f*, Nu, and *U*, resulting in a decreased L using the current method as seen in. However, roughness and wall thermal resistance are not included; yield the same tubing length as when thinner walled concrete is used. In the current method the length found out is average and its cost is affordable.

3.4.3 Instrumentation

It is desired to obtain air temperature in the ETHE at three locations -- at the entrance, middle (22 m) and at the end (44 m). One thermistor is installed at each of these three locations inside the tube at the center. A 15 cm long, 10 cm diameter coupler is used to build the thermistor assembly. A acrylic strip, 10 cm long (to fit sung across the inner diameter of the coupler) 2 cm wide and 2 mm thick and is placed horizontally at the center. Its ends are bonded to the pipe wall with adhesive. Thermistor is placed at the center and bonded to upper surface of the strip using a very thin layer of adhesive. Leads were taken out of the coupler via a 2 mm hole drilled on the side. Hole was then sealed to make it air tight. A 25 mm threaded hole was made on the top side of the coupler. Upper end of the riser is normally closed with a cap. Risers were provided to act as a back-up for obtaining tube air temperature, if built in sensors failed. The leads also are taped to the outside of concrete pipe and brought above ground and connected to a digital indicator. Indicators were housed in a wooden box to protect these from weather. Three such assemblies were made. One is installed at the entrance of the ETHE, one in the middle, and one at the end. Air velocity in the pipe is not high and therefore the convective cooling of thermistors due to their being immersed in air stream will be negligible.

3.4.4 Fan House

Blower, motor and controls are placed inside an over-ground fan house. Fan is direct drive industrial type 0.5 HP blower with backward radial blades. It is custom built to provide air flow rate of 6.4 m3/min at 32 mm static water pressure. Fan housing is insulated to prevent motor heat from entering. Motor rating is 400 watts. Actual energy used during operations was measured independently, using an energy meter.

The main advantages of EAHE system are its simplicity, high cooling and pre-heating potential, low operational and maintenance costs, saving of fossil fuels and related emissions . Pre-heated fresh air supports a heat recovery system and reduces the space heating demand in winter. In summer, in combination with a good thermal design of the building, the EAHE can eliminate the need for active mechanical cooling and air-conditioning units in buildings, which will result in a major reduction in electricity consumption of a building if the EAHE is designed well.

Technical Specification:

Climatic conditions:

Day	Dry Bulb Temperature in °C	Wet Bulb Temperature in °C	Relative Humidity	Specific Humidity Kg/kg dry air	Outlet Temperature of EAHX
May 9^{th} 12:00	39.5	27.18	39.09	0.017776	29.28

Table 3 Design Specification for a Design Summer Day

In the above condition the maximum ambient dry air temperature is to be 39.5 and the outlet temperature is found out to be 29.28 using a formula mention on the model calculation. The comfort level mentioned by ASHRAE is 27. The outlet temperature from the EAHX is not sufficient to meet the cooling requirement of the site. So the conventional systems like evaporative cooling can be utilized to meet the remaining cooling loads.

Baseline Cost Estimation:

Earth air tunneling Systems:

Materials	Numbers of quantity	Cost of the material
1. Concrete Pipes – 44.7 m each	6	Rs 6,000000/-
2. Blower – **Backward blade type**	1	Rs 67683.4/-
3. Elbow 90	2	Rs 21,000/-
4. Cost of Excavation	L= 44.7, D= 0.3, Depth= 3m Number of pipes-6 Total area for trenching for 6 pipes is 603.45 m3	Rs 90517.5/-
5. Total Cost		Rs 708200.9/-

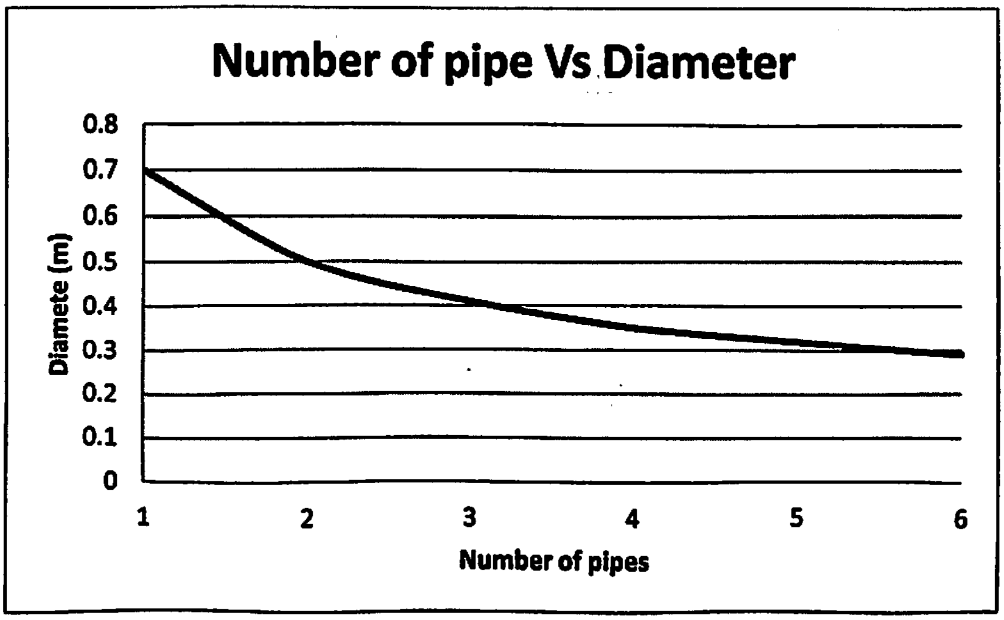
Table 4 Cost Estimation for Earth air tunneling systems

Chapter-4

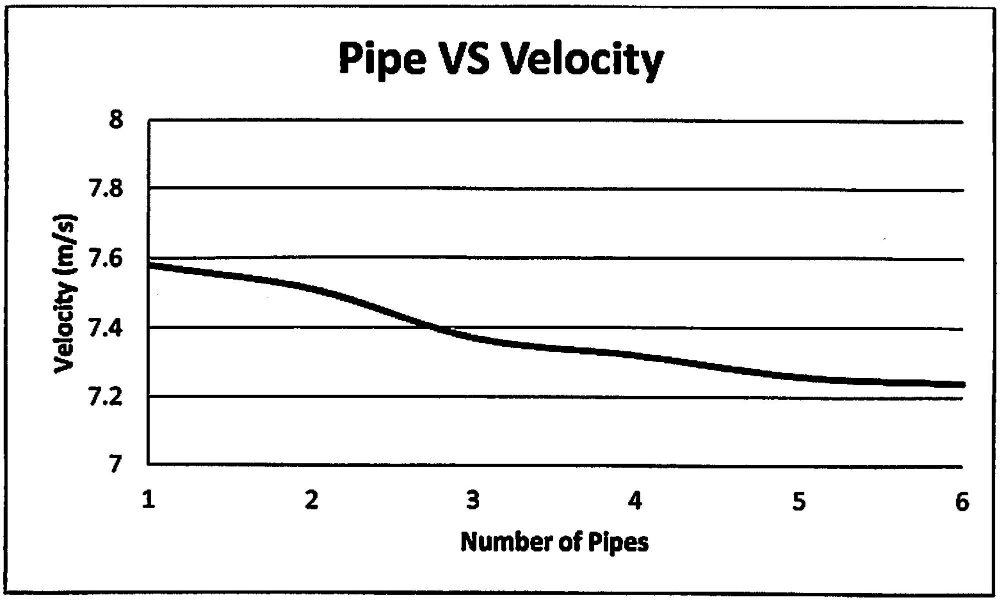
Results and Discussion

The earth air heat exchanger is designed to pre-cool the building. By using the conventional HVAC (Variable refrigerant Flow) which is of capacity 120 TR to cool the building from 39.5 °Cto 28°C, 8995.5 m^2 of the building area. The capacity selection for the day May 21st is 0.029 KW for the ambient outlet temperature of 39.5°C by using the conventional HVAC. And when using the same EAHX system the temperature is reduced from 39.5°C to 29.2°C with lesser power consumption to the EAHX as it has only blower. The capacity of the EAHX system will be 0.0014 KW. Though the EAHX system will reduce the cooling coil capacity of VRF by reducing the temperature of 39.5°C to 29.2°C, and the remaining cooling is done by the VRF.

From the design of Earth air heat exchange systems following graph are projected for consideration of using particular type of systems.



Graph 1 Number of pipes Vs Diameter



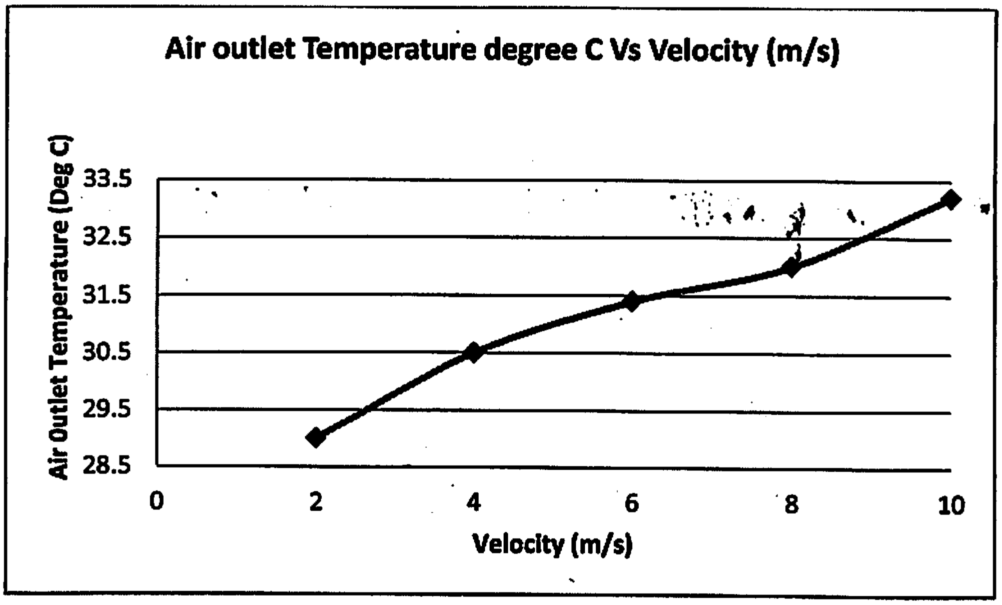
Graph 2 Showing Variation of velocity with number of pipes

From the graph, it concludes that the maximum diameter is selected for the single pipes as the velocity in the pipes will be greater than 7.8 m/s. As maximum the velocity of air inside the pipe will make some thermal cracks in the pipes. To reduce the velocity of the pipes to the recommended value it should have the number of pipes. The selection of design is 6 number of tubes and 0.3 m in diameter as the velocity which is 7.42 m/s.

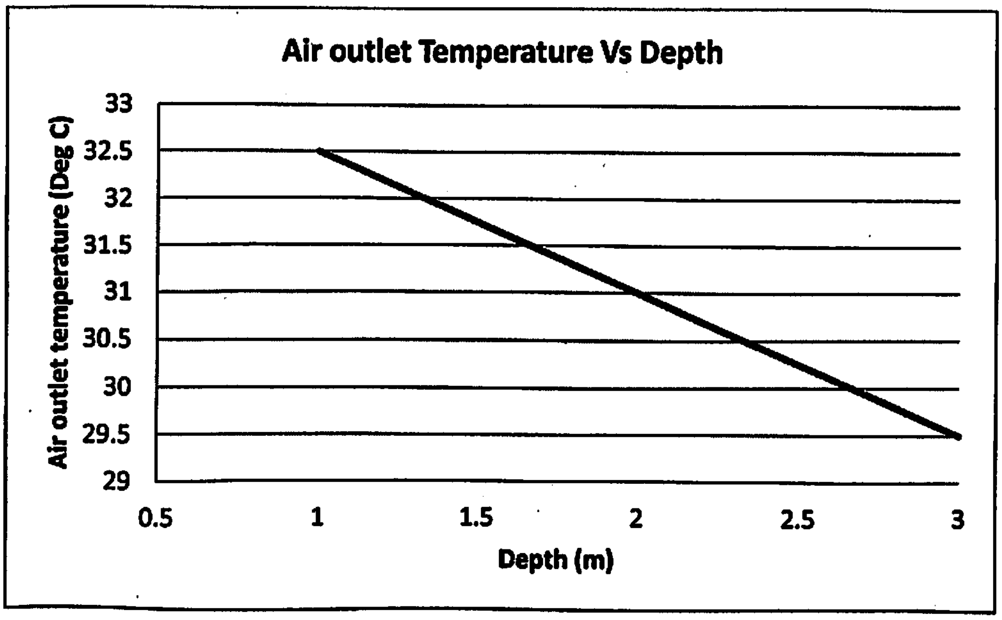
Effect of outlet air from EAHX:

Various graphs which show the influence of the outlet air temperature of parameters like velocity, Length of the pipe, Diameter of the pipe, and depth of the pipe.

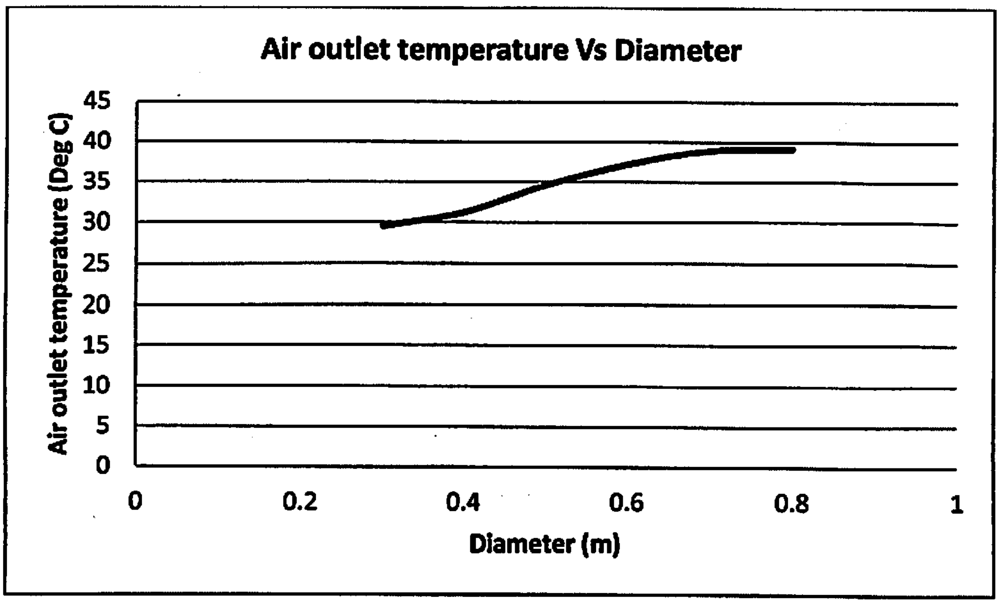
The velocity of the pipe used in this design requirement is 7.5 m/sec which will have a flow of air outlet temperature of 29.5 as the heat transfer will be maximum only when there is turbulence in the flow. For laminar flow the heat transfer will be less in accordance with flow types. Velocity of air in the pipes will be achieved by using the blower to transfer the air underground.



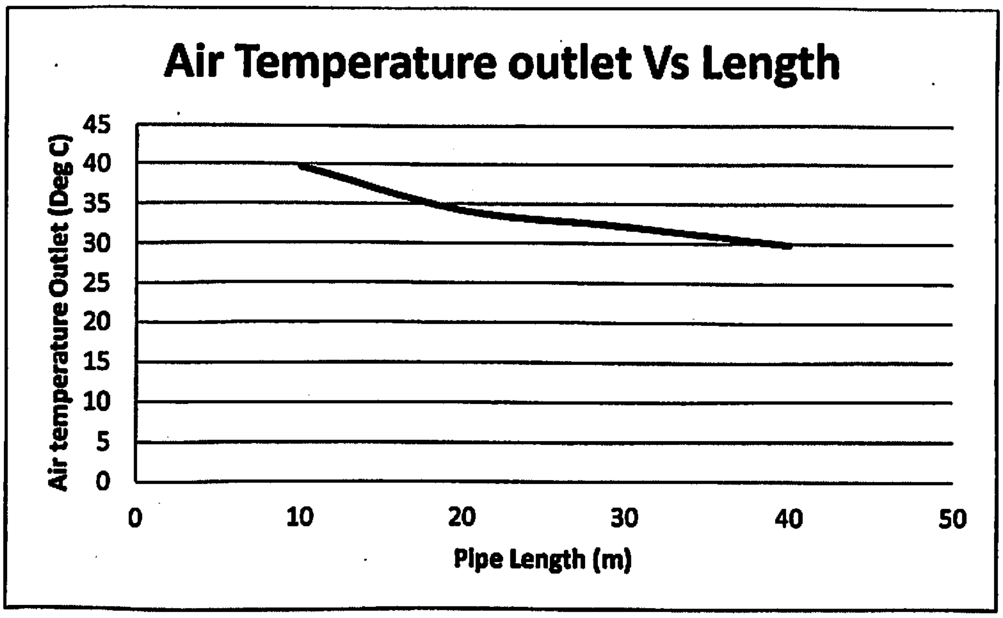
Graph 3 Air outlet temperature (29.5 - 33.5) with 3 m depth, 44.5 m long and 0.6 m diameter



Graph 4 Variation of outlet air temperature with depth



Graph 5 Variation of air outlet temperature with the diameter



Graph 6 Variation of air outlet temperature with desired length

The increase in length will make the heat transfer in the ground more stable only when the effectiveness of the heat exchanger is made to be more than 80%. The Number of transfer units will be enough to make the heat transfer perfect and it depends upon the surface area of the pipe. The upper or top layer i.e. 1.5 m depth will be having lesser heat storage capacity and whereas at 3 m depth the heat storage capacity will be more enough for the heat transfer. The concrete pipes are selected as their thermal conductivity of concrete is more (1.3 for a light weight concrete). The soil conductivity of dry sand mixture is around 15 – 75 W/m.K. The blower capacity is selected using the software.

Fan Type	DIDW Airfoil
Unit	ADA450/CM (CLI)
Operating Conditions	Ducted
Air Volume	11499 m3/h
Static Pressure	500 Pa
Velocity Pressure	58 Pa
Total Pressure	558 Pa
Outlet Velocity	9.90 m/s
Fan Total Efficiency	72.9 %
Fan Static Efficiency	65.6 %
Fan Speed	1548 rpm
Air Temperature	30.0 °C
Altitude	0 m
Fan Absorbed Power	2.43 kW
Recommended Motor	D100L (3.00 kW)
Motor Speed	-
Service Factor	0 %
Plenum Size	-
Outlet Size	-
Rec. Airflow Variation	-
Fan Pulley / Bush / Shaft	-
Motor Pulley / Bush / Shaft	-
Belt Length	-
Number of Belts / f	-
Static Belt Tension/Belt	-
Belt Deflection	-
Belt Speed (<40m/s)	-
Bearing Life (L10 / L50)	-
Starting Torque	-
Operating Limits	8.00 kW
Max. Absorbed Power	2250 rpm
Max. Fan Speed	-20° to +85°C
Temperature (Min-Max)	DIDW Airfoil

Table 5 Blower Specification Details

Chapter 5

Conclusion and Recommendations

The thermal design of the earth air heat exchanger are implemented in the Spreadsheet. It can be calculated by trial and error method by assigning the air flow requirements to the EAHX. The effect of heat transfer through the sides of the tubes which uses the correlation for the Nusselt Number and friction factor.The calculation predicts the required length of the tube for the desired heat exchanger efficiency of 80%. The analysis sheet predicts the monthly average and instantaneous heat transfer performance, the system pressure drop, and the required air fan power once a tube length has been selected. The importance of including heat transfer through the sides of the tube and heat transfer correlations that include surface roughness was shown by comparison to simplified methods that neglect those factors.

Using known value of the air flow rate, a combination of design parameters (length of EAHX, internal diameter of the pipe, and number of pipes) should be identified so that the EAHX will reach sufficient efficiency for defined operation pattern (i.e. thermal load of the surrounding soil). A range in which EAHX reaches sufficient efficiency is depicted in (design for air cooling NTU = 2.5, i.e. theoretical efficiency 92 %). In reality, three pipe diameters are applicable. Diameter DN 300 is limited to air flow rate 190 m3/h., DN 450 up to 400 m3/h, and DN > 500 up to 600 m3/h. which is v_a = 4 m/s. Higher air flow rates should be split into more pipes in order to ensure reasonable pipe pressure loss. The number of pipes manages the total cooling power of EAHX. However, the design of EAHX for removal of total cooling load need not be always effective. It could be a good practice to design EAHX so that it removes a significant part of total cooling load (e.g. one half). The value of cooling load should be primarily reduced by building-energy concept, of course. A good thermal stability of a building is crucial for design of realistic EAHX and effective cooling. For instance, cooling power of EAHX (usual size for family house) is so limited that one south oriented roof window may affect significantly the ratio cooling power of EAHX vs. cooling load of building. The effectiveness of the design and/or operation of EAHX could be further evaluated by a parameter called COP (coefficient of performance), i.e. the ratio between the expected cooling power and the electric power needed for transport of air through the exchanger. EAHX could be assumed to be more effective than standard air conditioning by SPLIT units, which reach mean COP roughly equal to 3.

Bibliography

S.M.A. Eben, Adobe as a thermal regulating material, Solar Wind Technology 7 (1990) 407 - 416.

A.H. Algifri, G.S.M. Bin, B.T. Nijaguna, Thermal behavior of adobe and concrete houses in Yemen, Renewable Energy 2 (6) (1992) 597–602

M.N. Bahadori, F. Haghighat, Passive cooling in hot-arid regions in developing countries by employing domed roofs and reducing the temperature of internal surfaces, Building and Environment 20 (2) (1985) 103–113.

G.N. Tiwari, Solar Energy Fundamentals, Design, Modeling and Applications, 1ed, Narosa Pub. House, New Delhi, 2006, pp. 452–487.

M.S. Sodha, A.K. Sharma, S.P. Singh, N.K. Bansal, A. Kumar, Evaluation of an earth air tunnel system for cooling/heating of a hospital complex, Building and Environment 20 (2) (1985) 115–122.

M. Ramamoorthy, H. Jin, Optimal sizing of hybrid ground source heat pump systems that use a cooling pond as a supplemental heat rejecter—a system simulation approach, ASHRAE Transactions 107 (1) (2001) 26–37.

H. Esen, M. Inalli, M. Esen, Numerical and experimental analysis of a horizontal ground-coupled heat pump system, Building and Environment 42 (2007) 1126– 1134.

P. Cui, H.X. Yang, Z.H. Fang, Heat transfer analysis of ground heat exchangers with inclined boreholes, Applied Thermal Engineering 26 (2006) 1169–1175.

Appendix A

Calculation of The Cooling Capacity and selection of the Equipment:

The Space contains the sensible and latent heat and it is calculated in the software (Hourly Analysis Program) or can be calculated manually.

At Summer Design Day

May 21st 13:00 (Max Temp of 39.5)

$$\text{Sensible heat} = \text{Air Quantity} \times 1.08 \times (t_{\text{aiir inlet}} - t_{\text{air outlet}})$$

$$= 191.6 \times 1.08 \times (39.5 - 28)$$

$$= 41.83 \text{ Btu/Hr}$$

Latent Heat:

$$\text{Air Quantity} \times 0.68 \times (\omega_{\text{air at ambient condition}} - \omega_{\text{comfor t Level temperature}})$$

$$= 191.66 \times 0.68 \times (0.01723 - 0.011829)$$

$$= 51.75 \text{ Btu/Hr}$$

Total Heat = Sensible Heat + Latent Heat

$$= 41.83 + 51.75$$

$$= 93.59 \text{ Btu/hr} / 12000$$

$$= 0.00849 \text{ TR} \times 3.5$$

$$= 0.029 \text{ kW}$$

This is calculated for 8760 hours for cooling the space by using the conventional HVAC i.e. Variable refrigerant flow and air handling unit from (39.5 °Cto 22°C) as mentioned by the ASHRAE Standard 90.1 the comfort level

Sensible heat	Latent Heat	Total Heat	Tons of Refrigeration	KW
44.963436	56.990101	101.953537	0.00849613	0.02973645

Table 6 Capacity calculation for Variable refrigerant Flow from Spreadsheet for 39.5 Degree C

By using conventional systems the cooling capacity is estimated to be 150KW.

The other option of using EAHX to cool the building from 29.5°C to 22°C as the outlet temperature from the EAHX is 29.5°C as Predicted in the design summer day which can have a relative small savings from conventional. This savings is calculated for using the EAHX on May 21st

Sensible Heat	latent heat	Total heat	Tons of refrigeration	KW	% Savings
5.01848268	0	5.01848268	0.00041821	0.00146372	95.0776767

Table 7 Capacity Calculation for earth air tunneling Systems

a. Capacity calculation for conventional HVAC from cooling it from (39.5°C - 22°C)

The savings for each hour has calculated i.e. 8760 Hours

Dry Bulb Temperature	Comfort temperature inside the Building	Sensible Heat Load Btu/hr	Latent Heat Load Btu/hr	Total Heat Btu/hr	In Tons of refrigeration	Coil Capacity In kW
39.5°C	22°C	44.963436	56.990101	101.953537	0.00849613	0.02973645
39.4°C	22°C	44.5724496	70.157143	114.729593	0.0095608	0.0334628
39.4°C	22°C	44.5724496	27.723619	72.2960686	0.00602467	0.02108635
39.4°C	22°C	44.5724496	40.766082	85.3385316	0.00711154	0.02489041
38.7°C	22°C	41.8355448	65.672299	107.507844	0.00895899	0.03135645
38.7°C	22°C	41.8355448	51.757783	93.5933278	0.00779944	0.02729805
38.7°C	22°C	41.8355448	53.837294	95.6728388	0.00797274	0.02790458
38.6°C	22°C	41.4445584	40.766082	82.2106404	0.00685089	0.0239781
38.6°C	22°C	41.4445584	85.451611	126.896169	0.01057468	0.03701138
38.6°C	22°C	41.4445584	21.590499	63.0350574	0.00525292	0.01838523
38.6°C	22°C	41.4445584	67.905138	109.349696	0.00911247	0.03189366
38.6°C	22°C	41.4445584	83.027112	124.47167	0.01037264	0.03630424
38.6°C	22°C	41.4445584	9.238012	50.6825704	0.00422355	0.01478242
38.5°C	22°C	41.053572	63.458626	104.512198	0.00870935	0.03048272
38.5°C	22°C	41.053572	55.935971	96.989543	0.00808246	0.02828862
38.4°C	22°C	40.6625856	41.733965	82.3965506	0.00686638	0.02403233
38.3°C	22°C	40.2715992	56.990101	97.2617002	0.00810514	0.028368
38.2°C	22°C	39.8806128	59.12711	99.0077228	0.00825064	0.02887725
38.2°C	22°C	39.8806128	74.7474	114.628013	0.00955233	0.03343317
38.2°C	22°C	39.8806128	77.076069	116.956682	0.00974639	0.03411237

Table 8 Calculation of coil capacity when using conventional HVAC

b. By using earth air heat exchanger the capacity of the coil is calculated

Air outlet temperature from EAHX	Comfort level	Sensible Heat Btu/Hr	latent heat Btu/Hr	Total heat Btu/Hr	Tons of refrigeration	Cooling Coil Capacity in KW
29.28354405	22	5.01848268	0	5.01848268	0.00041821	0.00146372
29.2652757	22	4.9470559	0	4.9470559	0.00041225	0.00144289
29.2652757	22	4.9470559	0	4.9470559	0.00041225	0.00144289
29.2652757	22	4.9470559	0	4.9470559	0.00041225	0.00144289
29.13739723	22	4.44706849	0	4.44706849	0.00037059	0.00129706
29.13739723	22	4.44706849	0	4.44706849	0.00037059	0.00129706
29.13739723	22	4.44706849	0	4.44706849	0.00037059	0.00129706
29.11912888	22	4.37564172	0	4.37564172	0.00036464	0.00127623
29.11912888	22	4.37564172	0	4.37564172	0.00036464	0.00127623
29.11912888	22	4.37564172	0	4.37564172	0.00036464	0.00127623
29.11912888	22	4.37564172	0	4.37564172	0.00036464	0.00127623
29.11912888	22	4.37564172	0	4.37564172	0.00036464	0.00127623
29.11912888	22	4.37564172	0	4.37564172	0.00036464	0.00127623
29.10086053	22	4.30421494	0	4.30421494	0.00035868	0.0012554
29.10086053	22	4.30421494	0	4.30421494	0.00035868	0.0012554
29.08259217	22	4.23278817	0	4.23278817	0.00035273	0.00123456
29.06432382	22	4.1613614	0	4.1613614	0.00034678	0.00121373
29.04605547	22	4.08993462	0	4.08993462	0.00034083	0.0011929
29.04605547	22	4.08993462	0	4.08993462	0.00034083	0.0011929

Table 9 Calculation of Coil capacity when EAHX

Savings in capacity by using earth air heat exchanger is average of 92.3%

Appendix B

Design of earth air heat exchanger

Model Calculation:

Once the air ventilation or air quantity is known from software (Hourly Analysis Program). The heating and cooling load calculation is done by the same software. The sizing of the earth air heat exchanger is done for a single selection. So the maximum temperature's length will be the fixed length for the exchanger design.

Site Location: **Appolo Tyres, Chennai**

Building Type: **Commercial Building**

Building Area: 8655.9 Square meter

Air conditioned zones: **One above the canteen and one auditorium**

Space: The heat exchanger will be laid on the backyard of the building.

Technical Details:

Ventilation air quantity: 3458.45 $\frac{Litres}{Second}$ for the specified floor area.

$$\dot{m} = 3.32 \frac{Kg}{Sec}$$

Number of tubes to be laid underground: **1 with no headers**

As there are no software for the earth air heat exchanger design it is to be calculated by trial and error method by the calculation done in the spreadsheet.

Density of air at standard Temperature and Pressure: **1.1824** $\frac{Kg}{m^3}$

Diameter of the pipe: **0.63 m**

Velocity of air in the tube:

$$\dot{m} = \rho \times A \times V$$

$$3.32 = 1.1824 \times \frac{\pi \times D^2}{4} \times V$$

$$V = \frac{3.32 \times 4}{1.1824 \times \pi \times 0.6^2}$$

$$V = 7.05\ \frac{m}{Sec}$$

Air temperature (OA) DBT: Maximum temperature **Design Summer Day = May 21st (39.62 °C ~ 40 °C).**

Specific Heat Capacity of Air: **1005** $\frac{J}{Kg.K}$

Thermal Conductivity of Air at STP: **0.02826** $\frac{W}{m.K}$

Dynamic or Absolute Viscosity of air at 40°C: $\mathbf{1.87 \times 10^{-5}}\ \frac{Kg}{m.Sec}$

Once the number of pipes is known by the designer the mass flow rate for individual pipes is calculated.

$$\dot{m}_{Air} \text{ in individual Tube} = \frac{\dot{m}_{Total\ Air}}{Number \text{ of Tubes in Parralel}}$$

No of pipes is one, $\dot{m}_{Air} \text{ in individual Tube} = \frac{3.32}{1}$

$$= 3.32\ \frac{Kg}{Sec}$$

As per the data in the Heat and mass transfer data book the equation for calculating the heat transfer convection coefficient of the air to the pipe can be calculated as

For flow in pipes Reynolds Number (Re) >10000 Air (0-200°C)

Reynolds Number $= \dfrac{\rho \times V \times D}{\mu}$

$$= \frac{1.1824 \times 7.05 \times 0.5}{1.87 \times 10^{-5}}$$

$$= \mathbf{305032.67}$$

As the Reynolds number > 10000

The flow is **Turbulent.**

$$h = \frac{(3.76-0.00497\, t) \times \dot{V}^{0.8}}{D^{0.2}}$$

$\dot{V} = \mathrm{A} \times V$

$$= \frac{\pi}{4} \times (0.5)^2 \times 7.05$$

$$= \mathbf{6.87\ \frac{m^3}{Hr}}$$

$$h = \frac{(3.76-0.00497\,(40\ ^\circ\mathrm{C})) \times 6.87^{0.8}}{0.5^{0.2}}$$

$$= \mathbf{26.51\ \frac{W}{m.K}}$$

Number of Transfer Units: $\dfrac{h \times A}{\dot{m}_{Air} \times C_{p_{Air}}}$

$$\mathrm{NTU} = \frac{17.61 \times 4.452}{3.32 \times 1005}$$

$$\mathbf{NTU = 1.7}$$

The effectiveness of the heat exchanger is determined by the non dimensionless units (Number of Transfer units). The effectiveness can be increased by increasing the number of transfer units.

$\epsilon = 1 - e^{-NTU}$

$\epsilon = 1 - e^{-1.72}$

$\epsilon = 0.7972 \sim 0.80$

The length L is the dependent of the NTU values. By trial and error method the diameter values have been found between 0.3 m which will have a velocity of 6.08 m/sec. which is a steady flow with with a constant pressure drop inside the tube.

The result of changing the Reynolds number will increase the flow velocity inside the pipe.

For a case the $\frac{NTU}{L}$ parameter can be calculated per unit length. The equation is further found out by freezing the NTU value.

$$\frac{NTU}{L} = \mathrm{Nu} \times \pi \times \frac{\lambda_{Air}}{Cp_{Air} \times \rho_{Air}} \times \frac{1}{\dot{V}}$$

$$= 228.620 \times \pi \times \frac{0.02826}{1005 \times 1.093} \times \frac{1}{6.87}$$

$$= 12.45$$

Lines for $\frac{NTU}{L}$ are given for small flow rates and large tube diameters. For the laminar flow the contour plot become vertical lines. And for the turbulent flow the contour plot is in horizontal.

Pressure Drop inside the pipe can be calculated by the below equation

Pressure Drop $(\Delta p) = \xi \times \frac{L}{D} \times \rho_{Air} \times \frac{V_{Air}^2}{2}$

$\xi = (1.82 \ log\, Re - 1.64)^{-2}$

$\xi = (1.82 \ log\, 115184.08 - 1.64)^{-2}$

$\xi = 0.0174$

$(\Delta p) = 0.0174 \times \frac{44.77}{0.3} \times 1.093 \times \frac{6.68^2}{0.3}$

$= 67.44$ pa

Proposed calculation:

As the NTU value will be fixed to 1.7 because the effectiveness will be relatively small after 2.5 which does not make any difference and by fixing the NTU value the length of the heat exchanger can be found out.

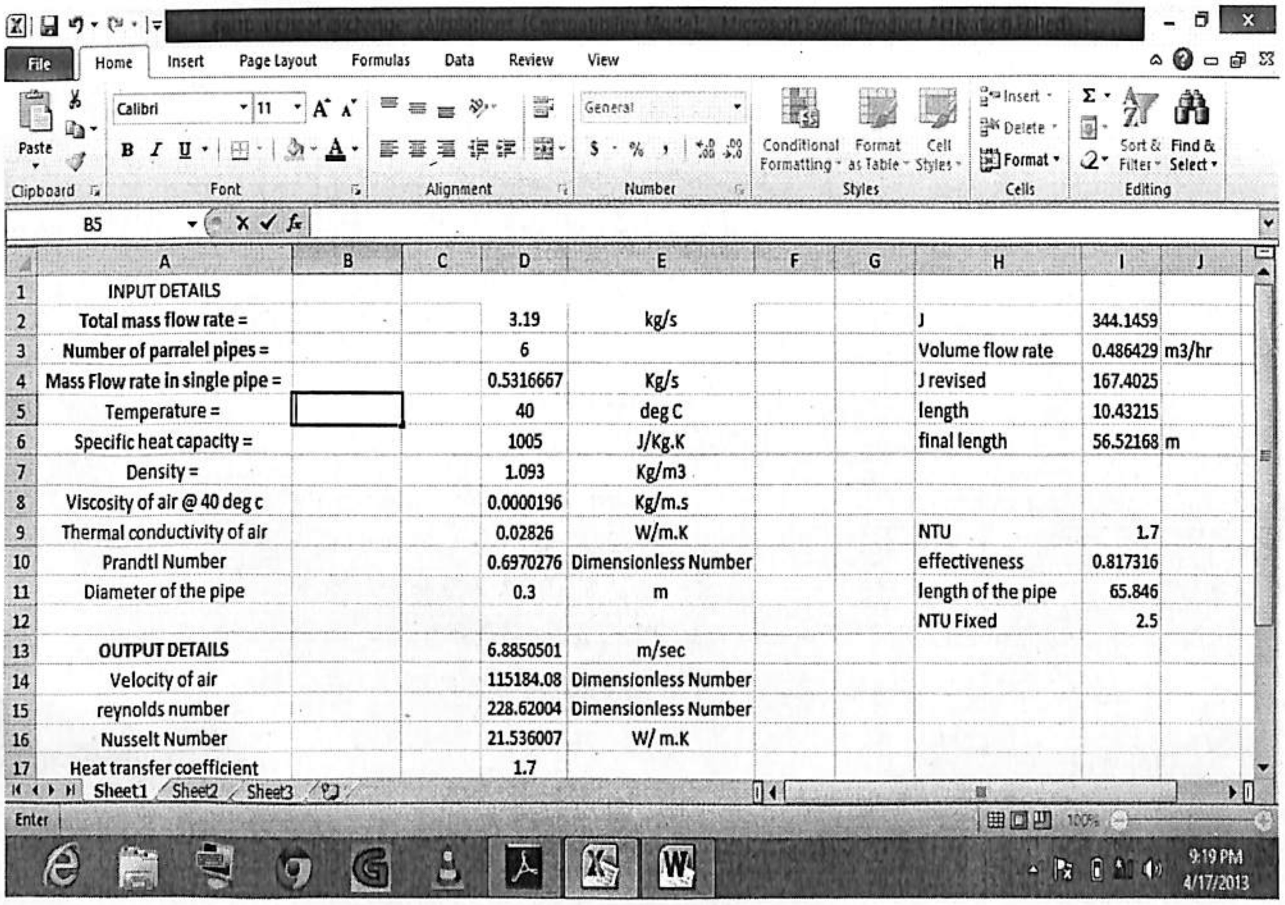
$$\text{NTU} = \frac{h_a \times A}{\dot{m}_a \times C_p} \qquad [\text{Heat transfer Area} = \pi \times D \times L]$$

$$1.7 = \frac{21.53 \times \pi \times 0.3 \times L}{0.053166 \times 1005}$$

L = 44.7 m

Appendix C

Design Tool in Spreadsheet



	A	B	C	D	E	F	G	H	I	J
1	INPUT DETAILS									
2	Total mass flow rate =			3.19	kg/s			J	344.1459	
3	Number of parralel pipes =			6				Volume flow rate	0.486429	m3/hr
4	Mass Flow rate in single pipe =			0.5316667	Kg/s			J revised	167.4025	
5	Temperature =			40	deg C			length	10.43215	
6	Specific heat capacity =			1005	J/Kg.K			final length	56.52168	m
7	Density =			1.093	Kg/m3					
8	Viscosity of air @ 40 deg c			0.0000196	Kg/m.s					
9	Thermal conductivity of air			0.02826	W/m.K			NTU	1.7	
10	Prandtl Number			0.6970276	Dimensionless Number			effectiveness	0.817316	
11	Diameter of the pipe			0.3	m			length of the pipe	65.846	
12								NTU Fixed	2.5	
13	OUTPUT DETAILS			6.8850501	m/sec					
14	Velocity of air			115184.08	Dimensionless Number					
15	reynolds number			228.62004	Dimensionless Number					
16	Nusselt Number			21.536007	W/ m.K					
17	Heat transfer coefficient			1.7						