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ENERGY AND BUILDING MATERIALS

B. SUREKHA[1], M. N. HEGDE[2] & K. S. JAGADISH[3]

[1]Research Scholar, PHD, Dr. A.I.T. Research Centre, Bengaluru, India

[2]Professor, Department of Civil Engineering, Dr. Ambedkar Institute of Technology, Bengaluru, India

[3]Former Professor, Department of Civil Engineering, IISC, Bangalore, Karnataka, India

ABSTRACT

The embodied energy of Building materials is presented. The energy intensity is calculated as per the data collected from manufactures in and around Bangalore City. Building materials include natural material, processed materials and Building elements. Embodied energy for alternative building materials and building elements is also presented.

KEYWORDS: Embodied Energy, Energy in Building Materials, Alternative Materials Energy

INTRODUCTION

Traditionally man has used local materials like earth stone, timber and bamboo to build his house. However, with the advent of civilization he has increasingly turned to materials like brick, tiles, steel etc in view their versatility and performance. With this change, he has also been using fuel energies to produce these materials. While traditional energy source was firewood with the development of industrialization there has been an explosive growth in the use of fossil fuels. Modern buildings make extensive use of coal, diesel and electricity to produce building materials and to construct and use the buildings. The resulting embodied and operational energy energies also contribute significantly to carbon emission. India now has dubious distinction of being the third largest emitter of carbon dioxide in the world after China and the U.S.

There is hence an urgent need to analyze the various materials and processes that contribute to the embodied energy of building materials to identify the materials which are most advantageous in reducing fossil fuel energy consumption.

An early study of Energy and Rural building was made by Jagadish [1] by looking at the production of rural building materials like brick and tiles. Later studies were made by Rai [2], Debnath [3], Venkatarama Reddy and Jagadish [4] and Chani et al [5]. These earlier studies often made use of energy consumption figures for building materials which were valid in seventies and eighties. However, recent trends in industry have lead to more efficient process for cement and steel melting. There is hence a need to revise the earlier values of energy consumption for cement and steel and the various materials based on them. In this paper an attempt has been made to arrive at energy consumption figures which are more appropriate to current building construction. It is also necessary to recognize that a plethora of new materials keep entering the market and there is a need to update our figures for embodied energy of a building. There is also an attempt to explore low energy alternatives which can lead to substantial reduction in embodied energy of building materials.

Energy in Building Materials

Energy in building materials is the energy required to manufacture the final usable material plus the transportation energy. Transportation energy includes the transportation of raw material from quarry to industry and finished product from industry to construction site. For natural materials transportation required is from source to the construction site.

Calculation of Embodied energy for building materials is different for each material. The process of manufacturing has to be identified and energy involved in its process has to be calculated.

Production of Building Materials

The production of a building material involves a series of processes, each process involving a certain expenditure of energy. The sequence of operations may be listed as follows.

- Extraction of raw material.
- Transportation of raw material to site of manufacture.
- Manufacture of building material involving mechanical and thermal energies. Mechanical energy may be in the form of pulverizing, mixing and compacting raw material. Thermal energy is usually in the form of heating / burning using a fuel. Very often, this represents one of the most energy intensive steps.
- Transportation of manufactured building material to the site of construction.

The sum of the energies of all the operations is known as the embodied energy of the building material.

It is sometimes possible to estimate the embodied energy of the machine/ plant involved in producing the building material. This energy may then be allocated to the total production of the building material during the life of the machine/ plant. This can be however a difficult task and is very often not taken up. However this energy is in general very small compared to the actual process energy of a material.

Since a variety of fuels are involved in the production of a building material, there is a need to know the energy released during the burning of the fuels. The typical fuels and their energy contents are listed in Table 1.

Table 1: Energies of Fuels

Sl. No	Fuel	Unit	Energy Per Unit MJ	Density
1	Fire Wood	Kg	15.0 – 17.0	650 Kg/m^3
2	Coal	Kg	19.98	1.27 – 1.45 gm/cc
3	Char Coal	Kg	25.12	170 – 190 Kg/m^3
4	Rice Husk	Kg	13.4	235 Kg/m^3 (Bulk)
5	Diesel	Litre	38.7	0.824 Kg/litre
6	Pet coke	Kg	34.33	-
7	Lignite	Kg	16.33	---
8	Natural Gas	Nm^3	25.3 – 38.1	Sp. Gr - 0.574

Electricity is another source of energy which is invariably needed in most of the building material productions. The unit of electrical energy is 1kWh. This energy is the result of conversion from either mechanical energy or Thermal energy. When the source is mechanical energy the energy spent by the source is close to the delivered energy of 1kWh which is equivalent to 3.6 MJ. However, when the source is thermal, the second law of thermo dynamics operates and the delivered energy of 1kWh is very much less than the thermal energy used up in producing it. Typically 1 kWh of delivered energy needs about 0.7 kg of coal whose energy is about 14MJ. This is nearly 4 times larger than 3.6MJ.

Energy Analysis of Basic Building Materials

- **Energy in Burnt Bricks**

Traditionally the process of brick making involves following steps:

- Clay is transported to site and then thoroughly wetted and allowed to soak for uniform moisture distribution. It is then mixed either manually or in pug mill.
- In case of table molded bricks a stiff mud process is used for molding in a 5 sided mould and the brick is transferred to a platform.
- It is then dried in a shade.
- In case of country bricks, a soft mud process is used for molding in a 4 sided mold and the brick is allowed to dry in open ground in the sun.
- Table molded brick is then stacked and burnt either in a Bull Trench Kiln or in a three parallel walled Kiln with roof.
- Country bricks are burnt in an open clamp.

Energy Calculation: Table Molded Bricks

Transport: 1 lorry load of soil = 400cft :11.33Cu.m in volume.

Transportation distance: say 20km

Up trip : 5km/litre of diesel.

Down trip : 4km/litre of diesel.

Total diesel : $\frac{20}{5} + \frac{20}{4} = 9$ Litres

Energy due to transportation of soil to kiln : 9 x38.7 = 348.3MJ.

Weight of 11.33 CuM of soil : 11.33 x 1.3 = 14.73 tons.

Number of bricks from this soil : $\frac{14730}{3} = 4910$ bricks

Soil transport energy for bricks : $\frac{348.3}{4910} = 0.071\text{MJ}/$ brick

Similarly, finished bricks transport to site (say 20km)

9litres of diesel for 3000 bricks

Therefore energy per brick : $\frac{348.3}{3000} = 0.12\text{MJ}$

Total transportation energy per brick : 0.12 MJ/brick.

- **Burning Energy (Fire Wood)**

At 0.32Kg of firewood per brick

Wastages of bricks = 10%

Hence fuel per bricks : $\frac{0.32}{0.9} = 0.356\text{kg}$

Burning energy per brick : 0.356 * 15.0 = 5.41 MJ.

Now total embodied energy per brick : 5.41 + 0.071 + 0.12 = 5.6 MJ

- ***Burning energy (Coal)***

0.2 Kg of coal per brick, assuming waste at 10% per brick.

Fuel per brick : $\frac{0.2}{0.9} = 0.222\text{kg}$

Burning energy per brick : 0.22x19.98 = 4.44 MJ/Brick.

Total energy per brick including soil

& transport : 4.44 + 0.071 + 0.12 = 4.63 MJ

In case of country made clamp burnt bricks, there is no clay transportation but wastage could be 20%.

Hence for country bricks energy : $\frac{0.32}{0.8} = 0.4\text{kg}$ for fire wood.

Then embodied energy for country bricks :0.4 * 15 + 0.12 = 6.12 MJ/brick.

- **Energy in sand**

Sand is usually extracted from river banks and then transported to construction site. A decade ago sand in Bangalore used to be transported from a distance of around 100 kM since there were no major rivers near Bangalore. However, with the depletion of sand resources the sand is sometimes transported form locations as far as Mangalore, where sand is cheap. The energy content of sand is primarily the diesel energy used for transportation.

Energy Calculation

Transportation data : 100 kMs.

Volume per lorry : 400 cft = 11.33 CuM.

Diesel

Loaded trip - 4Km/litre : 25litres

Unloaded trip - 5Km/litre : 20litres

The energy per cum based on distance is shown in Table 2.

Table 2: Embodied Energy of Sand

Sl. No.	Distance	Diesel Consumption In Litres			Energy In Diesel MJ	Energy Per Cum Of Sand
		Unloaded	Loaded	Total		
1	50 Km	10	12.5	22.5	870.75	76.85
2	100 Km	20	25	45	1741.5	153.7
3	300 Km	60	75	135	5224.5	461.1

The Table 2 shows the rapid increase of sand energy with transportation distance. This also explains the meteoric rise in the price of sand in recent times. There is a need for looking at alternatives to river sand for sustainable construction practices.

- **Energy in Coarse Aggregate**

Coarse Aggregate is usually produced by crushing stone extracted from quarries. The fines in the crushed stone are separated and aggregates of 12mm and 20mm down size is also graded. The energy of coarse aggregated per cum is then analyzed based on data from two sites.

Site No 1: Crusher plant near Bangalore (Muddenahalli)

Energy Calculation

Production of coarse aggregate per month	: 30,000 tons.
Monthly electricity consumption	: 1,21,380.00 kWh.
Diesel (for generator)	: 4000 litres
Diesel (for transport)	: 2400 litres
Diesel (for blasting)	: 320 litres
Total Diesel	**: 6720 litres.**

Energy consumption after allowing for 20% transportation loss

: $\frac{121380}{0.8} = 151725$ kWh

One unit of electricity needs 0.7 Kg of Coal

Energy due to electricity	: 1, 51,725 $*$ 0.7 $*$ 19.98 = 21, 22,026 MJ.
Energy due to Diesel	: 6,720.00 $*$ 38.7 = 2, 60,064 MJ.
Total Energy /month	**: 23, 82,090 MJ**
Energy per ton of aggregate	: $\frac{2382090}{30000} = 79.4$MJ
Energy per Kg	: 0.079 MJ
Energy per m^3 (1.5 T)	: 119.1MJ

Site No 2: Crusher plant on Mysore road (Seep katte)

Energy Calculation

Production of coarse aggregate per month	: 10,000 Tons.
Monthly electricity consumption	: 1668 kWh.
Diesel (for generator)	: 15,000 litres
Diesel (for transport)	: 380 litres

Total Diesel : 15,380 litres.

Energy consumption after allowing for 20% transportation loss

: $\frac{1668}{0.8} = 2085$ kWh

One unit of electricity needs 0.7 Kg of Coal

Energy due to electricity : 2085 * 0.7 * 19.98 = 29,160 MJ.

Energy due to Diesel : 15,380 * 38.7 = 5, 95, 206 MJ.

Total Energy /month : 6,24,369 MJ

Energy per ton of aggregate : $\frac{624369}{10000} = 62.44$ MJ

Energy per Kg : 0.062 MJ

Energy per m^3 (1.5T) : 93.66MJ

Average of Two Sites

Energy per ton :$\frac{79.4+62.44}{2} = 70.92$MJ

Energy per Kg : 0.071 MJ

Energy per m^3 (1.5T) : 106.4MJ

- **Energy of lime {$Ca(OH)_2$}:**

Lime stone {$CaCO_3$} is usually transported from quarries to lime production Kilns and then burnt using either firewood or coal. Coal is used in larger plants while firewood is used in smaller plants.

Energy Calculations

Transport of limestone $CaCO_3$: Assuming a transport distance of 100 Km.

The energy for a 12 tons transport uses : $\frac{100}{5} + \frac{100}{4}$ =45 litre of diesel

Hence transport energy per Kg of $CaCO_3$: $\frac{45X38.7}{12,000} = 0.145$MJ

BURNING ENERGY

- **Using Coal**

Assuming 0.2Kg of Coal is used to burn a Kg of lime stone in large plants.

Hence coal energy per Kg of $CaCO_3$:0.2 x 19.88 ≈ 4.0MJ

1Kg of $CaCO_3$ gives rise to 0.74 Kg of $Ca(OH)_2$ after hydration of Ca O.

Therefore energy per Kg of $Ca(OH)_2$: $\frac{4.0+0.145}{0.74} = 5.63$MJ

Assuming 10% wastage of limestone

Energy per Kg of $Ca(OH)_2$: $\frac{5.63}{0.9} = 6.22MJ$

- ***Using Firewood:***

About 0.35 Kg of firewood is used per Kg of $CaCO_3$ in small batch operated plants.

Hence energy per Kg of $CaCO_3$: $0.35 * 15.0 = 5.25$ MJ.

Energy per Kg of Ca $(OH)_2$ after adding transport energy

And accounting for losses: : $\frac{5.25+0.145}{0.74*0.9} = 8.1MJ$

ENERGY IN CEMENT

Embodied Energy Calculation

Coal Consumption : 0.084 Kg/ Kg of Cement.

Assuming imported Coal of 25MJ energy.

Energy due to Coal : $0.084 * 25 = 2.1$ MJ.

Energy consumed : 0.086 kWh/ Kg of Cement.

Taking transmission loss of 20%, into account

Actual energy : $\frac{0.086}{0.8} = 0.1075 \frac{kWh}{Kg} of\ cement$

Assuming a coal consumption of 0.7Kg/kWh

Energy due to electricity : $0.1075 * 0.7 * 19.98 = 1.5$ MJ.

Total embodied energy per Kg of Cement : 2.1 + 1.5 = <u>3.6 MJ.</u>

In an earlier paper, Venkatarama Reddy and Jagadish [4] used a value of 5.85 MJ per Kg since many cement production plants were using inefficient wet process. The significant reduction to 3.6MJ due to process efficiency is to be noted. Further blended cement using fly ash or GGBS can further reduce the energy increment.

Energy in Steel

The available data from steel manufacturers have been consolidated as indicated in Table 3.

Table 3: Data from Steel Manufacturers

Company	Energy/Ton (GJ)
ISPAT	26.38
TATA STEEL	25.47
SAIL	27.94
JSW	26.26
ROURKELA STEEL PLANT	28.17
AVERAGE	26.84

Average embodied Energy for steel : 26.84 MJ/Kg.

It may be observed that these energy values are the result of improved current processes using recycling of energy. The earlier figure that was used in energy in building was 42MJ/Kg of steel.

Energy of Other Building Materials

The embodied energy of other typical building materials is listed in table4. Some of the energies are based on calculations similar to what has been done in earlier section. Some of the energies are obtained by other sources like Bath University report [6] and the book by Ashby [7].

Table 4: Embodied Energy of Building Materials

Sl. No.	Material	Unit	Energy/ Unit mj	Type of Energy
1	Aluminium	1Kg	236.8	Electricity
2	Glass	1Kg	14 – 17	-
3	Marble (Rajasthan – Bangalore	1m^2	200	Diesel
4	Polyester	1Kg	84 – 93	Petroleum
5	GFRP	1Kg	107 – 118	-
6	Mangalore Tile	1 tile (3Kg)	5.2 – 15.8	Coal / Wood
7	Plywood 16mm	1m^2	166-218	Diesel/Electricity
8	Bamboo board 16mm	1m^2	216.0	-
9	Composite Aluminium Panel (4mm)	m^2	659.00	-

The energy of Mangalore tile depends on the type of kiln. The Hoffman Kiln Which operates continuously needs the lower energy of 5.2MJ. Batch operated down draught Kilns are very in efficient and account for 15.8MJ of Fire wood based energy.

The significant amount of energies needed for materials like Aluminium, Marble (from Rajasthan), GFRP and composite Aluminium panels may be noted. Although Aluminium has high energy content, there are two points in its favour which must be noted. Firstly Aluminium has a density which is one third of steel and hence its energy per unit volume is not as high as the value per Kg indicates. Secondly, Aluminium does not corrode and has potential of being recycled several times. GFRP has high energy content but its density is very low and hence its energy content is not as much a deterrent. It has also a rather high strength. Although plastics depend on petroleum as a raw material it is possible to think of biomass as the raw material in future. Uses of luxury items like marble and composite Aluminium panels are a definite drain of energy resources and need to be avoided to reduce embodied energy and attendant carbon emission.

Energy in Derived Building Materials

There are several materials produced by processing other materials. The stabilized mud block or the concrete blocks are such examples. It is useful to examine such materials. Four categories of such building materials namely Building Blocks, Mortars, wall elements and concrete may be listed. The energies in each of these are presented in the following.

- **Energy of Building Blocks:**

Table 5: Energy of Building Blocks

Material	Size Per Unit	Embodied Energy/Unit mj	Energy/Brick Equivalent mj
Brick	22.5 x 10.8 x 7.5 cm	4.63 – 5.6	4.63 – 5.6
Stabilized Mud Block	23 x 19 x 10 cm	2.85	1.14
Hollow Concrete Block	40 x 20 x 20 cm	7.6	0.88

Hollow Clay Block	40 x 20 x 20 cm	16.7	1.94
Cut Sandstone	45 x 23 x 15 cm	7.55	0.91

Here five building blocks including burnt brick are considered to compare the various energies. The stabilized Mud Block is produced by adding 8-10% cement to a sandy soil and pressing to its optimum moisture in a manually operated press. Hollow concrete blocks are made in mechanized hydraulic presses and achieved energy economy because of lower bulk density. Hollow clay blocks are made by extrusion process and burning in efficient tunnel Kilns. Sand stone cutting is mainly done in Kutch district using mobile electrically operated disc saws. Their energy is also low since they use minimal amount of electrical energy. All the four options other than brick are very energy efficient. It is hence clear that such alternatives can lead to significant reduction in embodied energy of buildings.

- **Energy in Mortars:**

Mortar is the main medium to join masonry units or to cover walls, floor and roofs with plaster. They are generally made by mixing a binder with sand and water. Cement or lime or lime and cement are the most common binders.

Table 6: Energy in Mortars

Type of Material	Ratio	Energy / Cum mj	Energy / SQM mj
Cement Mortar	1 Cement: 6 sand(20mm)	1561.5	31.23
	1 Cement: 5 sand(12mm)	1948	23.4
	1 Cement: 4 sand(12mm)	2160	25.9
Cement lime mortar	1Cement:1Lime:6sand (12mm)	2789	33.5
Cement soil mortar	1Cement:2 soil:6 sand (12mm)	1267.3	15.2
Lime fly ash	1Lime:2 fly ash:6 sand	1439.9	14.4

Table 6 compares various alternative mortars. The following observation is made. Cement Lime mortar 1:1:6 consumes more energy/cum. The cement mortar cm 1:4 is second in energy consumption. Cement Soil mortar has the lowest energy.

Mortar is one of the major materials which consume energy in a building. Again sand is very often in short supply. For sustainability and energy reduction, potential replacement of sand by soil, demolished building wastes, industrial wastes and pond ash is useful. The studies by Venkatarama Reddy and Ajay Gupta [11], Rashmi[12], M.R. Kalgal, et al [13] offer many such alternatives.

- **Energy In Wall Elements:**

Energy for wall elements: Masonry is built in wall units either as load bearing wall or as infill walls in multi-storey structures. Burnt Brick wall, solid concrete block and SMB are built for load bearing construction, where the density is high. The light weight block with low density such as hollow concrete blocks, cellular blocks and clay hollow block are used. Energy for brick masonry in CM 1:6 is at 2630.13 MJ/Cu M. SMB block masonry in cm 1:2:6 consumes 734.0 MJ/Cu M, and stone masonry consumes very less energy at 564.3MJ/Cu M.

Table 7: Energy in Wall Elements

Type Of Material	Wall Thickness, Mm	Mortar	Energy/Cu M Mj	Energy /Sqm Mj
Burnt Brick 230x108x75mm	230	CM 1:6	2630.13	604.9
Burnt Brick 230x108x75 mm lime mortar	230	CLM 1:1:6	2826.67	650.1
Stabilized mud block 8% cement	230	CSM	734.0	168.8

230x190x100mm		1:2:6		
Hollow concrete block 7% cement 400 x 200 x 200mm	200	CM 1:6	863.0.	172.6
Hollow Clay block 400 x 200 x 200 mm	200	CM 1:6	1490.7	298.1
Stone Masonry	400	CM 1:6	564.3	225.7
Solid concrete block Masonry 400 x 200 x 200 mm	200	CM 1:6	973.0	194.6

Table 8: Energy Due to Plastering on Both Surfaces of Walls

Masonry	Wall Thickness, mm	Mortar	Plaster Thickness, mm	Energy/m^2
Burnt Brick	230	CM 1:6	20	667.39
Burnt Brick	230	CLM 1:1:6	12	717.07
Stabilized mud block 8% cement	230	CSM 1:2:6	12	199.24
Hollow concrete block 7% with plastering in CM 1:6.	200	CM 1:6	20	235.05
Hollow Clay block	200	CM 1:6	20	360.6
Solid concrete block Masonry	200	CM 1:6	20	257.06

Table 7 and 8 bring out two facts. Use of burnt brick entails significant energy consumption and other alternative are desirable if embodied energy has to be brought down. Use of plastering makes wasteful use of scarce sand and energy. It is eminently desirable to use blocks which do not need plastering, especially on external surfaces. The stabilized mud block and the hollow concrete block or sand stone blocks offer such energy efficient alternatives.

- **Energy In Concrete:**

Energy for design mix of M20, M15, M10, and M7.5 considered. M20 manual mix includes energy for basic materials of cement, sand aggregate and for mixer and vibrator used while casting of concrete. Energy for M20 RMC mix included energy required for mixing of concrete in RMC plant and transportation energy required. OPC M20 manual mix is at 1674.90 MJ/cum.

Energy for M20 with 30% replacement of cement with GGBS is at 1212.85 MJ/cum. With 25% replacement of fly ash is at 1433.15 MJ/cum.

Table 9: Energy in Concrete

Type of Material	Grade of Concrete	Energy MJ/M^3
Concrete OPC Manual	M20	1674.90
	M15	1364.26
	M10	1011.24
	M7.5	826.32
Concrete RMC mix	M20	1550.85
RMC Concrete 30% GGBS	M20	1212.85
RMC Concrete 25% Fly ash	M20	1433.15

It is interesting to note in Table 9 that RMC mix without additives like fly ash and GGBS has more energy than concrete mixer mixed concrete for the same strength. This is especially due to the fact that considerable amount of energy has to be spent for pumping of concrete. However with additives like GGBS or fly ash RMC has lower energy. It is also instructive to note that brick masonry, even without plastering consumes significantly more energy than M20 concrete. Thus in a building brick masonry wall requires the largest amount of energy. Use of alternatives to brick becomes imperative for a low embodied energy building.

CONCLUSIONS

The details of embodied energy data presented hear lead to following important conclusions.

- Burnt brick is the major contributor to the embodied energy of a building since it represents the largest volume in a building besides having a high energy value ranging between 4.63MJ to 6.13MJ per unit. Alternatives to brick like the stabilized Mud Block, Hollow concrete Block and cut sand stone lead to significant reductions in embodied energy.
- Cement and steel represent the other major energy consuming building materials although recent manufacturing process have resulted in significant reductions in the energy levels. Use of blended cements is one way of reducing energy due to cement use.
- Materials procured from great distances entail significant transportation energies. Use of materials like marble or sand from distant locations need to be reduced for low energy buildings.
- Luxury materials like composite Aluminium panels require large amount of energy and are contraindicated for energy reduction.
- Concrete, whether of ready mix variety or the small concrete mixer variety is more energy efficient than brick masonry wall per unit volume even when plastering energy is discounted.

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AUTHORS DETAILS

B. Surekha,

Ph.D. Scholar, (VTU Belgaum), Dr. Ambedkar Institute of Technology, Bangalore, Karnataka, India. Email ID: surekhadesh@gmail.com. Contact No +91 9449270718.

M.N. Hegde,

Professor, Dept. of Civil Engineering, Dr. Ambedkar Institute of Technology, Bangalore, Karnataka, India. Email ID: mmmhegde@gmail.com. Contact No +91 9741006095

K.S. Jagadish,

Former Professor, Dept. of Civil Engineering, IISc, Bangalore, Karnataka, India. Email ID: ksjagadish@gmail.com. Contact No+91 9845553365