Global NEST Journal, Vol 25, No 1, pp 134-140

Life cycle energy and carbon analysis of commercial and residential buildings in India

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Received: 23/06/2022, Accepted: 08/08/2022, Available online: 24/08/2022
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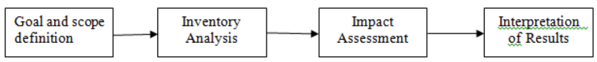
https://doi.org/10.30955/gnj.004379

Graphical abstract



Abstract

Throughout the various stages of a building's life cycle, a significant amount of CO_2 is releasedinto the atmosphere: in the production of materials and goods, the construction of the building itself, the preparation of the site, the exploitation, the repairs, the subsequent rehabilitations, and finally the final demolition. By judiciously selecting renewable building materials, it is possibleto cut embodied energy in building materials by up to 55% and CO_2 emissions by up to 43% during the construction process, according to the findings of this study. This study aims to quantify the cumulative quantity of CO_2 emissions and embodied energy that may be avoided byemploying the methodology described in the material selection process of a building's life cycle. This material selection and the bioclimatic features must be established from the onset of design.This research was undertaken as a case study on an existing high-rise residential structure in theUnited Arab Emirates, which was constructed conventionally without using any unique materials.The construction is equivalent to a hypothetical structure with the same qualities but manufactured from renewable materials.

Keywords: Embodied energy, materials, renewable, carbon analysis.

1. Introduction

Life cycle energy analysis (LCEA) is an approach in which all energy inputs to a productare accounted for, not only direct energy inputs during manufacture, but also all energy inputs needed to produce components, materials, and services needed for the manufacturing process. The building industry accounts for a large portion of India's total resource usage. The annual construction material demand in India exceeds 2 billion tones. Additionally, 20–25% of India's overall energy demand is spent on the production of building materials. Always, energy expenditure results in harmful emissions and pollution. The production and transportation of building materials contribute to negative environmental effects such as greenhouse gas (GHG) emissions, global warming, pollution, resource depletion, and biodiversity loss. India's construction industry is responsible for an estimated 30% of greenhouse gas emissions. The cement and steel sectors account for 7.5% and 6.8% of India's net GHG emissions (RezaChowdhury *et al.,* 2012; Liu *et al.,* 2020a; Manu *et al.,* 2019; Tanasiev *et al.,* 2021a). The transportation sector accounts for 8.22% of the country's total net GHG emissions. Globally, buildings account for forty percent of total energy consumption and thirty percent of total carbon dioxide emissions Buildings are one of the greatest energy consumers in industrialized nations, and office buildings account for a sizeable portion. As the global economy continues to shift toward service industries, investments in office and other commercial buildings increase. Therefore, it is essential to examine office buildings' energy and environmental effects over theirwhole life cycle (Junnila, Arpad Horvath, & Angela Acree Guggemos, 2006) (Dilip Mane, 2017; Jordan and Bleischwitz, 2020a; Wang *et al.,* 2012a; Gardner *et al.,* 2020; Lella *et al.,* 2017; Blok and Nieuwlaar, 2021; Su and Ang, 2010).

Life cycle assessments (LCA) are one strategy that can be used to aid decision makers who seek to reduce the environmental consequences of products or processes, or in the case of this study, buildings. LCA quantifies the environmental impacts of a product, process, or system based on input and output flows (e.g., materials, energy, and emissions). The International Organization for Standardization has standardized LCA methodology, which consists of four basic steps: aim and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA), and interpretation and analysis (Giordano *et al.,* 2017a; Jordan and Bleischwitz, 2020b; Hong *et al.,* 2018; Dixit *et al.,* 2013; Ameen *et al.,* 2015; Ding, 2008; Mane, 2017).

Population, industrial processes, and real estate all experienced rapid expansion because of the economic boom. As seen in Figure 1, India ranks thirteenth after Brazil in CO_2 emissionsper capita, with annual emissions of 28,213 kg CO_2 per thousand people. Figure 2 compares CO_2 emissions and per capita GDP for India and the world from 1990 to 2016. Compared to the global average of 1.920

tons of oil equivalent (toe) per capita, India's average annual energy consumption in 2014 was only 0.63 tons of oil equivalent (toe) per capita (WB, 2019b). This represents less than a third of the average global consumption. On page 5 of India's Nationally

Determined Contribution (NDC) submitted to the United Nations Framework Convention on Climate Change (UNFCCC) for the period 2021-2030, it is claimed that no country has ever achieved a Human Development Index of 0.9 or higher without an annual energy availability of at least 4 toe per capita (UNFCCC, 2019b) (Mohamad Bohari *et al.,* 2015; Kibwami and Tutesigensi, 2016; Lee, 2013; Liu *et al.,* 2020b; Tan *et al.,* 2011; Whang and Kim, 2015; Azari and Abbasabadi, 2018; Chastas *et al.,* 2017; Lolli *et al.,* 2017).

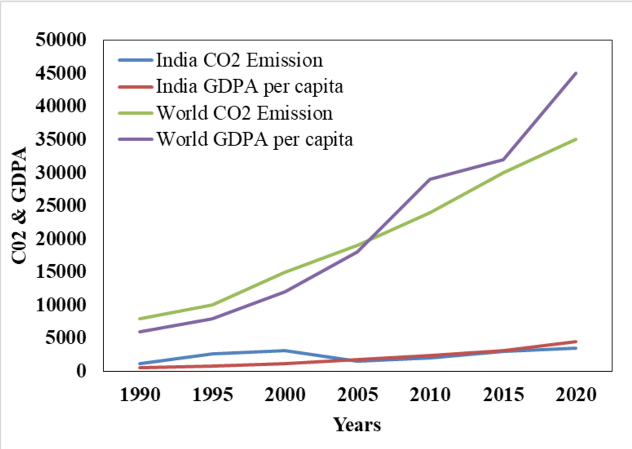


Figure 1. Comparison of CO 2 emission and GDP per capita for India and the world.

Carbon The analysis (also called CO_2 analysis or carbonate analysis) is used to determine the total carbon content or the content of different carbon fractions in a variety of sample materials. Considering that India's Human Development Index (HDI) in 2017 was 0.640 (UNDP, 2019), placing it in 130th place globally, there is still a long way to go for India's government to provide a more dignified living for its citizens (Giordano *et al.,* 2017b; Foraboschi *et al.,* 2014; Praseeda *et al.,* 2016; Lotteau *et al.,* 2017; Koezjakov *et al.,* 2018).

This study will examine the residential building construction sector in India's metropolitan area during the past several decades, analyzing the buildings' embodied and operational energy consumption and the consequent environmental pollutants (Mourão *et al.,* 2019; Cherian *et al.,* 2020; Ding and Ying, 2019; Su *et al.,* 2020). Compared to evaluations of other building types and infrastructures in the district, policymakers and city planners can use the findings of this study to improve the sustainability and energy efficiency of the metropolitan area. Further details about the project building. The elevation plan of the building is given in Figure 2. The elevation plan consists of details about the specification of floor levels. Floor plans of the buildings are given in Figure 3. Specification of each room is mentioned in the floor plan.

Figure 2. Elevation plan of the building.

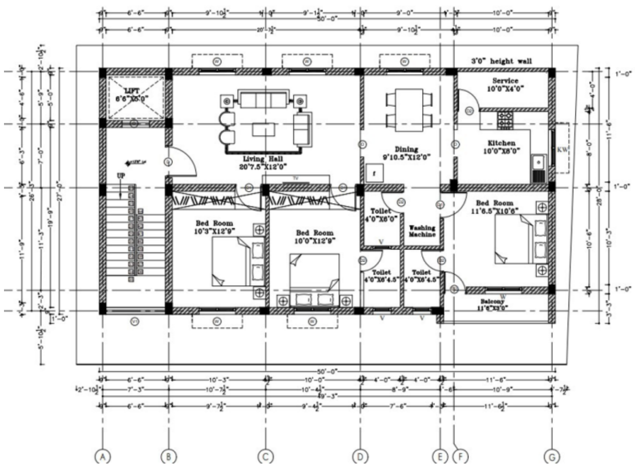


Figure 3. Floor plan of the building.

The building was constructed using Energy Conservation Building Code ECBC standardsthe building had not much environmental impact during its operational phase, and it was found by simulating the buildings energy consumption using energy plus software Design builder. Butto reduce the building's embodied energy, LCA must find the environmental impacts and providea solution to reduce it if the impact is higher.

2. Methodology

A commercial product, process, or service's entire life cycle can be examined in terms ofits environmental impact using a method known as life cycle assessment (LCA). Industrial buildings was not considered for the study because the infrastructure and elementary components. About a manufactured product, for example, environmental impacts are assessed from raw material sourcing to manufacturing, distribution, and use, and finally recycling or final disposal for materials that comprise it (the "cradle" in this case) (grave). An LCA study considers all the energy and materials needed to manufacture, process, or provide a service. As a result, LCA measures the total amount of harm human activities may cause to the environment over time. Thegoal is to collect data and improve the product's environmental profile.

Therefore, LCA seeks to compare all the environmental effects that can be assigned to a product or service through quantifying and assessing all material flows, both inputs and outputs.Use this data to improve processes, support policymaking and make informed decisions. Environmental impact is classified in LCA studies by the methodology used to measure it. The LCIA methods establish the link between each stage of the life cycle inventory and the corresponding environmental impacts. Various software and inventory databases have been usedto develop LCIA methods. LCA results may be affected by the variety and specificity of these methods. Moreover, it is important to understand the implications of LCA studies from a broader,more inclusive perspective that considers not only the environment but also human health, since important factors may be overlooked if an all-encompassing, holistic approach to environmental impact (Davies *et al.,* 2014; Himpe *et al.,* 2013; Pinky Devi and Palaniappan, 2019; Wang *et al.,* 2012b; da *et al.,* 2018; Dixit *et al.,* 2010).

Not implemented. LCA converts the corresponding resources and energy consumption into easily comprehensible impacts. For example, global warming, ozone layer depletion,eutrophication, acidification, and so on are examples of environmental impacts (Acquaye and Duffy, 2009). Categorized numerical entities, these definitions are referred to as “category indicators” in LCIA. These indicators express the severity of each impact category’s contribution to the environmental load. As depicted in the diagram, there are four distinct approaches to LCA as shown in Figure 4.

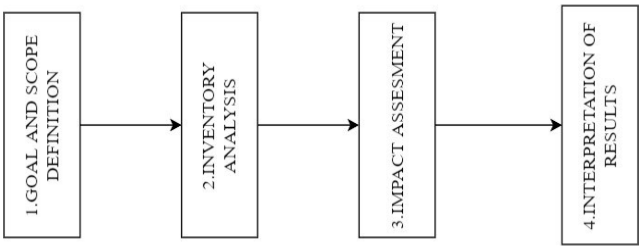


Figure 4. Flow of lifecycle assessment.

3. Data collection

The case study of building site was located in Guindy, Tamil Nādu, India. The construction of the building is 4602594 INR for a period of 13 months. The total plinth area of the building was in ground Floor 1886 sq.m and first floor and second floor 2700 sq.m. The data was collected from the contractor and data are provided in Tables 1 and 2. Some of the data collected are Bill of quantities, Barbending schedule, Site to material storage distance, material manufacturing plant to storage distance, Details of building and their build up areas. Table 1 shows the material quantity used in structural elements in the case study building. The quantity was derived from bill of quantities and bar bending schedule given by the respective contractor (Haynes, 2010).

Table 1. Quantity of materials in structural elements of the building

S.No	Element	Cement	Coarse aggregate	Fine aggregate	Reinforcement steel
1	Column	7071	23592	13762	3976
2	Beam	5845	20040	11690	2137
3	Slab	10230.5	35076	16261	3758
4	Sunshade and loft	280	283.4	675.8	562
5	Lintel	1230	1664	3968	685
6	Staircase	1368	1235	2945	784

A flow diagram is a simple tool to aid in the mapping of the inputs and outputs toa process or system. Interrelationships between individual unit processes should be illustrated tobuild a picture of the life cycle in terms of the essential inputs and outputs. Figure 5 indicatesa typical process flow diagram with generalized unit processes (Hu and Milner, 2020; Nizam *et al.,* 2018; Orr *et al.,* 2019; Opher *et al.,* 2021). It is not feasible to doinventory Analysis for all the material so there are certain databases which stores the inventoryprocess flows for material according to the region, type of material, type of manufacturing and type of transportation they are

1. 3EID.
2. Athena Institute.
3. Australian National Life Cycle Inventory Database (AusLCI).
4. Bath Inventory of Carbon and Energy (ICE).
5. CML 2001

The database used here is CML 2001, CML 2001 is developed by the Institute of Environmental Sciences, Leiden University, The Netherlands, and is published in a handbook with several different authors, see literature below. The main principles behind the methodology are not being further developed. A Microsoft Excel spreadsheet with characterization factors for more than 1700 flows can be downloaded from the CML website.The characterization factors are updated when new knowledge on substance level is available. Several additional characterization factors are calculated by think step and LBP-GaBi following the principles described in the CML 2001 methodology documents. The Figures 6 and 7 shows the inventory analysis of brick, steel, and cement (Mason and Grijalva, 2019; Tanasiev *et al.,* 2021b).

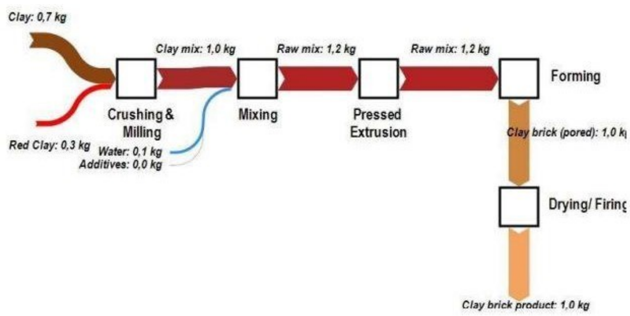


Figure 5. Inventory process flow for brick.

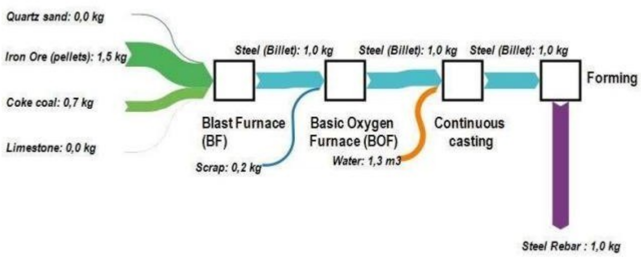


Figure 6. Inventory process flow for steel.

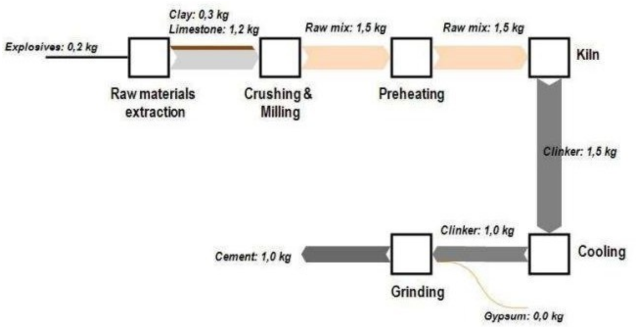


Figure 7. Inventory process flow for cement.

The relative importance of the contributing substances can be modelled and quantified for each impact category. This relative importance or impact potential is expressed relative to norm or reference substance. Eventually the impacts are converted to a proxy using an equivalency factor: Characterization factors (CF) (CF). The characterization step necessitates theability to model the categories using standardized indicators. The characterization step yields the equivalent amounts of emitted reference substance for each impact category as an expression ofcontribution to impact categories.

Table 2. Impact assessment table.

Impact assessment	Units
"Abiotic depletion"	"Kg Sb eq"
"Abiotic depletion (FUEL)"	"MJ"
"Global warming potential (GWP)"	"Kg CO_2 eq"
"Ozone layer depletion (OZP)"	"Kg CFC – 11 eq"
"Human toxicity"	"Kg 1,4-DB eq"
"Fresh water Aquatic"	"Kg 1,4-DB eq"
"Marine Aquatic ecotoxicity"	"Kg 1,4-DB eq"
"Terrestrial ecotoxicity"	"Kg 1,4-DB eq"
"Photochemical oxidation"	"Kg C2H4 eq"
"Acidification"	"Kg SO2"
"Eutrophication"	"Kg PO4- "

3.1. Environmental impact assessment of structural elements with traditionol mix

To conduct the life cycle assessment of the various products constituting the structuralelements of the building from the stages A3 to B7 (Cradle to gate with optional stages) explained in the system boundaries. In addition, determine the quantity of toxic gases emitted inthe atmosphere. The study is carried out to determine the product's impact in its life cycle andprovide an alternative solution to reduce the environmental impact caused by the buildings (Manu *et al.,* 2019).The impact categories to focus on are GWP, AP, EP, OZP, ADP, HTP, POCP. The LCA is carried out using LCA software Simapro.

The environmental impact analysis of the selected structural elements i.e., beam, columns, slabs of the case study building was carried out using simapro and the database used is CML 2001. The input of the materials is given in KG and the transport is given in TnKm. Theresults of each element's specific environmental impacts for traditional mix are given from Tables 3 to 8.

Table 3. Environmental impact of column

Impact assessment	GWP (Kg CO_2 eq)	OZP (Kg CFC – 11 eq)
Cement portland	6.24E3	0.000739
Gravel crushed[in]	811	0.000125
Reinforcing steel	7.78E3	0.000396
Sand market for sand	439	7.64E-5
Water decarbonised	0.552	1.33E-8
Transport freight lite	1.38	2.18E-7
TOTAL	1.53E4	0.000739

Table 4. Environmental impact of beam

Impact assessment	GWP (Kg CO_2 eq)	OZP (Kg CFC – 11 eq)
Cement portland	9.24E3	0.000264
Gravel crushed[in]	1.2E3	0.000185
Reinforcing steel	7.07E3	0.000394
Sand market forsand	518	9.03E-5
TOTAL	1.82E4	0.000934

Table 5 Environmental impact of slab

Impact assessment	GWP (Kg CO_2 eq)	OZP (Kg CFC – 11 eq)
Cement portland	9.24E3	0.0002264
Gravel crushed[in]	1.2E3	0.000185
Reinforcing steel	7.07E3	0.000394
Sand market forsand	518	9.03E-5
Water decarbonised	1.32	3.17E-8
Transport freightlite	1.38E4	0.00218
TOTAL	1.82E4	0.000185

3.2. Environmental impact assesment of structuralelementswith 30% of flyash

The environmental impact analysis of the selected structural elements i.e., beam, columns,slabs of the case study building was carried out using simapro and the database used is CML 2001. The input of the materials is given in KG and the transport is given in TnKm. The results of each element with their specific environmental impacts for 30% fly-ash are given from Figures 2 and 3.

Table 6. Environmental impact of fly ash column

Impact assessment	GWP (Kg CO_2 eq)	OZP (Kg CFC – 11 eq)
Cement portland	6.28E3	0.000115
Gravel crushed[in]	1.51E3	0.000282
Reinforcing steel	8.35E3	0.000374
Sand market forsand	698	9.3E-5
Water decarbonised	0.364	1.85E-8
Transport freightlite	1.56E3	0.000185
TOTAL	0.86E3	0.96E3

Table 7. Environmental impact of fly ash beam

Impact assessment	GWP (Kg CO_2 eq)	OZP (Kg CFC – 11 eq)
Cement portland	7.3E3	0.000143
Gravel crushed[in]	1.31E3	0.000186
Reinforcing steel	6.35E3	0.000374
Sand market forsand	412	10.6E-5
Water decarbonised	0.265	1.85E-8
Transport freightlite	1.11E3	0.000115
TOTAL	1.26E4	0.00098

Table 8 Environmental impact of fly ash Slab

Impact assessment	GWP (Kg CO_2 eq)	OZP (Kg CFC – 11 eq)
Cement portland	6.3E3	0.000143
Gravel crushed[in]	1.21E3	0.000186
Reinforcing steel	7.35E3	0.000374
Sand market for sand	518	9.03E-5
Total	1.54E4	0.000798

3.3. Results of structural elements with 30% flyash

The replacement of 30% cement with fly ash shows not much but acceptable results. Replacement led to the decrease in almost every environmental impact. Comparison chart in Figure 4 shows the difference in the range of global warming potential GWP i.e., global warming potential in the unit of kg CO_2eq. The other environmental are not compared in this chart because GWP creates enormous impact compared to the other effects.

Figure 8 chart shows the Global warming potential of traditional and fly ash elements.From this comparison we can say there is a minor decrease in the GWP value and other environmental impact factors. But replacing cement with 30% cement with fly ash could compromise the structural elements' strength, so strength should be considered before finalizing.

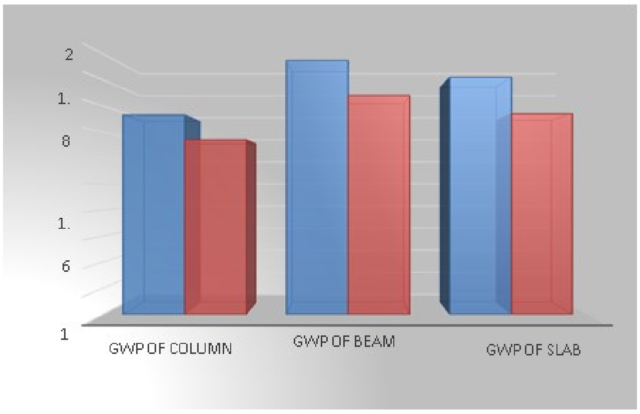


Figure 8. GWP of structural elements.

4. Conclusion

- Commercial buildings are simple structures but residential buildings are complex hence theyconsume more energy for usage.
- Above results shows that among all the structural element of the structure slab showed higher environmental impact. Among materials concrete and reinforcement steel contributes more to the environmental impact.
- Cement in the concrete can be replaced with 30% of pollozona fly ash to reduce theenvironmental impact.
- Following analysis is carried out for same structural element in which 30% of cement is replaced with fly ash.
- Same procedure is followed to identify the environment impact of structural elements of the case study building. The addition of fly ash could reduce the strength of the concrete so the strength

Conflict of Interest

The authors declare no conflict of Interest

Funding Statement

No Funding received.

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