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Life Cycle Energy and Carbon Analysis of Office Buildings in India

Shrankhla Jaiswal[1]

[1] MSc Sustainable Mega Buildings, Cardiff University, UK, correspondence email jaiswals3@cardiff.ac.uk.

Abstract
Over the course of a building's existence, it releases a significant amount of carbon dioxide (CO2) into the atmosphere due to its production, construction, to demolition. To comply with the United Nations Framework Convention on Climate Change (UNFCC 2019b, 2020) Paris Agreement's goal of restricting global temperature increase to 1.5°C above pre-industrial levels by 2050.This paper presents a study that showcases the potential for reduction in embodied energy and CO2 emissions, specifically in the construction phase, through the selection of renewable building materials. According to research findings, it has been discovered that materials have the potential to significantly decrease embodied energy by as much as 55% and CO_2 emissions by 43%.
This research aims to establish indicators that can be used to evaluate the environmental performance of materials. This paper presents a case study of a commercial building in India that was constructed using conventional methods.
Keywords: Carbon Analysis, Life Cycle Analysis, Embodied Energy, Life Cycle Inventory

1. Introduction

Buildings use 40% of the total energy consumed worldwide and produce 30% of the CO_2 emissions (Andric et al., 2020). Buildings represent a substantial portion of energy consumption in industrialized nations, with office buildings specifically contributing significantly to this demand. As the global economy increasingly shifts towards service industries, there is a corresponding increase in investments directed towards offices and various commercial buildings (Heinonen & Junnila, 2011). Therefore, it is crucial to research offices' energy and environmental impacts throughout their lifespan.

Life cycle assessments (LCA) represent a viable method for aiding decision-makers in their efforts to mitigate the environmental consequences associated with products or processes, specifically in the context of this study, buildings. Life Cycle Assessment (LCA) is a method used to measure the environmental consequences associated with the input and output flows (such as materials, energy, and emissions) of a specific product, process, or system. The International Organisation for Standardisation (ISO) has established a standardised approach, the Life Cycle Assessment (LCA) methodology. This methodology consists of four main steps, namely goal and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA), and interpretation and analysis (Gardner et al., 2020).

The economic expansion led to significant growth in various sectors, such as population, industrial processes, and real estate. India is ranked as the thirteenth highest country in terms of CO_2 emissions per capita, following Brazil. This information is depicted in Figure 1, which illustrates that India's annual emissions amount to 28,213 kilograms of CO_2 per 1000 individuals.

Figure 1 presents a comparative analysis of carbon dioxide (CO2) emissions and gross domestic product (GDP) per capita for both India and the global context, spanning the years

1990 to 2016. From an energy consumption perspective, it is noteworthy that India's average annual energy consumption in 2014 stood at a mere 0.637 tons of oil equivalent (toe) per capita, in contrast to the global average of 1.920 tons per capita. (World Bank, n.d.). That is, less than a third of the global average consumption. Finally, it is worth mentioning what is claimed in page 5 of India's NDC submitted to the United Nations Framework Convention on Climate Change (UNFCC 2019b, 2020) for the period 2021 -2030: "It may also be noted that no country in the world has been able to achieve a Human Development Index of 0.9 or more without an annual energy availability of at least 4 toes per capita" (UNFCC 2019b, 2020).

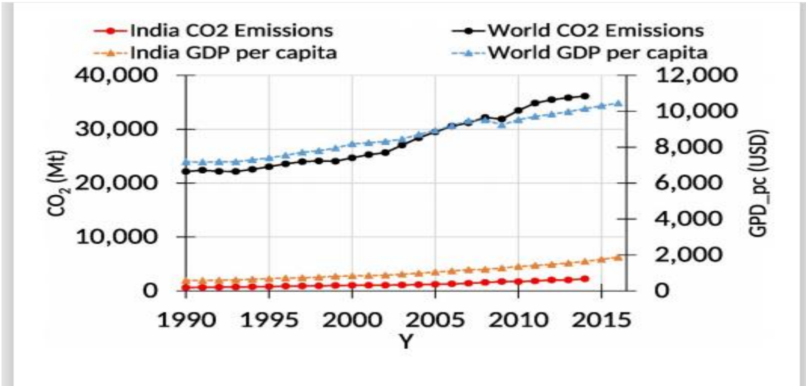

Figure 1 Comparison of CO_2 emissions and GDP per capita for India and the world

The United Nations Development Programme reported India's Human Development Index (HDI) as 0.640 in 2017. (Scope of This Report A Note on Terminology, 2020), placing it at the 130th position in the global ranking, it is evident that there remains a considerable distance for Indian authorities to traverse to enhance the quality of life for its populace. If no mitigation measures are implemented, a significant increase in India's emissions will be a consequence of the enhancement of the standard of living. among the Indian population (Ortega-Ruiz et al., 2020).

This study aims to examine the residential building construction sector in the metropolitan region of India, focusing on the past few decades. The primary focus will be on analyzing the embodied and operational energy of these buildings. use, as well as the resulting environmental pollution. The findings of this study, when compared with analyses of other building styles and the infrastructures within the district, can be used by policymakers and city planners to enhance the metropolitan area's sustainability and energy efficiency.

2. Methodology

As previously said, LCEA examines a system's overall energy consumption over its whole life cycle. Life Cycle Assessment (LCA), conversely, encompasses a collection of methodologies, tools, and information utilised for the purpose of quantifying material flows and assessing environmental impacts throughout the entire life cycle of a given product or service. The International Organisation for Standardisation (ISO) has developed internationally recognized guidelines for the implementation of a life cycle assessment, as outlined in ISO 14040 (2006). According to the United States Environmental Protection Agency (National Ambient Air Quality Standards for Particulate Matter, 2006), the process of Life Cycle Assessment (LCA) consists of four distinct stages.

These stages are as follows: (1) establishment of ranges and limits, (2) compilation of a Life Cycle Inventory (LCI), (3) estimation of impacts, and (4) interpretation of the results. The study's goal, functional unit, boundary state, assumption, and omissions are all specified in the first step.

The data collection and processing process is the next step. The products and energy used, In addition to environmental releases, such as air pollution, solid waste disposal, and wastewater discharges. are all quantified during this process. The impacts on human health and the atmosphere were assessed and inventoried in the third process. Finally, the findings are translated and integrated with the five steps to quantify the effects on one or more environmental problems (Matthews et al., 2020). The following is a list of the comprehensive discussions of each phase of this study:

Phase 1: Define the scope and parameters.

Phase 2: Inventory of the Life Cycle (LCI)

Phase 3: Evaluation of the Effects

Phase 4: Interpretation

Phase 5: Results

This process entails analysing the findings of previous phases to draw conclusions and make suggestions, which are detailed in the last part.

3. Study of Parametric

The project was completed in accordance with general architectural standards, in which the design incorporates traditional solutions for adapting the structure to extreme climatic environments, The utilization of automatic air conditioning and electrical lighting is among the notable features. The architectural design of the structure follows a common pattern observed in many buildings in India. The elevations of the structure are predominantly composed of glazed aluminum cladding, while the remaining portions of the house are adorned with a coating of marble or tiles. The architectural materials used are identical to those used in similar buildings in India. These are referred to as "traditional" construction materials.

The criteria play a big role in determining what constitutes a "conventional" material. The structure features a reinforced concrete foundation, concrete block walling, aluminum framed single glass windows, hardwood doors, marble and ceramic floor coating, chemical paintings, and internal wood treatment in PVC. are all used in the design of a residential building in India. Most of these goods are manufactured in large quantities to satisfy India's rapid growth in construction and manufacturing. This structure was not designed with sustainable solutions in mind. All the information about the energy consumed in the building can be classified into 4 groups.

1. Material energy
2. Transportation energy
3. Construction Energy
4. Embodied energy

The building is in Chennai, Tamil Nadu, India. The overall construction cost of the building and the construction were carried out by the private contractor. The Construction of the building was commenced on 7-01-2016. The period of the contract is 13 months. The total plinth area of the GF and SF is 868.00 Sq.m.

1.1. Material Energy of The Building

The material energy of the building depends upon the type of material used in the construction of the building. The total energy utilisation of the concrete and steel for the

Column, Beam, Roof, floor, foundation, and the wall is 6,22,84,597 MJ and 16354478 MJ. The Material Energy consumption for other materials and activities is 56,70,391 MJ.

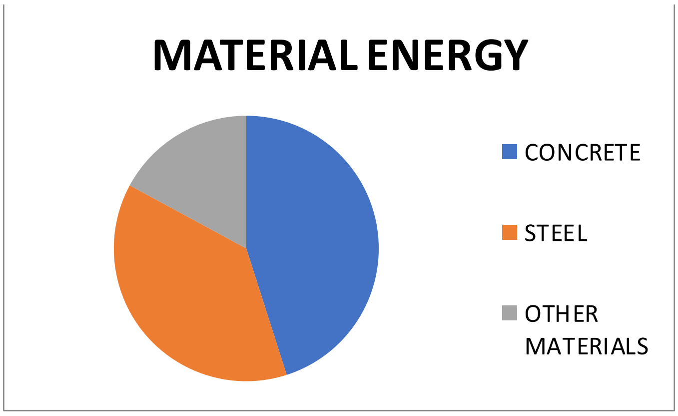

Figure 2 Material Energy Chart

From the above comparison of the materials, we can conclude that Steel and concrete are the major energy-consuming materials. Both steel and concrete constitute around 76% of the whole energy emission so to reduce the energy emission alternatives for steel and concrete should be given.

For concrete, concrete with fly ash can be provided to reduce the embodied energy of the materials. Concrete with fly ash has proven to be cost-efficient so this could have been eco-friendly and cost-friendly. The below graph compares the embodied energy and carbon of conventional concrete and concrete with fly ash.

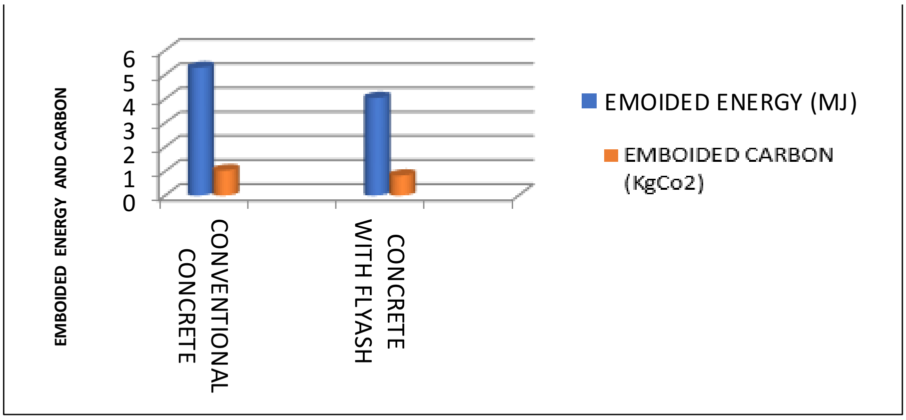

Figure 3 Embodied Energy and Carbon of Concrete

For steel, recycled steel is proven to be more efficient in controlling embodied carbon and carbon. The implementation of recycled steel in this building also showed positive results by reducing the overall embodied energy and carbon. The graph below compares the embodied energy and carbon emissions of conventional and recycled steel.

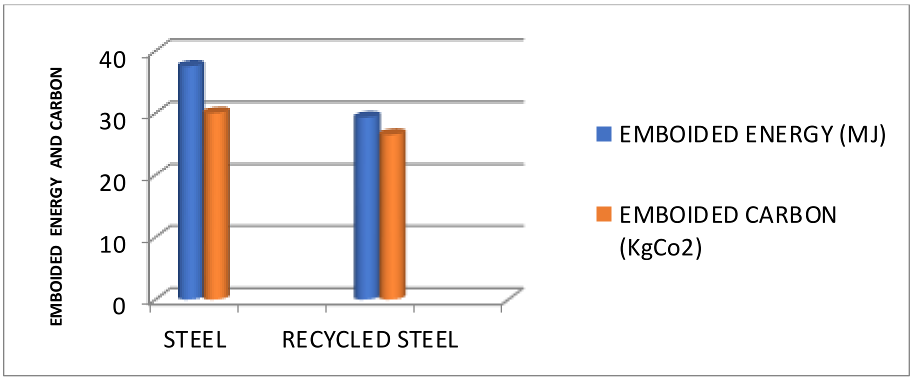

Figure 4 Embodied Energy and Carbon of Steel

1.2. Transportation Energy

Transportation energy can be analyzed based on various factors like the type of vehicle, capacity of the vehicle, mileage of the vehicle, material quantities, and distance between supplier and site. The vehicle used for transportation of the materials is Tata Ace gold with a capacity of 640 kg and a milage of 18km/l. The overall energy consumed for transportation is 1,778 MJ. The Embodied Energy and petrol/diesel/gas are calculated for round trip.

1.3. Construction Energy

Construction energy is the energy consumed by the construction equipment while constructing the house. Various construction equipment has varying hours of usage, and each piece of equipment exhibits a certain amount of energy in the process of construction energy is 514,913.1 MJ.

4. Results And Discussion

To lower the structure's embodied energy and CO2 emissions, there are 2 basic scenarios:

1. Reduce the structure's weight, i.e., utilise less of the materials used in traditional construction.
2. Use building materials that have a lower embodied energy. CO2 emissions and energy.

The conventional materials which were the reason for the excessive embodied energy and carbon were reduced by replacing them with their respective alternate materials without disturbing the structural strength and quality of the structure. The embodied energy and embodied carbon levels have been reduced by 42% and 56% by replacing the original materials with alternate materials.

1. Instead of conventional concrete, concrete with fly ash is used.
2. Steel is replaced with recycled steel (manufactured with recycled steel 20%)

As Concrete and steel contribute more to overall energy and embodied carbon value these two are replaced along with glass. Figure 4 shows the percentage difference before and after replacing the materials. The rest of the materials that cause the increase in embodied energy can be controlled but it may lead to financial problems. For example, the consumption of petrol can be reduced by manufacturing components of the building but it's not feasible due to monetary problems. So, it is important to control overall embodied energy and CO_2 emissions without much of the estimated project cost.

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