Global Cement and Concrete Association

India

Comparative Evaluation of Embodied Carbon of High-rise & Low-rise Buildings in India

Executive Summary

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EXECUTIVE SUMMARY

It is now widely accepted that the unprecedented rise in greenhouse gas (GHG) emissions is one of the major factors responsible for the climate change that is causing alarming increase in the occurrence of floods, cyclones, droughts, wildfires, heatwaves, rise in sea levels, etc. in different parts of the world. India is more vulnerable to such extreme events as demonstrated by the rise in the frequency and magnitude of such events in recent years.

The 2015 Paris Agreement adopted by 196 parties (countries) marked a watershed in the efforts to mitigate the adverse effects of climate change, in that different countries agreed to keep the global temperature rise this century well below 2°C above the pre-industrial levels and pursuing efforts to limit the temperature increase even further to 1.5°C. Unfortunately, despite a variety of mitigative measures initiated in many countries, the recent UNEP report observes that the global GHG emissions are setting new records (57.4 $GtCO_{2e}$ in 2022) and that the world is heading for a temperature rise far above the Paris Agreement goals [1]. This is a climate emergency beyond doubt!

Indian Scenario

India cannot be considered responsible for climate change as the country has contributed merely about 4% to the global cumulative GHG emissions between 1850 and 2019 [2]. Yet, the Indian Government took a praiseworthy step during the UNFCCC Convention COP-26 in Glasgow, presenting the five nectar elements (*Panchamrit*) of India's climate action that among others include the commitment to achieve 'net zero' emission by 2070 [3]!

The building and construction sector provide a great opportunity for decarbonization. Based on the report of Global Alliance of Building and Construction, building and construction sectors account for 34% of the total energy used globally and are responsible for 37% of carbon emissions [4]. Although similar India-specific data are not available, broad trends as available from few reports [5,6,7] indicate that carbon emissions from buildings in urban India would generally be comparable with the broad global trends. Further, the rapid urbanization happening in India currently and the expected increase in the next few decades will result in steep rise in the housing and infrastructure demands resulting in the exponential increase in the energy requirements in the near future.

With a view to cater to the escalating energy demand, India has already taken a great leap forward in increasing its renewable energy capacity. It is indeed creditable that as on April 2024, India has achieved the renewable energy (RE) capacity which is nearly 44% of the total power capacity [8]. Furthermore, India has an ambitious plan of raising the RE capacity to 500 GW till 2030 [9]. While all these steps are most welcome, India also needs to look at other avenues of reducing its future carbon emissions. The buildings and construction sectors in India provide one of the viable avenues to reduce these emissions.

Currently, major efforts taken in reducing carbon emissions have mainly focussed on reducing the operational carbon. However, with the global material consumption projected to get nearly doubled by 2060, a recent UNEP report warns that the embodied carbon contribution is likely to increase from 25% in 2021 to 49% in 2060. Hence, it is highly essential to focus attention on reduction of embodied carbon.

For the evaluation of the carbon emissions, it is essential to adopt a life cycle assessment approach. The building life cycle stages, as defined in the European Standard EN 15978, consist of five modules, namely, product stage (A1–3), construction stage (A4–5), use stage (B1–6), end of life stage (C1–4), and beyond the life cycle (D). It is observed that nearly 50% of the total carbon emissions happen during the product stage which involves extraction of raw materials, transportation and manufacturing – all requiring energy-intensive processes.

Operational & Embodied Carbon in Buildings

The World Green Building Congress has broadly divided carbon emissions into two main categories, namely, 'operational' carbon and 'embodied' carbon.

Operational & Embodied Carbon in Buildings

Types of Carbon Emissions in Buildings	
Operational Carbon	Embodied Carbon
Emissions from energy use during building operations including:	**Emissions during the life cycle of built assets, including:**
• Heating, cooling, ventilation, and lighting.	• Manufacturing, transportation, construction.
• Use of appliances (e.g., fridges, washing machines, TVs).	• Repair, maintenance, and refurbishment.
• Equipment like lifts and cooking systems.	• End-of-life phases like demolition and waste management.

Net Zero emissions : GCCA India Roadmap

The GCCA-India and TERI released the decarbonization Roadmap for the Indian Cement Sector: Net Zero CO_2 by 2070 in March 2025.

This roadmap aligns with the Government of India's commitment to net-zero emissions by 2070 and the interim target for 2047 in line with the vision of 'Viksit Bharat.'

The roadmap is divided in eight key areas. These areas along with their estimated percentage contributions to net zero by 2070 are shown as below.

1. Clinker efficiency (11.6%)
2. Alternative fuels (4.6%)
3. Supplementary Cementitious Materials (16.2%)
4. Decarbonization of electricity (6.2%)
5. New binders (0.2%)
6. Carbon capture, utilization and storage (25.1%)
7. Role of re-carbonization (5.9%)
8. Cement use efficiency (30.2%)

GCCA-India decided to undertake a project of comparative assessment of embodied carbon from a typical high-rise and low rise building, taking into consideration the current design and construction practice followed in India including the currently adopted technologies and the materials used in construction.

LCCF, on its part, took help from the professional architectural and structural designer agencies and in-house engineers, aided by support staff for back-office work. The architectural planning of both high-rise and low-rise 'virtual' buildings were done, duly adopting the passive architectural features to take maximum benefits from naturally available light, ventilation, etc. The structural and material designs were carried out strictly following the current Indian Standards. A rigorous process of peer reviews of the structural design of both high-rise and low-rise buildings were conducted by expert teams from an experienced professional structural design agency. Further, presentations on the work done for both high-rise and low-rise buildings were made before the team of Expert Committee set up by GCCA-India and the suggestions of the committee were duly considered in the work.

For the comparative evaluation of embodied carbon in high-rise building, a typical G+34 storeyed building located in a metropolitan city was considered. There are two flats on each floor, four lifts, two staircases and two mechanical parking towers. Total construction area is 15,878 m^2.

The G+34 storeyed building is essentially a reinforced concrete (RC) framed structure with columns/shear walls. For the comparative analysis, a total of 12 alternatives became available for the comparative evaluation of embodied carbon in high-rise buildings (Fig 1).

For the comparative assessment of embodied carbon in low-rise building, a typical G+3 storeyed building was considered. Conventional RC framing system with/without shear walls were considered. The M30 grade of concrete was found to be appropriate. For walling materials, four options were considered namely, fired clay bricks, AAC blocks, EPS sandwich panels and fly ash bricks. Considering that the use of blended cements is quite a popular choice in these areas, the use of three types of cements – Portland

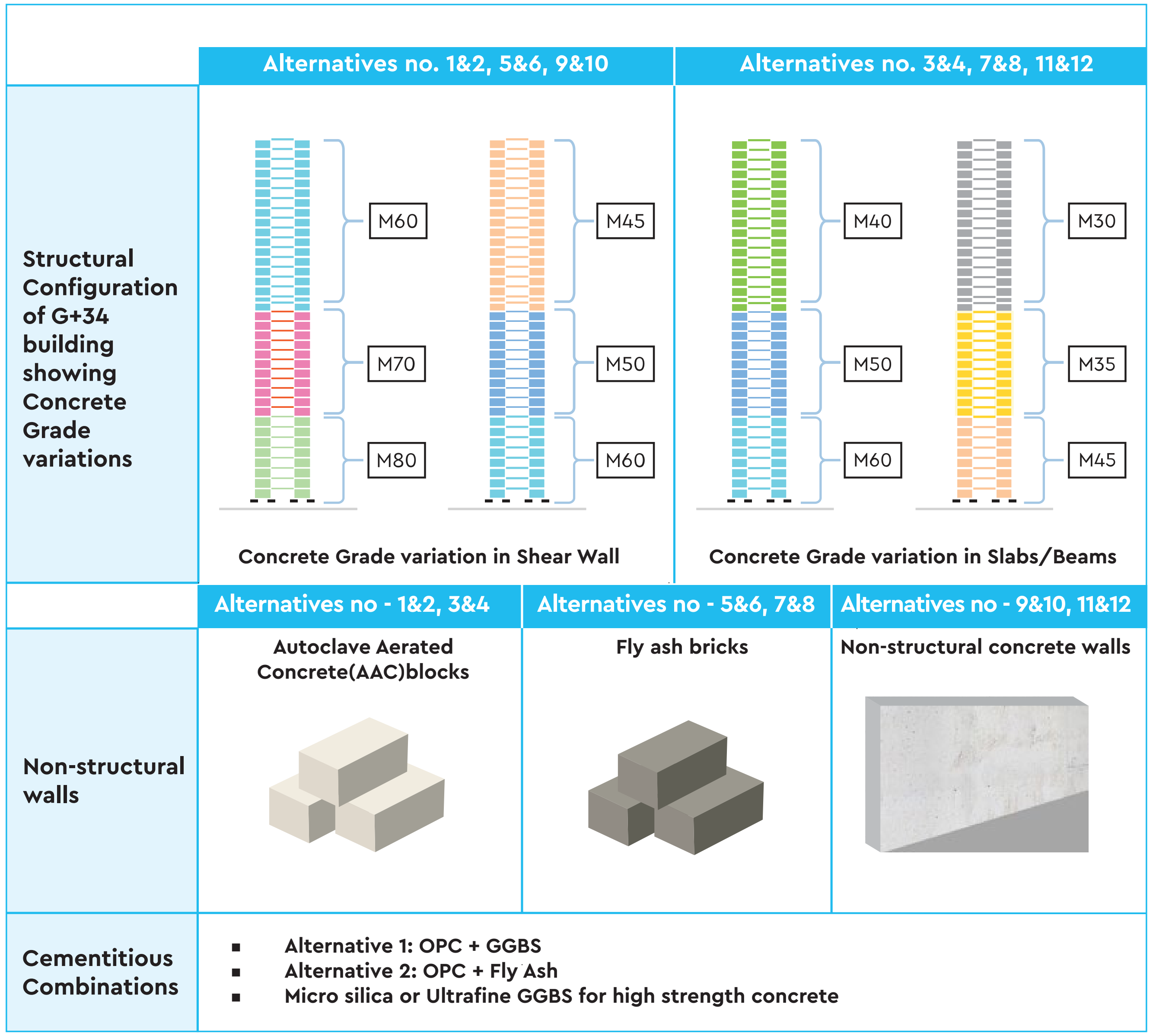

Fig 1: Alternatives considered for evaluation of embodied carbon in high-rise buildings

Pozzolana Cement (PPC), Portland Slag cement (PSC) and the Ordinary Portland cement (OPC) were considered for M30 grade concrete.

Thus, for the comparative evaluation of embodied carbon for low-rise building 24 alternatives become available as shown in Fig 2.

Based on the provisions in the relevant codes of the Indian Standards, the structural engineering teams carried out the design of high-rise and low-rise buildings and provided the design inputs and quantities of materials for calculations of the embodied carbon. For such calculations, it is essential to have the accurate values 'Embodied Carbon Factor (ECF)' or the 'Global Warming Potential (GWP)' of different materials. In India, under the study funded by the eco-cities programme, the International Finance Corporation (IFC) – a member of the World Bank group – and the European Commission developed a comprehensive database on the embodied energy and the global warming potential of building materials in 2017 [12].

For the purpose of the current work we have adopted the use of the ECF/GWP values from the IFC-EU database. For certain materials for which the ECF/GWP values are not available from IFC-EU database, we have taken such values either from the authentic reports of leading companies from India or from IStructE Guide [13].

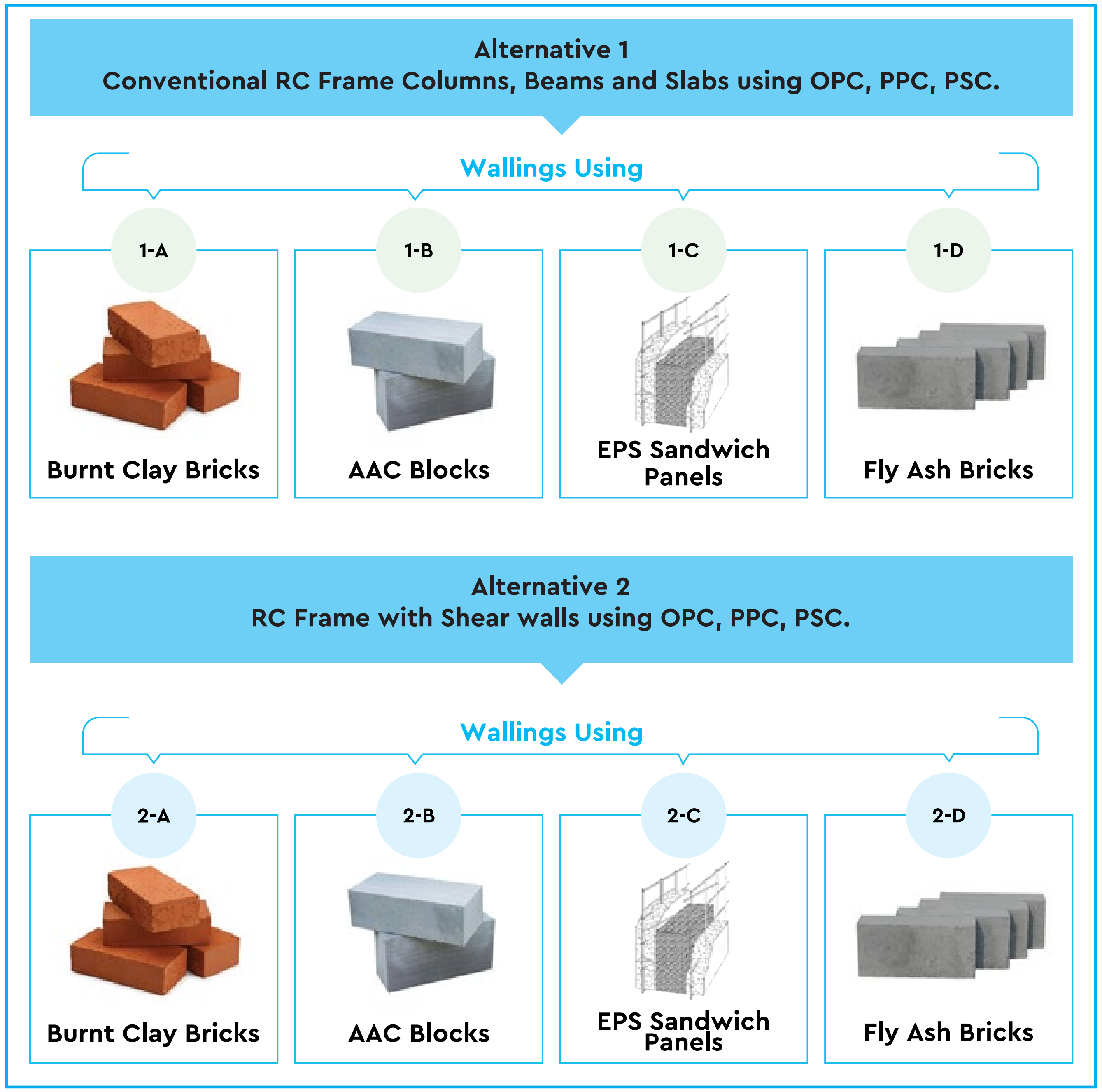

Fig 2 Alternatives for embodied carbon assessment of a low-rise building

For the comparative assessment of embodied carbon, we have restricted our calculations to the construction of reinforced concrete framework including the partition walls, formwork and plastering work.

Note: The carbon emissions that attribute to the use of items like doors, windows, floor finishing, external and internal painting work, accessories and finishes for bathrooms, kitchen, and other accessories are not considered in this study as these would be common for the different alternatives that we have considered in the architectural and structural design.

The comparative study of embodied carbon is done from the cradle stage to the completion of construction stage. In our work we have initially estimated the embodied carbon emissions from stages A1 to A3 and this is then followed by assessment from A4 to A5. For the assessment of the latter, no guidance is available from reliable sources in India. Hence, we have used the recommendations provided in the IStructE, U.K. Guide [13].

Conclusions

The results of the comparative analysis of the embodied carbon assessment revealed that for the high-rise building, embodied carbon emissions for A1 to A5 stages varied from 458 to 560 $kgCO_{2e}/m^2$ (Table 6.11) the **lowest value being obtained for the alternative using RC framed structure with concrete of grades M80 to 60 and AAC blocks for walling.** The alternative using AAC blocks was found preferable as it helped in reducing the total carbon emissions by nearly 17.9% to 18.3% (Table 6.11 note) when compared with the alternative using non-structural concrete walling system.

For the low-rise building, embodied carbon emissions varied from 230 to 393 $kgCO_{2e}/m^2$ (Table 8.12) (a) and (b) with the **lowest value being obtained for the alternative using a combination of RC frame/shear walls and EPS sandwich panels as the walling material.**

In the case of high-rise buildings, the current practice of using high strength pumped concrete and lightweight aluminium tunnel formwork system for RC shear walls/columns, which enabled higher speed of construction, left very little scope for optimization in the structural system. However, in case low-rise building the introduction of shear walls in duct portion and other 'dead' locations helped in reducing the carbon emissions from 0.8% to 10.6%. The adoption of EPS sandwich panel helped in further reduction of emissions. As a result, a combination of RC frame and shear walls along with the adoption of EPS sandwich panels helped in reducing the embodied carbon emissions in low-rise building from 21.29 to 28.14% (Table 8.13) when compared with the alternative using fired clay bricks.

Incidentally, in both high-rise and low-rise buildings, it is interesting to note that the alternative having lowest carbon emission also happened to the lowest cost alternative.

The lowest embodied CO_2 emissions are obtained using GGBS – either as SCM in ready-mixed concrete or as PSC in site-mixed concrete.

Recommendations

Considering the potential of EPS sandwich panels in reducing the embodied carbon emissions, it suggested that the use of such walling system may be considered in the low-rise and high buildings for non-structural walling applications. In case such panels are not available readily or are not found cost effective, the next best alternative is the use of AAC blocks There is also a need to develop a viable and cost-effective cement-based alternative for EPS sandwich panels which is lightweight and sturdy.

Considering that the material efficient design results in reducing embodied carbon emissions, an exercise was conducted in optimizing concrete mix proportions of few concrete grades. This exercise revealed that it is possible reduce the embodied concrete emissions in concrete of grades for M40 to M60 by around 12 to 17% (Table 10.1). This has been achieved without violating the current limits of SCMs specified in Indian Standards.

For achieving further reductions in the embodied carbon emissions, it is recommended to adopt two-pronged strategy – firstly requesting permission from BIS to the use of high-volume fly ash concrete (up to 50% replacement of OPC) and high-GGBS concrete (up to 70% replacement of OPC), and secondly seeking permission for the adoption of 56-day and/or 90-day acceptance criteria for concrete. It would be appropriate to seek such permission initially for mass concrete foundations and lower levels of columns, shear walls, beams, etc. in the buildings where the maximum loads occur at a much later age.

The adoption of performance-based specifications for concrete is one of the useful tools to achieve further reduction in embodied carbon emissions. Hence, it would be appropriate to adopt such approach, especially for large projects.

Improving long-term durability of concrete and hence its service life, helps in preserving non-renewable raw materials. In the present report, the scope of work is limited to evaluating the embodied carbon footprints from cradle to the end of construction stage (A1 to A5 stages). Yet, the requirements of durability as specified in IS 456:2000 have been duly considered in the present study. Further, the adoption of low water/binder ratio and incorporation of enough amount of reactive SCMs in the concrete mixes presented in our study will go a long way in ensuring the long-term durability of structures.

Finally, the most important objective of the whole exercise is to encourage the owners/structural consultants/architects to commence the practice of evaluating the embodied carbon emissions of all new projects and report the same to a repository which will enable in assessing the average carbon footprints of different grades of concrete, which in turn, will help the planners to plan future course of actions culminating in achieving 'net zero' by 2070. In this process, all stakeholders including the RMC producers in India need to take a prominent lead.

Once the average values of embodied carbon emissions become available from different parts of the country, the same could then be included in the Indian 'Low Carbon Code', the publication of which is strongly recommended. Such a code will go a long way in achieving the net zero emissions.

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About GCCA India

Global Cement & Concrete Association (GCCA) India works with the Indian cement & concrete sector on climate change, circular economy, health & safety, SDGs and communication. The GCCA India gathers and publishes data on the industry's sustainability commitments, guidelines, and initiating research. 'Decarbonization Roadmap for the Indian Cement Sector: Net-Zero CO_2 by 2070' is the collective aspiration of India's leading cement companies to contribute to building the sustainable world of tomorrow. GCCA India is affiliated to the Global Cement and Concrete Association - GCCA.

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