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INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS**

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**Enhancement of HVAC Load, Energy Consumption and Energy
Cost for a Proposed Residential Building, Bhaisepati, Lalitpur,
Nepal**

**By
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**A THESIS
SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND
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PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER IN SCIENCE IN
MECHANICAL SYSTEM'S DESIGN AND ENGINEERING**

**DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING
LALITPUR, NEPAL**

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DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled “**Enhancement of HVAC load, Energy Consumption and Energy Cost for A Proposed Residential Building, Bhaisepati, Lalitpur, Nepal**” submitted by Nabin Thapa, in partial fulfilment of the requirements for the degree of Master of Science in Mechanical System Design and Engineering.

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ABSTRACT

HVAC has become the most important infrastructure for ensuring human comfort in workplace, residencies and commercial hubs. However large energy consumption by HVAC system is the major factor limiting its usage. Proper material selection in building construction not only ensures physical comfort but also ensures low operational cost of HVAC system throughout the year. But deciding the proper material of construction for low HVAC operational cost needs knowledge about the HVAC load resulted by each of the materials available. The same gap has been intended to be filled by comparing the energy consumption resulted due to usage of different types of materials and equipment in constructing building.

A case study of a proposed residential building has been performed. The building model has been generated in Autodesk Revit and HVAC load has been determined by using Radiant Transfer Function Method, a HVAC load calculation method defined by ASHRAE. Similarly, the gbxml file of this model was extracted and it was run for energy simulation using Green Building Studio. The equipment like laptop, freezer, television and microwave have been considered for calculation process. Heat produced by light and energy consumed by them have also been considered for the calculation and simulation process. The HVAC heating load was found to be 5.96 TOR, HVAC cooling load was 5.36 TOR, EUI was 40 kWh/sq ft.yr. The annual energy consumption was 55244 units of electricity and annual energy cost was NRs. 710191. The simulation was run for operating the AC for 24/7 schedule.

The above processes were repeated by varying alternative options for walls, roofs, windows, equipment and sensors. Total of 1240 energy simulations were run and Energy Use Intensity (EUI) were compared for different materials. Walls described by ASHRAE edition 19 and 18 along with common walls used in Nepal were used for running simulations. Similarly, roofs were varied. Variation in windows, equipment and sensors option was made based upon the previous literatures.

After running all simulations and comparing the results, it was found out that wooden wall resulted in least EUI of 198kBTU/sqft.yr. However due to construction trend, it was not used and prefab that resulted in least EUI of 231 kBTU/sq.ft.yr among commonly used construction material in Nepal, was selected. In case of roof, R60 roof resulted in least EUI, but casted concrete roof was selected based upon the availability. Window with 0.3 wall window ratio, 2/3 window height shading and triple pane low-E

glass resulted in least EUI. It was possible to make in aluminum frame. So, it was finalized. Among different types of HVAC equipment for residential purpose, package terminal heat pump resulted in least energy consumption with EUI 122 kBtu/sq. ft.yr. Use of occupancy sensor and lighting sensor was also done. After finalizing all these parameters, model was regenerated using all these parameters and HVAC load, energy consumption and energy cost were calculated.

The final building was found to have HVAC peak heating load of 2.88 TOR, peak cooling load of 3.8 TOR, energy consumption of 37420kWh and energy cost of NRs. 478486. The EUI was decreased from 40 to 29 by this work. By simple alteration of building parameters without modifying any layout, rooms and outlook, HVAC load was seen to have decreased by large portion. Energy saving by almost 32% and energy cost saving by 33% was possible by this simple work. However, the cost involved in construction of enhanced building is higher than proposed building. But the cost is balanced by energy cost in 38 months.

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1. INTRODUCTION

1.1 Background

HVAC has become the most important infrastructure for ensuring human comfort in workplace, residencies and commercial hubs. However large energy consumption by HVAC system is the major factor limiting its usage. Manual calculation was the only load estimation method before 1970s. That resulted in many oversized HVAC systems. The energy crisis of 1973 and hike of price of petroleum by almost 300% within 2 years alarmed all concerned authorities to consider the energy efficiency of electrical equipment including HVAC systems. Many software has been developed since then for proper sizing of HVAC system.

Aghoul, (2017) studied about the usages of electricity in various components and found out that one third of total energy being produced is used in buildings and almost half of that energy consumed by building is used for HVAC system. He concluded that almost 10- 20 % of total energy is consumed in HVAC system depending upon the locations. This shows that proper sizing of HVAC system alone can save large energy.

For proper sizing of HVAC systems, ASHRAE has defined many calculation methods like Cooling Load Temperature Difference (CLTD), Transfer Function Method (TFM), Heat Balance Method (HBM), Radiant Time Series (RTS) Method. However, complexity in manual calculation by these methods pose limitation to strictly follow these processes. So, to aid for proper planning, designing and simulation of HVAC system, many software tools have been developed.

Proper sizing of HVAC system can save energy by avoiding over-sized HVAC system; however, it cannot reduce the total energy required for smooth operation of HVAC system. For reducing the total energy requirement, material selection plays vital role. Energy efficient building design has become the hot topic in construction field. Materials with low overall heat transfer are being researched and developed. So, many construction materials are being used now a days. In Nepal, brick, concrete block, interlocking brick, AAC block and prefab have become the common material for building construction. Similarly, non-envelop parameters like use of daylight sensor and occupancy sensor, selection of type of HVAC system play vital role in energy consumption by HVAC system.

Proper material selection in building construction not only ensures physical comfort but also ensures low operational cost of HVAC system throughout the year. But deciding the proper material of construction for low HVAC operational cost needs knowledge about the HVAC load resulted by each of the materials available. In context of Kathmandu, we need to know the resultant HVAC load per unit area for available materials of construction i.e. wall material, window material, roof material and other parameters like use of occupancy sensor and type of HVAC system to be used.

1.2 Problem Statement

For ensuring the low operational cost of HVAC system by minimizing the HVAC load in residential buildings of Kathmandu, comparative study of resultant HVAC load and energy cost, for using different available construction materials, must be done. So, it is good idea to determine the variation in HVAC load, energy consumption and energy cost for using different materials so that material resulting in low cost can be used and both load and cost would be enhanced.

1.3 Objectives

1.3.1 Main Objective:

The main objective of the proposal is:

- To enhance the HVAC load, energy consumed by HVAC system and energy cost for a proposed residential building located in Bhaisepati, Lalitpur, Nepal by comparing the energy use intensity resulted by each available material of construction.

1.3.2 Specific Objective:

The main objectives will be accomplished with the following auxiliary objectives:

1. To calculate HVAC load, Energy Consumption, Energy Use Intensity (EUI) and Energy Cost for the proposed building by using proposed material of construction.
2. To repeat the step 1. for each available construction materials, HVAC systems and sensors.
3. To compare EUI for each available option.
4. To finalize the parameter for building construction based on low value of EUI and availability such that HVAC load, energy consumption and energy cost is enhanced.

1.4 Scope of Work

There have been previous studies in the past related to calculation of the heat load for designing an HVAC system. Most of them are associated to what capacity of HVAC system required, what type of HVAC system is best suited, what will be the long-term energy cost, maintenance etc. Some studies are based on combining two or more systems to create a hybrid system which is capable of sufficing the HVAC needs. However, in the context of Nepal, there has not yet been study associated with determination of variation of HVAC load required by different available construction materials. Choosing proper material of construction helps to reduce the peak HVAC load, thus reducing both installation cost and operational cost of HVAC system.

This research is a case study focused on determining the variation of HVAC load and annual energy consumption by HVAC system that the building would require for using different materials of construction, by using both mathematical model and simulation tools, so that the proper material can be chosen for constructing the residential building based on energy efficiency. However, despite the cost saving through enhancement, the financial portion in building construction should not be missed. So this work also involves the financial analysis of enhanced building against proposed building.

2. REVIEW OF LITERATURE

2.1 Heat gain and cooling load

The undifferentiated heat flow into a space is generally described as 'heat gain', i.e. the amount of heat flowing in the space by any source that is capable of generating and transferring heat into the space is considered as 'heat gain'. The general methods through which significant heat is transferred in a space are as following (ASHRAE, Heating and Cooling Load Calculation Manual, 1980):-

1. Solar load through glazing which may be windows or open vents.
2. Heat conducted through walls exposed to exterior surroundings and roof.
3. Heat conducted through internal partitions, ceiling and floor.
4. Heat generated by the sources inside which may be the occupants, lights, electrical or electronic appliances, or any other heat generating sources.
5. Heat loads that are infiltrated into the system as a result of unwanted ventilation.

The portion of heat gain that contributes to increasing the air temperature (as opposed to building material and content) to an uncomfortable conditions at a given point in time is called as the cooling load. In other words, cooling load is the amount of heat that must be removed from a building to maintain comfort conditions for the occupants. In terms of the sources of generation there are specifically 2 types of heat gains: -

- i) Sensible heat gain:** Sensible heat gain is the load that is added directly to the system without changing the moisture content of the system which may be transferred through any mediums: conduction convection and radiation.
- ii) Latent heat gain:** Consider the level of moisture in the space is changed because of sources such as evaporation inside. Equal rate of evaporation and condensation maintains constant humidity. Heat required for phase changes gives latent heat gain.

The cooling load is the fundamental basis for designing of the HVAC system. The following are the types of loads based on designing of an HVAC system (Grondzik, 2007):-

- a. Block load:** The diversified load that is used to size the Heating, Ventilating, Air Conditioning, and Refrigerating (HVAC&R) systems. Different zones gain peak heat at different times. Peak measured value of heat gain gives block load. It is also called the refrigeration load and is less than the sum of the peak loads.
- b. Coincident load:** Two simultaneous load are coincident load.

- c. Design load:** It is the load represents the highest reasonable heating cooling load likely to be experienced by a building based upon statistically recorded climatic weather data. Design load is not the maximum load that may or can occur, but, rather the highest reasonable load for design cost consideration of equipment and energy-efficient operations.
- d. Diversified load:** The portion of the sum of the peak loads that is coincident. Load diversity accounts for the fact that the peak loads in different building zones often do not occur simultaneously. Therefore, the actual building peak load is generally smaller than the undiversified sum of the zone peak load. In a similar context, this term is also used to describe loads resulting from equipment or appliances that do not operate at full load at all times. Accurate cooling load estimates must reasonably account for such diversified operation patterns, particularly in spaces such as labs where equipment loads are an especially important concern.
- e. Dynamic load:** A load that has frequently changing value or variable value along the time period is dynamic load.
- f. Instantaneous load:** A load that occurs during a defined time step or period, usually one hour.
- g. Peak load:** The largest load occurring in a space, a zone, or an entire building. In the building load context, it is the maximum simultaneously or coincident load.

Significance of Load Calculation of an HVAC System

For a given space, the heating or cooling load produced can be affected by multiple factors. Setting up a HVAC system is time consuming as well as costly. In addition, setup the flexibility to modify the performance of the system is also very tedious. Thus, it is very essential that preliminary calculation be made before had to estimate to required system to be set up. Other than economic assistance load calculations help us to accomplish one or more of the following (ASHRAE, Heating and Cooling Load Calculation Manual, 1980):-

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

The parameters that construct up a building's envelope have the heat storage capacity. This property increases time taken for heat to transfer from outdoors to the space. Time

lag is defined as the time taken by peak heat to reach inner surface from outer surface. (Gut, Ackerknecht, & ILE, 1993). It is of importance, for instance, in the case where one wants to take advantage in the evening of day time surplus heat energy. It is not easy to find the point the maximum HVAC load occurrence. It happens due to different instances of happening of maximum heat load resulted from different source. For example: heat energy gain from roof may be highest at afternoon but heat gain from equipment is highest in evening. Conversely, the heat gains due to the sun shining through an east-facing window will be highest in the early morning when the sun is rising in the east and shining directly into the window.

2.2 Heat gain and cooling load calculation methods

2.2.1 Radiant time-series method

The radiant time series method RTSM is simple to apply than the heat balance method discussed earlier. The RTSM method makes several simplifications to the heat balance method such as there is no internal or external heat balance rather it is assumed all the surface are effectively at the zone air temperature and facilitates the use of single convection coefficients, radiation coefficients as well as fixed surface conductance independent of surface temperature, sky temperature etc. the zone air temperature is assumed to be constant. The storage and release of energy by the surfaces are approximated with predetermined zone response values. It is a simplified method for calculating peak design load, based directly on Heat Balance (HB) method, assuming steady periodic condition. It relies on a 24- term “response factor series” to generate conductive heat gain and on a 24-term “radiant time series” to convert instantaneous radiant heat gain into cooling loads (Jeffrey D Spitler, 1997). Manual Calculation of HVAC load by this method is repetitive and tedious. So, this method is generated using Heating and Cooling Load tool of Autodesk Revit. Weather data required for calculation of load is accessed by online platform of Autodesk server which provides weather data of target location through virtual weather station.

The procedure of calculation are as follows: -

1. Determination of exterior boundary conditions

$$q''_{convection,ext,j,\theta} = h_c(t_e - t_{os,j,\theta}) \quad 2.1$$

$$t_e = t_o + \frac{\alpha G_t}{h_o} - \frac{\epsilon \delta R}{h_o} \quad 2.2$$

where,

h_o = Combined exterior convection and radiation coefficients.
Btu/hrft²F or W/m²K

δR = Difference between thermal radiation incident on the surface from the sky and surroundings and the radiation emitted by a blackbody at outdoor air temperature. Btu/hrft² or W/m²

2. Conduction heat gains

$$q''_{conduction,in,j,\theta} = \sum_{n=0}^{23} Y_{pn} (t_{e,j,\theta-n\delta} - t_{rc}) \quad 2.3$$

where,

Y_{pn} = nth response factor, Btu/hrft²F or W/m²K

$t_{e,j,\theta-n\delta}$ = Sol-air temperature, n hours ago, F or C

t_{rc} = Presumed constant room air temperature, F or C

3. Application of radiant time series

The RTSM calculates the HVAC load resulted due to the radiative portion of each heat gain by applying a radiant time series. Heat flux is used to calculate the conduction heat flux based on the current and past values of sol-air temperature. It is analogous to radiant time factor which is used to calculate the cooling load based on the current and past values of radiative heat gains:

where,

$$\dot{q}_{\theta,CL} = r_0 \dot{q}_{\theta} + r_1 \dot{q}_{\theta-\delta} + r_2 \dot{q}_{\theta-2\delta} \dots \dots r_{23} \dot{q}_{\theta-23\delta} \quad 2.4$$

$\dot{q}_{\theta,CL}$ = Cooling load at the current hour, Btu/hr or W

$\dot{q}_{\theta-n\delta}$ = Heat gain n hours ago, Btu/hr or W

r_n = nth radiant time factor

Radiant time factors are calculated for a specific zone using a heat balance model. Essentially, with all walls having adiabatic boundary conditions, the heat balance model is pulsed with heat gain for a single hour every 24 hours. The response (hourly cooling load) is calculated until a steady periodic pattern is obtained. If the resulting cooling loads are divided by the magnitude of the heat gain pulse, the ratios for each hour are the radiant time factors.

2.3 Energy Consumption by HVAC system

In HVAC energy simulation, energy consumption varies among working cycles based on whether the operation is under design condition, part load condition or below minimum part-load ratio (Associates, 2005). Also depending upon the external weather condition, same sized equipment consumes different amount of energy as the required condition is reached at different time and thermostat controls the working cycle length as accordingly. Annual energy consumption calculation is iterative and hence it is accomplished using DoE2 simulation tool. Energy consumption by HVAC equipment vary as per the outdoor weather which is accessible through online platform of GBS.

2.3.1 DOE-2

DOE-2 is a simulation tool developed by James J Hirsch and Associates (JJH) in collaboration with Lawrence Berkeley National Laboratory (LBNL) for United States Department of Energy (USDOE). It is used to predict energy consumption and energy cost for all types of buildings. DOE-2 uses a description of the building layout, constructions, operating schedules, conditioning systems (lighting, HVAC, etc.) and utility rates provided by the user, along with weather data, to perform an hourly simulation of the building and to estimate utility bills. The “plain” DOE-2 program is a “Command Prompt” program which requires substantial experience to learn to use effectively while offering researchers and experts significant flexibility; eQUEST is a complete interactive Windows implementation of the DOE-2 program with added wizards and graphic displays to aid in the use of DOE-2.

At design condition, the energy consumed by system is given as:

$$\text{Energy} = (\text{CAP}) * (\text{EIR}_{\text{des}}) \quad 2.5$$

At part-load condition:

$$\text{Energy} = (\text{CAP}) * (\text{EIR}_{\text{des}}) * [\text{EIR}\{\text{PLR}\}] \quad 2.6$$

At operation below minimum part-load ratio:

$$\text{Energy} = (\text{CAP}) * (\text{EIR}_{\text{des}}) * [\text{EIR}(\text{MIN-RATIO})] * (\text{FRAC}) \quad 2.7$$

Where,

CAP= Design (rated) Capacity of Equipment

EIR_{des}= Design Electric Input Ratio

PLR= Part Load Ratio

EIR{PLR}= Electric Input Ratio Correction Factor at Part Load Ratio

EIR(MIN-RATIO) = Electric Input Ratio Correction Factor at Operation Below
Minimum Part Load Ratio

$$FRAC = \frac{PLR}{MIN-RATIO} \quad 2.8$$

2.4 Annual Energy Cost Calculation

The annual energy cost can be calculated as summation of monthly energy cost. Depending upon the ampere size of installed energy meter, both service charge and unit cost of electricity varies. 60A rated domestic system has been taken for cost calculation in this work. Monthly cost can be calculated as [8]:

$$Cost_i = S + U * R \quad 2.9$$

$$Annual \text{ Cost} = \sum_{i=jan}^{Dec} Cost_i \quad 2.10$$

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)

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

2.5 Previous Researches

(Garg & Bansal, 2000) studied the energy saving that can be done by smart sensors to control the operation of electrical and HVAC system as per the presence of occupants in room. A smart sensor was developed and study was conducted experimentally. It was found out that 5% of energy can be saved by the use of occupancy sensor for the operation of HVAC and electrical equipment.

(Gajda & Marceau, 2004) checked the thermal performance of insulated concrete house in Canada and USA. Insulated Concrete wall include insulating concrete form wall (ICF wall), cast-in place concrete wall, autoclaved aerated concrete wall, and insulated concrete masonry wall. They also compared the HVAC cooling load of insulated concrete house with wooden house and found out that use of insulated concrete wall

can downsize the HVAC system by 15 to 40% in comparison to identical wooden house. Thus they concluded that HVAC load can be enhanced by using wood instead of insulated concrete.

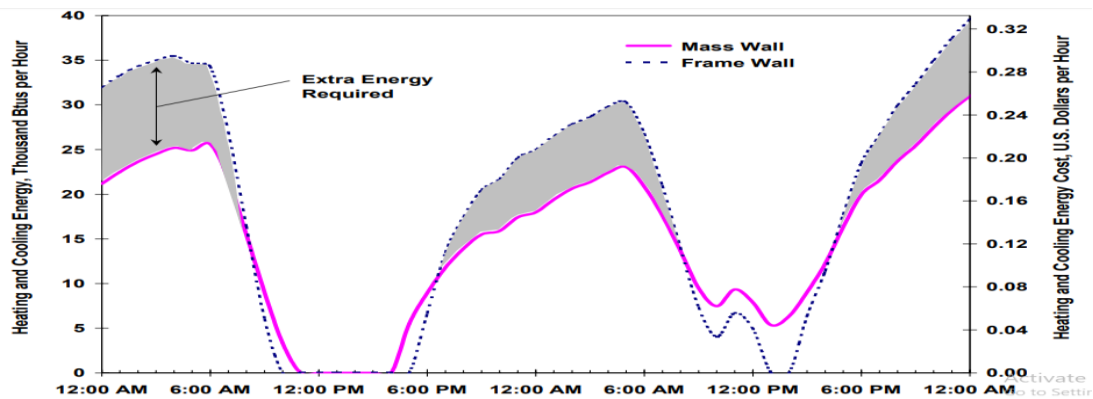


Figure 2:1: Variation in Load Between ICEB and Wooden Frame Wall (Gajda & Marceau, 2004)

HVAC design process by manual method is iterative and tedious. To overcome with it, various computer program has been developed. However, the accuracy of the program to be used must be verified before using them for HVAC design process. (Sandberg, 2011) checked accuracy of Autodesk Revit and concluded that it can be used to calculate HVAC load, however it cannot be used for energy simulation work. Use of Revit eases HVAC design process in load calculation, 3D modelling, scheduling and model revision.

(Abdulla, Bakar, & Rehman, 2013) tested the indoor thermal performance of office building using conventional brick and ICEB. Ecotect Simulation program was used for comparing the thermal performance of the office building. An office building at University Tun Hussein Onn Malaysia was used as model for testing the indoor thermal performance. The ICEB has more thermal mass than conventional brick. It was found out that conventional brick has low indoor temperature than ICEB during morning time. Later on, during day time, the indoor temperature was found to be higher in conventional brick building. ICEB was found to absorb heat during day time that resulted in higher indoor temperature during evening time.

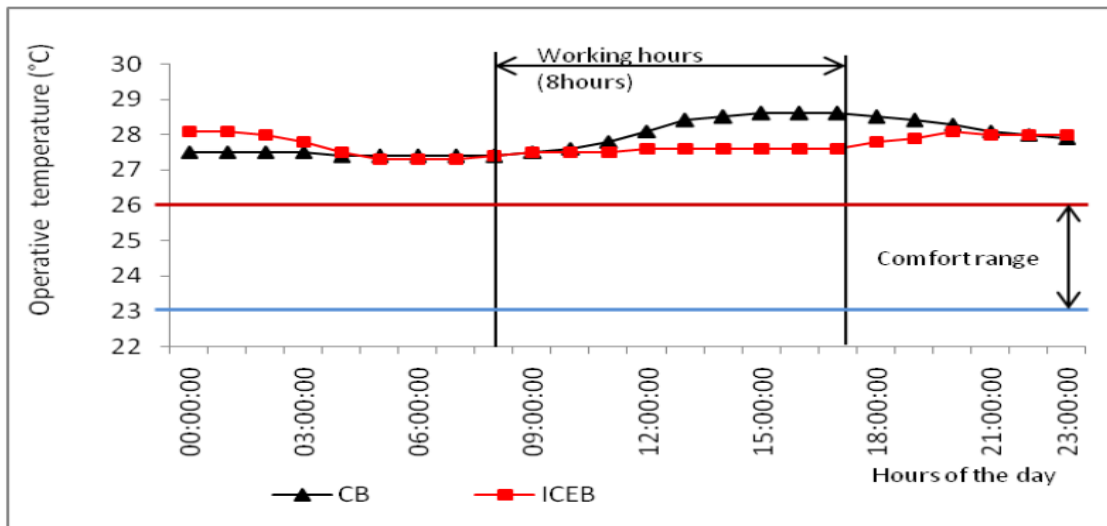


Figure 2:2: Load Variation Between Conventional Wall and ICEB: Ground Floor (Abdulla, Bakar, & Rehman, 2013)

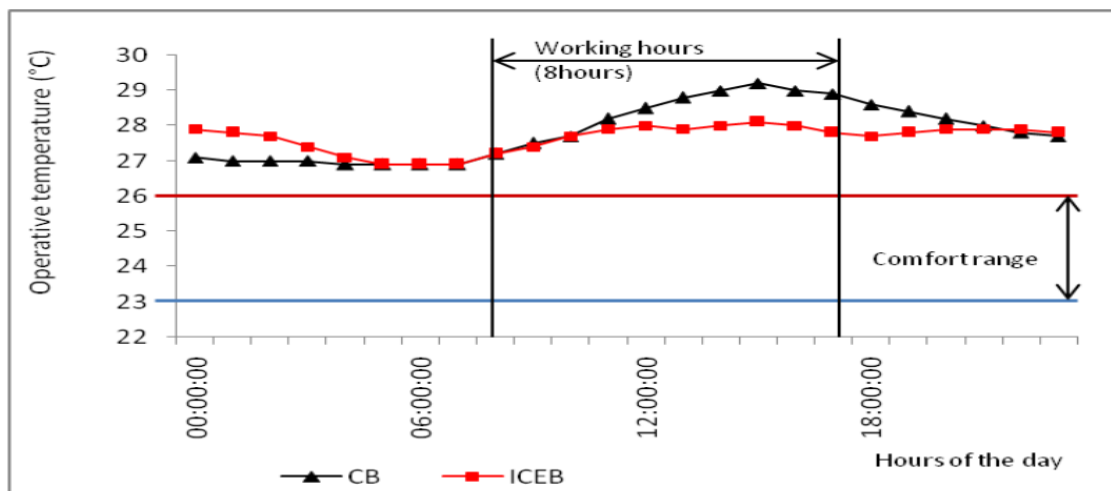


Figure 2:3: Load Variation Between CB and ICEB: First Floor (Abdulla, Bakar, & Rehman, 2013)

Felix (2013) checked the accuracy of CLTD method by creating the CLTD values for a building located at Ghana by using transfer function method and comparing it with CLTD values as given by ASHRAE. They also examined the pattern of temperature increase of different direction oriented walls and compared the patterns with that provided by ASHRAE. The result matched with that given by ASHRAE and thus they concluded that CLTD method can be used for accurate calculation of cooling load by manual method.

As of 2013, demand of energy in residential sector was found to be 7500 TJ and growth rate of energy requirement in residential sector was around 4 percent. The energy used in HVAC system was 4 percent of total residential demand (Utsav Shree Raj Bhandari, 2014). Complying with these facts, 144 TJ (40,000,000 kWh) of energy is used in HVAC system annually in Kathmandu in 2020.

Occupancy-based sensors can reduce energy use by either reducing lighting levels or providing on/off control based on space occupancy. (Facilities Net, 2014). Occupancy sensor senses the presence of occupants in spaces and send signal to switch on equipment. People normally do not think turning off lights and equipment while roaming inside home. This leads to increase in energy consumption. Also, light intensity is fixed in most lights in houses. When daylight enters the room, the required intensity might be low than that present by combination of lighting and daylight. Daylight sensor control light intensity as required, enabling to save energy. Case study done at University of California, Berkeley showed that 36% of energy could be saved by use of occupancy and daylight control sensors (Duong, 2016).

OTUH (2016) studied about the possibility of energy analysis/sustainability using Revit and their possible adoption in Finland. Case study methodology was used for this purpose. Hamk Visamaki Campus building was taken into consideration for the study. The result of Revit was compared with result of GBS. All other results were same except calculation of floor area. Revit showed floor area of 782 sq meter whereas GBS showed 1111 sq meter. Despite the different floor area, the total energy consumption was shown almost same in both analysis. So it has been concluded that revit can be used for BIM modelling of HVAC in Finland. Rather than developing model as per usage trend, use of models with matching U- value can be done for estimating heating and cooling load.

Benzarti (2017) checked the efficiency of Revit in heating and cooling load calculation in residential building in Sousse city of Tunisia. Spreadsheet ASHRAE, TRNSYS and Revit has been used for research purpose. Calculation for traditional and contemporary house has been done and compared by taking result of TRNSYS as standard accurate result. 5% and 11% energy saving could be done for heating and cooling loads respectively as per the results obtained from Revit. So, Revit has been concluded as efficient tool for calculating HVAC loads.

(Kraus & Senitkova, 2017) studied the indoor environment in residential prefabricated house. The study was focused on determining the indoor air condition in term of ppm of particulate matters, relative humidity and indoor temperature. Experiments were carried out from 1 October to 30 November 2016. The indoor air temperature [°C], relative humidity [%] and indoor air quality [ppm] were continuously measured in 10-minutes cycles in selected in residential prefabricated panel building. The mean daily outdoor temperature for Ostrava (Mošnov) is 8.3 °C in October and 5.0 °C in November. The minimum measured indoor air temperature is 20.52°C. Indoor air temperature in the apartment has never been less than optimal temperature (18 °C) during the experiment. The mean 10-minutes indoor air temperature is 22.43 °C. Maximum value of indoor air temperature is 25.76 °C. Indoor air temperature exceeded the upper limit of the optimum temperature for a total of 80.52 (5.50%) hours. Graphical representation of obtained values shows significant fluctuations from the mean. So, to maintain the proper indoor temperature with respect to human comfort by preventing the fluctuations, HVAC load analysis need to be done properly in prefabricated house.

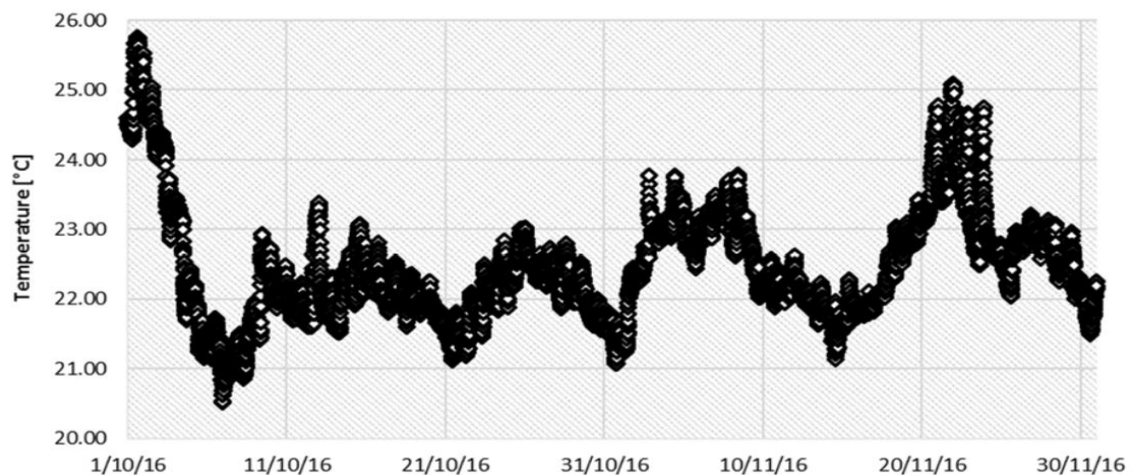


Figure 2:4: Indoor Condition of Prefab House (Kraus & Senitkova, 2017)

(Aghoul S. K., 2017) studied about the performance of different HVAC systems used in residential building. The packaged terminal heat pump was found to consume 44009 kWh energy for a year. It was lowest energy consumption in comparison to rooftop heat pump, VRF and unitary systems.

(Shen, Yu, Hou, & Wang, 2017) tested the indoor thermal environment of prefabricated house. A classroom of dimension 9000mmX7200mmX3200mm was taken for the study. Wall has been made up of prefabricated panel boards and roof has been made up of PVC panel. Upon experiment, heat transfer coefficient for prefab wall was found to

be $0.325 \text{ W/m}^2\text{K}$ and for roof, it was $0.265 \text{ W/m}^2\text{K}$. For comparing the result, traditional building made up of 240mm brick wall was taken as reference. Wall heat transfer coefficient for it was $2.12 \text{ W/m}^2\text{K}$ and for roof was $6.4 \text{ W/m}^2\text{K}$. the average indoor temperature was found to be 10.17°C in prefab room whereas it was found to be 9.29°C in traditional house. As the study was conducted in winter, the above result implies that low HVAC heating load would be required in prefab wall in comparison to traditional wall building.

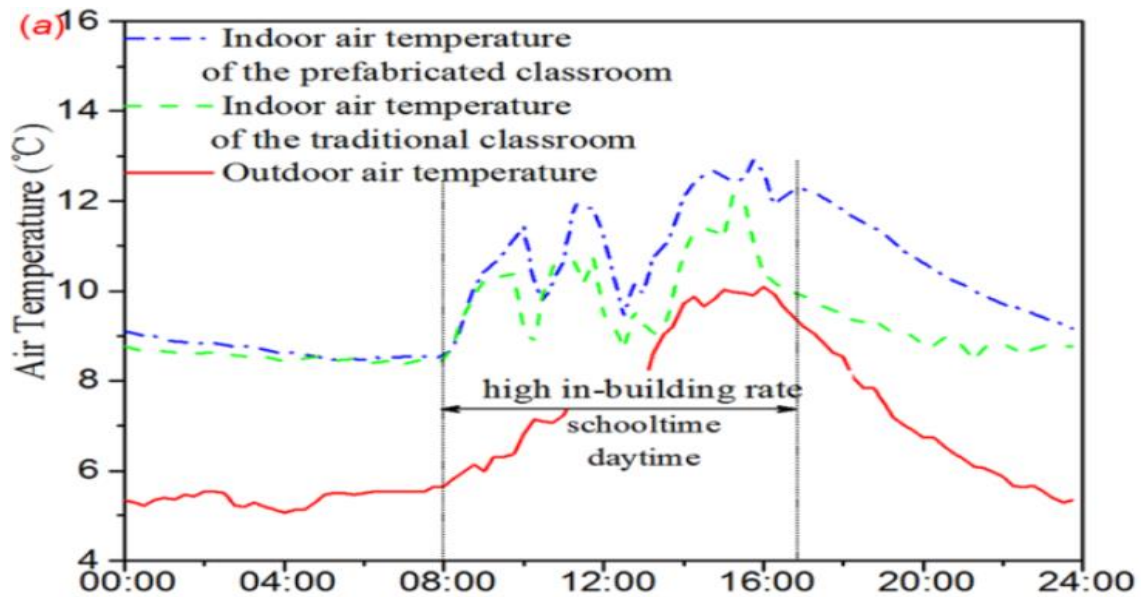


Figure 2:5: Internal and External Temperature Variation in Prefab House (Shen, Yu, Hou, & Wang, 2017)

(Mbereyaho, Baptiste, & Halera, 2018) studied the energy efficiency of compressed earth brick (CEB/ Interlocking Brick) in order to determine the usability of CEB in building construction. They used the sample having average moisture content of 10.74%. To determine the suitability in terms of energy efficiency, they compared it with burnt brick. Higher content of pozzolana in CEB resulted in decrease in thermal conductivity of CEB. The thermal conductivity of CEB was found to be 0.646 W/m.K . The energy efficiency of CEB was found to have increased by 1.6 to 2.3 times in comparison to that of normal brick in this research.

(Vengala, Mangloor, & Goud, 2019) checked the performance of AAC block under varying temperatures. They checked physical properties like cracking under high temperature, not adhering to plaster and thermal properties like thermal comfort and indoor resultant temperature. They compared the result with that of solid concrete block

in order to determine the thermal comfort level in a building made up of AAC block. AAC block of size 600mmX200mmX150mm was used for the study. They checked indoor temperature of building made up of AAC block and solid concrete block for 9 days under identical condition and found out that building made up of AAC block had 1-2 degree celcius low indoor temperature, thus ensuring better thermal confort and low HVAC energy requirement in AAC block made building in comparison to solid concrete block made building.

Day	Avg. Temperature (⁰ C) recorded in scaled model		Difference in Temp.(⁰ C)	Range of temp (⁰ C)
	AAC blocks	SC blocks		
1	29	31	2	1-2
	31	32	1	
	31	32	1	
2	29	29	0	0-1
	30	31	1	
	31	31	0	
3	28	30	2	1-2
	30	31	1	
	31	31	1	
4	29	31	2	1-2
	31	32	1	
	31	32	1	
5	29	31	2	0-2
	28	30	2	
	31	31	0	
6	28	30	2	0-2
	29	31	2	
	31	31	0	
7	27	29	2	2-3
	29	30	2	
	28	31	3	
8	29	29	0	0-1
	30	31	1	
	31	31	1	
9	28	30	2	0-2
	30	31	1	
	31	31	0	

Figure 2:6: Indoor Temperature Difference Between AAC house and Solid Concrete House (Vengala, Mangloor, & Goud, 2019)

(Shaeri, 2019) studied about the optimum wall window ratio (WWR) in different climates found in Iran. The study was focused on determining the wall window ratio that results in low value of HVAC load such that low energy would be consumed the

HVAC system. It was found out that the low value of HVAC load was resulted in WWR 20% to 40% depending upon the face of the house and climate.

Use of double and triple pane windows help to reduce HVAC load as well as energy consumption by the HVAC system. However, the cost involved in using double or triple pane may limit the use of pane by customer. Also, replacement of window from double pane to thin triple pane was found to have decreased the U-value of window by around 0.02 f. ft².hr/BTU. So, builders were found to have confused option between double pane and triple pane window usage in buildings (Gilbride, Selkowitz, & Dingus, June 2019)

2.6 Different Types of HVAC System

a) VAV System: VAV stands for variable air volume. It works by varying the airflow in a building at a constant temperature, For, larger commercial buildings, whatever may be its size, this is a pronounced advantage as it allows better temperature control. With buildings of large sizes, individual control is a necessity and accomplished via a main VAV/air box, zones, ductwork, and dampers. How this works is that the supply air temperature remains constant, and the airflow rate fluctuates to accommodate the loss-and-gain heating patterns of each connected zone.

Schematic

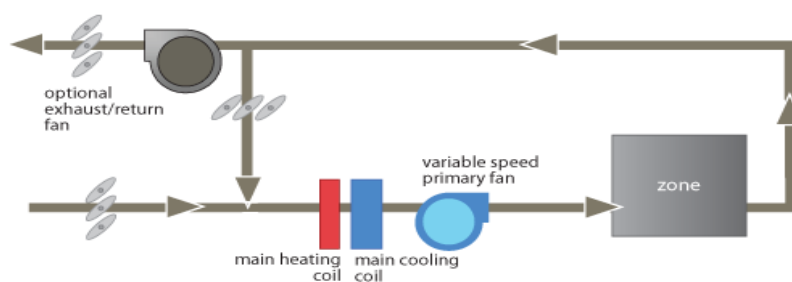


Figure 2:7: Schematic Diagram of VAV

Figure Source: (Sathyanandamoodya, 2017)

b) ASHRAE Package Terminal Heat Pump

A packaged terminal heat pump consists of a separate, un-encased refrigeration system installed in a cabinet of similar function and configuration to that of a packaged terminal

air-conditioner. It utilizes reverse cycle refrigeration as its prime heat source and should have available other supplementary heating by hot water, steam, or electric resistance. They are through the wall units. They are suitable for heating and cooling small rooms

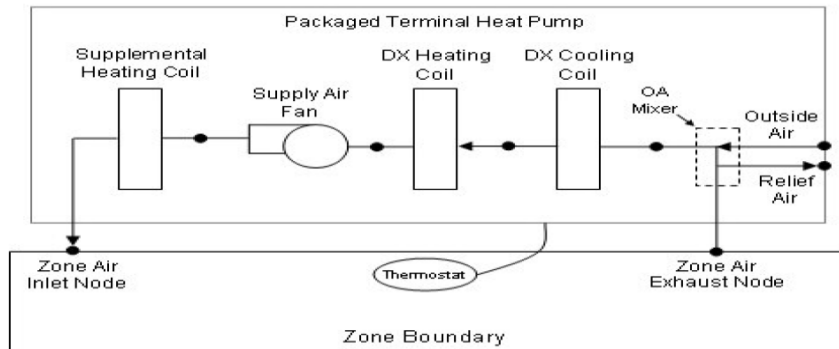


Figure 2:8: Package Terminal Heat Pump

c) Package System: A package air conditioner contains an air conditioner and an air handler.

d) Package Heat Pumps: Package heat pumps contain a heat pump and an air handler. These units are good for residents of the South where temperatures rarely drop below freezing. With one of these package units, you can get all-electric heating and cooling.

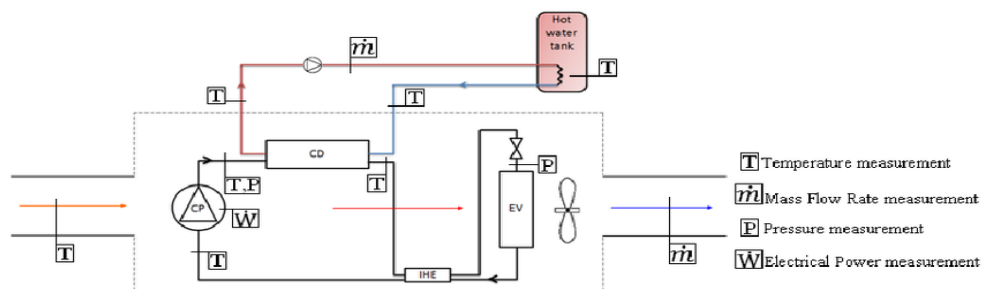


Figure 2:9: Package Heat Pump

3. RESEARCH METHODOLOGY

3.1 Step-wise Methods

The study involves the following methodologies:

1. Literature Review

Reviewing the articles and journal papers provide insights to the degree up to which any works or researches or studies are put forth by the scholars from the past to the present. Considering the importance of material selection for reducing the peak HVAC load and resultant HVAC load due to each of the different available construction materials, various research papers regarding thermal conductive behaviour and thermal comfort have been studied. Also, the accuracy and acceptance of used methodology for calculating the peak HVAC cooling load, researches regarding the accuracy of various calculation method have been gone through. Software simulation using Revit and DOE-2 have also been discussed.

2. Model Development of Structures Using Locally Used Resources and Their Properties

HVAC load depends upon the properties of materials being used for construction and the type of construction. So, in order to know the variation in cooling load of structures made up of various materials, models have been designed using the properties of available materials. Common materials used for construction nowadays are brick, concrete block, AAC block, prefab board and interlocking brick. For brick, wall thickness has been kept as 240 mm and for other materials wall thickness have been kept 150mm. inch. Concrete block, AAC block, interlocking brick, prefab and common brick have been used as wall material. For window, single, double and triple pane have been used. Similarly, use of daylight and occupancy sensor, use of different types of HVAC system have been done in simulation model.

3. HVAC load Calculation Using Revit

For calculating the heating and cooling load in Revit, initially the model has been brought to mechanical template. Then the location of building has been set to Kathmandu so that Revit takes the weather data automatically from internet. Also, the inbuilt walls in Revit was found to have different U-values than the

actual U-values. So, walls with equivalent U-values have been created. Then model has been developed in Revit and cooling load has been calculated.

4. Energy Analysis

The annual energy consumption by the HVAC system has been calculated by using simulation tool Green Building Studio (GBS). It works on calculation procedure as prescribed in DOE-2. The result shows option for both fuel and electricity as source of energy. However, considering the energy source in Nepal, only electricity has been taken as energy source.

5. Iteration of Process 3 and 4

The building parameters and non-envelope parameters have been varied in building model and energy use intensity (EUI) and determined for each alternative model. Total 1240 alternate design options have been found possible when each parameter was varied individually. EUI has been determined for each of those option.

6. Selection of Final Parameters for Building

Based on the lowest value of EUI, availability and construction trend, building construction parameters have been finalized.

7. Final Review

After finalizing the parameters, HVAC load, energy consumption and energy cost were evaluated for building made up of final parameters.

8. Documentation

Final report has been prepared based on task 1 to task as above.

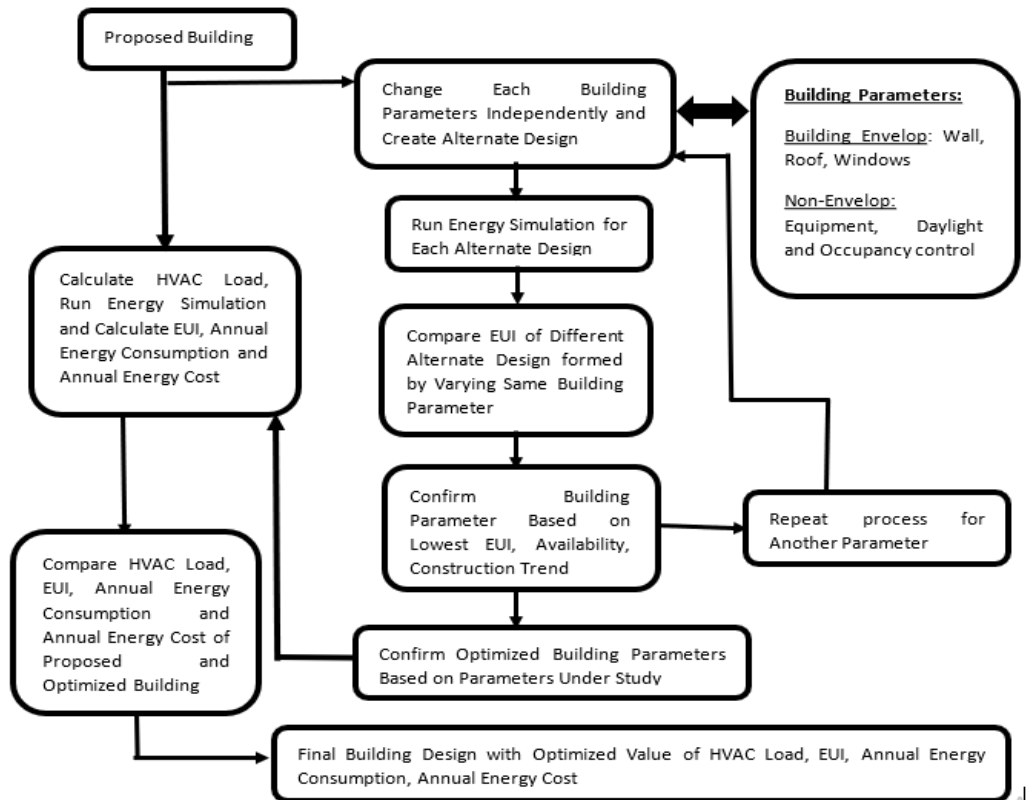


Figure 3:1: Research Methodology Chart

3.2 Description of the space

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

Table 3-1: Details of Proposed Building

Building Location	Bhaisepati, Lalitpur
Building Size	2 and half story
Floor Area	1400 sq ft
Wall Material	Common Brick with plaster
Wall Window Ratio	0.21
Roof Type	Flat
Roof Material	Concrete
Floor	Concrete
Window Type	Single pane clear glass
Number of rooms	12

3.3 Weather Statistics

The weather data essential for the calculations of the cooling loads are prerecord in (ASHRAE, 1993) and (ISHRAE, 2019) which are enlisted below.

Table 3-2: Weather of Kathmandu

Weather properties			
Data available			
Location	KTM valley	Summer design DBT	89 ⁰ F (31.67 ⁰ C)
Required indoor temp	74 ⁰ F (23.33 ⁰ C)	Summer co-incident WBT	78.8 ⁰ F (25.56 ⁰ C)
Elevation	4388ft	Summer daily range	25.2 ⁰ F (13.89 ⁰ C)
Latitude	27.7 deg	Winter design DBT	33.0 ⁰ F (0.56 ⁰ C)
Longitude	-85.2 deg	Winter co-incident WBT	27.3 ⁰ F (-2.78 ⁰ C)
Data assumed			
Criteria	Temperature	Remarks	
Ambient space max temp	89 ⁰ F (31.67 ⁰ C)	Design summer DBT	
Unconditioned space max temp	80 ⁰ F (26.67 ⁰ C)	Assumed to be 5 ⁰ C lower than design summer DBT	
Ambient space min temp	51.7 ⁰ F (10.39 ⁰ C)	Min winter temp	
Unconditioned space min temp	59.69 ⁰ F (15.94 ⁰ C)	Assumed to be 5 ⁰ C higher than min Jan winter WBT	

Table 3-3: Summer and Winter DBT and WBT of Kathmandu

Month	Summer		Winter	
	Max DBT (F)	Min WBT(F)	Max DBT(F)	Min WBT(F)
Jan	77.2	52.2	70.6	51.7
Feb	79.2	54.2	71.6	53.7
Mar	82.4	57.4	74.8	56.9
Apr	83.6	58.6	75.0	58.1
May	86.0	61.0	76.0	60.5

Jun	88.0	63.0	78.0	62.5
Jul	89.0	64.0	78.0	63.5
Aug	89.0	64.0	78.0	63.5
Sep	87.0	62.0	77.0	61.5
Oct	84.8	59.8	75.8	59.3
Nov	80.6	55.6	73.8	55.1
Dec	78.2	53.2	71.8	52.7

Design Conditions

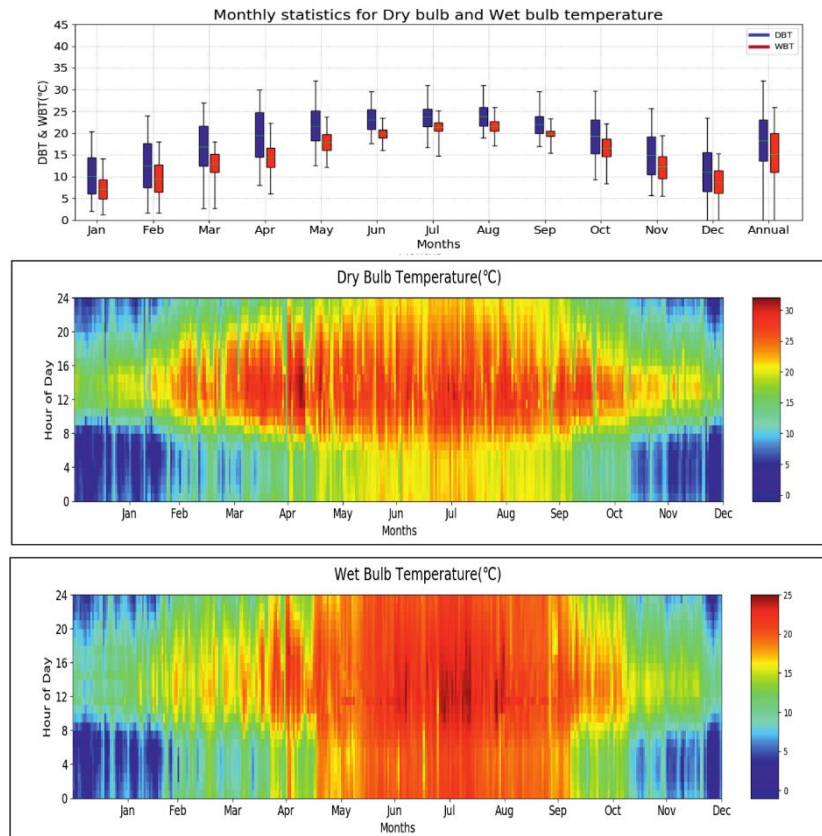


Figure 3:2: Weather Data of Kathmandu (ISHRAE, 2019)

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

While compare the weather statistics as well as the design temperatures provided by the two sources, we can see that even though the data were provided 26 years apart there is very little difference between the two. The summer design temperature provided by (ASHRAE, 1993) is 31.67⁰C while the one provided by (ISHRAE, 2019) is 30⁰C (for 0.4% confidence level) which is very close. Also the winter design temperature

provided by (ASHRAE, 1993) is 0.56°C while the one provided by (ISHRAE, 2019) is 2°C (for 99.6% confidence level) which is very also very close.

As calculation is being done in Revit, it takes weather of any location through virtual weather station monitored by Autodesk server (Autodesk, weathersanepalalitpurnepal, 2006).

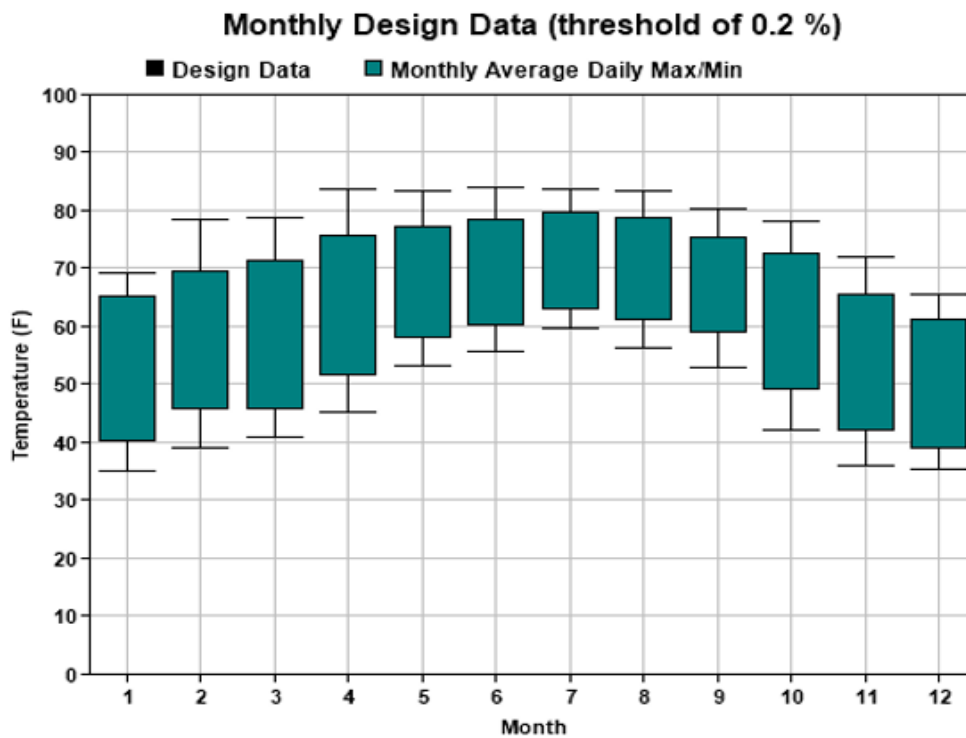


Figure 3:3: Design Condition at 0.2% of Weather Station at Sanepa

3.4 Autodesk Revit

Revit is a BIM tool developed by Autodesk. It is multi-disciplinary software with capability to work on architectural, mechanical, civil, structural and electrical design and analysis work. Autodesk Revit 2017 trial version have been used for analysis purpose in this thesis. Revit uses Radiant Time Series (RTS) method (Autodesk, Autodesk, 2020) for calculation of heat load. For this work, trial version has been used.

3.5 Geometry Modelling

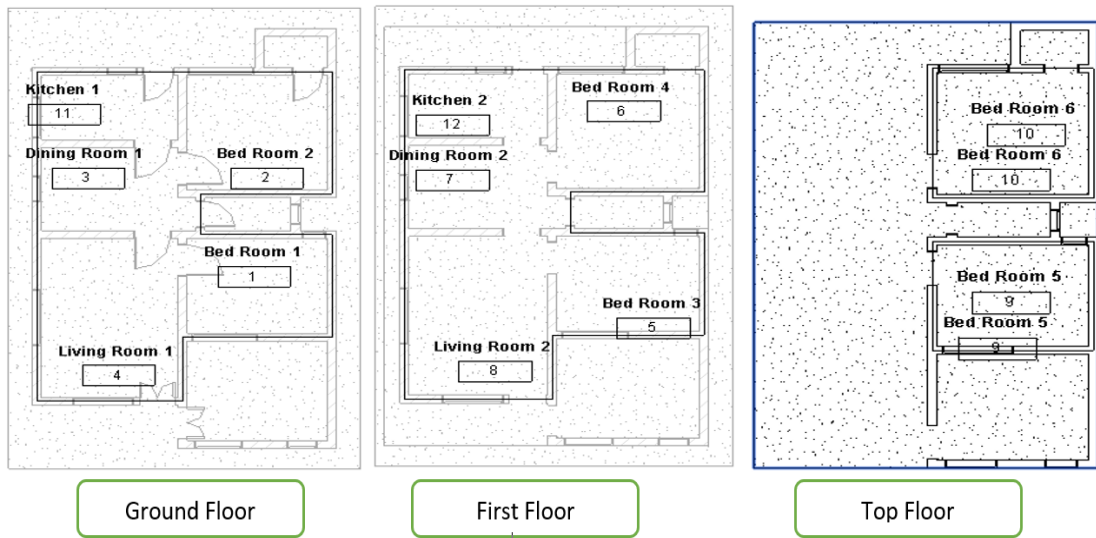


Figure 3:4: Floor Plan of Proposed Building

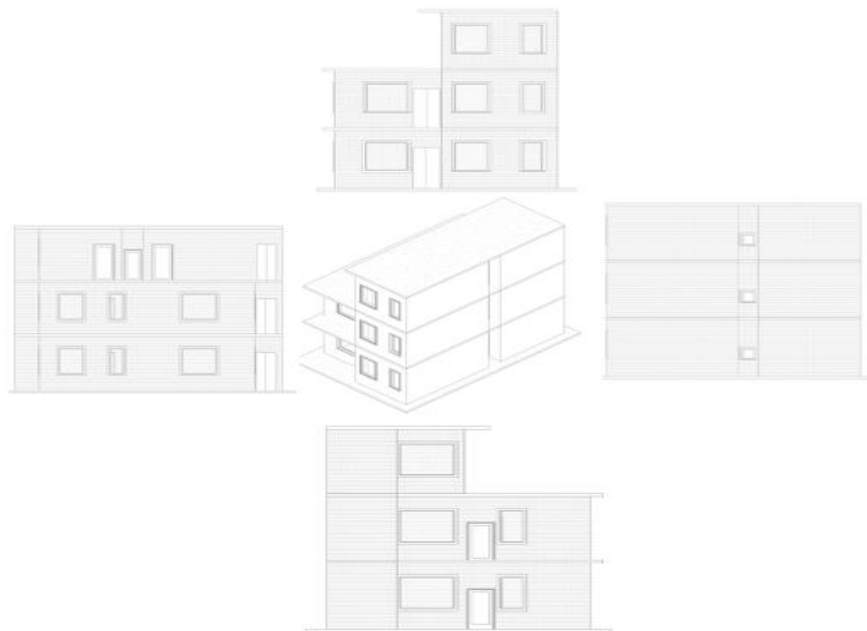


Figure 3:5: Elevation View Made in Revit

Then Revit model was recreated for software calculation of loads. The walls available in Revit directory was not matching with the actual walls in Nepal in term of thermal resistance. So, wall with equivalent thermal resistance was made. Windows with single pane clear glass with shading coefficient 0.81 was used. The size of windows are 3X5 sq. ft 8X5 sq. ft were used on west and east side respectively. The door of size 4X7 sq. ft have been used.

Table 3-4: Thermal Properties of Materials

SN	Description	R-value(hr ft ² F/BTU)	Size	Source
1	Brick Wall	3.339	240mm	(Mcquiston, Parker, & Spilter, 2005) (Development, 2064)
2	Concrete Block Wall	3.195	150 mm	(Mcquiston, Parker, & Spilter, 2005)
3	AAC Block Wall	4.479	150 mm	(Pruteanu, 2013)
4	Interlocking Brick Wall	2.544	150 mm	(Razman & Abdullah, 2010)
5	Prefab Wall	38.46	150 mm	(Ecopanel, 2020)
6	Windows	1.13	3X5, 8X5 sq ft	(Pita, 2002)
7	Roof	1.73	4"	(Mcquiston, Parker, & Spilter, 2005)

3.6 Alternate Parameters for Building Construction

Variations have been made on building parameters on both envelope and non-envelope factors. Building envelope determines the internal environment of building whereas, non-envelope parameters maintain favourable environment for human comfort inside building. Window shades, number of panes and glass type has been assumed on basis of data availability, practical implications and hence limited to few options as tabulated below:

Table 3-5: List of Building Envelope Parameters for Variation

Building Envelope	Variations
Wall	ASHRAE Walls ((ASHRAE, energy standard for buildings except low-rise residential buildings, 2019), (ASHRAE, energy efficient design of low-rise residential buildings, 2018)) Conventional Nepali Wall

Roof	ASHRAE Roof[(ASHRAE, Standard 90.1-2019–energy standard for buildings except low-rise residential buildings, 2019), (ASHRAE, energy efficient design of low-rise residential buildings, 2018)]
Window Wall Ratio	0.1, 0.2,,...0.9 (Alibaba, 2016)
Window Shades	0, 1/6, 1/4, 1/3, 1/2, 2/3
Number of Panes	Single, Double, triple
Glass Type	Clear, Low-E

Properties of the glass used are as follows (Pita, 2002):

Table 3-6: List of Properties Used for Window Glass

SN	Type	Number of Panes	Properties
1	Clear	Single	Thickness= 6mm, U=1.18 BTU/hr/ft ² F
2	Clear	Double	Thickness= 4mm, U= 0.35 BTU/hr/ft ² F
3	Clear	Triple	Thickness=4mm, U= 0.27 BTU/hr/ft ² F
4	Low-E	Single	U=1.18 BTU/hr/ft ² F, e=0.05
5	Low-E	Double	U= 0.35 BTU/hr/ft ² F, e=0.05
6	Low-E	Triple	U= 0.27 BTU/hr/ft ² F, e= 0.05

Study of non-envelope parameters are limited to equipment, occupancy sensor and daylight sensor as tabled below:

Table 3-7: List of Non- Envelope Parameters for Variation

Parameters	Variations
Equipment (assumption)	Heat pump, terminal heat pump, VAV, package system
Daylight and Occupancy Sensors	Not Installed, Daylight Sensor, Occupancy Sensor, Both Control

3.7 Occupancy

As the building is proposed for residency, occupancy would be low during day time and full during night time. Employment and education result low occupancy during day. Considering these factors occupancy of people has been assumed for 24 hours as follows:

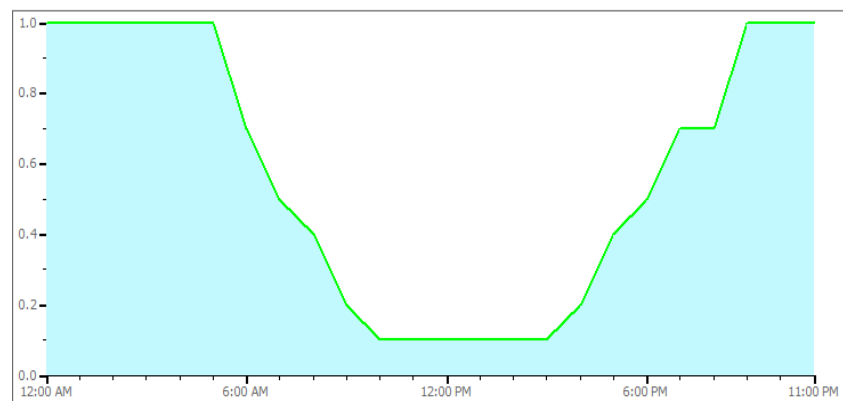


Figure 3:6: Occupancy in Proposed Building

3.8 Specifications of HVAC Systems

For analysis of different systems, the efficiency and COP has been taken same for each type of systems. These values have been assumed based on the research conducted by (Aghoul S. K., 2017).

Table 3-8: Specifications of HVAC Systems Used for Simulation

Type	Fan Efficiency	Motor Efficiency	Rated Heating COP	Rated Cooling COP
Package Terminal Heat Pump	70%	80%	5	3
Package System	70%	80%	5	3
VAV	70%	80%	5	3
Heat Pump	70%	80%	5	3

4. Result and Discussion

4.1 Results for Proposed Building

4.1.1 Calculation of Peak HVAC Load

HVAC load has been calculated using Heating and Cooling Load feature of Revit. The individual peak load for different rooms are as follows:

Table 4-1: HVAC Peak Loads for Different Rooms

SN	Space Name	Peak Cooling Load (Btu/h)		Peak Heating Load (Btu/h)		Size of Indoor Unit (ToR)
		BTU/h	ToR	BTU/h	ToR	
1	Bed Room 1	3,131.30	0.261	4,439.20	0.370	0.5
2	Bed Room 2	2,201.20	0.183	4,749.60	0.396	0.5
3	Dining Room 1	4,406.40	0.367	1,964.40	0.164	0.5
4	Living Room 1	6,771.70	0.564	5,255.50	0.438	0.75
5	Kitchen 1	4,072.60	0.339	3,013.30	0.251	0.5
6	Bed Room 3	3,148.00	0.262	4,347.40	0.362	0.5
7	Bed Room 4	2,186.90	0.182	4,641.80	0.387	0.5
8	Dining Room 2	8,185.90	0.682	4,134.10	0.345	0.75
9	Living Room 2	13,199.50	1.100	8,962.60	0.747	1.5
10	Kitchen 2	7,064.30	0.589	4,489.80	0.374	0.75
11	Bed Room 5	6,062.40	0.505	8,052.30	0.671	0.75
12	Bed Room 6	7,357.70	0.613	8,968.90	0.747	0.75

The size of indoor unit has been selected on basis of standard size available in market. Despite the load being lower than the rated capacity of selected indoor units, energy consumption would be in accordance with the required size. As the AC is operated, the oversized indoor unit will cause fast achievement of required indoor condition. Then thermostat reads the indoor temperature and turns compressor off. This leads to energy conservation and prevents high energy consumption by indoor unit despite being oversize. Load distribution in different rooms can be presented graphically as:

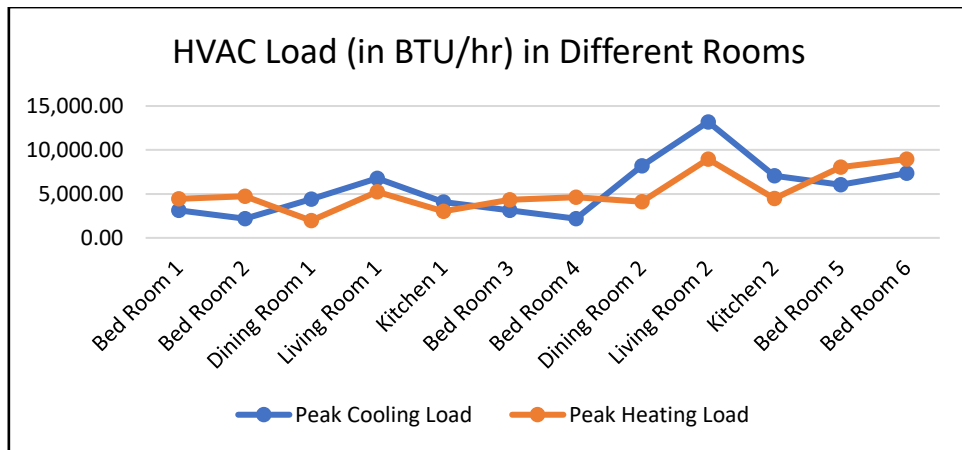


Figure 4:1: HVAC Peak Load in Different Rooms

4.1.1.1 Variation of Loads Among Rooms

In the proposed building, Bedroom 1, 3 and 5 are located on south-east orientation. The load pattern on these room have been found similar, i.e. the peak heating load is more in comparison to peak cooling load. Bedroom 2, 4 and 6 also have similar load pattern as they are also located on same orientation in building i.e. north east side. Remaining rooms which are located on western face have higher value of peak cooling load than peak heating load. The cooling load have been found higher on western faced rooms in Kathmandu as shown by above results.

Also, bedroom 1, 3 and 5 are same in size. But the load is different in each of these rooms. Bedroom 1 and 3 have almost equal load however, peak load on bedroom 5 is higher in comparison to bedroom 1. This because the roof of the bedroom 5 gets direct sunlight whereas bedroom 1 and 3 roof do not get direct sunlight as per the proposed design. Also, during winter, the heat loss occurs directly from the exposed roof. The case is similar for bedroom 2, 4 and 6. Bedroom 6 gets direct sunlight on its roof hence resulting in higher value of load in comparison to bedroom 2 and 4 despite having similar area, occupancy and orientation. The reason for variation in loads among dining, living and kitchen room is also same. The dining, living and kitchen room on first floor receive direct sunlight on roof.

Also heat loss from exposed surface accounts for higher value of peak heating load. The rooms having exposed roof: bedroom 5 and 6, living room 2, dining room 2 and kitchen 2 were found to have higher value of peak heating load in comparison to room lying below them as shown in following tables:

Table 4-2: Variation of Peak Load

Variation in Load Among Rooms of same area, purpose and orientation					
Room	Floor	Cooling Load		Heating Load	
		Peak Cooling Load(BTU/hr)	Variation Wrt Bedroom 1	Peak Heating Load(BTU/hr)	Variation Wrt Bedroom 1
Bed Room 1	Ground	3,131.30	0%	4,439.20	0%
Bed Room 3	First	3,148.00	1%	4,347.40	-2%
Bed Room 5	Second	6,062.40	94%	8,052.30	81%

Table 4-3: Variation of Peak Load

Variation in Load Among Rooms of same area, purpose and orientation					
Room	Floor	Cooling Load		Heating Load	
		Peak Cooling Load(BTU/hr)	Variation Wrt Bedroom 2	Peak Heating Load(BTU/hr)	Variation Wrt Bedroom 2
Bed Room 2	Ground	2,201.20	0%	4,749.60	0%
Bed Room 4	First	2,186.90	-1%	4,641.80	-2%
Bed Room 6	Second	7,357.70	234%	8,968.90	89%

Table 4-4: variation of Peak Load

Variation in Load Among Rooms of same area, purpose and orientation					
Room	Floor	Cooling Load		Heating Load	
		Peak Cooling Load(BTU/hr)	Variation Wrt ground floor	Peak Heating Load(BTU/hr)	Variation Wrt ground floor
Kitchen 1	Ground	4,072.60	0%	3,013.30	0%

Kitchen 2	First	7,064.30	73%	4,489.80	49%
Dining Room 1	Ground	4,406.40	0%	1,964.40	0%
Dining Room 2	First	8,185.90	86%	4,134.10	110%
Living Room 1	Ground	6,771.70	0%	5,255.50	0%
Living Room 2	First	13,199.50	95%	8,962.60	71%

4.1.1.2 Diversified Load

Each room has peak heating and peak cooling load. But the instance of occurrence of peak load have been found different for each room. So, the peak total load of whole building has been found less than the sum of individual peak load. Following table shows the occurrence of peak loads in different rooms:

Table 4-5: Instances of Peak Load in Proposed Building

SN	Space Name	Peak Load Month	Peak Load Time
1	Bed Room 1	July	4:00 PM
2	Bed Room 2	June	5:00 PM
3	Dining Room 1	June	4:00 PM
4	Living Room 1	June	4:00 PM
5	Kitchen 1	June	5:00 PM
6	Bed Room 3	July	4:00 PM
7	Bed Room 4	June	5:00 PM
8	Dining Room 2	June	4:00 PM
9	Living Room 2	June	4:00 PM
10	Kitchen 2	June	5:00 PM
11	Bed Room 5	July	4:00 PM
12	Bed Room 6	June	5:00 PM

The resultant peak load for whole building would occur at July 5 PM.

Table 4-6: Diversified Peak Load in Proposed Building

SN	Description	Peak Cooling Load (BTU/h)	Peak Heating Load (BTU/h)
1	Sum of Peak Load of Each Zones	67787.9	63018.9
2	Peak Load of Whole Building	64307	61747

In above table we can see the peak load for building is less than the sum of the peak load of each zone. It is because of the different instances of the occurrence of peak load in different zones. In case of using individual split AC system, the rooms need to be fitted with the AC having capacity as rated by individual peak load. However, while using VRF system, the outdoor unit can be sized as according to the peak load of whole building, thus decreasing the size of outdoor unit, which ultimately reduces installing cost as well as operational cost.

4.1.2 Energy Consumption in Proposed Building

Out of total energy used in the proposed building, 62% has been found to be consumed solely by HVAC system. Various equipment: microwave oven, freezer, television and laptop have been considered to be operating and heat from them were assumed while calculating HVAC load. Energy consumed by all of these including fans used for ventilation is shown by Misc. Equipment in below chart:

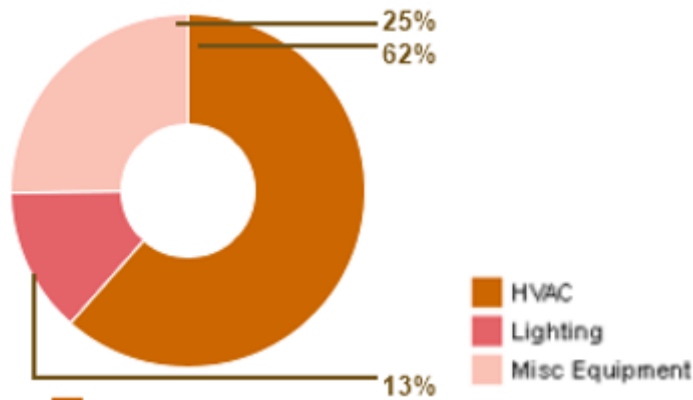


Figure 4:2: Energy Consumption Breakdown

4.1.2.1 Energy Gain/Loss Breakdown

Maximum cooling load has been resulted during July followed by August, and hence highest energy consumption for cooling is during the month of July as shown by following chart. Maximum energy loss for each month has resulted solely by window solar, i.e. radiation heat passing through window glass inside room. Reduction of this load can contribute to energy consumption significantly. More than 9.7 MBTU energy is added in rooms by various sources in month of July. Complying with above facts, 62% of this energy, i.e. 6.014 MBTU energy is consumed solely by HVAC equipment in month of July in order to overcome this heat gain. Energy through wall is significantly high in summer whereas there is no heat gain through wall in winters. At any instance, heat would be either flowing out of system or flowing inside system. If we separate the instances when net energy would be flowing either in or out of system, and prepare separate chart for those two instances indicating the sources and magnitude of heat energy being flown to or out of system, we get different charts as shown below.

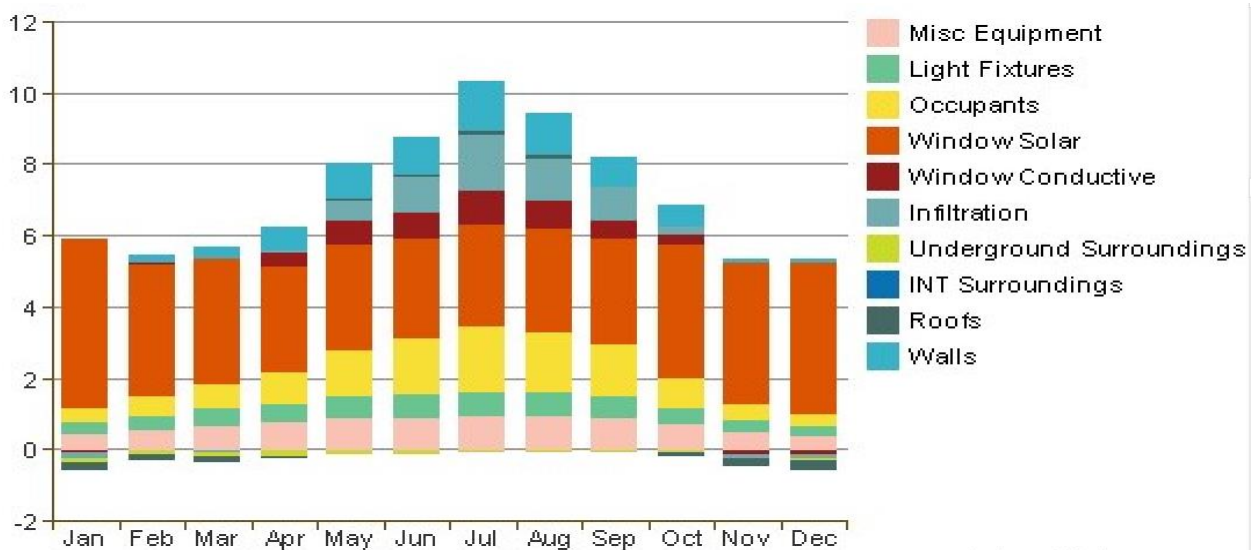


Figure 4:3: Heat Gain Breakdown

Maximum heating loss occurs during the month of December followed by January as shown by the following chart.

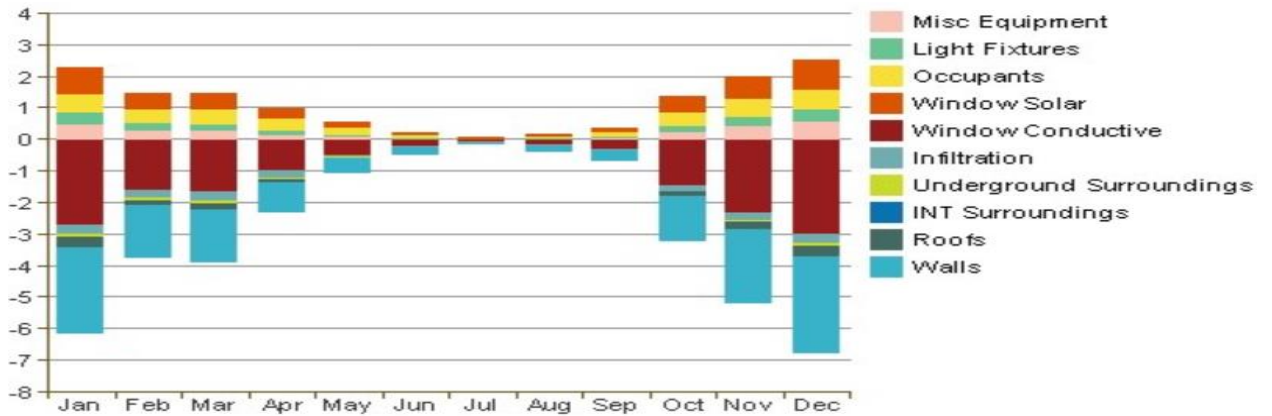


Figure 4:4: Heat Loss Breakdown

4.1.2.2 Electricity Consumption in Proposed Building

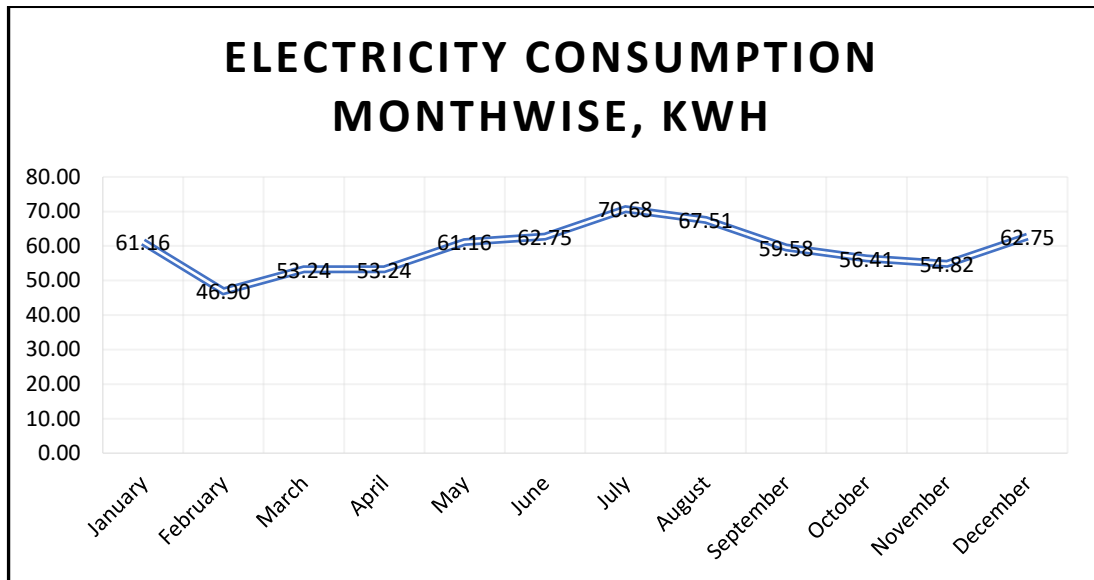


Figure 4:5: Electricity Consumption for Proposed Building

Maximum energy consumption occurs during the month of July with 5488 units of electricity consumption. The minimum occurs during the month of February. High cooling load requirement during summer has resulted in high value of energy consumption during that period. As 62% of the energy consumption has been resulted due to HVAC, it implies that 3402 units of electricity is solely consumed by HVAC system alone. However, the magnitude of maximum energy consumed in a single month for cooling (July) is higher than the maximum energy consumed in a single month for heating (December) despite the result that peak HVAC heating load (5.65

TOR) is higher than peak HVAC cooling load (5.15 TOR). This is because the COP of equipment during heating (Heat pump) is higher than during cooling (refrigeration). The total energy (electricity) consumption in a year would be 55244 units of electricity. The power required for heating is usually low in compared to power required for cooling operation. The peak power requirement in different months are shown in following figure. The electric connection must be arranged to supply the power in all situation without causing the failure. So, the power connection system should be managed as per the highest peak wattage requirement, which is on the month of July peaking to the value 4.95 kW.

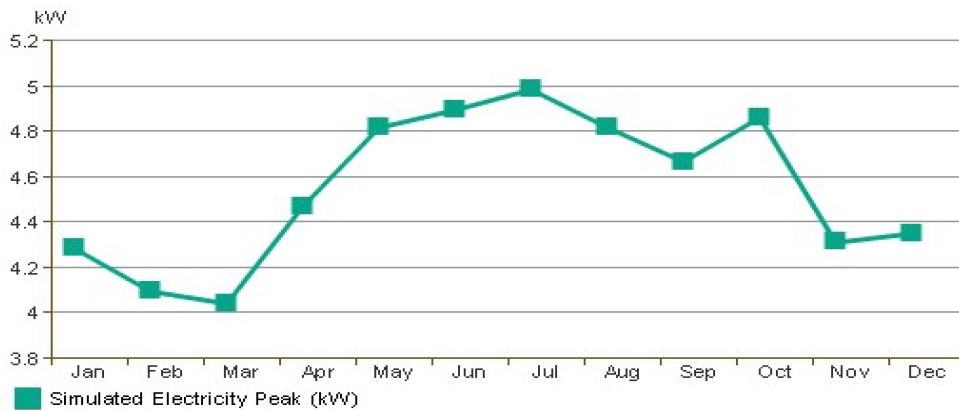


Figure 4:6: Peak Electricity Demand for Proposed Building

4.1.3 Electricity Cost

The cost of the electricity consumption is shown in following chart:

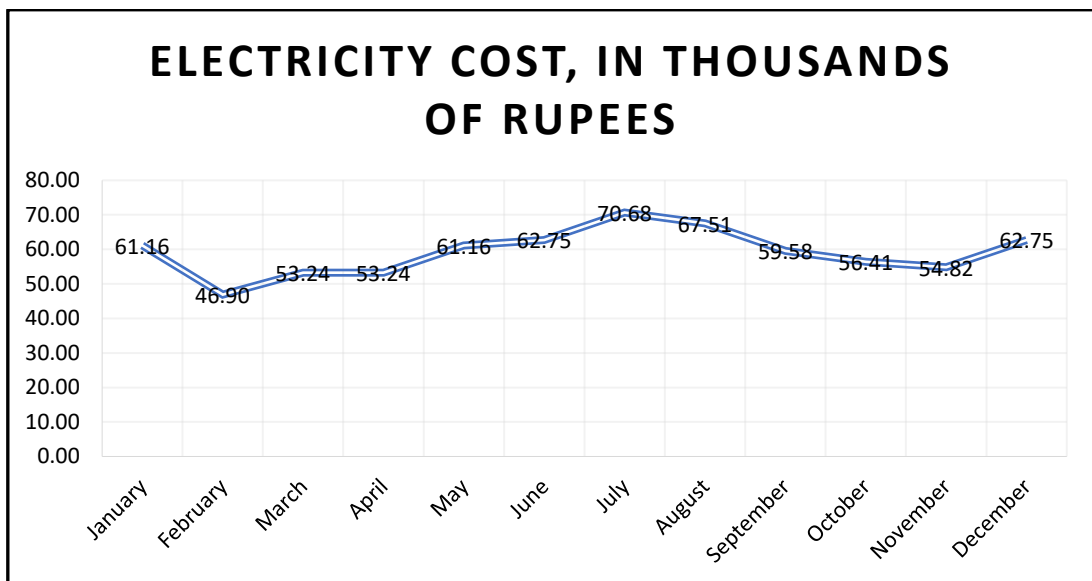


Figure 4:7: Electricity Cost for Proposed Building

Maximum cost would be incurred during the month of July amounted to NRs. 70676. Minimum cost would be incurred during the month of February. The cost incurred are in proportion the energy consumption. The annual energy cost would be NRs. 7,10,190. The cost presented above are the sum of operating AC, lights and other electrical appliances. Other appliances include laptop, freezer, microwave oven and television.

4.2 Enhancement Results

Simulation was run by varying windows on each face. Lower WWR results in low HVAC load but increases lighting load. It was found out that window wall ratio of 0.3 in east, west and north direction along with 2/3 of window height shading and triple pane low-E glass resulted in minimum energy use intensity. Same has been found in south face except no shading. EUI in east, west, north and south were 237.13, 225.22, 229.47 and 227.43 respectively. So, these windows were selected for optimized building.

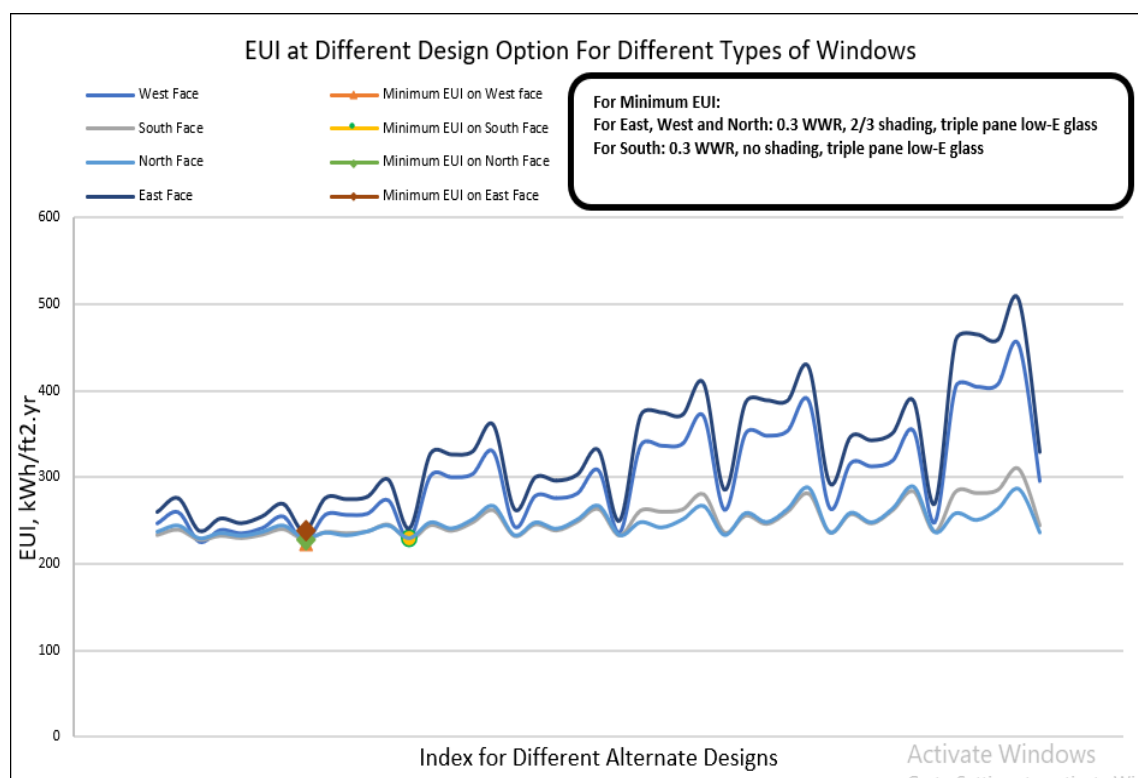


Figure 4:8: EUI at Different Window Option

Keeping everything constant, wall materials have been varied and energy simulation has been run. Minimum EUI has been resulted by R38 wood wall. But as many of ASHREA recommended walls are not constructed in Nepal, wall material has been

chosen from amongst the commonly available materials. Prefab resulted in minimum EUI among such material. In order to construct a prefab building, the reinforced concrete pillars need to be replaced by metal frame. Prefab has been considered for wall construction as per it's lower EUI and low cost.

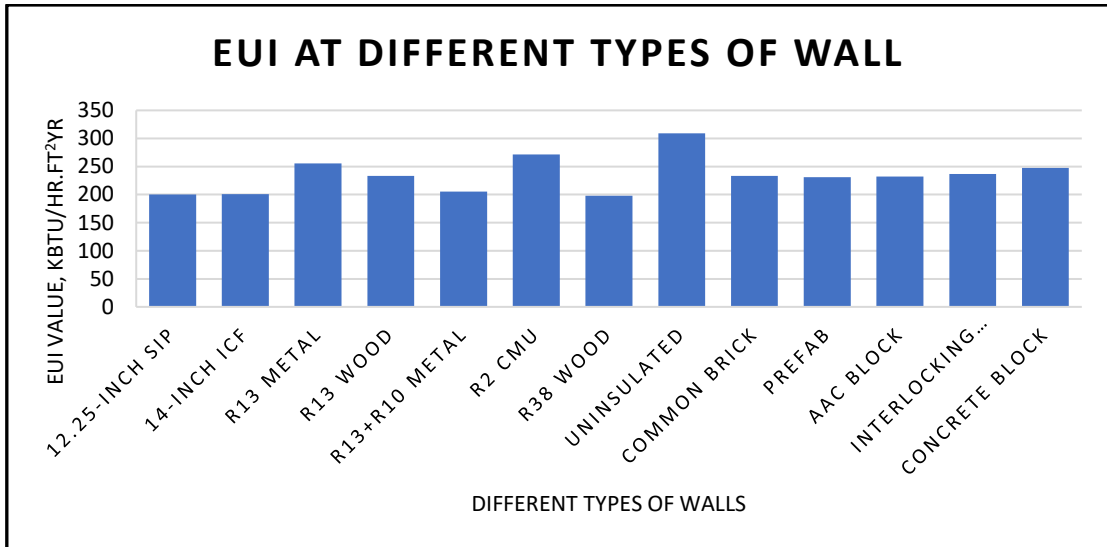


Figure 4:9: EUI for Different Walls

In case of roof, minimum EUI has been resulted by R60 insulated roof. But as insulated roof is rarely used in Nepal, materials required for constructing them are difficult to be found. Since 4" uninsulated concrete roof can be constructed both in metal frame or reinforced concrete frame, it has been chosen for final design despite resulting in high EUI.

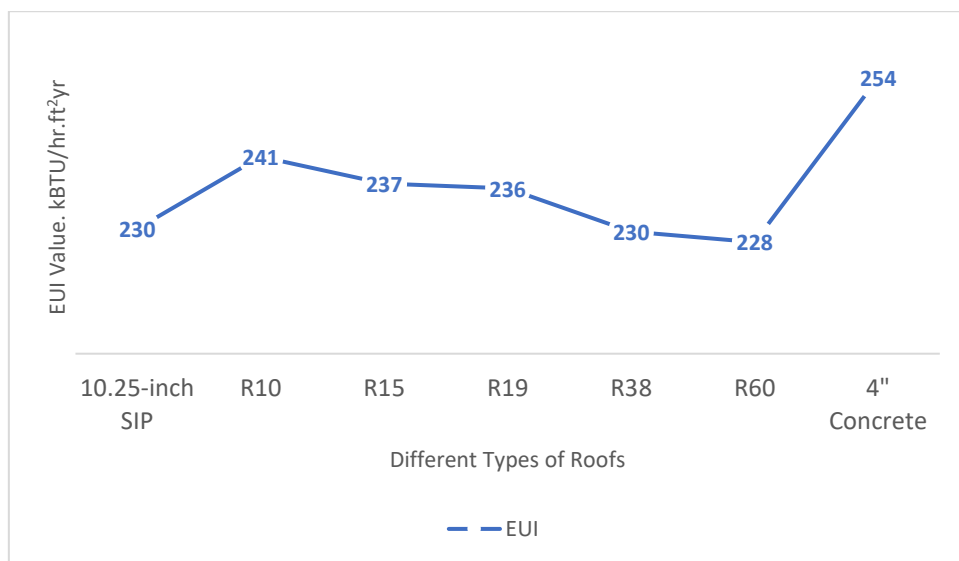


Figure 4:10: EUI for Different Roofs

Energy consumption varies as per the type of HVAC system installed. ASHRAE package terminal heat pump has been found more effective for this building.

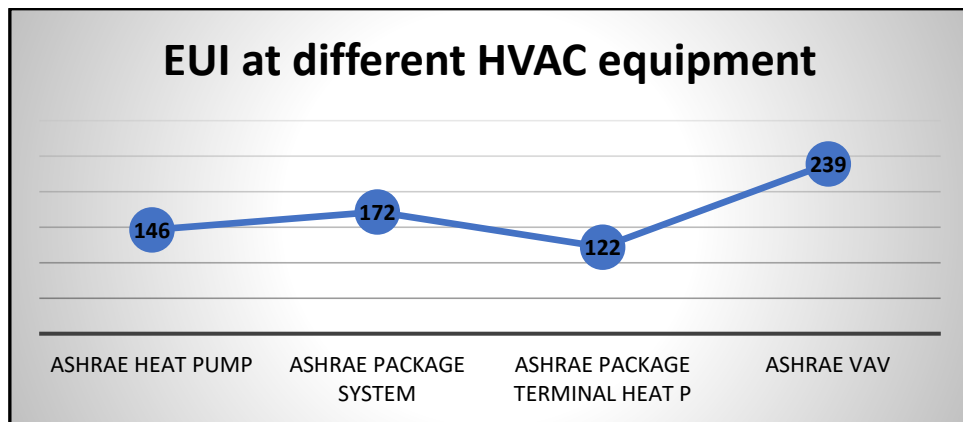


Figure 4:11: EUI at Different Equipment Option

In absence of occupant, occupancy sensor turns off all lighting, HVAC and other equipment automatically, resulting in energy saving. Daylight sensor senses the sunlight during day and turns off light if it has been left in on position. Use of these helps in saving energy as shown by following graph.

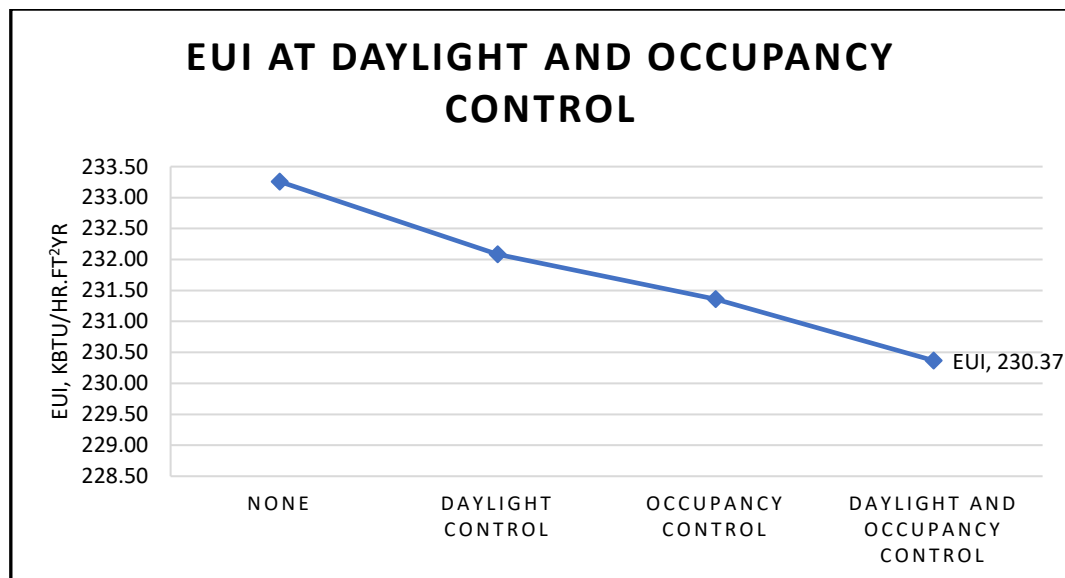


Figure 4:12: EUI When Sensors are Used

4.2.1 Finalization of Parameters:

Table 4-7: Final Parameters for Enhanced Building

SN	Parameters	Proposed	Final
1	Wall	Common Brick	Prefab

2	Window	0.21 WWR, single pane clear	0.3 WWR, 2/3 shading by overhang Triple pane low-E
3	Roof	Casted Concrete	Casted Concrete
4	Equipment	Not specified	ASHRAE Package Terminal Heat Pump
5	Daylight Sensor	Not specified	Used
6	Occupancy Sensor	Not specified	Used

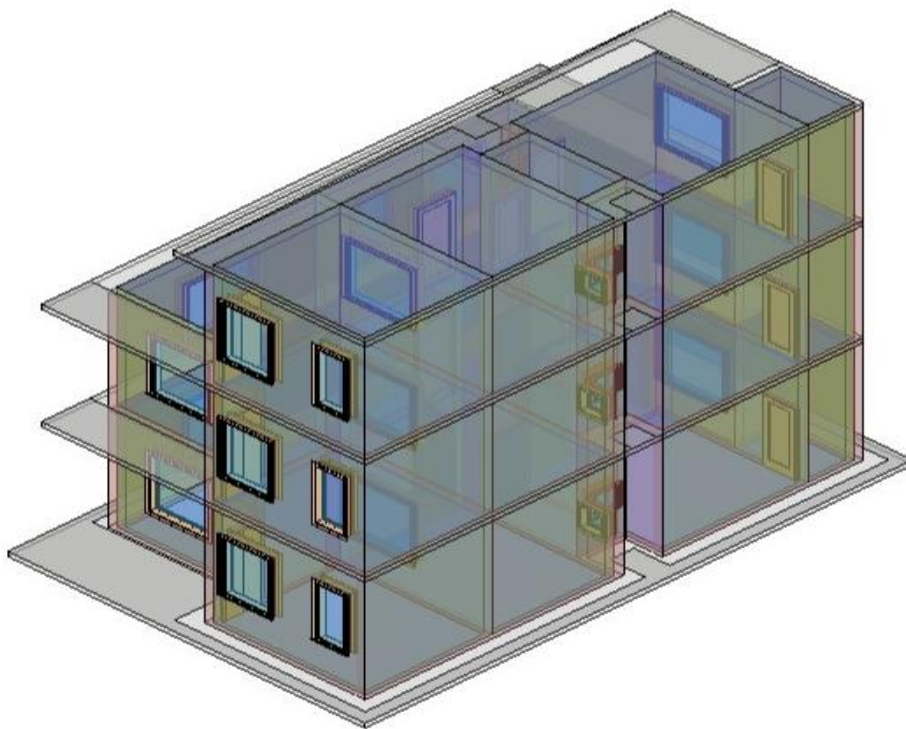


Figure 4:13: Energy Model of Proposed Building

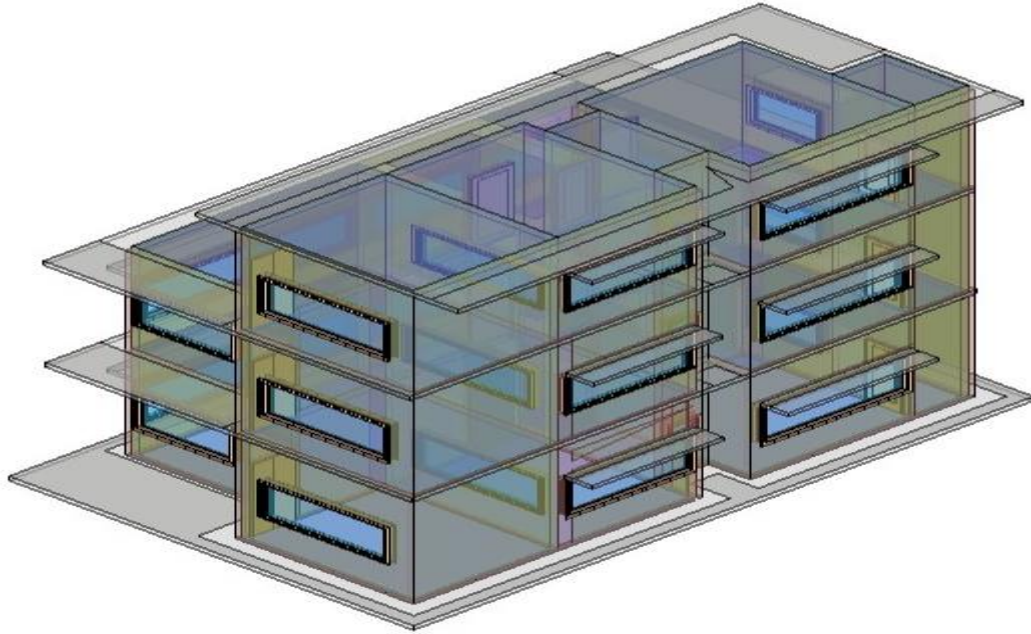


Figure 4:14: Energy Model of Enhanced Building

4.3 Results of Enhanced Building

4.3.1 HVAC Load in Enhanced Building

HVAC load in enhanced building can be seen to have reduced drastically in comparison to proposed building as shown in below table. Heating load has been seen to be reduced highly in comparison to cooling load.

Table 4-8: HVAC Peak Load in Enhanced Building

SN	Space Name	Peak Cooling		Peak Heating		Size of Indoor Unit (TOR)
		Load (Btu/h)		Load (Btu/h)		
		BTU/h	TOR	BTU/h	TOR	
1	Bed Room 1	2,345.70	0.20	1,803.70	0.15	0.5
2	Bed Room 2	2,395.50	0.20	2,097.10	0.17	0.5
3	Dining Room 1	3,304.40	0.28	1,658.10	0.14	0.5
4	Living Room 1	3,532.20	0.29	2,181.20	0.18	0.5
5	Kitchen 1	1,523.30	0.13	1,809.10	0.15	0.5
6	Bed Room 3	2,347.20	0.20	1,795.80	0.15	0.5
7	Bed Room 4	2,397.90	0.20	2,065.40	0.17	0.5
8	Dining Room 2	7,099.20	0.59	3,919.90	0.33	0.75
9	Living Room 2	10,392.20	0.87	6,142.40	0.51	1
10	Kitchen 2	4,433.60	0.37	3,415.40	0.28	0.5
11	Bed Room 5	5,370.80	0.45	4,851.80	0.40	0.5
12	Bed Room 6	6,187.80	0.52	5,618.40	0.47	0.5

4.3.2 Diversified Load in Enhanced Building

Table 4-9: Instances of Peak Load in Enhanced Building

SN	Space Name	Peak Load Month	Peak Load Time
1	Bed Room 1	July	5:00 PM
2	Bed Room 2	June	5:00 PM
3	Dining Room 1	June	5:00 PM
4	Living Room 1	June	5:00 PM
5	Kitchen 1	June	5:00 PM
6	Bed Room 3	July	5:00 PM
7	Bed Room 4	June	5:00 PM
8	Dining Room 2	June	5:00 PM
9	Living Room 2	June	5:00 PM
10	Kitchen 2	June	5:00 PM
11	Bed Room 5	July	5:00 PM
12	Bed Room 6	June	5:00 PM

The timing for peak load was at either 4 Pm or 5 PM for different rooms in proposed building. However, the peak load is at 5 PM for all rooms in enhanced building, however the month of peak load is different in different rooms, which matches with that of proposed building. The thermal lagging in prefab building is higher in comparison to common brick building as per this result.

Table 4-10: Diversified Peak Load in Enhanced Building

SN	Description	Peak Cooling Load (BTU/h)	Peak Heating Load (BTU/h)
1	Sum of Peak Load of Each Zones	51329.8	37358.3
2	Peak Load of Whole Building	45650.6	34605.6

4.3.3 Energy Consumption in Enhanced Building

Energy addition and reduction from system can be shown in different charts as follows (in MBTU):

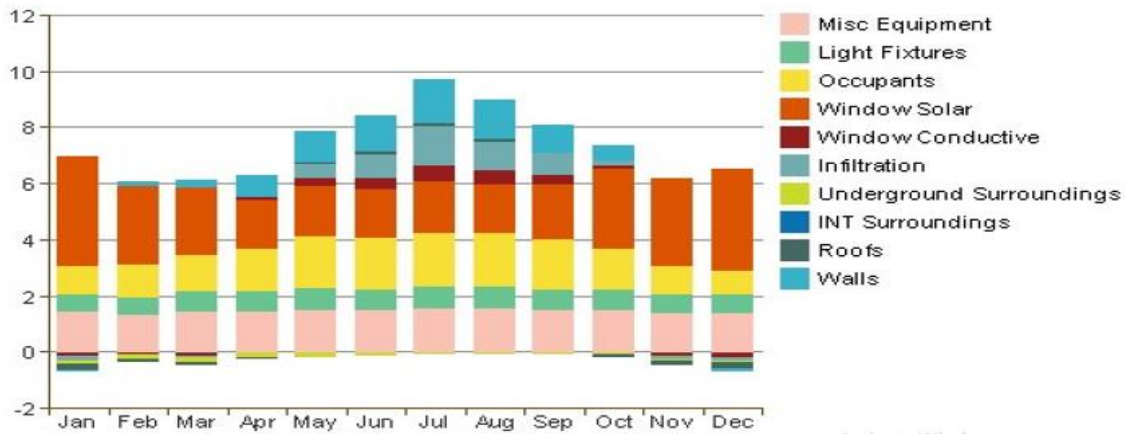


Figure 4:15: Heat Addition Breakdown for Enhanced Building

Above chart clearly shows that the amount of heat being added in zones are low in comparison to the heat added to system in proposed building. Similar is the case with heat removal condition from system. Refer to the charts presented in section 4.1.2.1 for comparison.

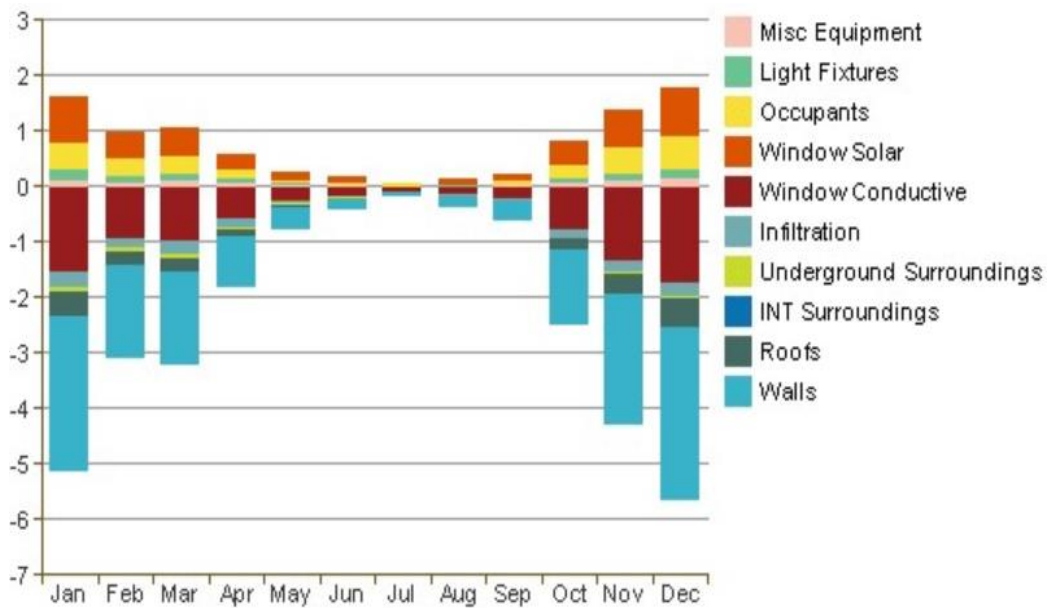


Figure 4:16: Heat Reduction for Enhanced Building

The energy consumed by HVAC system has been reduced proportionally. The energy consumed by HVAC system are as follows:

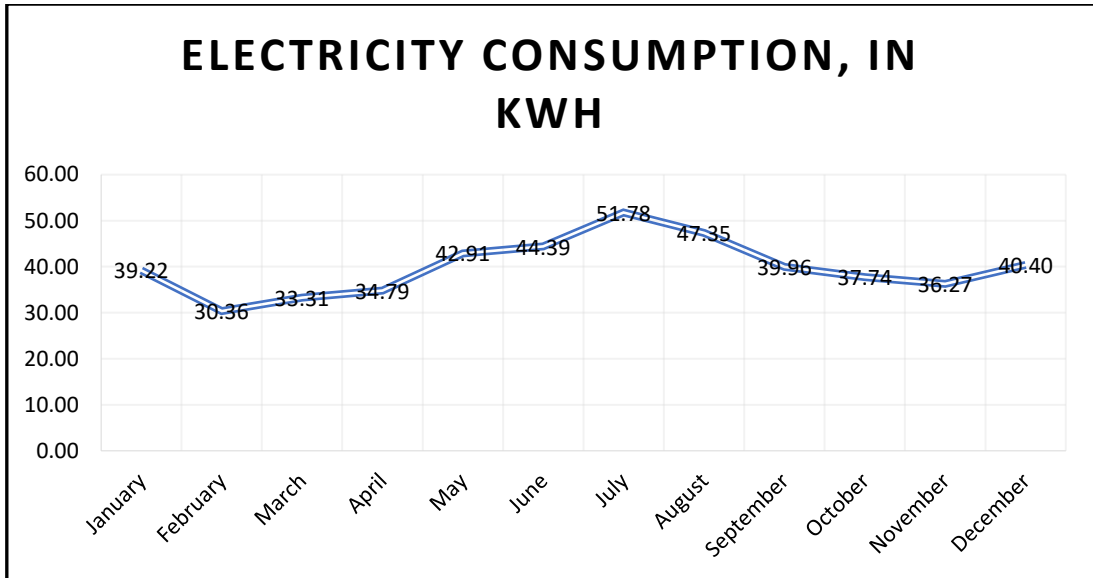


Figure 4:17: Electricity Consumption for Enhanced Building

The highest energy consumption takes place in the month of July and lowest on the month of February as in case of proposed building. Only difference is the reduction in magnitude of units of electricity consumed. Total of 37420 units of electricity would be consumed annually by this enhanced building.

The peak power requirement differs proportionally as shown in following chart:

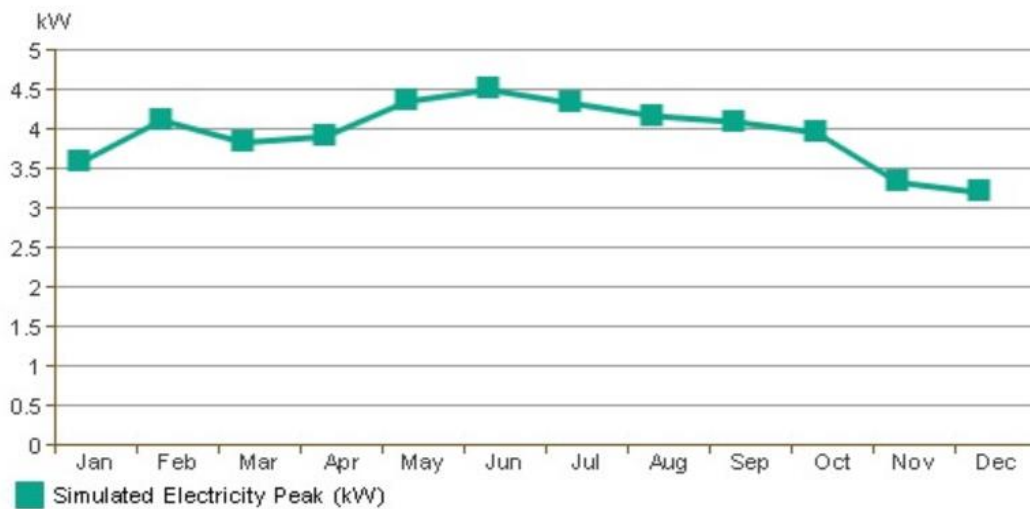


Figure 4:18: Peak Electricity Demand for Enhanced Building

The peak demand in proposed building was 4.95 kW, however it has reduced to 4.5 kW in enhanced building.

4.3.4 Energy Cost in Enhanced Building

The energy cost has reduced as energy consumption has reduced in enhanced building.

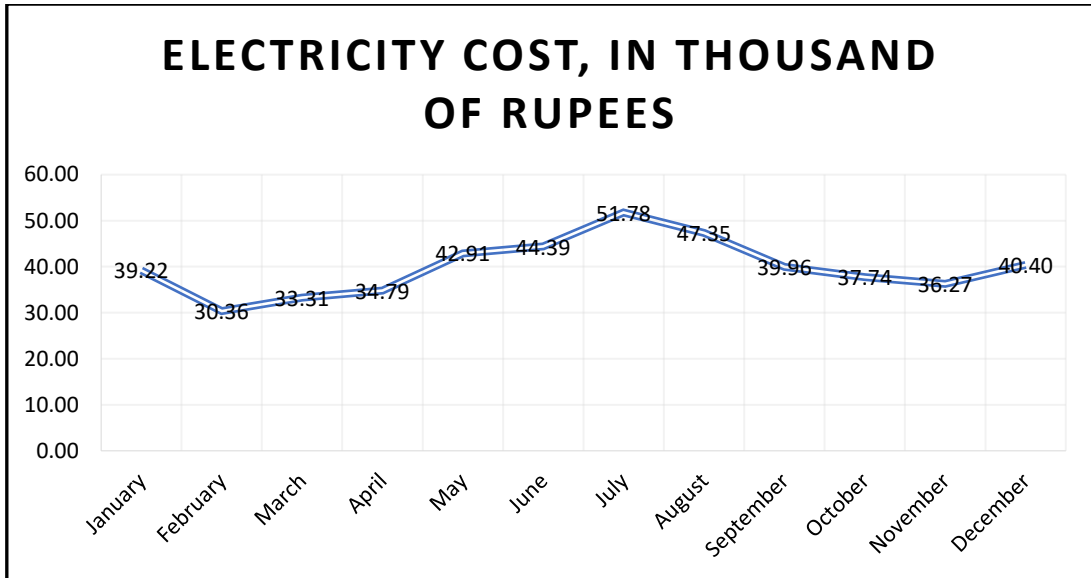


Figure 4:19: Electricity Cost for Enhanced Building

Maximum cost is incurred during July amounting to 51780. Lowest cost is incurred in February. The total electricity cost for a year is NRs. 478485.9.

4.4 Comparison of Results Between Proposed and Enhanced Building

Significant reduction in HVAC load, EUI, energy usage and energy cost were resulted. The reductions have been presented below:

Table 4-11: Comparison Between Enhanced and Proposed Building

Description	Initial	Final	Reduction
Peak Cooling Load, TOR	5.36	3.8	29%
Peak Heating Load, TOR	5.96	2.88	44%
EUI, kWh/ft ² .yr	40	29	28%
Annual Energy Use, kWh	55,244	37,420	32%
Annual Energy Cost, NRs.	710191	478486	33%

Highest reduction of energy consumption was seen in the month of December equivalent to 1719 kWh whereas lowest reduction was seen on February equivalent to 1272 kWh. Total of 17823 kWh of electricity consumption is reduced when system is operated for 24x7 throughout the year. Energy consumption on different months by proposed and optimized building are as follows:

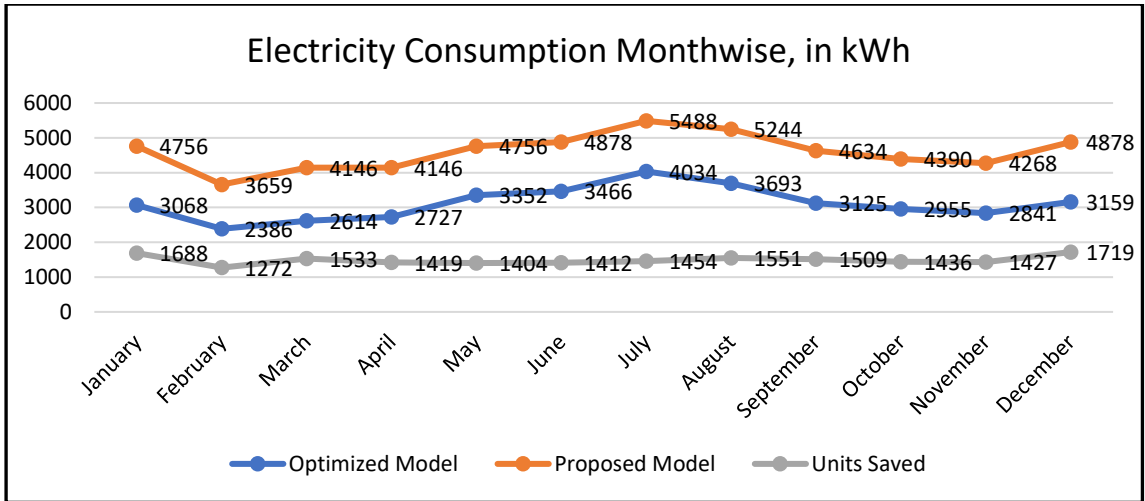


Figure 4:20: Energy Consumption Comparison

Total of NRs 2,31,705 could be saved on electricity cost in comparison to proposed building from optimized building. Maximum of cost saving is achieved during December worth Nrs 22,346. Lowest cost saving is achieved during February, equivalent to Nrs 16,538. Monthly savings along with cost involved in each design alternative has been shown below:

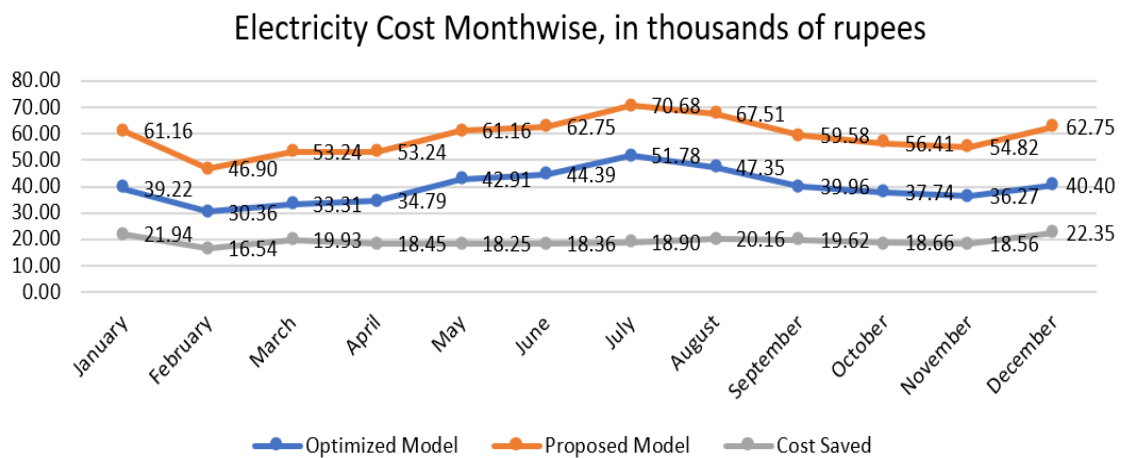


Figure 4:21: Electricity Cost Comparison

4.6 Cost Involved in Constructing Buildings

The cost analysis was done to check whether the performed task is financially feasible or not. The cost estimation has been done only for the materials that have been found to be altered.

Table 4-12: Cost Estimation for Proposed Building

S N	Parameter	Material/System	Quantity	Rate, NRs	Amount, NRs
1	Wall	Common Brick	37878 nos	14	530292
		Sand	21.6 m3, 3 tipper approx.	28000	84000
		Cement	104 bags (50 kg each)	850	88400
2	Pillars	Reinforced concrete	32 nos	25000	800000
3	Plaster	Sand	12.3 m3, 1.5 tipper approx.	28000	44100
		Cement	59 bags (50 kg each)	850	52657.5
4	Wages				800000
3	Window	Single pane clear glass	474.5 sq ft	300	142350
4	HVAC System	Split AC, 0.5 TR	6 nos	50000	600000
		Split AC, 1 TR	5 nos	103000	515000
		Split AC, 1.5 TR	1 no	146000	146000
		Copper pipes	12 sets	2500	30000
		MS stand	12	1500	18000
		Fitting charges	12	5000	60000
5	Sensors	-	-	-	-
Total					3910799.5

It was found out that NRs. 3910799.5 would be required for constructing structure and fitting AC as proposed. The final building was found to cost NRs. 4639225.

Table 4-13: Cost Estimation for Enhanced Building

SN	Parameters	Material	Quantity	Rate, NRs	Amount, NRs
1	Wall	Prefab (metal structure and wage included)	4197 sq ft	800	3357600
2	Pillars	I-beam pillar included above			
3	Plaster	Not required			

4	Wages	Included above			
3	Window	Triple pane low e glass	605 sq ft	525	317625
4	HVAC System	Package Terminal Heat Pump (Including accessories and fitting charge)			
		Indoor 0.5 TR	10 nos	49000	490000
		Indoor 1 TR	1 no	65000	69000
		Indoor 1.5 TR	1 no	90000	95000
		Outdoor, 8 hp	1	250000	250000
5	Sensors	Occupancy and Daylight Sensor	12 nos	5000	60000
	Total				4639225

The final building needs more cost for construction than proposed building. However, the final building is beneficial in terms of energy cost saving. Despite the enhanced building costs NRs. 728425.5 more than proposed building for construction, this cost is compensated by the energy cost saving within 38 months from the date of commissioning. The enhanced building will save energy cost of NRs 1588624.

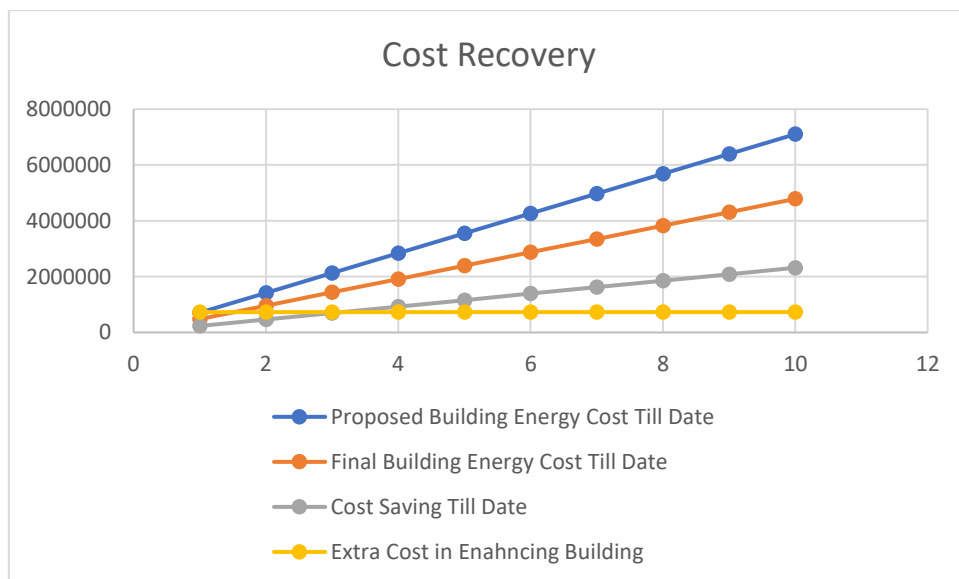


Figure 4:22: Cost Recovery Chart

4.5 Comparison with Previous Results

Use of prefabricated board for constructing residential building is an energy efficient way in comparison to traditional materials as shown by this study. The result is contradictory to the study conducted by Michal Kraus which shows that prefab building provides human comfort favorable environment for 90% of time while 10% time is

limited by infiltration, ventilation and sealing (Kraus & Senitkova, 2017), thus questioning the energy performance of prefab building. Result shows that WWR of 30% is better for improving energy efficiency. This result matches with the study conducted by Jalil Shaeri which shows that energy efficiency is high in WWR 20% to 40% depending upon the face of building (Shaeri, 2019). Use of triple pane glass cuts energy consumption and HVAC load as shown in this study. Same has been confirmed by US Department of Energy (Gilbride, Selkowitz, & Dingus, June 2019) but doubted about the preference by builders for using triple pane due to its high cost. Research on usability of clear, grey, clear low-e and tinted low-e glass by Qiong Hi (Shen, Yu, Hou, & Wang, 2017) showed that tinted low-e glass was best for using in Shanghai for energy efficiency, while this study showed that clear glass with low-e need to be used instead of tinted low-e in context of Kathmandu. Package terminal heat pump was found to be most energy efficient HVAC system for residential purpose in this study with EUI value 122 kWh/yr/sq. ft. The result is similar to the study performed by Aghoul which shows that energy consumption is lowest for package terminal heat pump (44009kWh) for residential purpose (Aghoul S. K., 2017)

5. Conclusion

Considering the importance of energy efficiency of buildings, the HVAC load, energy consumption and energy cost has been calculated. In order to minimize these parameters, iterative approach has been taken and these parameters have been calculated for each available option. The results have been analyzed and building parameters have been finalized. The HVAC load, energy consumption and energy cost have been calculated for final building. HVAC peak heating load, energy consumption and energy cost have been reduced by 29%, 44%, 32% and 33% respectively. However, wall and window colour that has been finalized for enhancement differ from those verified by previous researches in this field.

Use of prefab wall for residential building was previously found out to cause non-comfort, whereas prefab was found to be energy efficient as it can provide human comfort with minimum energy consumption. Also, roofs with insulations have been found out to be less energy consuming. However, as per the construction trend and availability, it has been neglected and casted concrete roof was finalized despite it results in high energy consumption. The window options are limited in Nepal as trend of using double and triple pane is rarely done. However, the construction of multi-pane window is simpler and does not involve high cost. So, use of triple pane has been finalized here. However, the cost involved in construction of enhanced building is higher than proposed building. But the cost is balanced by energy cost in 38 months.

The weather station that has been used in this project lies around 4.5 km away from the site of building. So, the actual weather may vary slightly from that of actual weather at site. Considering the availability of sensors, their use is prescribed. In overall, the energy efficiency of residential building can be improved largely by doing simple modification in building envelope. Further study along with material development for construction in this field can contribute to save energy consumed by HVAC by large portion.

References

- Abdulla, A. H., Bakar, S. K., & Rehman, A. A. (2013). *Indoor Thermal Performance of an Office Building Using Conventional brick Vs Interlocking Compressed Brick (ICEB) Wall*. Parit Raja: International Journal of Construction Technology and Management.
- Aghoul, S. K. (2017). A comparative study of energy consumption for residential hvac system using energyplus. *American Journal of Mechanical and Industrial Engineering*, 98-103.
- Aghoul, S. K. (2017). *A Comparative Study of Energy Consumption for Residential HVAC Systems Using EnergyPlus*. Tripoli: Science Publishing Group.
- Alibaba, H. (2016). *Determination of optimum window to external wall ratio for offices in a hot and humid climate*. . Iran: Sustainability.
- ASHRAE. (1980). *Heating and Cooling Load Calculation Manual*. Washington DC: U.S. Department of Housing and Urban Development.
- ASHRAE. (1993). *ASHRAE Handbook: Fundamentals*. American Society of Heating Refrigeration and air Conditioning Engineers.
- ASHRAE. (1997). *ASHRAE Handbook: Fundamentals*. Atlanta: American Society of Heating Refrigeration and Air Conditioning.
- ASHRAE. (2018). *energy efficient design of low-rise residential buildings*. ASHRAE.
- ASHRAE. (2019). *Standard 90.1-2019–energy standard for buildings except low-rise residential buildings*. ASHRAE.
- ASHRAE. (2019). *energy standard for buildings except low-rise residential buildings*. ASHRAE.
- Associates, J. J. (2005). *DOE-2*. Berkeley: United States Department of Energy.
- Autodesk. (2006). weathersanepalalitpurnepal. 92.
- Autodesk. (2020, 02 11). *Autodesk*. Retrieved from Autodesk: <https://knowledge.autodesk.com/support/revit-products/learn-explore/caas/CloudHelp/cloudhelp/2019/ENU/Revit-Analyze/files/GUID-B3E90100-0CC9-4874-AEFC-079727ECDA12-htm.html>
- Benzarti, H. G. (2017). *Modeling and thermal optimization of residential buildings using BIM and based on RTS method: application to traditional and standard house in Sousse city*. Polytechnic University of Catalonia, Sousse.
- Company, C. A. (1966). *handbook of Air Conditioning System Design*. New York: McGraw Hill Book Company.

Development, D. o. (2064). *Nepal National Building Code*. Kathmandu: Government of Nepal.

Duong, P. R. (2016). *How can occupancy modeling and occupancy sensor reduce energy usage in academic building: An application approach to university of San francisco*. San Francisco: University of San francisco.

Ecopanel, G. (2020, 2 11). *Gorkha Eco Panel*. Retrieved from Green Developer Nepal: <http://greendevolversnepal.com/services-products.php>

Facilities Net. (2014, 10 8). *Facilitynet*. Retrieved from [https://www.facilitiesnet.com/lighting/article/Occupancy-Sensors-Help-Reduce-Energy-Use--15388#:~:text=Occupancy%2Dbased%20sensors%20can%20reduce,control%20based%20on%20space%20occupancy.&text=Common%20applications%20include%20installing%20daylight,when%2](https://www.facilitiesnet.com/lighting/article/Occupancy-Sensors-Help-Reduce-Energy-Use--15388#:~:text=Occupancy%2Dbased%20sensors%20can%20reduce,control%20based%20on%20space%20occupancy.&text=Common%20applications%20include%20installing%20daylight,when%2:https://www.facilitiesnet.com/lighting/article/Occupancy-Sensors-Help-Reduce-Energy-Use--15388#:~:text=Occupancy%2Dbased%20sensors%20can%20reduce,control%20based%20on%20space%20occupancy.&text=Common%20applications%20include%20installing%20daylight,when%2)

Fahad AlHarbi, A. A. (2019). *Comparison of Cooling Load Calculations by E20 and HAP Software*. Qassim University. Saudi Arabia: Universal Journal of Mechanical Engineering.

Felix A. Uba, E. A. (2013). Cooling Load Temperature Differential Values For Buildings in Ghana. *INTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH*, Volume 2(Issue 12), 7.

Gajda, J., & Marceau, M. (2004). *HVAC Sizing Methodology for Insulated Concrete Homes*. Illinios: U.S Department of Housing and Urban Development.

Garg, V., & Bansal, N. (2000). *Smart Occupancy sensor to reduce energy consumption*. Energy and Buildings.

Gilbride, T., Selkowitz, S., & Dingus, O. (June 2019). Factores Influencing the window purchasing desicion of high performance home builders. *Pacific Northwest National Laboratory*, 86.

Grondzik, W. T. (2007). *Air Conditioning System Manual*. Atlanta: ASHRAE.

Gut, P., Ackerknecht, D., & ILE, S. K. (1993). *Climate Responsive Building*. Switzerland.

- Harris, S., & McQuiston, F. (1988). *A Study to Characterize Wall and Roof On Thermal Basis*. Ottawa.
- He, Q., Ng, S. T., & Hussain, U. (2019). Energy Efficient Window Retrofit for High Rise Residential Building in Different CLimatic Zone of CHina. *Sustainability*, 8-187.
- ISHRAE. (2019). *Nepal Weather Data 2019*. Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE).
- Jeffrey D Spitler, D. E. (1997). *The radiant time series cooling load calculation procedure*. Illinois: American Society of Heating, Refrigerating and Air- Conditioning Engineers.
- Kraus, M., & Senitkova, I. J. (2017). Indoor Environment in Residential Prefabricated Buildings. *IOP Cenference Series: Materials Science and Engineering* (p. 8). Ceske Budejovice: IOP Publishing.
- Mbereyaho, L., Baptiste, J., & Halera, J. (2018). *Study on Energy Efficiency of Earth Blocks*. Rwanda: INES Scientific Journal.
- Mcquiston, F., Parker, J., & Spilter, J. (2005). *Heating ventilation and Air Conditioning*. Danver: John Wley and Sons.
- Mohammed, A. K. (2016). *Comparison between Hand Calculation and HAP programs for estimating total*. Erbil: ZANCO Journal of Pure and Applied Sciences.
- Otuh, N. F. (2016). *BIM BASED ENERGY/SUSTAINABILITY ANALYSIS FOR EDUCATIONAL BUILDINGS – A CASE STUDY*. HAMK University of Applied Science, Department of Construction Engineering, Visamaki.
- Pita, E. G. (2002). *Air conditioning Principle and System*. Columbus: R. R Donnelley and Sons Company.
- Pruteanu, M. (2013). *Thermal Conductivity Determination For Autoclaved Aerated Concrete Block Used in Enclosed Masonry Walls*. IASI: BULETINUL INSTITUTULUI POLITEHNIC DIN IAȘI .
- Razman, R. b., & Abdullah, A. H. (2010). *Thermal and Structural Properties of Compressed Earth Brick (Laterite Soil)*. Batu Pahat.
- Rudoy, & Duran. (1975). Development of an improved cooling load calculation method. *ASHRAE Transaction*, 16-95.
- Sandberg, J. (2011). *Computer based tools in the hvac design process. interface and data transfer between modeling in revit and supporting draw-and simulation tools*. Goteborg: Chalmer University of Technology.

- Sathyanandamoodya. (2017, February 16). *Sathyanandamoodya.blogspot*. Retrieved from <http://sathyanandamoodya.blogspot.com>: <http://sathyanandamoodya.blogspot.com/2017/02/air-side-systems-vav-systems-hvac.html>
- Shaeri, J. (2019). e Optimum Window-to-Wall Ratio in Office Buildings for Hot-Humid, Hot-Dry, and Cold Climates in Iran. *Environments*, 1-16.
- Shen, Q., Yu, Y., Hou, J., & Wang, Q. (2017). *The Testing Research on Prefabricated Building Indoor Thermal Environment of Earthquake Disaster Region*. Jinan: Elsevier Ltd.
- Spilter, J. D., Mcquiston, F., & Lindsey, K. (1993). *The CLTD/SCL/CLF Cooling Load Calculation Method*. Oklahoma: ASHRAE Transaction.
- Utsav Shree Raj Bhandari, A. M. (2014). *Energy Consumption and Scenario Analysis of Residential Sector Using Optimization Model- A case of Kathmandu Valley*. Kathmandu: IOE Graduate Conference.
- Vengala, J., Mangloor, S., & Goud, T. K. (2019). Performance of Autoclaved Aerated Concrete Block Under Varying Temperatures. *International Journal of Recent Technology and Engineering*, 5.

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Annex 1: HVAC Load Calculation of Proposed Building

Location and Weather	Sanepa_Nepal
Project	Common Brick House
Address	Bhaisepati, Lalitpur
Calculation Time	Wednesday, May 13, 2020 3:03 PM
Report Type	Simple
Latitude	27.65°
Longitude	85.31°
Summer Dry Bulb	82 °F
Summer Wet Bulb	70 °F
Winter Dry Bulb	38 °F
Mean Daily Range	20 °F
Inputs	
Building Type	Single Family
Area (SF)	2,150
Volume (CF)	13,661.70
Calculated Results	
Peak Cooling Total Load (Btu/h)	64,307.0
Peak Cooling Month and Hour	July 5:00 PM
Peak Cooling Sensible Load (Btu/h)	61,747.0
Peak Cooling Latent Load (Btu/h)	2,560.0
Maximum Cooling Capacity (Btu/h)	68,797.5
Peak Cooling Airflow (CFM)	2,583
Peak Heating Load (Btu/h)	71,543.0
Peak Heating Airflow (CFM)	4,826
Checksums	
Cooling Load Density (Btu/(h·ft ²))	45.92
Cooling Flow Density (CFM/SF)	1.84
Cooling Flow / Load (CFM/ton)	481.98
Cooling Area / Load (SF/ton)	261.3
Heating Load Density (Btu/(h·ft ²))	51.09
Heating Flow Density (CFM/SF)	3.45

Annex 2: Energy Simulation of Proposed Building

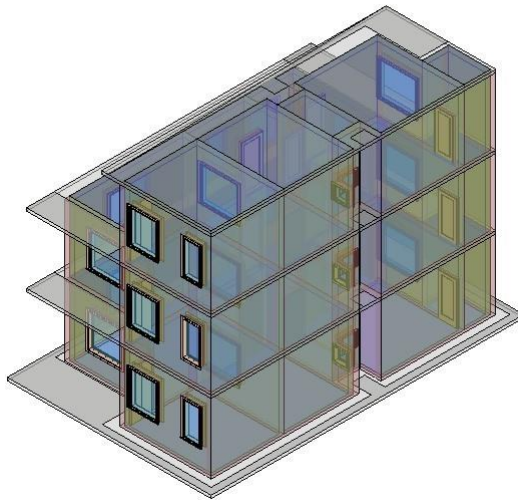


Common Brick House in Bhaisepati Common Brick House

Analysis Analyzed at 3/18/2020 12:40:56

Version 2019.0.47.6(DOE-2.2-48r)

Energy Analysis Result



Building Performance Factors

Location:	Sainbu Bhainsepati, Bagmati
Weather Station:	448961
Outdoor Temperature:	Max: 86°F/Min:
35°F Floor Area:	2,150 sf
Exterior Wall Area:	3,093sf
Average Lighting Power:	1.07W/ft ²
People:	10
people Exterior Window Ratio:	0.21

Energy Use Intensity

Electricity EUI: 40 kWh / sf / yr

Annex 3: HVAC Load Calculation of Enhanced Building

Location and Weather	Sanepa_Lalitpur
Project	Prefab House
Address	Bhaisepati, Lalitpur
Calculation Time	Wednesday, May 13, 2020 1:54 PM
Report Type	Simple
Latitude	27.65°
Longitude	85.31°
Summer Dry Bulb	82 °F
Summer Wet Bulb	70 °F
Winter Dry Bulb	38 °F
Mean Daily Range	20 °F
Inputs	
Building Type	Single Family
Area (SF)	2,150
Volume (CF)	14,307.89
Calculated Results	
Peak Cooling Total Load (Btu/h)	45,650.6
Peak Cooling Month and Hour	July 4:00 PM
Peak Cooling Sensible Load (Btu/h)	44,370.6
Peak Cooling Latent Load (Btu/h)	1,280.0
Maximum Cooling Capacity (Btu/h)	52,056.3
Peak Cooling Airflow (CFM)	1,938
Peak Heating Load (Btu/h)	34,605.6
Peak Heating Airflow (CFM)	1,940
Checksums	
Cooling Load Density (Btu/(h·ft ²))	31.13
Cooling Flow Density (CFM/SF)	1.32
Cooling Flow / Load (CFM/ton)	509.38
Cooling Area / Load (SF/ton)	385.5
Heating Load Density (Btu/(h·ft ²))	23.6
Heating Flow Density (CFM/SF)	1.32

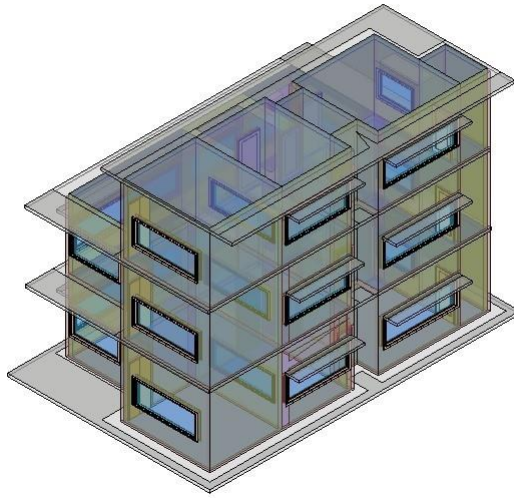
Annex 4: Energy Simulation of Enhanced Building



Enhanced Building

PrefabHouse Analysis (1) Analyzed at 5/13/2020 2:43:57 PM Version 2019.0.47.6(DOE-2.2-48r)

Energy Analysis Result



Building Performance Factors

Location:	Sainbu Bhainsepati, Bagmati
Weather Station:	448961
Outdoor Temperature:	Max: 86°F/Min: 35°F
Floor Area:	2,150 sf
Exterior Wall Area:	2,862 sf
Average Lighting Power:	1.07 W / ft ²
People:	10 people
Exterior Window Ratio:	0.3

Energy Use Intensity

Electricity EUI:	29 kWh / sf / yr
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Enhancement of HVAC Load, Energy Consumption and Energy Cost for A Proposed Residential Building, Bhaisepati, Lalitpur, Nepal

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ABSTRACT:

Almost 20% of total energy produced worldwide is consumed solely by HVAC system and it has alarmed all engineering and research society to consider energy enhancement of HVAC system as large portion of energy can be saved by this single task. Realizing the same, this task has been intended to enhance the HVAC system such that total energy consumption and cost related to it can be reduced. Study regarding the selection of materials for constructing building envelope in order to lower the HVAC load and energy consumption of a residential building has not been performed previously in context of Kathmandu, Nepal and same gap has been intended to be filled by running multiple energy simulations for each available building envelope construction materials and comparing energy use intensity (EUI) in order to select the material resulting in lowest EUI and ultimately finalizing the materials to be used for constructing building such that HVAC load, energy consumption and energy cost is enhanced. The proposed building was found to have 5.15 tons of refrigeration (TOR) peak cooling load and 5.65 TOR peak heating load which consumes 55,244 kWh electricity that costs NRs. 7,10,190.73 for 24X7 scheduled operation. After replacing building parameters on basis of EUI, the final building was found to have 3.63 TOR peak cooling load, 2.76 TOR peak heating load, 37,420 kWh annual energy consumption and NRs. 4,78,485.91 annual energy cost. The result shows that HVAC load, energy consumption and energy cost are function of building construction materials and proper selection of those materials determines the enhancement of HVAC load, energy consumption and energy cost.

Keywords— Heating Ventilation and Air-Conditioning, Autodesk Revit, Radiant Times Series Method, Energy Use Intensity, Green Building Studio

I. INTRODUCTION

Developmental activities are growing at an exponential rate in whole universe. Energy is the most basic requirement for developmental activities. But limitation of energy has created energy scarcity in many cities around the world. Long lasted load shedding in Nepal till 2016 is an example of energy scarcity. Total energy in universe is constant and the proper use of available energy in rational way is only way to ensure the sustainable development. Realization of this fact has dawned the whole engineering, research and development societies to design and develop energy efficient systems. Same applies to HVAC system which consumes major portion of energy in residential sector.

Around one third of total energy being produced is used in building of which 60 percent to 70 percent is used only by HVAC system [1], which concludes that Enhancement of HVAC load and energy alone can contribute large to energy conservation. HVAC load varies among different types of walls, roofs and windows [2,3]. Energy consumption also varies as per the type of equipment [4]. Apart from equipment features, the outdoor weather condition of installed location

plays vital role in energy consumption by HVAC system. Kathmandu valley lies at an average elevation of 1400m from sea level at 27°41'N, 85°02'E. Kathmandu experiences maximum temperature up to 32.5°C during summer and minimum temperature low to -2°C during winter [5]. With almost 8 months of summer (March to October) in a year, HVAC systems are mainly focused on cooling conditions. As of 2013, demand of energy in residential sector was found to be 7500TJ. Growth rate of energy requirement in residential sector was around 4 percent. The energy used in HVAC system was 4 percent of total residential demand [6]. Complying with these facts, 144TJ (40,000,000kWh) of energy is used in HVAC system annually in Kathmandu in 2020. So, it shows that large portion of energy can be saved by optimizing HVAC load. However, design of energy efficient HVAC system is an iterative and complex task. To deal with the complexity, sophisticated Building Information Management (BIM) tools are used in HVAC sizing and energy Enhancement. Accuracy of BIM tool Revit and Green Building Studio (GBS) in designing energy efficient HVAC system has already been verified [7]. Design of energy

efficient residential building by optimizing HVAC load in Sousse city has successfully been accomplished using Revit and GBS [8].

Despite the above presented fact that high amount of energy is consumed by HVAC system in Kathmandu and it can be reduced by selection of proper materials of construction and HVAC equipment, approach towards enhancement of HVAC load, energy consumption and energy cost by using various BIM and energy simulation tool is still a new topic in context of Nepal. So, the main goal of this study is to enhance the HVAC load, energy consumption and energy cost of a proposed residential building located at Bhaisepati using Autodesk Revit and GBS.

II. Methodology

The AutoCAD drawing was recreated in Autodesk Revit by allocating thermal properties of building envelope materials. The building was divided into 12 HVAC spaces and zones were allocated on each space separately. Using the location mapping feature, building location was entered. HVAC load size was calculated using heating and cooling load feature of Revit. The file was exported in gbxml format. New project template was created in Green Building Studio (GBS) and properties were allocated as available. The gbxml file was then uploaded to GBS and energy simulation was done in order to calculate the energy consumption and EUI for proposed building. Then, building envelope parameters (wall, roof and glass) and non-envelope parameters (occupancy sensor, daylight sensor and HVAC equipment) were varied and EUI for each alternate option were calculated. By keeping all features of building constant, one parameter was varied at a time and energy simulation was done. Total of 1240 energy simulations were performed and based on value of EUI, building parameters were finalized. Then final design was recreated in Revit. Energy simulation for final design was done and energy consumption was calculated. Comparison of HVAC load, energy consumption and energy cost were done in order to find out the benefits of enhancements. Various information, theory and assumptions used in this study are explained further.

A. Calculation Method

1) **Radiant Time Series Method (RTSM):** It is a simplified method for calculating peak design load, based directly on Heat Balance (HB) method, assuming steady periodic condition. It relies on a 24- term “response factor series” to generate conductive heat gain and on a 24-term “radiant time series” to convert instantaneous radiant heat gain into cooling loads [9,7]. Manual Calculation of HVAC load by this method is repetitive and tedious. So, this method is generated using Heating and Cooling Load tool of Autodesk Revit. Weather data required for calculation of load is accessed

by online platform of Autodesk server which provides weather data of target location through virtual weather station.

$$\frac{q}{A} = \alpha E_t + h_0(t_0 - t_s) - \varepsilon \Delta R \quad (1)$$

$$\frac{q}{A} = h_0(t_e - t_s) \quad (2)$$

$$t_e = t_0 + \frac{\alpha E_t - \varepsilon \Delta R}{h_0} \quad (3)$$

$$q_\theta = A * \sum_{j=0}^{23} Y_{pj} * (t_{e,\theta-j\delta} - t_{rc}) \quad (4)$$

$$Q_\theta = r_0 * q_\theta + r_1 * q_{\theta-\delta} + r_2 * q_{\theta-2\delta} + \dots + r_{23} * q_{\theta-23\delta} \quad (5)$$

Where:

α = absorptance of surface for solar radiation,

E_t = total solar radiation incident on surface, [Btu/h*ft²]

h_0 = coefficient of heat transfer by long wave radiation and convection at outer surface, [Btu/h*ft²*°F]

t_a = outdoor air temperature, [°F]

t_s = surface temperature, [°F]

ε = hemispherical emittance of surface, [-]

ΔR = diff. between long-wave radiation incident on surface from sky and surroundings and radiation emitted by black

body at outdoor air temp., [Btu/h*ft²]

q_θ =hourly conductive heat gain for the surface [W]

A =surface area [ft²];

Y_{pj} =j:th response factor;

$t_{e,\theta-j\delta}$ =sol-air temperature j hours ago[°F];

t_{rc} =presumed constant room air temperature [°F];

Q_θ =cooling load(Q) for the current hour (θ), [BTU/hr];

$q_\theta - n\delta$ =heat gain n hours ago;

r_0, r_1, etc =radiant time factors

2) **Energy Consumption Simulation:** In HVAC energy simulation, energy consumption varies among working cycles based on whether the operation is under design condition, part load condition or below minimum part-load ratio [10]. Annual energy consumption calculation is iterative and hence it is accomplished using DoE2 simulation tool. Energy consumption by HVAC equipment vary as per the outdoor weather which is accessible through online platform of GBS.

At design condition:

$$\text{Energy} = (\text{CAP}) * (\text{EIR}_{\text{des}}) \quad (6)$$

At part-load condition

$$\text{Energy} = (\text{CAP}) * (\text{EIR}_{\text{des}}) * [\text{EIR}\{\text{PLR}\}] \quad (7)$$

At operation below minimum part-load ratio:

$$\text{Energy} = (\text{CAP}) * (\text{EIR}_{\text{des}}) * [\text{EIR}(\text{MIN-RATIO})] * (\text{FRAC}) \quad (8)$$

Where,

CAP= Design (rated) Capacity of Equipment

EIR_{des} = Design Electric Input Ratio

PLR= Part Load Ratio

EIR{PLR}= Electric Input Ratio Correction Factor at Part Load Ratio

EIR(MIN-RATIO) = Electric Input Ratio Correction Factor at Operation Below Minimum Part Load Ratio

$$FRAC = \frac{PLR}{MIN-RATIO} \quad (9)$$

3) **Energy Cost Calculation:** The annual energy cost can be calculated as summation of monthly energy cost. Depending upon the ampere size of installed energy meter, both service charge and unit cost of electricity varies. 60A rated domestic system has been taken for cost calculation in this work. Monthly cost can be calculated as [11]:

$$Cost_i = S + U * R \quad (10)$$

$$Annual\ Cost = \sum_{i=j}^{Dec} Cost_i \quad (11)$$

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 ana 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)

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

B. Description of Proposed Building

The building has been proposed to be made by common brick wall of 240mm thickness including plaster of 12mm thickness on both sides. Single pane clear glass of 6 mm thickness with wooden frame is to be used for windows. All doors will be made up of wood. The information related to building is based on basic AutoCAD drawing of the building. The entry of building has been proposed on south face. The longer orientation is on North-South Direction.

Table I
INFORMATION RELATED TO BUILDING

Building Location	Bhaisepati, Lalitpur
Building Size	2 and half story
Floor Area	1400sqft
Wall Material	Common Brick with plaster
Wall Window Ratio	0.21
Roof Type	Flat
Roof Material	Concrete
Floor	Concrete
Window Type	Single pane clear glass

R-values of materials have been collected from secondary sources in order to calculate the HVAC loads.

Table II
LOAD PARAMETERS OF PROPOSED BUILDING

Description	R-Value hr.ft².F/BTU
--------------------	----------------------------------------

Brick Wall(240mm,[12]	3.339[13]
Roof,4"	1.73[13]
Floor	1.73[13]
Window	0.885[14]

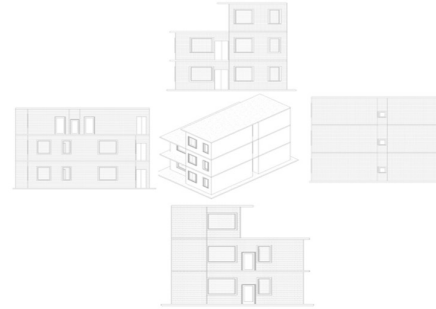


Figure 1: Building Outlook (Designed in Revit)

Total of 12 rooms with 6 bedrooms are proposed on the building excluding washroom: 5 on ground and first floor and 2 on top floor.

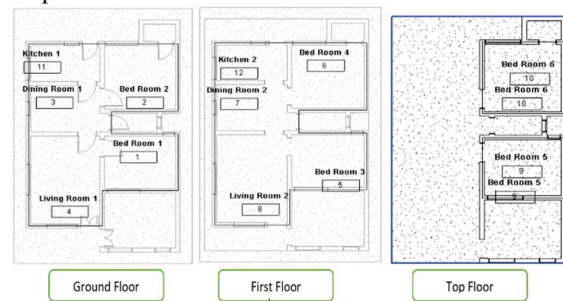


Figure 2: Floor Plan

C. Alternate Parameters for Construction

Variations have been made on building parameters on both envelope and non-envelope factors. Building envelope determines the internal environment of building whereas, non-envelope parameters maintain favourable environment for human comfort inside building. Window shades, number of panes and glass type has been assumed on basis of data availability, practical implications and hence limited to few options as tabulated below:

Table III
LIST OF BUILDING ENVELOPE VARIATION

Building Envelope	Variations
Wall	ASHRAE Walls [15,16] Conventional Nepali Wall

Roof	ASHRAE Roof [15,16] Conventional Nepali Roof
Window Wall Ratio	0.1,0.2,...0.9[17]
Window Shades	0,1/6,1/4,1/3,1/2,2/3
Number of Panes	Single, Double, triple
Glass Type	Clear, Low-E

Study of non-envelope parameters are limited to equipment, occupancy sensor and daylight sensor as given below:

Table IV
LISTOFNON-ENVELOPVARIAION

Parameters	Variations
Equipment (assumption)	Heat pump, Terminal heat pump, VAV, Package system
Daylight and Occupancy Sensors	Not Installed Daylight Sensor Occupancy Sensor Both Control

D. Occupancy

As the building is proposed for residency, occupancy would be low during day time and full during night time. Employment and education result low occupancy during day. Considering these factors occupancy of people has been assumed for 24 hours as follows:

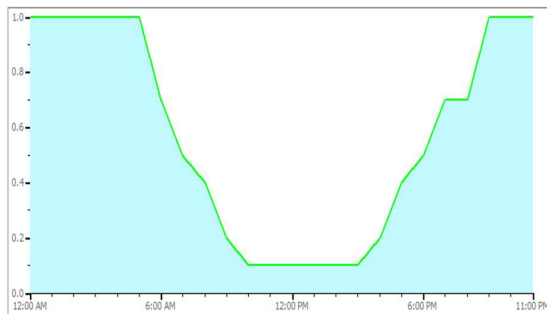


Figure 3: Occupancy of people

E. Weather Data

The range of DBT and WBT for each month is given below [18]. The design conditions are taken at 0.2%.

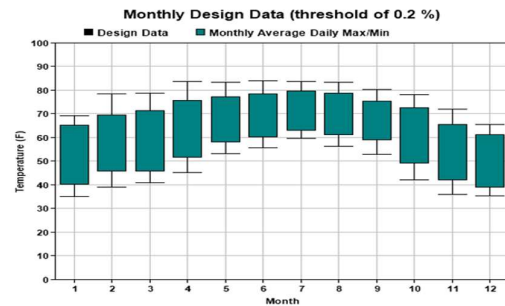


Figure4: HVAC Design Weather Data

F. Enhancement Process

Calculation of energy use intensity for each alternative building design was done through multiple energy simulation. Then based on lowest value of EUI, availability and construction trend, building envelope parameters were finalized.

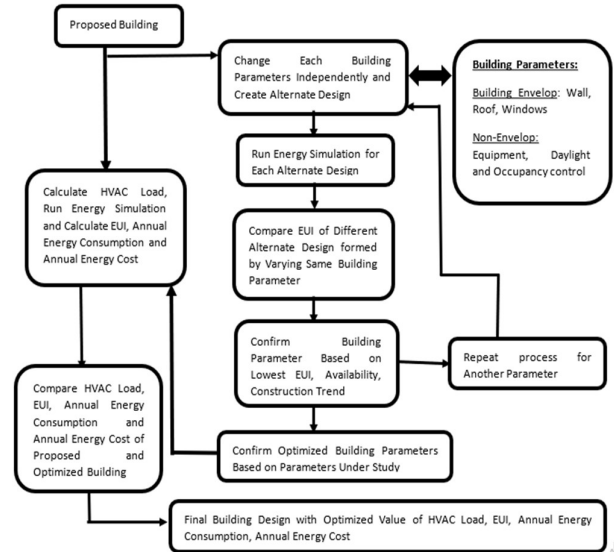


Figure 5: Enhancement Process

III. RESULT AND DISCUSSION

A. Results of Proposed Building

The HVAC peak load was calculated in order to size the HVAC equipment for the building. HVAC load calculation was done for both summer and winter. For energy consumption comparison, energy use intensity has been calculated. As the proposed building is a residential building, operation schedule has been taken 24 X 7 for calculation of annual energy consumption and hence resulted in high annual energy cost as shown below:

Table V
RESULTS FOR PROPOSED BUILDING

HVAC Peak Heating Load, TOR	5.15
HVAC Peak Cooling Load, TOR	5.65
Energy Use Intensity, kWh/ft ² .yr	40
Annual Energy Use, kWh	55,244
Annual Energy Cost, NRs	7,10,191

Out of total energy used in the proposed building, 62% is consumed solely by HVAC system. Various equipment: microwave oven, freezer, television and laptop were considered to be operating and heat from them were assumed while calculating HVAC load. Energy consumed by all of these including fans used for ventilation is shown by Misc. Equipment in below chart:

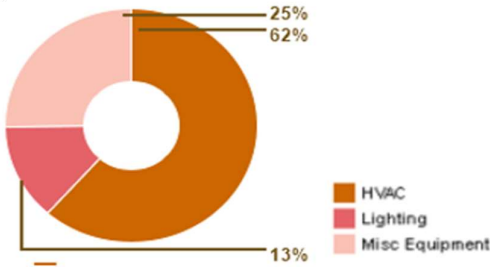


Figure 6: Electricity Consumption

Maximum cooling load occurs during July followed by August, and hence highest energy consumption for cooling is during the month of July as shown by following chart.

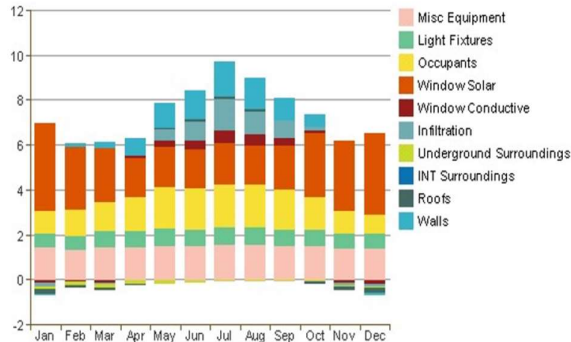


Figure 7: Monthly Cooling Load (in MBTU)

Maximum heating load occurs during the month of December followed by January as shown by the following chart. However, the magnitude of maximum energy consumed in a single month for cooling (July) is higher than the maximum energy consumed in a single month for heating (December) despite the result that peak HVAC heating load (5.65 TOR) is higher than peak HVAC cooling load (5.15 TOR). This is because the COP of equipment during heating (Heat pump) is higher than during cooling (refrigeration).

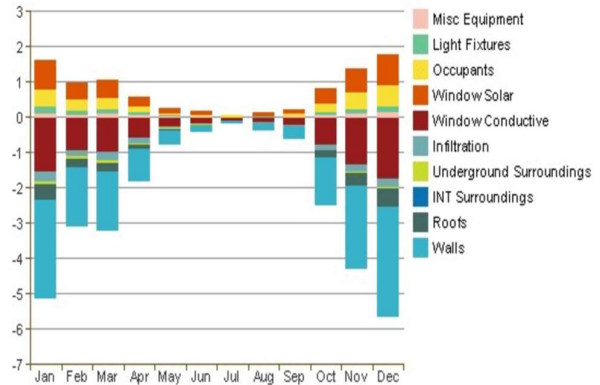


Figure 8: Monthly Heating Load (in MBTU)

B. Enhancement Result

Simulation was run by varying windows on each face. Lower WWR results in low HVAC load but increases lighting load. It was found out that window wall ratio of 0.3 in east, west and north direction along with 2/3 of window height shading and triple pane low-E glass resulted in minimum energy use intensity. Same was found in south face except no shading. EUI in east, west, north and south were 237.13, 225.22, 229.47 and 227.43 respectively. So, these windows were selected for optimized building.

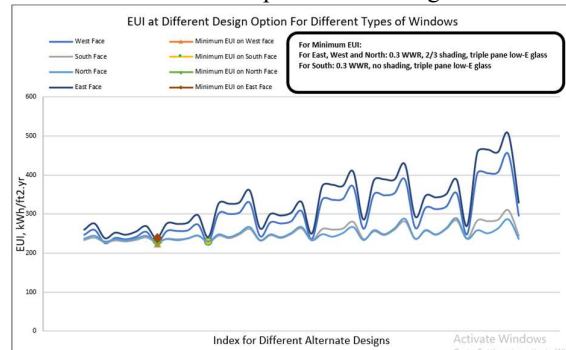


Figure 9: EUI at Different Design Option for Windows

Keeping everything constant, wall materials were varied and energy simulation was run. Minimum EUI was resulted by R38 wood wall. But as many of ASHREA recommended walls are not constructed in Nepal, wall material was chosen from amongst the commonly available materials. Prefab resulted in minimum EUI among such material. In order to construct a prefab building, the reinforced concrete pillars need to be replaced by metal frame. Prefab has been considered for wall construction as per its lower EUI and low cost.

EUI AT DIFFERENT TYPES OF WALL

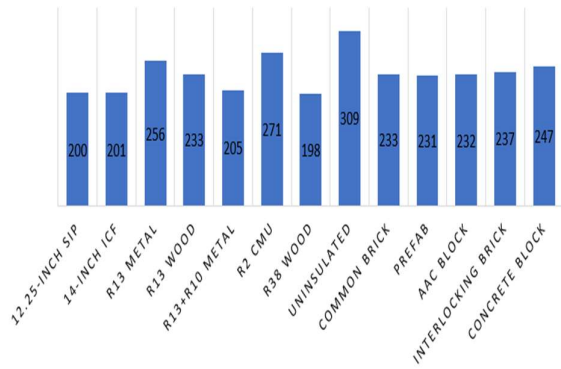


Figure 10: EUI at Different Design Option for Wall

In case of roof, minimum EUI was resulted by R60 insulated roof. But as insulated roof is rarely used in Nepal, materials required for constructing them are difficult to be found. Since 4” un-insulated concrete roof can be constructed both in metal frame or reinforced concrete frame, it has been chosen for final design despite resulting in high EUI.

EUI AT DIFFERENT ROOF OPTION

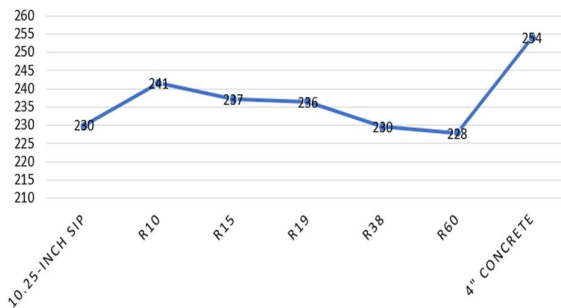


Figure 11: EUI at Different Design Option for Roof

Energy consumption varies as per the type of HVAC system installed. ASHRAE package terminal heat pump was found more effective for this building.

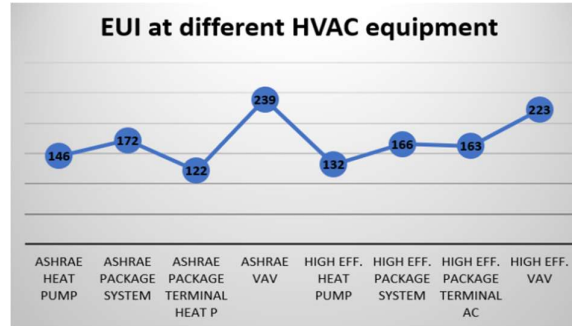


Figure 12: EUI at Different Type of HVAC Equipment

In absence of occupant, occupancy sensor turns off all lighting, HVAC and other equipment automatically, resulting in energy saving. Day light sensor senses the sunlight during day and turns off light if it has been left in on position. Use of these helps in saving energy as shown by following graph.

EUI AT DAYLIGHT AND OCCUPANCY CONTROL

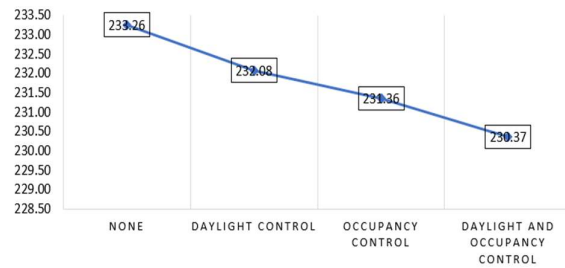


Figure 13: EUI When Day light and Occupancy Sensors Are Used

For final design wall, window and roof were finalized and building design was modified accordingly. Results of final building are as follows:

Table VI
RESULTS FOR OPTIMIZED BUILDING

HVAC Peak Heating Load, TOR	3.63
HVAC Peak Cooling Load, TOR	2.76
Energy Use Intensity, kWh/ft².yr	29
Annual Energy Use, kWh	37,420
Annual Energy Cost, NRs	4,78,486

C. Comparison of HVAC Load, Energy Use and Cost of Proposed and Enhanced Building

Reduction in HVAC peak load, EUI, energy use and energy cost are as follows:

Table VII
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%

Highest reduction of energy consumption was seen in the month of December equivalent to 1719 kWh whereas lowest reduction was seen on February equivalent to 1272 kWh. Total of 17823 kWh of electricity consumption is reduced when system is operated for 24x7 throughout the year. Energy consumption on different months by proposed and optimized building are as follows:

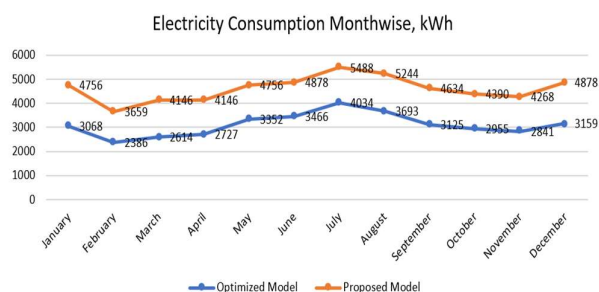


Figure 14: Electricity Consumption Month wise kWh

Total of Nrs 2,31,705 could be saved on electricity cost in comparison to proposed building from optimized building. Maximum of cost saving is achieved during December worth Nrs 22,346. Lowest cost saving is achieved during February, equivalent to Nrs 16,538. Monthly savings along with cost involved in each design alternative has been shown below:

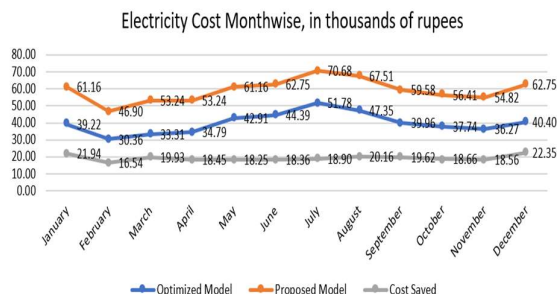


Figure 15: Electricity Cost Month wise, NRs

D. Comparison of Result with Previous Research

Use of prefabricated board for constructing residential building is an energy efficient way in comparison to traditional materials as shown by this study. The result is contradictory to the study conducted by Michal Kraus which shows that prefab building provides human comfort favourable environment for 90% of time while 10% time is limited by infiltration, ventilation and sealing [19], thus questioning the energy performance of prefab building. Result shows that WWR of 30% is better for improving energy efficiency. This result matches with the study conducted by Jalil Shaeri which shows that energy efficiency is high in WWR 20% to 40% depending upon the face of building [20]. Use of triple pane glass cuts energy consumption and HVAC load as shown in this study. Same has been confirmed by US Department of Energy [21] but doubted about the preference by builders for using triple pane due to its high cost. Research on usability of clear, grey, clear low-e and tinted low-e glass by Qiong Hi [22] showed that tinted low-e glass was best for using in Shanghai for energy efficiency, while this study showed that clear glass with low-e need to be used instead of tinted low-e in context of Kathmandu. Package terminal heat pump was found to be most energy efficient HVAC system for residential purpose in this study with EUI value 122 kWh/yr/sq. ft. The result is similar to the study performed by Aghoul which shows that energy consumption is lowest for package terminal heat pump (44009kWh) for residential purpose [4].

IV. CONCLUSION

Residential buildings in Kathmandu are not constructed with prospect of energy efficiency of HVAC system which results in high energy consumption and high energy cost during the operational phase of building. To address the same issue, the building has been created in Revit with all building parameters. The HVAC load has been calculated by heating and cooling load feature of Revit. Using GBS, annual energy and energy cost have been calculated. By changing the building parameters with available alternate option, energy simulations have been run and parameters resulting in enhanced energy consumption were selected. The enhancement of HVAC load, annual energy consumption and annual energy cost have been performed that have resulted in reduction of HVAC peak cooling load, HVAC peak heating load, energy consumption and energy cost by 51%, 30%, 32% and 33% respectively. However, wall and window colour that has been finalized for enhancement differ from those verified by previous researches in this field.

REFERENCES

[1] Samah K Alghoul, Hassan GR Jjabo, and Mohamed E Mashena. *Energy consumption in buildings: correlation for the influence of window to wall ratio*

- and window orientation in Tripoli, Libya. *Journal of Building Engineering*, 11:82–86, 2017.
- [2] Edward G Pita and Suci Stevenson. *Air conditioning principles and systems*. Prentice Hall Upper Saddle River, NJ, 1998.
- [3] R Sullivan, K Frost, D Arasteh, and S E Selkowitz. *Window value effect on residential cooling load*. 1993.
- [4] S Alghoul. *A comparative study of energy consumption for residential HVAC systems using energy plus*. *American Journal of Mechanical and Industrial Engineering*, 2(2):98–103, 2017.
- [5] ISHRAE. *Nepal weather data-2019*. 2019.
- [6] Utsav Shree Rajbhandari and Amrit Man Nakarmi. *Energy consumption and scenario analysis of residential sector using optimization model— a case of Kathmandu valley*. In IOE Graduate Conference, pages 476–483, 2014.
- [7] Jonas Sandberg. *Computer based tools in the HVAC design process. interface and data transfer between modeling in revit and supporting draw-and simulation tools (especially with focus on handling geometries and information-/data transfer)*. 2011.
- [8] Habiba Benzarti Ghedas. *Modeling and thermal optimization of residential buildings using BIM and based on RTS method: application to traditional and standard house in sous-secity*. 2017.
- [9] Jeffrey D Spitler, Daniel E Fisher, and Curtis O Pedersen. *The radiant time series cooling load calculation procedure*. Technical report, American Society of Heating, Refrigerating and Air- Conditioning Engineers... 1997.
- [10] USA Department of Energy. *Doe-2 engineers manual*. 1982.
- [11] Nepal Energy Forum. *NEA electricity tariff rates*. 2017.
- [12] Department of Urban Development and Building Construction. *Nepal building code 2064*. 2064.
- [13] Parker McQuiston, Spitler, “heating ventilation and air conditioning”, 2005.
- [14] G Pita Edward. *Air conditioning principles and systems*, 2002.
- [15] ASHRAE. *Standard 90.1-2019—energy standard for buildings except low-rise residential buildings*. 2019.
- [16] ASHRAE. *Standard 90.2-2018—energy efficient design of low-rise residential buildings*. 2018.
- [17] Halil Alibaba. *Determination of optimum window to external wall ratio for offices in a hot and humid climate*. *Sustainability*, 8(2):187, 2016.
- [18] Autodesk Server. *Weather sanepalaliturnepal*. page 92, 2006.
- [19] Michal Kraus. *Indoor environment in residential prefabricated buildings*. In IOE Conference Series: Materials Science and Engineering, volume 245, page 042072. IOE Publishing, 2017.
- [20] Jalil Shaeri, Amin Habibi, Mahmood Yaghoobi, and Ata Chokhachian. *The optimum window-to-wall ratio in office buildings for hot-humid, hot-dry, and cold climates in Iran*. *Environments*, 6(4):45, 2019.
- [21] O G Dingus Shaeri TL Gilbride, S E Selkowitz. *Factors influencing the window purchasing decisions of high performance home builders*. Pacific Northwest National Laboratory, 2019.
- [22] Qiong He, S Thomas Ng, Md Hossain, Martin Skitmore, et al. *Energy efficient window retrofit for high-rise residential buildings in different climatic zones of China*

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