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Embodied Energy Of Building And Alternative Building Materials

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Abstract - Considerable amount of energy is spent in the manufacturing processes and transportation of various building materials. Conservation of energy becomes important in the context of limiting of greenhouse gases emission into the atmosphere and reducing costs of materials. The paper is focused around some issues pertaining to embodied energy in buildings particularly in the Indian context. Energy consumption in the production of basic building materials (such as cement, steel, etc.) and different types of materials used for construction has been discussed. Energy spent in transportation of various building materials is presented. A comparison of energy in different types of masonry has been made. Energy in different types of alternative roofing systems has been discussed and compared with the energy of conventional reinforced concrete (RC) slab roof. Total embodied energy of a multi-storeyed building, a load bearing brickwork building and a soil–cement block building using alternative building materials has been compared. It has been shown that total embodied energy of load bearing masonry buildings can be reduced by 50% when energy efficient/alternative building materials are used.

Keywords- Energy and building material, Embodied energy, Energy efficient materials

I. INTRODUCTION

Selection of materials for the building construction should satisfy the felt needs of the user as well as the development needs of the society, without causing any adverse impact on environment. In recent years, awareness of environmental aspects has grown in the building and construction sector. Manufacturing processes of building materials contribute greenhouse gases like CO2 to the atmosphere. There is a great concern and emphasis in reducing the greenhouse gases emission into the atmosphere in order to control adverse environmental impacts. Energy requirements for production and processing of different building materials and the CO2 emissions and the implications on environment have been studied. These studies pertain to New Zealand, Japan and India.

Indian construction industry is one of the largest in terms of employing manpower and volume of materials produced (cement, brick, steel and other materials). Construction sector in India is responsible for major input of energy resulting in the largest share of CO2 emissions (22%) into the atmosphere. Apart from the office, commercial and industrial buildings, >2 106 residential buildings are built annually, in India. Demand and supply gap for residential buildings is increasing every year (20 million units in 1980 to 40 million units in 2000. Cement (>75 million tonnes per annum), steel (>10 million tonnes per annum) and bricks (>70 billion per annum) are the largest and bulk consumption items in the Indian construction industry.

Minimizing the consumption of the conventional materials by using alternative materials, methods and techniques can result in scope for considerable energy savings as well as reduction of CO2 emission. This paper presents a detailed account of embodied energy in alternative building materials and techniques and comparison of embodied energy in buildings built with conventional and the new building methods.

II. LITRETURE REVIEW

The building industry uses great quantities of raw materials that also involve high energy

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consumption. Choosing materials with high content in embodied energy entails an initial high level of energy consumption in the building production stage but also determines future energy consumption in order to fulfil heating, ventilation and air conditioning demands. This paper presents the results of an LCA study comparing the most commonly used building materials with some eco-materials using three different impact categories. The aim is to deepen the knowledge of energy and environmental specifications of building materials, analyzing their possibilities for improvement and providing guidelines for materials selection in the eco-design of new buildings and rehabilitation of existing buildings.

Studies in cold countries have shown that the major part of the LCE use is in the operating phase (80–90%) and production of building materials accounts for 10–20% [4–8]. Energy used for onsite construction (including transportation of materials to the site) of the buildings and its demolition at the end of its life accounts for a minor proportion (1%) of the life cycle. Some authors have studied the effect of change of envelope materials and construction on the LCE demand of the buildings. Cither let and Defaux and Mithraratne and Vale analyzed effect of insulation on buildings envelope so as to reduce LCE demand of the buildings and concluded that good insulation provides a significant reduction of energy (about 50%). Medgar and Martha presented a life cycle assessment of a single-family house modelled with two types of exterior walls: wood framed and insulating concrete form (ICF). The house was modeled in five cities of different climates in U.S. The results depict that in almost all cases, for a given climate, the energy use is greater for the wood house than for the ICF house.

Utama and Gheewala evaluated LCE of a residential apartment in Jakarta, Indonesia, with two envelope materials: (a) double walls having external walls made from clay bricks, inner walls with gypsum plaster board and air gap in between and (b) single walls with clay bricks. Double walls had resulted in better energy performance (40% less) than single walls. Xing et al. presented the life cycle assessment of an office buildings constructed in China using steel and concrete. They observed that embodied energy (EBE) and environmental emissions of steel framed building were superior to the concrete framed one. However, operating energy (OPE) use and associated emissions were larger for steel framed building due to the higher thermal conductivity of steel than concrete. As a result LCE consumption and environmental emissions of steel framed building were slightly higher. Only a few studies have been reported on LCE demand of the buildings from tropical and subtropical countries.

III. Energy in building materials

3.1 Basic building materials

Energy consumed during production of basic building materials is given in Table 1. These energy values pertain to production systems employed by the material manufacturers in India. Total energy values of various basic materials given in Table 1 have been used in the computations of energy in building materials/systems and buildings

Table 1. Energy in basic building materials

Type of material	Thermal energy (MJ/kg)
Cement	5.85
Lime	5.63
LP	2.33
Steel	42.0
Aluminium	236.8
Glass	25.8

3.2 Masonry materials

Masonry walls constitute one of the major energy consuming components of the building, especially in case of load bearing masonry structures. Varieties of materials are used for the construction of masonry walls. Three types of building blocks viz. stone, burnt clay brick, soil–cement block have been considered for the analysis.

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3.1.1 Stone block

Natural building stones have been extensively used for the building construction in India and elsewhere. In India, stone blocks are generally produced by splitting the hard natural stone into convenient sizes. Stone blocks of size approximately about 180mm x 180mm x180 mm are generally termed as size stones in the Indian construction practices. Only manual labour is employed in bulk of the sizing operations. Occasionally, very hard and big stones are reduced to smaller sizes (for the convenience of handling for further sizing by manual process) using detonators. Hence, hardly any thermal energy goes into the production of size stones. However, some energy is spent for transporting stone to the construction site.

3.1.2 Burnt clay bricks

These are very commonly used for building construction. It is estimated that about 70 billion bricks are produced in India annually. The common brick size is 230mmx110mm x60–75 mm. They require considerable amount of thermal energy during the burning process. Coal, coal cinder and firewood are the most commonly used fuels for brick burning in India. In general, each brick needs either 0.20 kg of coal or 0.25–0.30 kg of firewood for the burning process. This translates into a thermal energy of 3.75– 4.75 MJ per brick. An average value of 4.25 MJ per brick (size: 230mm x110mmx70 mm) has been considered for the comparison and computation of energy content of buildings and masonry

3.1.3 Hollow concrete blocks

These are light weight/low density blocks very commonly used for the construction of non-load bearing filler walls in multistoried buildings in India. They are also used for the construction of load bearing masonry walls to a limited extent. The basic composition of the blocks consists of cement, sand and coarse aggregates (˜6 mm size). The energy content of the block will mainly depend upon the cement percentage. Energy spent for crushing of coarse aggregate will also contribute to the block energy. The cement percentage generally varies between 7 and 10% by weight. Quality of the block, particularly compressive strength is the deciding factor for cement percentage. Energy content of the hollow concrete block of size 400mmx 200mm x200 mm will be in the range of 12.3–15.0 MJ

3.3 Energy in transportation of building materials

Transportation of materials is a major factor in the cost and energy of a building. Bulk of the building materials in urban and semi-urban centers are transported using trucks in India. The transportation distance may vary depending upon the location of construction activity. In urban areas, the materials travel anywhere between 10 and 100 km in the Indian context. Materials such as sand are transported from a distance of 70–100 km in cities like Bangalore, India. Similarly bricks/blocks crushed aggregate, etc. travel about 40–60 km before reaching a construction site, in urban and semi-urban centers.

Cement and steel travel even longer distances, of the order of 500 km or more. Long haul of cement and steel is handled through rail transport. Fancy building materials such as marble, paints, etc. are sometimes transported from great distances (>1500 km) in India.

Table 2. Energy in transportation of building materials

Num ber	Type of material	Energy (MJ)		
		Production	Transportation	
			50 km	100 km
1	Sand (m3)	0.0	87.5	175
2	Crushed aggregate (m3)	20.5	87.5	175
3	Burnt clay bricks (m3)	2550	100	200
4	Portland cement (tonnes)	5850	50	100
5	Steel (tonnes)	42000	50	100

3.4 Energy in mortars

Mortar is a mixture of cementitious material and sand. It is used for the construction of masonry as well as plastering. Cement mortar, cement–soil mortar, cement pozzolana mortar are used for masonry construction and plastering. Cement mortar is a common choice for masonry and rendering works. Cement–soil mortar has been used for the construction of SMB masonry. Cement–pozzolana and LP Mortars can also be used for masonry construction and other applications. Total energy content of these four types of mortars is given in Table 3. Details of mortar type, their proportions and energy content/m3 of mortar are given in this table. The following observations can be made from the data given in the table.

Table 3. Energy in mortars

Type of mortar Energy/m^3	Proportion of materials			(MJ)
	Cement	Soil	Sand	
Cement mortar	1 1	0 0	6 8	1268 1006
Cement pozzolana mortar	0.8:0.2[b] 0.8:0.2[b]	0 0	6 8	918 736
Cement–soil mortar	1 1	2 2	6 8	849 773
LP mortar	1 (1:2)[c]	0	3	732

1. Cement mortar consumes more energy than other types of mortars.
2. Replacing 20% of cement by pozzolana leads to a 25% reduction in energy of cement mortar.
3. Dilution of cement mortars by the addition of soil, leads to more than 25% savings in the energy content of mortar. It is to be noted here that cement–soil mortars are economical and have better characteristics than pure cement mortars. They have better plasticity, adhesion/ bond leading to higher values of masonry compressive strength [19,21].
4. LP mortar has the lowest energy value when compared with other mortars.

IV. Energy and choice of building technologies

The energy content of different building materials and building components such as masonry walls, roofs, floors, etc. have been discussed in the earlier sections. These energy values can be integrated into a computation of the total embodied energy in a building. Total embodied energy of three types of buildings is given in Table 4. This table gives details of the building specifications, total energy and an equivalent quantity of coal. A multistoried building, conventional two-storied load bearing brickwork building and another two-storied building using alternative building technologies (Fig. 6 shows the photograph) have been considered here for the purposes of comparison.

Embodied energy of the three buildings given in Table 4 is based on the actual quantities of materials used for the construction of these buildings. Energy content of doors and windows is not considered in the calculations of energy content of the buildings. Energy/100 m2 of built-up area is considered for the purposes of comparison. It is clear from the table that the multistoried building consumes highest amount of energy of 21 tonnes of coal/100 m2 (or 4.2 GJ/ m2). The two storied conventional building with load bearing brickwork is 30% energy efficient with energy of 14.6 tones of coal (or 2.9 GJ/m2). The soil–cement block building with filler slab roof and other alternative materials is however extremely energy efficient consuming 62% less energy than multistoried building. The conventional two storied building and the two-storeyed building with alternative building technologies have approximately similar built-up area, but there is a wide difference in the total embodied energy content. Soil–cement block building has consumed only 55% (1.6 GJ/m2) of energy when compared to the conventional brickwork building (2.9 GJ/m2). The major savings in energy can be attributed to the use of alternative building technologies such as soil–cement blocks for walls and SMB filler slab roof/floor.

Table 4. Total embodied energy in a building

Type of building and specifications	Number of storeys	Built-up area (m2)	Total embodied energy/100 m2 (GJ)	Equivalent amount of coal/100 m2 (tones)
RC framed structure with infilled burnt clay brick masonry walls	8	5120	421	21
Load bearing brickwork, RC solid slab roof/floor, mosaic floor finish	2	149.5	292	15
Soil–cement block filler slab roof/floor, terracotta tile floor finish	2	160.5	161	8

V. CONCLUSIONS

Embodied energy in basic building materials, different types of masonry materials, mortars, masonry and floor/roofing systems and the energy expenditure in transportation of building materials has been discussed in this paper. The paper focuses on materials and construction techniques as practiced in India. The following broad conclusions emerge.

1. Soil–cement block is the most energy efficient among the alternative materials for walling, consuming only one-fourth of the energy of burnt clay brick. Concrete blocks and steam cured blocks also consume much less energy during manufacturing process, when compared to burnt clay brick.
2. Building materials are transported over distances in excess of 100 km in many urban centers in India. Diesel energy spent for transportation could be about 5–10% of energy spent during manufacturing process for burnt clay bricks. Energy spent in transporting high-energy materials like steel and cement is negligible when compared to the energy spent in the manufacture of these materials.
3. LP mortars have lowest energy content when compared with other mortars like cement mortar, cement pozzolana mortar, etc.
4. Energy content of burnt clay brick masonry is 2141 MJ/ m3. Soil–cement block masonry is most energy efficient at one-third the energy of burnt clay brick masonry. Concrete block masonry has about 40–45% of energy content of burnt clay brick masonry.
5. Use of SMB filler blocks in solid RC roof/floor slabs leads to 20% reduction in energy content. Masonry vault roofs are more energy efficient than solid RC slab. Tile roofs have least energy content when compared with other roofing systems.

The results of the paper give useful tips for selecting an energy efficient building technology leading to considerable reduction in embodied energy of the building as a whole. Even though the results pertain to Indian conditions, many other developing nations have similar construction practices, where these results can be conveniently extrapolated and used.

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