Life Cycle Assessment as a tool for Material Selection - A comparison of Autoclaved Aerated Concrete and VSBK Brick Wall Assembly.

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1.0 ABSTRACT

Energy use of a building can be derived from five sources: Embodied Energy from mining and manufacturing of materials, Energy from transportation of materials, Energy from construction of the building, Energy use during operation of the building, and Energy used in the disposal of the building at the end of its life. Buildings use many materials with a high Embodied Energy, and it is estimated that, 10% of its total energy use comes from Embodied Energy in materials. Thus, the use of low Embodied Energy Materials for the sustainable development is preferred. Life cycle assessment (LCA) offers a comprehensive approach to evaluating and improving the environmental impacts of buildings materials, buildings and its products through all of its life stages.

Brick and Cement are majorly used materials in building industry. Kiln Burnt Brick is majorly use exterior wall material in the market. Also, Aerated Concrete (AAC) is a non-combustible, cementitious building material that is expanding into new worldwide markets.

The Paper will be aimed to compare the environmental impact of materials- Kiln Burnt Brick and Autoclaved Aerated Concrete used for wall assemblies. Study will be focused on evaluating the materials with respect to its Embodied Energy, Energy and Resource consumption, Environmental Impact in terms of CO2 Emissions, Cost, Health safety etc. The functional unit and unit distance will be defined to allow comparisons to be made between materials. The study will include interaction with the Manufacturers, Market study of the materials, and use of material in a particular building. The final objective of the paper is to evaluate the materials on the bases of Life Cycle Assessment Impact Categories which includes: Raw Material Index (RMI), Water consumption, Embodied Energy (EE) and Operational Energy (U-Value), Electricity, Occupational Health and Safety (OHS Index), Total Cost, CO2 Emissions.

Key words: - Life Cycle Assessment, Materials, Kiln Burnt Brick, Autoclaved Aerated Concrete, Life Cycle Assessment Impact Categories.

2.0 INTRODUCTION

Building construction in India is estimated to grow at a rate of 6.6% per year between 2005 and 2030 (McKinsey and Company, 2009). The building stock is expected to multiply five times during this period, resulting in a continuous increase in demand for building materials, which could have long lasting implications in terms of natural resource depletion, future energy demand, local pollution, contributions to greenhouse gas emissions as well as socio-economic conditions of a significant number of low-income workers. Thus it is an imperative and urgent need to have a comprehensive plan for development of walling materials production in India, with the least impact to the earth.
All materials have environmental implications. Thus the choice of materials for a project requires considerations of aesthetic appeal, initial and ongoing costs, life cycle assessment considerations (such as material performance, availability and impact on the environment) and the ability to reuse, recycle or dispose of the material at the end of its life. It is estimated that, 10% of buildings total energy use comes from embodied energy in materials. Thus, the use of low embodied energy materials for the sustainable development is preferred. Life Cycle Assessment (LCA) offers a comprehensive approach to evaluating and improving the environmental impacts of buildings materials, buildings and its products through all of its life stages from cradle-to-grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling).

Brick and Cement are majorly used materials in building industry. Kiln Burnt Brick is majorly use exterior wall material in the market. Also, Aerated Concrete (AAC) is a non-combustible, cementitious building material that is expanding into new worldwide markets.

3.0 AIM AND OBJECTIVE

The Paper is aimed to compare the environmental impact of materials—Kiln Burnt Brick and Autoclaved Aerated Concrete used for wall assemblies.

The final objective of the paper is to evaluate the materials on the bases of Life Cycle Assessment Impact Categories which includes: Raw Material Index (RMI), Water consumption, Embodied Energy (EE) and Operational Energy (U-Value), Electricity, Occupational Health and Safety (OHS Index), Total Cost, CO2 Emissions.

4.0 METHODOLOGY

In this assessment the tools of Life Cycle Assessment are integrated, which includes due consideration of all life cycle stages fixed in the ISO 14040 –14043 standards: Goal and Scope Definition, Life Cycle Inventory Analysis, Life Cycle Impact Assessment and Life Cycle Interpretation.

Life Cycle Inventory Analysis includes assembling data and analyzing it on a suitable system boundary. Life Cycle Impact Assessment is the evaluation of the material and energy flows raised in the inventory analysis according to certain environmental effects.

Figure 1  Methodology use for Life Cycle Assessment.

Thenafter, Impact Assessment categories are selected, which includes: Raw Material Index (RMI), Water Consumption, Embodied Energy (EE) and Operational Energy (U-Value), Electricity and other Resources, Occupational Health and Safety (OHS Index), Total Cost, CO2 Emissions. Life Cycle Interpretation consists of Identification of significant issues, evaluation and conclusions.
5.0 SCOPE AND LIMITATION

Study is focused on evaluating only two walling materials - Kiln Burnt Brick and Autoclaved Aerated Concrete with respect to its formulated Impact Assessment Categories. The functional unit and unit distance is defined to allow comparisons to be made between materials. The study includes interaction with the Manufacturers, Market study of the materials, and use of material in a particular building.

Building use: Evaluation of the materials and energy consumptions is restricted to the use of a building only, its maintenance and restoring, not considered within this study. Also, Transport of the wastes generated during the Construction and Demolition phase, not considered within this study. No consideration of labour cost as it will have negligible effect on the results.

To understand the implication of these materials, the live site data collection is limited to Pune (moderate climate), but to understand the impact of operational energy a theoretically comparative study base has been done with a case study of composite climate.

6.0 LIFE CYCLE ASSESSMENT

A Life Cycle Assessment (LCA) provides a mechanism for systematically evaluating the inputs, outputs and the potential environmental impacts linked to a product or process throughout its life cycle. (ISO 14040). LCA addresses the impacts of a product through all of its life stages.

Life Cycle Assessment is a technique to assess environmental impacts associated with all the stages of a product’s life from cradle to grave.

6.1 EMBODIED ENERGY

Embodied energy is the total energy required for the extraction, processing, manufacture and delivery of building materials to the building site. Energy consumption produces CO2, which contributes to greenhouse gas emissions, so embodied energy is considered an indicator of the overall environmental impact of building materials and systems. It does not include the operation or disposal of materials.

The total amount of embodied energy may account for 20% of the building’s energy use, so reducing embodied energy can significantly reduce the overall environmental impact of the building.

Energy consumption during manufacturing can give an approximate indication of the environmental impact of the material, and for most building materials, the major environmental impacts occur during the initial processes.

![Figure 2](typical_phases_of_materials_life_cycle_along_with_inputs_and_outputs_at_each_phase.png)

7.0 LIFE CYCLE INVENTORY ANALYSIS OF AAC BLOCKS AND VSBK BRICK

7.1 Autoclaved Aerated concrete and Vertical Shaft Brick Kiln (VSBK)

AAC is lightweight, precast building material that simultaneously provides structure, insulations, and fire & mold resistance. Main ingredients include fly ash, water, quicklime, cement, aluminium powder & gypsum. The block hardness is being achieved by cement strength, & instant curing mechanism by autoclaving. Gypsum acts as a long term strength gainer. The chemical reaction due to the aluminium paste provides AAC its distinct porous structure, lightness & insulation properties, completely different compare to other lightweight materials.

The VSBK is a vertical kiln with a stationary fire and a moving brick arrangement. The figure below shows the VSBK principle in a schematic diagram. The kiln operates like a counter current heat...
exchanger, with the heat transfer taking place between the air moving upwards and the bricks moving downwards.

Figure 4  (a) Process Flow Chart and (b) Table 1  Embodied Energy calculations for AAC Block Production.

Note: Data Collection for production process of AAC Blocks is taken from company Anjali Ventures Ltd., Surat.

Energy content of furnace oil = 42.25 MJ/l; energy content of grid electricity = 9.28 MJ/kWh; and energy content of cement = 4.20 MJ/kg. All Embodied Energy reference:

Figure 5  (a) Process Flow Chart and (b) Table 2  Embodied Energy calculations for VSBK Block Production.
### Table 3  Embodied Energy calculations involved in constructing the Wall Assembly of AAC and VSBK.

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Quantity</th>
<th>Unit</th>
<th>Embodied Energy Unit</th>
<th>Total Energy Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quantities of AAC Wall</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume of wall</td>
<td>107.54 m³</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume Green mortar</td>
<td>2.15 m³</td>
<td></td>
<td>11.03 MJ/m³</td>
<td>23.58 MJ</td>
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<tr>
<td>Transport</td>
<td>150 km</td>
<td></td>
<td>11.03 MJ/km</td>
<td>1659.3 MJ</td>
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<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>1782.9 MJ</td>
</tr>
<tr>
<td>Sand</td>
<td>0 m³</td>
<td></td>
<td>29.56 MJ/m³</td>
<td>0 MJ</td>
</tr>
<tr>
<td>Electricity</td>
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<td>9.28 MJ/kWh</td>
<td>27.84 MJ</td>
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<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>2060.74 MJ</td>
</tr>
<tr>
<td>0.098kg of CO₂ per MJ of embodied energy</td>
<td></td>
<td></td>
<td></td>
<td>497.27 MJ</td>
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<tr>
<td><strong>Quantities of brick Wall</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Volume of wall</td>
<td>107.54 m³</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume mortar</td>
<td>2.15 m³</td>
<td></td>
<td>3.2 MJ/m³</td>
<td>6.88 MJ</td>
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<tr>
<td>Cement</td>
<td>0 m³</td>
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<td>5999.7 MJ/m³</td>
<td>0 MJ</td>
</tr>
<tr>
<td>Sand</td>
<td>0.07 m³</td>
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<td>5999.7 MJ/m³</td>
<td>419.98 MJ</td>
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<tr>
<td>Transport</td>
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<td>11.03 MJ/km</td>
<td>551.5 MJ</td>
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<td>Total</td>
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<td>612.7 MJ</td>
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<td>1 kWh</td>
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<td>9.28 MJ/kWh</td>
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<td>Total</td>
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<td></td>
<td>621.98 MJ</td>
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<tr>
<td>0.098kg of CO₂ per MJ of embodied energy</td>
<td></td>
<td></td>
<td></td>
<td>65458.52 MJ</td>
</tr>
</tbody>
</table>

Source: embodied energy of various materials and technologies - data and summary - 1.pdf

About 0.098 tonnes of CO₂ are produced per gigajoule of embodied energy = 0.098Kg of CO₂ per MJ of embodied energy

8.0 CASE STUDIES (CLIMATE: COMPOSITE CLIMATE)

8.1 Fortis Hospital – 3 Star rated. (Location: Shalimar Bagh, New Delhi)

The 500 bedded Fortis hospital at Shalimar Bagh is designed with a vision to provide an environment friendly health care facility in an area of 64,400 sq mts. It is the first hospital building in India to have registered for the GRIHA green building rating system.

8.2 Turquoise is Apartment Flats of 2 bhk (1150 sq. ft), 2.5 bhk (1330 sq. ft), 3 bhk (1550 sq .ft).

9.0 LIVE CASE STUDY (CLIMATE: MODERATE)

9.1 Park Turquoise (Location: Wakad, Pune)

Turquoise is Apartment Flats of 2 bhk (1150 sq. ft), 2.5 bhk (1330 sq. ft), 3 bhk (1550 sq .ft).

A Park Turquoise is the luxurious 70-acre township boasting of ample landscaped and open areas.

9.2 Construction Techniques

The building envelope has used Autoclaved Aerated concrete blocks instead of conventional bricks. The windows are glazed units with low thermal transmittance. Building Envelop is of AAC blocks with external 1:4 cement and sand plaster and internal gypsum plaster.

U-value calculations for 150mm and 200 mm AAC wall=0.76 w/km² degC and 0.61 w/km² degC.

U-value calculations for 150mm and 230 mm VSBK wall = 1.95 w/km² degC and 1.77 w/km² degC.
9.3 Cost Analysis of the Project

All required quantities are referred based on the data collected from the Live Case Study to allow comparison between the two materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>AAC Blocks</th>
<th>Burnt Bricks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>0</td>
<td>499.50</td>
</tr>
<tr>
<td>Silt</td>
<td>0</td>
<td>582.75</td>
</tr>
<tr>
<td>Sand</td>
<td>450.00</td>
<td>499.50</td>
</tr>
<tr>
<td>Flyash</td>
<td>70</td>
<td>0</td>
</tr>
<tr>
<td>Lime</td>
<td>90.00</td>
<td>150.00</td>
</tr>
<tr>
<td>Alu Powder</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>Gypsum</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Raw material index</td>
<td>615.50</td>
<td>197.00</td>
</tr>
</tbody>
</table>

Raw Material Index = (Clay quantity x 2 + Silt x 1 + Sand quantity x 1 + Lime quantity x 1 + Cement quantity x 1 x 1.45 + Fly ash quantity x 0)/5

10.3 Energy Consumption (Embodied Energy and Operational Energy of 150 mm Non-Loadbearing wall).

![Embodied energy and operational energy](image)

About 0.098 tonnes of CO2 are produced per gigajoule of embodied energy = 0.098Kg of CO2 per MJ of embodied energy.

**Figure 11** Embodied energy (MJ/m3) and Operational Energy (W/m2.deg C) in Wall Assemblies.

10.4 Productivity and OHS (for 150mm Non Loadbearing wall)

![Occupational Health and Safety](image)

Scores for each sub-parameter: High (H) = 3’, ‘Moderate (M) = 2’ and ‘Low (L) = 1’; Available (A) = 1’, ‘Inadequate (I) = 2’ and ‘Not available (NA) = 3, NA=0 for (d), OHS Index = (Sum of scores for each sub-parameter)/9

**Figure 12** Occupational Health and Safety Assessment for masonry Wall Assemblies.

10.5 Wall cost for 150mm (AAC) and 230mm (VSBK) Non Loadbearing masonry Wall Assemblies:

![Wall Cost](image)

**Figure 13** Total Wall Cost for masonry construction of Wall Assemblies.

10.6 Emissions:

![Non-Load bearing walls 150mm thick.](image)

**Figure 14** Emissions related to Wall Assemblies (kg of CO2).
10.7 Resources used:

![Table showing resources used in wall assemblies](http://www.victoria.ac.nz/cbpr/documents/pdfs/ee-co2_report_2003.pdf)

The total emission factor for electricity is 16.43g CO2 / MJ.

About 0.098 tonnes of CO2 are produced per gigajoule of embodied energy = 0.098Kg of CO2 per MJ of embodied energy.

Figure 15  Resources used in wall assemblies /cu mt.

11.0 LIFE CYCLE INTERPRETATIONS

11.1 Overall Comparision

1. It is apparent that masonry units with the least or no clay content (i.e AAC blocks which contains waste material such as Fly Ash) have low impact. Density also influences raw material impact, thus AAC blocks resulting from the aerated nature (approximately 80% air) have lower raw material impact. Larger block size reduces the quantity of mortar wastage on construction site. Additionally, the raw materials that are consumed are generally abundant and found in most geographic regions, allowing them to be locally sourced. Furthermore, much of the raw materials used in AAC production may consist of recycled materials, including copper mine tailings and flyash, a byproduct of coal-fired power plants.

2. AAC blocks use cement in the production process and require curing. However, steam curing under high pressure (autoclaving) results in significantly lower water consumption. Larger block size reduces the quantity of mortar used in construction and thus the water requirement on site. Whereas, Water requires for curing Brick Masonry for 7 days is much large, thus the water consumption increases.

3. Burnt bricks show much higher embodied energy compared to AAC Blocks. The thermal performance of AAC wall assembly is also generally superior to Burnt bricks as reflected in the U-values. AAC blocks wall assembly have the lower U-value due to the porous nature of the material.

4. Burnt brick production is traditionally a labour intensive process. The use of manual labour for moulding therefore results in significantly lower productivity compared to mechanized processes. Block size also influences construction productivity and a larger block size requires less time and effort for construction. Poor conditions for labour at brick kiln sites are reflected in OHS index compared to AAC. Units producing AAC Blocks are generally located close to large urban areas and do not require labour to live on site during the production period as in the case of Burnt Brick.

5. Cost of AAC block is higher but the overall cost of the construction reduces drastically. Due to the larger block size of AAC masonry reduces the mortar quantity contributing to lower cost for the wall assembly. Also due to its lightweight characteristics the steel consumption reduces by 0.4kg which lower the total cost of construction.

6. CO2 emissions are lower for AAC Production and Wall Assembly compared to Burnt brick Walls and its production. Also, Resource Consumtion of AAC is lower and thus the CO2 emmissions.

ACKNOWLEDGEMENT

I would like to thank people of AAC block production company Anjali Ventures Ltd., Surat.

12.0 REFERENCES