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ENERGY CONTENT OF WALLING MATERIALS- A COMPARISON OF MUD CONCRETE BLOCKS, BRICKS CABOOK AND CEMENT BLOCKS IN TROPICS

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Abstract: The concept of embodied energy can be used to understand and develop energy saving products or services. By definition the embodied energy is sum of all the types of energy consumed while producing specific product or a service. The embodied energy can be calculated by dividing the total; process of production and measuring each and every process energy consumption. The mud concrete block is a novel ecological walling material. The intention of this paper is to calculate embodied energy and carbon emission, compare in a real world scenario of constructing one square (10ft x10ft) wall of mud concrete block and compare with industrialized walling materials such as brick and cement blocks.

The energy consumption of mud concrete block was on account of transport of raw materials (cement) to the factory and the already embedded energy of cement. The cement was a governing raw material in adding energy content to the total embedded energy of mud concrete block. The brick showed comparatively highest embedded energy. And the cement block had intermediate energy content. The Brick production was using more or less sustainable energy sources such as bio mass, bio mass is renewable. But mud concrete block and cement block using non renewable energy sources which can be replaced by renewable energy sources

Keywords: Embodied Energy, Energy content, process analysis, MCB, Brick block and cement block

1. Introduction

Selecting energy-efficient construction method or construction materials for affordable dwelling units have an effective impact on environment conservation[1]. Because the number of units is higher comparing other building types[2]. Calculating embedded energy content is in a way stepping toward environmental conservation[3]. Tropical countries such as Sri Lanka the construction energy cost is substantial than operation energy cost, simply because there is no heating load[4][5].

The energy throughout its manufacturing stages has to be analyzed according to the energy consumption. However, it's a process. And the total account of the energy consumption has to be analyzed in the same line to calculate the total energy cost of the building. The energy consumed in production transport and construction called the 'embodied energy' of the material. And the maintenance cost and repair energy cost consider as the life cycle cost of the building material[6].

1.1 Significance of walling material and its' energy content

Buildings are constructed with a variety of building materials and each material has some amount of embedded energy[7]. Walling materials are important because it plays an immense role in the total cost of the building, life cycle cost, and energy content. It accounts for more than 30% of the total cost of the building. And in tropics, the roof and wall material is important in reducing the external heat gain into the indoor.

walling materials help to reduce direct heat gain to the building[8]. Therefore, which is very important to understand life cycle cost incurred by walling materials[9]. At the same time, walling materials directly impact with the outdoor environment, especially in a tropical climate where the walling material direct impact with monsoon rain and wind conditions[10]. Therefore, the life span and life cycle cost are very important in analyzing the value of walling materials[11].

1.2 Recent attempts to compare different walling material's and their life cycle cost

Table 1: Recent attempts to calculate life cycle cost of different buildings and building materials

Source	Country	Nos. of cases	Type of building	Type of walling materials	Size (m^2)	Life-span
Adalberth [1]	Sweden	1-2	Res.m	Gypsum wall board	700-1520	50
Atsushi Takano[12]	Finland	5	Other	Brick ,Cement fiber board, Wood plank, Galvanized steel sheet	120	50
Cole and Kenan [13]	Canada	14-25	Office	Wood and steel frame	4620	50
Crawford, Robert H[14]	Australia	1	Res.	Bricks	254.2	50
Dutil, Rousse, Daniel[15]	Canada					
Emmanuel [16]	Sri Lanka	4	wall	Brick, Cement blocks, Wattle, and daub	10m²	60
Fay et al. [17]	Australia	26–27	Res		128	50
Feist [18]	Germany	28–33	Res	gypsum plaster covering all internal surfaces; woodchip wallpaper, water paint	156	80
Hallquist	Norway	–	Res m		?	40
Hamidul Islam D[19]	Australia	3	Res.	FC Sheet, Building paper (reflective foil) Insulation and Air gap Softwood plates, studs, noggins Plasterboard	101	50
Keoleian, Gregory a Blanchard, Steven Reppe, Peter[20]	USA	2 (re)	Res.	Brick	228 m2	50
Li, Zhuguo[21]	Japan	3	store	Steel structure, steel cladding	15000 2000 1800	--
Mithraratne and Vale [22]	New Zealand	36–38	Res	Timber studs and wall framing, plaster board, insulation, skirting, brickwork, mortar, cavity ties, ashings Fiber cement weatherboard Wooden paneling External rendering	94	100
Scheuer et al. [23]	USA	39	Other	aluminum/glass curtain wall, partially concrete masonry unit/brick facing, glass fiber heat insulation, U-value 0.134W/m² K (0.043 Btu/h ft2 F); fourth, fifth and sixth floor: pre-cast concrete planks, glass fiber heat insulation	1	75
Suzuki and Oka [24]	Japan	40–49	Res	wooden ,lightweight steel	1253–22,982	40
Thormark [25]	Sweden	50	Res		120	50
Winther and Hestnes	Norway	52–56	Res		110	50
Winther [26]	Norway	–	Office	Exposed brick	4800	1
Zimmermann et al. [27]	Switzerland	57–60	Other	Diff.	Na.Avg.	50
Fay et al. [17]	Australia	26–27	Res	Brick, Timber	128	100

***Res – residential Building re- retrofit**

1.3 The objective of this research

The objective of this research is to emphasize the energy content of different walling materials used to build affordable houses in Sri Lanka and compare their life cycle cost. And also, this research may help to make a concrete argument in selecting walling materials not only for the construction but also for the total lifespan of affordable dwellings in the country.

2. Methodology

2.1 Selecting walling materials for the comparison

There are plenty of walling materials in the world. Most of them are solid and few of them considered as lightweight materials. But in developing countries walling material was selected by considering only a few constraints; Availability of materials (Supply) and Construction technology (craftsmanship) [28].

Due to the high solar radiation and heavy monsoon rain, tropical countries such as Sri Lanka, people tend to select solid walling materials such as brick, cement blocks or stone etc. For an example brick and cement block are well-established industries.

Therefore, the capital cost of those walling materials is very low[29][30]. Mud concrete block was added because it's a trending walling material in Sri Lanka. This is not the typical cement stabilized compressed soil block [31][32]. Mud concrete block is a walling material made of concrete [33][34]. In the composition of MCB, sand and metal of concrete are replaced by fine and coarse aggregates of soil. The precise gravel and sand combination governs the strength of the MCB. Cement in this soil concrete is also used as a stabilizer in very low quantities.

But, walling materials such as timber posts steel sheets and wooden sheets were omitted from the research considering its structural changes due to the change in walling materials. And the wall thickness was considered as identical in all the buildings used to calculate the energy content and life cycle cost of the building. However, after the definition of all these walling materials, the energy content was analyzed accordingly. The next step of analyzing the walling materials is to compare and developed a base case for the comparison of walling materials analysis.

2.2 The base model for life cycle cost comparison.

The basic affordable house model for embodied energy comparison and life cycle cost was defined by previous research. The model house developed by the national housing authority as the affordable housing model was used to understand the life cycle cost of the residential house. The base model is consisting of basic housing requirement in the country.

Description of Basic House

Ministry of Housing & Samurdhi in Sri Lanka has launched a hundred-day program to develop hundred and fifty thousand houses in the country. Most of these designs are built all over the country. And these are a low-cost house designed developed by both government and institutional level units to remove poverty in the country.

These basic house designs were given to locals as a manual of building their house. The house manual was given to general public with a costing sheet and a material sheet. And these experimented in different locations in the country before commencing the final program in the country[35]. The house design was published by the national housing development authority and Samurdhi division[36].

The basic home is consisting of following spaces and it's very simple for any worker to understand.

- Level site
- Floor area of 500 Sq.Ft (46.4m2)
- Two bedrooms with open plan living to dine together
- Separate bathroom shower
- 10 lights, seven power units, and three fans

Figure 1: Sri Lankan basic home built over the entire island

And the passive building techniques such as orientation and ventilation techniques were used to develop the basic home design into the better building with the less operating cost to optimize the life cycle cost. And the material pallet was decided by considering the most common building materials in the country. And the model analysis assumed that the building location is in a non-land sliding location where no precautions should be taken in order to prevent any building collapse within the total life span of the house.

2.3 Energy accounting and LCC calculation for basic house model

Preliminary bills of quantities were calculated in order to account the amount of materials required to build the basic house model. Addition the costing was done in order to understand the cost variation of different walling materials. Subsequently, the total energy account was transformed into the life cycle model where the total energy consumption of a period of sixty years (one life span) was calculated considering the maintenance and replacement energy cost.

2.4 LCC accounting for period of sixty years

The sixty-year life span of the affordable house was defined by using British standards. The sixty-year definition helps the research to omit unnecessary calculation. However, all the selected walling materials have the life span more than sixty years, therefore, the replacement cost of walling materials was neglected from the LCC calculation process. But necessary maintenance cost was included while calculating the total life-cycle cost of the building. Hence, the total life cycle cost is

$$LCC = IC + (MC + EC + Oc) + Uc - Rv \quad (1)$$

IC	*-Initial cost (BOQ)*	CC	*-Cleaning Cost*
MC	*-Maintenance Cost*	Oc	*-Overheads Cost*
EC	*-Energy Cost(cooling load per sixty years)*		
UC	*-Utilization Cost*	Rv	*-Resale Value*

Initial Cost (IC)

The initial cost of the basic house was calculated by using Bills of quantity sheet considering 2016 market prices. Quantities were calculated by using TDS sheet. And then the walling materials changes and the quantity changes due to the change in walling material were added to BOQ.

Maintenance Cost (MC)

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.

Energy cost (EC)

By all mean basic houses in Sri Lanka doesn't use air conditioners to cool their houses. Therefore, the energy cost is more or less zero. But in order to understand the thermal comfort factors and the cooling load incurred by differentiating walling material, we assumed that all four types of different walling material used houses are using an air conditioner to cool their house. The energy cost of cooling loads was calculated by using design building software for a period of sixty years.

Table 2: U-value calculations of different walling materials

walling materials	U value	Reference
Brick	2.110 W/m²K	[39][40][16]
HCB	2.617 W/m²K	[39][40]
Cabook	3.756 W/m²K	[41]
MCB	2.315 W/m²K	(measured and tested via simulations)[42]

U-value

U-values measure the efficiency of a walling material as an insulator for buildings[37][38]. The lower the U-value is, the better the walling material is as a heat insulator for a tropical country. For example, brick is a comparatively better heat insulator than cement block walls. Thence brick u value is lower than cement block U value[19].

Perhaps, the efficiency of a walling materials can be easily compared by using u value. But at the same time, the thickness of the walling materials effect on U value.

U *values of different waling materials used in this study.*

Resale 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 reusability of materials is taken into consideration. Since this is about walling materials, walling materials resale value only taken into final comparison.

2.5 LCC techniques

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

Table 3: Embedded energy calculation for 570 Sqft. House

Item	Material	Brick	Cement Block	Cabook wall	MCB
Wall Thickness		Tks-150mm	Tks-150mm	Tks-150mm	Tks-150mm
Foundation	Random rubble	3516.5 MJ	3516.5 MJ	3516.5 MJ	3516.5 MJ
Wall (Square meter 150)		2269545.5 MJ	246174853.5 MJ	24906.1 MJ	51158.7 MJ
Roof Work	Wooden frame clay tile	480408.5 MJ	480408.5 MJ	480408.5 MJ	480408.5 MJ
Doors & Windows	Con. frame and wood	985.4 MJ	985.4 MJ	985.4 MJ	985.4 MJ
Floor concrete	concrete	6603.6 MJ	6603.6 MJ	6603.6 MJ	6603.6 MJ
Bathroom	Bathroom fittings	1840.9 MJ	1840.9 MJ	1840.9 MJ	1840.9 MJ
Electrical	Fittings	10676.0 MJ	10676.0 MJ	10676.0 MJ	10676.0 MJ
Internal wall plastering	Cement mortar	421.4 MJ	421.4 MJ	421.4 MJ	421.4 MJ
Internal Painting Work	Emulsion paint				
External wall plastering	Cement mortar	283.1 MJ	283.1 MJ	283.1 MJ	283.1 MJ
External Painting Work	Emulsion paint				
Septic tank	Precast concrete	80.6 MJ	80.6 MJ	80.6 MJ	80.6 MJ
Total material embedded energy		2775159.1 MJ	246679669.5 MJ	530519.7 MJ	556772.3 MJ

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 inflation and interest rates and cash flow or taxation were included in the calculation.

Net present values (NPV)

The net present value is simple as the value in the present of a sum of money incurred in the future. And the all the future financial investments arise throughout the life of an investment. In this case, NPV calculated for the period of sixty years (see the equation 2).

$$NPV = \sum_{t-1}^{T} \frac{Cash\ Flow_t}{(1+i)^t} - initial\ cash\ (investment) \quad (2)$$

t = Cash flow requirement

i = interest rate assumptions

3.Results

3.1 Embodied energy

Embodied energy in selected walling materials calculated without the internal and external plaster work. Plastering work was calculated separately to understand the materials contribution to the total embodied energy of the house. And it was assumed that all the walling material constructed with the similar smooth finish. In addition, stretcher bond was used to build all four types of walls.

It was assumed that all the labor available within the site. The mortar was mixed at the same place where the brick wall was being built. Mortar mixings done by using human labor, no machinery is being used whatsoever while building the house wall.

3.2 Life cycle cost

Calculating Life cycle cost of sixty years

The initial cost of the basic house was calculated by using bills of quantities. The bills of quantities were prepared according to 2016 market Prices. Quantities were calculated from the materials inventory used to calculate the embodied energy. The similar format was used to compare as well as to contrast the initial cost of walling materials in different walling type houses.

4. Analysis

4.1 Embodied energy

The analysis shows that roof and walling material govern the bigger portion of the total embedded energy of an affordable dwelling Sir Lanka. The comparison of different walling materials shows that Brick has the highest embedded energy content and cement shows the second highest embedded energy. The Cabook walling materials have the lowest embedded energy because of it is a natural walling material.

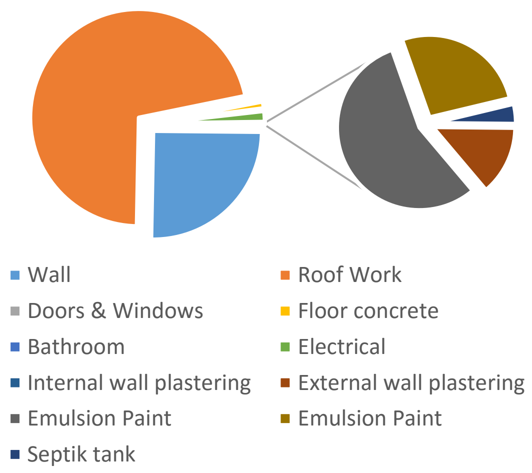


Figure 2: embedded energy comparison

The brick has the highest embedded energy on account of the biomass used to manufacture bricks in Sri Lanka [43]. However, mud concrete block as a walling materials and best substitute for the brick and hollow cement block shows the comparative lowest embedded energy.

4.2 Initial cost and walling material 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 percentage which included to the walling materials are lower in economic sustainability.

Considering, all the other walling materials, brick and cement block are very expensive. At the same time, they are contributing an expectant amount to the total cost of the house. Therefore, walling materials such as mud concrete block are much more cost effective. But the real analysis should consider the effect of walling material in the long run. Therefore, the research was extended with cooling load calculations. The cooling load is calculated basically to calculate the sustainability of different walling materials.

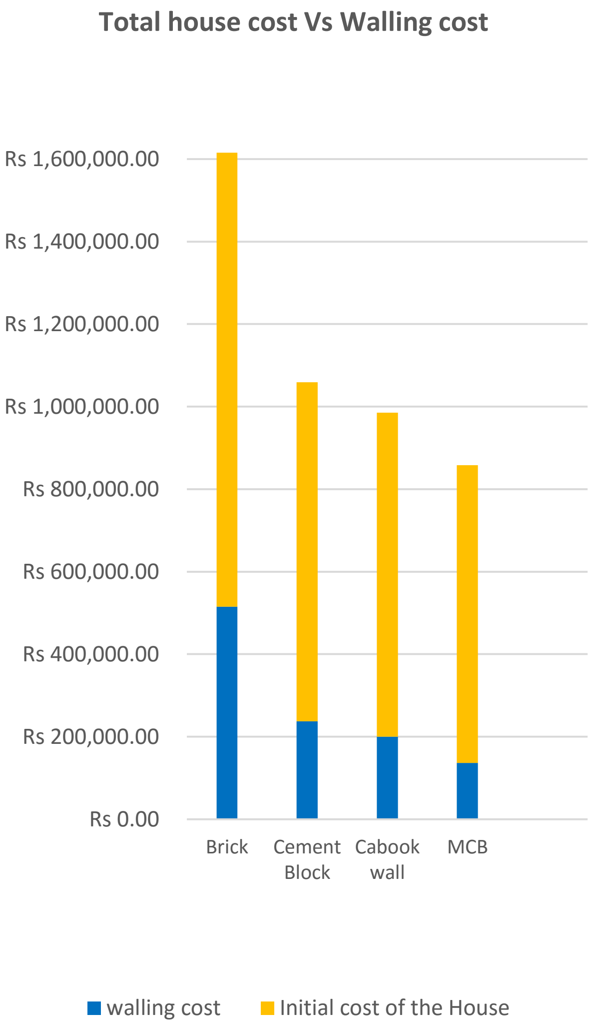
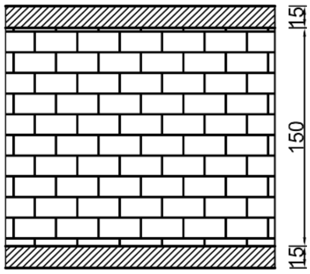
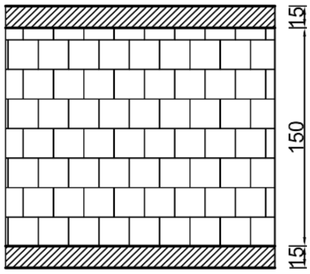
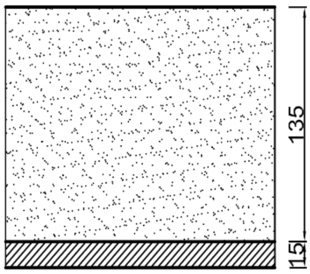
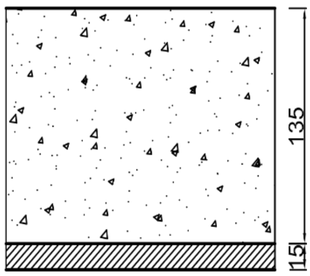


Figure 3: Initial cost and walling material cost

The cooling load was calculated by using design builder energy simulating software. The wall thickness and exterior surfaces were defined considering the materials property of the wall. For an example, walling materials such as mud concrete block don't need an exterior plaster.

Table 3: walling materials section layer details

walling materials	wall section detail	Layers
Brick		Plaster 0.015m brick 0.15m Plaster and lime 0.015m
HCB		Plaster 0.015m Hollow cement block 0.15m Plaster and lime 0.015m
Cabook		Cabook 0.15m Plaster and lime 0.015m
MCB		Mud concrete block 0.15m Plaster and lime 0.015m

The computer-based simulations were sued to calculate the annual cooling load of the house. The houses are not designed for the active cooling systems, therefore, the average cooling load of the house is combatively higher. But since we are comparing the similar model, the efficiency of the cooling load simulations was omitted. U value and the materials thickness were used as the key changes in the similar model.

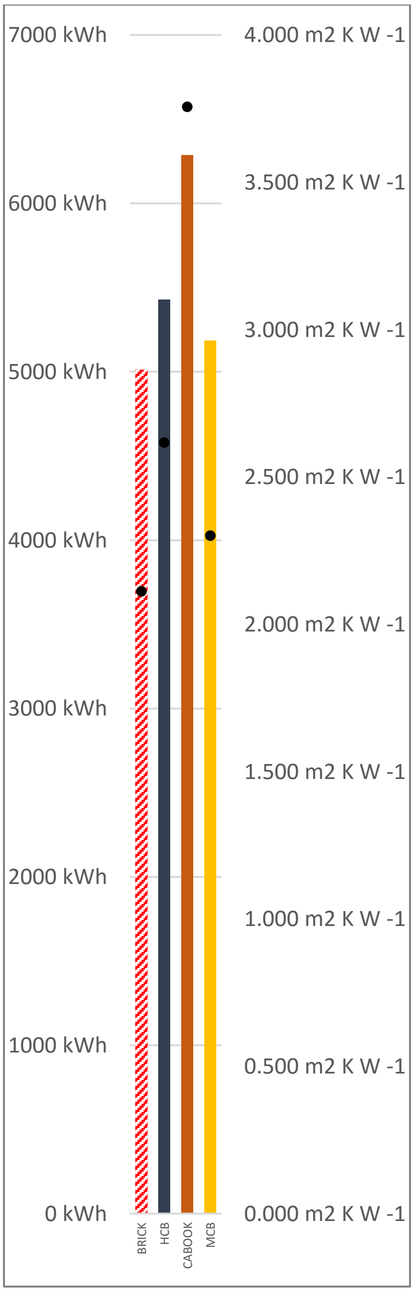


Figure 4: Annual cooling load and U-value Comparison

The annual cooling load was converted into money value by considering the cost per one-kilowatt. Then the money value of cooling load per year calculated for a period of sixty years by using present worth annuity formula.

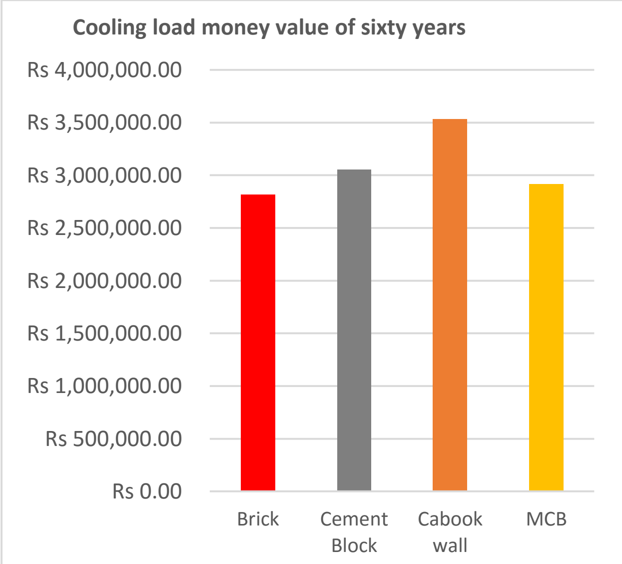


Figure 5: Cooling load money value of sixty years

4.3 Reusability and Resale value

The reusability was considered basically after calculating the total life span of the building material. Not only for the walling materials but also for the other building elements life span was measured accordingly to calculate the total reusability of the building. And it was assumed that the total lifespan of the building is sixty years and more than sixty-year life span building materials were multiplied by the reusability factor.

The purpose of this study is to calculate the durability of different walling materials, therefore, the reusability factor is important. However, the reusability was measured only for the similar usage in the future. The other alternative reuses or recycle were omitted because of their complexity in alternative reuses.

Error! Reference source not found. indicates the resell value and reusability of different walling materials. And the other building components were measured to understand the total life-cycle cost of the building.

Table 4: Reusability and resell value

	BRICK	CEMENT BLOCK	CABOOK WALL	MCB
REUSABILITY	60%	70%	60%	92%
RESALE VALUE	Rs260,968.32	Rs165,855.34	Rs133,124.54	Rs145,794.00

4.4 Life cycle cost

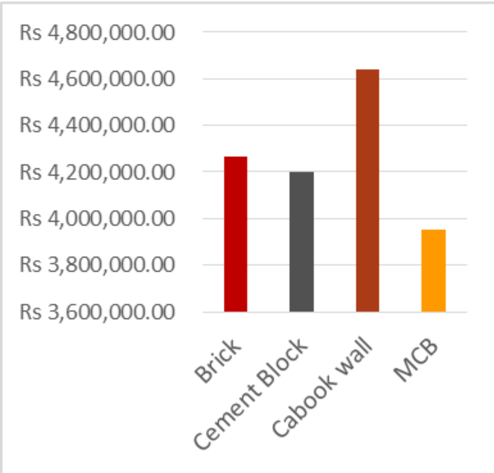


Figure 6: LCC for period of sixty years** NPV as of 1 Jan 2016

Life cycle cost, of course, 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 suing process initial cost, maintenance cost, and replacement cost. The reusable material cost was deducted from the total cost and calculated the total life-cycle cost of the building. Perhaps most of these building materials are recyclable and reusable for another use. But considering calculation the recycle cost and resale cost of different usages were omitted. But the reusable price for the similar use calculated and deducted from the total life-cycle cost of the building.

4.5 Sustainability indexing

Considering all four different walling materials, the brick shows the most prominent embedded energy but at the same time, its initial cost is comparatively higher. Since brick u value is lower the cooling load is lower as well. Hollow cement block embedded energy is moderately higher but the initial cost is comparatively lower than brick. But since its u value is higher the walls are not suitable for cooling the building. Cabook walling materials are natural therefore the embedded energy and the initial cost is lower. But Cabook walling materials u value is very higher due to the density of the material. Therefore, the cooling load and the life cycle cost of the Cabook basic house is comparatively higher than all four other walling materials.

Mud concrete block is the best alternative, its embedded energy is not the lowest, but mud concrete block house life cycle cost is comparatively lower. This is mainly because of its lower u value and the reusability of materials. Mud concrete block walling material can be used into another wall by crushing and building MCBs out of the same materials used to build mud concrete block walls. But keep in mind that the mud concrete block is not the cheapest walling materials used to build affordable houses in

Table 7: Summary

	Brick	Cement Block	Cabook wall	MCB
Basic House model with different walling materials				
Embedded energy	2775159.1 MJ	246679669.5 MJ	530519.7 MJ	556772.3 MJ
Total initial cost	Rs 1,100,263.60	Rs 822,007.60	Rs 806,945.64	Rs 743,543.14
Total energy cost	Rs 5,639,847.80	Rs 6,107,866.29	Rs 7,070,904.33	Rs 5,833,355.44
Over heads	Rs 88,021.09	Rs 65,760.61	Rs 64,555.65	Rs 59,483.45
Life cycle cost	**Rs 7,085,156.15**	**Rs 7,252,658.06**	**Rs 8,199,429.28**	**Rs 6,893,405.37**

Sri Lanka.

Nonetheless, the materials source and the environmental impact should be taken into consideration in order to define the sustainability for a walling materials. For an example, walling materials such as hollow cement block or Cabook can be extra cheaper for the construction. But their environmental impact and can be very high due to the destruction they made to the natural setting. And the same time their reusability for the similar use can be very low.

Conclusions

This study assays to approximate the sustainability of different walling materials used to build an affordable house in Sri Lanka. The walling materials were selected by considering their similarities and the popularity in the local market; Brick, Hollow cement block, Cabook and Mud concrete block. And the same time walling materials such as wood planks and steel sheets were omitted from the research due to their major structural changes to the building.

The results indicate two different indexes. One is the embedded energy of the walling materials and another thing is the life cycle cost incurred due to change in different walling materials. Mud concrete block walling materials have the lowest embedded energy considering all the other walling materials and it has the lowest life cycle cost too. However, subcomponents such as mortar and sand were not considered while doing the study. But walling materials such as mud concrete block do not need an exterior plastering.

One of the crucial findings of this study is not the life cycle cost but the reusability of the walling material. The wall can be ultra-low in embedded energy or the initial cost. But if they are not strong enough for the reuse, there is no sustainability. But for walling materials such as brick mud concrete block can be reused over and over again for the similar usage. Mud concrete block is 92% reusable. Its ingredient can be crushed and produce same walling material with an addition of cement ratio of 8%. And the brick can be reused over and over again for the similar use except its surface decays.

Brick has higher cooling capacity than other two walling materials. Therefore, brick wall materials used affordable houses have a lower operation cost. But keep in mind that the brick has the highest initial cost. The hollow cement block initial cost is lower, notwithstanding the operation cost is very high. However, mud concrete block is in the average condition, whereas the mud concrete block initial cost is not that expensive but at the same time, it has the lowest operation cost. Cabook is a natural walling material therefore the initial cost is lower. However, Cabook is not an eco-friendly walling materials because it decays the natural environment. Since Cabook has high density it is not a thermally sounding walling materials. The operation cost of the Cabook walled dwelling unit has the highest operation cost and life cycle cost. Consequently, Mud concrete block is the best alternative walling materials for constructing walls in tropical third world country like Sri Lanka.

Limitations

One of the glaring limitation of this research is to compare additional structural changes due to the walling materials change. Since this study used a basic house model with a single story building, there was only a few walling load. But if this study can be extended to two story or high rise buildings like apartments the comparison can be much advanced. However, at the very begging, the study was started with an eye on structural changes due to the walling materials change. But then it was realized that there are no major changes to the structure. The changes are so minimum and cannot implement in the real world scenario.

The other blazing limitation is the operation energy of this basic house. Perhaps, due to the walling materials change the operation energy can be change. For an example higher u value residential building daily water consumption can be higher than a lower u value residential building. But these things have logistical errors in calculating and comparing their impact to the Total life span of the house.

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