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Energy Audit of a Residential Building

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Abstract: The sum of all the energy embedded in products and processes used in constructing a building is known as embodied energy. Buildings demand energy in their life cycle right from its construction to demolition. Studies on the total energy use during the life cycle are desirable to identify phases of largest energy use and to develop strategies for its reduction. 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 that is embodied and operational energy. In this paper the review is given about energy consumption of the residential building. In this paper energy required for construction of residential building is calculated and also recurring embodied energy is calculated. Energy required for various materials is calculated and energy efficient Alternatives are suggested. Current interpretations of embodied energy are quite unclear and vary greatly
Keywords: Embodied, Operational, Energy, Joule, LCA.

I. INTRODUCTION

Indian construction industry is one of the largest in terms of economic expenditure, volume of raw materials/natural resources consumed, volume of materials and products manufactured, employment generated, environmental impacts, etc. Large variety of materials are manufactured and consumed in the construction industry. Production levels and energy expenditure of some of the building materials consumed in bulk quantities Total energy expenditure on bricks, cement aluminium and structural steel consumed in bulk quantities is 1684×10^6 GJ per annum. It has been estimated that 22% of greenhouse gas (GHG) emissions is contributed by the construction sector in India. There is an ever-increasing demand for building materials.

Bricks, cement, steel, aluminium, plastic products, paints, polished stone, ceramic products, etc. are the commonly used materials of construction today. These materials are energy intensive and are transported over large distances before being used for construction. The following points require attention, regarding the use of modern building materials: Energy consumed in the manufacturing processes energy intensity; Problems of long distance transportation; Natural resources and raw materials consumed; Recycling and safe disposal; Impact on environment, and Long-term sustainability. Thus the issues related to energy expenditure, recycling, biodegradable, and environmental and sustainability with respect to future demand need to be addressed during the manufacture and use of any new building material.

The energy consumption associated with buildings and construction materials can be categorised as follows:

Energy in use is the energy required by the occupants of an existing or planned building, primarily for space heating, water heating and lighting – and of the need to reduce it. Reduction in energy demand through more efficient buildings brings benefits for the global environment as well as lower costs and improved quality of life for the occupants.

Embodied energy is the energy consumed by all of the processes associated with the production of a building, from the mining and processing of natural resources to manufacturing, transport and product delivery.

Inherent energy- Inherent energy is the chemical energy contained in a material which can be released through combustion or chemical processing.

The goal of the paper is to give an overall idea of what is embodied energy and define embodied energy of several materials and also define energy efficient alternative materials. As the resources of raw materials and building materials are running low, we have to find new solutions to the problem. The reduction of the building'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 minimum 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 CO_2. The paper also includes a comparison between building materials with low embodied energy. 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 work involved in this project has been divided into four different stages. The details of the work in stages are as follows.

A. Stage-I

1) Study of literature of embodied energy.
2) Study of different methods of calculating embodied energy.
3) Calculating Embodied Energy of general materials.

B. Stage-II

1) Selection of a Residential building plan
2) Collecting the working drawing of residential building and preparing estimate.
3) Calculation of embodied energy of selected building components.

C. Stage-III

1) Identification of different energy efficient alternative materials for selected building materials.

D. Stage-IV

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

III.CALCULATION OF EMBODIED ENERGY

A There are three main embodied energy analysis methods are as follows:

A. Process Analysis

Process-based analysis delivers more accurate and reliable results & is one of the most widely used methods of embodied energy analysis. In this method energy data from the factory manufacturing the material is obtained to determine the energy used in creating it. The total embodied energy includes the energy required directly for the main manufacturing process and the indirect energy embodied in the material inputs to the process. For example, the direct energy may include the on-site 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 include energy embodied directly in the extraction and transport of iron ore.

B. Input-Output Analysis

An input/output-based analysis is used for direct and indirect energy inputs in the process of production of building materials and is therefore considered to be complete. In this process use of economic data of money flow among various sectors of industry in the form of input/output tables are made available by the national government. This results in transcribing economic data into energy data by applying average energy tariffs. Therefore, in an input/output analysis, the embodied energy is calculated by multiplying the cost of the product by the energy intensity of that product.

C. Hybrid Analysis

This method is a combination of both the input-output & process analysis in an attempt to achieve a more accurate value of embodied energy than that obtained by either of the methods individually. In this method data from input-output analysis of the sample is obtained, then the values are modified using process analysis to obtain more embodied energy than the Input-Output analysis alone.

On the basis of a hybrid analysis there are actually two possibilities:

1) Process-based hybrid analysis
2) Input-output-based hybrid analysis

IV. ENERGY REQUIRED FOR COUNSTRUCTION OF BUILDING

Construction of a building requires a number of building materials. Sufficient quantities of raw materials are to be transported from distances to the industry which actually requires further processing, consuming primary and commercial resources. The finished products from the industry are further needed to be distributed to the local areas and construction sites which eventually increase the pressure on the commercial fuels like petrol and diesel etc. The energy consumed in the manufacture or extraction is calculated below. The total amount of embodied energy associated with the building construction is calculated by using equation below. There are three main parts to calculate embodied energy required for building construction that is material manufacture, transportation of material and assembly embodied energy etc. The building materials used most commonly in construction activity today is cement, steel, bricks, stones, glass, aluminium, timber, etc.

EE = E mat + E Trans + E site

EE = Embodied energy.

E mat = Energy required for material manufacturing.

E Trans = Energy required for transportation of materials.

E site = Energy required for assemble material on site.

A. *Embodied Energy Of Materials*

Selection of building materials in the design process aims at not only future functionality of the building but also environmental performance. A building consists of various construction materials. These materials are available for the construction of building which helps in reduction of construction time as well as improving aesthetics of building. Material used for the construction includes following energy in calculation

1) Raw material extraction from quarries.
2) Transportation of raw material to the factories.
3) Processing on raw material to achieve final product.

EE Tmat = Q mat x EE mat

EE Tmat = Total embodied energy of building material.

Q mat = Quantity of building construction material.

EE mat = Embodied Energy associated with material manufacturing

TABLE I EMBODIED ENERGY OF MATERIALS

Sr No	Materials	Embodied energy
1	Cement	4.5 MJ/Kg
2	Sand	37.31 MJ/Cum
3	Aggregate	28.70 MJ/Cum
4	Steel	2.31 MJ/Kg
5	Brick	4.81 MJ/Brick

B. *Quantity of Material Required*

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

TABLE III QUANTITY OF MATERIALS REQUIRED

Sr.No	Material	Quantity	Unit
1	Cement	600	Bags
2	Sand	44.281	Cum
3	Aggregate	46.02	Cum
4	Steel	4318	Kg
5	Bricks	37500	No’s

C. Embodied Energy For Manufacturing Of Materials

Embodied energy associated with material manufacturing is calculated by multiplying quantity of materials into embodied energy of particular material shown in table given below.

TABLE IIIII
ENERGY FOR MANUFACTURING OF MATERIALS

Sr.No	Materials	Quantity	Embodied energy	Total EE (MJ)
1	Cement	30000 Kg	4.2 MJ/Kg	126000
2	Sand	44.218 Cum	37.31 MJ/Cum	1650
3	Aggregate	46.02 Cum	28.70 MJ/Cum	1320
4	Steel	4318 Kg	2.31 MJ/Kg	9975
5	Bricks	37500 No's	4.81 MJ/No	180375

D. Embodied Energy Required For Transportation Of Material

There are actually three functions involved in material transport energy, material weight, transport method and the distance travelled. From these three factors accurate calculations of transport embodied energy can be made. In calculating the transportation energy consumed by each material, the following steps are followed:

1) Finding out the quantities of material in the building.
2) Calculate the distance travelled by each material.
3) Determine the transportation vehicle for each material &each material's trips.
4) Calculate embodied energy associated with transportation by analysing the loading capacity of the vehicle.

EEtrans = Dm-s x EEveh

EEtrans = Embodied energy required for the transportation of building material.

Dm-s = Distance travelled by material.

EEveh = Embodied Energy Factor associated with the particular vehicle.

TABLE IVV
EMBODIED ENERGY FOR TRANSPORTATION OF MATERIALS

Sr. No	Materials	Distance Travelled(Km)	Total EE (MJ)
1	Cement	600	5712
2	Sand	300	2856
3	Aggregate	510	4855
4	Steel	120	1142
5	Bricks	112	1066

E. Assembly Embodied Energy

The onsite construction work of residential buildings involves a variety of activities. This actually requires the use of energy sources. Energy sources involve electricity, fuel, gases, etc. The site embodied energy calculation is based on the following:

1) Time span required for construction
2) Type of energy used for assembly of product.
3) Efficiency of machinery used for the installation.

EEsite = QEnergysite x EEenergy

EEsite = Embodied energy related to site.

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

EEenergy = Embodied Energy Factor associated with the energy.

TABLE V
ENERGY REQUIRED TO ASSEMBLE THE MATERIALS ON SITE

Sr. No	Type of Energy	Quantity	Embodied Energy	Total EE (MJ)
1	Electricity	1500 Kwh	2.77 MJ/Kwh	4155
2	Diesel	100 lit	38.08 MJ/lit	3808

F. Total Energy Consumption For Construction Of Building

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, a closer look at the industry of Building Materials suppliers and manufacturer is necessary.

TABLE V V
TOTAL ENERGY CONSUMPTION FOR CONSTRUCTION OF BUILDING

Sr. No	Type of Energy	Quantity(MJ)	Total Energy(MJ)
1	Material manufacturing	319110	342704
2	Transportation	15631	
3	Assembly embodied energy	7963	

G. Operational Embodied Energy

Energy used in buildings during their operational phase, as for: heating, cooling, ventilation, hot water, lighting and other electrical appliances. It might be expressed either in terms of end-use or primary energy. Approximately type of electric equipment used in residential building and their energy consumption per day has calculated as shown in table given below. Average electricity consumption per day, per month, per year and in full life of building is calculated. Average consumption per day has taken half of total consumption per day. Calorific value of electricity is 2.77 MJ/Kwh.

TABLE VIVI OPERATIONAL EMBODIED ENERGY

Sr. No	Type of Equipment	Numbers	Power(Watts)	Total power(Watts)	Consumption per day(Watts)
1	Tube lights	10	40	400	1600
2	Fan	4	75	300	3000
3	Television	2	150	300	1500
4	LED	14	10	140	280
5	Switches	20	1000	20000	2000
6	Refrigerator	1	200	200	4800
7	Air conditioner	2	3000	6000	6000
8	Heater	2	1000	2000	4000
9	Washing Machine	1	500	500	250
10	Oven	1	1000	1000	500
	Total				23.930 Kwh
Average consumption per day= 12 Kwh					
Average consumption per month= 360 Kwh					
Average consumption per year= 4320 Kwh					
Average consumption in life of building= 324000 Kwh					
Embodied energy= 324000*2.77= 897480 MJ					

V. ENERGY EFFICIENT ALTERNATIVE MATERIALS

A. Fly Ash Bricks And Fired Bricks

Bricks are masonry units composed of inorganic non-metallic material and are widely used as building components all over the world. By comparison of the embodied energies, fly ash bricks are best alternative for fired bricks. Fly ash bricks are cheaper than fired bricks by 20%. Fly ash bricks contain fly ash, sand/stone dust and OPC. These bricks are stronger and lighter than fired bricks so that it reduces the dead load on the structural members. 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 materials used for making bricks.

Embodied energy: Calorific value of diesel is 38.08 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 0.08) + (0.06x 38.08) = 2.5 MJ

TABLE VIIVII

COMPARISON OF EMBODIED ENERGY BETWEEN FLY ASH BRICKS AND CLAY BRICKS FOR 10 CUM

Type of brick	Quantity	Type of energy	Embodied energy	Total embodied energy
Fired brick	5000	Coal	4.55 MJ/Brick	24050
Fly ash brick	3450	Electricity	2.5 MJ/Brick	8798
Total energy saving per 10 Cum= 63.41%				

B. Ready Mix Concrete And Site Mix Concrete

RMC is an advanced technology of concrete mixing contains high degree of mechanization and automation. RMC plant consists of silos and bins for cement and aggregate storage respectively. Entire production system is computerized so that high efficiency mixing is possible. Quality of ready mix concrete is better than site mix concrete. RMC is preferred over site mix because of precision of mixture and reduces work site confusion. Concrete is mixed in factory and then transported to site by means of truck. Electricity used for making concrete. Approximately 1 kWh electricity used for making ½ cum of concrete. And for site mixing diesel is used for making concrete and approximately 5lit of diesel is required per100 bags of cement.

TABLE VIIIX

COMPARISON OF EMBODIED ENERGY BETWEEN SITE MIX CONCRETE AND RMC FOR 10 CUM

Method of mixing	Quantity	Type of energy	Energy required	Total energy
Site mixing	10 Cum	Diesel	4 Lit	152.32 MJ
RMC	10 Cum	Electricity	20 kWh	55.4 MJ
Total energy saving per 10 Cum= 63%				

C. River Sand And Crushed Sand

In future it is very much important to find out substitute to river sand. Over exploration of river sand affects the environment. Crushed sand is best alternative for river sand. Crushed Sand is a fine aggregate that is produced by crushing huge boulders and rocks by electrical energy. Crushed sand is also known as M-Sand or manufactured sand. Nowadays, all major building construction are done using crushed sand. Approximately 8 kWh electricity required for making 1Cum of crushed sand.

TABLE X

COMPARISON OF EMBODIED ENERGY BETWEEN RIVER SAND AND CRUSHED SAND FOR 1 CUM

Type of sand	Quantity	Type of energy	Energy required	Total energy
River sand	1 Cum	Diesel	31.31 MJ/Cum	31.31 MJ/Cum
Crushed sand	1 Cum	Electricity	22.16 MJ/Cum	22.16 MJ/Cum
Total energy saving per 10 Cum= 40.60%				

D. Filler slab and Conventional Slab

Conventional slab consists of compression zone and tension zone and that zone consists of concrete and steel respectively, so that in filler slab quantity of concrete from tension zone is reduced except concrete required for holding steel reinforcement together. Filler slab is an innovative, cost effective and environment friendly. Filler slab is constructed without compromising on the quality and life of structure. In filler slab filler material is placed instead of concrete portions in tension zone of slab. Bricks, tiles, cellular concrete blocks are used as a filler material. Approximate 10% of cost and 19% of concrete saved as compared to conventional slab.

TABLE XIX
COMPARISON OF EMBODIED ENERGY BETWEEN CONVENTIONAL SLAB AND FILLER SLAB FOR 10 CUM

Material	Conventional slab		Filler slab	
	Quantity	EE(MJ)	Quantity	EE(MJ)
Cement	80 bags	16800	72 bags	15120
Sand	4.14 Cum	165	3.675 Cum	138
Aggregate	8.28 Cum	238	7.35 Cum	211
Steel	785 Kg	1814	698 Kg	1613
Total EE		19017		17082
Total energy saving per 10 Cum= 10.17%				

VI. CONCLUSION

The research paper gives out the calculations to carry out the total embodied energy of a residential building. The total embodied energy of a residential building consists of material embodied energy, transportation embodied energy, assembly embodied energy & operational embodied energy. Construction materials like bricks, cement, sand, steel and construction of various structural elements are included in material embodied energy. While the transportation embodied energy is the energy consumed to transport a product from manufacturing plant to construction site. Onsite construction work of residential building by using various energy sources is the assembly embodied energy & the energy used in buildings during their operational phase is referred as operational energy. This paper gives idea about conservation of energy by use of energy efficient materials. A conclusion can be obtained from the dissertation work that:

A. In RCC structures, materials like Cement, Steel, Bricks and Sand contributes majorly to the total energy consumption.
B. The paper aims to minimize and replace the conventional high energy materials like bricks, cement, steel & sand with local and cheaper alternatives like fly ash bricks, RMC, filler slab & crushed sand which lead in reduction of the embodied energy in buildings.
C. Bricks and aggregates consume less transport energy than the other materials like cement, sand & steel as these materials are locally available materials & other materials are situated away from the site.
D. Steel and cement consume more manufacturing energy due to transportation of raw materials which is not available near the manufacturing plant.
E. By use of filler slab technique 10.71% energy may be saved than the conventional slab.
F. The use of alternative building material like fly ash bricks for masonry construction instead of conventional fired bricks reduces the energy by 63.40%
G. Use of ready mix concrete reduces 63% of energy consumption on site, which also gives the maximum strength than conventional method of concreting.
H. The use of crushed sand instead of river sand causes saving of energy by 40.60%
I. Proper site selection, building orientation & use of eco friendly materials plays an important role in extracting maximum benefits from natural resources.

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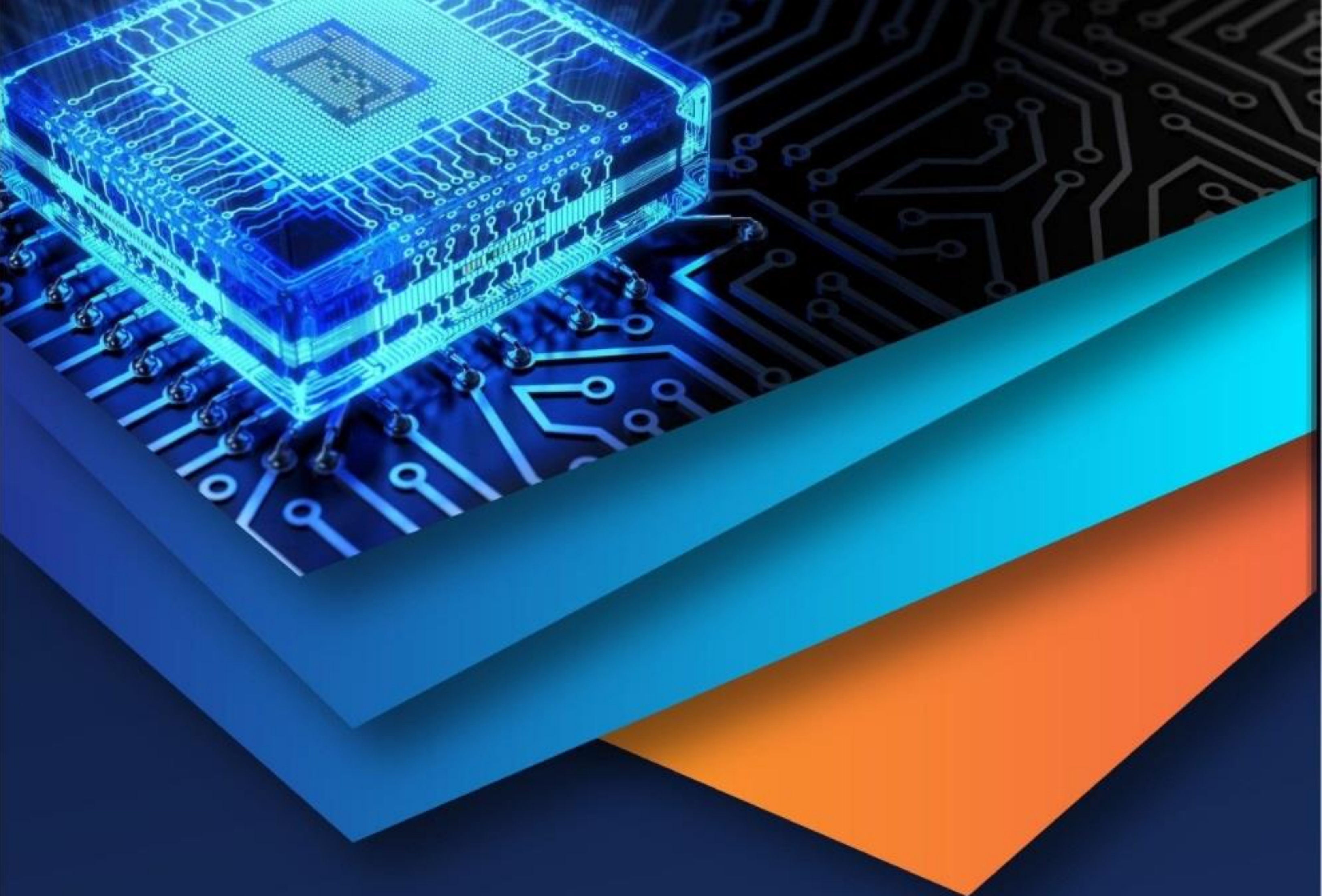

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