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Life cycle analysis and embodied energy: A review

Abhishek R. Patil
abhiz1008@gmail.com
JSPM's Imperial College of Engineering and Research, Pune, Maharashtra

Suraj D. Shinde
sdshinde_civil@jspmicoer.edu.in
JSPM's Imperial College of Engineering and Research, Pune, Maharashtra

ABSTRACT

Buildings consume a massive amount of energy during the life cycle stages of construction, use and demolition. Total life cycle energy use in building can be classified into two components: embodied and operational energy. Embodied energy is worn in the processes of building material production, on-site delivery, construction, maintenance, renovation and final demolition. Operational energy is used up in operating the buildings. Studies have discovered the growing consequence of embodied energy characteristic in buildings and have established its relationship to carbon emissions. Present understandings of embodied energy are quite indistinct and differ widely, databases of embodied energy agonize from the problems of variation and preeminence. This paper discusses the various types of embodied energy considered in the life cycle analysis of building and various methods along with there applications and limitations in the Calculation of Embodied energy.This Paper forms Part of a project that also studies the embodied energy calculation of a building throughout its life cycle.

Keywords— *Embodied energy, Life cycle energy, Green building rating (GBR)*

1. INTRODUCTION

India is a emerging nation with amazing rate of economic growth, in recent decade the rate of economic development has been theatrical and is set to be one of fastest evolving economics in the globe. The building segment of India is on the rise at fast 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 inventive 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 construction industry uses a substantial 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 utilization 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 lead 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.

2. LIFE CYCLE ANALYSIS (LCA)

Life cycle energy analysis is a method to determine the energy used over the lifetime of product. Buildings, building materials and components consume nearly 40 percent of global energy annually in their life cycle stages, such as production and procurement of building materials, construction, use and demolition. 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.

Different phases in LCA i.e. manufacturing phase, use phase and demolition phase

The Pre-Building Phase describes the production and delivery process of a material up to, but not including, the point of installation. This includes discovering raw materials in nature as well as extracting, manufacturing, packaging, and transportation to a building site. This phase has the most potential for causing environmental damage. Understanding the environmental impacts in the pre-building phase will lead to the wise selection of building materials. Raw material procurement methods, the manufacturing process itself, and the distance from the manufacturing location to the building site all have environmental consequences. An awareness of the origins of building materials is crucial to an understanding of their collective environmental impact when expressed in the form of a building.

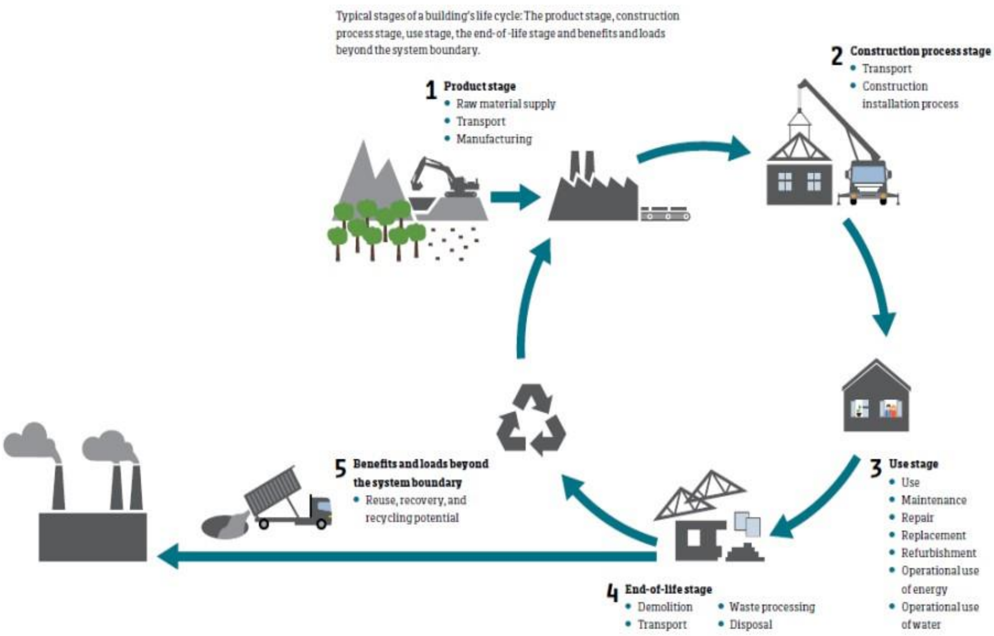

Fig. 1:Life cycle analysis

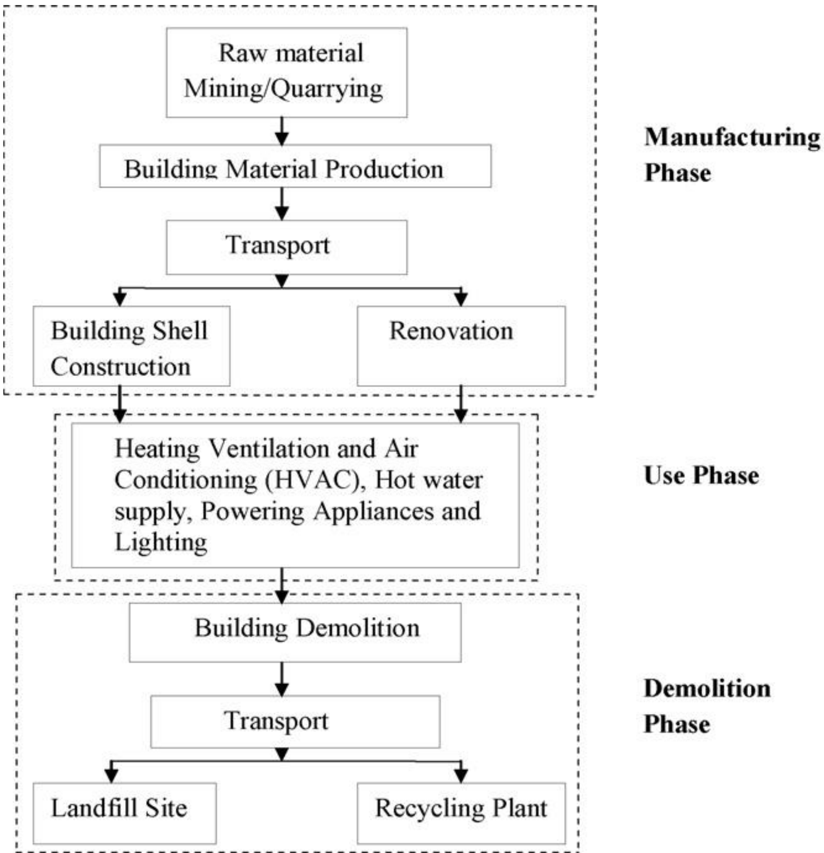

Fig. 2: Phases in life cycle analysis

The Building Phase refers to a building material's useful life. This phase begins at the point of the material's assembly into a structure, includes the maintenance and repair of the material, and extends throughout the life of the material within or as part of the building.

The Post-Building Phase refers to the building materials when their usefulness in a building has expired. At this point, a material may be reused in its entirety, have its components recycled back into other products, or be discarded. From the perspective of the designer, perhaps the least considered and least understood phase of the building life cycle occurs when the building or material's useful life has been exhausted. The demolition of buildings and disposal of the resulting waste has a high environmental cost. Degradable materials may produce toxic waste, alone or in combination with other materials. Inert materials consume increasingly scarce landfill space. The adaptive reuse of an existing structure conserves the energy that went into its materials and construction. The energy embodied in the construction of the building itself and the production of these materials will be wasted if these "resources" are not properly utilized.

Some building materials may be chosen because of their adaptability to new uses. Steel stud framing, for example, is easily reused in interior wall framing if the building occupants' needs should change and interior partitions need to be redesigned (modular office systems are also popular for this reason). Ceiling and floor systems that provide easy access to electrical and mechanical systems make adapting buildings for new uses quick and cost-effective.

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 this boundary condition is known as Cradle to Grave. It has become common practice to specify the embodied energy as Cradle to Gate, which includes all energy (in primary form) until the product leaves the factory gate. The final boundary condition is Cradle to Site, which includes all energy consumed until the product has reached the point of use (i.e. building site).

The main goal of embodied energy is to define the connection between construction materials, the process of building and after coming impact on the environment. The total embodied energy is primarily divided into two parts:

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.

$$\mathbf{EE_i = \sum m_i M_i + E_c [2]}$$

Where EE_i= initial embodied energy of building; m_i=quantity of building material (i); M_i= energy content of material (i) per unit quantity; E_c= energy used at site for the construction of building.

Recurring Embodied Energy

A large variety of materials are being used in building construction. Some of them may have a life span less than that of the building. As a result, they are replaced to rehabilitate the building. In addition to this, buildings require some regular annual maintenance. The energy incurred for such repair and replacement (rehabilitation) needs to be accounted during the entire life of the buildings. The sum of the energy embodied in the material, used in the rehabilitation and maintenance is called recurring embodied energy and can be expressed as:

$$\mathbf{EE_r = \sum m_i M_i [(L_b/L_{mi}) - 1][2]}$$

Where EE_r = recurring embodied energy of the building; L_b= life span of the building; L_{mi} = life span of the material (i)
Embodied energy largely depends on the type of the materials used, primary energy sources of energy, building techniques, and efficiency of conversion processes in making building materials and products.

Operating Energy

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.

$$\mathbf{OE = E_{OA} \times L_b [2]}$$

Where OE = operating energy in the life span of the building; E_{OA} = annual operating energy; L_b= life span of the building.

Demolition energy

At the end of buildings' service life, energy is required to demolish the building and transporting the waste material to landfill sites and/or recycling plants.

$$\mathbf{DE = E_D + E_T [2]}$$

Where DE= demolition energy; E_D = energy incurred for destruction of the building; E_T = energy used for transporting the waste materials.

Life Cycle Energy

Life cycle energy of the building is the sum of the all the energies incurred in its life cycle. It is thus expressed as

$$\mathbf{LCE = EE_i + EE_r + OE + DE[2]}$$

Studies on the life cycle energy use of the building are desirable, to evaluate strategies for reduction in energy requirement of the buildings. By performing life cycle energy analysis, the phases that have highest energy demand can be identified and targeted for improvement. Life cycle energy, if quantified in terms of primary energy can give a useful indication of the greenhouse gas emissions attributable to buildings and therefore its impact on the environment.

Life Cycle Analysis

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.[1] (Haynes, 2010)

As with every economic sector, the construction industry's purchases of materials and services sets into motion a chain of processes from raw material acquisition through manufacturing, transport, and retailing. All of these activities, in turn, have significant upstream (off-site) environmental implications, whether in terms of energy and raw resource use or emissions to air, land or water. Understanding both the usage phase and upstream impacts is essential. But to date, most potential upstream environmental costs and benefits have been unknown, invisible, and ignored.

To date, efforts to reduce the environmental impacts of buildings and construction have focused primarily on making them more energy efficient: a valid priority given the huge potential for improving a building's total life cycle environmental impacts through design initiatives targeting the usage phase. However, the usage phase is not the entire environmental story for buildings.

The paper addresses some of the practicalities and key data issues to be considered when applying life cycle assessment methods to whole buildings and building systems, and stresses the importance of ensuring comparability and equitable treatment of different materials and products through the use of accepted research protocols and transparent research processes.[2] (T. Ramesh et. al., 2010)

This paper performs a review of embodied energy and LCA and provides a survey of existing international LCA standards. Paper identify parameters causing variations in embodied energy data, and determine unresolved issues in existing international LCA standards.[3] (Dixit et. al., 2012)

This report outlines the importance of life cycle analysis (LCA) 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.

The embodied energy and carbon, associated with building construction, is the energy required and carbon emitted to construct a building (including extraction of raw materials, manufacture of building products and construction of the building.) The other stages of a building's full life cycle are operational energy and carbon (relating to the use of a building) and end-of-life energy and carbon (relating to its demolition and disposal).

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.

Nevertheless, there is a strong argument for retaining existing buildings – even if their embodied energy and carbon is of no relevance today. The use of durable, long-lasting materials – as used in many older existing buildings – can reduce refurbishment cycles, therefore requiring less energy and carbon long-term. However, existing buildings need to be affordable to occupy and maintain, and energy-efficiency upgrades might be needed to achieve this. A LCA is required to choose the best long-term upgrade solutions. For this, the building's construction type must be taken into account, as some upgrade options might be unsuitable for use in traditional buildings.

There will be an argument for replacing some existing buildings with new ones. However, this decision should not be taken lightly. A full LCA should be conducted for the replacement building and should include the end-of-life energy and carbon of the existing structure.

Decisions for energy-efficiency upgrades of existing buildings should be made on grounds of energy, carbon and financial costs, but other factors need to be considered, too. Historic buildings, for example, have a cultural and educational value, due to they can play a strong role in creating identity and have a significant economic impact for regeneration and tourism.

The sustainable use of existing buildings must be a national and global priority. Replacing a building has significant energy, carbon and financial cost implications. The retention of the existing building stock is, therefore, preferred, where its energy performance is good or can be improved to appropriate levels. Retaining existing buildings and seeking to enhance their energy performance in sensitive ways is in keeping with building conservation, sustainability and progress towards a low carbon society.[4] (Menzies, 2011)

Embodied energy

Building industry is one of the fastest growing and a major energy consuming sector in India. Needless to say, the buildings to form a link in the energy-spatial structure relationship. In context of the alarming rate of energy consumed in various sectors, building designs apart from their structural and functional requirements also need to be planned and designed for energy conservation.

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 expended in operating the buildings. Studies have revealed the growing significance of embodied energy inherent in buildings and have demonstrated its relationship to carbon emissions. Current interpretations of embodied energy are quite unclear and vary greatly, and embodied energy databases suffer from the problems of variation and incomparability.

Literature states that the current LCA standards fail to provide complete guidance and do not address some important issues. It also recommends developing a set of standards to streamline the embodied energy calculation process. This paper discusses parameters causing problems in embodied energy data and identifies unresolved issues in current LCA standards. The paper also recommends an approach to derive guidelines that could be developed into a globally accepted protocol.[3] (Dixit et. al., 2012)

Construction activities of all types involve expenditure of energy in one form or the other. In traditional construction, the source of energy was either animate energy which used the muscle power of human beings and animals or biomass energy which was used as a source of thermal energy. However, after the advent of Industrial Revolution, human society is increasingly dependent on fossil fuels for energy. Modern construction employs significant amounts of energy whether it is thermal energy or energy for transport. It is useful to recognize different categories of energy consumption in a building, and this may be listed as:
(a) Embodied energy in building materials.
(b) Energy consumption during building construction.
(c) Energy utilized for maintenance during the life span of a building.
(d) Energy spent in demolition of the building at the end of its life.

The four categories of energies listed here constitute the life cycle energy cost of a building. The energies in (*a*) and (*b*) together will constitute the energy embodied in a building. In item (*b*), one can consider energy spent in transporting materials to site, energy spent in hoisting materials/water and energy spent in concrete mixing, floor polishing etc. Item (*c*) refers to the energy spent to meet the needs of the occupant of a building. Very often, this is mostly electrical energy.

This study estimates the extent to which embodied CO_2 emissions are increased or reduced when a socioeconomic structural change occurs. Embodied CO_2 emissions were estimated by Input-Output models (I-O models) and a general Equilibrium model, and the respective results were compared. The embodied CO_2 emissions differ greatly depending on the assumptions of the total system. The embodied CO_2 emissions obtained by I-O models are much larger than those obtained by the GE (Global Energy) model. In some cases, the total CO_2 emissions increase even if less intermediate inputs are required owing to technological improvement. It is shown that taking I-O type embodied emissions alone into consideration is insufficient for the estimation of policy effects. Careful consideration is necessary to effectively reduce emissions when production and consumption are interconnected in a complex way.[6] (Kainuma et. al., 2000).

In order to reduce CO_2 emission and promoting energy efficiency in buildings through a number of measures including the Building Regulations, the Energy Efficiency Best Practice Programme and the Home Energy Conservation Act. It has also identified the importance of using materials more efficiently to reduce overall energy demand, stating that 'about 10% of national energy consumption is used in the production and transport of construction products and materials- embodied energy'.

This report:
(a) Examines the importance of embodied energy in relation to energy consumed in buildings in use.
(b) Compares embodied energy figures for a range of materials and building types.
(c) Suggests steps that Registered Social Landlords may wish to take in reducing total energy use of the homes they build and manage.
(d) Considers the importance of embodied energy in the context of life cycle environmental impact.
(e) Provides references and further reading on the subject of embodied energy. (Sustainable homes: A Guide for Registered Social Landlords).

3. METHODOLOGY TO CALCULATE ENERGY

To date, most of the focus on reducing carbon emissions from the built environment has been to manage and reduce the energy consumption from lighting, heating, ventilation and air conditioning of buildings through better design and management in use.
However, as more buildings are constructed to higher standards, they become increasingly energy efficient and the relative importance of the carbon emissions created shifts from the operational emissions (from gas and electricity and the like), to energy consumed during other life cycle stages of projects, such as the carbon emissions created in the manufacture of the materials used, their transportation, the construction activities themselves and the eventual demolition and disposal. Calculations of emissions associated with one of the stages – product manufacture – are based on the quantity of construction materials that make up a building.

The aim of this information paper is to provide practical guidance to quantity surveyors on how to calculate cradle-to-gate embodied carbon emissions associated with the projects.[7] (RICS, 2012)

This paper is focused upon identifying differing parameters that cause variation and inconsistency in embodied energy results and identifies the need to develop a protocol to standardize the embodied energy calculation process. Embodied energy analysis is an integral part of the process of LCA. The literature suggests that the results of neither embodied energy calculation nor LCA are valid and comparable. Therefore, these environmental practices can no longer fulfil their sustainability and energy efficiency goals accurately. The lack of comparability of the energy intensiveness of two building materials or products seriously hampers the process of selecting low-energy building materials and products.

The literature indicates that there is a stated need to adapt a tradition of selecting building materials that are low energy intensive. However, given the incomparable and differing embodied energy data, a decision to select a material no longer remains valid.[3] (Dixit et. al., 2012)

4. TRANSPORTATION AND ONSITE ENERGY

Assessment of building energy use is widely incorporated in building energy regulations, energy certification and standards. The majority of these assessments focus on a building's operational energy and on the indirect energy embodied in building materials. However there is limited data regarding direct embodied energy during the construction stage, while due to the increased focus on lowering operational energy the relative share of embodied energy is increasing significantly. Although this growing significance is recognized, current interpretations, quantification and analysis procedures of embodied energy throughout the whole construction process are unclear and needed.

This paper presents the results of an explorative study into energy used for onsite construction activities. A method was developed in order to catch the data needed for the quantification and analysis. Using a sample of residential building projects, this paper presents the data that was found and the statistical analysis that was used in order to investigate potential ways to assess and compare onsite energy usages of projects.[8] (Janssen, 2014)

Because of its low cost, its ease of use and relative robustness to misuse, its versatility, and its local availability, concrete is by far the most widely used building material in the world today. Intrinsically, concrete has a very low energy and carbon footprint compared to most other materials. However, the volume of Portland cement required for concrete construction makes the cement industry a large emitter of CO_2. The International Energy Agency recently proposed a global CO_2 reduction plan. This plan has three main elements: long term CO_2 targets, a sectorial approach based on the lowest cost to society, and technology roadmaps that demonstrate the means to achieve the CO_2 reductions.

5. BUILDING MATERIAL AND ENVIRONMENT

Green Building Rating (GBR) 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. A particular system might favour certain strategies over others 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 demand.[9] (Lee et. al., 2011)

Our planet is warming because of human activities affecting the environment. Climate change is caused by a number of things, and it will take an enormous amount of concerted effort to fix it. It involves thinkers, politicians, professionals, and the public. Architects and engineers will have a major role to play in resolving the associated problems. This paper explores various architectural and building technologies that are employed to achieve a low-energy built environment. The paper concludes that designers of the next generation of buildings, whether residential, commercial, or institutional, should aim for "zero energy" buildings in which there will be no need to draw energy from a region's power grid. In this approach, climate and environment are used to advantage rather than being treated as adversaries and buildings become sources of energy, like batteries. A few illustrative buildings are discussed that represent the new generation of sustainable or green buildings.[10] (M. Ali, 2008)

The paper addressed certain issues pertaining to the energy, environment, alternative building technologies and sustainable building construction. Brief history of developments in building materials is discussed. Energy consumption in manufacture and transportation of some common and alternative building materials and the implications on environment are presented. Brief details of some of the energy-efficient alternative building technologies developed by ASTRA are provided. Impacts of alternative building technologies on energy and environment are discussed. Some thoughts about utilizing industrial and mine wastes as well as recycling of building wastes for meeting the demand for buildings in a sustainable fashion have also been presented.[5] (Reddy and Jagadish, 2009)

The building and construction sector accounts for the largest share in the use of natural resources by land use and materials extraction. Worldwide, buildings are responsible for between 25% and 40% of total energy use. According to studies carried out by the Organization for Economic Cooperation and Development, the residential and commercial building sectors are responsible for approximately 30% of primary energy consumed in countries, and for about 30% of the greenhouse gas emissions of these countries.

As the world struggles to reduce energy consumption and greenhouse gas emissions, much attention is focused on making buildings operate more efficiently. However, there is another, less recognized aspect of the built environment: the embodied energy of buildings, which represents the energy consumed in construction, including the entire life cycle of materials used. Architects and structural engineers extensively perform designs of buildings with steel and reinforced concrete–materials that, to different degrees, are energy intensive. This presents an opportunity to use structural optimization techniques, which have traditionally been employed to minimize the total cost or total weight of a structure, to minimize the embodied energy. With this in mind, an analysis is carried out to determine the implications, from the point of view of cost, of optimizing a simple reinforced concrete structural member, in this case a rectangular beam of fixed moment and shear strengths, such that embodied energy is minimized. For the embodied energy and cost values assumed, results indicate a reduction on the order of 10% in embodied energy for an increase on the order of 5% in costs.[11] (Yeoa and Gabbaib, 2011)

This paper deals with the environmental resources consumed to construct tall building structures; the consumption is measured by the energy required to obtain tall building structures and is expressed in terms of cradle-to-gate embodied energy. A reference structure composed of central core (made of reinforced concrete) and rigid frames (made of either reinforced concrete or steel) is considered. The reference structure is dimensioned and detailed for buildings from 20 to 70 stories; the embodied energy of each building is then estimated (total, of the components, per net rentable area).The results show that, if some design decisions are dictated by the embodied energy, the premium for height of the embodied energy is not substantial, which proves that tall building structures can be sustainable. However, a structure with the lowest weight does not imply the lowest embodied energy. The results also prove that the embodied energy depends mainly on the flooring system, and that steel consumes more embodied energy than Reinforced Concrete. Ultimately, the embodied energy is confirmed to be a viable tool to design sustainable tall buildings, and the results presented herein may address design toward minimizing the embodied energy, which means to save environmental resources.

Tall buildings are often believed to be non-sustainable, mainly due to the large amount of materials required for the structure. The environmental resources consumed to construct a tall building structure may not be expressed just by the amount of material that is used, but also by the energy that is consumed to obtain the structure. A method to measure the energy consumption during the production of materials and construction is to use the embodied energy. This paper deals with the energy consumed to construct tall building structures and aims to address the design of tall buildings towards saving environmental resources.[12] (Foraboschi et. al., 2014)

Selection of building materials in the design process is an important factor influencing not only future functionality of the building but also environmental performance. This paper deals with the environmental analysis of two material alternatives of one conventional Slovak masonry family-house with commonly used material composition in selected structures. Environmental analysis was aimed at the calculation of embodied energy, embodied CO_2, and embodied SO_2 emissions expressed as primary energy intensity (PEI), global warming potential (GWP), and acidification potential (AP), respectively.

The objective of this paper was to analyze the embodied energy and embodied CO2 and SO2 emissions in two material alternatives of the typical masonry family house built by conventional construction techniques with the aim of the selecting the better one with potentially reduced environmental impact.[13] (Estokova and Porhincak, 2014).

"Sustainable Building Technical Manual: Green Building Practices for Design, Construction, and Operations" is intended to meet the building industry's need for a comprehensive manual of sustainable building practices. Its goal is to provide clear, easily applied guidelines and useful practices that can be readily introduced into new construction, renovation, and building operations. The manual is designed to synthesize the large volume of available information on green buildings and direct the reader to more detailed resources for further review and reference. The manual focuses on commercial-size building projects in both the public and private sectors. Building professionals who will find this manual a useful resource include landscape architects, planners, architects, interior designers, engineers, contractors, property managers, building owners and developers, product manufacturers, utility companies, building tenants, maintenance staff, and code officials.

This report was commissioned by Sustainable Homes as part of its work in promoting environmental good practice in social housing. The report has been prepared by Crane Environmental Limited.

Energy use is one of the most important environmental issues facing society. Without continuing supplies of energy we cannot maintain our current lifestyles. However, the fossil fuels (oil, gas and coal) from which we generate most of our energy are not inexhaustible, and burning them releases carbon dioxide (CO2), one of the principal "greenhouse gases" which are thought to be responsible for global warming.

6. CONCLUSION

A consent on embodied energy characterization and system boundary selection rules could be a credible research work, as it could help make embodied energy calculation guidelines. Besides, assessment of restriction impacts identified in this and other published studies on embodied energy data would be vital for embodied energy research.

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