A Project Report
on

PASSIVE COOLING SYSTEM
FOR
THE NEW BOYS' HOSTEL

Submitted in the Partial Fulfillment of the Requirements
For the award of

Bachelor of Technology
in
Production and Industrial Engineering
(2024-2025)

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Under the guidance of

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UNDERTAKING

This is to certify that the work contained in the project report entitled " **PASSIVE COOLING SYSTEM FOR THE NEW BOYS' HOSTEL** ", submitted by Ayush Vishwakarma, Chitra Ojha, Ashish Chaudhary and Nitish Kumar in the partial fulfillment of the requirement for the award of Bachelor of Technology in Production and Industrial Engineering Department, Motilal Nehru National Institute of Technology, Allahabad, is a genuine effort by the students conducted under my supervision.

Date: 18/12/2024
Place: Prayagraj

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CERTIFICATE

This is to certified that the work contained in this project entitled "Passive Cooling system for New Boys' Hostel" is being submitted by **Ayush Vishwakarma, Ashish Chaudhary, Chitra Ojha, Nitish Kumar** to the Department of Production and Industrial Engineering, Motilal Nehru National Institute of Technology Allahabad, for the requirement of 7th Semester Project. They have worked under my guidance and supervision and have fulfilled the requirements, which to my knowledge has reached the requisite standard for the submission of the Project.

Signature of Supervisor

Date: 18/12/2024

Prof . Ravi Prakash

Place: Prayagraj

Production and Industrial engineering
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ACKNOWLEDGEMENT

It gives us great pleasure to express our gratitude and admiration to **Prof. Ravi Prakash**, our supervisor at the Motilal Nehru National Institute of Technology in Allahabad's Department of Production and Industrial Engineering, for his unwavering support, invaluable direction, inspiration, support, advice, and supervision throughout the entire course of the work. We learned a lot from working with him during the project activity. The Department of Production and Industrial Engineering at MNNIT Allahabad also owes our sincere gratitude for providing us with this opportunity which has greatly enhanced our knowledge and expertise. Last but not least, our heads bow with reverence before Almighty God and our parents, who have given us strength, wisdom, and will to complete the work.

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PREFACE

This report, titled **Passive Cooling System for the New Boys' Hostel**, presents the comprehensive study, design, and application of a sustainable cooling solution tailored for large multi-storey buildings. The project was undertaken as a part of the requirements for the Bachelor of Technology degree in Production and Industrial Engineering at Motilal Nehru National Institute of Technology (MNNIT) Allahabad. It aims to address the critical challenges of high energy consumption, indoor comfort across varying climates, and environmental sustainability through innovative passive cooling techniques.

The motivation for this project arises from the global need to reduce carbon footprints while maintaining energy-efficient operations. By integrating systems such as the Earth Air Heat Exchanger (EAHE) and rainwater-fed cooling coils, this project exemplifies the potential of natural resources to meet modern building demands sustainably. These methodologies not only reduce operational costs but also enhance thermal comfort without relying on traditional air conditioning systems.

This report elaborates on the project's objectives, methodology, tools, and outcomes, providing a detailed analysis of the design process and simulation using eQUEST software. It includes evaluations of energy savings, cooling loads, and environmental impact, highlighting the significant potential for implementation in similar infrastructural settings. The challenges encountered during development and prospective improvements for scalability are also discussed.

We extend our deepest gratitude to our guide, **Prof. Ravi Prakash**, and all faculty members of the Production and Industrial Engineering Department for their invaluable guidance and encouragement throughout this project.

CHAPTER-1

INTRODUCTION

1.1 BACKGROUND

Passive cooling systems provide innovative solutions to combat high energy consumption, environmental concerns, and the need for indoor comfort in modern buildings. By utilizing natural processes, these systems reduce reliance on traditional HVAC technologies that are energy-intensive and contribute significantly to carbon emissions.

The Earth Air Heat Exchanger (EAHE) cools air by leveraging the stable temperature of the earth, while rainwater-fed cooling coils use harvested rainwater to absorb and dissipate heat. These systems are eco-friendly, cost-effective, and non-mechanical, making them ideal for large-scale buildings. In addition to lowering operational costs, they promote sustainability and align with global energy conservation goals.

This project focuses on integrating EAHE and rainwater-fed cooling systems in the New Boys' Hostel at MNNIT Allahabad, addressing its specific cooling needs through an energy-efficient and sustainable design. Through simulations and analysis, it demonstrates the potential for widespread application in similar infrastructural settings.

Fig. **EAHE(Earth Air Heat Exchanger)**

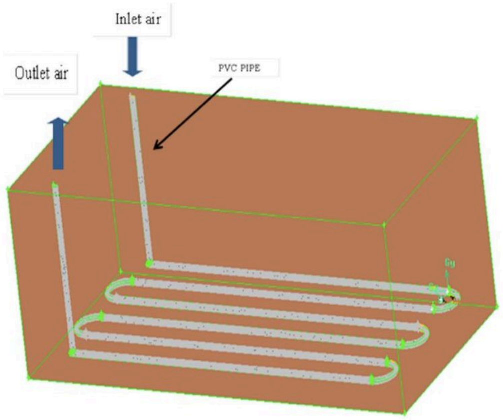


Fig. **Rainwater Harvesting**

1.2 OBJECTIVES

The primary objective of this project is to design and implement a sustainable passive cooling system for the New Boys' Hostel that addresses challenges like high energy consumption, indoor comfort maintenance, and carbon emissions reduction. The project focuses on leveraging natural resources and innovative engineering solutions to minimize reliance on energy-intensive air conditioning systems.

Key components include the design of an Earth Air Heat Exchanger(EAHE) system, which uses the earth's stable underground temperature to pre-cools the air before it enters the building. This ensures year-round thermal comfort with significantly reduced energy usage. Additionally, a rainwater harvesting system will be integrated into the cooling mechanism by channeling stored water through cooling coils installed in the rooms. The system aims to enhance energy efficiency by utilizing water at nearly 20°C for temperature regulation.

Advanced simulations using eQUEST software will guide the design process by calculating cooling loads and optimizing system parameters. The project also includes an assessment of economic feasibility and carbon footprint reduction to ensure practical implementation. Ultimately, the aim is to create an eco-friendly and cost-effective cooling solution that aligns with the goals of sustainability and energy conservation for large multi-storey buildings.

1.2 MOTIVATION

The core of motivation comes down to the fact that any problem in the world may be solved if one believes that change and progress can emerge through dedication, creativity, and resilience. This is particularly relevant for addressing pressing global issues like energy consumption and environmental sustainability, which impact not just current generations but also the future of the planet. A work like "*Passive Cooling System for the New Boys' Hostel"* is a perfect example of how innovation integrated with human determination can contribute to a greener and more energy-efficient world.

The rising demand for sustainable solutions to reduce the carbon footprint of large multi-storey buildings highlights the importance of eco-friendly alternatives to traditional HVAC systems. The opportunity to implement passive cooling systems such as the Earth Air Heat Exchanger (EAHE) and rainwater-fed cooling coils offers immense potential to lower energy consumption while maintaining indoor comfort. This realization serves as a powerful motivator to explore cutting-edge technologies for environmental and societal benefits. The pursuit of this project is driven by a deep commitment to sustainability—a challenge that is both technical and moral. The focus on passive cooling not only reduces operational costs but also aligns with the principles of environmental stewardship and resource efficiency.

From a technical perspective, passive cooling is a field with vast potential. Challenges like optimizing airflow in EAHE systems, designing rainwater-fed cooling systems, and ensuring their compatibility with varying climate conditions provide an opportunity to apply theoretical knowledge in a practical and impactful way. Each milestone in the project, whether it involves improving the heat transfer efficiency of EAHE or reducing cooling loads through simulation in eQUEST, reinforces the belief that technology can address complex problems effectively.

There is also the motivation to leave a legacy. The successful implementation of passive cooling systems in the New Boys' Hostel has the potential to serve as a benchmark for similar applications in residential, institutional, or commercial buildings across the country. The impact of such work goes beyond individual projects, contributing to the broader goals of energy conservation and environmental sustainability. Knowing that such efforts could inspire further advancements in green building technologies adds an even greater sense of purpose to the project.

The journey of designing and implementing passive cooling systems is not without its challenges. Technical obstacles such as optimizing the depth and layout of EAHE pipes, ensuring proper integration of rainwater-fed cooling systems, or achieving cost-effectiveness' demand persistence and innovative problem-solving.

1.4 TOOLS/PLATFORMS

eQUEST Software:

eQUEST is a specialized simulation tool for building energy analysis. It is used in this project to calculate cooling loads and optimize the performance of passive cooling systems like the Earth Air Heat Exchanger (EAHE) and rainwater-fed cooling coils. Its detailed modeling capabilities ensure accuracy in estimating energy consumption and savings.

Excel:

Excel is a versatile platform for tabulating and analyzing data. It is particularly useful in managing energy performance metrics, visualizing trends, and conducting cost-benefit analyses for the cooling systems.

Microsoft Teams/Google Meet:

These platforms are essential for ensuring efficient collaboration and communication among team members. They streamline project management tasks such as sharing updates, assigning roles, and tracking progress.

Microsoft Word/Google Docs:

Used for documenting project findings, drafting detailed reports, and maintaining records, these tools ensure that all project-related information is well-organized and easily accessible.

PowerPoint/Canva:

These tools play a crucial role in presenting the project's objectives, methodologies, and results. The visually engaging presentations help in effectively communicating the project's outcomes to stakeholders.

Data Sources:

Accurate and reliable data is crucial for the design and implementation of passive cooling systems. This project utilizes weather and climatic data from platforms like ASHRAE and local meteorological databases. Soil property databases are also referenced to ensure the optimal performance of the EAHE system by considering factors like thermal conductivity and specific heat capacity of the soil.

CHAPTER-2

Passive Cooling System Design

2.1 LITERATURE REVIEW

The passive cooling system proposed for the New Boys' Hostel has been developed to address challenges such as high energy consumption, maintaining indoor comfort, and reducing carbon footprints. It utilizes innovative techniques like the Earth Air Heat Exchanger (EAHE) and rainwater-fed cooling coils for energy-efficient cooling.

The EAHE system is designed to pre-cools the air before it enters the building using underground pipes that exploit the earth's stable temperature. This method relies on thermal inertia, where the ambient air temperature is lowered as it flows through the pipes buried 3–4 meters underground. Performance optimization, including the number and depth of pipes, ensures efficient heat exchange.

Rainwater-fed cooling coils enhance this design by circulating harvested rainwater, maintained at approximately 20°C, through embedded coils in walls or ceilings. The flowing water absorbs heat from surrounding surfaces, further cooling indoor spaces. This approach not only reduces energy use but also integrates sustainable practices by reusing rainwater.

Advanced simulation tools like eQUEST are used for calculating cooling loads and evaluating system performance. The simulations account for real-world conditions such as weather data from ISHRAE and local meteorological sources. Factors like soil thermal conductivity and building orientation are also integrated into the design to optimize energy efficiency.

The proposed system is non-intrusive and environmentally sustainable, reducing reliance on conventional HVAC systems. It incorporates measures to ensure reliability under varying climatic conditions, making it a viable solution for energy-efficient cooling in large buildings like the New Boys' Hostel.

CHAPTER-3

SURVEY
SITE ANALYSIS

The New Boys' Hostel, located on the MNNIT Allahabad campus in Prayagraj, Uttar Pradesh, India, is positioned at coordinates Latitude: 25° 29' 45" N and Longitude: 81° 52' 09" E. This 13-storey building currently lacks a heating and cooling system in the rooms for the students residing there. Each floor contains 26 rooms, with a floor-to-floor height of 9.56 ft and a floor-to-ceiling height of 9 ft. The building block is oriented South-West, and the rooms measure 11 x 8.5 x 9 ft^3.This overview provides a snapshot of the hostel's physical attributes, which are essential for designing and retrofitting solutions aimed at energy efficiency and sustainability.

Fig. New Boys' Hostel Building

Fig. Dining Hall Area Inside NBH

The dining hall of the New Boys' Hostel spans a functional area of approximately 1851 square feet. There are two types of windows in this area: one type measures 9.8 x 3.5 square feet, while the other measures 6.5 x 3.5 square feet. The doors measure 5 x 6.5 square feet. The floor-to-floor height is 9.5 feet, and the floor-to-ceiling height is 9 feet.

The passive cooling system that we want to install here is the Earth Air Heat Exchanger (EAHE)**.** The system operates Monday to Sunday for 5 hours per day. The roof is constructed of concrete with a thickness of 4 inches, and the building is oriented South-West.

Fig. Room in NBH

The building features 26 rooms per floor, each designed to meet student housing needs. The vertical distance between two consecutive floors, referred to as the floor-to-floor height, is 9.6 feet, while the internal floor-to-ceiling height of each room measures 9 feet. The dimensions of each room are 11 feet in length, 8.5 feet in width, and 9 feet in height, offering a compact living space.

To ensure proper ventilation and light, each room is equipped with windows and doors of specified dimensions. The windows measure 3.8 feet in width and 3.5 feet in height, allowing sufficient natural airflow and daylight penetration. The doors have a size of 6.4 feet in height and 3 feet in width, providing standard access to the room.

This description summarizes the spatial layout and design specifications of the rooms, which are crucial for comfort, energy optimization, and ventilation.

Fig. Working Area inside Dining Hall

The dining area in the New Boys’ Hostel is designed as a functional and comfortable communal space. Its layout ensures adequate ventilation and natural lighting, achieved through well-placed windows and doors that optimize airflow and daylight.

To maintain thermal comfort, the space incorporates a passive cooling system, such as the Earth Air Heat Exchanger (EAHE), which operates efficiently while conserving energy. The concrete roof adds durability and thermal insulation, contributing to the space’s sustainability.

The South-West orientation further enhances natural light and airflow, creating a pleasant environment that supports energy efficiency and occupant comfort.

2.2 BUILDING SPECIFICATION

2.2.1 NBH BUILDING SPECIFICATION:

No. of floor	13
No. of Room per floor	26
Floor to Floor Height	9.56 ft
Floor to Ceil Height	9 ft
Orientation of Block	South-West
Room Dimension	11 X 8.5 X 9 ft^3
Window Dimension	3.8 X 3.5 ft^2
Door Dimension	6.4 X 3 ft^2

2.2.2 DINING HALL SPECIFICATION:

Area	1851 ft^2
Dimension of Window(6)	9.8 X 3.5 ft^2
Dimension of Window(2)	6.5 X 3.5 ft^2
Dimension of Door(2)	5 X 6.5 ft^2
Floor to Floor Height	9.5 ft
Floor to Ceil Height	9 ft

2.2.3 eQuest Input: Building Envelope Construction

Categories	Roof Surfaces	Above Grade Walls
Construction	4 in. Concrete	4 in. HW Concrete
Ext. Finish / Colour	Roof, built-up, Medium	Concrete, Medium
Exterior Insulation	3 in. Polyurethane (R-18)	No ext board insulation
Add'l Insulation	No LtWt Conc Cap	No integral insulation
Interior Insulation		R-13 wd furred insulation

Ground floor

Categories	Details
Exposure	Earth Contact
Construction	6 in. Concrete
Ext. / Cav Insulation	No perimeter insulation
Interior Finish	Carpet (no pad)

Infiltration (Shell Tightness)

Parameter	Value
Perimeter Infiltration	0.003-8 CFM/ft² (ext wall area)
Core Infiltration	0.001 CFM/ft² (floor area)

MODEL OF THE BUILDING
MADE USING eQuest :-

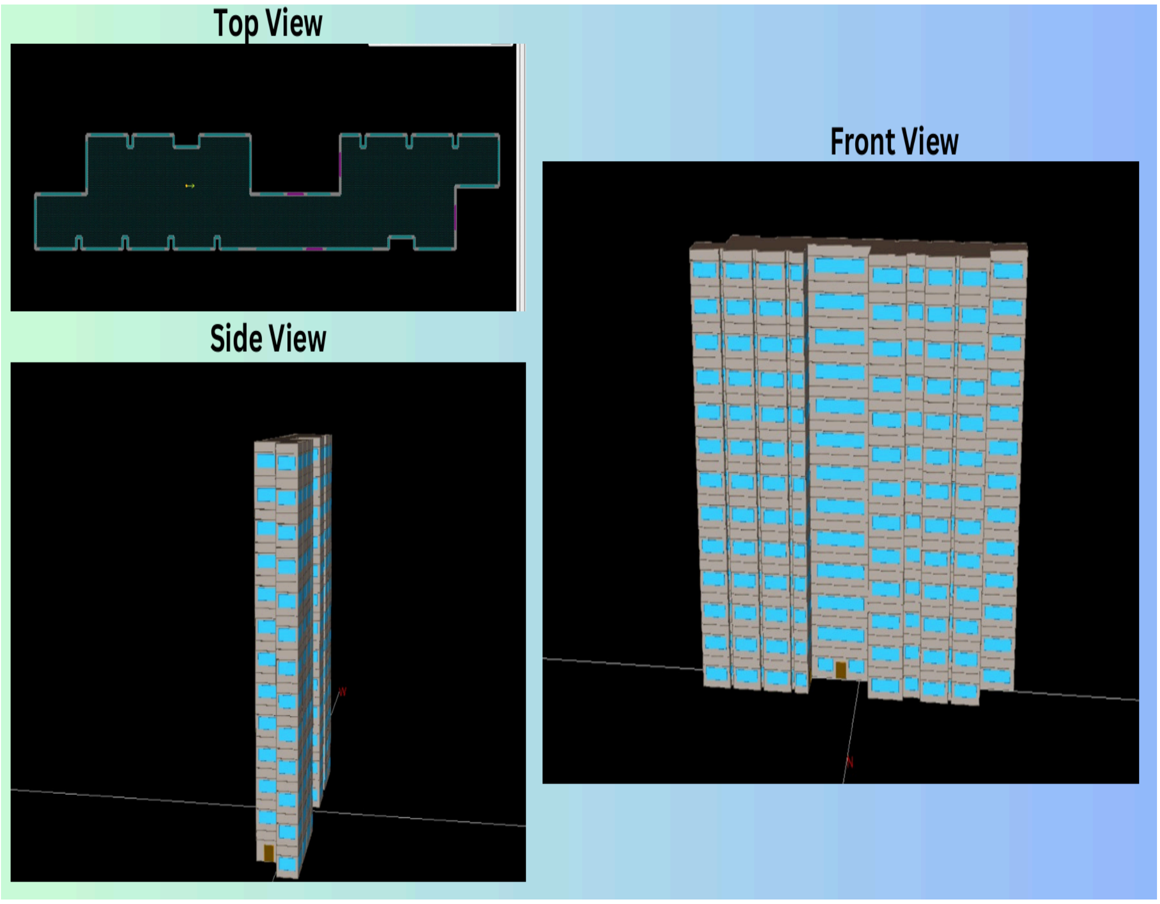


Fig. Model of NBH Building made using eQuest

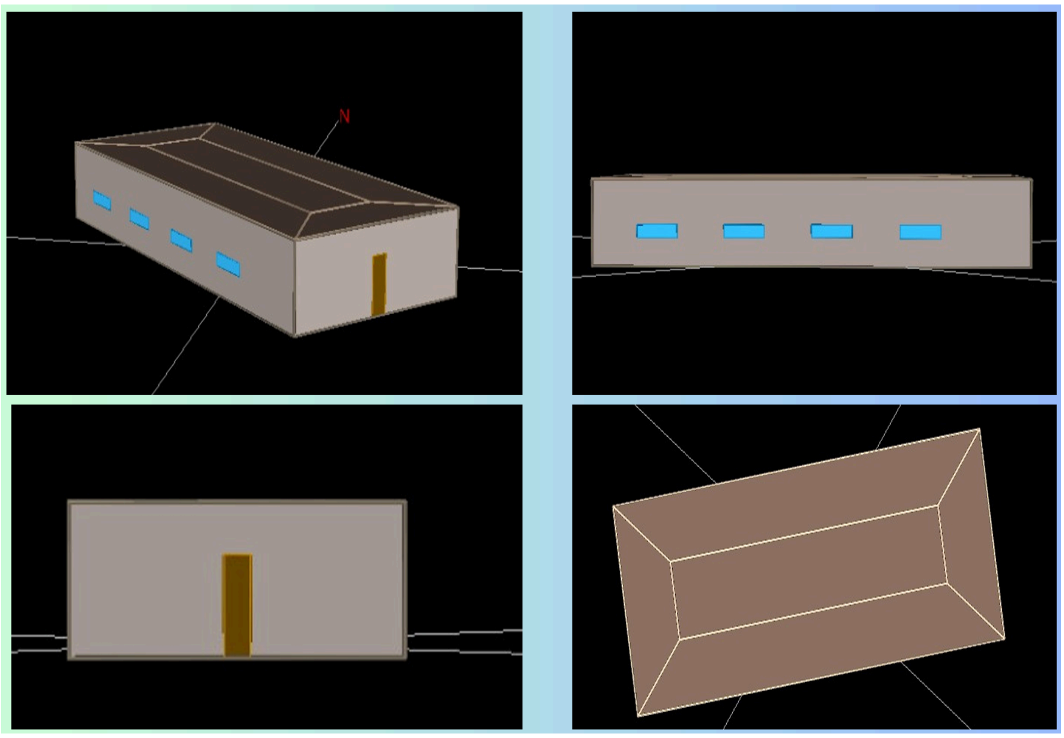


Fig. Model Dining Hall made using eQuest

CHAPTER-4

Calculation of Cooling Load

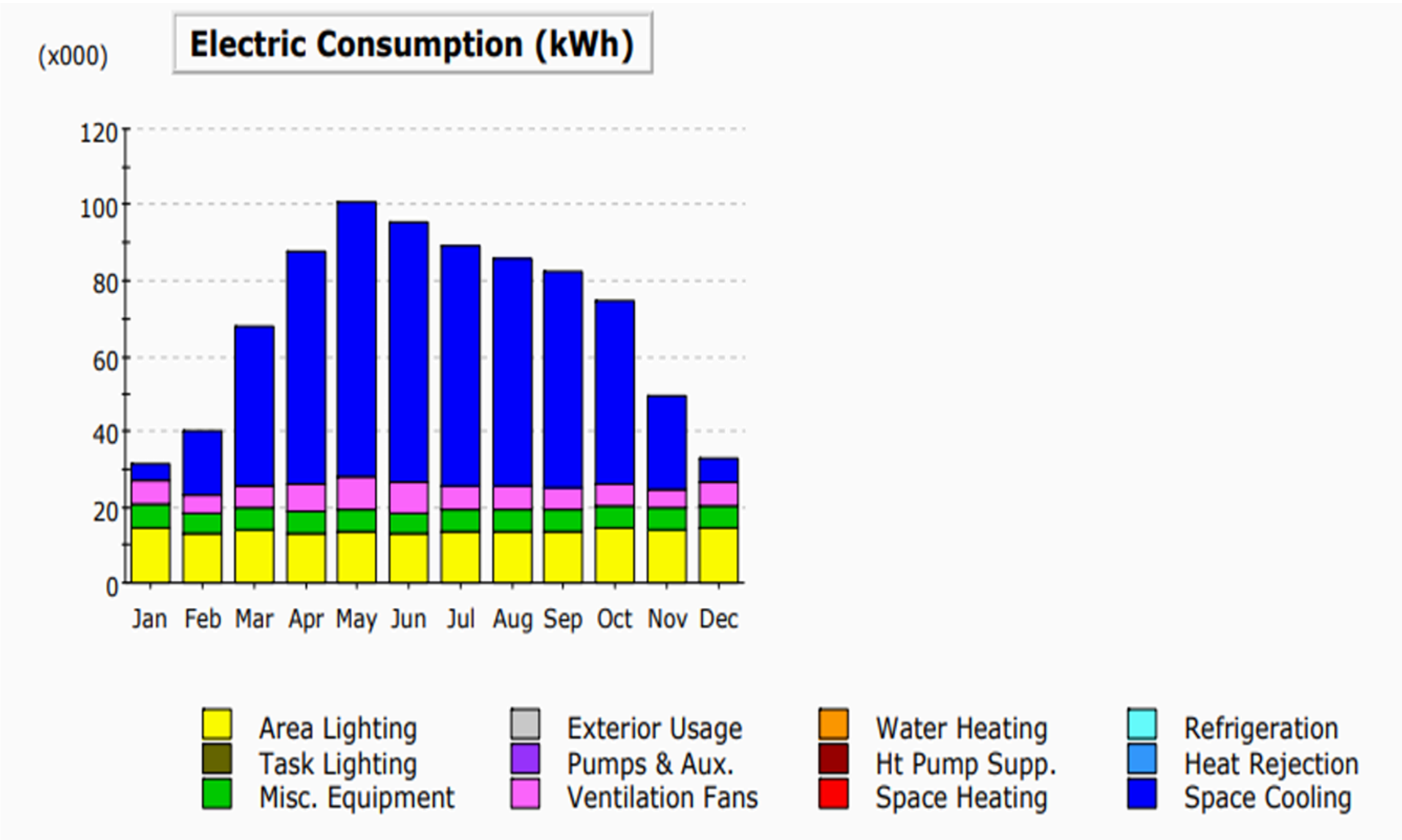
Cooling Load Formula:

$$Q = E.E.R * Wc / 3.5$$

where Q= Amount of heat
Wc= Work done on compressor
E.E.R= Energy Efficiency Ratio

Cooling Load for Dining Hall:

eQuest Output Electric Consumption(kWh) for Dining Hall:



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	4.13	17.06	42.38	61.62	72.71	68.95	63.66	60.23	57.31	48.77	25.25	6.49	528.57
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	6.65	4.97	5.68	7.40	8.91	8.06	6.54	5.92	6.08	5.52	4.73	6.01	76.47
Pumps & Aux.	0.06	0.00	-	-	-	-	-	-	-	-	-	0.01	0.08
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	5.79	5.23	5.81	5.60	5.80	5.59	5.79	5.81	5.58	5.80	5.60	5.76	68.18
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	14.69	12.97	14.04	13.14	13.33	12.85	13.30	13.62	13.52	14.47	14.05	14.56	164.55
Total	31.33	40.24	67.92	87.77	100.74	95.45	89.29	85.57	82.50	74.55	49.64	32.84	837.85

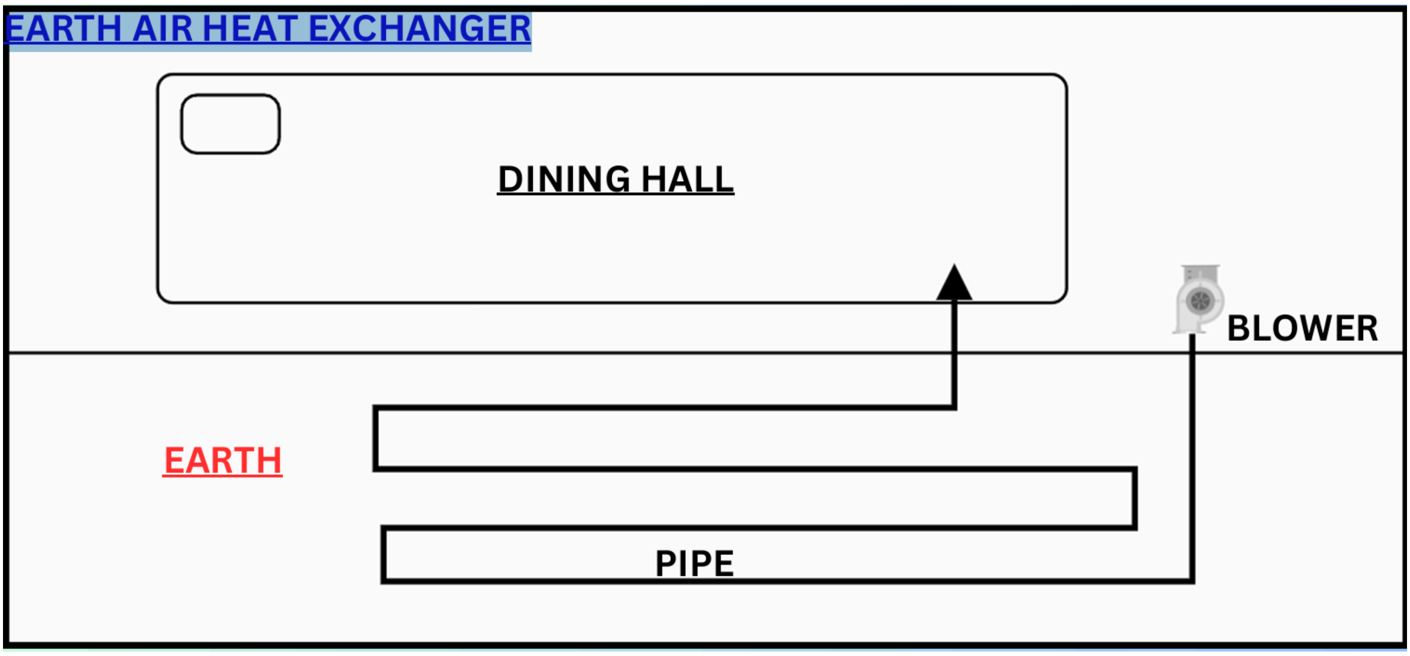
Based on the graph and table, it's clear that the cooling load peaks during May and June, while it is at its lowest in December and January.

Original Cooling Load:

Maximum energy consumption in the month of May = 2.55X10^3 kWh
No. of hours per month for which cooling is required = 150 hours
Cooling COP = 2.5
Total cooling load = (2550 *(9.7/2.5))/150
= 65.96 kW
Total cooling load in TR = 65.96/3.5
= 18 TR

According to the eQUEST model, the maximum cooling load for May is approximately 18 TR.

Proposed Diagram of EAHE for Dining Hall:



CHAPTER-5

Designing the Earth Air Heat Exchanger(EAHE) for Dining Hall

Designing Steps in EAHE

1. Understanding System Requirements
2. Initial Assumptions
3. Geometric Design
4. Calculating Heat Transfer
5. Determining Tube Length
6. Pressure Drop Analysis
7. Air Fan Power
8. Design Iteration

Understanding System Requirements

1. Define the purpose (cooling, heating, or both).
2. Analyze local climate conditions (mean annual air temperature, relative humidity, etc.).
3. Study the site's soil properties (thermal diffusivity, specific heat, and conductivity).
4. Assess the geographic location (latitude, longitude) for temperature stability at depth.
5. Consider site-specific factors:
    - Available Space: Length, breadth, and depth of the site.
    - Terrain: Elevation and uniformity.

Initial Assumptions:

- The temperature of the soil surrounding the tube is assumed to remain constant and uniform along the axial direction.
- The earth's ground temperature is considered consistent throughout the tube's length.
- The thermal resistance of the pipe is assumed to be negligible for simplicity.
- The tube's surface temperature is treated as uniform along its axial length and equal to the earth's undisturbed temperature.
- The tube is assumed to have a uniform cross-section with a smooth inner surface.
- The thermophysical properties of air and soil, including density, viscosity, thermal conductivity, and specific heat capacity, are considered constant.

Geometric Design

Determination of the physical parameters of the EAHE to meet the required thermal performance:

1.Tube Dimensions:

Diameter(D): Select an initial tube diameter. A smaller diameter increases turbulence and heat transfer but may result in higher pressure drops.
Length (L): The tube length depends on the desired cooling/heating capacity, air velocity, and heat exchange efficiency.

2.Number of Tubes (N):

Decide the number of parallel tubes to distribute airflow and reduce pressure drops.
Optimize the number of tubes and their arrangement based on site dimensions and airflow requirements.

3.Tube Depth:

Place the tubes 3 meters(10 ft) or 4 meters(13 ft) underground where the average temperature will be around 25 degree celsius.

4.Tube Material:

Choose materials with good thermal conductivity (e.g., PVC, metal).
Ensure durability, smooth internal surfaces (to minimize friction), and resistance to corrosion.

5.Tube Arrangement:

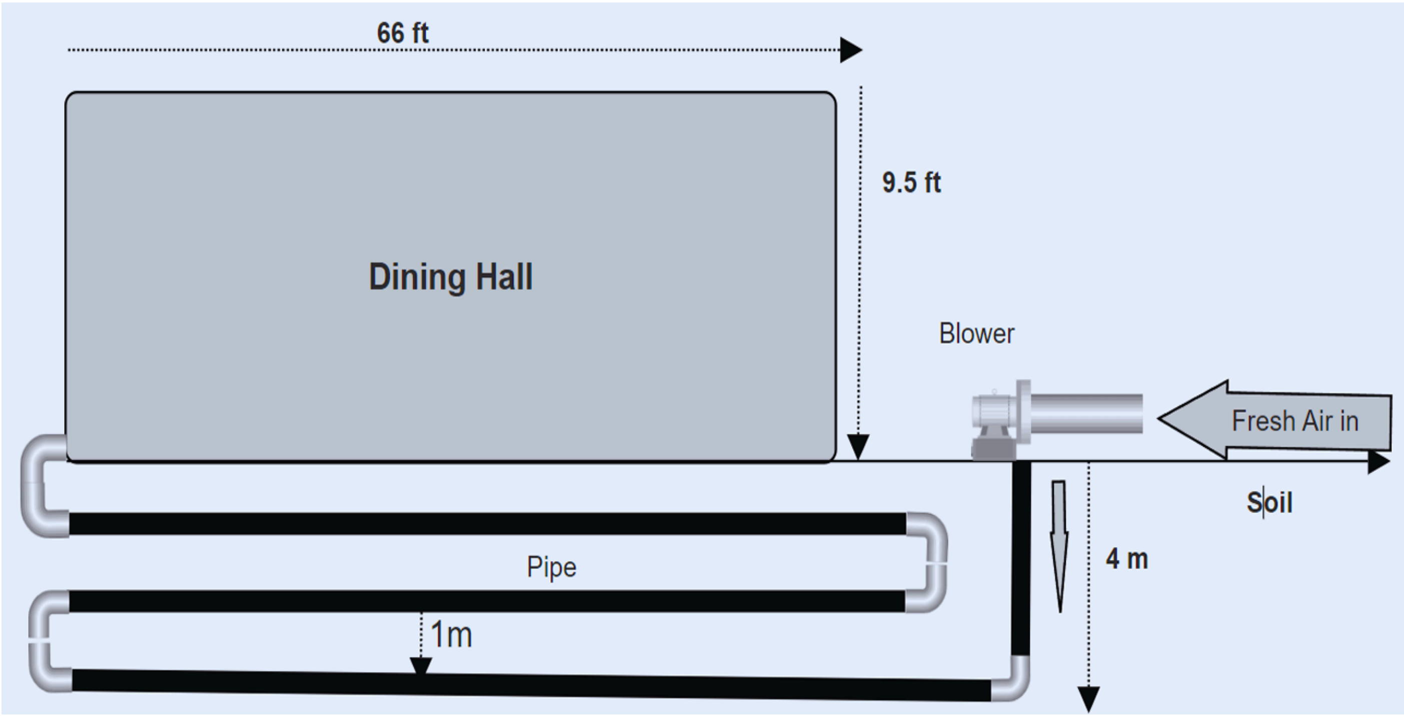
Linear Layout: Simple and easy to install but requires a larger site area.
Spiral or Serpentine Layout: Optimizes sp ace but can increase pressure drops.
Align the tubes to maximize contact with undisturbed soil.

6. Airflow Path:

Ensure an unobstructed airflow path inside the tubes with minimal bends to reduce friction and pressure losses. Integration with Site Dimensions
Fit the tube layout within the site's length and breadth, ensuring adequate spacing to avoid thermal

interference between tubes

Schematic Diagram of Proposed Design of EAHE



Calculating Tube Length

- Load Calculation and Mass Flow Rate: The load was determined using eQuest software. Based on the 18 TR cooling load for the dining hall, the necessary air mass flow rate was calculated to achieve the desired temperature reduction.
- Heat Transfer Mechanism: Heat is transferred through convection from the airflow to the inner wall of the tube and via conduction from the outer tube wall to the surrounding soil.
- Convective Heat Transfer Coefficient: This coefficient is calculated using the Nusselt number (Nu), which varies based on whether the airflow is laminar or turbulent.
- Overall Heat Transfer Coefficient: It accounts for contributions from the air, tube material, and soil and serves as an indicator of the total heat transfer occurring in the system.
- Determining Tube Length (L): The tube length is calculated using the below equation by putting A = π * D * L, where A is the surface area.

$$T_{\text{out}} = T_{\text{wall}} + \left(T_{\text{in}} - T_{\text{wall}}\right) e^{-\frac{(UA)}{mc_{p,a}}}$$

Determining Effectiveness and Blower Power

1. **NTU:**

   NTU(Net Transfer Unit) is determined using the overall heat transfer coefficient (Ut), surface area of the tube(A), and the minimum heat capacity rate.

$$NTU = \frac{U_t \times A}{C_{\text{air}} \times \dot{m}}$$

2. **Effectiveness (ε):**

An effectiveness of 80% is considered to be an optimum for an earth-air heat exchanger. It can be calculated using NTU as:

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

3. **Pressure Drop Considerations:**

Ensure that the tube length does not cause excessive pressure drop. The pressure drop can be calculated using the Darcy-Weisbach equation.

$$\Delta P = \rho f \frac{v^2}{4r_i} L$$

4. Blower Power:

It can be calculated as:

$$B_p = \frac{\Delta P \dot{m}}{\rho \eta_b}$$

5. Iterative Adjustment:

The tube length is optimized through an iterative procedure by adjusting parameters such as tube diameter and the number of tubes. This guarantees achieving both the desired heat transfer and an acceptable pressure drop. The process is ensured to guarantee that the tube length facilitates the required heat exchange while maintaining system efficiency and practicality.

EAHE Specifications

Components	Value
Soil Pipe Depth	4 m
Pipe Material	PVC
Pipe Diameter	0.25 m
Pipe Length	29 m
No. of Pipes	28
Pressure Drop	64 Pa
Blower Power	450 W
No. of Blower	6
Layout	Parallel

Calculations:

Step 1: **Given Values**

- Diameter, $D = 0.25\,\mathrm{m}$
- Density, $\rho = 1.168\,\mathrm{kg/m^3}$
- Heat Transfer Rate, $q = 6.3\,\mathrm{kW} = 6300\,\mathrm{W}$
- Temperature difference, $\Delta T = 45 - 30 = 15^{\circ}C$
- Specific heat, $C_p = 1006\,\mathrm{J/kgK}$

Step 2: **Mass Flow Rate ($\dot{m}$)**

The formula is:

$$q = \dot{m} \cdot C_p \cdot \Delta T$$

Rearranging for $\dot{m}$:

$$\dot{m} = \frac{q}{C_p \cdot \Delta T}$$

Substitute values:

$$\dot{m} = \frac{6300}{1006 \cdot 15} = 6.26\,\mathrm{kg/s}$$

Step 3: **Mass Flow Rate per Tube ($\dot{m}_{\text{tube}}$)**

The formula is:

$$\dot{m}_{\text{tube}} = \rho \cdot V \cdot D$$

Given: $\rho = 1.168\,\text{kg/m}^3$, $V = 4\,\text{m/s}$, $D = 0.25\,\text{m}$:

$$\dot{m}_{\text{tube}} = 1.168 \cdot 4 \cdot 0.25 = 0.22\,\text{kg/s}$$

Step 4: **Number of Pipes (N)**

The formula is:

$$N = \frac{\dot{m}}{\dot{m}_{\text{tube}}}$$

Substitute values:

$$N = \frac{6.26}{0.22} = 29\,\text{pipes}$$

Step 5: **Reynolds Number (Re)**

The formula is:

$$Re = \frac{\rho \cdot V \cdot D}{\mu}$$

Given: $\rho = 1.168$, $V = 4$, $D = 0.25$, $\mu = 1.865 \times 10^{-5}$:

$$Re = \frac{1.168 \cdot 4 \cdot 0.25}{1.865 \times 10^{-5}} = 69500$$

Step 6: **Prandtl Number (Pr)**

The formula is:

$$Pr = \frac{\mu \cdot C_p}{K_{\text{air}}}$$

Given: $\mu = 1.865 \times 10^{-5}$, $C_p = 1006$, $K_{\text{air}} = 0.025$:

$$Pr = \frac{1.865 \times 10^{-5} \cdot 1006}{0.025} = 0.748$$

Step 7: **Friction Factor (f)**

The formula is:

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

Substitute $Re = 69500$:

$$f = (1.82 \log 69500 - 1.64)^{-2}$$

Given $\log 69500 \approx 4.84$:

$$f = (1.82 \cdot 4.84 - 1.64)^{-2} = 0.019$$

Step 8: **Nusselt Number (Nu)**

The formula is:

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

Substitute $f = 0.019$, $Re = 69500$, $Pr = 0.748$:

$$Nu = \frac{0.019}{8}(69500 - 1000)(0.748) \Big/ \left(1 + 12.7\sqrt{\frac{0.019}{8}}(0.748^{2/3} - 1)\right)$$

Simplifying:

$$Nu = \frac{0.002375 \cdot 68500 \cdot 0.748}{1 + 12.7 \cdot 0.0172 \cdot (-0.27)} = 137$$

Step 9: **Heat Transfer Coefficient (h_c)**

The formula is:

$$h_c = \frac{Nu \cdot K}{D}$$

Given $Nu = 137$, $K = 0.025$, $D = 0.25$:

$$h_c = \frac{137 \cdot 0.025}{0.25} = 6.85\,\mathrm{W/m^2K}$$

Step 10: **Total Convective Heat Transfer Coefficient (U_t)**

Since only convective transfer is considered:

$$U_t = h_c = 6.85\,\mathrm{W/m^2K}$$

Step 11: **Outlet Temperature (T_{out})**

The formula is:

$$T_{\text{out}} = T_{\text{wall}} + (T_{\text{in}} - T_{\text{wall}})e^{\left(-\frac{U_t \cdot A}{\dot{m} \cdot C_p}\right)}$$

Here $A = \pi \cdot D \cdot L$, so solving for L:

Given:

$$\ln\left(\frac{4}{19}\right) = -\frac{U_t \cdot \pi \cdot D \cdot L}{\dot{m} \cdot C_p}$$

Rearranging for L:

$$L = \frac{\ln\left(\frac{4}{19}\right) \cdot \dot{m} \cdot C_p}{-U_t \cdot \pi \cdot D}$$

Substitute values:

$$L = \frac{-1.55 \cdot 6.26 \cdot 1006}{6.85 \cdot \pi \cdot 0.25} = 29\,\text{m}$$

Final Answer:

The required **pipe length** is:

$$\boxed{L = 29\,\text{m}}$$

Calculations	Value
$\dot{M} = \frac{Q_t}{C_{p,a}(T_{\text{out}} - T_{\text{in}})}$	6.26 Kg/s
$\dot{m} = \rho \times A \times V$	0.28 Kg/s
N (no. of pipes)	28
$h = \frac{Nu\lambda}{D}$	1070
$U_t = \left(\frac{1}{h_c} + \frac{1}{2\pi k_t} \ln \frac{r_o}{r_i}\right)^{-1}$	1070 W/Km^2
$T_{\text{out}} = T_{\text{wall}} + (T_{\text{in}} - T_{\text{wall}})e^{-\frac{(UA)}{\dot{m}C_{p,a}}}$	L = 29m
$\Delta P = \rho f \frac{v^2}{4r_i} L$	64 Pa
$B_p = \frac{\Delta P \dot{m}}{\rho \eta_b}$	450 W

Future Scope of Project

1.Integration with Renewable Energy Sources

The passive cooling system can be integrated with solar photovoltaic (PV) systems in order to power the blowers, pumps, and other components. This can make the system completely sustainable, thereby reducing the operational cost and carbon footprint further.

2.Advanced Energy Management Systems

Smart sensors and IoT-based control systems can optimize the operations of Earth Air Heat Exchangers (EAHE). This will provide real-time monitoring of temperatures, airflows, and energy saving.

3. Scalability for Large Infrastructure

The principles of this design can be scaled up to multi-story residential and commercial buildings. It provides an energy efficient and sustainable solution for campus, hospitals, and large hostels in extreme climate zones.

4.Utilization of Rainwater Beyond Cooling

Stored rainwater can also be used for non-potable purposes like irrigation, washing, and toilet flushing, enhancing the overall water sustainability of buildings.

5.Climate Adaptability

Further studies can go to diverse climatic conditions regarding performance from the proposed systems. This could give ways to refine the design on diverse soils, humidity levels, and ambient temperature levels for locations.

6.Economic and Environmental Feasibility Studies

Further analysis into life-cycle assessments, payback periods, and long-term environmental benefits will make the project more attractive for adoption by policymakers and building developers.

CONCLUSION

The EAHE system is very critical in terms of passive heating and cooling based on seasonal changes in the weather. Design calculations also show that an increase in airflow velocity enhances the effectiveness of the system, though, as proven by literature, this occurs only to a certain degree. As claimed by Bisoniya et al. (2013), above an NTU value of 4, the efficiency approaches stability. The experiments indicate that velocity has a minor influence on airflow while determining the efficiency of the EAHE system.

Idealized design calculations often yield higher effectiveness values compared to experimental results. The difference occurs because idealized design calculations neglect real-world complications during analysis.

All key parameters, such as the diameter of the pipe, the volume flow rate, Reynolds number, Nusselt number, friction factor, length of the pipe, and the pressure drop, were calculated using the design equations. Optimized values based on a comprehensive review of all published research studies indicated that for flow velocities of 3 m/s, 4 m/s, and 5 m/s, the effectiveness of the EAHE system attained 88.4%, 93.2%, and 95.7%, respectively. Higher flow velocities increase turbulence, thus resulting in a higher Reynolds number and better heat transfer rates. Moreover, it was seen that as NTU increases, the system effectiveness also increases, which is in line with results presented by Paepe et al. (2003) and Bisoniya et al. (2013).

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   TUNNEL HEAT EXCHANGER
   Dharmendrakumar Saini1, Lokesh Mohan Sharma2
   Ghanshayam Das Agarwal3, Rohit Mishra4

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—-------------------------------------THANK YOU—---

P1

by Arun Shukla

Submission date: 19-Dec-2024 12:50PM (UTC+0530)
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A Project Report
on

PASSIVE COOLING SYSTEM
FOR
THE NEW BOYS' HOSTEL

Submitted in the Partial Fulfillment of the Requirements
For the award of

Bachelor of Technology
in
Production and Industrial Engineering
(2024-2025)

By :

Ayush Vishwakarma(Reg no. 20216012)
Chitra Ojha(Reg no. 20216039)
Ashish Chaudhary(Reg no. 20216059)
Nitish Kumar(Reg no. 20216058)

Under the guidance of
Prof. Ravi Prakash

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UNDERTAKING

This is to certify that the work contained in the thesis titled " **PASSIVE COOLING SYSTEM FOR THE NEW BOYS' HOSTEL** ", submitted by, Ayush Vishwakarma, Chitra Ojha, Ashish Chaudhary and Nitish Kumar in the partial fulfillment of the requirement for the award of Bachelor of Technology in Production and Industrial Engineering Department, Motilal Nehru National Institute of Technology, Allahabad, is a genuine effort by the students conducted under my supervision.

Date: 18/12/2024
Place: Prayagraj

Ayush Vishwakarma(Reg no: 20216012)
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CERTIFICATE

This is to certified that the work contained in this project entitled "Passive Cooling system for New Boys' Hostel" is being submitted by **Ayush Vishwakarma(20216012), Chitra Ojha(20216039) ,Ashish Chaudhary(20215126), Nitish Kumar(20216058)** to the Department of Production and Industrial Engineering, Motilal Nehru National Institute of Technology Allahabad, for the requirement of 7th Semester Project. They have worked under my guidance and supervision and have fulfilled the requirements, which to my knowledge has reached the requisite standard for the submission of the Project.

Date:

Place: Prayagraj

Prof . Ravi Prakash
Professor
Production and Industrial engineering
MNNIT Allahabad

ACKNOWLEDGEMENT

It gives us great pleasure to express our gratitude and admiration to **Prof. Ravi Prakash**, our supervisor at the Motilal Nehru National Institute of Technology in Allahabad's Department of Production and Industrial Engineering, for his unwavering support, invaluable direction, inspiration, support, advice, and supervision throughout the entire course of the work. We learned a lot from working with him during the project activity. The Department of Production and Industrial Engineering at MNNIT Allahabad also owes our sincere gratitude for providing us with this opportunity which has greatly enhanced our knowledge and expertise. Last but not least, our heads bow with reverence before Almighty God and our parents, who have given us strength, wisdom, and will to complete the work.

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PREFACE

This report, titled **Passive Cooling System for the New Boys' Hostel**, presents the comprehensive study, design, and application of a sustainable cooling solution tailored for large multi-storey buildings. The project was undertaken as a part of the requirements for the Bachelor of Technology degree in Production and Industrial Engineering at Motilal Nehru National Institute of Technology (MNNIT) Allahabad. It aims to address the critical challenges of high energy consumption, indoor comfort across varying climates, and environmental sustainability through innovative passive cooling techniques.

The motivation for this project arises from the global need to reduce carbon footprints while maintaining energy-efficient operations. By integrating systems such as the Earth Air Heat Exchanger (EAHE) and rainwater-fed cooling coils, this project exemplifies the potential of natural resources to meet modern building demands sustainably. These methodologies not only reduce operational costs but also enhance thermal comfort without relying on traditional air conditioning systems.

This report elaborates on the project's objectives, methodology, tools, and outcomes, providing a detailed analysis of the design process and simulation using eQUEST software. It includes evaluations of energy savings, cooling loads, and environmental impact, highlighting the significant potential for implementation in similar infrastructural settings. The challenges encountered during development and prospective improvements for scalability are also discussed.

We extend our deepest gratitude to our guide, **Prof. Ravi Prakash**, and all faculty members of the Production and Industrial Engineering Department for their invaluable guidance and encouragement throughout this project.

CHAPTER-1

INTRODUCTION

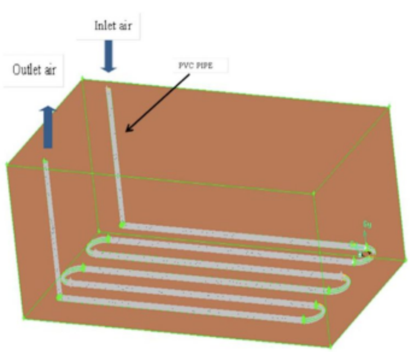
1.1 BACKGROUND

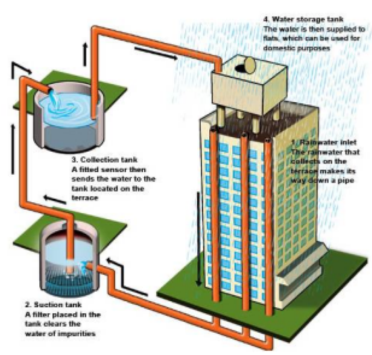
Passive cooling systems provide innovative solutions to combat high energy consumption, environmental concerns, and the need for indoor comfort in modern buildings. By utilizing natural processes, these systems reduce reliance on traditional HVAC technologies that are energy-intensive and contribute significantly to carbon emissions.

The Earth Air Heat Exchanger (EAHE) cools air by leveraging the stable temperature of the earth, while rainwater-fed cooling coils use harvested rainwater to absorb and dissipate heat. These systems are eco-friendly, cost-effective, and non-mechanical, making them ideal for large-scale buildings. In addition to lowering operational costs, they promote sustainability and align with global energy conservation goals.

This project focuses on integrating EAHE and rainwater-fed cooling systems in the New Boys' Hostel at MNNIT Allahabad, addressing its specific cooling needs through an energy-efficient and sustainable design. Through simulations and analysis, it demonstrates the potential for widespread application in similar infrastructural settings.

Fig. **EAHE(Earth Air Heat Exchanger)** Fig. **Rainwater Harvesting**





1.2 OBJECTIVES

The primary objective of this project is to design and implement a sustainable passive cooling system for the New Boys' Hostel that addresses challenges like high energy consumption, indoor comfort maintenance, and carbon emissions reduction. The project focuses on leveraging natural resources and innovative engineering solutions to minimize reliance on energy-intensive air conditioning systems.

Key components include the design of an Earth Air Heat Exchanger(EAHE) system, which uses the earth's stable underground temperature to pre-cools the air before it enters the building. This ensures year-round thermal comfort with significantly reduced energy usage. Additionally, a rainwater harvesting system will be integrated into the cooling mechanism by channeling stored water through cooling coils installed in the rooms. The system aims to enhance energy efficiency by utilizing water at nearly 20°C for temperature regulation.

Advanced simulations using eQUEST software will guide the design process by calculating cooling loads and optimizing system parameters. The project also includes an assessment of economic feasibility and carbon footprint reduction to ensure practical implementation. Ultimately, the aim is to create an eco-friendly and cost-effective cooling solution that aligns with the goals of sustainability and energy conservation for large multi-storey buildings.

1.2 MOTIVATION

The core of motivation comes down to the fact that any problem in the world may be solved if one believes that change and progress can emerge through dedication, creativity, and resilience. This is particularly relevant for addressing pressing global issues like energy consumption and environmental sustainability, which impact not just current generations but also the future of the planet. A work like "*Passive Cooling System for the New Boys' Hostel*" is a perfect example of how innovation integrated with human determination can contribute to a greener and more energy-efficient world.

The rising demand for sustainable solutions to reduce the carbon footprint of large multi-storey buildings highlights the importance of eco-friendly alternatives to traditional HVAC systems. The opportunity to implement passive cooling systems such as the Earth Air Heat Exchanger (EAHE) and rainwater-fed cooling coils offers immense potential to lower energy consumption while maintaining indoor comfort. This realization serves as a powerful motivator to explore cutting-edge technologies for environmental and societal benefits. The pursuit of this project is driven by a deep commitment to sustainability—a challenge that is both technical and moral. The focus on passive cooling not only reduces operational costs but also aligns with the principles of environmental stewardship and resource efficiency.

From a technical perspective, passive cooling is a field with vast potential. Challenges like optimizing airflow in EAHE systems, designing rainwater-fed cooling systems, and ensuring their compatibility with varying climate conditions provide an opportunity to apply theoretical knowledge in a practical and impactful way. Each milestone in the project, whether it involves improving the heat transfer efficiency of EAHE or reducing cooling loads through simulation in eQUEST, reinforces the belief that technology can address complex problems effectively.

There is also the motivation to leave a legacy. The successful implementation of passive cooling systems in the New Boys' Hostel has the potential to serve as a benchmark for similar applications in residential, institutional, or commercial buildings across the country. The impact of such work goes beyond individual projects, contributing to the broader goals of energy conservation and environmental sustainability. Knowing that such efforts could inspire further advancements in green building technologies adds an even greater sense of purpose to the project.

The journey of designing and implementing passive cooling systems is not without its challenges. Technical obstacles such as optimizing the depth and layout of EAHE pipes, ensuring proper integration of rainwater-fed cooling systems, or achieving cost-effectiveness' demand persistence and innovative problem-solving.

1.4 TOOLS/PLATFORMS

eQUEST Software:

eQUEST is a specialized simulation tool for building energy analysis. It is used in this project to calculate cooling loads and optimize the performance of passive cooling systems like the Earth Air Heat Exchanger (EAHE) and rainwater-fed cooling coils. Its detailed modeling capabilities ensure accuracy in estimating energy consumption and savings.

Excel:

Excel is a versatile platform for tabulating and analyzing data. It is particularly useful in managing energy performance metrics, visualizing trends, and conducting cost-benefit analyses for the cooling systems.

Microsoft Teams/Slack:

These platforms are essential for ensuring efficient collaboration and communication among team members. They streamline project management tasks such as sharing updates, assigning roles, and tracking progress.

Microsoft Word/Google Docs:

Used for documenting project findings, drafting detailed reports, and maintaining records, these tools ensure that all project-related information is well-organized and easily accessible.

PowerPoint/Canva:

These tools play a crucial role in presenting the project's objectives, methodologies, and results. The visually engaging presentations help in effectively communicating the project's outcomes to stakeholders.

Data Sources:

Accurate and reliable data is crucial for the design and implementation of passive cooling systems. This project utilizes weather and climatic data from platforms like ASHRAE and local meteorological databases. Soil property databases are also referenced to ensure the optimal performance of the EAHE system by considering factors like thermal conductivity and specific heat capacity of the soil.

CHAPTER-2

Passive Cooling System Design

2.1 LITERATURE REVIEW

The passive cooling system proposed for the New Boys' Hostel has been developed to address challenges such as high energy consumption, maintaining indoor comfort, and reducing carbon footprints. It utilizes innovative techniques like the Earth Air Heat Exchanger (EAHE) and rainwater-fed cooling coils for energy-efficient cooling.

The EAHE system is designed to pre-cools the air before it enters the building using underground pipes that exploit the earth's stable temperature. This method relies on thermal inertia, where the ambient air temperature is lowered as it flows through the pipes buried 3–4 meters underground. Performance optimization, including the number and depth of pipes, ensures efficient heat exchange.

Rainwater-fed cooling coils enhance this design by circulating harvested rainwater, maintained at approximately 20°C, through embedded coils in walls or ceilings. The flowing water absorbs heat from surrounding surfaces, further cooling indoor spaces. This approach not only reduces energy use but also integrates sustainable practices by reusing rainwater.

Advanced simulation tools like eQUEST are used for calculating cooling loads and evaluating system performance. The simulations account for real-world conditions such as weather data from ISHRAE and local meteorological sources. Factors like soil thermal conductivity and building orientation are also integrated into the design to optimize energy efficiency.
The proposed system is non-intrusive and environmentally sustainable, reducing reliance on conventional HVAC systems. It incorporates measures to ensure reliability under varying climatic conditions, making it a viable solution for energy-efficient cooling in large buildings like the New Boys' Hostel.

CHAPTER-3

SURVEY
SITE ANALYSIS

The New Boys' Hostel, located on the MNNIT Allahabad campus in Prayagraj, Uttar Pradesh, India, is positioned at coordinates Latitude: 25° 29' 45" N and Longitude: 81° 52' 09" E. This 13-storey building currently lacks a heating and cooling system in the rooms for the students residing there. Each floor contains 26 rooms, with a floor-to-floor height of 9.56 ft and a floor-to-ceiling height of 9 ft. The building block is oriented South-West, and the rooms measure 11 x 8.5 x 9 ft^3.This overview provides a snapshot of the hostel's physical attributes, which are essential for designing and retrofitting solutions aimed at energy efficiency and sustainability.

Fig. New Boys' Hostel Building

Fig. Dining Hall Area Inside NBH

The dining hall of the New Boys' Hostel spans a functional area of approximately 1851 square feet. There are two types of windows in this area: one type measures 9.8 x 3.5 square feet, while the other measures 6.5 x 3.5 square feet. The doors measure 5 x 6.5 square feet. The floor-to-floor height is 9.5 feet, and the floor-to-ceiling height is 9 feet.

The passive cooling system that we want to install here is the Earth Air Heat Exchanger (EAHE)**.** The system operates Monday to Sunday for 5 hours per day. The roof is constructed of concrete with a thickness of 4 inches, and the building is oriented South-West.

Fig. Room in NBH

The building features 26 rooms per floor, each designed to meet student housing needs. The vertical distance between two consecutive floors, referred to as the floor-to-floor height, is 9.6 feet, while the internal floor-to-ceiling height of each room measures 9 feet. The dimensions of each room are 11 feet in length, 8.5 feet in width, and 9 feet in height, offering a compact living space.

To ensure proper ventilation and light, each room is equipped with windows and doors of specified dimensions. The windows measure 3.8 feet in width and 3.5 feet in height, allowing sufficient natural airflow and daylight penetration. The doors have a size of 6.4 feet in height and 3 feet in width, providing standard access to the room.

This description summarizes the spatial layout and design specifications of the rooms, which are crucial for comfort, energy optimization, and ventilation.

Fig. Working Area inside Dining Hall

The dining area in the New Boys' Hostel is designed as a functional and comfortable communal space. Its layout ensures adequate ventilation and natural lighting, achieved through well-placed windows and doors that optimize airflow and daylight.

To maintain thermal comfort, the space incorporates a passive cooling system, such as the Earth Air Heat Exchanger (EAHE), which operates efficiently while conserving energy. The concrete roof adds durability and thermal insulation, contributing to the space's sustainability.

The South-West orientation further enhances natural light and airflow, creating a pleasant environment that supports energy efficiency and occupant comfort.

2.2 BUILDING SPECIFICATION

2.2.1 NBH BUILDING SPECIFICATION:

No. of floor	13
No. of Room per floor	26
Floor to Floor Height	9.56 ft
Floor to Ceil Height	9 ft
Orientation of Block	South-West
Room Dimension	11 X 8.5 X 9 ft^3
Window Dimension	3.8 X 3.5 ft^2
Door Dimension	6.4 X 3 ft^2

2.2.2 DINING HALL SPECIFICATION:

Area	1851 ft^2
Dimension of Window(6)	9.8 X 3.5 ft^2
Dimension of Window(2)	6.5 X 3.5 ft^2
Dimension of Door(2)	5 X 6.5 ft^2
Floor to Floor Height	9.5 ft
Floor to Ceil Height	9 ft

2.2.3 eQuest Input: Building Envelope Construction

Categories	Roof Surfaces	Above Grade Walls
Construction	4 in. Concrete	4 in. HW Concrete
Ext. Finish / Colour	Roof, built-up, Medium	Concrete, Medium
Exterior Insulation	3 in. Polyurethane (R-18)	No ext board insulation
Add'l Insulation	No LtWt Conc Cap	No integral insulation
Interior Insulation		R-13 wd furred insulation

Ground floor

Categories	Details
Exposure	Earth Contact
Construction	6 in. Concrete
Ext. / Cav Insulation	No perimeter insulation
Interior Finish	Carpet (no pad)

Infiltration (Shell Tightness)

Parameter	Value
Perimeter Infiltration	0.003-8 CFM/ft² (ext wall area)
Core Infiltration	0.001 CFM/ft² (floor area)

MODEL OF THE BUILDING
MADE USING eQuest :-

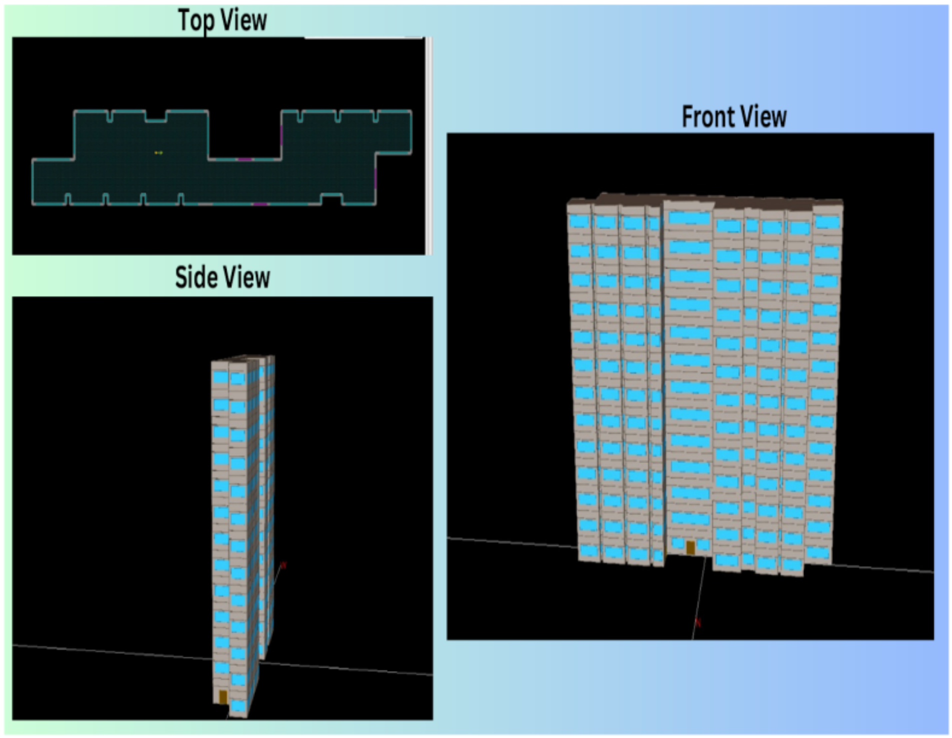


Fig. Model of NBH Building made using eQuest

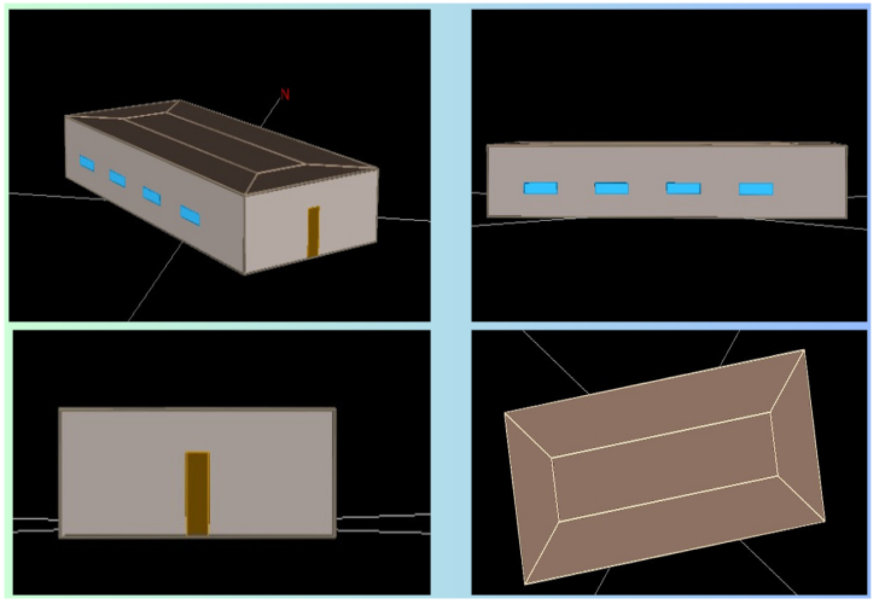


Fig. Model Dining Hall made using eQuest

CHAPTER-4

Calculation of Cooling Load

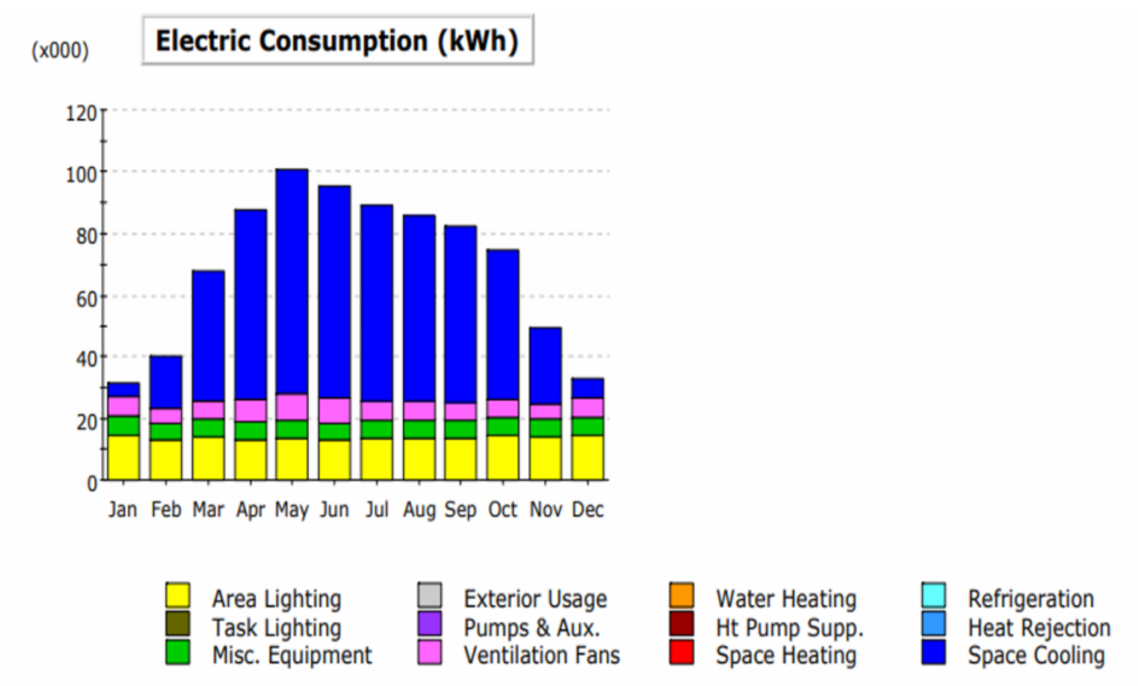
Cooling Load Formula:

Q=E.E.R*Wc/3.5

where Q= Amount of heat
Wc= Work done on compressor
E.E.R= Energy Efficiency Ratio

Cooling Load for Dining Hall:

eQuest Output Electric Consumption(kWh) for Dining Hall:



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	4.13	17.06	42.38	61.62	72.71	68.95	63.66	60.23	57.31	48.77	25.25	6.49	528.57
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	6.65	4.97	5.68	7.40	8.91	8.06	6.54	5.92	6.08	5.52	4.73	6.01	76.47
Pumps & Aux.	0.06	0.00	-	-	-	-	-	-	-	-	-	0.01	0.08
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	5.79	5.23	5.81	5.60	5.80	5.59	5.79	5.81	5.58	5.80	5.60	5.76	68.18
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	14.69	12.97	14.04	13.14	13.33	12.85	13.30	13.62	13.52	14.47	14.05	14.56	164.55
Total	31.33	40.24	67.92	87.77	100.74	95.45	89.29	85.57	82.50	74.55	49.64	32.84	837.85

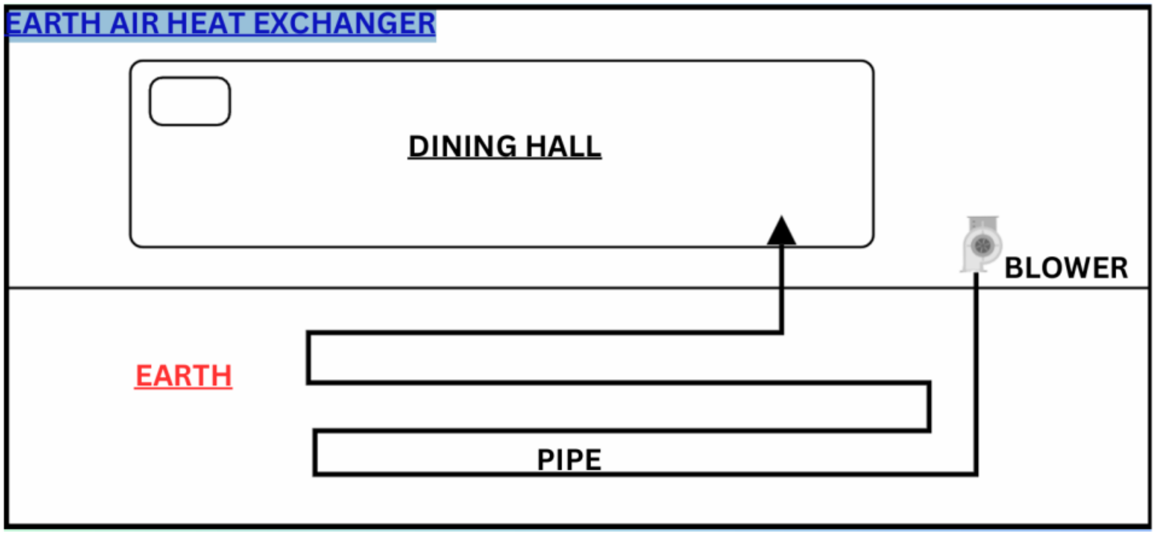
Based on the graph and table, it's clear that the cooling load peaks during May and June, while it is at its lowest in December and January.

Original Cooling Load:

Maximum energy consumption in the month of May = 2.55X10^3 kWh
No. of hours per month for which cooling is required = 150 hours
Cooling COP = 2.5
Total cooling load = (2550 *(9.7/2.5))/150
= 65.96 kW
Total cooling load in TR = 65.96/3.5
= 18 TR

According to the eQUEST model, the maximum cooling load for May is approximately 18 TR.

Schematic Diagram of Proposed System for Passive cooling of the Dining Hall:



CHAPTER-5

Designing the Earth Air Heat Exchanger(EAHE) for Dining Hall

Designing Steps in EAHE

1. Understanding System Requirements
2. Initial Assumptions
3. Geometric Design
4. Calculating Heat Transfer
5. Determining Tube Length
6. Pressure Drop Analysis
7. Air Fan Power
8. Design Iteration

Understanding System Requirements

1. Define the purpose (cooling, heating, or both).
2. Analyze local climate conditions (mean annual air temperature, relative humidity, etc.).
3. Study the site's soil properties (thermal diffusivity, specific heat, and conductivity).
4. Assess the geographic location (latitude, longitude) for temperature stability at depth.
5. Consider site-specific factors:
   - Available Space: Length, breadth, and depth of the site.
   - Terrain: Elevation and uniformity.

Initial Assumptions:

- Temperature of surrounding soil of tube is constant (uniform temperature in axial direction)
- Earth ground temperature (EUT) is constant along the length of the tube.
- Thermal resistance of the pipe is negligible.
- The temperature on the surface of the tube is taken as uniform in axial direction and which is equal to earth's undisturbed temperature.
- Uniform cross-section of tube with smooth surface at inner side.
- Thermo-physical properties (density, viscosity, thermal conductivity and specific heat capacity etc.) of air and soil are constant.

Geometric Design

Determination of the physical parameters of the EAHE to meet the required thermal performance:

1.Tube Dimensions Diameter (D):

Select an initial tube diameter. A smaller diameter increases turbulence and heat transfer but may result in higher pressure drops.
Length (L): The tube length depends on the desired cooling/heating capacity, air velocity, and heat exchange efficiency.

2.Number of Tubes (N):

Decide the number of parallel tubes to distribute airflow and reduce pressure drops.
Optimize the number of tubes and their arrangement based on site dimensions and airflow requirements.

3.Tube Depth:

Place the tubes 3 meters(10 ft) or 4 meters(13 ft) underground where the average temperature will be around 25 degree celsius.

4.Tube Material:

Choose materials with good thermal conductivity (e.g., PVC, metal).
Ensure durability, smooth internal surfaces (to minimize friction), and resistance to corrosion.

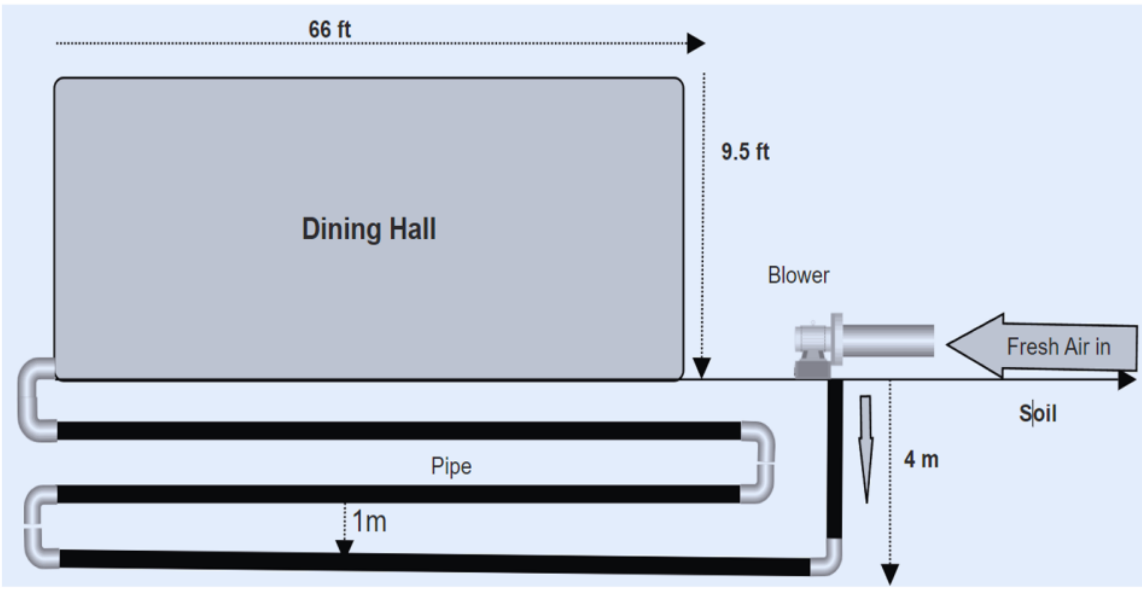
5.Tube Arrangement:

Linear Layout: Simple and easy to install but requires a larger site area.
Spiral or Serpentine Layout: Optimizes sp ace but can increase pressure drops.
Align the tubes to maximize contact with undisturbed soil.

6. Airflow Path:

Ensure an unobstructed airflow path inside the tubes with minimal bends to reduce friction and pressure losses. Integration with Site Dimensions
Fit the tube layout within the site's length and breadth, ensuring adequate spacing to avoid thermal interference between tubes

Schematic Diagram of Proposed Design of EAHE



Calculating Tube Length

- Load Calculation and Mass Flow Rate : Load was calculated by the eQuest software. Using the 18 TR cooling load for the dining hall, the required mass flow rate of air is calculated in order to achieve the needed temperature reduction.
- Heat Transfer Mechanism : Heat is transferred by convection from air to the inner tube wall and by conduction from the outer tube wall to the surrounding soil.
- Convective Heat Transfer Coefficient: This is derived from Nusselt number, NU depending on the airflow as whether laminar or turbulent
- Overall Heat Transfer Coefficient: This is considering the contribution from air, material of tubes and soil as well so it can be used as an indicator of the amount of overall heat transfer happening.
- Rate of Heat Transfer: Obtained by application of the log-mean temperature difference, LMTD using the available surface area of tubes.
- Determining the Tube Length(L) : Used the following equation for finding out the length of tube by taking A=π*D*L.

$$T_{\text{out}} = T_{\text{wall}} + (T_{\text{in}} - T_{\text{wall}})\, e^{-\frac{(UA)}{mc_{p,a}}}$$

Determining Effectiveness and Blower Power

1. **NTU:**

NTU(Net Transfer Unit) is determined using the overall heat transfer coefficient (Ut), surface area of the tube(A), and the minimum heat capacity rate.

$$NTU = \frac{U_t \times A}{C_{\text{air}} \times \dot{m}}$$

2. **Effectiveness (ε):**

An effectiveness of 80% is considered to be an optimum for an earth-air heat exchanger. It can be calculated using NTU as:

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

3. **Pressure Drop Considerations:**

Ensure that the tube length does not cause excessive pressure drop. The pressure drop can be calculated using the Darcy-Weisbach equation.

$$\Delta P = \rho f \frac{v^2}{4r_i} L$$

4. **Blower Power:**

It can be calculated as:

$$B_p = \frac{\Delta P \dot{m}}{\rho \eta_b}$$

5. **Iterative Adjustment:**

The tube length is optimized through an iterative procedure by adjusting parameters such as tube diameter and the number of tubes. This guarantees achieving both the desired heat transfer and an acceptable pressure drop. The process is ensured to guarantee that the tube length facilitates the required heat exchange while maintaining system efficiency and practicality.

EAHE Specifications

Components	Value
Soil Pipe Depth	4 m
Pipe Material	PVC
Pipe Diameter	0.25 m
Pipe Length	29 m
No. of Pipes	28
Pressure Drop	64 Pa
Blower Power	450 W
No. of Blower	6
Layout	Parallel

Calculations:

Step 1: **Given Values**

- Diameter, $D = 0.25\,\mathrm{m}$
- Density, $\rho = 1.168\,\mathrm{kg/m^3}$
- Heat Transfer Rate, $q = 6.3\,\mathrm{kW} = 6300\,\mathrm{W}$
- Temperature difference, $\Delta T = 45 - 30 = 15°C$
- Specific heat, $C_p = 1006\,\mathrm{J/kgK}$

Step 2: **Mass Flow Rate ($\dot{m}$)**

The formula is:

$$q = \dot{m} \cdot C_p \cdot \Delta T$$

Rearranging for $\dot{m}$:

$$\dot{m} = \frac{q}{C_p \cdot \Delta T}$$

Substitute values:

$$\dot{m} = \frac{6300}{1006 \cdot 15} = 6.26\,\mathrm{kg/s}$$

Step 3: **Mass Flow Rate per Tube ($\dot{m}_{\text{tube}}$)**

The formula is:

$$\dot{m}_{\text{tube}} = \rho \cdot V \cdot D$$

Given: $\rho = 1.168\,\text{kg}/\text{m}^3$, $V = 4\,\text{m}/\text{s}$, $D = 0.25\,\text{m}$:

$$\dot{m}_{\text{tube}} = 1.168 \cdot 4 \cdot 0.25 = 0.22\,\text{kg}/\text{s}$$

Step 4: **Number of Pipes (N)**

The formula is:

$$N = \frac{\dot{m}}{\dot{m}_{\text{tube}}}$$

Substitute values:

$$N = \frac{6.26}{0.22} = 29\,\text{pipes}$$

Step 5: **Reynolds Number (Re)**

The formula is:

$$Re = \frac{\rho \cdot V \cdot D}{\mu}$$

Given: $\rho = 1.168$, $V = 4$, $D = 0.25$, $\mu = 1.865 \times 10^{-5}$:

$$Re = \frac{1.168 \cdot 4 \cdot 0.25}{1.865 \times 10^{-5}} = 69500$$

Step 6: **Prandtl Number (Pr)**

The formula is:

$$Pr = \frac{\mu \cdot C_p}{K_{\text{air}}}$$

Given: $\mu = 1.865 \times 10^{-5}$, $C_p = 1006$, $K_{\text{air}} = 0.025$:

$$Pr = \frac{1.865 \times 10^{-5} \cdot 1006}{0.025} = 0.748$$

Step 7: **Friction Factor (f)**

The formula is:

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

Substitute $Re = 69500$:

$$f = (1.82 \log 69500 - 1.64)^{-2}$$

Given $\log 69500 \approx 4.84$:

$$f = (1.82 \cdot 4.84 - 1.64)^{-2} = 0.019$$

Step 8: **Nusselt Number (Nu)**

The formula is:

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

Substitute $f = 0.019$, $Re = 69500$, $Pr = 0.748$:

$$Nu = \frac{0.019}{8}(69500 - 1000)(0.748) \Bigg/ \left(1 + 12.7\sqrt{\frac{0.019}{8}}(0.748^{2/3} - 1)\right)$$

Simplifying:

$$Nu = \frac{0.002375 \cdot 68500 \cdot 0.748}{1 + 12.7 \cdot 0.0172 \cdot (-0.27)} = 137$$

Step 9: **Heat Transfer Coefficient (h_c)**

The formula is:

$$h_c = \frac{Nu \cdot K}{D}$$

Given $Nu = 137$, $K = 0.025$, $D = 0.25$:

$$h_c = \frac{137 \cdot 0.025}{0.25} = 6.85 \,\mathrm{W/m^2K}$$

Step 10: **Total Convective Heat Transfer Coefficient (U_t)**

Since only convective transfer is considered:

$$U_t = h_c = 6.85 \,\mathrm{W/m^2K}$$

Step 11: **Outlet Temperature (T_{out})**

The formula is:

$$T_{\text{out}} = T_{\text{wall}} + (T_{\text{in}} - T_{\text{wall}})e^{\left(-\frac{U_t \cdot A}{\dot{m} \cdot C_p}\right)}$$

Here $A = \pi \cdot D \cdot L$, so solving for L:

Given:

$$\ln\left(\frac{4}{19}\right) = -\frac{U_t \cdot \pi \cdot D \cdot L}{\dot{m} \cdot C_p}$$

Rearranging for L:

$$L = \frac{\ln\left(\frac{4}{19}\right) \cdot \dot{m} \cdot C_p}{-U_t \cdot \pi \cdot D}$$

Substitute values:

$$L = \frac{-1.55 \cdot 6.26 \cdot 1006}{6.85 \cdot \pi \cdot 0.25} = 29\,\text{m}$$

Final Answer:

The required **pipe length** is:

$$\boxed{L = 29\,\text{m}}$$

Calculations	Value
$\dot{M} = \frac{Q_t}{C_{p,a}(T_{\text{out}} - T_{\text{in}})}$	6.26 Kg/s
$\dot{m} = \rho \times A \times V$	0.28 Kg/s
N (no. of pipes)	28
$h = \frac{Nu\lambda}{D}$	1070
$U_t = \left(\frac{1}{h_c} + \frac{1}{2\pi k_t} \ln\frac{r_o}{r_i}\right)^{-1}$	1070 W/Km^2
$T_{\text{out}} = T_{\text{wall}} + (T_{\text{in}} - T_{\text{wall}})e^{-\frac{(UA)}{\dot{m}C_{p,a}}}$	L = 29m
$\Delta P = \rho f \frac{v^2}{4r_i} L$	64 Pa
$B_p = \frac{\Delta P \dot{m}}{\rho \eta_b}$	450 W

Future Scope of Project

1.Integration with Renewable Energy Sources

The passive cooling system can be integrated with solar photovoltaic (PV) systems in order to power the blowers, pumps, and other components. This can make the system completely sustainable, thereby reducing the operational cost and carbon footprint further.

2.Advanced Energy Management Systems

Smart sensors and IoT-based control systems can optimize the operations of Earth Air Heat Exchangers (EAHE). This will provide real-time monitoring of temperatures, airflows, and energy saving.

3. Scalability for Large Infrastructure

The principles of this design can be scaled up to multi-story residential and commercial buildings. It provides an energy efficient and sustainable solution for campus, hospitals, and large hostels in extreme climate zones.

4.Utilization of Rainwater Beyond Cooling

Stored rainwater can also be used for non-potable purposes like irrigation, washing, and toilet flushing, enhancing the overall water sustainability of buildings.

5.Climate Adaptability

Further studies can go to diverse climatic conditions regarding performance from the proposed systems. This could give ways to refine the design on diverse soils, humidity levels, and ambient temperature levels for locations.

6.Economic and Environmental Feasibility Studies

Further analysis into life-cycle assessments, payback periods, and long-term environmental benefits will make the project more attractive for adoption by policymakers and building developers.

CONCLUSION

The EAHE system is very critical in terms of passive heating and cooling based on seasonal changes in the weather. Design calculations also show that an increase in airflow velocity enhances the effectiveness of the system, though, as proven by literature, this occurs only to a certain degree. As claimed by Bisoniya et al. (2013), above an NTU value of 4, the efficiency approaches stability. The experiments indicate that velocity has a minor influence on airflow while determining the efficiency of the EAHE system.

Idealized design calculations often yield higher effectiveness values compared to experimental results. The difference occurs because idealized design calculations neglect real-world complications during analysis.

All key parameters, such as the diameter of the pipe, the volume flow rate, Reynolds number, Nusselt number, friction factor, length of the pipe, and the pressure drop, were calculated using the design equations. Optimized values based on a comprehensive review of all published research studies indicated that for flow velocities of 3 m/s, 4 m/s, and 5 m/s, the effectiveness of the EAHE system attained 88.4%, 93.2%, and 95.7%, respectively. Higher flow velocities increase turbulence, thus resulting in a higher Reynolds number and better heat transfer rates. Moreover, it was seen that as NTU increases, the system effectiveness also increases, which is in line with results presented by Paepe et al. (2003) and Bisoniya et al. (2013).

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