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THESIS NO: M-48-MSMDE-2019-2022

Design and Analysis of HVAC system using Earth Air Tunnel Heat Exchanger

by

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A THESIS

SUBMITTED TO DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN MECHANICAL SYSTEMS DESIGN AND ENGINEERING

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

LALITPUR, NEPAL

MARCH, 2022

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The undersigned certify that they have read, and recommend to the Institute of Engineering for acceptance, a thesis entitled "**Design and Analysis of HVAC system using Earth Air Tunnel Heat Exchanger**" submitted by Apurba Dahal in partial fulfillment of the requirements for the degree of Master in Mechanical Systems Design and Engineering.

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ABSTRACT

The Earth Air Tunnel Heat Exchanger (EATHE) is a passive cooling and heating system for interior spaces. The hybrid method uses an active agent fan for air movement, but a passive agent ground soil is used to cool and heat the air. Since the temperature of the earth underneath remains constant and around human comfort levels, pipes are placed underground and air is blown through them to cool or heat according to the season. EATHE may be used to cool homes, buildings, and other systems, and it is still in use in some locations. There is a need to transition from high-energy active user tactics to low-energy ones. One of these strategies is EATHE. There has been a lot of study done on it, including the creation of methods for heat exchanger design, CFD analysis, and so on. The purpose of this work is to contribute to the further development of EATHE. We devised an approach in which we assume a maximum cooling load in a building and construct a heat exchanger based on this input factor, determining the needed pipe diameter and length to cool the load inside the building. We assume certain conditions, such as the needed room temperature, the maximum outside temperature, and the air velocity. The purpose of this publication is to promote the usage and research of ground source heat energy. Although EATHE has a higher initial installation cost than a VRF air-conditioning system, it saves greatly on both power and costs over time. We recognize the limitations of EATHE systems in comparison to AC systems and hope that my research will assist others in overcoming them.

ACKNOWLEDGEMENT

I would like to express sincere gratitude to my supervisor Associate Prof. Vishwa Prasanna Amatya for the valuable suggestions and guidelines throughout the course project study. Their understanding, expertise, and continuous support have been very important in completing this work. It was a great honor for me to pursue this work under his supervision.

I would like to express my due respect to Prof. Dr. Surya Prasad Adhikari, Head of Department of Mechanical and Aerospace Engineering for his valuable and kind support. I would like to thank all the professors, lecturers, and administrative staffs of the department for their precious suggestion and kind support throughout the work. I am also very much thankful to Asso. Prof. Dr. Hari Bahadur Darlami for helping to solve queries that was ahead during the research.

Last but not the least, I extend my special thanks to my friends Sunil Khadka, Manoj Bashyal, Raman Koirala, Binaya Kumar Lamichhane, William Shrestha and Ashesh Ghimire for providing guidelines on research paper writing. I am always grateful to my families and relatives for their continuous support and motivation.

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LIST OF ACRONYMS AND ABBREVIATIONS

HVAC : Heating Ventilation and Air-Conditioning

EATHE : Earth Air Tunnel Heat Exchanger

CLTD : Cooling Load Temperature Difference

LMTD : Log Mean Temperature Difference

IAQ : Indoor Air Quality

EAT : Earth Air Tunnel

CHAPTER ONE: INTRODUCTION

11.1 Background

In the workplace, residences, and commercial centers, HVAC has become the most crucial infrastructure for maintaining human comfort. However, the HVAC system's high energy consumption is a primary issue restricting its use. Before the 1970s, the only way to estimate load was to do it by manual. As a result, many HVAC systems were oversized. The 1973 energy crisis prompted all interested authorities to study the energy efficiency of electrical equipment, including HVAC systems, as the price of petroleum increased by about 300 percent in less than two years. Since then, a lot of software has been designed to assist with HVAC system sizing.

Alghoul et al.[1] Investigated the use of electricity in various components and discovered that buildings utilize one-third of all energy generated, with the HVAC system accounting for nearly half of all energy consumed by buildings. According to him, the HVAC system consumes between 10- 20% of overall energy, depending on the site. This demonstrates how appropriate HVAC system sizing may save a significant amount of electricity.

ASHRAE has specified a number of calculating techniques for optimum HVAC system size, including the Cooling Load Temperature Difference (CLTD), Transfer Function Method (TFM), Heat Balance Method (HBM), and Radiant Time Series (RTS) Method. The difficulty of manual computation using these approaches, on the other hand, makes it difficult to precisely follow these processes. As a result, various software tools have been created to help in the appropriate planning, designing, and modeling of HVAC systems.

While proper HVAC system sizing can save energy by avoiding over-sized HVAC systems, it cannot minimize the overall energy required for HVAC system operation. Material selection is critical for lowering total energy use. In the construction industry, energy efficient building design has become a trendy issue. Materials having a low total heat transfer coefficient are being studied and produced. As a result, many different construction materials are used nowadays. Brick, concrete block, interlocking brick, AAC block, and prefab have all become popular building materials in Nepal. Similarly, non-envelop characteristics such as the utilization of daylight and occupancy sensors, as well as the kind of HVAC system used, have a significant impact on HVAC system energy usage.

To enhance energy efficiency and decrease environmental effect, many strategies must be performed on HVAC systems. Various control and optimization tactics have been utilized in recent years to enhance these systems' energy consumption rates [1]. However, these techniques are either prohibitively expensive or extremely difficult to execute, and they need ongoing monitoring [2]. One approach to achieve this aim is to combine several HVAC components to create an energy-efficient configuration. Because a building's cooling load varies throughout the day, an HVAC system should be designed with an optimum design scheme that keeps process variables at their required set-points to ensure comfort under all load conditions. While changing the mechanical design of a normal HVAC system costs more up front, it can save money in the long term by minimizing the costs of ongoing maintenance associated with control and optimization strategies. Previous research has examined a variety of technologies that can help reduce HVAC energy use. However, a thorough study that identifies and analyzes a wide variety of various options for HVAC energy savings is lacking in the existing body of research in the HVAC industry.

The HVAC system was created with the goal of creating a healthy and comfortable interior environment by managing temperature, pressure, moisture, and indoor air quality (IAQ). Cooling or heating the interior air helps adjust temperature and moisture levels. Humidifiers and/or dehumidifiers can be used to keep the humidity level at a comfortable level for humans. The employment of a damper in the stream of incoming air from the atmosphere can adjust pressure. An air handling unit (AHU) can be utilized to provide the system with the needed amount of fresh air. There are two types of HVAC systems: self-contained unitary systems and centralized systems. All conditioning parameters are controlled by a single package in a unitary system, which is restricted to small space conditioning. A centralized system, on the other hand, contains sub-systems/terminals that perform specific tasks and is commonly employed in big spaces. Variation in system parameters, changeable circumstances, interaction between climatic parameters, severe non-linear components, and model uncertainty are all problems in the HVAC system. When constructing any HVAC system, these elements must be taken into account.

Because of the enormous growth in energy consumption and in-herent expense of buildings, the usage of earth to air heat exchangers has gained huge ground in the heating and cooling of structures. Based on seasonally variable inflow temperature and tunnel-wall temperature, which is dependent on ground temperature, an earth-air-tunnel (EAT) system efficiently supplies heating and cooling energy loads to a structure. The temperature of the ground changes annually up to a depth of 4 m, according to Bharadwaj et al., and stays unchanged beyond this depth. The temperature and humidity distribution in the ground, as well as the surface conditions, influence the functioning of an EAT system [2].

11.2 Problem Statement

Heating, ventilation, and air conditioning (HVAC) systems are among the greatest energy users in buildings, and they play a vital role in assuring occupant comfort. As a result, performance improvements to classic HVAC systems present an attractive prospect for large energy savings. In commercial buildings, thermal indoor comfort conditions make up more than half of all energy usage. Additionally, given most people are spending more than 90% of the time inside, creating energy-efficient HVAC system that do not uses fossil fuels will be crucial to reducing energy use. A detailed examination of global energy use by HVAC equipment reveals the following figures: HVAC systems utilize more than half of all building electrical energy in the United States. Building energy use in China has been expanding at a rate of roughly 10% per year over the previous 20 years, accounting for about 20.7 percent of total national energy consumption in 2004. In Europe, business and residential buildings amounts for around 40% of total energy usage. HVAC systems account for 70% of electricity usage in non-residential buildings in Australia. In India, HVAC systems account for around 32% of building's power usage. In 2006, air cooling and refrigeration systems accounted for 33% of all air condition and refrigeration systems in Hong Kong's subtropical climate. In the Middle East, cooling systems amounts for more than 70% of total building energy use. Between 2001 and 2005, global energy consumption was expected to have climbed by 58 percent. However, fossil fuels still amount for around 80% of total energy usage. Increasing usage of HVAC systems in domestic, commercial, and industrial applications has resulted in higher energy consumption, particularly during the summer season. Energy-efficient HVAC systems are necessary both to prevent consumers from growing power bills and to safeguard the environment from the negative impacts of greenhouse gas emissions caused by the use of energies in efficient electrical equipment.

11.3 Objectives

The main objective of this study is to calculate the actual HVAC load required for the sample building with its electrical consumption data forecast and design an Earth Air Tunnel Heat Exchanger and demonstrate its possibility to improve the performance of HVAC systems while lowering energy consumption and costs in context of Nepal.

The specific objectives for the study are,

- To calculate cooling load required for the building with its energy consumption data
- To collect the data of the existing system dimensions, features and performance
- To determine EATHE required for that building and its analysis
- To make a comparison study with or without those energy saving approaches

CHAPTER TWO: LITERATURE REVIEW

12.1 Cooling Load

The total building cooling load includes heat transferred through the building envelope (walls, ceiling, floor, windows, and doors, etc.) as well as heat generated by occupants, equipment, and lights. Heat transport via the envelope causes external loads, whilst diverse sources create inside loads. The exterior-to-interior load ratio varies based on the type of building, the environment on the site, and the design. The entire cooling load of any building is made up of both obvious and latent load components. The sensible load affects the temperature of the dry bulb, while the latent load affects the moisture levels of the conditioned ambient.

Buildings are divided into two categories: externally loaded and internally loaded. The cooling load on externally loaded buildings is mostly due to heat transfer between the surrounding environment and the inside conditioned area. The cooling load of an externally loaded structure changes greatly depending on the surrounding circumstances on any particular day. Internal heat producing sources such as inhabitants, lighting, and appliances account for the majority of the cooling load in internally loaded structures. In general, heat generation from internal heat sources may remain quite constant, and because heat transfer from the fluctuating surroundings is significantly less than heat transfer from internal heat sources, the cooling load of an internally loaded structure may remain relatively constant. Obviously, the system design approach for an externally loaded building is important in terms of energy efficiency and economics.

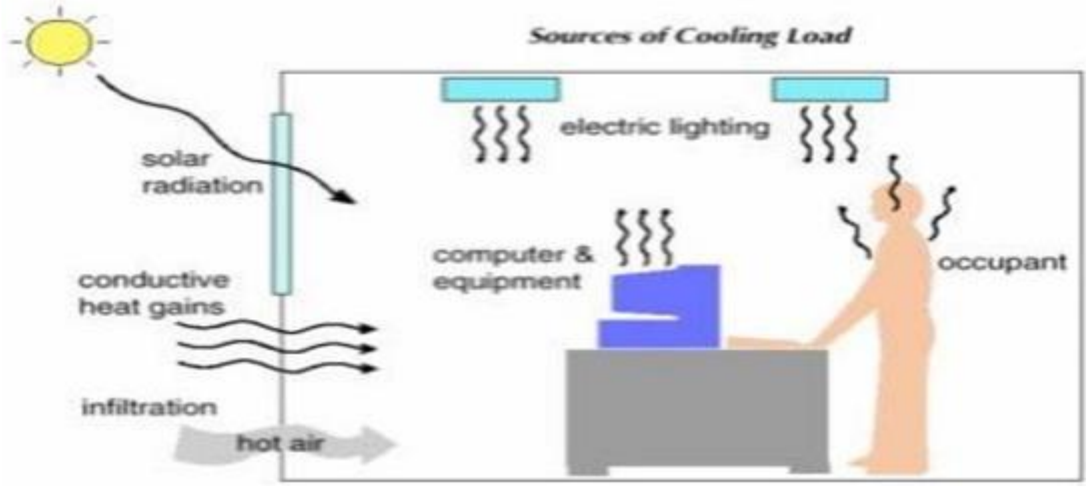


Figure 12-1: Components of cooling load

12.1.1 Cooling Load Principles

The variables that influence cooling load estimates are complex, difficult to specify exactly, and always closely interconnected. During a 24-hour period, the magnitude of several cooling load components varies widely.

- **Calculation accuracy:** A well calculated cooling load produces values that are suitable for optimal performance. Variations in heat transfer coefficients of popular construction materials and composite assemblies, as well as the motives and talents of those who physically construct the building and how the building is actually operated, all complicate a numerically precise computation.
- **Heat flow rates:** In air-conditioning design, four related heat flow rates must be recognized, each of which varies with time: (1) the space's heat gain, (2) the space's cooling load, (3) the space's heat extraction rate, and (4) the space's cooling coil load
- **Space heat gain:** The rate at which heat enters and/or is created within a place at any particular time is referred to as the instantaneous rate of heat gain. Heat gain is classed as sensible or latent depending on (1) how it enters the space and (2) whether it is sensible or latent.
    - **Mode of entry:** All possible modes of heat gain include solar radiation through transparent surfaces, heat conduction through exterior walls and roofs, heat conduction through interior partitions, ceilings, and floors, heat generated within the space by occupants, lights, and appliances, energy transfer as a result of ventilation and infiltration of outdoor air, and miscellaneous heat gains.
    - **Sensible or latent heat:** Sensible heat gain is added directly to the conditioned region by conduction, convection, and/or radiation. Latent heat accumulation occurs when moisture is introduced to a location.
    - **Space cooling load:** This is the rate at which heat must be taken from a location in order to maintain a constant air temperature..
    - **Radiant heat gain**: Radiative heat gain in the space does not immediately translate to cooling load. The space's surrounding surfaces (walls, floor, and ceiling) as well as the items within it must first absorb radiant radiation (furniture, etc.). As soon as these surfaces and objects become warmer than

the space air, convection transfers some of their heat to the air in space. The rate at which the relative surface temperatures of various surfaces and objects rise for a given radiant input is defined by their composite heat storage capacity, which determines the relationship between the radiant part of heat gain and its equivalent component of the space cooling load.

  - **Space Heat Extraction Rate**: The rate at which heat is evacuated from the conditioned area equals the space cooling load only to the degree that the room air temperature remains constant.
  - **Cooling Coil Load**: The rate at which energy is extracted at the cooling coil that feeds one or more conditioned areas equals the sum of the instantaneous space cooling loads (or space heat removal rate if the space temperature does not fluctuate) for all the spaces supplied by the coil, plus any external loads.

- **Thermal Transmission Data for Building Components**

Building components' steady-state thermal resistances (R-values) can be calculated using the thermal properties of the materials in the component, or the heat flow through the assembled component can be measured directly using laboratory equipment such as the guarded hot box (ASTM Standard C 236) or the calibrated hot box (ASTM Standard C 976. In practice, problems like incorrect installation and insulation shrinkage, settling, or compression can drastically affect total thermal performance. The majority of the values in these tables were acquired using ASTM test procedures outlined in ASTM Standards C 177 and C 518 for materials and ASTM Standards C 236 and C 976 for building envelope components respectively. Due to the wide range of commercially accessible materials, not all values apply to all items. Testing a representative sample with a hot box method is the most accurate way to determine the total thermal resistance of a mix of building materials combined as a building envelope component. However, not all combinations may be examined in this manner since it is inconvenient or cost prohibitive. Calculated R-values correlate pretty well with values measured by hot box measurement for several simple structures. The quality of workmanship during building and installation has a significant impact on the performance of materials manufactured in the field. As the insulation need grows, good craftsmanship becomes increasingly critical. As a result of their experience, several engineers integrate more insulating or other safety considerations in their designs. Convection influences the surface conductance of numerous materials. Moisture through condensation or any other sources can lower insulation's thermal resistance, but still the effect of moisture on each substance must be established. Some materials with large air gaps, for example, remain unaffected even if the moisture content is less than 10% by mass, although the effect of moisture on other materials is nearly linear. When computing total R-values, ideal conditions of components and installations are considered (i.e., insulating materials are of uniform nominal thickness and thermal resistance, air spaces are of uniform thickness and surface temperature, moisture effects are not] involved, and installation details are in accordance with design). Measured values for certain insulated constructions differ from calculated values, according to the National Institute of Standards and Technology Building Materials and Structures Report BMS 151. As a result, some engineers reduce calculated R-values by a little amount to allow for construction deviations from specifications and norms. Because of air movement caused by natural and artificial convection, field applications might differ significantly from laboratory performance.

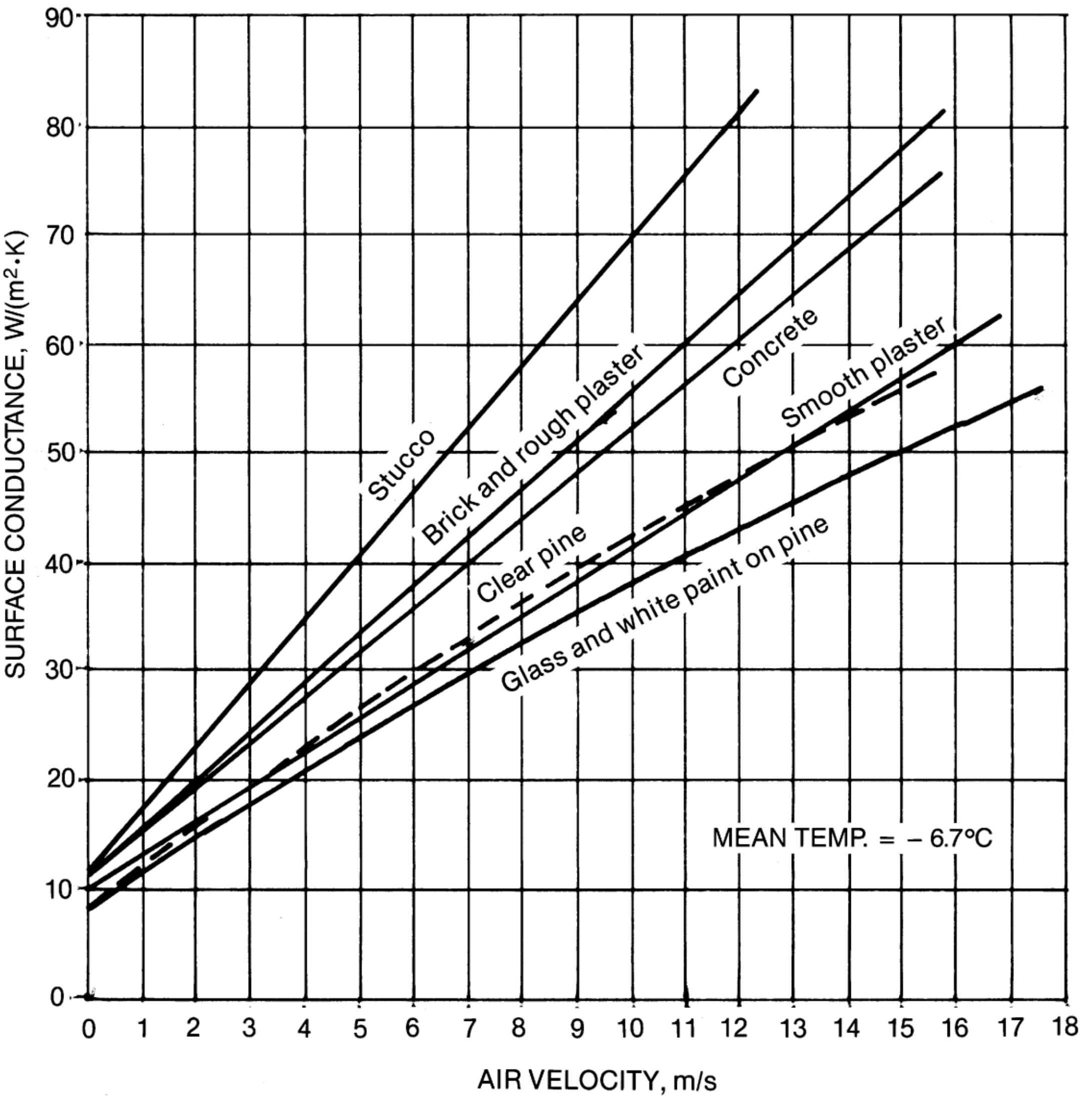


Figure 12-2: Conductance for Various Surfaces Affected by Air Movement

Condition for calculation of overall resistance

Thermal bridges, which are relatively tiny, highly conductive components in an insulating layer, can significantly lower a component's average thermal resistance. Wood and metal studs in frame walls, concrete webs in concrete masonry walls, and metal ties or other components in insulated wall panels are all examples of structural elements. The following examples show how to calculate R-values and U-factors for thermal bridge-containing components.

When computing the design R-values, the following criteria are assumed:

- Heat transport in equilibrium or steady-state, ignoring the effects of thermal storage
- Surfaces in the immediate vicinity are at room temperature.

- Outside wind speeds of 6.7 m/s (24 km/h) in the winter (surface R = 0.03 m2K/W) and 3.4 m/s (12 km/h) in the summer (surface R = 0.044 m2K/W)
- Ordinary construction materials have a surface emittance of 0.90.

Wood Frame Walls

By presuming either parallel heat exchange pathways across sections with differing thermal resistances or isothermal planes, the overall average R-values and U-factors of wood - framed walls may be determined. The framing factor, or the percentage of a building component that is framed, varies depending on the kind of construction and local construction practices—even within the same type of construction. The proportion of insulating cavity may be as low as 0.75 for stud walls 400 mm on centre (OC), where the fraction of stud, plate, and sill is 0.21 and the fraction of header is 0.04. The respective values for studs 600 mm OC are 0.78, 0.18, and 0.04. Many studs, plates, sills, additional framing around window, header, and band joists are all factored into these fractions. These estimated framing fraction are used in the subsequent example to show how important it is to consider the influence of framing when calculating a building's total thermal conductivity. For each situation, the real framing fraction must be computed.

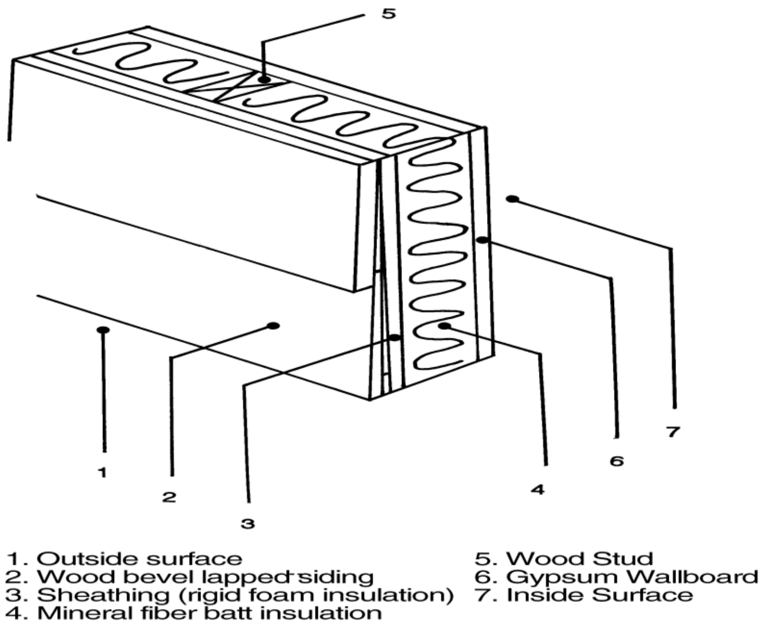


Figure 12-3: Insulated Wood Frame Wall

Masonry Walls

By assuming a succession of layers, some or all of which offer parallel routes, the overall average R-values of brick walls may be determined. Heat travels laterally across block face shells, resulting in transverse isothermal planes, which is why this approach is utilized. The sum of the resistance values of the layers between these planes is the average total resistance RT(av).

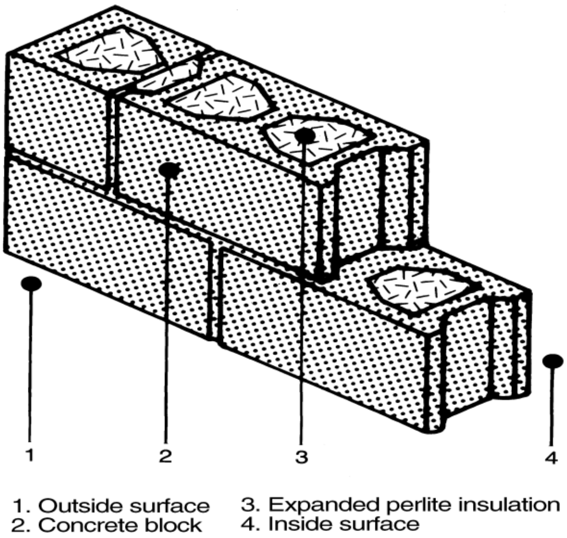


Figure 12-4: Insulated Concrete Block Wall

12.1.2 Heating versus cooling load calculations

Heating load computations are used to evaluate the building's heat loss in the winter and determine the needed heating capabilities. During the winter, the peak heat load usually comes before daybreak, and exterior temperatures do not fluctuate greatly during the season. Internal heat sources, such as people or appliances, are also advantageous since they compensate for part of the heat losses. As a result, heat load computations are often performed under steady state settings (no solar irradiance and constant external temperatures) while interior heat sources are ignored. This is a straightforward yet cautious strategy that results in a small overestimation of heating capacity. The thermodynamic potential of the wall and interior heat sources must be included for a more accurate assessment of heating loads, which complicates the situation. Because the greatest cooling load occurs throughout the day and the outside circumstances fluctuate greatly during the day owing to solar radiation, unstable state processes must be considered when predicting cooling loads. Furthermore, all internal sources contribute to cooling loads, and ignoring them would result in an overestimate of the needed cooling capacity and the risk of failing to maintain the appropriate interior conditions. As a result, cooling load calculations are fundamentally more difficult due to the fact that they need the solution of unsteady equations with unstable boundary condition and internal heat sources. The balanced outside temperature for commercial buildings with high internal loads and tiny heat transfer spaces might be as low as 2 degrees Celsius, meaning a long cooling season and a short heating season. When there are no additional heat sources and solar radiation is minimal, the heat balancing equation, T out,bal = Tin, states that if the outside temperature is higher the desired interior temperature (say, 25 C for comfort), cooling is required; otherwise, heating is required. As a result, the necessity for either a cooling system or a heating system is determined by the unique characteristics of the structure. This also necessitates improving building insulation based on exterior circumstances and building heat generation, so that free cooling given by the environment may be used during specific hours without the usage of an external cooling system.

Space Heat Gain

The rate at which heat enters and/or is created within a place at any particular time is referred to as the instantaneous rate of heat gain.

Heat gain is defined according to the following factors:

- How heat enters the area
- Solar radiation from transparent surfaces such as window
- Heat transfer via external walls and roofs
- Heat transfer via internal partitions, ceilings, and floors
- Loads as a consequence of ventilation and penetration of exterior air
- Other miscellaneous heat gains
- Heat created within the room by inhabitants, lighting, appliances, equipment, and processes

12.1.3 Sensible heat

Heat that a substance absorbs but does not change its condition as its temperature rises. By conduction, convection, and/or radiation, sensible heat gain is added directly to the conditioned space. Because of it's stored heat in the building envelope, the sensible heat gain entering the conditioned room does not match the sensible cooling load within the same time span. Only convective heat converts to cooling load in an instant.

Sensible heat load is total of :

- Heat transferred via floors, ceilings, and walls
- Occupant body heat
- Appliance and light heat
- Solar heat gain through windows
- Outside air infiltration
- Air introduced by ventilation

12.1.4 Latent Heat Loads

Moisture is introduced to the area from either internal sources (e.g., vapor created by inhabitants and equipment) or from outside air via ventilation or infiltration to maintain adequate indoor air quality.

Latent heat load is total of:

- Moisture-laden outside air from infiltration and ventilation
- Respiration and activities of occupants
- Equipment & Appliance Moisture

Water vapor should condense on cooled apparatus at the rate equal to its rate of addition into the area to maintain a constant humidity ratio. This is known as dehumidification, and it is a very energy-intensive operation. For example, eliminating 1 kilogram of humidity needs around 0.7 kWh of energy.

12.2 Cooling Load Calculation

Detail building information, location, site, and weather data, internal layout information, and operation schedules are all needed to compute the space cooling load. The load calculation begins with information on the external design parameters and intended inside conditions, which is detailed further down.

12.2.1 Outdoor Design Weather Conditions

The design conditions can be used to compute the building's maximum temperature gain and maximum heat loss. It is advised to utilize the 2.5 percent incidence for comfort chilling and 99 percent values for comfort heating. The 2.5 percent design condition states that the outside summer temperatures and the coincident air moisture levels will be surpassed only 2.5 percent of the time from June to September, or 73 out of 2928 hours, i.e. 2.5 percent of the time in a year.

The average warmest day of 2019-2020 was used to determine the external humidity and temperature of Kathmandu. The data comes from ISHRAE and shows that the temperature is approximately 30 degrees with a relative humidity of 70%.

12.2.2 Indoor Design Conditions and Thermal Comfort

Human comfort is intimately tied to the circumstances of home design. Current comfort standards, such as ASHRAE Standard 55-201 and ISO Standard 7730, define a "comfort zone" as the optimal range and combinations of thermal (air temperature, air velocity, radiant temperature, humidity) and other personal (clothing and activity level) factors with which at least 80% of building occupants should be satisfied. The following are the key environmental elements that influence the thermal comfort of inhabitants in an air-conditioned space:

- The metabolic rate, which is measured in met (1 met = 18.46 kJ/hr.m2), determines the quantity of heat that must be expelled from the human body and is mostly determined by the intensity of physical activity.
- Mean radiant temperature (Trad) and indoor air temperature (Tr), both in degrees Celsius. Trad influences solely sensible heat exchange, while Tr impacts both sensible heat transfer and evaporative losses.
- Relative humidity of indoor air in percent, which is the most important element affecting evaporative heat loss.
- Indoor air velocity in fpm, which influences heat transfer rate and hence sensible thermal transfer and evaporative loss. The sensible heat loss is affected by clothing insulation in clo (1 clo = 0.88 h.m2.°F/KJ). In the summer, clothing insulation for residents is approximately 0.6 clo, and in the winter, 0.8 to 1.2 clo.

According to ANSI/ASHRAE Standard 55-2017 and ASHRAE/IES Standard 90.1-1989, for conditioned rooms where the occupant's activity level is 1.2, indoor space relative humidity is 50% (in summer only), and Tr = Trad, the following interior design temperatures and air velocities apply:

Table 12.1: Indoor temperature and air velocity applied for conditioned spaces

season	Clothing insulation(clo)	Indoor temperature (˚F)	Air velocity(m/s)
Winter	0.8-0.9	69-74	<30
Summer	0.5-0.6	73-79	<50

If residents wear suit jackets in the summer, the summer indoor design temperatures should be reduced to 23 to 24°C.

Table 12.2: Recommended relative humidity for indoors

Season	**Relative Humidity**	
	Tolerance Range %	**Preferred Range %**
Summer		25-30
Winter	30-65	40-55

More information on this topic may be found in the Psychometric part of the ASHRAE Fundamentals Handbook (Chapter 6, 2001). Typical load estimations are based on a temperature of 23°C and a relative humidity of 50%.

Requirements for Indoor Air Quality and Outdoor Air

According to the National Institute for Occupational Safety and Health (NIOSH), insufficient external ventilation air is the source of interior air quality problems in buildings.

- Eliminate or minimize air pollution problem,
- Improve the effectiveness of air filtration, and
- Increase ventilation (outside) air intake are the three primary ways to improve indoor air quality.

Table 12.3: Recommended indoor relative humidity

Application	**cmf/ person**
Offices, conference room, offices	20
Retail store	34
Classroom, theatre, auditoriums	15
Hospital patient room	25

These ventilation needs are derived from a study of CO2 dilution as a typical human bio discharge. According to the ASHRAE standard, human bio-effluent comfort standards are likely to be met if carbon dioxide indoor concentrations are kept under 700 ppm of outside carbon dioxide concentrations.

Building Characteristics

The following building envelope data is needed to calculate space heat gain:

- Sections and elevations of architectural designs for estimating building dimensions, area, and volume.
- Orientation of Building (N, S, E, W, NE, SE, SW, NW, and so on), as well as location
- Ground reflectance, external/internal shading, etc.
- Construction materials for exterior walls, roofs, windows, doors, interior walls, partitions, and ceilings, insulating materials and thicknesses, external wall and roof colors - choose and/or compute U-values for walls, roofs, windows, doors, partitions, and other structures. Examine the structure to see if it is insulated and/or exposed to strong winds.
- The amount of glass, the kind of glass, and the shading on windows.

Operating Schedules

The inhabitants', lights, equipment, appliances, and processes' schedules that contribute to internal loads and decide whether air conditioning equipment will be used constantly or occasionally (such as, night set-back, shut down during off periods and weekend shutdown). Different heat sources must provide the following information:

- Lighting needs, as well as the many types of lighting system
- Computers, printer, fax machines, coolers, refrigerators, microwaves, assorted electrical panels, cables, and other appliances
- Heat emitted by the HVAC system
- The number of residents, the length of time the structure was occupied, and the kind of building occupation

12.2.3 Ventilation

Ventilation is a series of actions and techniques for arranging air exchange and maintaining a specified air medium condition in buildings and workplaces. In accordance with established sanitary rules and technological requirements, ventilation maintains optimum interior climatic conditions.

Figure 12-5: Ventilation system example

Importance of ventilation

Every day, we breathe in / out 20,000 liters of air since we are surrounded by it. What percentage of the air we breathe is healthy? There are several factors that go into determining air quality.

- The amount of oxygen and carbon dioxide in the air. The reduction in oxygen and increase in carbon dioxide promotes stuffiness in the workplace.
- The amount of hazardous substances and dust with in air. High levels of dust, cigarette smoke, and other pollutants in the air are hazardous to human health and can lead to a variety of respiratory and skin disorders.
- Bad odors cause discomfort and offend others.
- Humidity in the air: Extremely high or low humidity helps people feel uneasy and can even trigger an acute sickness attack in sick persons. Air humidity is also significant for the inside climate. Doors, windows, and furniture, for example, may shrink in the winter due to low humidity and swell in humid environments, such as swimming pools and restrooms.
- Air temperature: In the summer, a suitable interior temperature is between 21 and 23 degrees Celsius. Temperature has an impact on physical and mental activities as well as health.
- Air motion: In a building, increased air motion generates drafts, whereas low air motion creates blanketing.

12.2.4 Ventilation System

In this circumstance, only a well-designed ventilation system will suffice. It delivers filtered air in the summer and filtered and warmed air in the winter, as well as removing stale air from the premises.

Any ventilation system must have a synchronized supply of fresh air and a synchronous exhaust of exhaust air to maintain the appropriate air balance in the space. When there is a lack of or poor outside air intake, the oxygen content drops, the humidity rises, and the dustiness level rises. Polluted air, odors, humidity, and dangerous substances are not eliminated if exhaust ventilation is not supplied or is ineffective. The cooperative operation of inlet and exhaust air vents is another crucial aspect in a well-designed ventilation system. If only air exhaust is given, such as by a bathroom extractor fan, the only feasible air supply source is the space between windows, doors, and structural parts. Dust infiltration, odor, and draughts are all caused by an uncontrollable air supply.

The only natural supply air stream that may compensate for air extraction is ventilation grilles in bathroom doors, wall or windows vents, and an open window.

Mechanical ventilation, on the other hand, is the sole way to offer centralized air supply in the rooms.

12.2.5 Ventilation Air

The amount of outdoor air necessary to compensate for air leaving the area owing to equipment exhaust, exfiltration, and/or to maintain Quality Of Indoor air for the occupants is known as ventilation air. (For minimum ventilation needs, see ASHRAE Standard 62.) Heat is frequently introduced into the airstream just before cooling coil and has little effect on the space conditions. Calculate the extra cooling coil load as follows:

$$Q\ \text{sensible} = 1.08 \times CFM \times (T_o - T_c) \qquad 2.1$$

$$Q\ \text{latent} = 4840\ x\ CFM\ x\ (Wo - Wc) \qquad 2.2$$

$$Q\ \text{total} = 4.5\ x\ CFM\ x\ (ho - hc) \qquad 2.3$$

$$Q\ \text{sensible} = 1.08\ x\ CFM\ x\ (To - Tc) \qquad (i)$$

$$Q\ \text{latent} = 4840\ x\ CFM\ x\ (Wo - Wc) \qquad (ii)$$

$$Q\ \text{total} = 4.5\ x\ CFM\ x\ (ho - hc) \qquad (ii)$$

Where,

CFM stands for cubic feet per minute of ventilation airflow.

To = Outdoor dry bulk temperature, in degrees Celsius

Tc = Dry bulk air temperature exiting the cooling coil in degrees Celsius.

kg (water) per kg = Outdoor humidity ratio (dry air)

kg (water) per kg Wc = Humidity ratio of air exiting the cooling coil (dry air)

ho = enthalpy of outside/inside air, kJ per kilogram (dry air)

hc = kJ per kilogram enthalpy of air exiting the cooling coil (dry air)

12.3 Energy Conservation Strategy For HVAC System

Heating, ventilation, and air-conditioning systems account for about half of a building's overall energy consumption, posing a significant opportunity and challenge to minimize energy consumption through the use of various creative system designs. Selecting the proper temperature (no overcooling or overheating), reducing the space for air-conditioning, and closing dampers / grills for places where air-conditioning is not necessary are some of the measures for air-conditioning systems.

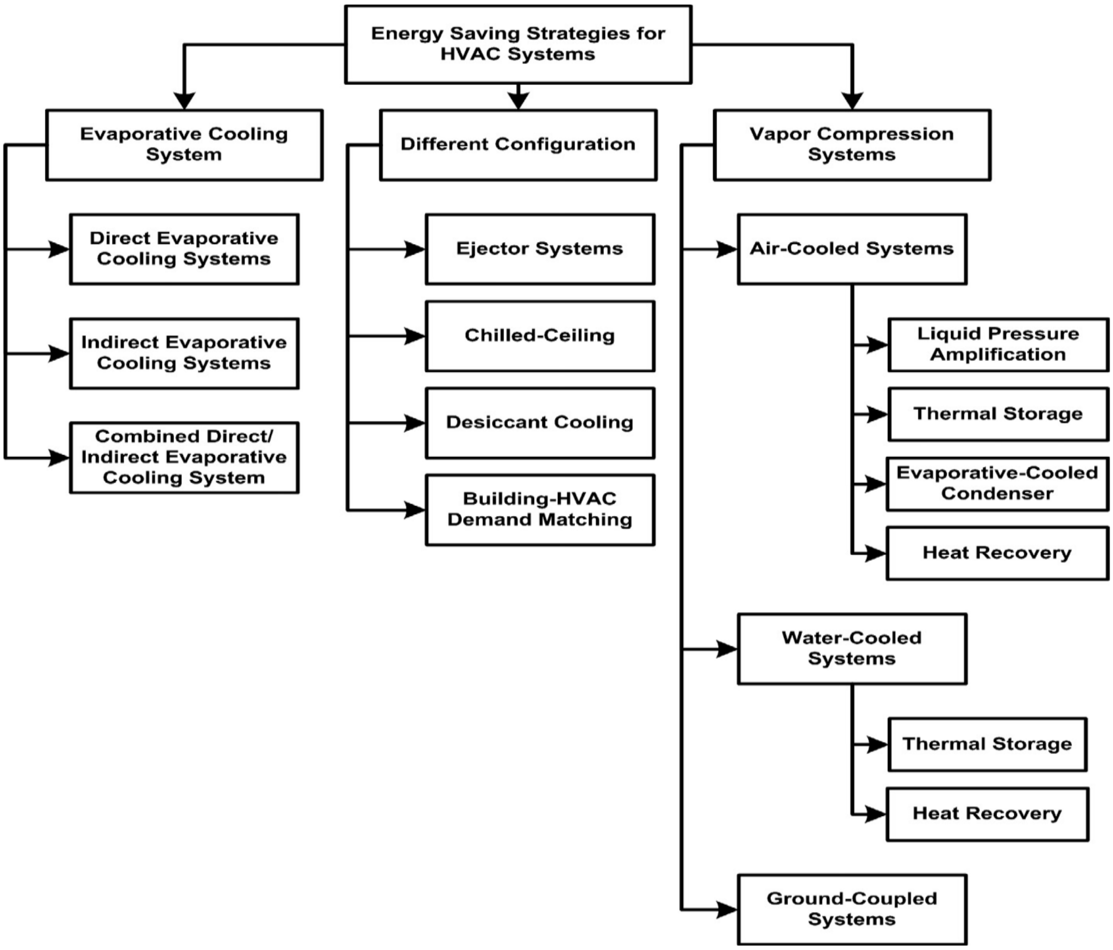


Figure 12-6: HVAC energy saving strategies

12.4 Geothermal System

Butwal Power Company's head office in Baneshwor, Kathmandu, has implemented an innovative air-conditioning scheme that utilizes geo-thermal energy. The basic premise is that the temperature at roughly 3 meters below ground level stays unchanged throughout the year at around 18 degrees Celsius.

The heat exchange takes place underneath the ground via ducts, tunnels, and ventilation fans, and the interior air is taken below the earth. The system does not require additional cooling or heating since the average temperature inside the chamber is the same as that found 3 meters below earth.

Energy usage for heating and cooling loads has improved in recent years. Renewable energy sources such as solar, geothermal, and wind can be used to save energy. The earth may be used as a source of heat in the winter and a heat sink in the summertime to heat and cool buildings. Earth air tunnel heat exchangers can be used to implement geothermal energy's benefits in heating and cooling areas (EATHE). Because of the enormous growth in energy usage and in-herent spending of buildings, the usage of earth to air exchangers has gained significant ground in the heating and cooling of structures. Based on seasonally variable inflow temperature and tunnel-wall temperature, which is dependent on ground temperature, an earth-air-tunnel (EAT) system efficiently supplies heating and cooling energy loads to a structure. The temperature of the ground changes annually up to a depth of 4 m, according to Bharadwaj et al., and stays unchanged beyond this depth. The temperature and humidity distribution in the ground, as well as the surface conditions, affect performance of an EAT system.

For an EATHE pipes with a 0.1 m in diameter and a 19.2 m length, Bisoniya et al.[3] examined 3 different air flow speed (2 m/s, 3.5 m/s, and 5 m/s) and found that the highest and minimum temperature declines were 12.9 °C and 11.3 °C, accordingly, for intake air velocity of 2 m/s and 5 m/s.

Ahmed et al.[4] used a numerical parametric study to look into the influence of inlet air velocity on the thermal behavior of an earth-pipe cooling system for four different air velocities: 0.41 m/s, 1.0 m/s, 1.5 m/s, and 2.0 m/s, and found that the 1.5 m/s air velocity offered the best cooling performance.

In Delhi, India, Sodha et al.[5] computed the required pipe lengths for composite climates using various ground-surface treatments. If air is supplied at 3 m/s and pipe is buried at 4 m depth, a tunnel with a length of 150 m is sufficient to sustain the required cooling conditions, whereas for shaded exterior, wet layer, and wet shaded ground conditions, the required pipe size was 105 m, 78 m, and 70 m, respectively, for the specified air velocity.

Krarti et al. [6] investigates the energy performance of an earth air tunnel using a basic analytical model. The model is a heat transfer study between the earth and the air tunnel. This model may also be used to calculate the daily mean and amplitude of the overall cooling/heating impact of the tunnel, but only when condensation does not occur (relative humidity of pipe does not reach 100 percent).

Bojic et al.[7] examine the mathematical model for heat transfer from the soil to the air via two pips, as well as the design of this model for two steel poly venial chlorides materials (PVC). At 1.5 m deep in soil, the pipe has a length of 50 m and an inner and outer diameter of 140 mm and 150 mm, respectively.

Kumar et al.[2] examine the effectiveness of an earth air tunnel heat exchanger system as well as the possibilities for energy reduction in non-air-conditioned buildings. In this research, a numerical model for the energy potential of an earth to air heat exchanger system was constructed. The temperature of the output was decreased from 9.75°C with a 20 m earth air tunnel heat exchanger system and 4°C with an 80 m earth air tunnel, which is necessary for room air conditioning.

Jens et al.[8] Energy efficiency of earth-to-air heat exchangers is evaluated using a standardized method. The goal of this study is to determine the efficiency of three earth air tunnel heat exchangers currently in use in mid-European office buildings. The operation of an earth air tunnel heat exchanger was compared using a generic manner. First, plots over time and characteristic lines are used to depict temperature behavior, which is then compared using standardized duration curves. Secondly, on standardized graphs, energy gain is depicted. Third parametric model is then utilized to generate broad efficiency requirements. Both dynamic temperature behavior and energy performance must be used to determine thermal efficiency.

Tiwari et al.[9] employ an earth-air heat exchanger to assess the greenhouse's annual thermal performance. A year of experimental study at IIT Delhi, India, confirmed the thermal model given by Cihoshal and Tiwari in this paper. To validate the thermal model, the correlation coefficient and root-mean-square percent deviation were determined for each month. The greenhouse temperatures with an earth to heat exchanger was 0.99 % and 4.24 % in January. Ghoshal and Tiwari's thermal model backs up the experimental findings. The temperature of the greenhouse increases and falls by 8°C and 4°C in summer and winter, respectively, due to the construction of an earth air tunnel heat exchanger. The earth air tunnel heat exchanger seems to be more efficient in the summer than in the winter due to the higher temperature in the greenhouse.

M.K. Ghosal and G.N. Tiwari[9] examine the modeling and parametric studies for the thermal performance of an earth to air heat exchanger combined with a greenhouse. The thermal model was created to look at the possibility of utilizing ground-stored thermal energy for greenhouse heating and cooling using an earth air heat exchanger system combined with a greenhouse on the campus of IIT Delhi, India. When compared to temperatures without the EAHE, the temperature for greenhouse air rises up to 7–8 °C in the winter and falls by 5–6 °C in the summer.

In a desert climate, Al-Ajmia et al.[10] study the cooling potential of earth to air heat exchangers for household structures. In a hot, arid area, a theoretical model of an earth to air heat exchanger is built to determine the output air temperature and the cooling potential of these devices. The model has been verified against other published models and found to be in good agreement. The earth air tunnel heat exchanger provides a decrease of 1700 W in peak cooling demand, with an interior temperature drop of 2.8 °C during summer peak hours, according to simulation data (middle of July). EAHE has been found to have the ability to reduce cooling energy consumption in a typical dwelling by 30% during the summer peak season.

Kumar et al.[11] used a genetic algorithm to investigate a design optimization tool for an earth-to-air heat exchanger. This work proposes a design tool for optimizing earth-to-air heat exchanger input variables. The GA developed model contains better precision than the previous models in determining the heating and cooling potential of two EATHE models. The suggested model accounts for circulating air humidity fluctuations, natural temperature stratification of the ground, latent and sensible heal transmission, and ground surface characteristics, among other things. The findings are in good accord with experimental data and other model predictions. The sensitivity analysis was used to investigate the impact of four factors on the output temperature of EATHE, air humidity, ambient temperature, ground surface temperature and ground temperature at burial depth.

Cucumoa et al.[12] examine a one-dimensional transient analytical model for earth-to-air heat exchangers that accounts for condensation and thermal disturbance from the top free surface as well as surrounding the buried pipes. The performance of earth air tunnel heat exchangers installed at various depths for building heating and cooling is estimated using a one-dimensional transient and analytical model. Two coordinates are taken into account: one in the longitudinal direction of the buried pipe and another in the vertical direction through the earth. Analytical method predicts the temperature fields of fluid in pipe and soil in the vicinity of buried pipe with suitable simplifications, taking into consideration thermal disturbance of the top free surface and probable phase change in buried pipes.

The performance of an earth–pipe–air heat exchanger for winter heating is investigated by Bansal et al.[13] In the winter, earth air tunnel heat exchanger systems can be utilized to minimize building heating loads. Analysis of thermal performance and heating capacity of earth air tunnel heat exchanger systems using a transient and implicit model based on CFD. The influence of operational factors (such as pipe material and air velocity) on the thermal performance of earth air tunnel heat exchanger systems is investigated. This study discusses the 23.42 m long EATHE system, which provides heating in the range of 4.1–4.8 0C with air flow velocities of 2–5 m/s.

Tittelein et al.[14] use the convoluted response factors approach to study earth-to-air heat exchanger performance. In this article, a new numerical model of an earth air tunnel heat exchanger is investigated. The system is divided into "n" pieces that run parallel to the exchanger pipe. To save processing time, the issue of conduction is tackled using the response factors technique in each step. The finite element software, which solves two-dimensional conduction problems, is used to calculate each response factor. The uniqueness of this problem is that the time constants are quite large, making it difficult to minimize the amount of computations by using traditional response factor characteristics.

Sujata Nayak and G.N. Tiwari [15]employ energy and exergy analytic methodologies to examine the theoretical performance of an integrated solar and earth heat exchanger greenhouse. The purpose of that research was to create a simple mathematical model to examine the year-round efficiency of photovoltaic/thermal and earth air tunnel heat exchangers combined with a greenhouse at IIT Delhi, India. With the assistance of a simple mathematical model, the solar energy application via photovoltaic system and soil to air heat exchanger for greenhouse heating and cooling was explored. In New Delhi, India, calculations are made for the four types of meteorological conditions (a, b, c, and d). The study compares greenhouse air temperatures when the photovoltaic/thermal system is used during the day and the earth air tunnel heat exchanger is used at night, with air temperatures when the photovoltaic/thermal system and earth air tunnel heat exchanger are used exclusively for 24 hours. When the system is operated with photovoltaics paired with an earth air tunnel heat exchanger at night, the air temperature within the greenhouse may be boosted by 7-8 °C during the winter season. The results show that when the system is operated with photovoltaic linked with the earth air tunnel heat exchanger, the hourly usable thermal energy generated during the day and night is 33 MJ and 24.5 MJ, respectively. Annual thermal energy generated by the system is calculated to be 24728.8 kWh, with net electrical energy savings of 805.9 kWh and annual thermal exergy energy created of 1006.2 kWh.

M. Maerefat and A.P. Haghighi[16] study passive cooling of buildings utilizing an integrated earth to air heat exchanger and solar chimney. The results of this study reveal that system performance is influenced by solar radiation, outside air temperature, and the SC and EATHE arrangement. According to the findings of the study on EATHE diameter, there is an ideal diameter for cooling pipes (0.5 m) that provides the smallest number of SCs and EAHEs. Long EATHE with a length of more than 20 m has also been discovered to be useful in providing thermal comfort. The results also reveal that, even if providing thermal comfort is challenging when ambient temperature and cooling demand are high, correct setups may give satisfactory interior conditions even with low solar intensity of 100 W/m2 and high ambient air temperature of 50°C.

Bansal et al.[17] investigated the performance of a summer cooling earth–pipe–air heat exchanger. To predict the thermal performance and cooling capacity of earth air tunnel exchanger systems, a transient model based on computational fluid dynamics was created. The model was created within FLUENT. The created model has been tested in Ajmer (Western India) and found to be valid. The 23.42 m long EATHE is used to cool air flow velocities of 2–5 m/s in the range of 8.0–12.7 °C. Investigations on steel and PVC pipes have revealed that the EATHE system's performance is unaffected by the buried pipe's material (pipe).

Hiresh et al.[18] conducted an experiment to test the performance of an earth to air heat exchanger. The material pipe utilized as a model was manufactured of PVC and had the following dimensions: pipe diameter, pipe length, and burial depth (0.106m, 19.2m and 2m). They discovered that at a velocity of 5 m/s, the highest quantity of heat transmission from air to surrounding soil was around 261.5W. They also revealed that when the temperature of the entrance air changed from 32 to 40.3°C, the temperature of the output air increased by 4.5°C at 5 m/s.

CHAPTER THREE: METHODOLOGY

This chapter describes the methodology that is opted to apply for the work from start of the project till the completion. The methods used during the thesis period are separated into different stages.

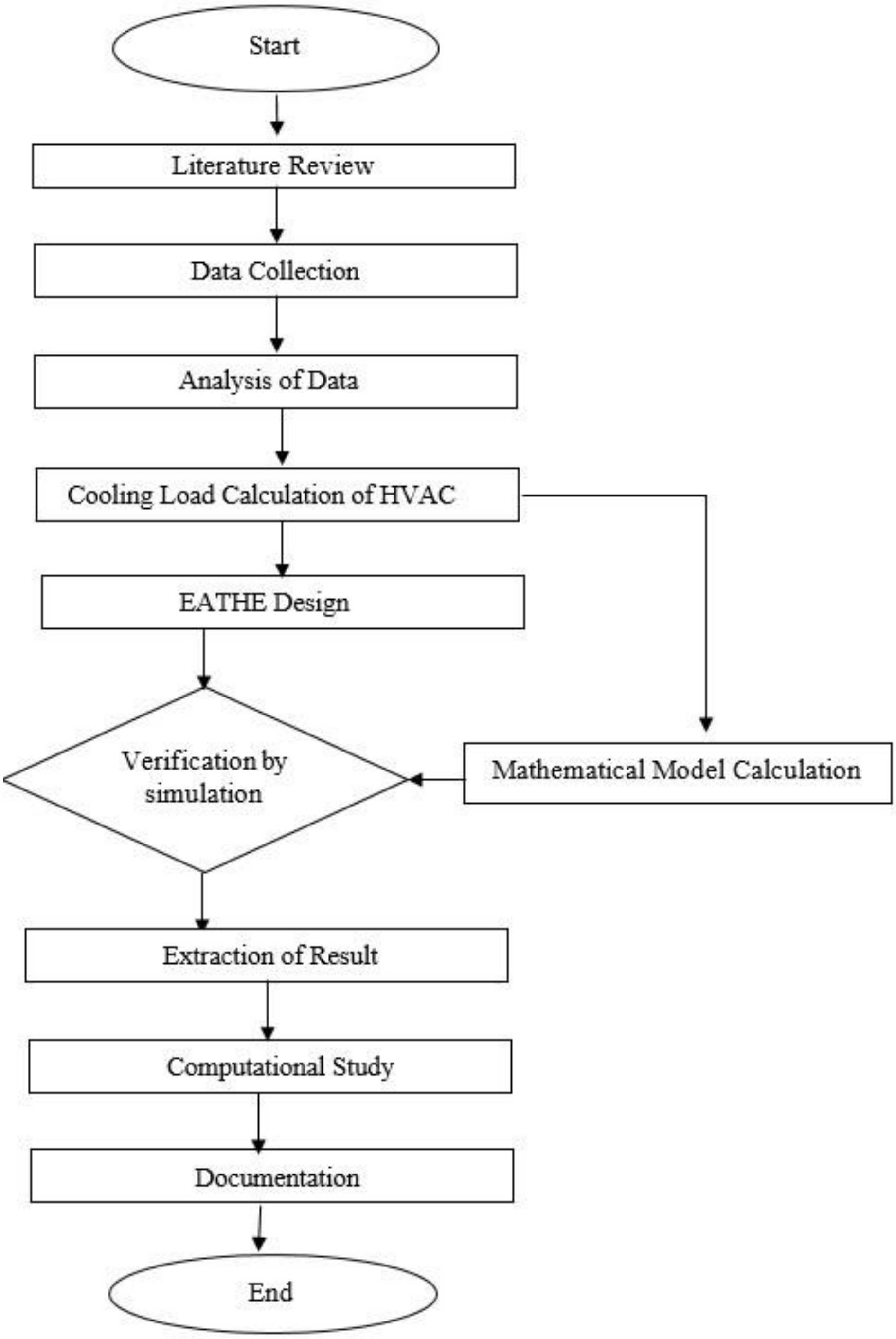


Figure 13-1: Methodology Flowchart

13.1 Data collection

For the outdoor atmosphere varying temperature and relative humidity data and for underground temperature data, Government of Nepal, department of hydrology and meteorology was approached. The HVAC design parameters like building properties, occupants, lighting, equipment used, windows, etc of sample space are considered.

For indoor condition, temperature of 24°C will be used considering section 5.3.2 of Thermal Environmental Conditions for Human occupancy of American Society of Heating, Refrigeration and Air Conditioning (ASHRAE) standard 55-2017.

This study is particularly focused on calculation of HVAC load and annual energy consumption associated with the proposed office building located at Kathmandu. Since the development of the project is in the preliminary phase, there are very less data associated with the building. What is currently available are space availability and proposed layout. Some of the information given in AUTOCAD drawing are as follows:

Table 13.1: Details of Proposed Building

Building Location	Balwatar, Kathmandu
Building Size	2 and half-story
Floor Area	1400sqft
Wall Material	Common Brick with plaster
Wall Window Ratio	0.21
Roof Type	Flat
Roof Material	Concrete
Floor	Concrete
Window Type	Double glazed
Number of rooms	12

13.2 Weather Statistics

The weather data is taken from ISHRAE Nepal Weather Data.

Table 13.2: Summer and Winter weather data

Month	**Summer**		**Winter**	
	Max DBT (F)	**Min WBT(F)**	**Max DBT(F)**	**Min WBT(F)**
Jan	77.2	52.2	70.6	51.7
Feb	79.2	54.2	71.6	53.7
Mar	82.4	57.4	74.8	56.9
Apr	83.6	58.6	75.0	58.1
May	86.0	61.0	76.0	60.5
Jun	88.0	63.0	78.0	62.5
Jul	89.0	64.0	78.0	63.5
Aug	89.0	64.0	78.0	63.5
Sep	87.0	62.0	77.0	61.5
Oct	84.8	59.8	75.8	59.3
Nov	80.6	55.6	73.8	55.1
Dec	78.2	53.2	71.8	52.7

Design Conditions

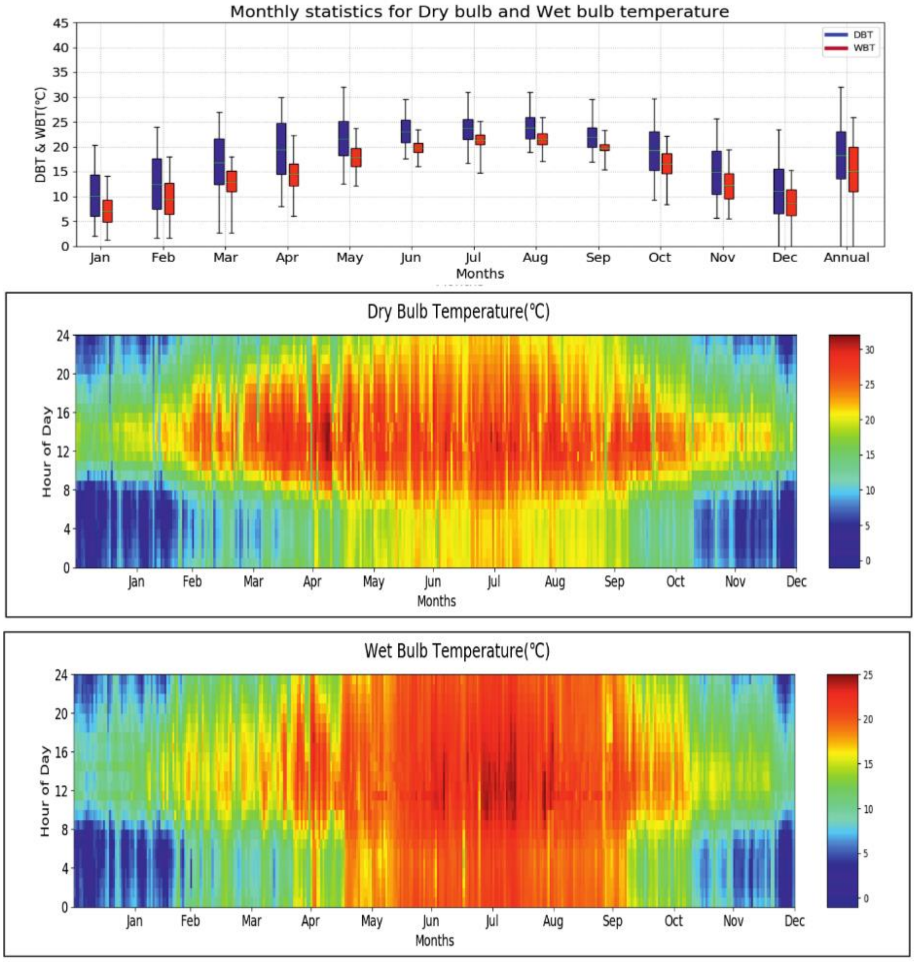


Figure 13-2: Weather Data of Kathmandu (ISHRAE, 2019)

Heating DBT	Cooling DB/MCWBT						
99.6%	99%	0.4%		1%		2%	
2	3	30	26	29.4	25	28.7	25

Taking the weather statistics as well as the design temperatures provided by ISHRAE, we can see that the summer design temperature provided (ISHRAE, 2019) is 30ºC (for 0.4% confidence level). Also the winter design temperature is 2ºC (for 99.6% confidence level). As ISHRAE's data being latest, we would like to take 30 degrees as maximum temperature for calculations for cooling load.

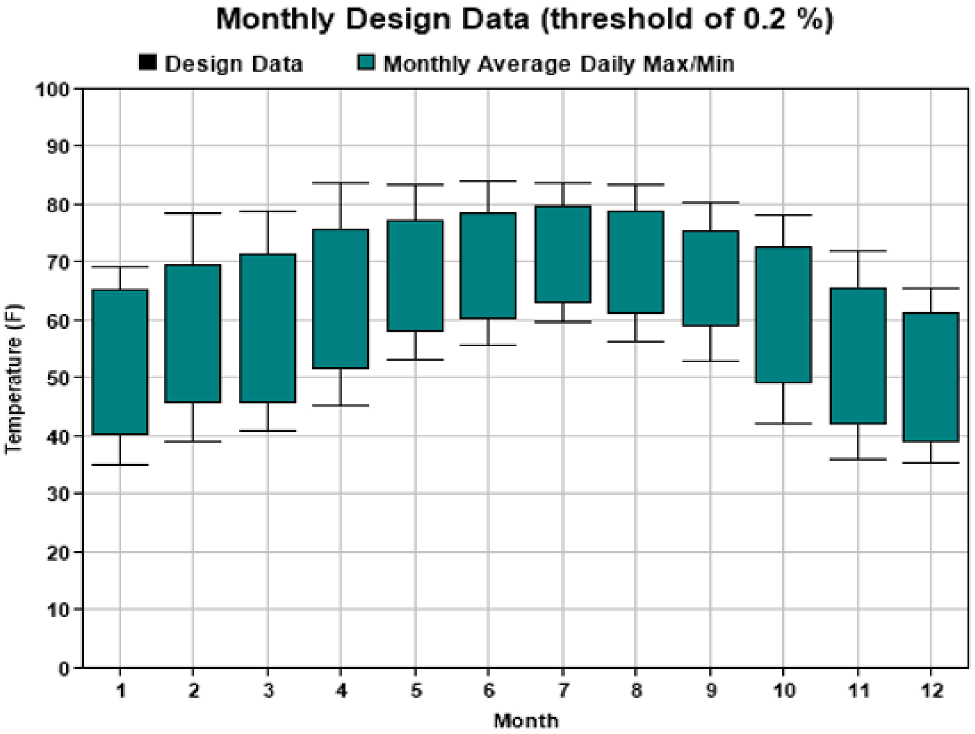


Figure 13-3: Design Condition at 0.2% of Weather Station at Kathmandu

13.3 Analyzing of data

Collected data of temperature, humidity and inside ground temperature from Government of Nepal, department of hydrology and meteorology and ISHRAE will be used in cooling load calculation and design of energy saving approach i.e. Earth Air Tunnel Heat Exchanger.

13.4 Load Calculation of an HVAC System

Multiple factors can influence the heating or cooling load produced in a particular location. Setting up an HVAC system is both time-consuming and expensive. Furthermore, setting up the flexibility to change the system's performance is time-consuming. As a result, it is critical to do preliminary calculations prior to estimating the needed system to be installed. Aside from financial aid, load calculations assist us in achieving one or more of the following: (ASHRAE, Heating and Cooling Load Calculation Manual, 1980)

a. Helps in selecting equipment.
b. Helps to consider load reduction and its possibilities.
c. Helps to analyze the system operation in partial load.

The heat storage capacity of a building's envelope is determined by the factors that make up the envelope. This attribute lengthens the time it takes for heat to flow from the outside to the interior. The time it takes for peak heat to reach the inner surface from the outside surface is known as time lag as discussed by ILE, Gut, Ackerknecht, and Gut (1993). It's crucial, for example, if you wish to take advantage of daytime surplus heat energy later in the evening. It's not easy to pinpoint the exact location where the highest HVAC load occurs. It occurs as a result of several occurrences of maximal heat load resulting from various sources. For example, whereas heat gain from the roof is greatest in the afternoon, heat gain from equipment is greatest in the evening. Heat gains from the sun beaming through an east-facing window, on the other hand, will be greatest early in the morning when the sun is rising in the east and shining straight into the window.

Development of EATHE

There are two types of EATHE systems: (1) open loop, in which ambient air is extracted and transported to a specific area after the heat exchange process, and (2) closed loop, in which room air is recirculated for the heat exchange process. The design and performance of the EATHE system are influenced by a number of factors. (1) Parameter of design (tube depth, length of tube, diameter of tube, flow velocity of air, tube material etc.) (2) The current weather conditions (relative humidity, ambient air temperature, undisturbed soil temperature, etc.) (3) Features of the soil (thermal diffusivity, thermal capacity etc.). (4) Convective heat transfer coefficient. Heat transfer between earth and air is affected by the tube's surface area and the thermal resistance of the tube diameter.

Many studies have been undertaken in recent years to establish an analytical and numerical study of the EATHE system, but most of them have been constrained to space restrictions and economic boundary conditions. They lead to a complicated computation section that isn't suitable for general use. The simplified design equations are required for general use.

Depending on the input conditions, there are primarily two ways for designing a heat exchanger. The efficacy and number of transfer units (NTU) technique or the logarithmic mean temperature difference (LMTD) approach can both be used. When the input and exit temperatures, as well as the flow rate and total heat transfer coefficient, are known, the LMTD technique is used to design the heat exchanger's diameter and length. When there is insufficient information to compute the Logarithmic Mean Temperature Difference, the Number of Transfer Units method is used to calculate the rate of heat transfer in heat exchangers (specifically counter current exchangers). The LMTD approach is employed for our study.

Assumptions:

- The soil around the pipe is isotropic, with uniform heat conductivity throughout all layers of the earth.
- The pipe material's thermal resistance is negligible (thickness of the pipe is very small).
- The ambient air temperature, which matches the inlet air temperature, may be used to approximate the ground surface temperature.
- The pipe has a circular cross-section that is uniform.
- Because the pipe has no effect on the temperature of the earth surrounding it, the pipe's surface temperature is uniform in the axial direction.
- Air and soil have constant thermo-physical properties (density, viscosity, thermal conductivity, and specific heat capacity).

A general equation for the rate of heat transfer is given by,

$$Q = \dot{m} \times Cp \times \Delta T$$

Where,

- Q = maximum cooling load in the room (system) (Joule/sec). Since the main aim of this paper is to replace AC with an EATHE system giving equivalent output, hence the maximum cooling load is the maximum cooling capacity of AC that meant to be replaced.
- $\dot{m}$ = mass flow rate of air into the room(kg/sec). This is to be found out from the above equation.
- C_p = specific heat of air at an average temperature of air(J/kg/K).
- ΔT = temperature difference between both the air at the pipe's entrance, which is ambient temperature Ta, and the air at the pipe's output, which is room temperature Tr (Kelvin). For this data, the input and output temperatures must be set to the highest ambient temperature and the room's necessary temperature, respectively. Because we are constructing the system for an

extreme environment, the input temperature would be the highest external temperature. And the requisite room temperature would be the outlet temperature of the pipe.

From the above equation the mass flow rate for the required cooling load and the temperature difference is found out. Since,
Discharge (volume flow rate of air),

$$d = \frac{mass\ flow}{density\ of\ air\ at\ average\ temperature}$$

Diameter(d) of the duct of the heat exchanger can be calculated using the continuity equation, $q = AV$.
Hence,

$$q = V * \frac{(\pi * d^2)}{4}$$

The velocity at inlet of EATHE is 2-5m/s which is economical.

Now to find the length of the heat exchanger LMTD methods used which is govern by the equation,

$$Q = h_a \times A \times T_{lm}$$

Where,

- Q = is the cooling load.
- h_a = is the heat transfer coefficient.
- A = surface area of heat exchanger from where heat will be exchanged between the pipe and the soil.
- T_{lm} = logarithmic mean temperature difference.

The calculations process for the above parameters takes place as follows

i. Calculation of heat transfer coefficient.

Since for forced convection heat transfer coefficient is given by,

$$h_a = \frac{Nu * k}{d}$$

Where,

- Nu=Nusselt no.
- k=Conductivity.
- D=diameter of air.

For Nusselt no. Renolds no.(Re) need to be found out,which is given by

$$Re = \frac{V * d}{v}$$

Where,

- V = velocity
- d = diameter

- ə = dynamic viscosity of air. It is constant at constant temperature

If RE < 10000, it would be laminar flow If Re>10000, hence it is at turbulent flow For most of the cases Re>10000.So for turbulent flow in circular tube Nusselt number is given by Petukhov equation i.e,

$$NU = \frac{\left(\frac{f}{8}\right) * \left(Re \ - 1000\right) * Pr}{1 - 12.7 * \sqrt{\frac{f}{8}} * (Pr^{\frac{2}{3}} - 1)}$$

Where, f is friction coefficient,

$$f = (1.82 log Re - 1.64)^{-2}$$

Now, putting the values Nu can be found out.
Hence, now the heat transfer coefficient can be found out using,
Calculation of logarithmic mean temperature difference is given by:

$$T_{lm} = \frac{\theta 1 - \theta 2}{\ln(\frac{\theta 1}{\theta 2})}$$

Where,

- $\Theta 1 = T_a - T_s$
- $\Theta 2 = T_r - T_s$

However, computer simulations of EATHE Energy Plus and TRNSYS are available, but they are time-consuming and not often used. Computational Fluid Dynamics (CFD) is presently the most widely utilized method for researching and modeling the EATHE system's performance. To establish the tube diameter and effective tube length of the EATHE system, I utilize the most basic correlation, which is then confirmed using CFD simulation data.

13.5 Simulation

The goal of the study is to compute the optimal length for EATHE that is acceptable for Nepalese climatic circumstances. Hdpe (High Density Polyethylene) pipe was used in the research. Ansys FLUENT was used to do the Computational Fluid Dynamics study. Ansys FLUENT is a computational fluid dynamics (CFD) program that may be used to address turbulence, flow models, heat transfer, and other problems. This program gives a constant stream of data to the user, allowing them to portray correct analytical findings. This program was utilized in this study to assess how well EATHE worked in order to get a comfortable outlet temperature. The expected results will be in the form of length of the EATHE system.

The workflow for Ansys simulation is given below:

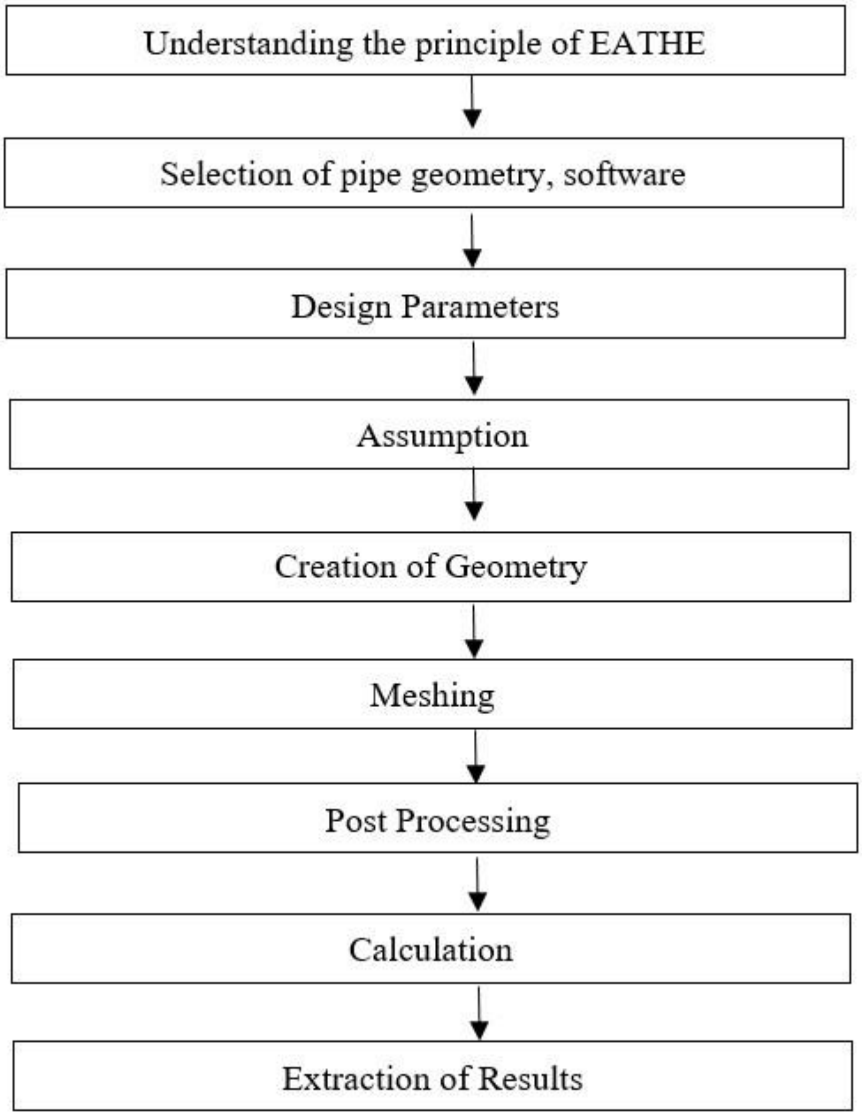


Figure 13-4: CFD simulation workflow

Pipe Geometry : Circular

Pipe diameter : 400 mm

Pipe material : Hdpe pipe

13.5.1 Assumptions:

- The air is incompressible, and the soil qualities are uniform.
- The soil temperature is 291K, and the pipe's wall surface temperature is 291K.
- The temperature of the soil remains consistent throughout the duration.

- The thickness of the walls is minimal, and the temperature of the walls is the same as the temperature of the soil.

13.5.2 Geometry:

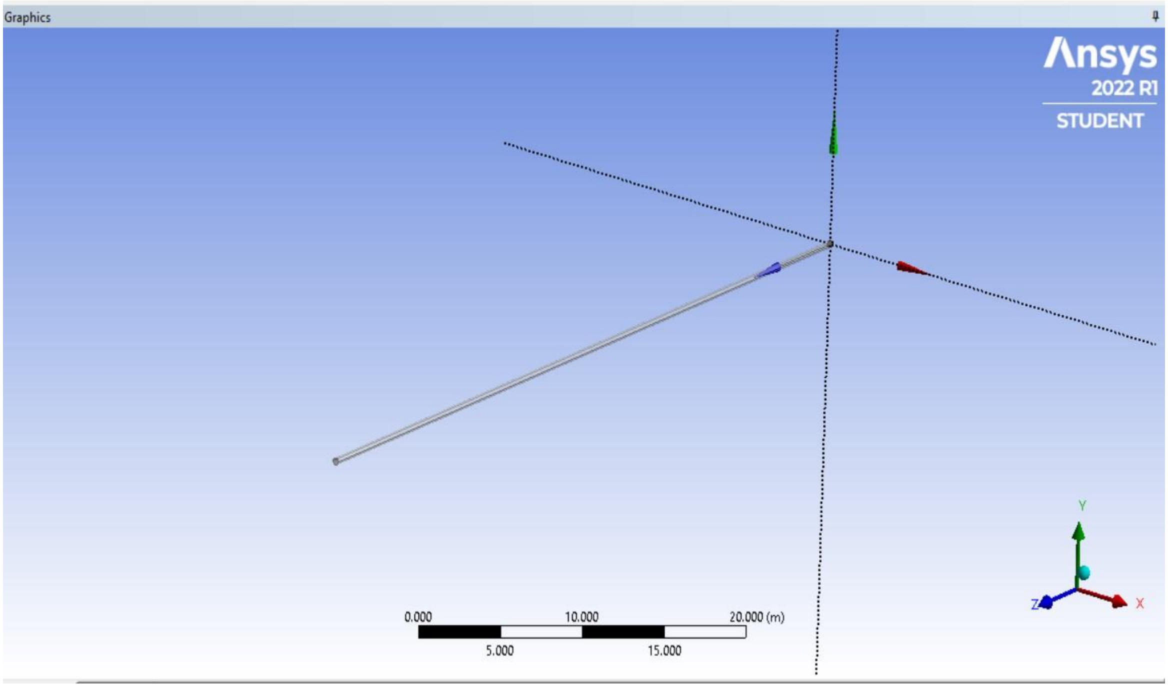


Figure 13-5: Geometry creation

13.5.3 Mesh :

Solidworks 3D is used to construct a three-dimensional parametric model of the geometry, and Ansys CFD is used to mesh it. The research considers a pipe length of 100 meters. A vast number of points in the form of a numerical grid or mesh are used to link the CFD model. The values in huge numbers of points are obtained using these grids. Mesh elements can be tetrahedral, pyramidal, hexahedral, and other forms. For all pipe geometries, a general meshing was investigated without going through any mesh independence tests.

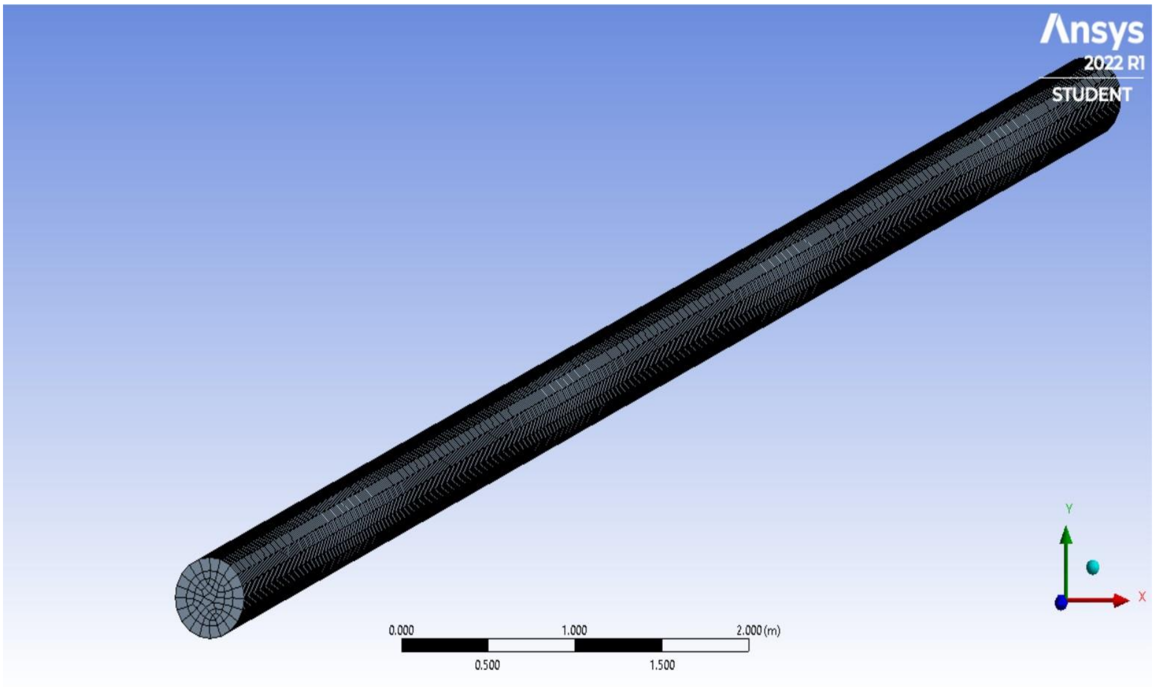


Figure 13-6: Meshing

13.5.4 Boundary Conditions :

Inlet Condition:

Temperature inlet : 303K

Velocity at inlet : 2 and 5 m/s

13.5.5 Post Processing :

The results of the simulation were processed using a steady-state, pressure-based, and turbulence model that enabled the energy equation. The K-epsilon, K-omega, Spart-allaras, and other turbulence models are the most often employed. In general, the K-epsilon model consists of three models. For viscous heating, buoyancy effect, and other effects, a standard, RNG, and realizable model is utilized. The RNG models can be employed in differential viscosity models where turbulent viscosity has a low Reynolds number. For thermal modeling of flows with Reynolds numbers larger than 4000, the turbulence model is chosen. The K-epsilon model with conventional wall treatment is used in this investigation.

13.5.6 Selection of model and materials :

i. Steady State
ii. Pressure based
iii. Energy Equation
iv. K-epsilon Model
v. Fluid medium: Air
vi. Solid Medium: Hdpe

13.5.7 Extraction of Result:

The results of the CFD simulation were extracted for given flow, diameter, temperature of wall, temperature inlet and given length of pipe. The results show variation of temperature along the length of pipe.

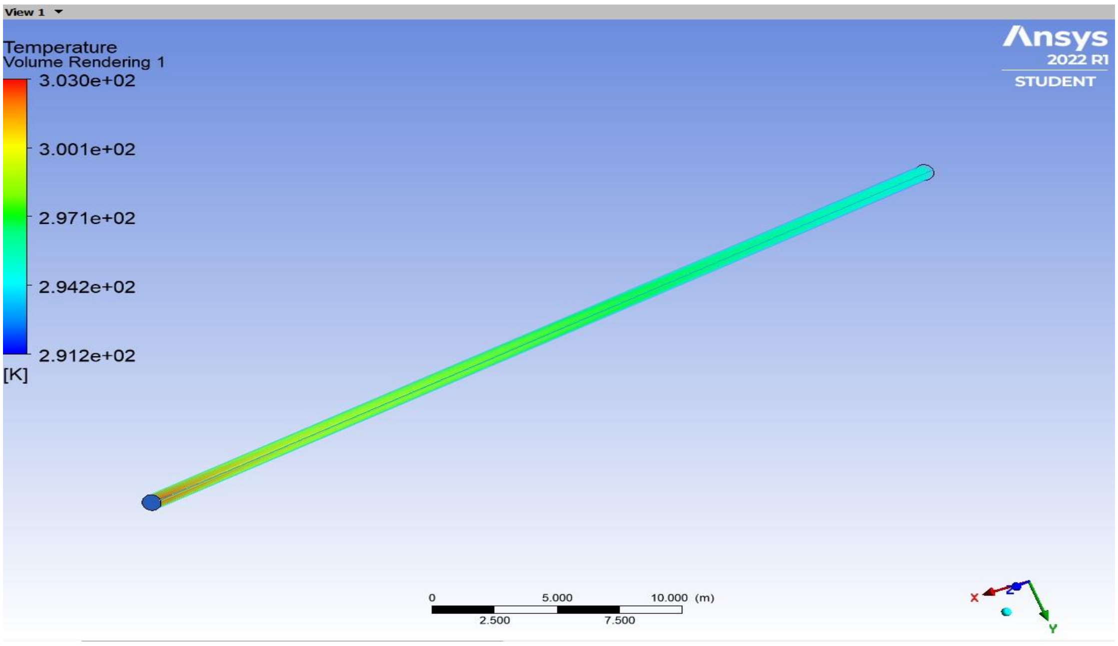


Figure 13-7: Temperature Profile

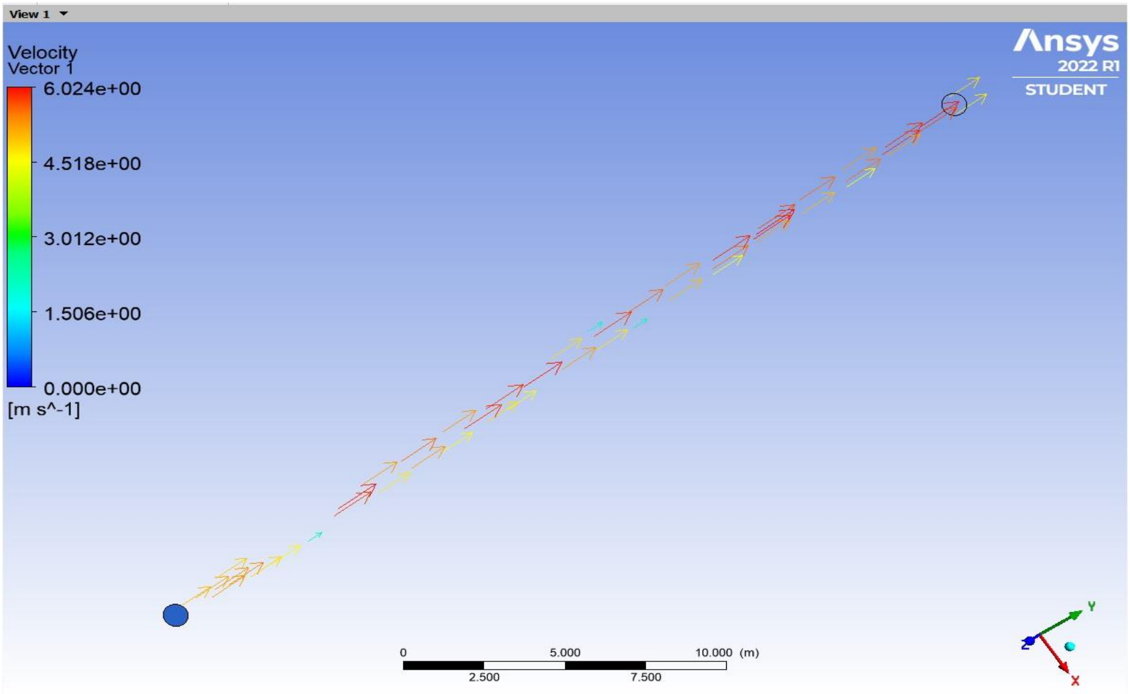


Figure 13-8: Velocity Profile

Case 1: Velocity 2m/s, inlet air temperature 303.15℃, soil temperature 18℃ for pipe diameter 0.4m.

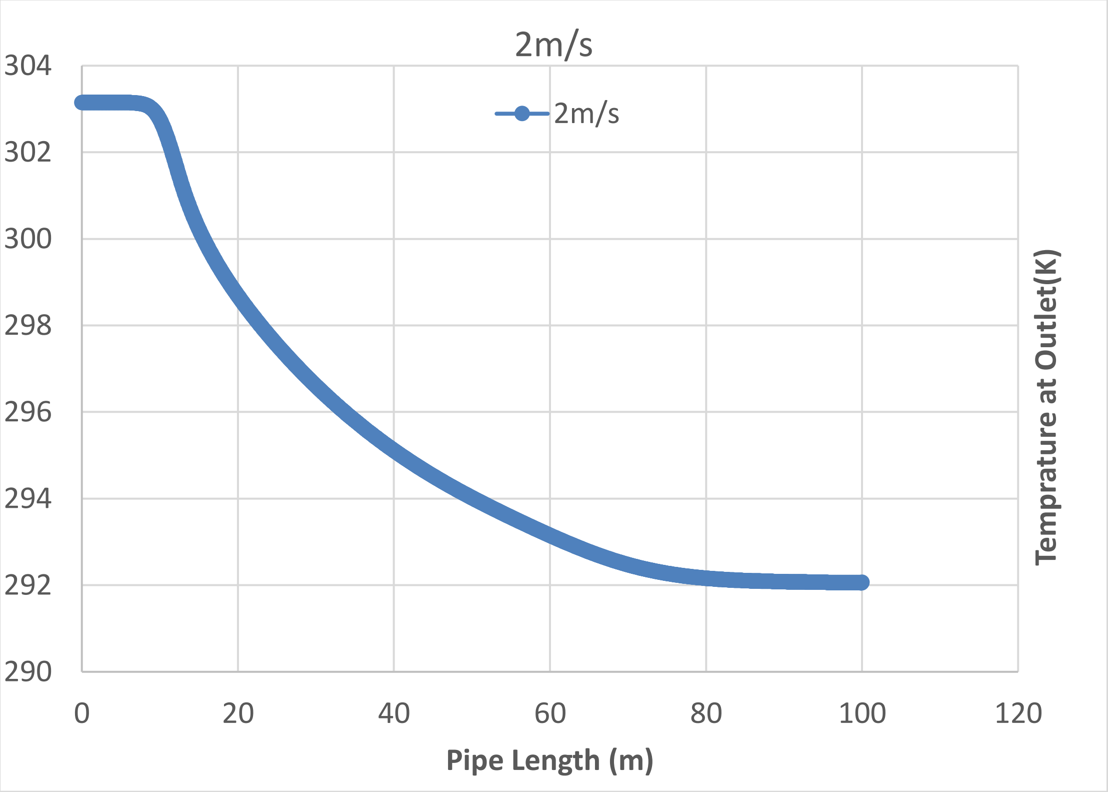


Figure 13-9:Pipe Length vs. Outlet temp.(For velocity 2m/s)

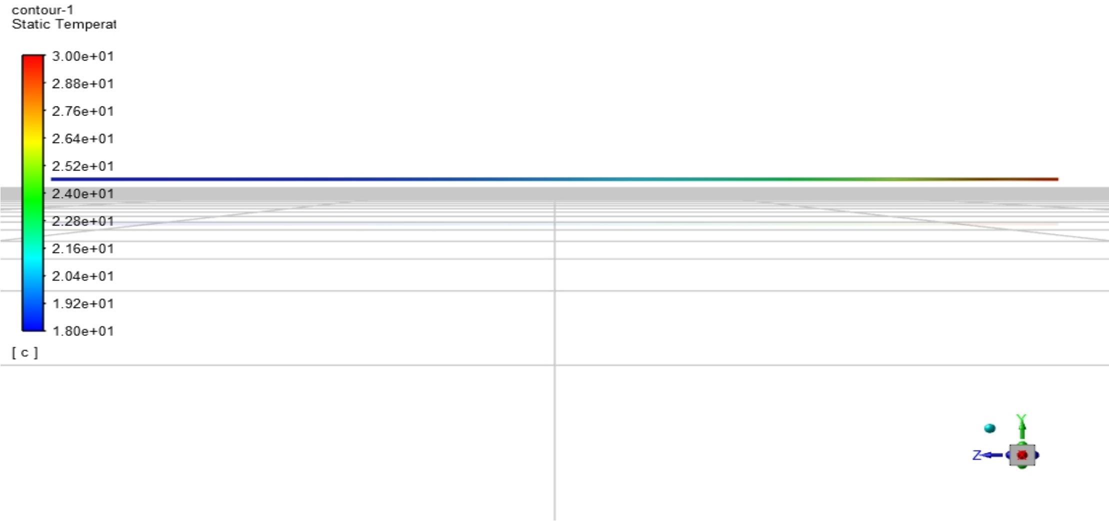


Figure 13-10:Temperature contour at velocity 2m/s

The length of heat exchanger was obtained to be around 75-80m for air velocity of 2m/s with the temperature at the outlet 18℃.

Case 2: Velocity 5m/s, inlet air temperature 303.15℃, soil temperature 18℃ for pipe diameter 0.4m.

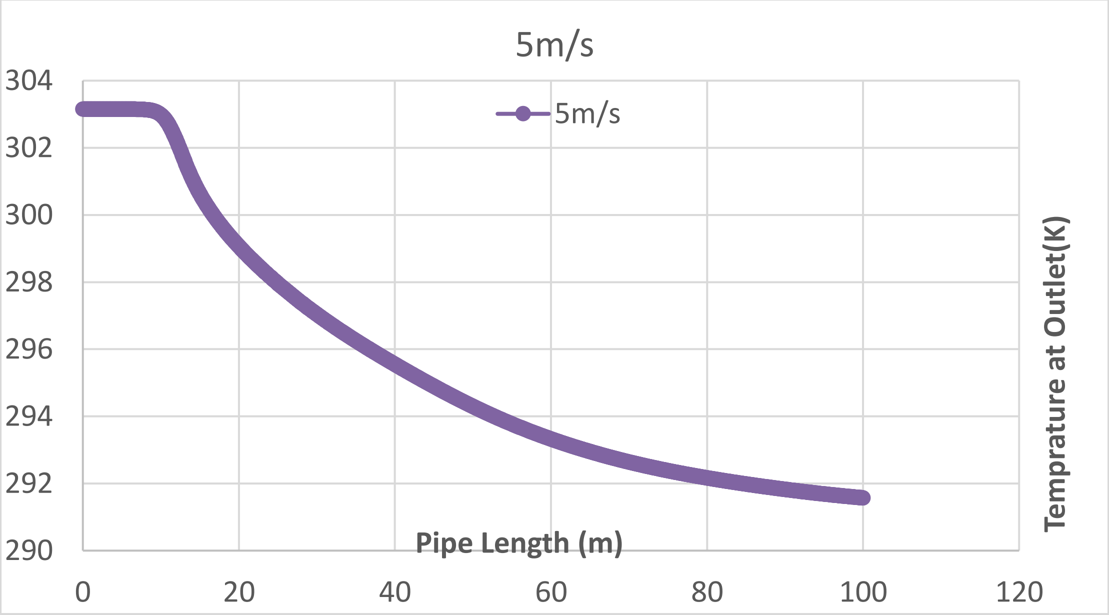


Figure 13-11: Pipe length vs. Outlet temperature(for velocity 5m/s)

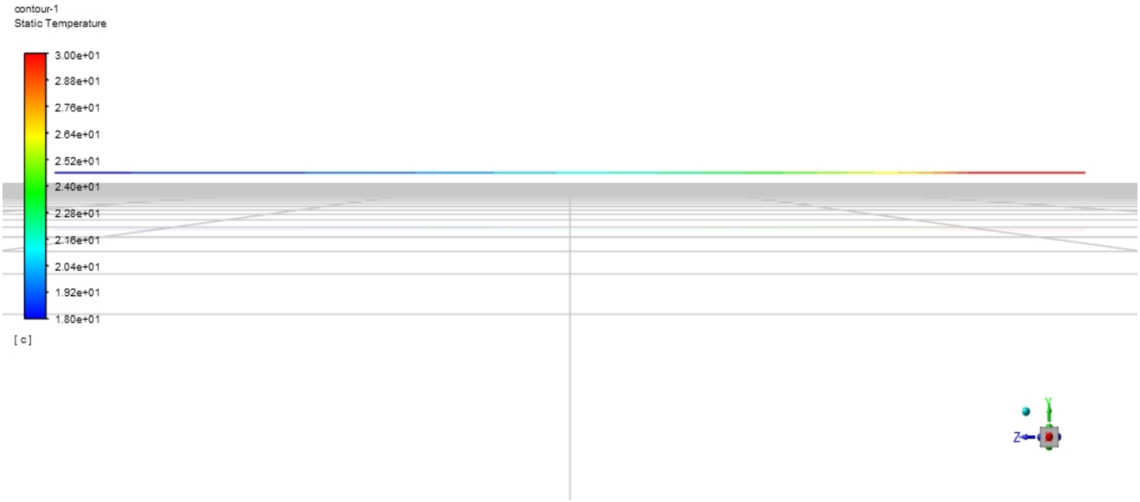


Figure 13-12: Temperature contour for velocity 5m/s

The length of heat exchanger was obtained to be around 95-100 m for air velocity of 5m/s with the temperature at the outlet 18℃ which is much longer than the previous case of 2m/s.

HDPE pipes available in Nepal’s market comes in diameter of 20mm-500mm. Among them 400mm diameter pipe is widely used. Optimum diameter in terms of length calculated for this study seems to be 400mm as the length has to stay below 100m for ease of construction of EATHE system

13.6 Comparative study and validation of the research

Analysis and design outcomes are studied for the proposed EATHE system with the simulation results. Further comparison to normal HVAC VRF system to study energy saving characteristics. Validated results will be further compared with VRF system to get their establishment cost and operation cost.

13.7 Documentation

The acquired data, along with its calculation and relevance, will be archived on a regular basis once a specific cluster of tasks is completed. The obtained data, along with its calculation and significance, will be included in the report.

CHAPTER FOUR: RESULTS AND DISCUSSION

14.1 Cooling Load Calculation of the Building

All the calculations are done in Excel. Formulae and mathematical relation that are used are mentioned above section.

Table 14.1: Cooling load calculation summary

S.N.	Floor	Cooling load(TR)
1.	Ground	11
2.	First	12
3.	Second	2.5
Total		25.5

Total cooling load of Office building was obtained to be 26.7 TR from our calculation with standard assumption and reference of actual blue print of the building.

System Selection

We have discussed few major air conditioning systems that we can use in our projects such as chiller/boiler system, single and multi- split system and VRF system, among these systems we select VRF system for the comparative study with EATHE system. Following are some reasoning why we have chosen the VRF system

- Chiller boiler system requires boiler plant, chiller, and pumps requires more structural space with sensitive control and fittings, so it is not selected for the commercial building.
- Single and multiple split AC system requires separate indoor units and less longer spacing out unit position which is not feasible for all of the rooms in whole building, so this system is not selected.
- VRF system has outdoor units that can supply refrigerants and gas up to many indoor ceiling cassette units in a floor or multiple floors of the buildings. So we choose efficient and effective. VRF system for the building with less architectural change required inside the building for installation and easy operation mechanism.

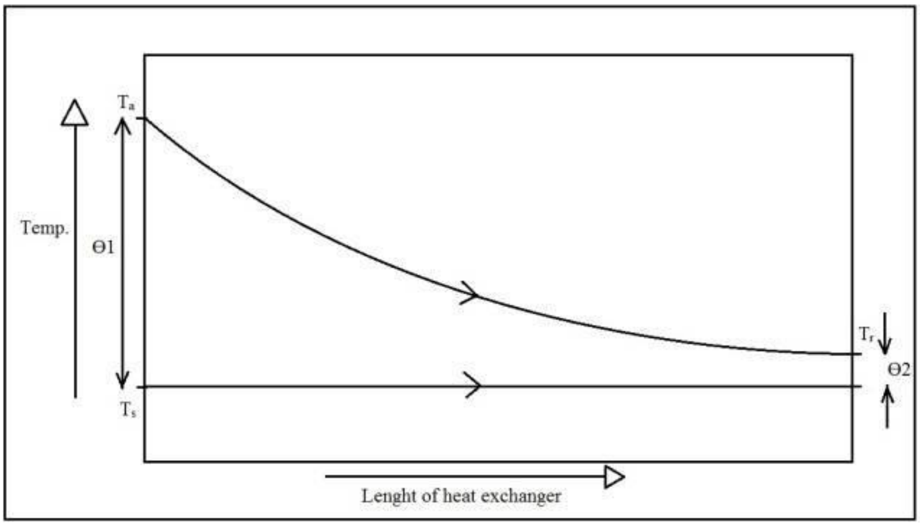
To study the VRF system for the proposed building**,** AC units can be used of any commercial brands like Mitsubishi, Hitachi, Daiken, Lenox etc.

The selection of equipment with their electrical consumption data are mentioned below in Table 7.

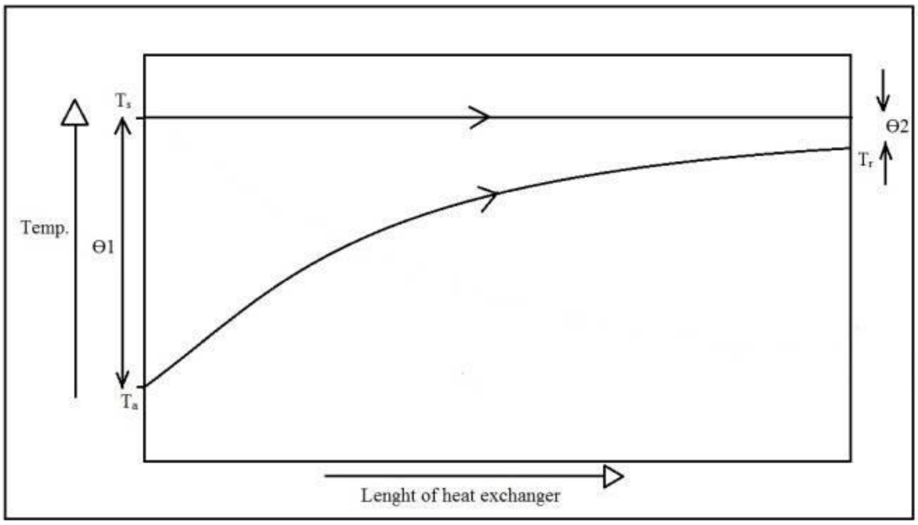
14.2 EATHE System Design

There would be two conditions between the room temperature T_r and soil temperature T_s.

- When$T_r \geq T_s$. During summer climatic conditions,



- $T_r \leq T_s$, During winter climatic conditions,



The temperatures are needed to be fixed as we are using LMTD method and so we are designing the heat exchanger according to the inlet and outlet temperatures as an input for extreme summer climatic conditions. This can be fixed according to our needs and environmental data. The temperature of the soil is different in different geographical areas. For this study for Kathmandu Valley, 18°C is considered the soil temperature below 3 meters ground level. The temperature of the room is fixed to a human comfort temperature that lies between 22-27 degrees. The temperature of the environment is variable naturally. It changes with time. And so we need to take the maximum temperature as 30°C according to weather data as we are designing for an extreme condition.

14.3 Calculation of Length of heat exchanger

Because the heat exchanger's surface area where the heat will be exchanged is merely the curved surface area of the duct, and because we're utilizing cylindrical tubing and assuming no heat exchange in any other region.

Hence putting this equation,

$$A = 2\pi * r * l$$

Also,

$$Q = h_a * A * T_{lm}$$

Length of pipe can be determined.

Parameters	**Velocity (2m/s)**
Re	49947.45
Pr	0.712
f	0.01715
Nu	119.2
hc	7.8612
Tlm	7.281
L(m)	76.47

Thermal Properties Used:

Paramaters	**Material**		
	Air	Soil	Hdpe
Density(kg m3)	1.1644	2050	1380
Specific heat capacity	1006	1840	900
Thermal Conductivity	0.0263	0.52	0.19

Hence, design of heat exchanger is complete.

The length of pipe required for Earth Air Tunnel was calculated to be 76.47m (say 76m).

The parametric simulation to evaluate length at different velocity and diameter was conducted and appropriate length was found to be 75-80 m suitable at velocity 2m/s.

14.4 Financial Analysis

The cost estimation of both VRF Air-conditioning system and EATHE was computed with the actual rates from the market. The costing for both the cases is tabulated below.

Table 14.2: Cost Estimation

EATHE Cost Estimation					
S.N.	**Items**	**Quantity**	**Unit**	**Rate**	**Amount**
1	Cost per cubic meter of earth air tunnel setup	182.4	cubic meter	8,000	14,59,200
2	Cost of 5.5 kW blower fan	5.5	kW	2,50,000	2,50,000
3	Cost of 5000 cfm AHU with Outdoor Condensing Unit	5000	cfm	8,80,000	8,80,000
4	Ducting with insulation and all accessories	410	Sq.mtr.	3,335	13,67,350
5	Grille, Diffusers, Filters, Dehumidifier and other accessories	1	lot	3,20,000	3,20,000
	Total				**42,76,550**

VRF Air-Condition Cost Estimation					
S.N.	**Items**	**Quantity**	**Unit**	**Rate**	**Amount**
1	Cost of VRF Indoor Units				
2	1 TR	6	Nos.	85,000	5,10,000
3	1.5 TR	4	Nos.	98,000	3,92,000
4	2 TR	7	Nos.	1,08,000	7,56,000
5	Cost of VRF Outdoor Unit (35kW)	2	Nos.	5,60,000	11,20,000
6	Low Side Works(Installation,Copper Piping, Insulation, Drain, Electrical Connection and all required accessories)	1	Lot	9,27,900	9,27,900
	Total				**37,05,900**

Initial investment for EATHE seems to be more during the establishment of system. But during the operation of the system, VRF Air-Condition consumes more electrical energy which is shown in table below.

Table 14.3: Electrical Consumption data

S.N.	Particulars	Specifications	Unit	Quantity	Electrical Consumption (kW)
	For VRF Air-Condition				
1	Electrical Consumption by VRF Indoor Units				
	1 TR	0.6	kW	6	3.6
	1.5 TR	0.75	kW	4	3
	2 TR	1.35	kW	7	9.45
2	Electrical Consumption by VRF Outdoor Units	12.2	kW	2	24.4
	Total Electrical Consumption for VRF Air-Condition				**40.45**
	For EATHE				
1	Electrical Consumption of Blower fan and Dehumidifier	5.5	kW	1	5.5
2	Electrical Consumption of AHU	24	kW	1	24
	Total Electrical Consumption for EATHE				**29.5**

The cost of energy during the operation throughout the year for both systems were calculated which is mentioned below.

Table 14.4:Energy cost for VRF and EATHE systems

Energy Cost for VRF Air-Condition		**Unit**
Yearly Runtime of VRF Air-Condition	2400	Hrs
Energy Consumption by VRF Air-Condition	97080	Whrs
Energy Cost for VRF Air-Condition operation throughout the year	**970800**	Nrs
Energy Cost for EATHE		
Yearly Runtime of AHU	1000	Hrs
Yearly Runtime of Blower	2400	Hrs
Energy Consumption by AHU	24000	Whrs
Energy Consumption by Blower	13200	Whrs
Energy Cost for AHU	240000	Nrs
Energy cost for blower fan	132000	Nrs
Total Energy cost for EATHE operation throughout the year	**372000**	Nrs

Total heat energy obtained from single EAT according to our design was obtained to be 5.465kW. When we place four pipes, the heat energy obtained increases to 21.86kW.

Now, for total cooling load required, 24.88% heat energy is supplied from EATHE, to supplement the remaining load and for winter climatic conditions, Air Handling Unit with cooling and heating coil is required of capacity 66kW. Dehumidifier is also required for Nepali climatic conditions. EATHE system consumes less electricity than VRF Air-conditioning system.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Cooling load for the commercial building with its architectural and characteristic features is obtained to be 89.25 Kw using CLTD method. Hence, with the reference of cooling load, Earth Air Tunnel Heat Exchanger(EATHE) is designed. Appropriate design parameters for EATHE is determined to be 0.4m diameter with flow velocity 2m/s and length 76 meters.

Although, initial establishment cost for EATHE is observed more than VRF Air-Condition system, electrical consumption is decreased by 10.95kW while using EATHE over VRF Air-Conditioning system and it can save 5,98,800 Nrs yearly during its operation.

5.2. Recommendation

Further case study of existing EATHE at Butwal Power Company can be done for the actual performance evaluation of EATHE in context of Nepal. Solar integrated EATHE and other Hybrid systems can be integrated for more energy efficient HVAC system.

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