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Embodied Energy Audit of Residential Building

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Abstract— *Buildings consume a vast amount of energy during the life cycle stages of construction, use and demolition. Total life cycle energy use in a building consists of two components: embodied and operational energy. Embodied energy is expended in the processes of building material production, on-site delivery, construction, maintenance, renovation and final demolition. Operational energy is consumed in operating the buildings. In this paper the review is given about energy consumption of the residential building. Energy required for various materials is calculated and energy efficient alternatives are suggested. Studies have revealed the suggestion of energy efficient alternatives materials and comparison of energy consumed by using each material. Current interpretations of embodied energy are quite unclear and vary greatly as change in site source of raw materials and embodied energy databases suffer from the problems of variation and incomparability.*

Keywords— Embodied, Energy, Lifecycle, Joule, Emitted.

I. INTRODUCTION

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.

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 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.

Embodied Energy of the selected alternative walling elements and comparing the rates to identify the most suitable option. The study is limited to walling elements of single brick or block thickness and plastering work has been excluded from the computations. Moreover, the alternative building materials included in this work are only in relation to the comparison of their EER. Hence, comprehensive life cycle assessments fall outside the purview of this work.

The goal of the paper is to give an overall idea of what low embodied energy is and define several low embodied energy materials. As the resources of raw energy and building materials are running low, we have to find new solutions to the problem. The reduction of the building industry’s energy consumption is of great importance and low embodied energy is the key to a great success in solving that issue. The paper describes methods of estimating low embodied energy, such as LCA. It also provides information on the usage of low embodied energy materials and life cycle assessments as helpful tools in decreasing the negative impact on local and global eco systems, by lowering the emissions of CO2. The paper also includes a comparison between building materials with low embodied energy, as a result of which the material with the lowest embodied energy is timber. It also reflects on the great significance in the differentiation between renewable and non-renewable resources and their importance to the environment.

II. METHODOLOGY

The total experimental approach involved in this work has been divided into four different phases. The details of the work in phase are narrated below.

Phase-I:-

1) Study of available literature on embodied energy.
2) Identifying different methods of calculating embodied energy.
3) Collecting the working drawing of residential building and preparing estimate.

Phase-II:-

1) Calculating Specific Energy of general materials.
2) Calculation of embodied energy of selected building components.

Phase-III:-

1) Identification of different energy efficient alternatives for selected building components.

Phase-IV:-

1) Analysis of different alternatives of selected building components with respect to cost, strength and embodied.
2) Recommendation of the energy efficient materials.
3) Report writing.

III. CALCULATION OF EMBODIED ENERGY

The three main embodied energy analysis methods are described:

A. Process analysis

Process-based analysis is one of the most widely used methods of embodied energy analysis, as it delivers more accurate and reliable results. This method involves using the energy data from the factory manufacturing the material to determine the energy used in creating it. The total embodied energy comprises the energy required directly for the main manufacturing process and the indirect energy embodied in the material inputs to the process. For the construction of a building, for example, the direct energy may include that used on-site for the operation of power tools, while the indirect energy may include that used directly in the manufacture of material used in the building. The indirect energy of the steel would in turn comprise energy embodied directly in the extraction and transport of iron ore.

Process analysis, according to definitions, comprises four steps:

1) *Measurement* of the direct energy requirements of the process
2) Measurement of the output of the process.
3) Quantification of the products required directly by the process and the application of steps 1 and 3 to the products quantified in step 3.

The speed and relative simplicity of this method make it preferable to Input-Output analysis as these would relate to lower costs in an industry setting.

B. Input-output analysis

An input/output-based analysis could account for most direct and indirect energy inputs in the process of production of building materials and thus is considered relatively complete. This process makes use of economic data of money flow among various sectors of industry in the form of input/output tables made available by the national government, thereby transcribing economic flows into energy flows by applying average energy tariffs. Thus, in an input/output analysis, the embodied energy is calculated by multiplying the cost of the product by the energy intensity of that product expressed in MJ or GJ/$1000 and dividing it by $1000.

There are two types of input-output tables commonly used:

1) Elements of the direct input-output matrix represent the amount of the row sector (for example, cement) in dollars required directly to make each dollar of output of the column sector (for example, concrete). These values are called ‘direct requirements coefficients.
2) Leontief inverse input-output matrices

Elements of the Leontief inverse input-output matrix represent the amount of the row sector (for example, cement) in dollars required to directly and indirectly make each dollar of output of the column sector (for example, concrete). These values are called ‘total requirements coefficients’, and represent the direct plus the indirect requirements.

The main disadvantage of this method is that it is time consuming if the Leontief matrix is not supplied. There are also identifiable sources of error such as varying energy and materials prices, as well as methods of data collection as sources of error for Input-Output calculations. The age of the data is also a potential source of error.

C. Hybrid analysis

This combines elements of both the input-output analysis in an attempt to achieve a more accurate value of embodied energy than that obtained by either of the methods individually. The method uses data from input-output analysis of the sample building then modifies the values using process analysis to obtain a value containing 48% more embodied energy than the Input-Output analysis alone

1) There are two possible options for the basis of a hybrid analysis

a) Process-based hybrid analysis

Process-based hybrid analysis involves the derivation of product quantities for an individual product and the subsequent application of total energy intensities derived using input-output analysis. The essential premise of process-based hybrid analysis methods is that the errors in the input-output model for the sector which produces a particular product can be obviated by determining the quantities of inputs of goods and services into the main process.

b) Input-output-based hybrid analysis

This method incorporates identification and extraction of direct energy paths from input/output-based analysis in order to integrate the reliable and accurate process based data to avoid indirect effects. Where the direct energy intensity of a material is relatively small, compared to its total energy intensity, the material inventory of a process-based hybrid analysis is occasionally extended a further stage upstream so that more certainty can be attributed to these materials.

Input-output-based hybrid methods can be classified into three options:

- Substitution of process analysis data into the input-output model.
- Adding a column to the input-output model for the process analysis data.
- Modification of direct energy paths with process analysis data.

The selection of the most appropriate allocation method is not straight forward. Results may vary widely according to the method chosen.

IV. ESTIMATING CONSTRUCTION ENERGY FOR BUILDING BY CONVENTIONAL METHODS

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 is cement, steel, bricks, stones, glass, aluminum, timber, etc. The estimates of the energy consumed in the manufacture/extraction is calculated below.

The total amount of embodied energy associated with the building construction is calculated by using following equation.

$$EE = E\ mat + E\ trans + E\ site$$

EE = Embodied energy.

E mat = Energy from material / product manufacturing.

E trans = Energy from material / product transport.

E site = Energy from site works.

A.ESTIMATING CONSTRUCTION ENERGY FOR BUILDING

Material quantity required to construct the building is first estimated from the drawing. The quantity calculated is shown in table below.

TABLE I: QUANTITY OF MATERIAL REQUIRED

Sr. No.	Material	Quantity	Unit
1	Bricks	83000	Numbers
2	Cement	3000	Bags
3	Steel	19.27	MT
4	Aggregates	70	Brass
5	Sand	85	Brass

B. EMBODIED ENERGY ASSOCIATED WITH MATERIAL

A building is made of different construction materials. Different and attractive materials are available for the construction which helps in reducing time of construction as well as good looking. Cradle to Gate energy is related to the material used for the construction which include following energy in calculation-

- Extraction of raw material from quarry
- Transport raw material to the factory
- Processing on raw material to get final product

Further, with for each building construction material / product

$$EE\ Tmat = Q\ mat \times EE\ mat$$

Where;

EE Tmat = Total embodied energy of building material.

Q mat = Quantity of building construction material / product.

EE mat = Embodied Energy associated with material / product manufacturing.

TABLE II: QUANTITY OF MATERIAL REQUIRED

Sr. No	Material	Qty.	Unit	EE	Unit	Total EE (MJ)
1	Bricks	83000	Nos.	5.87	MJ/brick	487210
2	Cement	3000	Bags	4.2	MJ/Kg	630000
3	Steel	19.27	MT	23.23	MJ/Kg	447642.1
4	Aggregate	70	Brass	32.32	MJ/cum	6413.90
5	Sand	85	Brass	37.31	MJ/cum	8990.78

C. TRANSPORT EMBODIED ENERGY

Transport energy is a function of material weight, transport method and the distance travelled. From these three factors very reasonably accurate calculations of transport embodied energy can be made. In calculating a figure for the transportation energy consumed by each material, the following steps are followed:

- Quantify each material in the building.
- Calculate the distance travelled by each material.
- Determine the transportation type for each part of each material's trips between nodes, as well as the fuel efficiency of those modes of transportation.
- Analyze the loading capacity of the modes of transportation, and calculate the quantity of that portion of this loading capacity for which the construction project is responsible.

Many materials involve two types of transportation method (e.g. import by sea, travel to site with rigid truck) and the model allows for this input.

EEtrans = Dm-s x EEveh

Where;

EEtrans = Embodied energy related to the transport of building material.

Dm-s = Distance manufacturing to site.

EEveh = Embodied Energy Factor associated with the vehicle. It varies depending upon the vehicle used.

TABLE III: MATERIAL EMBODIED ENERGY FOR BUILDING

Sr. No.	Material	Total distance (Km)	Total EE (MJ)
1	Bricks	6	753.72
2	Cement	440	20106.24
3	Steel	46	875.84
4	Aggregates	20	11852.86
5	Sand	40	8529.92

D. ASSEMBLY EMBODIED ENERGY ESTIMATES

The onsite construction work of residential buildings involves a variety of activities that requires the use of energy sources. The site embodied energy calculation is based on the following:

- Time period of construction
- Type of energy used (Electricity, fuel, Gases etc.)
- Efficiency of machinery used for the installation

EEsite = QEnergysite x EEenergy

Where;

EEsite = Embodied energy related to site.

QEnergysite =Quantity of energy used on site for the construction.

EEenergy = Embodied Energy Factor associated with the energy. It varies depending upon the type of energy (Electricity, fuel, Gases etc.) used.

TABLE IV: MATERIAL INSTALLATION ENERGY FOR BUILDING

Sr. No.	**Energy Source**	**Unit**	**Quantity**	**EE**	**Total EE**
1	Electricity	1440	KWh	3.6 MJ/kWh	5184
2	Diesel	83.65	Litres	38.08MJ/Lit	3185.39

E. TOTAL ENERGY CONSUMPTION OF BUILDING

A closer look at the industry of Building Materials suppliers and manufacturer is necessary to understand the impact of construction materials on the environment, and specifically how the manufacturing of building materials cause depletion of energy consumption of material.

TABLE V: TOTAL EMBODIED ENERGY OF BUILDING

Sr. No.	**Type of energy**	**Amount of energy (MJ)**	**Total**
1	Material manufacture	1580256.68	1630.74 GJ.
2	Material transport	42118.58	
3	Material installation	8369.39	

V. ESTIMATION CONSTRUCTION ENERGY FOR BUILDING BY ENERGY EFFICINET METHODS

A. FLY ASH BRICKS

Bricks are masonry units composed of inorganic non-metallic material and are widely used as building components all over the world. The bricks could be sun-dried or burnt. Burnt bricks are usually stronger than sundried bricks, especially if they are made of clay or clayey material. There are different categories of the bricks, depending upon the admixtures and raw material used for making bricks.

1) Embodied energy

Calorific value of diesel is 338.08 MJ/lit and that for electricity is 2.77 MJ/ kwh. Hence as per the energy requirement for the manufacturing one brick

EE = (2.77 x 0.03) + (0.02 x 38.08) = 0.88 MJ

TABLE VI: ENERGY COMPARISON BETWEEN THE FLY ASH BRICKS AND CLAY BRICKS FOR ROOM SIZE 3.66 X 3.66 X 3.05 M

Type of brick	**Quantity required**	**Type of energy used for manufacturing**	**Energy required**	**Total embodied energy (MJ)**
Clay	4679	Coal	5.87	27465.73

brick			MJ/brick	
Fly ash brick	3128	Electricity	0.88 MJ/brick	2752.64

B. FILLER SLAB

The filler slab is based on the principle that for roofs which are simply supported, the upper part of the slab is subjected to compressive forces and the lower part of the slab experience tensile forces. Concrete is very good in withstanding compressive forces and steel bears the load due to tensile forces. Thus the lower tensile region of the slab does not need any concrete except for holding the steel reinforcements together.

The quest for cost-effective, innovative and environment-friendly housing has focused on the appropriate use of locally available materials, skill and technology without compromising on the quality and life of the structure. Filler slabs are one such cost – effective and environmental friendly roofing system which is based on the concrete portions and instead placing filler material there. The material used as a replacement includes bricks, tiles, cellular concrete blocks.

TABLE VI: EMBODIED ENERGY CALCULATION FOR THE $1M^3$ QUANTITY OF SLAB

Material description	Embodied energy	Conventional slab		Filler slab	
		Qty	EE	Qty	EE
Cement (kg)	5.5 MJ/kg	422.67	2324.69	342.35	1882.93
Sand (cum)	37.37 MJ/cum	0.48	17.94	0.39	14.57
Aggregate (cum)	10.98 MJ/cum	0.96	10.54	0.78	0.75
Steel (kg)	20.6 MJ/kg	28.2	580.92	17.48	360.09
Total EE (MJ)			2934.09		2258.34
% Saving of energy= 23%					

C. READY MIX CONCRETE

In India concrete has traditionally been produced on site with the primitive equipment's and use of large labour. Ready mix concrete is advanced technology, involving high degree of mechanization and automation. A typical RMC plant consists of silos and bins for the storage of cement and aggregate respectively, weigh batchers for proportioning different ingredients of concrete, high efficiency mixer for through mixing of ingredients, and a computerized system controlling the entire production process. The quality of the resulting concrete is much superior to site mixed concrete.

The concrete is mixed at the factory or batching plant, according to the set recipe, and then deliver to the site by truck mounted in transit mixer. RMC is preferred over on site mixing concrete because of the precision of the mixture and reduced work site confusion. The energy used for the mixing of concrete on RMC plant is electricity, approximately 1 kwh electricity is required to mix half cum of concrete.

TABLE VII
ENERGY COMPARISON BETWEEN RMC AND SITE MIXING

Method of mixing	**Quantity of concrete**	**Type of energy used for mix**	**Energy required**	**Total embodied energy (MJ)**
RMC	239 cum	Electricity	1kwh/Half cum	1882.125
Site mixing	239 cum	Diesel	5lit/100 bags	3185.39
% Saving in energy=40.8%				

D. CRUSHED SAND

Natural sand are weathered and worn out particles of rocks and are of various grades or size depending on the accounting of wearing. The main natural and cheapest resource of sand is river. Dams are constructed on every river hence these resources are erasing very fast. Now a day's good sand is not readily available, it should be transported from long distance. Those resources are also exhausting very rapidly. So it is a need of the time to find some substitute to natural river sand.

The artificial sand produced by proper machines can be a better substitute to river sand.

TABLE VII: ENERGY DIFFERENCE BETWEEN CRUSHED SAND AND RIVER SAND

Type of sand	**Quantity required**	**Type of energy used for manufacturing**	**Energy required**	**Total embodied energy (MJ)**
Crushed sand	85 brass	Electricity	20.98 MJ/cum	4226.421
River sand	85 brass	Diesel	37.31 MJ/cum	8991.11
% Saving of energy=52%				

VI. OBJECTIVES

This report presents the energy required to the building in its life cycle. The total energy consumption that can be attributed to a building throughout its life will depend upon the energy consumed for the production of the building materials, construction, operation, maintenance and for demolition and disposal or recycling.

The total life cycle energy consumption of a building includes embodied energy as well as operational energy. Embodied energy is the combined energy required to extract the raw materials, transport and refine the raw materials and then to manufacture the components, deliver to site and assemble the product. Different materials have an effect on the amount of energy required to produce the buildings.

1) Introduction to "Embodied energy" and its necessity in present scenario.
2) Study various methods of calculation of embodied energy.
3) Study the steps in calculating embodied energy for all building materials and construction.
4) Calculation of specific energy of building materials and converting it into embodied energy.
5) Calculation of embodied energy of selected building components.
6) Identification of different energy efficient alternatives for selected building components.
7) Analysis of different alternatives of selected building components with respect to cost, strength and embodied energy.
8) Recommendation of the energy efficient materials.
9) Calculate the embodied energy for a building by taking case study.
10) To comment on energy consumption for a building of case study.
11) To suggest alternative building material and construction techniques to reduce energy consumption.
12) Collection and study of literature pertaining to the dissertation work.
13) Collecting the working drawing of residential building and preparing estimate.
14) Identify the material requirement and the best resource of the material.
15) Analyzing and calculating energy required for production of building material and energy required for execution.
16) To prepare the energy audit of the building.
17) To comment on the suitability of the building material used for construction.

VII. CONCLUSION

This research paper deals with the overall energy calculations of construction materials like bricks, cement, sand steel, aluminum, and construction of various structural elements. This paper gives idea about conservation of energy and an attempt was made to find out the conservation also will be require for modifications with some software's will be used to calculate exact energy calculation.

The current environmental practices such as environmental selection of building materials, eco-labelling, and green building assessment, in the construction industry, depend mainly embodied energy analysis of the building.

From the dissertation work, it can be concluded that:

- Materials like Cement, Steel and Bricks and Sand are the major contributors to the total energy consumption in Reinforced Concrete buildings.
- Attempts in minimizing or replacing the conventional high energy materials like cement, steel, bricks with cheaper and local alternatives will lead to reduction in the embodied energy in buildings.
- As the bricks and aggregates are locally available materials transport energy consumed by these materials is less than the other materials as the manufacturing plants of other materials are situated away from the site.
- Manufacturing energy consumption is more for steel and cement due to consideration of raw material transport energy which is not available near the manufacturing plant.
- A 23% energy saving may be achieved in 1m^3 quantity when slab made by filler technique than the conventional slab.
- The use of alternative building units like fly ash bricks for masonry construction reduces the energy consumption by 89% as compared to brick masonry.
- Use of ready mix concrete is eco-friendly technique compare to on site concrete method, which reduces up to 40% energy consumption on site. And also gives the maximum strength than conventional method of concreting.
- Manufacturing building materials using different technologies in the same time and at the same geographic location could reflect dissimilar energy consumption. Use of differing production technology and type of energy used in the process could bring large differences to embodied energy figures.
- The use of crushed sand in the replacement of river sand causes the energy difference 4764.69 MJ. Hence the use of crushed sand is preferable as compare to river sand for energy efficient building.
- Proper site selection and proper building orientation plays an important role in deriving maximum benefits from natural resources, availability of material and transportation of material to site.
- Uses of 10-20% fly ash in one bag of cement causes the energy as well as cost reduction.

- The embodied energy includes the material transport energy (factory to dealer and factory to site); hence maximum use of locally available material causes the reduction in transport energy.

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