NUMERICAL STUDY OF A GEOTHERMAL EARTH TO AIR HEAT EXCHANGER

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NUMERICAL STUDY OF A GEOTHERMAL EARTH TO AIR HEAT EXCHANGER

A Project Report

submitted in partial fulfillment of the

requirement for the award of the degree of

Bachelor of Technology

In

Mechanical Engineering

By

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April, 2024

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I certify that

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This project report entitled **NUMERICAL STUDY OF A GEOTHERMAL EARTH TO AIR HEAT EXCHANGER** by **Mr. N.UDAY KIRAN,** approved for the award of the Degree Bachelor of Technology in **Mechanical Engineering.**

Examiners **Supervisor(s)**

Principal

Date:

Place:

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With gratitude

N.UDAY KIRAN(20951A0358)

Abstract

In response to escalating demand for cooling energy and improved thermal comfort attributed to the effects of global warming, innovative approaches become increasingly imperative. One such solution, the Earth-air heat exchanger (EAHE) or earth tube heat exchanger, capitalizes on the stable temperatures found at depths between 8 to 10 meters underground. This technology exploits the consistent temperature differential between the Earth's subsurface and the ambient air, functioning as a versatile heating and cooling system. By channeling air through buried pipes, the EAHE can cool incoming air during hotter months and warm it during colder periods before it's circulated for ventilation purposes, effectively fulfilling year-round heating and cooling requirements..

Keywords – Earth-air heat exchanger; Ambient air; Buried pipes

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SYMBOLS	ABBREVATION
Cp	Specific heat
L	Length
Cm	Centimetre
M	Meter
Z	Depth
R	Radius
V	Velocity

LIST OF ABBREVIATIONS

SHORT FORM	ABBREVIATIONS
HE	Heat Exchanger
EAHE	Earth-To-Air Heat Exchanger
GCHE	Ground Coupled Heat Exchanger
GHE	Ground Heat Exchanger
COP	Coefficient Of Performance

CHAPTER -I

INTRODUCTION

Rapid expansion in construction and industrial sectors led to this swift growth in buildings and infrastructure resulting increased energy consumption, especially electricity usage.. To address this issue, various passive cooling techniques are being developed, one of which is Space Cooling with Underground Heat Exchangers (UHE). Previous studies have shown that at depths below the earth's surface, temperature differences may occur. However, at depths ranging from approximately 5 to 10 meters, the temperature remains relatively constant throughout the year, approximating the annual average temperature of the location. This stability is attributed to the high thermal inertia of the soil, resulting in diminished temperature fluctuations as depth increases. Additionally, there exists a time lag between surface temperature changes and those within the ground. Furthermore, ground temperature tends to be lower than the atmospheric air temperature is warmer in summer and cooler in winter. By utilizing Underground Heat Exchangers (UHE), both of these conditions can be leveraged to reduce energy consumption, offering a sustainable approach to space cooling.

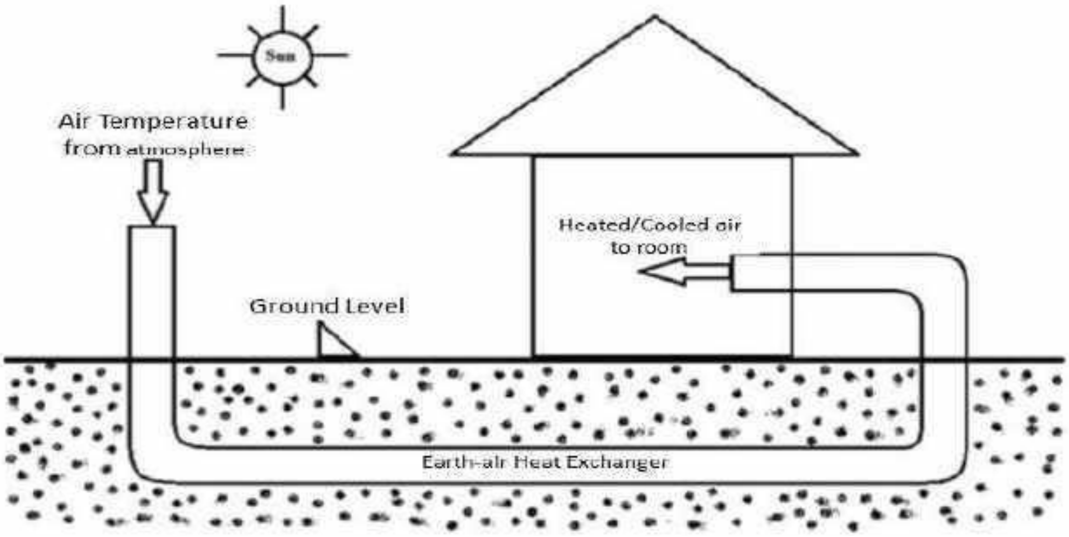

Figure 1.1: Heat Exchanger

Studying the influence of various factors such as pipe material, diameter, length, burial depth, airflow rate, and soil types on the thermal efficacy of Earth-Air Heat Exchanger (EAHE) systems is vital for achieving optimal thermal comfort. An Earth Air-Pipe Heat Exchanger (EAPHE) system has been proposed to evaluate its technical feasibility for thermal applications, particularly in hot and arid regions. This system has shown a significant decrease in air temperature of up to 24°C, indicating its effectiveness in dissipating heat in air-cooled condenser units. Importantly, soil at certain depths below the earth's surface has the capacity to remain cool during summer and relatively warmer during winter compared to ambient temperatures. Given the limited availability of traditional energy sources, it is imperative to explore alternative energy sources to conserve energy and mitigate environmental impact. The rising energy demand for building heating and cooling highlights the significance of energy conservation, especially in desert climates. Human comfort typically requires temperatures ranging from 20°C to 26°C and relative humidity between 40% and 60%. Achieving these conditions often involves conditioning the air. Current systems involve directing air through buried pipes using fans. During summer, the air supplied to buildings is cooled as the surrounding ground temperature is lower than the ambient temperature. Conversely, in winter, when ambient temperatures drop below ground temperatures, the air is preheated. Earth Air Heat Exchangers are increasingly recognized as effective alternatives for heating or cooling buildings. These systems typically comprise metallic, plastic, or concrete pipes buried underground at specific depths. Fresh atmospheric air passes through these pipes with the aid of blowers, facilitating heat transfer between the soil and air based on temperature differences. Efficient system design, including considerations of pipe cross-section area, type, airflow velocity, and soil characteristics, is crucial for optimal performance. EAHE systems aim to minimize pollution and reduce conventional energy consumption by harnessing green and clean energy sources. Major types of Earth Air Heat Exchangers include open-loop and closed-loop systems.

- Open type earth tube heat exchanger

- Closed type earth tube heat exchanger

- Open System In open system Fig.1.2 configuration, ambient air flows through tubes that are buried in the ground to undergo preheating or pre-cooling. Subsequently, the air is further heated or cooled using a standard air conditioning system prior to being introduced into the building. This setup allows for the utilization of the ground's natural temperature to moderate the air temperature before it undergoes additional conditioning within the building's HVAC system..

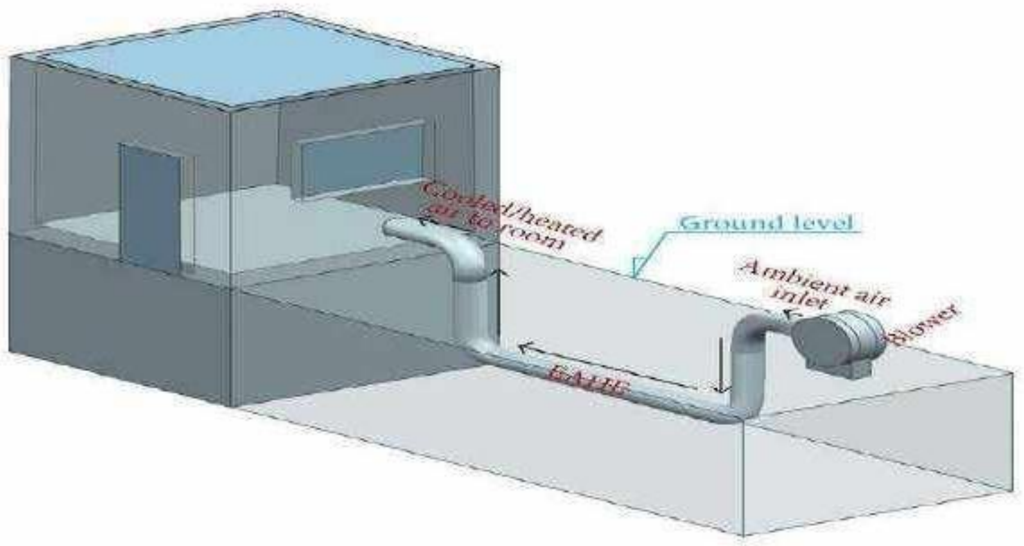

Fig. 1.2: Open Loop System

- In a closed system configuration as depicted in Figure 1.3, heat exchangers are situated underground, typically in horizontal or vertical positions. Within these heat exchangers, a heat carrier medium circulates, facilitating the transfer of heat between the ground and the air, or vice versa. This closed-loop setup ensures efficient heat exchange between the ground and the air, contributing to the overall thermal management of the system..

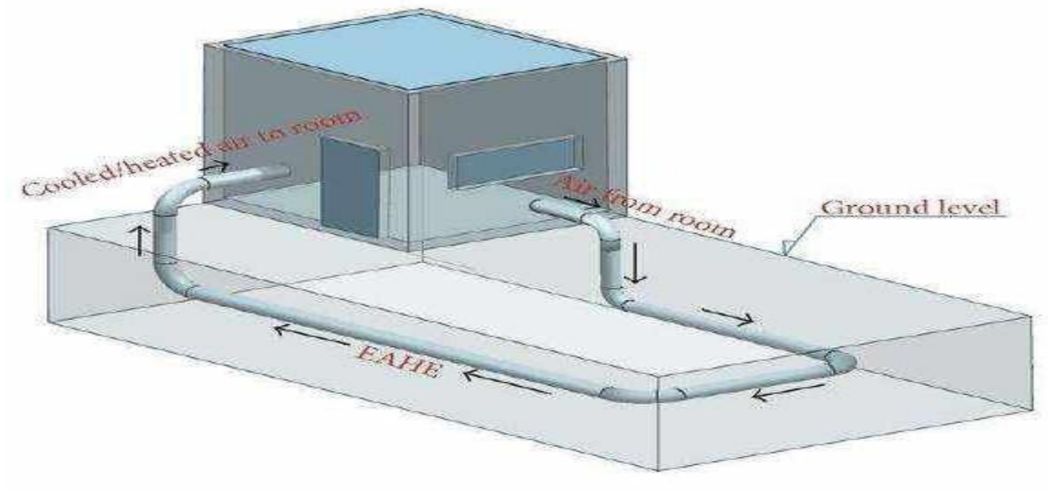

Fig. 1.3 : Closed Loop System

- Earth Air Heat Exchangers (EAHE) offer a viable alternative to conventional air conditioning systems, especially in hot climates. Hybrid systems combining EAHE with evaporative cooling are particularly effective for summer cooling. The thermal performance of EAHE is influenced by the thermal conductivity of the soil; higher thermal conductivity results in better performance.
- Optimizing EAHE performance involves several factors.Lengthening the pipe while reducing its diameter, reducing mass flow rate of air within the buried pipe, and increasing burial depth up to 1.5 to 2 meters all contribute to enhanced EAHE performance. These adjustments maximize heat exchange efficiency between the air and the surrounding soil, leading to improved cooling outcomes for buildings.

1.1 Benefits of the CFD Analysis for Heat Exchangers

- **Cost Savings:**

  CFD analysis enables virtual testing and optimization of heat exchanger designs, reducing the need for costly physical prototypes and experimental testing. This leads to significant cost savings in the design and development process.

- **Time Efficiency:**

  Virtual simulations with CFD can accelerate the design iteration process, allowing engineers to quickly evaluate multiple design alternatives and identify optimal solutions in a shorter timeframe compared to traditional methods.

- **Performance Prediction:**

CFD provides detailed insights into the fluid flow behavior, temperature distributions, and heat transfer characteristics of heat exchangers under various operating conditions. This enables engineers to predict and optimize performance parameters with greater accuracy, leading to more efficient and reliable designs.

- **Risk Mitigation:**

By identifying potential design issues and performance limitations early in the design phase, CFD analysis helps mitigate risks associated with heat exchanger development. Engineers can proactively address design shortcomings, ensuring the final product meets performance requirements and regulatory standards.

- **Customization and Tailoring:**

CFD analysis allows for the customization and tailoring of heat exchanger designs to meet specific application requirements and constraints. Engineers can optimize exchanger configurations for different fluid types, operating conditions, and performance objectives with precision.

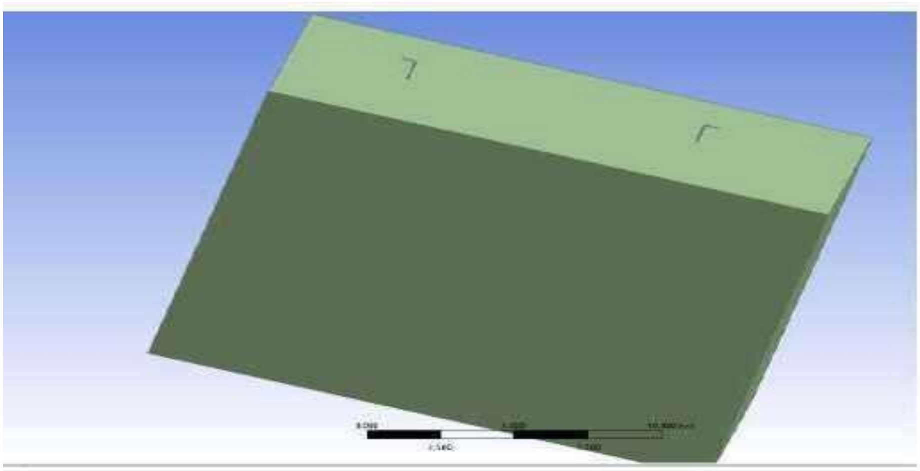

Fig. 1.4: Single Pipe Heat Exchanger

1.2 Feasibility

The feasibility of an Earth-to-Air Heat Exchanger (EAHE), also known as a ground-coupled heat exchanger or earth tube system, depends on several factors. Here's an overview of key considerations when assessing the feasibility of implementing an EAHE system:

- **Geographic Location:**

  The feasibility of an EAHE system can vary depending on the geographic location and climate conditions. It's more suitable for regions with moderate climates where there's a significant temperature difference between outdoor air and the underground soil throughout the year.

- **Soil Characteristics:**

  The type and characteristics of the soil (such as composition, moisture content, and thermal conductivity) play a crucial role in determining the effectiveness of an EAHE system. Soil with high thermal conductivity and good moisture content is more favorable for heat exchange.

- **System Design and Sizing:**

  Proper design and sizing of the EAHE system are essential for its feasibility. Factors such as the length and diameter of the buried tubes, depth of burial, and arrangement of the tubes influence the heat exchange efficiency and overall performance of the system.

- **Building Requirements:**

  The feasibility of an EAHE system also depends on the specific requirements and constraints of the building or facility it's intended to serve. Factors such as available land area, building orientation, space for buried tubes, and compatibility with existing HVAC systems need to be considered.

- **Energy Savings Potential:**

  Assessing the potential energy savings achievable with an EAHE system is crucial for determining its feasibility. This involves evaluating the heating and cooling demands of the structure, as well as estimating the expected reduction in energy consumption for heating and cooling purposes.

- **Cost Considerations:**

  The upfront installation costs of an EAHE system, including excavation, piping, and system components, need to be balanced against the potential long-term energy savings and operational benefits. Conducting a cost- benefit analysis can help determine the economic feasibility of the system.

- **Regulatory and Permitting Requirements:**

  Compliance with local building codes, regulations, and permitting requirements is essential for the feasibility of an EAHE system. This includes considerations such as environmental impact assessments, groundwater protection measures, and land use regulations.

- **Maintenance and Durability:**

  Assessing the maintenance requirements and durability of the EAHE system over its operational lifespan is necessary for its feasibility. Regular inspection, cleaning, and maintenance of buried tubes are essential to ensure long-term performance and reliability.

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1.3 Requirements for CFD analysis of Heat Exchanger

To conduct a Computational Fluid Dynamics (CFD) analysis of an Earth-to-Air Heat Exchanger (EAHE) effectively, several requirements must be addressed. Here's a comprehensive list:

- **Geometry:**

  Obtain or create a detailed 3D CAD model of the Earth-to-Air Heat Exchanger geometry, including the buried tubes, surrounding soil, inlet, and outlet ports. The geometry should accurately represent the physical dimensions and configuration of the EAHE system.

- **Soil Properties:**

  Gather data on soil properties, such as thermal conductivity, specific heat, density, moisture content, and porosity. These properties play a crucial role in determining the heat transfer behavior between the buried tubes and the surrounding soil.

- **Climate Data:**

  Obtain climate data for the location where the EAHE system will be installed, including outdoor air temperature variations, humidity levels, solar radiation, and wind speeds. This data is essential for simulating realistic environmental conditions.

- **Boundary Conditions:**

  Define appropriate boundary conditions for the CFD simulation, including inlet and outlet conditions for the airflow through the buried tubes, as well as boundary conditions for the soil surface and surrounding environment.

- **Fluid Properties:**

  Specify the properties of the air flowing through the EAHE system, including temperature, pressure, density, viscosity, and thermal conductivity. These properties may vary with temperature and humidity, so it's essential to account for any variations appropriately.

- **Soil-Fluid Interaction:**

  Model the interaction between the airflow through the buried tubes and the surrounding soil. Consider heat transfer mechanisms such a conduction, convection, and radiation between the soil and the fluid flowing through the tubes.

- **Solver Settings:**

  Select suitable numerical methods, turbulence models, and solver settings for the CFD simulation. Choose an appropriate solver capable of handling the coupled fluid-flow and heat-transfer phenomena in the EAHE system.

- **Heat Transfer Modeling:**

  Incorporate heat transfer modeling techniques into the CFD simulation to accurately predict the thermal efficiency of the Earth-to-Air Heat Exchanger (EAHE) system. This may involve solving energy equations for both the airflow and the soil, considering heat conduction and convective heat transfer.

- **Transient Analysis:**

  Consider performing transient CFD simulations to capture time- dependent variations in airflow and soil temperature within the EAHE system. This is especially important for assessing system performance during different seasons and weather conditions.

- **Post-Processing Tools:**

  Utilize post-processing tools and techniques to analyze and visualize the results of the CFD simulation effectively. This may include plotting temperature distributions, airflow patterns, heat transfer rates, and thermal efficiency metrics.

- **Validation:**

  Confirm the computational fluid dynamics (CFD) outcomes through comparison with empirical observations or experimental measurements or analytical solutions, if available. Conducting validation studies helps assess the accuracy and reliability of the CFD model and its predictions.

- **Computational Resources:**

  Ensure access to sufficient computational resources, including hardware (such as high-performance computing clusters) and software licenses, to perform the CFD analysis efficiently. EAHE simulations can be computationally intensive, especially for models with complex geometries and transient conditions.

- **Expertise:**
  Have access to personnel with expertise in CFD, heat transfer, fluid dynamics, and geotechnical engineering. Experienced analysts can help guide the simulation setup, interpret results, and make informed design decisions based on the simulation findings.

1.4 Earth-Air Heat Exchanger Components

A heat exchanger functions as a mechanism to effectively convey thermal energy from one fluid medium to another, ensuring that the fluids remain segregated throughout the exchange process. This technology finds extensive application across industrial, commercial, and residential sectors, serving to enable processes such as heating, cooling, and heat recuperation with optimal efficiency..

Principle of working

The Earth Air Heat Exchanger (EAHE) comprises a pipe buried underground, featuring specific dimensions such as length (L), internal diameter (di), and a thickness of 5 mm. Its operation involves circulating outdoor air, which is either cooled during summers or heated during winters as it passes through the buried pipe. A blower facilitates the movement of hot air during summers and cool air during winters through the exchanger, where a heat exchange process occurs, resulting in either heat gain or loss depending on the season. This mechanism contributes to maintaining the desired temperature within the system.

- **Buried Tubes or Pipes:**

  These are the primary components through which outdoor air flows into and out of the underground soil. The tubes or pipes are typically made of materials such as PVC, polyethylene, or metal and are buried horizontally or vertically in the ground.

Fig. 1.5: pvc pipes

- **Inlet and Outlet Ports:**

Inlet ports draw outdoor air into the buried tubes, while outlet ports allow conditioned air to exit the tubes and enter the building. These ports are connected to ductwork or ventilation systems.

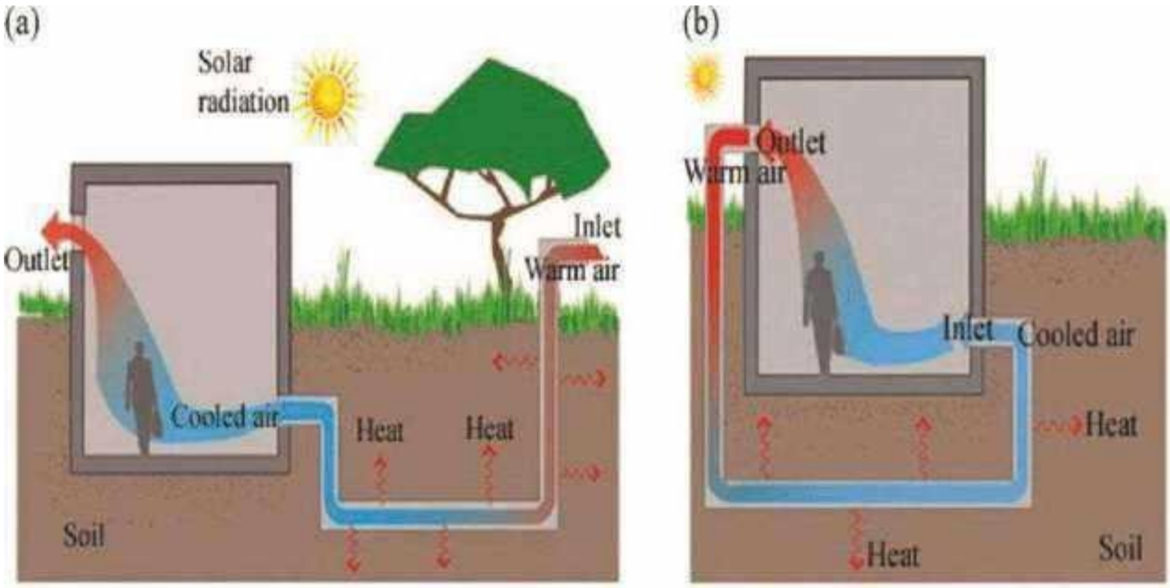

Fig. 1.6: Inlet and Outlet Ports

- **Distribution Ductwork:**

Larger EAHE systems may use distribution ductwork to distribute conditioned air from the outlet ports to various spaces within the building. The ductwork ensures even distribution of air and integration with existing HVAC systems

.

Fig. 1.7: Distribution Ductwork

- **Backfill Material:**

Backfill material such as gravel or sand may be used to surround the buried tubes, providing support and ensuring good thermal contact between the tubes and the surrounding soil.

Fig. 1.8: Sand

- . **Geothermal Heat Exchanger Loop:**

In some geothermal EAHE systems, a closed-loop geothermal heat exchanger may be installed in addition to the buried tubes. This loop circulates a heat transfer fluid (such as water or antifreeze) through a closed-loop system to further enhance heat exchange with the ground.

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Fig. 1.9: closed loop heat exchanger

- **Insulation :**

  In colder climates or to enhance system efficiency, insulation may be added around the buried tubes to minimize heat loss or gain from the surrounding soil. Insulation helps maintain the temperature gradient between the outdoor air and the soil.

- **Manifolds and Distribution Systems:**

  In larger EAHE systems with multiple buried tubes or zones, manifolds and distribution systems may be used to control the flow of outdoor air and distribute it evenly among the tubes. Manifolds ensure balanced airflow and optimize heat exchange efficiency.

- **Monitoring and Control Systems:**

  Monitoring and control systems may be installed to monitor factors such as outdoor air temperature, airflow rates, soil temperature, and system performance. These systems help optimize the operation of the EAHE system and ensure efficient heat transfer.

- **Maintenance Access Points:**

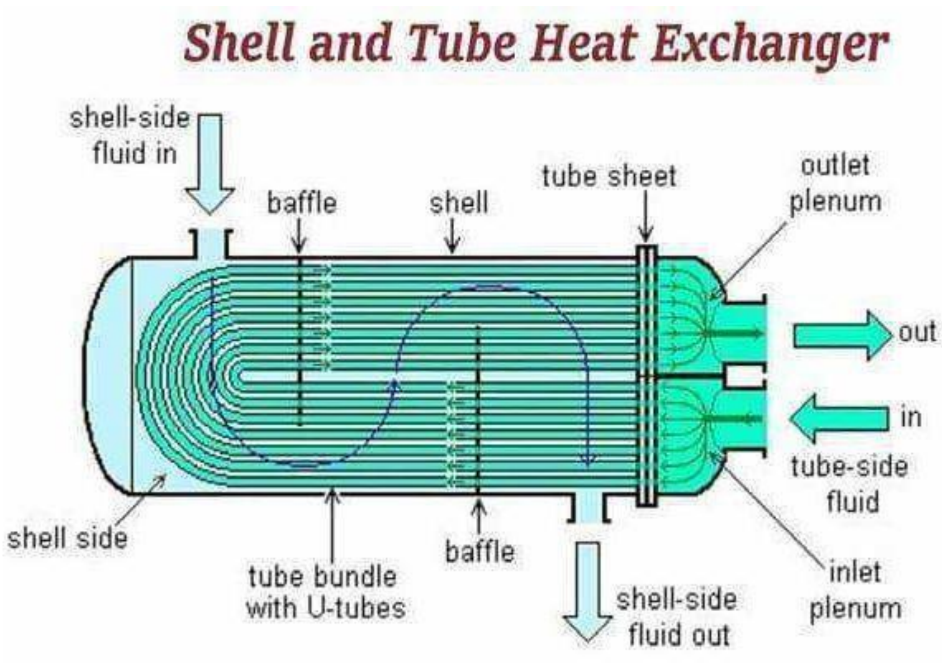
  Access points or inspection ports may be installed at strategic locations along the buried tubes to facilitate maintenance and inspection activities. These access points allow for visual inspection, cleaning, and repair of the buried tubes if needed. soil for sustainable heating, cooling, and ventilation of buildings. The design and configuration of these components can vary based on factors such as climate, soil conditions, building size, and energy requirements.

1.5 Types of Heat Exchangers

Various categories of heat exchangers are engineered to suit specific applications and operating conditions. Here are some common types of heat exchangers:

- **Shell and Tube Heat Exchangers:**

  The shell and tube heat exchanger is a prevalent type of heat exchanger found across many industries. Its design typically features a cylindrical shell containing a bundle of tubes. One fluid passes through these tubes, while another fluid circulates around the tubes within the shell. This configuration offers versatility and widespread applicability in diverse industrial settings..



. Fig. 2.0: Shell and tube heat exchanger

- **Plate Heat Exchangers:**

Plate heat exchangers are constructed using multiple thin plates arranged in a stacked configuration, featuring alternating channels for the flow of hot and cold fluids. Heat transfer occurs through the plates, allowing for efficient heat exchange in a compact design. Plate heat exchangers are often used in HVAC systems, refrigeration, and food processing.

. Fig. 2.1: Plate heat exchanger

- **Finned Tube Heat Exchangers:**

  Finned tube heat exchangers are comprised of tubes with extended fins affixed to the outer surface. These fins serve to enhance the available surface area for heat transfer, thereby boosting overall efficiency.Finned tube heat exchangers are commonly used in air conditioning, heating, and refrigeration systems

.

. Fig. 2.2: Finned Tube heat exchanger

- **Double-Pipe Heat Exchangers:**

  Double-pipe heat exchangers consist of two concentric pipes (inner and outer) through which the hot and cold fluids flow in opposite directions. Heat transfer occurs through the walls of the inner pipe. Double-pipe heat exchangers are simple in design and suitable for low-pressure and low-temperature applications

Fig. 2.3: Double-Pipe heat exchanger

- **Plate-Fin Heat Exchangers:**

  Plate-fin heat exchangers consist of stacked plates with fins welded between them to create alternating fluid passages. They are compact and lightweight, making them suitable for high-pressure and high-temperature applications in aerospace, automotive, and oil and gas industries.

Fig. 2.4: Plate-Fin heat exchanger

- **Air-to-Air Heat Exchangers (Heat Recovery Ventilators):**

  Air-to-air heat exchangers transfer heat between two airstreams without mixing them. They harvesting heat from exhaust air and transferring it to incoming fresh air enhances energy efficiency and indoor air quality within buildings.

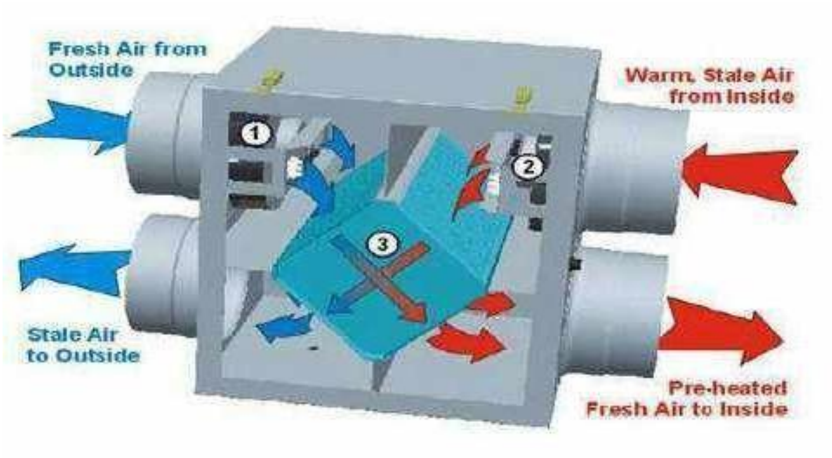


Fig. 2.5: Air-to-Air Heat Exchangers

- **Regenerative Heat Exchangers:**
  Regenerative heat exchangers use a rotating or oscillating matrix to alternately absorb heat from one fluid stream and transfer it to another. They are often used in applications where high temperatures and thermal efficiency are required, such as in industrial furnaces and gas turbines.

Fig. 2.6: Regenerative Heat Exchangers

- **Phase-Change Heat Exchangers:**

  Phase-change heat exchangers utilize the latent heat of a phase change (such as vaporization or condensation) to transfer heat between fluids. They are used in applications involving phase-change processes, such as refrigeration, air conditioning, and thermal energy storage systems.

Fig. 2.7 Phase-Change Heat Exchangers

These examples represent a subset of the various types of heat exchangers that are available. The choice of heat exchanger depends on factors such as the application, fluid properties, operating conditions, space constraints, and efficiency requirements.

1.6 Problems with Earth-Air Heat Exchanger :

While geothermal Earth-to-Air Heat Exchangers (EAHE) offer many advantages, there are also some potential challenges and problems associated with their implementation. Here are some common issues:

- **Inadequate Heat Transfer:**
  In some cases, the heat transfer between the soil and the air may not be sufficient to meet the heating or cooling needs of the building. This can occur if the soil has low thermal conductivity, is too dry, or if the EAHE system is undersized for the building's requirements.
- **Soil Contamination:**
  Contaminants in the soil, such as chemicals, pollutants, or organic matter, can affect the performance of the EAHE system and may even pose health risks if they are drawn into the building's ventilation system. Proper site assessment and

Fig. 2.8: Soil Contamination

- **Seasonal Variations:**

The effectiveness of EAHE systems can vary seasonally, depending on factors such as outdoor air temperature, humidity levels, and soil temperature. In colder climates, the soil may freeze during winter months, reducing heat transfer efficiency. In warmer climates, the soil may become too hot, limiting cooling capacity.

- **Clogging and Blockages:**

Over time, the buried tubes or pipes in the EAHE system may become clogged or blocked by soil infiltration, debris, or biological growth, such as roots or fungi. This can restrict airflow and reduce heat transfer efficiency, requiring maintenance or cleaning of the system.

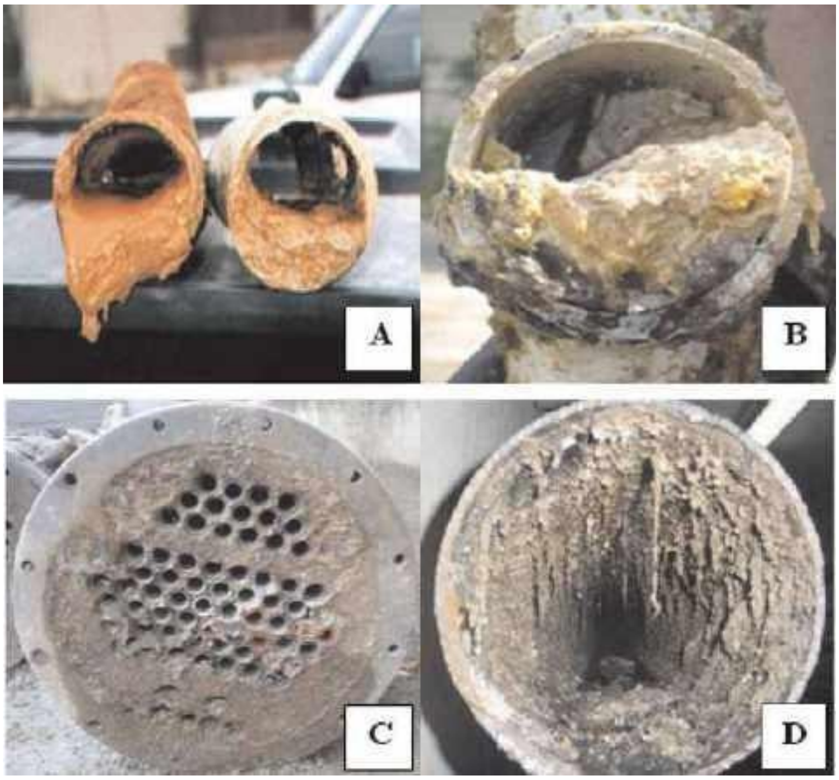


Fig. 2.9: Clogging and Blockages

- **Maintenance Requirements:**
  EAHE systems require regular maintenance to ensure optimal performance and longevity. This may include periodic inspection, cleaning of the buried tubes, replacement of filters, and monitoring of airflow rates and soil conditions. Neglecting maintenance can lead to decreased efficiency and increased operating costs.
- **Installation Challenges:**
  Installing a geothermal EAHE system requires careful planning and site preparation. Excavation for burying the tubes or pipes can be labor-intensive and may require specialized equipment. Proper backfilling and compaction of the soil are essential to ensure good thermal contact and prevent settling or shifting of the buried components.
- **Initial Cost:**
  While EAHE systems can provide long-term energy savings and environmental benefits, the initial cost of installation can be higher compared to conventional heating and cooling systems. Factors such as site accessibility, soil conditions, and system size can influence installation costs.

- **Regulatory and Permitting Issues:**
  Depending on local regulations and building codes, installing an EAHE system may require permits and approvals from regulatory authorities. Compliance with environmental regulations, such as groundwater protection measures, may also be necessary.

Despite these challenges, geothermal Earth-to-Air Heat Exchangers can still offer significant advantages in terms of energy efficiency, sustainability, and long-term cost savings when properly designed, installed, and maintained. Working with experienced professionals and conducting thorough site assessments are essential steps in mitigating potential problems and optimizing the performance of EAHE systems.

1.2 Advantages of Heat Exchangers :

- **Efficient Heat Transfer:**
  Heat exchangers efficiently transfer heat from one fluid to another, allowing for effective heating or cooling processes.
- **Energy Savings:**
  By transferring heat between fluids, heat exchangers help conserve energy, leading to reduced energy consumption and lower operating costs.
- **Temperature Control:**
  Heat exchangers enable precise temperature control, ensuring consistent temperatures for industrial processes or HVAC systems.
- **Compact Design:**
  Many heat exchangers are designed to be compact, making them suitable for installations where space is limited.
- **Versatility:**
  Heat exchangers come in various types and configurations, making them adaptable to a wide range of applications and operating conditions.
- **Environmental Benefits**:
  By optimizing energy use and reducing waste heat, heat exchangers contribute to environmental sustainability by lowering greenhouse gas emissions.
- **Cost Savings:**
  Heat exchangers can lead to significant cost savings over time by reducing energy consumption and minimizing downtime.

- **Process Optimization**:

  Heat exchangers are essential for optimizing industrial processes, resulting in higher productivity and improved product quality.

- **Safety:**

  Properly designed and maintained heat exchangers help maintain safe operating conditions, preventing overheating and equipment failures.

1.8 THERMAL BEHAVIOUR OF SOIL

Utilizing Underground Heat Exchangers (UHE) for buildings necessitates an understanding of the soil's temperature profile, which is influenced by various factors including climatic conditions and seasonal changes. Soil temperatures are impacted by solar radiation, rainfall, local vegetation cover, soil type, and depth within the ground. Within the first 3-5 meters of depth, ground temperatures exhibit significant variability due to solar exposure and precipitation. The nature of the soil plays a critical role in the performance of the heat exchanger, as it facilitates the transmission of heat to the exchanger. The depth at which the pipe is buried depends on the diffusivity of the ground, with different soil types affecting heat transfer rates. Surprisingly, the material of the pipe itself does not influence the heat exchanger's performance. Researchers have developed methodologies and instrumentation systems for indirectly measuring the thermal diffusivity of soils, particularly in very low enthalpy geothermal energy (VLEGE) systems. They have observed that the amplitude of ground temperature variation decreases exponentially with depth, ultimately tending to stabilize at the average temperature of the local area. This insight is crucial for optimizing the design and operation of UHE systems for efficient temperature regulation within buildings.

1.9 Objectives of the CFD Analysis for Heat Exchangers

- **Heat Transfer Optimization**:

  The primary objective of CFD analysis for heat exchangers is to optimize heat transfer efficiency. This involves studying fluid flow patterns, temperature distributions, and heat transfer rates within the exchanger to ensure effective thermal exchange between the fluid streams.

- **Pressure Drop Reduction:**

  Minimizing pressure drop across the heat exchanger is crucial for improving energy efficiency and reducing pumping costs. CFD analysis helps engineers optimize the design to minimize flow resistance while maintaining adequate heat transfer performance.

- **Flow Distribution Improvement:**
  Uniform flow distribution is essential for maximizing heat transfer effectiveness. CFD enables engineers to study flow patterns and velocities within the exchanger, identifying areas of flow maldistribution and optimizing the design to achieve uniform fluid distribution across the heat transfer surface.
- **Fouling Mitigation:**
  Fouling, the accumulation of deposits on heat transfer surfaces, can degrade heat exchanger performance over time. CFD analysis helps in predicting and mitigating fouling by simulating fluid-solid interactions, deposition rates, and flow velocities, allowing engineers to optimize the design and operating conditions to reduce fouling propensity.
- **Transient Performance Analysis:**
  Heat exchangers often operate under transient conditions due to fluctuations in flow rates, temperatures, and environmental factors. CFD enables engineers to simulate transient heat transfer phenomena, such as startup/shutdown processes and transient flow instabilities, to assess the dynamic performance of the exchanger and optimize its design for transient operation.

Chapter 2

LITERATURE REVIEW

Rohit Misra, [2020] Variations in pipe length, diameter, and burial depth exert significant influence on the performance of Earth-to-Air Heat Exchanger (EAHE) systems. Longer pipes lead to lower outlet air temperatures, particularly notable within the initial 10 meters; however, beyond 20 to 30 meters, further increases do not notably improve performance, suggesting an optimal design range for hot and dry climates like Bhopal. Furthermore, Misra observed that increasing pipe diameter results in higher outlet air temperatures, attributed to reduced convective heat transfer coefficients at the inner pipe surface and overall heat transfer coefficients at the earth-pipe interface with larger diameters. Similarly, deeper burial of pipes decreases outlet air temperature, although this enhances performance, it also escalates excavation costs. Hence, Misra recommends maintaining a burial depth of around 2 meters to balance performance and installation expenses. Moreover, the outlet air temperature of the EAHE system rises as air flow velocity increases, as higher velocity reduces the contact time between air and ground. However, merely decreasing air flow velocity is insufficient to improve performance, as cooling capacity depends on both velocity and temperature difference. Therefore, optimizing both parameters simultaneously is crucial for enhancing EAHE system efficiency.

Capozza (2019) conducted extensive theoretical and experimental investigations on Earth tube heat exchanger (EAHE) systems, providing valuable insights into their heat transfer processes. Previous research papers were comprehensively reviewed, illuminating the operational principles of these systems. A one-dimensional numerical model was developed to assess EAHE system performance at different depths. The study concluded that while EAHE systems alone may not be sufficient to establish thermal comfort, they can effectively reduce energy demand in buildings, especially in regions like South Algeria, when integrated with conventional air conditioning systems. Furthermore, Capozza conducted a simplified analytical model to evaluate the year-round effectiveness of an EAHE-integrated greenhouse in New Delhi, India. Their findings indicated that the greenhouse's air temperature was typically 6-7 °C higher during winter and 3-4 °C lower during summer compared to the same greenhouse operating without EAHE. Additionally, Capozza developed a thermal model to investigate greenhouse heating using different combinations of an inner thermal curtain, an earth-air heat exchanger, and geothermal heating. Moreover, Capozza analyzed the performance of EAHE for summer cooling in Jaipur, India, focusing on a 23.42-meter-long EAHE operating in cooling mode with air temperatures ranging from 8.0 to 12.7 °C and flow rates between 2 to 5 m/s for steel and PVC pipes. Their study revealed that the system's performance was significantly influenced by air fluid velocity rather than the material of the buried pipe, with the coefficient of performance (COP) varying between 1.9 to 2.9 with increasing velocities from 2 to 5 m/s.

N.K. Bansal, [2021] Earth-to-Air Heat Exchangers (EATHE) offer a promising alternative to traditional air conditioning systems, with the potential for even greater efficiency when combined with evaporative cooling during warmer seasons. Bansal emphasizes the crucial role of soil thermal conductivity in determining the performance of EAHE systems, where higher conductivity leads to better outcomes. Additionally, Bansal identifies various factors that can enhance the performance of EAHE systems, such as increasing pipe length, reducing pipe diameter, lowering the mass flow rate of air within the buried pipes, and maximizing burial depth, up to 4 meters. These adjustments collectively contribute to improving the overall efficiency and effectiveness of EAHE systems..

According to Kim S K, [2018] In an Earth-to-Air Heat Exchanger (EAHE) system, its effectiveness may be compromised if the length of the pipes is inadequate and the blower operates at high voltage. This occurs because of the minimal temperature difference between the incoming and outgoing air streams, which diminishes the system's efficiency. Interestingly, Kim also observed that the material chosen for the pipes does not significantly affect the system's output. To enhance cooling or heating rates, Kim recommends maintaining a minimum pipe length of 100 meters and utilizing a blower with a power rating of approximately 400 watts. These adjustments are essential for optimizing the performance of the EAHE system.

In Bisoniya's research (2016), Earth–air heat exchangers (EAHE) have demonstrated significant potential for efficiently preheating air in winter and cooling it in summer. Various researchers have made substantial contributions to advancing EAHE design equations and methodologies. Bisoniya proposes the use of fundamental heat transfer equations for initial EAHE system design. They developed a one-dimensional model incorporating methods to compute the Effective Utilization Temperature (EUT) and integrating recent correlations for friction factor and Nusselt number to enhance heat transfer accuracy. In their study focusing on Bhopal (Central India), they determined the EUT to be 25.2 °C and observed a direct relationship between Nusselt number and Reynolds number. The design process of an earth–air heat exchanger is primarily guided by the heating/cooling load requirements of the target building. Once the load is determined, design considerations revolve around geometrical constraints and cost analysis. Key parameters include the diameter and length of the pipe, as well as the number of pipes. Bisoniya emphasizes that increasing the length of the pipe enhances both pressure drop and thermal performance. They specifically highlight that a longer pipe with a smaller diameter, buried at greater depth, and with lower air flow velocity contributes to improved EAHE system performance.

Thankur (2015) conducted a study on an Earth-to-Air Heat Exchanger (EAHE) utilizing a finned mild steel pipe, measuring 1.2 meters in length and 0.0889 meters in diameter, buried within the soil. They observed that this configuration yielded a temperature reduction of up to 3°C across various daily temperatures. In instances of higher inlet temperatures, the outlet temperature differential typically fell within the range of 2-3°C. The Coefficient of Performance (COP) of the heat exchanger fluctuated between 0.928 and 2.785 for temperature differences spanning from 1°C to 3°C, respectively. Thankur pointed out that achieving a higher COP is feasible when the temperature difference is widened. This can be achieved by employing longer pipes to enhance heat transfer. With a pipe length of 1.2 meters, the temperature decrease predominantly ranged from 1-3°C. However, employing longer pipes at the same depth of 5 feet would yield a more pronounced temperature reduction. This is attributable to the prolonged duration of air flow through the pipe, allowing for extended convective heat transfer, ultimately resulting in a greater temperature difference and an elevated COP.

Hollmuller proposed an analytical approach for modeling heat diffusion in Earth-to-Air Heat Exchanger (EAHE) systems, accounting for variables like fluctuating inlet air temperature, cylindrical pipe configuration, and boundary conditions of either adiabatic or isothermal nature. Li et al. delved into the effects of soil moisture content, composition, and thermal characteristics on the heat transfer dynamics of vertically buried pipes, elucidating their impact on EAHE system efficiency. Sehli et al., Misra et al., and Bansal et al. conducted separate investigations into diverse factors influencing the outlet air temperature of EAHE systems, encompassing analyses of parameters such as Reynolds number, form factor, pipe depth, soil thermal conductivity, and operational duration. Each study contributed unique insights toward enhancing the operational effectiveness and energy efficiency of EAHE systems across varying environmental and operational contexts.

Amanowicz investigation was conducted into the flow dynamics of multi-pipe Earth-to-Air Heat Exchangers (EAHE), aimed at analyzing thermal performance under varying airflow conditions. Results revealed that the actual heat and cooling gains over a year were approximately 20% lower compared to the theoretically maximum gains assuming uniform airflow distribution among parallel branch-pipes. Separately, Misra et al. examined the thermal characteristics and performance of four distinct hybrid Earth Air Tunnel Heat Exchangers (EATHE). Their findings demonstrated a significant reduction in power consumption for a conventional 1.5-ton window-type air conditioner. Specifically, when the EATHE system's cold air was fully utilized for condenser cooling, the air conditioner's power consumption decreased by 18.1%. These findings underscore the potential of hybrid EATHE systems to enhance energy efficiency and decrease power consumption in air conditioning applications.

Tiantian Zhao and co-researchers undertook a study concentrating on determining the distribution of ground temperature and borehole wall temperature, while also assessing changes in ground enthalpy over a 20-year operational period. Their analysis encompassed the effectiveness of different configurations of Ground Heat Exchangers (GHEs) under varying loading conditions. This extensive examination contributes valuable insights into the thermal efficacy and enduring performance of GHE systems, offering significant implications for sustainable energy utilization and geothermal utilization.

Ravindra Singh Jhala conducted an analysis of Earth Air Tunnel Heat Exchangers (EATHE), investigating their potential as alternatives to traditional air conditioning systems, particularly for improved summer cooling. Their study emphasized that the design of EATHE systems is chiefly influenced by the heating or cooling load requirements of the target building. Moreover, Jhala observed that the Coefficient of Performance (COP) of EATHE systems exceeds that of conventional air conditioners. These findings underscore the practicality and efficiency of EATHE systems as sustainable solutions for building climate control, especially during warmer seasons. In a comprehensive review led by Suresh Kumar Soni and colleagues, the effectiveness of

Hybrid Ground Coupled Heat Exchanger (GCHE) systems was assessed. Their findings showcased the significant advantages of hybrid systems integrating evaporative coolers, resulting in a notable increase in cooling efficiency by up to 69%. Furthermore, these hybrid configurations enabled a considerable reduction in the length of buried pipes, potentially decreasing them by up to 93.5%. The study also highlighted the effectiveness of coupling Ground Source Heat Pumps (GSHP) with traditional air conditioning systems, leading to a significant reduction in power consumption by 15.5%. Earth Tunnel Heat Exchangers (ETHE) were identified as pivotal elements in optimizing the utilization of soil heat capacity, thereby enhancing system efficiency when paired with heat pumps. To aid in the design and performance prediction of ETHE systems, the researchers developed simulation tools and mathematical models. These tools assist in accurately sizing the system components and predicting their operational performance, thereby facilitating the effective implementation of ETHE systems in various climate control applications.

Trilok S. Bisonia and colleagues conducted a study on Earth-to-Air Heat Exchanger (EAHE) systems, highlighting their efficacy in reducing building cooling loads during hot and dry summer conditions. They found that the choice of pipe materials had minimal impact on system performance, which mainly relied on factors such as air flow rate and ambient air temperature. Their research introduced a metallic earth-air tunnel system aimed at managing cooling and heating loads, regulating underground temperatures, and considering soil weight on underground ducts. Results demonstrated a significant temperature reduction of 13°C, with optimal performance observed during peak summer periods. Additionally, the study explored an Air Conditioner System with Ground Source Heat Exchanger (ACSWGSHE), initially tested with air and later with water, which substantially improved the system's Coefficient of Performance (COP) from 2.11 to 3.72. Replacing conventional air conditioning systems' air-cooled condenser with ACSWGSHE resulted in a notable 29% decrease in power consumption. However, the study acknowledged that while ACSWGSHE offers energy-saving advantages, its initial implementation cost is higher. Earth Air Heat Exchangers (EAHE) are custom-designed for specific room dimensions, optimizing parameters such as air changes, pipe length, and burial depth. Wenke Zhang and colleagues analyzed heat transfer in borehole and ground heat exchangers (GHEs) for ground-coupled heat pump systems, emphasizing the reduction of building heating and cooling loads, power consumption, and emissions of harmful gases. Thermal performance was found to improve with longer and deeper buried pipes but decrease with larger pipe diameters and higher air velocities. Silvia Cocchi simulated an air conditioning system with a geothermal heat pump using TRNSYS 17 software, observing a 5-6°C decrease in outlet air temperature. Gaffar G. Momin investigated closed-loop geothermal cooling systems, conducting experimental analyses and heat transfer calculations. V. Bansal and team developed a transient mathematical model using FLUENT simulation to estimate the cooling capacity and thermal performance of EPAHE systems. These studies collectively contribute to understanding and optimizing the performance of various geothermal cooling technologies.

Freire and colleagues, an investigation was conducted on a horizontal multi-pipe and multi-layered Earth Air Heat Exchanger (EAHE). Their research unveiled that while this configuration exhibited lower performance compared to a single-layer EAHE, it occupied notably less space. Additionally, the multi-pipes could be organized in either series or parallel configurations depending on airflow demands. Furthermore, diverse pipe shapes including U-shape, ring-shape, helix, and spiral were examined to potentially enhance the system's efficiency for individual pipes. For clusters of pipes, arrangements such as lateral, parallel, or radial configurations were explored. These variations present avenues for optimizing EAHE system performance tailored to specific design considerations and operational needs.

Hsu and colleagues introduced an integrated system wherein air pipes were embedded within the water-filled raft foundation of a high-density residential building. Their findings revealed that the cooling capacity of this integrated system closely approached that of soil-based Earth Air Heat Exchangers (EAHE) installed at depths of 2 meters or deeper. This innovative approach demonstrates the feasibility of integrating EAHE systems directly into building foundations, thereby eliminating the need for additional land area and construction costs.In a separate study, Zukowski and Topolanska compared the performance of an innovative plate exchanger, which facilitates direct contact between the air and the ground, to that of a standard EAHE with pipes. Their results indicated that the thermal efficiency of the plate exchanger surpassed that of the pipe exchanger, showcasing the potential for improved performance and energy savings with innovative heat exchange designs. Hsu et al. introduced an innovative system where air pipes were incorporated within the water-filled raft foundation of a high-density residential building. Their research findings demonstrated that this integrated system's cooling capacity closely rivaled that of soil-based Earth Air Heat Exchangers (EAHE) installed at depths of 2 meters or deeper. This approach showcases the viability of integrating EAHE systems directly into building foundations, thereby eliminating the necessity for additional land area and construction expenses. In a distinct study, Zukowski and Topolanska conducted a comparison of the performance between an inventive plate exchanger, enabling direct contact between air and ground, and a conventional EAHE equipped with pipes. Their results indicated that the plate exchanger exhibited superior thermal efficiency compared to the pipe exchanger, highlighting the potential for enhanced performance and energy conservation through innovative heat exchange designs.

Hamada et al. introduced an enhanced subterranean heat exchange method without excavation, leading to a notable 78% decrease in primary energy usage during system installation in contrast to vertical underground heat exchange systems. Recep Yumrutas and collaborators presented a theoretical and computational framework for a cooling system integrating an underground water storage tank, promising energy efficiency and effective cooling solutions across various contexts. Open-loop and closed-loop air tunnel setups were observed to achieve a Coefficient of Performance (COP) almost three times higher than traditional air conditioning systems, making them particularly advantageous for agricultural structures requiring substantial air temperature reductions ranging from 70°F to 100°F. Furthermore, Ochifuji et al. conducted a study investigating the heat transfer dynamics crucial for developing sustainable long-term thermal energy storage methods, offering valuable insights into sustainable energy management and storage technologies.

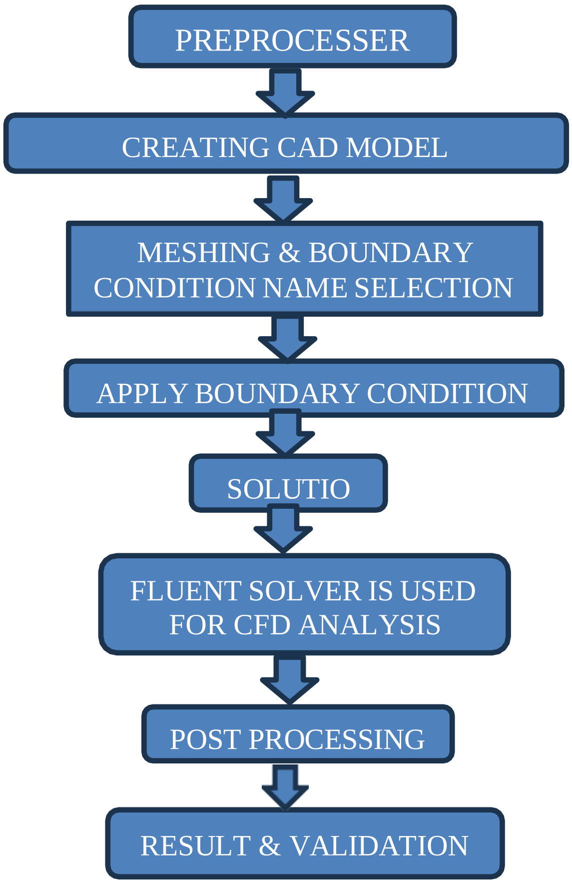
Fazlikhani et al. and Belatrache et al. devised methodologies with the aim of forecasting the thermal efficiency and performance of Earth Air Heat Exchanger (EAHE) systems across different climate settings. Fazlikhani's method concentrated on cold and hot arid climates prevalent in Iran, while Belatrache's approach was tailored for arid climates in Algeria. These methodologies integrated both conductive heat transfer in soil and convective heat transfer for air flow within the tube. They formulated models to predict soil temperature distribution at various depths, as well as calculate air temperature inside the pipe. By applying principles of heat transfer theory, both models numerically solved differential equations, demonstrating successful validation against experimental data. These studies offer significant insights for enhancing the design and functionality of EAHE systems across diverse climatic conditions.

Rodrigues and his team developed a dynamic numerical framework to replicate the thermal dynamics of an Earth Air Heat Exchanger (EAHE) system across a range of soil compositions and geographical settings within Brazil's coastal areas. Their methodology integrated heat conduction principles to model the thermal profile of the soil, while employing a series of differential equations to simulate airflow within the tube and predict air temperature variations. This holistic approach facilitated a comprehensive examination of the EAHE system's efficacy under varying environmental circumstances, offering significant guidance for enhancing system efficiency and performance through optimal design and operational strategies.

Chapter 3

METHODOLOGY

3.1 CFD Analysis Methodology for Heat Exchangers



Algorithm used for Computational fluid dynamics analysis

An experimental setup comprising an open-loop flow system has been meticulously designed and constructed to investigate various parameters related to an Earth Air Heat Exchanger (EAHE). The primary objectives include analyzing temperature differences between the inlet and outlet sections, assessing heat transfer rates, determining the coefficient of performance, and examining fluid flow characteristics of parallel-connected pipes. The setup, illustrated in Figure 3.1, features a horizontal pipe with an inner diameter of 100 mm and a total length of 10 m. Three pipes, one measuring 5 m in length and the other two measuring 2 m each, are connected in parallel. These pipes, constructed from PVC material, are buried at a depth of 2 m in a flat land with dry conditions.To facilitate air circulation, ambient air is drawn through the pipes using a centrifugal blower powered by a 2-phase, 0.25 HP, 230 V, and 2800 rpm motor. During summer conditions, the blower extracts hot ambient air through the pipelines, delivering cooled air to the desired location. Conversely, in winter, the blower facilitates the circulation of hot air to provide warmth as required. This experimental setup aims to generate valuable data for assessing the efficacy of EAHE systems in both cooling and heating applications under varying climatic conditions.

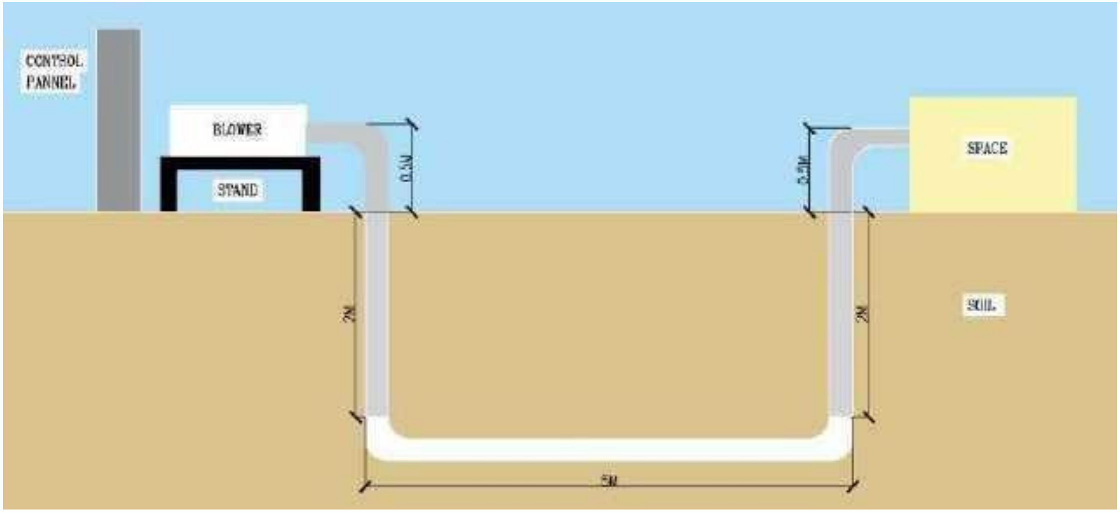


Fig. 3.1: Setup Diagram of EAHE

Software and Tools Selection:

Selecting the appropriate software and tools for a Computational Fluid Dynamics (CFD) analysis is a critical step that significantly influences the accuracy and efficiency of the simulation.

Solver Capabilities:

Choose CFD software with solver capabilities suitable for simulating fluid flow and heat transfer in porous media. Look for solvers that can accurately model airflow through soil, heat exchange between soil and air, and thermal gradients within the system.

- **Porous Media Modeling:**
  Ensure that the software has capabilities for modeling porous media, including defining soil properties such as porosity, permeability, thermal conductivity, and moisture content. Look for options to incorporate empirical correlations or user-defined models for soil properties.

- **Multiphase Flow Modeling**:
  Consider software that supports multiphase flow modeling, as EAHE systems involve airflow through both soil and air domains. Look for options to model airflow as a multiphase system, accounting for interactions between soil and air phases.
- **Meshing Tools:**

  Evaluate the meshing capabilities of the software for generating meshes suitable for porous media simulations. Look for options to generate structured or unstructured meshes with appropriate refinement near the soil-air interface and airflow boundaries.

- **Post-Processing Features:**

  Assess the post-processing capabilities of the software for visualizing and analyzing simulation results. Look for tools to visualize temperature distributions, airflow patterns, and heat transfer rates within the EAHE system. Consider options for generating plots, animations, and quantitative data analysis.

- **User Interface and Workflow:**

  Choose software with an intuitive user interface and workflow that facilitates setting up, running, and analyzing simulations of EAHE systems. Look for features that streamline model setup, boundary condition definition, and result interpretation.

- **Solver Performance:**

  Consider the computational performance of the software's solver for efficiently simulating EAHE systems. Look for solvers that are robust, scalable, and capable of handling the computational demands of porous media simulations with large and complex geometries

- **Compatibility and Integration:**

  Ensure that the software is compatible with other engineering software packages and data formats commonly used in EAHE analysis. Look for options to import CAD geometries, export simulation results, and integrate with pre-processing and post- processing tools.

- **Cost and Licensing:**

  Evaluate the cost of the software license, including upfront fees, annual maintenance, and additional modules or features. Consider options for academic licenses, trial versions, or open-source alternatives to manage costs effectively.

Based on these considerations, some software options suitable for CFD analysis of EAHE systems may include:

- ANSYS Fluent
- COMSOL Multiphysics
- Open FOAM
- Autodesk CFD
- STAR-CCM+ by Siemens

3.2 Performing analysis of a heat exchanger in CFD

- **Problem Definition**:

a) Clearly define the objectives of the analysis, such as predicting temperature distribution, heat transfer rates, pressure drop, or optimizing the design of the heat exchanger.

b) Specify the type of heat exchanger (e.g., shell and tube, plate, finned tube) and its operating conditions (fluid properties, flow rates, temperatures).

- **Geometry and Mesh Generation:**

a) Create a detailed 3D model of the heat exchanger geometry using CAD software or import existing geometries.

b) Define the internal components, such as tubes, baffles, headers, and any additional features relevant to the analysis.

c) Generate a computational mesh around the geometry, ensuring that it resolves the boundary layers and captures flow features accurately. Use appropriate mesh refinement near critical regions like the tube walls and flow inlets/outlets.

- **Boundary Conditions:**
  a) Specify boundary conditions for the fluid flow and heat transfer, including inlet velocities, temperatures, pressures, and thermal boundary conditions.
  b) Define the properties of the heat transfer fluids (density, viscosity, thermal conductivity, specific heat) based on the operating conditions and fluid properties.
- **Solver Settings:**
  a) Select appropriate numerical methods and solver settings for solving the governing equations of fluid flow and heat transfer (e.g., Navier-Stokes equations, energy equation).
  b) Choose turbulence models based on the flow regime and complexity (e.g., k-ε, k-ω, SST).
  c) Set convergence criteria and time-stepping parameters to ensure accurate and stable solutions.
- **Simulation Run:**
  a) Run the CFD simulation using the defined geometry, mesh, boundary conditions, and solver settings.
  b) Monitor the convergence of the solution during the simulation and adjust solver settings if necessary to ensure convergence.
- **Post-Processing and Analysis:**
  a) Post-process the simulation results to extract relevant data, such as temperature profiles, velocity contours, pressure distribution, and heat transfer rates.
  b) Analyze the flow patterns, temperature gradients, and pressure drops within the heat exchanger.
  c) Evaluate the performance metrics of the heat exchanger, such as effectiveness, thermal efficiency, and pressure drop.
- **Validation and Verification:**
  a) Validate the CFD results by comparing them with experimental data or analytical solutions if available.
  b) Verify the accuracy and reliability of the simulation results by assessing grid convergence, sensitivity analysis, and uncertainty quantification.

- **Optimization and Design Improvement:**
  a) Utilize the CFD results to optimize the design of the heat exchanger, such as improving heat transfer efficiency, reducing pressure drop, or enhancing thermal performance.
  b) Explore different design configurations, geometry modifications, or operating conditions to achieve the desired objectives.
- **Documentation and Reporting:**
  a) Document the methodology, assumptions, and results of the CFD analysis in a comprehensive report.
  b) Present key findings, insights, and recommendations for design improvements or further analysis..

Boundary Conditions and Simulation Setup:

Establishing accurate boundary conditions and configuring the simulation setup are critical aspects of preparing a Computational Fluid Dynamics (CFD) analysis for a muffler. Properly defining boundary conditions ensures that the simulation reflects real-world conditions, and configuring the setup is essential for obtaining meaningful results.

The following boundary conditions were used in the one-dimensional model of the EAHE system.

- **Inlet boundary conditions**:
  For the EAHE pipe's inlet, it was necessary to specify the values ofair flow velocity, denoted as va (m/s), and the static temperature of the air, represented by Tin (°C). Furthermore, the thermodynamic properties such as density and specific heat capacity of the air, as well as transport properties including dynamic viscosity and thermal conductivity, were to be determined based on the static temperature of the air at the inlet. These parameters are essential for accurately characterizing the airflow and heat transfer processes within the EAHE system, providing crucial inputs for experimental analysis and computational modeling studies.

- **Outlet boundary conditions:**
  In the subsonic flow regime, the relative pressure at the outlet of the EAHE pipe was set to zero atmospheric pressure**.**

- **Wall :**

  The temperature across the surface of the pipe (referred to as the wall) was assumed to be uniformly distributed in the axial direction, matching the undisturbed temperature of the surrounding earth. Additionally, it was assumed that there was no slip condition at the inner surface of the pipe, which was considered to be smooth. These assumptions regarding temperature uniformity and wall surface characteristics were crucial for accurately modeling the heat transfer processes occurring within the Earth Air Heat Exchanger (EAHE) system, providing a foundation for further analysis and prediction of thermal performance**.**

3.3 Design Stage Of Open System Single Pipe Heat Exchanger

Assumptions:

- The ground surface temperature is considered to be equivalent to the ambient air temperature, which aligns with the inlet air temperature.
- The Effective Underground Temperature (EUT) can be estimated to be approximately equal to the annual average temperature of the particular location.
- The PVC pipe used in the Earth Air Heat Exchanger (EAHE) maintains a consistent cross-sectional area along its entire length.
- Due to its small thickness, the thermal resistance of the pipe material is considered negligible.
- Across the surface of the pipe, the temperature remains uniform in the axial direction.

- **Geometry and Mesh:**

  a. Mesh Quality:

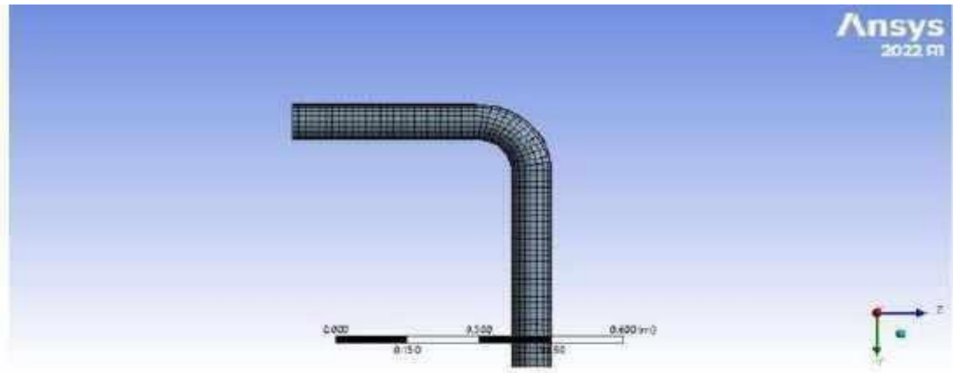
NAME	TYPE	Min Orthogonal Quality	Max Aspect Ratio
Air-domain	Hex Cell	0.89073329	3.1688036
Pipe_wall	Mixed Cell	0.19519938	17.469216
soil	Tet Cell	0.0067689102	39.815162

Table 3.1: Mesh Quality

b. Mesh Size:

Cells	Faces	Nodes
140005	449827	172514

Table 3.2: Mesh Size



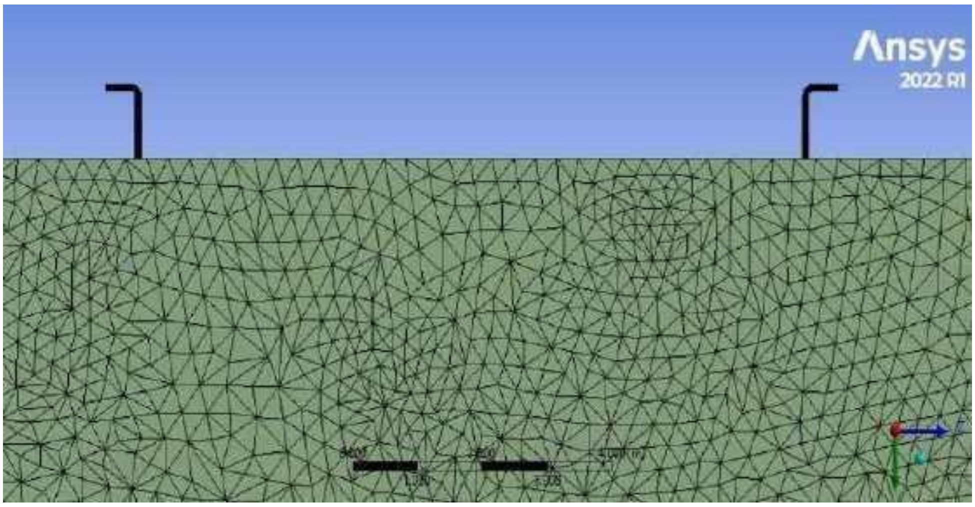


Fig. 3.2: Mesh

- **Simulation Setup**

  a. Models:

Model	Settings
Space	3D
Time	Steady

Viscous	Realizable k-epsilon turbulence model
Wall Treatment	Scalable Wall Function
Heat Transfer	Enabled

Table 3.3: model

- Material Properties :

− Fluid	
− air	
Density	1.225 kg/m^3
Cp (Specific Heat)	1006.43 J/(kg K)
Thermal Conductivity	0.0242 W/(m K)
Viscosity	1.7894e-05 kg/(m s)
Molecular Weight	28.966 kg/kmol
Thermal Expansion Coefficient	0
Speed of Sound	none
− Solid	
− pvc-pipe	
Density	1350 kg/m^3
Cp (Specific Heat)	900 J/(kg K)
Thermal Conductivity	0.16 W/(m K)
− soil	
Density	1500 kg/m^3
Cp (Specific Heat)	1000 J/(kg K)
Thermal Conductivity	0.56 W/(m K)
− aluminum	
Density	2719 kg/m^3
Cp (Specific Heat)	871 J/(kg K)
Thermal Conductivity	202.4 W/(m K)

Table 3.4: Material properties

- **Boundary Conditions**:

− Inlet	
− pipe_inlet	

Velocity Specification Method	Magnitude, Normal to Boundary
Reference Frame	Absolute
Velocity Magnitude [m/s]	5
Supersonic/Initial Gauge Pressure [Pa]	0
Temperature [K]	325
Turbulent Specification Method	Intensity and Viscosity Ratio
Turbulent Intensity [%]	5
Turbulent Viscosity Ratio	10
− Outlet	
− pipe_outlet	
Backflow Reference Frame	Relative to Adjacent Cell Zone
Gauge Pressure [Pa]	0
Pressure Profile Multiplier	1
Backflow Total Temperature [K]	300
Backflow Direction Specification Method	Normal to Boundary
Turbulent Specification Method	Intensity and Viscosity Ratio
Backflow Turbulent Intensity [%]	5
Backflow Turbulent Viscosity Ratio	10
Backflow Pressure Specification	Total Pressure
Build artificial walls to prevent reverse flow?	no
Radial Equilibrium Pressure Distribution	no
Average Pressure Specification?	no

Specify targeted mass flow rate	no
— Wall	
— wall-part-air_domain-pipe_wall	
Wall Thickness [m]	0
Heat Generation Rate [W/m^3]	0

Material Name	pvc pipe
Thermal BC Type	Coupled
Enable shell conduction?	no
Wall Motion	Stationary Wall
Shear Boundary Condition	No Slip
Wall Roughness Height [m]	0
Wall Roughness Constant	0.5
Convective Augmentation Factor	1
— pipe-wall	
Wall Thickness [m]	0.005
Heat Generation Rate [W/m^3]	0
Material Name	pvc pipe
Thermal BC Type	Temperature
Temperature [K]	300
Enable shell conduction?	no
Convective Augmentation Factor	1
— wall-soil	
Wall Thickness [m]	0
Heat Generation Rate [W/m^3]	0

Table 3.5: Boundary Conditions

- **Contours**

a. Flow-velocity:

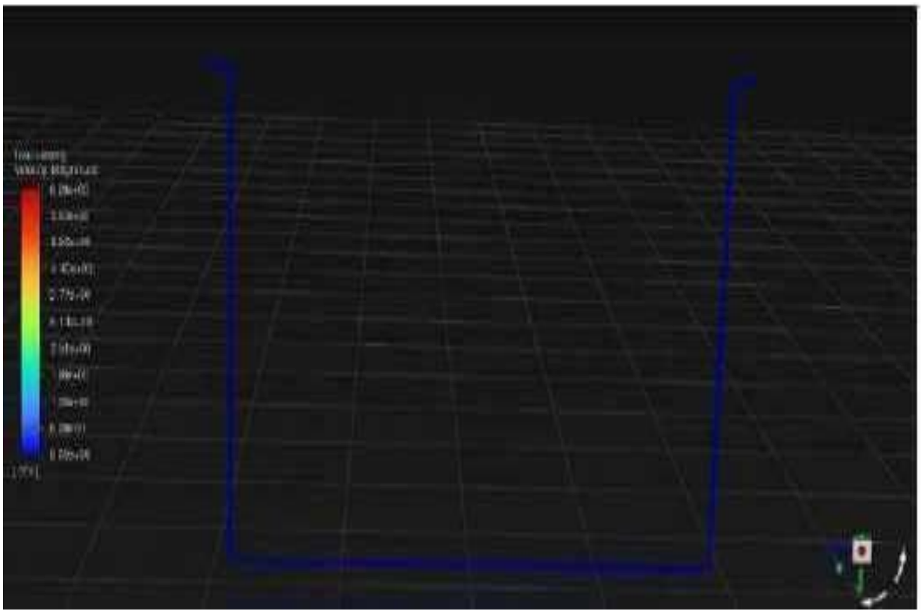


Fig. 3.3: Flow-velocity

b. Heat-flux:

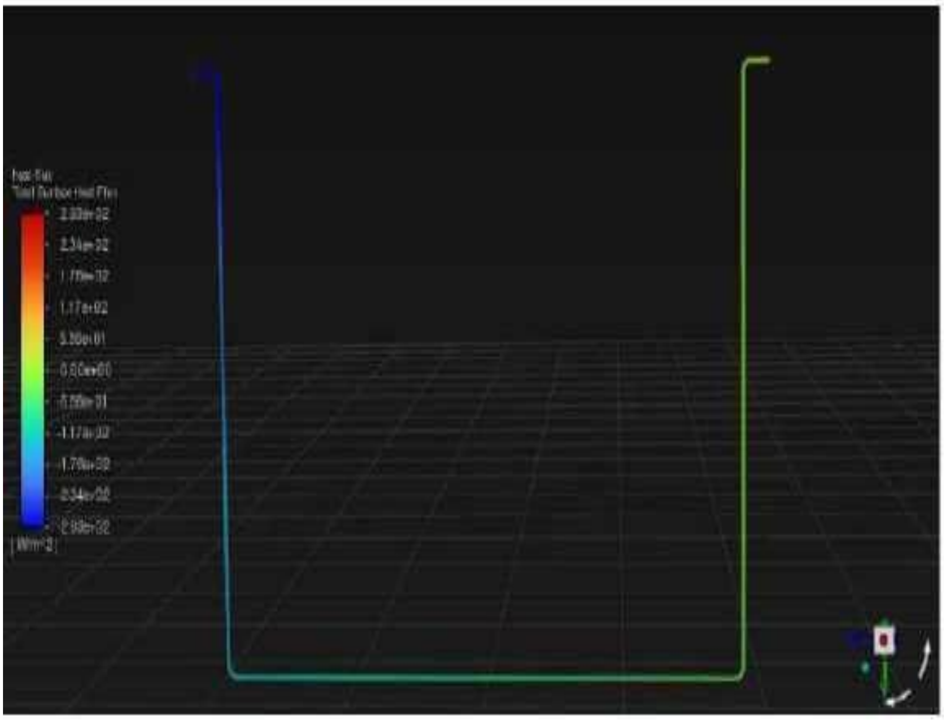


Fig. 3.4: Heat-Flux

- **Temperature Variation:**

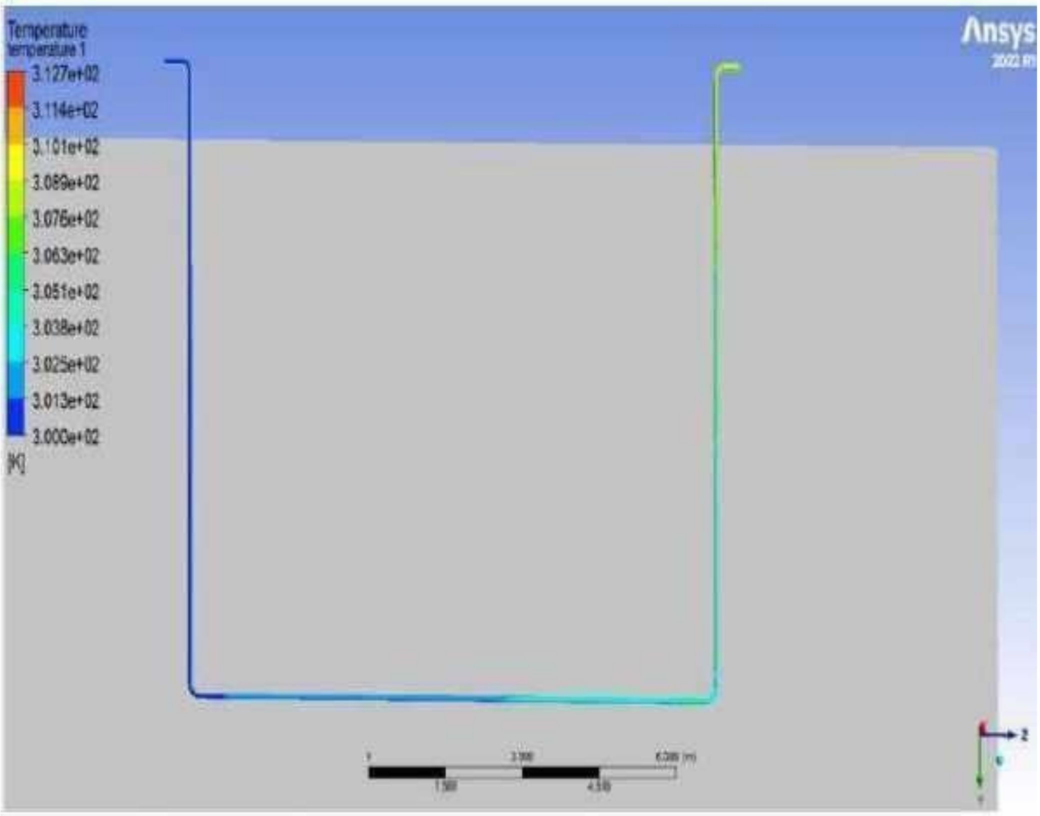


Fig. 3.5: Temperature Variation

3.4 Performance Analysis Of Open System Double Pipe Heat Exchanger

- **Geometry and Mesh**

a. Mesh Size

Cells	**Faces**	**Nodes**
102090	508271	150780

Table 3.6: Mesh Size

b.Mesh Quality:

Name	Type	Min Orthogonal Quality	Max Aspect Ratio
Pipe_air_domain	Hex Cell	0.75634142	3.634461
Pipe_wall_pvc	Mixed Cell	0.12240205	16.08209

a. Table 3.7: Mesh Quality

- Cad Model:

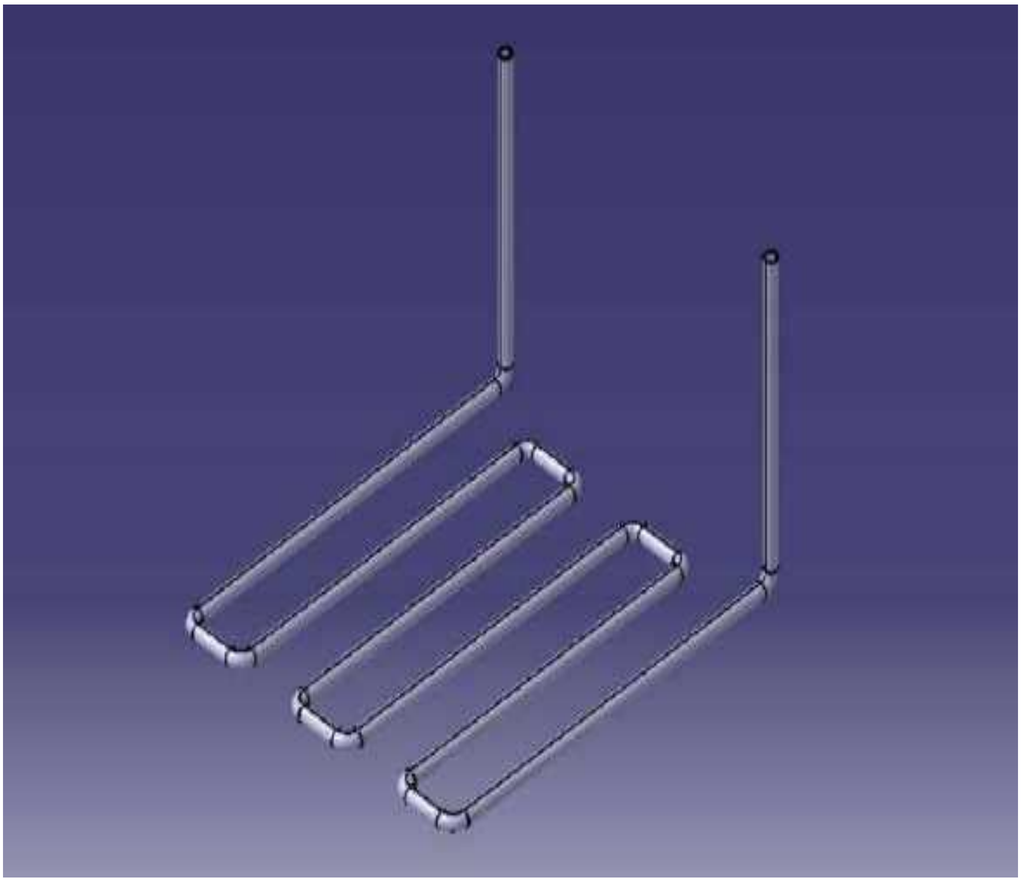


Fig. 3.6: Design of Double pipe

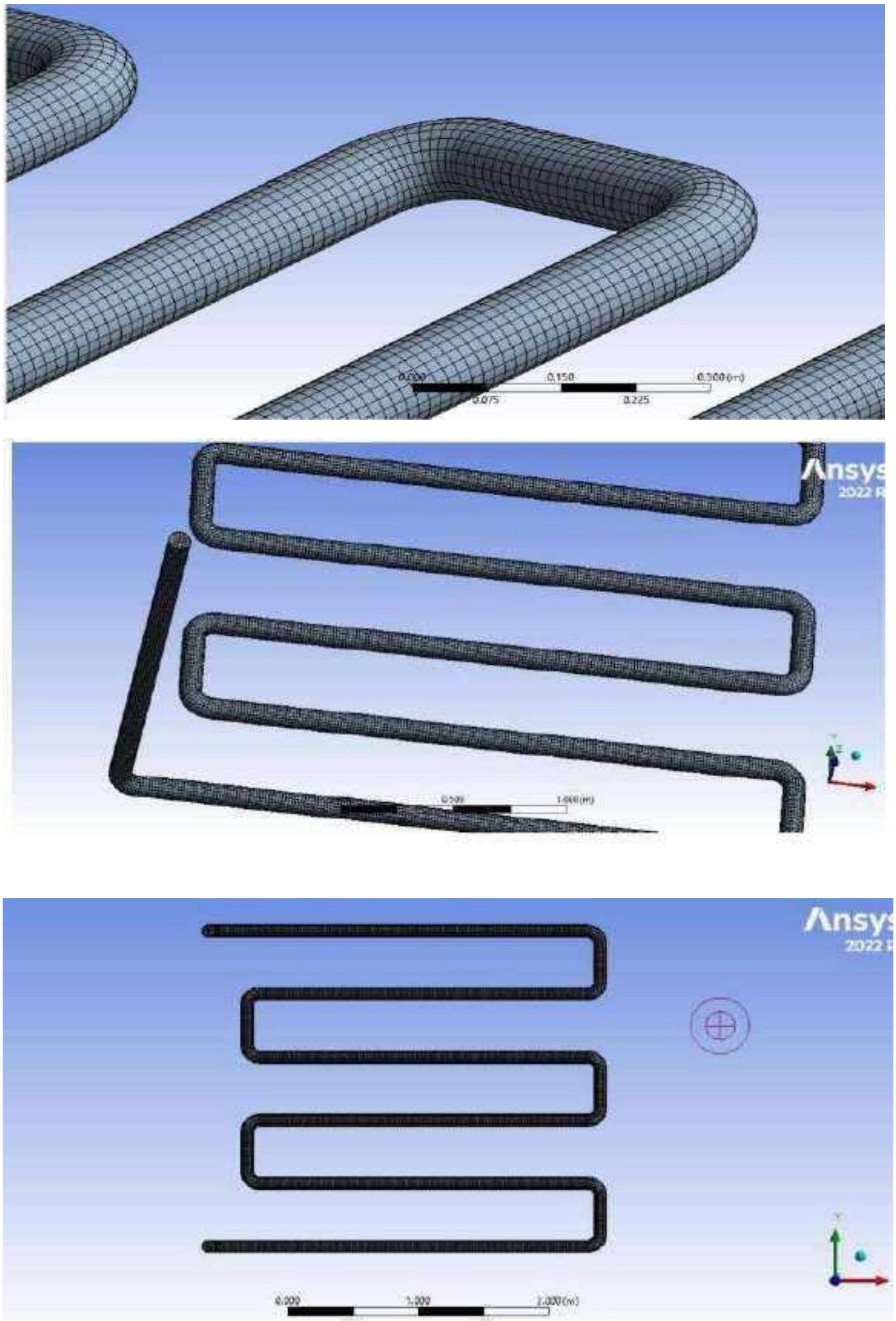


Fig. 3.7: Meshing

- . Material Properties:

− Fluid	
− air	
Density	1.225 kg/m^3
Cp (Specific Heat)	1006.43 J/(kg K)
Thermal Conductivity	0.0242 W/(m K)
Viscosity	1.7894e-05 kg/(m s)
Molecular Weight	28.966 kg/kmol
Thermal Expansion Coefficient	0
Speed of Sound	none
− Solid	
− plastic-pvc-rigid-high-impact	
Density	1373 kg/m^3
Cp (Specific Heat)	1048.8 J/(kg K)
Thermal Conductivity	0.18 W/(m K)
− soil-pvc-combination	
Density	1450 kg/m^3
Cp (Specific Heat)	1100 J/(kg K)
Thermal Conductivity	0.35 W/(m K)

Table 3.7: Material Properties

- Temperature Variation:

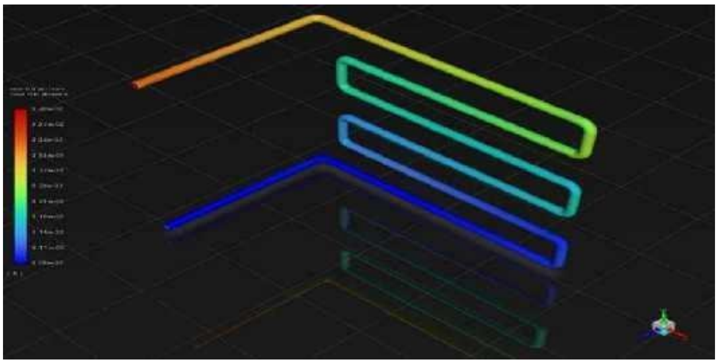


Fig. 3.8: Temperature Variatiation

CHAPTER 4

RESULTS AND DISCUSSIONS

- The optimized depth for the monthly average ground temperature is determined to be 8 meters, where the ground temperature remains constant at 32°C, aligning with the annual average temperature of the location.
- It is evident that with increasing depth, the fluctuations in temperature diminish, eventually approaching a consistent value.
- the variation of outlet air temperature of the Underground Heat Exchanger (UHE) is illustrated along its length for four different numbers of air changes: N=5, N=6, N=7, and N=8, with a pipe diameter of 0.08 meters.
- From the figure, it can be inferred that when using larger pipes, the outlet air temperature tends to stabilize and gradually approach the constant ground temperature.
- With a summer average ambient temperature of 35°C, the outlet temperatures of the Underground Heat Exchanger (UHE) are measured as 35°C and 32°C for different lengths of 5 meters and 10 meters, respectively, with 5 air changes per hour.

4.1. COST ANALYSIS

A comparative cost analysis was conducted, contrasting traditional air conditioning systems with both geothermal air cooling and geothermal water cooling systems. To facilitate this comparison, a Split 1.5 Ton, 5-star air conditioner with a cooling capacity of 5000 W was chosen as the baseline. The coefficient of performance (COP) for the selected air conditioning system was assumed to be 3. Power consumption of the air conditioner was determined using the Energy Efficiency Ratio (EER), representing the number of BTUs per hour utilized for each watt of power drawn. EER serves as the efficiency rating for room air conditioners, while for central air conditioners, it is denoted as the Seasonal Energy Efficiency Ratio (SEER). These ratings are prominently displayed on an Energy Guide Label affixed to all new air conditioners. Moreover, many AC manufacturers voluntarily participate in the Energy Star labeling program, signifying high EER and SEER ratings for energy-efficient appliances.

Type of System	Cost of System (Rs.)	Operating cost per month (Rs.)
Air Conditioner (1.5 Ton)	45,000- 50,000	1,768
GACS	40,000	1,435
GWCS	45,000	732

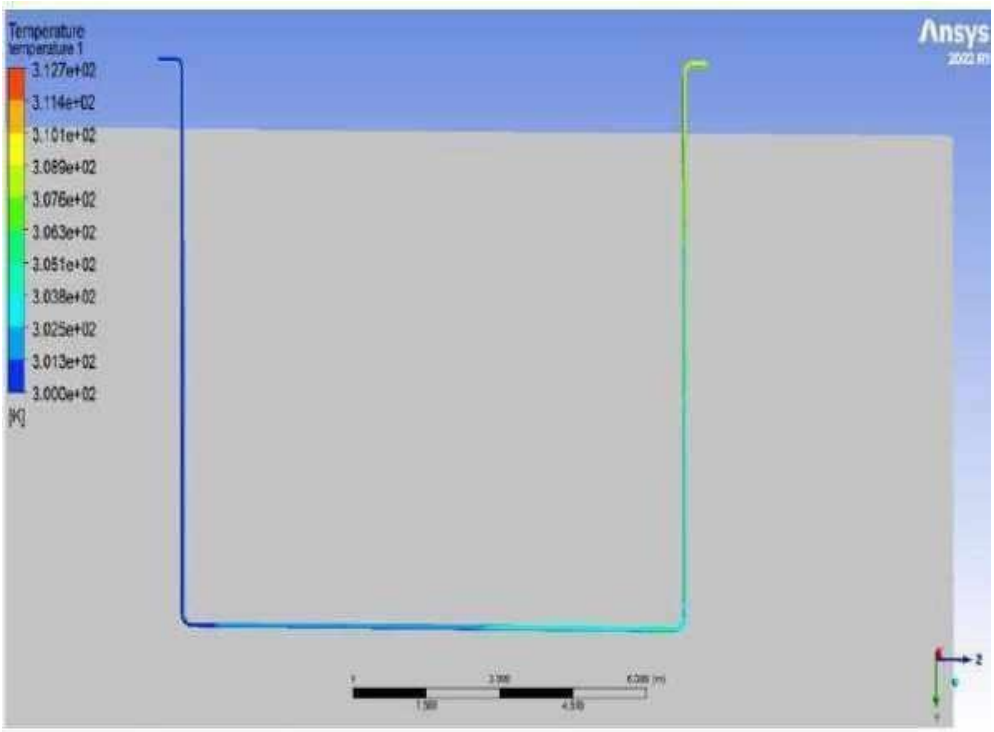


Fig.4.4: Temperature Variation for open system single pipe Heat Exchanger

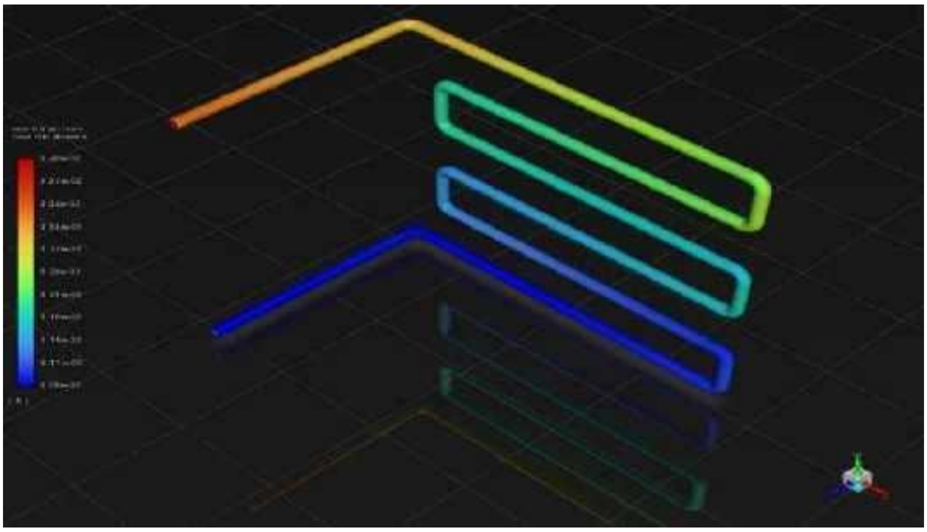


Fig.4.5: Temperature Variation for open system Double pipe Heat Exchanger

CHAPTER 5

Conclusion

- Higher air velocity, ideally within the range of 2 to 5 meters per second, contributes to reducing the temperature difference between outlet and inlet air. At a depth of 8 meters, the Earth's Undisturbed Temperature (EUT) stabilizes, suggesting depths exceeding 2 meters are adequate for achieving the desired effect.

- Due to the rapid attainment of soil temperature by the air, larger tube diameters are unnecessary.

- The design of an earth-air heat exchanger is primarily influenced by the heating/cooling load requirements of the building being conditioned.

- After determining the heating/cooling load, the design of the earth-air heat exchanger is driven by considerations of geometric constraints and cost analysis.

- Important factors to consider include the diameter, length, and quantity of the pipes. Increasing the length of the pipe improves both pressure drop and thermal performance.

- The Earth-Air Heat Exchanger (EAHE) system achieves optimal performance by utilizing a longer pipe with a smaller diameter buried at greater depth, along with lower air flow velocity.

Future Scope

The main aim of this study is to explore different arrangements of piping systems within earth tube heat exchangers to improve thermal comfort. Computational Fluid Dynamics (CFD) simulations have been carried out on various earth tube heat exchanger designs for both summer and winter conditions at the Dundigal site. Although the study has been conducted rigorously, there are opportunities for further improvement. Recommendations for future research encompass.

Suggestions for future research include:

- Recommendations for future research include broadening the range of CFD analyses to incorporate different designs of earth tube heat exchangers beyond those examined in the current investigation, thereby facilitating further advancements.

- Additionally, it is suggested to explore variable dimensions in CFD analysis for both summer and winter seasons instead of utilizing fixed dimensions as in the present study, in order to explore a broader spectrum of optimization possibilities.
- Furthermore, while the current study primarily focuses on temperature and velocity distributions, future research could benefit from incorporating the analysis of additional parameters to gain deeper insights into the performance of earth tube heat exchangers.

These suggestions are intended to provide guidance for future research efforts aimed at enhancing the understanding and optimization of earth tube heat exchanger systems to improve thermal comfort across diverse climatic conditions.

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