

Embodied Energy Audit of Residential Building

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Abstract— Embodied energy refers to the total amount of energy used in production of a material and this helps in choice of materials and construction techniques, to maximize the energy efficiency of a building during its operation. The embodied energy in products and energy conservation are the environmental characteristics included in eco-labelling schemes. Embodied energy in buildings and their constituent materials and components can be used as an important criterion in green building rating systems. This paper explores the impact of different building materials on the embodied energy of the building structure.

Key words: Embodied energy, Buildings, Cement, Steel and Brick

I. INTRODUCTION

India is developing country with amazing rate of economic development, in recent decade the rate of economic growth has been dramatic and is set in one of fastest developing economics in the world. Increasing urbanization has led to pressure on urban infrastructure and deteriorating services delivery in urban areas is worrisome trend. In

India building sector is growing at rapid pace. Increasing urbanization and industrialization has given boost to construction industry and number of bungalows, apartments, commercials complexes, skyscrapers and many other structures including industrial building, dams, and roads are being designed by architects and engineers with innovative concepts and enhanced features. However, it is observed that in many cases, environmental aspects are ignored leading to uncomfortable habitat and increased maintenance requirements causing threat to environment. The build environment has vast impact on the environment, human health and economy.

The building industry uses a significant portion of resources for the construction and remodelling of buildings. Processing technical and environmental data on building materials, components, and systems has become more important during the last few years. Sustainable building guidelines and building rating system aim is to reduce the environmental impact due to the building construction. The view of sustainability is that satisfying the needs of present generation without compromising the ability of future generation to meet their demand. The key factors in achieving the goal of sustainability are energy consumption management and pollution control (during and after building construction).

To address this problem, simulation and evaluation methods for efficient and meaningful resource use, if integrated in the planning and design process of architects and engineers, can contribute to the improvement of the environmental performance of buildings and their sustainability. Increased sensitivity towards environmental and energy problems has led to the demand for simulation and evaluation of the long term behaviour of buildings. The results of such simulations are expected to enable architects

and engineers to develop a broader, interdisciplinary understanding of the impact of their products (buildings) on the environment.

Energy is needed not only to run a building - it also takes energy to create the building products and build it. Put at its simplest, embodied energy is the energy needed to transform a product from raw materials in the ground to the final article. The embodied energy of a building is therefore the total energy required to construct it that is to win the raw materials, process and manufacture them as necessary, transport them to site and put them together. The total embodied energy is primarily divided into two parts-

A. Initial Embodied Energy:

The energy in buildings represents the energy consumed in the acquisition of raw materials, their processing, manufacturing, transportation to the site, and construction. The initial embodied energy has two components. The direct energy, that is the energy used to manufacture and transport building products to the site and to construct the building. The indirect energy is the energy use associated with processing, transporting, converting and delivering fuel and energy to its point of use.

B. Recurring Embodied Energy:

The energy in buildings represents the non-renewable energy consumed to maintain, repair, restore, refurbish or replace materials, components or systems during the life of the building.

The operating energy of the building is the amount of energy that is consumed by a building to satisfy the demand for heating, cooling, ventilation, lighting, equipment and appliances. Operating energy is convenient way to compare the energy consumption of different building system as it is independent of material used.

II. LITERATURE REVIEW

In this connection the following literature has been studied. **Bruno Lee, Marija Trcka and Jan Hansen, "Embodied energy of building materials and green building rating system- a case study for industrial hall", published in 9th international Conference on Sustainable Energy Technologies; Shanghai, China, (Aug 2010).**

Green Building Rating systems are developed to provide independent assessment standards that evaluate in a few categories about the performance and sustainability of buildings. However, same category might weight differently in each of the GBR systems, which are different in objectives. A particular system might favour certain strategies over another due to difference in weighting. This is particularly the case for industrial halls since current GBR systems are catered more for commercial buildings than for industrial halls, which pose a significantly different geometry.

This paper explores the impact of different building materials (concrete vs. steel) on the embodied energy of the

building structure, and compares that to the GBR score earned under the material category for the same structure. Through a sensitivity analysis in the calculation of embodied energy, the major source of uncertainty is identified and its effect on GBR score is discussed. This paper forms part of a project that also studies the operation energy and the demolition energy of building, which together with the embodied energy constitute the total life-cycle-energy.

Dr. Arcot Ramachandran, “Energy for Building–Improving Energy Efficiency in Construction and in the Production of Building Materials in Developing Countries”, published by United Nations Centre for Human Settlements, Nairobi 1991.

This publication examines the question of energy efficiency in building materials from the point of view of producers of building materials, building designers and builders. Producers will want to know how they can change their production processes so as to reduce energy consumption (and cost), how energy consumption can be reduced by changing the raw materials, the product mix or specification used, and how energy costs can be reduced by changing to different energy sources. This paper helps to know how to go about conducting an energy audit of their operations; how the choice of building materials affect the total embodied energy content of a building; how much energy is used in construction and how this can be minimized; how substitutions between materials might be made to save energy without sacrificing performance in other respects; and how building-materials selection affects the lifetime energy consumption of a building, including manufacture, construction, use and maintenance, and demolition.

This also helps to know how to make estimates of energy consumption for proposed buildings by techniques available.

Richard Haynes, “Embodied Energy Calculations within Life Cycle Analysis of Residential Buildings”, 2010.

The principles of Life Cycle Design provide important guide lines for the selection of building materials. Each step of the manufacturing process, from gathering raw materials, manufacturing, distribution, and installation, to ultimate reuse or disposal, is examined for its environmental impact. The evaluation of building materials’ environmental impact at each stage allows for a cost-benefit analysis over the lifetime of a building, rather than simply an accounting of initial construction cost.

In residential buildings, embodied energy represents between 30 and 100% of total life cycle energy consumption. This paper details the important contribution of embodied energy to global greenhouse gas emissions and explains in detail a comprehensive and repeatable approach to estimating the embodied energy in new developments. A case study is also presented to demonstrate outputs.

Gillian F. Menzies, “Embodied energy considerations for existing buildings”, Historic Scotland Technical Paper 13 (September 2011).

This report gives the importance of life cycle analysis in assessing the sustainability of new buildings and of maintaining, refurbishing and replacing existing buildings. Embodied energy and carbon is only one part of a building’s life cycle, but is of increasing significance.

This report, intending to support a discussion about energy and carbon assessment of existing buildings,

provides an introduction to life cycle thinking generally, before presenting considerations specifically for existing buildings.

Werner W. and Burns J, “Quantification and Optimization of Structural Embodied Energy and Carbon”, ASCE journal of construction engineering and management, Structures Congress 2012: pp. 929-940.

At this time, embodied energy and carbon impacts related to the design and construction of buildings in general, and load-bearing structures in particular, are not (yet) considered as a matter of course during the design process. Consequently, the relative magnitude of such impacts associated with fundamental structural design parameters is generally not well understood. This paper reviews some of the scientific background related to structural embodied energy and carbon and conceptually introduces two tools developed and that are aimed at quantifying and optimizing the embodied energy and carbon impacts associated with the design and construction of structural system.

III. NEED FOR ENERGY EFFICIENT BUILDING

In conventional project management, project performance is assessed in three dimensions: time, cost and quality. Today’s most important issue is knowledge of environmental emissions during the execution of construction processes. As per the various researchers, construction industry is responsible for emitting nearly 40% of global warming gases into atmosphere. So from this, the pollution caused by the construction industry is very high and needs immediate attention. So there is increasing pressure on the industry to design and construct buildings that induce minimal or no impact on the environment. In this regard, engineers need information that can enable them to make informed decisions that address environmental impacts of buildings.

When environmental impact due to construction industry is the driving force in the creation of a building, engineers and architects need additional knowledge to assist them in making decisions about the choice of building materials and the way in which they are used. This article is bringing together embodied energy values in different materials with a view to adjusting decisions made by engineers and architects that will have the effects of extending the life of a building and increasing its environmental value. “Investment in energy conservation at a margin provides a better return than investment in energy supply”.

IV. ENERGY AND BUILDING MATERIALS

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, aluminium, timber, etc. The estimates of the energy consumed in the manufacture/extraction of a few major

building materials chosen from various sources have been discussed below.

A. Cement:

The principal methods for the manufacture of the Portland cement are 1) Wet process, 2) Dry process, 3)Semi dry process. The dry process is preferred on account of very significant fuel economy. The dry process is adopted in most of the cement industries. The heat energy required per Kg of the clinker in dry process is 1.57 – 2.35 MJ/Kg while in wet process it is about 2.6 – 4.2 (MJ/Kg). The highest value of 4.2 MJ/Kg has been considered for further computations in this paper.

B. Steel:

The transportation of various raw materials like Iron ore lumps, sinters and pellets, coke and fluxes such as limestone, dolomite and the various processes like Melting, Refining, Casting, Rolling makes steel as a highly energy intensive material. The total energy in steel is estimated to be 36MJ/Kg, including transportation.

C. Brick:

The manual production of the bricks involves mainly four operations namely, Soil preparation, Moulding, Drying and Firing. The main process in which energy is consumed is firing of bricks. The amount of total coal required is about 200 kg per 1000 bricks depending upon the weather condition, quality of coal, etc. A tonne of coal gives about 12.3MJ to 13.3MJ depending upon quality of the coal generally transported from far off distances. The energy required to produce each brick inclusive of transportation comes to about 4MJ per brick.

D. Sand:

Sand Mining is a coastal activity referring to the process of the actual removal of sand from the foreshore including rivers, streams and lakes. Sand is mined from beaches and inland dunes and dredged from ocean beds and river beds. The energy required to sand excavation is 30 -40 MJ/cum depending upon depth of sand and machinery used for the excavation.

Sr. No.	Building Material	Quantity	E.E of Building Material	Total E.E of Building Material (MJ)	E.E. of Material Transport from factory to site (MJ)	Total E.E energy (MJ)
1.	Brick	8300 No.	4MJ/ brick	332000	1264.25	333264.25
2.	Sand	85 brass	38.82 MJ/cum	9345.54	7552.53	16898.07
3.	Cement	3000 bag	5.5 MJ/kg	825000	16907.52	841907.52
4.	Steel	19.27 MT	36 MJ/kg	693720	1000.43	694720.43
Total Embodied Energy of Some Building Material						1886790.23

Table 1: Embodied Energy Calculation for Different Building Material

V. REDUCING EMBODIED ENERGY AND SUSTAINABILITY OF BUILDING MATERIALS

The environmental effects and cost of standard building materials are generally assessed with a Life Cycle Assessment (LCA). LCA ties in closely with embodied energy of materials in the sense that both consider the concept of the potential environmental and energy inputs from cradle to grave, in other words from production through to use and disposal of a material. LCA is a useful tool that can be used to identify problem areas in the life cycle of a building that have the most impact on the environment. It is also useful to compare different building materials with the same function, for example steel, timber or concrete frame structure.

To reduce the embodied energy of a building over its life span architects need to understand the environmental impacts of all the aspects of a building such as the transportation costs of building materials, and the ease with which building components can be disassembled for refurbishment and recycling. Designs need to minimise energy usage by employing passive systems for heating, cooling, lighting and ventilation.

To reduce the impact of raw material extraction, it is suggested that the built environment looks into using salvaged material, maximize the recycled content of materials, use renewable resources in the extraction of the

materials, use non-toxic constituents, and minimize the environmental impact of activities such as strip mining and dredging. When avoiding high embodied energy materials care should be taken not to create differential durability in the finished product.

The location of the conversion site should be as close to the source of the raw material or to the end-user to reduce the transport expenses associated with the relocation of materials. The reduction of waste is essential and a closed-loop material use is ideal where recovered materials are the raw materials for new products.

The reduction in embodied energy and the environmental impact of material selection needs to be balanced against reducing the operating energy requirements of the building, such as the energy required for heating and cooling. For example the embodied energy in a high level of well insulated thermal mass can significantly offset the energy used for heating and cooling. Creating a healthy internal environment should also be taken into consideration in the selection of materials. The easiest way to minimize the embodied energy is to design a dwelling that is sized appropriately for the needs of the occupant. A smaller dwelling requires the use of less material; hence the overall embodied energy will be much less.

VI. CONCLUSION

The following are the conclusions drawn from the studies conducted above:

- The use of alternative building units like hollow concrete blocks for masonry construction reduces the energy consumption by 60% as compared to brick masonry.
- Materials like Cement, Steel and Bricks and Glass are the major contributors to the total energy consumption in RC buildings.
- Buildings with lesser number of storey are more energy efficient than multi-storeyed 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.
- Design for long life (at least 60 years and preferably more).
- If possible, specify a high proportion of recycled or recyclable materials.

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