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Life Cycle Cost Analysis of External Walls in Residential Building for Temperate Climate: A Comparative Study of AAC and CSEB block

by

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A THESIS

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Life Cycle Cost Analysis of External Walls in Residential Building for Temperate Climate: A Comparative Study of AAC and CSEB block"** submitted by Luna Shah Thakuri, in partial fulfillment of the requirements for the degree of Master in Technology and Innovation Management.

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ABSTRACT

The use of green building material is one of five design principles proposed by UN Habitat in the year 2013 for Nepal. The construction industry is rapidly evolving and has surmounted difficult economic and technical obstacles in recent decades due to high cost. Operational savings of buildings can be recover the initial construction cost is still a debatable topic. Nevertheless, the implementation of sustainable building practices is still at its lowest edge.

This paper aims to empirically examine the above question by conducting a life cycle cost analysis of residential building that utilizes green building material by evaluating the Life Cycle Costs, Construction Costs, operational cost, Residual and maintenance cost for AAC, CSEB solid walls of a single family detached house in Tokha Municipality within a 60 years perspective for temperate climate. Preliminary Bill of quantity (BOQ) was prepared to estimate the amount of material that will be used to construct the base house according to 2019 market Prices. Activity Based life LCC model was used to calculate the Life cycle costing. Autodesk Ecotect Analysis software was used to calculate total heating and cooling load and later converted into operational cost. Lastly, the total initial cost of construction was transformed into life cycle cost model in spreadsheet. Detail Financial analysis was conducted to determine the economy of residential building. And finally alternative wall system was proposed.

It was found that the LCC, CC of residential buildings are NRs (Nepalese Rupees) 483.13/m^2 and 420.06/m^2 respectively for conventional external solid walls with no significant influence on operational cost. The result shows that construction cost contributed to 69% to 75%, maintenance cost contributed 0.03% to 0.43% while repair and reusable costs varied from 0.08% to 0.04%.Similarly, for AAC solid walls it was found to be 478/m^2 with initial construction cost at 74.41% and CSEB solid walls it was 539.18/m^2 with construction cost contributing to 65.54%.Also the NPV of CSEB block masonry is less than AAC block walls by 46 %.

Keywords: *Life cycle cost, Alternate walling material, solid walls.*

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LIST OF ACRONYMS AND ABBREVATION

AAC	Autoclaved Aerated concrete
BTU	British thermal unit
CSEB	Compressed Stabilized Earth Block
GDP	Gross Development Product
WLC	Whole Life Cost
LCCA	Life cycle cost analysis
LCA	Life cycle analysis
LCC	Life cycle cost
NPV	Net present value

CHAPTER ONE: INTRODUCTION

1.1 Background

The design and constructing new house can be resource-intensive as well as economically challenging decisions to be made. Nepalese residential buildings built since 1992 follows building code of Nepal (NBC) guidelines to achieve minimum performance requirements (Prajuli, 2000).40% of population is accounted for urban population in Nepal after addition of municipality in 2015 , the urban population now accounts for 40 %. When Nepal faced an earthquake of 7.8 Richter scale magnitudes on 25th April 2015, the earthquake destroyed 498,852 and damaged 256,697 numbers of houses and According to Post Disaster Need Assessment there will be a requirement of 609,938 numbers of new houses (Authority, 2016).

These migrated people are not able to afford the housing in large urban centers due to high cost in land prices. The household sector utilizes 87 % of total energy (Malla, 2013). Nepalese construction industry contributes 10 to 11 % of nations GDP and utilizes 35 % of government budget in which 60 % is spent through infrastructure development (Baral, 2009). Construction is a major productivity enhancement sector that can influence overall national economy.

Table1.1Housing types % in Nepal (CBS, 2011)

Type of Housing	Percentage	Amount
Permanent (Pakki)	27.81	1509333
Semi -Permanent(Arda-Pakki)	25.15	1364966
Temporary (Kachhi)	44.46	2412978
Other	2.58	140024
Total	100	5427302

Building construction dates back to 2550 AD in Nepal, with palaces, canals built out of masonry system. Adobe wooden framed and rubble stone masonry constructions are found in rural areas of Nepal, meanwhile most of urban and suburban’s used stone or brick masonry with 20 % reinforced concrete construction. So, it can be concluded that 80 % of the buildings implement poor construction technique even though they are urban areas (Gautam, 2016).

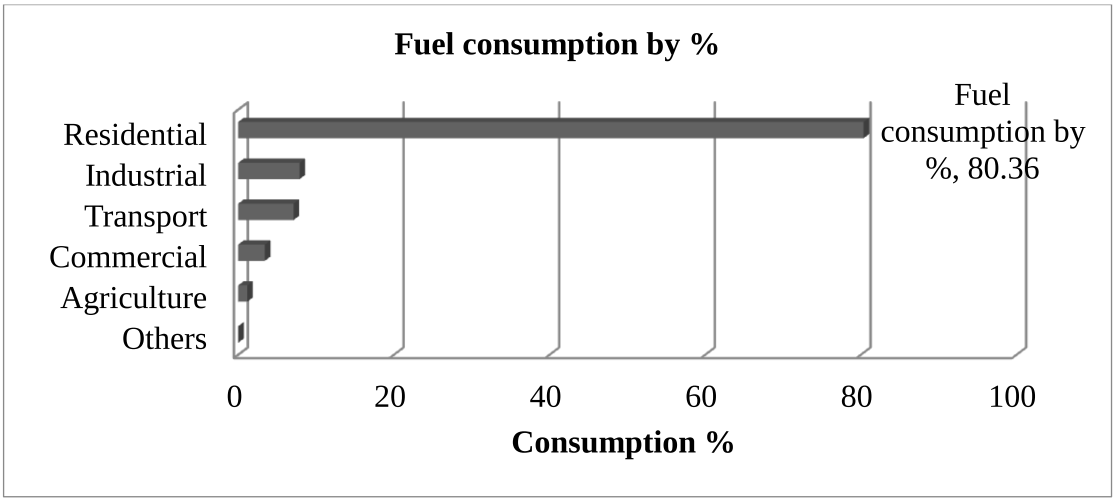


Figure 1.1 Consumption Situations by residential sector in Nepal from 2011/2012 (Singh et al. (2017))

After the oil embargo in the fall of 1973, people paid more attention on energy, fuel consumption. Different energy saving techniques, energy efficient alternatives were searched on (Pierquet, 1998). As a result, energy codes were made mandatory for efficient new home construction.

Consumption of material goods are expected to double from 2017 to 2060 AD. It can be concluded that economic growth by consumption of material goods is no longer a viable option (UN DESA, 2019) .Tanuj (2016) reported that use of cost effective building materials he in reduction of overall cost of the project and aid to minimization of the energy footprint. Initial high cost seems to be the hurdle in adoption of green building techniques. It was found that it cost nearly three dollar to nine dollar more to build a green building, in comparison to conventional building.

The building assembly varies from one geographical location to another (Agyekum, 2014).The buildings so constructed are built to cater to the needs of the external environment conditions and meet their desired level of functionality. In order to understand how these materials work, energy flows within them and the cost related requires a better understanding of application of industrial tools (Keoleian et al., 2000).

Due to lack of reliable data on operational costs have become a very crucial gap that needs to be overcome for better adoption of LCC technique in the construction sector (Wong et al., 2010). 74.96% of the households has 3 to 6 members (NRB, 2015). In

Tokha Municipality, 74% are mixed buildings built from 2001 to 2011 (CBS, 2011). Also Mixed used residential buildings accounted for 86% of all permanent structure with 38% with 3 or more storey according to building typology and researching on the mixed used residential buildings is meaningful.

The scope of this work enables investors and stakeholders to identify the optimum material solution to achieve the desired level of functionality and thermal comfort, As there is growing need to ensure sustainable construction with cost-effectiveness.

With change in design parameters, the cost analysis model changes as well, which establishes a relationship between cost and the design components. There are many empirical methods to calculation of such LCC. In this thesis Activity based Life cycle costing technique is used for assessment. The ABC model was chosen because it thoroughly analyses each cost meters and its uncertainties associated with it, projecting nearly true cost, which should be the basis for alternate design selection.

Due to different design condition, there are software's which are used to find the LCC of building and are sensitive to parameters like discount rates and inflation n rate. For the sake of this study I have computed all the data's in spreadsheet and Ecotect.

1.2 Problem statement

In the urban areas of Kathmandu, it is estimated that 11 percent of existing building stock are built by contractors. (Dixit, 2004). According to Post Disaster Need Assessment there will be requirement of 609,938 numbers of new houses (Singh et al., 2017). National Recovery Framework recommends reconstructing the private houses following both "sustainability" and "disaster resiliency" criteria. Disaster resilient house ensures the safety during another earthquake while sustainable house ensures that a house fulfills the socio-cultural needs without excessive exploitation of environmental and economic resources. With rapid urbanization of 7 % the land prices in the Kathmandu valley is likely to soar followed by more compact design of mixed used residential buildings with attached external walls? These are walls that are non-load bearing i.e. doesn't support floor roof loads above, which can be built lighter and livable without endangering the safety of the building.

Brick masonry is one of the oldest construction technologies for at-least seven millennia and will continue its legacy in existing architecture as a desirable, architectural choice in many locations. All the reinforced concrete framed construction in Nepal has heavy brick infill (Adhikari et al., 2015). With sustainability index of 0.23, it was found out that brick is most socio-cultural sustainable wall material. (Singh et al., 2017) .Without compromising the socio cultural index of the brick and workability these non- functional walls can be replaced with more workable and cost efficient conventional masonry blocks ,as production of bricks is resource-intensive.

Thus, checking the effectiveness of the conventional blocks along with other alternative block material will yield beneficial results both for users of the housing facility, and also for the economy of the country, i.e. if we consider housing sector based on construction material related expenditures

1.3 Research Gap

Shelter for all is a challenge to be overcome by all the developing countries (Tam, 2011).Post 2015 Earthquake Nepal is facing a shortage of 609,938 numbers of new houses (Singh et al., 2017) . But the soaring land prices and migration has made a difficult reality for the inhabitants to owning a house. So, there is need to understand to adoption so proposed innovative and environmentally friendly techniques for proper economic feasibility.

Nepal Building Code NBC 205 1994 recommended studies on alternative building materials and techniques along with seismic and risk hazard assessment (Parajuli, 2000). However, development of efficient building technology in Nepal is still lagging because of the lack of reliable construction data. Unlike public buildings, residential construction sector is affected by geographical place, climatic condition, income and socio economic values and this cannot be changed. Optimum cost efficiency must be determined to symmetrically align with building energy cost for proper assets management and investment decision .Thus the researcher recommended that there is a need of LCC analysis for innovative material selection and safer building practice.

Shrestha (2019) reported that CSEB and AAC blocks were the most efficient material as these had the lowest embodied energy and low carbon emission in manufacturing and construction phase. While The simulated results showed that 9 inch brick masonry consumed less energy for heating and AAC block of 8 inch thickness consumed less energy for cooling whereas 6 inch thick CSEB block higher energy for both heating and cooling making CSEB block highest consumer of operational energy. Further based on physical comparison AAC being the lightest in weight out of both Brick and CSEB blocks, with high thermal transmittance and conductivity value will help in reducing the dead load of the building. The researcher recommended that AAC and CSEB blocks could be a viable option for construction of Residential building and further life cycle cost based analysis should be considered.

Shrestha et al. (2017) reported that the actual average family size is approximately 3.7-4.5 persons per household. By investigating relationship between building materials and indoor thermal environment, affordable housing is commonly considered on a cost basis. On the basis of these findings, the study recommended 8" thick HCB and CSEB as alternative walling materials and RCC filler slab and ventilated CGI roof with plastic bottle insulation as alternative roofing technology for indoor thermal comfort. Further the author added that a social and environmental benefit also needs to be accounted for when calculating life cycle cost assessment.

Further Shrestha et al (2017) reported that 54.6% agree to live in a house that did not required appliances for heating and cooling and can be lived by achieving its own thermal comfort. NPV a typical contemporary house is 1.75 times more than the passive house which has thermal insulating materials, which is again 2.62 times higher than passive solar home. The researcher recommends to thorough financial analysis of such proposed design.

Singh et al. (2017) reported that sustainability score of stone is 0.278 while that of CGI sheet is 0.244.Further the socio-cultural sustainability of brick is 23% and stone has highest environmental 33%and economic score 29% among wall materials. For roof materials, CSEB roof, Clay tile have highest socio-cultural sustainability score of 41% , environmental score 33% and economic score 27% respectively.

Lakhe et al. (2017) concluded that the goal to achieve efficient zero energy buildings for energy efficiency is hindered by cost and the optimal cost effective energy saving strategies for a particular location should be calculated. .Automated optimization tools can evaluate individual energy measures and determine the marginal accompanied by uncertainties analysis for various options to incorporate it as optimum design strategies.

Sthapit et al (2006) proposed wall section required for the residential homes in the Kathmandu valley and the comparative rate analysis suggested the so proposed wall section to be cheaper than the existing building wall section. It was recommended that Life time economic analysis of the proposed building be conducted to study cost effectiveness of so proposed section on building life cycle and determine the energy and cost savings in the residential and commercial buildings.

1.4 Objective

The main objective of this thesis is:

Analysis of the life cycle costs of external walls of residence in temperate climate.

The specific objectives are:

1. To calculate and compare the total life cycle cost of external walls made out of AAC and CSEB blocks.
2. To compare financial analysis in terms of Net present value and Simple payback period.
3. To suggest alternative wall section for external walls in residential building for temperate climate.

1.5 Limitations

1. The study is conducted based on available information published in research papers and reports with regard to bricks and AAC blocks with contractors and home owners. And Secondary data's in internet.
2. The study does not include technical details of building components other than wall.
3. The study covers study of only Aerated autoclaved blocks and compressed stabilized earth blocks.
4. The study does not cover embodied energy calculation and water consumption costs and environment benefit cost.
5. The resale value of CSEB was considered null.
6. Only stretcher bond was considered for brick masonry.

The cost of construction is increasing at the rate of 15 % per year due to increase in basic cost of materials such as steel, cement, bricks, timber as well as other inputs including cost of labor (Gangwar, 2016). As a result cost of construction using conventional technologies and building materials is increasing beyond the affordable limits of low income group of people as well as large section of middle income group people too.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction to Life cycle cost Analysis

With increasing demand in economic viability of green building, it is needless to say that construction practices are attracting more and more research. SBI energy (2012) stated that certified green building construction around the world was approximately 70 billion in 2011 and is expected to double. The growing urban sprawl are bound to be followed by compact design and implementation of smarter greener technology either on design, construction technique. What is lacking is the quantitative information of such proposed design. So it has become a necessity to study cost effectiveness and benefit of those context in order to make a decision either to adopt the strategy or not.

Life cycle costing (LCC) helps in calculates the total cost of ownership (OGC, 2003). In Building construction industry, it aids in estimation of total costs that will be invested in buildings systems, components or material. Further, it helps in investment projects as a decision making tool (Flanagan, 1989). A LCC process includes problem identification, development of cost breakdown structure, identification of uncertainties, and application, evaluation of LCC results (NSWT, 2004).

2.2 Life Cycle Cost Analysis

The criteria of sustainability index (refer Figure 2.1) shows that lifecycle cost possesses the highest priority followed by cost for space conditioning i.e. 32 % and 15 % respectively. It was found out that economic sustainability possesses the highest priority among general criteria i.e. 47.5% followed by socio-cultural sustainability and environmental sustainability i.e. 28.8% and 23.7%. Which means economic sustainability is far more important than socio-cultural and environmental criteria for selecting envelope material for private house reconstruction (Shrestha et al., 2017).

LCC study are mostly suitable for building design evaluation based on the availability of alternatives so available in order to achieve required level of output design at given discount rates. The output may be depended upon occupant comfort, safety, building codes. Reliability and sometimes aesthetics also.

Mainly, LCC analysis are suitable for the evaluation of design alternative of building(including occupant comfort, safety, adherence to building codes and engineering standards, system reliability and even aesthetics considerations), but these components will have different costs, lives and discount rates associated with them.

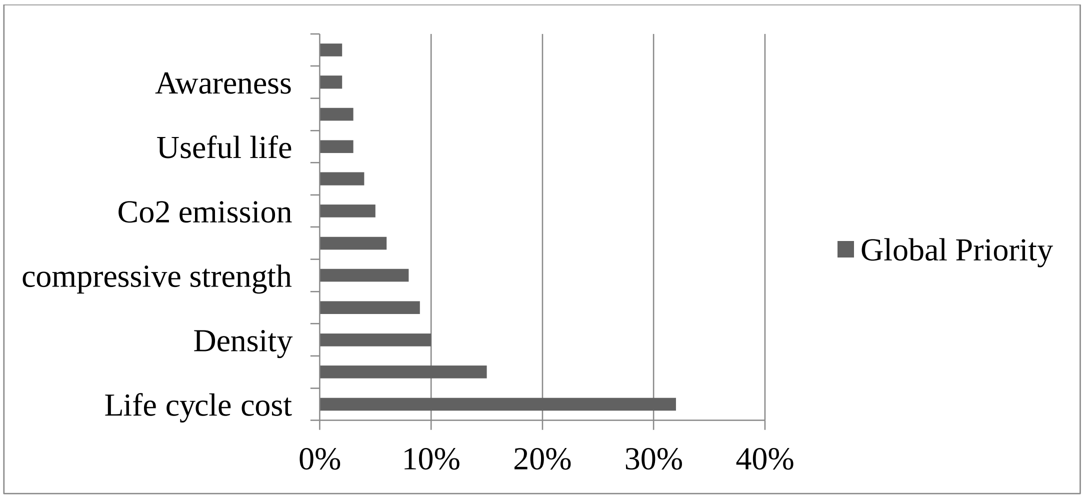


Figure 2.1 Global Priority of all end notes. (Singh (2017)

It can be concluded that LCC are applicable to any kind of capital investment decision that can aid in reduction and recovery of all future cost obligations. (Fuller et al., 1996).

The LCC helps in determining whether the project work so taken into account justify the project from an investors point of view, taking into consideration all the future costs and uncertainties. So it helps in the proper allocation of all the funding into a hierarchy of priorities with a design facility.

2.3 LCC model

Primarily, the LCC model divides the total cost of a product or a system into four categories, namely:

1. Initial costs
2. Production and construction costs
3. Operation and maintenance costs
4. Disposal costs

At first selection a base case is selected for analysis. After which a problematic functional part that needs to be worked on is identified which is followed by a suitable cost breakdown structure is developed. Then alternative for those problematic parts is found. With computational cost model developed. Finally sensitivity analysis is performed for different scenarios. And lastly all the cost are analyzed and the most cost effective part is designed. (Dahlstorm, 2011).

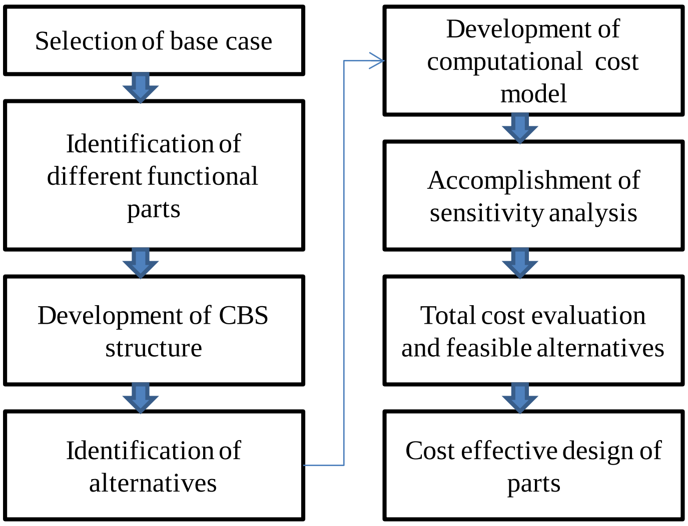


Figure 2.2 Flowchart of the Life cycle cost analysis Durairaj et al. (2002)

2.4 Life cycle cost studies of residential building

LCC in residential buildings were initiated back in the 1960s by the Department of defense, US (White & Ostwald, 1976). According to ISO Standard 15686-5, LCC is the calculation of all the cost which includes construction, operation, annually and non-annually occurring maintenance cost to it end of life cost or salvage value. NPV and Simple pay back periods are the most sought after financial evaluation method of LCC analysis.

Chethana et al. (2018) reported that maintenance cost was 13 % to 29 % and other costs 13% to 45 % for external walls when NPV technique was implemented to study various insulation material for five cities in Australia.

Islam et al. (2015) reported that, construction contributed to 58 -88 %, operational cost 11 to 34 %, maintenance cost ranged from 2 to 20 % and disposal 0 to 2 %. Of the total LCC. The final results were directly depended on the different assumptions made.

Islam et al. (2014) analyzed the alternative wall design systems of a base case house. The life time period of the house was assumed to be 50years, repair and maintenance time was 25years, repainting time 6-25 years, disposal costs were not taken into consideration, with discount rate at 6 %. It was found that 63%, was contributed by construction, 9 % by operation, 26 % by maintenance and 3 % by disposal on total LCC.

(Mitropoulouet al. (2011)) reported that LCC may vary up to 30% so at least 10-20 records on material property and the design variables are needed reliable analysis of LCC

Bostancıoğlu et al. (2008) reported that Brick was the most cost-effective wall body material in terms of initial investment costs but Gasbeton is the most cost-effective alternative in terms of annual operating costs for reinforced concrete frame and load bearing systems. Further alternatives to be constructed with load bearing system has 4,23- 8,49 % lower initial investment costs, 1,18- 4,60 % lower operating costs and 3,51- 6,53 % lower life-cycle costs as compared to the alternatives to be built with reinforced concrete frame system.

Lu et al. (2000) reported that the optimum sustainable choice was to buy a suitable site with new construction when LCC study was conducted on the selection of properties and construction options in Melbourne.

Schade (2007) reported that Net present value, simple payback period and internal rate of return were the most frequently used financial evaluation method. Out of all three NPV was the most preferred one as it gave the discounted present value from all future cost associated with the investment. NPV method was used by Yuksel (2013) to compare the cost effectiveness of bio-gas, solar system .NPV method was used by Morrissey (2011) to study alternate energy efficiency strategy, to compare life cycle costs with environmental savings in Melbourne for a house.

HienWong et al. (2003) reported that the economic benefit of green material can be calculated along with energy costs and be transformed into life cycle costs. Three scenarios were taken into account with Lifetime of 9 years, 40 years and 40 years with maintenance years of 10, 25 and 20 years respectively .The results showed that the life cycle cost was sensitive to discount rates i.e. 5.15 %. It was found that even with or without energy consideration the total LCC was least for green roofs in comparison to the exposed ones even if they had high initial first cost.

Due to lack of valid data and uncertainties on running costs, discount rate, residual value and other unforeseen scenarios, sensitivity analysis need to be performed to analyze how data uncertainties affect the final LCC result (Wang, 2020:). Islam et al.

(2015) studied effect of discount rate by changing it from 3% to 6% and found increase in total LCC. Also, LCC is studied only of building components (Wong, 2010), materials (Yang, 2017:Tam, 2011) and technologies (Horne, 2011:Giuseppe, 2010).

2.5 Locally available building materials

Based on construction materials used. Houses in Nepal are mainly of four category. See table 1.1. The Table shows the distribution of households by foundation of house, most of the urban area is constructed with RCC with pillar i.e. 41.4% and most of the rural areas consist of mud bonded with bricks or stone i.e. 44.9%.Climatic and geographic conditions influence the availability of building material. Finding organic construction material in harsh climate like in the Mountain region is difficult. Due to this reason hard stones, rocks and mud with galvanized sheet for roofing are used. While on the contradictory, due to easy access of roads and infrastructure hilly regions have modern construction practices and materials.

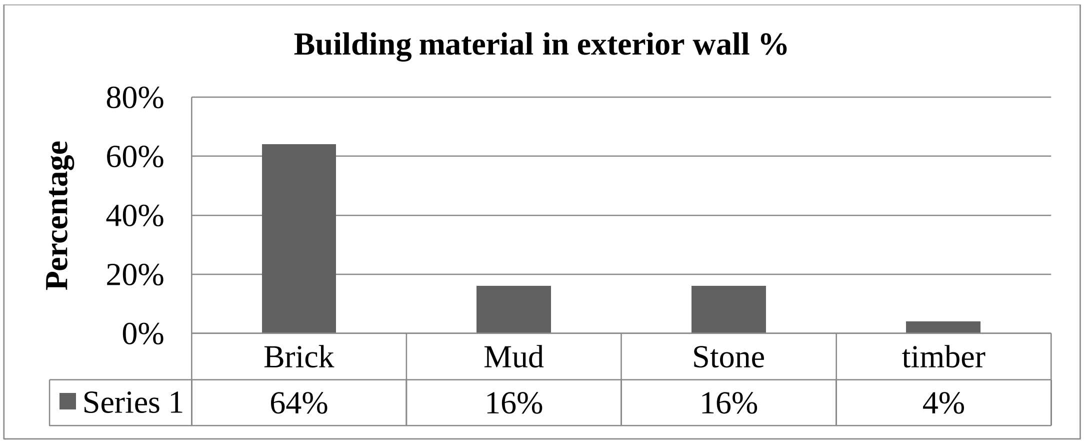


Figure 2.3 Building material used for outer wall (Shrestha et al. (2017)

2.5.1 Selection of wall material

Conventional materials are in short supply because of less production as these cause degradation to the environment. A cost effective alternative materials is necessity of the construction industry. The construction industries in many developing countries like Nepal, Srilanka, Congo in Africa still use adobe, sand, lime, stones for construction (Jayasinghe, 2016).The production process of such raw materials will incur low embodied energy.

High price of the conventional building materials lead to research and development of alternative building materials and systems (Jayasinghe et al., 2005).Compressed stabilized earth blocks (CSEB), Autoclaved aerated concrete block, fly ash brick and clay bricks are some materials prevailing in market and are being successfully used. Brick and stone are indigenous walling materials around the world having many researches done and their heat conductivity are measured. But AAC and CSEB are relatively new construction walling materials in Nepal. For this reason AAC and CSEB were chosen.

2.5.2 Burnt Bricks

Burnt bricks are conventionally used walling material used in Nepal. The manufacturing of brick is done by preparing of clay mix, molding, drying and burning of those sundried bricks. These are rectangular in shapes and do not require any dressing compared to rubber masonry. The size may differ according to the class of the brick (First class, second class and third class bricks).These bricks consists of 20-30 % of alumina, silica 50-60 %, lime less than 5 % and oxide of iron not more than 5 % and few amount of magnesia.

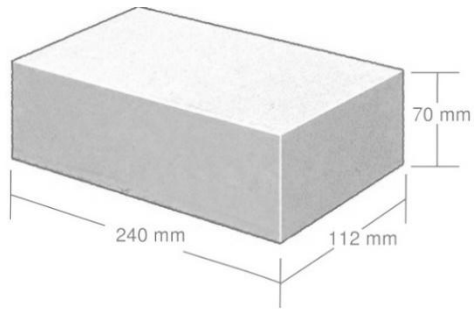


Figure 2.4 Picture of standard size bricks

Table 2.1 Dimension of Standard Nepalese Fire Burnt Brick used in this thesis

Dimension of Nepalese Standard Brick (mm)				
Length	Breadth	Height	Vertical joint	Remarks
240	115	57	10	10mm joint

70 % of the fuel type being used in brick kilns is coal whereas 24 % used saw dust and 6 % used wood and other (Shrestha et al, 2019).The carbon emission during its manufacturing process has lead respiratory and other health effects often leading to death.

2.5.3 Compressed stabilized earth Brick

Compressed stabilized earth block (CSEB) is a mud based building material .It is an internationally recognized earthquake resistant construction material produced by compressing soil, sand and cement in manual machine.

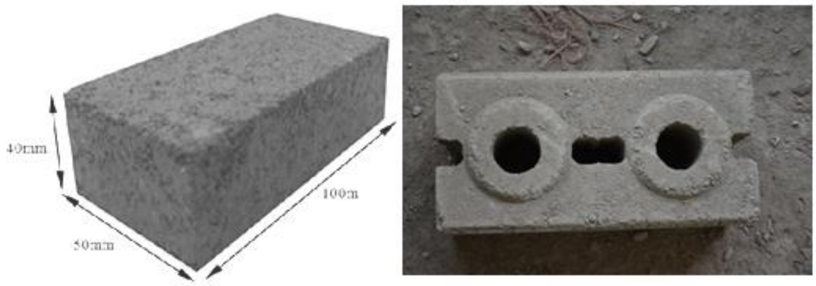


Figure 2.5 CSEB prototype block (Abdullah, 2017)

Table 2.2 CSEB block used in this thesis

Length	Breadth	Height	Remarks
300	150	100	No Vertical joint

CSEB consists of less than 15 % of gravel and silt, 20 % clay, 50 % sand, and 5% cement for stabilization. The mixture are pressed in earth compressive machine which results in a compacted brick. A CSEB has a similar behavioral and mechanical property as concrete or ordinary fired brick (Shrestha et al., 2017).Further, these blocks are earthquake resistant due to reinforcement and these emit 60 % less carbon monoxide compared to the fire burnt bricks (Shrestha et al., 2017).

2.5.4 Aerated Autoclaved concrete Blocks

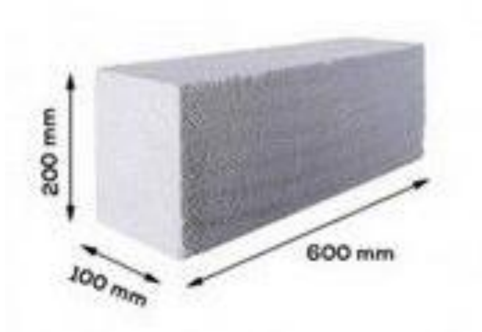


Figure 2 .6 AAC prototype block (construction, 2020)

Table 2.3 AAC block used in this thesis

Length	Breadth	Height	Remarks
600	200	200	-

Aerated autoclaved concrete blocks is a lightweight building product which are produced in variety of sizes and strength (Sudhanshu & Bhatia, 2018).The AAC block was first invented by Swedish architect John Axel Eriksson. The manufacturing process involves preparation of slurry, foaming, cutting and steam curing. AAC blocks are produced by mixing fly ash mix with cement, lime, water and an aluminum that acts as an aerating agent which helps in 2-5 times its original volume. The ratio of Fly ash to lime to cement to gypsum mix is 69 to 20 to 8 to 3with aluminum at 0.08% of total dry mix with water ratio of 0.60 to 0.65. Millions of tiny air pores (50 – 60 %) are formed due to reaction between aluminum and silica forming macro pores, which are cut into blocks of varying sizes and are steam cured for 21 days.

Table 2.4 Comparison of Physical properties of Brick,CSEB and AAC block

Thermal Performance	Burnt Brick	CSEB Block	AAC Block
Size	240x115X57	300x150x100	600x200x200
Compressive Strength	2.5-3Mpa	3-6 Mpa	3-4 Mpa
Density	1600-1800 Kg/m^3	1700-2200 Kg/m^3	550-700 Kg/m^3
Sp Heat capacity	0.61-0.74	0.94-1.10	0.79
Thermal Conductivity	0.81 -0.98w/ mK	0.84-1.3 w/ mK	0.51-0.184 w/ mK
Acoustics at 500 HZ	50db for 230mm	50db for 400mm wall	45db for 200mm

Around 10% to 15% of AAC can be reused for new production as reported by Kreft (2018)**.** The sizes of AAC block ranges from 600x200x200, 600x200x150 and 600x200x100 mm manufactured in Nepal.

Table 2.5 Thermal properties of building material in study

S.no.	Walling Material	K-Value	Energy consumption(MJ/m^2)	Carbon Emission (Kg/m^2)
1	Brick	0.7	539	126
2	AAC	0.24	125	26
3	CSEB	0.7	110	16

According to Goodhew et al. (2005) the lower the U-Value, better the walling material as a heat insulator. From above table AAC is better heat insulator than brick and CSEB block as it consists of lowest U-Value.

2.5.5 Density of Brick, AAC and CSEB blocks

Density of construction materials can be defined as a mass per unit volume of material. It determines the compactness of building material. Higher the density more compacted the material. Lower dense material occupies more volume .Brick have the highest density at around 2000 Kg/m3. CSEB has density at 1800 Kg/m3.These are highly dense so low volume occupied resulting in late construction completion and no. of blocks required may be high. Whereas, AAC have density at around 500-600Kg/m^3 .These are less dense but high in volume so construction is rapid and may take less time in completion of work.

Density value of construction material helps in finding out amount of material needed in a particular space. Brick having the highest density will require high amount of mortar which is balanced out by frogging. CSEB on the other hand have two holes of 50mm diameter which will also balance out the amount of mortar required. And lastly AAC being the least dense material requires less mortar in construction. At the end, the amount of mortar require for brick, AAC and CSEB are balanced out.

But the density of blocks alone does not determine the economic feasibility and construction process. The availability, use of local material and indigenous architecture of the selected site highly influences the building envelope. For that U and K value of material needs to be calculated.

2.6 Relation between building envelope and operation cost

Building envelope is the structural barrier between the external and indoor climate in construction, working together to provide a better thermal comfort. And with precise design of it, indoor heating and cooling objectives can be improved .With all this, identifying the energy consuming building components is necessary to reduce building energy consumption.

The thermal performance influences the annual energy consumption, therefore helps in determining the consumed operating costs for building heating, cooling and humidity control. It stimulates peak loads that determines the size of opening and thickness of walls that helps in determining investment costs

2.7 Analysis Tool

2.7.1 Analysis tool-Ecotect

It is a tool that helps in the calculation of building performances by simulating different environmental conditions with reference to the geographical location of the so proposed building. It takes into buildings earliest toil conceptual design considerations. The user is allowed to import 3DS and DXF files to carry out the simulation. This software can analyses climate data files of different geographical location and size orientation to name some. It helps in analyzing sun paths of the building model. This software can analyze thermal, ventilation and wind calculations. The main limitation of this software is that it can’t perform simulation for ventilation and wind movement outside the building.

2.7.2 Mahoney Table

It is a set of table used for architectural analysis by designers and architects. There are six tables of which four analyses climatic data to compare with the required level of thermal comfort and two for design recommendation.

CHAPTER THREE: METHODOLOGY

3.1 Life cycle costing approach

LCC is the calculation of all the cost which includes construction, operational, annually and non-annually occurring maintenance cost to its end of life cost or salvage value cost. (Wonga et al., 2003).

Table 3.1 LCC stages in EN 15804:2012 (Schade, 2007)

Product Phase			Construction Phase		Use Phase							End of Life Phase				Benefits after end phase		
Raw Material supply	Transport	Manufacturing	Transport to site	Installation to	Use	Annually occurring Maintenance	Non Annually	Repair	Replacement	Operational cost	Operational water	Demolition	Transport	Waste process	Disposal	Reuse	Recovery	Recycle
*	*	*	*	*		*	*	*	*	*					*	*		
*Marked modules are included in this thesis																		

Net present value method is preferred for calculation of future costs based on the present data collected. Following formula used for LCC calculations (Kale et al., 2015)

LCC = investment cost + Replacement cost – resale cost+ annually maintenance cost + non annually occurring maintenance cost + operating cost.............. [1]

The original amount is increased on yearly basis and is discounted proportionally throughout the building life cycle.

Present value (PV) = $\frac{Ct}{(1+r)t}$ ……... [2]

Where, Ct = Net Cash flow in a year at r% discount rate

3.2 Site selection

3.2.1 Urban growth in Kathmandu Valley

Among this Kathmandu is the largest metropolis in Nepal among 4, metropolitan cities. After the completion of 27Km Ring-road, Peri-urban settlement grew at nodal points where radial roads diverging from central Kathmandu intersected with the ring-road the koteswor,Satdobato,gongabu,Dhapasi,Mandikatar,SukeDhara,Jorpati,sinamangal and other areas can be attributed to this urbanization trend. Peri-Urban buildings are characterized by modern RCC frame structures followed by load bearing walls. These buildings are built on newer plot sizes which on average are larger than those in city core areas. Many infrastructure services like water supply, sewerage, electricity and drains were properly managed.

3.2.2 Site – Gongabu

Gongabu is a peri-urban settlement that was emerged after the completion of ring road. It lies in Tokha municipality of province 3 in Kathmandu district as shown in figure 3.1.

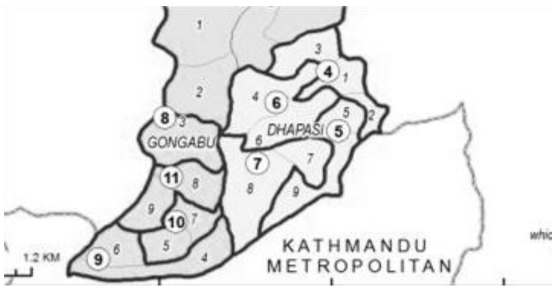


Figure 3.1 Map of Tokha Municipality (Maze, 2017)

Tokha was declared municipality on December 2014.It consists of Dhapasi, gongabu, Tokhs sarswoti, Chandeswori, and Jhormahankal. Gongabu consist of only 10% of traditional building, 60% of modern RCC frame building, followed by 30% of modern load bearing wall system building (ISP, 2016).

According to CBS 2011, Gongabu consists of maximum number of owned housing unit and even rented housing unit in compare to other places in Tokha municipality, whereas 70% of housing units are rented with mixed use housing units. Also it can be interpreted that about 5% of houses are traditional and 95% buildings are modern .It shows that, Gongabu as a peri-urban area consisting of larger number of modern buildings and is growing rapidly (Shrestha , 2019).

3.2.3 Earthquake 2015

In Gongabu about 1363 houses were affected in which 150 houses were completely damaged and 1213 were partially damaged. However despite being a peri urban settlement with modern construction techniques, there was an extensive damage to the building. After this, massive reconstruction programs and schemes were carried out in this area where more focus was given to strengthening of structural stability and neglecting to thermal performance and Life cycle cost.

Table 3.2 Household by building typology

<table>
<tr><th>S.n</th><th>Building typology</th><th colspan="4">Types</th></tr>
<tr><td>1</td><td>Use</td><td colspan="2">Mixed used (74%)</td><td colspan="2">Commercial (26%)</td></tr>
<tr><td>2</td><td>Type of Structure</td><td>Temporary (3%)</td><td>Semi-permanent (11%)</td><td colspan="2">Permanent (86%)</td></tr>
<tr><td>3</td><td>Number of storey</td><td>1(15%), 2(16%)</td><td>3(24%)</td><td>4(38%)</td><td>5(5%). 6(2%)</td></tr>
<tr><td>4</td><td>Construction Technique</td><td>Rcc frame (74%)</td><td>Load bearing</td><td>Steel Str</td><td>Tempo rary Str</td></tr>
<tr><td colspan="2"></td><td colspan="2">Cement and mud</td><td colspan="2">AAC Block and load bearing wall</td></tr>
</table>

From above table it can be concluded that 74%, 3 and half storied mixed used residential structure was chosen for in-depth LCC investigation.

3.2.4 Base Case building

The sample building belongs to Mr. Ghima Gurung .It is located 200meters from Gongabu Chowk heading towards Manmaiju in North. It is constructed at the west of the plot next to the road facing towards north.

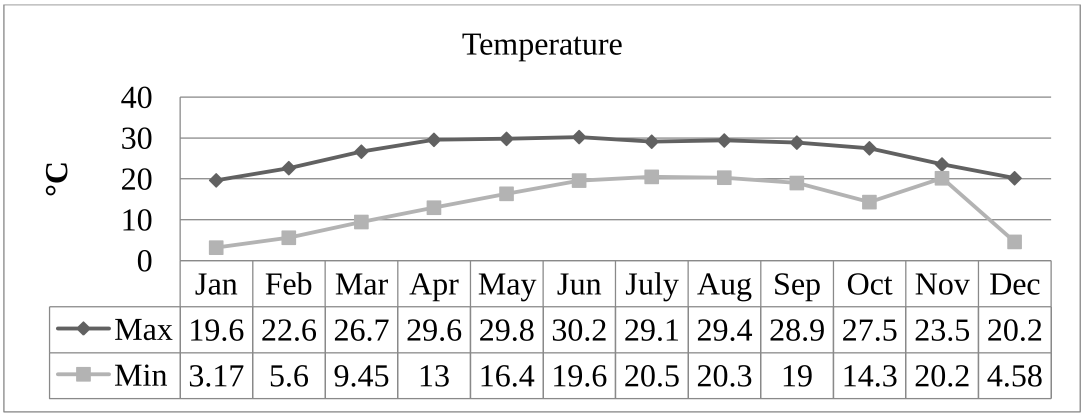
The house is in detached housing unit where there are no adjacent buildings at all three sides. The building is in rectangular shape with plinth area of 100.89m^2 and oriented at north direction. The main entrance of the building is at north. It is a 3 and half storey RCC frame structure. The sample building is a mixed use residential building where lower 2 storey are commercially rented and upper storey is residential. The selected wall assemblages were brick, Compressed stabilized earth block and Autoclaved aerated concrete block.

3.3 Analysis of Climatic Data of the selected site

The parameters were obtained from department of meteorology, 10 years climatic data from 2009 to 2019 of Kathmandu was taken regarding temperature, relative humidity, rainfall and wind.

3.3.1 Temperature Data interpretation

The figure below shows that the monthly mean maximum temperature reaches up to 30.24°C, minimum temperature reaches to 3.17°C in winter.

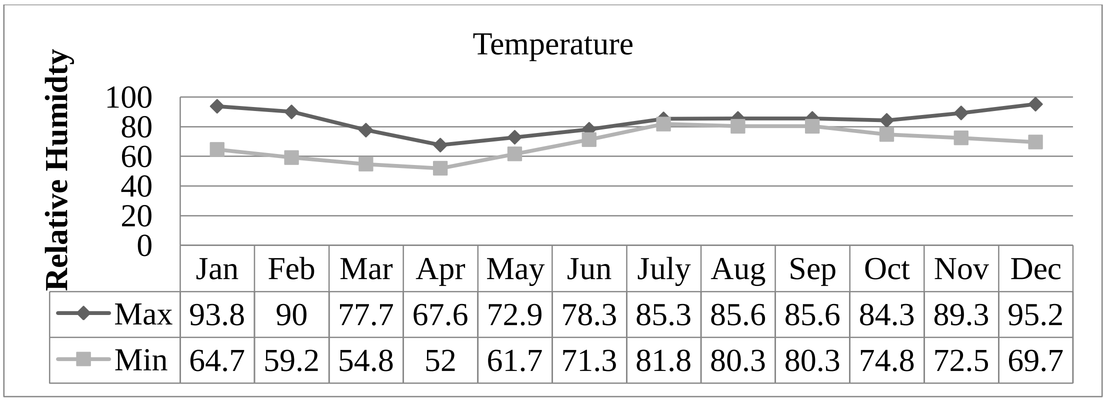


	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Max	19.6	22.6	26.7	29.6	29.8	30.2	29.1	29.4	28.9	27.5	23.5	20.2
Min	3.17	5.6	9.45	13	16.4	19.6	20.5	20.3	19	14.3	20.2	4.58

Figure 3.2 Maximum and minimum temperature of Kathmandu valley 2009-2019

The average wind speed is about 0.95m/s and the maximum wind speed reaches up to 3.14m/s in May. Westerly wind prevails in the Tokha valley. 6.3 hours is the average hour of sunshine and varies between 3.3 to 8.4 hours. The sun's angle at noon during equinox (March 21 and September 22) is 62.3°.The summer solstice on June 22 is 85.5°. The winter solstice on December 22 is 38.8°.

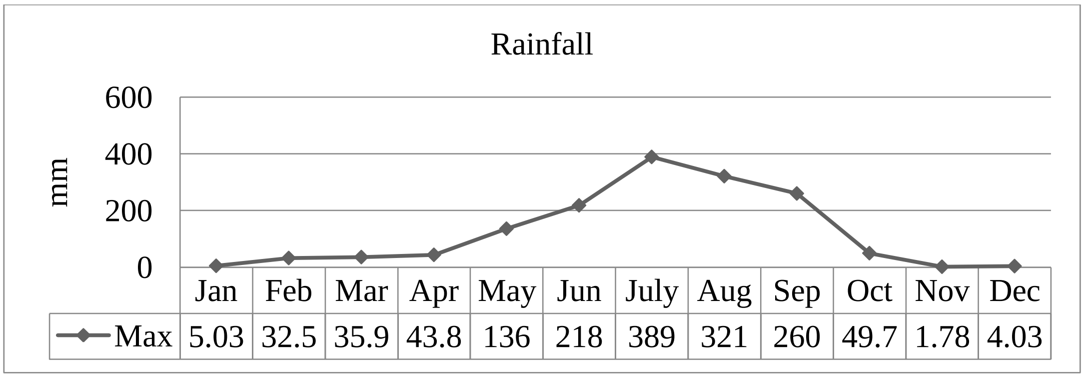
3.3.2 Relative humidity analysis



	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Max	93.8	90	77.7	67.6	72.9	78.3	85.3	85.6	85.6	84.3	89.3	95.2
Min	64.7	59.2	54.8	52	61.7	71.3	81.8	80.3	80.3	74.8	72.5	69.7

Figure 3.3 Maximum / minimum relative humidity chart

The above figure shows average monthly maximum humidity from 2009 to 2019, which is 95.2%in the morning and 52% in the average daytime.



	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Max	5.03	32.5	35.9	43.8	136	218	389	321	260	49.7	1.78	4.03

Figure 3.4 Average monthly temperature variation

During 2009 to 2019, high rainfall was observed during july with average rainfall of 1337mm in Kathmandu valley.

3.3.3 Climatic analysis and findings

Table 3.3 Climatic analysis of Szoklay and Giovani chart

S.no	Particulars	Szoklay bioclimatic chart	Givoni Bioclimatic chart
1	Average comfort range	20.8°C to 25.8°C	20°C to 27°C
2	Comfort Zone(CZ)	Certain days from March April and May	Few days of March,April and May
3	Mass Effect	-	Few days of April needs high mass
4	Mass effect with night ventilation	April to August	April, May and August
5	Air movement	June to august	May to October
6	Passive solar heating (PSH)	January to May	No definite lines for PSH
7	Active means	January to December	No define so needed

3.3.4 Mahoney Table

Based on the temperature data from meteorological department from the year 2009 to 2019, Mahoney table was developed. It is gives guideline for climate appropriate strategy for design.

Table 3.4 Mahoney Table results for Tokha

List of recommended specifications		
1	Layout	Orientation north and south (long axis east-west)
2	Spacing	Open spacing but sun and wind protection needed
3	Air movement	Rooms single banked, cross ventilation
4	Openings	Medium openings,20%-40%
5	Walls	Heavy external and internal walls
6	Roofs	Light ,insulated roofs
7	Rain Protection	heavy rain so protection necessary
List of recommended specifications		
1	Size of Opening	Medium 25-40%
2	Opening Position	North and south walls on windward side
3	Opening Protection	Exclude direct sunlight
4	Walls and floors	Heavy,over8th time lag
5	Roofs	Light ,well insulated
6	External features	Adequate rainwater drainage

3.4 Building operation Model-Ecotect

Heating and cooling load is calculated using Ecotect software. About the data available, the weather data format acceptance by the Ecotect is another limitation we face so the EPW file used for climate consultant is converted to weather data file and then imported to Ecotect software. The dimensions from plans and elevations have been verified as per actual building construction and modeling has been done. The Zoning of all the floors were done as follows:

- Ground floor: Product Display
- First Floor: Office and training Center
- Second floor: Residence
- Third Floor: Residence Laundry, Kitchen and Terrace

In the process of analyzing, firstly an original 3Ds model was prepared in sketch up and later imported in Ecotect which is considered a base case scenario. Then two other alterations in building material are done creating total of three scenarios in building material heating / cooling loads calculation.

3.4.1 Zone properties and data input

The model of the building is made by assigning different zones inside the building depending upon use and occupancy. Average annual comfort range is incorporated based on climatic analysis on previous climatic analysis in Table 3.4 .And based on those results the comfort ranges are:

Winter comfort range: 18.8°C to 23.8°C

Summer comfort range: 22.8°C to 27.8°C

Average Comfort range: 20.8°C to 25.8°C

After this, each zone assigns its own occupancy, lighting level, air change rate, wind rate and hours of operation.

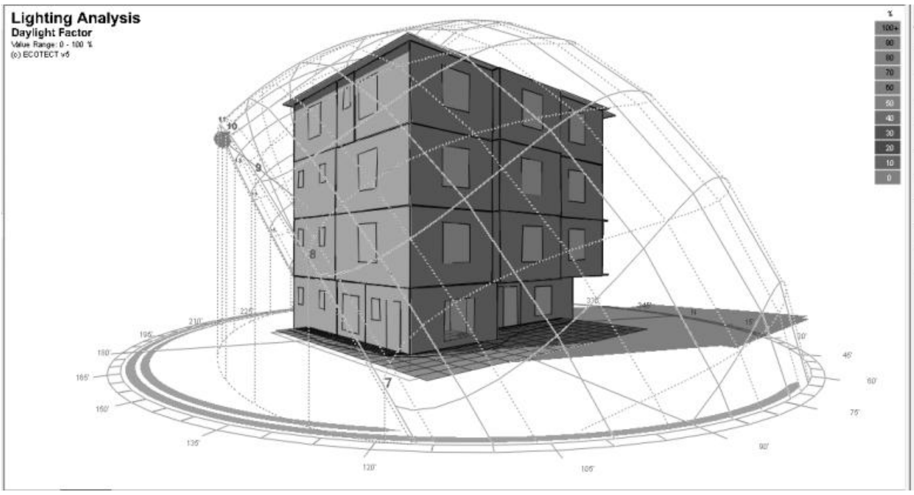


Figure3.5 Average Sun path in Ecotect Modeling

The blue line of above figure 3.8 shows the annual sun path and yellow line shows the daily sun path. The analysis result from the Ecotect for solar exposure analysis shows that there is non-uniform solar exposure for different facades. The front façade is mostly protected from direct solar radiation which is also seen in above figure.

However, EPS panels, wooden posts, veneers were omitted from the research as there will be change in structural changes due to these materials.

Table 3.5 Different scenario detail

Building Element	Scenario 1	Scenario 2 (AAC)	Scenario 3 (CSEB)
Wall	0.23m exterior 0.1m interior wall	0.3m exterior 0.15m interior wall	0.26m exterior wall 0.09m interior wall
Door	Timber paneling inside room Aluminum door in toilet and verandah	Timber paneling inside room Aluminum door in toilet and verandah	Timber paneling inside room Aluminum door in toilet and verandah
window	Single glazed Al frames	Double glazed Al frames	Double glazed Al frames
floor	150mm thick RCC	150mm thick AAC	150mm thick RCC
Roof	150mm thick RCC	150mm thick RCC block	150mm thick RCC

After proper definition of scenarios, the total energy consumption used in heating and cooling needs to be analyzed.

Table 3.6 U-Value calculation of different scenarios

<table>
<tr><th>Material</th><th>U-Value calculation</th><th>Thermal properties</th></tr>
<tr><td>Solid brick wall of 230mm thickness</td><td>Thermal Gradient of Base case scenario
<table>
<tr><th>Sn</th><th>Section of wall</th><th>Conductivity (K) W/m °C</th><th>Conductance(C) W/ m² °C</th><th>Wall Resistance(Ra) m² °C/W</th></tr>
<tr><td>1</td><td>Outside air film</td><td></td><td>13.18</td><td>0.076</td></tr>
<tr><td>2</td><td>20mm plaster work</td><td>0.5</td><td></td><td>0.040</td></tr>
<tr><td>3</td><td>230mm brick wall</td><td>0.84</td><td></td><td>0.3</td></tr>
<tr><td>4</td><td>16mm plaster work</td><td>0.5</td><td></td><td>0.032</td></tr>
<tr><td>5</td><td>Inside air film</td><td></td><td>8.12</td><td>0.123</td></tr>
<tr><td colspan="4">Total Resistance(Ra)</td><td>0.545</td></tr>
<tr><td colspan="4">U-Value</td><td>1.835</td></tr>
</table></td><td><table>
<tr><td>U-Value (W/m²K)</td><td>0.545</td></tr>
<tr><td>Admittance(W/m²K)</td><td>3.360</td></tr>
<tr><td>Solar Absorption (0-1)</td><td>0.418</td></tr>
<tr><td>Visible Transmittance (0-1)</td><td>0</td></tr>
<tr><td>Thermal Decrement(0-1)</td><td>0.09</td></tr>
<tr><td>Thermal Lag (hrs)</td><td>3</td></tr>
<tr><td>Thickness (mm)</td><td>274.0</td></tr>
<tr><td>Weight (Kg)</td><td>160.065</td></tr>
</table></td></tr>
<tr><td>Internal Brick wall of 110mm</td><td>Thermal Gradient of Half brick wall
<table>
<tr><th>Sn</th><th>Section of wall</th><th>Conductivity (K) W/m °C</th><th>Conductance(C) W/ m² °C</th><th>Wall Resistance(Ra) m² °C/W</th></tr>
<tr><td>1</td><td>Outside air film</td><td></td><td>13.18</td><td>0.076</td></tr>
<tr><td>2</td><td>16mm plaster work</td><td>0.5</td><td></td><td>0.032</td></tr>
<tr><td>3</td><td>110mm brick wall</td><td>0.84</td><td></td><td>0.1</td></tr>
<tr><td>4</td><td>16mm plaster work</td><td>0.5</td><td></td><td>0.032</td></tr>
<tr><td>5</td><td>Inside air film</td><td></td><td>8.12</td><td>0.123</td></tr>
<tr><td colspan="4">Total Resistance(Ra)</td><td>0.394</td></tr>
<tr><td colspan="4">U-Value</td><td>2.53</td></tr>
</table></td><td><table>
<tr><td>U-Value (W/m²K)</td><td>2.53</td></tr>
<tr><td>Admittance(W/m²K)</td><td>5.280</td></tr>
<tr><td>Solar Absorption (0-1)</td><td>0.47</td></tr>
<tr><td>Visible Transmittance (0-1)</td><td>0</td></tr>
<tr><td>Thermal Decrement(0-1)</td><td>0.48</td></tr>
<tr><td>Thermal Lag (hrs)</td><td>8</td></tr>
<tr><td>Thickness (mm)</td><td>177.0</td></tr>
<tr><td>Weight (Kg)</td><td>581.800</td></tr>
</table></td></tr>
</table>

Solid wall of AAC 200mm thickness

Thermal Gradient of 200mm AAC Block Component

Sn	Section of wall	Conductivity (K) W/m °C	Conductance(C) W/ m² °C	Wall Resistance(Ra) m² °C/W
1	Outside air film		13.18	0.076
2	16mm plaster work	0.16		0.100
3	200mm AAC Block	0.16		0.6
4	Inside air film		8.12	0.123
			Total Resistance(Ra)	2.03
			U-Value	0.25

U-Value (W/m²K)	0.25
Admittance(W/m²K)	3.360
Solar Absorption (0-1)	0.418
Visible Transmittance (0-1)	0
Thermal Decrement(0-1)	0.09
Thermal Lag (hrs)	3
Thickness (mm)	274.0
Weight (Kg)	160.065

CSEB Solid wall of 300mm

Thermal Gradient of 300 mm CSEB wall

Sn	Section of wall	Conductivity (K) W/m °C	Conductance(C) W/ m² °C	Wall Resistance(Ra) m² °C/W
1	Outside air film		13.18	0.076
2	20mm plaster work	0.5		0.040
3	300mm brick wall	0.7		0.1
4	16mm plaster work	0.5		0.032
5	Inside air film		8.12	0.123
			Total Resistance(Ra)	2.5
			U-Value	0.394

U-Value (W/m²K)	0.394
Admittance(W/m²K)	3.360
Solar Absorption (0-1)	0.418
Visible Transmittance (0-1)	0
Thermal Decrement(0-1)	0.09
Thermal Lag (hrs)	3
Thickness (mm)	274.0
Weight (Kg)	160.065

RCC floors

Thermal Gradient of Concrete floor

Sn	Layer name	Width	Density	Sp heat	Conduct	Type
1	Cement Plaster	12	1900	840	1.5	35
2	Concrete	125	3800	656	0.753	35
3	Cement Screed	40	2100	650	1.4	35

U-Value (W/m²K)	2.53
Admittance(W/m²K)	5.280
Solar Absorption (0-1)	0.47
Visible Transmittance (0-1)	0
Thermal Decrement(0-1)	0.48
Thermal Lag (hrs)	8
Thickness (mm)	177.0
Weight (Kg)	581.800

Zone 1: Product Display/Shops

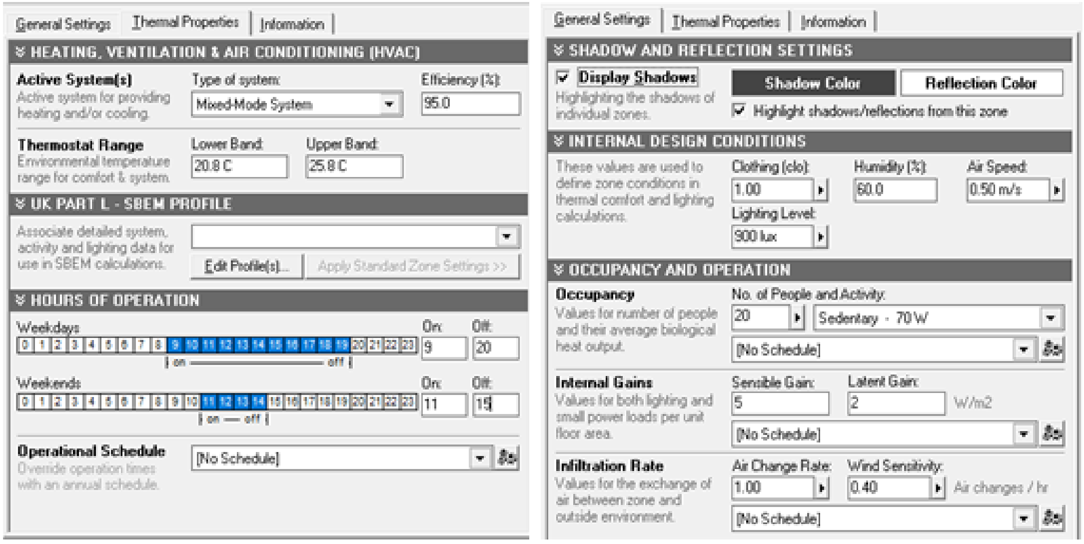


Figure 3.6 Properties' of Zone 1

Zone 2: Office, Training Center

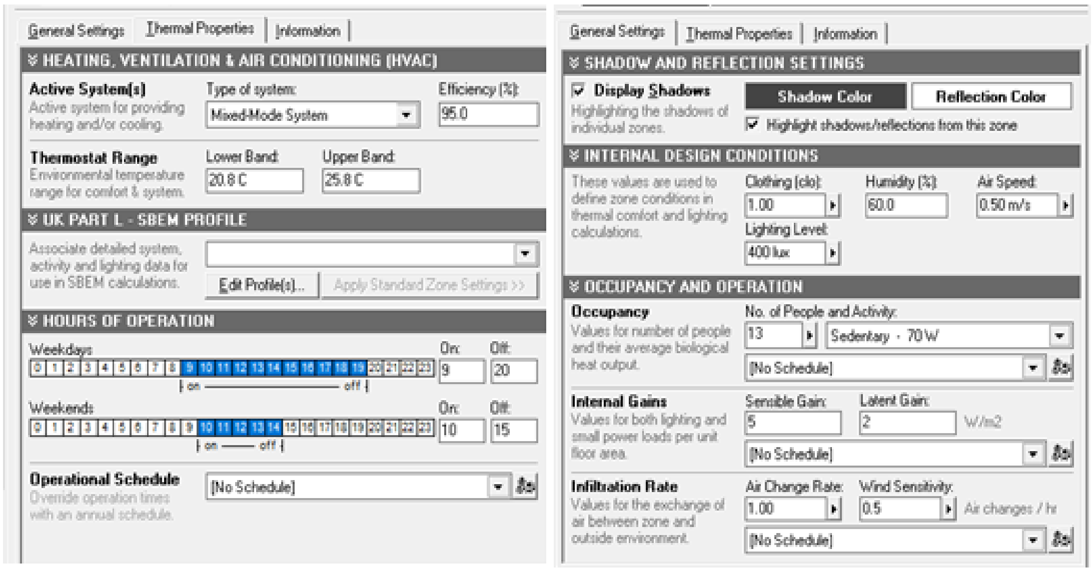


Figure 3.7 Properties' of Zone 2

Zone 3: Residence living room bedroom

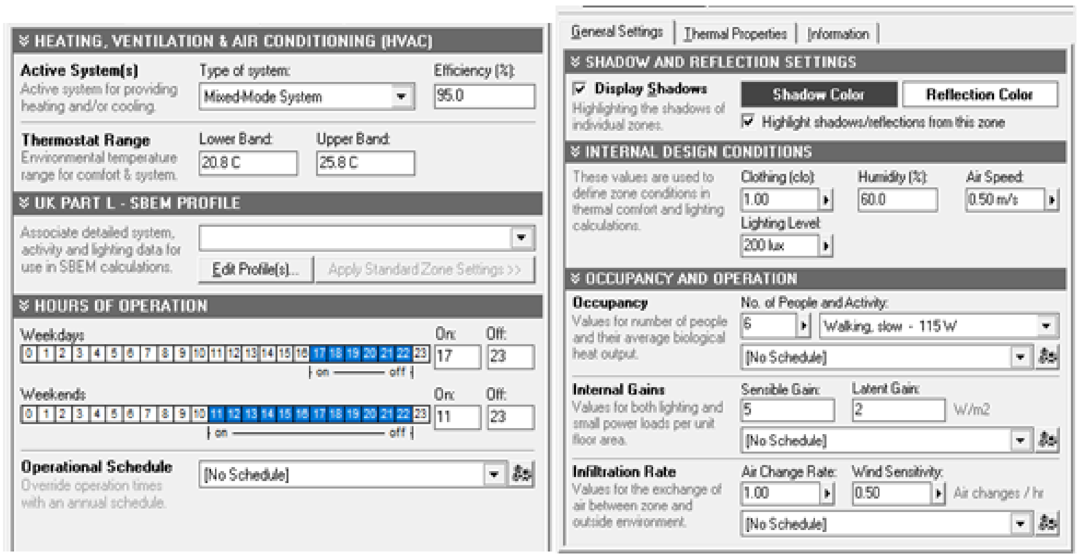


Figure 3.8 Properties' of Zone 3

Zone 4: Laundry, Kitchen and Terrace

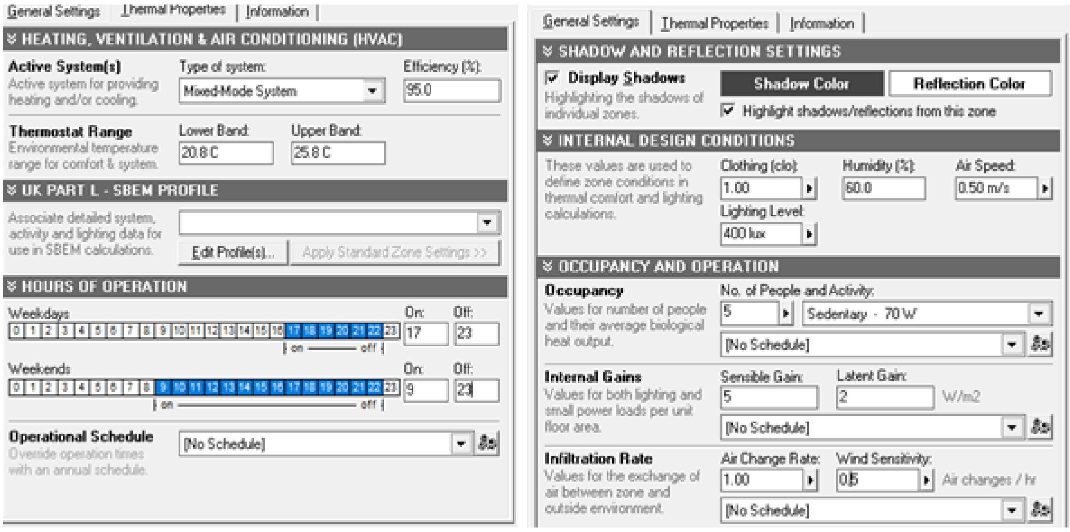


Figure 3.9 Properties' of Zone 4

For operating hours, Saturday is assigned as standard holiday and other days as working days as it is a commercial area for Zone 1and 2.similarly for Zone 3 and above, Saturday is categorized as standard working day at home and other weekdays as day off.

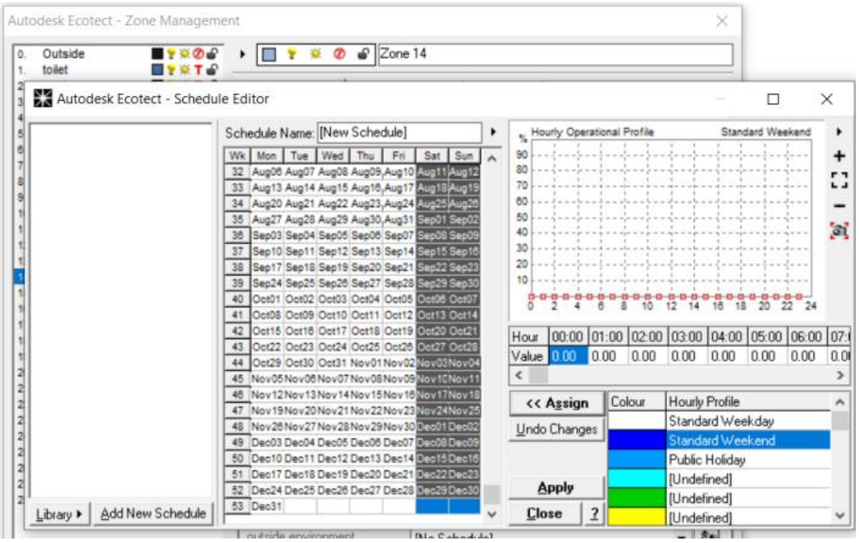


Figure3.10 Operational Schedule

3.5 Data generation

Preliminary Bill of quantities (BOQ) was calculated in order to account the amount of material required to build the base house according to 2019 market Prices. Rate analysis was done to understand the variation of different walling material needed. Subsequently, the total initial cost of construction was transformed into life cycle cost model in spreadsheet for a period of sixty years (one life span) .The similar format was used to compare as well as to contrast the initial cost of alternate cases.

3.6 LCC Assumptions

3.6.1 Life time

The sixty-year life spans were defined as standard housing guidelines on the affordable housing by the British standards. The life of building is governed by the usefulness of the materials. The projected service for brick houses is usually around 60-70 years, but that considers the house as a whole system. The brickwork itself will almost certainly outlast that timeframe, but the electrical and other components within the building envelope (even with regular maintenance) will not (Shukla, 2014). AAC blocks have service life of 100 years. So LCC calculations are designed with consideration of 50 to 80 years so that the block will last until designed life (Sudhanshu et al., 2018). The minimum service life of a CSEB is 75 years (Obonyo et al., 2010).However, for the calculation, equal life is assumed by taking average of all three blocks i.e. 60 years.

3.6.2 Discount Rate

The discount rate can be defined as the valuation of today's cost after discounting taking into consideration all future obligation costs. It is a very important step in LCC calculation to define the right discount rate for true cost benefit analysis. Variety of discount rates can be found implemented by developed and developing nations (Suwal, 2009). For the calculation of life cycle cost benefit analysis in this thesis, discount rate was assumed from 3.5-15 % in order to check and review the robustness of the final result in case of occurrence of different uncertainties.

3.7 Over all Methodology

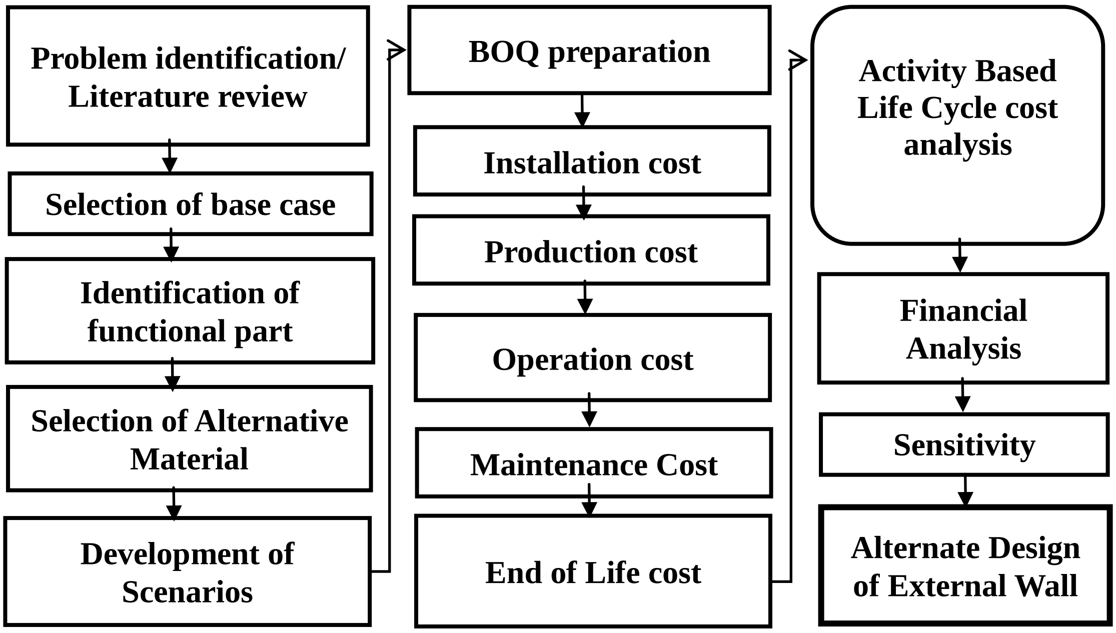


Figure 3.11 Overall Methodology

The methodology of this thesis can be divided into three stages. All the parameters associated with LCC were defined including construction cost, operational costs, discount rates and average service life in the first step. In second stage Preliminary Bill of quantities (BOQ) was calculated in quantify the amount of material that will be used to build the base house according to 2019 market Prices. In the third stage, the total initial cost of construction was transferred into spreadsheet .The same model was used to compare as the initial cost to total cost of alternate scenarios. Detail Financial analysis was conducted to determine the economy of residential building. Lastly, sensitivity analysis was performed to check the results and the effects due to different assumption made. And finally suitable external wall type was proposed.

CHAPTER FOUR: RESULT AND DISCUSSION

4.1 Cost Estimation

4.1.1 Rate Analysis

An estimate is needed to give an idea of the financial investment of the project. Simply Rate Analysis is a process of finding rate of any work involved during construction work. The rates of these works also help in determining cost of the project. The current rate of the materials is taken from the government rate of 2076 of Tokha Municipality and current rate of CSEB block taken from DUDBC manual.

a. Quantity of materials:

Table 4.1Quantity of materials for 10 'x 9'4" wall

S.no	Description	No.	Length	Breadth	Height	Total	Unit
1.	Full Brick Masonry works (1”6 c/s)						
	9” thick Brick Wall	1	10	0.75	9.33	69.98	
		Total of Brick Masonry				69.98	Ft^3
2.	AAC Block Masonry						
	7” thick AAC wall	1	10	0.58	9.33	54.2	
		Total of AAC Masonry				54.2	Ft^3
3.	CSEB Block Masonry						
	8” thick CSEB wall	1	10	0.67	9.33	62.51	
		Total of CSEB Masonry				62.51	Ft^3

As shown in table 4.1, the volumetric area of 10’ length and 9’4” height wall is taken into consideration. The breadth of the wall varies on the wall material used, as for the brick wall 9”, AAC 7” and CSEB 8” thickness breadth is taken.

b. Rate analysis of brick work

Table 4.2 Rate analysis for brick wall masonry in superstructure

1					
S No.	**Particulars**	**Unit**	**Quantity**	**Rate**	**Amount**
A	Labors				
	Skilled	No.	1.5	660	990
	Unskilled	No.	2.90	420	924
	Unskilled for scaffolding	No.	0.4	420	168
	Sub Total				2568
B	Materials				
	First class Brick	No.	560	13.50	7560
	cement	Bag	1.40	880	1232
	sand	cu m	0..30	3955	1186.50
	Scaffolding 3% of labor			0.03	77.04
	Sub Total				10055.54
	Total(A+B)				12623.54
C	15% Contactor overhead and profit				2272.23
	Total (A+B+C)				14895.77
Rate for 1 cubic meter of brickwork in 1:6 cement mortar					14895.77
Rate per cubic feet in 1;6 Cement mortar					421.85
No. of bricks in 1m^3					870 no.

c. Rate analysis of AAC Block

Table 4.3 Rate analysis for AAC masonry in superstructure

1					
S No.	**Particulars**	**Unit**	**Quantity**	**Rate**	**Amount**
A	Labors				
	Skilled	No.	1	960	960
	Unskilled	No.	1	790	790
	Unskilled for scaffolding	No.	0.7	790	553
	Sub Total				2303.00
B	Materials				
	AAC block	No.	32	310	10166.67
	cement	Bag	0.033	880	29.04
	sand	cu m	0.09	3955	355.95
	Water	lit	12	0.30	3.6
	Sub Total				10555.26
	Total(A+B)				12858.26
C	15% Contactor overhead				1928.73
	Total (A+B+C)				14786.99
Rate for 1 cubic meter of brickwork in 1:6 cement mortar					14786.99
Rate per cubic feet in 1;6 Cement mortar					418.77
No. of blocks in 1m^3					41
8burnt brick=1 AAC block					
1unit=14 kg (14kg=36kg brick masonry)					

d. Rate analysis of CSEB Block

Table 4.4 Rate analysis for CSEB masonry in superstructure

1					
S No.	**Particulars**	**Unit**	**Quantity**	**Rate**	**Amount**
A	Labors				
	Skilled	No.	1	960	960
	Unskilled	No.	1	790	790
	Unskilled for scaffolding	No.	0.7	790	553
	Sub Total				2303
B	Materials				
	CSEB block	No.	123	60	7380
	cement	Bag	2.64	880	2323.2
	sand	cu m	0.09	3955	355.95
	Water	lt	12	0.30	3.6
	Sub Total				10062.75
	Total(A+B)				12365.75
C	15% Contactor overhead				1854.86
	Total (A+B+C)				14220.61
Rate for 1 cubic meter of brickwork in 1:6 cement mortar					14220.61
Rate per cubic feet in 1;6 Cement mortar					402.73
No. of blocks in $1m^3$					196
4CSEB =1 AAC block					
1 unit=7.5Kg Source (Shrestha, 2019)					

As shown in Table 4.1, 4.2, 4.3 and 4.4 the rate analysis for brick wall masonry is 421, AAC block 418 and CSEB block to be 402.73 Rs per square feet.

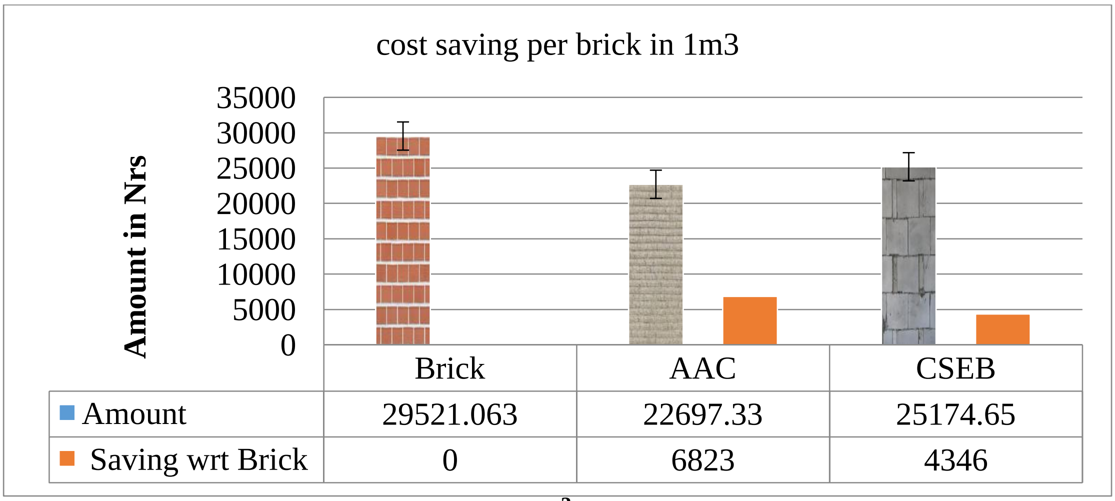


Figure 4.1 Cost saving in $1m^3$ wall Vs Block types in Nrs

As shown in figure 4.1 the cost saving in cubic meter when using AAC was 6823Nrs and 4346 for CSEB.

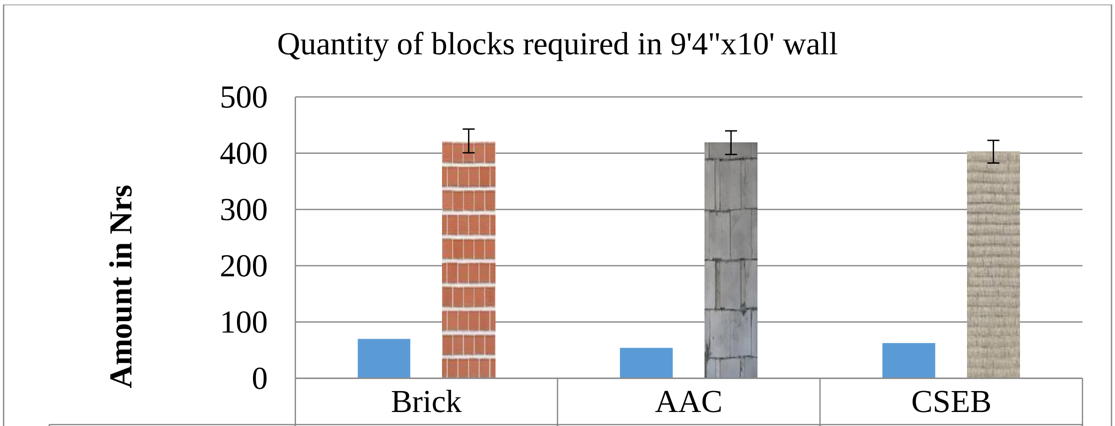
e. **Comparison of the rate and amount of walling material for 10’x 9’4” wall**

Table 4.5 Rate analysis for CSEB masonry in superstructure

Item no.	Description of works	Unit	Quantity	Rate (NPR)	Amount (NPR)
1	Brick Masonry (1:6 c/s) Procurement and laying first class chimney brick	Ft^3	69.98	**421.85**	29521.063
2	AAC Block Masonry (1:5 c/s) (AAC block masonry in ground level with 600x200x100mm size AAC block and 1;5 Cement sand mortar for 1 m^3 ,strength>3.0 N/mm^2 for structure walls up to 30m carrying)	Ft^3	54.2	418.77	22697.33
3	CSEB Block Masonry (1:5c/s) (CSEB block masonry in ground level with 600x200x100mm size AAC block and 1;5 Cement sand mortar for 1 m^3 ,strength>3.0 N/mm^2 for structure walls up to 30m carrying)	Ft^3	62.51	**402.73**	25174.65

The above estimation in table 4.5 for 10’x9’4” wall shows:

- The cost of brick wall masonry -The cost of AAC wall masonry = 3 Nrs
- Implies 6823Nrs can be saved if AAC block wall is used.
- The cost of brick wall masonry -The cost of CSEB wall masonry = 19 Nrs
- Implies 4346 Nrs can be saved if CSEB block wall is used.
- The cost of CSEB wall masonry -The cost of AAC wall masonry = 16 Nrs
- Implies 2477 Nrs can be saved if AAC block wall is used.

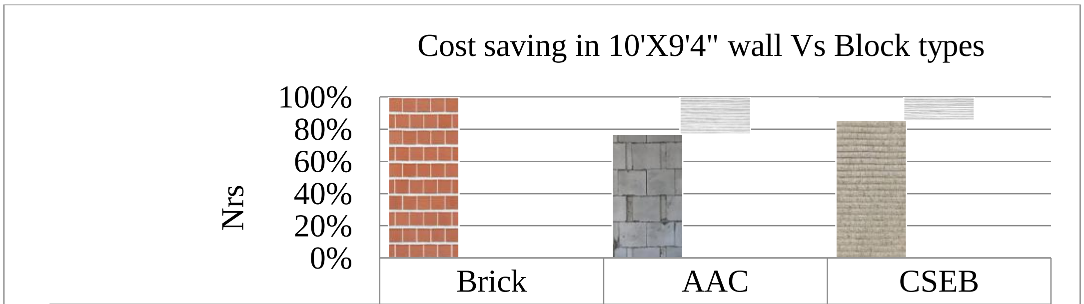


	Brick	AAC	CSEB
Quantity (Cu.ft)	69.98	54.2	62.51
Rate	421.85	418.77	402.73

Figure 4.2 Comparison of Number of blocks required per floor and Amount

Considering the construction of single wall the initial cost of AAC wall was found to be comparatively low by 23% AND CSEB blocks by 14% with respect to brick.

Considering the construction of single wall the initial cost of AAC wall was found to be comparatively low by 23% AND CSEB blocks by 14% with respect to brick.



	Brick	AAC	CSEB
Percentage saving wrt Brick		23%	14%
Cost Saving wrt Brick (Rs)		6823	4346
Amount (Rs)	29521.063	22697.33	25174.65

Figure 4.3 Comparison of cost saving in Number of blocks required per floor and Amount

f. Cost analysis of walling materials for whole building

Table 4.6 Cost analysis of walling materials for whole building

S. no.	Particulars	Unit	Quantity	Rate (NPR)	Amount (NPR)
1	Full Brick Masonry				
	Brick Masonry (1:6 c/s) Procurement and laying first class chimney brick	Ft^3	4412.21	421.85	1861290.78
2	Full AAC Block Masonry				
	AAC Block Masonry (1:3 c/s) (AAC block masonry in ground level with 600x200x100mm size AAC block and 1;5 Cement sand mortar for 1 m^3 ,strength>3.0 N/mm^2 for structure walls up to 30m carrying)	Ft^3	3971 (1112 no in m^3)	418.77	1662935.67
3	Full CSEB Block Masonry				
	CSEB Block Masonry (1:3;2c/s) (CSEB block masonry in ground level with 600x200x100mm size AAC block and 1;5 Cement sand mortar for 1 m^3 ,strength>3.0 N/mm^2 for structure walls up to 30m carrying)	Ft^3	4089 (4255 no in m^3)	402.73	1713705.67

As shown in Table 4.6 the walling material used in baseline scenario is brick masonry where the total volumetric area of brick masonry of sample building is 4412.21 cubic feet. And the total volumetric area of AAC block needed for whole building is 3971 cubic feet and 3612.21 for cubic feet for CSEB block respectively. The chart above shows the total cost analysis and comparison of bricks and AAC and CSEB wall masonry based on current government rate of 2074-2075 of Tokha district.

By the above calculation, it shows that:
Initial cost of brick wall for whole building; NRS 1861290.78
Cost of AAC block for whole building: NRS 1662935.67
And cost of CSEB block for whole building: NRS 1713705.67
Now, Cost difference /Money saved:

- = cost or Brick - Cost of AAC= NRS 198355.11

- = cost or Brick - Cost of CSEB= NRS 406545.45
- = cost or AAC - Cost of CSEB = NRS 24924.24

Table 4.7 Comparative Construction cost for Base case, AAC and CSEB block

Cases	Construction cost (NRS)
Brick	9,714,937.63
AAC construction	9516582.52
CSEB construction	9567352.52

This shows that when using AAC in place of Brick 10% cost of construction can be saved in building material. When using CSEB block in place of brick 8% cost of construction can be saved and when using AAC in place of CSEB 3% cost of construction can be saved.

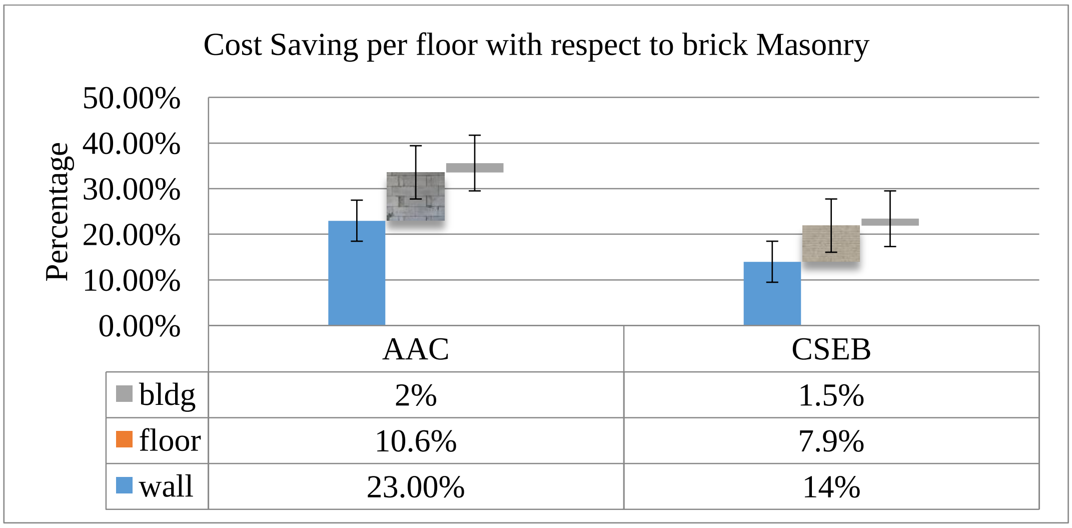


Figure 4.4 Comparison of % saving with respect to brick Masonry

4.2 Life cycle Cost (LCC)

For calculation, cost categorized into following sections:

Calculation to find out the annual worth (AW) and present (PW) of different costs like Installation cost, repair and maintenance costs are given in this appendix.

The PW and AW is calculated using following formula:

$$PW = FW\left(\frac{1}{(1+I)^N}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$AW = PW\left(\frac{I(1+I)^N}{(1+I)^N-1}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where,

PW= Present Worth

AW= Annual Worth

FW= Future worth

I= Discount Rate

N=Number of years

Depend upon the rate per cubic feet, the installation charge of all three walls were calculated and converted into annual worth.

4.2.1 Initial Cost (IC)

It is the cost required for its construction that includes Land acquisition costs and construction cost. The land acquisition costs are only included which is zero, as the land type in the base case and alternative is same.

For the case of construction cost the initial cost of installment of walling material is taken into account from BOQ. This cost includes all the labor, material, scaffolding, and 13 % contractor overhead charges.

Table 4.8 Brick, AAC and CSEB block initial cost

S.N	Name	Initial cost NRS
1	Construction cost of Brick	1861290.78
2	Construction cost of AAC	1662935.67
3	Construction cost of CSEB	1713705.67

Initial cost is the installation cost of the walls. This is one time payment at year 0.This cost is zero for other years so they need not be discounted, the PW of initial cost is:

PW of Initial cost of Brick masonry wall = NRS 1861290.78

PW of Initial cost of AAC masonry wall = NRS 1662935.67

PW of Initial cost of CSEB masonry wall = NRS 1713705.67

AW is calculated using equation (2), here I=10% and N=60 years,

PW of Brick masonry wall =1861290.78 NRS

$$AW = PW\left(\frac{I(1+I)^N}{(1+I)^N-1}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (4)$$

$$= 1861290.78 \left(\frac{0.1(1+0.1)^{60}}{(1+0.1)^{60}-1}\right)$$

= Nrs 186129.178

PW of AAC wall =1662935.67 NRS

$$AW = PW\left(\frac{I(1+I)^N}{(1+I)^N-1}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (4)$$

$= 1662935.67 \left(\frac{0.1(1+0.1)^{60}}{(1+0.1)^{60}-1}\right)$

= Nrs 166293.56

PW of CSEB wall =1713705.67NRS

AW = PW$\left(\frac{I(1+I)^{N}}{(1+I)^{N}-1}\right)$………….……….. (4)

$= 1713705.67\left(\frac{0.1(1+0.1)^{60}}{(1+0.1)^{60}-1}\right)$

= Nrs 171370.6

After the calculation of PW and AW, cost per cubic meter is calculated.

Brick masonry wall (Rs/ m^3) = $\frac{AW}{quantity}$

$= \frac{186129.178}{4412.21}$

= 42

AAC wall (Rs/ m^3) = $\frac{AW}{quantity}$

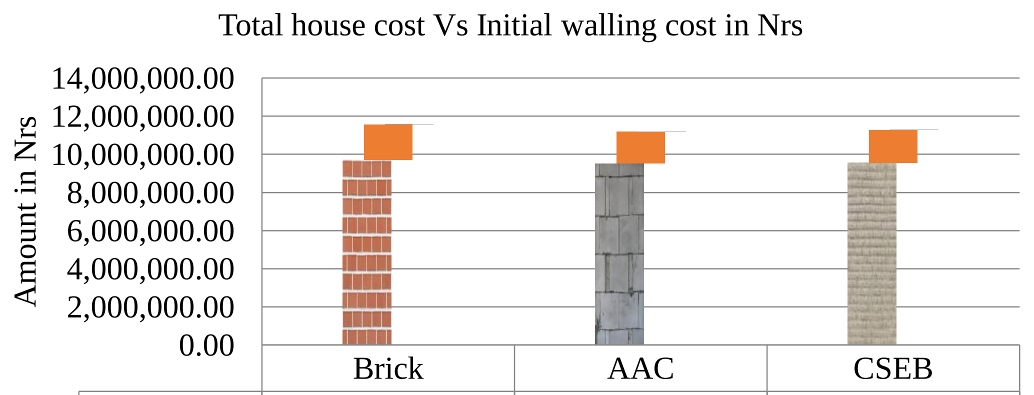
$= \frac{166293.56}{3971}$

= 41

CSEB wall (Rs/ m^3) = $\frac{AW}{quantity}$

$= \frac{171370.6}{4089}$

= 41.9



	Brick	AAC	CSEB
%	19.2	17.5	17.9
Initial Cost	1861290.78	1662935.67	1713705.67
Total Cost	9,714,937.63	9516582.52	9567352.52

Figure 4.5 Comparison of Total house cost and walling cost

4.2.2 Production cost (PC)

It is clear from Table4.6 that the total number of bricks required for the construction of external walls only for the base case was 20504,AAC blocks of size 24”x8”x4” required 1112 and 4255 numbers of CSEB blocks.

Table 4.9 Calculation of total production cost for all three scenarios

Particulars	No. required	unit price(Nrs)	Total (Nrs)
Brick	20504	8	164032
AAC	1112	180	200160
CSEB	4255	35	446775

The unit price production cost includes costs from procurement of raw material to the delivery to the site of manufacture and does not include transportation to site of installation.

4.2.3 Operation costs (OC)

4.2.3.1. Scenario 1-Brick walls

The base scenario was modeled as existing scenario. All the specifications were as per actual site measurements and calculations. This scenario was modeled with best possible way to represent the actual findings in site.

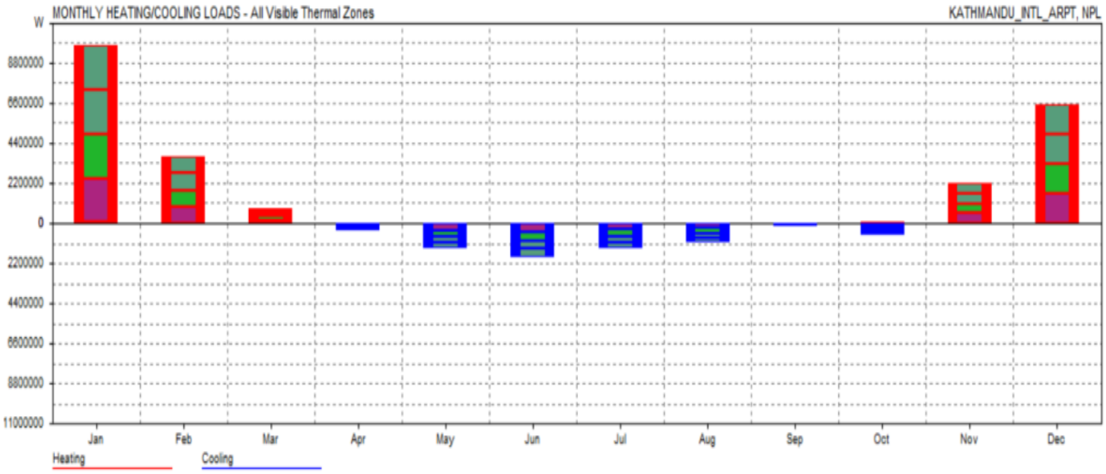


Figure 4.6 Base case scenario heating/cooling load calculation

The above figure shows that heating load is needed in January, February, December and November. Whereas cooling load is needed in May, June and July. The result for base case scenario shows that base case consumes total load of 30567.452Kwh with total cooling load of 7886.857Kwh and total heating load of 22681.452Kwh.The highest amount of cooling load which is 3314.00Kwh which falls on the month of June while the highest amount of heating load which is 6644.196Kwh which falls on the month of January. The baseline scenario of the sample building consumes 209.22Kwh per m^2 area per year.

4.2.3.2 Scenario 2 – AAC block

For this, conventional brick wall was replaced with 24"x8"x8" AAC blocks on the external walls and other internal entities were kept as they are. The figure 4.7 shows that heating load is needed in January, February, December and November, while cooling load is needed in May, June and July. The result for scenario 2 shows that total load of 29342.4 Kwh with total cooling load of 7886.857Kwh and total heating load of 21456.43Kwh.

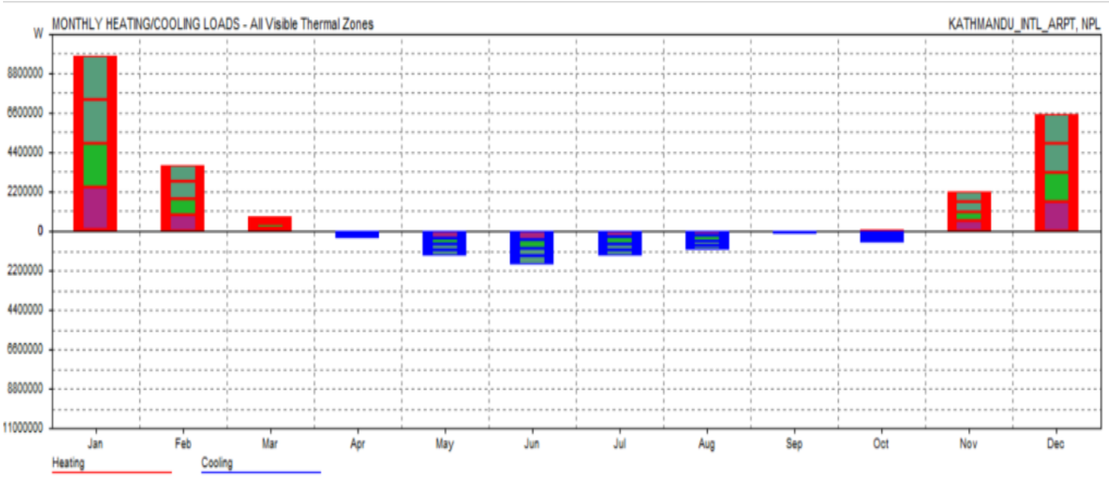


Figure 4.7 Scenario 2 heating/cooling load calculation

The baseline scenario of the sample building consumes 204Kwh per m^2 area per year. See appendix for detail calculation.

4.2.3.3 Scenario 3 – CSEB block

For this, conventional brick wall was replaced with 6”x4”x12” CSEB blocks. The below figure 4.8 shows that heating load is needed in January and December, whereas cooling load is needed in June. The result for scenario 3 shows that total load of 28464.337 KHz with total cooling load of 7841.64Kwh and total heating load of 21343.40Kwh.The baseline scenario of the sample building consumes 194Kwh per m^2 area per year.

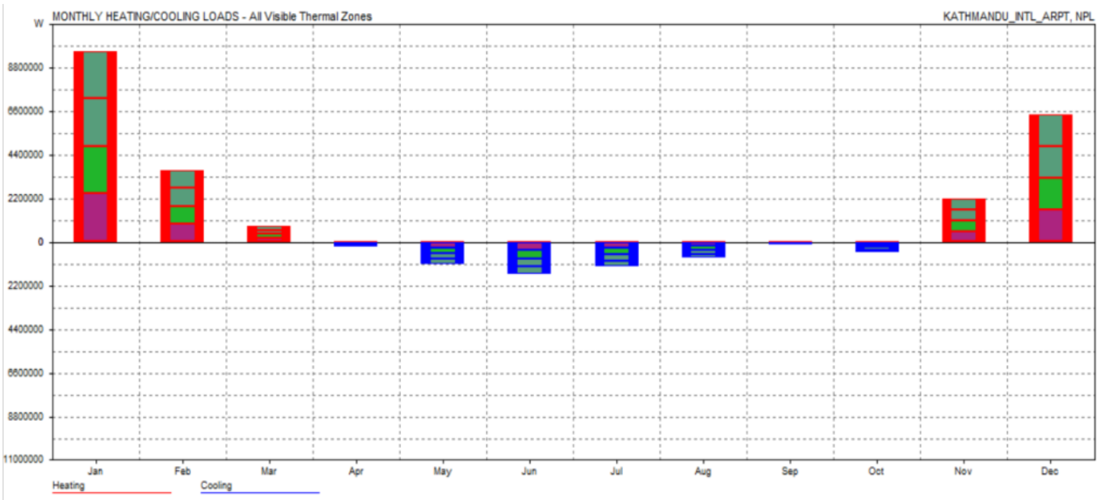


Figure 4.8 Scenario 3 heating/cooling load calculation

4.2.3.4 Total operational cost from total energy consumption

It is calculated by converting total heating and cooling load obtained from the different case scenarios. The energy cost is calculated based on NEA electricity tariff. Mathematically, Operation Cost= (energy charge x total heating and cooling load) + service charge

Rate of NEA per unit (KHz) = 13Nrs

Service charge= 1100Nrs

Table 4.10 Calculation of total operation cost for all three scenarios

Calculations			
Particulars	**Scenario 1**	**Scenario 2**	**Scenario 3**
Energy Consumed per year	30575.76	29342.43	28646.34
Energy Consumed per month	2547.98	2434.60	2387.19
Total Consumed per month	35497.73	33967.14	33327.13
Total Consumed per year	425972.81	407605.63	399925.55
Energy difference		1360.532	1929.427
Saved consuption%		4.4	3.6

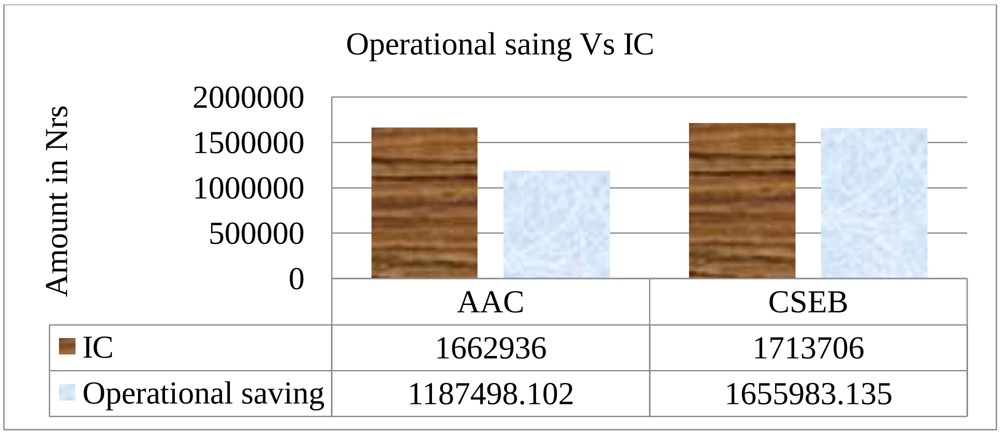


Figure 4.9 Operational saving Vs Initial cost

According to Table 4.10 it was found that the operational saving % in case of scenario 2 was 4.5% while it was 6.3 for CSEB block walls. In Figure 4.13 it can be observed that the operational saving cannot recover the initial construction cost for external walls in case of solid wall system but the condition may vary in other wall system.

However in case of the difference seems very small with 57722.8655Nrs for CSEB and 475437.898 Nrs which can be overcome by adopting passive design strategies.

4.2.4 Replacement costs (RC)

Due to lack of valid information and proper data base of disposal and replacement manual from the manufacturer and supplier the replacement cost is assumed to be zero for the completion of the thesis.

4.2.5 Maintenance Cost (MC)

Works that are undertaken for maintaining proper condition of buildings are considered as maintenance works. The purpose for which the building soley governs the amount of repair and maintenance cost. The main types of repair service:

- Plumbing and water supply which are categorized as day to day repairs service.
- White washing and painting are categorized as Annual repairs works.

Technical guideline of the plaster suggests that it is necessary to clean facade with pressurized water in every three to five years whereas plastered surface in every ten to fifteen years.Pressurized water cleaning bears the equal cost for all types of plasters. Which is why only the coating type can be determined by plaster type.

The types of coating for thin plaster:

Table 4.11 Coating types and plaster types

Type of Thin plaster	Type of coating
Mineral Plaster	Lime
Acrylic plaster	acrylic
Silicate plaster	Silicate
Silicone and Silicone silicate plaster	Silicone

Since these all are one time investment although painting, patching work may have to done in every 6-7 years, depending upon the use, site and weather condition. Plaster is onetime payment at year 0.This cost is zero for other years.

Initial plaster cost of Brick masonry wall = 565362.08 NRS

Initial plaster cost of AAC masonry wall = 282681.04 NRS

Initial plaster cost of CSEB masonry wall = 362844.32NRS NRS

Table 4. 12 Initial plaster cost in Nrs of Brick, AAC and CSEB

Name	Yrs	Unit	Quantity	Rate	Amt	Plaster
Plaster repair cost of Brick(1;3)	25-30	Sq ft	8438.24	67	565362.08	10mm both exterior n interior
Plaster repair cost of AAC(1;3)	25-30	Sq ft	4219.12	67	282681.04	10mm acrylic plaster
Plaster repair cost of CSEB (1;3)	25-30	Sq ft	8438.24	43	362844.32	Lime plaster

So, the PW of M & R cost is,

AW is calculated using equation (4), here I=10% and N=60 years,

PW of Brick masonry wall = 565362.08 NRS

AW = PW$\left(\frac{I(1+I)^N}{(1+I)^N-1}\right)$………………….. (4)

= 565362.08 $\left(\frac{0.1(1+0.1)^{60}}{(1+0.1)^{60}-1}\right)$

= Nrs 56536.208

PW of CSEB wall = 362844.32NRS

AW = PW$\left(\frac{I(1+I)^N}{(1+I)^N-1}\right)$………………….. (4)

= 362844.32 $\left(\frac{0.1(1+0.1)^{60}}{(1+0.1)^{60}-1}\right)$

= Nrs 36284.40

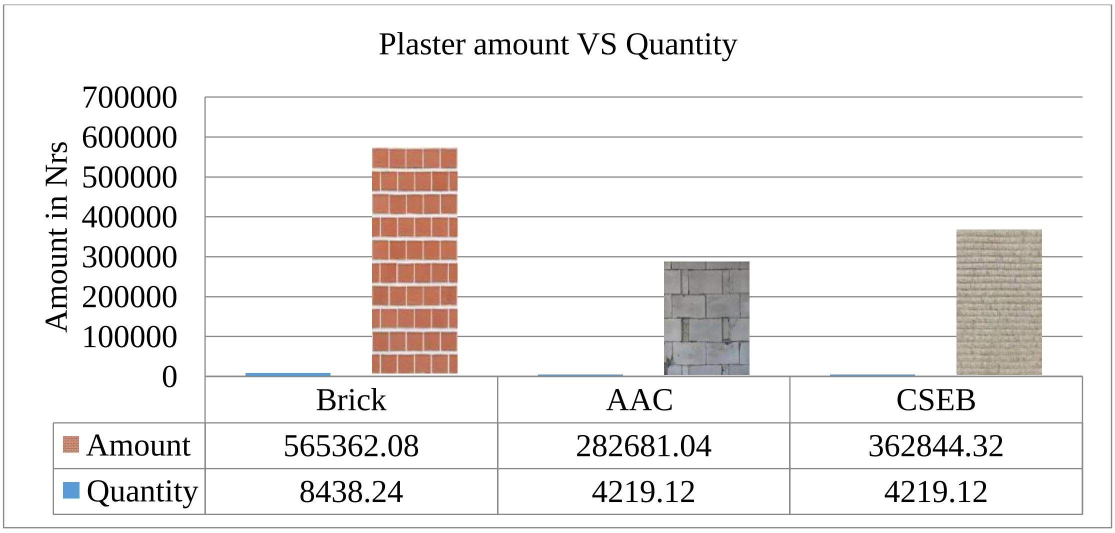


Figure 4.10 Comparison of Plaster amount and plaster quantity according to block type

It is clear from figure 4.10 that the amount of plaster work required in AAC is high for CSEB blocks than AAC block walls.

PW of AAC wall == 282681.04 NRS

$$AW = PW\left(\frac{I(1+I)^N}{(1+I)^N-1}\right)\text{………………….. (4)}$$

$$= = 282681.04 \left(\frac{0.1(1+0.1)^{60}}{(1+0.1)^{60}-1}\right)$$

= Nrs 28268.104

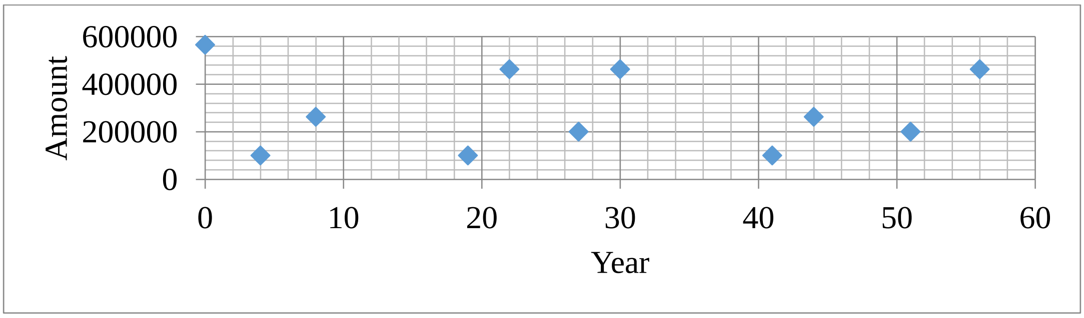


Figure 4.11 Repair cost for Conventional brick

All the data's obtained from local contractors and material suppliers were combined and probability and frequency of maintenance and repair were calculated. The frequency of repair for Brick was highest in its initial construction at and later in years 22, 30, 56 years. The major maintenance were patching, sealing, sealing, plaster of the corners and bases below 3 feet.

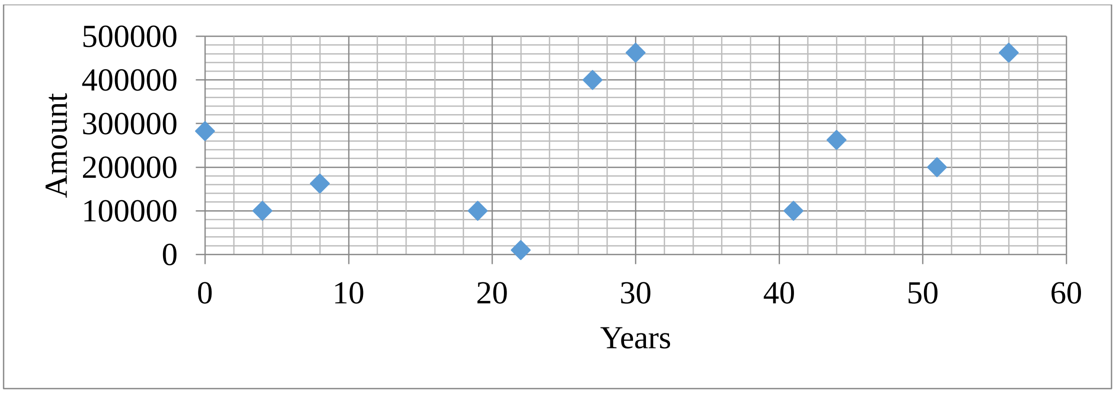


Figure 4.12 Repair cost for AAC

The frequency and amount of repair for AAC was highest by 2,542,681Nrs in its life time of 60years with peak maintenance years at 10, 16,31,45,56 years whereas peak maintenance for AAC were at 30 and 56 years.

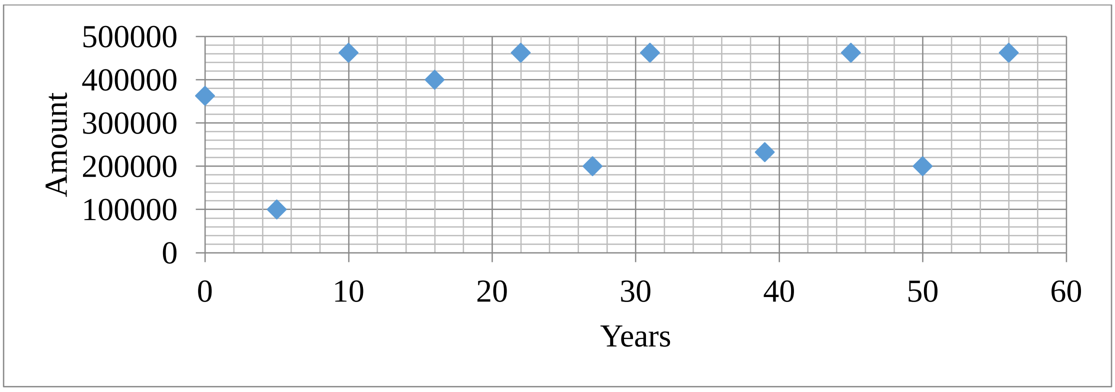


Figure 4.13 Repair cost for CSEB

The frequency and amount of repair for CSEB was highest by 3,807,844Nrs in its life time of 60years with peak maintenance years at 10, 16,31,45,56 years whereas peak maintenance for AAC were at 10,16,31,45 and 56 years. See annex for detail calculation in spreadsheet.

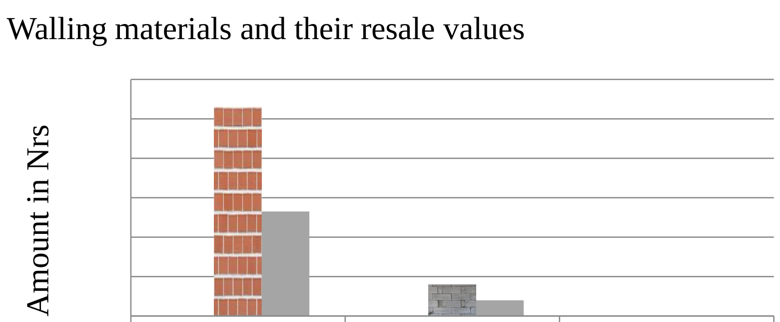
4.2.6 Resale value

Resale value is the final salvage tradable value of a building after its service life, which is 60 years in this study. Only walling materials resale value was taken for final calculation.

Table 4.13 Reusability of Brick, AAC and CSEB block

	Brick	AAC	CSEB
Reusability	60% Jayasinghe C at el. (2005)	10-15% Kreft (2018)	0
Resale Value	60% of 4421.21 =2652.72 x 2 =5305.44	10% of 3971 =397.1 x 2 =794.2	0
Rate per block	2-3 NRs	2-3 NRs	0

The reusability of brick was 60% while it was 10-15% for AAC but was assumed 0 as was cement mix soils and had null resale value.



	Brick Wall	AAC Block	CSEB
Reusability %	60%	10%	0
Resale Value	5305.44	794.2	0
T.Waste @ of Life Cu ft.	2652.72	397.1	0

Figure 4.14 Graph showing Reusability Value of Walling Materials

4.2.7 Comparison of LCC of all scenarios

The costs are calculated in cost per sq ft.The total LCC of Brick was 426.87Nrs/m^2, 425.71 Nrs/m^2 for AAC and 407.28 Nrs/m^2 for CSEB when the production cost and operational cost were excluded from the total life cycle costing.

Table 4.14 Total Life cycle cost of Brick, AAC and CSEB block without Production cost and operation cost

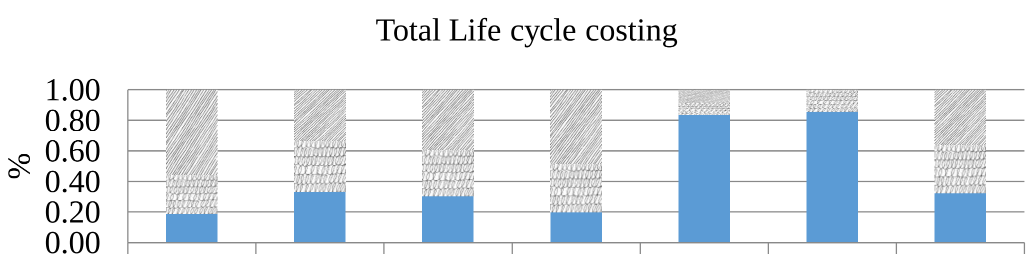
Description	Brick (Rs/m^2)	%	AAC(Rs/ m^2)	%	CSEB(Rs/ m^2)	%
Initial Cost	420.06	76.4	418.77	85.14	419.101	82.06
Plaster Cost	6.7*	23.20	6.7*	14.47	8.6	17.37
Maintenance cost	0.11	0.03	0.17	0.39	0.27	0.55
Resale value	0.06*	0.02	0.01	0.04	0	0
Total (Rs/m^2)	**426.87**	**100**	**425.65**	**100**	**427.98**	**100**

It was found that the initial cost for AAC was lowest compared to CSEB and Brick walls by 23%and 14% respectively. Further, the initial construction of AAC and CSEB contributed to 17% and 15% of the total construction cost when production and operation cost were not considered. But when the operation and maintenance cost were considered AAC contributed to 74.4% and 65.54% of total LCC.

Table 4.15 Total Life cycle cost of Brick, AAC and CSEB block with Production cost and operation cost

Particulars	S1%	scenario 1	S2%	scenario 2	S3%	scenario 3
Production cost	**6.1**	**37.01**	**8.96**	**50.4**	**17.09**	**109.26**
Initial Construction Cost (Nrs)	**69.3**	**420.06**	**74.41**	**418.77**	**65.54**	**419.1**
R&M Cost (Nrs)	**21.2**	**6.7**	**12.65**	**6.7**	**13.88**	**8.6**
Maintenance cost	**0.03**	**0.11**	**0.33**	**0.1757**	**0.43**	**0.268**
Operating cost	**3.17**	**19.23**	**3.65**	**1.93**	**3.06**	**1.89**
Reusability Cost (Nrs)	**0.08**	**0.06**	**0.04**	**0.01**	**0**	**0**
Grand Total	**100**	**483.17**	**100**	**477.99**	**100**	**539.118**

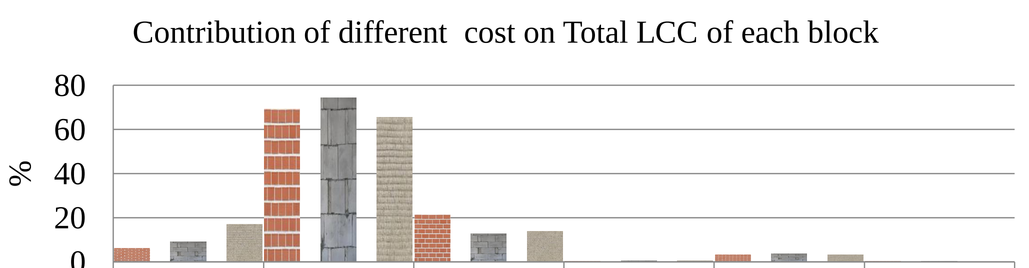
The Initial cost of installation for AAC wall seems to be lowest as compared to conventional and Brick Wall in per m^2. Also the Plastering cost on brick wall and AAC wall were similar as acrylic plaster was assumed for both types whereas lime plaster was assumed for CSEB wall.



	PC	IC	MC	AMC	OC	RC	Total
S3	109.26	419.10	8.60	0.27	1.89	0.00	539.12
S2	50.40	418.77	6.70	0.18	1.93	0.01	477.99
S1	37.01	420.06	6.70	0.11	19.23	0.06	483.17

Figure 4.15 Comparison of % of total Life cycle cost of all three wall materials of sixty years with NPV as of January 1, 2020

The Maintenance cost for CSEB was higher because of patching work charges due to different labor rates as these required more skillful and trained manpower. Further the reusability value of brick exceeds the reusability of AAC and CSEB block, making CSEB the most eco-friendly and 0 waste material in terms of environment pollution. But the LCC of such building material was high with 539.12Nrs/m^2.The brick on the other hand has the second highest LCC at 483.1712Nrs/m^2 and AAC with 477.99Nrs/m^2 as shown in figure 4.17. The results so obtained were similar to that of Morrissey (2011).



	PC	IC	AMC	NMC	OC	RC
S1%	6.1	69.3	21.2	0.03	3.17	0.08
S2%	8.96	74.41	12.65	0.33	3.65	0.04
S3%	17.09	65.54	13.88	0.43	3.06	0

Figure 4.16 Comparison of total Life cycle cost of all three wall materials of sixty years with NPV as of January 1, 2020

It is clear from above figure that initial construction cost contributes which s followed by annually occurring maintenance cost, operation cost and residual cost in descending order.

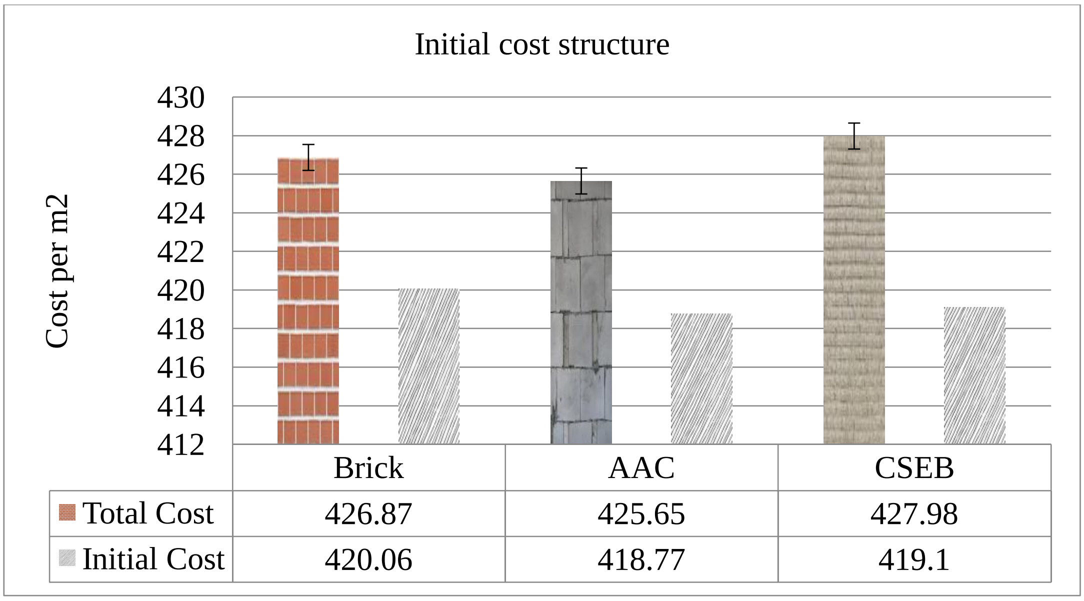


Figure 4.17 Comparison of initial cost wart to total life cycle cost

In the above figure, the initial costs of AAC blocks are highest at 74.41 %, 65.54 % for CSEB and 69.3 for conventional brick walls.

4.3 Financial analysis

NPV and simple payback period are the most efficient methods of calculating LCC of a residential building, Equipment cost, household costs were not taken into account.

1. Simple payback period
2. Net present value (NPV)

4.3.1 Simple Pay Back Period

The amount of time taken to recover the cost invested in any project is known as simple payback period. The shorter the project more desirable the investment. But it ignores the time value of money (TMV).

$$\text{Payback Period} = \frac{\textit{initial Investment made}}{\textit{Net Annual Cash Flow}} \text{........ (5)}$$

The Total investment needed for base case can be seen in BOQ in Annex. If the two floors of the given building is rented for ten thousand rupees per floor (assuming there is no rise in rent i.e. even cash flow annually) and the remaining floors are occupied by the owner.

So,

Annual Cash Flow = Nrs 10000 x 2 floor x 12 months

= 4, 80,000 Nrs per year

For Brick Masonry case,

$$\text{Payback Period} = \frac{9,714,937.63}{480000}$$

$$= 20 \text{ years}$$

For AAC Masonry case,

$$\text{Payback Period} = \frac{9516582.52}{480000}$$

$$= 19 \text{ years } 6 \text{ months}$$

For CSEB Masonry case,

$$\text{Payback Period} = \frac{\mathbf{9567352.52}}{480000}$$

$$= 19 \text{ years } 9 \text{ months}$$

The buildings with the shortest payback are to be accepted. Not only AAC masonry has lower construction cost but the payback period is also shorter in comparison to Brick and CSEB construction. So, AAC can be a better investment for construction of building.

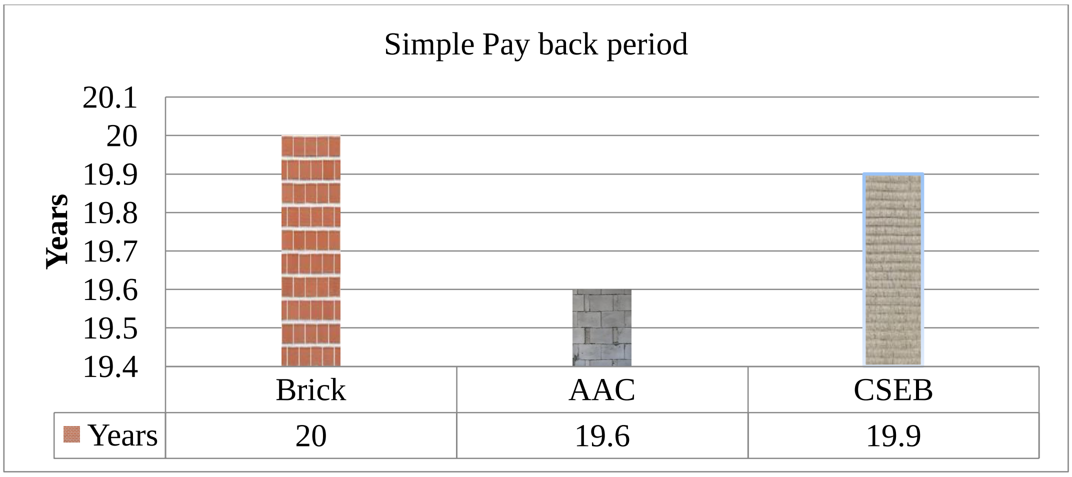


Figure 4.18 Comparison of simple payback period of different blocks

In above figure, AAC block had least payback period at 19 years giving investors the opportunity to recover money in comparatively lesser time.

4.3.2 Computation of Net present Value

Net present value (NPV) uses the net value of all the cash inflows and the cash outflows over. NPV is a capital budgeting and investing technique that helps in analyzing the profitability of investment. Any investment with a negative NPV is not to be perused because it will result in a net loss.

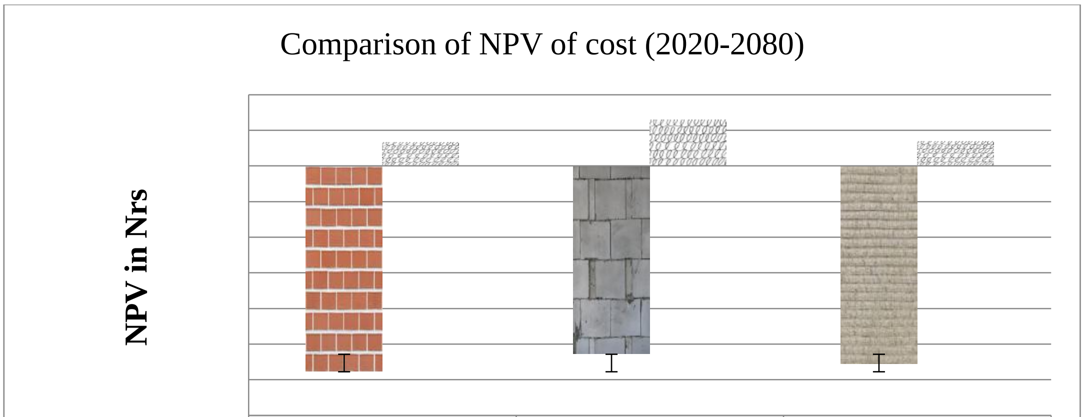
NPV= PW of future Cash Flow-Initial Investment…….. (6)

IRR<Discount rate, NPV= negative value

Table 4 .16 Result of Net present value for Brick, AAC and CSEB

Description	Brick (NRS)	AAC (NRS)	CSEB (NRS)
Investment	9,714,937.63	9,516,582.52	9,567,352.52
Cost of wall	1,861,290.78	1,662,935.67	1,713,705.67
Life span (yrs)	60	60	60
Discount Rate 1	10%	10%	10%
Present Value 1	3,949,812.97	4,241,098.72	4,014,828.98
NPV 1	-5,765,124.66	-5,275,483.82	-5,552,524.04
Discount Rate 2	3.5%	3.5%	3.5%
Present Value 2	10,375,389.07	10,807,999.10	10,262,640.62
NPV 2	660,451,44	1,291,416.58	695,288.10
IRR	4%	8%	6%

The total investment to construct from Brick, AAC and CSEB wall is 9,714,937.63, 9,516,582.52, 9,567,352.52.18 and will be paid back in 20, 19.5 and 19.9 years respectively. In table 4.16, the value of NPV in minus sign shows that 5,765,124.66, 5,275,483.82, 5,552,524.04 will be in loss in 60 years if we use Brick, AAC and CSEB block at 10% but at 3.5% discount rate AAC has double the profit. The detail calculation is shown in Appendix.



	Brick	AAC	CSEB
NPV (10%)	-5,765,124.60	-5,275,483.80	-5,552,524.04
NPV (3.5%)	660,451.44	1,291,416.58	695,288.10

Figure 4.19 Comparison of NPV of cost of different blocks for 2020-2080

The figure above shows that NPV for AAC at 10% and 3.5%, IRR were 4%, 8% and 6% for brick, AAC and CSEB. Any investment with positive NPV is to be perused. It is advisable to per sue NPV with highest amount. In this case the NPV for CSEB block is less by 46% proving cost of AAC to be more profitable in terms of investment.

4.4 Sensitivity analysis

In this study, different assumptions were made on discount rate as it the most important parameter to evaluate the results robustness and is shown in figure 4.25, 4.26, 4.27. With every increase unit in interest rate the actual price of house will depreciate down by 6,49,700 Nrs for AAC and 6,53,670 Nrs for CSEB.

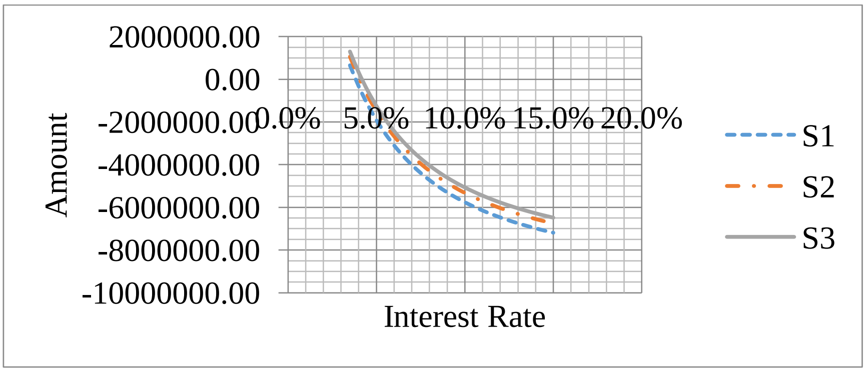


Figure 4.20 Sensitivity analysis for change in interest rate for Npv for base case

Also, if the interest had been zero, buildings salvage value of AAC will be 1,58,932 Nrs for the base case residential building.

4.5 Proposed Design for external wall

It is clear from above calculations that AAC is profitable and consist of lower LCC in comparison with brick and CSEB for temperate climate .The macro pores in its composition restricts the capillary action and provides better insulation and thermal function. However Rainfall in Tokha municipality is particularly high at 1344mm and considering the habitable life of CSEB it was more affected by moisture and humidity which resulted in high maintenance cost. From LCC analysis it is clear that initial, Maintenance and operation cost are the three key parameters on selection of walling material when LCC was considered. Also the solid walls operational saving did not recover the initial construction cost. To address the issue a composite AAC wall section of block size 600x200x100mm can be used.The so proposed wall section can be constructed at same LCC as that of normal AAC block used in this study.

Table 4.17 Details of proposed 250mm AAC composite wall section

U-Value

Thermal Gradient of 100mm AAC Block Component

Sn	Section of wall	Conductivity (K) W/m °C	Conductance(C) W/ m² °C	Wall Resistance(Ra) m² °C/W
1	Outside air film		13.18	0.076
2	16mm plaster work	0.16		0.100
3	100mm AAC Block	0.16		0.6
4	50mmAir Cavity	0.025		2.00
5	100mmAAC Block	0.16		0.6
6	16mmPlaster Work	0.16		0.100
7	Inside air film		8.12	0.123
			Total Resistance(Ra)	3.649
			U-Value	0.2740

Thermal properties

U-Value (W/m²K)	0.274
Admittance(W/m²K)	3.360
Solar Absorption (0-1)	0.418
Visible Transmittance (0-1)	0
Thermal Decrement(0-1)	0.09
Thermal Lag (hrs)	3
Thickness (mm)	274.0
Weight (Kg)	160.065

The above table shows the calculation for U value for the so proposed composite AAC wall of 250 mm. The calculated U value of the proposed section was found to be 0.274.The biggest question in utilizing the alternate wall material was whether the used wall system will aid in operational saving in the long run or not.Thus by calculation it was found that the so proposed composite wall will recover initial high construction cost by 17.8%.Thus ,the proposed wall section can be beneficial in terms of operational saving in the total service life of the residential building in the temperate climate.

Table 4.18 Calculation of operational cost saving for proposed scenario

Calculation		
	Scenario 2	**Proposed**
Particulars	**AAC Solid wall**	**AAC Cavity wall**
Block size	600x200x200	600x200x100
Energy consumed per year	29215.23	25120.89
Energy consumed per month	2434.60	2093.40
Total consumed per month	33967.14	29361.01
Total consumed per year	407605.63	352332.147
Energy difference	1360.532	5454.86
saved consumption%	4.4	17.8

See Appendix:A-D for detail calculation of proposed case.

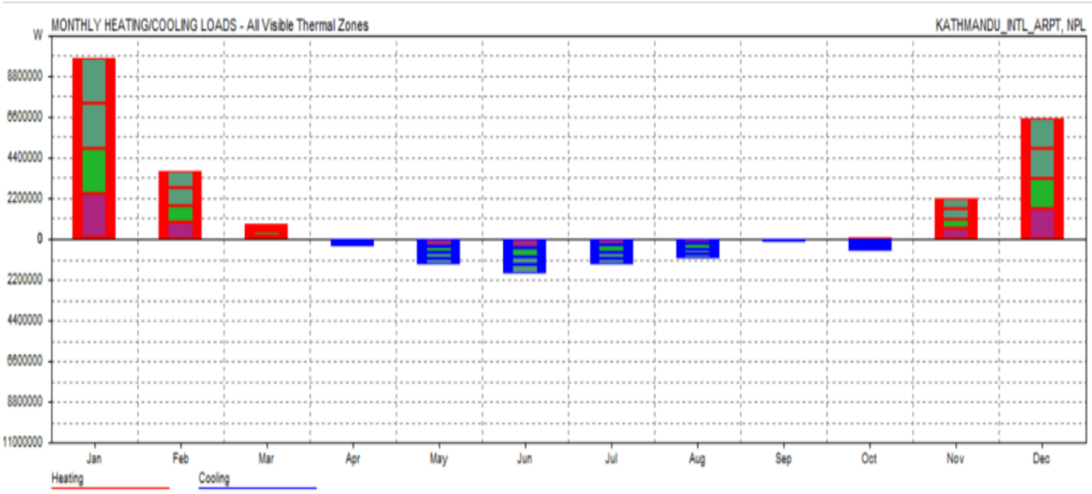


Figure 4.21 Proposed case heating/cooling load calculation

Henceforth, an alternative solution for external walls would be to use composite wall system to recover both initial construction cost from operational saving and achieve thermal comfort as well. From above table it is clear that operational saving can be maximized when using AAC composite structure.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusions

The thesis report depicts results of an effort made to calculate the life cycle costs for AAC, CSEB blocks for external walls with respect to conventional fire burnt clay bricks. The LCC model used in this thesis report can be used for calculation of any type of alternate walling composed of hollow concrete blocks,CLC,rat trap bonds and roofing material provided that the details on quantity of materials, frequency of maintenance, repair and their reusable values are available.

An alternative wall section was proposed after careful evaluation of all the cost and operational saving parameters. It was found that the LCC was lowest for the AAC blocks due to less cost in maintenance and residual cost .The LCC for Brick was found to be Nrs 426/m^2, 425/m^2 for AAC and CSEB 427/m^2respectively .When production and operation costs were considered the LCC was 483.13/m^2,477.98/m^2,539.13/m^2 for brick, AAC and CSEB respectively. The result shows that construction cost contributed to 69% to 75%, maintenance cost contributed 0.03% to 0.43% while repair and reusable costs varied from 0.08% to 0.04%.Similarly, for AAC solid walls it was found that initial construction cost was 74.41% and for CSEB solid walls it was 65.54%.The Simple payback period for AAC blocks were found to be only 19 years in a 60 years life span which is less in comparison to other blocks in this study. Likewise, the NPV of CSEB block masonry is less than AAC block walls by 46% proving AAC to be most profitable in terms of construction and investment point of view. The NPV results were sensitive to discount rates.

The proposed wall section is a modified wall section of 250mm AAC composite wall system. The operational saving of such wall could recover the initial high cost by 17.8%, proving it to be an alternative external wall system for temperate climate homes.

In this manner from LCC point of view AAC proves to be most cost effective material and has least LCC .The obtained results suggest that AAC blocks are worth investing in terms of construction as well as are profitable both for individual clients and as well as big housing projects.

5.2 Recommendations

This research can be further extended to new dimension as well as some of the limitation faced in this research can be overcome in future works to get more accurate Life cycle costs results.

In this present work Life cycle of only external walls of a residential building is calculated and the cost used here assumes disposal and resale value of CSEB block to be zero assuming it is a zero waste block so further work can be carried to study and produce papers on the reusability values of CSEB blocks like AAC and Brick masonry have.

Provided the valid data's and information on operational water usage values, the LCC results could have been more accurate and the Whole Life cycle cost for the residential building could have been calculated.

Also LCC approach here can be used to study green roofs and insulated walls composed of Concrete hollow blocks,CLC blocks, Rat trap bonds in different locations.

It is advisable to use LCC technique for evaluation of alternative option when procuring new construction materials as future cost are crucial parameters.

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APPENDIX

APPENDIX A:HEATING AND COOLING LOAD CALCULATION

FOR SCENARIO 1AND 2

MONTHLY HEATING/COOLING LOADS
All visible Thermal Zones
Comfort
Max Heating: 26.985kW at 20:00 ON 13th January
Max Cooling: 19.801kW at 20:00 ON 20th May

MONTH	HEATING (KWh)	COOLING (KWh)	TOTAL (KWh)
Jan	6644.196	0.000	6644.196
Feb	2638.250	0.000	2638.250
Mar	2197.200	517.000	2714.200
Apr	944.000	670.000	1614.000
May	308.000	940.000	1248.000
Jun	515.000	3314.000	3829.000
Jul	421.000	1418.000	1839.000
Aug	1971.000	176.000	2147.000
Sep	1049.000	293.000	1342.000
Oct	1863.176	558.000	2421.176
Nov	1314.690	0.000	1314.690
Dec	2815.940	0.000	2815.940
TOTAL	22681.452	7886.000	30567.452
PER M2	108.524	37.732	146.256
FLOOR AREA:	209.000		

MONTHLY HEATING/COOLING LOADS
All visible Thermal Zones
Comfort
Max Heating: 25.285kW at 20:00 ON 13th January
Max Cooling: 18.231kW at 20:00 ON 20th May

MONTH	HEATING (KWh)	COOLING (KWh)	TOTAL (KWh)
Jan	9922.196	0.000	9922.196
Feb	5307.000	0.000	5307.000
Mar	157.250	517.000	674.250
Apr	0.000	670.000	670.000
May	0.000	940.000	940.000
Jun	0.000	3314.000	3314.000
Jul	0.000	1418.000	1418.000
Aug	500.000	176.000	676.000
Sep	565.000	293.000	858.000
Oct	524.290	558.000	1082.290
Nov	2005.569	0.000	2005.569
Dec	2475.128	0.000	2475.128
TOTAL	21456.433	7886.000	29342.433
PER M2	105.179	38.657	143.835
FLOOR AREA:	204.000		

FOR SCENARIO 3 AND PROPOSED CASE

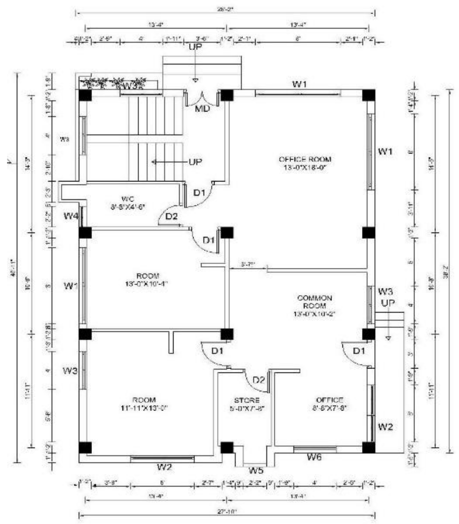
MONTHLY HEATING/COOLING LOADS
All visible Thermal Zones
Comfort
Max Heating: 22.285kW at 20:00 ON 13th January
Max Cooling: 16.231kW at 20:00 ON 20th May

MONTH	HEATING (KWh)	COOLING (KWh)	TOTAL (KWh)
Jan	6500	4589	9607192
Feb	2000	3655	3626505
Mar	703685	2072	785760
Apr	816	259201	260017
May	1223	1140273	1141496
Jun	1870	1636871	1638741
Jul	1707	1249341	1251048
Aug	1420	806782	505184
Sep	774	112339	112013
Oct	51681	536057	587758
Nov	2162246	2900	2165146
Dec	6400573	4373	6404946
TOTAL	21343.4	7841.64	28464.337
PER M2	110.0175258	40.42082474	146.7233866
FLOOR AREA:	194		

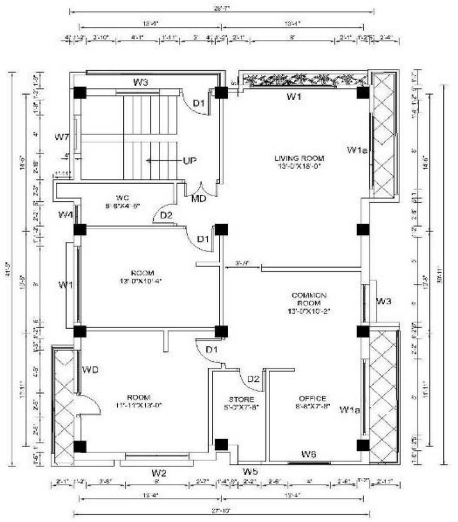
MONTHLY HEATING/COOLING LOADS
All visible Thermal Zones
Comfort
Max Heating: 19.294kW at 20:00 ON 13th January
Max Cooling: 13.824kW at 20:00 ON 20th May

MONTH	HEATING (KWh)	COOLING (KWh)	TOTAL (KWh)
Jan	5522.196	0.000	5522.196
Feb	5307.000	0.000	5307.000
Mar	157.250	517.000	674.250
Apr	0.000	470.000	470.000
May	0.000	940.000	940.000
Jun	0.000	2624.000	2624.000
Jul	0.000	1418.000	1418.000
Aug	500.000	176.000	676.000
Sep	565.000	293.000	858.000
Oct	1524.290	558.000	2082.290
Nov	2005.569	0.000	2005.569
Dec	2475.128	0.000	2475.128
			25120.890
TOTAL	18056.433	6996.000	25052.433
PER M2	91.194	35.333	126.527
FLOOR AREA:	198.000		

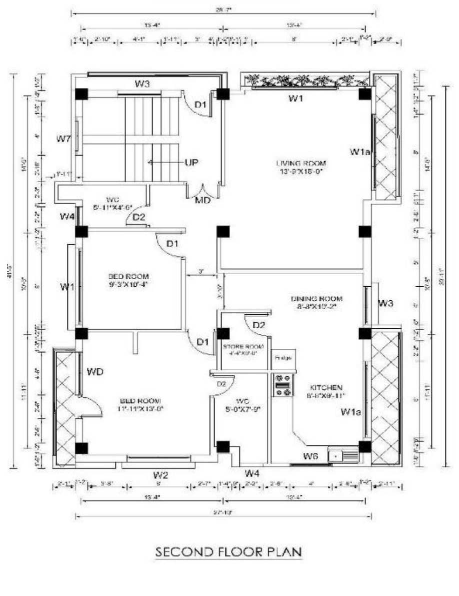
APPENDIX B:TECHNICAL DETAIL OF BASE CASE HOUSE



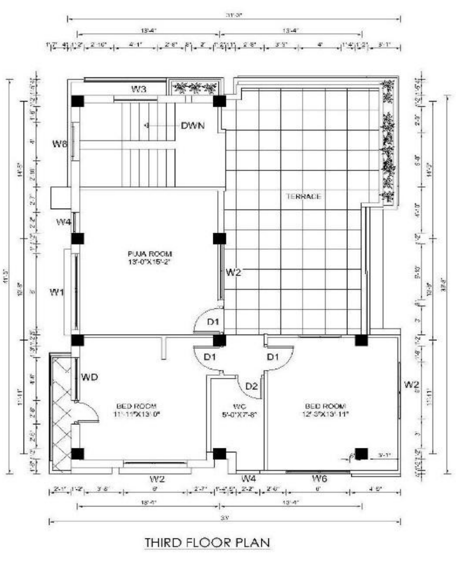
GROUND FLOOR PLAN



FIRST FLOOR PLAN



SECOND FLOOR PLAN



THIRD FLOOR PLAN

APPENDIX C: COST ESTIMATES

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APPENDIX D: CASHFLOW

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APPENDIX E: NPV CALCULATION

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APPENDIX F: SIMILARITY INDEX

Luna_III

ORIGINALITY REPORT

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SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Institute of Engineering, Pulchock Campus, Tribhuvan University Student Paper	1%
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APPENDIX G: PUBLISHED PAPER

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