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LIFE CYCLE ASSESSMENT OF CONSTRUCTION MATERIALS: A SUSTAINABLE DEVELOPMENT APPROACH

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Abstract

The progress of this study is presented on the design and implementation of technology for sustainable development of buildings using life cycle assessment (LCA). The paper summarizes the significance of life cycle assessment (LCA) for sustainable construction of new and existing buildings. The work is conducted in various parts, the first part being the theory and methodology of sustainable development using LCA. A flexible design and framework were developed to measure the quantity of energy used in different stages of building construction. The second path includes the study on embodied energy. Out of the three major stages of LCA Study, the embodied energy of building materials is the most important part to be focused because it contains around 30% – 35% of total building energy and not visible. The other stages include the operational and end of life energy of building. The study explains the theory including its importance and its impact on buildings life cycle. The methodology was developed through two case studies on “Doug Mitchell Thunderbird Building” & “Richmond Olympic Oval Building” in Canada, which was done to measure the embodied energy used during the construction of these two buildings with proper impact assessments. Another part of the study discusses about the construction material causing the most impact in the environment and finding alternative use to reduce its effect. Low energy cement: Alkali-Activated Cement (AAC) comprises of ground granulated blast furnace slag (GGBFS), soda ash and limestone, are used in some parts of the world. This might lead our modern construction industry to different direction. Like AACs, different kind of low carbon cement is practice widely in some parts of the world. The current study shows that there is an increase of public awareness of environmental problems due to building construction. Therefore, LCA and embodied energy study is becoming very common, helping future building constructions for sustainable development.

Index Terms- embodied energy, fly ash, ground granulated blast furnace slag, high performance building, life cycle assessment, Sustainable development, recycled materials.

1. INTRODUCTION

Embodied energy is defined as the total energy consumed through the product life cycle. Initial embodied energy represents the energy used for the extraction of raw materials (mining), transportation to factory, processing and making, moving to site, and building. According to Cole [1], *embodied energy* is generally measured in MJ/kg, where a mega joule (MJ) is equal to 0.95 kBtu or 0.28 kWh.

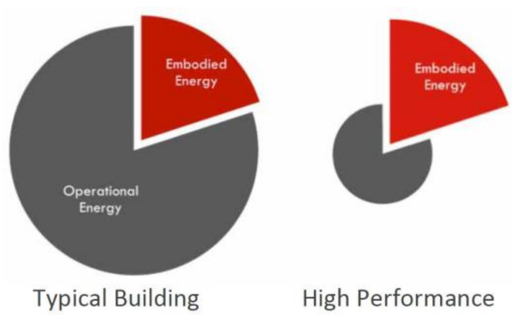

Figure 1: Embodied energy in typical and high-performance building

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Embodied energy measurement is a part of LCA. Buildings embodied energy is the energy which is consumed by all the activities associated with the production of the building, consisting of both direct and indirect components [2]. Direct energy: Building assembly, and indirect energy: embodied energy in building materials. Energy in the building is consumed in the past, being consume now and will continue to consume in future (Canadian architect; G. Hammond, 2008). If the energy consumed in the past is called *'Sunk energy'*, for a building ready for construction but not build, the 'Sunk energy' will be zero. Similarly, for a building at the end of buildings life, ready to get demolished, got 'Sunk energy'. In accumulation to the embodied energy, at some point of time during the production of building materials, it releases carbon dioxide, majorly due to the use of fossil fuels and carbonaceous materials [1]. Hence, they are directly relevant to the embodied energy of the building and being discussed below.

The embodied energy may include: (a) energy used for the transportation of the material to the building site, (b) energy used in manufacturing of the products associated with building construction. (c) The upstream energy used in making the materials such as factory lighting, office lighting, etc. (d) energy used in maintenance of factory machines that makes construction materials. (e) embodied energy in roads, drains, water and energy supply during construction, (f) materials used to construct building shell and complete building including bathroom, kitchen fittings, driveways, outdoor plays, etc., (g) about 40% of all extracted materials are used in construction sector [1].

2. IMPORTANCE OF EMBODIED ENERGY

The Embodied energy of the building is very important factor because it is an essential and inevitable part of building construction. Due to higher efficiency of green buildings and low energy houses, the implication of embodied energy is increased. There are possibilities that if the operational energy is reduced, then the embodied energy is increased. Through proper selection of building product from the construction will reduce the embodied energy of the building. For example: to increase the insulation of external wall of the building, proper insulation material is used which results more embodied energy. Therefore, according to a Canadian architect, embodied energy is increased to reduce operational energy.

The life cycle energy of the building contains operational, embodied and end of life energy. Therefore, the reduction of embodied energy might increase its operational energy and vice versa. The operational energy depends on the life of the building but embodied and end of life energy are free from this. The embodied energy and end of life energy are fixed and does not depend on the life of the building, whereas, operational energy can vary a lot depending on buildings life [3].

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TABLE 1

DIFFERENCE IN EMBODIED ENERGY USING RECYCLED MATERIALS

Embodied energy	Embodied Energy (MJ/kg)	Embodied carbon kg CO_2 (e/kg)
Aluminium(100%virgin)	218	12.79
Aluminium (33% recycle)	29	1.81
Steel (100%virgin)	35.4	2.89
Steel (39%recycle)	25.3	1.95

2.1 Reduction of Embodied Energy

The required energy in the initial process of building construction, which include mining, manufacturing, processing, transportation, etc. uses a considerable amount of energy which plays a big role in the environmental impact of construction material. Hence, Gian Andrea Blengini [4] showed that the majoring of the impact occurs during the initial phase of the construction.

The embodied energy in any building construction ranges from 20 – 35% of total buildings energy consumption. Therefore, it is very important to make embodied energy as low as possible. The embodied energy of a building also continues throughout the whole life of the building, sometime any building product with higher embodied energy creates less operational energy. For example; a material with very long life span like aluminum has very high embodied energy given by B. V. Venkatrama Reddy, 2003 [5] in 2011. It states that, if the embodied energy of the building increases, then sometimes the operational energy will also decrease and vice versa. Therefore, the embodied energy of the building material is also important.

2.2 Previous Case Studies

Studies on substance flow analysis imitation traditionally been used to record the manufacture, use, and consumption of materials. For climate system analysis economic inlet and outlet modelling have been in application, with a primary profit living the capability to estimate direct and indirect economic and climatic effect across the whole supply chain of production in an economy. They combine these two types of representation to create a mixed-unit input-output model and it’s capable to better track economic arrangement of material flows all over the abridgement associated with changes in production. A 13 by 13 economic input-output direct requirements matrix developed by the U.S. Bureau of Economic U.S. Bureau of Economic Analysis is expended along substantial discharge data derived from those published by the U.S.

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Geological Survey in the formulation of illustrative mixed-unit input-output models for lead and cadmium. The particular figure provides the basic prospects of material flow and input-output models. The total substance tracking through entire supply chains in response for any monetary or substances demand, this study identify A different-unit input-output representation with economic transactions and flows of lead and cadmium for the U.S. Their intent is to present an MUIO representation made by using substances flow data uploaded by the U.S. Geological Survey (USGS) and dollar transactions data from the U.S. Bureau of Economic Analysis (BEA) monetary and to explore its usefulness for environmental life-cycle analysis.

Manish K. Dixit and others [2] demonstrated that buildings absorbed a huge amount of energy from the time of life cycle stages of construction work, use and dismasting. Normally the life cycle related energy is contained in two components: embodied and operational energy form. Presently materialized energy is suddenly developed for the purpose of building material making, on-site delivery, construction, maintenance, renovation and final demolition. Those operational energies are consumed at the time of operating the buildings. According to previous studies, embodied energy have significantly increased inherent in buildings and have developed relationship to emission rate of carbon. Lot of database on embodied energy databases suffer from the problems of variation and incomparability along with unclear interpretations of embodied energy parameters. Previous research studies either followed the norms of international Life Cycle Assessment (LCA) standards or did not mention.

T.Y. Chen, ET. al. [6] demonstrated that sustainable treatments of construction and demolition material have become an increasingly urgent in our surrounding, environmental, and economic point of view in worldwide. Based on a filter of 370 articles which told about construction and demolition waste management, that review-based study adopted a science mapping technic to calculating the recent decade’s construction and demolition waste management programme. With the help of a three-step workflow structure of bibliometric literature search, sociometric analysis, and qualitative discussion, that study point out the most influential journals, scholars, articles, and countries that have been active and authoritative in the construction and demolish material management programme since 2009.It was found some results and indicate that Construction and demolition (C&D) material refer to a mixture of surplus materials generated from construction, renovation, and demolition activities including site clearance, roadwork, and dismasting C&D wastes may consist of different kind of incoming sources such as asphalt, concrete, and wood as predicted by Poulakis et al. [7]. C&D wastes account for 30% to 40% of the total solid wastes.

3. LIFE CYCLE IMPACT OF EMBODIED ENERGY

As already explained, the embodied energy of a building id the energy spent on extraction, manufacturing, and construction of building itself, including transportation of materials on site. The following categories impacting embodied energy are explained in detail; use of recycled materials, carbon intensity and energy use and using low carbon supply chain.

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3.1 Use of Recycled Materials

To make any item, energy is, as a matter of first important thing required for the extraction of materials. This implies that, if an item is created out of existing materials, no raw materials are required and the energy is 'saved'. This could be shown with an example that the energy would have used to transform an Aluminium window. Aluminium is for the most part connected with very high amount of embodied energy. As shown in the table below, use of recycled materials reduces a lot of embodied energy.

3.2 Carbon Intensity of Energy Supplies

Energy is majorly generated from fossil fuels and it produces a huge number of carbon products than biomass. Energy is also generated by the use of alternate sources of energy like solar power, wind and hydro power. By the use of alternative sources of energy, there is no carbon emission and is highly sustainable. By using the example of aluminium again, using this energy while making aluminium frames can save a huge amount of embodied energy. But there kind of energy are not readily available anywhere and production process is sometimes difficult and complicated.

The generation of electricity in recent days are changing rapidly. There is an Implementation of '20:20:20' initiative which aims to generate 20% of electricity from renewable sources by 2020. Applying this method will reduce the carbon emission formed while producing electricity.

In recent figuring, embodied energy and carbon could be treated to a degree correspondingly, when utilized as sustainability indicators. On the other hand, as the power of carbon and high temperature distribution reduces, the attention of centre will change to energy in carbon, as opposed to embodied energy. It is important to find maximum ways

to create sustainable ways to produce heat energy and electricity. This will maintain social and economic sustainability in building material production. A definitive point is, obviously, to help to accomplish 2020/2050 emission decrease targets.

3.3 Low Carbon Supply Chains

There is no use of spending low embodied energy products in the building construction, if the site is very far and it has to travel long distance to reach its location. For example, using cement from local industry is much cheaper as compared to buying the less embodied energy cement blocks china. It uses travelling cost and more carbon dioxide emission resulting major impact to the environment.

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TABLE 2

MEANS OF TRANSPORT

Means of transport Average	Road	Rail	Shipping
CO_2 emission of building materials(kg/tkm)	0.32	0.04	0.01

4. ENERGY OF MATERIALS OR ELEMENTS

The four focal building components that should be measured in the materialized energy study of building are the envelope, structure, inside part and finishes, and building service system. The energy embodies in steel and aluminium, are the first two largest energy demand amongst all material embodied energy. These may account for more than 35% of the total embodied energy used in residential buildings. Energy consumption for the steel and reinforced construction of multi-storeyed family house is 8 to 10 GJ per meter square, where for wooden house is 3 GJ per meter square. Wooden houses score more than other types of construction in relations of energy requirement and carbon dioxide requirement.

4.1 Energy in Building Materials

It is observed that around 9730 million kWh per year of energy is used in the production of UK construction materials during 1980s. Similarly, huge amount of energy is consumed worldwide. As given by B. V. Venkatrama Reddy [5], the following list of materials and assumed embodied energy content are: **Aggregates** - low embodied energy; **Cement** - moderate embodied energy; **Brick and clay products** - moderate embodied energy; **Wood** - moderate embodied energy (depending on source); **Glass** - relatively high embodied energy; **Steel** - relatively high embodied energy and **Plaster and plasterboard** - moderate embodied energy. It can be clearly observed that most of the materials have low embodied energy as compared to cement, glass and steel. Hence, the energy in building materials is explained below as given by G. F. Menzies [8].

4.2 Basic Building Materials

Portland cement symbolizes one of the major building materials consumed in bulk numbers for construction. There are about 2.8 billion tons of Portland cement used in building construction globally, and due to its 100% carbon dioxide production ratio, it leads to a production of 2.8 tons of carbon dioxide into the atmosphere. This results about 5% of global carbon dioxide release only because of cement production. Coal is used in the rotary kilns and for crushing and grinding the clinker for making cements. Sometimes, cement is made by using both dry and wet process. Wet process used in former cement

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plants leads to an energy intake of 7.5 MJ/kg of cement, whereas modern plants using pre calcination and dry process which eat 4.2 MJ/kg of cement. Overall is 5.85 MJ/kg.

4.2.1 Energy in building materials

Lime-Pozzolana (LP) cement is regarded as an effective alternative material to Portland cement. Lime –Pozzolana can be implemented for secondary applications such as masonry mortar, plastering, base/sub-base for flooring, etc. A typical LP is assumed to contain 30% lime, 60% pozzolana and 10% calcined gypsum. LP cement possess an energy content of 2.33 MJ/kg.

TABLE 3

ENERGY OF BUILDING MATERIAL

Type of material	Thermal energy(MJ/kg)
Cement	5.85
Lime	5.63
LP	2.33
Steel	42.0
Aluminium	236.8
Glass	25.8

(A.) Masonry Materials

Masonry walls contain one of the major energy eating elements of the building. There is a variety of materials which are used for the construction of masonry walls. Five types of building materials such as stone, burnt clay brick, soil-cement block, hollow concrete block and steam cured mud block are widely used.

(B.) Stone block

Generally, manual labour is employed in bulk for the sizing of stones and detonators are used for bigger blocks. Hence, hardly any energy is used in making these elements. Some energy is used for transportation.

(C.) Burnt clay bricks

These are widely produced in the world. About 70 billion bricks are produced annually only in India. Coal cinder and firewood are the most commonly used fuels for making bricks, which takes around 4.25 MJ of energy per brick.

(D.) Hollow concrete block

These are light weight/low density blocks very frequently used in the construction of non-load bearing filler walls. The basic arrangement of the blocks consists of cement, sand and coarse aggregates. Block energy consists of the energy used for making its primary materials separately.

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(E.) Soil-cement block

These are produced by pressing a wetted soil–cement mixture into a solid block using a machine and then cured. They contain 6 to 8 percent of cement and consist of 2.75–3.75 MJ of energy per block.

(F.) Steam cured mud block

These are lime stabilised blocks using extensive and high clay soils. They are made by mixing appropriate amount of lime, clayey soil and sand and then pressing into a block of convenient size. The blocks made in this manner are cured in a steam chamber at about 80^0C for 10–12 hours. Total energy required will be about 6.70 MJ per block.

The following points are clear from the data given in the table:

1. There is no thermal energy consume while making stone blocks, while maximum amount of energy is consumed in making burnt clay bricks.

2. The most efficient cement block is the soil cement block having 6% of cement it consumes only 23.5% of energy consumed by burnt clay brick.

3. Hollow concrete block and soil cement block are very similar. Both with 7 to 8% cement have identical embodied energy of 30% burnt clay brick energy.

4. 60% of burnt clay brick energy is consumed while making Steam cured mud blocks. (B. V. Venkatrama Reddy, 2003)

TABLE 4

ENERGY IN MASONRY MATERIALS (B. V. VENKATRAMA REDDY, 2003)

Type of material	Size(mm)	Energy in one Bricks/Blocks (MJ)	Energy per brick Equivalent (MJ)	(Block Energy) (brick energy)%
Stone block	180x180x180	0	0	0
Burnt clay brick	230x105x70	4.25	4.25	100
Soil cement block	230x190x100 230x190x100	2.60 (6 %cement) 3.50 (8 %cement)	1.00 1.35	23.5 31.7
Hollow concrete block	400x200x200 400x200x200	12.30 (7 %cement) 15.00 (10 %cement)	1.32 1.62	31.2 38.1
Steam cured block	230x190x100	6.70 (10 %lime)	2.58	60.6

Note- From "Embodied energy of common and alternative building materials and technologies. *Department of Civil Engineering, Indian Institute of Science, Bangalore* (Energy and buildings)" by B. V. Venkatrama Reddy and K. S. J. (2003).

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4.2.2 Energy in Building Types

Every building is different and different types of building have different kind of embodied energy in it. In general, if the building is more high-tech, then the embodied energy of that building will be maximum than other structures. It is seen that the building made from timber structures has lower embodied energy than other structures. It is also seen that the flat system buildings have more embodied energy which include heavy concrete structures and deep steel and concrete foundations, which is not there while making the structure with timber. Hence, embodied energy of different types of building is shown below.

TABLE 5

ENERGY IN DIFFERENT BUILDING TYPES

Type of Building	**Embodied Energy**		**Embodied CO_2 (Kk CO_2/mm^2**
	Delivered (kWh/m^2)	Primary (kWh/m^2)	
House	140-280	280-550	500-1000
Flat	125-220	250-360	800-1200
Office	140-280	280-500	500-1000

5. MODEL OF EMBODIED ENERGY ANALYSIS

Chen [6] suggested an equation for calculating the embodied energy of building materials and hence it is mentioned below:

The total embodied energy measured in the analysis includes the energy used in the production, transportation, installation, and end of the building materials and its components during the initial stage of the production, and also for the renovation of the building. It can be expressed as:

$$E_e = E_m + E_t + E_p \qquad (1)$$

Where, the following symbols bear respective designations

E = Energy used

e = Embodied energy

m = energy used form manufacturing of building substance and element to and from the building site during construct, renovation and demolishing the building.

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p = energy used in job like crane lifting and settle of soil, during the production and demolition of buildings.

The energy used in manufacturing the building materials and components may be intended using:

$$E_m = \sum_{j=1}^{k} (1 + \lambda_j)\ \mu_j\ [\sum_{i=1}^{n} (q_{i,j} e_{i,j}) \qquad (2)$$

Where,

k = digit of building materials and elements

$q_{i,j}$ = Quantity of building material j imported from country i (kg).

$e_{i,j}$ = energy required for making the building substance j in country i (MJ/kg).

n= number of countries from where construction materials j is imported.

λ_j= Factor for waste of the materials j during the life span of the buildings.

μ_j= is the substitution for building material j during the lifespan of a building [$\mu_j \geq 1$ and (μ_j-1) represent a factor for the recurring embodied energy of building materials j]

Sometimes, accidents like damaged windows and doors, etc effect during the lifespan of buildings, while other things like walls, ceilings and floor finishes may need to be completely replaced each time. Therefore, work involving less than 100% replacement is considered to be maintenance and the replacement factor, and it is computed by:

$$\mu_j = \frac{L_b}{l_j}$$

(3)

For full replacement,

Where,

L_b = Lifetime of the building

l_j = average lifetime of building materials and contents j.

| | = Mathematical operator for finding the least integer which is greater than or equal to the number itself.

Energy used in convey the building material and components from the building site description for a large percentage of embodied energy. It may be computed by:

$$E_t = \sum_{j=1}^{k} (1 + \lambda_j)\ \mu_j\, Q_j (\bar{e}_{t,j} + e_d)$$

(4)

Where,

E_t = energy required for conveying of the building materials and component (MJ/ (kg·km))

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Q_j =amount of building material j (kg)

e_d = energy used in bring down buildings and transporting the pull down building constituent from building site to landfill.

Subscript t= transportation

e^{-} = average energy use for moving the materials to the construction site (MJ/kg), which may be:

$$e^{-}_{t,j} = \sum_{j=1}^{n} \frac{q_{i,j}}{Q_j} \left[\sum_l e_{t,l\, d_l} \right]$$

(5)

Where,

$q_{i,j}$ is the amount of building material or component j imported from country i

$e_{t,l}$ is the energy use for shifting of building materials by means of conveyance l (MJ/(kg·km))

d_l is the transportation distance by the conveyance *l* (km).

$$E_p = \sum_{j=1}^{k} Q_{p,j\ e_{p,j}}$$

(6)

$Q_{p,j}$ is the amount of building material *j* dealt with in a process during producing and demolishing the building (kg, m^3 or MJ/m^2),

$e_{p,j}$ is the energy intensity required for this process and building material *j* (MJ/kg, MJ/m^3 or MJ/m^2 usable floor area).

6. CONCLUSION

The current study has drawn the importance of Embodied energy in LCA, hence, the calculation of Embodied energy of building materials is very important because it is invisible and contains about 30 to 35% of total building energy. Numerous studies are commended for future work, especially for finding ways to reduce embodied energy in concrete. The study of Alkali-Activated Cement (AAC) can bring some change to future construction. The study is not 100 percent successful but with the growth of technology, the study should be extended in different level by working on small projects with proper research & development (R&D). Previous studies should be measured and learned carefully to modify the ways for proper execution. The cement made from its R&D can be initially used in labs and for field testing in various applications like making mortar, ready-mix concrete (RMC), pre-cast concrete and cement blocks. The benefit of this study can also be used in sustainable design of buildings. For future work, the author assumes to concentrate on the practical application of AAC or similar product, to reduce the carbon dioxide level and embodied energy in concrete. This will eventually encourage developing and developed nation for sustainable construction.

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