# EMBODIED ENERGY COMPUTATIONS IN BUILDINGS

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***ABSTRACT***

*Building industry is one of the fastest growing and a major energy consuming sector in India. Needless to say, the buildings too form a link in the energy-spatial structure relationship. In context of the alarming rate of energy consumed in various sectors, building designs apart from their structural and functional requirements also need to be planned and designed for energy conservation.*

*This paper seeks to cover the issues and problems with the current materials and techniques used in the building industry at present. The choice of appropriate materials and technologies considering their embodied energy utilized during construction will also have to be considered for producing energy efficient and environment friendly houses. This paper also makes an attempt towards the assessment of the embodied energy in various types of buildings.*

## INTRODUCTION

Although the Indian economy uses both commercial and non-commercial energy sources, the share of these fuels in the primary energy supply has declined from over 70% in the early 50's to a little over 30% as of today. The traditional fuels are gradually getting replaced by the commercial fuels such as coal, lignite, petroleum products, natural gas and electricity (Sarma, E.A.S. et. al.).

The ominous outcry for energy crisis in various sectors like agriculture, transportation, land use and built environment are widely recognized during the past couple of decades as a threat for the future generation. Building Industry is one of the fastest growing and a major energy consuming sector in India. Needless to say, the buildings too form a link in the energy-spatial structure relationship. Apart from the structural and functional efficiencies, building infrastructure also needs to emphasize on the energy conservation issues.

The energy in buildings may be looked from two different perspectives. Firstly the energy that goes into the construction of the building using a variety of materials. Secondly the energy that is required to create a comfortable environment within the building during its lifetime. Quite a few studies regarding the energy consumed during the maintenance of the building (heating, cooling and lighting) have been published.

However the assessment of the embodied energy in buildings is still in its nascent stage in India and requires some research.

## NEED FOR ENERGY EFFICIENCY IN BUILDINGS

The concept of green buildings is still at an emerging stage in India. The concept of sustainable buildings and use of environmentally friendly construction materials like stones, timber, thatch, mud etc have been practiced since ancient times. But the perception of people about strong and durable buildings have changed with the advent and lavish use of the present modern materials like steel, cement, aluminium, glass etc. A large amount of fuel energy gets consumed in producing such materials. These materials being industrial products further need to be transported to large distances before getting consumed in the buildings thus making them energy intensive. An estimate of the energy consumed in buildings using different permutations of materials and techniques will facilitate their appropriate selection and reduce the embodied energy consumption.

Some of the salient features to optimize the energy consumption in buildings are to:

1. Minimal disturbance to landscape and site conditions
2. Use of renewable energy
3. Use of water recycling
4. Use of Energy efficient equipments.
5. Use of environmental friendly building materials
6. Use of appropriate techniques to minimize energy intensive materials
7. Effective controls for lighting and temperature for human comfort

## ENERGY AND BUILDING MATERIALS

Constructions consume a variety of building materials. Abundant raw materials are to be transported from far off distances to the industry which requires further processing thus consuming primary and commercial resources. The finished products from the industry further need to be distributed to the local areas and construction sites which increase the pressure on the commercial fuels like petrol/diesel etc.

The most common building materials used in construction activity today are cement, steel, bricks, stones, glass, aluminium, timber, etc. The estimates of the energy consumed in the manufacture/extraction of a few major building materials chosen from various sources have been discussed below.

**i) Cement**

The principal methods for the manufacture of the Portland cement are 1) Wet process, 2) Dry process, 3) Semi dry process. The dry process is preferred on account of very significant fuel economy. The dry process is adopted in most of the cement industries. The heat energy required per Kg of the clinker in dry process is 3000- 4500(KJ/Kg) while in wet process it is about 5000 – 8000 (KJ/Kg).

ii) **Steel**

The transportation of various raw materials like Iron ore lumps, sinters and pellets, coke and fluxes such as limestone, dolomite and the various processes like Melting, Refining, Casting, Rolling makes steel as an highly energy intensive material. The total energy in steel is found to be 8600 Kcal / Kg, including transportation.

**iii) Bricks**

The manual production of the bricks involves the mainly four operations namely, Soil preparation, Moulding, Drying and Firing. The main process in which energy is consumed is firing of bricks. The amount of total coal required is about 18 tonnes to 22 tonnes depending upon the weather condition, quality of coal, etc. A tonne of coal gives about 5600Kcal/Kg to 6100 Kcal / Kg depending upon quality of the coal generally transported from far off distances. The energy required to produce each brick inclusive of transportation comes to about 5MJ per brick.

**iv) Glass**

Raw materials used in Manufacture of glass are 1) Glass sand 2) Soda ash 3) Salt cake 4) Lime stone 5) Lead oxides, pearl ash, boric acid, etc. The various processes used are 1) Melting. 2) Shaping or Forming 3) Annealing 4) Finishing The embodied energy of glass is some what high due to melting process comes out to be 15.9 MJ/ Kg.

## COMPUTATION AND COMPARISON OF EMBODIED ENERGY IN BUILDINGS

An attempt has been made in this section to evaluate the energy consumed in buildings. The estimates are based on the energy consumed in the production of the materials required and their transportation. The contribution of human labour/equipment energy for the assemblage is not considered. Four types of case studies have been considered for the computation of energy.

1. Contributions of energy due to masonry walls in a three storeyed building.
2. Estimation of energy consumption for various roofing technologies designed for a span of 3.0 m.
3. Comparison of energy for load bearing and framed G+1 structure.
4. Embodied energy comparison for G+1, G+2 and G+7 structures.

## 1. Masonry Walls In A Three Storeyed Building

The energy consumed in the masonry walls for a three storeyed building using three different building units namely bricks, stones and concrete blocks have been computed and presented in Table 1.

**Table 1. Energy consumption in masonry walls for a three storeyed building**

| Sr. No | Type of Masonry adopted | Consumption of materials for masonry | Energy contribution of each material (Kcal x $10^6$) | Total energy consumed by masonry for entire building (Kcal x $10^6$) | Energy saving in % |
|---|---|---|---|---|---|
| 1 | Brick Masonry | Bricks | 129 | 160.4 | --- |
| | | Cement | 31 | | |
| | | Sand | 0.4 | | |
| 2 | Stone Masonry | Stones | 44 | 136.1 | 15 |
| | | Cement | 91 | | |
| | | Sand | 1.1 | | |
| 3 | HC Block Masonry | Cement | 55 | 64.5 | 60 |
| | | Sand | 0.45 | | |
| | | Aggregates | 9.0 | | |

In case of the building constructed using bricks the energy contribution of the masonry walls is about 160 x $10^6$Kcal. About 80% of the overall energy is due to the energy intensive clay bricks. A 15% reduction is observed in the masonry if the bricks are replaced by stones. With the use of hollow concrete blocks the energy consumption in masonry walls drastically reduces by 60% as compared to the energy consumed by brick masonry. The additional advantage of using hollow concrete block is that its strength can be altered by varying the proportions of the raw materials as per the design requirements.

## 2. Energy Consumption In Roofs

Table 2 gives the details of the various building materials required and the total energy consumed per square metre for each roofing alternative. The structural elements have been designed for a room of 3m x 6m and a roof slope of 25º is considered.

In case of Mangalore tiled roof the tile which needs controlled firing in kiln is the major energy consuming material. The conventional supporting structure generally consists of timber which does not consume any fossil fuel. However adequate plantations are to be grown to bridge the gap between demand and supply of timber and also for the protection of the environment. The use of RC rafters shows a 27% increase in the energy for such roof which may turnout to be apparent as the solar energy necessary for growing timber is not considered.

**Table 2. Energy estimates of roofing technologies (for 3.0 m span)**

| Sr No | Type of Roof | Load in Kg/sq.m. | Quantities of Material | | | | Energy in MJ/sq.m. of plinth area |
|---|---|---|---|---|---|---|---|
| | | | Tiles/Bricks No/$m^2$ | Cement kg/$m^2$ | Timber cu.m/$m^2$ | Steel Kg/$m^2$ | |
| 1 | **Mangalore Tiled Roof** | | | | | | |
| | a) Gable roof Casurina Poles | 120 | 26 | -- | 0.01 | 0.3 | 231 |
| | b) Gable roof (Sawn timber) | 120 | 26 | -- | 0.02 | 0.3 | 256 |
| | c) Gable roof (R.C. rafters) | 148 | 26 | 5.9 | -- | 2.17 | 318 |
| 2 | **AC Sheet roof** | | | | | | |
| | a) Angle iron purlins | 83 | -- | 13.6 | -- | 5.0 | 283 |
| | b) Steel Truss | 83 | -- | 13.6 | -- | 0.9 | 135 |
| | c) Ferrocement Beams | 100 | -- | 16.3 | -- | 0.4 | 137 |
| 3 | Precast Ferrocement Channel Unit roof | 180 | -- | 23.0 | -- | 1.7 | 235 |
| 4 | Brick Vault | 220 | 45 | 18 | -- | 0.9 | 393 |
| 5 | Composite Beam panel roof | 202 | 40 | 25.0 | -- | 2.5 | 479 |
| 6 | Hourdi Tile roof | 286 | 19.5 | 24.0 | -- | 3.5 | 540 |
| 7 | Reinforced concrete roof | 387 | -- | 54.0 | -- | 3.9 | 548 |

The asbestos cement (AC sheet) sheet is lighter than Mangalore tiled roof mainly consists of 80% cement and 20% asbestos fibres. The use of steel truss or ferrocement beams as purlins instead of angle sections for the supporting structure required for fixing the sheets proves to be more energy efficient. Even though AC sheet roof seems to be less energy intensive than Mangalore tiled roof the former is already proven to be a hazardous material and also is unsuitable for tropical climates. The choice of the conventional RC roof or the Hourdi tile roof (popular in Southern India) shoots up the energy value to about 548 $MJ/m^2$ and 540 $MJ/m^2$ respectively. The composite beam-panel roof provides an energy efficiency of about 13% as compared to the RC roof.

Of the various alternatives considered the option of precast ferrocement channel units and the brick vaulted roof seem to be the best choices in context of energy efficiency. A 50% energy saving in the ferrocement roof and 25% in case of brick vaulted roof as compared to the RC roof may be achieved.

## 3. Embodied Energy In Different Types Of Buildings

Table 3 contains the estimated energy values for buildings with different number of storeys. A comparison of G+1 load bearing and framed structure shows that the energy consumption in both are found to be similar. However the major energy contributing materials vary in both cases. In the load bearing structure the contribution of cement is about 50% that of the R.C building. On the other hand the bricks contribute to 60% increase in the energy consumption in case of load bearing structure as that to the R.C structure. Steel is another material which influences the increase in the energy value in case of R.C structure which is about 2.7 times as compared to load bearing structure.

A study on three R.C. buildings with different number of storeys obviously indicates a high energy value in the tallest building. The energy value for G+1, G+2 and G+7 storeyed buildings are 846493MJ, 1691342MJ, and 10053683MJ respectively. The G+7 building consumes 12 times while in case of G+2 building it is 2 times that of the energy required for the G+1 building. However the increase in the energy is not proportional to the increase in the number of storeys. This may be explained to the fact that the size of the concrete columns and steel consumption in the tallest buildings depends on the various structural parameters, the proportion used in concrete and assumed sizes of columns due to which the steel requirement vary.

Brick is the major energy consuming materials in the load bearing building. The contribution of bricks is about 85% of the total energy of building On the other hand in the framed G+1 RC structure cement, bricks and steel contribute to about 43%, 25%, 24% respectively in total energy consumption of building. A comparison of the three RC buildings reveal that the % energy shared by cement, bricks and steel hardly change irrespective of the number of storey in the building.

However a meaningful comparison could be possible if the ratio of energy consumed to that of total area of the entire floor in each building is considered. Thus Table 4 gives the energy consumed per $m^2$ of the floor area in each of the building. Thus the G+1 R.C. building consumes about 3702 MJ/ $m^2$. The G+2 R.C building is more efficient than the G+7 building indicating a 27% less energy consumption as that of G+1 building.

**Table 3. Embodied energy comparison for G+1, G+2 and G+7 storeyed building**

| Material | Embodied Energy in MJ | | | |
|---|---|---|---|---|
| | Load bearing G+1 building | Framed G+1 building | Framed G+2 building | Framed G+7 building |
| Cement | 166938 | 364506 | 699286 | 4620000 |
| Sand | 1080 | 1990 | 10815 | 21974 |
| Aggregate | 6218 | 11598 | 21111 | 149423 |
| Bricks | 544275 | 215540 | 294000 | 1725575 |
| Glass | 2072 | 2072 | 19646 | 99509 |
| Aluminium | -- | -- | 10991 | 33202 |
| Tiles | 13335 | 13335 | 55755 | 246225 |
| Timber | 8475 | 8475 | 7150 | 30325 |
| Steel | 73629 | 204606 | 504524 | 2844062 |
| Paint | 24371 | 24371 | 58064 | 283388 |
| **TOTAL** | **840393** | **846493** | **1691342** | **10053683** |

**Table 4. Energy consumption per unit area for various buildings**

| Type of building | Floor Area ($m^2$) | Energy per square meter of floor area (MJ / $m^2$) |
|---|---|---|
| **G+1 R.C.C. structure** | **228.87** | **3702.344** |
| **G+2 R.C.C. structure** | **579.40** | **2911.233** |
| **G+7 R.C.C. structure** | **2783.93** | **3611.977** |

## CONCLUSIONS

The following are the conclusions drawn from the studies conducted above:

1) The use of alternative building units like hollow concrete blocks for masonry construction reduces the energy consumption by 60% as compared to brick masonry.

2) The conventional RC roof or the Hourdi tile roof are energy intensive with embodied energy values of 548 MJ/$m^2$ and 540 MJ/$m^2$ respectively. The composite beam-panel roof is 13% energy efficient as compared to the RC roof.

3) A 50% and 25% energy saving may be achieved in roofs made of ferrocement channel units and brick vaults as relative to RC roofs and thus are the most energy efficient choices amongst the various alternatives considered.
4) The energy consumption in short buildings remain unchanged irrespective of the structural system adopted. However if possible it is better to adopt a load bearing structure as it encourages decentralized products like bricks which supports the rural economy.
5) Materials like Cement, Steel and Bricks and Glass to some extent are the major contributors to the total energy consumption in RC buildings.

6) Buildings with lesser number of storeys are more energy efficient than multi-storeyed buildings. Wherever possible it is favorable to adopt two or three storeyed buildings than eight storeyed buildings.

7) Attempts in minimizing or replacing the conventional materials like cement, steel, bricks with cheaper and local alternatives will lead to reduction in the embodied energy in buildings.

## REFERENCES:


1. Sarma, E.A.S., Maggo, I.N., Sachdeva, A. S. “India's energy scenario in 2020” World Energy Council.
2. Susan Owens (1986) “Energy, Planning and Urban Form”, Pion Limited.
3. K.S.Jagadish, “Energy Efficient Building Materials and Technologies” Lecture Notes, ASTRA, IISc, Bangalore.
4. Trilok Singh (1999) “Energy Conservation : need of the hour”, Indian Journal of Power and River Valley development, pp. 12-13.
5. S.S.Verma, (June 1999) “An Approach Towards Renewable Energy Education”, Environment and People, pp. 47 -51.
6. “Mainstreaming Sustainable Buildings in India” Sustainable Habitat Design Advisor, Issue 1, June 2005.
7. B.V.V. Reddy (Oct 2004), “Sustainable Building Technologies”, Current Science, Vol 87, No7, pp 899 – 907.
8. Green Habitat, A news letter on Green Buildings from Indian Green Building Council, CII- Sohrabji Godrej Green Building centre.
9. K.S.Gumaste, B.V.Venkatrama Reddy, K.S.Nanjunda Rao and K.S.Jagadish, (Jan. 2004) “*Properties of Burnt Bricks and Mortars in India*”, Masonry International, Journal of the British Masonry Society, Vol. 17, No. 2, pp. 45 – 52.