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An Evaluative Study on Energy Efficient Building Materials

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Abstract — ***Due to growing demand for floor space, and to accommodate emerging service industries and urban migration, India expects a doubling of floor space by 2030. Use of low embodied energy and cost effective building materials, in the building construction, can reduce the overall energy consumption significantly and thus eventually minimize energy footprint of buildings. In existing residential and small commercial buildings, over 50% of the energy loss is associated with heat transfer and air leakage through building envelope components. This paper suggest the various alternative building materials, their production and evaluation based on three components i.e. Embodied Energy, CO_2 emission and Thermal Conductivity (K Value). Evaluation is done by calculating the normalised value of above three components and analysed. It is observed that Stabilized mud blocks have the least environmental impact followed by AAC Blocks, while Solid concrete blocks has the highest environmental impact. Waste material such as fly ash, used in large quantities, such as in AAC blocks, fly ash concrete blocks and FaL-G blocks, has a low impact on environment. Materials that use stone dust from stone crushing units also have a lower environmental impact. Cement based walling materials such as FaL-G blocks and solid concrete blocks require more water than other materials due to the curing process involved in their production. Clay based walling materials requires the least water.***

Keywords— Embodied Energy, Thermal Conductivity, Walling materials, AAC Blocks

I. INTRODUCTION

The tremendous growth in economic activity across the globe is placing pressure on natural and environmental resources. There is increasing evidence that human activities are causing an irreversible damage to the global environment, which will have an adverse impact on the quality of life of future generations. The rising concern for the environment in response to global warming is driving thinkers to seek sustainable solutions. The real estate industry is a significant contributor to the global warming due to extensive emissions of greenhouse gases (GHGs) from the energy use in buildings. In some countries, the built environment accounts for about 40% of the energy used. Therefore, there is an imperative for the industry to develop sustainable building technologies and green buildings. The construction industry in India is growing rapidly at a rate of 10% compared with the world average of 5.2%. It is observed that buildings in India consume about 20% of the total electricity in the country. Hence, real estate activity in India has a significant impact on the environment and resources. This indicates that there is a real opportunity to develop green buildings in the country. *(Residential Buildings in India: Energy Use Projections and Savings Potentials, India – Technical Report)*

India's domestic energy consumption has increased from 80 TWh in 2000 to 186 TWh in 2012, and constitutes 22% of total current electrical consumption (CEA , 2013). An increase of 400% in the aggregate floor area of buildings and 20 billion m2 of new building floor area is expected by 2030 (Dr Satish Kumar, USAID ECO - III Project, 2011). Furthermore, due to the constant increase of Indian GDP, consumer purchasing power is predicted to grow leading to greater use of domestic appliances. Consequently, household electrical demand is expected to rise sharply in the coming decade. This growth of residential floor space, combined with expectations of improved domestic comfort, will require an increase in electricity production, leading to a significant escalation in damaging emissions.

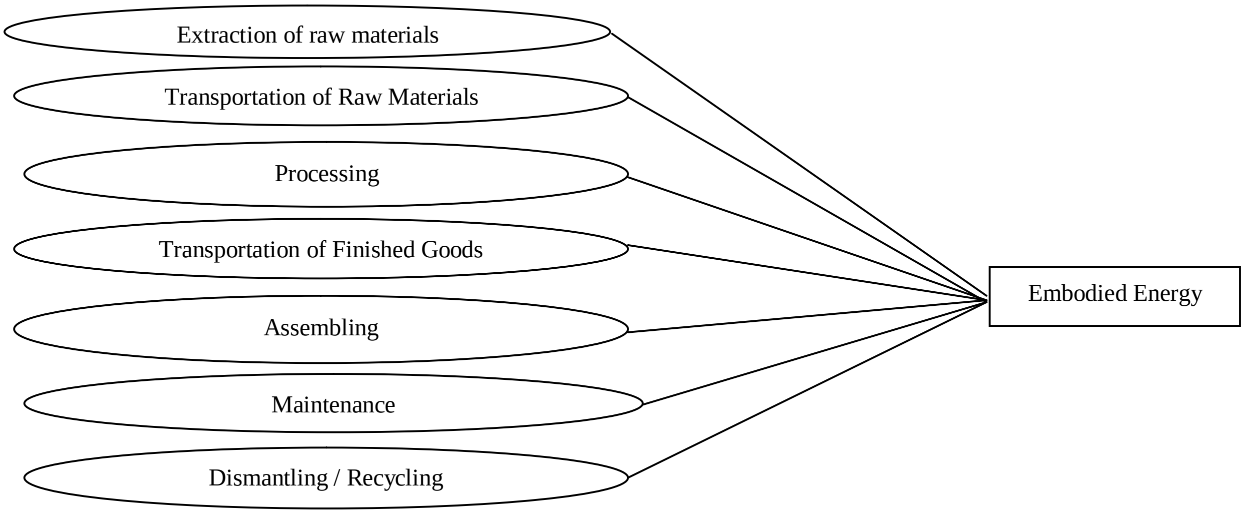
USAID: United States Agency for International Development
CEA: Central Electricity Authority

As energy consumption from residential buildings is predicted to rise by more than eight times by 2050 under the business as usual scenario, it is of vital importance for India to develop energy-efficiency strategies focused on the residential sector to limit the current trend of unsustainable escalating energy demand.

II. EMBODIED ENERGY AND THERMAL CONDUCTIVITY

A. Embodied Energy

Gupta et al. (2013) defined Embodied Energy as the energy required to construct and maintain the campus, for example, in reinforced concrete construction, the energy required to quarry the coarse and fine aggregate, transport them to site, lay them, plaster them and (if necessary) paint and re-plaster over the life of the respective element. Best practice would also include energy calculations for demolition and recycling. A flowchart mentioning various activities involved from quarry of the material to the final finished product of the elements, required to estimate embodied energy is given below:



B. Thermal Conductivity

Thermal conductivity is a specific property of a gas, liquid, or solid. The coefficient of thermal conductivity k is a measure of the rate at which heat (energy) passes perpendicularly through a unit area of homogeneous material of unit thickness for a temperature difference of one degree; k is expressed as Btu × in./(h × ft2 × °F)[W/(mK)]. The less the thermal conductivity of any material, the more it is energy efficient.

III. ENERGY AND BUILDING MATERIALS

The materials which are evaluated are Solid concrete blocks, Fly ash-Lime-Gypsum (FaL-G) Blocks, Autoclaved Aerated Concrete Blocks, Stabilized Mud Blocks, Fired clay fly ash bricks and Fired clay bricks. The following parameters are considered to calculate the environmental impact:

i) *Embodied Energy*
ii) *CO_2 Emission*
iii) *Thermal Conductivity*

A. Solid concrete blocks

The basic raw materials for the manufacture of cement concrete blocks are cement, coarse aggregate and fine aggregate. Blocks typically manufactured are solid or hollow and are available in sizes of 400 mm x 200 mm x 200 mm, 400 mm x 200 mm x 150 mm, and 400 mm x 200 mm x 100 mm. In areas with poor quality of fired bricks , this material has high potential.

Case Study: A concrete block unit in Bangalore

TABLE I - Solid Concrete Blocks - Raw Materials and Embodied energy

Weight of block (kg)	23.20
Size of block (mm)	400 x 200 x 200
Raw materials	
Sand (%)	25
Cement (%)	15
Stone dust (%)	60
Water (including curing) (l/block)	33.0
Embodied Energy	
Total (MJ/block)	22.41
Excluding raw material transportation (MJ/block)	15.43

B. FLY ASH-LIME-GYPSUM (FAL-G) BLOCKS

Fly ash reacts with lime in the presence of moisture at ordinary temperature to form a compound possessing cementitious properties. This reaction between fly ash and lime results in the formation of calcium silicate hydrates (CSH) which impart high strength to the material, therefore, chemically bonded bricks. In the case of fly ash-lime-gypsum (FaL-G) mixes, the early strengths are imparted by calcium alumina-sulphate hydrates (CASH) supplemented by CSH for late-age and ultimate strengths. The production of FaL-G blocks does not involve any sintering process.

Case Study: Fly Ash concrete block unit on the outskirts of Nagpur city, Maharashtra

TABLE II- FAL-G BLOCKS - RAW MATERIALS AND EMBODIED ENERGY

WEIGHT OF BLOCK (KG)	2.80
SIZE OF BLOCK (MM)	230 x 115 x 75
RAW MATERIALS	
FLY ASH (%)	33
SAND (%)	50
LIME (%)	17
WATER (INCLUDING CURING) (L/BLOCK)	15.5
EMBODIED ENERGY	
TOTAL (MJ/BLOCK)	3.92
EXCLUDING RAW MATERIAL TRANSPORTATION (MJ/BLOCK)	3.15

C. AUTOCLAVED AERATED CONCRETE BLOCKS

Aerated concrete is produced by mixing finely powdered quartz (about 50% by weight) with lime, gypsum, cement, and water, along with a small proportion (about 0.1%) of aluminum powder, which reacts to release hydrogen. AAC blocks are typically manufactured in large scale plants requiring heavy investment. The blocks are produced in a highly controlled mechanized environment and are regular shaped, uniform, high performance masonry units.

Case Study: An AAC block unit in Pune

TABLE IIII -AUTOCLAVED AERATED CONCRETE BLOCKS - RAW MATERIALS AND EMBODIED ENERGY

WEIGHT OF BLOCK (KG)	15.60
SIZE OF BLOCK (MM)	650 x 240 x 200
RAW MATERIALS	
FLY ASH (%)	61
CEMENT (%)	31
SAND (%)	8
WATER (INCLUDING CURING) (L/BLOCK)	8.0
EMBODIED ENERGY	
TOTAL (MJ/BLOCK)	70.17
EXCLUDING RAW MATERIAL TRANSPORTATION (MJ/BLOCK)	45.51

D. STABILIZED MUD BLOCKS (SMB)

The soil, raw or stabilized, for a compressed earth block is slightly moistened, poured into a steel press (with or without stabiliser) and then compressed either with a manual or motorized press. SMB can be compressed in many different shapes and sizes.

TABLE IV - STABILIZED MUD BLOCKS (SMB) - RAW MATERIALS AND EMBODIED ENERGY

WEIGHT OF BLOCK (KG)	8.94
SIZE OF BLOCK (MM)	305 x 143 x 100
RAW MATERIALS	
SAND (%)	65
SILT (%)	12
CLAY (%)	17
CEMENT (%)	6
WATER (INCLUDING CURING) (L/BLOCK)	6.0
EMBODIED ENERGY	
TOTAL (MJ/BLOCK)	3.73
EXCLUDING RAW MATERIAL TRANSPORTATION (MJ/BLOCK)	2.25

E. FIRED CLAY FLY ASH BRICKS

The fly ash is mixed with the soil for making the brick, at a local kiln site. The mixtures of clay available at the site and the fly ash with different percentage by weight are prepared. These mixtures are mixed thoroughly by adding the appropriate amount of water and used to make the bricks of clay and fly ash with different proportions.

Case Study: Fly ash concrete block on the outskirts of Nagpur city, Maharashtra, and is located within 10 km of a thermal power plant.

TABLE V - FIRED CLAY FLY ASH BRICKS - RAW MATERIALS AND EMBODIED ENERGY

WEIGHT OF BLOCK (KG)	2.60
SIZE OF BLOCK (MM)	230 x 115 x 75
RAW MATERIALS	
FLY ASH (%)	30
CLAY (%)	70
WATER (INCLUDING CURING) (L/BLOCK)	0.65
EMBODIED ENERGY	
TOTAL (MJ/BLOCK)	5.01
EXCLUDING RAW MATERIAL TRANSPORTATION (MJ/BLOCK)	3.09

F. FIRED CLAY BRICKS

The primary material used in the production of bricks is clay. Argillaceous materials used are mixed well with sand to improve the workability. Clay is relatively easy to extract as it does not usually lie too deep in the ground. After the top soil has been removed and the clay extracted, it is sieved, blended and mixed well with water, either manually or with mechanical mixers. The forming of bricks with the prepared clay is done manually or by moulding machines.

TABLE VI - FIRED CLAY BRICKS - RAW MATERIALS AND EMBODIED ENERGY

WEIGHT OF BLOCK (KG)	2.91
SIZE OF BLOCK (MM)	230 x 115 x 75
WATER (INCLUDING CURING) (L/BLOCK)	0.18
EMBODIED ENERGY	
TOTAL (MJ/BLOCK)	4.56
EXCLUDING RAW MATERIAL TRANSPORTATION (MJ/BLOCK)	3.26

IV. METHODOLOGY

Evaluation of the materials defined below by using data from different sources on the basis of Embodied Energy, CO2 emission and Thermal conductivity. Analysis is done by normalising the obtained data between -1 & 1, given all the three components defined above have equal weightage, given as NEI (Normalised Environment index).

TABLE VII - DIFFERENT MASONRY MATERIALS

MATERIALS	SIZE	VOLUME (M^3) OF A BLOCK/BRICK	THERMAL CONDUCTIVITY (W/M°C OR W/MK)	EMBODIED ENERGY (MJ/BLOCK)
SOLID CONCRETE BLOCK	400 x 200 x 200	0.016	1.35	28.15
FLY ASH-LIME-GYPSUM (FAL-G) BLOCKS	230 x 115 x 75	0.00198375	0.35	3.15
AUTOCLAVED AERATED CONCRETE (AAC) BLOCKS	650 x 240 x 200	0.0312	0.15	70.17
STABILIZED MUD BLOCKS (SMB)	230 x 190 x 100	0.00437	0.9	4.62
FIRED CLAY FLY ASH BRICKS	230 x 115 x 75	0.00198375	0.5	5.01
FIRED CLAY BRICKS	230 x 115 x 75	0.00198375	1.00	4.56

Sources: Deboucha Sadek & Hashim Roslan (2011),
Sabapathy et al. (2011)

The observed Embodied Energy from literature survey is in MJ/block, which has to be converted to MJ/m^3 as different blocks have different sizes.

A. CALCULATION FOR EMBODIED ENERGY/M^3

Solid concrete block size = 400 x 200 x 200 (mm)
Volume of one block = 0.016 m^3
One block of solid concrete block has 28.15 MJ Embodied Energy
1 m3 of solid concrete block will have (28.15/0.16) MJ Embodied Energy, which is 1759.375 MJ.
Embodied Energy/m^3 = (Embodied Energy/block) ÷ (Volume/block)

B. *Calculation for Normalised value*

To have a set of normalized data, with zero being the central point, then the following equation can be used to normalize the data:

$$X_{i-1\,to\,1} = \frac{X_i - \left(\frac{X_{Max} + X_{Min}}{2}\right)}{\left(\frac{X_{Max} - X_{Min}}{2}\right)}$$

Where,
X_i = Each data point i

X_{Min} = The minima among all the data points
X_{Max} = The maxima among all the data points
$X_{i, -1 \text{ to } 1}$ = The data point i normalized between -1 and 1

C. *Calculation of NEI*

NEI = Embodied Energy + CO_2 Emission + Thermal Conductivity (Normalised Values)

V. RESULTS AND DISCUSSIONS

A. Analysis of Masonry Materials

TABLE VIII - Parameters of different masonry materials

Materials	Embodied energy		CO_2 (g/m²)		Thermal Conductivity
	MJ/block	MJ/m³	Production emissions	Transportation emissions	W/m°C or W/mK
Solid concrete block	28.15	1759.375	30277.0	4808.8	1.35
Fly ash-Lime-Gypsum (FaL-G) Blocks	3.15	1587.901	50051.0	5040.9	0.35
Autoclaved Aerated Concrete (AAC) blocks	70.17	2249.038	28137.4	7785.3	0.15
Stabilized Mud Blocks (SMB)	4.62	1057.2082	21544.1	4071.7	0.9
Fired clay fly ash bricks	5.01	2570.888	18693.4	9830.7	0.5
Fired clay bricks	4.56	2298.676	18698.5	8073.5	1.00

AAC block have the highest amount of Embodied Energy, but least Thermal conductivity, which makes it the most efficient material in terms of operational energy of any building. Stabilized Mud Block has the least impact on environment during its production (CO_2 emissions) and also in terms of embodied energy due to locally available materials. Its conductivity is six time the AAC Block. AAC Blocks have low thermal conductivity which provides more uniform temperature behaviour inside a house and reduces the heat losses.Thus to evaluate these materials on same scale, Normalised value of each is calculated and analysed, keeping the weightage same for all the three parameters (Embodied Energy, CO_2 emission and Thermal Conductivity). The Cumulate of all the normalised value is given by NEI (Normalised Environment Index).

TABLE IX - Analysis of different masonry materials (Normalised Value)

Materials	Embodied energy	CO_2	Thermal Conductivity	NEI	Rank
Solid concrete block	-0.072	-0.357	1	0.571	6
Fly ash-Lime-Gypsum (FaL-G) Block	-0.298	1.00	-0.666	0.036	4
Autoclaved Aerated Concrete (AAC) block	0.575	-0.295	-1	-0.72	2
Stabilized Mud Blocks (SMB)	-1	-1.00	0.25	-1.75	1
Fired clay fly ash brick	1	-0.802	-0.416	-0.218	3
Fired clay brick	0.64	-0.977	0.416	0.079	5

Table IX indicates that the material listed above with least environmental impact is SMB Blocks (most negative), followed by AAC Blocks. On other hand Solid Concrete is the most unfavourable choice, because of its high Embodied Energy, high CO_2 Emission and high Thermal Conductivity.

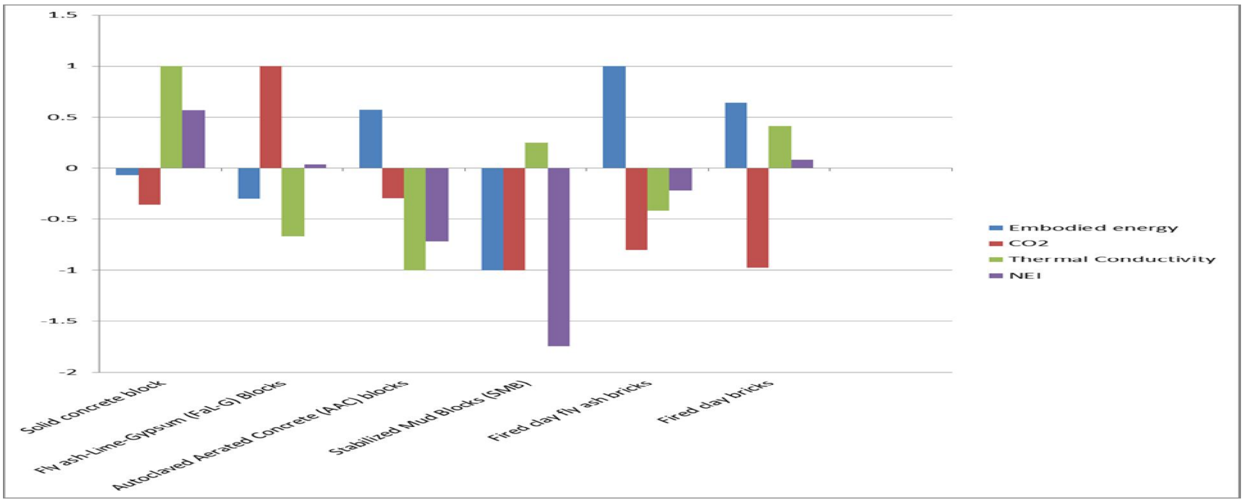


Fig. 1 Analysis of Materials with cumulated normalised values or NEI

VI. CONCLUSION

The real estate industry is a significant contributor to the global warming due to extensive emissions of greenhouse gases (GHGs) from the energy use in buildings. In some countries, the built environment accounts for about 40% of the energy used. Therefore, there is an imperative for the industry to develop sustainable building technologies and green buildings. The construction industry in India is growing rapidly at a rate of 10% compared with the world average of 5.2%. It is apparent that masonry units with the least clay content have the least raw material impact. Where waste material such as fly ash is used in large quantities, such as in AAC blocks, fly ash concrete blocks and FaL-G blocks, the impact is low. Materials that use stone dust from stone crushing units also have a lower raw material impact. It is very important to keep a check on embodied energy, carbon emission and Thermal conductivity. It is seen that SMB blocks have the least embodied energy and CO_2 emission. AAC block have the lowest thermal conductivity. Cumulative values of the normalised score (given as NEI) of Embodied Energy, CO_2 emission and Thermal Conductivity refers SMB as most energy efficient material. But considering long time interval and operational energy i.e. thermal conductivity, AAC block is the best energy efficient material. Solid Concrete blocks have the highest embodied energy (1759.375 MJ/m^3) compared to the SMB (1057.2082 MJ/m^3).

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