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Indexing of Building Materials with Embodied, Operational Energy and Environmental Sustainability with Reference to Green Buildings

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There is good number of options to design energy efficient/green buildings. One of the objectives of green building is to conserve the natural resources and substantial energy is consumed in the operation of air conditioning system. In this paper total usage of energy (embodied and operational energy) has been calculated for fire clay bricks and ash blocks building material. Energy and environment indices were calculated and it was found that use of ash block as replacement of fire clay bricks can reduce significantly the heat load, size of air conditioning system and hence contributes towards saving of natural resources and environment.

Keywords: Green Building, Embodied Energy, Operational Energy.

1. INTRODUCTION

Ever Since the first world's oil crisis in the year 1973, intensive efforts were made all over the world to reduce energy consumption in all the sectors of a nation's economy. Building sector is one of the most energy consuming sectors of any National economy and hence efforts were made to develop building designs and national energy building codes for saving energy in buildings. As a result of mandatory provisions of these codes substantial reduction of energy consumption in buildings was achieved particularly for heating and cooling of buildings.

The construction sector consumes considerable amount of energy from the production of basic building materials, its transportation and assembling called embodied energy. Energy conscious and eco-friendly development hold the key potential to significantly reduce thermal loads and electricity use in commercial buildings. Low embodied energy materials conserve energy and limit Green House Gases (GHG) emissions thus limiting the impact on the environment. Energy requirements for the production and processing of common building materials and respective CO_2 emissions have been cited by Buchanan *et al.*[1], Suzki *et al.*[2], Oka *et al.*[3], and Debnath *et al.*[4]. Embodied energy of common building materials has been presented by Venkatarama Reddy *et al.*[5]. Total expense of energy consumed on bricks, cement, aluminum and steel that are used for building structure amounts to 1684x106 GJ per annum. The GHG emission contributed by construction sector in India is 22% and there is an ever-increasing demand for building materials[6]. For the construction of multistoried apartment buildings the use of Reinforced Concrete Cement (RCC) framed structure is very common. Studies have shown that most commonly used

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materials viz. cement, fire clay brick, iron/steel etc are energy intensive and highly polluting building materials[7,8]. As per Indian buildings construction practices, Indian buildings are highly energy intensive with specific energy consumption ranging from 280 kWh/m^2 to 400 kWh/m^2, depending upon the climatic conditions and/or the type of buildings[9,10]. The increasing energy consumption in buildings as well as in the other sectors has led to growing environmental concerns. Moreover, convention building materials were found to contain toxic contaminants leading to health hazards[11]. The attention in the last decade has therefore been towards energy and environmentally sustainable buildings, often termed as also the Green buildings encompassing wider perspectives of water, energy, material, and resources. Environmental sustainability analysis of such buildings has however remained empirical. Factors govern the energy usage in the buildings are (a) climatic zones, (b) building design, (c) energy building material properties and building components and (d) building use.

The objective of this paper is to develop quantified index energy and environment index based on energy consumption both in building materials and buildings usage as well as the related environmental emissions and to conserve finite natural resources. The developed index can be applied to large size of buildings in India.

2. SAMPLE ROOM: LOCATION AND CLIMATIC CONDITIONS AND SPECIFICATIONS

2.1. Description of Building

Sample room considered for evaluation is assumed located at Delhi (Latitude 28.65° N & Longitude 77.25° E) in the composite climate of India. Size of the test room was 3.0 m x 3.0 m x 3.0 m (L x W x H) and has only one window north of 2.23 m^2. All walls and roof are exposed to sun. Using air conditioning equipment indoor temperature was maintained Total indoor space is air conditioned and temperature maintained at 24.0°C. Building materials considered for simulation were fire clay bricks and ash aerated blocks and the performance in terms of total energy usage and thermal has been compared for these materials without and with various thickness of insulation. One of feature of green building is the energy conservation and the sample room has been considered as a green building in terms of usage of energy in air conditioning system.

2.2. Design Parameter Constants

The following parameters of space and material specifications for the Interiors and the building skin have been kept constant for all the patterns:

Floor Area	9 m^2
Room Dimensions	3.0 m x 3.0 m
Glass Window Area	2.23 m^2
Wall Area	35 m^2

Specifications of Materials:

Roof insulation	50 mm thick insulation board
Window	5 mm clear float glass
Cooling system	Chilled water system
Heating	No heating considered
Operation schedules	8-12 Hours/day

2.3. Building Construction Material

Standard Indian fireclay bricks (0.23 m x 0.11 m x 0.076 m) and ash blocks (0.23 m x 0.11 m x 0.076 m) were used for analysis purposes. The ash blocks were manufactured using autoclaved aerated concrete material having 60% - 65% as the basic raw material other materials used are lime cement, gypsum and aluminum powder. Due to millions of tiny pores, it has low density and thermal conductivity[12]. Various thickness of insulation was used on the wall to reduce the inflow of heat flux. Generally, cost of aerated ash block is 3 times of the cost of fire clay brick. However, due to light in weight of ash block the requirement of structure strength in terms of used material like iron, cement, aggregate etc would reduced considerably for multistoried buildings and total cost would be nearly same. A comparison between the quantities used for building material, embodied energy and cost in walls and roof and supported structure of the unfinished test room with fire clay bricks and ash blocks is given in Tables 1 & 2. Thermo-physical properties[12, 13] of ash blocks, burnt fireclay and insulation are given in Table 3a. Values of other parameters used for heat load calculations during peak summer day is also given in Table 3b. Cost of material, air conditioning system and electrical tariff are given in Table 4.

Table 1: Quantity, Cost and Embodied Energy of Various Materials used with Fire Clay Bricks

Material	Unit	Quantity	Total Cost (Rs)	Embodied Energy (MJ)	CO_2 Emissions (MT)
Fire clay bricks	No.	2791	8373	36004	7.60
Cement	Kg	3000	18000	13500	2.85
Iron	Kg	200	8000	5000	1.05
Double glass (5 mm thick)	m^2	2.16	1470	405	0.08
Aggregate	m^3	2.75	3570	512	0.11
Total			39413	55421	11.69

Table 2: Quantity, Cost and Embodied Energy of Various Materials used with Ash Blocks

Material	Unit	Quantity	Total Cost (Rs)	Embodied Energy (MJ)	CO_2 Emissions (MT)
Fire clay bricks	No.	2791	25119	11234	2.37
Cement	Kg	1800	10800	8100	1.71
Iron	Kg	156	6240	3900	0.82
Double glass (5 mm thick)	m^2	2.16	1470	405	0.08
Aggregate	m^3	1.73	2240	321	0.07
Total			45869	23960	5.05

Table 3a: Thermo-Physical Properties of Ash Block, Fire Clay Bricks and Insulation Board

Parameter	Ash Block	Fire Clay Brick	Insulation Board
Density	600 kg/m^3	1600 kg/m^3	32-35 kg/m^3
Thermal conductivity	0.162 W/m-K	0.675 W/m-K	0.028 W/m-K

Table 3b: Values of other Parameters used for Heat Load Calculations during Peak Summer day

Parameter	Value
Uroof	0.235 W/m^2K
Double glass shading factor	1.64 W/m^2K
Transmittivity factor	3.12 W/m^2K
Outdoor temperature	43.3 °C
Indoor temperature	24.0 °C
Outdoor relative humidity	19%
Indoor relative humidity	50%
Coil bypass factor	0.1

Table 4: Cost of Various Components used to Calculate Costs

Material/System	Cost
Fire clay brick	Rs 3.0 per brick
Ash block	Rs 9.0 per block
Insulation board	Rs 13/m^2/mm
AC system	Rs 17094/kW
Electric tariff	Rs 4.0/kWh

2.4. Embodied Energy of Building Material

Embodied Energy is the energy consumed by all the processes associated with the production of a product from the acquisition of natural resources to the product delivery. This includes the mining and manufacturing of materials and equipment, the transport of materials and the administrative functions. Typically, embodied energy is measured as a quantity of non-renewable energy per unit of building material, component or system. Embodied energy per unit mass of materials used in building varies enormously and is tabulated in Table 5[5].

Table 5: Embodied Energy, CO_2 Emission and Density of Various Building Materials

Material	Energy MJ/kg	Carbon $kgCO_2/kg$	Density kg/m^3
Aggregate	0.083	0.0048	2240
Concrete (1:1.5:3 e.g. in-situ floor slabs, structure)	1.11	0.159	2400
Bricks (common)	3.0	0.24	1700
Concrete block (Medium density $10N/mm^2$)	0.67	0.073	1450
Aerated block	3.50	0.30	650
Steel (general - average recycled content)	20.10	1.37	7800
Steel (section - average recycled content)	21.50	1.42	7800
Steel (pipe - average recycled content)	19.80	1.37	7800
Stainless steel	56.70	6.15	7850
Timber (general - excludes sequestration)	10.00	0.72	480-720
Sawn hardwood	10.40	0.86	700-800
Glass fibre insulation (glass wool)	28.00	1.35	12
Flax insulation	39.50	1.70	30
Rockwool (slab)	16.80	1.05	24
Expanded Polystyrene insulation	88.60	2.55	15-30
Polyurethane insulation (rigid foam)	101.50	3.48	30
Clay tile	6.50	0.45	1900
Aluminum (general & incl 33% recycled)	155	8.24	2700
Plywood	15.00	1.07	540-700
Plasterboard	6.75	0.38	800
Gypsum plaste	1.80	0.12	1120
Glass	15.00	0.85	2500
PVC (general)	77.20	28.1	1380
Linoleum	25.00	1.21	1200
Vinyl flooring	65.64	2.92	1200
Ceramic tiles	12.00	0.74	2000
Iron (general)	25	1.91	7870
Copper (average incl. 37% recycled)	42	2.60	8600
Lead (incl 61% recycled)	25.21	1.57	11340

Every building is a complex combination of many processed materials, each of which contributes to the building's total embodied energy. Generally, focus has been on understanding energy use during the operational period of the building (use phase). With this approach, an important factor had been neglected; the embodied energy of construction materials.Measure of embodied energy are the associated with environmental implications of resource depletion, greenhouse gases, environmental degradation and reduction of biodiversity. As a rule of thumb, embodied energy is a reasonable indicator of the overall environmental impact of building materials, assemblies or systems.

Material selection can influence heating and cooling energy, e.g. through building material, insulation and design & specifications. Therefore, rather than focusing on either operational energy or embodied energy, building designers should adopt an integrated design approach.

3. CALCULATION OF ENERGY

3.1. Embodied Energy and Emission

The calculation of embodied energy and emissions has been calculated as follows:

Embodied energy=Quantity of the material* Embodied energy coefficient -(1)

CO_2 Emissions (MT) = Energy Consumption (kWh) x Emission Factor/1000 -(2)

Emission Factor = 0.76 (kg/kWh) -(3)

Using equations (1) and (2), embodied energy and CO_2 emissions for fire clay brick and ash block brick structure were calculated and are tabulated in Tables 1 and 2 along with the cost and quantity of materials used.

3.2. Calculation of Heat Load and Air-Conditioning

The behavior of building in terms of cooling load was investigated for composite climate. The various other parameters used are given in Table 3b. Thermal performance calculations of the building were based on ISHRAE handbook of Air Conditioning and ASHRAE Handbook 'Fundamentals System Design'[14,15] and required climate data and correction factors has also been taken from ISHRAE Handbook. Following assumptions were made to evaluate the air conditioning load to provide the basis for selecting the conditioning equipment (i) all calculations were made for steady state and (ii) occupancy, addition of fresh air, lighting load and equipment load were considered zero. Heat load and over all heat transfer values for various configurations are given in Table 6. This calculated heat load is to be removed by air conditioning system.

Table 6: Variation of over all Heat Transfer Coefficient with Insulation Thickness

Description	Thickness of Insulation (mm)									
	0	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5	52.5
U value of Fire clay brick (W/m^2 K)	2.113	1.204	1.050	0.939	0.856	0.792	0.740	0.697	0.662	0.632
U value of Ash block (W/m^2 K)	0.874	0.728	0.687	0.654	0.625	0.600	0.579	0.560	0.543	0.528

3.3. Total Usage of Energy:

Total usage of building includes embodied energy of the building material, insulation and operational energy used by air conditioning system in 20 years to remove the heat for various structure configurations and given in Tables 7 and 8. Specific energy usage and specific CO_2 emissions per square meter of floor area were calculated and named as 'energy' and 'environment' indices.

4. RESULTS AND DISCUSSION

Embodied energy, CO_2 emissions and cost of raw materials associated the fire clay bricks and ash blocks are given in Tables 1 and 2. One can see from these Tables 1 and 2 that the cost of material with clay bricks and ash block is Rs 39413 and Rs 45869 respectively, however, embodied energy with clay bricks and ash block 15394 kWh and 6655 kWh are respectively. Cost of ash block structure is 16% higher as compared to fire clay brick structure but the embodied energy content for ash block structure is 57% less.

Values obtained for energy usage, total cost and CO_2 emissions are tabulated in Tables 7 and 8. It is also an evident from Tables 7 and 8 that the requirement of air conditioning system is reduced 59% due to the use of ash blocks without insulation; hence, it has resulted in significant reduction in size of the air conditioning machine. If one compares the total energy usage by the building (embodied energy & operational energy) in 20 years, it varies from 57753 kWh to 23890 kWh.

Table 7: Variation of Various Energy and Costs of Fire Clay Brick Structure with Insulation Thickness

Description	Thickness of Insulation (mm)									
	0	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5	52.5
Embodied Energy of insulation material (kWh)	0	358	498	639	782	924	1066	1207	1351	1492
Cost of insulation material (Rupees)	0	5640	7896	10152	12408	14664	16920	19176	21432	23688
Heat load (kW)	2.11	1.20	1.05	0.94	0.86	0.79	0.74	0.70	0.66	0.63
Cost of Air Conditioning System (Rs)	36118	20573	17943	16057	14638	13533	12647	11922	11316	10804
Operational Energy of A.C. System for 20 years (kWh)	57753	32896	28690	25675	23407	21639	20223	19063	18095	17275
Operational Cost of A.C. System for 20 years (Rs)	231011	131585	114761	102699	93628	86557	80892	76251	72379	69099
Total usage of Energy of Building (kWh)	73147	48648	44582	41708	39583	37957	36683	35664	34840	34161
CO_2 Emissions (MT)	56	37	34	32	30	29	28	27	26	26
Total usage Energy Cost of Building (Rs)	270424	176638	162070	152264	145449	140634	137225	134840	133224	132200
Energy Index (KWh/m^2)	8127	5405	4954	4634	4398	4217	4076	3963	3871	3796
Environment Index (MT/m^2)	6.2	4.1	3.8	3.5	3.3	3.2	3.1	3.0	2.9	2.9

Table 8: Variation of Various Energy and Costs of Ash Block Structure with Insulation Thickness

Description	Thickness of Insulation (mm)									
	0	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5	52.5
Embodied Energy of insulation material (kWh)	0	358	498	639	782	924	1066	1207	1351	1492
Cost of insulation material (Rupees)	0	5640	7896	10152	12408	14664	16920	19176	21432	23688
Heat load (kW)	0.87	0.73	0.69	0.65	0.62	0.60	0.58	0.56	0.54	0.53
Cost of Air Conditioning System (Rs)	14941	12442	11751	11173	10681	10258	9890	9567	9281	9027
Operational Energy of A.C. System for 20 years (kWh)	23890	19895	18791	17865	17079	16402	15814	15298	14841	14434
Operational Cost of A.C. System for 20 years (Rs)	95560	79580	75162	71461	68316	65609	63256	61190	59363	57736
Total usage of Energy of Building (kWh)	30545	26908	25944	25159	24516	23981	23535	23160	22847	22581
CO_2 Emissions (MT)	23	20	20	19	19	18	18	18	17	17
Total usage Energy Cost of Building (Rs)	141429	131089	128927	127482	126593	126142	126045	126235	126664	127293
Energy Index (KWh/m^2)	3394	2990	2883	2795	2724	2665	2615	2573	2539	2509
Environment Index (MT/m^2)	2.6	2.3	2.2	2.1	2.1	2.0	2.0	2.0	1.9	1.9

Further use of insulation on the walls reduces the heat load, energy usage & cost and the pattern can be seen in Fig. 1, 2 and 3 being plotted against the thickness of insulation and the total cost and energy used are always much lower for ash block than the fire clay brick structure. Similarly, the building material cost with 20 year operational cost is much lower in the case of ash blocks building. Energy and Environment index of the room were also calculated and are tabulated in Tables 7 and 8, it can be seen from the data that there is a considerable reduction in the each index on replacing fire clay brick to ash block as building construction material.

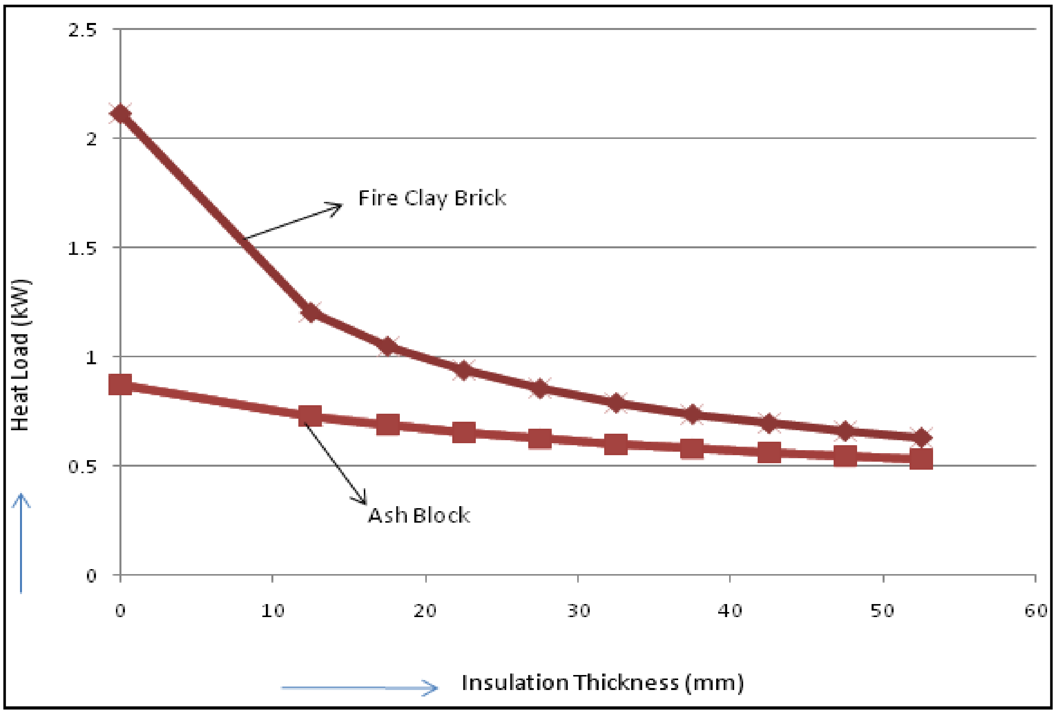

Fig. 1: Variation of Heat Load of the Room of Fire Clay Brick and Ash Block Structure with the Thickness of Insulation on Walls

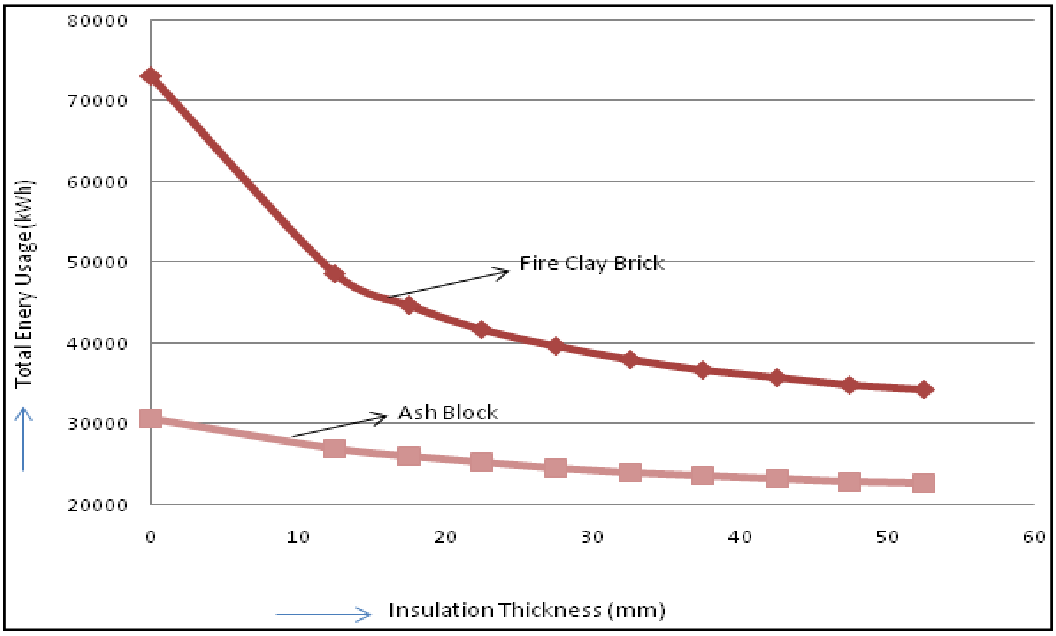

Fig. 2: Variation of Total Energy usage in the Room of Fire Clay Brick and Ash Block Structure with the Thickness of Insulation on Walls

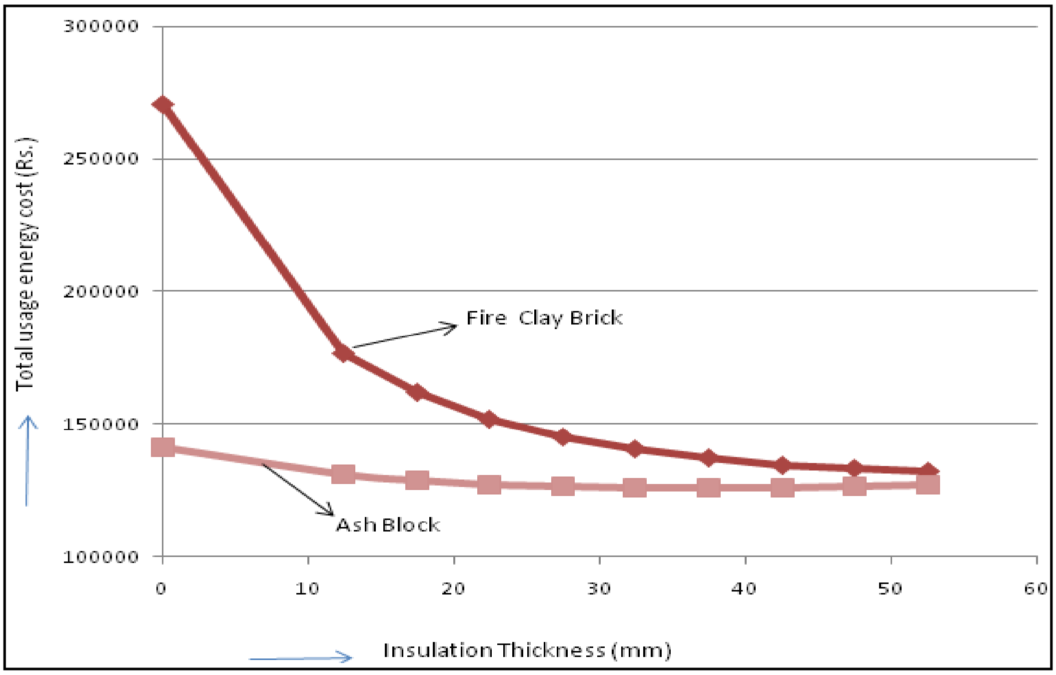

Fig. 3: Variation of Total Energy usage Cost in the Room of Fire Clay Brick and Ash Block Structure with the Thickness of Insulation on Walls

3. CONCLUSION

The use of embodied energy and total energy has been discussed in this paper for a given sample room. The paper focuses upon comparison of two types of structures using fire clay bricks and ash blocks structure. Though ash blocks are 3 times costlier than fire clay bricks but the use of ash blocks has considerably reduced the size of air conditioning system, total usage of energy and finally the total cost of building due to its light weight and insulating nature. Hence, use of ash blocks has helped in conserving the natural resources, energy and environment.

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