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A comparison study of HVAC load and energy consumption by varying wall materials of a residential building

by

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ABSTRACT

HVAC system is the most prominent system responsible for utilization of energy in any household. This operation of HVAC costs massively for overall energy consumption of a residential building. However, with preliminary study on design factor of any residential building that accommodates for less HVAC load and can result in less economic burden for operation can help for lessening HVAC load and overall cost of energy.

Model house with all the floor plans and elevation view has been created in Autodesk Revit. Autodesk Revit is a modelling software for designing buildings and various infrastructure used by architects, mechanical engineers, and structural engineers.

In this case study of residential building, wall material varied twelve times with widely used wall material in the context of Nepal during preliminary study of design of this building. Mixed type of wall material has been used in this study. Common brick wall with variation as AAC block, CLC block, ply board and Cement board is used. HVAC system used for the building is ASHRAE package terminal heat pump. HVAC load for each type of wall material of the building has been calculated with Radiant Time Series Method defined by ASHRAE in Autodesk Revit. Also, the gbxml file of this model has been extracted and run for energy simulation using Green Building Studio. Equipment and furniture inside of the house has been considered for this calculations. Energy consumed by these equipment and heat produced by light has been considered. HVAC load of building for each kind of wall material has been calculated from the Autodesk Revit itself. Likewise, energy consumption by the building for each kind of wall material has been calculated from simulation feature of Autodesk DOE-2.Eventually energy cost has been calculated. So the final results suggests mixed wall type of brick with 8 inch CLC block wall as inner wall material most accommodates for less HVAC load in the residential building which resulted in least energy consumption and finally least energy cost. HVAC heating load with this combination was found to be 18,938 Watt and cooling load was found to be 6273 Watt. The annual energy consumption was 61.1 % of total energy use. Also, energy cost of this combination was found to be Rs. 253848.7 which is least of all the combination. Hence with use of eight inches CLC block as wall material one can benefit from least energy consumption and energy cost.

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Research is never complete without help of wonderful people behind. Pertaining to this research, I would like to express my sincerest gratitude towards my supervisor, Dr. Sanjeev Maharjan for his continuous effort and the guidance he has given me in accomplishing my dissertation. Constant brainstorming, idea generation on refining the main motive of the research with him has given me great confidence in narrowing down the objective of the study. My due respect to the Department of Mechanical Engineering for the constant coordination and support. I am grateful to all the department professors and lecturers for providing valuable suggestions and kind support throughout the project.

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LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
HVAC	Heating, Ventilation and Air Conditioning
CLTD	Cooling Load Temperature Difference
AAC	Autoclaved aerated concrete
TFM	Transfer Function Method
HBM	Heat Balance Method
RTS	Radiant Time Series
EUI	Energy Use Intensity
IAQ	Indoor Air Quality
EMCS	Energy Management and Control Systems
CTF	Conduction Transfer Function
GBS	Green Building Studio
RTS	Radiant Time Series
CLF	Cooling Load Factor
SCL	Solar Cooling Load
WBT	Wet Bulb Temperature
DBT	Dry Bulb Temperature
ISHRAE	Indian Society of Heating, Ventilation, Refrigeration and Air Conditioning Engineers
KTM	Kathmandu
HBM	Heat Balance Method
CLC	Cellular Lightweight Concrete

CHAPTER ONE: INTRODUCTION

1.1 Background

Heating, ventilation and Air conditioning (HVAC) refers to the different systems used to control the temperature, humidity, and quality of the air in a building or any other enclosed space. HVAC has become the most important infrastructure for ensuring human comfort in workspace, residences and commercial hubs. HVAC plays a significant role for maximum building energy consumption. Limiting the HVAC load is major challenge for minimizing energy consumption globally.

Electricity is the primary source of energy in various part of the world. 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. Almost 10- 20% of the total energy is consumed in HVAC system depending upon the locations (Aghoul, 2017).This shows that proper sizing of HVAC system can save large energy.

HVAC effectiveness is affected by building materials. For HVAC to run effectively, one needs building material that reduces overall demand on the system. Proper sizing of HVAC system can save energy by avoiding over-sized HVAC system. Energy efficient building design plays signification role for reducing HVAC load and hence energy. Materials with low overall heat transfer are being researched and developed. So, many construction materials are being used. In Nepal, brick, concrete block, interlocking brick, AAC block and prefab are common building materials used. Other factors such as window placement, building core, no. of occupancy, selection of type of HVAC system also plays vital role in energy consumption by HVAC system.

Physical comfort is dependent on material selection of building construction. Proper material ensures low operational cost of HVAC system. For this proper knowledge on HVAC load is required. Hence, selection of building material is vital.

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), and Radiant Time Series (RTS) Method. However, complexity in manual calculation by these methods pose limitations to strictly follow these calculations methods. So, to aid for proper planning, designing and simulation of HVAC system, many software tools have been developed.

1.2 Problem Statement

Though HVAC systems have been installed in workspace, buildings and facilities, optimum benefit from the AC is not extracted from it. For ensuring the optimum benefit from the HVAC system for thermal comfort HVAC Load, energy consumption, and hence energy cost must be determined for selecting best building material so that both HVAC load and energy cost can be reduced. Wall materials of commercial building is the most used material for construction of any residential building. Through study of wall material and HVAC system one can benefit from low operation cost and energy consumption and overall cost.

1.3 Objectives

1.3.1 Main Objective

The main objective of this research is to compare building wall material for a model house to ensure optimum HVAC load, energy consumption and hence energy cost.

1.3.2 Specific Objectives

The specific objectives of the thesis are:

1. To calculate HVAC load for the proposed building by using combination type of wall material construction.
2. To compare energy consumption for each available wall material.
3. To finalize the best combination of wall material that has least HVAC load, least energy consumption.

CHAPTER TWO: LITERATURE REVIEW

Heating Ventilation and Air conditioning Unit in any building is a must to regulate the flow of air, heat, and ventilation in a building. The main objective of having an HVAC in a building is to make a comfortable living inside of a building, which is attained through thermal comfort and attaining indoor air quality (IAQ).

HVAC systems assure this thermal comfort through a regulated flow of air and heat. It controls the overall climate inside of a building.

2.1 Working principle of HVAC inside a building

In an HVAC system, the cold water produced by an HVAC water chiller is sent to the cooling coils in air handling units (AHU); the AHUs are located in the spaces where temperature is to be changed. Blowers help in moving the air on cooling coils to distribute into various areas of the building.

Supply ducts are used to distribute the treated air whereas return ducts are used to take in the return air. Cooling water pumps are used to circulate the chilled water throughout the system.

There are also HVAC Valves installed at various points in piping to make the maintenance of the HVAC system convenient. In case heating is required, an HVAC heat pump, hot water generator, or furnace may be employed to heat the air. Cooling coils work as heating coils in the heating mode. (Editorial, 2021).

2.2 HVAC Heating Load and Cooling Load

HVAC Load is the energy required to keep the inside condition of a building in thermal comfort for the occupants. This Heating and cooling load is also termed as thermal load.

Heating load refers to the amount of heat energy to be supplied to an area to maintain the temperature in the desired range. Similarly, cooling load refers to the amount of heat energy that is to be removed from an area to maintain the temperature in the desired range.

In the design of air conditioning, there are three types of heat flow rates, they are all time-dependent: (ASHRAE, Cooling and Heating Load Calculation Manual, 1980)

1. Heat Gain or Loss

2. Cooling Load or Heating Load

3. Heat Extraction or Heat Addition Rate.

Heat gain is the amount of heat flowing into the space by a source that is capable of generating and transferring heat into the space. In terms of the sources of generation there are specifically two types of heat gains.

1. Sensible Heat Gain: Sensible heat gain is addition of heat to an area directly by conduction, convection and/or radiation, without any change in the moisture content. Sensible heat gain results in the change of temperature. (ASHRAE, Cooling and Heating Load Calculation Manual, 1980)

2. Latent Heat Gain: Latent heat gain refers to the energy added to the space through moisture addition, for example, vapor emitted by the people in the room or through air infiltration from outdoors.

2.3 Purpose of HVAC load Calculations

HVAC load calculations helps in estimation of energy requirement of the building which helps in energy metering of the building and the cost of energy use can also be estimated. Thus, it is essential that preliminary calculations be done before setting up the system. Apart from that, load calculation helps in accomplishing one or more of the following (ASHRAE, Cooling and Heating Load Calculation Manual, 1980):

a. Provides basis for equipment selection, sizing and system design.
b. Provides information for assessing the optimum possibilities for load reduction.
c. Allows to study and analyze the partial loads required for system design and operation.

2.4 Cooling Load and heat gain calculation methods

It is necessary to forecast energy for the HVAC system in the design, commissioning, operation and management, and to test and assess the control strategies and algorithm in Energy Management and Control Systems (EMCS) by employing simulation models. Prediction models of cooling and heating loads are an essential part of building energy and HVAC system simulations program. The heat transfer through the building constructions is the principle component of the cooling/heating loads and it contributes mainly to the energy requirements for HVAC in a building. It is necessary to carry out a transient thermodynamic analysis for heat flow in building constructions for the thorough assessment of energy consumption and dynamic simulation of the HVAC system. (A.Kalogirou, 2014).

2.4.1 Conduction Transfer Function Model

Conduction Transfer Function (CTF) is the numerical solution of the diffusion equation and Fourier's law for transient heat transfer in a building construction. CTF method is extensively used to calculate cooling loads and energy calculations in buildings because of its convenience to use and implement. (Xiang Qian Li, 2009).C Lou. used the original CTF method (derived from the EnergyPlus source codes) and modified CTF method (that uses a higher order discretization scheme for the surface heat flux as well as finer grids at the layer boundaries for multi-layer constructions) to determine wall surface heat fluxes based on wall surface temperatures as the inputs. Prediction results from the original CTF method derived from the original EnergyPlus software source codes and the present modified CTF method were found to compare well with other numerical results and measurements for smoothed temperature inputs such as the inner cavity brick-plaster construction. In case of natural outer surface temperature inputs, the modified CTF method was found to provide a better comparison with other numerical results and measurements than the original CTF method, especially for the cavity brick wall and the brick veneer wall (C. Lou, 2010).

2.4.2 Radiant time-series method

The radiant time series (RTS) method is a recent approach; it is based on the heat balance method, and it is used to carry out cooling load calculations. The RTS approach uses a 24-term response factor series to calculate conductive heat gain, whereas it uses a 24-term "radiant time series" to get cooling loads from instantaneous radiant heat gain. (Spitler, 1997). Conductive Heat Gain is computed for every type of wall and roof using 24 response factors. The response factor expression yields a time series solution to the transient, one-dimensional conductive heat transfer case. The conductive heat gain for the surface, q_{Θ},, for any hour, Θ, is calculated as the summation of the response factors multiplied by the difference in temperature across the surface, as

$$q_{\Theta} = A\sum_{n=0}^{23} Y_{Pn}(t_{e,\Theta-n\delta} - t_{rc}) \qquad (4)$$

where,

q_{Θ} = conductive heat gain for the current hour, Btu/h (W), for the surface;

A= surface area, ft^2 (m^2);

Y_{Pn} = n^{th} response factor;

$t_{e,\Theta-n\delta}$ = sol-air temperature, ˚F (˚C), n hours ago; and

t_{rc} = assumed constant room air temperature, ˚F (˚C).

This conductive heat gain and convective heat gain is divided into two portions: convective and radiative heat gains which is expressed into cooling loads. The radiative heat gain is stored in the thermal mass in the building which is released to the zone by convection.

Converting Radiative Heat Gains into Cooling Loads

The RTS method is used to convert the hourly radiant heat gains to hourly cooling loads with the use of radiant time factors which are the coefficients of the radiant time series. Like response factors, radiant time factors are used to compute the cooling load for the current hour based on the current and previous heat gains. The radiant time series for a particular zone gives the time-dependent response of the zone to a single steady periodic pulse of radiant energy. The series shows the portion of the radiant pulse that is convected to the zone air for each hour. Thus, r0 is the fraction of the radiant pulse convected to the zone air in the current hour, r1 in the last hour, and so on. The radiant time series thus generated is used to convert the radiant portion of hourly heat gains to hourly cooling loads according to Equation 2.

$$Q_{\Theta} = r_0 q_{\Theta} + r_1 q_{\Theta-\delta} + r_2 q_{\Theta-2\delta} + r_3 q_{\Theta-3\delta} + \ldots + r_{23} q_{\Theta-23\delta} \quad (5)$$

Where

Q_{Θ} = hourly cooling load (Q),

q_{Θ} = hourly heat gain,

$q_{\Theta-n\delta}$ = heat gain n hours ago, and

r_0,r_1, etc. =radiant time factors.

Radiant time factors are computed for a particular zone employing a heat balance model. Assuming all walls have 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 computed until a steady periodic pattern is reached. The ratio of resulting cooling loads and the magnitude of the heat gain pulse gives the radiant time factors for each hour.

2.4.3 Cooling Load Temperature Difference Method

Cooling Load Temperature Difference is an equivalent temperature difference used for the calculations of instantaneous external cooling load across a wall or roof. This Method is derived from the TFM method and uses tabulated data to simplify the calculation process. This temperature difference accounts for the aggregated effects of inside and outside air temperature difference, daily temperature range, solar radiation and heat storage in the construction assembly/ building mass. It depends on various factors such as orientation, tilt, month, day, hour, latitude, etc. CLTD factors are used to adjust the conductive heat gains through walls, glass, roof and floor (Bhatia).

In the cooling process, contrary to expectation, the rate of heat gain is not equal to the heat removed (cooling load) from a space or a building because of the heat storage and time lag effects. In general. the actual total cooling load is less than that of the peak total instantaneous heat gain, thus smaller equipment is required than by the heat gain calculation. A portion of heat gain heats the room air immediately through convection and other part is absorbed by the furnishings and building structure through radiation process. The radiation process is termed as heat storage effect. The heat absorbed by the building structures and the furnishings then convects the heat into the room air after a delayed time. The CLTD value accounts for the thermal response (lag) in the heat transfer through the wall or roof, and the response (lag) due to the radiation portion of energy from the inside surface of the wall to the object within the space which varies with heat gain with time, the size of the structure, and the geographical location. Thus, CLTD also facilitates with providing cooling loads at various hour of the day. CLTD, SCL and CLF data calculated using the transfer function method gives cooling loads for standard outdoor conditions and zone types (ASHRAE, 2001).

2.5 Power Consumption by HVAC System

The importance of thermal comfort and air quality has been increasingly garnering attention in regards to health and productivity of the occupants. HVAC systems contributes to a significant portion of energy consumption in buildings and are also responsible for indoor environment quality. Hence, upgrading of HVAC system also helps in lessening power consumption. The energy consumption in a commercial office building with a modernized HVAC system can reduce energy consumption by 50 % while also upholding acceptable indoor thermal comfort (Wen Wei Che, 2019).

The best method for energy modelling of buildings integrates the design process together with the energy modeling process. Use of Building Information Modeling (BIM) tools like Revit, to create building geometry and apply all the energy analysis configurations (Wei PAN, 2017), BIM (Building Information Modeling) design data can be integrated with energy performance simulation software such as Green Building Studio (GBS), Ecotect and Project Vasari, and this integration makes them powerful planning tools for designing a high-efficiency energy building (Han-Soo RYU, 2016).

2.5.1 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). A widely accepted freeware building energy analysis program, it is used to forecast the energy consumption and estimate the cost for various types of buildings. It utilizes data such as building layout information, constructions, indoor systems (illuminations, HVAC, etc), weather data and utility rates provided by the consumer to carry out an hourly simulation of the building and to calculate utility bills. The “plain” DOE-2 program is a “Command Prompt” program and it requires significant amount of experience to learn to use effectively and it provides significant flexibility to researchers and experts; eQUEST is a complete interactive Windows implementation of the DOE-2 program with added wizards and graphic displays to assist in the use of DOE-2. eQUEST is an advanced but very user-friendly freeware tool for building energy use analysis that provides high- level results without a lot of effort. eQUEST was designed to carry out thorough comparative analysis of a building designs and technologies by applying advanced building energy use simulation techniques without requiring much experience in building performance modelling.

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

Energy = (CAP)*(EIR_{des})…………………………………………………………1.6

At Part-load condition:

Energy= (CAP)*(EIR_{des})*[EIR{PLR}]…………………………..…………………………1.7

At operation below minimum part-load condition:

Energy=(CAP)*(EIR_{des})*[EIR(MIN-RATIO)]*(FRAC)…………………………………………..…………………..1.8

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 = PLR/MIN-RATIO ……………………………………………...…….1.9

2.6 Annual Energy Cost Calculation

Annual energy cost can be calculated as summation of monthly energy cost. Depending upon the size of installed energy meter, both service charge and unit cost of electricity varies. 0 A rated domestic system has been taken for cost calculation in this work monthly cost can be calculated as:

$Cost_i$=S+U*R……………………………………………………………………1.10

Annual Cost = $\sum^{Dec}_{i=jan} Cost_i$ …………………………………….…...………1.11

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 and unit consumed),

U = Unit of electricity consumed, Kwh,

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

2.7 Wall material of the building

Walls in buildings forms a fundamental part of the superstructure. In this case study walls considered for design specification are common brick wall, prefab wall, ACC block wall, Concrete block wall and interlocking wall. Common brick wall is widely used and the most conventional wall used in residential building in the context of Nepal. Prefabricated wall panels also known as Prefab are factory-built units produced in an indoor environment. Manufacturers cut, nail and fasten the units together in a quality-controlled environment to make a stronger, more lasting wall structure. Autoclaved aerated concrete (AAC) block wall is a light, precast, foam concrete building material appropriate for producing concrete masonry unit like blocks. Concrete block unit is a standard-sized rectangular block used in building constructions.

2.8 VAV Single Duct HVAC System

Variable air volume (VAV) is the simplest type of heating, ventilating, and/or air-conditioning (HVAC) system. As opposed to constant air volume (CAV) system, that supplies a constant airflow at a variable temperature, VAV systems vary the airflow at a constant temperature. There are many advantages of VAV systems over constant-volume systems such as more precise temperature control, reduced compressor wear, lower energy consumption by system fans, reduced fan noise, and additional dehumidification. A basic VAV system utilizes a single supply duct that distributes air at a constant temperature of about 55 °F (13 °C) in cooling mode. As the supply air temperature is constant, the air flow rate has to vary in order to meet the fluctuating heat gains or losses within the thermal zone. In a single-zone VAV unit, the fan speed varies accordingly with the actual indoor temperature and the temperature setpoint, and the compressor regulates the refrigerant flow in order to maintain a constant supply air temperature. This results in more precise temperature control.

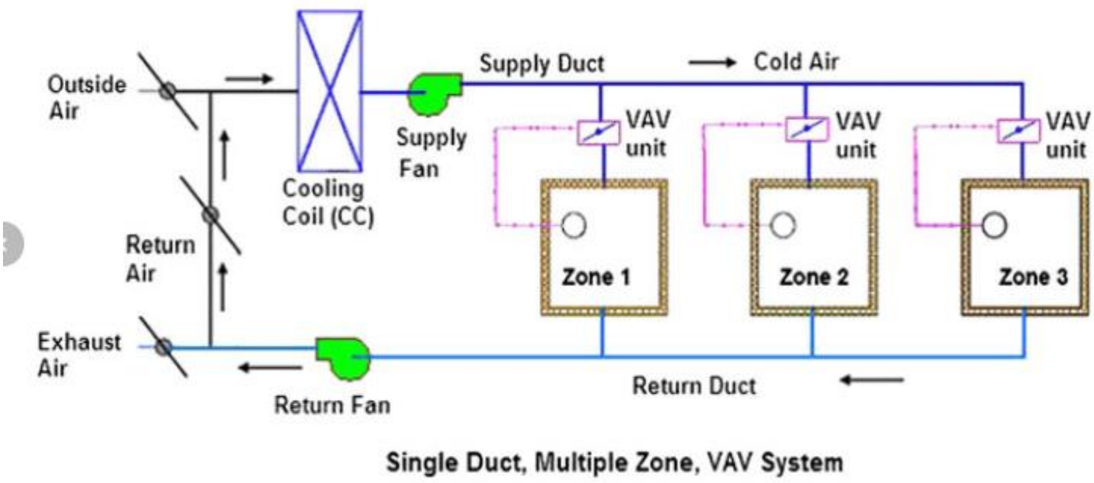

Figure 2.1 Schematic diagram of a Single Duct, VAV System [Farag Weal, 2016]

2.9 Previous Researches

Thermal simulation using ECOTECT program to study and compare the indoor thermal performance of a building using common brick and Interlocking Compressed Earth Brick (ICEB) as wall material shows that with the use of ICEB for wall construction reduces indoor operative temperature of a building by 1˚C in the daytime. And with ICEB the percentage of indoor operative temperature remains in comfort condition during the working hour increase at about 22 % on the ground floor and 30 % on the first floor. Also, the conventional brick has low indoor temperature than ICEB during morning time that resulted in higher indoor temperature during evening time (Abd Halid Abdullah S. K., 2013).

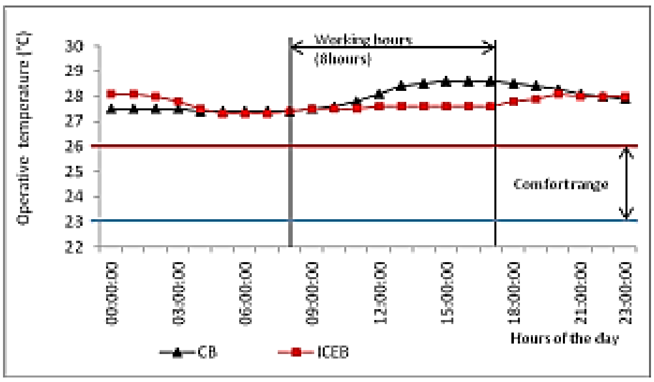

Figure 2. 2: HVAC load variation throughout the day between conventional brick and ICEB on ground floor [Abd Halid Abdullah,2013]

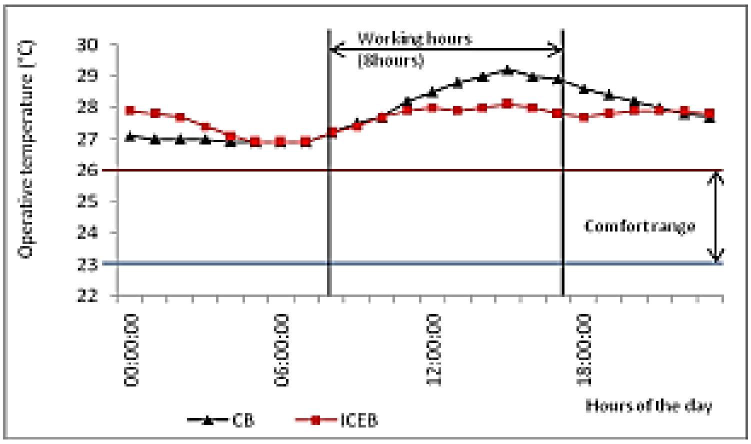

Figure 2. 3: HVAC load variation throughout the day between conventional brick and ICEB on first floor [Abd Halid Abdullah,2013]

In a study of performance of Autoclaved Aerated Concrete Blocks under varying temperature, performance of AAC block under varying temperature was checked. Check for physical properties like cracking under high temperature, not adhering to plaster and thermal properties like thermal comfort and indoor resultant temperature was carried. Comparison of result with solid concrete block for thermal comfort was carried. Indoor temperature of building made up of AAC block and solid concrete block for 9 days under identical condition showed that the building made up of AAC Block had 1-2˚C low indoor temperature which ensured better thermal comfort and low HVAC energy requirement in AAC block made building in comparison to solid concrete block made building as shown on table 2.2. (Jagadish Venagala, 2019)

In another study of thermal performance of phase change materials-enhanced cellulose insulation in passive solar residential building walls, it showed that with cellulose concrete placed in building wall absorbs a substantial portion of heat is being propagated from the hotter outside environment during the day and convect the stored heat at night and early morning hours which resulted in peak-space cooling load reduced and a part of it is shifted to off-peak hours. Hence the building walls lined with phase change materials (PCM) save energy, peak space cooling load shifting, and increased thermal comfort in the buildings. (Kyoung Ok Lee, 2018)

Table 2. 1 Indoor Temperature Difference between AAC built house and Solid concrete built house. [G. Jagadish Venagala, 2019]

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	

CHAPTER THREE: METHODOLOGY OF RESEARCH

This research is an applied research, which aims to derive best wall alternative for a building construction so as to achieve minimum HVAC load, energy consumption and overall energy cost. Simulation approach has been used wherein an established set of theory has been used to simulate analytical reasoning for the results obtained.

The following methods have been executed to meet the objectives of the research:

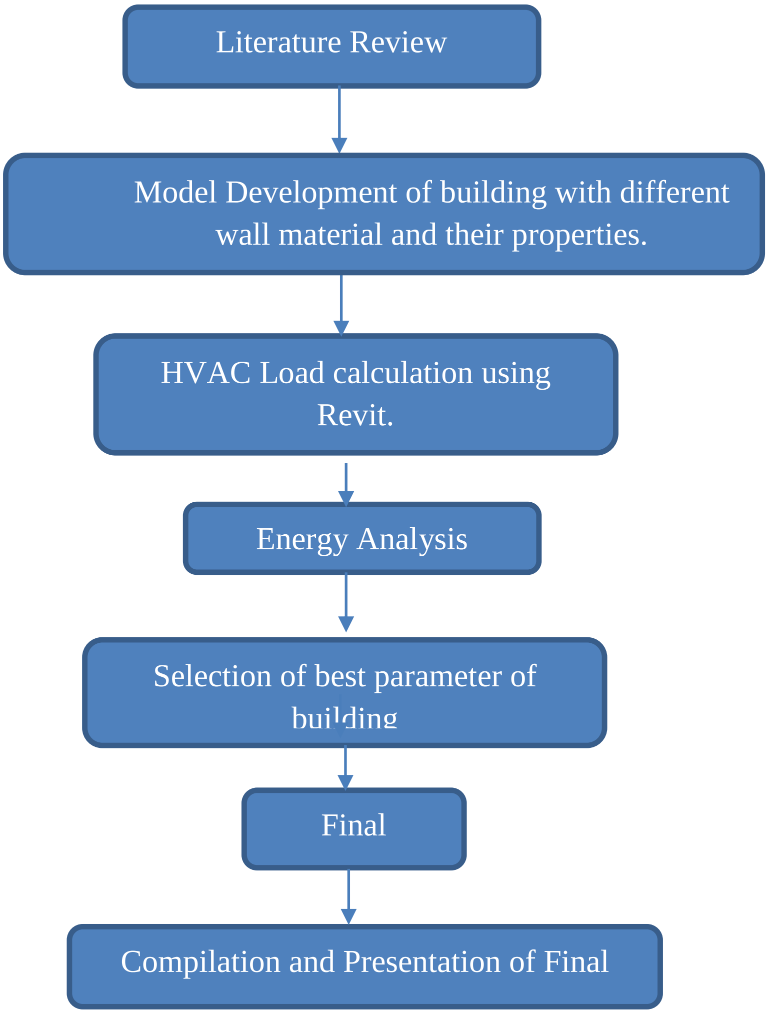

Figure 3.1: Research methodology used in this study

The above steps have been explained in detail below:

3.1 Literature Review

Literature review on related topics, research papers, thesis reports, books, citations in relevant materials have been studied to get an insight into what the topic is about, and where the research gap, and how to address it. The issue of value addition to the existing research will be searched as a result. Findings, theoretical background has been looked into to develop the research work. Mainly, the following will be studied under literature review:

- Research on importance of material selection for reducing HVAC load.
- Research on locally available and widely used wall material in the context of Nepal.
- Regarding thermal comfort of the occupancy and thermal conductive behavior of the material used.
- Software simulation using Different software and their usefulness.
- Finally software usage like Autodesk Revit and DoE-2.

3.2 Model Development of building with different wall material and their properties

Properties of material used for construction determines the HVAC load. In order to know the influences of these material on building, model was designed using these different materials available. Common wall material used in the context of Nepal are brick, concrete brick, AAC block, prefab board, and interlocking brick. These wall materials are considered in this research work. Windows, roof, glass material are not considered here in this study.

3.3 HVAC load Calculation using Revit

For calculation of heating load and cooling load in Revit, initially the model was brought into mechanical template. Then the location of the building set to Bhaktapur, so that Revit takes the weather data automatically from internet. Also, the inbuilt walls in Revit was found to have different U-values. So, walls with equivalent U-values were created. Then model was developed in Revit and cooling load was calculated.

3.4 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 as energy. However, electricity is used mostly for HVAC usage as energy source in Nepal.

3.5 Selection of Best construction material for building

From the analysis for the residential building, wall material with minimum HVAC load, energy consumption and energy cost will be the best construction material to be used in building.

3.6 Compilation, Discussion and Presentation of Final Report

This is the last phase, which includes compilation of all information, comparison and presenting them in a formal report. From the results obtained, discussions and recommendations were made for reasoning and have been filed in the report.

3.7 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 2022 trial version have been used for analysis purpose in this thesis. Revit uses Radiant Time series (RTS) method for calculation of heat load. Trial version of the software have been used for this study.

CHAPTER FOUR: RESULTS AND DISCUSIONS

4.1 Description of properties of the building

This is the case study focused on calculation of HVAC load and energy consumption of a residential building located at Bhaktapur. This building is on preliminary design phase, so has incomplete data associated. Design factor such as space, elevation, plan layout are available data on this building. Some of the information given in the drawing are as follow:

Table 4.1 Details of the proposed building

Building Location	Bhaktapur
Building Size	Two and half Story
Total Floor Area	227 sq. m
Wall Material	Common Brick with variation of inner wall
Wall Window Ratio	0.21
Roof type	Flat
Roof Material	Concrete
Floor	Concrete
Window type	Single Pane clear glass
Number of Rooms	11

4.2 Weather Statistics

The weather data required for the calculations of the cooling loads are prerecorded in (ASHRAE, 1993) and (ISHRAE, 2019) which are enlisted below:

Table 4.2 Weather properties

Data Available			
Location	KTM valley	Summer design DBT	89˚F 31.67˚C
Required Indoor Temp	74˚F 23.33 ˚C	Summer Co-incident WBT	78.8˚F 25.56˚C
Elevation	1337 m	Summer daily range	25.2˚F 13.89 ˚C
Latitude	27.7 ˚	Winter Design DBT	33.0˚F 0.56˚C
Longitude	-85.2 ˚	Winter Co-incident WBT	27.3˚F -2.78˚C

Table 4.3 Summer and winter DBT and WBT of Kathmandu

Month	**Summer**		**Winter**	
	Max DBT	**Min WBT**	**Max DBT**	**Min WBT**
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

Month	Summer		Winter	
	Max DBT	Min WBT	Max DBT	Min WBT
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

4.3 Geometry Modelling

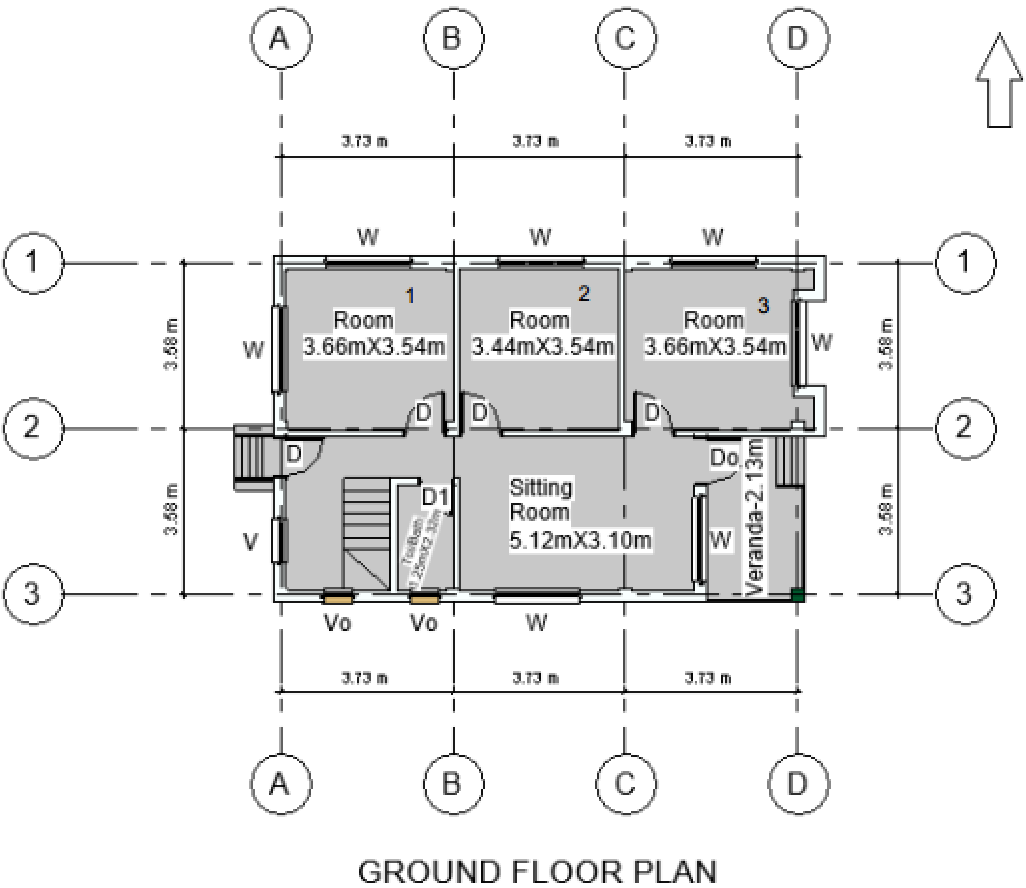

Figure 4. 1 Ground Floor Plan

Ground floor has the area of 80.12 m^2 having four rooms. Three rooms are situated in the northern orientation while living/ sitting room is largest room facing south direction.

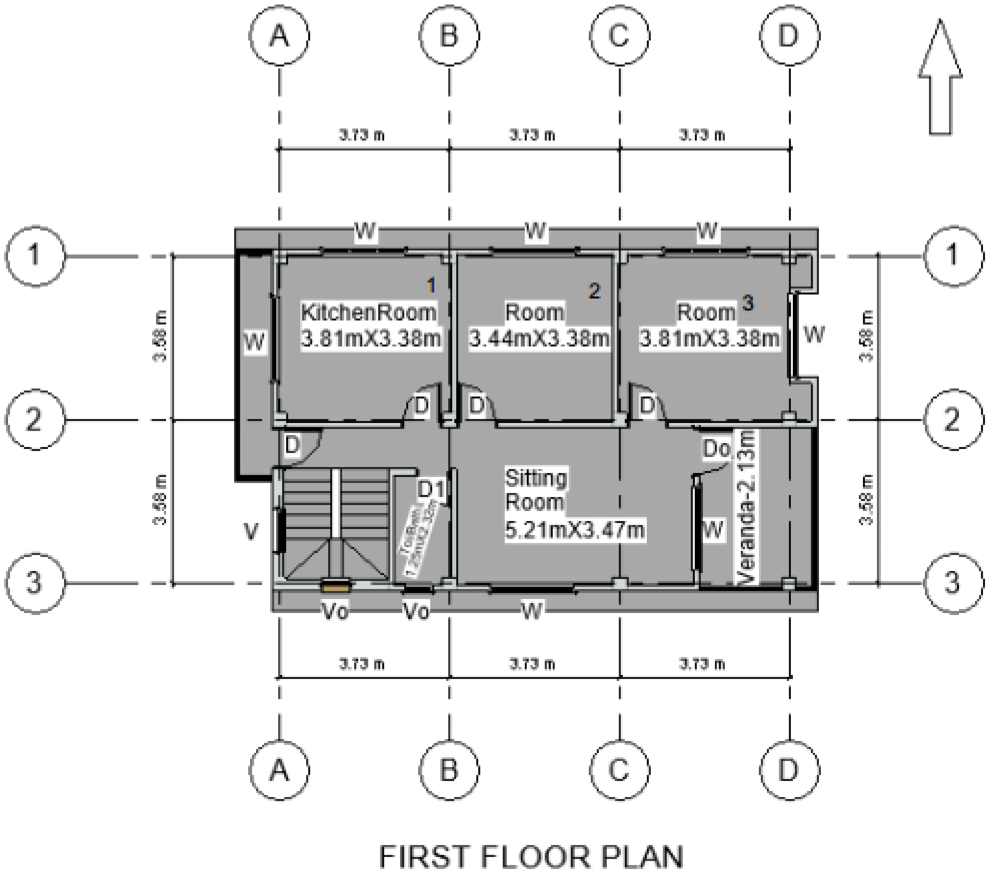

Figure 4. 2 First Floor Plan

First floor has the same area as that of ground floor of 80.12 m^2 having four rooms. Three rooms are situated in the northern orientation while living/ sitting room is largest room facing south direction as shown in figure 4.2.

Second floor has the wall area of 66.76 m^2 having three rooms. Three rooms are situated in the northern orientation while lower terrace is situated facing southern direction as shown in figure 4.3.

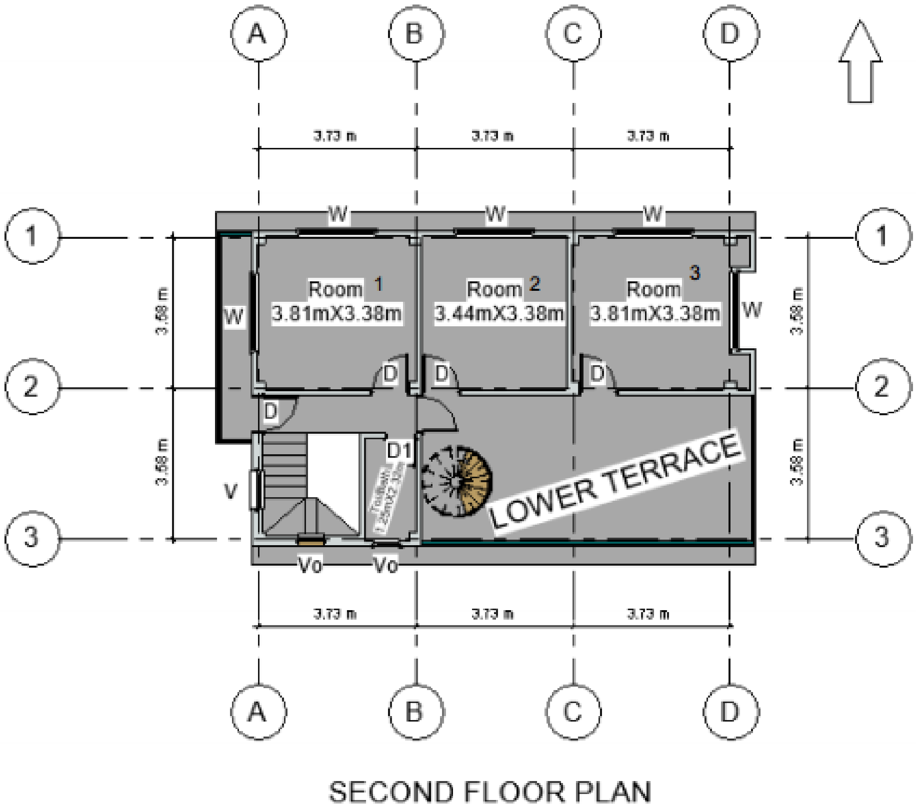

Figure 4. 3 Second Floor Plan

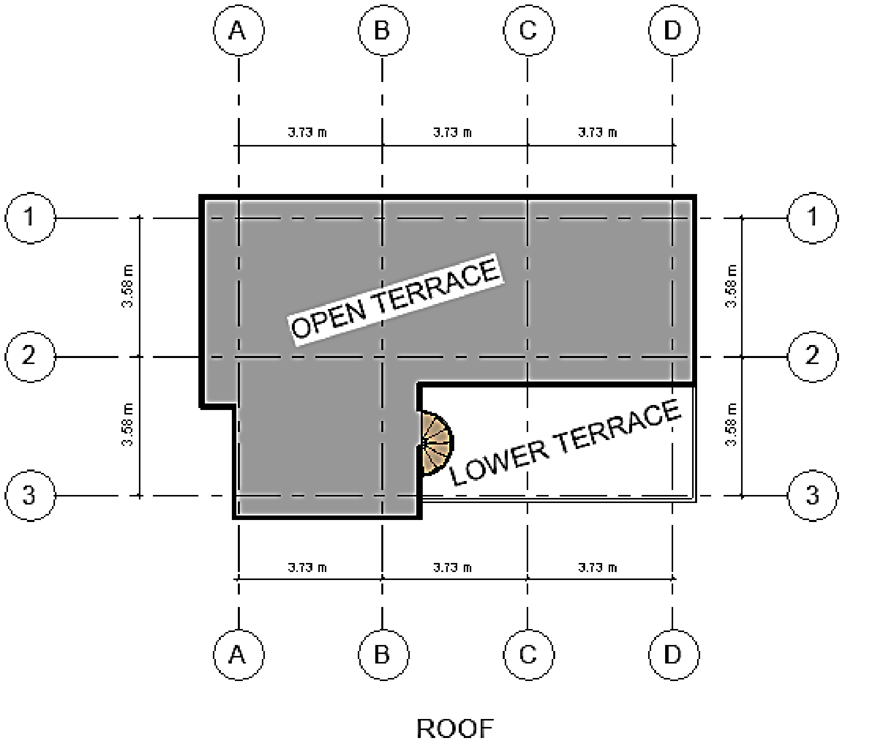

Figure 4. 4 Roof plan

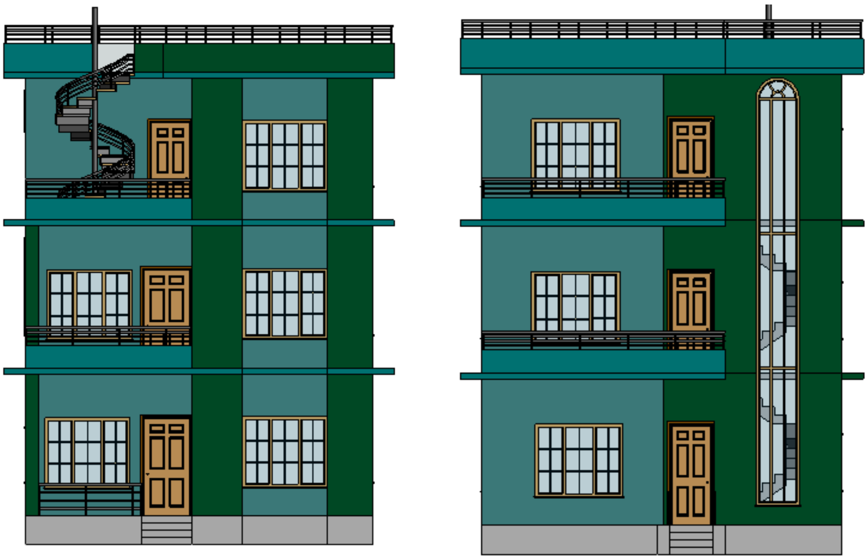

Figure 4.5 Front View Elevation (East) and Back View Elevation (West)

Figure 4. 5 Side View Elevation (North) and (South)

4.4 Description of the Orientation

The house is two and half storied house with the front elevation facing east. This side of the house gets direct sunlight till the mid-day. Room 1 of each floor is exposed to the morning direct sunlight in the house. Likewise Room 2 lies in-between of Room 1 and room 3, which is faced towards northern elevation. Room 3 is located on the north-west orientation, evening sunlight is prominent in this side of the house. Living room/ sitting room is located in the south orientation.

4.5 Variation of wall materials used

Brick wall is the most common building wall material used widely in Nepal. It is typically made of clay, concrete or silicate bricks. It is used to form the external walls of buildings, internal partitions, freestanding walls, retaining walls and so on. In this study common brick wall is used as outer wall. Size of the brick wall used is four inch brick. Autoclaved Aerated Concrete (AAC) block is used as inner wall material for the building. This light, precast, foam concrete building material are made by curing under heat and pressure in an autoclave. Standard sizes of this block available are 2 inch, 6 inch and 8 inch. All these variations are studied upon for HVAC load. CLC block is another variation used as inner wall material for the building. This is produced by mixing cement and flyash slurry with pre-foamed foam. Standard sizes of this block available are 2 inch, 6 inch and 8 inch. All these variations are studied upon for HVAC load. Ply board is another variation used with 2 inch and 3 inch air gap in-between inner wall and outer wall. Cement board is another variation for inner wall. This cement board is a mixture of cement and reinforcing fibers shaped into sheets, of different thicknesses. This gives more impact resistance and strength to the wall surface.

Twelve variations has been used for this study. They are:

1. Brick wall and two inch AAC block
2. Brick wall and six inch AAC block
3. Brick wall and eight inch AAC block
4. Brick wall and two inch CLC block
5. Brick wall and six inch CLC block
6. Brick wall and eight inch CLC block
7. Brick wall and ply board
8. Brick wall with two inch air gap and ply board
9. Brick wall with three inch air gap and ply board
10. Brick wall and cement board
11. Brick wall with two inch air gap and cement board
12. Brick wall with three inch air gap and cement board

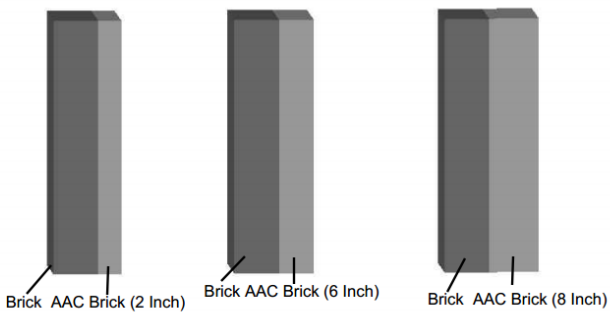

Figure 4.6 Variation of wall material with AAC block as inner wall

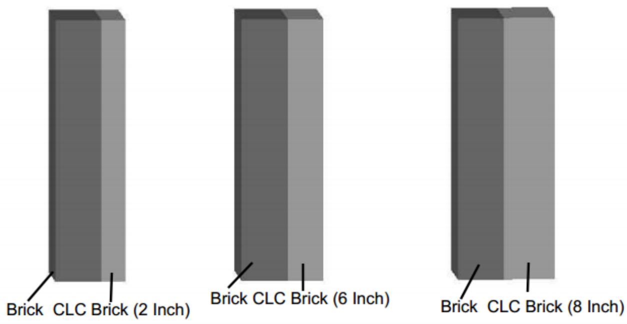

Figure 4.7 Variation of wall material with CLC block as inner wall

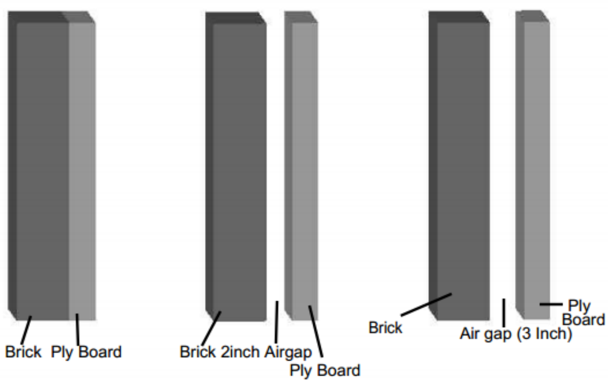

Figure 4.8 Variation of wall material with Ply board as inner wall

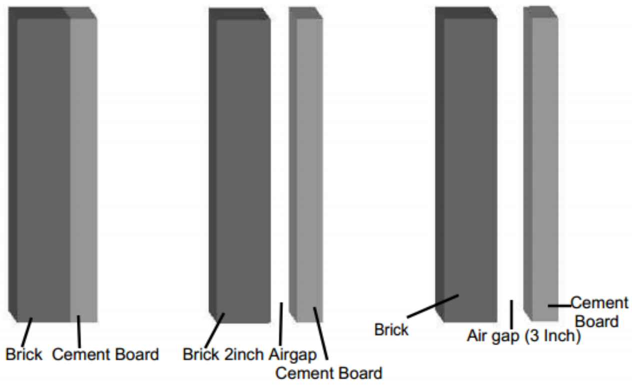

Figure 4.9 Variation of wall material with Cement board as inner wall

For calculations of HVAC load Autodesk Revit model is to be recreated. Thermal resistance of common wall material from Revit directory didn't match with the resistance of real material found in Nepal.

Table 4.4 Thermal Properties of Material Used

S No.	Description	Thermal Conductivity(K) (Wm/K)	Source
1	Brick Wall	1.2	(F. Mcquiston, 2005)
2	AAC Block Wall	0.308	(Pruteanu, 2013)
3	Windows	0.96	(Pita, 2002)
4	Roof (concrete Heavy)	1.5	(F. Mcquiston, 2005)
5	CLC Block	0.44	(Siram, December 2012)
6	Ply Board	0.13	(Pruteanu, 2013)
7	Cement Board	0.924	(Tianyu Li, 2017)

4.6 Occupancy

Occupancy has been considered low at daytime and full during night time as the proposed building is residential. Occupant is out all day due to employment and education. This factor has been considered while calculation of the load.

4.7 Specifications of HVAC systems

ASHRAE terminal heat pump type of HVAC system is most suitable for residential building in Nepal (Thapa, 2020).Hence, ASHRAE Terminal Heat pump type of HVAC system is used in this study as HVAC system. Also, the system has Fan efficiency to be 70% .Motor Efficiency is 80%, rated heating COP to be 5 and rated cooling COP is 3 (Thapa, 2020).

4.8 Calculation of Peak HVAC Load

HVAC Load has been calculated using Heating and Cooling Load feature of Revit.

4.8.1 Peak Cooling load for twelve variation of wall type

HVAC peak cooling load for each kind of variation of wall material are as follows:

Table 4.5 HVAC Peak Cooling Loads with variation of wall material.

S. No.	Wall Material Variation	Peak cooling load	
		Watt	TOR
1	Brick wall and 2 inch AAC Block	13396	3.83
2	Brick wall and 6 inch AAC Block	7281	2.08
3	Brick wall and 8 inch AAC Block	6905	1.97
4	Brick wall and 2 inch CLC Block	14582	4.17
5	Brick wall and 6 inch CLC Block	7326	2.09
6	Brick wall and 8 inch CLC Block	6273	1.79
7	Brick wall and 20 mm ply board	14513	4.15
8	Brick wall with 2 Inch air gap and 20 mm ply board	11472	3.28
9	Brick wall with 3 Inch air gap and 20 mm ply board	11169	3.19
10	Brick wall and 20 mm cement board	18634	5.32
11	Brick wall with 2 Inch air gap and 20 mm cement board	11521	3.29
12	Brick wall with 3 Inch air gap and 20 mm cement board	11187	3.20

Brick wall has been used as the constant outer wall material. With this brick wall as outer wall, inside wall layer is varied with AAC Block wall, CLC Block wall, Ply board, Cement board. With this inner wall, size of the block has been varied each time with commercially available sizes i.e, 2”, 6”, 8” wall. With Cement board and Ply board air gap of 2“and 3“ has been added in-between the inner and outer wall. Peak HVAC cooling load with Brick wall and 8 inch CLC block wall has been found the least.

This shows that combination of brick wall and CLC block inner wall is most favorable wall combination as with the same unit of HVAC unit, commercial HVAC load is least with the combination for summer or warmer environmental condition. This is due to the high insulation value of CLC block.

4.8.2 Peak heating load for twelve variation of wall type

Table 4.6 HVAC Peak Heating Loads with variation of wall material.

S. N.	Wall Material Variation	Peak Heating load	
		Watt	TOR
1	Brick wall and 2 inch AAC Block	41080	11.74
2	Brick wall and 6 inch AAC Block	25741	7.35
3	Brick wall and 8 inch AAC Block	22631	6.47
4	Brick wall and 2 inch CLC Block	52216	14.92
5	Brick wall and 6 inch CLC Block	32770	9.36
6	Brick wall and 8 inch CLC Block	18938	5.41
7	Brick wall and 20 mm ply board	42659	12.19
8	Brick wall with 2 Inch air gap and 20 mm ply board	17536	5.01
9	Brick wall with 3 Inch air gap and 20 mm ply board	15655	4.47
10	Brick wall and 20 mm cement board	47510	13.37
11	Brick wall with 2 Inch air gap and 20 mm cement board	17732	5.07
12	Brick wall with 3 Inch air gap and 20 mm cement board	15687	4.48

From the report of heating and cooling load calculation of Autodesk Revit, wall with brick with 3 inch air gap and 20 mm ply board has least heating load. Also, combination wall of brick as outer layer with 3 inch air gap in between and ply board as inner wall most favors the cooler or winter environmental condition and takes the least heating load.

4.9 Variation of Loads among Room in Different Floor

Living room for this residential building is situated in ground floor and first floor. Area for the both room is same and lies in same orientation. HVAC load variation for the room

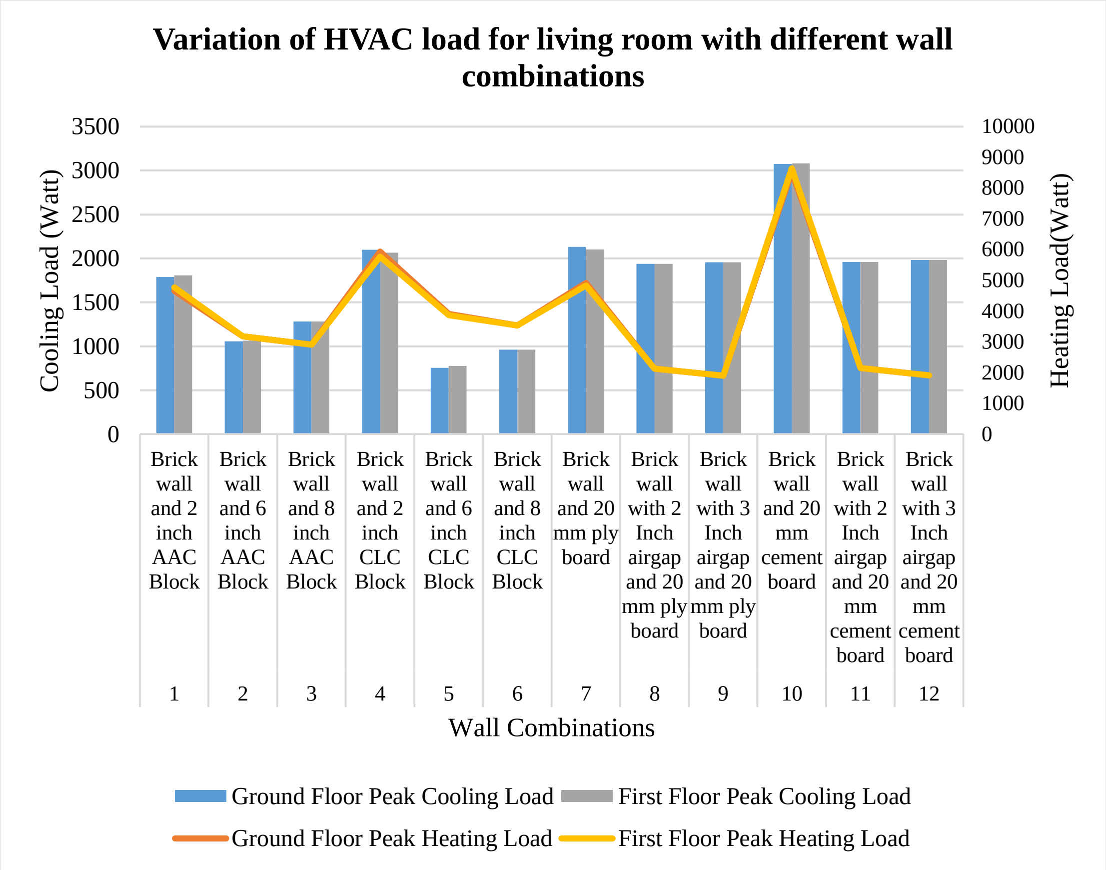

Figure 4.10 Variation of Peak Heating Load and Peak Cooling Load of living room in different floor.

Above figure 4.10 represents the variation of Peak Cooling load and peak heating load of living room in ground floor and first floor. Living room from the proposed building are situated in ground floor and first floor only. From load calculation, combination of brick wall with 6 inch CLC block has least cooling load on ground floor. Also, the same combination of wall system has least cooling load. Hence brick wall with 6 inch CLC block is best suited for cooling load.

For HVAC heating load, the wall system with brick wall with 3 inch air gap and 20 mm ply board has least heating load for both ground floor and first floor. Hence, brick wall with 3 inch air gap and 20 mm ply board is best suited for peak heating load.

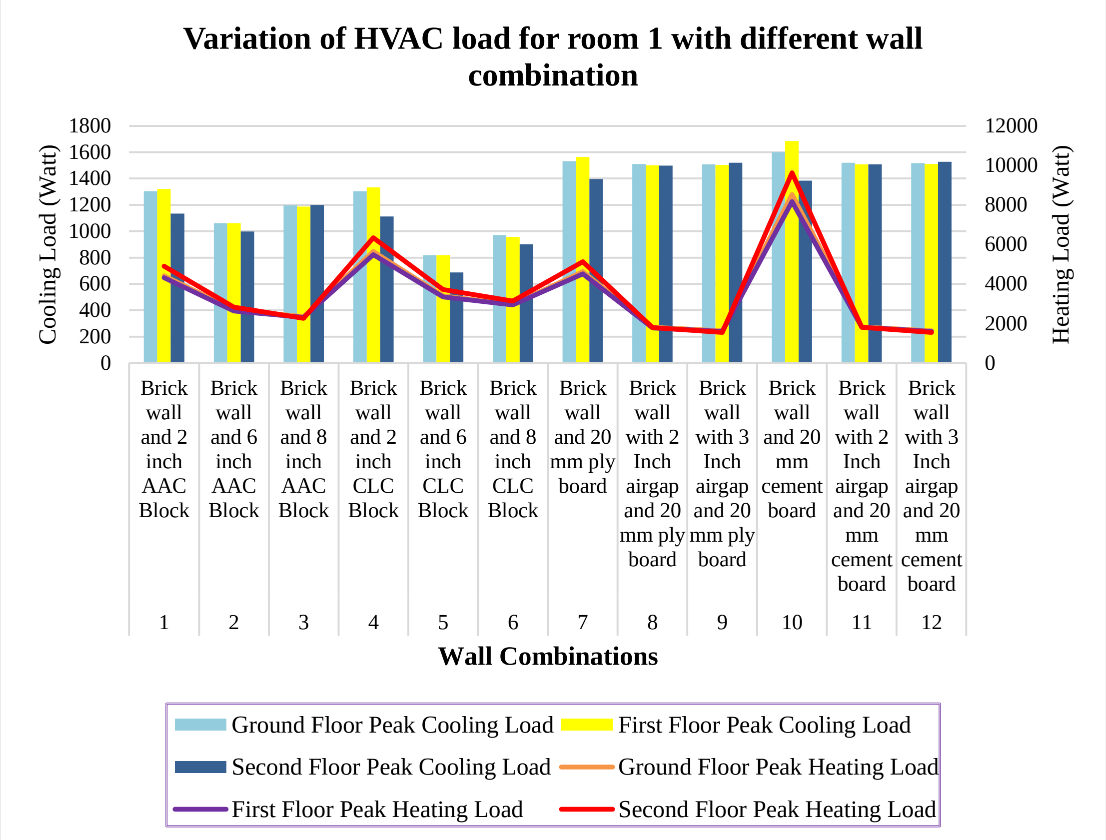

Figure 4.11 Variation of Peak Heating Load and Peak Cooling Load of room 1 in different floor.

Room 1 is situated in every floor of the proposed building ie, on ground floor, first floor and second floor. These room 1 situated in same orientation. From load calculation, wall system with brick wall and 6 inch CLC block has least peak cooling load on ground floor, first floor and second floor.

For peak heating load of room 1, wall combination of type 9 i.e, (brick wall with 3 inch air gap and 20 mm ply board) has least value for each floor. Hence type 9 wall combination is best suited with least peak heating load for room 1 on each floor.

In figure 4.11 for room 2, least peak cooling load is of wall type 6 i.e, brick wall and 8 inch CLC block for ground floor and first floor. For second floor, wall type 3 i.e, brick wall and 8 inch AAC block has least peak cooling load.

Peak heating load value is least for wall type 9 (brick wall with 3 inch air gap and 20 mm ply board) for room 2 of all the floor. Hence type 9 is best suited combination wall type for room 2.

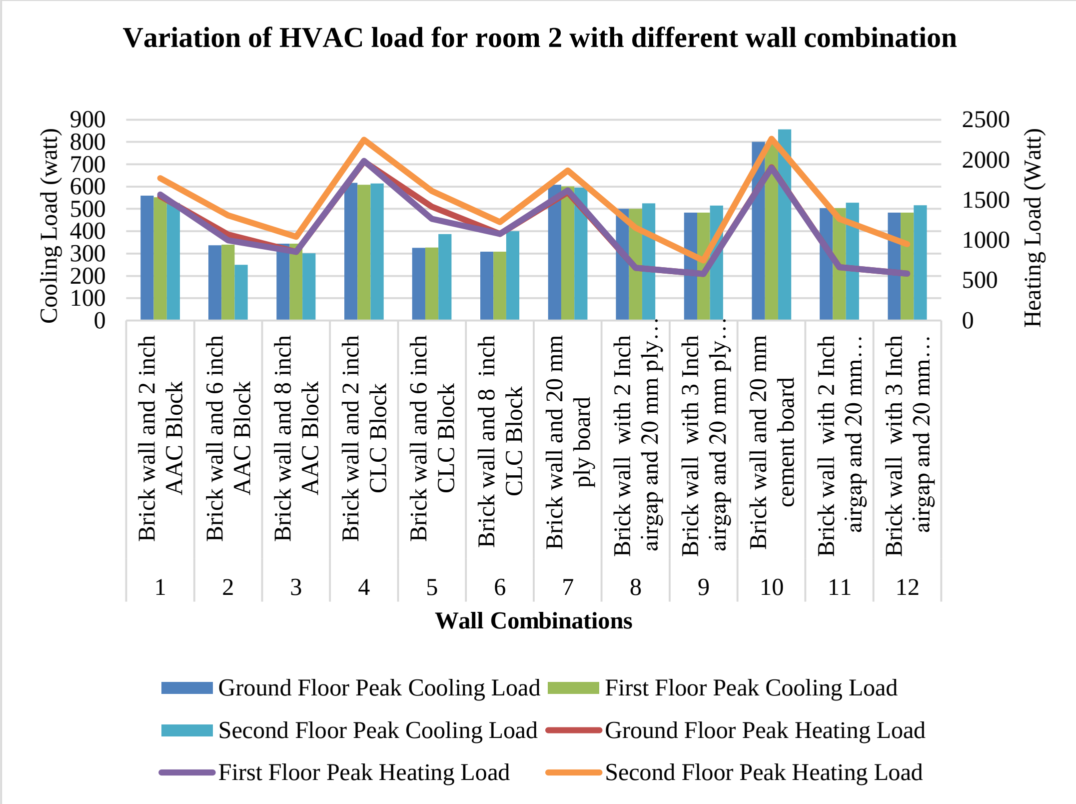

Figure 4.12 Variation of Peak Heating Load and Peak Cooling Load of room 2 in different floor.

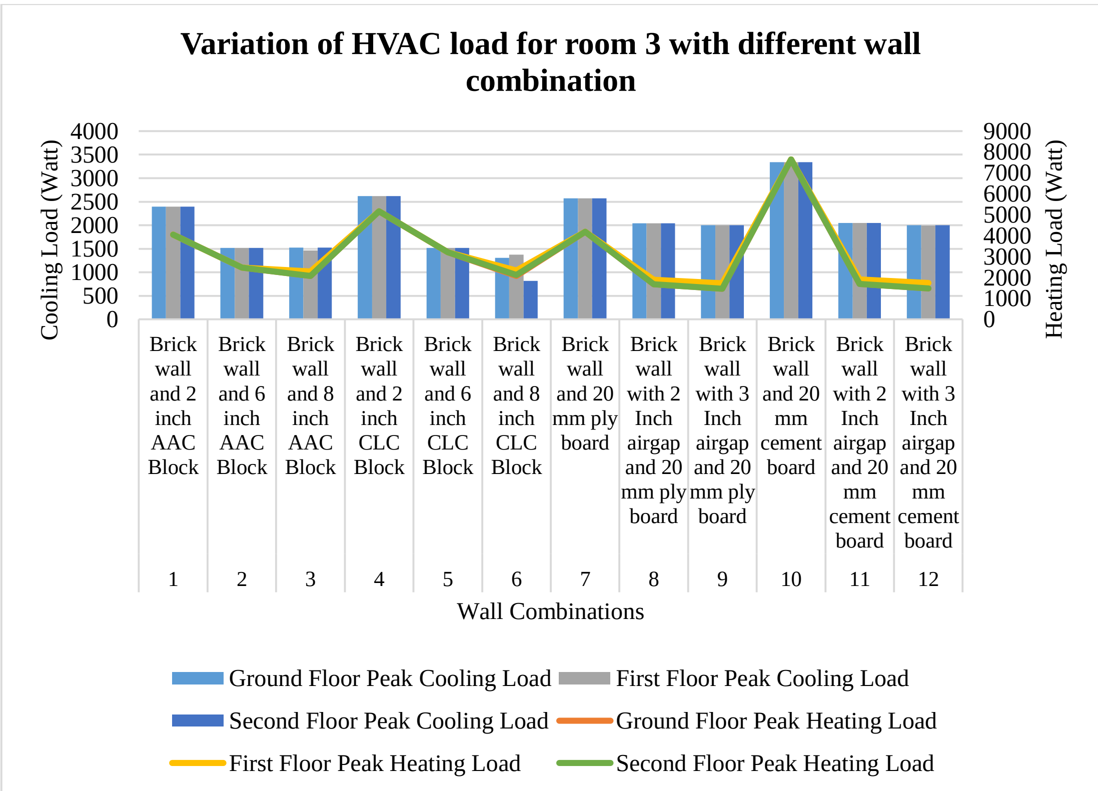

Figure 4.13 Variation of Peak Heating Load and Peak Cooling Load of room 3 in different floor.

In figure 4.13, for room 3, least peak cooling load is of wall type 6 i.e., brick wall and 8 inch CLC block for ground floor, first floor and second floor. Hence type 6 is best suited combination wall type for room 3.

Peak heating load value is least for wall type 6 (Brick wall and 8 inch CLC Block) for room 3 of ground floor. Type 9 (brick wall with 3 inch air gap and 20 mm ply board) wall combination has least value of peak heating load for room 3 of first floor and second floor. Hence type 6 and type 9 is best suited combination wall type for room 3.

4.10 Variation of load with same material with different sizes

AAC block has been varied three times as wall variation. The commercially available sizes of AAC block are 2 inch, 6 inch and 8 inch blocks. Variation with respect to sizes of block has been studied. Same variation has been studied with CLC block. With ply board and cement board as inner wall material, air gap of 2 inch and 3 inch has been introduced in-between to see the variation of HVAC load in each room space of different floor of the proposed building.

4.10.1 Variation of load with AAC block of different sizes

Peak cooling load is least for room 2 of second floor with all type of wall material. Among the least peak cooling load in room 2 wall type with 8 inch AAC block has the least cooling load. Hence 8 Inch AAC block is most suited.

Peak heating load is least for room 2 first floor with 2 inch AAC block, with 6 inch AAC block least peak heating load is for room 2 of ground floor. Wall type with 8 inch AAC block peak heating load is least for room 2 of ground floor and first floor.

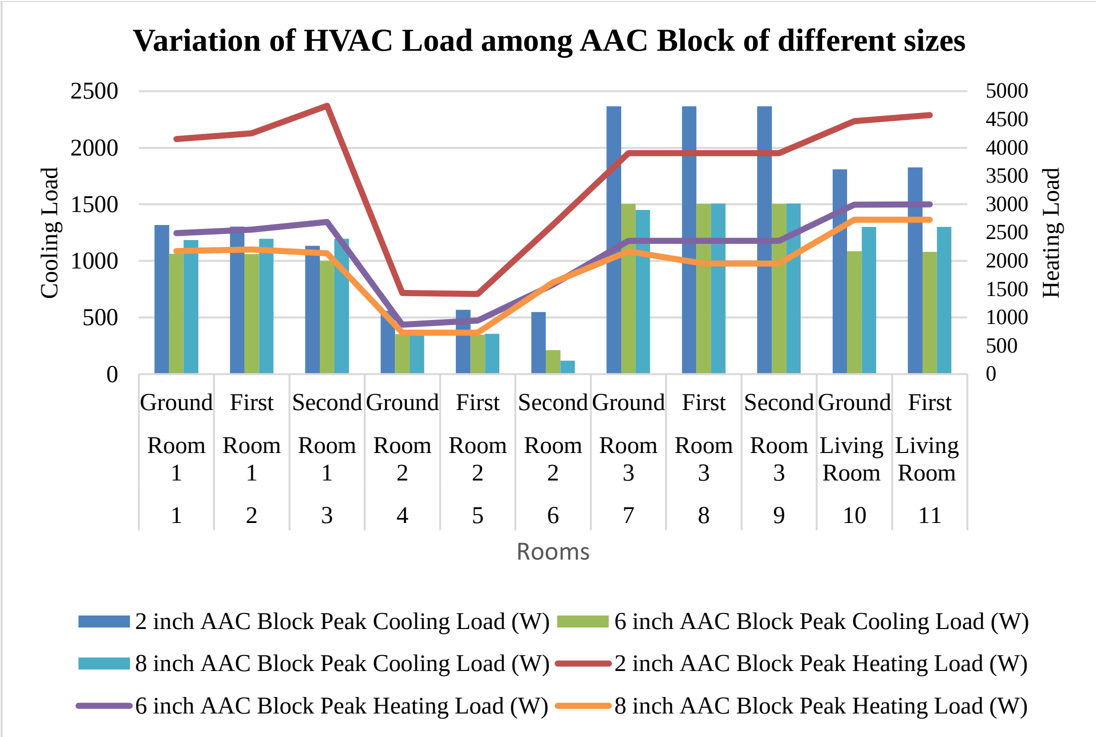

Figure 4.14 Peak Load variation with brick wall type and AAC block of different sizes.

4.10.2 Variation of load with CLC block of different sizes

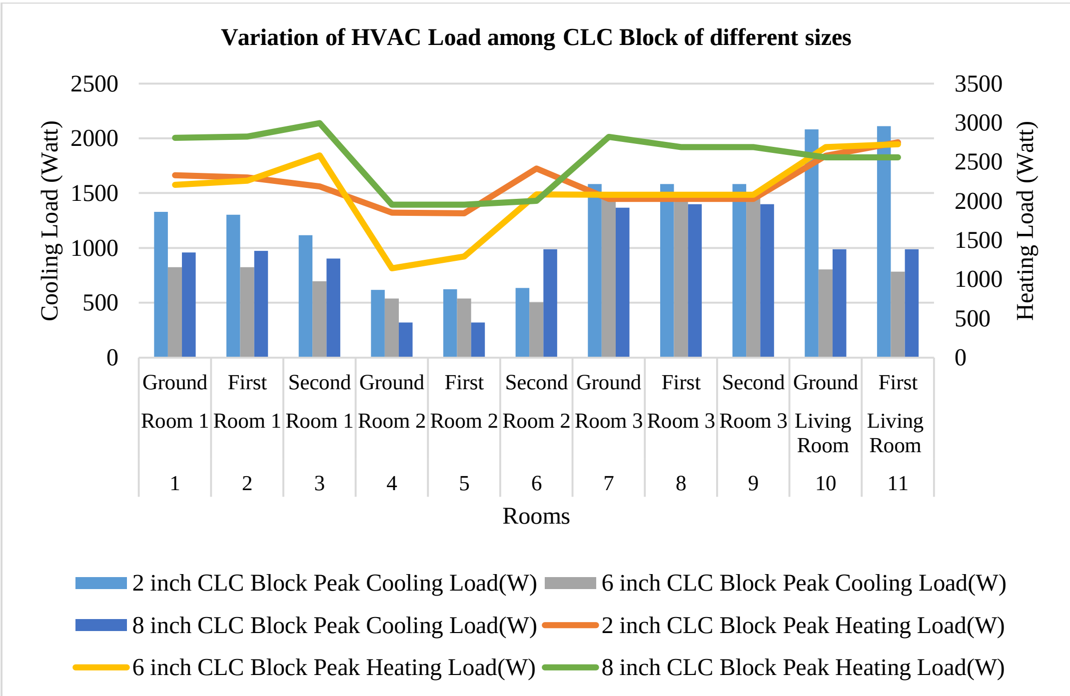

Figure 4.15 Peak Load variation with brick wall type and CLC block of different sizes.

In figure 4.15 with CLC block as inner wall material, peak cooling load is least for room 2 of ground floor with size 2 inch. With size 6 inch CLC block, peak cooling load is least for room 2 of second floor and with 8 inch CLC block least peak cooling load is at room 2 of second floor. Hence the least peak cooling load is with wall type 8 inch CLC block.

Also, peak heating load is least for room 1 of first floor with size 2 inch. With size 6 inch CLC block, peak heating load is least for room 2 of ground floor and with 8 inch CLC block least peak heating load is at room 2 of first floor. Hence the least peak heating load is with wall type 8 inch CLC block.

4.10.3 Variation of load with Ply board with air gap in-between the inner and outer wall

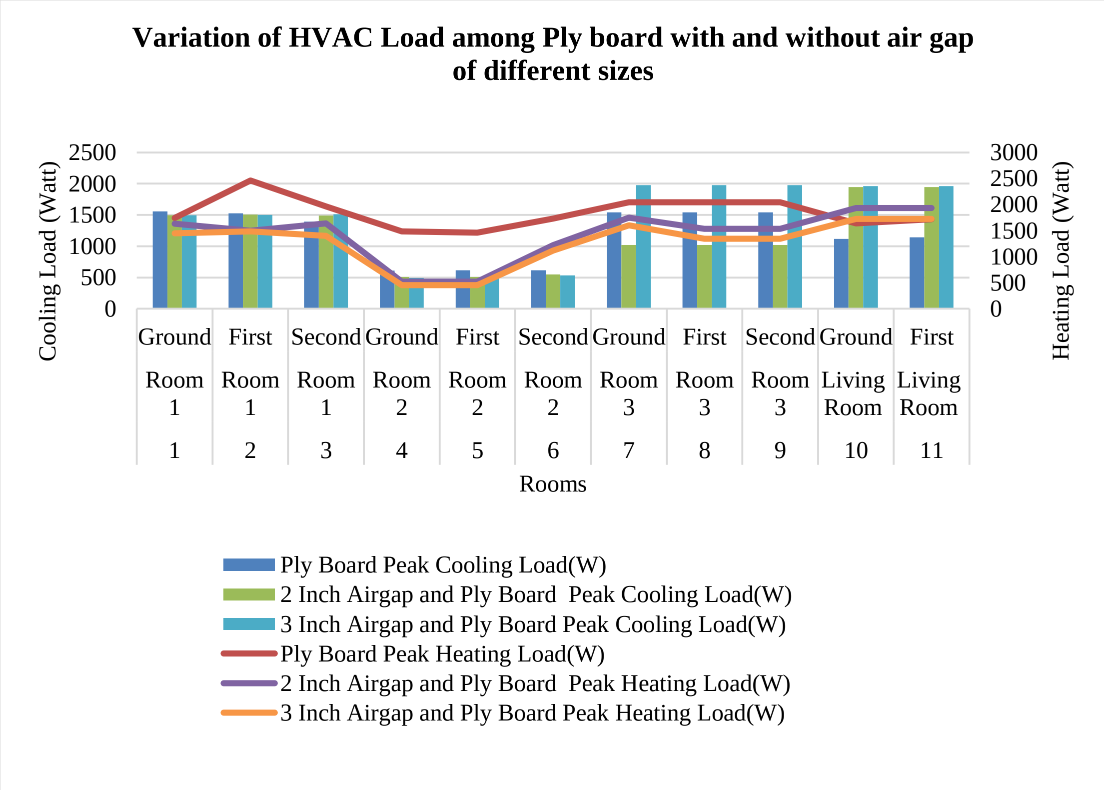

Figure 4.16 Peak Load variation with brick wall type and ply board with and without air gap in-between.

Comparison of peak cooling and heating load has been done among wall with ply board as inner wall. Air gap has been introduced two times with thickness 2 inch and 3 inches. Also, no air gap is introduced between the inner and outer wall. It has been found that the least peak cooling load is bared by wall type with 3 inch air gap and 20 mm ply board as inner wall. Least peak heating load is also bared by wall type with 3 inch air gap and 20 mm ply board as inner wall.

4.10.4 Variation of load with Cement board with air gap in-between the inner and outer wall

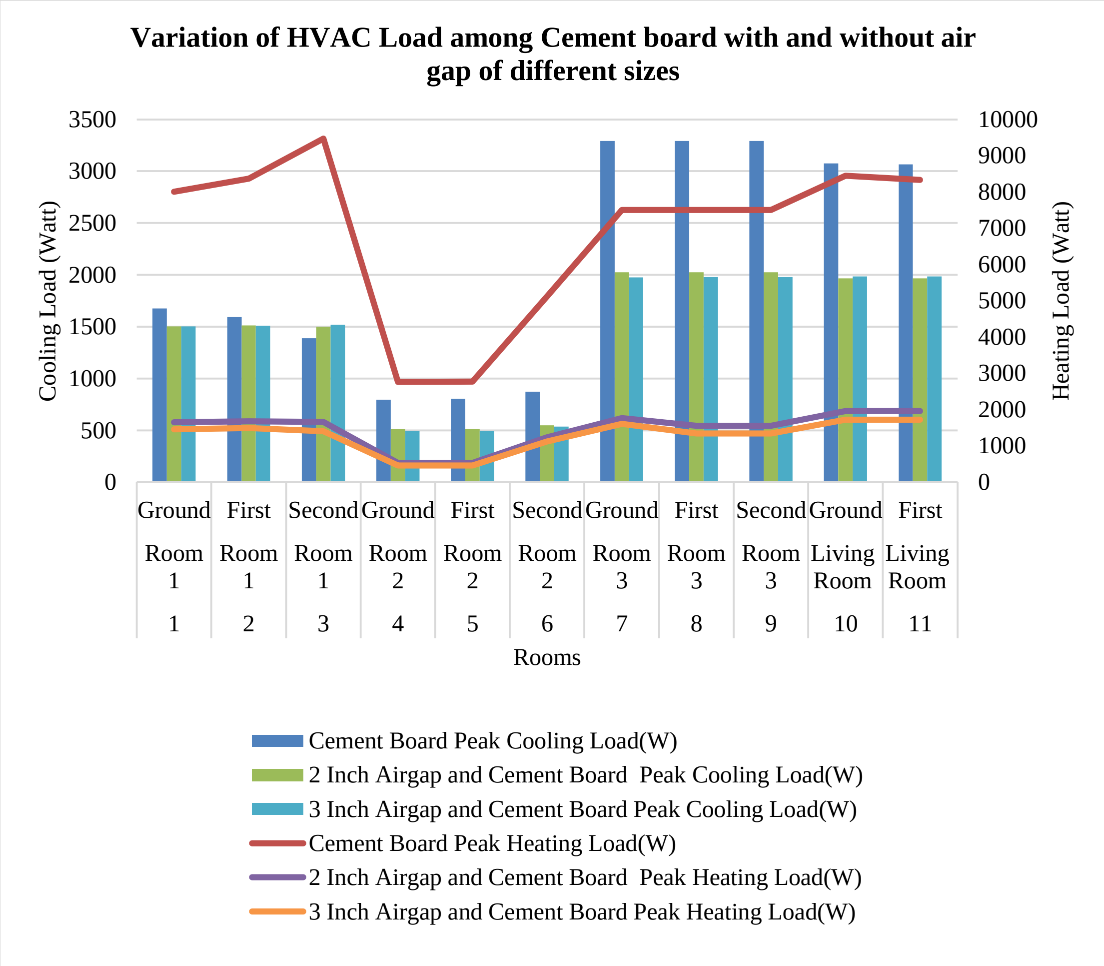

Figure 4.17 Peak Load variation with brick wall type and cement board with and without air gap in-between.

Comparison of peak cooling and heating load has been done among wall with cement board as inner wall. Air gap has been introduced two times with thickness 2 inch and 3 inches. Also, no air gap is introduced between the inner and outer wall. It has been found that the least peak cooling load is bared by wall type with 3 inch air gap and 20 mm cement board as inner wall. Least peak heating load is also bared by wall type with 3 inch air gap and 20 mm cement board as inner wall.

4.11 Variation of HVAC load among AAC Block and CLC Block

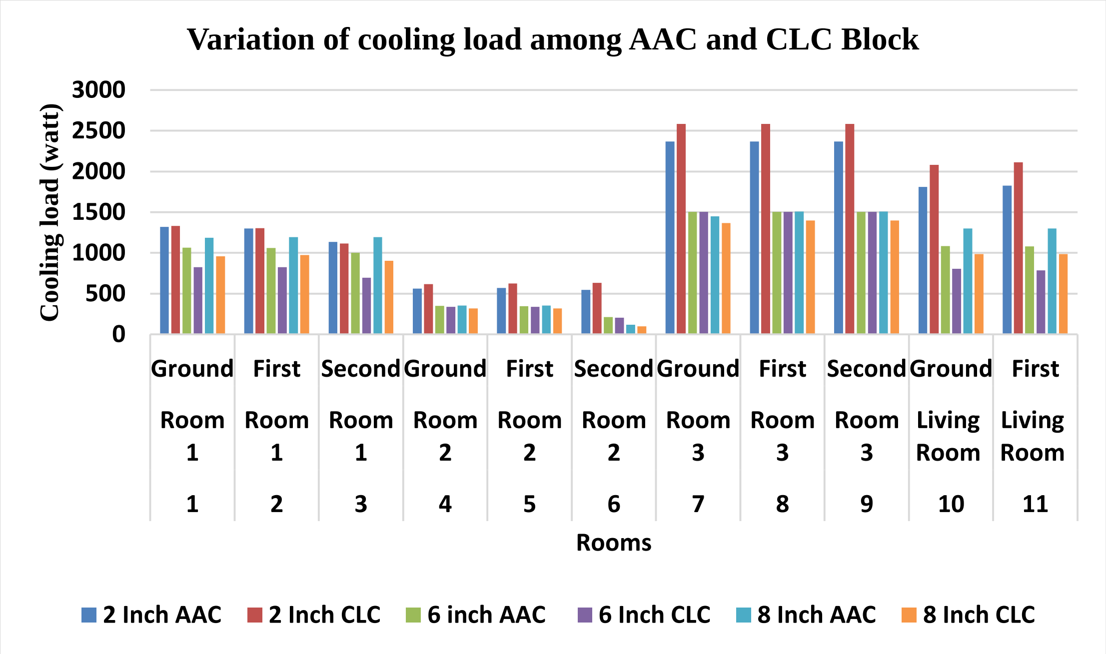

Figure 4.18 Variation of cooling load with variation of sizes of AAC and CLC block wall material.

Above graph in figure 4.18 shows the variation of cooling load with respect to AAC and CLC block of different sizes. From graph for same size of two blocks, cooling load is almost same. Also overall cooling load is minimum for room 2 of each different floor. This is due to the sunlight not reaching room2 as it is faced on northern side and lies in-between room1 and room 3.Least cooling load is for the room 2 of second floor with 8 inch CLC block as inner wall material.

Below graph in figure 4.19 shows the variation of heating load with respect to AAC and CLC block of different sizes. From graph for same size of two blocks, heating load is almost same. Also overall heating load is minimum for room 2 of each different floor. This is due to the sunlight not reaching room 2 as it is faced on northern side and lies in-between room1 and room 3.Least heating load is for the room 2 of ground and first floor with 8 inch AAC block as inner wall material.

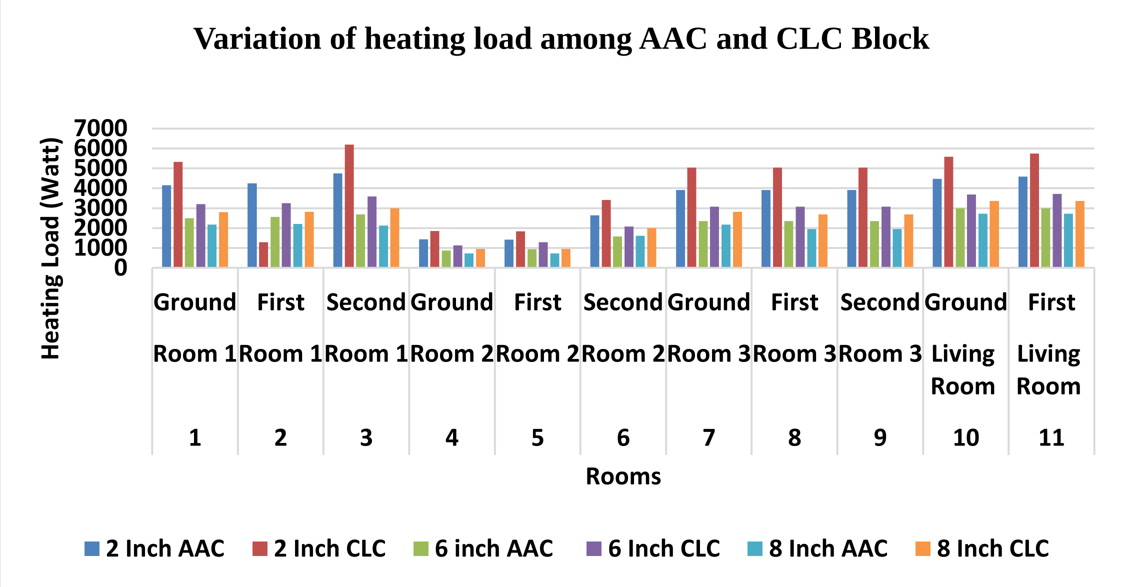

Figure 4.19 Variation of heating load with variation of sizes of AAC and CLC block wall material.

4.12 Annual Electricity Consumption

Electricity consumption in the residential building has been categorized as HVAC usage, lighting purpose and other miscellaneous usage. From the energy consumption breakdown graph from simulation, it has been found that HVAC used the most electricity in the household as it is operated as 24/7 facility.

4.12.1 Electricity consumption with AAC variation of inner wall

From the figure 4.20, it is evident that almost 60 % of the electricity consumption of the household is by HVAC system. Among the AAC block variation, combination wall type of brick wall and 8 inch AAC block has least 61.1% electricity consumption by the HVAC system installed.

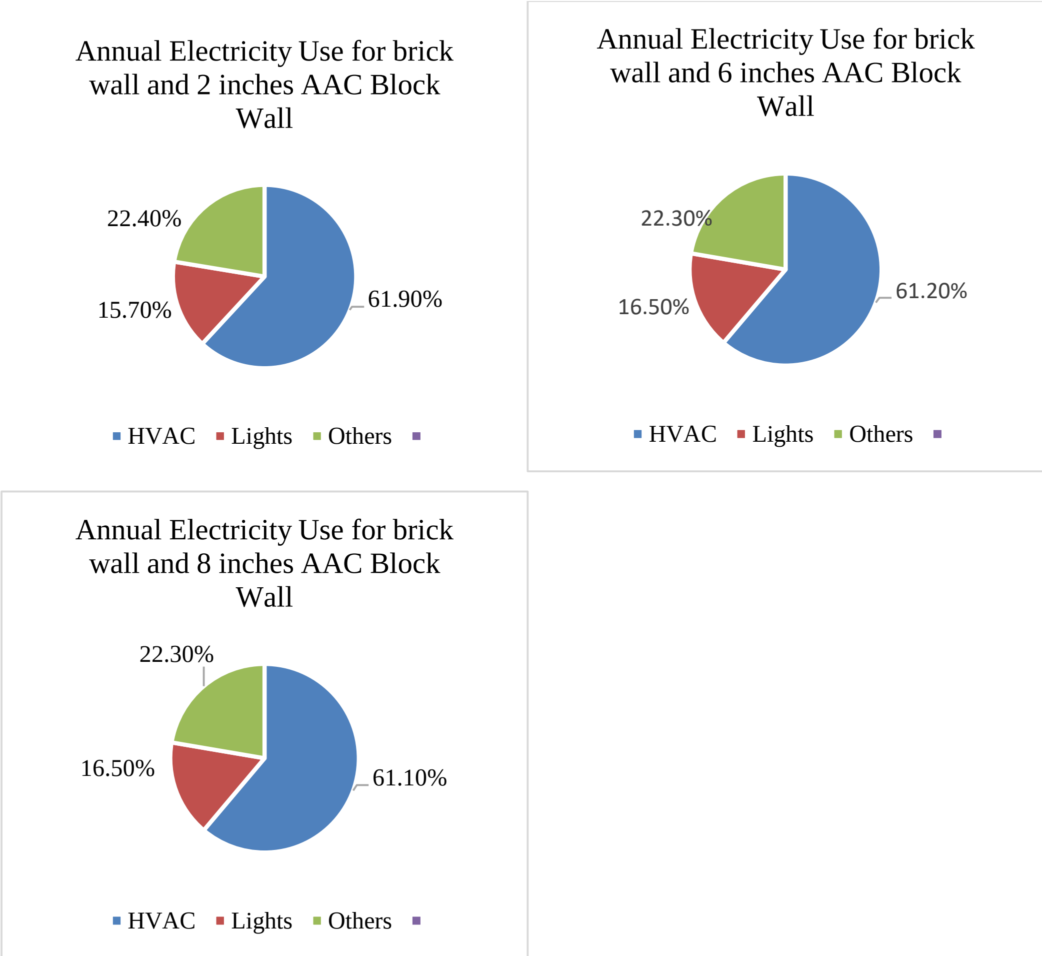

Figure 4.20 Annual Electricity consumption with AAC block Variation as inner wall

4.12.2 Electricity consumption with CLC variation of inner wall

From the figure 4.21, among the CLC block variation as inner wall, combination wall type of brick wall and 8 inch CLC block has least 61.1% electricity consumption by the HVAC system installed.

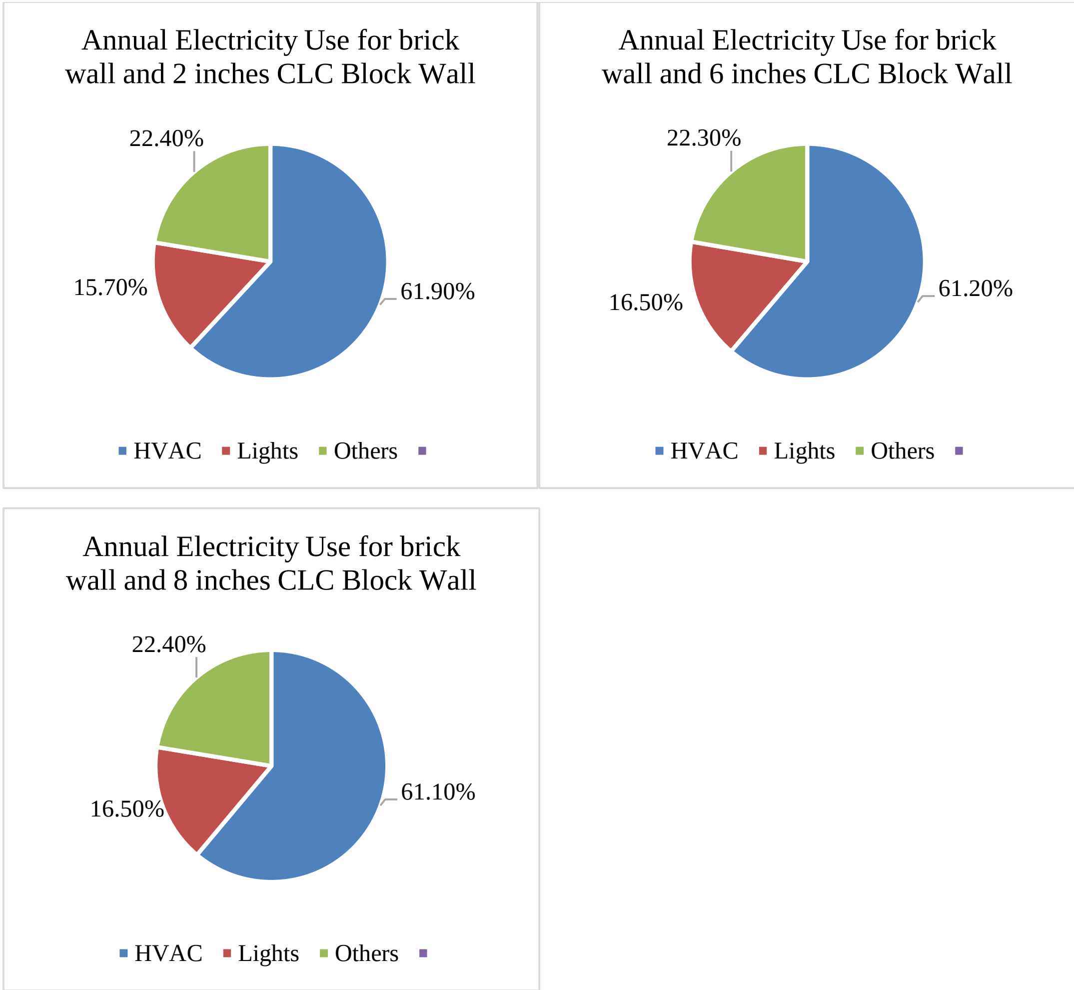

Figure 4.21 Annual Electricity consumption with CLC block Variation as inner wall

4.12.3 Electricity consumption with Ply Board variation of inner wall

From the figure 4.22, among the ply board variation as inner wall, combination wall type of brick wall and 20mm Ply board has least 58.0% electricity consumption by the HVAC system installed.

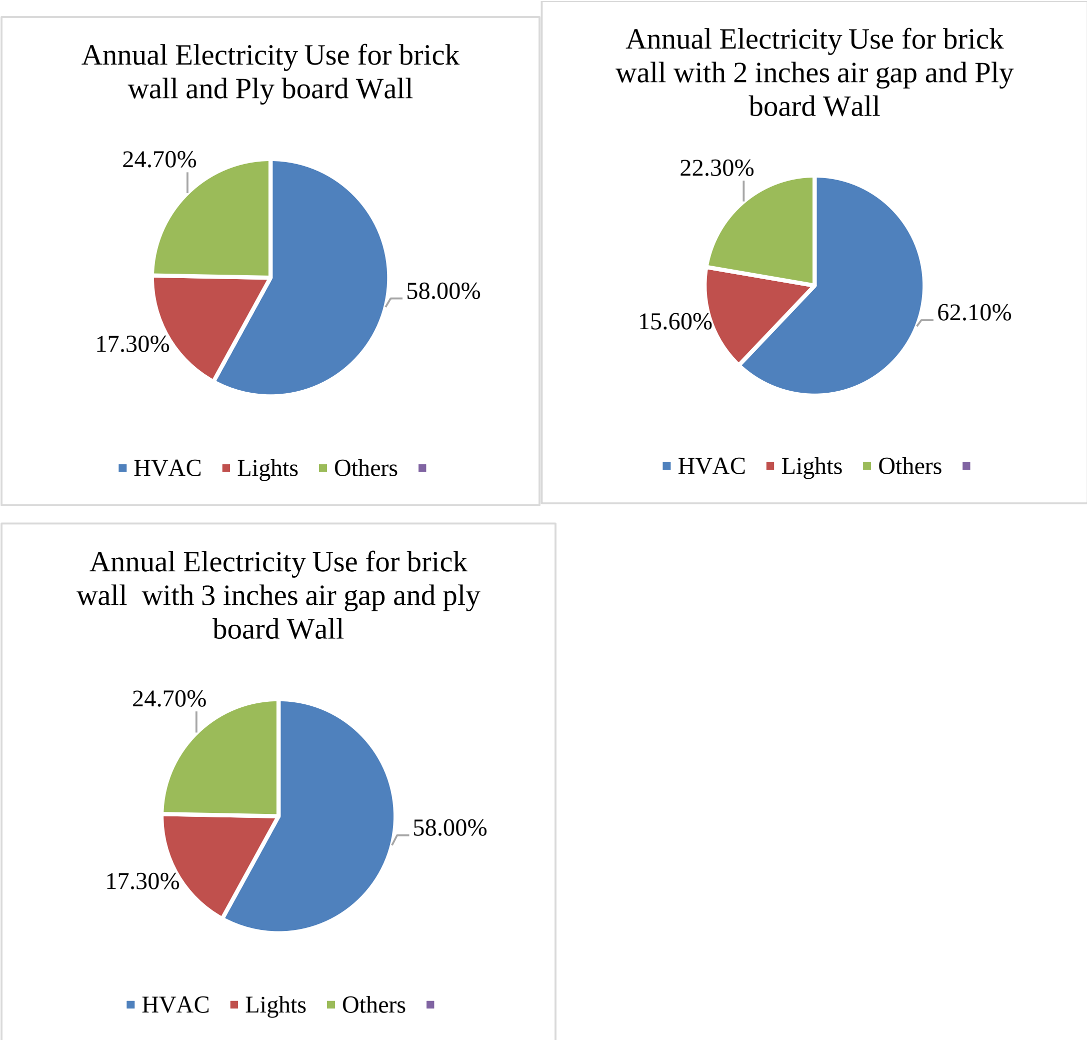

Figure 4.22 Annual Electricity consumption with Ply Board Variation as inner

4.12.4 Electricity consumption with Cement Board variation of inner wall

From the graph in figure 4.23, among the cement board variation as inner wall, combination wall type of brick wall with 3 inch air gap and 20mm cement board has least 61.2 % electricity consumption by the HVAC system installed.

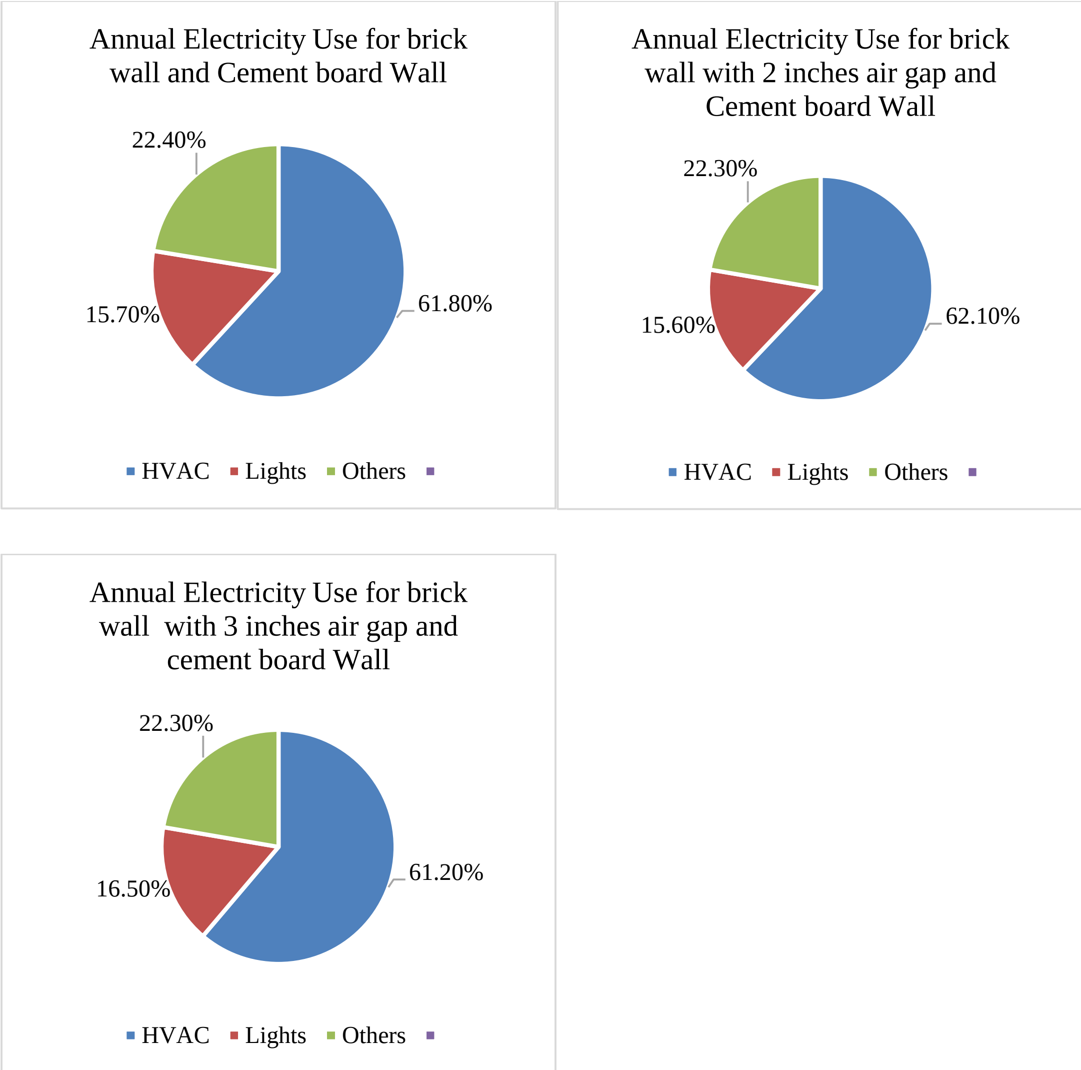

Figure 4.23 Annual Electricity consumption with Cement Board Variation as inner wall

With the comparison of twelve combinations of wall type in the proposed residential building, least energy consumption by HVAC system installed is with the mixed wall type of brick wall and 20mm ply board with 58.0 % of energy consumption.

4.13 Electricity Cost

In the context of Nepal, electricity is used for the operation of HVAC rather than fuel energy. According to Electricity Regulation Commission (ERC), electricity cost allocated differs as per the type of customer. In this study, the type of building being residential. Hence, electricity rate as per the installed capacity of thirty Ampere-meter, average cost per unit has been considered as Rs.10 per unit (www.nea.gov.np, 2021)

For each combination type of wall system, with calculation of peak heating and cooling load cost for electricity for HVAC system operation has been calculated. Assumed utilization of the HVAC system is eight hours.

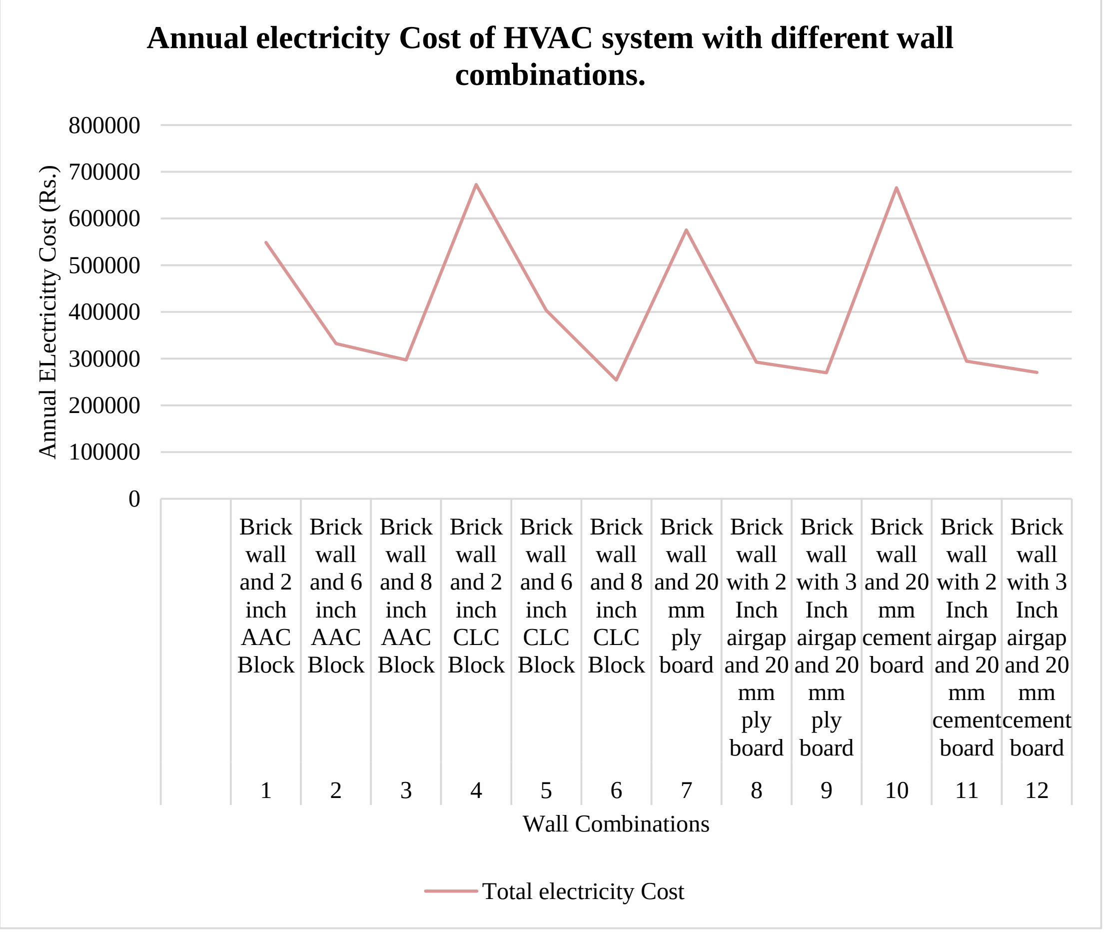

Figure 4. 24 Annual electricity cost of HVAC system of a residential building with different wall combinations.

Figure 4.24 shows the annual electricity consumption by HVAC system with different variations of wall system. From graph, it shows that least electricity cost is of wall type with brick wall as outer wall and eight inches CLC block as inner wall material. Hence residential building constructed with eight inches CLC block is energy efficient for HVAC system.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

Energy efficiency of HVAC systems and thermal comfort is least looked upon criteria while constructing residential building. With study of operation of HVAC during preliminary design phase, one can benefit from energy cost saving, which not only helps in financial burden, also helps in energy saving in this global crisis of energy.

From this study it can be concluded that combination wall type can create favorable indoor condition inside of a residential building which is favorable indoor condition inside of a residential building, which is favorable both in summer and winter weather condition. With wall type of brick wall as outer wall and eight inches CLC block as inner wall can accommodate with favorable indoor condition both in summer and winter weather condition with least utilization of energy consumption and helps with minimum energy cost. Total HVAC heating load with this combination is 18,938 Watt and cooling load is 6,273 Watt with annual energy consumption of 61.1 % of total energy usage. Annual energy cost of this combination is Rs. 2, 53,848.7 which is least of all the combination. Four lakhs rupees can be saved annually with this combination.

Though use of ply board as inner wall with three inches air gap can save overall energy consumption, cost of construction for brick wall, with air gap in-between is expensive and construction of such building is complex. From the study, energy consumption by HVAC system with all type of variation is almost 60 %. Hence minimizing the energy consumption for HVAC system is vital for energy cost saving.

However, wall construction material is not only the determining factor for HVAC load reduction. Other components of building construction such as windows, door type, roof type, infiltration and so on also plays vital role for HVAC load consumption. Study of these building material for accommodating less HVAC load by the building can also be studied to further reduce the load, energy consumption and overall saving of energy cost.

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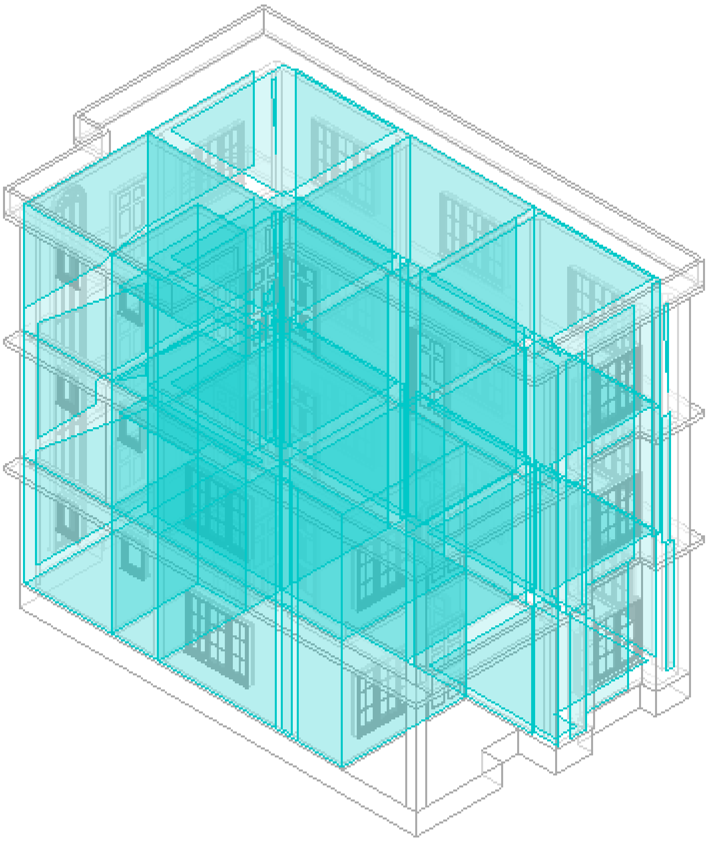
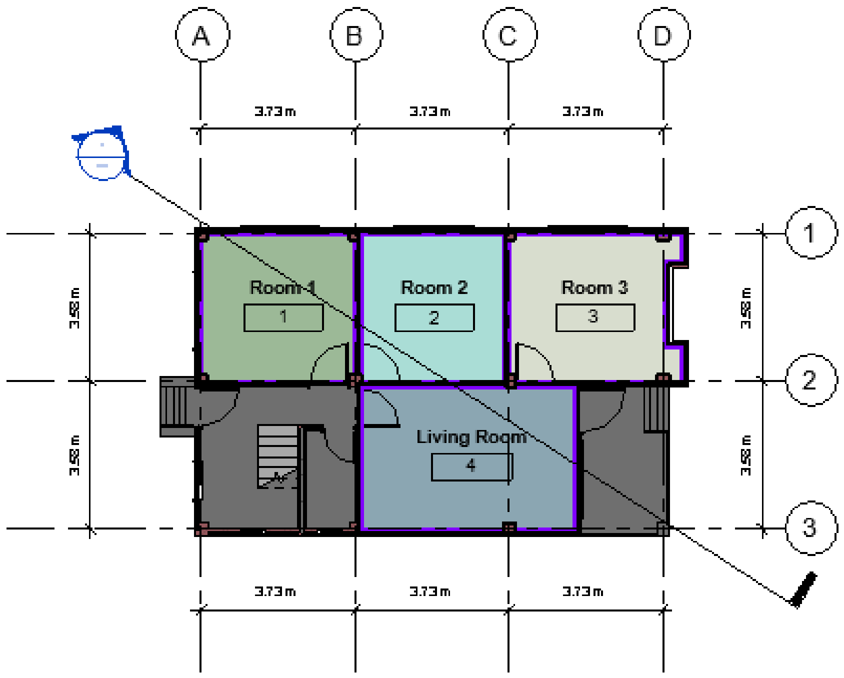
APPENDICES

1. **Analytical model of the residential building created in Autodesk Revit**

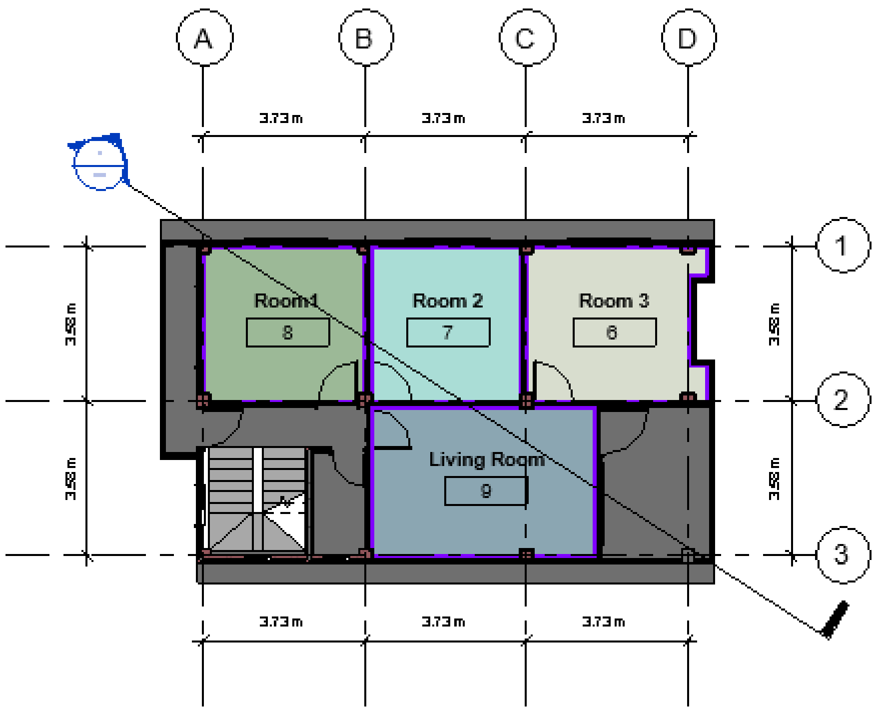


2. Conceptual masses and elements created for Ground Floor



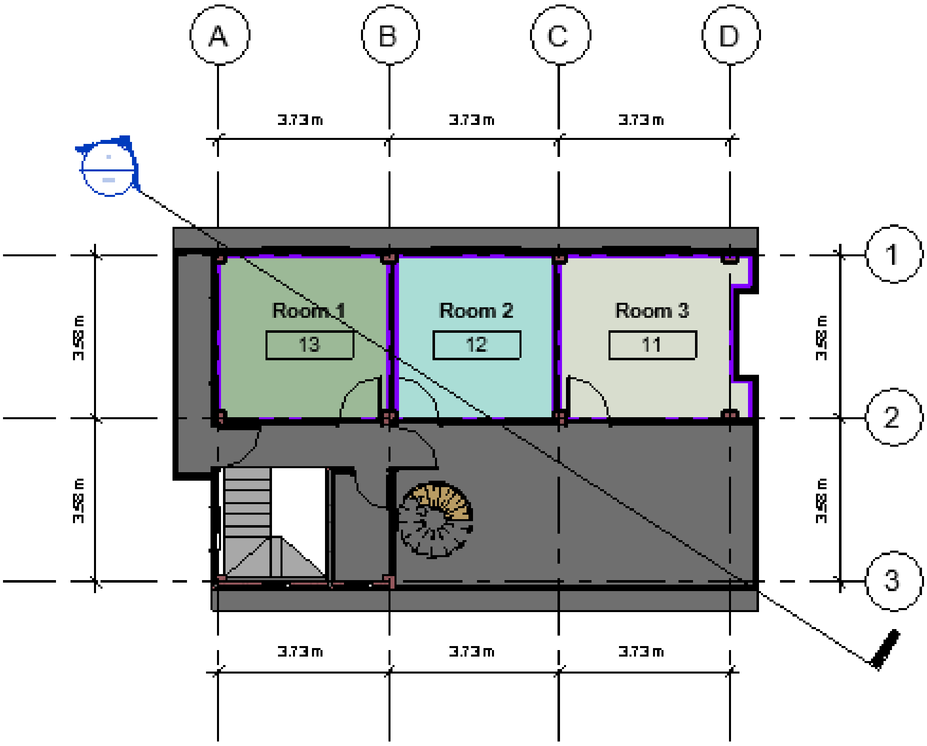
Ground Floor (Spaces)

3. Conceptual masses and elements created for First Floor



First Floor (Spaces)

4. Conceptual masses and elements created for Second Floor



Second Floor (Spaces)

5. Electricity Tariff for the Residential building.

विद्युत महसुल दर

१. ग्राहस्थ वर्ग

१.१ सिङ्गल फेज तल्लो भोल्टेज (२३० भोल्ट)

क्र. सं.	किलोवाट-घण्टाः युनिट (मासिक)	५ एम्पियर		१५ एम्पियर		३० एम्पियर		६० एम्पियर	
		मासिक न्यूनतम शुल्क (रु.)	इनर्जी शुल्क (रु.प्रति किलोवाट-घण्टाः युनिट)	मासिक न्यूनतम शुल्क (रु.)	इनर्जी शुल्क (रु.प्रति किलोवाट-घण्टाः युनिट)	मासिक न्यूनतम शुल्क (रु.)	इनर्जी शुल्क (रु.प्रति किलोवाट-घण्टाः युनिट)	मासिक न्यूनतम शुल्क (रु.)	इनर्जी शुल्क (रु.प्रति किलोवाट-घण्टाः युनिट)
१	० देखि २०	३०	०	५०	४.००	७५	५.००	१२५	६.००
२	२१ देखि ३०	५०	६.५०	७५	६.५०	१००	६.५०	१२५	६.५०
३	३१ देखि ५०	५०	८.००	७५	८.००	१००	८.००	१२५	८.००
४	५१ देखि १००	७५	९.५०	१००	९.५०	१२५	९.५०	१५०	९.५०
५	१०१ देखि २५०	१००	९.५०	१२५	९.५०	१५०	९.५०	२००	९.५०
६	२५० भन्दा माथि	१५०	११.००	१७५	११.००	२००	११.००	२५०	११.००

नोटः ५ एम्पियरका ग्राहकको हकमा यदि मासिक २० किलोवाट-घण्टाः युनिटभन्दा बढी खपत गरेमा १ देखि २० किलोवाट-घण्टाः युनिटसम्मको इनर्जी शुल्क रु. ३.०० प्रति युनिटका दरले लाग्ने छ।

१.२ थ्री-फेज तल्लो भोल्टेज (४०० भोल्ट)

क्र.सं.	किलोवाट-घण्टाः युनिट (मासिक)	१० के.भि.ए.सम्म			१० के.भि.ए.भन्दा माथि		
		मासिक न्यूनतम शुल्क (रु.)	इनर्जी शुल्क (रु.प्रति किलोवाट-घण्टाः युनिट)		मासिक न्यूनतम शुल्क (रु.)	इनर्जी शुल्क (रु.प्रति किलोवाट-घण्टाः युनिट)	
			बाँसाबदेखि कार्तिकसम्म	मङ्सिरदेखि चैत्रसम्म		बाँसाबदेखि कार्तिकसम्म	मङ्सिरदेखि चैत्रसम्म
१	जुनसुकै खपतको लागि	१,१००	१०.५०	११.५०	१,८००	१०.५०	११.५०