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Life Cycle Assessment as a Tool for Material Selection – Comparison of Three Walling Material

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Abstract

The building energy are derived from different sources viz; energy from mining, energy from manufacturing of materials, energy from transportation of material to manufacturing site and the into construction site of building, energy use during the operation of the building and energy used for the disposal of the materials after the end of life of the building. According to the study, building use many materials that has high embodied energy and 10 percent of total building energy comes from the embodied energy in materials. Hence, low embodied energy means more sustainable and energy efficient. Life Cycle Assessment (LCA) assists in evaluating the building materials, environmental impacts of the building materials through all of its life stages.

The paper is aimed to compare the environmental impact of three walling materials- Kiln Burnt brick, Compressed Stabilized Earth Block (CSEB) and Autoclaved Aerated Concrete (AAC) used for wall assembly. The study is focused in evaluating the materials on the basis to its embodied energy, raw material consumption, environmental impact on the basis of CO2 emission and the operation energy.

Keywords

Life Cycle Assessment, Walling materials, burnt brick, Compressed Stabilized Earth Block, Autoclaved Aerated Concrete

1. Introduction

The housing demand is expected to increase five times during the year between 2005 to 2030 as shown by the research in India (Bhatia, 2014)and Nepal can't be an exception. With the increasing demand, there results in continuous demand in materials. The resources used for production of these construction materials have caused depletion in the natural resources, pollutions, increase in greenhouse gas emission. Hence, it is important to develop the materials with least impact in the environment. The choice of material should have low environmental impact with low operation cost and life cycle assessment considerations like material performance, easy manufacturing process, easy availability. Life cycle Assessment (LCA) offers a comprehensive approach to evaluating and improving the environmental impacts of building materials through all of its stages from cradle -to -grave.

Bricks are commonly used materials in building sector worldwide. In context of Nepal, autoclaved Aerated Concrete (AAC) and Compressed Stabilized Earth Block (CSEB) have come in market as alternative building walling material after 2015 Gorkha Earthquake. The objective of the paper is to evaluate the walling material on the basis of Life cycle impact assessment which includes: Embodied Energy (EE), CO2 Emission, Raw Material consumption, Water Consumption and total cost.

2. Methodology

The quantitative research approach is carried out for achieving the objectives of the study. The method includes the study of conventional walling material i.e., burnt brick, CSEB, AAC. The literature study is done on the physical properties and thermal properties from various journal articles, conference proceedings and related websites. The housing residential building at Thadodhunga, Lalitpur is chosen as the case study area in context of Kathmandu Valley. The field data is collected from the interview with manufacturers, marketing officers and site visit which is used for computing different values during the manufacturing phase of three walling materials. The construction phase values for external and internal walls are computed for the case study building constructed with three walling materials. The manufacturing energy and construction energy are computed using Life cycle impact assessment approach. The operation phase values are computed using the simulation software making three scenarios where walling material are changed and all other building envelope parameters remaining constant. The simulation is done with Energy plus in open studio. Finally, comparisons are done between three walling materials on different parameters to find out the results and conclusions.

3. Limitation

The study is limited to the evaluation of energy use during manufacturing, construction and operation phase only.

4. Literature Review

4.1 Life Cycle Assessment

Life cycle assessment is a cradle to grave process such as to assess the environmental impacts related with all the stages of life of the products. The process includes the technique to evaluate the environmental impacts, total energy used by the material from its extraction to disposal phases.

4.2 Embodied Energy

Embodied energy is the energy consumed by all of the processes associated with the production of a building. The process includes the steps from the mining and processing of natural resources to manufacturing, transport and product delivery to the building site. The important factor to reduce the embodied energy is the selection, manufacturing process reduction in transportation cost such as the output material is cheap, durable, environment friendly, and low energy consuming[?]Milne, 2013).

4.3 Walling materials

The present study indicates that AAC and CSEB are energy efficient material which has better thermal performances than brick and manufactured from clean energy sources that has less environmental impact. CSEB if produced manually with hand machine consumes zero energy for its production, requires less amount of material for mortar. Similarly, AAC is light weight material which is considered to have very good thermal insulation property.

4.3.1 Burnt brick

Brick is considered as the oldest building material worldwide. Initially sundried bricks were used and with the development of multistoried buildings burnt bricks were developed. Although brick has good thermal properties, easy workability and cheap but different studies show that its embodied energy is higher than other materials. Also burnt brick has higher environmental impact as shown by different research and daily newsletter in context of Kathmandu Valley.

4.3.2 Compressed Stabilized Earth Block(CSEB)

Constructing masonry using earth is one of the oldest building techniques in the world. The Compressed Stabilized Earth Block is a technique for making blocks out of soil. CSEB is different to ordinary kiln fired bricks in its production process, no kiln is needed instead it is compacted. CSEB has many advantages, the most important properties can be summarized as its structural strength, environmentally friendliness, durability, architectural beauty, low maintenance and comparably low cost.

4.3.3 Autoclaved Aerated Concrete(AAC)

Autoclaved aerated concrete is a precast product manufactured by combining silica (either in the form of sand, or recycled flash), cement, lime, water, and an expansion agent - aluminum powder, and pouring it into a mold. The block consists of 40percent -60percent of the void and aluminum powder assists in increasing the volume of the block by 2-5 times its original volume making the block lightweight and good insulation.

5. Research Context

Prime Colony is a joint venture Project of CE Construction and Landmark Developers. CE has privileged its clients with three options, ranging from 1100,1800 and 2500 square feet as built up area most suitable for the Single-Family system. The housing type ‘C’ is chosen as case study building whose plinth area is 695 Sq. ft. The building entrance is faced North. Setback of 5’ is set all three side of the building.

Figure 1: Prototype Housing Case Study

5.1 Construction Material

Column Size: 1' x 9"
Walling material: Burnt brick
Window: single glazed window
Door: wooden doors
Wall thickness: external wall 230mm, internal walls 125mm
Wall Finish: External plaster 20 mm thick, internal 12 mm thick

6. Data Collection and Analysis

6.1 Life Cycle Inventory Analysis of three walling materials

Approach:

- Data collected through the manufacturing site visit, interviews with the manufacturers.
- Standard values for calculating embodied energy and carbon emissions are taken from secondary sources.
- The functional unit taken for calculating the raw material consumption is 1 m3 quantity during production process.

System Boundary:

- Includes the energy required for Manufacturing and execution phases only.
- Extraction and demolition energy are not accounted

For Burnt brick,data are collected from the Bhaktapur brick factory, Jagati.The soil is transported to the site from Tikathali (12.5 Km) from the site. The coal is imported from Assam (1109 Km) from Bhaktapur. Other data are calculated as per the data given by the manufacturer.

Table 1: Embodied energy calculation for Burnt brick production

Quantities of Burnt Brick per cum (215 x 112 x 65) mm						
Particulars	Quantity	Unit	Embodied Energy	Unit	Total Energy	Unit
Fired Brick	635	units/ cu. M	7.9	Mj/unit	5016.5	
Total RM EE						
SoilTransport	12.5	km	11.93	Mi/Km	149.125	
Coal Transport	1109	km	11.93	Mj/Km	13230.37	
Total					13379.495	
Electricity(kWh)	1	Kwh	9.28	Mj/KWh	9.28	
Diesel(lt)	12.7		11.93	Mj/km	151.511	
Coal (Kg)	0.635	ton	18	Mj/ton	11.43	
Total					172.221	
All total					18568.216	
0.098kg of co2 per MJ of embodied energy					1819.685	co2/cu.m

Table 2: Embodied energy calculation for CSEB production

Quantities of CSEB per cu.m (300x150x100)mm						
Particulars	Quantity	Unit	Embodied Energy	Unit	Total Energy	Unit
cement	50	kg	4.2	Mj/Kg	210	Mj
Total Raw material EE					210	Mj
Transport						
sand	38.5	km	11.93	Mi/Km	459305	Mj
soil	32.8	km	11.93	Mi/Km	391.304	Mj
cement	227	km	11.93	Mj/Km	2708.11	Mj
Total					3558.719	Mj
Electricity (KwH)	2	Kw/h	9.28	Mj/Kwh	18.56	Mj
Total						
All total					3787.279	Mj
0.098kg of co2 per MJ of embodied energy					371.153342	co2/cu.m

Table 3: Embodied energy calculation for CSEB production

Quantities of AAC production per Cu.m						
Particulars	Quantity	Unit	Embodied Energy	Unit	Total Energy	Unit
Lime	50	kg/cu.m	5.63	Mj/Kg	281.5	Mj
Gypsum powder	19.64	kg/cu.m	1	Mj/Kg	19.64	Mj
Aluminium powder	0,45	kg/cu.m	260	Mj/Kg	117	Mj
Cement	148.81	kg/cu.m	4.2	Mj/Kg	625.002	Mj
sand	428.57	kg/cu.m	0	Mj/Kg	0	Mj
Total Raw material EE					1043.142	Mj
Transport						
Gypsum powder	1002	km	11.93	Kj/Km	11953.86	Mj
aluminium powder	1002	km	11.93	Kj/Km	11953.86	Mj
Cement	64.7	km	11.93	Kj/Km	771.871	Mj
lime	1002	km	11.93	KjfKm	11953.86	Mj
Total transportation					36633.451	Mj
Electricity (KWH)	10.71	kwh/cu.m	9.28	Mj/Kwh	99.3888	Mj
Coal (Kg)	0.009	ton/ cu.m	18	Mj/ton	0.162	Mj
Total					9955	Mj
All total					37776.1438	Mj
0.098kg of co2 per MJ of embodied energy					3702.06	CO2/cu.m

Data are collected from Himalayan Bricks, Jagati Himalayan Bricks are the manufactures of CSEB block which was established in 2015 and started its production after 2 year. The manufactures are using 14 percent cement in total volume of the mix. The cement is transported from Siraha (227 km) from the site. Soil is transported from Panchkhal and sand is transported from Melamchi to the site.

Data are collected from Aero bricks, Chitwan. Aero brick is the manufacturer of AAC Block which also came in market after the devastating 2015 earthquake. The high technology plant has the capacity to produce more than 14000 blocks per day of varioes sizes. Cement is transported from Hetauda and other raw materials are imported from India.

Energy content of grid electricity = 9.28 Mj/kWh, energy content of cement = 4.2MJ/Kg, energy content of transportation is 11.93 Mj/Km

6.2 Life Cycle impact assessment of three walling materials

Based on the material estimation data of the case study, comparative analysis is done between three wall materials on various parameters. The volume of brick wall assembly is 54.08 cu.m and area of plaster work is 290.6 Sq. for 9” thick external wall and 5” thick interior wall.1: 5 ratio cement sand mortar is used. The volume of 6” thick CSEB wall assembly is 44 cu.m. Plaster work is not required in CSEB. The slurry for mortar is made at 1: 3 ratio. Similarly, the volume of 8” thick AAC block wall assembly is 49.5 cu.m and plaster work is done for 290.6 sq. area. Mortar slurry of 1: 3 ratio is used for calculating the volume of mortar work.

The results and comparison are shown as below. The figure shows that AAC emits more carbon and has higher embodied energy during its production phase. It is due to the transportation energy of raw material imported from India. CSEB has the lowest carbon emission and embodied energy than burnt brick.

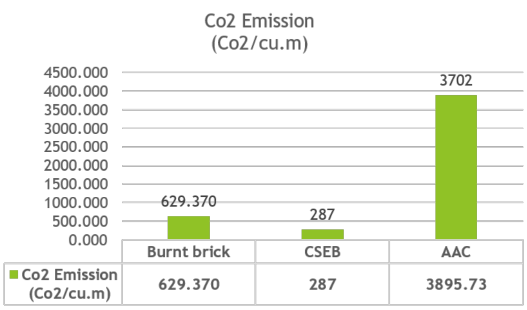

Figure 2: Carbon emission during production phase

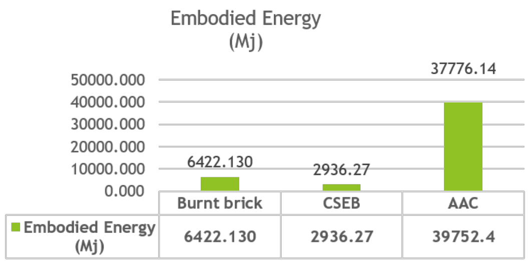

Figure 3: Embodied energy during production phase

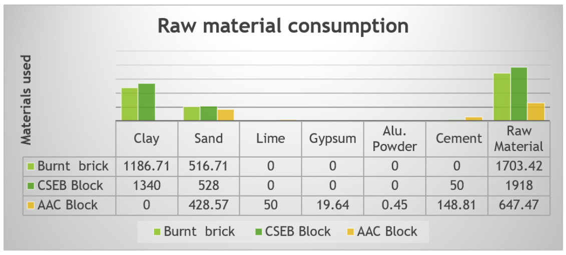

Figure 4: Raw Material Consumption

AAC block consumes very less amount of raw material during production. Burnt brick and CSEB consumes about 4 times and 4.5 times more raw material respectively as compared to AAC block.

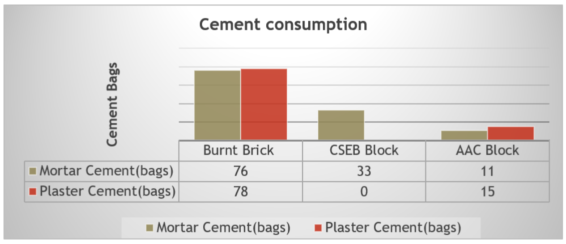

Figure 5: Cement Consumption for whole wall assembly during construction

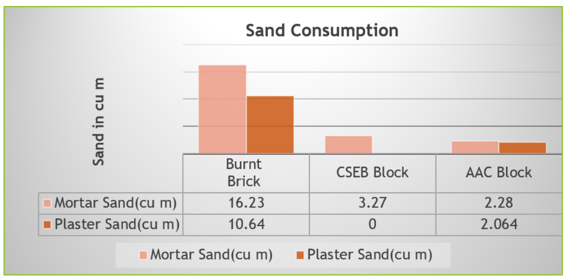

Figure 6: Sand Consumption for whole wall assembly during construction

The graph indicates that brick masonry consumes higher amount of cement and sand for binding and plaster work followed by AAC wall masonry. Earth block masonry consumes very less amount of sand only for binding mortar purpose.

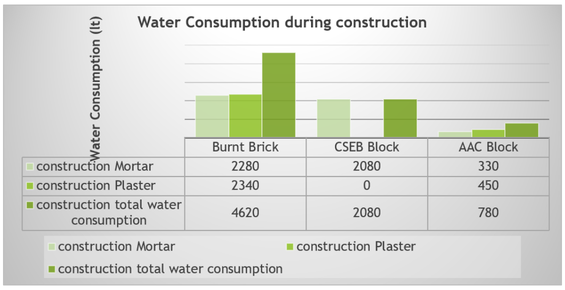

Figure 7: Water Consumption for whole wall assembly during construction

The graph shows brick masonry wall requires the highest amount of water for plaster and binding work. Very low amount of water is used for both AAC and CSEB mortar.

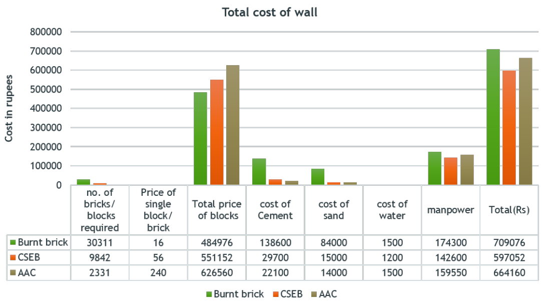

Figure 8: Total cost of Wall Assembly

The overall cost for the wall assembly is higher for brick wall masonry followed by AAC masonry and CSEB masonry. This indicates that earth block masonry and AAC block masonry is cheaper than brick masonry.

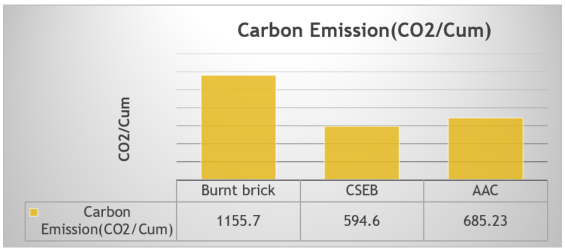

Figure 9: carbon emission during construction

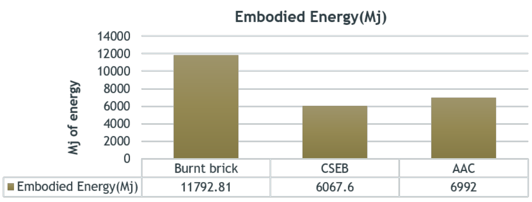

Figure 10: Embodied energy during construction

Table 4: Simulation base case and Scenarios

Building Element	Base Case Scenario	Scenario-I CSEB Block	Scenario-II AAC Block
Wall	9” burnt brick	6” thick	8” thick
Door	Wooden frame panel door	Wooden frame oanel door	Wooden frame panel door
Window	Aluminum frame single Glazed	Aluminum frame single Glazed	Aluminum frame single Glazed
Roof	5” thick RCC	5” thick RCC	5” thick RCC
Wall Finish	20mm thick cement sand plaster external, 12mm thick at internal face	-	12mm thick cement sand plaster in external wall only

The charts below show that CSEB and AAC wall assembly consumes less embodied energy of 6067.6 Mj and 6992 Mj respectively during construction phase. Brick wall assembly consumes 2 times more energy during construction of the case study building.

7. Simulation by Energy Plus

Energy Plus in Open Studio is used as the simulation software for calculating the operational load i.e., heating and cooling loads of the building. Three scenarios model are created; base case model, scenario I and scenario II. In all scenario the walling materials are only changed and other building envelop are kept as constant parameter [1].

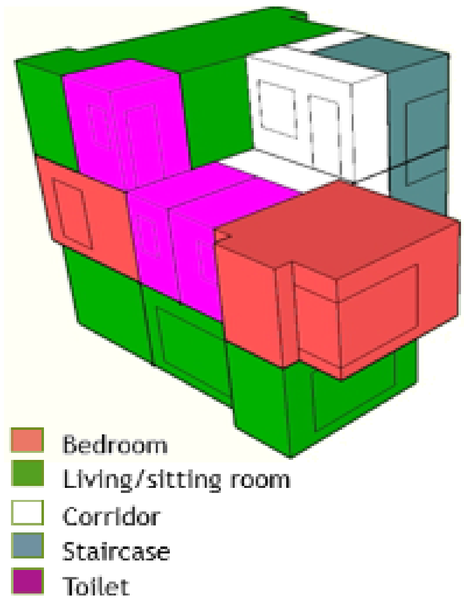

Figure 11: Model for space type

7.1 Simulation Results

Table 5: Simulation result for Heating Load

	Heating Load-Gj
Base Case (Burnt Brick wall) in Gj	9.9
Scenario-I (CSEB wall) in Gj	12.66
Scenario-II (AAC wall) in Gj	12.78

Table 6: Simulation result for Cooling Load

	Cooling Load-Gj
Base Case (Burnt Brick wall) in Gj	36.4
Scenario-I (CSEB wall) in Gj	33.69
Scenario-II (AAC wall) in Gj	26.7

The result from simulation shows that 9" thick brick masonry consumes less energy for heating and AAC block 8" thick consumes less energy for cooling.It is because of thickness in wall section. CSEB, 6' thick consumes higher energy for both heating and cooling. This indicates that higher the thickness of section, lower is the operational energy for heating and cooling of the building.

8. Findings and Discussions

CSEB is the energy efficient and environmentally good material that has low embodied energy and low carbon emission compared to burnt brick (54.39 percent less) during its manufacturing phase. CSEB is the energy efficient and environmentally good material that has low embodied energy and low carbon emission compared to burnt brick (48.5percent less) during its construction phase.

The operational energy is 2094 kWh less for building built with 8" thick AAC while 14 KWh more for CSEB annually as compared with burnt brick. The cost saving of Rs. 23,036 can be achieved with the use in AAC block. CSEB and burnt brick use has similar units of annual energy consumption during operation phase.

The huge amount of energy is consumed by transportation of raw material. If the locally available material is used large amount of energy can be saved i.e. promotion in production of CSEB

9. Conclusion

Burnt brick has adverse effect in the environment and emits large amount of carbon gases. The use of AAC and CSEB blocks leads to savings in overall project cost; enables to speed up the construction process, reduce environmental impact.CSEB and AAC can be the best alternative material to the kiln burnt brick. Therefore, we can conclude that use of CSEB and ACC blocks over burnt clay bricks is recommended. However, it is difficult to replace 7 millennium old materials with new one but it is advisable to developers, contractors, and individuals to encourage environment friendly product as its use is beneficial to nation.

10. Recommendation

- Promotion of CSEB from government sector emphasizing as environment friendly, low cost, clean, green material and energy efficient walling material.

- If subsidy provided by the government to the manufactures, it can be a motivation/support for investing in CSEB industry in the country. CSEB blocks in large quantity can be manufactured mechanically that can fulfill be demand and supply side of the walling material.

- The government can bring the policy for subsidizing the consumer consuming the energy efficient and environment friendly materials.

- Fly ash is the by-product produced after incinerating the waste materials that has good thermal properties than sand based AAC block. If fly ash can be produced within the country, the problem of waste management can be reduced to minute level.

References

[1] Geoff Milne and Chris Reardon. Materials, embodied energy–your home australia's guide to environmentally sustainable homes, 2013.