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Life Cycle Cost Analysis of External Walls:A Comparative Study of AAC and CSEB blocks

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Abstract

Use of green building material is one of five design principles developed by UN Habitat Nepal in the year 2013.The construction industry is rapidly evolving and is in need of many alternative building materials since the conventional materials are in short supply and are causing degradation of the environment. Similarly, the green building drive has surmounted difficult economic and technical obstacles in recent decades due to high cost. Whether the Operational savings of green buildings could recover the initial construction cost is still under debate. Present regulation for projects procured by means of the Private Finance Initiative (PFI) route supports the application of LCC methods precisely as they deliver an evaluation of the long-term cost evaluation of projects. Nevertheless, the implementation of sustainable building practices is still at its lowest ebb. This paper aims to empirically examine the above question by conducting a Whole life cycle cost analysis of residential green building material by comparing the Life Cycle Costs (LCC), Construction Costs (CC), Residual and maintenance cost for AAC,CSEB blocks. The findings show that the annualized average values of LCC, CC and OC of green buildings are NRs 426.87/m^2, 425.65/m^2 and 427.98/m^2 respectively with no significant influence on the OC .The study does not cover energy and water consumption costs. The result shows that construction cost contributed to 76% to 88.64%, maintenance cost contributed 23% to 11% while repair and reusable costs varied from 1% to 2%. Also the NPV of CSEB block masonry is less than AAC block walls by 46 %.

Keywords

Building, Alternate wall material, Life cycle cost

1. Introduction

1.1 Background

The design and construction of a new house is one of the most resource-intensive and economically significant decisions made by developers and consumers. As there is growing pressure to ensure sustainable construction with stricter demands on the cost-effectiveness of construction and operation of buildings with reduction of their environmental impact. Nepalese construction industry contributes 10 to 11 % of nations GDP and uses 35 % of government budget in which 60% is spent through infrastructure development[1]. It is clear that construction is a major sector and any productivity enhancement activity in this sector will have a positive impact in the overall improvement in national economy.

Post 2015 Earthquake Nepal is facing a shortage of 609,938 numbers of new houses[2].Adequate shelter for all people is one of the soughed challenges faced by the developing countries[3].Consumption of material goods is projected to double in 2017 to 2060 AD by United Nation [4]. Hence it has become a necessity to adopt cost effective, innovative and environment friendly housing technologies for construction.

Five design principles have been developed by UN Habitat Nepal [5] in their project–"Promoting Sustainable Housing in Nepal",which includes use of green building materials along with passive solar design, energy efficiency, water conservation and waste management.Further,Nepal Building Code NBC 205 1994 has also recommended studies of alternative building materials and technologies along with seismic hazard mapping and risk assessment[6]. However,the development of efficient building technology in Nepal is still lagging because of the lack of reliable construction data.

Among all types of building blocks in Nepal ,more than 80% buildings [7] are mixed used residential buildings built under contracts and researching on these buildings is meaningful.So,Optimum cost efficiency must be determined to symmetrically align with building energy cost for proper assets management and investment decision.Thus the researcher recommends that there is a need for life cycle cost analysis in terms of innovative material selection and safer building practice.

Acronyms

AAC Autoclaved aerated concrete

CSEB Compressed stabilized earth blocks

LCC Life cycle cost

NPV Net present value

RCC Reinforced cement concrete

2. Related Work

The LCC analysis approach was established in the 1960s and applied by the US Department of Defense[8].In the ISO Standard 15686-5 [9] , LCC is defined as “the cost of an asset or its parts throughout its life cycle, which comprises all stages from construction, operation and maintenance to end-of-life”. Chethana et al. [10] carried out Life cycle costs for various types of insulation material, Wood Panels and different types of external wall structures in the five main cities in Australia and concluded that the maintenance cost of the external walls varies from 13 % to 29 % and the costs of demolition range from 13% to 25 % of life-cycle costs.

Tam et al. [11] carried out LCC analysis of timber materials for green residential buildings in Australia and concluded that the Radiata Pine was the most cost-effective timber for the applications of non-structural works . Wong et al.[12] compared the LCC of roof gardens and average flat roofs. Lu et al.[13] performed LCC analysis on the selection of properties and construction options for a commercial office building in Melbourne. The results showed that the optimum environmentally sustainable development choice was to buy a suitable site with new construction.

The economic evaluation methods for LCC analysis mainly include net present value (NPV), payback period (including both simple payback and discount payback), internal rate of return (IRR). Among them, the NPV is widely utilized in the building industry. It is calculated as the result of the future costs discounted to the present value, based on a discount rate [14]. Esen & Yuksel [15] used the NPV method to compare the cost effectiveness of the greenhouse heating methods (bio-gas, solar and ground energy). Morrissey & Horne [16]calculated the NPV of different energy efficiency alternatives, so as to investigate life cycle costs and environmental savings for volume housing design options in Melbourne.

In the process of applying the LCC analysis method, it is necessary to consider several sources of uncertainties, such as life span, future running costs, discount rate, residual value and other distributional assumptions. In general, sensitivity analysis can be used to examine how data uncertainties affect LCC results and assumptions to be considered [9],[17].Empirically, Islam et al.[18] applied the sensitivity analysis to analyze the effect of discount rate by changing the discount rate from 3% to 6% and found increase in total LCC, operation, maintenance and disposal costs . Furthermore, LCC analysis is mainly applied from the perspective of building components [19], materials[20], [3] and technologies [16],[21],[22].That is, although there are wide ranges of LCC studies applied to the building industry, most researchers only studied the costs of buildings components and/or energy-efficient technologies or the costs of one or several entire building.

3. Methodology

The research methodology can be summarized into three stages.In the first stage,relevant parameters regarding LCC were defined including construction cost,operation costs,discount rates and life span.In second stage Preliminary Bill of quantities (BOQ) were calculated in order to account the amount of material required to build the base house according to 2019 market Prices.In the third stage, 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.

Detail Financial analysis was conducted to determine the economy of residential building.The sensitivity analysis was conducted in the end to evaluate the robustness of the results and the effects caused by the value of main parameters.The Life cycle stages according to EN 15804:2012 in table 1 in page number92.

3.1 Base case house

This study considers the building at Tokha Municipality as a case study [23].It has proposed housing morphology's for the proposed area.[24].It is a rapidly growing rural market developed at the edge of Prithivi highway with temperate climate.[24].

Technical drawings of ground and upper level and facade for base case house is shown in figure 1 in page number 92.

The building is oriented in the north–east. It is a 41-ft tall double story building and occupies the floor area of 1086sq. ft. with two bedrooms open plan living to dine together on each floor, Separate bathroom shower and a store room on each floor. It has total building wall surface of around 32,481sq. ft including window area of 2000sq. ft. The layout of the selected building is shown in Figure 2, and its external wall configuration and physical properties is illustrated in table 2 in page 92 .

3.2 Walling material selection

According to passive design tool kit, thermal insulation has impact on the interior surface temperature of the envelope which in turn directly affects the thermal comfort.The inside surface temperature must remain high enough to-avoid condensation during winter and heat exchange is in the direction of decreasing temperature.(i.e either by conduction ,convection and/or Radiation). To contribute to this effect,building envelopes should ensure high thermal mass material like concrete,brick and tiles.

With sustainability index of 0.23, it was found out that brick is most socio-cultural sustainable wall material[2] .Without compromising the socio cultural index of the brick and work ability external walls of buildings can be replaced with more workable and cost efficient conventional masonry blocks like CSEB and AAC blocks, as these have the lowest embodied energy and low carbon emission in manufacturing and construction phase [25].This research paper has studied only the affect of external walls and the internal walls were kept fix i.e. of 4 inch brick for all cases.

CSEB consists of soil 15% gravel,50% sand ,15% silt nd 20% clay and uses 7-10% cement for stabilisation.Also AAC consists of Fly ash or sand:Lime:Cement:Gypsum of 59:20:8:3 mix with 0.08% of aluminium powder.Due to 40% to 60% of void and aluminum used ,these assists in increasing its volume by 2-5 times its original volume.

Comparison of Thermal and physical properties of Brick, CSEB and AAC block is shown in table 3 in page number 93.

3.3 Life cycle cost accounting for period of 60 years

The life of building is determined by the usefulness of the materials used in construction. The projected lifecycle for brick houses is usually around 35–60 years, AAC blocks have an estimated life of almost 100 years and the minimum service life of a CSEB is 50 years. The material itself will almost certainly outlast that time frame,, but the electrical and other components within the building envelope even with regular maintenance will not comply in that time frame [26]. However, for the calculation of life cycle cost, equal life is assumed average 60 years.

4. Result and Discussion

4.1 Rate analysis summary

The rate analysis for brick wall masonry was taken as 421,418 AAC block and CSEB block to be 402.73 NRs per square feet.

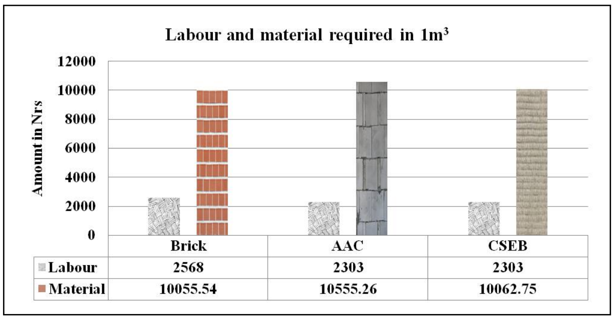

Figure 2: Comparison of amount of labor and material required in $1/m^3$

The amount of Material required between CSEB and Brick differs only by 7rs while in terms of labor 265Rs between both AAC ,CSEB and Brick.

Table 1: Life cycle stages according to EN 15804:2012 [14]

product stage			Construction Process stage		Use Stage							End of Life Stage				Benefits beyond system boundary		
Raw Material supply	Transport	Manufacturing	Transport to site	Installation to building	Use	Annually occurring Maintenance	Non Annually occurring Maintenance	Repair	Replacement	Operational energy use	Operational water use	Demolition	Transport	Waste process	Disposal	Resale	Recovery	Recycle
1	2	3	4	*5	*6	*7	*8	*9	*10	11	12	13	14	*15	*16	*17	*18	19
*Marked modules are included in the paper																		

Table 2: System description of case study building

SN	Building Element	Description of case study building
1	Wall	0.23m exterior walls with uncolored mortar,no insulation, Acrylic paint finish except for wet areas walls,0.1m Interior wall with 10mm smooth finish
2	Foundation	RCC strip footing and 100mm concrete slab on ground
3	Floor	Tongue and wooden groove wooden board on 0.15m thick RCC concrete slab and tiles for Wet areas.Floor decking:Plywood, joist spacing as per manufacturer specification. 100.89/m^2 per floor
4	Roof and Ceiling	0.15m thick RCC concrete slab, 10mm smooth finish plasterboard ceiling. Total roof area: 100.89 /m^2
5	Door	Timber paneling inside room Aluminum door in toilet and verandah
6	Window	Single glazed aluminum frames with powder coating and iron grill on outside for ground floor.Fly screen not included. Total area of doors and windows 22/m^2
7	Painting	External walls:Two coat of acrylic glazing, Doors: two coats of glass acrylic and mouldings:two coats gloss enamel

Figure 1: Technical drawings of typical floor plan,wall section and facade for base case house

Table 3: Comparison of Thermal and physical properties of Brick, CSEB and AAC blocck

Thermal Performance	Burnt Brick	CSEB Block	AAC Block
Size(mm)	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
Specific Heat capacity (J/K)	0.84Kj/Kg K	0.85 Kj/Kg K	0.84 Kj/Kg K
Thermal Conductivity(K)	0.81 w/ mK	0.86 w/ mK	0.16 w/ mK
Acoustics at 500 HZ	50db for 230mm wall	50db for 400mm wall	45db for 200mm wall

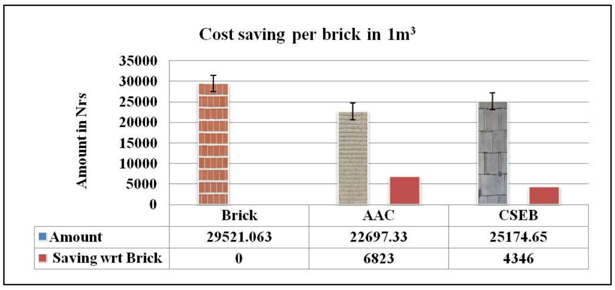

Figure 3: Cost saving in 1/m^3 wall Vs Block types in Nrs

The amount difference between CSEB block and brick wall was found to be 180rs while AAC exhibited 14 times more then Brick walls (2606 Nrs) in terms of blocks

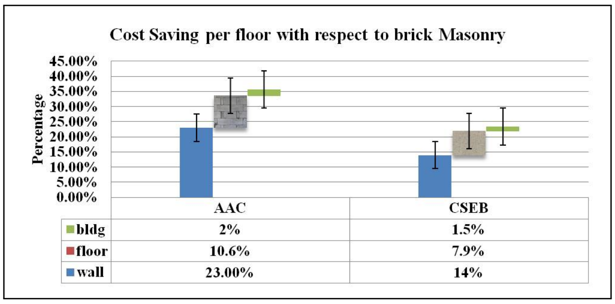

Figure 4: Comparison of % Saving with respect to brick Masonry

It was found that 1.5% of saving can be done on total construction when CSEB was used.

4.2 Initial cost

The initial cost of different walling materials was taken into consideration in respect to the total cost of the building. The ratio of the walling materials cost indicates the economic feasibility of the walling materials. The higher the % which included to walling materials is lower in economic sustainability.

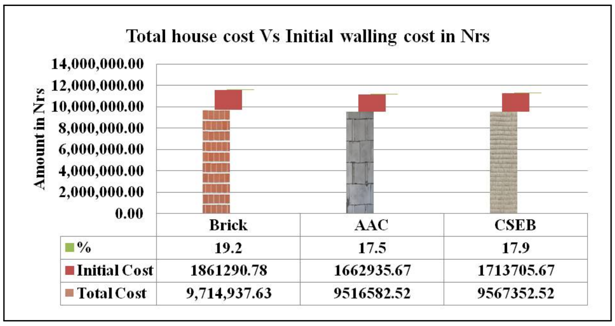

Figure 5: Comparison of Total house cost and walling cost

When intial cost to total cost was taken into consideration CSEB governed 17.9% of total construction and 17.5% of AAC block.So higher the % of initial construction lesser in economical sustainability.

4.3 Maintenance cost

Maintenance cost of the building calculated only for the walling material. Other maintenance works such as roof flooring etc. were omitted from the analysis in order to understand the cost changes due to walling materials.

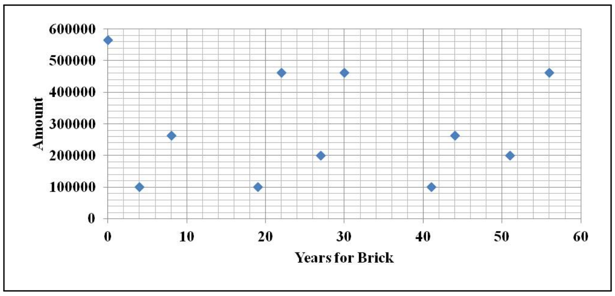

Figure 6: Frequency of maintenance for Brick in 60years

The major maintenance work taken into consideration were patching,sealing of cracks,plaster of the corners and bases of wall below 3 feet.

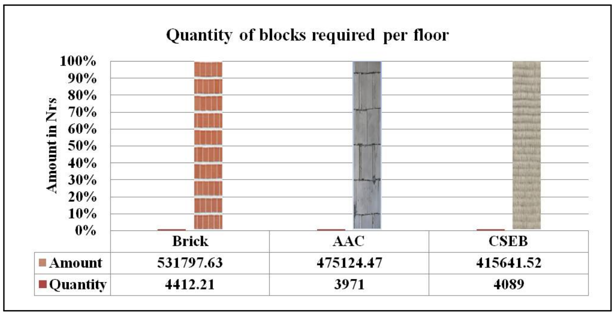

Figure 7: Frequency of maintenance for AAC in 60years

The frequency and amount of repair for AAC was highest with 25,42,681 Nrs in it 60yrs life cycle with peak repairs at 30 and 56 yearsrespectively.

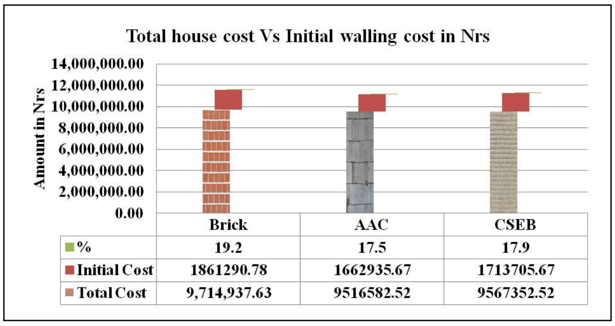

Figure 8: Frequency of maintenance for CSEB in 60years

The frequency and amount of repair for CSEB was highest by 38,07,844 Nrs in it 60yrs life cycle with peak repairs at 10,16,31,45 and 56 years.

4.4 Replacement cost

The replacement of a structure is assumed to occur at the end of the given functions life time, where the replacement costs are determined by the sum of disposal costs and the acquisition costs. 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 LCC calculation.

4.5 Re-usability value

Resale value is the trade value of a building after using for a specific period. But in this case, it is sixty years. But the problem is after sixty years the basic house cannot resale. Therefore, the re usability of materials is taken into consideration. Since this is about walling materials, walling materials resale value only taken into final comparison.

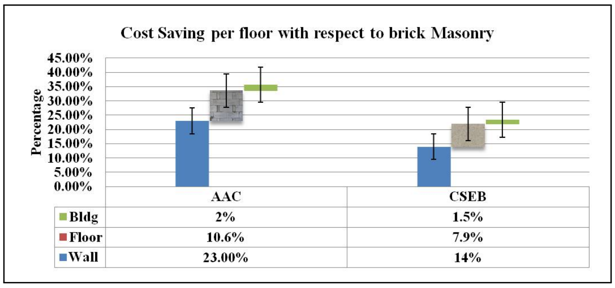

Figure 9: Graph showing Reusability Value of Walling Materials

4.6 Total life cycle cost

Life cycle cost is a combination of all the cost incurred from construction to the end use of the building. The LCC comes from three different stages in the building process: initial cost, maintenance cost, and replacement cost. Most of these building materials are recyclable and reusable for another use. The reusable material cost was deducted from the total cost and total life-cycle cost of the building was calculated. 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 calculation. It is assumed that material with lowest LCC is to be pursued.

Table 4: Comparison of LCC

Description cost	Brick (Rs/m^2)	AAC (Rs/m^2)	CSEB (Rs/m^2)
Initial	420.06	418.77	419.101
Maintenance	6.7	6.7	8.6
Repair	0.11	0.17	0.26
Reusability	0.06	0.01	0
Total (Rs//m^2)	426.87	425.65	427.98

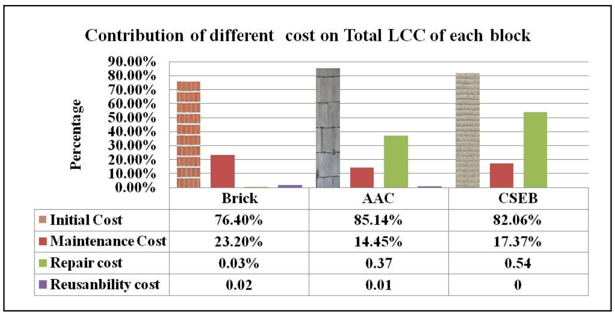

Figure 10: Comparison of total Life cycle cost of all three wall materials of sixty years with NPV as of January 1,2020

It was found that LCC for AAC was 425.65/$m^2$and 427.98/m^2 respctively.And by rule the one with the Lowest LCC are to be per sued.

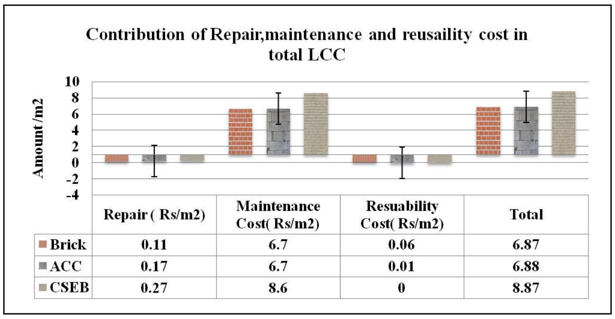

Figure 11: Contribution of Repair, maintenance and reusability cost in total LCC

4.7 Financial analysis

There are many methods of calculating life cycle cost of a residential building. Since this research is to compare walling material LCC, equipment cost and other household expenses were neglected. But the most common LCC costing techniques were used to calculate the life cycle cost of single affordable housing unit while changing the walling materials.
1. Simple payback period
2. Net present value (NPV)

4.7.1 Simple payback period

Simple payback period is the time taken to return the investment to build the house. This is simple as "if the house is rented to similar use the payback period of the house" And the interest rates and cash flow or taxation were included in the calculation.

$$Paybackperiod = \frac{initialinvestmentmade}{netannualcashflow} \quad (1)$$

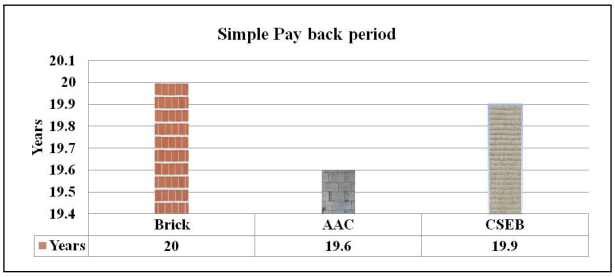

Figure 12: Comparison of simple payback period of different blocks

The building with the shortest payback are to be accepted.In this case the AAC block had the least payback period of 19 years giving investors the opportunity to recover money in comparatively lesser time.

4.7.2 Net present value

Net present value method is preferred for calculation of future costs based on the present data collected [14].It is used in capital budgeting and investment planning to analyze the profitability of a project. Following formula was used for NPV calculation.

$$NPV = \sum_{i=t-1}^{t} \frac{cashflow}{(1+i)t} - initialinvestment \quad (2)$$

The figure 13 shows that NPV for AAC at 10% and 3.5% , IRR 4% for both cases. It is assumed that an investment with a positive NPV will be profitable.

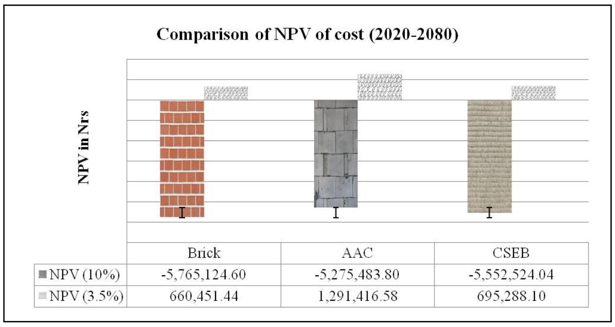

Figure 13: Comparison of NPV of cost of different blocks for 2020-2080

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.

4.8 Sensitivity Analysis

On account of the uncertainties of parameters and assumptions,the sensitivity analysis can be applied to evaluate the effects on NPV,LCC of projects by changing the parameters main value.In this study,discount rate is the most important parameter to evaluate the results robustness and is shown in Figure 14.

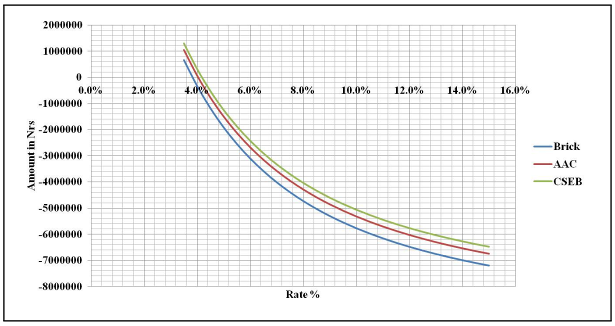

Figure 14: Sensitivity analysis for change in interest rate for Npv

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.Also if the interest had been zero at the end of building life cycle the salvage value for construction out of AAC will be 15,89,327 Nrs for the base case residential building.

5. Conclusions and future works

This paper presents evaluation of different costs that are incurred during construction of a single family residential house .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 which is similar to those reported by McLeod [27].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 426m^2,425m^2 for AAC and CSEB 427m^2respectively.Also these blocks exhibited similar characteristics to that of a conventional brick wall in terms of maintenance and re usability.Also 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 when different assumptions such as frequency of repair and resale value, building life span, different discount rate were made.

In this manner from LCC point of view AAC proves to be best cost effective material and has the lowest Life cycle cost. Further,this study suggests that if valid information and proper data base of operational water usages and disposal were available the calculation of LCC would have been more accurate. The LCC modeling approach presented in this research can be applied to study green roofs and insulated walls in different locations.

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