TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS

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Comparative Analysis of HVAC Load, Energy Consumption and Cost for a Commercial Building with Different Wall and Roof Insulation Using HAP.

By

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A THESIS SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN MECHANICAL SYSTEMS DESIGN AND ENGINEERING

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The undersigned hereby certify that they have read, and recommended to the Institute of Engineering for acceptance, thesis entitled "Comparative Analysis of HVAC Load, Energy Consumption and Cost for a Commercial Building with Different Wall and Roof Insulation Using HAP." submitted by Krishna Dev Shah in partial fulfillment of the requirements for the degree of Master of Science in Mechanical System Design and Engineering.

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ABSTRACT

The HVAC system alone consumes over 20% of the world's total energy production, which has scared the engineering and research community to think about improving the system's energy efficiency because it can save a significant amount of energy. Acknowledging this, the goal of this Research is to improve the HVAC system so that overall energy consumption and associated costs can be decreased. This study provides a comparative analysis of HVAC results for a standard commercial building by evaluating the impact of different wall and roof insulation materials and thicknesses. The selected building model consists of seven stories, a basement, and a ground floor. It has an HVAC system equipped with split air handling unit(AHU).

The HVAC loads, energy consumption, and the corresponding Energy costs were determined for the purpose of analysis, using Carrier HAP 6.2. Eight different types of insulation materials, each of different thickness, were analyzed for the walls as well as the roofs. The results obtained from the simulation revealed that the energy consumption and HVAC loads of the HVAC system depend upon the type and thickness of the insulation material. Among the different materials analyzed, Polyisocyanurate of 1-inch thickness insulation exhibited the best possible results for the Exterior walls and Cellulose of 4-inch thickness exhibited the best result for the Roof.

It was discovered that the proposed building has a peak cooling load of 232.9 tons of refrigeration (TOR) and a peak heating load of 75.1 (TOR). During working scheduled operation, this structure uses 541630 kWh of electricity, which costs NRs. 5849603. After applying the wall insulation, 1-inch Polyisocyanurate the Cooling load dropped to 226.4 (TOR) and heating load to 72.8 (TOR) with the change in Energy to 526610 kWh and Electricity cost to NRs.5687405.

Similarly, with the addition of 4-inch Cellulose to Roof the Energy Consumption changes to 528050 and cost to NRs.5702916. On combined form to the wall and Roof the peak Cooling and Heating load was found to be 220.4 (TOR) and 71.2 (TOR) while Energy consumption and Cost found was to be 515763 kWh and NRs.5570227.

ACKNOWLEDGEMENTS

Research is never completed without the assistance of excellent people. I am grateful to my supervisor, Vishwo Prasanna Amatya and Laxman Motra for their support and advice throughout this research project.

Throughout this journey, I've gained a lot of confidence in my ability to focus the study's goal thanks to our ongoing brainstorming sessions and idea generating. I would like to express my gratitude to the Department of Mechanical and Aerospace Engineering for their ongoing assistance and coordination. I am appreciative to all the department lecturers and professors for their helpful advice and considerate assistance during the assignment.

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LIST OF ABBREVIATIONS

HVAC	Heating, Ventilation and Air Conditioning
EIA	Energy Information Administration
CAGR	Compound Annual Growth Rate
XPS	Extruded Polystyrene
EPS	Expanded Polystyrene
CLTD	Cooling Load Temperature Difference
TFM	Transfer Function Method
HBM	Heat Balance Method
RTS	Radiant Time Series
AHU	Air Handling Unit
EMCS	Energy Management and Control Systems
CTF	Conduction Transfer Functions
SCL	Solar Cooling Load Factors
CLF	Cooling Load Factors
TEDA	Total Equivalent Temperature Difference
TA	Time Average
EPS	Energy Simulation Software Tool
ICE	Indoor Climate Energy
IESVE	Integrated Environmental Solution Virtual Environment
HAP	Hourly Analysis Program
NEA	Nepal Electricity Authority

CHAPTER ONE: INTRODUCTION

1.1 Background

Heating, Ventilation, and Air Conditioning(HVAC) is a mechanical system that regulates the temperature, humidity, and airflow in a building or other enclosed area. HVAC system are extensively utilized in residential, commercial, and industrial environments for both comfort and protection from the elements or the consequences of inadequate air circulation, as well as for sufficient ventilation through the control of the exchange of indoor and outdoor air. For maximizing the building energy efficiency HVAC systems are very crucial. Lowering global energy consumption levels, Limiting HVAC load is very critical. (V.Nagda, 2022)

According to surveys, building activities account for 27% of all energy sector emissions and 30% of worldwide energy consumption, making up a sizable share of the world's energy consumption (Pan, 2023). Building are the major source of energy consumption and account for 48% of energy consumption. HVAC energy utilization in commercial buildings, as opposed to residential ones, usually entails intricate HVAC configurations that may consist of several subsystems with complementary roles. Space heating makes up around 45% of all commercial building HVAC energy usage, according to the U.S. Energy Information Administration (EIA). HVAC is the main source of energy use in the majority of commercial buildings, frequently making up 40–60% of the total. An estimated $175 billion will be spent on energy-efficient commercial building worldwide in 2023. Over the following five years, this industry is expected to increase at a compound annual growth rate (CAGR) of almost 7%, reaching a projected value of $250 billion by 2028 (Francis, 2025)

In building industries energy saving HVAC play a very crucial role in increasing energy efficiency. With the advancement of HVAC system Engineering has evolved to include more energy-efficient technology. Walls and roof of a building and its thermal characteristics have a significant impact on HVAC system performance and also its efficiency. HVAC load analysis determines how much heating or cooling is needed to maintain comfortable indoor temperatures. This technique considers factors such as building size, orientation, occupancy, internal heat gains, and, most critically, the amount and type of insulation used in the walls and roof. Adequate insulation reduces undesired heat transmission, lowering the HVAC load and energy consumption.

To keep the interior rooms, warm in the winter and cool in the summer, walls and roof insulation act as a heat barrier. Insulating the walls and roof can significantly reduce overall energy loss, resulting in the lower operational loads for HVAC systems and corresponding energy savings. For the determination of the effective insulation it is identified by its thickness and material-specific thermal resistance (R-value), which affects the amount of energy saved.

Fiberglass, Cellulose, Polystyrene, Mineral wool, and Advanced foams are all insulation materials that can be used in building structures. Each material has unique thermal properties, environmental impacts, installation requirements, and costs. For example, while fiberglass is inexpensive and widely used, contemporary materials such as extruded polystyrene (XPS) or closed-cell spray foam offer higher R-values and enhanced moisture resistance at a higher price.

Insulation of building envelopes, both opaque and transparent, might be one of the most crucial strategies for building energy saving. The most crucial components of energy-efficient homes are insulation for the walls, roof, attic, basement walls, and even the foundation. In a commercial building for the decrease in the HVAC load and energy costs, Insulation materials play a very important role as insulation have a direct impact on the thermal performance of the building envelope, which ultimately influence how much the heating or cooling must deliver. For lower heat transmission through walls and roof the insulation should be well-chosen, lowering indoor temperature variations and reducing the need for HVAC system to compensate for external temperature extremes.

ASHRAE provides several HVAC system size calculation approaches, including the Cooling Load Temperature Difference (CLTD), Transfer Function Method (TFM), Heat Balance Method (HBM), and Radiant Time Series (RTS) Method. Conversely, exact application of manual calculations is challenging. To help with HVAC system design, planning, and simulation, a variety of software applications have been created.

1.2 Statement of problem

Heating, Ventilation, and air conditioning (HVAC) systems account for a significant share of the global increase in commercial building energy use. Due to insufficient insulation, commercial building demonstrates uncontrolled energy consumption that result in the higher utility bills. Numerous number of insulation are available with their respective thermal, economic, and environmental qualities. Due to lack of concord data materials provide the most effective balance of performance and cost under diverse climate and building situations. To maximize the benefits of the HVAC system for thermal comfort, the best insulation must be selected after calculating the HVAC load, energy consumption, and consequently energy cost. material to reduce HVAC load and energy expenses. The efficiency and operating costs of HVAC systems are directly impacted by the thermal performance of the building envelope, particularly the insulation used in walls and roofs. Despite the widespread availability and use of many insulating materials, major ambiguities remain about their comparative impact on HVAC load, overall energy consumption and the cost-effectiveness.

1.3 Objective

1.3.1 Main Objective

The main objective of this research is to compare different types of insulation to walls and roof in a commercial building based on HVAC load, Energy Consumption, and Energy Cost.

1.3.2 Specific Objectives

The specific objective of this thesis are:

i. Analyze how various insulation materials lower the HVAC load and Energy Consumption.
ii. Evaluate the cost effectiveness of different insulation types in terms of electricity savings.
iii. Determine the best insulation material combinations for energy efficiency and cost effectiveness.

1.4 Limitations

The limitations of this thesis are:

i. This study is based on simulated findings from Carrier HAP 6.2.
ii. This research is based on a single commercial building model.
iii. The study assumes fixed working hours (e.g., 9 AM-5 PM, six days per week).
iv. The weather data utilized is limited to Kathmandu and may not reflect variances in microclimates or future climate change.
v. Only certain insulating materials and thicknesses were analyzed.
vi. Energy costs are calculated using a set electricity rate (NRs. 10.8/kWh).
vii. The analysis focuses only on energy expenditures and does not account for installation, lifespan, or maintenance costs of insulating materials.

CHAPTER TWO: LITERATURE REVIEW

One of the very big energy consumers is a Commercial Building, with heating, ventilation, and air conditioning (HVAC) loads accounting for a large part of overall energy consumption. HVAC in a commercial building i.e. Hospitals are placed for maintaining precise temperature, humidity and air quality for patient safety. The best way for lowering the HVAC loads, energy consumption, and expenses is by placing the insulation in walls and roof. Various insulation materials are available and various research are being done to provide critical insights for improving building performance.

2.1 HVAC System Operation within a Building

Operation of HVAC system in a building is done by regulating indoor temperature, air quality, and humidity to maintain comfort for occupants.

Working of this HVAC display the entering of outside fresh air to the building via a controlled intake and then flow through manual and motorized dampers to regulate airflow before being filtered and conditioned by the AIR Handling Unit (AHU).
After the air get treated it is to be distributed to various rooms and is done via supply ducts, while the used air is collected back to the AHU through return ducts for re-conditioning. Separate exhaust systems are used to remove humid or contaminated air from bathrooms and kitchen to maintain good air quality directly to the outside, for ensuring a continuous circulation of clean, comfortable air throughout both floors of the building. (Bhaveshk, 2024).
During cooling, a compressor compresses low-pressure refrigerant gas, which is then condensed into a high-pressure liquid that releases heat outdoors; this liquid refrigerant then expands and evaporates inside coils, absorbing heat from indoor air and cooling it before the blower distributes the chilled air through ducts.

During heating, the furnace or boiler generates heat by burning fuel or using electricity, which warms air circulated throughout the building by the blower through ductwork.

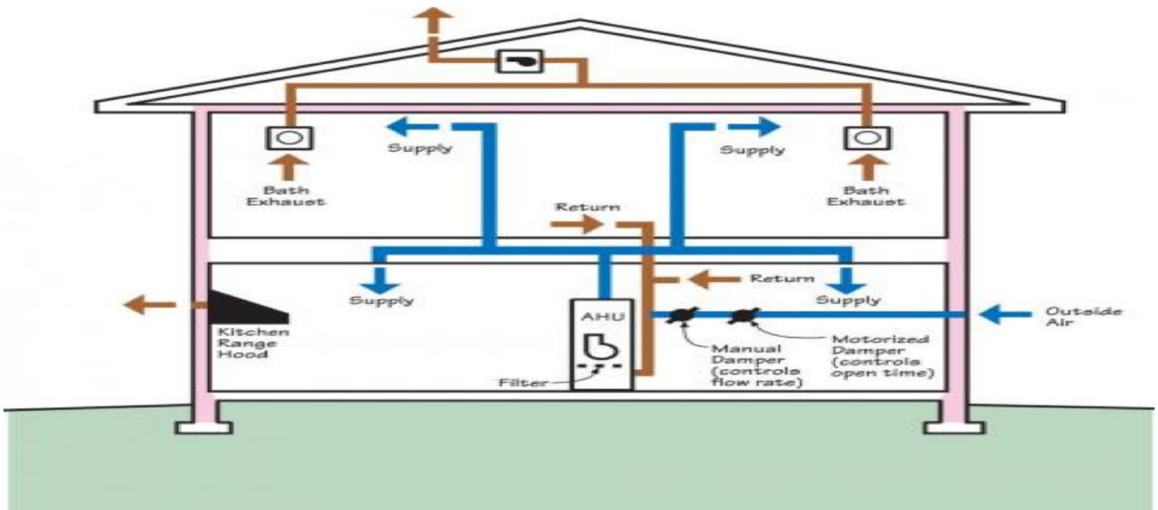

Figure 2.1: Air distribution in a building *(Bhaveshk, 2024)*

2.2 HVAC load and Energy Consumption

HVAC load refers to the amount of work any system must do to keep the structure comfortable.

The quantity of heat energy needed to keep a space's temperature within a suitable range is referred to as heating loads. Conversely, cooling loads are the quantity of heat energy that must be extracted from a space in order to keep the temperature within a suitable range. (Frederick, 2025)

To make sure getting the right capacity, it's crucial to learn more about these three types of HVAC equipment before making a purchase.

- Design load: Directly linked to the designated design specifications The typical load under expected conditions used for system sizing.
- Extreme load: Refers to the hottest and coldest temperatures any given place experiences.
- Part load: Take into consideration the average requirements for cooling or heating during an average day. (rinaldi's air conditions)

Three different forms of time-dependent heat flow rates are used in air conditioning design:

1. Gain or loss of Heat.
2. Heating or Cooling Load.
3. The rate of heat addition or extraction.

The quantity of heat that enters a place from a source that may produce and transfer heat is known as heat gain. There are two distinct kinds of heat gains in terms of the sources of generation.

1. Sensible Heat Gain: The direct Heat accumulation within a space through radiation, convection, or conduction without altering Water vapor content is known as sensible heat gain. Temperature variations are caused by sensible heat gains.

2. Latent Heat Gain: Latent heat gain is the energy that is added to a place by moisture addition, such as vapor released by occupants or air infiltration from the outside. (Meredith, 1998)

Commercial buildings are complex systems with numerous parts that use energy in different ways. The U.S. Energy Information Administration (EIA) estimates that commercial buildings use around 19% of the country's total energy. Opportunities for cost savings and efficiency gains can be found by knowing the precise locations where energy is used.

Primary energy consumers in commercial buildings (Dmytriyeva, 2024)

- HVAC systems (approximately 40% of total energy use)
- Lighting systems (approximately 14% of total energy use)
- Office equipment and plug loads (approximately 10–15%)
- Heat rejection systems (approximately 13%)
- Elevators and escalators (approximately 9%)
- Domestic hot water systems (approximately 4–7%)

Calculating the amount of energy used in homes that are still under construction or are being retrofitted makes it possible to determine design fees more precisely and to determine the most accurate gadgets that may be used in a room (restricted zone) or home. (Sousa, 2012)

2.3 Thermal Insulation and Its role in Building Energy Efficiency

In this modern era of building construction thermal insulation is very important and play a very important role for creating energy-efficient environment. Thermal Insulation helps to maintain comfortable indoor temperature year-round by minimizing the transfer of heat through the building envelopes where the insulation is applied. Insulation to the building envelopes acts as a barrier that block or reduces the movement of heat between the inside and outside of a building. By lowering the need for heating and cooling, insulation helps maintain a steady interior temperature. Installing insulation reduces energy consumption and improves energy efficiency, which is essential for comfort and cost savings.

Air is trapped inside the structure of insulation materials. Heat flow is resisted by this trapped air, which slows it down. The R-value of various materials indicates how well they insulate. Better insulation is indicated by higher R-values. By installing enough insulation, buildings become more energy-efficient by reducing the amount of heat that departs in the winter and enters in the summer. (Chawla, 2024). Buildings lose 50% of their heat through external walls, 20% through roofs, 20% through windows and doors, and 10% through basement and foundation walls. Your building's thermal insulation provides more effective use of energy and natural resources while cutting your heat and electricity costs by 50%. (teknopanel, 2026)

2.4 Heat Gain and Cooling Load Calculation Methods

Energy forecasting is necessary for the HVAC system's design, commissioning, operation, and management. Simulation is also used to evaluate control approaches and optimization algorithms in Energy Management and Control Systems (EMCS). models. Building energy and HVAC system simulation systems depend on prediction models for heating and cooling loads. The primary factor influencing cooling and heating loads and a major contributor to a building's energy needs for HVAC systems is heat transmission through the building. A transient thermodynamic analysis of heat flow in building constructions is necessary for the thorough assessment of energy consumption and dynamic modeling of the HVAC system. (Kalogirou, 2014)

2.4.1 Conduction Transfer Function Model

Building cooling load and energy calculations frequently use conduction transfer functions (CTFs) to compute conduction heat transfer. Conduction calculations can be easily performed using any load and energy calculation method. (Youming Chen, 2006)

The CTF method expresses the heat flux (heat flow per unit area) at the inside and outside surface of a building element as a linear combination of current and past surface temperature and past heat fluxes. It converts what is essentially a transient heat conduction problem into a time series linear equation with constant coefficients, called the conduction transfer function coefficients. These coefficients are calculated once for each wall or construction type, enabling fast computation during simulation without repeatedly solving differential heat conduction equations.

Conduction heat transfer is typically treated as a one-dimensional, transient process with constant material properties in energy analysis, building modeling, and cooling load and energy calculations. Equation (2.1) displays the simplified heat diffusion equation in Cartesian coordinates.

$$\frac{\partial^2 T(x,\tau)}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T(x,\tau)}{\partial \tau} \quad \text{……} (2.1)$$

where T, x, α and τ are the temperature, heat flow direction, thermal diffusivity and time, respectively.

Equation (2.2) of Fourier's law describes the conduction heat flux in terms of the material's thermal conductivity and temperature gradient across a differential thickness.

$$q = -k\frac{\partial T(x,\tau)}{\partial x} \quad \text{……} (2.2)$$

where q and k are heat flux, thermal conductivity, respectively.

Equations (2.3) and (2.4) illustrate how the method yields a straightforward linear equation that represents the current heat flux in terms of the current temperature and temperature and heat flux histories.

$$q_{o,\Theta} = -\sum_{n=0}^{Ny} Y_n T_{os,\Theta-n\delta} + \sum_{n=0}^{Nx} X_n T_{os,\Theta-n\delta} + \sum_{n=1}^{N\Phi} \Phi_n q_{o,\Theta-n\delta} \quad \text{……} (2.3)$$

$$q_{i,\Theta} = -\sum_{n=0}^{Nz} Z_n T_{is,\Theta-n\delta} + \sum_{n=0}^{Ny} Y_n T_{os,\Theta-n\delta} + \sum_{n=1}^{N\Phi} \Phi_n q_{i,\Theta-n\delta} \quad \text{……} (2.4)$$

where, $q_{o,\Theta}$ and $q_{i,\Theta}$ represent the heat flux at the outer and interior surfaces, respectively. Surface-to-surface exterior, cross, and interior CTF coefficients are denoted by X_n, Y_n and Z_n respectively. The internal surface temperature is denoted by T_{is}, while the outside surface temperature is denoted by T_{os}. The numbers of exterior, cross, and inner CTF terms are denoted by N_x, N_y, and N_z, respectively. The flow coefficient is denoted by φ_n. The number of flux history terms is N_φ. The time step is denoted by δ, while the current time is represented by the subscript θ. A current value is indicated by the zero subscript.

2.4.2 Cooling Load Temperature Difference Method(CLTD)

This is a manual load calculation procedure that produces cooling load on an hourly basis if desired. The CLTD approach uses cooling load factors (CLF) for internal heat sources, solar cooling load factors (SCL) for solar gain through windows, and a temperature difference (CLTD) for walls and roofs. The CLTD, SCL, and CLF change with time and depend on the building's specifications and the surrounding environment.

For walls and roofs,

$$q_0 = UA(CLTD) \quad (2.5)$$

Where,

U = overall heat transfer coefficient, Btu/(hr- ft^2-F) or W/(m^2-C)

A = area, ft^2 or m^2

CLTD = temperature difference which gives the cooling load at time Θ, F or C

For Solar gain through glass,

$$q_0 = A(SC)SCL_0 \quad (2.6)$$

where,

A = area, ft^2 or m^2

SC = Shading coefficient (internal shade)

SCL_0 = Solar cooling load factor, Btu/(hr- ft^2-F) or W/(m^2-C)

For Internal heat gains,

$$q_0 = q_i(CLF)_0 \ldots\ldots\ldots \qquad (2.7)$$

where,

q_i = instantaneous heat gains from lights, people, and equipment, Btu/hr. or W

CLF_0 = Cooling load factor for time Θ

Calculations for every hour of the day take too much time when done by hand. In this situation, it is possible to estimate the time of day when the cooling demand will be at its highest. In actuality, it might be necessary to identify two distinct kinds of peaks. The air amount for each room must first be calculated using the peak load time for that room. Second, a central unit's size depends on the peak load time for a zone it serves. Cooling load estimations should be done during these peak periods. Together with the orientation and physical attributes of the room or space, the tables of CLTD, SCL, and CLF values are used to estimate when the peak load will occur. (Ali Vedavarz, 2007)

2.4.3 Radiant Time-Series Method

A simplified technique for determining design cooling loads based on the heat balancing (HBM) method is the radiant time series (RTS) approach. All other simplified (non-heat balance) methods, such as the transfer function method (TFM), the cooling load temperature difference/cooling load factor (CLTD/CLF) technique, and the total equivalent temperature difference/time averaging (TETD/TA) method, are virtually eliminated. This technique was developed to offer a rigorous method that measures each component's contribution to the overall cooling load without requiring iterative computations. (D.Spitler, 1997).

Two time-delay effects that are present in building heat transfer processes must be taken into account when calculating cooling loads. The RTS approach multiplies hourly heat gains by 24-hour time series to account for both conduction time delay and radiant time delay effects.

General procedure for calculating cooling load is as follow:

- Determine the component heat gain profile over a 24-hour period for the design day (for conduction, use conduction time series to account for conduction time delay).
- Divide heat gains into convective and radiative components.
- To account for the time delay in conversion to cooling load, apply the proper radiant time series to the radiant portion of heat gains.
- To calculate the cooling load for each hour for each cooling load component, add the convective and delayed radiant parts of heat gain.

Once the cooling loads for each component have been calculated for each hour, add them up to find the overall cooling load for each hour. Then, choose the hour with the highest load for the air conditioning system's design.

The conductive heat gains for the surface, qϴ, for any given hour are obtained by multiplying the total response factors by the temperature differential throughout the surface. ϴ.

$q\Theta = A\sum_{n=0}^{23} Y Pn(te,\Theta\text{-}n\delta\text{-}trc)$…………………………………………………..…. (2.8)

where YPn = nth response factor;

A = surface area, $ft^2\ or\ m^2$;

qϴ = conductive heat gains for the current hour, Btu/h (W), for the surface; trc is the presumed constant room air temperature, ˚F (˚C), and

te,-nδ is the sol-air temperature, ˚F (˚C), n hours ago.

The hourly radiant heat gains are converted to hourly cooling loads using the RTS method. According to Equation, the radiant portion of hourly heat gains is converted to hourly cooling loads using the radiant time series that is thus produced.

2.4.4 Heat Balance Method

The Heat Balance Method addresses how mass, conduction, convection, and radiation interact. Mass can be absorbing energy in one form (radiation) while giving off energy in another form (convection). Because air is transparent, radiation does not impact air in a room (practically speaking, we are ignoring how a large amount of air and air chemistry can impact radiation, such as the earth's atmosphere). The ASHRAE Heat Balance Method is the most comprehensive, physics-based method available today. It forms the foundation of Energy Plus, DOE-2, and other modern simulation engines, and it's also at the core of our Buildings AI load & energy simulation engine.

Figure 2.2: Heat balance process flow diagram

Heat Gain:

Instantaneous rate at which heat enters or is generated in a room.

Heat is transferred into a room by:

-Conduction

-Convection

-Radiation

To calculate the sensible cooling load for our room we need to determine the convection from internal heat generators, such as people, lights and equipment, we need to determine the convection from surfaces in the room (we need to know the surface temperatures first in order to do that), and we need to determine the contribution from infiltration. Summing the results of all three and that gives us our room sensible cooling load.

The Heat Balance Method solves for a room cooling load by writing heat balance equations for every surface in the room. Those heat balance equations include every conduction, convection and radiation process associated with a surface. In addition, a heat balance is written for the room air mass. Because all of these heat balance equations are interrelated, they must be solved simultaneously to determine the temperatures and heat flows at each surface. That allows us to calculate the sensible load for the room. Explicitly calculating the radiation heat flows is one of the elements of the Heat Balance Method that is not present in the other simplified methods that have been used in the past. And that is one of reason why Heat Balance Method can provide results that are more faithful to building physics and can be more accurate.

Outside surface heat balance

$q''_{sol} + q''_{LWR} + h_o (T_o - T_{so}) = q''_{cond}$ .... (2.10)

Conduction through wall

$q''_{cond,t} = \sum_{j=0}^{n} X_j T_{o,t-j} + \sum_{j=0}^{n} Y_j T_{i,t-j} + \sum_{j=1}^{n} Z_j q''_{cond,t-j}$ .... (2.11)

Inside surface heat balance

$q''_{cond} + q''_{sw} + q''_{LWX} = h_i(T_{si} - T_z)$ .... (2.12)

Zone air Heat Balance

$\sum h_i A_i (T_{si} - T_z) + m_{sys} c_p (T_s - T_z) + m_{inf} c_p (T_o - T_z) + Q_{int} = 0$ .... (2.13)

Where,

- q_{sol}'' = absorbed solar radiation
- q_{LWR} = net long-wave radiation (sky + surroundings)
- h_o = outside convective heat transfer coefficient
- T_o = outdoor air temperature
- T_{so} = outside surface temperature
- q_{cond}= conduction heat flux into wall

-X_j, Y_j, Z_j = conduction transfer function coefficients

- T_o, T_i = outside and inside surface temperatures

- $t-j$ = previous time steps

- q_{SW}'' = absorbed short-wave radiation (solar inside)

-q''_{LWX} = long-wave radiation exchange with other surfaces

-h_i= inside convective heat transfer coefficient

-T_{si} = inside surface temperature

-T_z = zone air temperature

-A_i = surface area

-m_{sys} = supply air mass flow rate

-T_s = supply air temperature

-m_{inf} = infiltration air flow rate

-Q_{int} = internal heat gains (people, lights, equipment)

-c_p = specific heat of air

To use the Heat Balance Method, you have to solve the equations for the heat balance of the outside surface, the inside surface, and the zone air all at once. These equations use conduction (through conduction transfer functions), convection, and radiation heat transfer methods to figure out the heating and cooling loads of a building. (T.Agami Reddy, 2017)

2.5 Simulation Models for Evaluating Energy Consumption

Simulation approaches for assessing energy consumption in buildings rely on complex whole-building energy modeling software that incorporates thermal, HVAC, lighting, and occupant behavior dynamics. These models assist in predicting how design decisions, insulation, systems, and operational techniques affect energy consumption, comfort, and efficiency. (Jingjing An, 2019)

Over time, improvements have been made to building energy simulation software tools in addition to building materials and construction methods. There are currently a number of energy simulation software programs available, each with varying degrees of sophistication and variable responsiveness. The HAP, Energy Plus, ESP-r (Energy Simulation Software tool), IDA ICE (Indoor Climate Energy), IES-VE (Integrated Environmental Solutions - Virtual Environment), and TRNSYS are some of the most comprehensive simulation software programs. (Sousa, 2012)

From the given list of energy simulation tools in this, research HAP as energy simulation tool were used.

2.5.1 HAP (Hourly Analysis Program)

The Carrier Hourly Analysis Program (HAP) is a widely used HVAC system design and energy analysis software developed by Carrier Global Corporation. HAP helps engineers design commercial buildings' HVAC systems. HAP is a combination of two tools. It is first used as a tool for HVAC system design and peak load calculations. It is also a tool for estimating energy expenses and simulating energy consumption. For load estimates and comprehensive hour-by-hour energy simulation methods, HAP employs the ASHRAE Heat Balance Method. HAP determines the necessary sizes for HVAC system components by calculating peak cooling and heating loads for commercial buildings. By simulating building operation for each of the 8,760 hours in a year, HAP determines annual energy use and energy expenses for HVAC and non-HVAC energy consuming systems in a project.

Building loads are calculated for three different purposes in HAP:

- For design cooling conditions in order to size cooling equipment.
- For design heating conditions in order to size heating equipment.
- For observed hour by hour operating conditions during energy modeling calculations to determine annual energy performance.

HAP offers tools that make it easy to compare the energy costs of various HVAC design options throughout both the project's preliminary and detailed design phases:

1. The purpose of energy modeling during a project's preliminary or schematic design phase is to swiftly assess the energy cost performance of numerous design options in order to select a limited number of designs with the best performance for more, in-depth research.

2. The objective of energy modeling during a project's detailed design phase is to thoroughly examine and improve the design.

2.6 Types of Wall and Roof Insulation Materials

As known already that insulation reduces the heat transfer and energy consumption ultimately the cost. Using the insulation in wall and roof is the appropriate place for using it for maximum energy consumption. Choosing the right insulation for wall and roof can also be the another best way for maximizing the energy consumption. Choosing the right insulation depends on application, climate, budget, and installation constraints. For roof and wall the following insulation materials can be taken as a references and analysis are to be done for all to choose the best and appropriate insulation materials. The Insulation materials are:

1. Expanded Polystyrene (EPS).
2. Extruded Polystyrene (XPS).
3. Polyisocyanurate (Polyiso/PIR).
4. Fiberglass Batt.
5. Mineral wool Batt.
6. Cellulose.
7. Spray Foam (Open cell).
8. Spray Foam (Closed cell).

2.7 Annual Energy Cost Calculation

The annual energy cost can be computed as the sum of monthly energy costs. The service charge and unit cost of power vary based on the installed energy meter size. In this paper, we used a rated household system to calculate costs. Monthly costs can be computed as follows:

$Cost_i = S + U * R$ ………………………………………………………………….. (2.14)

Annual Cost = $\sum_{i=jan}^{Dec} Costi$ ……..…………………………………………...…….. (2.15)

Where,

$Cost_i$ = Energy Cost for month i,

i = Jan, feb, mar…dec,

S = Service Charge (varies as per the Ampere rating of supply line and unit consumed),

U = Unit of electricity consumed, kWh,

R = Rate of electricity per unit (varies as per the Ampere rating of supply line and unit consumed),

2.8 Previous Research

Changing the building envelope materials (like walls, roofs and windows) affects the HVAC load, annual energy consumption and energy cost of a proposed residential building in Bhaisepati, Lalitpur, Nepal. Initial design had high HVAC loads (5.15 TOR heating, 5.65 TOR cooling), annual energy uses of 55,244 kWh, and energy cost of NRs. 710,191. By selecting and optimizing envelope materials with the lowest energy use intensity (EUI), the final design reduced peak HVAC (to 2.76 TOR heating, 3.63 TOR cooling), annual energy use (to 37,420 kWh), and annual cost to NRs .478486. (Thapa, 2020)

Table 2. 1 Comparison of Proposed and Optimized Design

Description	Initial	Final	Reduction
Peak Heating Load, TOR	5.15	3.63	30%
Peak Cooling Load, TOR	5.65	2.76	51%
EUI, kWh/ ft^2.yr	40	29	28%
Annual Energy Use, kWh	55,244	37,420	32%
Annual Energy Cost, NRs.	7,10,191	4,78,486	33%

The building's HVAC equipment was sized based on the HVAC peak demand. Both summer and winter HVAC loads were calculated. Energy use intensity has been computed and a 24-hour operation plan has been taken for annual energy consumption in order to compare energy consumption.

A window ratio of 0.3 in the east, west, and north directions, together with two thirds of the window height shade and triple pane, were discovered by running the simulation with different windows on each face. Low-E glass was chosen for building optimization since it produced the least amount of energy use intensity. In a similar manner, the wall simulation was conducted with all variables held constant. R38 wood walls produced the lowest EUI, however as they are not built in Nepal, reinforced concrete has been taken into consideration while building walls. R60 insulated roofs produced the lowest EUI, but they are uncommon in Nepal, so a 4" uninsulated concrete roof was selected for the final design even though it produced a high EUI.

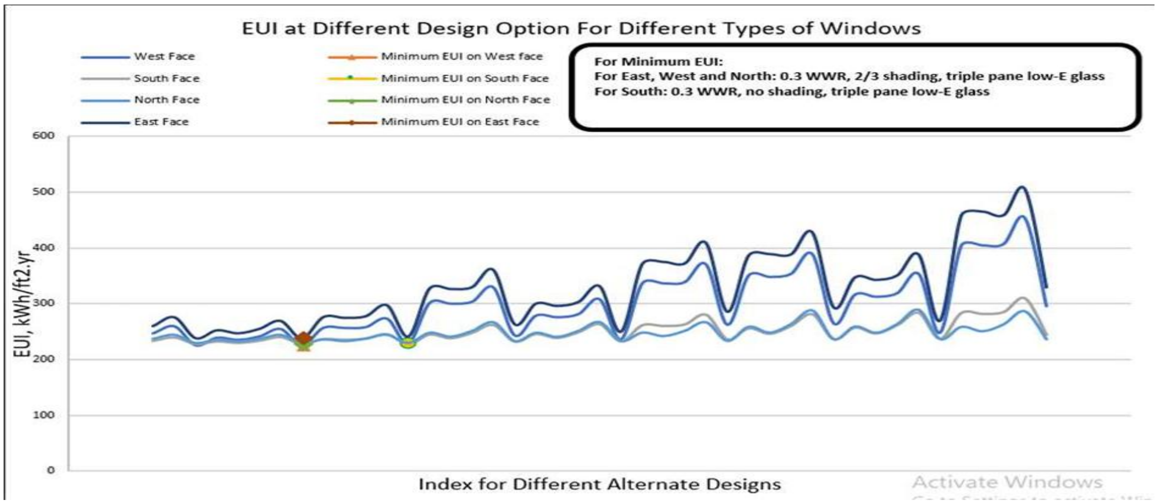

Figure 2.3: EUI at Different Design option for window *(Thapa, 2020)*

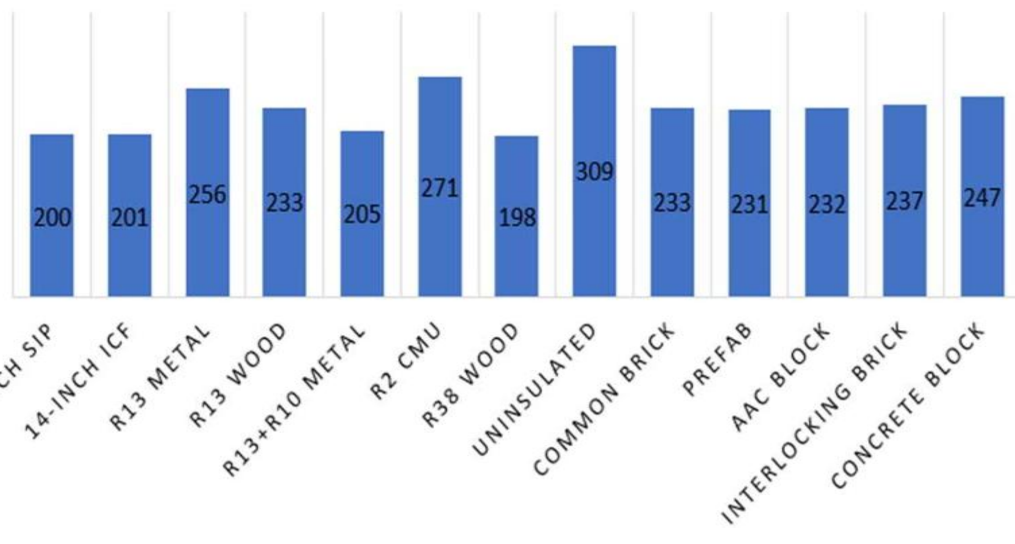

Figure 2.4: EUI at Different Design Option for wall *(Thapa, 2020)*

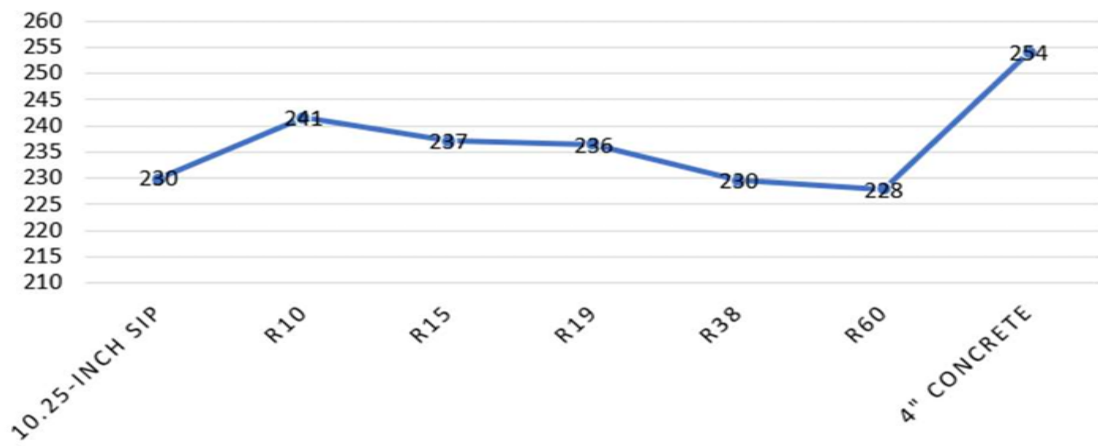

Figure 2.5: EUI at Different Design Option for Roof *(Thapa, 2020)*

Using eQUEST, a simulation to obtain building energy consumption data for a range of R-values of walls, roof, and windows of a typical two-story single-family home in the United States in two climate zones (Detroit, Michigan cold; Miami, Florida hot), it is possible to quantify the impact of insulation of different parts of building envelopes on building energy consumption. The results show that:

In cold climate (Detroit, Michigan)

- Walls contribute for approximately 25.5% of annual heat loss. Maximally insulating walls can save up to 25.5% on space heating energy and 11.9% on overall home energy. Diminishing returns: Increasing wall insulation over R-40 (US) provides little incremental economic benefit.
- In Roof insulation compared with the base-case roof insulation consume 22% more energy respectively. Diminishing returns: increasing roof insulation over R-80 (US) reduces less than 5% of annual heating and cooling energy. (Kim, 2009)

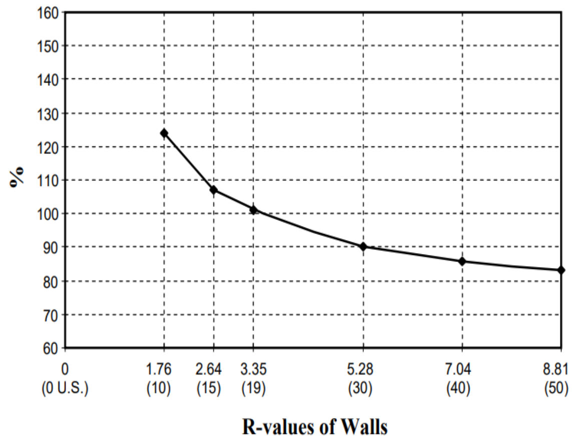

Figure 2.7: Energy Consumption Rate Vs R-value of Wall (Detroit, Michigan) *(Kim, 2009)*

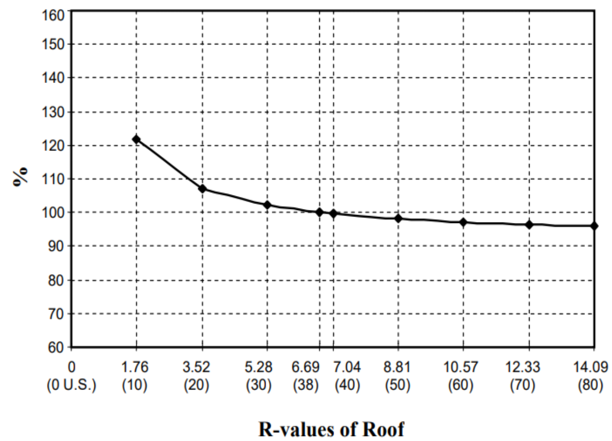

Figure 2.6: Energy Consumption Rate Vs R-values of Roofs (Detroit, Michigan) *(Kim, 2009)*

In hot climate (Miami, Florida)

- ➢ Wall insulation does not influence home energy consumption, when R-19 (US) wall insulation increases less than 5% of home energy consumption. When wall insulation is R-30 (US) home energy consumption decreases less than 2%.
- ➢ In roof insulation in the range R-10 and R-80 (US) does not influence home energy consumption unless roof value R-value is extremely low, less then R-10 (US) for instance, addition roof insulation does render significant energy benefits.

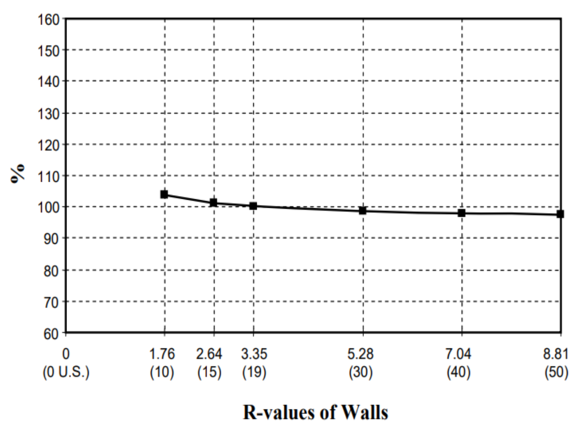

Figure 2.9: Energy Consumption Rate Vs R-value of walls (Miami, Florida) *(Kim, 2009)*

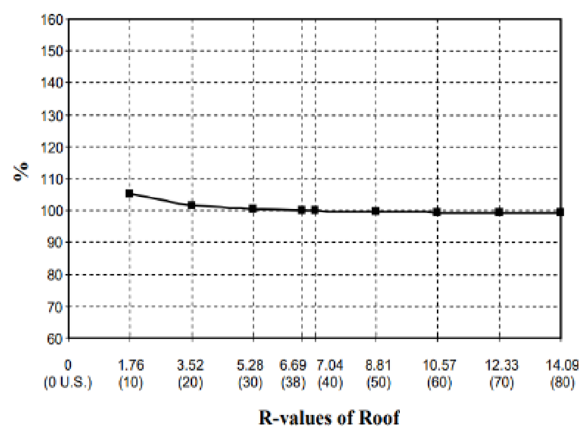

Figure 2.8: Energy Consumption Rate vs R-value of roofs (Miami, Florida) *(Kim, 2009)*

When comparing energy consumption in different insulating scenarios: The energy consumption and heating/cooling loads of mid-rise residential buildings were determined using Kabul city version 4.9 of the HAP program. By adding insulation to the envelope's different components (walls, roofs, windows, etc.), buildings under study can reduce their energy consumption by 30 to 40 percent while also improving indoor thermal comfort. In winter, wall and roof insulation significantly reduces heating, but in summer, their impact on cooling loads is negligible because of the small temperature changes between the outside and inside.

Increasing insulation thickness reduces heating loads considerably at first, but energy saving diminish beyond a certain optimum thickness in this study. Window improvements (switching from single-glazing to double-glazing) yield about 11% annual energy savings, especially by reducing winter heat losses. Solar gain through windows is the biggest source of summer heat gain, so shading and efficient window technologies are important for reducing cooling loads. (Rasuli, 2023)

Thicker wall insulation results in lower primary energy usage. Heating loads use more energy than cooling loads. From 0 to 4 cm of insulation thickness, the heating energy consumption drops significantly; beyond that, the impact of insulation thickness is negligible. The ideal thickness is determined to be 4 cm of polystyrene insulation R-1.93 (SI).

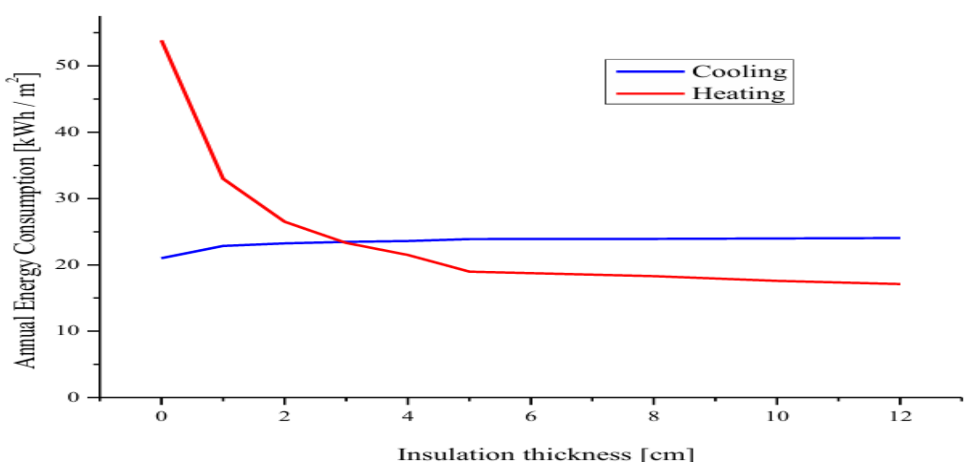

Figure 2.10: Energy Consumption for heating and cooling loads at various insulation thickness *(Rasuli, 2023)*

When windows are insulated, energy consumption is reduced by roughly 11%. Heat loss is more affected by window insulation than heat gain. Heat gain drops from 62.74W/m^2 to 52.5W/m^2, while heat loss falls from 62.01W/m^2 to 36W/m^2.

Heat intake and loss are greatly decreased for roof insulation as the roof's R-value rises. Roof insulation reduces the building's overall energy usage by 3%, according to an annual energy analysis. The amount of energy used drops from 74.9 kWh/m^2-to 72.65 kWh/m^2-. Heat gain and loss research reveals a 31.5% increase in heat gain and a 23.3% decrease in heat loss through to the building's roof on the last story.

The comparison for double-glazed windows with vinyl frames, 4 cm thick wall insulation overall (R-13 SI), roof insulation (R-30 SI), and no insulation. In this instance, energy consumption is 75.9 kWh/m^2 without insulation and drops to 55.84 kWh/m^2 (25.44%) with just 4 cm of polystyrene insulation applied to the walls. Lastly, an energy analysis of the entire building is carried out for 4cm wall-insulated, roof-insulated, and double-glazed windows. The annual energy consumption was significantly reduced by around 33.59% (49.74 kWh/m^2).

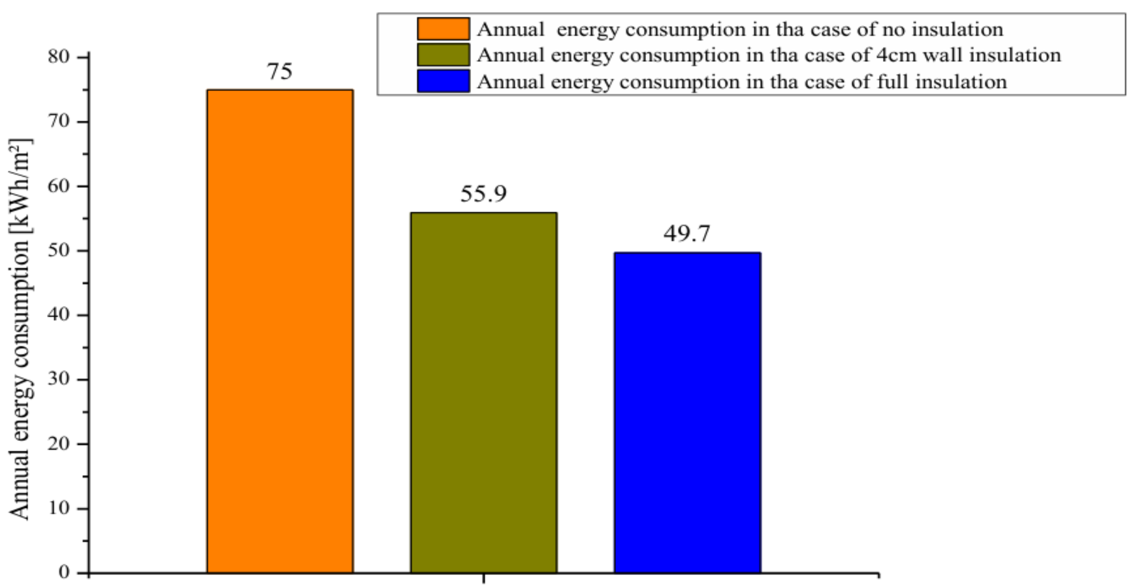

Figure 2.11: Annual energy consumption for three cases (no insulation, only wall insulation, and full insulation) *(Rasuli, 2023)*

2.9 Research Gap and Necessity for Comparative Analysis

The current literature offers fragmented insights into the performance of insulating materials, with most studies focusing on either energy savings or cost, but rarely both in a through, side-by-side analysis. In context of Nepal, no comprehensive studies specifically on HVAC load calculations and energy consumption for hospitals exist. As a result, comprehensive research into HVAC load, energy consumption, and cost impacts for commercial buildings i.e. Hospital using various wall and roof insulation materials is needed to guide optimal material selection for energy-efficient, economically viable, and environmentally responsible commercial building design.

CHAPTER THREE: METHODOLOGY

This research examines the effect of different types of walls and roof insulation in HVAC load, energy use and cost in commercial buildings. This study employs a quantitative comparative research design that relies heavily on building energy modeling tools and economic analysis to assess various insulation materials applied to the walls and roof of a representative commercial building.

The framework for the research follow the following methods:

3.1 Conceptual Framework

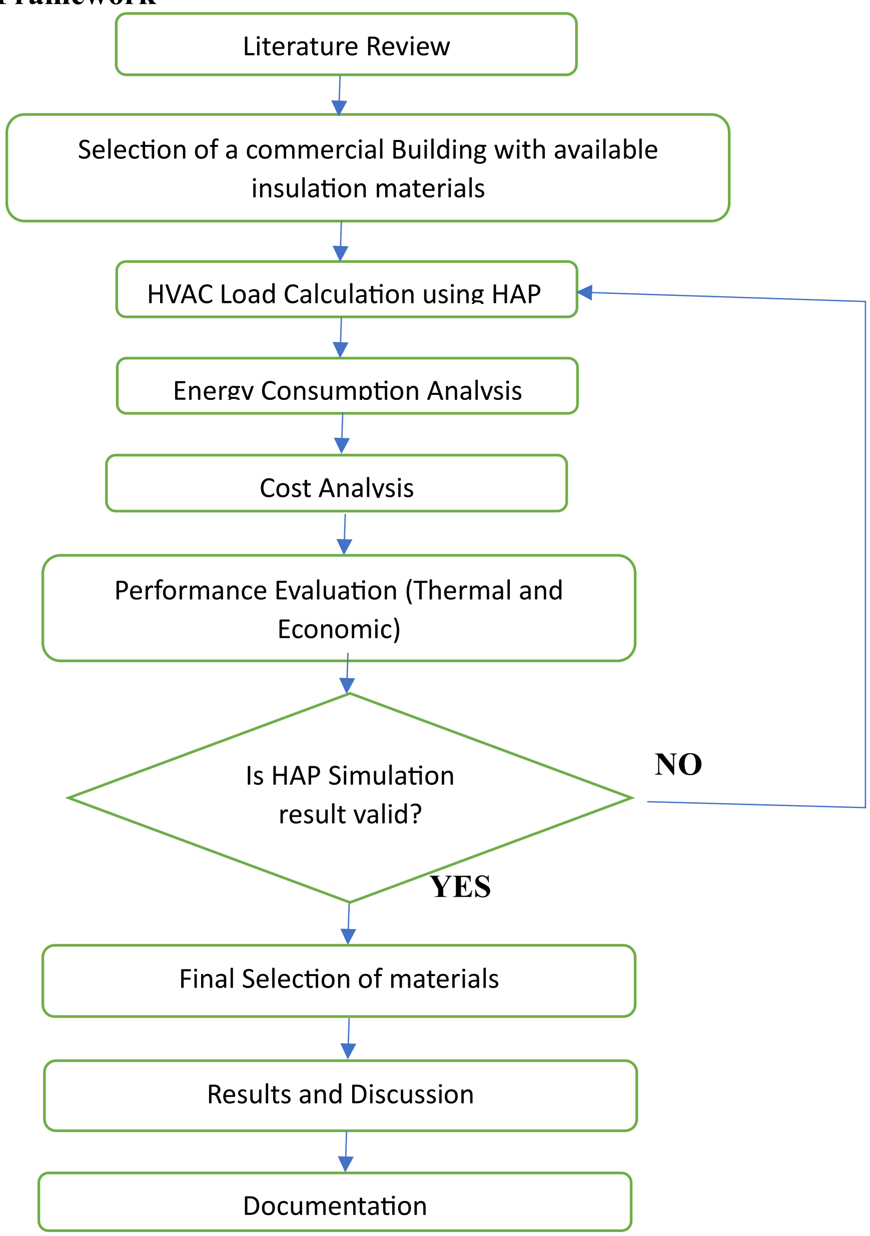

Figure 3.1: Framework for methodology

3.2 Literature

A literature review examines and evaluates published data in a certain field. A well-written literature review adds to scholarly discussions on the subject, shows that the researcher is knowledgeable about the body of current literature, and provides context for the researcher's own work. Its main purpose is to provide a comprehensive overview of what is already known summarizing, evaluating, and organizing relevant studies, theories, methodologies, and debates within the field. It will be carried out with the aid of various books, scholarly publications, and academic reports from the campus library. As a result, the problem of adding value to the current research will be investigated. This study includes a variety of literature reviews for various theoretical findings, such as:

- Research on the significance of material selection in lowering HVAC load.
- Conduct research on different types of wall and roof insulations used.
- Research for software Simulation of the modal development and energy consumption.
- Evaluate thermal comfort and material conductivity.
- Finally, software utilization includes HAP.

This will lay the groundwork for successfully completing the thesis.

3.3 Selection of a type commercial building with available insulation materials

A Commercial building located in Kathmandu was selected for the analysis. The qualities of several insulating materials were examined and compiled. Architectural models with accessible insulation materials were entered into the software to determine the effects of these materials on buildings. The model's material library defines each insulation material based on material attributes such as thermal conductivity, density, and thickness. Also various insulation types specification (e.g., mineral wool, fiberglass, spray foam, loose fill, rigid foam etc.) can be used or can be import by the user having precise thermal data to simulate real-world products.

3.4 HVAC Load calculation using HAP 6.2

Calculating the heating and cooling loads necessary to maintain a building's interior temperature and humidity conditions is known as HVAC load modeling using HAP. The design of an effective and efficient HVAC system depends on accurate HVAC load modeling (Roth, 2024). HAP provides a user-friendly environment to perform accurate HVAC heating and cooling load calculations by inserting the Floor plan or the Building Wizard for a proposed building. The building's location should then be set to Kathmandu. The weather data of the Kathmandu is to be set by placing the EPW file from Energy plus. The other parameter like occupancy, space area, sensible and latent heat and other. The Zoning of Every floor plan are done. The load calculation before insulation and after placing with double glazing window are done. The different insulations are to be set with the wall and the roof keeping other parameters unchanged. Based on the different parameters i.e. building geometry, materials, insulation, weather data, and zone definitions HAP does dynamic calculations. The heating and cooling load determined are of peak load data. The finding of the load calculation can also be exported for further investigation is specialized simulation programs if necessary.

3.5 Energy consumption Analysis

Energy consumption analysis in buildings is methodically assessing the overall energy consumed by all building functions, such as HVAC (heating, ventilation, and air conditioning), lighting, water heating, refrigeration, plug loads, and occupant activity. This research seeks to quantify energy demand trends, uncover inefficiencies, and advise measures for reducing use and expenditures. Advanced technologies forecast consumption trends and benchmark energy use by fusing physical modeling with data-driven techniques like data mining and clustering algorithms. The modeling program HAP is used in this study to determine the HVAC system's yearly energy usage. The result shows that electricity and gasoline are both practical energy sources. But in Nepal, electricity is mostly used as an energy source for HVAC systems.

3.6 Cost Analysis

Cost analysis is an important component in HVAC load and energy consumption assessments because it quantifies economic implications and guides sustainable and financially sound building design decisions. Cost analysis in building energy studies involves evaluating the cost without insulation and the cost after placing double glazing window and then implementing different insulations materials for walls and roofs. It assesses whether the upfront expenses of installing particular materials or technologies are justified by future energy savings and reduced HVAC operational costs. cost analysis compares a baseline building with an improved version incorporating energy-saving measures.

3.7 Selection of the best insulation material for wall and roofs

Insulation play a most important factor for lowering HVAC loads, increasing efficiency, and maintaining pleasant inside temperature, it is very critical step for choosing the right insulation materials for walls and roof. The various factors that influence choosing the right insulation materials are thermal resistance (R-value), moisture resistance, ease of installation, affordability, and compatibility with local climate conditions. The optimal insulation materials for residential building is one with low HVAC load, Energy Consumption and is Cost Effectiveness.

3.8 Compilation, Discussion and Presentation of the Report

In order to help readers, make well-informed decisions about insulation materials for improved building energy performance, this final phase thoroughly compiles and analyzes building energy simulation and cost data, clearly discusses the significance of findings, and presents the information with a structured narrative and supporting visuals. Based on the findings, discussions and recommendations for explanation were made.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Description of a Commercial Building

Evaluation of HVAC load and energy consumption of a commercial building in Kathmandu is the aim of this case study. The building's architectural and HVAC layout CAD model contains incomplete data because it is a commercial project. Space, elevation, and plan layout are among the design aspects of this building that are known. The following details are illustrated in the drawing.

Table 4.1: Details of the Type Building

Building Location	**Kathmandu**
Building Size	Nine Story with Basement
Wall Material	Common Brick with variation of inner wall
Roof type	Flat
Roof Material	Concrete
Floor	Concrete
Window type	Single pane clear glass
Exterior Wall thickness	9 inch
Window to wall ratio	0.312

4.2 Weather Data Analysis

The Department of Metrology and Hydrology provides the most recent weather information needed to calculate the cooling and heating load, which is listed below:

Table 4.2: Weather Conditions

Data Available			
Location	KTM Valley	Summer design DBT	89F
Required Indoor Temp	72F	Summer Co-incident WBT	78F
Elevation	4388ft	Summer daily range	25F
Latitude	27.7N	Winter Design DBT	36F
Longitude	85.35	Winter Co-incident WBT	25.5F

Table 4.3: Summer and Winter DBT and WBT of Kathmandu

Month	Summer		Winter	
	Max DBT(F)	Min WBT(F)	Max DBT(F)	Min WBT(F)
Jan	65.9	37.6	58.3	33.6
Feb	75.8	49.2	69.3	45.3
Mar	81.7	53.0	76.1	49.8
Apr	82.9	59.2	77.5	55.7
May	83	61.4	77.7	57.7
Jun	85.2	68.9	80.2	65.1
Jul	85.3	69.3	80.4	65.5
Aug	86.4	68.9	81.7	65.7
Sep	81.9	64.3	76.5	60.3
Oct	80.1	53.2	74.3	49.6
Nov	71.7	43.4	64.8	39.6
Dec	63.7	34.4	55.9	30.6

As each floor is being separated in two zones, first is Conditioned Zone and Second is the Un-conditioned zone. The Area for the zone wise and floor wise is below in the table:

Table 4.4: Area of the Floor and Zone

Floor	Zone	Zone Area(Sq.)	Floor Area(Sq.)
Ground Floor	Ground Floor Zone 1	7166.7	14584.8
	Ground Floor Zone 2	7418.1	
First Floor	First Floor Zone 1	5766.4	13119
	First Floor Zone 2	7352.6	
Second Floor	Second Floor Zone 1	8069.2	13704.3
	Second Floor Zone 2	5635.1	
Third Floor	Third Floor Zone 1	8658.0	14505.3
	Third Floor Zone 2	5847.3	
Fourth Floor	Fourth Floor Zone 1	7358.8	12526.3
	Fourth Floor Zone 2	5167.5	
Fifth Floor	Fifth Floor Zone 1	7397.9	12778.5
	Fifth Floor Zone 2	5380.6	
Sixth Floor	Sixth Floor Zone 1	3966.7	7959.2
	Sixth Floor Zone 2	3992.5	
Seventh Floor	Seventh Floor	1732.6	1732.6

4.3 Space Model of the Building

As the building is a commercial building with a lot of spaces in every floor and only conditioned space are being taken into consideration for the calculation.

The data for the ventilation is of according to the ASHRAE Standard 62.1-2019 space usage.

Similarly, the value for the overhead lighting is taken as of ASHRAE Standard 90.1-2019

The schedule for the electric equipment is of 90.1 office lights/Elec.

The Schedule for occupancy is taken of 90.1 office occupancy and The Schedule for Miscellaneous Heat Gain is taken of 90.1 Assembly/Light/Elec.

The thermal properties used with Insulation are below in the table:

Table 4.5: Thermal Characteristics of Materials

S.N	Description	Thermal Conductivity(K)(hr sqft F/BTU)
1	¾ inch Gypsum Plaster	0.4807
2	9 inch Concrete Brick	1.78875
3	5/8 inch Gypsum Board	0.56306
4	½ inch Gypsum Plaster	0.32051
5	6Inch HW Concrete	0.5
6	Slate or Tile	0.08
7	Acoustic Tile	1.78571
8	4inch LW Concrete	1.08108
9	Carpet with rubber pad	1.23
10	Expanded Polystyrene(EPS)	4.2
11	Extruded Polystyrene(XPS)	5
12	Polyisocyanurate	6
13	Fiberglass Batt	3.1
14	Mineral Wool Batt	4.2

15	Cellulose	3.4
16	Spray Foam (Open Cell)	3.8
17	Spray Foam (Closed Cell)	7

4.4 Results of a Building before Insulation

The building's HVAC equipment was sized based on the HVAC peak demand. Both summer and winter HVAC loads were calculated. The operation schedule for energy consumption and cost comparison is from 9:00 AM to 5:00 PM, with Saturday being a no-work day, or eight hours a day, six days a week. Based on the Nepal Electricity Authority (NEA) Electricity Tariff 2022/23, the cost per kWh for the commercial building is estimated to be NRs. 10.8. This resulted in a high yearly energy cost because it was calculated using Nepal's typical working hours.

Table 4.6: HVAC load for type building before Insulation

Zone Wise	Peak Cooling Load(TOR)	Peak Heating Load(TOR)
Ground Floor Zone 1	35.1	9.5
First Floor Zone 1	34.1	9.6
Second Floor Zone 1	34.8	8.6
Third Floor Zone 1	36.3	12.4
Fourth Floor Zone1	32.1	10.4
Fifth Floor Zone 1	33.1	12.2
Sixth Floor Zone 1	18.8	8.3
Seventh Floor Zone	8.6	4.1
Overall Building	**232.9**	**75.1**

Components	Energy Consumption (kWh)	Annual Cost (NRs.)	Percent of Total (%)
HVAC Component	204805	2,211,886	37.8
NON-HVAC Component	336825	3,637,717	62.2
Total	**541630**	**5,849,603**	**100**

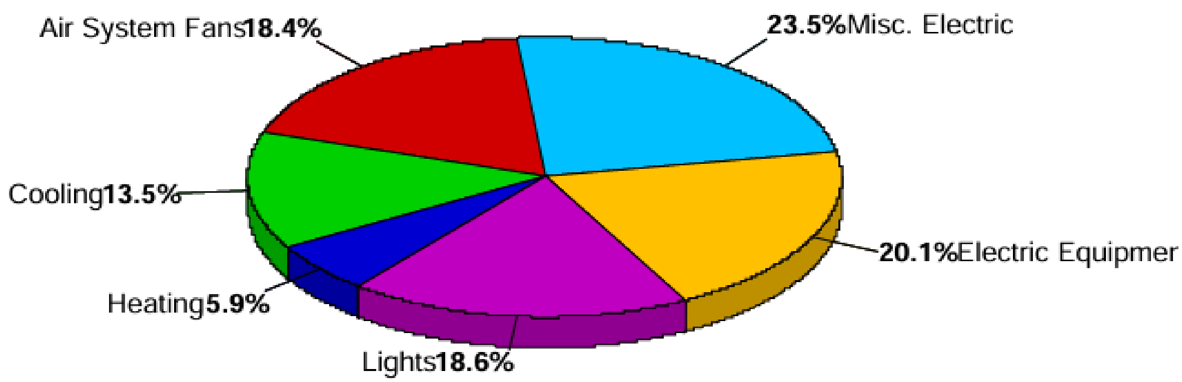

Figure 4.1: Annual Operating Costs Components wise

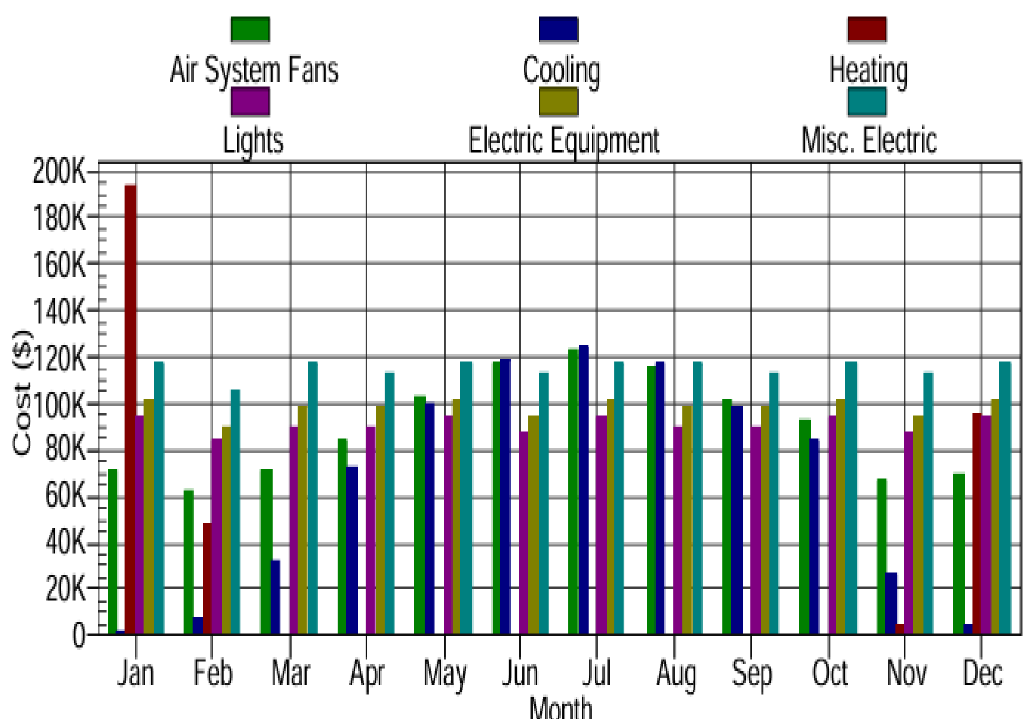

Figure 4.2: Component wise Monthly Operating Cost

From the above chat it is found that maximum cooling and heating cost is at the month of July and January with the cost of NRs.124828 and NRs.193676.

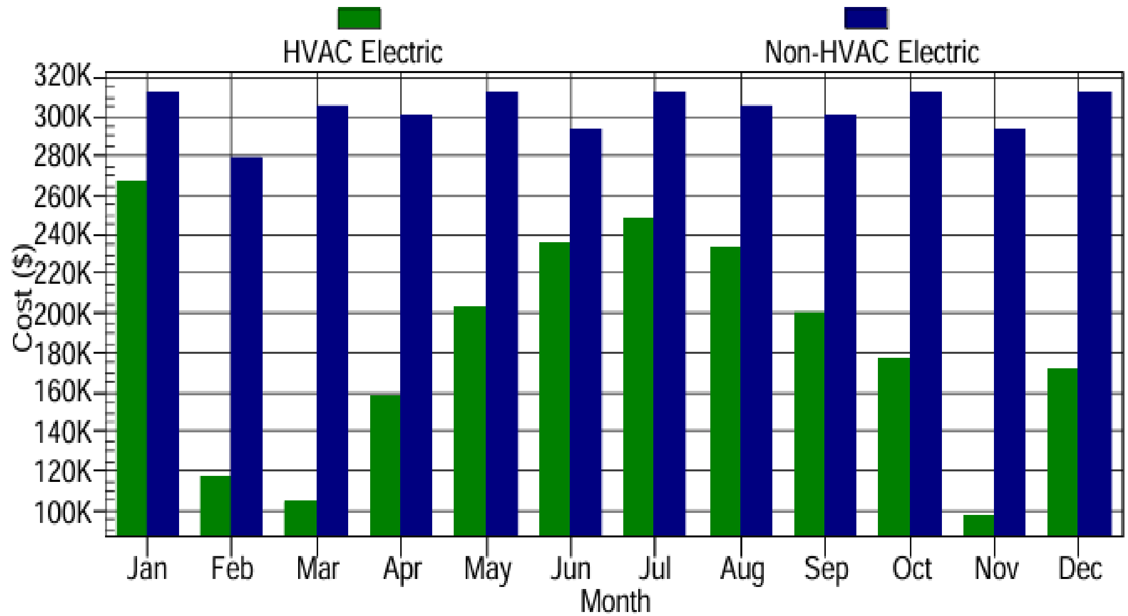

Figure 4.3: Monthly Energy Cost

Maximum HVAC cost occur at the month of January with NRs.267723 and total energy cost in January is NRs.579694.

Also, from the Energy analysis report it is found that Maximum Energy Consumption is in month of July with 53675 kWh and the table data is provided in APPENDIX.

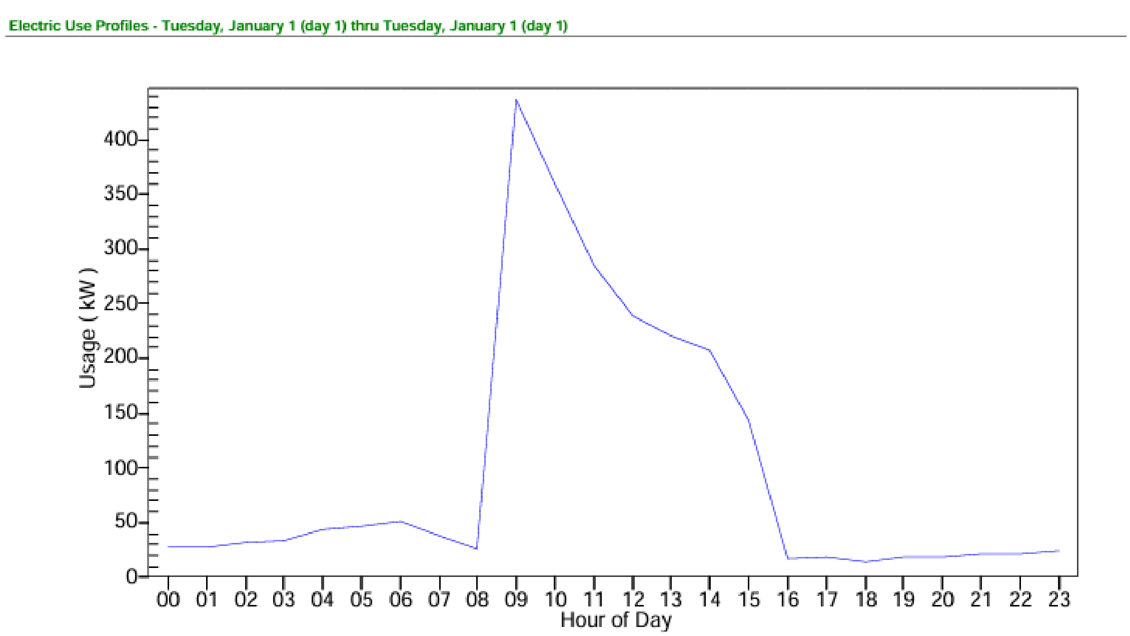

Figure 4.4: Energy Consumption Vs Working Hour Per day

4.5 Results of HVAC load for 8 different Insulation to Exterior wall

This part is done for the selection of the insulation material. In this part the results for HVAC Load, energy consumption and cost for 1Inch insulation thickness keeping other parameter constant is being taken.

4.5.1 For Expanded Polystyrene (EPS)

The HVAC results after applying 1-inch insulation to the exterior wall is given in the table below:

Table 4.7: HVAC load for Expanded Polystyrene

Zone Wise	Peak Cooling Load (TOR)	Peak Heating Load (TOR)
Ground Floor Zone 1	34.5	9.2
First Floor Zone 1	33.3	9.4
Second Floor Zone 1	33.4	8.4
Third Floor Zone 1	35.4	12.1
Fourth Floor Zone1	31.3	10.1
Fifth Floor Zone 1	32.5	11.9
Sixth Floor Zone 1	18.3	8.1
Seventh Floor Zone	8.4	4
Overall Building	**227.1**	**73.2**

Components	Energy Consumption (kWh)	Annual Cost (NRs.)	Percent of Total (%)
HVAC Component	191513	2068339	36.2
NON-HVAC Component	336825	3637717	63.8
Total	**528339**	**5706056**	**100**

The peak Cooling load and Heating load after applying of 1-inch Expanded polystyrene insulation to the exterior wall found to be 227.1 TOR and 73.2 TOR with the change of HVAC component from 37.8% to 36.2% and % change is of 4.23% after insulation is been added to the external wall.

4.5.2 For Extruded Polystyrene (XPS)

The HVAC results after 1-inch insulation is given in the table below:

Table 4.8: HVAC load for Extruded Polystyrene

Zone Wise	Peak Cooling Load (TOR)	Peak Heating Load (TOR)
Ground Floor Zone 1	34.2	9.2
First Floor Zone 1	33.2	9.4
Second Floor Zone 1	33.9	8.4
Third Floor Zone 1	35.2	12.1
Fourth Floor Zone1	31.3	10.1
Fifth Floor Zone 1	32.3	11.8
Sixth Floor Zone 1	18.3	8.1
Seventh Floor Zone	8.4	3.9
Overall Building	**226.8**	**73**

Components	Energy Consumption (kWh)	Annual Cost (NRs.)	Percent of Total (%)
HVAC Component	190632	2058816	36.1
NON-HVAC Component	336825	3637717	63.9
Total	**527458**	**5696533**	**100**

The peak Cooling load and Heating load after applying of 1-inch Extruded polystyrene insulation to the exterior wall found to be 226.8 TOR and 73 TOR with the change of HVAC component from 37.8% to 36.1% and percentage change is of 4.49% after insulation is been added to the external wall.

4.5.3 For Polyisocyanurate (polyiso/PIR)

HVAC result after 1-inch insulation is given in the table below:

Table 4.9: HVAC load for Polyisocyanurate

Zone Wise	Peak Cooling Load (TOR)	Peak Heating Load (TOR)
Ground Floor Zone 1	34.1	9.2
First Floor Zone 1	33.2	9.3
Second Floor Zone 1	33.9	8.4
Third Floor Zone 1	35.3	12.1
Fourth Floor Zone1	31.2	10
Fifth Floor Zone 1	32.2	11.8
Sixth Floor Zone 1	18.2	8.1
Seventh Floor Zone	8.3	3.9
Overall Building	**226.4**	**72.8**

Components	Energy Consumption (kWh)	Annual Cost (NRs)	Percent of Total (%)
HVAC Component	189785	2049687	36
NON-HVAC Component	336825	3637717	64
Total	**526610**	**5687405**	**100**

The peak Cooling load and Heating load after applying of 1-inch Polyisocyanurate insulation to the exterior wall found to be 226.4 TOR and 72.8 TOR with the change of HVAC component from 37.8% to 36% and percentage change is of 4.8% after insulation is been added to the external wall.

4.5.4 For Fiberglass Batt

HVAC results for 1-inch insulation is:

Table 4.10: HVAC load for Fiberglass Batt

Zone Wise	Peak Cooling Load (TOR)	Peak Heating Load (TOR)
Ground Floor Zone 1	34.4	9.3
First Floor Zone 1	33.5	9.5
Second Floor Zone 1	34.1	8.5
Third Floor Zone 1	35.6	12.2
Fourth Floor Zone1	31.5	10.2
Fifth Floor Zone 1	32.4	11.9
Sixth Floor Zone 1	18.4	8.1
Seventh Floor Zone	8.4	3.9
Overall Building	**228.3**	**73.6**

Components	Energy Consumption (kWh)	Annual Cost (NRs.)	Percent of Total (%)
HVAC Component	194301	2098460	36.6
NON-HVAC Component	336825	3637717	63.4
Total	**531126**	**5736177**	**100**

The peak Cooling load and Heating load after applying of 1-inch Fiber Glass Batt insulation to the exterior wall found to be 228.3 TOR and 73.6 TOR with the change of HVAC component from 37.8% to 36.6% and percentage change is of 3.2% after insulation is been added to the external wall.

4.5.5 For Mineral Wool Batt

HVAC result after applying 1-inch insulation is:

Table 4.11: HVAC load for Mineral Wool Batt

Zone Wise	Peak Cooling Load (TOR)	Peak Heating Load (TOR)
Ground Floor Zone 1	34.5	9.2
First Floor Zone 1	33.3	9.4
Second Floor Zone 1	33.4	8.4
Third Floor Zone 1	35.4	12.1
Fourth Floor Zone1	31.3	10.1
Fifth Floor Zone 1	32.5	11.9
Sixth Floor Zone 1	18.3	8.1
Seventh Floor Zone	8.4	4
Overall Building	**227.1**	**73.2**

Components	Energy Consumption (kWh)	Annual Cost (NRs.)	Percent of Total (%)
HVAC Component	191427	2067401	36.2
NON-HVAC Component	336825	3637717	63.8
Total	**528252**	**5705118**	**100**

The peak Cooling load and Heating load after applying of 1-inch Mineral Wool Batt insulation to the exterior wall found to be 227.1 TOR and 73.2 TOR with the change of HVAC component from 37.8% to 36.2% and percentage change is of 4.23% after insulation is been added to the external wall.

4.5.6 For Spray Foam (Open Cell)

HVAC result after applying 1-inch insulation is:

Table 4.12: HVAC load for Spray Foam (open cell)

Zone Wise	Peak Cooling Load (TOR)	Peak Heating Load (TOR)
Ground Floor Zone 1	34.3	9.3
First Floor Zone 1	33.4	9.4
Second Floor Zone 1	34.1	8.4
Third Floor Zone 1	35.5	12.1
Fourth Floor Zone1	31.4	10.1
Fifth Floor Zone 1	32.4	11.9
Sixth Floor Zone 1	18.4	8.1
Seventh Floor Zone	8.4	3.9
Overall Building	**227.9**	**73.2**

Components	Energy Consumption (kWh)	Annual Cost (NRs.)	Percent of Total (%)
HVAC Component	193290	2087512	36.5
NON-HVAC Component	336825	3637717	63.5
Total	**530115**	**5725230**	**100**

The peak Cooling load and Heating load after applying of 1-inch Spray Foam (Open Cell) insulation to the exterior wall found to be 227.9 TOR and 73.2 TOR with the change of HVAC component from 37.8% to 36.5% and percentage change is of 3.43% after insulation is been added to the external wall.

4.5.7 For Cellulose

HVAC result after applying 1-inch insulation is:

Table 4.13: HVAC load for Cellulose

Zone Wise	Peak Cooling Load (TOR)	Peak Heating Load (TOR)
Ground Floor Zone 1	34.4	9.3
First Floor Zone 1	33.4	9.4
Second Floor Zone 1	34.1	8.4
Third Floor Zone 1	35.7	12.2
Fourth Floor Zone1	31.5	10.2
Fifth Floor Zone 1	32.3	11.9
Sixth Floor Zone 1	18.4	8.2
Seventh Floor Zone	8.4	3.9
Overall Building	**228.2**	**73.5**

Components	Energy Consumption (kWh)	Annual Cost (NRs.)	Percent of Total (%)
HVAC Component	193747	2092477	36.5
NON-HVAC Component	336825	3637717	63.5
Total	**530572**	**5730194**	**100**

The peak Cooling load and Heating load after applying of 1-inch Cellulose insulation to the exterior wall found to be 228.2 TOR and 73.5 TOR with the change of HVAC component from 37.8% to 36.5% and percentage change is of 3.43% after insulation is been added to the external wall.

4.5.8 For Spray Foam Closed cell

HVAC results after applying 1-inch insulation is:

Table 4.14: HVAC load for Spray Foam Closed Cell

Zone Wise	Peak Cooling Load (TOR)	Peak Heating Load (TOR)
Ground Floor Zone 1	34	9.2
First Floor Zone 1	33.1	9.3
Second Floor Zone 1	33.7	8.3
Third Floor Zone 1	35.2	12
Fourth Floor Zone1	31.2	10.1
Fifth Floor Zone 1	32.1	11.8
Sixth Floor Zone 1	18.3	8.1
Seventh Floor Zone	8.5	3.9
Overall Building	**226.1**	**72.7**

Components	Energy Consumption (kWh)	Annual Cost (NRs.)	Percent of Total (%)
HVAC Component	189078	2042053	36
NON-HVAC Component	336825	3637717	64
Total	**525903**	**5679770**	**100**

The peak Cooling load and Heating load after applying of 1-inch Spray Foam Closed Cell insulation to the exterior wall found to be 226.1 TOR and 72.7 TOR with the change of HVAC component from 37.8% to 36% and percentage change is of 4.76% after insulation is been added to the external wall.

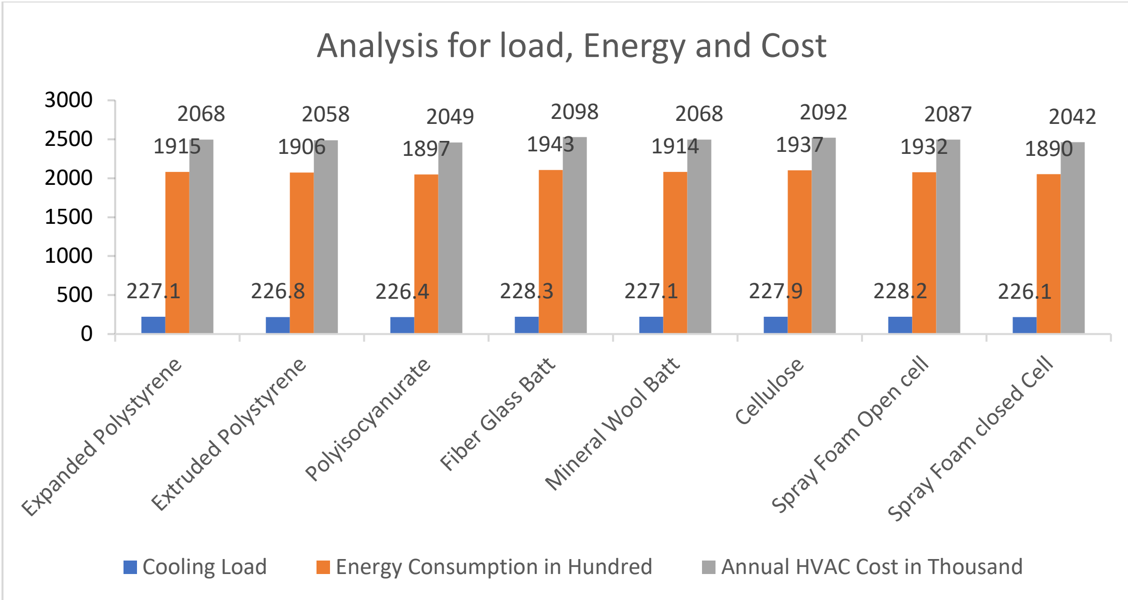

Figure 4.5: Analysis for Load, Energy and Cost

From the above chat it is found that the insulation material Spray Foam Closed Cell reduce the load, Energy Consumption and Annual Cost more than other So, the material can be selected as the appropriate material for Type Commercial Building.

From the Literature review done previously it came to know that, the required U-value (Thermal Transmittance) for the building wall lies in the range of 0.088Btu/hr. sq. ft. F-0.1233 Btu/hr. sq. ft. F for the maximum thermal Comfort.

For the location of Kathmandu valley with the given condition the required U-value for wall for maximum thermal comfort is 0.104Btu/hr. sq. ft. F. (Bodach, 2016)

Initially before insulation the U-value of wall was found to be 0.265Btu/ hr. sq. ft. F. After the insulation of 1-inch thickness to the wall the U-value found are listed as:

Table 4.15: Materials with corresponding U-Value

Insulation Material	Thickness (Inch)	U-value (Btu/hr. sq. ft. F)
Expanded Polystyrene(EPS)	1	0.125
Extruded Polystyrene(XPS)	1	0.114
Poyisocyanurate(Polyiso)	1	0.102
Fiberglass Batt	1	0.143

Mineral Wool Batt	1	0.125
Spray Foam(Open Cell)	1	0.132
Cellulose	1	0.139
Spray Foam(Closed Cell)	1	0.093

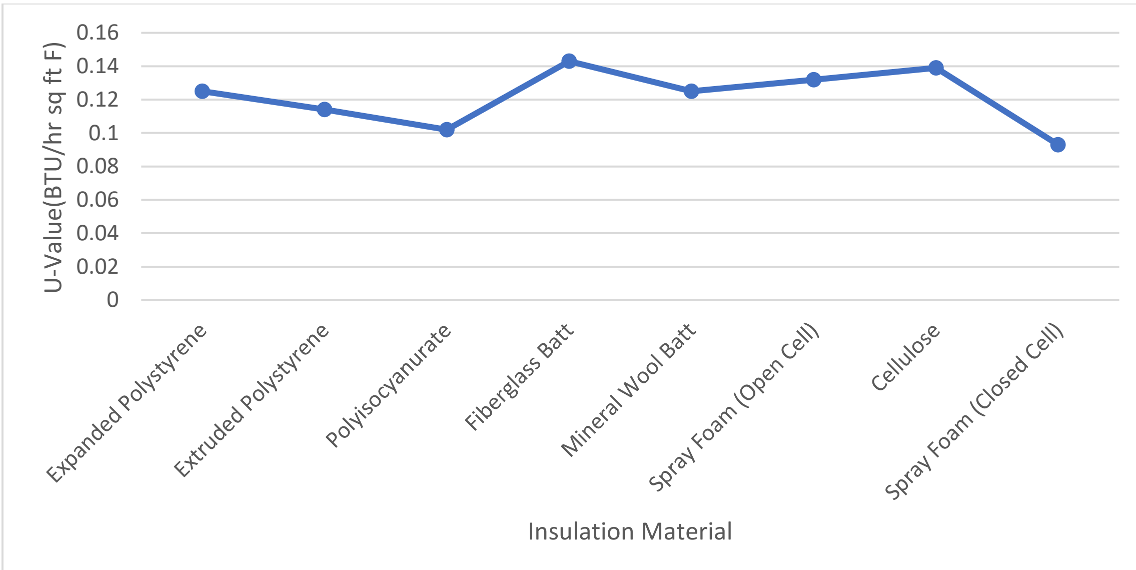

Figure 4.6: Material with U-value for 1 inch thickness

From the above chat Polyisocyanurate material is approx. to the required comfort value of 0.104Btu/hr. Sq. ft. F.

For the reference purposes only, here's a pricing table detailing the different types of insulation materials.

Table 4.16: Material with its Price per Sq. *(renoquotes.com, 2026)*

Insulation Materials	**Price per Sq.ft/Rooms($)**
Expanded Polystyrene(EPS)	$2-$4
Extruded Polystyrene(XPS)	$3-$6
Polyisocyanurate(Polyiso)	$1.50-$8
Fiberglass Batt	$0.9-$5.9
Mineral Wool Batt	$1.40-$5.90
Spray Foam (Open Cell)	Approx.$3

Cellulose	Approx.$1
Spray Foam (Closed Cell)	$3-$8

So, from the above Energy and cost analysis data for 8 different insulation materials Spray Foam (Closed Cell) reduces the most Annual Energy and Cost but 1-inch thickness of this material did not align with the required comfort factor also the cost of material is comparatively high than other.

Considering to the cost of materials, Annual Energy and Cost saving and Comfort factor Polyisocyanurate insulation material of 1-inch thickness was selected as our wall insulation material.

4.6 Results for 8 different Insulation to Roof

As done for the Exterior Wall in the same way this part is done for the selection of material for the Roof. In this section the results for Energy consumption and cost for different material for different thickness keeping other parameter constant is being taken.

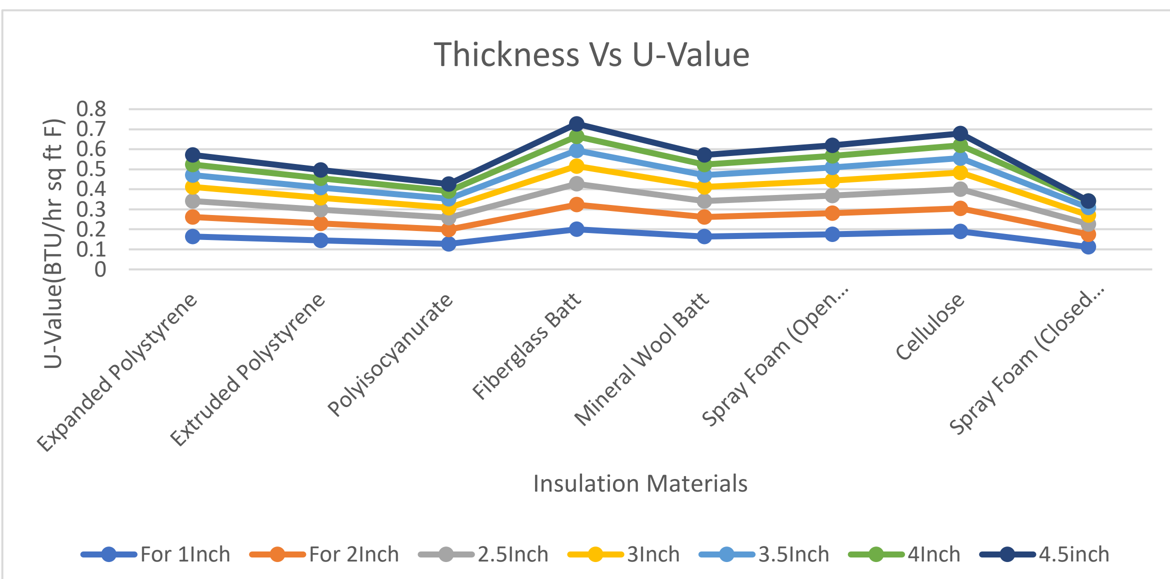

Figure 4.7: Materials Vs U-Value for different thickness

Above chat show the corresponding U-value for different thickness for the given 8 different materials.

As done previously for the wall insulation in a similar manner for Roof the required thermal comfort value for U lie in the range of 0.0441-0.07BTU/ hr. sq. ft. F.

For the location of Kathmandu Valley, the required value for U is 0.0652BTU/hr. sq. ft. F. At initial condition before insulation the U-Value for roof is 0.526BTU/hr. sq. ft. F.

From the above chat for different material for the required thermal comfort different thickness and Energy and Cost analysis were done.

4.6.1 For Expanded Polystyrene(EPS)

From the above chat for Expanded Polystyrene (EPS) 3-inch thickness can be selected with the U-Value of 0.069BTU/hr sq. ft. F and the corresponding Energy Consumption and Cost data is given as:

Table 4.17: Expanded Polystyrene with Energy Consumption, Cost and % Consumption

Components	Energy Consumption (kWh)	Annual Cost (NRs.)	Percent of Total (%)
HVAC Component	192564	2079688	36.4
NON-HVAC Component	336825	3637717	63.6
Total	**529389**	**5717406**	**100**

4.6.2 For Extruded Polystyrene (XPS)

From the above chat for Extruded Polystyrene (XPS) 2.5-inch thickness can be selected with the U-Value of 0.069BTU/hr. sq. ft. F and the corresponding Energy Consumption and Cost data is given as:

Table 4.18: Extruded Polystyrene with Energy Consumption, Cost and % Consumption

Components	Energy Consumption (kWh)	Annual Cost (NRs.)	Percent of Total (%)
HVAC Component	192586	2079921	36.4
NON-HVAC Component	336825	3637717	63.6
Total	**529411**	**5717638**	**100**

4.6.3 For Polyisocyanurate (Polyiso)

From the above chat for Polyisocyanurate (Polyiso) 2.5-inch thickness can be selected with the U-Value of 0.059BTU/hr. sq. ft. F and the corresponding Energy Consumption and Cost data is given as:

Table 4.19: Polyisocyanurate with Energy Consumption, Cost and % Consumption

Components	Energy Consumption (kWh)	Annual Cost (NRs.)	Percent of Total (%)
HVAC Component	191987	2073468	36.3
NON-HVAC Component	336825	3637717	63.7
Total	**528813**	**5711185**	**100**

4.6.4 For Fiberglass Batt

From the above chat for Fiberglass Batt 4.5-inch thickness can be selected with the U-Value of 0.063BTU/hr. sq. ft. F and the corresponding Energy Consumption and Cost data is given as:

Table 4.20: Fiber Glass with Energy Consumption, Cost and % Consumption

Components	Energy Consumption (kWh)	Annual Cost (NRs.)	Percent of Total (%)
HVAC Component	191162	2064542	36.2
NON-HVAC Component	336825	3637717	63.8
Total	**527987**	**5702259**	**100**

4.6.5 For Mineral Wool Batt

From the above chat for Expanded Polystyrene (EPS) can be selected 3-inch thickness with the U-Value of 0.069BTU/hr. sq. ft. F and the corresponding Energy Consumption and Cost data is given as:

Table 4.21: Mineral wool with Energy Consumption, Cost and % Consumption

Components	Energy Consumption (kWh)	Annual Cost (NRs)	Percent of Total (%)
HVAC Component	192564	2079688	36.4
NON-HVAC Component	336825	3637717	63.6

Total	**529389**	**5717406**	**100**

4.6.6 For Spray Foam (Open Cell)

From the above chat for Expanded Polystyrene (EPS) 3.5-inch thickness can be selected with the U-Value of 0.066BTU/hr. sq. ft. F and the corresponding Energy Consumption and Cost data is given as:

Table 4.22: Spray Foam (Open cell) with Energy Consumption, Cost and % Consumption

Components	Energy Consumption (kWh)	Annual Cost (NRs)	Percent of Total (%)
HVAC Component	192404	2077971	36.4
NON-HVAC Component	336825	3637717	63.6
Total	**529229**	**5715688**	**100**

4.6.7 For Cellulose

From the above chat for Expanded Polystyrene (EPS) 4-inch thickness can be selected with the U-Value of 0.065BTU/hr. sq. ft. F and the corresponding Energy Consumption and Cost data is given as:

Table 4.23: Cellulose with Energy Consumption, Cost and % Consumption

Components	Energy Consumption (kWh)	Annual Cost (NRs)	Percent of Total (%)
HVAC Component	191225	2065199	36.2
NON-HVAC Component	336825	3637717	63.8
Total	**528050**	**5702916**	**100**

4.6.8 For Spray Foam (Closed Cell)

From the above chat for Expanded Polystyrene (EPS) 2-inch thickness can be selected with the U-Value of 0.063BTU/hr sq. ft. F and the corresponding Energy Consumption and Cost data is given as:

Table 4.24: Spray Foam (Closed Cell) with Energy Consumption, Cost and % Consumption

Components	Energy Consumption (kWh)	Annual Cost (NRs)	Percent of Total (%)
HVAC Component	192290	2076748	36.3
NON-HVAC Component	336825	3637717	63.7
Total	**529115**	**5714465**	**100**

From the above data of Energy Consumption and cost for different Insulation material with selected thickness considering to the thermal comfort and also the cost of insulation material, the material as Cellulose with the thickness of 4-inch can be selected having the U-Value of 0.065BTU/hr. sq. ft. F that is very ideal to the required value for Kathmandu Valley.

Hence, Finalizing the material, the selection of material as 1-inch of Polyisocyanurate material for wall insulation and 4-inch of Cellulose for Roof Insulation was done.

4.7 Result for HVAC Load, Energy and Cost for 1-inch Polyisocyanurate and 4-inch Cellulose

Table 4.25: Final Result for HVAC, Energy and Cost

Zone Wise	Peak Cooling Load(TOR)	Peak Heating Load(TOR)
Ground Floor Zone 1	33.2	9
First Floor Zone 1	32.3	9.1
Second Floor Zone 1	33	8.1
Third Floor Zone 1	34.2	11.6
Fourth Floor Zone1	30.4	9.8
Fifth Floor Zone 1	31.4	11.5
Sixth Floor Zone 1	17.8	7.8
Seventh Floor Zone	8.1	3.8
Overall Building	**220.4**	**70.7**

Components	Energy Consumption (kWh)	Annual Cost (NRs)	Percent of Total (%)
HVAC Component	178938	1932510	34.7

NON-HVAC Component	336825	3637717	65.3
Total	**515763**	**5570227**	**100**

From the calculation above done it can be seen that before insulation the Cooling load, Heating Load, Annual Energy Consumption and Energy cost were 232.9 TOR, 75.1TOR, 541630 kWh and NRs.5846603 and after the insulation of the selected materials of 1 inch Polyisocyanurate and 4 inch of cellulose the result were of 220.4 TOR, 70.7 TOR, 515763 kWh and NRs.5570227.

The Annual HVAC energy consumption and Energy Cost changes from 204805 kWh and NRs.2211886 to 178938 kWh and NRs.1932510, which is the change of 12.6%.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

This research completely focuses on the analysis of the type commercial building reducing the HVAC load, Energy Consumption and the electricity Cost. The study looks at how different types of wall and roof insulation affect the HVAC load, yearly energy use, and annual costs. Carrier HAP 6.2, a program software has been used to look at HVAC load, energy use and annual cost.

From the study it can be concluded that a small change can have a huge impact in energy and cost saving, adding of insulation to wall and roof changes the Annual HVAC Energy Consumption and Cost from 204805 kWh and NRs.2211886 to 178938 kWh and NRs.1932510, which show that addition of insulation to wall and roof change the HVAC energy and cost by 12.6%.Similarly, the analysis shows that the insulation materials used in walls and roofs have a big effect on the HVAC cooling load, energy use, and annual electric costs of a building.

According to the simulation results, insulation materials with higher thermal resistance and lower thermal conductivity perform better at preventing heat from entering the building. Out of the eight materials listed, the simulation resulted in the selection of 1-inch Polyisocyanurate insulation material for the external wall and 4-inch Cellulose material for the roof calculation.

However, adding insulation does not just affect HVAC load, energy consumption, and cost savings. Other factors influencing load consumption include window glazing, infiltration, door style, wall materials, and others. So, a study of commercial buildings made of alternative materials can be conducted for HVAC load, energy and cost savings, as well as a financial analysis based on the materials chosen.

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APPENDICES

1. Annual Cost, Components wise monthly cost and Monthly Energy Use before Insulation

1. Annual Costs

Component	Annual Cost ($)	($/sqft)	Percent of Total (%)
Air System Fans	1,077,931	9.601	18.4
Cooling	790,447	7.040	13.5
Heating	343,509	3.059	5.9
Pumps	0	0.000	0.0
Heat Rejection Fans	0	0.000	0.0
HVAC Sub-Total	2,211,886	19.700	37.8
Lights	1,088,161	9.692	18.6
Electric Equipment	1,177,740	10.490	20.1
Misc. Electric	1,371,816	12.218	23.5
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	3,637,717	32.399	62.2
Grand Total	5,849,603	52.099	100.0

1. HVAC Component Costs

Month	Air System Fans ($)	Cooling ($)	Heating ($)	Pumps ($)	Heat Rejection Fans ($)	HVAC Total ($)
January	71,496	2,552	193,676	0	0	267,724
February	61,898	7,517	48,260	0	0	117,675
March	71,121	32,372	843	0	0	104,336
April	84,669	72,747	2	0	0	157,418
May	103,006	100,478	0	0	0	203,484
June	116,563	118,118	0	0	0	234,681
July	123,046	124,828	0	0	0	247,874
August	116,361	117,202	0	0	0	233,563
September	100,700	99,054	0	0	0	199,754
October	93,216	84,245	0	0	0	177,461
November	66,149	26,225	4,701	0	0	97,075
December	69,706	5,109	96,026	0	0	170,841
Total	**1,077,931**	**790,447**	**343,509**	**0**	**0**	**2,211,886**

2. Non-HVAC Component Costs

Month	Lights ($)	Electric Equipment ($)	Misc. Electric ($)	Misc. Fuel Use ($)	Non-HVAC Total ($)	Grand Total ($)
January	93,867	101,594	116,510	0	311,971	579,695
February	83,437	90,306	105,235	0	278,979	396,654
March	90,391	97,832	116,510	0	304,733	409,069
April	90,390	97,831	112,752	0	300,973	458,391
May	93,867	101,594	116,510	0	311,971	515,455
June	86,914	94,069	112,752	0	293,736	528,417
July	93,867	101,594	116,510	0	311,971	559,845
August	90,391	97,832	116,510	0	304,733	538,296
September	90,390	97,831	112,752	0	300,973	500,727
October	93,867	101,594	116,510	0	311,971	489,432
November	86,914	94,069	112,752	0	293,736	390,811
December	93,867	101,594	116,510	0	311,971	482,812
Total	**1,088,161**	**1,177,740**	**1,371,816**	**0**	**3,637,717**	**5,849,603**

1. Monthly Energy Use by System Component

Component	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air System Fans (kWh)	6620	5731	6585	7840	9538	10793	11393	10774	9324	8631	6125	6454
Cooling												
Electric (kWh)	236	696	2997	6736	9303	10937	11558	10852	9172	7800	2428	473
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote CW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Heating												
Electric (kWh)	17933	4469	78	0	0	0	0	0	0	0	435	8891
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Pumps (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Heat Rej. Fans (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Lighting (kWh)	8691	7726	8370	8369	8691	8048	8691	8370	8369	8691	8048	8691
Electric Eqpt. (kWh)	9407	8362	9059	9058	9407	8710	9407	9059	9058	9407	8710	9407
Misc. Electric (kWh)	10788	9744	10788	10440	10788	10440	10788	10788	10440	10788	10440	10788
Misc. Fuel												
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0

2. Annual Cost, Components wise monthly cost and Monthly Energy for Expanded Polystyrene

1. Annual Costs

Component	Annual Cost ($)	($/sqft)	Percent of Total (%)
HVAC Components			
Electric	2,068,341	18.422	36.2
Natural Gas	0	0.000	0.0
Fuel Oil	0	0.000	0.0
Propane	0	0.000	0.0
Remote Hot Water	0	0.000	0.0
Remote Steam	0	0.000	0.0
Remote Chilled Water	0	0.000	0.0
HVAC Sub-Total	**2,068,341**	**18.422**	**36.2**
Non-HVAC Components			
Electric	3,637,715	32.399	63.8
Natural Gas	0	0.000	0.0
Fuel Oil	0	0.000	0.0
Propane	0	0.000	0.0
Remote Hot Water	0	0.000	0.0
Remote Steam	0	0.000	0.0
Non-HVAC Sub-Total	**3,637,715**	**32.399**	**63.8**
Grand Total	**5,706,056**	**50.821**	**100.0**

1. HVAC Component Costs

Month	Air System Fans ($)	Cooling ($)	Heating ($)	Pumps ($)	Heat Rejection Fans ($)	HVAC Total ($)
January	67,350	3,511	169,563	0	0	240,424
February	58,416	8,646	43,534	0	0	110,596
March	67,877	32,190	928	0	0	100,995
April	80,694	68,299	4	0	0	148,997
May	97,319	93,638	0	0	0	190,957
June	109,503	109,579	0	0	0	219,082
July	116,159	116,384	0	0	0	232,543
August	109,966	109,392	0	0	0	219,358
September	95,787	93,067	0	0	0	188,854
October	88,910	79,448	0	0	0	168,358
November	62,810	26,717	4,348	0	0	93,875
December	65,721	6,580	82,000	0	0	154,301
Total	**1,020,512**	**747,450**	**300,377**	**0**	**0**	**2,068,339**

2. Non-HVAC Component Costs

Month	Lights ($)	Electric Equipment ($)	Misc. Electric ($)	Misc. Fuel Use ($)	Non-HVAC Total ($)	Grand Total ($)
January	93,867	101,594	116,510	0	311,971	552,395
February	83,437	90,306	105,235	0	278,979	389,575
March	90,391	97,832	116,510	0	304,733	405,728
April	90,390	97,831	112,752	0	300,973	449,970
May	93,867	101,594	116,510	0	311,971	502,928
June	86,914	94,069	112,752	0	293,736	512,818
July	93,867	101,594	116,510	0	311,971	544,514
August	90,391	97,832	116,510	0	304,733	524,091
September	90,390	97,831	112,752	0	300,973	489,827
October	93,867	101,594	116,510	0	311,971	480,329
November	86,914	94,069	112,752	0	293,736	387,611
December	93,867	101,594	116,510	0	311,971	466,272
Total	**1,088,161**	**1,177,740**	**1,371,816**	**0**	**3,637,717**	**5,706,056**

1. Monthly Energy Use by System Component

Component	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air System Fans (kWh)	6236	5409	6285	7472	9011	10139	10755	10182	8869	8232	5816	6085
Cooling												
Electric (kWh)	325	801	2981	6324	8670	10146	10776	10129	8617	7356	2474	609
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote CW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Heating												
Electric (kWh)	15700	4031	86	0	0	0	0	0	0	0	403	7593
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Pumps (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Heat Rej. Fans (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Lighting (kWh)	8691	7726	8370	8369	8691	8048	8691	8370	8369	8691	8048	8691
Electric Eqpt. (kWh)	9407	8362	9059	9058	9407	8710	9407	9059	9058	9407	8710	9407
Misc. Electric (kWh)	10788	9744	10788	10440	10788	10440	10788	10788	10440	10788	10440	10788
Misc. Fuel												
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0

3. Annual Cost, Components wise monthly cost and Monthly Energy for extruded Polystyrene

1. Annual Costs

Component	Annual Cost ($)	($/sqft)	Percent of Total (%)
Air System Fans	1,020,298	9.087	17.9
Cooling	744,122	6.628	13.1
Heating	294,396	2.622	5.2
Pumps	0	0.000	0.0
Heat Rejection Fans	0	0.000	0.0
HVAC Sub-Total	**2,058,816**	**18.337**	**36.1**
Lights	1,088,161	9.692	19.1
Electric Equipment	1,177,740	10.490	20.7
Misc. Electric	1,371,816	12.218	24.1
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**3,637,717**	**32.399**	**63.9**
Grand Total	**5,696,533**	**50.736**	**100.0**

1. HVAC Component Costs

Month	Air System Fans ($)	Cooling ($)	Heating ($)	Pumps ($)	Heat Rejection Fans ($)	HVAC Total ($)
January	67,103	3,617	166,563	0	0	237,283
February	58,234	8,796	42,624	0	0	109,654
March	67,789	32,269	928	0	0	100,986
April	80,661	67,923	4	0	0	148,588
May	97,390	93,097	0	0	0	190,487
June	109,648	108,907	0	0	0	218,555
July	116,262	115,625	0	0	0	231,887
August	110,142	108,735	0	0	0	218,877
September	95,938	92,531	0	0	0	188,469
October	88,958	79,022	0	0	0	167,980
November	62,687	26,850	4,281	0	0	93,818
December	65,487	6,748	79,997	0	0	152,232
Total	**1,020,297**	**744,122**	**294,396**	**0**	**0**	**2,058,816**

2. Non-HVAC Component Costs

Month	Lights ($)	Electric Equipment ($)	Misc. Electric ($)	Misc. Fuel Use ($)	Non-HVAC Total ($)	Grand Total ($)
January	93,867	101,594	116,510	0	311,971	549,254
February	83,437	90,306	105,235	0	278,979	388,633
March	90,391	97,832	116,510	0	304,733	405,719
April	90,390	97,831	112,752	0	300,973	449,561
May	93,867	101,594	116,510	0	311,971	502,458
June	86,914	94,069	112,752	0	293,736	512,291
July	93,867	101,594	116,510	0	311,971	543,858
August	90,391	97,832	116,510	0	304,733	523,610
September	90,390	97,831	112,752	0	300,973	489,442
October	93,867	101,594	116,510	0	311,971	479,951
November	86,914	94,069	112,752	0	293,736	387,554
December	93,867	101,594	116,510	0	311,971	464,203
Total	**1,088,161**	**1,177,740**	**1,371,816**	**0**	**3,637,717**	**5,696,533**

1. Monthly Energy Use by System Component

Component	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air System Fans (kWh)	6213	5392	6277	7469	9018	10153	10765	10198	8883	8237	5804	6064
Cooling												
Electric (kWh)	335	814	2988	6289	8620	10084	10706	10068	8568	7317	2486	625
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote CW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Heating												
Electric (kWh)	15423	3947	86	0	0	0	0	0	0	0	396	7407
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Pumps (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Heat Rej. Fans (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Lighting (kWh)	8691	7726	8370	8369	8691	8048	8691	8370	8369	8691	8048	8691
Electric Eqpt. (kWh)	9407	8362	9059	9058	9407	8710	9407	9059	9058	9407	8710	9407
Misc. Electric (kWh)	10788	9744	10788	10440	10788	10440	10788	10788	10440	10788	10440	10788
Misc. Fuel												
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0

4. Annual Cost, Components wise monthly cost and Monthly Energy for Polyisocyanurate

1. Annual Costs

Component	Annual Cost ($)	($/sqft)	Percent of Total (%)
Air System Fans	1,018,740	9.073	17.9
Cooling	742,610	6.614	13.1
Heating	288,338	2.568	5.1
Pumps	0	0.000	0.0
Heat Rejection Fans	0	0.000	0.0
HVAC Sub-Total	**2,049,687**	**18.256**	**36.0**
Lights	1,088,161	9.692	19.1
Electric Equipment	1,177,740	10.490	20.7
Misc. Electric	1,371,816	12.218	24.1
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**3,637,717**	**32.399**	**64.0**
Grand Total	**5,687,405**	**50.655**	**100.0**

1. HVAC Component Costs

Month	Air System Fans ($)	Cooling ($)	Heating ($)	Pumps ($)	Heat Rejection Fans ($)	HVAC Total ($)
January	66,845	3,778	163,434	0	0	234,057
February	58,042	9,028	41,738	0	0	108,808
March	67,646	32,450	925	0	0	101,021
April	80,540	67,738	4	0	0	148,282
May	97,291	92,736	0	0	0	190,027
June	109,493	108,343	0	0	0	217,836
July	116,186	115,103	0	0	0	231,289
August	110,112	108,274	0	0	0	218,386
September	95,952	92,257	0	0	0	188,209
October	88,863	78,798	0	0	0	167,661
November	62,525	27,097	4,214	0	0	93,836
December	65,243	7,009	78,023	0	0	150,275
Total	**1,018,740**	**742,610**	**288,338**	**0**	**0**	**2,049,687**

2. Non-HVAC Component Costs

Month	Lights ($)	Electric Equipment ($)	Misc. Electric ($)	Misc. Fuel Use ($)	Non-HVAC Total ($)	Grand Total ($)
January	93,867	101,594	116,510	0	311,971	546,028
February	83,437	90,306	105,235	0	278,979	387,787
March	90,391	97,832	116,510	0	304,733	405,754
April	90,390	97,831	112,752	0	300,973	449,255
May	93,867	101,594	116,510	0	311,971	501,998
June	86,914	94,069	112,752	0	293,736	511,572
July	93,867	101,594	116,510	0	311,971	543,260
August	90,391	97,832	116,510	0	304,733	523,119
September	90,390	97,831	112,752	0	300,973	489,182
October	93,867	101,594	116,510	0	311,971	479,632
November	86,914	94,069	112,752	0	293,736	387,572
December	93,867	101,594	116,510	0	311,971	462,246
Total	**1,088,161**	**1,177,740**	**1,371,816**	**0**	**3,637,717**	**5,687,405**

1. Monthly Energy Use by System Component

Component	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air System Fans (kWh)	6189	5374	6264	7457	9008	10138	10758	10196	8884	8228	5789	6041
Cooling												
Electric (kWh)	350	836	3005	6272	8587	10032	10658	10025	8542	7296	2509	649
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote CW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Heating												
Electric (kWh)	15133	3865	86	0	0	0	0	0	0	0	390	7224
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Pumps (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Heat Rej. Fans (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Lighting (kWh)	8691	7726	8370	8369	8691	8048	8691	8370	8369	8691	8048	8691
Electric Eqpt. (kWh)	9407	8362	9059	9058	9407	8710	9407	9059	9058	9407	8710	9407
Misc. Electric (kWh)	10788	9744	10788	10440	10788	10440	10788	10788	10440	10788	10440	10788
Misc. Fuel												
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0

5. Annual Cost, Components wise monthly cost and Monthly Energy for fiberglass batt

1. Annual Costs

Component	Annual Cost ($)	($/sqft)	Percent of Total (%)
Air System Fans	1,023,206	9.113	17.8
Cooling	764,872	6.812	13.3
Heating	310,382	2.764	5.4
Pumps	0	0.000	0.0
Heat Rejection Fans	0	0.000	0.0
HVAC Sub-Total	**2,098,460**	**18.690**	**36.6**
Lights	1,088,161	9.692	19.0
Electric Equipment	1,177,740	10.490	20.5
Misc. Electric	1,371,816	12.218	23.9
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**3,637,717**	**32.399**	**63.4**
Grand Total	**5,736,177**	**51.089**	**100.0**

1. HVAC Component Costs

Month	Air System Fans ($)	Cooling ($)	Heating ($)	Pumps ($)	Heat Rejection Fans ($)	HVAC Total ($)
January	67,767	3,387	174,805	0	0	245,959
February	58,701	8,593	45,002	0	0	112,296
March	68,036	32,649	939	0	0	101,624
April	80,817	70,002	4	0	0	150,823
May	97,613	96,131	0	0	0	193,744
June	109,815	112,520	0	0	0	222,335
July	116,305	119,325	0	0	0	235,630
August	110,208	112,250	0	0	0	222,458
September	95,844	95,258	0	0	0	191,102
October	89,032	81,333	0	0	0	170,365
November	63,018	27,009	4,475	0	0	94,502
December	66,051	6,415	85,158	0	0	157,624
Total	**1,023,206**	**764,872**	**310,382**	**0**	**0**	**2,098,460**

2. Non-HVAC Component Costs

Month	Lights ($)	Electric Equipment ($)	Misc. Electric ($)	Misc. Fuel Use ($)	Non-HVAC Total ($)	Grand Total ($)
January	93,867	101,594	116,510	0	311,971	557,930
February	83,437	90,306	105,235	0	278,979	391,275
March	90,391	97,832	116,510	0	304,733	406,357
April	90,390	97,831	112,752	0	300,973	451,796
May	93,867	101,594	116,510	0	311,971	505,715
June	86,914	94,069	112,752	0	293,736	516,071
July	93,867	101,594	116,510	0	311,971	547,601
August	90,391	97,832	116,510	0	304,733	527,191
September	90,390	97,831	112,752	0	300,973	492,075
October	93,867	101,594	116,510	0	311,971	482,336
November	86,914	94,069	112,752	0	293,736	388,238
December	93,867	101,594	116,510	0	311,971	469,595
Total	**1,088,161**	**1,177,740**	**1,371,816**	**0**	**3,637,717**	**5,736,177**

1. Monthly Energy Use by System Component

Component	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air System Fans (kWh)	6275	5435	6300	7483	9038	10168	10769	10204	8874	8244	5835	6116
Cooling												
Electric (kWh)	314	796	3023	6482	8901	10419	11049	10394	8820	7531	2501	594
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote CW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Heating												
Electric (kWh)	16186	4167	87	0	0	0	0	0	0	0	414	7885
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Pumps (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Heat Rej. Fans (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Lighting (kWh)	8691	7726	8370	8369	8691	8048	8691	8370	8369	8691	8048	8691
Electric Eqpt. (kWh)	9407	8362	9059	9058	9407	8710	9407	9059	9058	9407	8710	9407
Misc. Electric (kWh)	10788	9744	10788	10440	10788	10440	10788	10788	10440	10788	10440	10788
Misc. Fuel												
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0

6. Annual Cost, Components wise monthly cost and Monthly Energy for mineral wool batt

1. Annual Costs

Component	Annual Cost ($)	($/sqft)	Percent of Total (%)
Air System Fans	1,019,927	9.084	17.9
Cooling	746,823	6.652	13.1
Heating	300,650	2.678	5.3
Pumps	0	0.000	0.0
Heat Rejection Fans	0	0.000	0.0
HVAC Sub-Total	**2,067,401**	**18.413**	**36.2**
Lights	1,088,161	9.692	19.1
Electric Equipment	1,177,740	10.490	20.6
Misc. Electric	1,371,816	12.218	24.0
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**3,637,717**	**32.399**	**63.8**
Grand Total	**5,705,118**	**50.812**	**100.0**

1. HVAC Component Costs

Month	Air System Fans ($)	Cooling ($)	Heating ($)	Pumps ($)	Heat Rejection Fans ($)	HVAC Total ($)
January	67,349	3,509	169,608	0	0	240,466
February	58,414	8,641	43,582	0	0	110,637
March	67,870	32,168	932	0	0	100,970
April	80,673	68,267	4	0	0	148,944
May	97,286	93,607	0	0	0	190,893
June	109,378	109,468	0	0	0	218,846
July	116,020	116,259	0	0	0	232,279
August	109,873	109,309	0	0	0	219,182
September	95,681	92,961	0	0	0	188,642
October	88,865	79,395	0	0	0	168,260
November	62,800	26,677	4,357	0	0	93,834
December	65,719	6,564	82,167	0	0	154,450
Total	**1,019,927**	**746,823**	**300,650**	**0**	**0**	**2,067,401**

2. Non-HVAC Component Costs

Month	Lights ($)	Electric Equipment ($)	Misc. Electric ($)	Misc. Fuel Use ($)	Non-HVAC Total ($)	Grand Total ($)
January	93,867	101,594	116,510	0	311,971	552,437
February	83,437	90,306	105,235	0	278,979	389,616
March	90,391	97,832	116,510	0	304,733	405,703
April	90,390	97,831	112,752	0	300,973	449,917
May	93,867	101,594	116,510	0	311,971	502,864
June	86,914	94,069	112,752	0	293,736	512,582
July	93,867	101,594	116,510	0	311,971	544,250
August	90,391	97,832	116,510	0	304,733	523,915
September	90,390	97,831	112,752	0	300,973	489,615
October	93,867	101,594	116,510	0	311,971	480,231
November	86,914	94,069	112,752	0	293,736	387,570
December	93,867	101,594	116,510	0	311,971	466,421
Total	**1,088,161**	**1,177,740**	**1,371,816**	**0**	**3,637,717**	**5,705,118**

1. Monthly Energy Use by System Component

Component	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air System Fans (kWh)	6236	5409	6284	7470	9008	10128	10743	10173	8859	8228	5815	6085
Cooling												
Electric (kWh)	325	800	2979	6321	8667	10136	10765	10121	8608	7351	2470	608
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote CW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Heating												
Electric (kWh)	15704	4035	86	0	0	0	0	0	0	0	403	7608
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Pumps (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Heat Rej. Fans (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Lighting (kWh)	8691	7726	8370	8369	8691	8048	8691	8370	8369	8691	8048	8691
Electric Eqpt. (kWh)	9407	8362	9059	9058	9407	8710	9407	9059	9058	9407	8710	9407
Misc. Electric (kWh)	10788	9744	10788	10440	10788	10440	10788	10788	10440	10788	10440	10788
Misc. Fuel												
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0

7. Annual Cost, Components wise monthly cost and Monthly Energy for spray foam open cell

1. Annual Costs

Component	Annual Cost ($)	($/sqft)	Percent of Total (%)
Air System Fans	1,019,917	9.084	17.8
Cooling	763,688	6.802	13.3
Heating	303,907	2.707	5.3
Pumps	0	0.000	0.0
Heat Rejection Fans	0	0.000	0.0
HVAC Sub-Total	**2,087,512**	**18.592**	**36.5**
Lights	1,088,161	9.692	19.0
Electric Equipment	1,177,740	10.490	20.6
Misc. Electric	1,371,816	12.218	24.0
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**3,637,717**	**32.399**	**63.5**
Grand Total	**5,725,230**	**50.991**	**100.0**

1. HVAC Component Costs

Month	Air System Fans ($)	Cooling ($)	Heating ($)	Pumps ($)	Heat Rejection Fans ($)	HVAC Total ($)
January	67,490	3,588	171,350	0	0	242,428
February	58,503	8,879	44,098	0	0	111,480
March	67,867	32,937	938	0	0	101,742
April	80,622	69,852	4	0	0	150,478
May	97,256	95,695	0	0	0	192,951
June	109,382	111,934	0	0	0	221,316
July	115,875	118,736	0	0	0	234,611
August	109,855	111,755	0	0	0	221,610
September	95,592	94,970	0	0	0	190,562
October	88,824	81,229	0	0	0	170,053
November	62,834	27,371	4,404	0	0	94,609
December	65,816	6,743	83,115	0	0	155,674
Total	**1,019,917**	**763,688**	**303,907**	**0**	**0**	**2,087,512**

2. Non-HVAC Component Costs

Month	Lights ($)	Electric Equipment ($)	Misc. Electric ($)	Misc. Fuel Use ($)	Non-HVAC Total ($)	Grand Total ($)
January	93,867	101,594	116,510	0	311,971	554,399
February	83,437	90,306	105,235	0	278,979	390,459
March	90,391	97,832	116,510	0	304,733	406,475
April	90,390	97,831	112,752	0	300,973	451,451
May	93,867	101,594	116,510	0	311,971	504,922
June	86,914	94,069	112,752	0	293,736	515,052
July	93,867	101,594	116,510	0	311,971	546,582
August	90,391	97,832	116,510	0	304,733	526,343
September	90,390	97,831	112,752	0	300,973	491,535
October	93,867	101,594	116,510	0	311,971	482,024
November	86,914	94,069	112,752	0	293,736	388,345
December	93,867	101,594	116,510	0	311,971	467,645
Total	**1,088,161**	**1,177,740**	**1,371,816**	**0**	**3,637,717**	**5,725,229**

1. Monthly Energy Use by System Component

Component	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air System Fans (kWh)	6249	5417	6284	7465	9005	10128	10729	10172	8851	8224	5818	6094
Cooling												
Electric (kWh)	332	822	3050	6468	8861	10364	10994	10348	8793	7521	2534	624
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote CW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Heating												
Electric (kWh)	15866	4083	87	0	0	0	0	0	0	0	408	7696
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Pumps (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Heat Rej. Fans (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Lighting (kWh)	8691	7726	8370	8369	8691	8048	8691	8370	8369	8691	8048	8691
Electric Eqpt. (kWh)	9407	8362	9059	9058	9407	8710	9407	9059	9058	9407	8710	9407
Misc. Electric (kWh)	10788	9744	10788	10440	10788	10440	10788	10788	10440	10788	10440	10788
Misc. Fuel												
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0

8. Annual Cost, Components wise monthly cost and Monthly Energy for Cellulose

1. Annual Costs

Component	Annual Cost ($)	($/sqft)	Percent of Total (%)
Air System Fans	1,022,584	9.108	17.8
Cooling	762,515	6.791	13.3
Heating	307,379	2.738	5.4
Pumps	0	0.000	0.0
Heat Rejection Fans	0	0.000	0.0
HVAC Sub-Total	**2,092,477**	**18.637**	**36.5**
Lights	1,088,161	9.692	19.0
Electric Equipment	1,177,740	10.490	20.6
Misc. Electric	1,371,816	12.218	23.9
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**3,637,717**	**32.399**	**63.5**
Grand Total	**5,730,194**	**51.036**	**100.0**

1. HVAC Component Costs

Month	Air System Fans ($)	Cooling ($)	Heating ($)	Pumps ($)	Heat Rejection Fans ($)	HVAC Total ($)
January	67,635	3,443	173,155	0	0	244,233
February	58,621	8,668	44,559	0	0	111,848
March	67,994	32,674	938	0	0	101,606
April	80,801	69,775	4	0	0	150,580
May	97,528	95,694	0	0	0	193,222
June	109,756	112,029	0	0	0	221,785
July	116,319	118,891	0	0	0	235,210
August	110,185	111,807	0	0	0	221,992
September	95,826	94,902	0	0	0	190,728
October	89,000	81,070	0	0	0	170,070
November	62,956	27,058	4,438	0	0	94,452
December	65,962	6,503	84,284	0	0	156,749
Total	**1,022,583**	**762,515**	**307,379**	**0**	**0**	**2,092,477**

2. Non-HVAC Component Costs

Month	Lights ($)	Electric Equipment ($)	Misc. Electric ($)	Misc. Fuel Use ($)	Non-HVAC Total ($)	Grand Total ($)
January	93,867	101,594	116,510	0	311,971	556,204
February	83,437	90,306	105,235	0	278,979	390,827
March	90,391	97,832	116,510	0	304,733	406,339
April	90,390	97,831	112,752	0	300,973	451,553
May	93,867	101,594	116,510	0	311,971	505,193
June	86,914	94,069	112,752	0	293,736	515,521
July	93,867	101,594	116,510	0	311,971	547,181
August	90,391	97,832	116,510	0	304,733	526,725
September	90,390	97,831	112,752	0	300,973	491,701
October	93,867	101,594	116,510	0	311,971	482,041
November	86,914	94,069	112,752	0	293,736	388,188
December	93,867	101,594	116,510	0	311,971	468,720
Total	**1,088,161**	**1,177,740**	**1,371,816**	**0**	**3,637,717**	**5,730,194**

1. Monthly Energy Use by System Component

Component	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air System Fans (kWh)	6262	5428	6296	7482	9030	10163	10770	10202	8873	8241	5829	6108
Cooling												
Electric (kWh)	319	803	3025	6461	8861	10373	11008	10353	8787	7507	2505	602
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote CW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Heating												
Electric (kWh)	16033	4126	87	0	0	0	0	0	0	0	411	7804
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Pumps (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Heat Rej. Fans (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Lighting (kWh)	8691	7726	8370	8369	8691	8048	8691	8370	8369	8691	8048	8691
Electric Eqpt. (kWh)	9407	8362	9059	9058	9407	8710	9407	9059	9058	9407	8710	9407
Misc. Electric (kWh)	10788	9744	10788	10440	10788	10440	10788	10788	10440	10788	10440	10788
Misc. Fuel												
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0

9. Annual Cost, Components wise monthly cost and Monthly Energy For spray foam closed cell

1. Annual Costs

Component	Annual Cost ($)	($/sqft)	Percent of Total (%)
Air System Fans	1,016,401	9.053	17.9
Cooling	742,239	6.611	13.1
Heating	283,412	2.524	5.0
Pumps	0	0.000	0.0
Heat Rejection Fans	0	0.000	0.0
HVAC Sub-Total	**2,042,053**	**18.187**	**36.0**
Lights	1,088,161	9.692	19.2
Electric Equipment	1,177,740	10.490	20.7
Misc. Electric	1,371,816	12.218	24.2
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**3,637,717**	**32.399**	**64.0**
Grand Total	**5,679,770**	**50.587**	**100.0**

1. HVAC Component Costs

Month	Air System Fans ($)	Cooling ($)	Heating ($)	Pumps ($)	Heat Rejection Fans ($)	HVAC Total ($)
January	66,616	3,890	160,858	0	0	231,364
February	57,871	9,179	41,004	0	0	108,054
March	67,510	32,598	919	0	0	101,027
April	80,386	67,656	4	0	0	148,046
May	97,072	92,548	0	0	0	189,620
June	109,206	108,075	0	0	0	217,281
July	115,922	114,867	0	0	0	230,789
August	109,877	108,077	0	0	0	217,954
September	95,780	92,127	0	0	0	187,907
October	88,751	78,765	0	0	0	167,516
November	62,374	27,283	4,164	0	0	93,821
December	65,038	7,175	76,462	0	0	148,675
Total	**1,016,401**	**742,239**	**283,412**	**0**	**0**	**2,042,053**

2. Non-HVAC Component Costs

Month	Lights ($)	Electric Equipment ($)	Misc. Electric ($)	Misc. Fuel Use ($)	Non-HVAC Total ($)	Grand Total ($)
January	93,867	101,594	116,510	0	311,971	543,335
February	83,437	90,306	105,235	0	278,979	387,033
March	90,391	97,832	116,510	0	304,733	405,760
April	90,390	97,831	112,752	0	300,973	449,019
May	93,867	101,594	116,510	0	311,971	501,591
June	86,914	94,069	112,752	0	293,736	511,017
July	93,867	101,594	116,510	0	311,971	542,760
August	90,391	97,832	116,510	0	304,733	522,687
September	90,390	97,831	112,752	0	300,973	488,880
October	93,867	101,594	116,510	0	311,971	479,487
November	86,914	94,069	112,752	0	293,736	387,557
December	93,867	101,594	116,510	0	311,971	460,646
Total	**1,088,161**	**1,177,740**	**1,371,816**	**0**	**3,637,717**	**5,679,770**

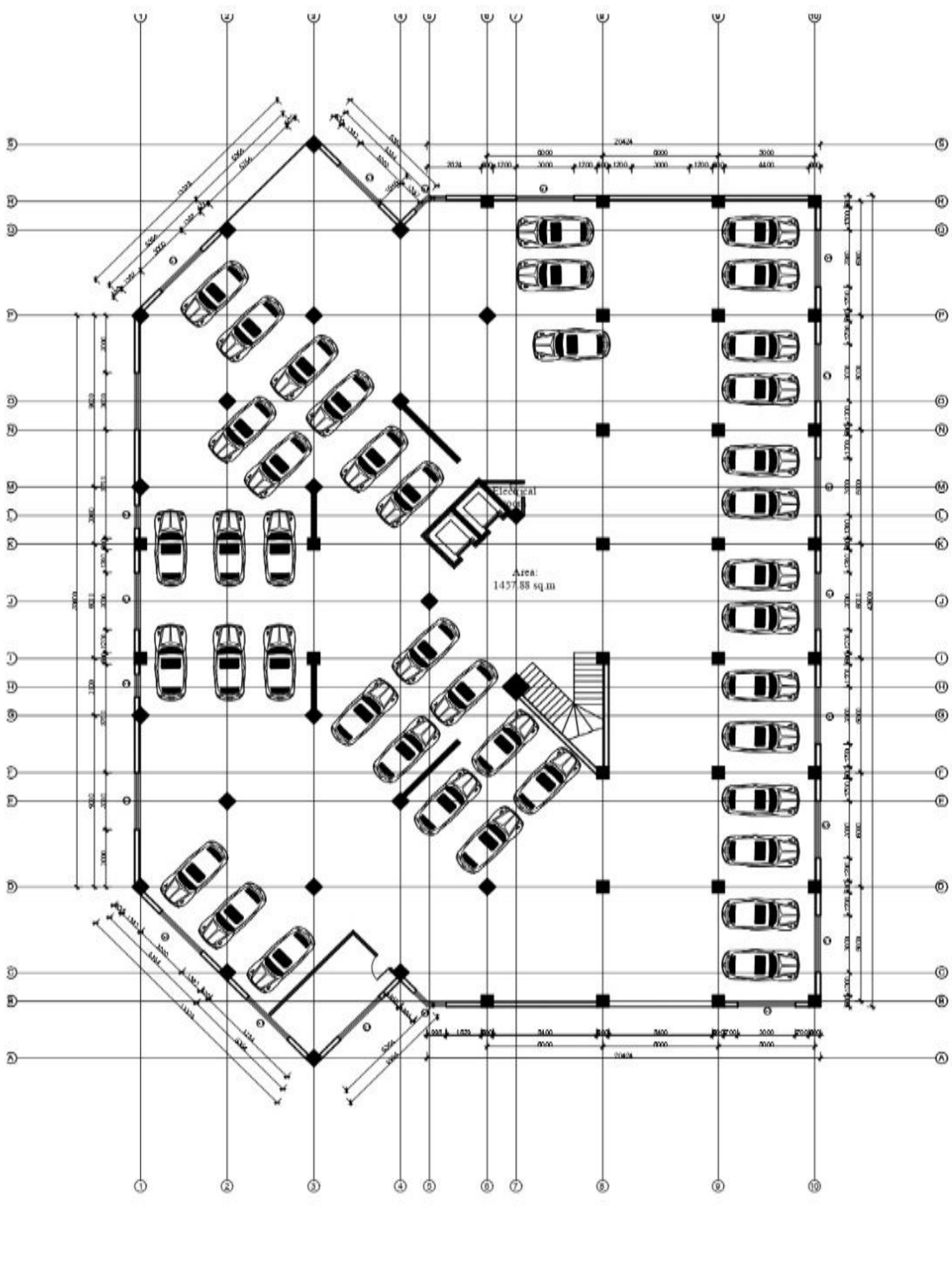
1. Monthly Energy Use by System Component

Component	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Air System Fans (kWh)	6168	5358	6251	7443	8988	10112	10733	10174	8868	8218	5775	6022
Cooling												
Electric (kWh)	360	850	3018	6264	8569	10007	10636	10007	8530	7293	2526	664
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote CW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Heating												
Electric (kWh)	14894	3797	85	0	0	0	0	0	0	0	386	7080
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0
Pumps (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Heat Rej. Fans (kWh)	0	0	0	0	0	0	0	0	0	0	0	0
Lighting (kWh)	8691	7726	8370	8369	8691	8048	8691	8370	8369	8691	8048	8691
Electric Eqpt. (kWh)	9407	8362	9059	9058	9407	8710	9407	9059	9058	9407	8710	9407
Misc. Electric (kWh)	10788	9744	10788	10440	10788	10440	10788	10788	10440	10788	10440	10788
Misc. Fuel												
Natural Gas (na)	0	0	0	0	0	0	0	0	0	0	0	0
Fuel Oil (na)	0	0	0	0	0	0	0	0	0	0	0	0
Propane (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote HW (na)	0	0	0	0	0	0	0	0	0	0	0	0
Remote Steam (na)	0	0	0	0	0	0	0	0	0	0	0	0

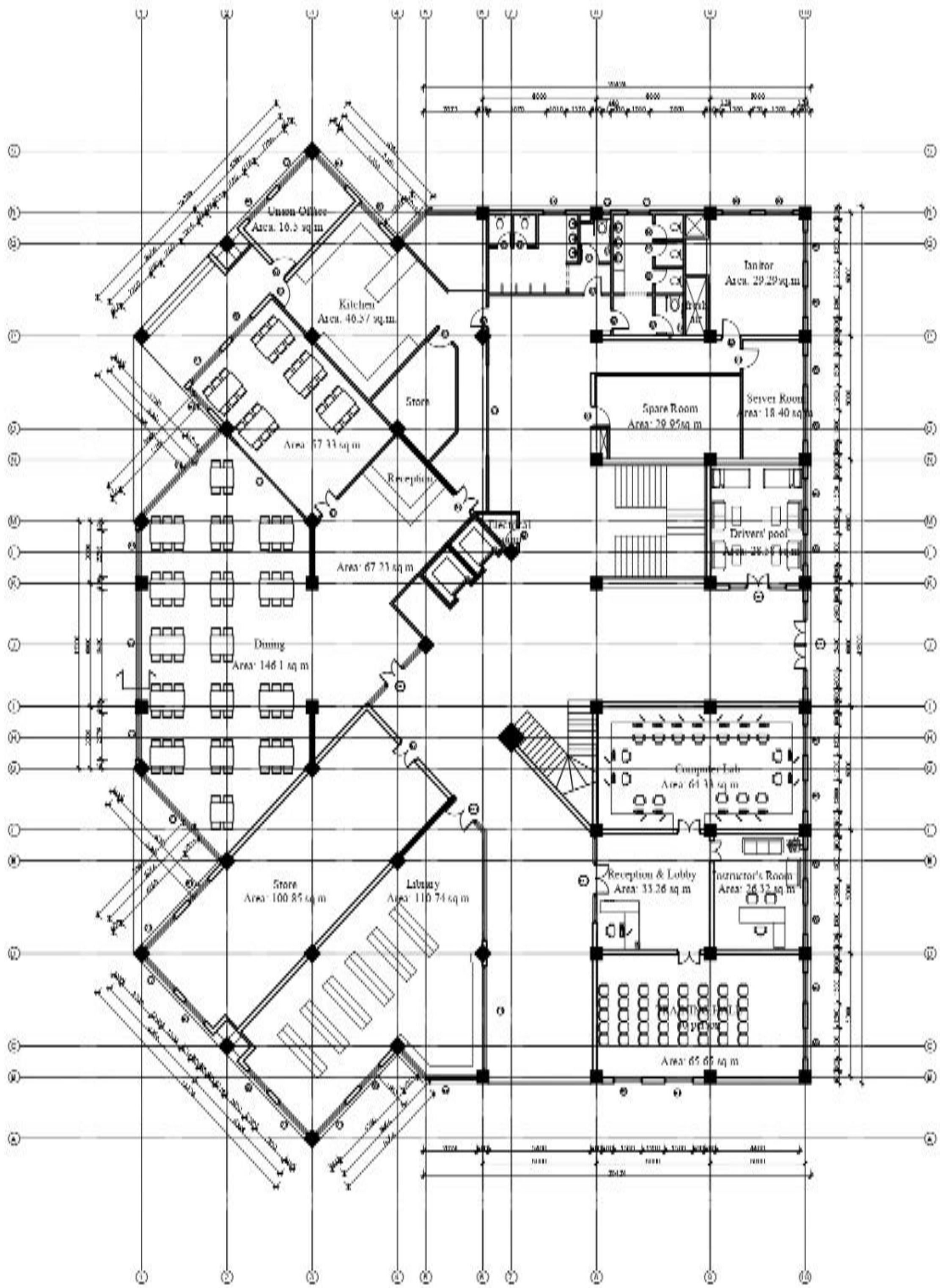
10. Electricity Tariff for Commercial Building.

Consumer Category	Demand Charge Nrs./KVA/month	Energy Charge Nrs./kWh
A. High Voltage		
1. Industrial (132 kV)	230.00	8.20
2. Industrial (66 kV)	240.00	8.30
B. Medium Voltage (33 KV)		
1. Industrial	255.00	8.40
2. Commercial	315.00	10.80
3. Non-commercial	240.00	11.40
4. Irrigation	-	2.50
5. Water Supply		
a) Community Water Supply	-	4.60
b) Other Water Supply	160.00	6.60
6. Transportation		
a) Public Transportation (Charging Station)	230.00	5.60
b) Other Transportation	255.00	8.60
7. Non-Domestic	350.00	12.55
8. Entertainment Business	350.00	13.50

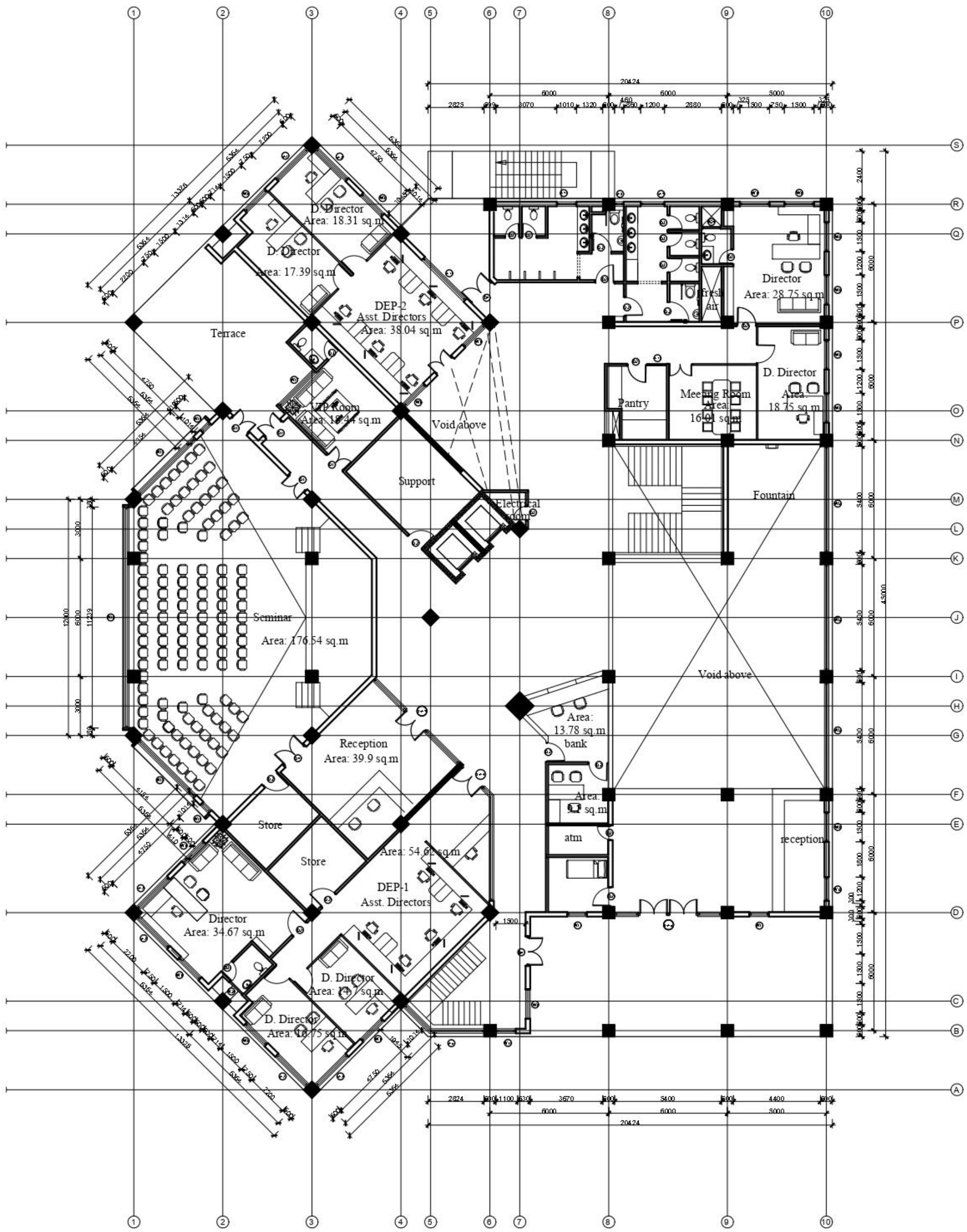
11. Floor Plans of a building



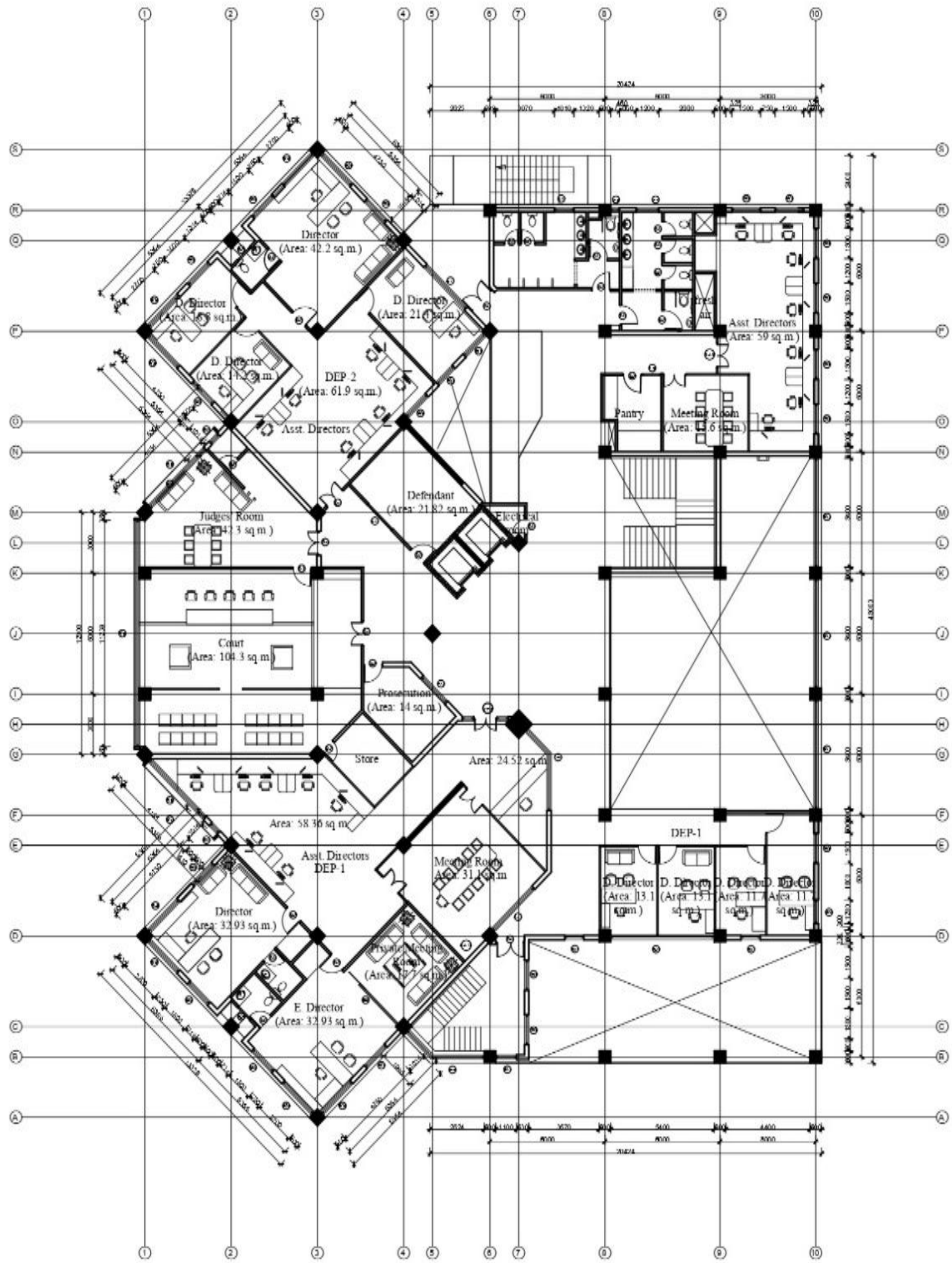
BASEMENT PLAN



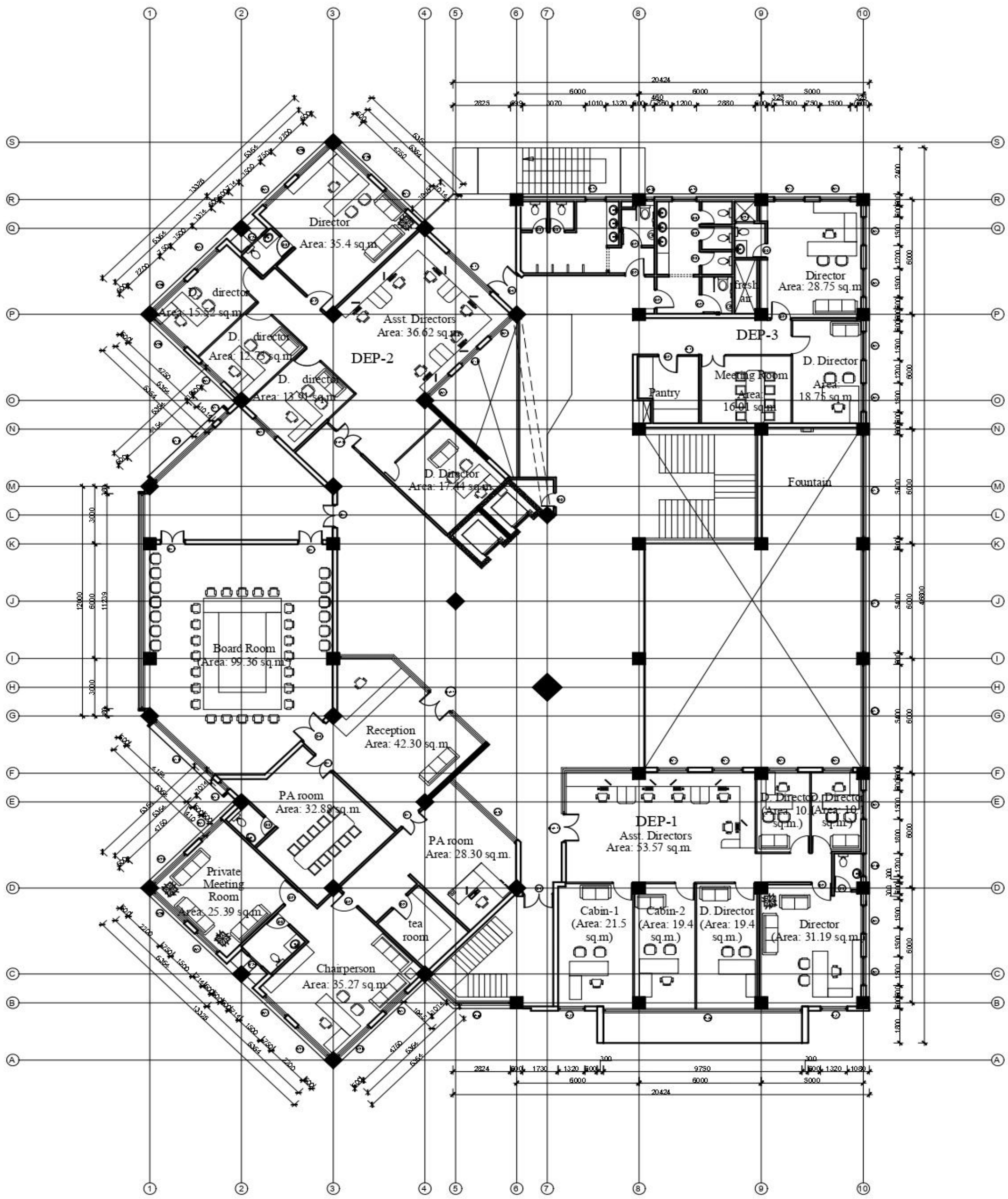
GROUND FLOOR PLAN



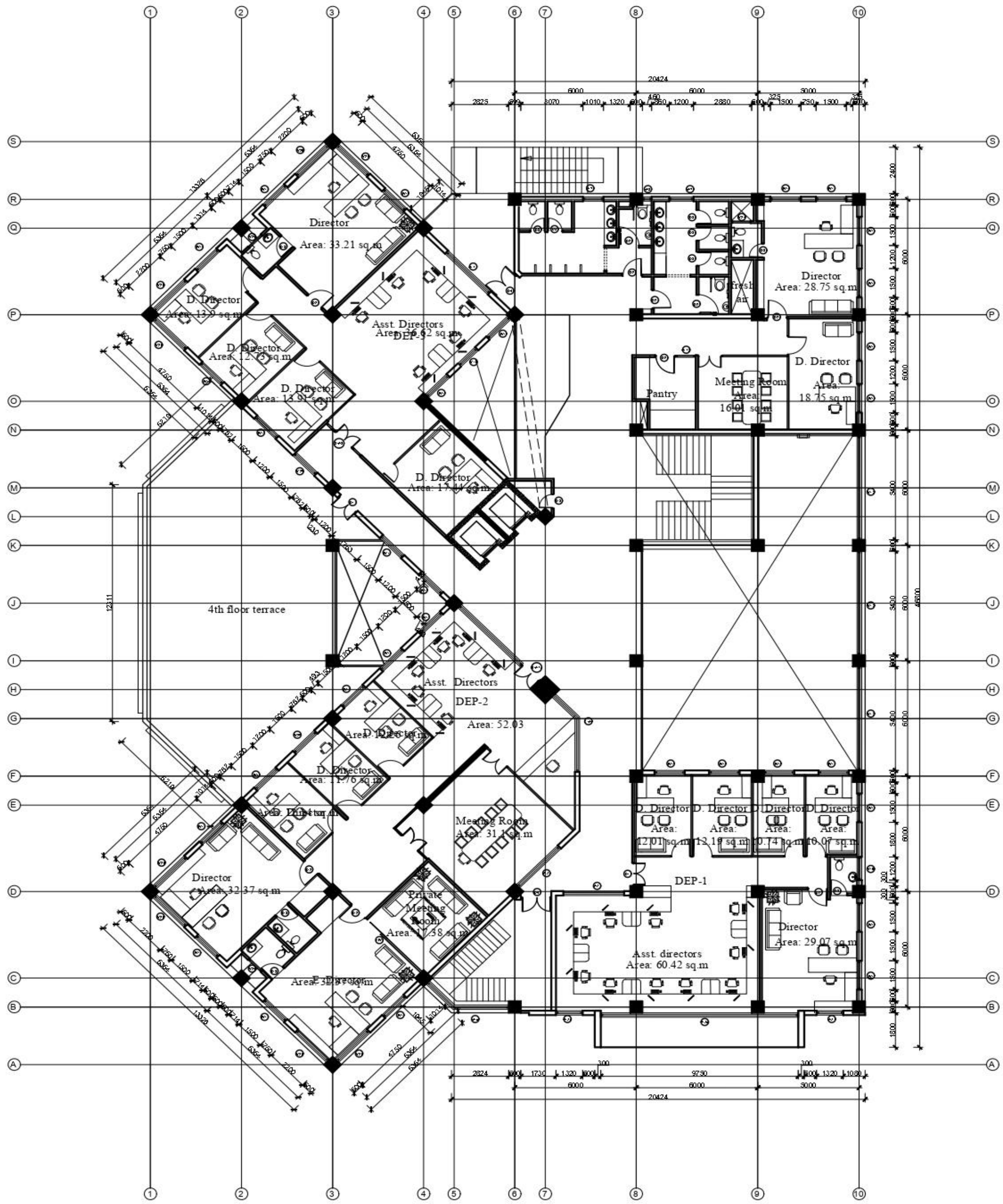
FIRST FLOOR PLAN



SECOND FLOOR PLAN



THIRD FLOOR PLAN



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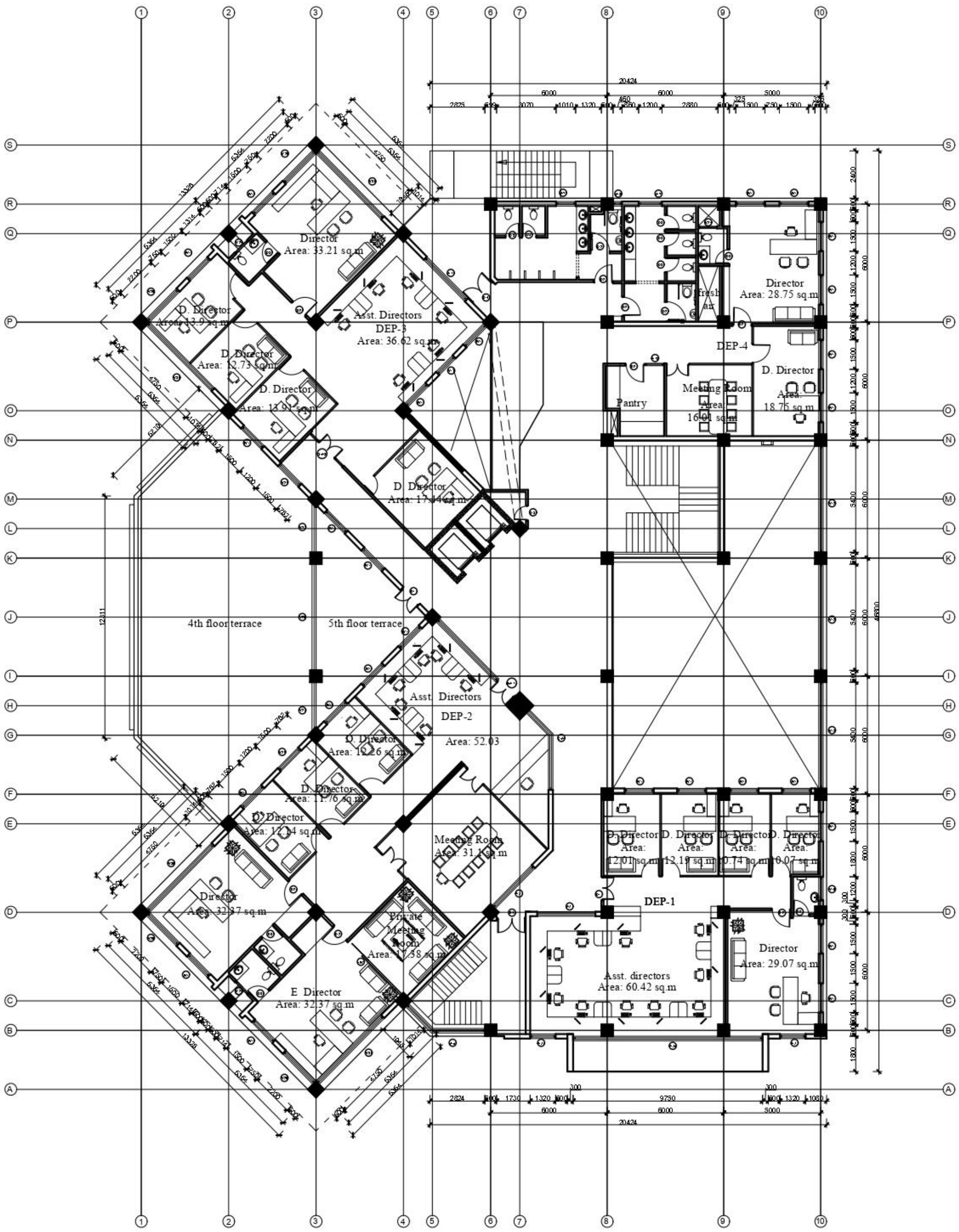
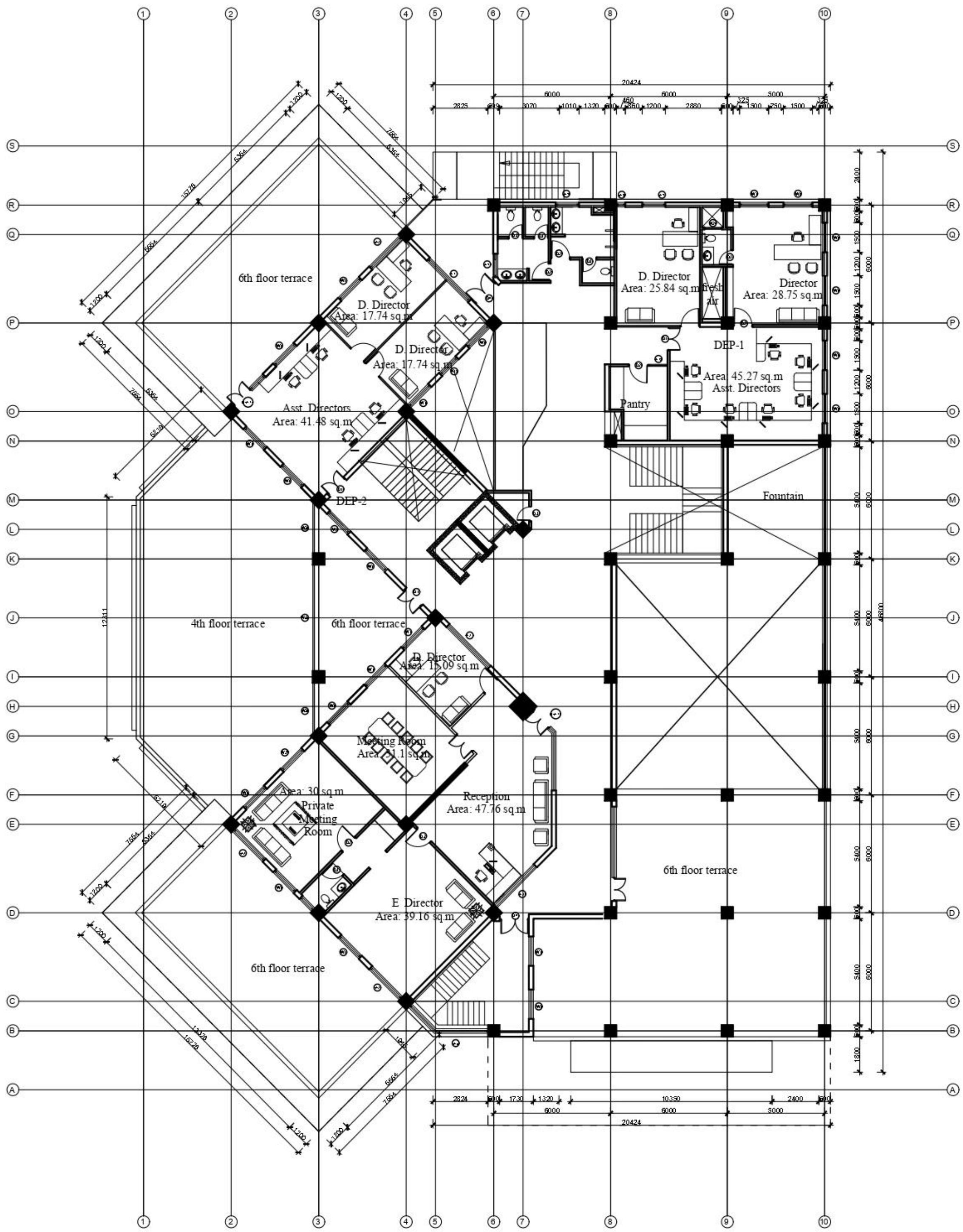
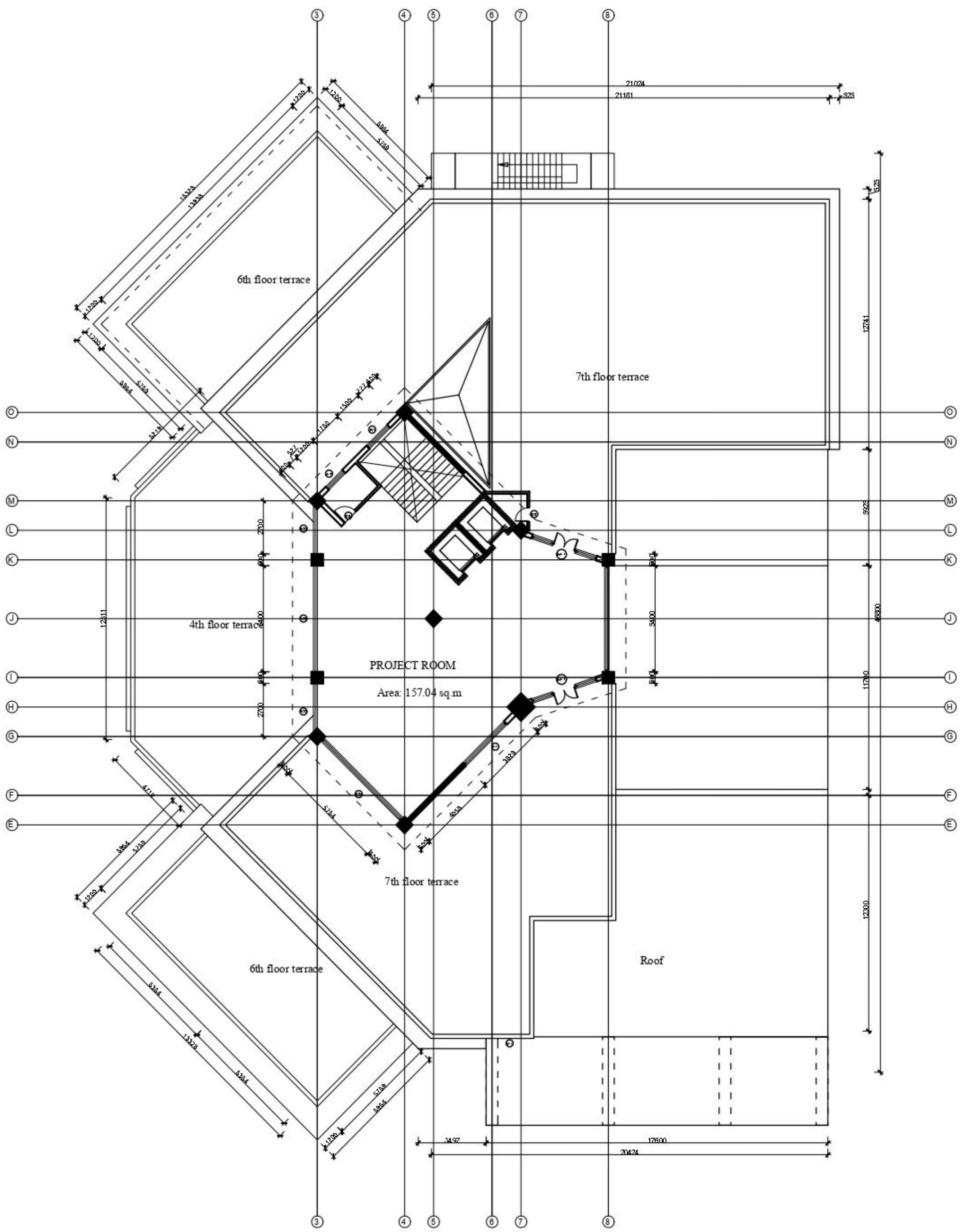


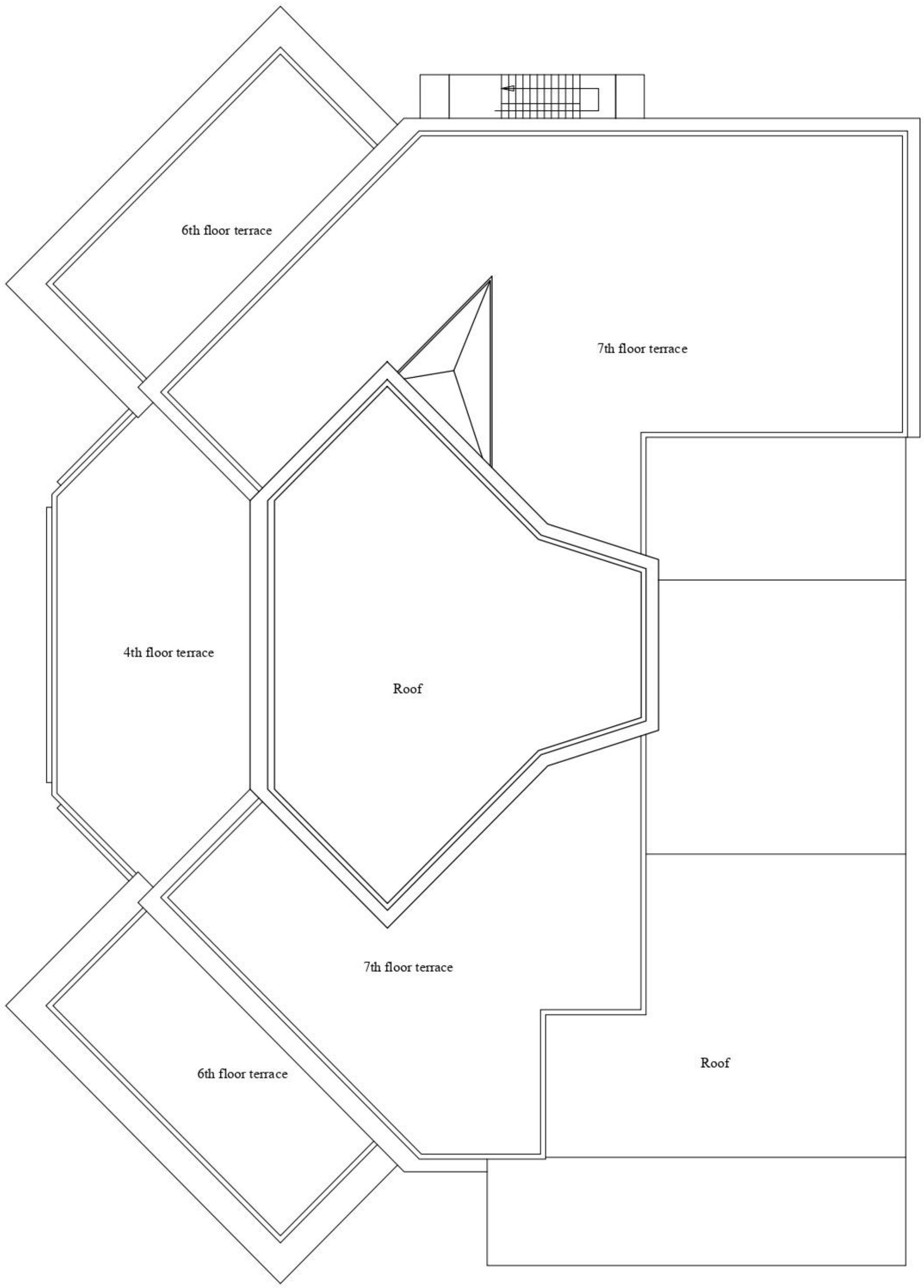
FIFTH FLOOR PLAN



SIXTH FLOOR PLAN



SEVENTH FLOOR PLAN


6th floor terrace
7th floor terrace
4th floor terrace
Roof
7th floor terrace
6th floor terrace
Roof

ROOF PLAN

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16th April, 2026

Letter of Acceptance

Krishna Dev Shah, Laxman Motra, Vishwa Prasanna Amatya

The Editorial Board of Journal of Advanced College of Engineering and Management (jacem) (ISSN No: 2392-4853), is pleased to inform you that your manuscript **"Comparative Analysis of HVAC Load, Energy Consumption and Cost for a Type Commercial Building with Different Wall and Roof Insulation using HAP"** has been reviewed by the referee and accepted for the publication. Your article will be published in the coming issue of Journal of Advanced College of Engineering and Management, Vol. 13.

We are delighted and thankful for considering this Journal as a venue of your valuable research work.

With Regards

Er. Ajaya Shrestha
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