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Quantification and Analysis of Embodied Energy in High-rise RCC Building: A Case Study

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Abstract—*The conceptual stage of a building is always focused on three main aspects-cost, time and quality. Addressing these three aspects mainly, will not progress to sustainability, unless environmental impact is also a considerable factor. Energy saving techniques are usually adopted in the operational stage only, but not often in the manufacturing and execution stage of building materials and building. The study is to analyze the embodied energy consumed from the manufacturing stage of building materials to the establishment of the building. A total embodied energy calculation model is developed along with the alternative choices to reduce the embodied energy consumption in an RCC building without compromising the structure and design.*

1. INTRODUCTION

Our planet earth is a reservoir of fossil fuels, minerals, fresh water and resources for our raw materials and this source is the natural capital for meeting all our requirements. This resource reservoir has enough to satisfy the needs of humans but it's exploitation by humans has raised the question regarding sustainability. "The global population, which is over 7 billion currently, is expected to reach 9-10 billion by the end of 2050" (Bruce, 2012; UNDESA, 2011). Assuming the Earth's population to be about 10 billion people in 2050, the state of resource consumption would be critical. Extraction of the raw materials and manufacturing of building materials lead to large energy consumption. The transportation of these materials over long distances to their respective sites further leads to consumption of more energy.

EE is defined as "the energy consumed by all the processes associated with the production of a building, from the mining and processing of natural resources to manufacturing, transport and product delivery". EE does not include the operation and disposal of the building material. This would be considered in a life cycle approach. EE is a topic of rising concern. In fact, it is normally possible to reduce the EE of a building or construction project by using alternative energy efficient materials without altering the building design.

The case study building is a RCC shear wall building consisting of 5 towers with 40 storeys each. The total built up area is 142140.35 sqm..

2. METHODOLOGY

The study consists of three different phases as shown in figure 1,

Phase 1:-

1. Study of literature on EE.
2. Identifying different methods for calculating EE.
3. Establishing system boundary.
4. Collecting the working drawing of the reference building and tabulating quantities.

Phase 2:-

1. Study of EE coefficients from various inventories.
2. Development of a EE quantification model.
3. Calculation of EE for specific building materials.
4. Comparison of the obtained values with the existing literature values.

Phase 3:-

1. Identification of different energy efficient alternatives for major contributors.
2. Calculation of EE for the alternatives.

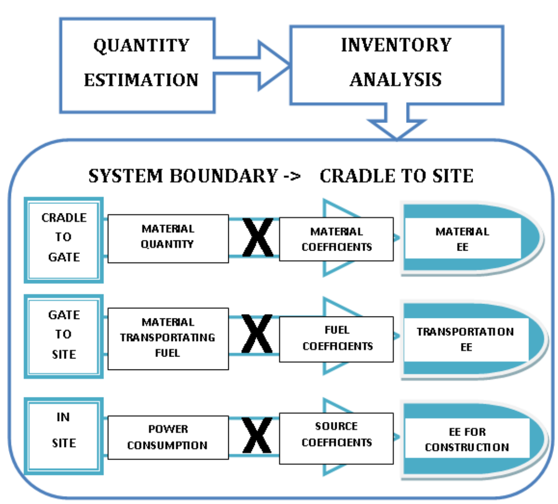

Figure 1: Methodology model

The quantities (volume/area) of specific building materials obtained from a standard bill of quantities is estimated to mass (kg) with respect to its density, in order to make the units of measurement compatible with selected inventories. The standard unit for EE is MJ/kg material.

Information on EE coefficients are scattered in different academic papers in Indian scenario. Although, for building assessment some trusted and government approved inventories are used in this study. [5][8]

The approach chosen for selecting system boundary is cradle to site (Fig.2). The system boundary of EE quantification consists of cradle to gate, gate to site and at site erections. Cradle to gate is the manufacturing stage, which is stage 1 of the building material production. This stage includes resource extraction, material processing, manufacturing and finishing. The stage 1 finished goods are transported to site through different means of transportation and this is the gate to site stage, which is stage 2. In this study, we are considering roadway transportation. Gate to site stage includes EE consumed for diesel. After procurement of building materials in site, the energy used for the erection of building materials at site is included in stage 3.

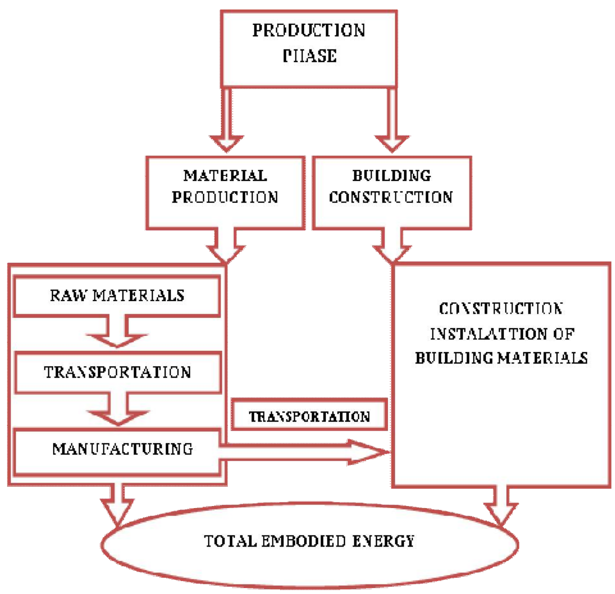

Figure 2: Cradle to site system boundary

The model for EE quantification is based on, the principle of energy accounting for buildings.

$$TEE = EC\text{-}G + EG\text{-}S + ES \quad (1)$$

Where, TEE = Total EE, EC-G = EE from cradle to gate, EG-S = EE from gate to site, ES = EE at site

In above models, wastage factor is not considered since the quantity estimated for the analysis part already accounts for wastage

3. EE CALCULATION

EE from cradle to gate (E_{C-G})

$$EC\text{-}G = \sum_{i=1}^{n} \alpha_i Q_i$$

Where, i = Specific materials used in the building, Qi = Quantity of material i in kg,

αi = EE coefficient for material i in MJ/kg.

EE from cradle to gate is obtained by the addition of product of quantity of materials in mass and their EE coefficients. Table 1 shows EE required for manufacture of specific materials to its final finishing state.

Table 1: EE from cradle to gate calculation

Sl No	Material	Quantity in kg	EE coeff(MJ/kg)	EE in MJ
	I	**Qi**	**αi**	**EE**
1	Cement	1475410.449	4.9	7229511.202
2	Steel	12587000	30	377610000
3	M-sand	5348362.879	0.11	588319.9167
4	RMC	146560691.4	1.17	171476008.9
5	MIVAN steel	1815940.5	25	45398512.5
6	Concrete block	1165626	1.3	1515313.8
7	Vitrified Tile	4062061.014	8.2	33308900.31
8	Granite	592209.4888	3.7	2191175.109
9	Wooden flooring	172914	64	11066496
10	Putty	2643396	1.3	3436414.8
11	Paint	334543.66 sqm	21 MJ/sqm	7025416.86
12	Gypsum false ceiling	386343.1215	3.3	1274932.301
13	Upvc	143371.2	61	8745643.2
14	Glass 6mm	321138.4125	23.5	7546752.694
15	Wooden frame	116745.216	10	1167452.16
16	Wooden shutter 40mm	208813.3151	10.4	2171658.477
EE from cradle to gate, EC-G				681752508.2

EE from gate to site (E_{G-S})

In this case study the site is in East Bangalore.

$$EG\text{-}S = \sum_{i=1}^{n} \beta_i D_i Q_i$$

Where, i = Transportation energy coefficient for specific distance and capacity

Di = Distance travelled by specific materials through road transport in km

Q_i = Total quantity of materials transported to site.

$$\beta i = \frac{\text{EE of diesel in MJ/L}}{\text{Mileage of vehicle in } \left(\frac{km}{L}\right) \text{ X Load capacity of specific material in one trip}}$$

EE of diesel in MJ/L= 35.8, Mileage of vehicle in (km/L) = 4

Materials used for construction are transported from various locations based on their bulk availability and quality. Locally available sources are also used for the purchase and procurement. Many materials have local distributors but their actual manufacturing with the raw materials is in a specific location.

In Table 2, the EE of the total diesel used in transportation of total quantity of materials from different manufacturing plants is calculated. Addition of the product of each material with correspondence with their distance travelled and quantity transported, and transportation energy coefficient will give the transportation EE in materials or EE of gate to site. Here the transportation is considered only in roadways.

Table 2: EE from gate to site calculation

Materials	βi	Quantity (Qi)	Unit	Distance(Di) in km	EE(MJ)
Cement	0.358	1475.41	T	350	184868.873
Steel	0.2983	12587	T	1800	6759219
M-sand	0.4475	3688.526	Cum	40	66024.61761
RMC	1.2786	66618.5	Cum	5	425882.5285
MIVAN steel	1.79	231.33	Cum	900	372672.63
Concrete block	0.5594	803.88	Cum	30	13490.11125
Vitrified Tile	0.0179	169252.5	Sqm	1700	5150354.86
Granite	0.6393	223.4753	Cum	200	28572.91065
Wooden flooring	0.0298	12351	Sqm	15	5527.0725
Putty	0.895	2643.39	T	1000	2365834.05
Paint	0.895	1338.174	T	170	203603.1741
Gypsum false ceiling	0.0298	11038.37	Sqm	15	4939.672768
Upvc	0.0099	51204	M	2000	1018390.667
Glass 6mm	0.7458	321.138	T	60	14370.9255
Wooden frame	0.0149	36482.88	M	1100	598623.256
Wooden shutter 40mm	1.79	208.813	T	1100	411152.797
EE from gate to site (EG-S)					17623527.15

EE in site (E_S)

EE in site is the third stage in calculation for total EE. The EE in site includes manpower energy, machine energy, and energy consumed by equipment and tools. In table 3, the EE for site for 1200 working days is tabulated using the formula,

$$ES = \sum_{i=1}^{n} 1200\, \gamma_i Q_i$$

Where, γi = EE coefficient in MJ/unit, Qi = Number of units of specific items.

Table 3: EE at site calculation

Items	Details	Unit	Energy	Unit	EE (MJ)
	Qi		γi		
Human energy	200	Nos	10.04	MJ/person	2409600
Truck	4	Hour	67.13	MJ/hr	322224
Excavator/ crane	4	Hour	214.8	MJ/hr	1031040
Hydro electricity	500	KWH	0.055	MJ/KWh	33000
EE at site (ES)					3795864

4. RESULTS AND DISCUSSIONS

The total EE from cradle to site of the building materials is given in table 4 using (1).

Table 4: Total EE from cradle to instalment

Description	Location	EE (MJ)	Area (m2)	EE/area (MJ/m2)	% contribution
Material EE	Cradle to Gate	681752508.2	142140.35	4796.334	97.01152
Transportation EE	Gate to Site	17623527.15	142140.35	123.9868	2.458869
Erection EE	In Site	3795864	142140.35	26.70504	0.529606
TEE		703171899.4	TEE/sqm	4947.025	

The total EE equals 703171899.4 MJ for the total built up area. Therefore, for unit built up area, the EE estimated is 4947.025MJ/m2(4.9 GJ/m2). The contribution of EC-G ie. manufacturing stage is 97.01% and is the maximum. Transportation EE and erection EE has come upto 2.45% and 0.529% respectively, which is minimum. This corroborates with the literature stating that the EE of materials from cradle to site is the major contributor of EE.

The EE distribution from various sectors is represented in figure 3.

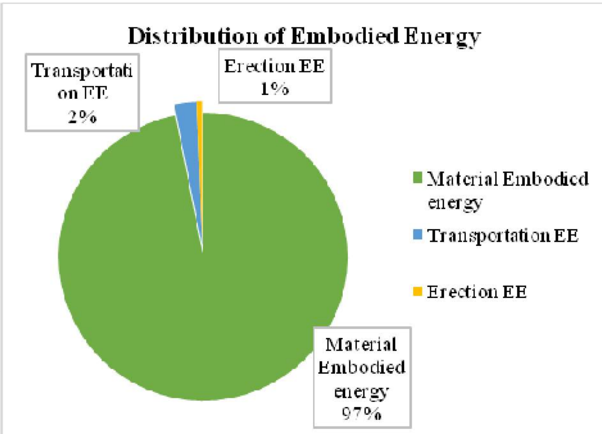

Figure 3: Distribution of EE

From the total EE analysis, the major contributor of EE is the stage 1 material manufacturing process.

Figure 4 depicts the EE contribution by varied materials in stage 1.

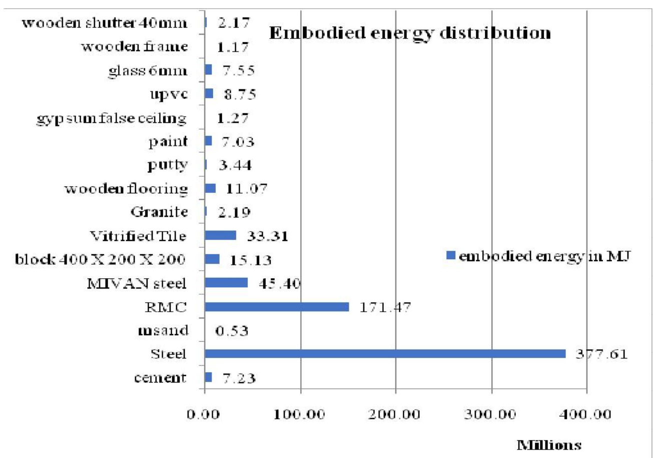

Figure 4: EE distribution of materials in stage 1, cradle to gate

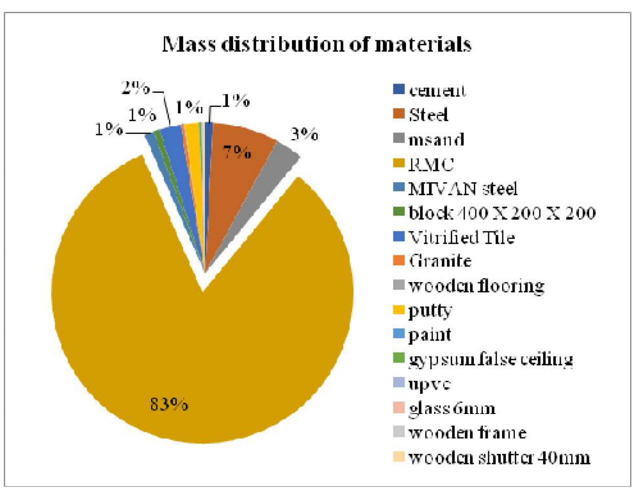

Figure 5: Mass distribution of materials

From figure 5, it can be noted that ready mix concrete has major share in the mass of the reference building, ie. 83% but contributes only 22% of the total EE. In contrast, steel is accounting only 7% of the total material mass but the EE contribution is above 55%. For a RCC shear wall building, compromising the steel quantity is not applicable or else the design should be altered.

Another way to reduce EE is to use recycled building materials. But, this method is not applicable for all building materials. As observed, in this study the major contributor is steel and this can be reduced by the use of recycled steel bars having a very low EE coefficient of 8.80 MJ/kg as compared to the EE coefficient of 30 MJ/kg of steel.

The percentage reduction of EE of steel is shown in figure 6. It is showing a reduction of almost 70% of EE ie. EE of virgin steel rebar is almost 3.4 times as that of recycled steel rebars.

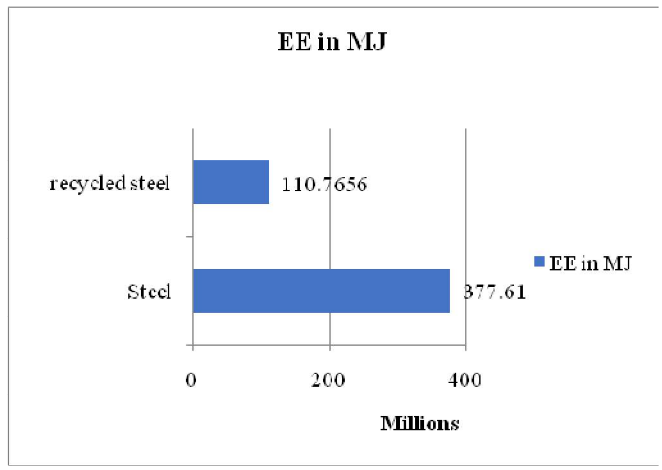

Figure 6: EE comparison of virgin steel and recycled steel

The second major EE contributing material is RMC. Procuring concrete from ready mix plant results in minimum EE compared to cast in-situ concrete due to heavy diesel consumption and manpower. Another method to reduce EE in RMC is to use RMC with fillers like pozzolona and GGBS. The EE coefficient of RMC with fly ash (30% Pozzolona) is 0.99 and that of GGBS is 0.87. It is negligible compared to EE coefficient of RMC (1.03), still it is accounted for the analysis.

The third major EE contributing material is MIVAN formwork which is already a recycled material and the material can be again reused and remoulded for a number of times as formwork. The EE contribution of all other materials is less than 5%.

Summarizing the results obtained on using alternatives for virgin steel and RMC and from the analysis, the total EE using replacement materials in stage 1 is obtained as 384500929 MJ. Comparing this value with the initial EE value of 695313536.3 MJ, it is observed that by using replacement materials for steel and RMC, the EE can be reduced by 44.7%.

Table 5: Total EE from cradle to instalment

Description	Location	EE (MJ)	Area (m2)	EE/area (MJ/m2)	% contribution
Material EE	Cradle to Gate	370939900.8	142140.35	2609.67	94.54
Transportation EE	Gate to Site	17623527.15	142140.35	123.98	4.49
Erection EE	In Site	3795864	142140.35	26.70	0.96
Total EE	392359292	Total EE/Area	2760.36		

The new total EE after the replacement and the stage wise contribution is shown in table 5. The new total EE for the reference building is 4947.025 MJ/m2. This significant reduction in EE has occurred due to the use of alternative materials for steel and RMC in stage 1. This reduction shows a better hope for the construction of RCC shear wall structure with lesser energy consumption.

In stage 2 (transportation) EE from gate to site is negligible (4%) compared to the 94.7% contribution by manufacturing stage 1. This 4% contribution is due to the EE consumption of diesel for the long-distance run from factories to site and it can be further reduced by the use of locally available good quality materials. In stage 3, a mere reduction is possible by wisely using resources, its proper planning and by using equipment's and machinery having better performances.

5. CONCLUSION

It is interesting to know that the EE per square metre value of reference building is less than the buildings in the previous studies as shown in table 6.

Table 6: Comparison of total EE with the previous studies

Sl. No	Building types	no. of storeys	Embodied Energy (GJ/sqm)	Area (Sq-m)	Reference
1	conventional building	8	4.21	5120	2
2	conventional building with load bearing walls	2	2.92	149.5	2
3	building with soil cement block and filler slab roof	2	1.61	160.5	2
4	Adobe house	2	3.8	120	6
5	steel reinforced concrete house	35	9.56	3 x 105	9
6	RCC shear wall building	40	4.9	1.42 x 105	Current study

The reason may be due to the energy efficiency in construction using improved technology and, in those case, EE of cement used for mixing in-situ concrete is responsible for high EE value. For the reference study, the concrete mixing is done completely through RMC plants resulting better values.

The result of this study shows that the major contributor to EE is stage 1, which is the cradle to gate manufacturing stage. In stage 1, steel is the major contributor, followed by RMC and MIVAN formwork for the total energy consumption. For steel, the best alternative is the use of recycled steel than changing the structural design. Recycled steel is showing a great impact in the reduction of energy values by almost 70%, which is a good result. The second major contributor is RMC. Technically, RMC is the best way to mix concrete in the most advanced approach with minimum energy. Further reduction in energy consumed can be achieved by the partial replacement of cement with GGBS/pozzolana. . The results show a total reduction of EE by 44.7%.

The limitation of the embodied energy study is the lack of standard codes for embodied energy coefficients. Foreign databases were also depended for some material coefficients due to lack of information in Indian scenario. The data of embodied energy varies depending upon the inventory chosen. To overcome this, intensive efforts should be taken to identify, evaluate and standardise the EE coefficients. This will help the professionals to choose energy efficient techniques and materials to attain sustainability.

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