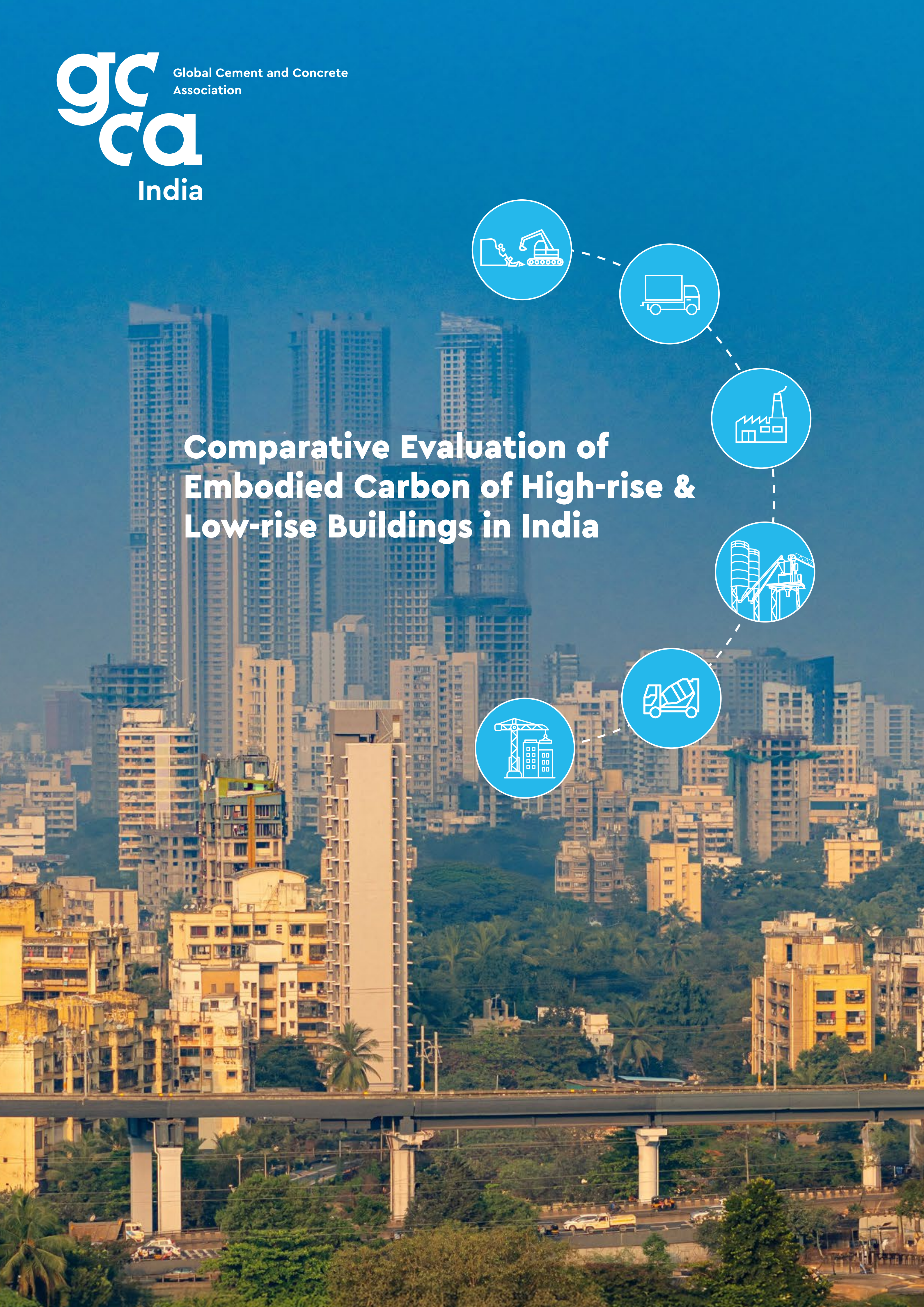
Global Cement and Concrete Association

India

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



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This report is prepared by the Low Carbon Construct Forum (LCCF) on its research and the information/data available in public domain, but does not necessarily reflect those of individual GCCA India member companies. The structural design and quantity estimation work has been done by Sterling Engineering Consultancy Pvt. Ltd. for high-rise building and by the Strucknik Designers and Consulting Engineers for low-rise buildings. The peer review work was carried out by Raje Structural Consultants.

Message from the Chief Executive Officer

Thomas Guillot
Chief Executive Officer
Global Cement and Concrete Association (GCCA)

Cement and concrete are well recognised as the backbone of modern society – enabling strong and resilient infrastructure, buildings and homes, and allowing communities to flourish. However, there is also an increasing recognition and demand for more sustainable construction and built environment which we live in. Customers, designers, developers and society are rightly asking that these essential materials reduce their carbon footprint. At the same time the need for greater transparency and action has never been more urgent.

Amidst India's rapid development and burgeoning infrastructure needs, the Global Cement & Concrete Association (GCCA) is at the forefront of advocating for the prioritization of low-carbon materials. To empower the construction sector with knowledge and tools, we have developed a pioneering Low Carbon Rating System for cement and concrete, paving the way for sustainable practices.

This report on the Comparative Analysis of Embodied Emissions of High-Rise and Low-Rise Buildings is a significant step in that direction. It addresses the challenges of embodied carbon by evaluating India-specific materials and construction techniques, presenting insights on reducing CO_2 emissions across both building types. Importantly, the analysis highlights that many low-carbon materials are not only effective in reducing emissions, but perform as well and sometimes better than traditional materials.
In addition they can also be among the most cost-efficient solutions available – making them a win for the planet, a win for durable and safe built environment, and potentially a win for the bottom line.

This report, designed to be an indispensable resource for architects, structural engineers, and builders, underscores the pivotal role of low-carbon cement and concrete in sustainable construction practices. By championing the use of these materials, together we can foster the development of low-carbon buildings and contribute to a more sustainable future, while at the same time meet India's evolving infrastructure demands.

Through our collective effort and a commitment to innovation, we can decarbonise the built environment and achieve a greener tomorrow, and we encourage all those working in the built environment to be an integral part of this transformation journey.

Preface

Vijaykumar R Kulkarni
Founder – Director, LCCF

The repeated and growing occurrence of a series of extreme events such as flash floods, droughts, wildfires, cyclones, heat waves, etc. in one or other parts of the world are now attributed to the human induced phenomenon of global warming and of climate change. In the history of the Earth, it is for the first time in the year 2024 that we witnessed the breaching of the global warming temperature by more than 1.5^{0}C from the pre-industrial level, which according to many climate scientists may lead to irreversible and cascading extreme events caused by climate change, unless urgent corrective actions are taken.

According to the 'Sustainable Building Material Hub' of Global ABC, the building and construction sectors are responsible for 37% of the total carbon emissions worldwide. The Hub predicts that the share of embodied carbon emissions is going to increase steeply from 21% in 2021 to 49% by 2050. Although considerable efforts are being made worldwide, including India, to increase the renewable energy potential and to counterbalance the same to reduce the operational carbon emissions, the efforts in reducing the embodied carbon emissions – mainly coming from the use of energy-intensive materials like cement, steel, walling materials, etc. are lagging.

India is currently witnessing rapid urbanization and the same is poised to grow further in the next few decades. This is bound to result in the exponential rise in the housing and infrastructure demands in the urban and semi-urban centres, resulting in steep increase of the use of cement, steel, walling materials etc. Presently, very little efforts are being made in the country to assess the embodied carbon emissions from buildings and construction.

In this context it is indeed noteworthy that the Global Cement & Concrete Association-India (GCCA-India) in collaboration with The Energy and Resources Institute (TERI) with support of various stakeholders released a 'Decarbonization Roadmap for the Indian Cement Sector: Net-Zero CO_2 by 2070' during the stakeholder consultations, it was highlighted that there is a lack of reliable indigenous data on the efficiency in design and construction which is one of the major levers for reducing carbon footprints. As a result, GCCA-India decided to conduct a study on comparative evaluation of embodied carbon from typical high-rise and low-rise buildings in India. The assignment to carry out the study was entrusted to the subject matter expert – Low Carbon Construct Forum (LCCF), which is a not-for-profit Company, engaged in creating awareness on the urgent need to reduce carbon footprints from buildings and construction.

LCCF team, which included experts from structural design and the materials design areas, carried out the job of the comparative evaluation of embodied carbon for both high-rise and low-rise buildings, closely working with the GCCA-India's Expert Committee and the team of peer-reviewers from a reputed consulting engineering firm appointed by GCCA-India, namely, M/s Raje Structural Consultants, Mumbai. The work of structural design and the estimation of embodied carbon underwent several changes based on the comments of peer-reviewer team and the recommendations of GCCA-India's Expert Committee. LCCF team satisfactorily complied with all comments and recommendations.

We have great pleasure in presenting the final work of our study on the embodied carbon from buildings and construction and sincerely hope that the same will prove useful to the engineering fraternity in India.

Despite taking due care in preparing this document, it is quite possible that some minor errors would have remained unaddressed, for which LCCF takes the responsibility.

Acknowledgements

We would like to take this opportunity to thank GCCA-India, especially Mr. Kaustubh Phadke, India Head, for the coordination of the work and time-to-time help rendered by him and his team to LCCF.

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Finally, we would like to appeal to the architects, structural consultants, clients and builders/contractors to consider different alternative designs in the planning stage of their projects, evaluate the embodied carbon of each alternative and finally adopt the alternative which provides the lowest embodied carbon.

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Abbreviations

Abbreviation	Full Form
AAC	Autoclaved Aerated Concrete
Auto-CAD	Automatic Computer-Aided Design
BIS	Bureau of Indian Standards
CCUS	Carbon Capture Utilization & Storage
CDRI	Coalition for Disaster Resilient Infrastructure
CEA	Central Electricity Authority
CEEW	Council for Energy, Environment and Water
COP	Conference of Parties
CSE	Centre for Science and Environment
DEA	Department of Economic Affair
ECBC	The Energy Conservation Building Code of India
ECF	Embodied Carbon Factor
EPBD	Energy Performance of Buildings Directive
EPD	Environmental Product Declaration
EPS	Expanded Polystyrene Sandwich
EU	European Union
FA	Fly Ash
FAL-G	Fly Ash Lime, Gypsum
GCCA	Global Cement & Concrete Association
GDP	Gross Domestic Product
GGBS	Ground Granulated Blast Furnace Slag
GHG	GreenHouse Gases
GWP	Global Warming Potential
HR	High-Rise
HSC	High-Strength Concrete
IEA	International Energy Agency
IFC	International Finance Corporation
IMD	India Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
ISA	International Solar Alliance
LCA	Life Cycle Assessment
LCCF	Low Carbon Construct Forum
LETI	London Energy Transformation Initiative
LT-LEDS	Long-Term Low-Carbon Development Strategy
LR	Low-Rise
MoEFCC	Ministry of Environment, Forest and Climate Change
MS	Micro Silica
MT	Metric Tonne
NS	Non-Structural Wall
OPC	Ordinary Portland cement
PPC	Portland Pozzolana Cement
PSC	Portland Slag cement
RC	Reinforced Concrete
RMC	Ready Mix Concrete
RTS	Roof Top Solar
SCM	Supplementary Cementitious Material
SLS	Serviceability Limit State
TERI	The Energy and Resources Institute
UGGBS	Ultrafine Ground Granulated Blast Furnace Slag
UNDRR	United Nation Office for Disaster Risk Reduction
UNEP	United Nations Environment Programme
UNFCCC	United Nation's Framework Convention for Climate Change
WGBC	The World Green Building Council

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^{0}C above the pre-industrial levels and pursuing efforts to limit the temperature increase even further to 1.5^{0}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%)

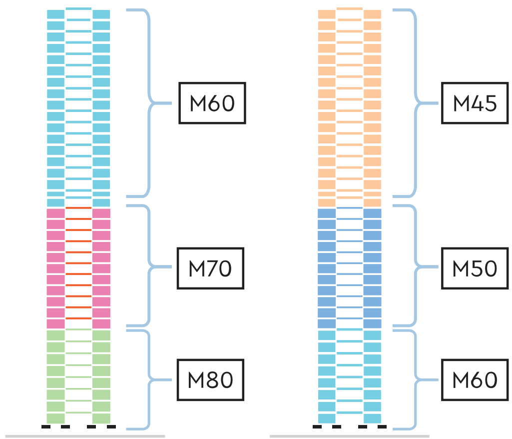
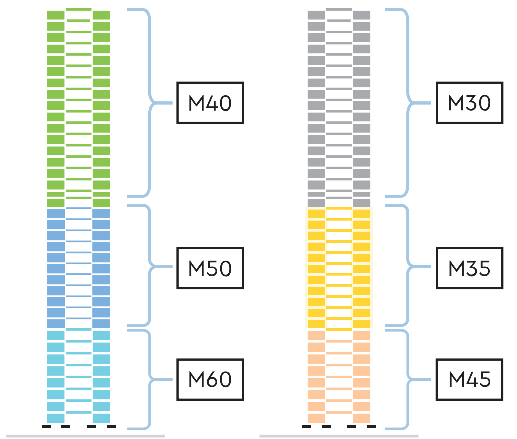
GCCA-India decided to undertake a project of comparative assessment of embodied carbon from a typical high-rise and low rise building, taking into consideration the current design and construction practice followed in India including the currently adopted technologies and the materials used in construction.

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

	Alternatives no. 1&2, 5&6, 9&10	Alternatives no. 3&4, 7&8, 11&12
Structural Configuration of G+34 building showing Concrete Grade variations	 **Concrete Grade variation in Shear Wall**	 **Concrete Grade variation in Slabs/Beams**

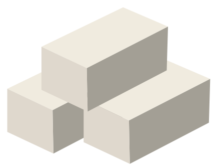
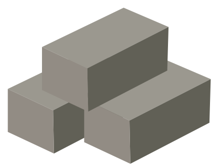
	Alternatives no - 1&2, 3&4	Alternatives no - 5&6, 7&8	Alternatives no - 9&10, 11&12
Non-structural walls	**Autoclave Aerated Concrete(AAC)blocks** 	**Fly ash bricks** 	**Non-structural concrete walls** 
Cementitious Combinations	▪ **Alternative 1: OPC + GGBS** ▪ **Alternative 2: OPC + Fly Ash** ▪ **Micro silica or Ultrafine GGBS for high strength concrete**		

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

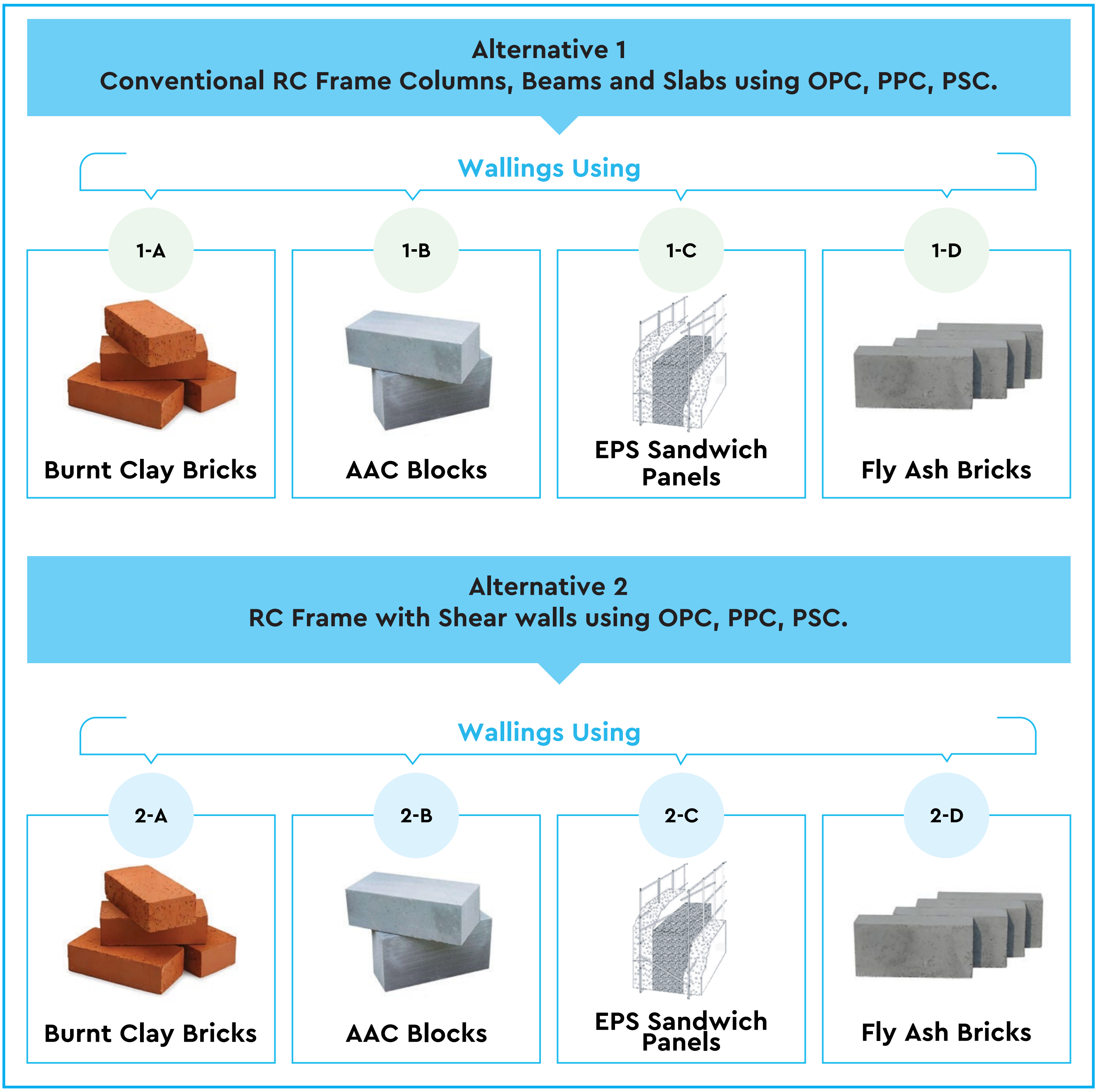


Fig 2 Alternatives for embodied carbon assessment of a low-rise building

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].

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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CLIMATE CHANGE: INDIAN SCENARIO

CHAPTER 1

Globally, there has been an unprecedented rise in greenhouse gas (GHG) emissions which mainly consists of carbon dioxide (CO_2), methane (CH_4) and Nitrous oxide (N_2O). According to the report of the Intergovernmental Panel on Climate Change (IPCC), CO_2 emissions reached the highest level of 400 ppm in 800,000 years and that the period from 1983–2012 was the warmest 30-year period in 1400 years! [1]. Fig 1.1 shows globally averaged GHG emissions from 1850–2020. The 2018 report by IPCC warned that the global warming reaching 1.5^{0}C would be the "tipping point", causing irreversible environmental changes [2]. The latest IPCC document 'Climate Change 2023 - Synthesis Report' states that the global atmospheric temperature has already reached 1.1^{0}C above 1850–1900 level during 2011–2020 [3].

There has been a broad agreement amongst leading world scientists that anthropogenic emissions of CO_2 and other greenhouse gases are the primary cause of climate change and global warming. These phenomena are changing the weather patterns worldwide, resulting in the rise of extreme events such as unprecedented floods, intense droughts, heat waves, melting of glaciers, rise in sea levels and warming of oceans.

In recent years, there has been a steep increase climate centric disasters. A report by UN Office for Disaster Risk Reduction (UNDRR) reveals that during the period 2000 to 2019, there were 7,348 major recorded disaster events claiming 1.23 million lives, affecting 4.2 billion people (many on more than one occasion), resulting in approximately US$ 2.97 trillion in global economic losses [4].

With a view to mitigate the adverse effects of climate change, world leaders gathering at the United Nation's Framework Convention for Climate Change (UNFCCC) held in Paris (COP21) in 2015 agreed to keep the global temperature rise this century well below 2^{0}C above the pre-industrial levels and pursuing efforts to limit the temperature increase even further to 1.5^{0}C. The Paris Agreement is a legally binding international treaty on climate change, adopted by 196 Parties.

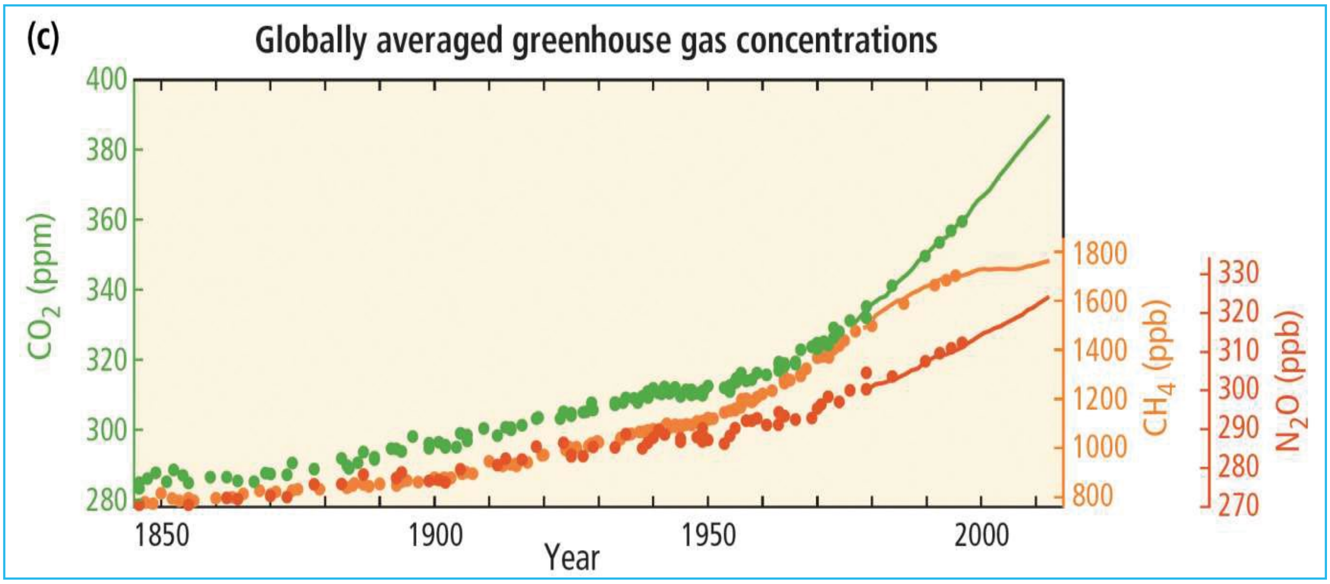

Fig 1.1 Unprecedented rise in GHG Emissions [1]

Glimpses of some Extreme Events in different parts of India during 2021–24

Incidentally, it was reported that 2023 was the warmest extra tropical summer in North Hemisphere over the past 2000 years, exceeding the 95% confidence range of natural climate variability by more than half a degree Celsius [5]. All these warning signals point out that the Climate Emergency has already arrived. The United Nations Environment Program (UNEP) declares "The world is in a state of climate emergency, and we need to shift into emergency gear. Humanity's burning of fossil fuels has emitted enough greenhouse gases (GHGs) to significantly alter the composition of the atmosphere and average world temperature has risen between 1.1 and 1.2°C." [6]

1.1 GLOBAL WARMING: INDIAN SCENARIO

With a view to mitigate the adverse effects of the climate change and global warming, 151 countries, responsible for 88% of GHG emissions and covering 89% of world population (as on January 2024) have made commitments to achieve 'net zero' emissions by 2070 [7].

The latest UNEP report advocates immediate stringent emission reduction strategy to bridge the current massive GHG emission gap (1990–2022) of around 22 $GtCO_{2e}$ for achieving the Paris Agreement goal of keeping the temperature rise 1.5–2.0°C [8].

Extreme Events

India cannot be an exception to the global trend of rising disasters. In fact, India is more vulnerable to natural disasters. The report of United Nation Office for Disaster Risk Reduction (UNDRR) mentioned above reveals that India stands 3rd amongst the top 10 countries ranked by the occurrence of disasters during 2000–2019 [3]. A news item from the *Economic Times*, citing the report from State Bank of India highlighted that nearly 1 billion persons from India were affected due to disasters since 2001 to 2020 and 83,000 lives were lost, and the financial loss (adjusted with current prices) was estimated as Rs.13 lakh crore or 6% of country's GDP [9]!

Fig 1.2 Floods in Uttarakhand September 2021

Fig 1.3 Floods in Kerala September 2021

Fig 1.4 Flood in Jaipur, Rajasthan
Source: Source: https:/youtu.be/j0e7hW_MApM

Fig 1.5 Urban flooding, Bengaluru, 2022
Source: https:/www.google.com search?q=photos+recent+flooding +Bangalore

Glimpses of some Extreme Events in different parts of India during 2021–24

Fig 1.6 A woman walks through a flooded area following rains in Nagaon (North-East Region) (June 1, 2024)
Source: https:/www.indiatoday.in/india/story/floods-in-assam-manipur-tripura-mizoram-meghalaya-2546418–2024–05–31

Fig 1.7 Wayanad's Mundakkai village, or what was left of it, days after the landslide in August 16, 2024
Source: https:/frontline.thehindu.com/environment/wayanad-mundakkai-chooralmala-landslides-army-bodies-kerala-climate-change-impact-gadgil-western-ghats/article68528102.ece

Fig 1.8 Cyclone Varda, Tamil Nadu, December 2021

Fig 1.9 Cyclone Biparjoy, leaves a trail of destruction in Gujarat,2023;
Source: https:/www.indiatoday.in/india/photo/cyclone-biparjoy

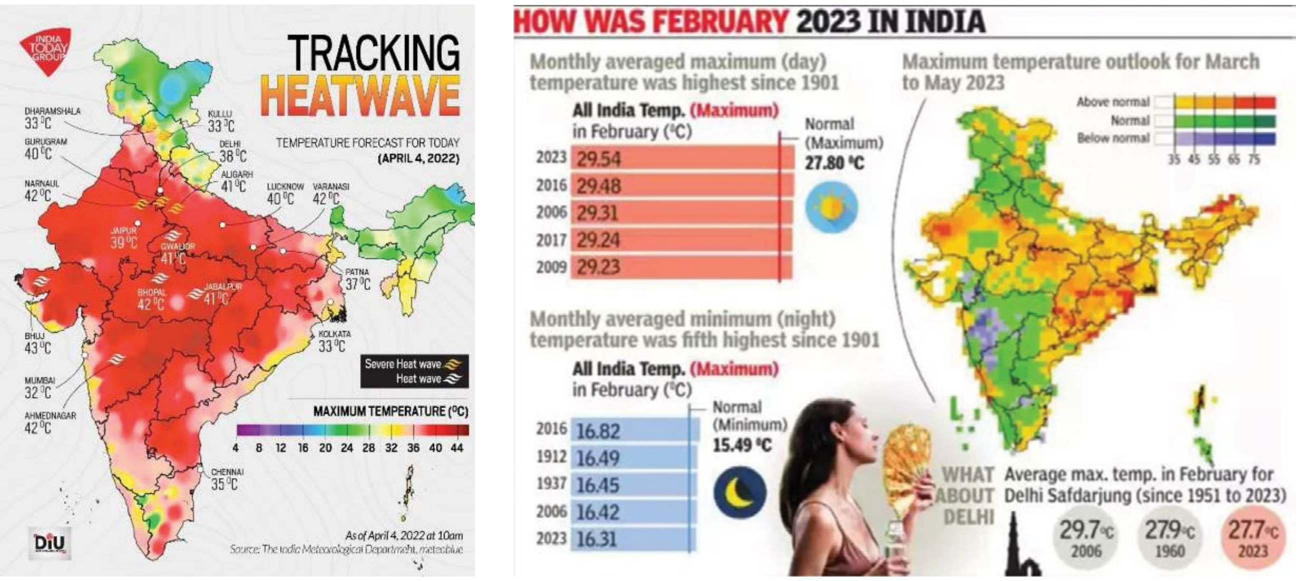

Fig 1.10 While April 2022 witnessed highest temperature in last 122 years (Left: Source: IMD)
February 2023 was the hottest February since 1901 (Right) [10]

It seems that the frequency and intensity of hydrological and meteorological disasters are on the rise in India. The large-scale damages due to extreme events witnessed during the last four consecutive years, which are listed below, can be considered as the vivid examples of climate change hitting India:

Heavy floods

- Kerala, Uttarakhand and Rajasthan in 2021 (Fig 1.2, 1.3, 1.4)
- Urban flooding in Bengaluru and Kolkata in 2022 (Fig 1.5)
- Himachal Pradesh, Chandigarh and Delhi during 2023
- North-east region during May-June 2024 (Fig 1.6)
- Waynad, Kerala (July 2024) (Fig 1.7)

Severe Tropical Cyclones

- Varda in 2021 (Fig 1.8)
- Sitrang and Asani in 2022
- Biparjoy in 2023. (Fig 1.9)
- Remal in May 2024

Simultaneously, India has been witnessing higher ambient temperature regimes, breaking earlier records. The India Meteorological Department (IMD) reported that while the north-west and the central India witnessed the highest temperatures in the past 122 years during April 2022, the year 2023 saw the warmest February since 1901, Fig 1.10[10]!

In the year 2024, India experienced exceptionally high temperatures in different parts of Rajasthan, Maharashtra, Telangana, and other states, with Delhi recording the highest ever temperature of 52.9^{0}C [11].

1.2 CLIMATE-FRIENDLY ACTIONS

India happens to be the 3rd largest carbon emitting country in the world; however, the country's contribution to GHG emissions in per capita terms is meagre, Fig 1.11.

Despite supporting 17% of the world population, India has contributed only about 4% to the global cumulative GHG emissions between 1850 and 2019 [12]. Thus, India cannot be considered responsible for climate change. Yet, the country is resolutely addressing climate change domestically and is doing more than its fair share.

Indian Government took a bold step during the UNFCCC Convention COP-26 in Glasgow and made the commitment that the country will achieve 'net zero' carbon emission by 2070! During the COP-26, India presented the following five nectar elements (*Panchamrit*) of India's climate action [13]:

- Reach 500 GW Non-fossil energy capacity by 2030.
- 50 percent of its energy requirements from renewable energy by 2030.
- Reduction of total projected carbon emissions by one billion tonnes from now to 2030.
- Reduction of the carbon intensity of the economy by 45 percent by 2030, over 2005 levels.
- Achieving the target of net zero emissions by 2070.

Incidentally, India also launched the International Solar Alliance (ISA) and Coalition for Disaster Resilient Infrastructure (CDRI) to address climate change challenges.

In November 2022, India submitted its Long-Term Low-Carbon Development Strategy (LT-LCDS) [14]. A 100-page document submitted by the Indian government to the United Nations Framework Convention on Climate Change (UNFCCC) in November 2022 outlines India's strategy (Fig 1.12).

The LT-LEDS rests on the following seven key transition pathways:

1. Low carbon development of electricity systems consistent with enhanced development benefits
2. Development of integrated, efficient, inclusive low-carbon transport system

"The climate crisis has arrived and is accelerating faster than most scientists expected. It is more severe than anticipated, threatening natural ecosystems and the fate of humanity". - Statement by 11,000 leading Scientists

Source: BioScience, Jan 2020/Vol.70 No.1

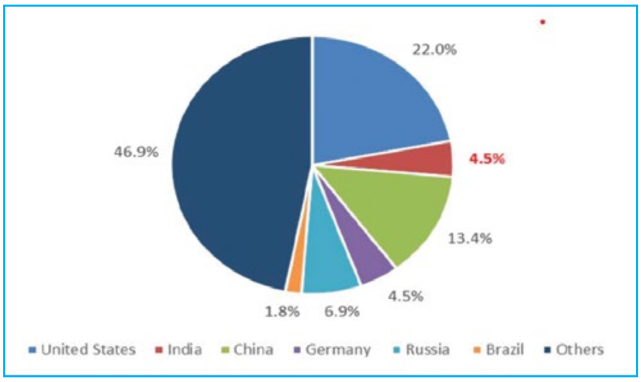

Fig 1.11 Share of cumulative GHG emissions from select countries [12]

Fig 1.12 India's Long-term Low Carbon Development Strategy [14]

India & climate change:
Impact, Action & the Road Ahead

The Global Climate Crisis

- 1.1°C rise already (2011-2020 vs. 1850-1900)
- 7,348 Disasters (2000-2019) $2.97 trillion losses
- 400 ppm CO_2- highest in 800,000 years
- GHG emission gap (1990-2022): 22GtCO_2

India's Climate Vulnerability

3rd most disaster-prone nation

Adverse effect of disasters (2001-20)

- 1 Billion people affected
- 83,000 lives lost
- ₹ 13 lakh Cr. (~6% GDP) in losses

India's Initiatives

- Net Zero emissions by 2070
- Increase non fossil energy capacity to 500GW by 2030
- Meet 50% of its energy requirements from renewable energy by 2030
- Reduce total projected carbon emission by one billion tonnes by 2030
- Reduce carbon intensity of its economy by less than 45% by 2030

Green Urban Development

- LT-LEDS strategy promotes sustainable cities
- Emphasis on energy-efficient buildings
- Focus on construction adaptation & low-carbon design

Private Sector Commitments

- Reliance: Net zero by 2035
- L&T: Carbon neutral by 2040
- India CEO Forum voluntary goals: TATA, JSW, Mahindra, Adani, Dalmia committed to decarbonization
- Many More...

3. Promoting adaptation in urban design, energy and material efficiency in buildings and sustainable urbanization
4. Promote economy-wide decoupling of growth from emissions and development of an efficient, innovative low emission industrial system
5. CO_2 removal and related engineering solutions
6. Enhancement of forest and vegetative cover consistent with socio-economic and ecological considerations
7. Economic and financial aspects of low-carbon development.

Amongst the above mentioned pathways, item No. 3 pertains to the building and construction industries in India. The MOEFCC report states "Exploring and encouraging adaptation measures in urban design will be critical in the context of developing urban areas. This will be a major focus alongside measures to promote sustainable urban design in the context of expanding cities." This aspect is dealt with in more details in Chapter No. 2.

1.3 PRIVATE SECTOR INITIATIVES

Incidentally, it may be mentioned that some public and private sector companies in India are becoming aware about the need to make sweeping reduction in carbon emissions. In the joint declaration released on November 5th, 2020, the 'India CEO Forum on Climate Change' agreed to set voluntary in-house targets and achievable GHG reduction and energy conservation goals [15]. Two important goals mentioned in the declaration include achieving enhanced energy efficiency and promotion of renewable energy (RE).

Several Indian corporate houses have set decarbonisation targets internally to become carbon neutral by 2050 or before. These include Vedanta, Aditya Birla Group, JSW Group, Adani Transmission, Mahindra & Mahindra, Tata Group and Dalmia Cement, among others. While the Reliance Industries has set a target of net-zero by 2035, L&T aims to be carbon neutral by 2040. The list is likely to get expanded in the near future as many other corporates would be joining the 'net zero' pledge.

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BUILDING & CONSTRUCTION SECTORS IN INDIA

CHAPTER 2

In Chapter 1 it was mentioned that one of the key transition pathways of India's Long-Term Low-Carbon Development Strategy (LT-LCDS) includes promoting adaptation in urban design, energy and material efficiency in buildings and sustainable urbanization. In this context, it would be appropriate to look into the current status and certain futuristic trends – especially those related with of the GHG emissions – from the building and construction sectors from India.

2.1 CARBON EMISSIONS FROM BUILDINGS & CONSTRUCTION

According to the latest report of Global Alliance of Building and Construction, the building and construction sectors account for 34 % of the total energy used globally and are responsible for 37% of carbon emissions (see Fig 2.1) [1]. Although similar India-specific data is not available, broad trend from urban India would generally be comparable.

The recent report of the Ministry of Environment, Forest and Climate Change (MoEFCC) of the Government of India, quoting the publication by Ahuja, M. and Soi, U, shows that buildings account for more than 40 % of India's energy consumption in cities [2].

Earlier data (2018) of the Ministry of Statistics and Program Implementation – Government of India, showed that the building sector in India consumes over 30% of the total electricity consumed in India, out of which 75% is used in residential buildings [3]. The Energy Conservation Building Code of India (ECBC) refers to the projections made by NITI Aayog, which showed that the electricity consumptions in residential buildings is going to rise from 260 TWh in 2016–17 to anywhere from 630 and 940 TWh in 2032 – a jump of nearly 2 to 3.5 times [4,5]!

Rising Urbanization Trend

India is currently one of the fastest growing economies in the world. The country has embarked on large-scale development of its physical infrastructure and housing to cater to the needs of its vast population – currently around 1.45 billion.

Nearly a third of India's population presently lives in cities and the urbanization trend is catching up faster as more and more people are moving away from rural areas to find work and make a living in the cities.

Accurate and reliable data on futuristic trends in urbanization in India are not readily available. Yet, certain glimpse of the trends can be obtained from other reliable publications. For example, quoting the estimate of the Department of Economic Affair (DEA) [6], the MoEFCC report mentioned above points out the urban Indian population is estimated to increase sharply from 377 million in 2011 to 600 million by 2030.

Admitting that urban areas are engines of growth; the CBRE Research Report 2019 quotes a study which estimated that nearly 75% of India's GDP will be generated from the urban regions by 2030 [7].

A recent report of the International Energy Agency (IEA) estimated that 270 million people are likely to be added to India's urban population from 2020 to 2040, requiring extra 30 billion m^2 of residential floor space by 2040! Fig 2.2 [8]. This means that on an average, around 1,500 million m^2 floor space needs to be built every year from 2020 to 2040!.

While presenting the interim budget on February 1st, 2024, India's Finance Minister announced that the government will target to construct 20 million additional houses during the next five years. The finance minister also announced that while the rural 'housing for all' scheme – named as Pradhan Mantri Awas Yojana Gramin (PMAY-G) – was able to achieve the target of 29.5 million households as of February 1, 2024, the government intends to launch a scheme to help deserving sections of middle class living in rented houses or slums [9].

The cement industry in India was quick to provide a matching response to the government's efforts in developing physical infrastructure and housing in the country. During 2018–19, the Indian cement industry has an installed capacity of 537.21 million tonnes and

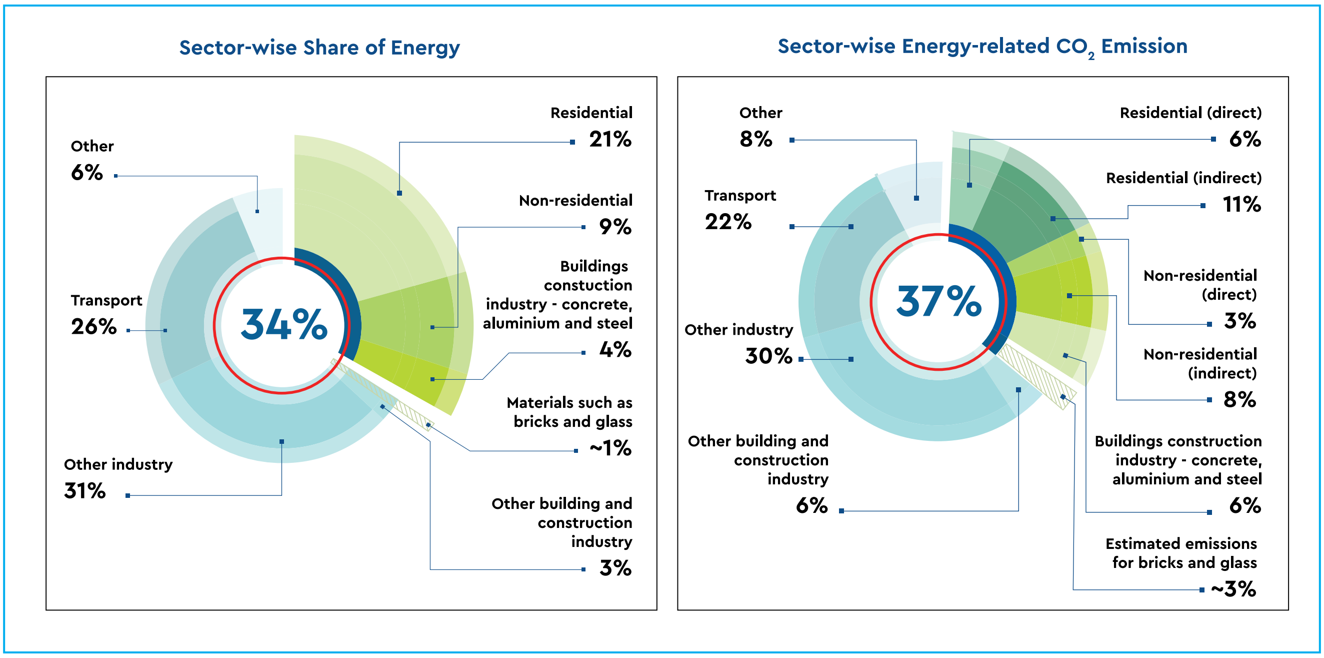

Fig 2.1 Sector-wise share of energy and energy-related carbon emission [1]

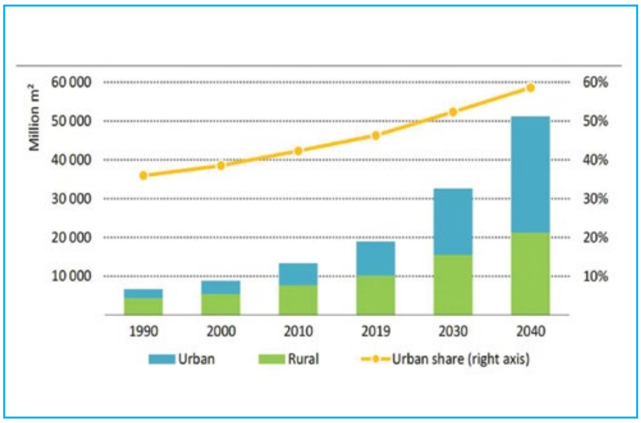

Fig 2.2 Housing requirement in India: IEA estimate [8]

production of 334.37 million tonnes, Fig 2.3 [10]. According to the Press Information Bureau of the Government of India, the installed capacity of cement reached 600 million tonnes and the production jumped to 391 million tonnes in 2022–23 [11]. Considering the growth plans of some of the major cement companies, the Decarbonization Roadmap for the Indian Cement Industry by GCCA India and TERI reports that the cement production growth will be at 6% CAGR.

Energy Demand

Expanding economy and increased urbanization and industrialization are bound to lead to an increase in the energy demand. While stating that buildings account for more than 40% of India's total energy consumption, the MoEFCC report quotes an estimate from the IEA which projects that the residential electricity demand in India is likely to triple by 2050 [8]. The IEA report also postulates that "to meet growth in electricity demand over the next twenty years, India will need to add a power system the size of the European Union to what it has now."

In addition to housing, suitable infrastructure in terms of additional roads, schools, hospital, malls, water storage tanks, pipelines etc. is also required to be provided to the new entrants in the urban area. This is indeed a gigantic and challenging task.

Considering these futuristic projections, one can imagine the likely surge in the demand of energy intensive materials like cement, steel, walling materials, etc.

2.2 THRUST ON RENEWABLE ENERGY

Fulfilling the needs of the rising population especially in the urban area will be one of the major challenges before India. Based on the data of the Central Electricity Authority (CEA), the total installed power capacity in India was 442,856 MW as on April 2024 [13].

Out of the total installed capacity, nearly 54.19% of the capacity was based on the use of fossil fuels and 43.94% on renewable sources of energy [13].

Great Leap Forward in installed RE Capacity

India has taken a great leap forward in increasing its renewable energy capacity. It is indeed creditable that India stands at 3rd position in the world in terms of installed RE capacity [13].

India is fortunate to have been bestowed with a huge RE potential, estimated to be 1000 GW-plus or even more. As on April 2024, out of the total power capacity of 442.8GW, India has achieved the RE capacity of 191.7 GW which is nearly 44% of the total power capacity. It is claimed by the government that the recent RE capacity addition by India was the fastest in world.

Further, the government of India has an ambitious plan of raising the RE capacity to 500 GW till 2030 [14].

The IEA report states that India would be "adding the equivalent of a city the size of Los Angeles to its urban population each year. To meet growth in electricity demand over the next twenty years, India will need to add a power system the size of the European Union to what it has now."[8]

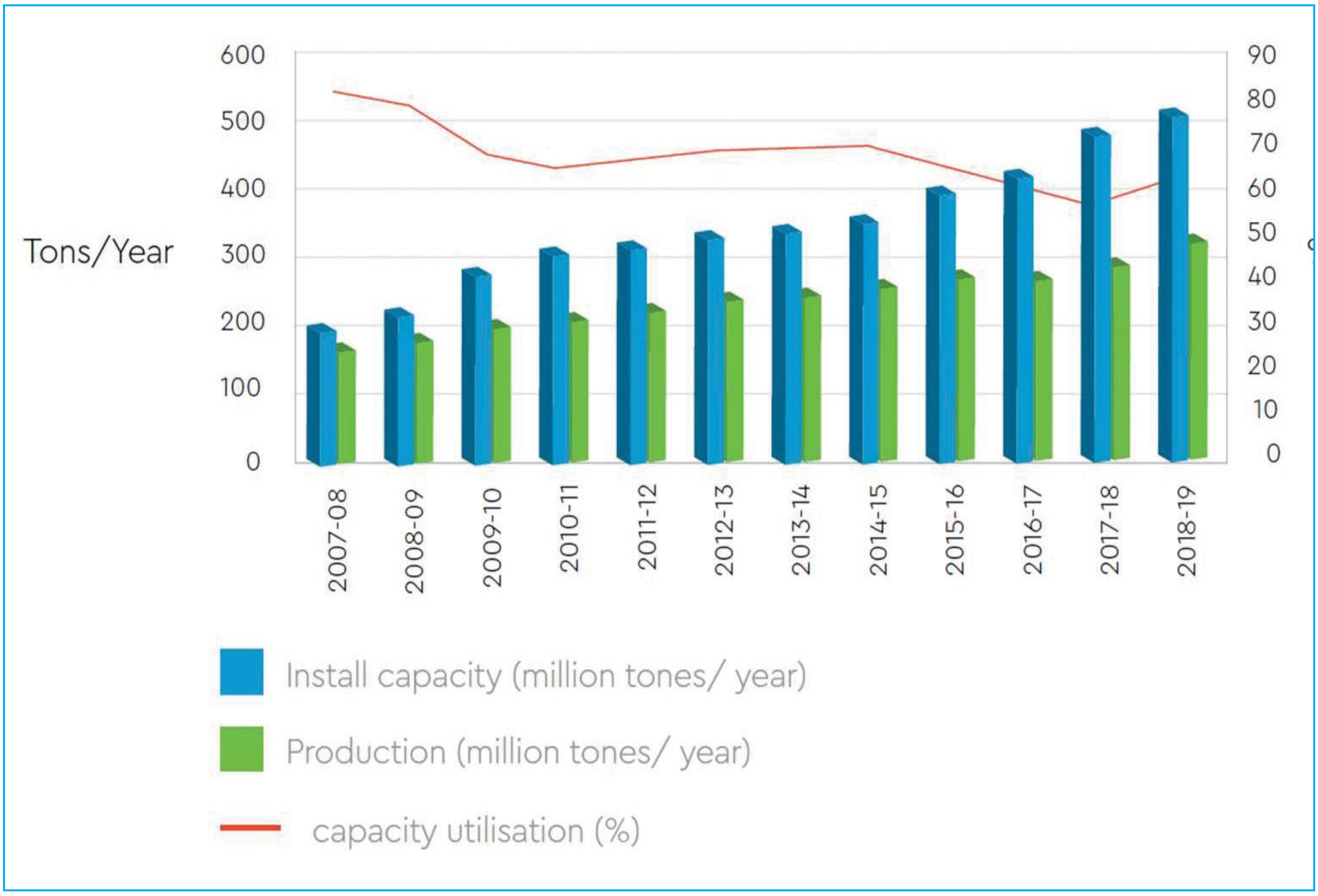

Fig 2.3 Installed cement capacity and production during 2007-08 to 2018-19 [10]

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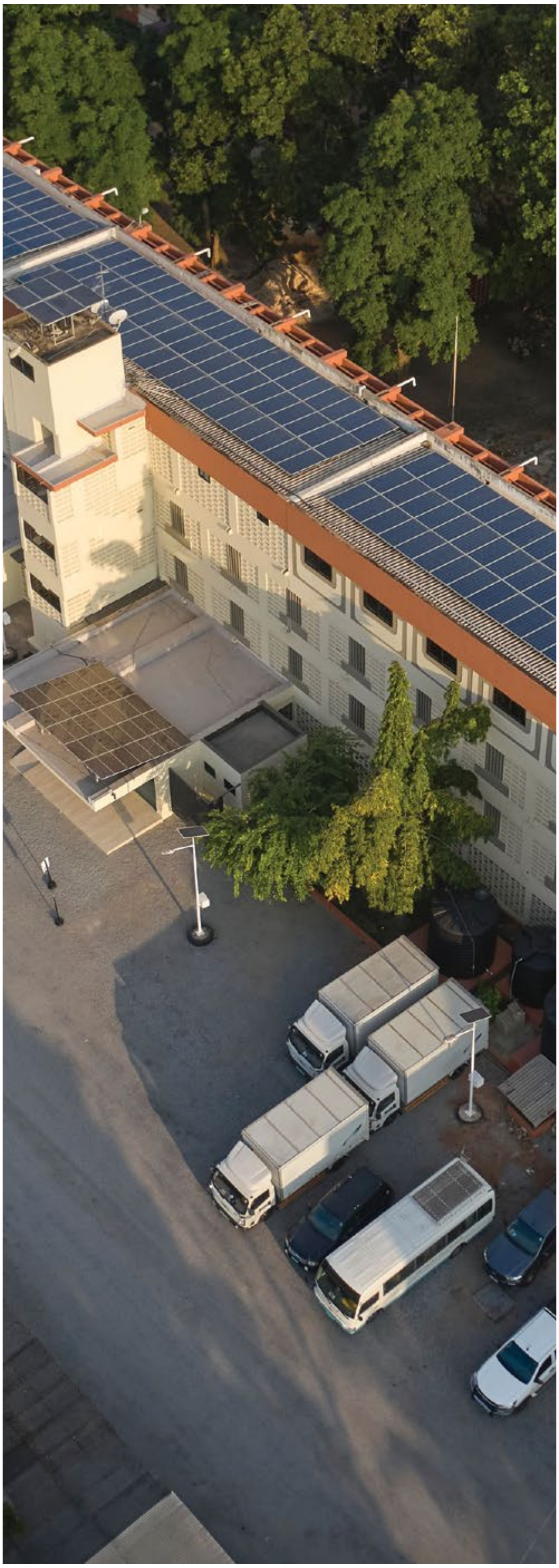

OPERATIONAL & EMBODIED CARBON

CHAPTER 3

3.1 BUILDING LIFE CYCLE STAGES

The greenhouse gas emissions from the building and construction can be attributed to its different life cycle stages. The building life cycle stages or modules are defined in the European Standard EN 15978 and the same are adopted universally. The life cycle stages as defined in the EN standard are divided into the following five main areas (see Fig.3.1):

1. Product stage (A1–3)
2. Construction stage (A4–5),
3. Use stage (B1–6)
4. End of life stage (C1–4), and
5. Beyond the life cycle (D).

The carbon emissions are broadly divided into two main categories, namely, 'operational' carbon and 'embodied' carbon. The World Green Building Congress (WGBC) defines operational carbon as the emissions associated with energy used to operate the building or in the operations of its infra-structure [2]. The operational carbon comprises of the carbon generated because of the energy consumed in buildings for a variety of operations such as heating, cooling, ventilation and lighting systems, as well as energy used by equipment such as fridges, washing machines, TVs, computers, lifts, and cooking.

Carbon emissions are released not only during operational life but also during the manufacturing, transportation, construction, repair, maintenance, refurbishment and end of life phases of the built assets – buildings and infrastructure. These emissions, commonly referred to as 'Embodied Carbon'; and it can be seen from Fig 3.1 that these occur during the product and construction stage (A1–5), use stage (B1–5) and end-of-life stage (C1–4).

The 'Whole Life Carbon' encompasses carbon emissions from all life stages, i.e. from A1 to C4.

Amongst the greenhouse gases, CO_2 is the well-known and most abundantly emitted greenhouse gas; but there are several other gases such as methane, nitrous oxide, fluorinated gases, etc. that contribute to the overall effect. For convenience, CO_2 or carbon emission is a more common terminology used in the literature and the same is adopted in this publication too. To account for other greenhouse gases, carbon emission is quantified in units of 'CO_2 equivalent' commonly referred as CO_{2e}. One kg of CO_2 has a Global Warming Potential (GWP) of 1 $kgCO_{2e}$.

Operational & Embodied Carbon in Buildings

Types of Carbon Emissions in Buildings		
	Operational Carbon:	**Embodied Carbon:**
Reducing Carbon Emissions	• Use passive architectural designs.	• Minimize material use through efficient structural designs.
	• Install energy-efficient appliances.	• Opt for sustainable and low-carbon materials.
	• Transition to renewable energy sources.	• Promote recycling and reuse of materials.
	Focus Areas:	**Future Challenges:**
Key Insights	• Most carbon-reduction efforts target operational carbon.	• Global material consumption expected to double by 2060. • Embodied carbon contribution may increase from 25% in 2021 to 49% by 2060 (UNEP report).

3.2 HOW TO ACHIEVE NET ZERO OPERATIONAL CARBON?

Operational carbon refers to the GHG emissions owing to the use of energy in buildings during their life cycle. Traditionally, efforts on reduction in carbon have focused on reducing operational carbon and improvement in efficiencies of the energy-consuming products in operation. In India, the data on the energy required for the operations of buildings and the operational carbon emissions are unfortunately not readily available.

For reducing the operational energy requirements in buildings, architects adopt 'passive' architectural measures that focus on utilising the natural environment to provide heating, cooling, ventilation etc. (see Fig 3.2). They also suggest the use energy efficient appliances for lighting, air-conditioning, etc. All such measures go a long way in reducing the operational energy requirements. Yet, certain balance operational

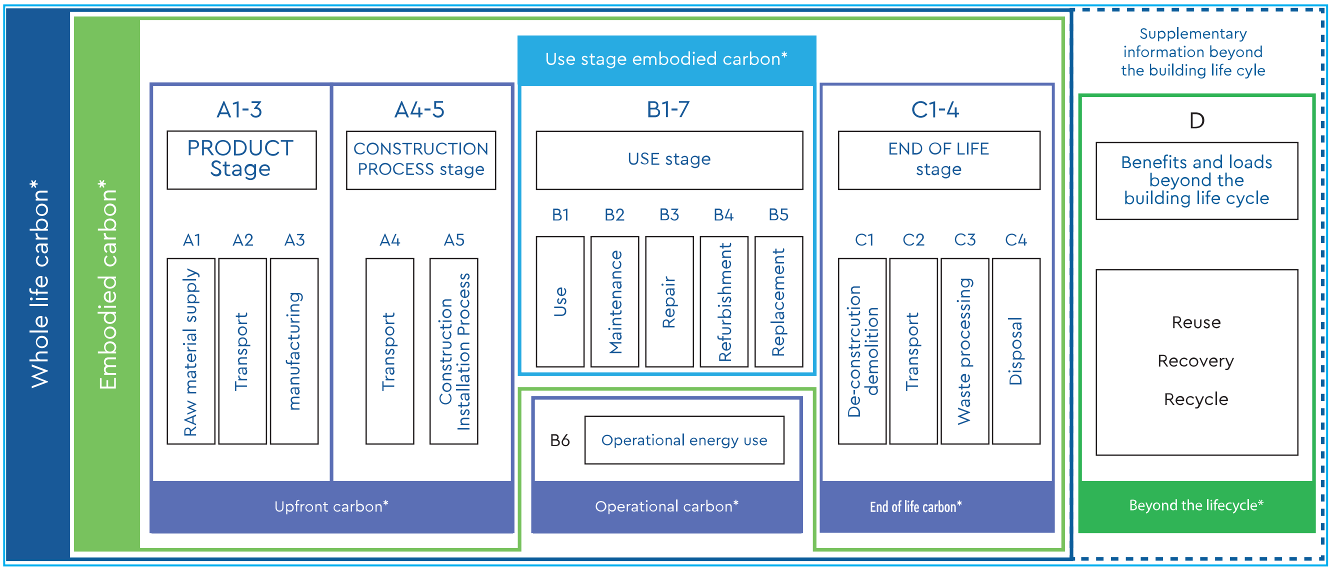

Fig 3.1 Stages in Building life cycle [1]

energy requirements remain to be satisfied. The same can then be met with the use of renewable energy.

To achieve net zero operational carbon, it would be ideal if all new buildings are designed without the use of fossil fuels and that the operational energy demand be entirely met with passive architectural measures, adoption of energy-efficient measures and appliances and of course, the use of renewable energy. World Green Building Congress's (World GBS's) goal is to achieve net zero operational carbon from all new buildings by 2030 and then achieve similar feat for the existing buildings by 2050 [3]. In India, it will be appropriate to start implementing such provisions for new buildings from now onwards.

Yet, if it is not be possible for the high-rise buildings to fulfil their power demand from renewable energy through RTS system or off-site RE farms, then it is suggested by the World GBC that the total renewable energy potential at national level should at least be equal to the operational energy requirements of all buildings in the country.

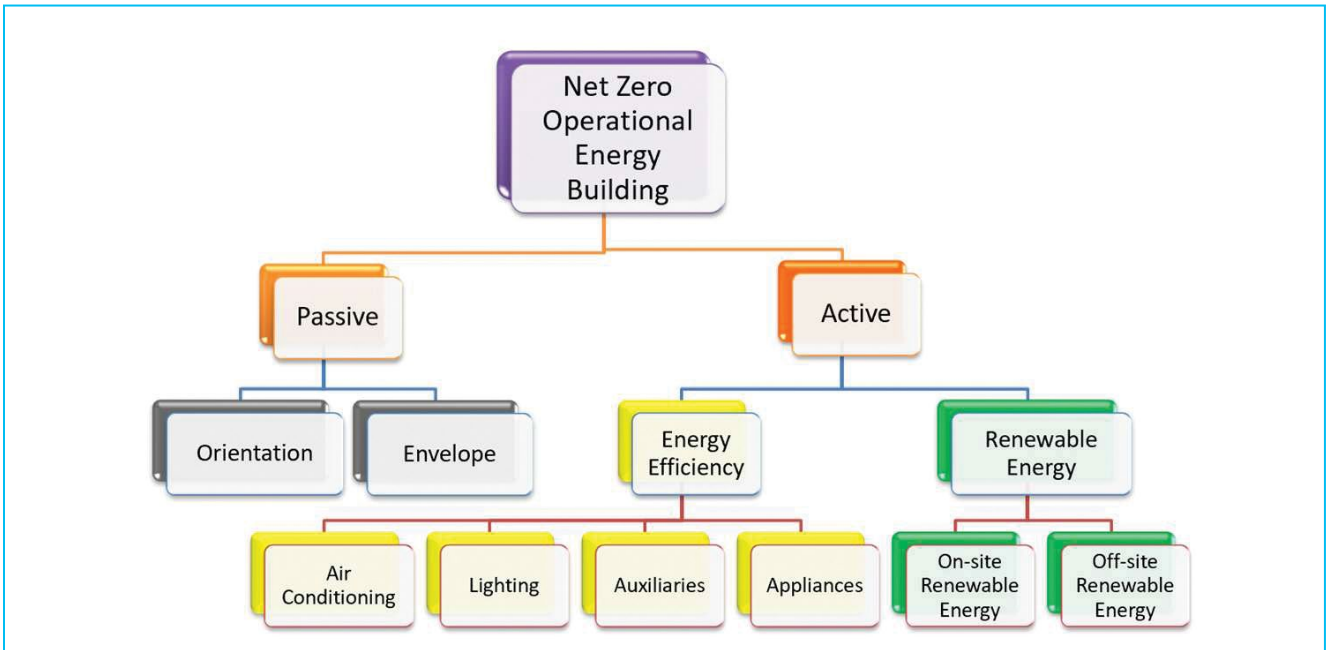

Fig 3.2 How to achieve net zero Operational Energy
(Source: CII Green Business Centre)

For low-rise buildings – for example, grounplus one or two storeyed structures – the total operational energy consumption can be met with the adoption of the combination of passive architectural measures, use of energy-efficient appliances and renewable energy – the latter using roof-mounted photovoltaic (PV) panels. (Fig 3.3) Since multistoreyed buildings have a smaller proportion of roof-to-floor area, investment in 'additional' off-site renewable energy (say solar or wind farms) will become imperative (Fig 3.4). Currently, several local municipal and metropolitan authorities in India have made it mandatory to adopt renewable energy measures wherever possible. Since it is not technically and economically feasible to use of RTS system in high-rise building construction, certain efforts are seen in tapping solar energy using PV panels over open parking areas, walkways, internal roads, etc.

Fig 3.3 Typical roof-top solar

Roof Top Solar (RTS)

A recent report published by the Council for Energy, Environment and Water (CEEW) shows that over 250 million households across India have the potential to deploy a massive 637 GW of solar energy capacity on rooftops [4]! The CEEW report clarifies that the 637 GW potential is the estimated 'technical' potential, which gets reduced by nearly onefifth to 118 GW (which the report terms as 'economic' potential) after factoring the current electricity consumption of the Indian households, which happens to be in the lower consumption range.

The high roof-top solar (RTS) potential estimated by CEEW is indeed the good news. Currently, India is reported to be successful in tapping only around 11 GW of the RTS capacity, of which only 2.7 GW is from the residential sector.

India needs to take a quantum jump in increasing its RTS potential. Four main factors support this proposition. Firstly, as confirmed by the CEEW report, there exists a huge 'technical' and 'economical' RTS potential in India. Secondly, there has been a steep decline in the tariff of both solar and wind energy in India. Thirdly, the government encourages setting up of RTS facility and even provides subsidies for this purpose. The recently launched Pradhan Mantri Suryodaya Yojana, aims to deploy rooftop solar systems for 10 million households throughout India [5]. Fourthly, the availability of net metering facility has made the adoption of RTS system more attractive for the users.

Fig 3.4 Typical solar and wind farms

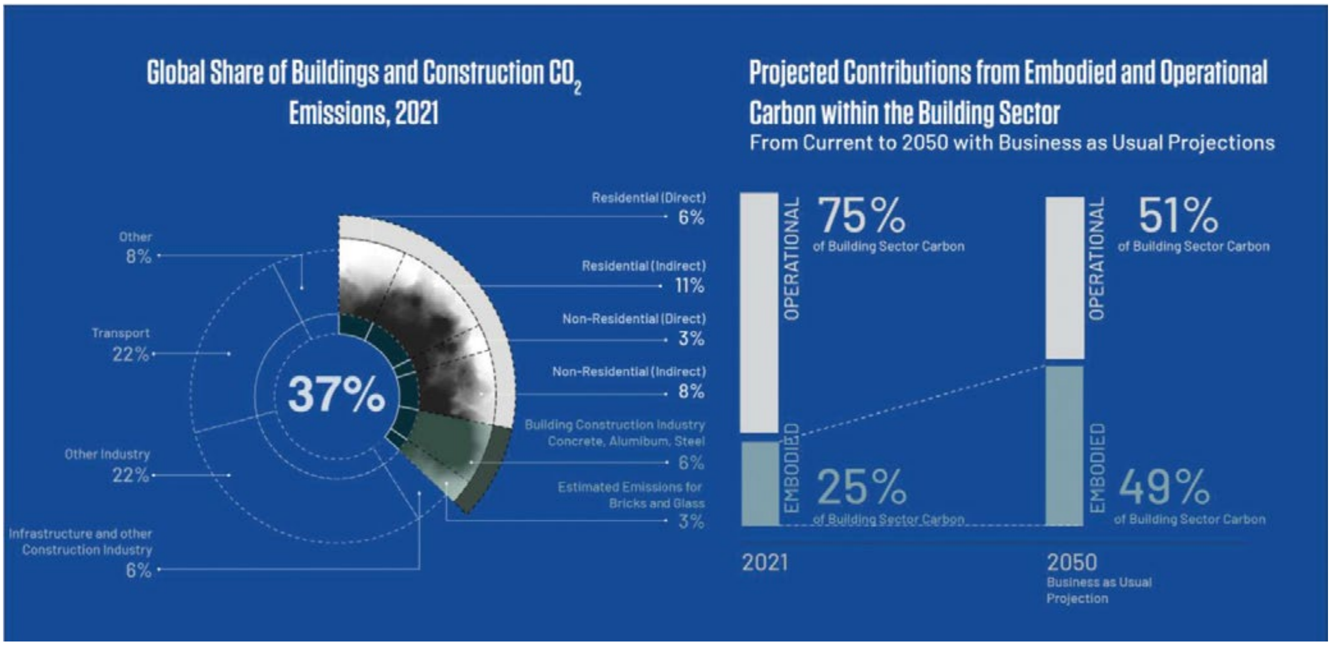

Fig 3.5 Embodied carbon contribution from buildings and construction is slated to increase from 25% (2021) to 49% (2050) under 'business-as-usual' condition [7]

India's building and construction industry needs to respond positively and speed up the practice of specifying and providing RTS systems wherever possible.

3.3 HOW TO REDUCE EMBODIED CARBON FROM BUILDINGS?

As mentioned earlier, major efforts taken in reducing carbon emissions have mainly focussed on reducing the operational carbon. According to the report of the UNEP/Global ABC, out of the 37% of energy-centric carbon emissions from the building and construction sector, nearly 9% emissions came from building materials like concrete, steel, aluminium, glass and bricks [6].

Under the 'business-as-usual' scenario, the global material consumption is expected to nearly double by 2060, and the embodied carbon contribution is estimated to increase from 25% in 2021 to 49% in 2060, Fig 3.5! [7]. It is therefore highly essential to focus attention on the reduction of embodied carbon.

The commonly used construction materials employ energy intensive, mineral based extractive processes. Under the 'business-as-usual' scenario the GHG emissions from concrete, steel, bricks, aluminium, glass, and copper are slated to increase till 2060 as shown in Fig 3.6 [8].

As mentioned earlier, the embodied carbon is generated from the use of energy and materials during each of the five life cycle modules.

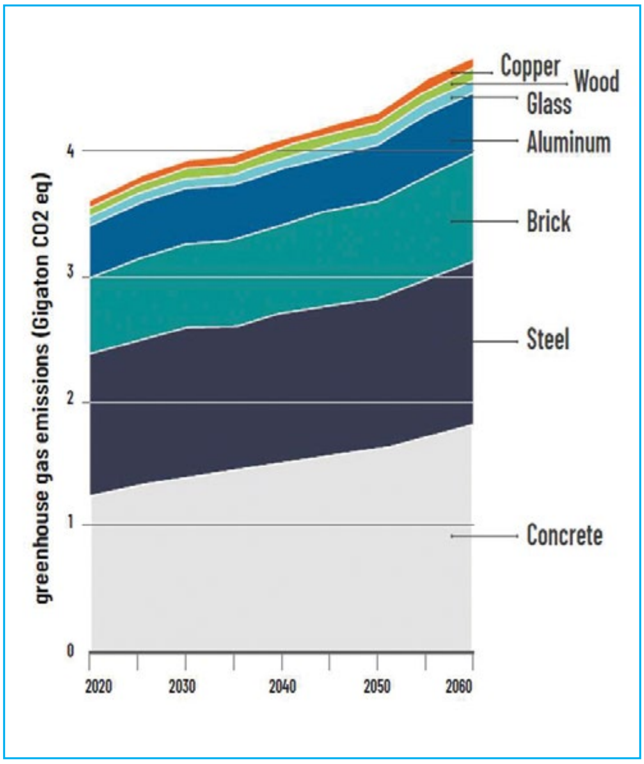

Fig 3.6 Projected GHG emissions from building materials in a 'business-as-usual' scenario to 2060[8]

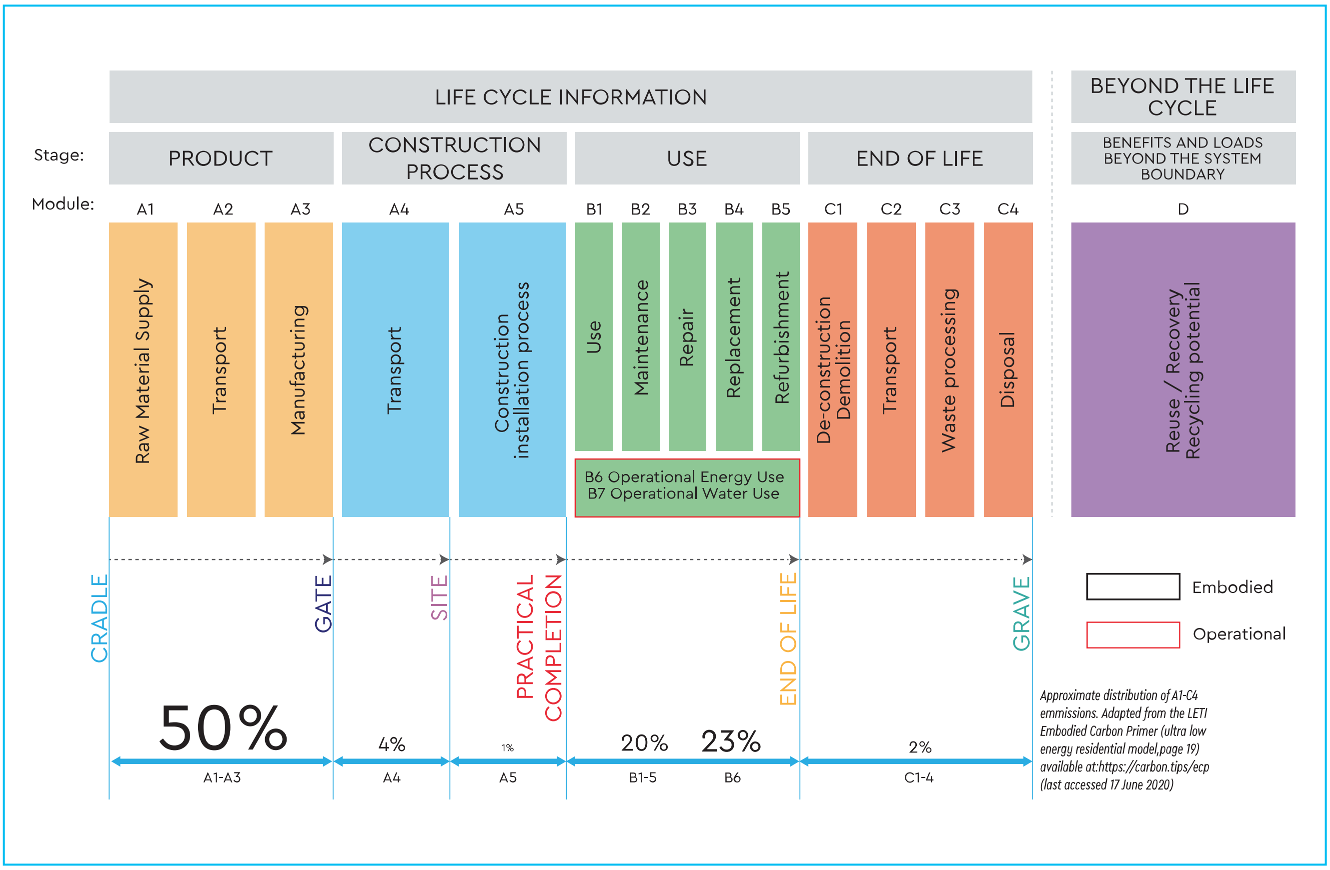

Fig 3.7 Nearly 50% of the embodied carbon is generated during the product stage [9]

However, based on embodied concrete primer published by Low Energy Transformation Initiative (LETI), John Orr, Gibbons and Arnold reports that nearly 50% of the embodied carbon is generated during the product stage, around 4% during transport and 1% during the construction stage, Fig 3.7 [9].

Construction materials have the potential to be used even after the end of the service life of buildings and these can be reused in new construction – of course, after necessary processing (e.g. recycled concrete aggregates). However, for achieving this, the architects and structural engineers need to design buildings for disaggregation and disassembly.

For the current work, we have considered embodied carbon from the "Cradle to practical completion of construction" stage i.e. from life cycle stages A1 to A3 and A4 and A5. Although the estimation and reduction of embodied carbon from other stages is important, it is suggested that one needs to concentrate on the estimation and reduction of embodied carbon from A1 to A5 stage. As mentioned in the IAStruct's guide on 'How to calculate embodied carbon', A1–A5 emissions will be released before 2050; therefore, with a view to keep the global warming within 1.5°C, it would be essential to focus on reducing the emissions during the A1–5 stage [10].

The most appropriate time to carry out calculations of the embodied carbon is in the early design stages. During this stage, the structural engineer has the necessary time to calculate the embodied carbons of different alternative designs so that a meaningful carbon comparison of these designs is available to advocate decision in favour of the lowest embodied carbon alternative.

The detailed evaluation of embodied carbon for high-rise building is included in Chapter 6 and that on the low-rise building is provided in Chapter 8.

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ROADMAP TO ACHIEVE 'NET ZERO'

CHAPTER 4

Considering the climate emergency and also the urgent need to keep global warming temperature below 1.5^{0} C, nearly 151 countries (as on January 2024), responsible for 88% of GHG emissions and covering 89% of world population have made commitments to achieve 'net zero' carbon emissions [1]. While certain advanced countries made commitments to achieve net zero emissions by 2050, India announced to achieve net zero emissions by 2070. Incidentally, the European Union (EU) recently adopted the revised Energy Performance of Buildings Directive (EPBD) in May 2024, with new rules aimed at reducing energy use and emissions from buildings across the EU, including targets for all new buildings to be zero emissions by 2030, and to phase out the use of fossil fuels in building heating systems by 2040 [2].

4.2 WHAT IS NET ZERO EMISSIONS?

In recent times, the term 'Net Zero' emission is being mentioned quite often in the media. The term refers to greenhouse gas (GHG) emissions. For achieving the Net Zero emissions, the balance between the GHG emitted by the state (or by the industry) and the amount of GHG emissions removed from the atmosphere needs to be zero. When Net Zero refers to a product, it means the GHG emissions by the product over its entire life span.

With a view to mitigate the adverse effects of climate change, it is highly crucial that those nations, industries and companies, who have made commitments to achieve net zero emissions, should have well drawn plans and targets to achieve the same. It is heartening to note that a number of global industry organizations and big sized companies from different sectors have already drawn plans and targets to achieve net zero emissions.

Organisations such as Science Based Target Initiative (SBTi) have developed pathways for companies to validate their net zero greenhouse gas reduction targets. It is reported that over 5,000 businesses across regions and industries have set emissions reduction targets through the Science Based Targets Initiative (SBTi) [3].

4.3 BUILDING & CONSTRUCTION SECTORS

As far as the building and construction industries are concerned, two sectors – namely cement and concrete and steel are the hard-to-abate energy intensive sectors. While cement and concrete sector account for nearly 7% of the carbon emissions globally, steel accounts for nearly 8% of carbon emissions, Fig 4.1 [4].

Fortunately, the global leaders of different sectors are fully aware of their responsibilities on the carbon emission front. The global organizations of certain sectors have already drawn plans and outlined pathways to achieve Net Zero emissions. They are also actively supporting and pursuing R&D in new technologies such as Carbon Capture, Storage & Utilization (CCSU), green/blue hydrogen, etc.

One such global organization which has drawn the Net Zero roadmap for the cement and concrete sectors is the Global Cement & Concrete Association (GCCA).

4.4 GCCA ROADMAP for NET ZERO 2050

The GCCA is a global body of companies from the cement and concrete sectors. GCCA members account for 80% of the global cement industry volume outside of China including some key Chinese manufacturers such as CNBM, West China, Taiwan Cement Corporation. Leading cement companies from India are GCCA members. Also, several national and regional industry associations are the affiliate members of GCCA.

GCCA released its global roadmap for the cement and concrete sectors before the 2021 Glasgow Summit (COP 27). The salient features of the roadmap are included in GCCA publication "Our Concrete Future" and the same can be downloaded from GCCA website [5].

The GCCA report clearly mentions that such a carbon reduction can only be achieved with the full-scale participation and support from all stakeholders from the cement and concrete sectors and others groups

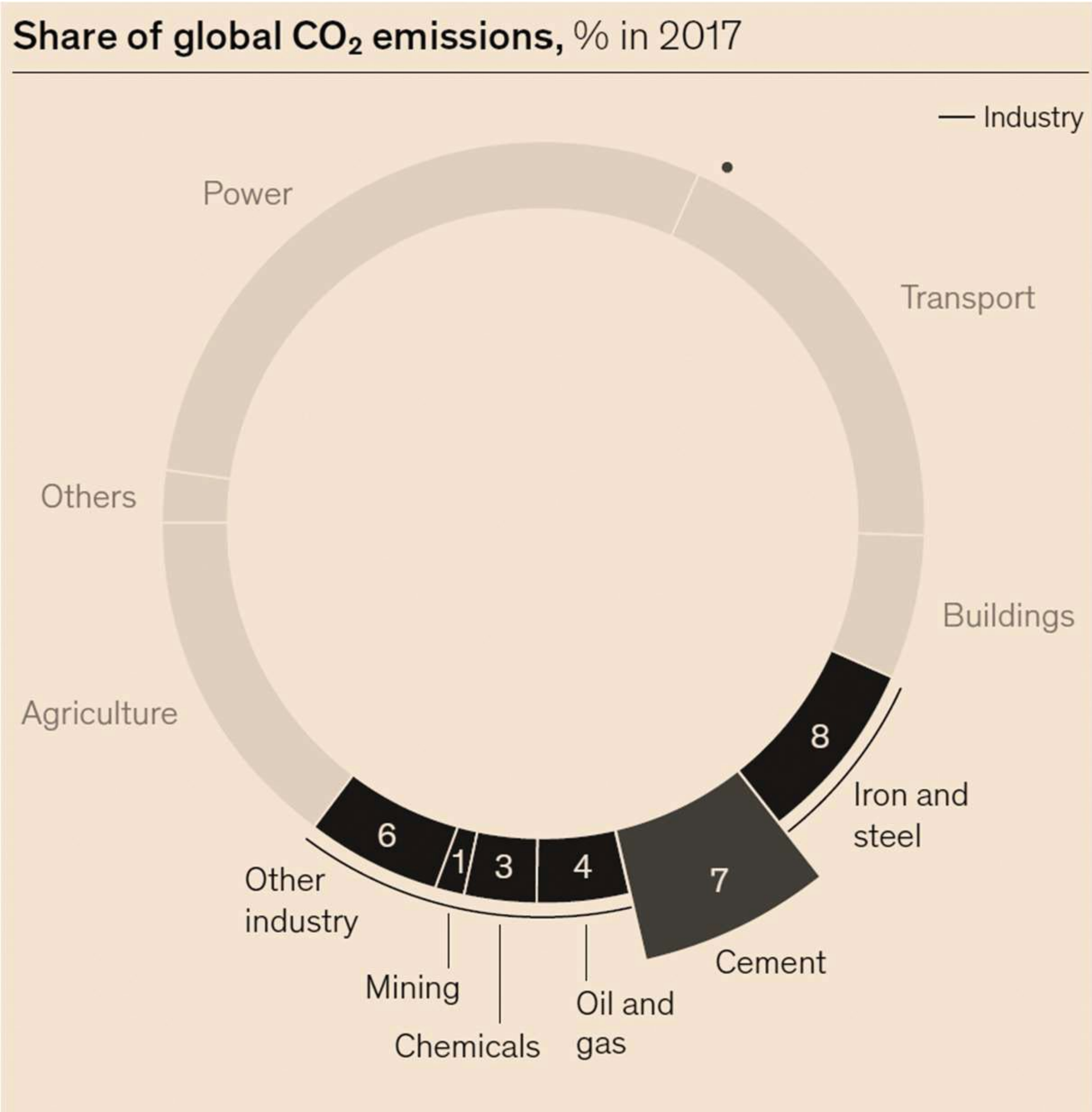

Fig 4.1 Cement and steel sectors together accounts for nearly 15% of carbon emissions globally [4]

consisting of policymakers, governments, investors, researchers, innovators, customers, end-users and financial institutions, who need to help in providing the right resources, tools and policies to deliver net zero concrete for the world.

4.5 INDIA-SPECIFIC NET ZERO ROADMAP

The GCCA-India and TERI launched the roadmap for Net Zero CO_2 emission by 2070 for the Indian cement sector 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 GCCA India-TERI roadmap is divided in eight key areas. These areas along with their estimated percentage contributions to net zero emissions 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%)

The GCCA India-TERI roadmap is diagramatically shown in Fig 4.2.

The lever of cement use efficiency includes reduction of embodied emissions, design optimization and material efficient approach, thus highlighting the need of this (embodied carbon report) report.

The roadmap is an aspiration of the Indian Cement Sector. The roadmap highlights the need of policy and incentives to reach the goal of a decarbonized cement sector.

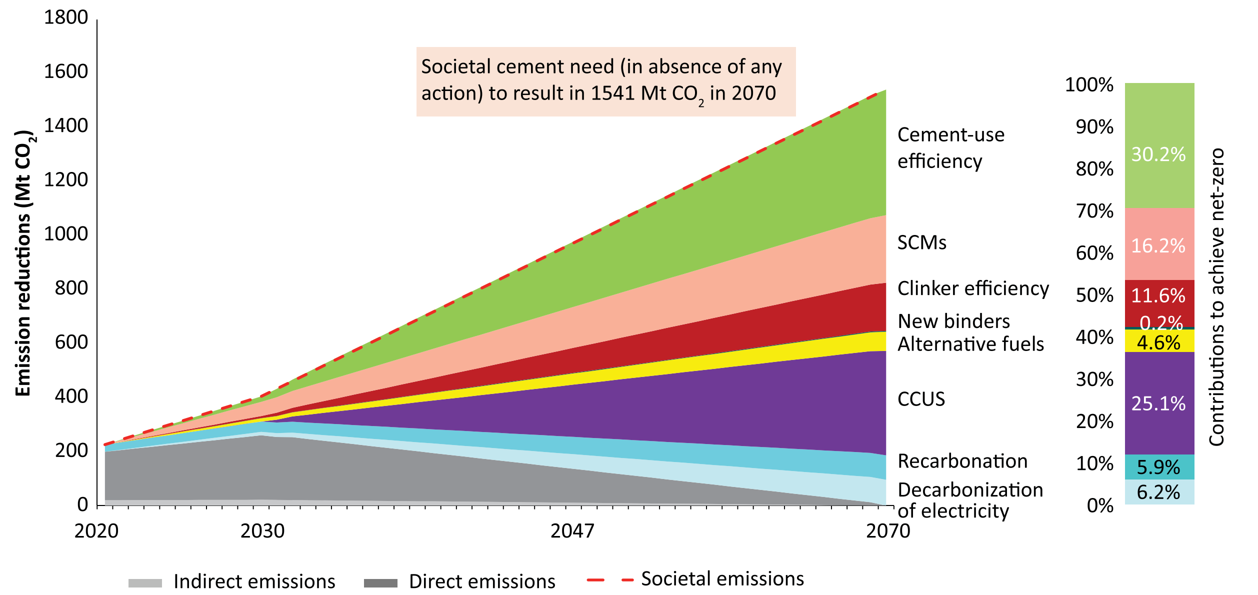

Fig 4.2 Net-zero CO_2 2070 pathway for Indian cement sector

Role of LCCF

The Low Carbon Construct Forum (LCCF) has been one of the active members of TERI's Task Group. Formed as Section 8 Company, LCCF is a not for profit forum. Its mission is to create awareness amongst architects, engineers, contractors, material suppliers, building owners and users, infrastructure facilitators, policymakers etc. about the dangers of climate change and to advocate pursuit of sweeping reductions in the carbon emissions from buildings and construction sectors in India.

LCCF highlighted the need for assessing embodied carbon from buildings in India. They proposed that a comparative study of embodied carbon from residential buildings should be carried out to encourage industry professionals to adopt low-carbon design alternatives. Following discussion and revision, GCCA-India approved LCCF's proposal to conduct 'Comparative Assessment of Embodied Carbon from Low-rise and High-rise Buildings in India'.

The Fig 4.3 indicates the flow chart of the work conducted by LCCF under the guidance of the Expert Committee and Task Force set up by GCCA-India.

The work of assessment of embodied carbon from buildings needed joint working with two main groups, one having expertise and experience in structural design and knowledge of software used for such work, and the second having expertise in concrete technology and construction. Taking help from the locally available resources, LCCF spearheaded both groups.

Comparative Assessment of Embodied Carbon: High-rise Building

Review of the structural design work of the high rise building was done by a peer review team. One of the major peer review comments pertained to the need of complying with the provisions of IS 16700, which got revised during September 2023, while the initial design of the high-rise building work done by LCCF team was based on the then prevailing version of IS 16700–2017. This necessitated redesign of the modelling and structural work completely.

For the redesign of the high-rise building, the structural designer team decided to choose a new G+34 storey building for their assessment. The comments of the reviewer team on the revised assessment were shared by GGCA-India with LCCF.

The design team of LCCF successfully clarified the points raised by the reviewer team, which approved the structural design and the embodied carbon assessment report.

Comparative Assessment of Embodied Carbon: Low-rise Building

Besides the comparative assessment of embodied carbon in a high-rise building, LCCF simultaneously undertook similar exercise for low-rise (G+3) building. During the review meeting it was suggested that LCCF team should consider one more option of walling material that consisted of the use of fly-ash based bricks. Certain written comments on the LCCF report were received from the reviewer team.

The work of revised structural design of the G+3 building along with assessment of embodied carbon was completed and sent for approval to the peer reviewer and GCCA-India by LCCF. Final approval to the work was received by LCCF.

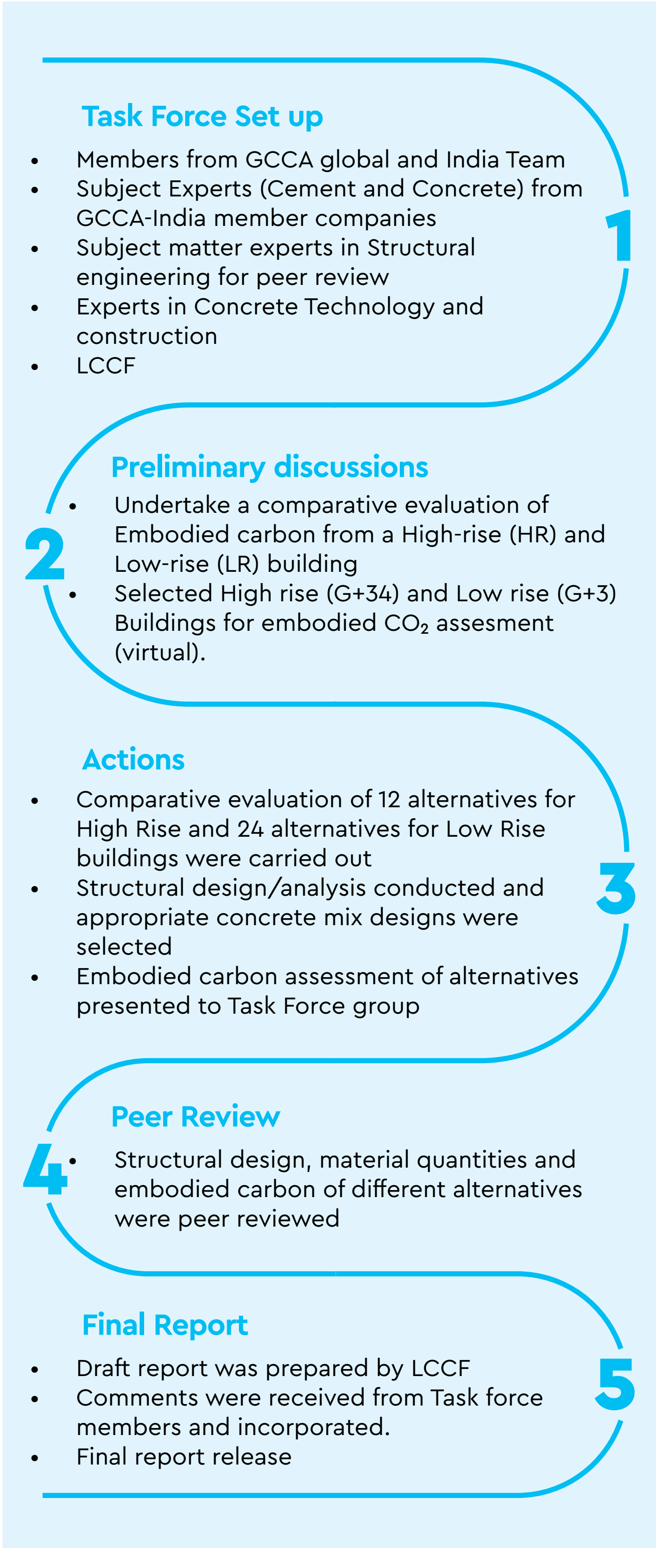

Fig 4.3 Infographic showing the flow chart of the work involved

Final Report

In the meantime, LCCF has prepared the draft of the Final Report on the Comparative Assessment of both high-rise and low-rise buildings and the draft of the same was sent to GCCA-India. A meeting of the GCCA-India team and LCCF was held to review the contents on the final draft report. GCCA-India raised certain comments on the report which were complied with. LCCF team made the presentation on the final report to the stakeholder committee on October, 2024.

The second draft of the final report was submitted to GCCA-India in November 2024. The draft was further revised by adding the Executive Summary and it was again discussed with GCCA-India team on December, 2024. Minor corrections suggested by GCCA-India were carried out by LCCF and the draft was then finalized.

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CASE STUDY OF A HIGH-RISE BUILDING: SALIENT FEATURES OF STRUCTURAL DESIGN AND ANALYSIS

CHAPTER 5

For the comparative evaluation of embodied carbon in high-rise buildings we have considered a typical Ground+34 storeyed building located in a metropolitan city. The scarcity of land in the metropolitan cities in India is driving the land prices sky high and is compelling developers and builders to build taller buildings. The building is designed to be occupied by families from higher middle-income group of the society.

The typical plan of the building shown in Fig 5.1 is prepared by a professional architect firm, duly considering incorporation of "passive" architectural features catering to the maximum use of natural light, ventilation, etc.

5.2 STRUCTURAL SYSTEMS

Majority of tall buildings presently constructed in India predominantly uses the alternative of Reinforced Concrete (RC) framed construction with different types of infill walls. Our study of evaluating the embodied carbon follows the prevailing practice which will throw light on the broad baseline of the embodied carbon in tall buildings in India.

The supply of concrete for tall buildings in big cities is mainly obtained from commercial Ready Mix Concrete (RMC) plants or from site based batching plants, the latter becomes possible provided sufficient space is available at site to locate such plants. Several concrete mixes are being presently produced from commercial/captive ready-mixed concrete plants and

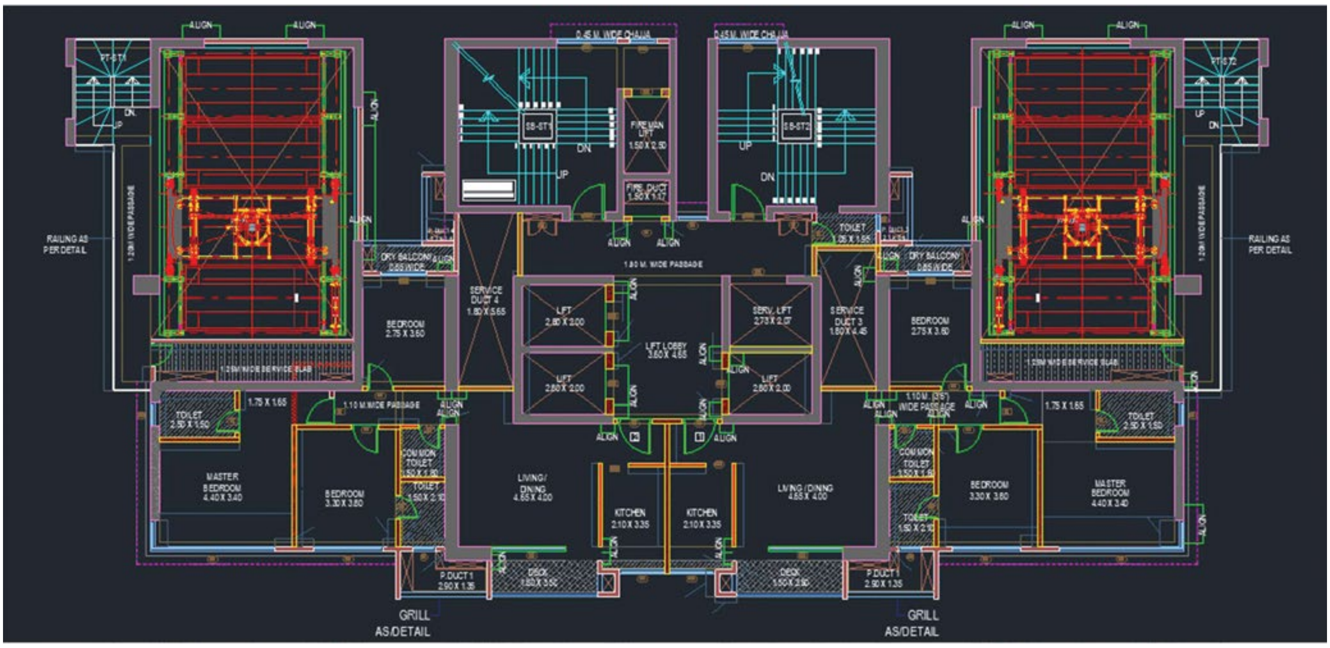

Fig 5.1 Typical architectural plan of G+34 building to obtain The north direction arrow from the architect

used in tall buildings. These concrete mixes invariably include supplementary cementitious materials (SCMs) such as fly ash, ground granulated blast furnace slag (GGBS), microfine material (for highstrength concrete) and chemical admixtures. We have considered different alternatives in concrete grades in our work in evaluating the embodied carbon.

The G+34 building for which embodied carbon is being evaluated is essentially a reinforced concrete (RC) framed structure with columns/shear walls. The columns/shear walls are connected to each other with a network of beams and slabs with the slabs acting as in-plane rigid diaphragms at each of the floors. In the RC framing system, use of box type aluminum formwork system (commonly known as MIVAN system in India) is now widely used and hence considered in one of the alternatives.

For the study of embodied carbon content comparison, following three basic alternatives have been considered as listed below:

1. **Reinforced concrete frame with infill walls of autoclave aerated concrete (AAC) blocks**
2. **Reinforced concrete frame using MIVAN system with infill walls of non-structural concrete**
3. **Reinforced concrete frame with infill walls of fly ash-based bricks**

Following two sets of concrete grades are then considered for each of the three options mentioned above:

1. **M80, M70, M60 grades of concrete for shear walls/columns and M60, M50, M45 for slabs and beams**
2. **M60, M50, M40 grades of concrete for shear walls/columns and M45, M35, M30 for slabs and beams**

Further sub-division is considered in the concrete mixes. Both fly ash (FA) and ground granulated blast furnace slag (GGBS) are available near Mumbai and are being presently used widely in ready-mixed concrete production. So, we considered both these alternatives.

The use of microfine materials like condensed silica fume/ultrafine GGBS (UGGBS) is considered essential for high-strength concrete i.e. for M60, M70 and M80 grades, in addition to FA and GGBS.

Thus, as shown in Fig 5.2, a total of 12 alternatives become available to us for the comparative evaluation of embodied carbon in high-rise buildings. For more clarity on the different alternatives, refer Fig 1 in Executive Summary.

Table 5.1 Some salient features of ground+34 storeyed building

Building Location	Metropolitan city (near Mumbai)
Building configuration	Ground + 34 floors.
Size of building	34.5m (length) x17m (width) x 132.18m (height)
Flats/floor	2 Nos (3BHK)
Configuration of the typical flat	Living room + 3 bedrooms (1 master + 2 other) + 3 toilets + 1 balcony
Approximate area of flat	84m^2
Construction area	15, 878m^2
Lifts	4 Lifts (including one service lift)
Staircases	2 Nos
Parking	2 mechanical parking towers
Foundations	Rocky strata having safe bearing capacity 2500 kN/m^2

	Concrete grades and walling material	OPC + Supplementary Cementitious Materials
Alternative – 01 & 02	M80 M60 with Autoclave Aerated Concrete blocks	OPC+GGBS+(Microfine material for HSC)
		OPC+FA+(Microfine material for HSC)
Alternative – 03 & 04	M60 M40 with Autoclave Aerated Concrete blocks	OPC+GGBS+(Microfine material for HSC)
		OPC+FA+(Microfine material for HSC)
Alternative – 05 & 06	M80 M60 with Fly Ash Bricks	OPC+GGBS+(Microfine material for HSC)
		OPC+FA+(Microfine material for HSC)
Alternative – 07 & 08	M60 M40 with Fly Ash Bricks	OPC+GGBS+(Microfine material for HSC)
		OPC+FA+(Microfine material for HSC)
Alternative – 09 & 10	M80 M60 with NS Wall	OPC+GGBS+(Microfine material for HSC)
		OPC+FA+(Microfine material for HSC)
Alternative – 11 & 12	M60 M40 with NS Wall	OPC+GGBS+(Microfine material for HSC)
		OPC+FA+(Microfine material for HSC)

Fig 5.2 A total of 12 alternatives are considered in the evaluation of embodied carbon

Schematic Elevation & Plans of Typical Alternatives

The schematic elevation showing concrete grade variations in shear wall/columns of the two alternatives is shown in Fig 5.3. Similarly, the concrete grade variations in slabs/beams in two alternatives is depicted in Fig 5.4.

Typical Plans of Different Alternatives

The building floor plan is similar from the ground floor to the 19th floor. While the next floor is the Service floor, the 20th floor is for the 'other service amenities', which accommodates a swimming pool, gymnasium, etc. The building floor plan changes from the 21st floor and remains similar till 34th floor.

The typical schematic plans of the floors are shown in Annexures 5 as given below.

- Annexure 5-A-1: Typical floor plan – 1st to 19th floor
- Annexure 5-A-2: Service floor plan above 19th floor
- Annexure 5-A-3: Service floor plan showing swimming pool, gymnasium
- Annexure 5-A-4: Typical floor plan – 21st to 34th floor

5.3 CODES AND STANDARDS

Specific applicable codes and standards are identified and adopted in the design philosophies as appropriate to the structural elements. The latest editions of the Codes and Standards are used in designs as listed in Table 5.2. All design work is based on Indian Standards and Codes with latest revision, with amendments if any, as on date.

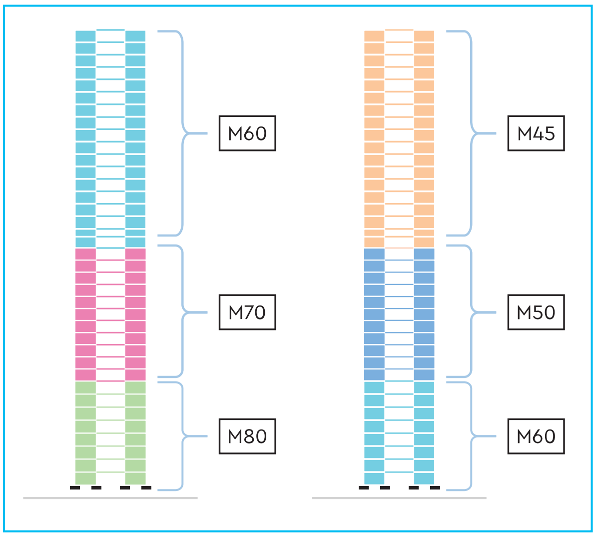

Fig 5.3 Elevation showing Concrete Grade variation in Sheat Wall /columns Alternatives 01 and 02

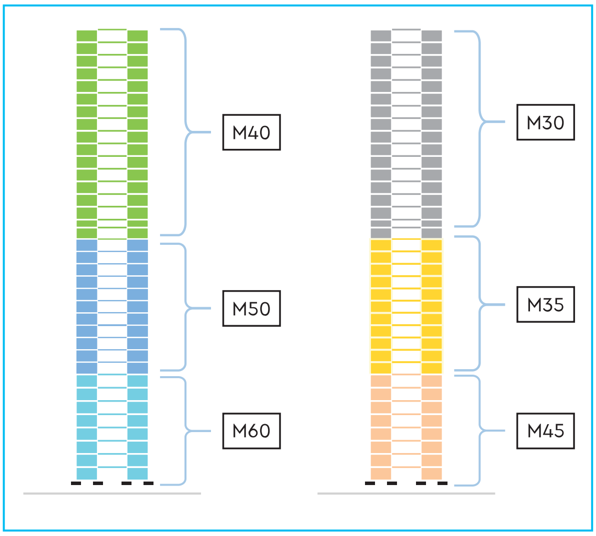

Fig 5.4 Elevation Showing Concrete Grade variation in Slabs/Beams Alternatives 03 and 04

Table 5.2 Indian Standards adopted in design

(a) Design of Elements

IS Code	Description
IS 456:2000	Plain and Reinforced Concrete – Code of Practice, Bureau of Indian Standards (BIS), New Delhi.
SP 16:1980	Design Aids for Reinforced Concrete to IS. 456:1978, BIS.
SP 34:1987	Handbook on Concrete Reinforcement and Detailing, BIS.
IS 1904:2021	Code of Practice for Design and Construction of Foundations in Soil: General Requirements, BIS.
IS 2950:1981	Code of Practice for Design and Construction of Raft Foundation (Part – 1)
IS 3370 (Part 1 & 2):2009	Concrete Structures for Storage of Liquids, Code of Practice, BIS
IS 3370 (Part III & IV):1967	
IS 16700:2023	Criteria for Structural Safety of Tall Buildings, First Revision, BIS.
IS 800:2007	General Construction in Steel – Code of Practice, BIS.
IS 1786:2008	High Strength Deformed Steel Bars for Concrete reinforcement
IS 12251:1987	Code of Practice for Drainage of Building Basements, BIS.

(b) Design loads (Other than Earthquake Loads)

IS 875 (Part 1):1987	Design Dead loads (Unit weights of building material and stored materials) for Buildings and Structures, BIS
IS 875 (Part 2):1987	Code of Practice for Design Loads (Other Than Earthquake) For Buildings and Structures, Part 2: Imposed Loads, BIS
IS 875 (Part 3):2015	Design Loads (Other than Earthquake) for Buildings and Structures – Code of Practice Part 3 Wind Loads, BIS

(c) Design for Earthquake Resistant Structure

IS 1893 (Part1):2016	Criteria for Earthquake Resistant Design of Structures; Part 1 General Provisions and Buildings, BIS
IS 4326:2013	Earthquake Resistant Design and Construction of Buildings – Code of Practice, BIS
IS 13920:2016	Ductile Design and Detailing of Reinforced Concrete Structures subjected to Seismic Forces – Code of Practice, BIS
SP 22	Explanation to IS 1893 & IS 4326

(d) Design for Fire Safety

IS 1642	Fire Safety Building Materials
SP 7(2)	National Building Code of India

(e) Cement and Concrete Standards

IS 269:2015	Ordinary Portland Cement – Specification (6^{th} revision)
IS 3812:Part 1:2013	Pulverized Fuel Ash: part 1: For Use as Pozzolana in Cement, Cement Mortar and Concrete
IS 16714:2018	Ground Granulated Blast-Furnace Slag for Use in Cement, Mortar and Concrete – Specifications
IS 15388:2003	Specifications for Silica Fume
IS 16715:2018	Ultrafine Ground Granulated Slag – Specifications
IS 9103:1999 (reaffirmed 2018)	Specifications for Concrete Admixtures
IS 383:2016	Coarse and fine aggregates for concrete – Specifications

5.4 DESIGN PHILOSOPHY

For the design of reinforced concrete elements, Limit State Method specified in IS 456:2000 is used.

Ductile detailing norms have been adopted to make the building earthquake-resistant in accordance with IS 13920:2016. Criteria specified in IS 16700:2023 have also been duly considered in the design.

5.5 Materials of Construction

Concrete: Ingredients, threshold limits in Mix design and durability criteria

The grades of concrete proposed for different elements of the project are given in Table 5.3. The modulus of elasticity for different grades of the concrete are included in Table 5.4

Ordinary Portland Cement:

Ordinary Portland Cement (OPC) of grade 53 confirming to IS 269 is used in concrete mix design

Aggregates

The sizes of coarse aggregates shall confirm to IS 383. The nominal maximum size of coarse aggregate is 20mm, suitably graded as per the requirement of mix design.

Water

Mixing water shall confirm to IS 456:2000.

Durability Criteria for Concrete

a. Based on IS 456:2000, the Environmental Exposure Class for the building is considered as "moderate"

b. It is ensured that the minimum cementitious content and water cement ratio as specified in IS 456:2000 are satisfied.

c. The upper limits on the supplementary cementitious materials contents as specified in the Indian Standards are followed in the mix designs of various grades of concrete for the baseline condition.

Table 5.3 Grades of concrete for different elements

Element	Cube strength (N/mm²)
Miscellaneous/non-structural concrete, curbs, sidewalks	30
Slabs on ground	30
Foundation: Raft, Isolated and combined footings	40
Beams, slabs, staircases	Varies from M60, 50, 45, 35 to 30
Columns	Varies from M80, 70, 60, 50 to 40
Core and shear walls, coupling beams and non-structural walls	Varies from M80, 70, 60, 50 to 40
Ramps	40

Table 5.4 Modulus of elasticity for different grades of concrete

Concrete Designation	28-day Compressive strength Cubes	Elastic modulus, E (MPa)
M80	80 N/ mm²	44721
M70	70 N/ mm²	41833
M60	60 N/ mm²	38729
M50	50 N/ mm²	35355
M40	40 N/ mm²	31622
M30	30 N/ mm²	27386

Density of reinforced concrete assumed in design is 25 kN/m³.

Table 5.5 Clear cover to reinforcement for different structural members

Sr No.	Structural Member	Clear cover, mm	Minimum Dimension, mm	Remarks
1	Foundation	75	-	-
2	Shear walls	40	300 (coupled shear walls)	-
3	Beams	40	230	2 hour fire resistance
4	Slabs	35	125	2 hour fire resistance

Reinforcement

High yield strength deformed bars confirming to IS 1786 with fy = 500 N/mm² are used, with specified elongation of more than 14.5%.

Clear Cover to Reinforcement

Clear cover for all reinforced concrete members is considered in accordance with IS 456:2000 corresponding to moderate exposure conditions for the superstructure as well as the substructure and to satisfy a fire rating of 2 hours.

The clear cover to outermost layer of reinforcement for listed elements is based on the exposure condition/fire rating requirements and the same is included in Table 5.5.

5.6 LOAD CONSIDERATIONS

The loads considered in the design are as specified in the Indian Standards and the same are included in Annexure 5-B.

Load Combinations

The results obtained from the computer analysis in the form of member forces and reactions are used to design the structural members. Load combinations of the member forces considered for arriving at the design forces are in shown in Table 5.6.

Table 5.6 Load combinations considered in design

Comb. No.	Load Combination	Load Factors					
		DL	LL	EQX	EQY	WX	WY
1	1.5 DL + LL	1.5	1.5	-	-	-	-
2	1.2 (DL + LL ± EQX)	1.2	1.2	1.2	-	-	-
3	1.2 (DL + LL ± EQY)	1.2	1.2	-	1.2	-	-
4	1.5 (DL ± EQX)	1.5	-	1.5	-	-	-
5	1.5 (DL ± EQY)	1.5	-	-	1.5	-	-
6	0.9DL ± 1.5EQX	0.9	-	1.5	-	-	-
7	0.9DL ± 1.5EQY	0.9	-	-	1.5	-	-
8	1.2 (DL + LL ± WX)	1.2	1.2	-	-	1.2	-
9	1.2 (DL + LL ± WY)	1.2	1.2	-	-	-	1.2
10	1.5 (DL ± WX)	1.5	-	-	-	1.5	-
11	1.5 (DL ± WY)	1.5	-	-	-	-	1.5
12	0.9DL ± 1.5WX	0.9	-	-	-	1.5	-
13	0.9DL ± 1.5WY	0.9	-	-	-	-	1.5

Notes:
Suffixes x and y mentioned in the table indicate the direction in which the force is applied.

Notations:
DL = Dead Load
LL= Live Load
EL = Earthquake Load
EQX = Earthquake Load in X-direction
EQY = Earthquake Load in Y-direction
WLX = Wind Load in X-direction
WLY = Wind Load in Y-direction

All members have been designed for the largest value of the design forces obtained due to positive as well as negative values of reversible forces (Wind and Earthquake).

Service Load Combinations

The service load combinations considered in the design are shown in Table 5.7.

Table 5.7 Load combinations considered in design

Comb. No.	Load Combination	Load Factors			
		DL	LL	EL	WL
1	DL + LL	1	1		
2	DL ± EL	1		1	
3	DL+ 0.8LL ± 0.8EL	1	0.8	0.8	
4	DL ± WL	1			1
5	DL+ 0.8LL ± 0.8WL	1	0.8		0.8

Self-Weights

The self-weight of the structural members considered in the design are included in Table 5.8.

Table 5.8 Self weight of structural members considered in the design

Density of reinforced concrete	25 kN/m³
Density of plain concrete	24 kN/m³
Density of steel	78.5 kN/m³
Density of water	10 kN/m³
Density of floor finishes / plasters	20 kN/m³
Density of fly ash Bricks	20 kN/m³
Density of light weight blocks	10 kN/m³

5.7 ANALYSIS METHOD ADOPTED FOR MODEL ON ETABS

Auto-CAD files have been used as the geometrical database to generate floor-wise geometry. Vertical members have been connected from floor to floor to assemble space frame. Preliminary sectional properties have been assigned to all the structural elements. The floor slabs have been modeled as Membrane connected by horizontal diaphragms.

Appropriate moment releases have been given wherever required. Appropriate grades of concrete as mentioned earlier have been assigned. Gravity loads (Dead load and Live load) have been applied to all the respective areas as per the location and occupancy. Seismic analysis has been carried out independently using procedures mentioned in IS 1893 (Part 1):2016. Wind load analysis has been carried out using procedures mentioned in IS 875 (Part 3):2015. Provisions in IS 16700:2023 have also been considered.

The computer analysis evaluates individual internal member forces, reactions at foundation level and deflection pattern of the entire structure and in the individual members. Analysis of results obtained from both exercises are used to arrive at the universal solution.

This data are then used to verify the adequacy of the member sizes adopted and after further iterations arrive at the most appropriate reinforcement design of the structural members. Some reruns of the analysis program is required for arriving at the optimum structural space frame characteristics that satisfy the strength and stability criteria in all respects.

P-Delta Analysis

P-Delta Analysis is carried out with the 'Iterative based on load' option in ETABS considering the scale factors included in Table 5.9.

Table 5.9 Scale factors for load patterns

Load Pattern	Scale Factor
Dead Load	1.2
Superimposed Dead Load	1.2
Live Load	0.5

Design eccentricity

For design, semi rigid diaphragm has been assigned; hence nominal eccentricity of 5 % has been assigned. Along with this, eccentricity for response spectrum cases have been assigned according to the IS 1893 (Part I):2016.

Stiffness Modifiers

The modifiers included in Table 5.10 are used for properties of cracked RC section as per IS 1893 (part 1):2016 Clause 6.4.3.1 and IS 16700:2023 (Table No 5).

Table 5.10 Stiffness modifiers

(a) Service Condition

BEAMS	Scale Factor	COLUMNS	
Cross section (axial) Area	1	Cross section (axial) Area	1
Shear area in 2 direction	1	Shear area in 2 direction	1
Shear area in 3 direction	1	Shear area in 3 direction	1
Torsional Constant	0.01	Torsional Constant	1
Moment of inertia about 2 axis	0.7	Moment of inertia about 2 axis	0.9
Moment of inertia about 3 axis	0.7	Moment of inertia about 3 axis	0.9
Mass	1	Mass	1
Weight	1	Weight	1
SLABS (shell slabs only)	**SLABS (shell slabs only)**	**SHEAR WALLS**	**SHEAR WALLS**
Bending m11 Modifier	0.35	Membrane f11 Modifier	0.9
Bending m22 Modifier	0.35	Membrane f22 Modifier	0.9
Bending m12 Modifier	0.35	Membrane f12 Modifier	0.9
		Bending m11 Modifier	0.9
		Bending m22 Modifier	0.9
		Bending m12 Modifier	0.9

Table 5.10 Stiffness modifiers

(b) Ultimate condition

BEAMS	Scale Factor	COLUMNS	
Cross section (axial) Area	1	Cross section (axial) Area	1
Shear area in 2 direction	1	Shear area in 2 direction	1
Shear area in 3 direction	1	Shear area in 3 direction	1
Torsional Constant	0.01	Torsional Constant	1
Moment of inertia about 2 axis	0.35	Moment of inertia about 2 axis	0.7
Moment of inertia about 3 axis	0.35	Moment of inertia about 3 axis	0.7
Mass	1	Mass	1
Weight	1	Weight	1
SLABS (shell slabs only)	**SLABS (shell slabs only)**	**SHEAR WALLS**	**SHEAR WALLS**
Bending m11 Modifier	0.25	Membrane f11 Modifier	0.7
Bending m22 Modifier	0.25	Membrane f22 Modifier	0.7
Bending m12 Modifier	0.25	Membrane f12 Modifier	0.7
		Bending m22 Modifier	0.7
		Bending m12 Modifier	0.7

Table 5.11 Serviceability checks: RC Frame using M80, M70, M60 and AAC Blocks

(b) Ultimate condition

Sr. No.	Threshold limits for serviceability		RC Frame using M80-70-60 and AAC Walls			
1	Permissible Displacement • 528 mm (For EQ) • 264 mm (For Wind)	EQPX	80.98			
		EQPY	66.32			
		EQNX	81.23			
		EQNY	60.92			
		WX	132.56			
		WY	83.45			
2	Storey Drift (permissible value 0.001)	EQPX	0.00079			
		EQPY	0.00064			
		EQNX	0.00080			
		EQNY	0.00058			
		SPECX	0.00036			
		SPECY	0.00032			
3	Torsional Irregularity Check (Max/Avg ratio should be less than 1.2)		**Max**	**Min**	**Avg**	**Max/Avg**
		EQPX	80.98	68.43	74.71	1.08
		EQPY	66.23	53.75	60.30	1.10
		EQNX	81.23	68.26	74.74	1.10
		EQNY	60.88	56.16	58.64	1.04
		SPECX	34.65	32.22	33.81	1.02
		SPECY	31.93	22.81	27.25	1.17
4	Modal Mass Participation [The ratios (marked in yellow) should be greater than 0.65]		**Time Period**	**UX**	**UY**	**RZ**
		1	3.36	0.6733	0.0000	0.0000
		2	2.99	0.0001	0.6682	0.0304
		3	2.35	0.0001	0.0379	0.688
5	Diaphragm Irregularity Check (The ratio of Mid/Avg should be less than 1)		**Avg**		**Middle**	**Mid/Avg**
		SPECX	34.57		30.64	0.89
		SPECY	25.03		24.42	0.98

5.7 SERVICEABILITY CHECKS

All serviceability models have been created under the given serviceability criteria. The stiffness modifiers have been assigned as per 7.3 for Serviceability Limit State (SLS) Model.

Typical serviceability checks done for the model related to RC Frame using M80, M70 M60 concrete and AAC Blocks are included in Table 5.11.

The serviceability checks for other following models are included in Annexures 5-C-1 to 5.

- Annexure 5-C-1 Serviceability checks: RC Frame using M60, M50, M40 and AAC Blocks
- Annexure 5-C-2 Serviceability checks: RC Frame Using M80, 70, 60 with Non-structural walls
- Annexure 5-C-3 Serviceability checks: RC Frame Using M60, 50, 40 with Non-structural walls
- Annexure 5-C-4 Serviceability checks: RC Frame Using M80, 70, 60 with fly ash brick walls
- Annexure 5-C-5 Serviceability checks: RC Frame Using M60, 50, 40 with fly ash brick wall

Conclusion

All serviceability models have been created under the structural design and analysis of the G+34 building satisfies the requirements specified in different Indian Standards such as IS 456:2000,

IS 16700:2023, IS 1893-Part 1:2016, IS 875-Part 3:2015 and other relevant standards.

CASE STUDY OF A HIGH-RISE BUILDING: EVALUATION OF EMBODIED CARBON

CHAPTER 6

It was pointed out in Chapter 3 that for the present work, we have planned to evaluate the embodied carbon from the "cradle to practical completion of construction" stage i.e. from life cycle stages A1 to A3 and A4 and A5.

In our work of 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 attributes to the use of materials 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.

6.2 EMBODIED CARBON FACTOR (ECF)

The crux of the embodied carbon calculations is based on the estimation of the so called 'Embodied Carbon Factor (ECF)' of each material or product.

ECF is an index that is used to determine the energy absorption caused by the emissions of different gases associated with product, normalized to an equivalent mass of carbon dioxide. ECF factor is also termed as global warming potential (GWP) factor.

The unit of ECF and GWP are the same, i.e. $kgCO_{2e}$ and usually it is expressed as $kgCO_{2e}/kg$ or $kgCO_{2e}/m^2$.

The embodied carbon of the material/product is calculated as below:

(respective quantity of material) x (ECF/GWP of material measured in $kgCO_{2e}$)

Ideally, it is the responsibility of the material manufacturer to provide an accurate value of the embodied carbon factor of his material to the team of architects/structural engineer/client, after due verification from accredited third party auditing agency. Many manufacturers from Europe and north America provide Environmental Product Declaration (EPD), which is based on the Life Cycle Assessment (LCA) of their product. The EPD data usually also include the ECF/GWP factors too.

Many professional bodies provide carbon factor/EPD databases. Some prominent names include ICE (U.K.), ASTM EPD, EC3 (USA), Australian EPD (Australia & New Zealand). Some private agencies have also come up to provide EPD and ECF/GWP values for specific products.

In India, under the study funded by the ecocities 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 [1]. This database is now available as 'User document' at IFC's Edge website (https://edgebuildings.com/) under the title 'Resources' and the same is freely downloadable.

For the purpose of the current work we have adopted the use of the ECF/GWP values from the IFC-EU database only for materials which do not need heavy energy-intensive processing (for example, coarse and fine aggregate) and supplementary cementitious materials (for example, fly ash), which are waste by-products from other industries. For cement and steel, which need heavy energy intensive techniques during production, we have used ECF factors from the published reports mainly from corporate companies from India (e.g. Tata Steel for steel, Ultratech Cement Ltd. for PPC and PSC). For EPS panel we have used the ECF factor obtained from Emmedue S.p., Italy. The ECF/GWP factors used in the present work along with their data source are included in Table 6.1.

6.3 ESTIMATION OF GWP FROM CRADLE TO GATE STAGES A1-A3

The following paragraphs cover the estimation of the GWP of all 12 alternatives as proposed in Chapter 5 for the lifecycle stages A1 to A3 initially, i.e. from cradle to gate (of site). This is then followed by estimation of GWP during LCA stage A4 and A5.

Concrete

For concrete, we have used the mix proportions adopted by a typical commercial ready mixed concrete (RMC) plant from Mumbai. The selected RMC facility has modern plant and machinery. It has twin shaft central mixer and separate silos to store ordinary Portland cement (OPC) and supplementary cementitious materials (SCMs) like fly ash, ground granulated blast furnace slag (GGBS) and micro silica (MS)/ultrafine ground granulated blast furnace slag (UGGBS). The plant has been supplying concretes of grades M20 to M80 to different projects in Mumbai.

Tables 6.2 to 6.6 include the mix proportions of concrete grades M20 to M80 as produced and supplied by the commercial RMC plant to different projects in Mumbai. Depending upon client specifications, the RMC plant uses both fly ash and GGBS as partial replacement of OPC. Table 6.2 shows mix proportions of OPC+ GGBS and Table 6.4 shows OPC+ FA mixes for grades M20 to M50. The commercial RMC plant adopts 50% replacement of OPC by GBBS (Table 6.2) for all grades from M20 to M50, while the percentage of replacement of OPC in case of OPC+FA mixes vary from 29.85% for M20 to 22.81% for M50 mix. The SCM replacement levels adopted by the RMC producer conform to the permissible limits specified in the Indian Standards. It can also be seen that the 28 day compressive strengths achieved for different grades of concrete are satisfactory. All concrete mixes are designed to provide pumpable concrete having slump of 150 mm at pouring site.

Table 6.1 ECF/GWP factors used in High-Rise (HR) & Low-Rise (LR) Project

Material	ECF/GWP, kg CO_{2e} /kg	Source
OPC	0.91	Annex A Table 14*, IFC-EU database
Fly ash	0.064	Annex A Table 14*, IFC-EU database
GGBS	0.066	Annex A Table 14*, IFC-EU database
UGGBS	0.060	Source : JSW Cement Ltd.
Coarse Aggregates	0.009	Annex A Table 14* IFC-EU database
Fine aggregates	0.009	Annex A Table 14* IFC-EU database
Chemical admixture	0.075	Annex A Table 14* IFC-EU database
PPC	0.709	'EPD Report OPC, PPC, PSC, PCC', Ultratech Cements Ltd, 2022–27, The International EPD System, www.environdec.com
PSC	0.487	'EPD Report OPC, PPC, PSC, PCC', Ultratech Cements Ltd, 2022–27, The International EPD System, www.environdec.com
AAC Block	0.5	Annex A Table 14* IFC-EU database
Fired clay brick	0.32	Annex A Table 14, IFC-EU database
Fly ash brick/Block	0.20	Annex A Table 14, IFC-EU database
Steel Reinforcement	2.34	Annual reports of Tata Steel, JSW^^
Aluminium formwork	13.2	Table 2.3 page 13 IStructE Guide [2]
Plywoood shuttering formwork	0.681	IStructE Guide Page 13 database**
Timber for formwork support	0.263	IStructE Guide Page 13 database**
EPS Panels	12.96kgCO_{2e} /m^2	Emmedue S.p.A.#

Notes
** Source: Table 14: India Construction Materials Database from IFC-EU [1]*
*** Source: "How to calculate embodied Carbon" IStructE Guide, U K*
^^ Based on Annual Reports of major producers like Tata Steel and JSW Steel (more details under sub-head 'Steel reinforcement')
 # Environmental sustainability: Emmedue S.p.A, https:/www.mdue.it/en/

Table 6.6 provides the mix proportions used by the commercial RMC plant for grades M60, M70 and M80. Here, it becomes essential to use a triple blend cementitious system containing the addition of microfine material like silica fume (MS) or ultrafine ground granulated blast furnace slag (UGGBS) to the conventional SCMs like fly ash and GGBS to achieve the desired compressive strengths and other properties of concrete. The % replacement of OPC by the combined SCMs (triple blend) in the M60, M70 and M80 grades of concrete are well within the permissible limits specified by the Indian Standards – varying from 25 to 33% in OPC+FA+MS/UGGBS mixes and from 37 to 45% in OPC+GGBS+MS/UGGBS mixes. All concrete mixes are designed to provide pumpable concrete having slump flow of over 500 mm at pouring site.

Using the ECF/GWP factors mentioned in Table 6.1, the GWP values of M20 to M50 grades of concrete (per m^3) are calculated for OPC+GGBS mixes in Table 6.3 and for OPC+FA mixes in Table 6.5. The GWP values of M60, 70 and 80 grades of concrete (per m^3) are included in Table 6.6.

In place of micro silica, the use of Ulrafine Ground Granulated Blastfurnance Slag has been growing in India as an alternative microfine material for concrete. UGGBS has both pozzolanic and hydraulic properties and it is a reactive material.

There is an Indian Standard IS 16715-2018 on UGGBS. Besides being reactive, the 'broader' particle size distribution of UGGBS helps in reducing the water demand in concrete. As far as the practical performance of UGGBS is concerned, mix design data from RMC industry indicates that one can replace MS in high-strength concretes with the equal amount of UGGBS in the mix to achieve similar compressive strengths. Incidentally, from the circularity and sustainability points of view, the use of UGGBS would certainly be preferable over silica fume as the latter is mostly imported from abroad in India. For the current work, we have considered the use of equal amount of MS and UGGBS in the M60, M70 and M80 mixes and included the estimated embodied carbon footprints for both alternatives in Table 6.6. It is observed that the difference between total values of the embodied carbon footprints of concrete mixes using MS and UGGBS is less than 0.1%. Hence from practical viewpoint, the use of UGGBS is considered like that of MS as far as the embodied carbon footprints are concerned.

The structural design and analysis work carried out by the structural engineering team (see Chapter 5) estimated the elementwise and grade wise quantities of concretes for all 12 alternatives and the same have been included in Annexture 6-A.

Table 6.2 Concreate mix proportions of OPC+GGBS

Concrete Grade	Cement, kg	GGBS, kg	SCM %	CA II, kg	CA I, kg	CSS, kg	Chem. Adm., kg	28-day Strength, MPa
M20	160	160	50.00	625	417	948	3.84	24.10
M25	175	175	50.00	632	426	913	4.20	29.20
M30	195	195	50.00	642	437	858	4.68	34.80
M35	220	220	50.00	647	440	786	5.28	39.40
M40	245	245	50.00	652	445	718	5.88	44.20
M45	275	275	50.00	642	438	654	6.60	49.30
M50	290	290	50.00	645	442	608	6.96	56.80

Table 6.3 GWP of OPC+GGBS mixes

	Cement	GGBS	CA II	CA I	CSS	Adm.	Total GWP, $kgCO_{2e}$
GWP Factor	0.91	0.066	0.009	0.009	0.009	0.075	
M20	145.60	10.56	5.63	3.75	8.53	0.29	174.36
M25	159.25	11.55	5.69	3.83	8.22	0.32	188.85
M30	177.45	12.87	5.78	3.93	7.72	0.35	208.10
M35	200.20	14.52	5.82	3.96	7.07	0.40	231.97
M40	222.95	16.17	5.87	4.01	6.46	0.44	255.90
M45	250.25	18.15	5.78	3.94	5.89	0.50	284.50
M50	263.90	19.14	5.81	3.98	5.47	0.52	298.82

Table 6.4 Concrete mix proportions of OPC+FA

Concrete Grade	Cement, kg	FA, kg	SCM %	CA II, kg	CA I, kg	CSS, kg	Chem. Adm., kg	28-day Strength, MPa
M20	235	100	29.85	612	402	924	4.02	24.80
M25	270	110	28.95	618	405	862	4.56	30.60
M30	315	105	25.00	622	412	826	5.04	35.80
M35	350	100	22.22	626	422	790	5.40	40.40
M40	385	105	21.43	634	426	742	5.88	46.50
M45	415	105	20.19	642	436	698	6.24	51.10
M50	440	130	22.81	652	442	618	6.84	57.70

Table 6.5 GWP of OPC+FA mixes

	Cement	FA	CA II	CA I	CSS	Adm.	Total GWP, $kgCO_{2e}$
GWP factor	0.91	0.064	0.009	0.009	0.009	0.075	
M20	213.85	6.40	5.51	3.62	8.32	0.30	237.99
M25	245.70	7.04	5.56	3.65	7.76	0.34	270.05
M30	286.65	6.72	5.60	3.71	7.43	0.38	310.49
M35	318.50	6.40	5.63	3.80	7.11	0.41	341.85
M40	350.35	6.72	5.71	3.83	6.68	0.44	373.73
M45	377.65	6.72	5.78	3.92	6.28	0.47	400.82
M50	400.40	8.32	5.87	3.98	5.56	0.51	424.64

CA1: Coarse aggregate (10 mm down); CA2: Coarse aggregate (20mm down); CSS: Crushed stone sand

Table 6.6 Mix proportions and GWP of M60, M70 and M80 concretes

Concrete Grade Ingradient	GWP factor, $kgCO_{2e}$	M60				M70				M80			
		OPC+PFA+MS/UGGBS		OPC+GGBS+MS/UGGBS		OPC+PFA+MS/UGGBS		OPC+GGBS+MS/UGGBS		OPC+PFA+MS/UGGBS		OPC+GGBS+MS/UGGBS	
		Quantity, kg	Carbon, $kgCO_{2e}$	Quantity, kg	Carbon, $kgCO_{2e}$	Quantity, kg	carbon, $kgCO_{2e}$	Quantity, kg	Carbon, $kgCO_{2e}$	Quantity, kg	Carbon, $kgCO_{2e}$	Quantity, kg	Carbon, $kgCO_{2e}$
OPC	0.91	450	409.500	335	304.850	450	409.500	360	327.600	450	409.500	420	382.200
PFA	0.064	125	8.000	0	0.000	150	9.600	0	0.000	150	9.600	0	0.000
GGBS	0.066	0	0.000	240	15.840	0	0.000	240	15.840	0	0.000	180	11.880
MS (UGGBS)*	0.066 (0.060)	25	1.65 (1.5)	25	1.65 (1.5)	60	3.96 (3.6)	60	3.96 (3.6)	70	4.62 (4.2)	70	4.62 (4.2)
20mm	0.009	540	4.860	542	4.878	570	5.130	580	5.220	540	4.860	540	4.860
10mm	0.009	442	3.978	445	4.005	376	3.384	385	3.465	540	4.860	540	4.860
CSS	0.009	766	6.894	770	6.930	0	0.000	0	0.000	0	0.000	0	0.000
Wsand	0.009	0	0.000	0	0.000	722	6.498	735	6.615	695	6.255	690	6.210
Water	0.00053	162	0.086	162	0.086	158	0.084	158	0.084	146	0.077	146	0.077
Admixture	0.075	6.0	0.450	6.0	0.450	6.6	0.495	6.6	0.495	6.65	0.499	6.65	0.499
W/b		0.27		0.27		0.24		0.24		0.22		0.22	
Density		2516		2525		2493		2525		2598		2593	
Av. 28-d Strength, MPa		72.3		67.9		77.6		75.7		89.5		85.6	
Carbon footprint using MS, $kgCO_{2e}$*	0.066 for MS		435.42		338.69		438.65		363.28		440.27		415.21
Carbon footprint using UGGBS**, $kgCO_{2e}$	0.060 for UGGBS		435.27		338.54		438.29		362.92		439.85		414.79

*Notes 1: *Micro Silica (MS) and Ultrafine slag (UGGBS) have been used in the calculations. The UGGBS related values are provided in brackets.*
*** The difference between total values of carbon footprints of concrete mixes using MS and UGGBS is found to be less than 0.1 %.*

Notes 2: FA: Fine aggregate; CA : Coarse aggregates; CCS: Crushed Stone Sand

Steel Reinforcement

The IFC-EU database of 2017 provides a value of 2.6tCO_{2e}/tcs for steel reinforcement. The brochure of Tata Steel titled "Emission Control" (https://www.tatasteel.com/tata-steel-brochure/sustainability.html) gives a value of 2.34tCO_{2e}/tcs and mentions that the Company is aiming to achieve <2tCO_{2e}/tcs by 2025. The JSW report states that the Company would be aiming to achieve less than 2tCO_{2e}/tcs by 2030. Considering this we feel it would be appropriate to assume a value of 2.34tCO_{2e}/tcs in our report as that happens to be well documented value.

The structural engineering team has worked out the elementwise quantities of reinforcing steel and the same is included in Annexure 6-B.

Formwork

In India, the use of 'MIVAN' type formwork is quite popular for the construction of high-rise buildings and mass housing. Mivan formwork is an advanced formwork system made of strong and sturdy aluminium components that has sufficiently high strength and durability. It is simple to install and disassemble. The Mivan system is lightweight and can be reused several times. The formwork can be used for walls, columns, beams, slabs etc.

For the entire RC framework construction in the three different alternatives of high-rise building, we have assumed that aluminium formwork will be used. For the ease and speed of the construction operations, the current practice in high-rise construction in India is to use the same aluminium formwork even for the construction of the non-structural walls. It is reported that the aluminium formwork can be reused for around 80 times. In our case, one fresh set of aluminium formwork is proposed to be reused for the construction for the entire project.

We have used the GWP factor for aluminium formwork from the IStructE Guide [2]. The GWP value of extruded aluminium given in Table 2.3 of IStructE guide is 13.2 kgCO_{2e}/kg, Table 6.1.

Walling Materials

We have considered three different types of walling materials for the three alternative schemes of the high-rise building. These include Autoclave Aerated Concrete (AAC) blocks, fly ash bricks and Non Structural (NS) walls. The use of these three types of walling system is prevalent in India. For Fly ash bricks, we have considered the adoption of Fly Ash – Lime Gypsum (FAL-G) bricks, which have been quite popular in India. There are over 12,000 operating plants throughout the country producing over 24–36 billion bricks or equivalent volume of blocks [3]

In recent years, as the requirements of high-rise building construction has increased in urban areas owing land scarcity, the use of AAC blocks has increased, mainly because the lighter weight of such blocks helps in reducing the dead loads on the structure.

The India Construction Materials database of IFC-EU provides the GWP factor for AAC blocks as 0.5 $kgCO_{2e}$ and that of fly ash (FAL-G) bricks as 0.2 $kgCO_{2e}$/kg, Table 6.1.

Annexture 6-C includes the estimated quantities of AAC blocks and fly ash bricks, The quantities of the third walling material, namely N. S. wall, is included in concrete quantities under Annexture 6-A.

Table 6.7: Summary of Materials and GWP Factors

Quantity	M80 M60 With AAC Blocks	M60 M40 With AAC Blocks	M80 M60 With Fly Ash Bricks	M60 M40 With Fly Ash Bricks	M80 M60 With NS Wall	M60 M40 With NS Wall	GWP Values, $kgCO_{2e}$		Unit
Grades of Concrete	Option 01 & 02	Option 03 & 04	Option 05 & 06	Option 07 & 08	Option 09 & 10	Option 11 & 12			
							GGBS	Fly Ash	
M80	1,277	0	1,281	0	1,281	0	415.21	440.27	kg CO_{2e}/m^3
M70	1,496	0	1,507	0	1,507	0	363.28	438.65	kg CO_{2e}/m^3
M60	2,807	1,502	2,854	1,465	2,854	1,469	338.69	435.42	kg CO_{2e}/m^3
M50	1,885	1,229	2,290	1,229	2,290	1,229	298.82	424.64	kg CO_{2e}/m^3
M45	1,885	2,532	1,842	2,487	1,842	2,487	284.50	400.82	kg CO_{2e}/m^3
M40	12	2,413	33	2,400	33	2,400	255.90	373.73	kg CO_{2e}/m^3
M35	0	948	0	942	0	942	231.97	341.85	kg CO_{2e}/m^3
M30	41	1,620	16	1,568	2,244	3,740	208.10	310.49	kg CO_{2e}/m^3
M20	41	41	36	41	36	41	174.36	237.99	kg CO_{2e}/m^3
Reinforcement (MT)	952	1,118	964	1,098	1,135	1,276	2.34		kg CO_{2e}/t
Aluminum Formwork (m^2)	60,802	64,227	61,826	63,788	93,471	95,169	13.20	-	kg CO_{2e}
AAC Block Wall	2,477	2,375	0	0	0	0	254.52	-	kg CO_{2e}/m^3
Fly Ash Bricks Wall	0	0	2,228	2,248	0	0	335.12	-	kg CO_{2e}/m^3
External Plaster	21,904	21,904	21,904	21,904	0	0	319.22	-	kg CO_{2e}/m^2
Internal Plaster	5,628	5,628	5,628	5,628	5,628	5,628	319.22	-	kg CO_{2e}/m^2
Gypsum Plaster	50,748	50,748	50,748	50,748	50,748	50,748	0.099	-	kg CO_{2e}/kg

Note: For calculations of GWP potentials of AAC Blockwork and plaster, please refer Annexure 6 O.

External and Internal Plaster

We have considered the use of 25 mm thick external plaster for the two types of walling materials, namely, AAC blocks and fly ash bricks. For external plaster, it is proposed to use ready-mixed plaster which is now available in ready to use condition in bags in major urban centres of India. We have proposed 1:4 cement sand plaster. In the commercially available ready mix plasters, nearly 25% of the ordinary Portland cement is replaced with fly ash. We propose that for the bedding material of AAC blocks and fly ash bricks, the same ready-mixed plaster shall be used. Incidentally, for non-structural (N. S.) concrete walls, no external plaster is essential. Hence the same is not considered in the N. S. wall alternatives. For internal plaster, we have considered 12 mm thick plaster for AAC blocks and fly ash bricks.

On the internal side, we also proposed the use of 10 mm thick gypsum plaster, which is the normal practice in India. For the non-structural walls, no external/internal plaster is needed.

The GWP of 1:4 external cement-fly ash-sand plaster is calculated as 319.22 $kgCO_{2e}/m^3$. For gypsum plaster we used the GWP value of 0.099 $kgCO_{2e}/kg$ as provided in the IFC-EU database.

Annexture 6-D provides the estimated quantities of the external and internal cement fly ash sand plasters and the gypsum plaster.

Table 6.8 : Summary of GWP of Different Alternatives

Embodied Carbon Calculation	Alternative -01 & 02		Alternative – 03 & 04		Alternative – 05 & 06		Alternative – 07 & 08		Alternative – 09 & 10		Alternative – 11 & 12	
Grades of Concrete	M80 M60 With AAC		M60 M40 With AAC		M80 M60 With Fly Ash Bricks		M60 M40 With Fly Ash Bricks		M80 M60 With NS Wall		M60 M40 With NS Wall	
	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)
M80	5,30,068	5,62,061	0	0	5,32,002	5,64,111	0	0	5,32,002	564111	0	0
M70	5,43,576	6,56,352	0	0	5,47,488	6,61,076	0	0	5,47,488	6,61,076	0	0
M60	9,50,547	12,22,023	5,08,607	6,53,865	9,66,762	12,42,869	4,96,176	6,37,884	9,66,762	12,42,869	4,97,639	6,39,765
M50	5,63,317	8,00,506	3,67,186	5,21,792	6,84,264	9,72,377	3,67,186	5,21,792	6,84,264	9,72,377	3,67,186	5,21,792
M45	5,36,322	7,55,602	7,20,321	10,14,829	5,24,085	7,38,361	7,07,509	9,96,779	5,24,085	7,38,361	7,07,509	9,96,779
M40	3,061	4,470	6,17,554	9,01,909	8,375	12,232	6,14,167	8,96,962	8,375	12,232	6,14,167	8,96,962
M35	0	0	2,19,923	324097	0	0	2,18,409	3,21,865	0	0	2,18,409	3,21,865
M30	8,533	12,732	3,37,106	5,02,969	3,288	4,906	3,26,225	4,86,735	4,66,990	6,96,759	7,78,266	11,61,191
M20	7,150	9,759	7,099	9,690	6,272	8,561	7,099	9,690	6,272	8,561	7,099	9,690
Total Carbon Footprints of Concrete, $kgCO_{2e}$	31,42,574	40,23,504	27,77,795	39,29,151	32,72,535	42,04,492	27,36,769	38,71,706	37,36,237	48,96,346	31,90,274	45,48,043
Reinforcement, $kgCO_{2e}$	22,27,455	22,27,455	26,16,914	26,16,914	22,54,774	22,54,774	25,69,399	25,69,399	26,56,192	26,56,192	29,85,198	29,85,198
Aluminum Formwork, $kgCO_{2e}$	4,61,489	4,61,489	4,87,483	4,87,483	4,69,257	4,69,257	4,84,147	4,84,147	7,09,444	7,09,444	7,22,331	7,22,331
AAC Block Wall	6,30,440	6,30,440	6,04,578	6,04,578	0	0	0	0	0	0	0	0
Fly Ash Bricks Wall	0	0	0	0	7,46,736	7,46,736	7,53,248	7,53,248	0	0	0	0
External Plaster	1,74,809	1,74,809	1,74,809	1,74,809	1,74,809	1,74,809	1,74,809	1,74,809	0	0	0	0
Internal Plaster	21,558	21,558	21,558	21,558	21,558	21,558	21,558	21,558	21,558	21,558	21,558	21,558
Gypsum Plaster	37,680	37,680	37,680	37,680	37,680	37,680	37,680	37,680	37,680	37,680	37,680	37,680
Total Embodied Carbon, $kgCO_{2e}$	66,96,006	75,76,936	67,20,817	78,72,173	69,77,350	79,09,307	67,77,610	79,12,547	71,61,112	83,21,221	69,57,041	83,14,810
Construction Area, m^2	15,878	15,878	15,878	15,878	15,878	15,878	15,878	15,878	15,878	15,878	15,878	15,878
Embodied Carbon $kgCO_{2e}/m^2$	**421.72**	**477.20**	**423.28**	**495.79**	**439.44**	**498.13**	**426.86**	**498.33**	**451.01**	**524.07**	**438.16**	**523.67**

Summary of Embodied Carbon for Different Alternative Designs (A1 to A3)

The summary of the data from Annexures 6-A to 6-D is provided in Table 6.7, which also includes the ECF/GWP factors for different materials.

The estimated summary of the GWP for the 12 alternative designs for the lifecycle stages A1 to A3 is included in Table 6.8. This table also provides the values of total embodied carbon for the different alternatives as well as the carbon emission in terms of GWP/m^2.

6.4 ESTIMATION OF GWP DURING CONSTRUCTION STAGE

STAGES A4 and A5

The following paragraphs cover the estimation of the GWP of all 12 alternatives for the lifecycle stages A4 and A5, i.e. during the construction stage.

Since no reliable India-centric data are available on the carbon emission during construction stage, we have used the recommendations provided in the *IStructE*, U.K. Guide. [2] It provides guidance on estimation of carbon emissions during A4 and A5 stages, which is divided into the following three areas.

- Emissions owing to the transportation of all materials from factory to site (A4)
- Emissions owing to material wastage (A5w), which is further divided into following four areas:
    - o Emission attributed to wasted materials (A13)
    - o Emissions of transporting the wasted materials to site (A4w)
    - o Emissions due to transporting wasted materials away from site (C2)
    - o Emissions from processing and disposal of waste materials (C34)
- Emission during construction installation process (A5), mainly involving emissions due to the use of electrical energy and fuels during the construction operations.

Emissions owing to the Transportation of Materials (A4)

The lifecycle stage A4 involves emissions due to the transportation of materials or products from the factory gate to the construction site.

The default ECF values for U.K. used for module A4 are specified in Table 2.5 of the IstructE Guide [2].

It is assumed that the transportation emission values for urban India may largely be the same as those in the U.K. Therefore, the following values from Tables 2.4 and 2.5 of the IStructE Guide have been adopted:

- Road transport emission factor for average laden weight: 0.1065 gCO_{2e} /kg/km
- ECF factor for material transported locally For 10 km distance (0.1065×10/1000): 0.0011 $kgCO_{2e}$ /kg
- ECF factor for material transported nationally: 0.032 $kgCO_{2e}$/kg

In the present report we have assumed that the commercial RMC plant supplying concrete to the site is located within 10 km distance from the site and that AAC block and fly ash bricks are procured from their respective plants located at 30 km from the site. For these materials, the ECF factor of 0.1065gCO_{2e}/kg/km as proposed in the IstructE guide is adopted.

The aluminium formwork and steel reinforcement are the materials which are transported nationally. For these materials, we have used the ECF factor of 0.032 $kgCO_{2e}$/kg as mentioned in the *IStructE* Guide.

The carbon emissions on account of transportation of different materials are included in Annexure 6-E (concrete), Annexure 6-F (steel reinforcement), Annexture 6-G (walling materials) and Annexure 6-H (plasters). The summary of emissions owing to the transportation of all materials used in the current project is included in Annexure 6 I.

Emission due to Material Wastage

In the present project, we have assumed the following percentages of material wastage at site. These wastage percentages are based on the information obtained from authorities of project sites of high-rise buildings in Mumbai.

These average values mentioned below provide a broad trend in wastages of materials.

- RMC : 2%
- Steel reinforcement : 5%
- AAC blocks and fly ash bricks : 2%
- External/internal plaster : 2%

- Gypsum plaster : 10%

  As mentioned earlier the following wastages are considered and estimated for the present work:

- Emissions attributable to wasted materials:
  - o Estimates of emissions due to wastages are included in Annexure 6-J (concrete), Annexure 6-K (reinforcement), Annexure 6-L (walling materials) and Annexure 6-M (plasters).

The Annexures 6-J to 6-M includes wastages on account of the following factors suggested in the *IStructE* guidelines [2].

- Emissions due to transporting wasted materials to site (termed as A4w in *IStructE* guide)
- Emissions due to transport of waste materials away from site (termed as C2 in *IstructE* guide)
  - o In absence of better data, *IStructE* guide suggests that the nearest reuse/recycling site is located 50 km away by road. For this category, the guide suggests using a factor of 0.005 $kgCO_{2e}$/kg. We have adopted the same value in the current project.
- Emission for processing and disposal of wasted materials (termed as C34 in *IStructE* guide)
  - o The *IStructE* guide suggests that in absence of better data, assume a factor of 0.013 $kgCO_{2e}$/kg for all materials other than timber.
- Based on the inputs from Annexures 6-I to 6-L, the summary of emissions owing to the wastage of different materials of the current project is included in Annexure N.

Emissions during Construction Installation Process (A5)

The emissions during the construction process vary depending on the construction method used, material choices, and site set up. The emissions owing to site activities is estimated from the electricity consumption and fuel use. This is termed as A5a in *IstructE* guide.

For a typical high-rise building construction site in India, electrical energy is used for a variety of operations such as tower crane use, operations of material cum passenger lift, use of cutting bending machine for reinforcement, concrete pumping, lighting during night shift (if any) and lighting/fans/air conditioning for the site office.

Table 6.9 Electrical energy consumption data from a construction site in Mumbai

Month	Electicity Consumption kWh
Dec-22	65,352
Jun-23	62,871
Feb-23	47,881
Mar-23	52,832
Apr-23	53,463
May-23	57,156
Jun-23	57,390
Jul-23	55,577
Aug-23	59,315
Sep-23	57,271
Oct-23	60,060
Nov-23	59,289
Total for 12 months	6,88,457

We have obtained the electricity consumption of a typical high-rise building construction site, having 3 towers and total construction area of 92,950 m^2. We could obtain the yearly electricity consumption data from this construction site and the same is included in the Table 6.9

In our present case of high-rise building design, the total construction area is 15, 878 m^2.

Therefore, the electricity consumption that can be considered for our present case is:

(158,78/92950) x 688,457 = 117,604 kWh.

Assuming that the construction of the high-rise building considered in the present case requires two years, the electrical consumption requirement will be 117,604 × 2 = 235,208 kWh For converting electricity consumption to GHG emissions, the emission factor of 0.716 $kgCO_{2e}$/kWh is used based on the India's Central Electricity Authority's report "CO_2 Baseline Database for the Indian Power Sector" [4].

Therefore, the carbon emission due to electricity use owing to site activities:

Table 6.10 Summary of carbon Emissions for A4 and A5 Stages

Embodied Carbon Calculation	Alternative 01 & 02		Alternative 03 & 04		Alternative 05 & 06		Alternative 07 & 08		Alternative 09 & 10		Alternative 11 & 12	
Concrete (m^3)	M80 – M60 with AAC Blocks		M60 – M40 with AAC Blocks		M80 – M60 with Fly Ash Bricks		M60 – M40 with Fly Ash Bricks		M80 – M60 with NS Walls		M60 – M40 with NS Walls	
	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)
Carbon Emission during Transportation of All Materials (A4) [Annexure 6I]	1,90,504	1,90,504	1,97,777	1,97,777	2,77,445	2,77,445	2,84,955	2,84,955	1,49,209	1,49,209	1,55,485	1,55,485
Carbon Emission due to Wastage of all Materials [Annexure 6 N]	2,11,170	2,29,869	2,20,786	2,43,809	2,16,122	2,34,707	2,21,456	2,44,155	2,26,850	2,50,025	2,32,602	2,59,783
Total Electricity Consumption during 24 Months periods, kWh	2,35,209	2,35,209	2,35,209	2,35,209	2,35,209	2,35,209	2,35,209	2,35,209	2,35,209	2,35,209	2,35,209	2,35,209
Electricity Emission Factor from CEA, $kgCO_{2e}$/kWh	0.716	0.716	0.716	0.716	0.716	0.716	0.716	0.716	0.716	0.716	0.716	0.716
Emission Due to Site Activities, $kgCO_{2e}$	1,68,408	1,68,408	1,68,408	1,68,408	1,68,408	1,68,408	1,68,408	1,68,408	1,68,408	1,68,408	1,68,408	1,68,408
Final Total of A4+A5 Emissions, kg CO_{2e}/kg	5,70,082	5,88,781	5,86,970	6,09,993	6,61,975	6,80,560	6,74,818	6,97,517	5,44,467	5,67,642	5,56,494	5,83,675
Final Total of A4+A5 Emissions, kg CO_{2e}/m^2	35.90	37.08	36.97	38.42	41.69	42.86	42.50	43.93	34.29	35.75	35.05	36.76

Table 6.11 Combined Carbon Emission during LCA Stages A1 to A5

Embodied Carbon Calculation	Alternative 01 & 02		Alternative 03 & 04		Alternative 05 & 06		Alternative 07 & 08		Alternative 09 & 10		Alternative 11 & 12	
	M80 – M60 with AAC		M60 – M40 with AAC		M80 – M60 with Fly Ash Bricks		M60 – M40 with Fly Ash Bricks		M80 – M60 with NS Walls		M60 – M40 with NS Walls	
	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)
Carbon Emission during Transportation of All Materials (A4) [Annexure 6I]	1,90,504	1,90,504	1,97,777	1,97,777	2,77,445	2,77,445	2,84,955	2,84,955	1,49,209	1,49,209	1,55,485	1,55,485
Carbon Emission due to Wastage of all Materials [Annexure 6 N]	2,11,170	2,29,869	2,20,786	2,43,809	2,16,122	2,34,707	2,21,456	2,44,155	2,26,850	2,50,025	2,32,602	2,59,783
Emission due to site activity, $kgCO_{2e}$	1,68,408	1,68,408	1,68,408	1,68,408	1,68,408	1,68,408	1,68,408	1,68,408	1,68,408	1,68,408	1,68,408	1,68,408
Total Carbon Emission for A4 & A5	5,70,082	5,88,781	5,86,970	6,09,993	6,61,975	6,80,560	6,74,818	6,97,517	5,44,467	5,67,642	5,56,494	5,83,675
Total Carbon Emission for A1 to A3	66,96,006	75,76,936	67,20,817	78,72,173	69,77,350	79,09,307	67,77,610	79,12,547	71,61,112	83,21,221	69,57,041	83,14,810
Total Carbon Emission for A1 to A5	72,66,088	81,65,717	73,07,788	84,82,166	76,39,325	85,89,867	74,52,429	86,10,064	77,05,579	88,88,863	75,13,535	88,98,485
Total Carbon Emission per m^2	**457.62**	**514.28**	**460.25**	**534.21**	**481.13**	**540.99**	**469.36**	**542.26**	**485.30**	**559.82**	**473.20**	**560.43**
% of Carbon Emission during A4 & A5 to emission during A1 to A5	7.85	7.21	8.03	7.19	8.67	7.92	9.06	8.10	7.07	6.39	7.41	6.56

Note: Reduction in carbon emission (560.43–457.62)/560.43 = 18.3% (for Alt.1); (560.43–460.25)/560.43 = 17.9% (Alt.3)

0.716x 235,208 = 168,408 kg CO_{2e}.

Summary of Carbon Emissions for A4 and A5 stages

Table 6.10 provides the summary of Carbon Emissions for A4 and A5 stages.

The final summary of the combined embodied carbon emission for lifecycle stages A1 to A3 and A4 and A5 is included in Table 6.11.

It can be seen from this table that the lowest carbon emission of **457.62 $kgCO_{2e}/m^2$** is obtained in **Alternative 1 using M80–60 grades of concrete, AAC blocks and GGBS mixes.** This is closely followed by Alternative 3 having carbon emission value of

460.25 $kgCO_{2e}/m^2$, using a combination of M60–40 grades of concrete, ACC Blocks and GGBS mixes.

It can also be seen from Table 6.11 that the percentage of embodied carbon emission for the lifecycle stages A4 and A5 varies from 6.39 to 9.0% of the corresponding total emissions from A1-A5 stages.

6.5 COST COMPARISON

The cost comparison of different alternatives is included in Table 6.12. The per unit costs of the materials and products considered in Table 6.12 are based on the information obtained from market. As is well known, the cost of the materials and products varies depending upon the market forces; hence the comparison presented here may be considered as tentative.

The cost comparison values show that the Alternative 5 and 6 using M80–60 grades of concrete and the use of fly ash bricks has the lowest emissions with a value of ₹19,326/m², followed quite closely by the Alternative 1 and 2 using M80–60 grade concretes and AAC Blocks with a value of ₹19,343/m².

Thus, the Alternative 1 having lowest carbon

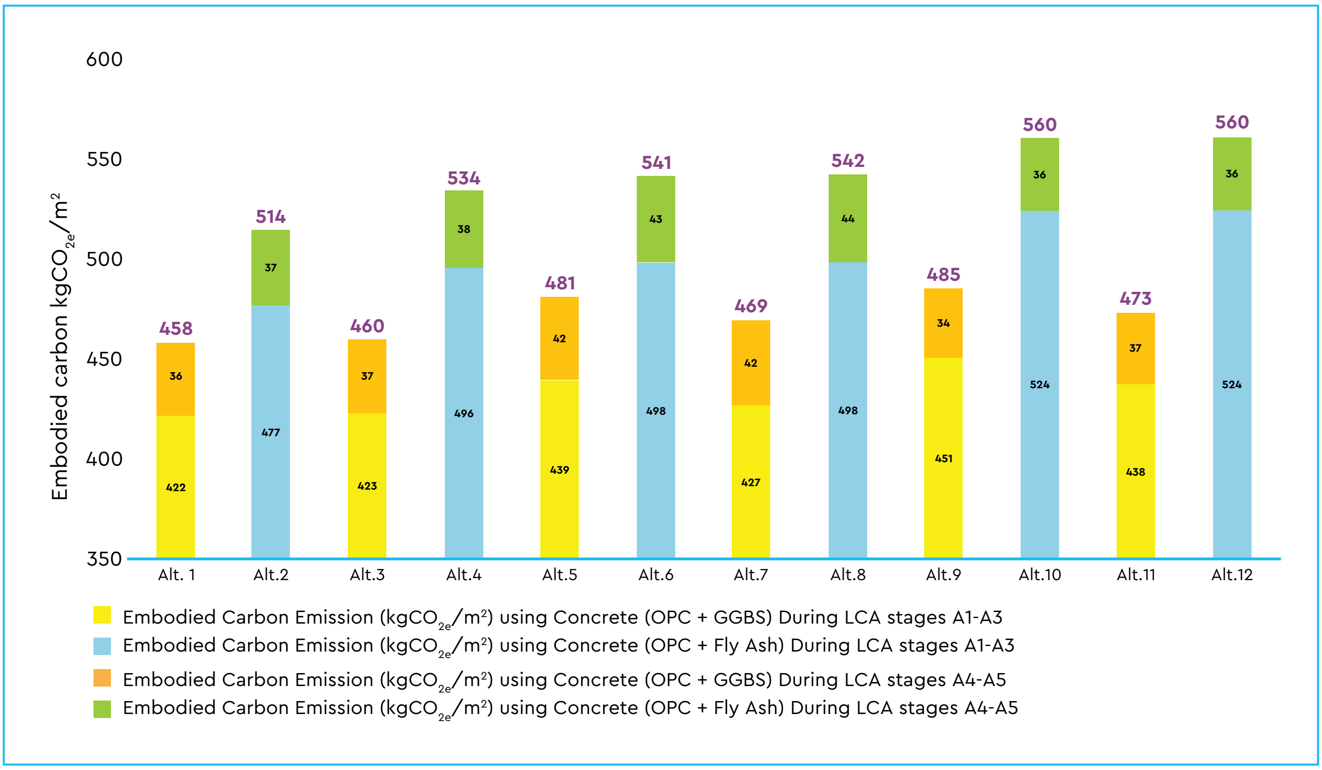

Fig 6.1. High-rise Building: Embodied Carbon Emission during LCA Stages A1-A3 (Product Stage) and A1-A5 (Construction Stage)

footprints of 457.62 $kgCO_{2e}/m^2$ happens to be 2nd lowest cost alternative.

However, since difference between 1st lowest and 2nd lowest cost is hardly ₹17/m², one can conclude that the lowest carbon alternative also happens to be lowest cost alternative.

Table 6.12 Summary of comparison of costs of all alternatives

Costing	Unit	M80 M60 With AAC Blocks	M60 M40 With AAC Blocks	M80 M60 With Fly Ash Bricks	M60 M40 With Fly Ash Bricks	M80 M60 With NS Wall	M60 M40 With NS Wall
Material		Option 01 & 02	Option 03 &04	Option 05 & 06	Option 07 & 08	Option 09 & 10	Option 11 & 12
Concrete							
M80	m³	₹1,65,96,150	₹0	₹1,66,56,683	₹0	₹1,66,56,683	₹0
M70	m³	₹1,83,29,681	₹0	₹1,84,61,591	₹0	₹1,84,61,591	₹0
M60	m³	₹3,22,75,195	₹1,72,69,414	₹3,28,25,775	₹1,68,47,323	₹3,28,25,775	₹1,68,97,003
M50	m³	₹2,53,84,200	₹1,32,09,452	₹2,46,16,276	₹1,32,09,452	₹2,46,16,276	₹1,32,09,452
M45	m³	₹1,97,93,965	₹2,65,84,770	₹1,93,42,313	₹2,61,11,925	₹1,93,42,313	₹2,61,11,925
M40	m³	₹1,19,600	₹2,41,32,633	₹3,27,293	₹2,40,00,260	₹3,27,293	₹2,40,00,260
M35	m³	₹0	₹90,06,646	₹0	₹ 89,44,611	₹0	₹89,44,611
M30	m³	₹1,02,241	₹1,53,89,249	₹1,50,105	₹1,48,92,531	₹2,13,18,610	₹3,55,28,739
M20	m³	₹3,48,555	₹3,46,060	₹3,05,767	₹3,46,069	₹3,05,767	₹3,46,069
Reinforcement	mt	₹8,09,11,829	₹9,50,58,829	₹8,19,04,194	₹9,33,32,870	₹9,64,85,602	₹10,84,36,669
Formwork	m²	₹5,16,81,881	₹5,45,93,009	₹5,25,51,825	₹5,42,19,379	₹7,94,50,278	₹8,08,93,446
Block Work							
AAC Block Wall	m³	₹1,85,77,336	₹1,78,15,230	₹0	₹0	₹0	₹0
Fly Ash Bricks Wall	m³	₹0	₹ 0	₹1,67,11,978	₹1,68,57,715	₹0	₹0
Plaster							
External Plaster	m²	₹1,86,18,808	₹1,86,18,808	₹1,86,18,808	₹1,86,18,808	₹0	₹0
Internal Plaster	m²	₹28,13,938	₹28,13,938	₹28,13,938	₹28,13,938	₹28,13,938	₹28,13,938
Gypsum Plaster	m²	₹2,15,67,755	₹2,15,67,755	₹2,15,67,755	₹2,15,67,755	₹2,15,67,755	₹2,15,67,755
Total Amount							
Construction Area, m²	15878	₹30,71,21,134	₹31,64,05,793	₹30,68,54,301	₹31,17,62,636	₹33,41,71,881	₹33,87,49,867
Cost /m²		₹19,343	₹19,927	₹19,326	₹19,635	₹21,046	₹21,335
Costwise Ranking		**2**	**4**	**1**	**3**	**5**	**6**

Notes: Approximate unit rates assumed in calculation

M80	13,000/m³
M70	12,250/m³
M60	11,500/m³
M50	10,750/m³
M45	10,500/m³
M40	10,000/m³
M35	9,500/m³
M30	9,500/m³
M20	8,500/m³

Reinforcement	85,000/t
Formwork	850/m²
AAC Block Wall	7,500/m³
Fly Ash Bricks Wall	7,500/m³
External Plaster	850/m²
Internal Plaster	500/m²
Gypsum Plaster	425/m²

References

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3. Case study on Development and dissemination of Fal-G Technology, Eco-Carbon Pvt Ltd., https://fal-g.com/wp-content/uploads/2021/10/Case-Study-INSWAREB-ECPL-May-2011.pdf
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CASE STUDY OF A LOW RISE BUILDING: EVALUATION OF EMBODIED CARBON

CHAPTER 7

Besides high-rise building, structural design and analysis were carried out for a typical low-rise building, using different alternatives. For the comparative evaluation of embodied carbon in low-rise building we have considered a typical Ground-plus 3-storeyed building located in proximity of a major city which falls in earthquake zone III as specified in IS 1893. The building is designed to be occupied by families from the middle-income group of the society.

The typical plans of the building as shown in Fig 7.1 and 7.2 are prepared by a professional architect firm, duly considering incorporation of "passive" architectural features catering to the maximum use of natural light, ventilation, etc. Fig 7.2 shows the diagrammatic representation of how the natural light and ventilation system would perform in the building.

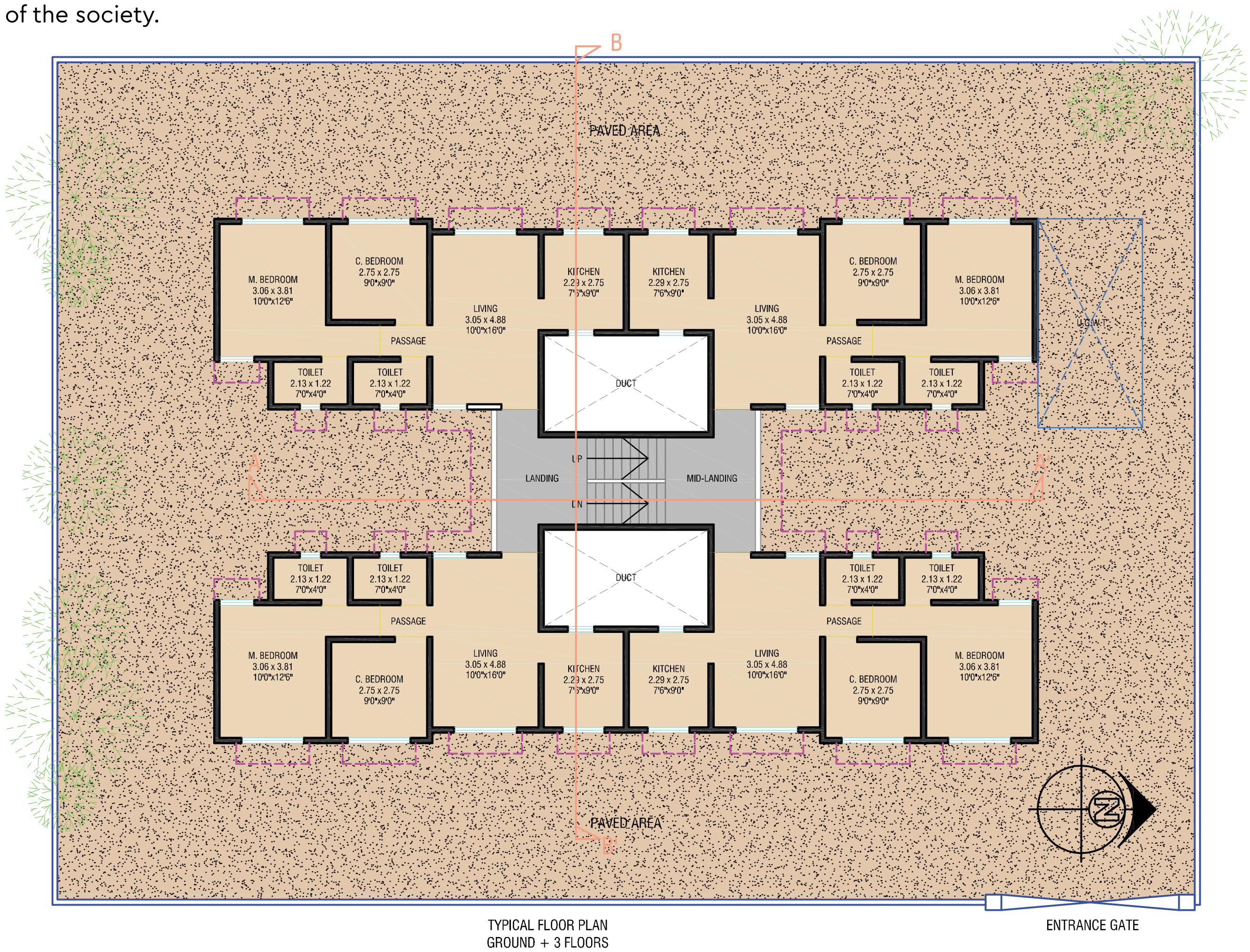


Fig 7.1 Typical architectural plan of the G+3 building

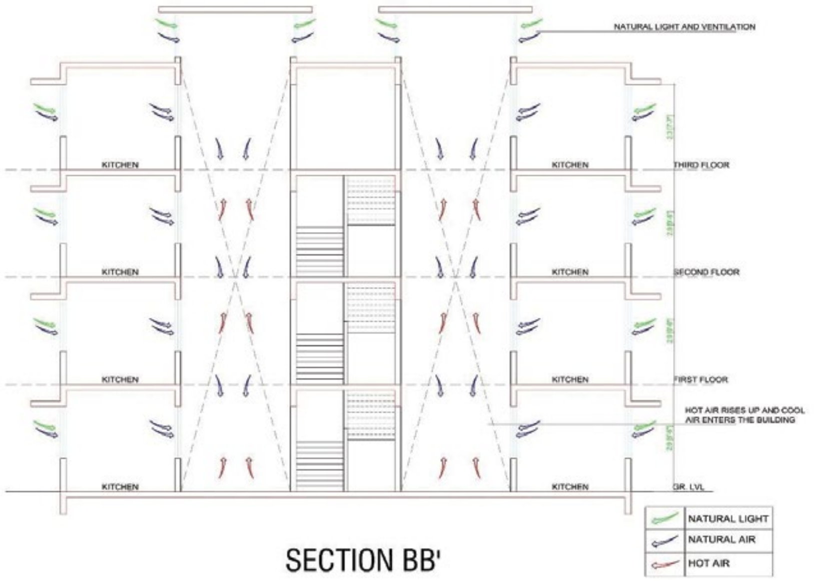


Fig 7.2 The arrangement of natural light and ventilation in the G+3 building

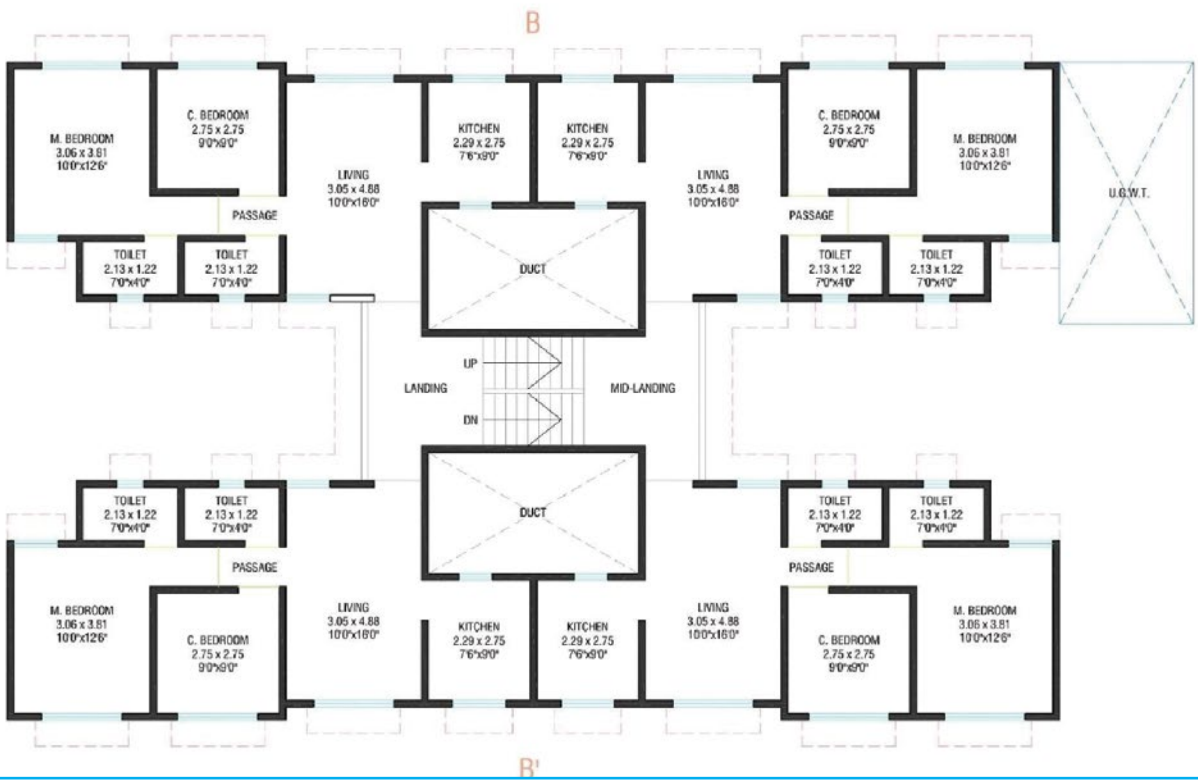


Fig 7.3 Another view of the architectural plan showing details of room sizes in a typical flat

7.2 STRUCTURAL SYSTEMS

The current practice of construction of low-rise buildings in India involves the use of reinforced concrete framed system consisting of columns, beams and slab with infill brick walls.

In the present work, the salient features of the G+3 building are included in Table 7.1. There are four flats on each floor, each having 2 bedrooms and one living room. The built-up area of the flat is 55.8 m^2. There is one common staircase, and the car parking is provided in the stilt area. Two ducts are provided in the centre for ventilation and other services.

Table 7.1: Some Salient Features of Ground+3 storeyed building

Building Location	Suburban area of a major city
Building configuration	Ground + 3 storey
Size of building	22 m (length) x 15.25m (width) x 13.25 m (height)
Flats/floor	4 Nos.
Configuration of the typical flat	Living room + 2 bedrooms + 2 W.C. + Kitchen + Balcony
Approximate area of flat	55.8 m^2
Built-up area	979 m^2
Staircases	one common staircase (No lifts)
Parking	stilt parking
Additional feature	Two ducts for ventilation and services
Foundations	Rocky strata having safe bearing capacity 1000 kN/m^2

For the comparative evaluation of embodied carbon, following 2 structural alternatives are considered:

- **Alternative 1:** Reinforced concrete framed structure wherein the columns are connected with a network of beams and slabs with the slabs acting as in plane semi rigid diaphragms for each of the floors
- **Alternative 2:** Reinforced concrete framed structure of columns/beams/slab (as in Alternative 1); however, with the introduction of shear walls in the duct portion and some other 'dead' locations.

For the infill walls in the RC frame, we have considered following four alternatives:

A. Conventional fired clay bricks with cement-fly ash sand plaster on both sides

B. Autoclave Aerated Concrete (AAC) blocks with cement-fly ash-sand plaster on both sides

C. Expanded Polystyrene (EPS) sandwich panels (prefabricated), plastered on both sides.

D. Fly ash bricks with cement-fly ash-sand plaster on both sides

For all the above alternatives, gypsum plaster is considered for internal applications.

It is assumed that the G+3 building is resting on soft rock having safe bearing capacity of 1000 kN/m^2 and that the building falls in the "moderate" zone of exposure category as specified in IS 456–2000.

From structural design considerations, the M30 grade of concrete was found to be appropriate for use in the structural elements.

We have considered that the building is in a proximity of a major city. Although the penetration of commercial ready-mixed concrete (RMC) plants has reached such localities, the plant capacities and equipment used are comparatively smaller when compared with those available in big cities. For the construction of G+3 building, we assumed that such small-capacity RMC plant would be able to cater to the requirements of concrete for our project.

One of the limitations of having small capacity RMC plants is the inability of these plants to supply blended concrete using different Supplementary Cementitious Materials (SCMs) as demands for such concretes is limited. Hence these plants tend to use limited number of silos. Also, the use of blended cements is quite popular in these areas. For our project, we have considered the use of blended cements – Portland Pozzolana Cement (PPC), Portland Slag cement (PSC) – in addition to the Ordinary Portland cement (OPC) for M30 grade concrete.

For walling materials, we have considered four options, namely:

(A) Fire clay bricks,

(B) AAC blocks,

(C) EPS sandwich panels

(D) Fly ash bricks

In recent years, factories producing sandwich EPS Panel with double electro-welded wire mesh have come up at few locations such as Pune, Indore, Kochi, etc. and use of such panels has commenced.

Thus, as shown in Fig 7.4, eight basic alternative designs become available to us for the evaluation of embodied carbon in low-rise buildings. With the use of M30 grade concrete mixes with three different types of cements, the number of alternatives becomes 24 as shown in Fig 7.4!

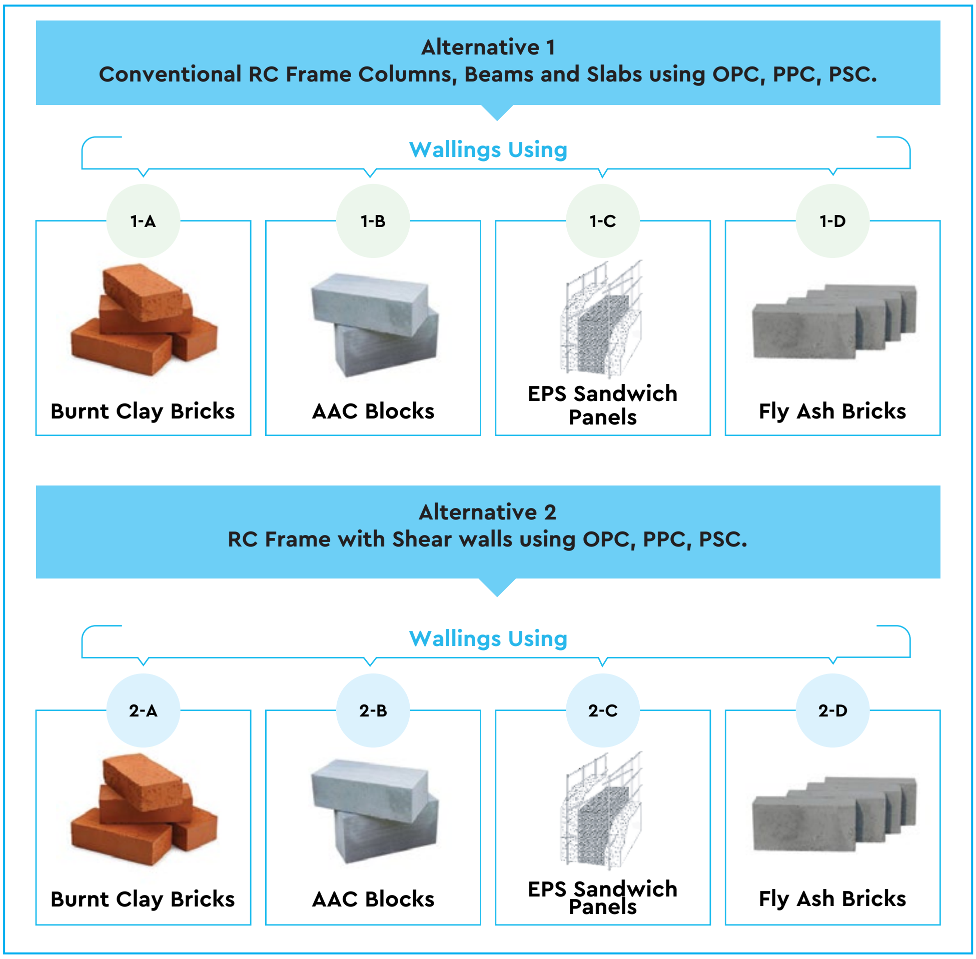


Fig 7.4 Embodied carbon evaluation: Proposed alternatives

Foundations

The building is assumed to be founded on a strata having soft rock which is available at 2m depth below ground level. With an assumed safe bearing capacity of 1000 kN/m^2, open foundations become feasible.

The typical cross section of the foundation is shown in Fig 7.5.

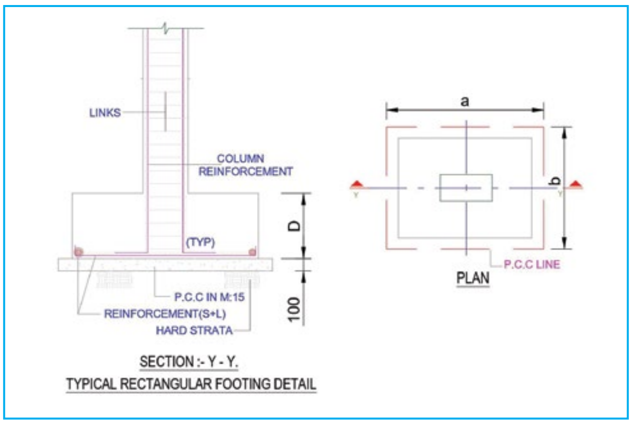


Fig 7.5 Typical foundation plan and cross section

Typical Building Floor Plans and Layouts

The building floor plan showing column and foundation layout for Alternative 1 is included in Fig 7.5. and that for Alternative 2 in Fig 7.6.

In Alternative 2, it may be noted that shear walls are introduced at 'dead' locations to resist lateral forces efficiently. The 'dead' locations are selected in such a way that they do not adversely affect the needs and requirements of the occupants nor to the passage of light and ventilation.

The slab layouts for Alternatives 1 and 2 are shown in Fig 7.7.

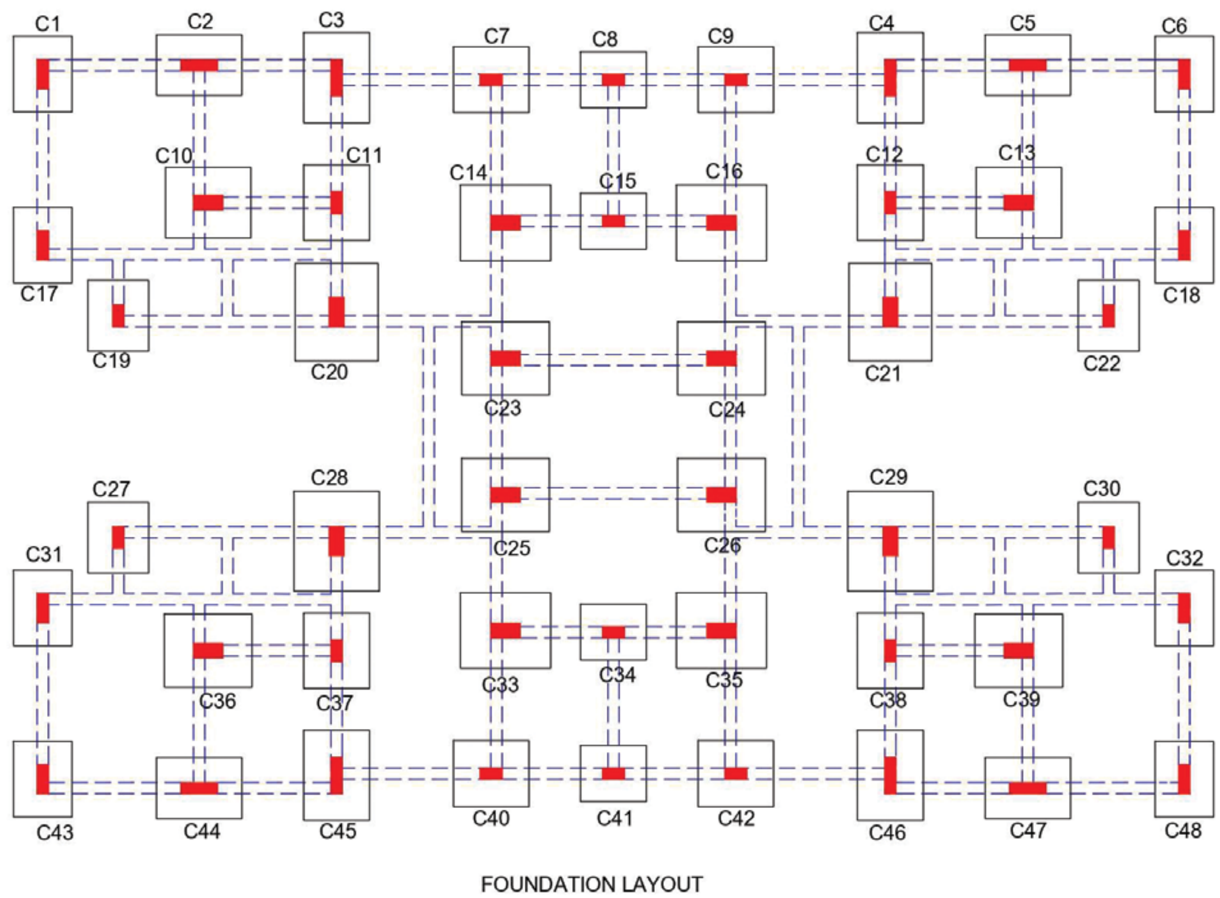


Fig 7.5 Building floor plan showing column and foundation layout for Alternative 1 (drawing not to scale)

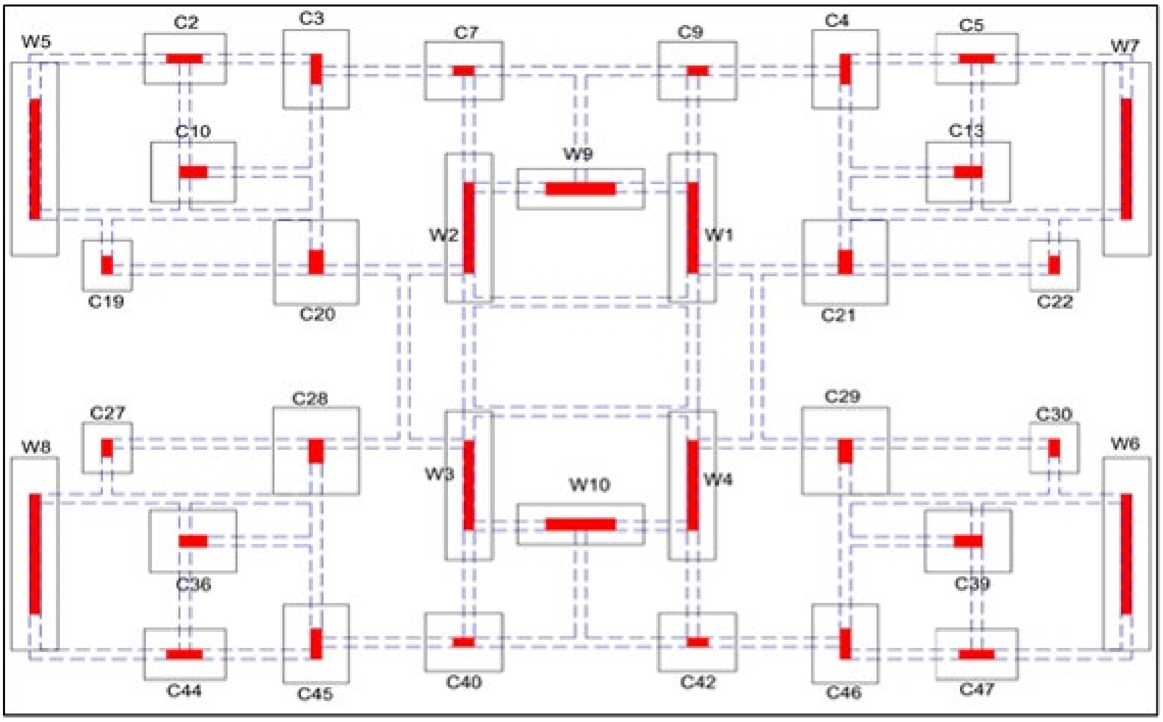
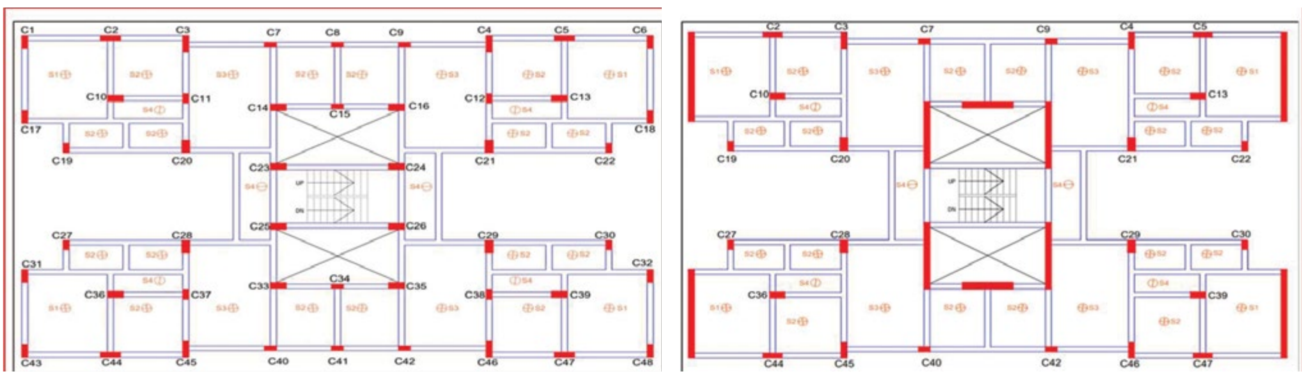


Fig 7.6 Building floor plan showing column and foundation layout for Alternative 2 (drawing not to scale)



Alternative 1: Conventional Framing Layout

Alternative 2: RC Frame with Shear Wall at select locations

Fig 7.7 Slab layouts for in Alternatives 1 and 2

7.3 SOFTWARE USED IN DESIGN AND ANALYSIS

The engineering software ETABs has been used in the design and analysis of the G+3 building. Both static and dynamic analysis has been carried out using ETABs Ultimate Version 18.1.1. The drafting has been carried out by using AUTO CAD 2024 version.

The model of the ETABs layout for Alternative 1 is shown in Fig 7.8 and that of Alternative 2 in Fig 7.9.

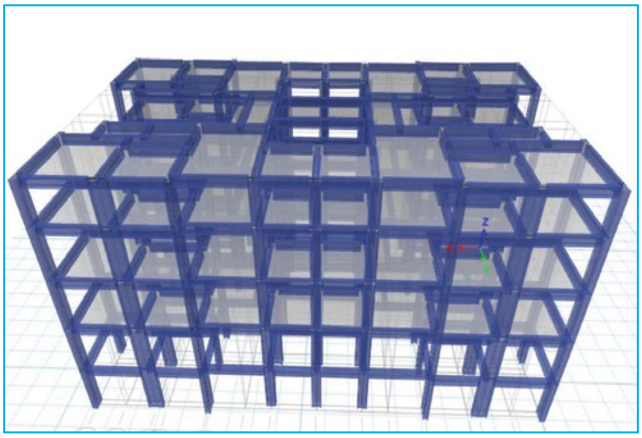


Fig 7.8 ETABs Model layout for Alternative 1

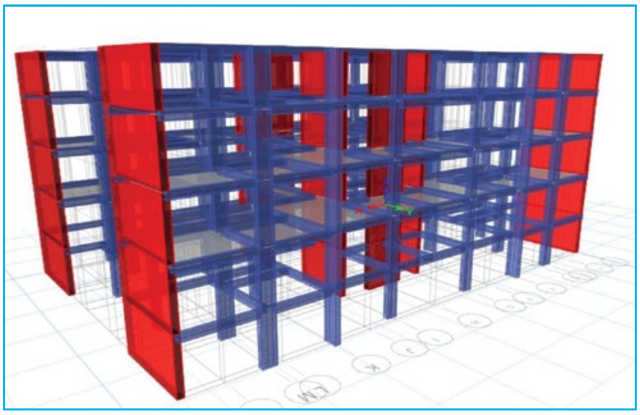


Fig 7.9 ETABs Model layout for Alternative 2

7.4 **CODES AND STANDARDS**

Specific applicable codes and standards are identified and adopted in the design philosophies as appropriate to the structural elements. The latest editions of the Codes and Standards are used in the designs (Table 7.2). The design work is based on Indian Standards and Codes with latest revision, with amendments if any, as on date.

Table 7.2 Indian Standards adopted in design

(a) Design of Elements

IS Code	Description
IS 456:2000	Plain and Reinforced Concrete - Code of Practice, Bureau of Indian Standards (BIS), New Delhi.
SP 16:1980	Design Aids for Reinforced Concrete to IS 456:1978, BIS.
SP 34:1987	Handbook on Concrete Reinforcement and Detailing, BIS.
IS 1904:2021	Code of Practice for Design and Construction of Foundations in Soil: General Requirements, BIS.
IS 2950:1981	Code of Practice for Design and Construction of Raft Foundation (Part - 1)
IS 3370 (Part 1 & 2):2009	Concrete Structures for Storage of Liquids, Code of Practice, BIS
IS 3370 (Part III & IV):1967	
IS 800:2007	General Construction in Steel - Code of Practice, BIS.
IS 1786:2008	High Strength Deformed Steel Bars for Concrete reinforcement
IS 12251:1987	Code of Practice for Drainage of Building Basements, BIS.
IS 383:2016	Coarse and fine aggregates for concrete - Specifications

(b) Design loads (Other than Earthquake Loads)

IS 875 (Part 1):1987	IS Code Design Dead loads (Unit weights of building material and stored materials) for Buildings and Structures, BIS
IS 875 (Part 2):1987	Code of Practice for Design Loads (Other Than Earthquake) For Buildings and Structures, Part 2: Imposed Loads, BIS
IS 875 (Part 3):2015	Design Loads (Other than Earthquake) for Buildings and Structures - Code of Practice Part 3: Wind Loads, BIS

(c) Design for Earthquake Resistant Structure

IS 1893 (Part 1):2016	Criteria for Earthquake Resistant Design of Structures; Part 1 General Provisions and Buildings, BIS
IS 4326:2013	Earthquake Resistant Design and Construction of Buildings - Code of Practice, BIS
IS 13920:2016	Ductile Design and Detailing of Reinforced Concrete Structures subjected to Seismic Forces - Code of Practice, BIS
SP 22	Explanation to IS 1893 & IS 4326

(d) Design for Fire Safety

IS 1642	Fire Safety Building Materials
SP 7 (2)	National Building Code of India

7.5 DESIGN PHYLOSOPHY

For the design of reinforced concrete elements, Limit State Method specified in IS 456:2000 is used.

Ductile detailing norms have been adopted to make the building earthquake-resistant in accordance with IS 13920:2016.

7.6 MATERIALS OF CONSTRUCTION

Concrete: Ingredients, threshold limits in Mix design and durability criteria

The grades of concrete and the modulus of elasticity proposed for different elements of the project are given in Table 7.3 and 7.4.

Cement
Ordinary Portland Cement (OPC) of grade 53 confirming to IS 269, Portland Pozzolana Cement conforming to IS 1489 Part 1:2015 and Portland Slag Cement conforming to IS 455:2015 are used in the concrete mix design.

Aggregates
The sizes of coarse aggregates shall confirm to the requirements of IS 383. The nominal maximum size of coarse aggregate is 20 mm, suitably graded as per the requirement of mix design.

Water
Mixing water shall confirm to the requirements of IS 456:2000.

Durability Criteria for Concrete

a. Based on The IS 456:2000, the Environmental Exposure Class for the building is considered as "moderate"

b. It is ensured that the minimum cementitious content and water cement ratio as specified in IS 456:2000 are satisfied.

Table 7.3 Grade of concrete and modulus of elasticity for different elements

Element	Cube strength (N/mm²)
Miscellaneous/non-structural concrete, curbs, sidewalks	30
Slabs on ground	30
Foundation: Raft, Isolated and combined footings	30
Beams, slabs, staircases	30
Columns, shear walls	30

Table 7.4 Modulus of elasticity for different grades of concrete

Concrete Designation	28-day Compressive strength Cubes	Elastic modulus, E (MPa)
M30	30 N/mm²	27386

Density of reinforced concrete assumed in design is 25 kN/m³.

Table 7.5 Clear cover to reinforcement and fire rating

Sr No.	Structural Member	Clear cover, mm	Minimum Dimension, mm	Remarks
1	Foundation	75	-	-
2	Shear walls	40	300 (coupled shear walls)	-
3	Beams	40	230	2 hour fire resistance
4	Slabs	35	125	2 hour fire resistance

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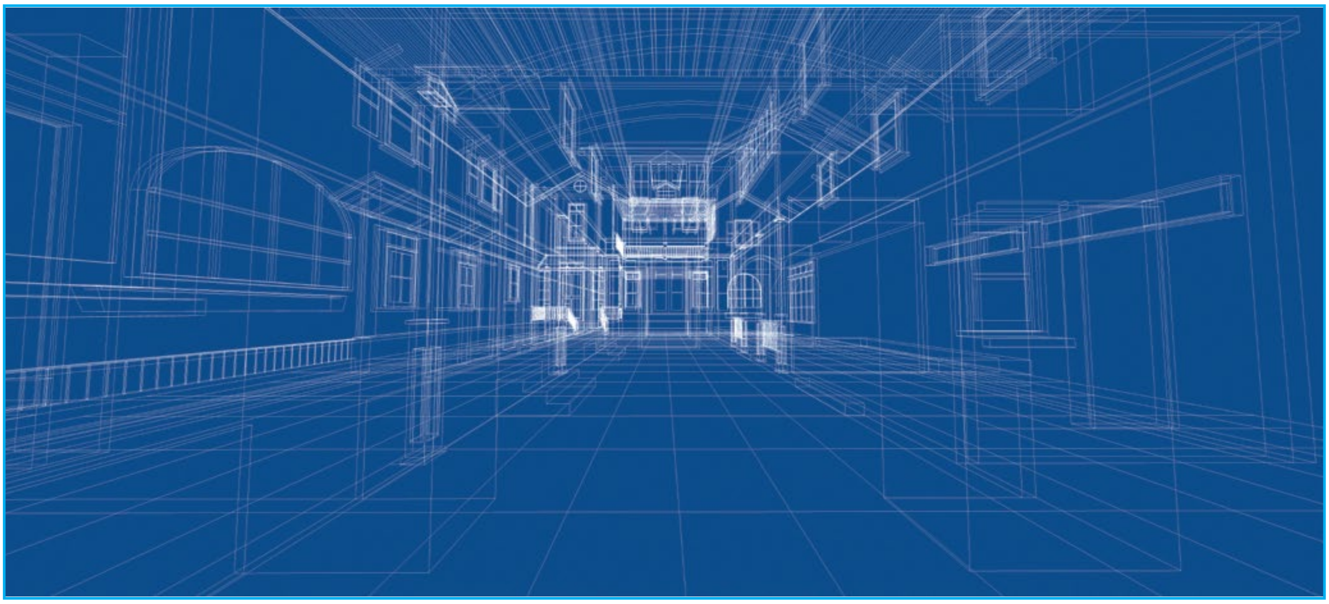


Reinforcement
High yield strength deformed bars confirming to IS 1786:2008 with fy = 500 N/mm^2 are used, with specified elongation of more than 14.5%.

Clear Cover to Reinforcement
Clear cover for all reinforced concrete members is in accordance with IS 456:2000 corresponding to moderate exposure conditions for the superstructure as well as the substructure and to satisfy a fire rating of 2 hours. The clear cover to outermost layer of reinforcement for listed elements is based on the exposure condition/fire rating requirements. (Table 7.5)

7.7 LOAD CONSIDERATIONS

Loading for different elements are based on the guidance of IS Standards. The values of loading included in Annexure 5-B (considered in Chapter 5) will also be applicable for low-rise building.

Load Combinations
The results obtained from the computer analysis in the form of member forces and reactions is used to design the structural members. The load combinations of the member forces as given in Table 7.6 are considered for arriving at the design forces.

Table 7.6 Load combinations and Load Factors

Comb. No.	Load Combination	Load Factors					
		DL	LL	EQX	EQY	WX	WY
1.	DL + LL	1.5	1.5	-	-	-	-
2.	1.2 (DL + LL ± EQX)	1.2	1.2	1.2	-	-	-
3.	1.2 (DL + LL ± EQY)	1.2	1.2	-	1.2	-	-
4.	1.5 (DL ± EQX)	1.5	-	1.5	-	-	-
5.	1.5 (DL ± EQY)	1.5	-	-	1.5	-	-
6.	0.9DL ± 1.5EQX	0.9	-	1.5	-	-	-
7.	0.9DL ± 1.5EQY	0.9	-	-	1.5	-	-
8.	1.2 (DL + LL ± WX)	1.2	1.2	-	-	1.2	-
9	1.2 (DL + LL ± WY)	1.2	1.2	-	-	-	1.2
10.	1.5 (DL ± WX)	1.5	-	-	-	1.5	-
11.	1.5 (DL ± WY)	1.5	-	-	-	-	1.5
12	0.9DL ± 1.5WX	0.9	-	-	-	1.5	-
13.	0.9DL ± 1.5WY	0.9	-	-	-	-	1.5

Notes:

- *Suffixes x and y mentioned in the above table indicate the direction in which the force is applied.*
- *WT represents 24 cases of wind tunnel forces applied in combination.*

Notations:
DL = Dead Load
LL = Live Load
EQX = Earthquake Load in X-direction
EQY = Earthquake Load in Y-direction
WLX = Wind Load in X-direction
WLY = Wind Load in Y-direction

All members have been designed for the largest value of the design forces obtained due to positive as well as negative values of reversible forces (Wind and Earthquake).

Service Load Combinations
The service load combinations as given in Table 7.7 are adopted in design.

Table 7.7 Service load combinations

Comb. No.	Load Combination	Load Factors			
		DL	LL	EL	WL
1.	DL + LL	1	1		
2.	DL ± EL	1		1	
3.	DL + 0.8LL ± 0.8EL	1	0.8	0.8	
4.	DL ± WL	1			1
5.	DL + 0.8LL ± 0.8WL	1	0.8		0.8

Self-Weights
Self-weight of the structural members considered in the design are as given in Table 7.8.

Table 7.8 Self weight of members

Density of reinforced concrete	25 kN/m^3
Density of plain concrete	24 kN/m^3
Density of steel	78.5 kN/m^3
Density of water	10 kN/m^3
Density of floor finishes/plasters	20 kN/m^3
Density of fly ash Bricks	20 kN/m^3
Density of light weight blocks	10 kN/m^3

7.8 ANALYSIS METHOD ADOPTED FOR MODEL ON ETABs

Auto-CAD files have been used as the geometrical database to generate floor-wise geometry. Vertical members have been connected from floor to floor to assemble space frame. Preliminary sectional properties have been assigned to all the structural elements. The floor slabs have been modelled as Membrane connected by horizontal diaphragms.

Appropriate moment releases have been given wherever required. Appropriate grade of concrete as mentioned earlier has been assigned. Gravity loads (Dead load and Live load) have been applied to all the respective areas as per the location and occupancy. Seismic analysis has been carried out independently using procedures mentioned in IS 1893 (Part 1):2016. Wind load analysis has been carried out using procedures mentioned in IS 875 (Part-3):2015.

The computer analysis evaluates individual internal member forces, reactions at foundation level and deflection pattern of the entire structure and in the individual members for both codes. Analysis results obtained from both exercises are used to arrive at the universal solution.

This data is then used to verify the adequacy of the member sizes adopted and after further iterations arrive at the most appropriate reinforcement design of the structural members. Some re-runs of the analysis program were required for arriving at the optimum structural space frame characteristics that satisfy the strength and stability criteria in all respects.

P-Delta Analysis
P-Delta Analysis is carried out with the 'Iterative based on load' option in ETABS considering the scale factors as given in Table 7.9.

Table 7.9 Scale factors for load patterns

Load Pattern	Scale Factor
Dead Load	1.2
Superimposed Dead Load	1.2
Live Load	0.5

Design eccentricity
For design, semi rigid diaphragm has been assigned; hence nominal eccentricity of 5% has been assigned. Along with this eccentricity for response spectrum cases has been assigned according to the IS 1893 (Part I):2016.

Stiffness Modifiers
The following modifiers are used for properties of cracked RC section as per IS 1893(part 1):2016 Clause 6.4.3.1 and IS 16700:2023 Table No 5.

The stiffness modifiers for service and ultimate conditions are included in Table 7.10.

Table 7.10 Stiffness modifiers for service and ultimate conditions

(a) Service Condition

BEAMS	Scale Factor	COLUMNS	
Cross section (axial) Area	1	Cross section (axial) Area	1
Shear area in 2 direction	1	Shear area in 2 direction	1
Shear area in 3 direction	1	Shear area in 3 direction	1
Torsional Constant	0.01	Torsional Constant	1
Moment of inertia about 2 axis	0.7	Moment of inertia about 2 axis	0.9
Moment of inertia about 3 axis	0.7	Moment of inertia about 3 axis	0.9
Mass	1	Mass	1
Weight	1	Weight	1
SLABS (shell slabs only)	**SLABS (shell slabs only)**	**SHEAR WALLS**	**SHEAR WALLS**
Bending m11 Modifier	0.35	Membrane f11 Modifier	0.9
Bending m22 Modifier	0.35	Membrane f22 Modifier	0.9
Bending m12 Modifier	0.35	Membrane f12 Modifier	0.9
		Bending m11 Modifier	0.9
		Bending m22 Modifier	0.9
		Bending m12 Modifier	0.9

Table 7.10 Stiffness modifiers for service and ultimate conditions

(b) Ultimate condition

BEAMS	Scale Factor	COLUMNS	
Cross section (axial) Area	1	Cross section (axial) Area	1
Shear area in 2 direction	1	Shear area in 2 direction	1
Shear area in 3 direction	1	Shear area in 3 direction	1
Torsional Constant	0.01	Torsional Constant	1
Moment of inertia about 2 axis	0.35	Moment of inertia about 2 axis	0.7
Moment of inertia about 3 axis	0.35	Moment of inertia about 3 axis	0.7
Mass	1	Mass	1
Weight	1	Weight	1
SLABS (shell slabs only)	**SLABS (shell slabs only)**	**SHEAR WALLS**	**SHEAR WALLS**
Bending m11 Modifier	0.25	Membrane f11 Modifier	0.7
Bending m22 Modifier	0.25	Membrane f22 Modifier	0.7
Bending m12 Modifier	0.25	Membrane f12 Modifier	0.7
		Bending m22 Modifier	0.7
		Bending m12 Modifier	0.7

Table 7.11 Alternative 1A – Conventional frame model: Walling with burnt clay bricks

(b) Ultimate condition

Sr. No.	Threshold limits for serviceability		RC Frame using M80-70-60 and AAC Walls			
1	Displacement For EQ = 54mm* For Wind = 27 mm**	EQX	23.84			
		EQY	17.17			
		WX	2.77			
		WY	2.21			
2	Storey Drift (should not exceed 0.004 x H = 12mm)	EQX	0.0022			
		EQY	0.0016			
		SPECX	0.0019			
		SPECY	0.0016			
3	Torsional Irregularity Check (Max/Avg ratio should be less than 1.2)		Max		Avg	Max/Avg
		EQX	23.84		23.56	1.01
		EQY	17.17		17.12	1.00
4	Modal Mass Participating Ratios (shall be greater than 0.65 for UX, UY and RZ)		Time Period	UX	UY	RZ
		1	1.176	0.81	0	0
		2	1.013	0	0.837	0
		3	0.994	0	0	0.8199
5	Soft Storey Check		No Soft Storey			

*Notes: *For Earthquake the displacement should be less than H/250 (Clause 5.4.1 of IS 16700). **For Wind condition, the displacement should be less than H/500 (clause 29.5 of IS 456:2000)*

7.9 SERVICEABILITY CHECKS

All the serviceability models have been created under the given serviceability criteria. The modifiers have been assigned as per Clause 6.4.3.1 of IS 1893 Part1:2016 (70% of Igross of columns and 35% for Igross of beams). The serviceability checks for Alternative 1A (Conventional frame model with burnt clay bricks) are included in Tables 7.11. The serviceability checks for the remaining following alternatives have been evaluated and the results are included in Annexure 7 (a) to 7 (g) as mentioned below.

- Annexure 7-(a): Alternative 1B – Conventional frame model: Walling with AAC block
- Annextxure 7-(b): Alternative 1C – Conventional frame model: Walling with EPS Panels
- Annextxure 7-(c): Alternative 1D – Conventional frame model: Walling with fly ash bricks
- Annexure 7-(d): Alternative 2A – Conventional frame-shear wall model: Walling burnt clay bricks
- Annexure 7-(e): Alternative 2B – Conventional frame with shear wall model: Walling with AAC blocks
- Annexure 7-(f): Alternative 2C – Conventional frame with shear wall : Walling with EPS sandwich Panels
- Annexure 7-(g): Alternative 2D – Conventional frame with shear wall : Walling with fly ash bricks

CONCLUSION

The structural design and analysis of the G+3 building satisfies the requirements specified in different Indian Standards such as IS 456:2000, IS 1893-Part 1:2016, IS 875-Part 3:2015 and other relevant standards.

LOW-RISE BUILDING: EVALUATION OF EMBODIED CARBON

CHAPTER 8

This Chapter includes evaluation of the embodied carbon of low-rise building from the "cradle-to-practical completion of construction" stage i.e. from life cycle stages A1 to A3 and A4 and A5.

In our work of comparative assessment of embodied carbon, we have restricted our calculations to the construction of Reinforced Concrete (RC) framework including the partition walls, formwork and plastering work.

Note: The carbon emissions attributable to the use of materials 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 been considered in the architectural and structural design.

8.2 ECF/GWP FACTORS

As mentioned in Chapter 6, the crux of the embodied carbon calculations is based on the estimation of the so-called 'Embodied Carbon Factor (ECF)' or Global Warming Potential (GWP) factor of each material or product. It was also mentioned in Chapter 6 that the embodied carbon of the material/product is calculated by multiplying the material quantity with ECF/GWP factors of respective materials as below:

(respective quantity of material) x (ECF/GWP of material measured in $kgCO_{2e}$)

Chapter 6 includes detailed deliberation on ECF/GWP factors. Table 6.1 in Chapter 6 provides ECF/GWP factors used in High-Rise (HR) and Low-Rise (LR) Projects. The values in Table 6.1 have been used in the calculations of embodied carbon of low-rise building.

8.3 ESTIMATION OF GWP FROM CRADLE TO GATE

STAGES A1-A3

The following paragraphs cover the estimation of the GWP of all 24 alternatives described in Fig 7.4 of Chapter 7 for the lifecycle stages A1 to A3 initially, i.e. from cradle to gate (of site). This is then followed by estimation of GWP during LCA stage A4 and A5.

Concrete
For concrete, we have used M30 grade for all structural components. For comparative assessment we have used three alternative types of cements, namely, OPC, PPC and PSC. The mix proportions adopted for three types of cements and the corresponding 28-day compressive strengths obtained are included in Table 8.1. The carbon emissions of the concrete mixes are also included in Table 8.1.

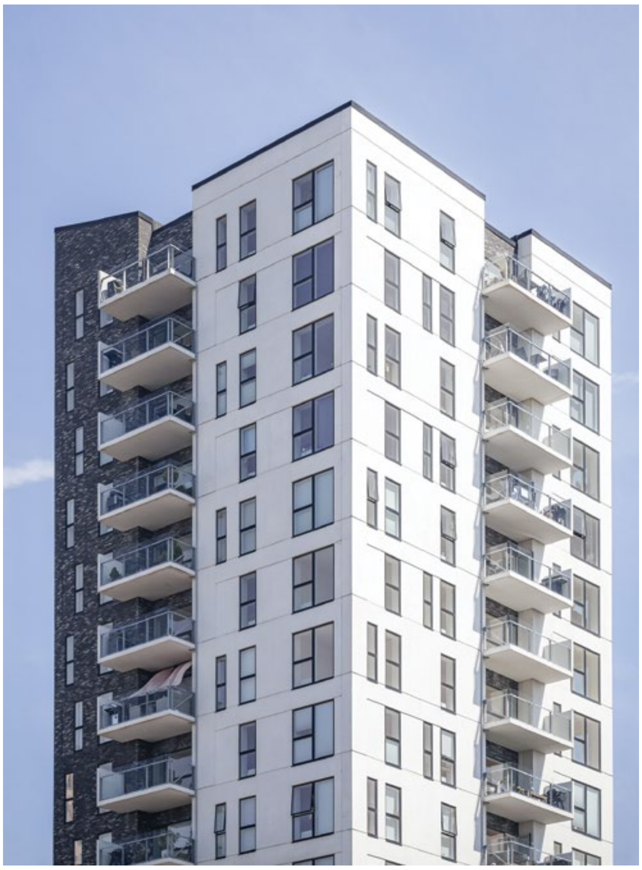


Table 8.1 Concrete mix proportions for M30 grade using different types of cements and their GWP

Grade of concrete	OPC Mix	PPC Mix	PSC mix		Grade of concrete	Carbon Footprints of Concrete Mix, $kgCO_{2e}/m^3$			
	M30	M30	M30			GWP factor, $kgCO_{2e}/kg$	M30 OPC mix	M30 PPC mix	M30 PSC mix
Binder content,kg	380	420	420						
OPC, kg	380	-	0		OPC	0.91	345.8	0	0
PPC, kg	0	420	0		PPC	0.709	0	297.78	0
PSC, kg	0	0	420		PSC	0.487	0	0	204.54
CSS, kg	880	805	828		CSS	0.009	7.92	7.245	7.452
20mm, kg	610	612	600		20mm	0.009	5.49	5.508	5.4
10mm, kg	410	404	400		10mm	0.009	3.69	3.636	3.6
Chem. Adm., kg	4.56	5.04	5.04		Chem. Adm	0.075	0.342	0.378	0.378
Free water	156	164	164		Free water	0	0	0	0
28-d Comp. strength, MPa	38.7	36.6	35.2		Total GWP		363.24	314.55	221.37

As discussed earlier in Chapter 7, we have assumed that all requirements of concrete of M30 grade for the low-rise project will be satisfied by a small-capacity RMC plant located within the 10 km distance from the site. The RMC industry in India has now spread its wings to tier II and tier III cities. Small-capacity RMC plants are now located in major semi-urban centres of India.

All concrete mixes are designed to provide concrete having slump of 150mm at the pouring site.

Steel Reinforcement

As described in Chapter 6 under the subtitle "Steel Reinforcement", ECF/GWP value of $2.34tCO_{2e}/tcs$ is used in the calculations of embodied carbon emissions.

Formwork

It is a common practice in India to use plywood timber combination of formwork for low-rise buildings. It is easy to fetch locally available timber ballies and plywood which incidentally has proved to be economical for small construction applications.

For the RC framework construction of the low-rise building it is assumed that 12mm thick plywood forms supported with timber framework are used in the project. There are 12 flats in the building and the construction area is $979m^2$. For such comparatively lower volume of construction plywood-cum-timber formwork may suffice and would prove to be economical too.

Walling Materials

We have used the following four types of walling materials in different alternatives as shown in Fig 7.4 of Chapter 7.

- Burnt clay bricks
- AAC Blocks
- Fly ash bricks
- EPS Panels

Generally, the first three types of walling materials are commonly used in India as these are available locally.

The fourth type of alternative, namely expanded polystyrene (EPS) Sandwich Panel is comparatively a new addition for the construction industry in India. However, recently the use of such panels has commenced for small-size buildings, bungalows and certain selected projects.

The EPS panels of are manufactured in a factory set up. Zinc-coated electro-welded wires are stitched on both sides of flame-retardant EPS, Fig 8.1(a). The cut-outs for window, door, etc can easily be made in the walling. Once the panels are fixed at site between the beams/columns, these are covered on both sides with a minimum thickness of 30 mm plaster of 1:3 mortar. The EPS sandwich panels are lighter and strong. The typical details of the EPS sandwich panel are shown in Fig 8.1(a) and (b).

One of the major hurdles faced in the adoption of EPS sandwich panels has been the lack of confidence amongst users to fix storage shelfs on the sandwich walls. To overcome this hurdle, one of the EPS panel manufacturers has shared a video clip which shows that the plastered EPS can be nailed with the help of a drilling machine.

The video also shows that two anchor bolts drilled into the panel can easily bear the weight of a loaded storage frame weighing about 150kg. Load test report is available from NBP Nirman Bharat Panels LLP (www.nbpanels.com)

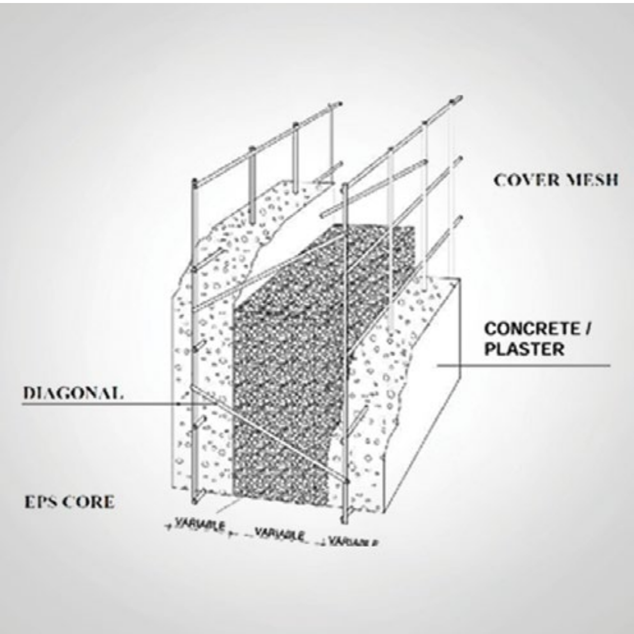


Fig 8.1 (a) Typical EPS sandwich Panel
(Source: Beardsell Ltd. Quickbuild Construction System) [1]

It is understood that nearly four factories manufacturing EPS Sandwich panels have been set up in India till date and more are in the pipeline. Since the panels are lighter in weight, the handling and transportation are easy. The panels are so light that

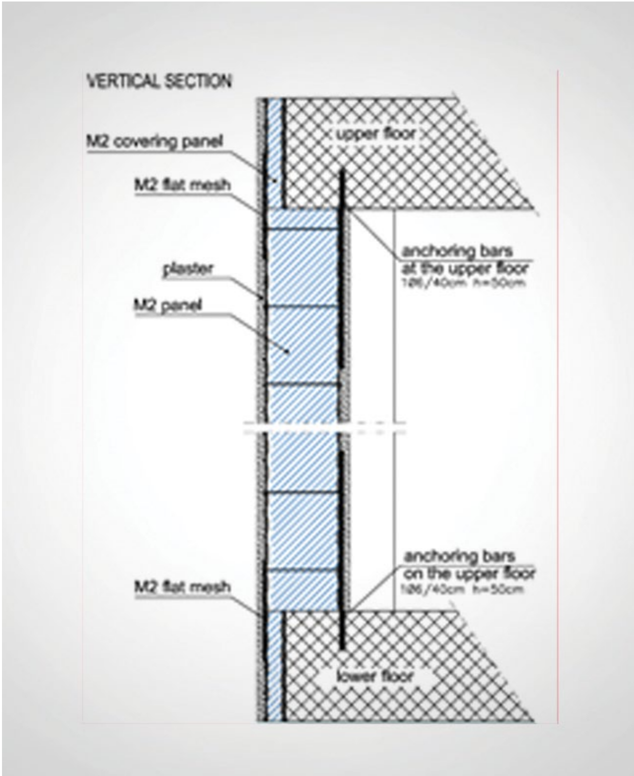


Fig 8.1 (b) Typical cross section of EPS sandwich panel
(Source: Emmedue) [2]

one manual worker can easily carry it and place it in position. Besides the lightweight characteristic of EPS panel, its property of providing better thermal insulation is also attractive for a tropical country like India.

It is assumed that the EPS panels will be obtained from the nearest factory and used in the current project.

External and Internal Plasters

We have considered the use of 25 mm thick external plaster for three types of walling materials i.e. AAC blocks, fired clay bricks and fly ash bricks. For internal plaster, 12 mm thick plaster is proposed for the same. For EPS panels, it is essential to have 30 mm plaster on both external and internal sides.

For external plaster, it is proposed to use ready-mixed plaster which is now available in ready-to-use condition in bags in major semi urban centres of India. We have proposed 1:3 cement-sand plaster. In the commercially available ready-mix plasters, nearly 25% of the ordinary Portland cement is replaced with fly ash. We propose that for the bedding material of AAC blocks, fired clay bricks and fly ash bricks, the same ready-mixed plaster shall be used.

On the internal side, it is suggested to use gypsum plaster. Since internal sand-cement plaster is being used in all internal application, the lower thickness of 10 mm is suggested for the gypsum plaster.

Material Summary

Based on the structural design, quantities of the materials have been worked out and the summary of materials used in different alternatives is provided in four tables. While Tables 8.2, 8.3 include the summary of materials used in Alternative 1, Tables 8.4, 8.5 provide the summary of materials in Alternative 2.

Table 8.2 Material summary: Alternatives 1A & 1B

	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block		
M30 Grade concrete, m³	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX
Total concrete quantity, m³	391.42	391.42	391.42	385.78	385.78	385.78
Reinforcement quantity (tonne)	49.33	49.33	49.33	48.03	48.03	48.03
Formwork (m²)						
12 mm Plywood	480.70	480.70	480.70	453.70	453.70	453.70
Timber	6.32	6.32	6.32	6.05	6.05	6.05
Walling (m³)						
150/80 mm thick	208.95	208.95	208.95	208.95	208.95	208.95
Plaster						
External Sand Plaster (25 mm) m³	49.45	49.45	49.45	49.45	49.45	49.45
Internal Sand Plaster (12 mm) m³	37.43	37.43	37.43	37.43	37.43	37.43
Internal Gypsum Plaster (10 mm) m³	31.19	31.19	31.19	31.19	31.19	31.19

Table 8.3 Material summary: Alternatives 1C & 1D

	Alternative 1-A EPS panel			Alternative 1-B Fly Ash Brick		
M30 Grade concrete, m³	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX
Total concrete quantity, m³	326.67	326.67	326.67	388.90	388.90	388.90
Reinforcement quantity (tonne)	39.08	39.08	39.08	48.92	48.92	48.92
Formwork (m²)						
12 mm Plywood	371.01	371.01	371.01	456.66	456.66	456.66
Timber	5.22	5.22	5.22	6.32	6.32	6.32
Walling (m³)						
150/80 mm thick	94.72	94.72	94.72	208.95	208.95	208.95
Plaster						
External Sand Plaster (25 mm) m³	45.20	45.20	45.20	49.45	49.45	49.45
Internal Sand Plaster (12 mm) m³	79.53	79.53	79.53	37.43	37.43	37.43
Internal Gypsum Plaster (10 mm) m³	26.51	26.51	26.51	31.19	31.19	31.19

Table 8.4 Material summary: Alternatives 2A & 2B

	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block		
M30 Grade concrete, m3	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX
Total concrete quantity, m³	443.00	443.00	443.00	439.48	439.48	439.48
Reinforcement quantity (tonne)	39.06	39.06	39.06	36.39	36.39	36.39
Formwork (m²)						
12 mm Plywood	396.62	396.62	396.62	383.06	383.06	383.06
Timber	5.47	5.47	5.47	5.34	5.34	5.34
Walling (m³)						
150/80 mm thick	153.15	153.15	153.15	153.15	153.15	153.15
Plaster						
External Sand Plaster (25 mm) m³	49.45	49.45	49.45	49.45	49.45	49.45
Internal Sand Plaster (12 mm) m³	37.43	37.43	37.43	37.43	37.43	37.43
Internal Gypsum Plaster (10 mm) m³	31.19	31.19	31.19	31.19	31.19	31.19

Table 8.5 Material summary: Alternatives 2C & 2D

	Alternative 2-C EPS Panel			Alternative 2-D Fly Ash Brick		
M30 Grade concrete, m³	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX
Total concrete quantity, m³	381.13	381.13	381.13	442.36	442.36	442.36
Reinforcement quantity (tonne)	29.88	29.88	29.88	38.35	38.35	38.35
Formwork (m²)						
12 mm Plywood	437.57	437.57	437.57	376.78	376.78	376.78
Timber	5.88	5.88	5.88	5.47	5.47	5.47
Walling (m³)						
150/80 mm thick	94.72	94.72	94.72	153.15	153.15	153.15
Plaster						
External Sand Plaster (25 mm) m³	45.20	45.20	45.20	49.45	49.45	49.45
Internal Sand Plaster (12 mm) m³	79.53	79.53	79.53	37.43	37.43	37.43
Internal Gypsum Plaster (10 mm) m³	26.51	26.51	26.51	31.19	31.19	31.19

8.4 EMBODIED CARBON EMISSIONS

A1 – A3

The estimation of embodied carbon emissions is based on the ECF/GWP factors included in Table 6.1 (Chapter 6) and Table 8.1 from the current chapter. The material quantities from Tables 8.2, 8.3 and Tables 8.4, 8.5 have been used in the estimation.

The carbon emissions from Alternative 1(1-A and 1-B) are included Table 8.6 and those from Alternative 1 (1-C and 1-D) in Table 8.7.

Table 8.6 Carbon Emission : Alternatives 1-A & 1-B

	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block		
M30 Grade concrete, m^3	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX
Total concrete quantity, m^3	391.42	391.42	391.42	385.78	385.78	385.78
GWP, $kgCO_{2e}/m^3$	363.24	314.55	221.37	363.24	314.55	221.37
Carbon emissions of Concrete	1,42,179	1,23,121	86,649	1,40,131	1,21,347	85,400
Reinforcement quantity (tonne)	49.33	49.33	49.33	48.03	48.03	48.03
GWP, $kgCO_{2e}/kg$	2,340	2,340	2,340	2,340	2,340	2,340
Carbon emissions of Reinforcement	1,15,432	1,15,432	1,15,432	1,12,390	1,12,390	1,12,390
Formwork (m^2)						
12 mm Plywood	480.70	480.70	480.70	453.70	453.70	453.70
GWP, $kgCO_{2e}/m^2$	0.681	0.681	0.681	0.681	0.681	0.681
Carbon emissions of Plywood	327	327	327	309	309	309
Timber, kg	6,320	6,320	6,320	6,050	6,050	6,050
GWP, $kgCO_{2e}/kg$	0.263	0.263	0.263	0.263	0.263	0.263
Carbon emissions of Timber	1,662	1,662	1,662	1,591	1,591	1,591
Walling (m^3)						
150/80 mm thick	208.95	208.95	208.95	208.95	208.95	208.95
GWP, $kgCO_{2e}/m^3$	361.76	361.76	361.76	254.52	254.52	254.52
Carbon emissions of Walling	75,590	75,590	75,590	53,182	53,182	53,182
Plaster						
External Sand Plaster (25 mm) m^3	49.45	49.45	49.45	49.45	49.45	49.45
GWP, kg CO_{2e}/m^3	319.22	319.22	319.22	319.22	319.22	319.22
Carbon emissions of External Plaster	15,785	15,785	15,785	15,785	15,785	15,785
Internal Sand Plaster (12 mm) m^3	37.43	37.43	37.43	37.43	37.43	37.43
GWP, kg CO_{2e}/m^3	319.22	319.22	319.22	319.22	319.22	319.22
Carbon emissions of Internal Plaster	11,948	11,948	11,948	11,948	11,948	11,948
Internal Gypsum Plaster (10 mm) kg	23,393	23,393	23,393	23,393	23,393	23,393
GWP, kg CO_{2e}/kg	0.09	0.09	0.09	0.09	0.09	0.09
Carbon emissions of Gypsum Plaster	2,105	2,105	2,105	2,105	2,105	2,105
Total sum of embodied Carbon emissions	3,65,030	3,45,972	3,09,499	3,37,442	3,18,659	2,82,712
Total Carbon emissions (per m^2)	**372.86**	**353.39**	**316.14**	**344.68**	**325.49**	**288.78**

Table 8.7 Carbon Emission : Alternatives 1-C & 1-D

	Alternative 1-C EPS Panel			Alternative 1-D Fly Ash Brick		
M30 Grade concrete, m^3	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX
Total concrete quantity, m^3	326.67	326.67	326.67	388.90	388.90	388.90
GWP, $kgCO_{2e}/m^3$	363.24	314.55	221.37	363.24	314.55	221.37
Carbon emissions of Concrete	1,18,660	1,02,754	72,315	1,41,264	1,22,328	86,091
Reinforcement quantity (tonne)	39.08	39.08	39.08	48.92	48.92	48.92
GWP, $kgCO_{2e}/kg$	2,340	2,340	2,340	2,340	2,340	2,340
Carbon emissions of Reinforcement	91,447	91,447	91,447	1,14,473	1,14,473	1,14,473
Formwork (m^2)						
12 mm Plywood	371.10	371.10	371.10	456.66	456.66	456.66
GWP, $kgCO_{2e}/m^2$	0.681	0.681	0.681	0.681	0.681	0.681
Carbon emissions of Plywood	253	253	253	311	311	311
Timber,kg	5,220	5,220	5,220	6,320	6,320	6,320
GWP, $kgCO_{2e}/kg$	0.263	0.263	0.263	0.263	0.263	0.263
Carbon emissions of Timber	1,373	1,373	1,373	1,662	1,662	1,662
Walling (m^3)						
150/80 mm thick	1,184.05	1,184.05	1,184.05	208.95	208.95	208.95
GWP, $kgCO_{2e}/m^3$	12.96	12.96	12.96	335.12	335.12	335.12
Carbon emissions of Walling	15,345	15,345	15,345	70,023	70,023	70,023
Plaster						
External Sand Plaster (25 mm) m^3	45.20	45.20	45.20	49.45	49.45	49.45
GWP, kg CO_{2e}/m^3	319.22	319.22	319.22	319.22	319.22	319.22
Carbon emissions of External Plaster	14,429	14,429	14,429	15,785	15,785	15,785
Internal Sand Plaster (12 mm) m^3	79.53	79.53	79.53	37.43	37.43	37.43
GWP, kg CO_{2e}/m^3	319.22	319.22	319.22	319.22	319.22	319.22
Carbon emissions of Internal Plaster	25,388	25,388	25,388	11,948	11,948	11,948
Internal Gypsum Plaster (10 mm) kg	19,883	19,883	19,883	23,393	23,393	23,393
GWP, $kgCO_{2e}/kg$	0.09	0.09	0.09	0.09	0.09	0.09
Carbon emissions of Gypsum Plaster	1,789	1,789	1,789	2,105	2,105	2,105
Total sum of embodied Carbon emissions	2,68,683	2,52,778	2,22,339	3,57,572	3,38,636	3,02,399
Total Carbon emissions (per m^2)	**274.45**	**258.20**	**227.11**	**365.24**	**345.90**	**308.89**

The carbon emissions from Alternative 2 (2-A and 2-B) are included Table 8.8 and those from Alternative 2 (2-C and 2-D) in Table 8.9.

The summary of embodied carbon emissions for different alternatives during A1 to A3 stages is included in Table 8.10.

It can be seen from Table 8.10 that the lowest carbon emission of 218 $kgCO_{2e}/m^2$ is obtained for Alternative 2 using EPS panels as walling material and concrete using PSC. The second lowest value of the embodied carbon emission of 227 $kgCO_{2e}/m^2$ is again obtained for Alternative 1 using EPS panels as walling material – but using concrete with PPC. The highest embodied carbon emission of 373 $kgCO_{2e}/m^2$ is obtained in Alternative 1 using burnt clay bricks as walling material and using concrete containing OPC.

8.5 EMBODIED CARBON EMISSIONS

A4 – A5

The following paragraphs cover the estimation of the GWP of all 24 alternatives for the lifecycle stages A4 and A5, i.e. during the transportation and construction stage.

As mentioned in Chapter 6, since no reliable India centric data are available on the carbon emission during construction stage, we have used the recommendations provided in the *IStructE* Guide. [3] It provides guidance on estimation of carbon emissions during A4 and A5 stages, which is divided into the following three areas.

Table 8.8 Carbon Emission : Alternatives 2-A & 2-B

	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block		
M30 Grade concrete, m^3	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX
Total concrete quantity, m^3	443.00	443.00	443.00	439.48	439.48	439.48
GWP, $kgCO_{2e}/m^3$	363.24	314.55	221.37	363.24	314.55	221.37
Carbon emissions of Concrete	1,60,915	1,39,346	98,067	1,59,637	1,38,238	97,288
Reinforcement quantity (tonne)	39.06	39.06	39.06	36.39	36.39	36.39
GWP, $kgCO_{2e}/kg$	2,340	2,340	2,340	2,340	2,340	2,340
Carbon emissions of Reinforcement	91,400	91,400	91,400	85,153	85,153	85,153
Formwork (m^2)						
12 mm Plywood	396.62	396.62	396.62	383.06	383.06	383.06
GWP, $kgCO_{2e}/m^2$	0.681	0.681	0.681	0.681	0.681	0.681
Carbon emissions of Plywood	270	270	270	261	261	261
Timber, kg	5,470	5,470	5,470	5,340	5,340	5,340
GWP, $kgCO_{2e}/kg$	0.263	0.263	0.263	0.263	0.263	0.263
Carbon emissions of Timber	1,439	1,439	1,439	1,404	1,404	1,404
Walling (m^3)						
150/80 mm thick	153.15	153.15	153.15	153.15	153.15	153.15
GWP, $kgCO_{2e}/m^3$	361.76	361.76	361.76	254.52	254.52	254.52
Carbon emissions of Walling	55,404	55,404	55,404	38,980	38,980	38,980
Plaster						
External Sand Plaster (25 mm) m^3	49.45	49.45	49.45	49.45	49.45	49.45
GWP, $kgCO_{2e}/m^3$	319.22	319.22	319.22	319.22	319.22	319.22
Carbon emissions of External Plaster	15,785	15,785	15,785	15,785	15,785	15,785
Internal Sand Plaster (12 mm) m^3	37.43	37.43	37.43	37.43	37.43	37.43
GWP, $kgCO_{2e}/m^3$	319.22	319.22	319.22	319.22	319.22	319.22
Carbon emissions of Internal Plaster	11,948	11,948	11,948	11,948	11,948	11,948
Internal Gypsum Plaster (10 mm) kg	23,393	23,393	23,393	23,393	23,393	23,393
GWP, $kgCO_{2e}/kg$	0.09	0.09	0.09	0.09	0.09	0.09
Carbon emissions of Gypsum Plaster	2,105	2,105	2,105	2,105	2,105	2,105
Total sum of embodied Carbon emissions	3,39,266	3,17,697	2,76,418	3,15,273	2,93,875	2,52,924
Total Carbon emissions (per m^2)	**346.54**	**324.51**	**282.35**	**322.04**	**300.18**	**258.35**

Table 8.9 Carbon Emission : Alternatives 2-C & 2-D

	Alternative 2-C EPS Panel			Alternative 2-D Fly Ash Brick		
M30 Grade concrete, m^3	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX
Total concrete quantity, m^3	381.13	381.13	381.13	442.36	442.36	442.36
GWP, $kgCO_{2e}/m^3$	363.24	314.55	221.37	363.24	314.55	221.37
Carbon emissions of Concrete	1,38,442	1,19,884	84,371	1,60,683	1,39,144	97,925
Reinforcement quantity (tonne)	29.88	29.88	29.88	38.35	38.35	38.35
GWP, $kgCO_{2e}/kg$	2,340	2,340	2,340	2,340	2,340	2,340
Carbon emissions of Reinforcement	69,919	69,919	69,919	89,739	89,739	89,739
Formwork (m^2)						
12 mm Plywood	437.57	437.57	437.57	376.78	376.78	376.78
GWP, $kgCO_{2e}/m^2$	0.681	0.681	0.681	0.681	0.681	0.681
Carbon emissions of Plywood	298	298	298	257	257	257
Timber, kg	5,880	5,880	5,880	5,470	5,470	5,470
GWP, $kgCO_{2e}/kg$	0.263	0.263	0.263	0.263	0.263	0.263
Carbon emissions of Timber	1,546	1,546	1,546	1,439	1,439	1,439
Walling (m^3)						
150/80 mm thick	1184.05	1184.05	1184.05	153.15	153.15	153.15
GWP, $kgCO_{2e}/m^3$	12.96	12.96	12.96	335.12	335.12	335.12
Carbon emissions of Walling	15,345	15,345	15,345	51,324	51,324	51,324
Plaster						
External Sand Plaster (25 mm) m^3	45.20	45.20	45.20	49.45	49.45	49.45
GWP, $kgCO_{2e}/m^3$	319.22	319.22	319.22	319.22	319.22	319.22
Carbon emissions of External Plaster	14,429	14,429	14,429	15,785	15,785	15,785
Internal Sand Plaster (12 mm) m^3	79.53	79.53	79.53	37.43	37.43	37.43
GWP, $kgCO_{2e}/m^3$	319.22	319.22	319.22	319.22	319.22	319.22
Carbon emissions of Internal Plaster	25,388	25,388	25,388	11,948	11,948	11,948
Internal Gypsum Plaster (10 mm) kg	19,883	19,883	19,883	23,393	23,393	23,393
GWP, $kgCO_{2e}/kg$	0.09	0.09	0.09	0.09	0.09	0.09
Carbon emissions of Gypsum Plaster	1,789	1,789	1,789	2,105	2,105	2,105
Total sum of embodied Carbon emissions	2,67,156	2,48,599	2,13,085	3,33,279	3,11,741	2,70,522
Total Carbon emissions (per m^2)	**272.89**	**253.93**	**217.66**	**340.43**	**318.43**	**276.32**

Table 8.10 Summary of embodied carbon emissions for different alternatives during A1 to A3 stages

Alternative 1

	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS Panel			Alternative 1-D Fly Ash Brick		
	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX
Total sum of embodied Carbon emiwssions	3,65,030	3,45,972	3,09,499	3,37,442	3,18,659	2,82,712	2,68,683	2,52,778	2,22,339	3,57,572	3,38,636	3,02,399
Total Carbon emissions (per m^2)	373	353	316	345	325	289	274	258	227	365	346	309
Rank	24	22	13	19	16	10	7	4	2	23	20	12

Alternative 2

	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS Panel			Alternative 2-D Fly Ash Brick		
	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX
Total sum of embodied Carbon emissions	3,39,266	3,17,697	2,76,418	3,15,273	2,93,875	2,52,924	2,67,156	2,48,599	2,13,085	3,33,279	3,11,741	2,70,522
Total Carbon emissions (per m^2)	347	325	282	322	300	258	273	254	218	340	318	276
Rank	21	17	9	15	11	5	6	3	1	18	14	8

- Emissions owing to the Transportation of all Materials from factory to site (A4)
- Emissions owing to material wastage (A5w), which is further divided into following four areas:
  - o Emission attributed to wasted materials (A13)
  - o Emissions of transporting the wasted materials to site (A4w)
  - o Emissions due to transporting wasted materials away from site (C2)
  - o Emissions from processing and disposal of waste materials (C34)
- Emission during construction installation process (A5), mainly involving emissions due to the use of electrical energy and fuels during the construction operations.

Emissions due to Transportation of all Materials (A4)
The carbon emissions due to transportation of different materials in Alternative 1 are included in Annexure 8–1-T (i) to 8–1-T (vii).

Similar annextures for carbon emissions due to transportation of materials in Alternative 2 are included in Annexures 8–2-T (i) to 8–2-T (vii).

The summary of emissions due to transportation of materials in Alternative 1 and Alternative 2 are respectively included in Annexures 8–1-T (viii) and 8–2-T (viii).

Carbon Emissions due to wastage (A5w) and Energy use during Construction process
As mentioned earlier, the *IStructE* document provides useful guidance to evaluate the carbon emissions owing to wasted materials (A13), transportation of wasted materials (A4w), transporting wasted materials away from site (C2) and processing and disposal of waste materials (C34). In India, no guidance is available on these aspects. Based on the recommendations provided in *IStructE* guidelines, the carbon emissions due to wastages of materials in Alternative 1 are included in Annexture 8–1-W (i) to 8–1-W (vii) and for Alternative 2 in Annextures 8–2-W (i) to 8–2-W (vii).

The summary of emissions due to wastage of materials in Alternative 1 is provided in Annexure 8–1-W (viii) and those in Alternative 2 in Annexure 8–2-W (viii).

As regards the energy use in the construction of low-rise building, it needs to be mentioned here that the level of mechanization in the low-rise building construction is still low in India. The use of labour-intensive techniques involving large force of unskilled labourers is still practiced in semi-urban India on most low-rise building construction sites. The adoption of machines using electric energy or equipment using fossil fuels are kept to a very minimal level.

Considering the above aspects, we have assumed that at the most 10% of energy used in high-rise building construction (see Chapter 6) would be used in the construction of the low-rise building. The carbon footprints of energy use in high-rise building construction have been worked out as 168,408 $kgCO_{2e}/m^2$ (Table 6.9 of Chapter 6). It is further proportionately reduced considering area of construction in both options as below:

168,408 × 0.1 = 16840.8 x (979/158,78) = 1038$kgCO_{2e}/m^2$

Table 8.11 (a) includes the total carbon emissions from A4 and A5 for Alternative 1 and those from Alternative 2 in Table 8.11 (b).

Table 8.11 (a): Total carbon emissions from A4 and A5 for Alternative 1

	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Emission During A4 [Annexure 8 – 1T (viii)]	5,588	5,588	5,588	4,067	4,067	4,067	3,444	3,444	3,444	5,421	5,421	5,421
Total Emission during A5 [Annexure 8 – 1W (viii)]	12,663	12,282	11,553	11,834	11,458	10,739	9,572	9,254	8,645	12,453	12,074	11,349
Emission due to site activity, $kgCO_{2e}$	1,038	1,038	1,038	1,038	1,038	1,038	1,038	1,038	1,038	1,038	1,038	1,038
Total A4+A5	19,290	18,909	18,179	16,939	16,563	15,845	14,055	13,737	13,128	18,912	18,534	17,809

Table 8.11 (b) : Total carbon emissions from A4 and A5 for Alternative 2

	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS Panel			Alternative 2-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Emission During A4 [Annexure 8 – 2T (viii)]	4,858	4,858	4,858	3,690	3,690	3,690	3,299	3,299	3,299	4,726	4,726	4,726
Total Emission during A5 [Annexure 8 – 2W (viii)]	11,286	10,854	10,029	1,0491	10,063	9,244	9,053	8,682	7,972	11,091	10,661	9,836
Emission due to site activity, $kgCO_{2e}$	1,038	1,038	1,038	1,038	1,038	1,038	1,038	1,038	1,038	1,038	1,038	1,038
Total Emission (A4+A5)	17,182	16,751	15,925	15,220	14,792	13,973	13,391	13,020	12,309	16,856	16,425	15,601

8.6 COMBINED CARBON EMISSIONS FROM A1 TO A5 STAGES

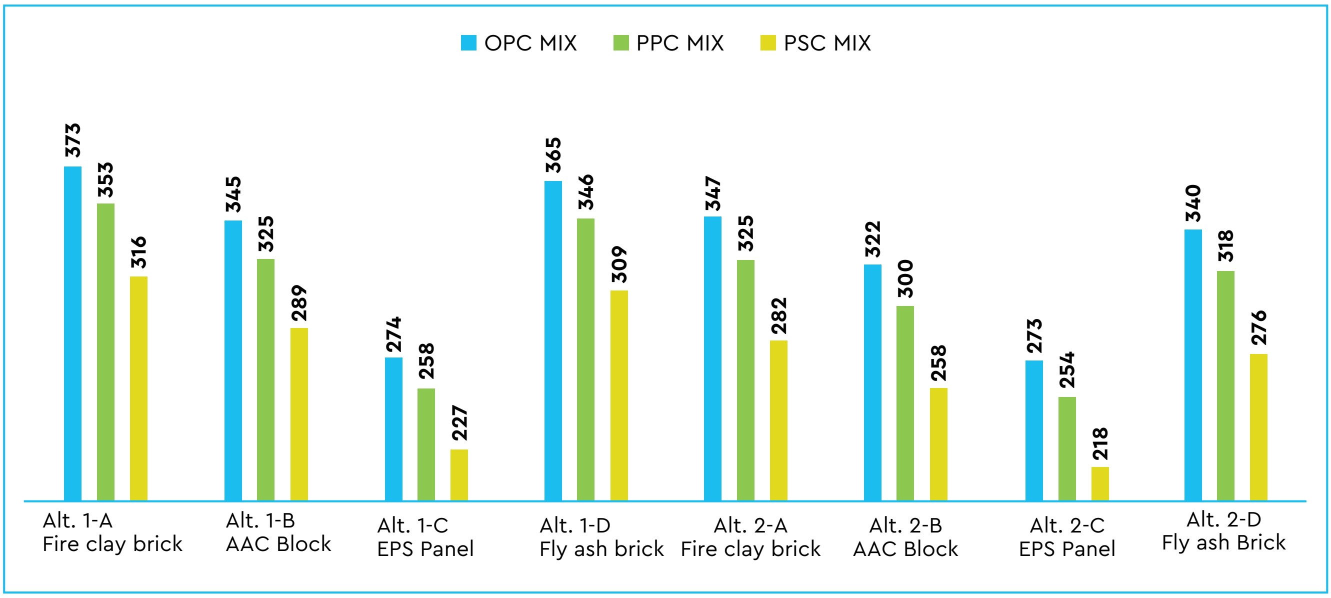
Table 8.12 (a) shows the total carbon emissions for A1 to A5 modules for Alternative 1 and Table 8.12 (b) shows the total carbon emissions for A1 to A5 modules for Alternative 2.

Table 8.12 (a) : Total carbon emissions from A1 to A5 for Alternative 1

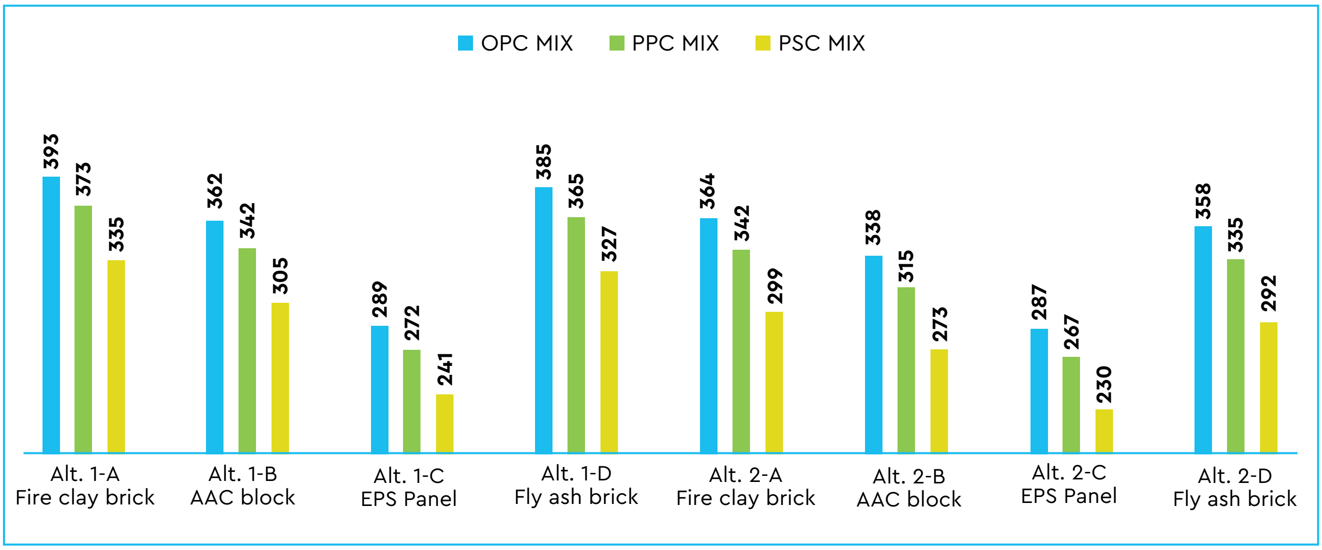
	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS Panel			Alternative 1-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Sum of Carbon emissions during A1-A3 (Table 8.6 & 8.7)	3,65,030	3,45,972	3,09,499	3,37,442	3,18,659	2,82,712	2,68,683	2,52,778	2,22,339	3,57,572	3,38,636	3,02,399
Total Emission during A4 +A5 [Table 8.10(a)]	19,290	18,909	18,179	16,939	16,563	15,845	14,055	13,737	13,128	18,912	18,534	17,809
Total Carbon emission from A1 to A5	3,84,320	3,64,881	3,27,679	3,54,381	3,35,222	2,98,556	2,82,738	2,66,515	2,35,467	3,76,484	3,57,170	3,20,208
Total Carbon Emission from A1 to A5 per m^2	**392.56**	**372.71**	**334.71**	**361.98**	**342.41**	**304.96**	**288.80**	**272.23**	**240.52**	**384.56**	**364.83**	**327.08**
Ratio of Emission during A4A5 to Total Emission A1 to A5	5.02	5.18	5.55	4.78	4.94	5.31	4.97	5.15	5.58	5.02	5.19	5.56

Table 8.12 (b): Total carbon emissions from A1 to A5 for Alternative 2

	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS PANEL			Alternative 2-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Sum of Carbon emissionsduring A1-A3 (Table 8.8 & 8.9)	3,39,266	3,17,697	2,76,418	3,15,273	2,93,875	2,52,924	2,67,156	2,48,599	2,13,085	3,33,279	3,11,741	2,70,522
Total Emission during A4 + A5 [Table 8.10(b)]	17,182	16,751	15,925	15,220	14,792	13,973	13,391	13,020	12,309	16,856	16,425	15,601
Total Carbon Emission from A1 to A5	3,56,449	3,34,448	2,92,343	3,30,493	3,08,666	2,66,897	2,80,547	2,61,619	2,25,395	3,50,135	3,28,166	2,86,122
Total Carbon Emission from A1 to A5 per m^2	**364.09**	**341.62**	**298.61**	**337.58**	**315.29**	**272.62**	**286.56**	**267.23**	**230.23**	**357.65**	**335.21**	**292.26**
Ratio of Emission during A4A5 to Total Emission A1 to A5	4.82	5.01	5.45	4.61	4.79	5.24	4.77	4.98	5.46	4.81	5.01	5.45



8.2(a) Low-Rise Building: Embodied Carbon Emission During Product Stage (A1-A3)



8.2(b) Low-Rise Building: Total Carbon Emission Upto Construction Stage (A1-A5)

For the A1 to A5 life cycle stages the lowest carbon emission observed in Alternative 1 is 240.52 $kgCO_{2e}/m^2$ [Table 8.12 (a)] and that in Alternative 2 is 230.23 $kgCO_{2e}/m^2$ [Table 8.12 (b)]. Both lowest values have been obtained in the Alternative using EPS sandwich panels as walling material and concrete containing PSC cement. The ratio of emissions from A4 and A5 modules to the total emissions from A1 to A5 modules varied from 4.78 to 5.58 in Alternative 1 and 4.61 to 5.46 in Alternative 2.

Incidentally, based on London Energy Transformation Initiative's (LETI's) embodied carbon primer, John Orr *et al* mentions that the combined total of embodied carbon emitted during transport and construction i.e. A4 and A5 stages is 5% of the total embodied carbon (see Fig 3.7 from Chapter 3 of current document) [4].

The comparison of percentage reduction in the carbon footprints of different alternatives with respect to the base alternative of fire clay bricks is summarised in Table 8.13.

It can be observed from Table 8.13 that maximum reductions in carbon emissions varying from 28.14% (Alt. 1) to 22.90 % (Alt. 2) are obtained in the alternative using EPS panels as walling and concrete containing and PSC cement, when compared with the alternative using fired clay bricks.

Table 8.13 : Comparative Assessment of Reduction in Carbon Footprints in A1 to A5 Stages with respect the control values of Fire Clay Bricks

Alternative 1

	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Carbon Emission from A1 to A5 per m^2 [Table 8.12 (a)]	392.56	372.71	334.71	361.98	342.41	304.96	288.80	272.23	240.52	384.56	364.83	327.08
% Reduction in the Carbon Footprint with respect to Alternative 1A	-	-	-	7.79	8.13	8.89	26.43	26.96	28.14	2.04	2.11	2.28

Alternative 2

	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS Panel			Alternative 2-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Carbon Emission from A1 to A5 per m^2 [Table 8.12 (b)]	364.09	341.62	298.61	337.58	315.29	272.62	286.56	267.23	230.23	357.65	335.21	292.26
% Reduction in the Carbon Footprint with respect to Alternative 2A	-	-	-	7.28	7.71	8.70	21.29	21.78	22.90	1.77	1.88	2.13

Table 8.14 Percent reduction in carbon emissions between Alternative 1 and Alternative 2

Walling Material	Fire Clay Brick			AAC Block			EPS PANEL			Fly Ash Brick		
Concrete	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total embodied carbon ($kgCO_{2e}$ per m^2) from A1 to A5 for Alternative 1	392.56	372.71	334.71	361.98	342.41	304.96	288.80	272.23	240.52	384.56	364.83	327.08
Total embodied carbon ($kgCO_{2e}$ per m^2) from A1 to A5 for Alternative 2	364.09	341.62	298.61	337.58	315.29	272.62	286.56	267.23	230.23	357.65	335.21	292.26
Reduction (Alt 1 – Alt2) in $kgCO_{2e}$ per m^2	28.47	31.09	36.09	24.40	27.13	32.34	2.24	5.00	10.29	26.91	29.63	34.82
% Reduction of total carbon emission between Alternative 1 and 2	7.3	8.3	10.8	6.7	7.9	10.6	0.8	1.8	4.3	7.0	8.1	10.6

Reduction in embodied carbon emissions owing to optimization in structural system

In Alternative 2, we have tried to bring in optimization in structural design by introducing shear walls in the duct portion and some other 'dead' locations in the reinforced concrete framing system adopted in Alternative 1. This has resulted in reducing the embodied carbon emissions in the four alternatives as shown in Table 8.14.

It can be seen from Table 8.14 that embodied carbon reduction varies with alternative walling system and the type of cement used in concrete – 7.3 to 10.8% for fired clay walling, 6.7 to 10.6% for AAC block walling, 7.0 to 10.6% for fly ash brick walling and 0.8 to 4.3% for EPS panel walling.

8.7 COST ESTIMATION

Based on the current market rates of different materials and products, an attempt has been made to estimate the tentative total cost of different alternatives, in addition to the embodied carbon emissions.

The cost estimates of Alternatives 1 and 2 are presented in Annexure 8-3C to Table 8-4C. Table 8.15 provides the summary of cost estimates.It can be seen from Table 8.15 that the Alternative 1 using EPS panels and concrete containing PPC cement provides the lowest cost alternative (Rs. 10,175/m^2), closely followed by Alternative 2 using EPS sandwich panel and concrete containing PSC cement (Rs.10,261/m^2).

The highest cost (Rs.14,533/m^2) is obtained for Alternative 1 using fire clay bricks and concrete using OPC.

Table 8.15 Summary of cost comparison of different alternatives

Description	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS Panel			Alternative 1-D Fly Ash Brick		
	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX
Total Cost	1,42,27,935	1,40,91,721	1,41,77,442	1,38,47,507	1,37,13,255	1,37,97,741	1,02,65,876	1,01,52,195	1,02,23,735	1,40,56,239	1,39,20,902	1,40,06,071
Cost per m^2	14,533	14,394	14,482	14,145	14,007	14,094	10,486	10,370	10,443	14,358	14,220	14,307
Rank	24	22	23	18	16	17	6	4	5	21	19	20

	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS Panel			Alternative 2-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Cost	1,31,73,655	1,30,19,491	1,31,16,508	1,27,93,022	1,26,40,083	1,27,36,329	1,00,94,439	99,61,806	1,00,45,274	1,30,22,635	1,28,68,694	1,29,65,571
Cost per m^2	13,456	13,299	13,398	13,067	12,911	13,010	10,311	10,175	10,261	13,302	13,145	13,244
Rank	15	12	14	9	7	8	3	1	2	13	10	11

8.17 REFERENCES

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CONCLUSIONS

CHAPTER 9

Climate Change is stark reality, threatening the planet's eco-system and may be its very existence. As buildings and construction are responsible for nearly 37% of the carbon emissions, it is highly essential that the construction sector in India take steps to make sweeping reductions in the carbon emissions from construction.

This report on the comparative assessment of embodied carbon emissions from high-rise and low-rise buildings is restricted to the assessment of emissions from cement and concrete-centric applications such as the construction of reinforced concrete framework including the partition walls, formwork and plastering work. The carbon emissions attributable to the use of materials like doors, windows, floor finishing, painting work, accessories and finishes for bathrooms, kitchen, etc. are not considered in this study as these would be common for the different alternatives that have been considered in the architectural and structural design.

Provisions in different Indian Standards have been strictly followed in the structural designs of both high-rise and low-rise buildings. Similarly, the design of concrete mixtures and plasters follow the permissible limits specified in the Indian Standards.

Based on the findings of the study following broad conclusions have been drawn.

9.1 Conclusions of study on high-rise buildings

a. Out of 12 alternative combinations using different structural arrangements and different concrete mix parameters, lowest carbon footprint is obtained by:

   i. RC framed structure (Grade M80 to 60 using ordinary Portland cement, Gound granulated blastfurnace slag and microsilica/ultrafine slag (OPC+GGBS+MS/UGGBS) and AAC Blocks (457.62 $kgCO_{2e}/m^2$) (Table 6.11)

   ii. Followed by RC framed structure (Grade M60 to 40 using OPC+GGBS+MS/UGGBS) and AAC blocks (460.25 $kgCO_{2e}/m^2$) (Table 6.11)

b. Highest carbon footprints belongs to RC Framed structure with N.S. walls (Grade M60–40 using (OPC+FA+MS) (560.43 $kgCO_{2e}/m^2$) (Table 6.11)

c. The lowest carbon footprints are obtained for mixes using OPC+GGBS+MS/UGGBS.

d. It is observed that use of AAC blocks for the walling system is preferable as it can reduce the carbon footprints by nearly 18.3% (Alt. 1) to 17.9% (Alt. 3) when compared with the highest emission provided by the non-structural wall system (Alt. 11). (see Note below Table 6.11)

e. For the given configuration of the building, use of higher grades of concrete (M80-M50) proved marginally advantageous over M60 to M40 grades (when using AAC blocks) as far as carbon emissions are concerned. Here, the reduction in the carbon emission ranged from 0.57 to 3.7% thus higher strength does not necessarily mean higher carbon emissions.

f. The difference in the cost/m^2 between the first lowest (Rs.19, 326/m^2 for Alt. 5–6) and the second lowest (Rs.19, 343/m^2 for Alt. 1–2) is just Rs.17 (Table 6.12). The difference between the two values being marginal, one can conclude that the lowest carbon alternative is practically the lowest cost alternative.

g. It is observed that the carbon emissions of modules A4 to A5 stages varied from 6.39 to 9.06% of the total emissions obtained during A1 to A5 modules (Table 6.11).

9.2. Conclusions of study on low-rise buildings

a. The study considered 24 alternative combinations using different structural arrangements and different concrete mix parameters.

b. The study considered four types of walling materials such as fired clay bricks, fly ash bricks, AAC blocks and EPS Sandwich panels. The study also considered the use of OPC, PPC and PSC cements in the concrete mix designs.

c. In both Alternatives 1 and 2, EPS sandwich panels lead to the reduction of dead weight of materials thereby achieving reduction in the quantities of concrete and steel.

d. Alternative 2 (combination of RC Frame and shear walls) using EPS sandwich panels and PSC cement provided the lowest carbon emission of 230.23 $kgCO_{2e}/m^2$ (Table 8.12-b). The second lowest carbon emissions of 240.55 $kgCO_{2e}/m^2$ (Table 8.12-a) is achieved again in using EPS panels and PSC cement in Alternative 1.

e. It can be observed from Table 8.13 that maximum reductions in carbon emissions varying from 21.29% (Alt. 2-C) to 28.14% (Alt. 1-C) are obtained in the alternative using EPS panels as walling and concrete containing and PSC cement, when compared with the alternative using fired clay bricks.

f. Optimization in structural design achieved by introducing shear walls in the duct portion and some other 'dead' locations in the reinforced concrete framing system in Alternative 2 resulted in reducing embodied carbon emissions. The reduction in emissions varied from 0.8% to 10.8% (Table 8.14).

g. The lowest cost of Rs.10,175/m^2 was achieved in Alternative 1 using EPS panels and PPC cement (Table 8.15). The second lowest cost of Rs.10,261/m^2 is achieved in Alternative 1 which used EPS sandwich panels and PSC cement. The difference between the two costs being meagre, one can conclude that the lowest carbon alternative is practically the lowest cost alternative. Also, both the alternatives provide similar or low CO_2 footprints.

h. The lowest carbon footprints are achieved with the use of PSC cement.

i. It is observed that the ratio of carbon emissions of modules A4-A5 to A1 to A5 varies from 4.78% (Alt. 1-B) to 5.46% (Alt. 1-D) (Tables 8.12 (a) and (b).

9.3. Common Conclusions

a. Reduction in the load of non-structural elements in the case of both high-rise and low-rise buildings resulted in the decrease in the overall loading on the buildings, which in turn helped in reducing the total embodied CO_2 emissions. This is demonstrated in the use of lightweight autoclave aerated concrete (AAC) blocks in place of fly ash bricks or non-structural wall in high-rise building and the adoption of lightweight EPS Panels in the case of low-rise building.

b. In high-rise building, the use of ground granulated blast-furnace slag (GGBS) as a supplementary cementitious material in ready-mixed concrete permitted higher replacement of ordinary Portland cement, which helped in the reducing of overall embodied CO_2 footprints. Similarly, in the case of low-rise building, the use of Portland slag cement (PSC) helped in reducing the overall embodied CO_2 footprints.

c. Concrete mix optimization which helps in the optimum use of cement is a good tool to reduce the embodied CO_2 footprints.

d. Our study revealed that the alternative having the lowest embodied CO_2 footprints also happens to be the lowest cost alternative.

Comparative analysis of the embodied carbon assessment: Results at a glance	
High-Rise Building	• Carbon Emission Range (A1 to A5): **458 to 560 $kgCO_{2e}/m^2$** • Lowest Emission Alternative: RC Frame (Concrete M80 to M60) + AAC Blocks • Carbon Reduction with AAC Blocks: **17.9% to 18.3%** compared to a non-structural concrete walling system. • Key Limitation: High-strength pumped concrete and aluminium tunnel formwork system allow for faster constructions, but permit minimal optimization of the structural system.
Low-Rise Building	• Carbon Emission Range (A1 to A5): **230 to 393 $kgCO_{2e}/m^2$** • Lowest Emission Alternative: RC Frame/Shear Walls + EPS Sandwich Panels • Carbon Reduction: **21.29% to 28.14%** compared to RC frame and fired clay bricks. • Structural Optimization: Introduction of shear walls in 'dead' spaces reduced emissions by **0.8% to 10.8%**

- Alternative with the lowest carbon emissions also emerged as the lowest-cost option.
- Using GGBS as SCM in RMC or as a blend in PSC cement helped reduce oeverall embodied CO_2 footprints

RECOMMENDATIONS & THE WAY AHEAD

10.1 LEVER TO REDUCE EMBODIED CARBON EMISSIONS

(a) Improving efficiency in structural design

In case high-rise buildings, the use of AAC blocks for the walling system is preferable as it can reduce the carbon footprints by nearly **17.9%** (Alt.3) to **18.3%** (Alt.1) when compared with the highest emission provided by the non-structural wall system (Alt.11). (see Table 6.11)

In high-rise buildings, a strong, durable and resilient structural framing system become necessary to resist earthquake and wind loadings (Nearly 67% of India's land mass come under strong-to-medium earthquakes). Construction using MIVAN-type system provides higher speed of construction and hence preferred by builders and developers in India. Adoption of ribbed slab, voided slab, hollow core slab, flat slab etc. does help in reducing material consumption and carbon footprints. However, the adoption of such techniques do not provide the higher speed of construction in the current Indian context and hence not found favourable..

The attempt of structural optimization was successful in low-rise buildings wherein the introduction of shear walls in the duct portion and some other 'dead' locations in the reinforced concrete framing system in Alternative 2 resulted in reducing embodied carbon emissions, which varied from 0.8% to 10.8%. (see Table 8.14)

For low-rise building, the two changes in the structural and walling systems – one involving introduction of shear walls at 'dead locations' (i.e. locations which do not affect the light and ventilation requirements of the occupants in the buildings) and second involving the use of EPS sandwich panels as a walling material resulted in dramatic savings in carbon footprints – the maximum savings ranging from **21.19% (Alt.2-C) to 28.14% (Alt. 1-C)** when compared with the base alternative of fire clay bricks, Table 8.13.

In the case of high-rise buildings, one can consider the use of EPS sandwich panels in place of fly ash bricks or AAC blocks. However, some of the structural consultants expressed apprehensions and opined that the adoption of such system will adversely affect the speed of construction.

However, in our opinion, one can certainly consider the use of EPS sandwich panel walling systems for the **internal non-load-bearing walls** for high-rise buildings. This is bound to result in reducing the dead loads, which in turn, would optimize the structural design, leading to reduction in carbon footprints. Furthermore, as the density of EPS is very low (15–20 kg/m^3), the use of EPS panels provides a good sound insulation.

Incidentally, development of other innovative alternative lightweight non-structural walling system would be most welcome. Further, innovations in the structural system that permit faster and economic and low-carbon construction would also be most desirable.

(b) Improving Material Efficiency

It is possible to have a reduction in carbon footprints by optimizing concrete mix designs. LCCF conducted experiments in an NABL-accredited lab to optimize three concrete mixes M40, M50 and M60. The objective was to increase the SCM contents in the mixes to higher levels, without compromising the required 28-day compressive strengths. Higher SCM replacement along with lower water-binder ratio would also help in improving the durability of these concrete mixes. The lab trial data is included in Table 10.1. It demonstrates that the increase in the GGBS replacement level from 50% to 60% in M40 and M50 concrete mixes has helped in reducing the GWP by 16.66 to 17.02% without affecting the compressive strength requirement at 28 days and without violating the IS requirements on the maximum level of SCM replacement. Similarly, increasing the replacement of OPC from 21–22% by fly ash to 35%, it was possible to achieve reduction in GWP by 12.86 to 14.71% in M40 and M50 grade concrete. Even in case of M60 grade concrete similar exercise of optimization has resulted in the reduction of GWP by 11.51% (OPC + Fly ash + microsilica) mix and 16.48% in (OPC + GGBS + MS) mix.

It needs to be underlined here that in actual practice

Table 10.1 Optimization of three concrete mixes to achieve reduction in carbon footprints

	Concrete mix proportions of OPC+GGBS											GWP of OPC+GGBS mixes										
	Con crete Grade	Cem ent, kg	GGBS, kg	Micro fine mat., kg	SCM %	CA II, kg	CA I, kg	CSS, kg	Chem. Adm., kg	w/b ratio	28-D Stren-gth, MPa		Ce-ment	GGBS	Micro-fine Mat.	CA II	CA I	CSS	Adm.	Total GWP, kg-CO2e	% reduc-tion in GWP
Commercial Mixes												GWP Factor	0.91	0.066	0.066	0.009	0.009	0.009	0.075		
	M40	245	245	0	50.00	652	445	718	5.88		44.20	M40	222.95	16.17	0.00	5.87	4.01	6.46	0.44	255.90	-
	M50	290	290	0	50.00	645	442	608	6.96		56.80	M50	263.90	19.14	0.00	5.81	3.98	5.47	0.52	298.82	-
	M60	335	240	25	44.17	542	445	770	6	0.27	67.9	M60	304.85	15.84	1.65	4.878	4.005	6.93	0.45	338.153	-
Optimized mixes												GWP Factor	0.91	0.066	0.066	0.009	0.009	0.009	0.075		
	M40	195	295	0	60	652	445	718	5.88	0.32	45.3	M40	177.45	19.47	0.00	5.87	4.01	6.46	0.44	213.26	**16.66**
	M50	230	350	0	60.34	530	415	785	5.51	0.29	58.23	M50	209.30	23.10	0.00	4.77	3.74	7.07	0.41	247.97	**17.02**
	M60	270	285	15	52.63	589	478	812	6.06	0.26	68.47	M60	245.70	18.81	0.99	5.30	4.30	7.31	0.45	282.41	**16.48**

	Concrete mix proportions of OPC+GGBS											GWP of OPC+ FA mixes										
	Con-crete Grade	Ce-ment, kg	FA, kg	Micro-fine Mat., kg	SCM %	CA II, kg	CA I, kg	CSS, kg	Chem. Adm., kg	w/b ratio	28-day Stre., MPa		Ce-ment	FA	Micro-fine Mat.	CA II	CA I	CSS	Adm.	Total GWP, kg-CO2e	% reduc-tion in GWP
Commercial Mixes												GWP Factor	0.91	0.064	0.066	0.009	0.009	0.009	0.075		
	M40	385	105	0	21.43	634	426	742	5.88		46.50	M40	350.35	6.72	0.00	5.71	3.83	6.68	0.44	373.73	-
	M50	440	130	0	22.81	652	442	618	6.84		57.70	M50	400.40	8.32	0.00	5.87	3.98	5.56	0.51	424.64	-
	M60	450	125	25	25	540	442	766	6	0.27	72.3	M60	409.5	8.00	1.65	4.86	3.98	6.89	0.45	435.332	-
Optimized mixes												GWP Factor	0.91	0.064	0.066	0.009	0.009	0.009	0.075		
	M40	320	170	0	34.69	634	426	742	5.88	0.32	48.1	M40	291.2	10.88	0	5.706	3.834	6.678	0.441	318.74	**14.71**
	M50	375	205	0	35.34	530	415	744	6.38	0.29	62.47	M50	341.25	13.12	0	4.77	3.735	6.696	0.478	370.05	**12.86**
	M60	395	120	20	26.17	488	522	799	6.69	0.30	67.2	M60	359.45	7.68	1.32	4.392	4.698	7.191	0.502	385.23	**11.51**

such a type of optimization needs to be accompanied by a higher level of quality control during the entire construction process – from production to curing of concrete.

With a view to achieve further reduction in embodied carbon emissions it is possible to increase the replacement levels of OPC further than those shown in Table 10.1. However, for this all stakeholders in the project need to agree to change the acceptance criteria of concrete which is discussed in para 10.2 and 10.3 below.

10.2 HIGH VOLUME FLY ASH/GGBS CONCRETES

A plethora of lab and field studies are available, which have proved that there are substantial improvements in the variety of properties of concrete – mainly compressive strength and durability – with the use of higher replacement levels of OPC by SCMs like fly ash and GGBS. The technologies of high-volume fly ash concrete (HVFAC) permitting up to 50% replacement of OPC by fly ash and high-volume GGBS concrete, permitting up to 70% replacement of OPC by GGBS, have been well established and adopted in actual practice the world over. However, for using such concretes, it would be appropriate to change the current 28-day acceptance criteria for compressive strength and other properties to 56-day or even 90-day.

It is suggested that the use of such high-SCM concrete can reliably be used for mass concrete foundations and lower levels of columns, shear walls, beams, etc. in buildings where the maximum loads occur at a much later age. Incidentally, in many cases, sizes of such structural elements are comparatively large, necessitating adoption of temperature control measures applicable for mass concrete. In such applications, the use of large volumes of SCMs becomes not only useful but essential too. Of course, it is imperative that good quality control measures are essential in the production and execution of high-SCM concretes.

The adoption of high-volume SCM concrete would be one of the potential levers to reduce the carbon footprints.

The GCCA-India, TERI and other stakeholders in the Committee should approach BIS Committees (CED 2.2) to introduce the following changes in the concrete specifications as below:

- Permit the use of high-volume fly ash concrete (up to 50% replacement of OPC) and high-GGBS concrete (up to 70% replacement of OPC), especially for mass concrete applications
- Permit the adoption of 56-day/90-day acceptance criteria in place of 28-day criteria for high-SCM concrete, provided supporting data on 56-day/90-day are available from lab and/or field results. Further, the design and execution of such concretes are done by adopting good quality control measures.

LCCF will be happy to participate in the meetings with BIS.

10.3 PERFORMANCE-BASED SPECIFICATIONS FOR CONCRETE

Recommendations mentioned in 10.1 and 10.2 are the immediate steps essential to undertake the process of embodied carbon reduction of concrete. In the long run, it would be imperative to move away from the currently practiced 'prescriptive specifications' to 'performance-based' specifications. This will go a long way in advancing the agenda of making significant reductions in embodied carbon of concrete on a fast track.

10.4 DURABILITY OF CONCRETE

The durability of concrete is a crucially important issue. It has been observed that the rates of many chemical reactions that occur within concrete at room temperature are approximately doubled with a temperature increase of 10°C. Therefore, it is highly essential to ensure the long-term durability of concrete structures to enhance their service life, which will go a long way in preserving the non-renewable raw materials on the earth.

In the present report, our scope of work is limited to evaluating the embodied carbon footprints from cradle to the end of construction stage (A1 to A5 stages). However, essential precautions have been taken to design concrete mixes to conform to the current durability provisions specified in IS 456:2000. Further, due care has been taken to use low water/binder ratio in the concrete mix designs while simultaneously incorporating enough amount of reactive SCMs in the mixes, which in turn is bound to ensure long-term durability of concrete mixes.

10.5 NEW INDIAN STANDARD ON LOW CARBON CONCRETE

We also recommend approaching BIS to take up the publication of a new BIS Standard on **"Low Carbon Concrete"**. Considering the fact that the publication of any code/standard is a long-drawn process, a beginning can be made right now.

The objective of this code will be to provide requirements for limiting the maximum GWP of concrete.

GCCA India and LCCF will be glad to provide inputs to the new standards.

10.6 AWARENESS BUILDING

The objective of our work on Comparative Evaluation of Embodied Carbon Emissions for high-rise and low-rise Buildings is to showcase and encourage the stakeholders in the building and construction industries to carry out similar exercise for all new projects and advocate adoption of the alternative design that provides lowest embodied CO_2 emissions.

For spreading our message to the stakeholders in the industry, it is suggested to take help of the professional organizations of civil and structural engineers and architects.

We also recommend that technical sessions on embodied CO_2 assessment and reduction should be organized in major cities like Mumbai, Bengaluru, Delhi, Chennai, Kolkata, Hyderabad, etc.

10.7 PUBLICATIONS OF TECHNICAL PAPERS/ARTICLES

As a part of the awareness building exercise, it is highly essential to publish technical papers/articles on our work in major Indian Journals/Magazines. This will help us in addressing a large section of architects/engineers for better reach.

10.8 INDUSTRY AVERAGE GWP OF MAJOR CONCRETE GRADES

It will be essential to find out the **industry average** of embodied carbon emissions of dominant (major) concrete grades (say M20, M25, M30, M35, M40 and M50) of concretes produced by the RMC/site-based batching plants located in different parts of India. Once the industry average values of embodied carbon emissions of different grades of concrete are known, GCCA-India and the representatives from the stakeholder groups from the construction industry can then plan to set yearly/quarterly targets, culminating in achieving net zero CO_2 emissions by 2070.

For this purpose, we would need help from major RMC producers who have nation-wide presence on the one hand and third-party agencies which can help in finding out the GWP of different mixes. Additionally, we may approach some leading Indian companies (who use concrete produced from their captive plants) for collection of data of concrete mixes.

Furthermore, since there are variations in the mix proportions of concrete for achieving the similar strengths, we suggest that it would be appropriate to collect the data zone-wise – say South Zone, West Zone, East Zone, and North Zone. The proposed format for collecting data is shown in Table 10.2.

With a view to protect the secrecy/copyright of the data from individual RMC producers/contractors, it is suggested that such information may be collected in a data base without mentioning the names of the producer and the client to whom the concrete is supplied.

Once the zone-wise average values are evaluated, it will be possible to include the same in the proposed Low Carbon Concrete code with a recommendation that procurement of the concrete for new structures should have GWP lesser than the average values. The data can then be monitored continuously with a plan to achieve net zero CO_2 by 2070 for the built environment.

Table 10.2: Proposed format for collecting data

			Mix Design Parameters					
Compressive strength	Type of cement SCM	SCM Range	Cement Kg	Coarse aggregate, Kg	Fine Aggregate, Kg	Chem. admixture, Kg	Water, kg	Average Comp.strenth obtained MPa
M20	PPC	Nil						
	PSC	Nil						
	OPC	0%						
	FA	0-15%						
	FA	15-25						
	FA	25-25						
	GGBS	<35%						
	GGBS	35-50						
	GGBS	50-60						

10.9 INNOVATIVE INGREDIENTS OF CONCRETE FOR FUTURE

Currently, considerable efforts are being made worldwide to develop and use low-carbon cement and concrete, including innovative SCMs, chemical admixtures, etc.

In India, the Bureau of Indian Standards has taken the lead in publishing IS Standards on both Composite Cement (IS 16414:2015) and Limestone Calcined Clay Cement (LC3 – IS 18189:2003). Both these cements, which contain lower proportions of clinker, have a large potential in reducing embodied carbon emissions. Wherever such cements are commercially available, the same may be used initially for low and medium-strength concretes. Later, as more experience is gained in their use and their market availability improves, these cements can be used for higher grades of concrete, provided the resulting concretes satisfy different codal requirements.

While considerable R&D efforts are being made worldwide to develop and use innovative SCMs, few new varieties of SCMs are being made available and used currently In India too (e.g. *UGGBS*). This trend is bound to get strengthened in the near future.

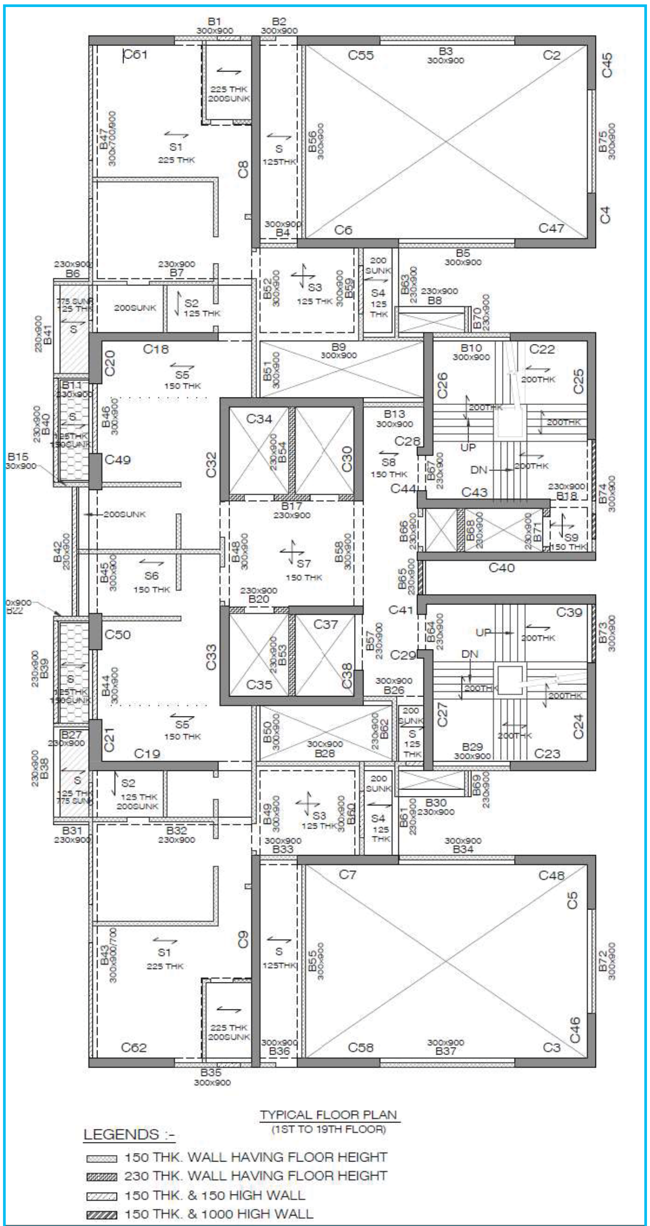
As regards aggregates, the country is facing shortage of aggregates, especially the finer variety in metropolitan areas. The use of recycled aggregates has not picked up. It is reported that presently the construction industry uses only 1% of the recycled aggregates. The stakeholders in the industry therefore need to start using recycled aggregates in concrete on a bigger scale with a view to save the non-renewable resource of aggregates. Further, the use of both structural-grade and non-structural-grade lightweight aggregates also needs a boost in near future as their use will go a long way in reducing embodied carbon.

With a view to achieve the objective of 'net zero' carbon emissions by 2070, the construction industry in India needs to gear up right now for low-carbon concrete construction.

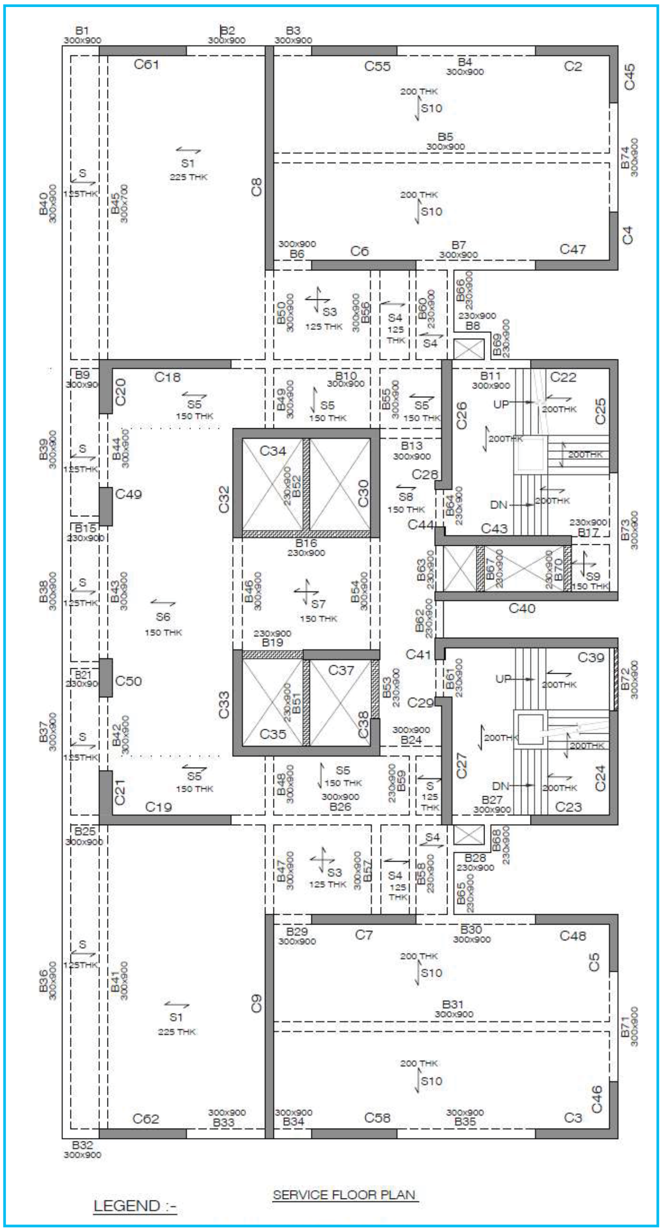
10.10 BUILDING RATING SYSTEMS

In India, Green Building Rating systems such as GRIHA (Green Rating for Integrated Habitat Assessment) developed by TERI, and others developed by IGBC (Indian Green Building Council) and LEED India are being used in the real estate sector. It is highly essential that these rating agencies increase the weightage of the embodied CO_2 emissions (as of now it is very low) from buildings in their rating systems.

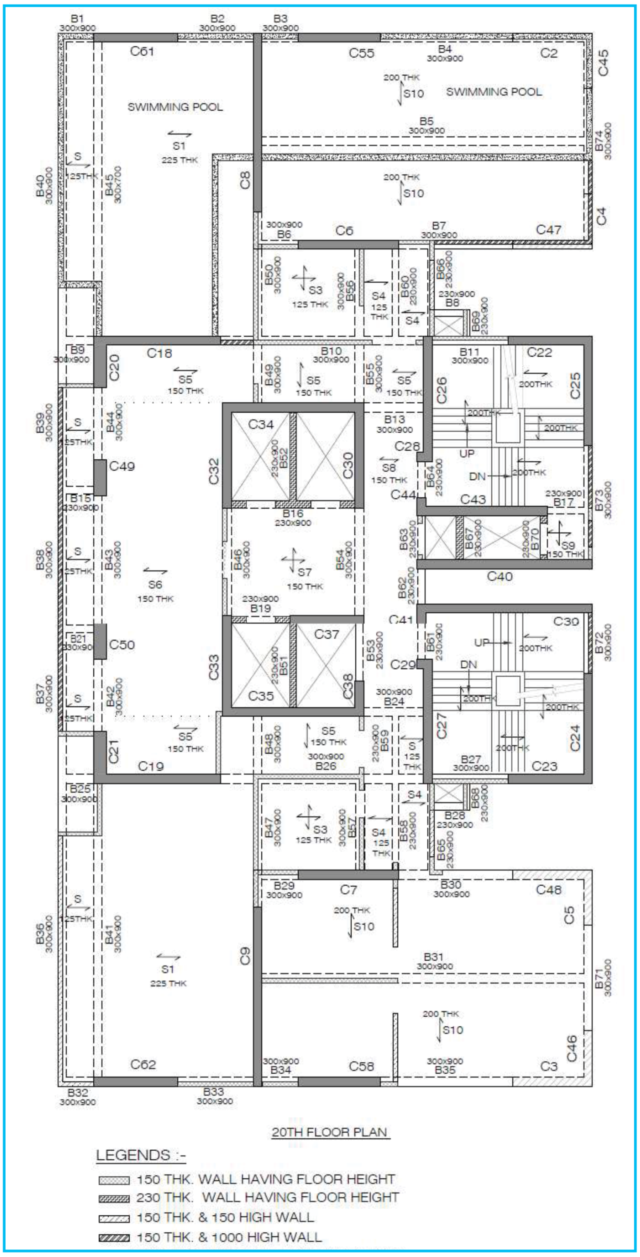
CHAPTER 5 : ANNEXURES



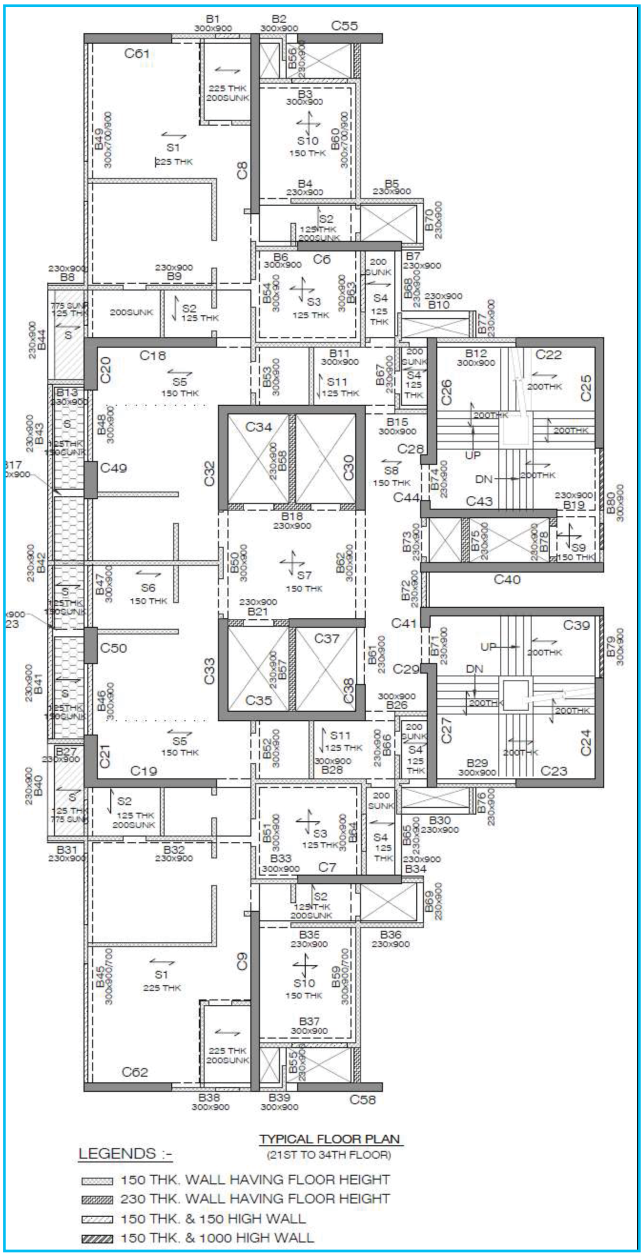
Annexure 5-A-1 : Typical Floor Plan – 1st to 19th floor



Annexure 5-A-2 : Typical Service Floor Plan above 19th floor



Annexure 5-A-3 : Service floor plan showing swimming pool, gymnasium



Annexure 5-A-4 : Typical Floor Plan – 21st to 34th Floors

Chapter 5 : Annexures

Annexure 5-B : Design loads for different structural elements

(a) Rooms

Load Component	Thickness (mm)	UDL (kN/m²)
Floor finish	75	1.50
False ceiling	-	0.50
Live load	-	2.00

(b) Toilet area:

Load Component	Thickness (mm)	UDL (kN/m²)
Floor finish	75	1.50
Filling in sunken area*	200	2.00
Live load	-	2.00

*Light weight filling.

(c) Refuge Area:

Load Component	Thickness (mm)	UDL (kN/m²)
Floor finish	75	1.50
Services	-	0.50
Live load	-	3.00

(d) All corridors, passages, lobbies, balconies:

All corridors, passages, lobbies, balconies:	Thickness (mm)	UDL (kN/m²)
Floor finish	75	1.50
Services	-	0.50
Live load	-	3.00

(e) Staircases:

Load Component	Thickness (mm)	UDL (kN/m²)
Floor Finish	75	1.50
Filling / Steps	150 (Riser) / 300 (Tread)	2.50
Live load	-	3.00

(f) Amenity Level:

Load Component	Thickness (mm)	UDL (kN/m²)
Floor finish	75	1.50
False ceiling	-	0.50
Live load	-	3.00

(g) Swimming pool

Load Component	Thickness (mm)	UDL (kN/m²)
Floor finish	75	1.50
Waterproofing	150	3.00
Water load	1200	12.0

(h) Terrace

Load Component	Thickness (mm)	UDL (kN/m²)
Floor Finish	-	1.50
Light weight coba including Waterproofing (Screed)	200 (Average)	2.00
False ceiling	-	0.50
Live load	-	3.00

(i) Wall Loads (Considering AAC Block)

Wall Type	Thickness (mm)	Height (m)	UDL (kN/m)	Remarks
Parapet Wall	150	1.2	1.8	
Full Window	-		1.5	50kg/m²
Part Window	150		3.0	50kg/m²
150mm thick. Wall	150	4.2	4.95	
150mm thick Wall	150	3.66	4.14	

(j) Wall Loads (Considering Non-Structural Wall)

Wall Type	Thickness (mm)	Height (m)	UDL (kN/m)	Remarks
Parapet Wall	150	1.2	4.5	
Full Window	-		1.5	50kg/m²
Part Window	150		3.0	50kg/m²
150mm thick. Wall	150	4.2	12.375	
150mm thick Wall	150	3.66	10.35	

(k) Wall Loads (Considering Fly ash Brick Wall))

Wall Type	Thickness (mm)	Height (m)	UDL (kN/m)	Remarks
Parapet Wall	150	1.2	3.6	
Full Window	-		1.5	50kg/m²
Part Window	150		3.0	50kg/m²
150mm thick. Wall	150	4.2	9.9	
150mm thick Wall	150	3.66	8.28	

Note: 1. Internal wall load has been considered on slab as wall load. Loading for OHWT considered

Annexure 5-C-1 Serviceability checks : RC Frame using M60, M50, M40 and AAC Blocks

Sr. No.	Threshold limits for serviceability		RC Frame using M80-70-60 with non-structural walls			
1	Displacement (mm) 528mm (For EQ) 264mm (For Wind)	EQPX	82.767			
		EQPY	64.472			
		EQNX	80.293			
		EQNY	59.795			
		WX	122.19			
		WY	75.199			
2	Storey Drift	EQPX	0.000804			
		EQPY	0.000609			
		EQNX	0.000812			
		EQNY	0.000546			
		SPECX	0.000364			
		SPECY	0.000309			
3	Torsional Irregularity Check (Max/Avg ratio should be less than 1.2)		**Max**	**Min**	**Avg**	**Max/Avg**
		EQPX	82.767	68.3	75.5326	1.0957
		EQPY	64.408	55.829	60.3317	1.0674
		EQNX	80.293	70.479	75.3843	1.0651
		EQNY	59.666	57.877	58.7308	1.0159
		SPECX	35.799	31.887	33.967	1.0539
		SPECY	30.908	26.667	28.3175	1.0914
4	Modal Mass Participating Ratios		**Time Periotd**	**UX**	**UY**	**RZ**
		1	3.329	0.6506	0.0018	0.0004
		2	2.961	0.0017	0.6917	0.0018
		3	2.299	0.0002	0.0042	0.6984
5	Diaphragm Irregularity Check		Avg		Middle	Mid/Avg
		SPECX	34.785		30.682	0.8820
			27.047		25.87	0.9564

Annexure 5-C-2 Serviceability checks : RC Frame Using M80, 70, 60 with Non-structural walls

Sr. No.	Threshold limits for serviceability		RC Frame using M80-70-60 with non-structural walls			
1	Displacement (mm) 528mm (For EQ) 264mm (For Wind)	EQPX	81.767			
		EQPY	64.28			
		EQNX	82.071			
		EQNY	57.932			
		WX	122.932			
		WY	76.937			
2	Storey Drift	EQPX	0.000804			
		EQPY	0.000609			
		EQNX	0.000812			
		EQNY	0.000546			
		SPECX	0.000364			
		SPECY	0.000309			
3	Torsional Irregularity Check (Max/Avg ratio should be less than 1.2)		Max	Min	Avg	Max/Avg
		EQPX	81.767	68.573	75.169	1.0877
		EQPY	64.201	53.317	59.029	1.0876
		EQNX	82.077	68.33	75.202	1.0914
		EQNY	57.922	56.456	57.218	1.0123
		SPECX	34.964	32.382	34.062	1.0264
		SPECY	31.746	23.703	27.477	1.1553
4	Modal Mass Participating Ratios		**Time Period**	**UX**	**UY**	**RZ**
		1	3.349	0.6685	0.00001	0.0000
		2	2.956	0.00008	0.6794	0.0253
		3	2.406	0.00002	0.0305	0.6944
5	Diaphragm Irregularity Check		**Avg**		**Middle**	**Mid/Avg**
		SPECX	34.8365		30.71	0.8815
		SPECY	25.466		24.535	0.9634

Annexure 5-C-3 Serviceability checks : RC Frame Using M60, 50, 40 with Non-structural walls

Sr. No.	Threshold limits for serviceability		RC Frame using M60-50-40 and non-structural walls			
1	Displacement (mm) 528mm (For EQ) 264mm(For Wind)	EQPX	84.862			
		EQPY	62.73			
		EQNX	82.414			
		EQNY	62.132			
		WX	115.478			
		WY	70.154			
2	Storey Drift	EQPX	0.000843			
		EQPY	0.000605			
		EQNX	0.000826			
		EQNY	0.000591			
		SPECX	0.000380			
		SPECY	0.000293			
3	Torsional Irregularity Check (Max/Avg ratio should be less than 1.2)		**Max**	**Min**	**Avg**	**Max/Avg**
		EQPX	82.414	71.915	77.1625	1.0680
		EQPY	61.641	54.849	58.0753	1.0613
		EQNX	115.478	113.836	114.656	1.0071
		EQNY	38.855	37.12	38.0295	1.0210
		SPECX	84.862	69.781	77.3203	1.0975
		SPECY	62.683	56.286	59.6473	1.0508
4	Modal Mass Participating Ratios		**Time Period**	**UX**	**UY**	**RZ**
		1	3.353	0.6474	0.0013	0.0003
		2	2.948	0.0011	0.6963	0.0012
		3	2.341	0.0003	0.0002	0.6972
5	Diaphragm Irregularity Check		**Avg**		**Middle**	**Mid/Avg**
		SPECX	35.2525		31.014	0.8797
		SPECY	28.0605		26.499	0.9443

Annexure 5-C-4 Serviceability checks : RC Frame Using M80, 70, 60 with fly ash brick walls

Sr. No.	Threshold limits for serviceability		RC Frame using M80-70-60 and fly ash brick walls			
1	Displacement (mm) 528mm (For EQ) 264mm(For Wind)	EQPX	79.976			
		EQPY	62.975			
		EQNX	80.237			
		EQNY	56.848			
		WX	122.836			
		WY	76.877			
2	Storey Drift	EQPX	0.000787			
		EQPY	0.000592			
		EQNX	0.000793			
		EQNY	0.000547			
		SPECX	0.000358			
		SPECY	0.000306			
3	Torsional Irregularity Check (Max/Avg ratio should be less than 1.2)		**Max**	**Min**	**Avg**	**Max/Avg**
		EQPX	80.131	67.347	73.738	1.086
		EQPY	62.337	52.642	57.729	1.079
		EQNX	80.069	67.469	73.768	1.085
		EQNY	57.696	54.963	56.391	1.023
		SPECX	34.744	32.117	33.789	1.028
		SPECY	31.483	23.409	27.211	1.156
4	Modal Mass Participating Ratios		**Time Period**	**UX**	**UY**	**RZ**
		1	3.317	0.6694	0.00001	0.00001
		2	2.932	0.00001	0.6788	0.0266
		3	2.38	0.00002	0.0318	0.694
5	Diaphragm Irregularity Check		Avg		Middle	Mid/Avg
		SPECX	34.457		30.402	0.8823
		SPECY	25.1465		24.261	0.9647

Annexure 5-C-5 Serviceability checks : RC Frame Using M60, 50, 40 with fly ash brick walls

Sr. No.	Threshold limits for serviceability		RC Frame using M60-50-40 and fly ash brick walls			
1	Displacement (mm) 528mm (For EQ) 264mm(For Wind)	EQPX	83.069			
		EQPY	61.482			
		EQNX	80.636			
		EQNY	60.72			
		WX	115.394			
		WY	70.105			
2	Storey Drift	EQPX	0.000825			
		EQPY	0.000576			
		EQNX	0.000807			
		EQNY	0.000567			
		SPECX	0.000379			
		SPECY	0.000286			
3	Torsional Irregularity Check (Max/Avg ratio should be less than 1.2)		**Max**	**Min**	**Avg**	**Max/Avg**
		EQPX	83.058	68.723	75.889	1.0944
		EQPY	59.698	56.518	58.190	1.0259
		EQNX	80.329	71.161	75.742	1.0605
		EQNY	59.134	55.868	57.420	1.0290
		SPECX	36.137	31.984	34.162	1.0570
		SPECY	29.823	26.83	28.487	1.0468
4	Modal Mass Participating Ratios		**Time Period**	**UX**	**UY**	**RZ**
		1	3.321	0.6483	0.0014	0.0003
		2	2.92	0.0012	0.6971	0.0009
		3	2.317	0.0003	0.0001	0.6985
5	Diaphragm Irregularity Check		Avg		Middle	Mid/Avg
		SPECX	34.8805		30.713	0.8805
		SPECY	27.7565		26.243	0.9454

CHAPTER 6 : ANNEXURES

Annexure 6A : Combined summary of concrete quantities – Elementwise and grade-wise

	Quantity in m³											Total (m³)
Alternative 1 & 2	Grade of Concrete	Raft	Column	Lift Wall	Beam	Slab	Stair case	NS Wall	Grade Slab	Parapet Wall	RC Wall	
	M80		73	1204								1277
	M70		87	1409								1496
	M60		130	1804	439	328	105					2806
	M50	1229			537	451	145					2362
M80 – M60 with AAC	M45				826	836	223					1885
	M40										12	12
	M35											0
	M30									11		11
	M20								41			41
	Total	1229	290	4417	1802	1615	473	0	41	11	12	9890

	Quantity in m³											Total (m³)
Alternative 3 & 4	Grade of Concrete	Raft	Column	Lift Wall	Beam	Slab	Stair case	NS Wall	Grade Slab	Parapet Wall	RC Wall	
	M80											0
	M70											0
	M60		66	1330			105					1501
	M50	1229										1229
M60 – M40 with AAC	M45		78	1574	409	326	145					2532
	M40		129	2050			223				11	2413
	M35				500	448						948
	M30				773	836				11		1620
	M20								41			41
	Total	1229	273	4954	1682	1610	473	0	41	11	11	10284

	Quantity in m³											Total (m³)
Alternative 5 & 6	Grade of Concrete	Raft	Columns	Lift Wall	Beams	Slab	Stair	NS Wall	Grade Slab	Parapet Wall	RC Wall	
	M80		44	1234								1282
	M70		49	1458								1507
	M60		105	1930	429	288	102					2854
	M50	1229			525	396	141					2291
M80 – M60 with fly ash bricks	M45				784	836	222					1842
	M40										33	33
	M35											0
	M30									16		16
	M20								36			36
	Total	1229	198	4626	1738	1520	465	0	36	16	33	9861

	Quantity in m³											
Alternative 7 & 8	Grade of Concrete	Raft	Column	Lift Wall	Beam	Slab	Stair case	NS Wall	Grade Slab	Parapet Wall	RC Wall	Total (m³)
M60 – M40 with Fly Ash Bricks	M80											0
	M70											0
	M60		66	1294			105					1465
	M50	1229										1229
	M45		82	1531	404	326	145					2488
	M40		215	1931			224				30	2400
	M35				494	448						942
	M30				757	794				16		1567
	M20								41			41
	Total	1229	363	4756	1655	1568	474	0	41	16	30	10132

	Quantity in m³											
Alternative 9 & 10	Grade of Concrete	Raft	Column	Lift Wall	Beam	Slab	Stair case	NS Wall	Grade Slab	Parapet Wall	RC Wall	Total (m³)
M80 – M60 with NS Walls	M80		44	1238								1282
	M70		49	1458								1507
	M60		105	1930	429	288	102					2854
	M50	1229			525	396	141					2291
	M45				784	836	222					1842
	M40										33	33
	M35											0
	M30							2228		16		2244
	M20								36			36
	Total	1229	198	4626	1738	1520	465	2228	36	16	33	12089

	Quantity in m³											
Alternative 11 & 12	Grade of Concrete	Raft	Columns	Lift Wall	Beams	Slab	Stair	NS Wall	Grade Slab	Parapet Wall	RC Wall	Total (m³)
M60 – M40 with NS Walls	M80											0
	M70											0
	M60		66	1298			105					1469
	M50	1229										1229
	M45		82	1531	404	326	145					2488
	M40		215	1931			224				30	2400
	M35				494	448						942
	M30				757	794		2172		16		3739
	M20								41			41
	Total	1229	363	4760	1655	1568	474	2172	41	16	30	12308

Annexure 6-B : Element-wise quantities of reinforcing steel for various alternatives

Alternatives	Raft	Column	Lift & Shear Walls	BEAMS	Slab	Grade Slab	Drop Panel	Stair Case	RC Wall	Parapet Wall	N.S Wall	Total (t)
Alternative 1 & 2 M80 – M60 with AAC	98	35	384	254	129	2	-	47	1	1	0	951
Alternative 3 & 4 M60 – M40 with AAC	98	28	575	237	129	2	-	47	1	1	0	1118
Alternative 5 & 6 M80 – M60 with Fly Ash Bricks	98	26	421	245	122	2	0	47	2	1	0	964
Alternative 7 & 8 M60 – M40 with Fly Ash Bricks	98	41	547	233	125	2	-	47	2	1	0	1096
Alternative 9 & 10 M80 - M60 with NS Walls	98	26	425	245	122	2	-	47	2	1	167	1135
Alternative 11 & 12 M60 - M40 with NS Walls	98	41	562	233	125	2	-	47	2	1	163	1274

Annexure 6-C : Quantities of Walling Material, m^3

Alternatives	Walling Material, m^3	
	AAC Block	Fly Ash Bricks
Alternative 1 & 2 M80 – M60 with AAC	2477	-
Alternative 3 & 4 M60 – M40 with AAC	2375	-
Alternative 5 & 6 M80 – M60 with Fly Ash Bricks	-	2228
Alternative 7 & 8 M60 – M40 with Fly Ash Bricks	-	2248
Alternative 9 & 10 M80 – M60 with NS Walls	-	-
Alternative 11 & 12 M60 – M40 with NS Walls	-	-

Annexure 6-D : Quantities of External and internal cement-fly ash-sand plaster and Gypsum plaster, m^3

Alternatives	External Plaster	Internal Plaster	Gypsum Plaster
Alternative 1 & 2 M80 – M60 with AAC	548	68	507
Alternative 3 & 4 M60 – M40 with AAC	548	68	507
Alternative 5 & 6 M80 – M60 with Fly Ash Bricks	548	68	507
Alternative 7 & 8 M60 – M40 with Fly Ash Bricks	548	68	507
Alternative 9 & 10 M80 – M60 with NS Walls		68	507
Alternative 11 & 12 M60 – M40 with NS Walls		68	507

Annexture 6 E : Carbon Emissions during Transportation of Concrete

Embodied Carbon Calculation	Alternative 01 & 02		Alternative 03 & 04		Alternative 05 & 06		Alternative 07 & 08		Alternative 09 & 10		Alternative 11 & 12	
Concrete (m^3)	M80-M60 with AAC		M60-M40 with AAC		M80-M60 with Fly ash Bricks		M60-M40 with Fly ash Bricks		M80-M60 with NS Walls		M60-M40 with NS Walls	
	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)
M80	1277	1277	0	0	1282	1282	0	0	1282	1282	0	0
M70	1496	1496	0	0	1507	1507	0	0	1507	1507	0	0
M60	2806	2806	1501	1501	2854	2854	1465	1465	2854	2854	1469	1469
M50	2362	2362	1229	1229	2291	2291	1229	1229	2291	2291	1229	1229
M45	1885	1885	2532	2532	1842	1842	2488	2488	1842	1842	2488	2488
M40	12	12	2413	2413	33	33	2400	2400	33	33	2400	2400
M35	0	0	948	948	0	0	942	942	0	0	942	942
M30	II	II	1620	1620	16	16	1567	1567	2244	2244	3739	3739
M20	41	41	41	41	36	36	4 1	4 1	36	36	41	41
Total concrete Qty. m^3	9890	9890	10284	10284	9861	9861	10132	10132	12089	12089	12308	12308
Density. kg/m^3	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
Total Concrete. kg	23736000	23736000	24681600	24681600	23666400	23666400	24316800	24316800	29013600	29013600	29539200	29539200
Carbon Footprinting of Material Transportation	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	O.OOll	0.0011	O.OOll
Emission during Transportation (A4).kgCO_{2e}	26110	26110	27150	27150	26033	26033	26748	26748	31915	31915	32493	32493

Note: 1) A4 ECF of locally manufactured material = 0.0011 kgCO_{2e}/kg (For 50 km travelled by Road)

Annexure 6 F : Carbon Emissions during Transportation of Steel

	Altemative I & 2 M8O – M60 with AAC	Altemative 3 & 4 M60 – M40 with AAC	Altemative 5 & 6 M8O – M60 wirh Fly Ash Bricks	Altemative 7 & 8 M60 – M40 wirh Fly Ash Bricks	Altemative 9 & 1O M80 – M60 wirh NS Walls	Alternative 11 & 12 M60 – M40 wirh NS Walls
Raft	98	98	98	98	98	98
Column	35	28	26	41	26	41
Lift & Shear Walls	384	575	421	547	425	562
BEAMS	254	237	245	233	245	233
Slab	129	129	122	125	122	125
Grade Slab	2	2	2	2	2	2
Drop Panel	-	-	0	-	-	-
Srair Case	47	47	47	47	47	47
RCC Wall	1	1	2	2	2	2
Parapet Wall	1	1	1	1	1	1
Non-Structural Wall	0	0	0	0	167	163
Total (t)	951	1118	964	1096	1135	1274
Total in kg	951000	1118000	964000	1096000	1135000	1274000
Transporatiou A4 Factor	0.032	0.032	0.032	0.032	0.032	0.032
Emission during Transportation (A4), kg$C0_{2e}$	30432	35776	30848	35072	36320	40768

Annexure 6 G : Carbon Emissions during Transportation of Walling Materials (AAC Block)

ACC block		
	Alt. 1 & 2	Alt. 3 & 4
	M80-M60 with ACC	M60-M40 with ACC
Total Qty. m^3	2477	2375
Density, kg/m^3	500	500
Qty. kg	1238500	1187500
Carbon footprinting of material Transportation	0.005	0.005
Emission during Transportation (A4), $kgCO_{2e}$	6193	5938

Annexure 6 G : Carbon Emissions during Transportation of Walling Materials (Fly Ash Bricks)

Fly Ash bricks		
	Alt. 5 & 6	Alt. 7 & 8
	M80-M60 with with Fly Ash Bricks	M60-M40 with Fly Ash Bricks
Total Qty. m^3	2228	2248
Density, kg/m^3	1760	1760
Qty. kg	3921280	3956480
Carbon footprinting of material Transportation	0.005	0.005
Emission during Transportation (A4), $kgCO_{2e}$	19606	19782

Annexure 6 H : Carbon Emissions during Transportation of Plaster

Internal Plaster						
	Alt. 1 & 2	Alt. 3 & 4	Alt. 5 & 6	Alt. 7 & 8	Alt. 9 & 10	Alt. 11 & 12
	M80-M60 with ACC	M60-M40 with ACC	M80-M60 with Fly Ash Bricks	M60-M40 with Fly Ash Bricks	M80-M60 with with NS Wall	M60-M40 with NS Wall
Total Qty. m^2	5628	5628	5628	5628	0	0
Total Qty. m^3	68	68	68	68	0	0
Density, kg/m^3	1900	1900	1900	1900	0	0
Qty. kg	128318	128318	128318	128318	0	0
Carbon footprinting of material Transportation	0.005	0.005	0.005	0.005	0	0
Emission during Transportation (A4), $kgCO_{2e}$	642	642	642	642	0	0

External Plaster				
	Alt. 1 & 2	Alt. 3 & 4	Alt. 5 & 6	Alt. 7 & 8
	M80-M60 with ACC	M60-M40 with ACC	M80-M60 with Fly Ash Bricks	M60-M40 with Fly Ash Bricks
Total Qty. m^2	21904	21904	21904	21904
Total Qty. m^3	548	548	548	548
Density, kg/m^3	1900	1900	1900	1900
Qty. kg	1040440	1040440	1040440	1040440
Carbon footprinting of material Transportation	0.005	0.005	0.005	0.005
Emission during Transportation (A4), $kgCO_{2e}$	5202	5202	5202	5202

Gypsum Plaster

	Alt. 1 & 2	Alt. 3 & 4	Alt. 5 & 6	Alt. 7 & 8	Alt. 9 & 10	Alt. 11 & 12
	M80-M60 with ACC	M60-M40 with ACC	M80-M60 with Fly Ash Bricks	M60-M40 with Fly Ash Bricks	M80-M60 with with NS Wall	M60-M40 with NS Wall
Total Qty. m^2	50748	50748	50748	50748	50748	50748
Total Qty. m^3	507	507	507	507	507	507
Density, kg/m^3	750	750	750	750	750	750
Qty. kg	380610	380610	380610	380610	380610	380610
Carbon footprinting of material Transportation	0.005	0.005	0.005	0.005	0.005	0.005
Emission during Transportation (A4), $kgCO_{2e}$	1903	1903	1903	1903	1903	1903

Annexure 6 I : Summary of Carbon Emission during Transportation of All Materials (A4)

	Alternative 01 & 02		Alternative 03 & 04		Alternative 05 & 06		Alternative 07 & 08		Alternative 09 & 010		Alternative 11 & 12	
	M80-M60 with ACC		M60-M40 with ACC		M80-M60 with Fly Ash Brick		M60-M40 with Fly Ash Brick		M80-M60 with NS Wall		M60-M40 with NS Wall	
	OPC +GGBS (+MS for HSC)	OPC+FA (+MS for HSC)	OPC +GGBS (+MS for HSC)	OPC+FA (+MS for HSC)	OPC +GGBS (+MS for HSC)	OPC+FA (+MS for HSC)	OPC +GGBS (+MS for HSC)	OPC+FA (+MS for HSC)	OPC +GGBS (+MS for HSC)	OPC+FA (+MS for HSC)	OPC +GGBS (+MS for HSC)	OPC+FA (+MS for HSC)
Total Concrete Qty, m^3	9890	9890	10284	10284	9861	9861	10132	10132	12089	12089	12308	12308
Total Concrete, kg	23736000	23736000	24681600	24681600	23666400	23666400	24316800	24316800	29013600	29013600	29539200	29539200
Emission Factor of Concrete Transportation	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011
Emission during Transportation of steel (A4), $kgCO_{2e}$	26110	26110	27150	27150	26033	26033	26745	26745	31915	31915	32493	32493
Total Steel Reinforcement, kg	951000	951000	1118000	1118000	964000	964000	1096000	1096000	1135000	1135000	1274000	1274000
Emission Factor of Steel Transportation	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
Emission during Transportation of Steel (A4), $kgCO_{2e}$	30432	30432	35776	35776	30848	30848	35072	35072	36320	36320	40768	40768
Aluminium Shuttering Area m^2	60802	60802	64227	64227	61826	61826	63788	63788	93471	93471	95169	95169
Aluminium Shtuttering, kg	1398446	1398446	1477221	1477221	1421991	1421991	1467 113	1467 113	2149831	2149831	2188881	2188881
Emission Factor of Aluminium	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
Emission during Transportation of Aluminum (A4), $kgCO_{2e}$	44750	44750	47271	47271	45504	45504	46948	46948	68795	68795	70044	70044

Annexure 6 I : Summary of Carbon Emission during Transportation of All Materials (A4) (continued)

	Alternative 01 & 02		Alternative 03 & 04		Alternative 05 & 06		Alternative 07 & 08		Alternative 09 & 010		Alternative 11 & 12	
	M80-M60 with ACC		M60-M40 with ACC		M80-M60 with Fly Ash Brick		M60-M40 with Fly Ash Brick		M80-M60 with NS Wall		M60-M40 with NS Wall	
	OPC +GGBS (+MS for HSC)	OPC+FAC (+MS for HSC)	OPC +GGBS (+MS for HSC)	OPC+FAC (+MS for HSC)	OPC +GGBS (+MS for HSC)	OPC+FAC (+MS for HSC)	OPC +GGBS (+MS for HSC)	OPC+FAC (+MS for HSC)	OPC +GGBS (+MS for HSC)	OPC+FAC (+MS for HSC)	OPC +GGBS (+MS for HSC)	OPC+FAC (+MS for HSC)
Total Qty of walling material, kg	1238500	1238500	1187500	1187500	3921280	3921280	3956480	3956480	0	0	0	0
Emission Factor of walling material Transportation	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
Emission during Transportation of walling material (A4), kgCO_{2e}	39632	39632	38000	38000	125481	125481	126607	126607	0	0	0	0
Total Qty of External Plaster, kg	1040440	1040440	1040440	1040440	1040440	1040440	1040440	1040440	0	0	0	0
Total Qty of Internal Plaster, kg	128318	128318	128318	128318	128318	128318	128318	128318	0	0	0	0
Total Qty of Gypsum Plaster, kg	380610	380610	380610	380610	380610	380610	380610	380610	380610	380610	380610	380610
Total Qty. of Plaster, kg	1549368	1549368	1549368	1549368	1549368	1549368	1549368	1549368	380610	380610	380610	380610
Emission Factor of Plaster Transportation	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
Total Transportaion Emission kgCO_{2e}	49580	49580	49580	49580	49580	49580	49580	49580	12180	12180	12180	12180
Total Transportation Emission kgCO_{2e}/Kg	19054	19054	197777	197777	277445	277445	284955	284955	149209	149209	155485	155485

Annexure 6 J : Carbon Emissions due to Wastage of Concrete

Embodied Carbon Calculation	Alternative 01 & 02		Alternative 03 & 04		Alternative 05 & 06		Alternative 07 & 08		Alternative 09 & 10		Alternative 11 & 12	
Concrete (m^3)	M80 – M60 with AAC		M60 – M40 with AAC		M80 – M60 with Fly Ash Bricks		M60 – M40 with Fly Ash Bricks		M80 – M60 with NS Walls		M60 – M40 with NS Walls	
	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)
Carbon Footprints of Concrete (A-1 to A-3)	3280194	4215140	2779688	3930848	3274596	4203839	2739200	3874147	3738020	4896747	3192332	4551379
Carbon Footprints of Concrete (A-1 to A-3) with 2% Wastage (A13)	65604	84303	55594	78617	65492	84077	54784	77483	74760	97935	63847	91028
Total Quantity in kgs	23736000	23736000	24681600	24681600	23666400	23666400	24316800	24316800	29013600	29013600	29539200	29539200
2% wastage in quantity in kgs	474720	474720	493632	493632	473328	473328	486336	486336	580272	580272	590784	590784
Carbon Footprints of Wasted Concrete transportation (2% of total) (A4-W), 0.005kgCO_{2e}	2374	2374	2468	2468	2367	2367	2432	2432	2901	2901	2954	2954
C2 Transporting Wasted Material away from Site (0.005 kgCO_{2e})	2374	2374	2468	2468	2367	2367	2432	2432	2901	2901	2954	2954
Carbon footprints for processing of wastage material (0.013kgCO_{2e}) (C34)	6171	6171	6417	6417	6153	6153	6322	6322	7544	7544	7680	7680
A5W = (A13+A4W+C2+C34)	76523	95222	66948	89971	76379	94964	65970	88669	88106	111281	77435	104616

Annexure 6 K : Carbon Emissions due to Wastage of Steel

Embodied Carbon Calculation	Alternative 01 & 02		Alternative 03 & 04		Alternative 05 & 06		Alternative 07 & 08		Alternative 09 & 10		Alternative 11 & 12	
Concrete (m3)	M80 – M60 with AAC		M60 – M40 with AAC		M80 – M60 with Fly Ash Bricks		M60 – M40 with Fly Ash Bricks		M80 – M60 with NS Walls		M60 – M40 with NS Walls	
	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)
Carbon Footprints of Reinforcement (A-1 to A-3)	2225340	2225340	2616120	2616120	2255760	2255760	2564640	2564640	2655900	2655900	2981160	2981160
Carbon Footprints of Reinforcement (A-1 to A-3) with 5% Wastage (A13)	111267	111267	130806	130806	112788	112788	128232	128232	132795	132795	149058	149058
Total Quantity in kgs	951000	951000	1118000	1118000	964000	964000	1096000	1096000	1135000	1135000	1274000	1274000
5% wastage in total quantity	47550	47550	55900	55900	48200	48200	54800	54800	56750	56750	63700	63700
Carbon Footprints of Wasted Reinforcement Transportation (0.005kgCO_{2e}) (A4-W)	238	238	280	280	241	241	274	274	284	284	319	319
C2 Transporting Wasted Material away from Site (0.005 kgCO_{2e})	238	238	280	280	241	241	274	274	284	284	319	319
Carbon footprints for processing of wastage material (0.013 kgCO_{2e}) (C34)	618	618	727	727	627	627	712	712	738	738	828	828
A5W = (A13+A4W+C2+C34)	112361	112361	132092	132092	113897	113897	129492	129492	134100	134100	150523	150523

Annexure 6 L : Carbon Emissions due to Wastage of Walling Materials

ACC block		
	Alt. 1 & 2	Alt. 3 & 4
	M80 – M60 with AAC Blocks	M60 – M40 with AAC Blocks
Carbon Footprints of AAC Block (A1 To A3)	630440	604578
Total Quantity in kgs	1238500	1187500
2% wastage in quantity in kgs	24770	23750
Carbon Footprints of AAC Block (A1 To A3) with 2% Wastage (A13)	12609	12092
Carbon Footprints of Transportation (A4)	6193	5938
Carbon Footprints of wasted Block Transportation (2% of total) (A4-W), 0.005 $kgCO_{2e}$	124	119
C2 Transporting Wasted material away from site @ 2% (C2), 0.005 $kgCO_{2e}$	124	119
C34, Carbon Footprints for processing of wastage of brick @ 0.013 (C34)	322	309
A5W = (A13+A4W+C2+C34)	13179	12638

Fly Ash bricks		
	Alt. 5 & 6	Alt. 7 & 8
	M80 – M60 with Fly Ash Bricks	M60 – M40 with Fly Ash Bricks
Carbon Footprints of Fly Ash Brick (A1 To A3)	746736	753248
Carbon Footprints of Fly Ash Brick (A1 To A3) with 2% Wastage (A13)	14935	15065
Total Quantity in kgs	3921280	3956480
2% wastage in quantity in kgs	78426	79130
Carbon Footprints of Transportation (A4)	19606	19782
Carbon Footprints of wasted Fly Ash Brick Transportation (2% of total) (A4-W)	392	396
C2 Transporting Wasted material away from site @ 2% (C2)	392	396
C34, Carbon Footprints for processing of wastage of brick @ 0.013 (C34)	1020	1029
A5W = (A13+A4W+C2+C34)	16739	16885

Annexure 6 M : Carbon Emissions due to Wastage of Plaster

External Plaster				
	Alt. 1 & 2	Alt. 3 & 4	Alt. 5 & 6	Alt. 7 & 8
	M80 – M60 with AAC	M60 – M40 with AAC	M80 – M60 with Fly Ash Bricks	M60 – M40 with Fly Ash Bricks
Carbon Footprints of External Plaster (A1 To A3)	174809	174809	174809	174809
Carbon Footprints of External Plaster (A1 To A3) with 2% Wastage (A13)	3496	3496	3496	3496
Total Quantity in kgs	1040440	1040440	1040440	1040440
2% wastage in quantity in kgs	20809	20809	20809	20809
Carbon Footprints of Transportation (A4)	5202	5202	5202	5202
Carbon Footprints of wasted External Plaster Transportation (2% of total) (A4-W)	104	104	104	104
C2 Transporting Wasted material away from site @ 2% (C2), 0.005 $kgCO_{2e}$	104	104	104	104
C34, Carbon Footprints for processing of wastage of External Plaster @ 0.013 (C34)	271	271	271	271
A5W = (A13+A4W+C2+C34)	3975	3975	3975	3975

Internal Plaster						
	Alt. 1 & 2	Alt. 3 & 4	Alt. 5 & 6	Alt. 7 & 8	Alt. 9 & 10	Alt. 11 & 12
	M80 – M60 with AAC	M60 – M40 with AAC	M80 – M60 with Fly Ash Bricks	M60 – M40 with Fly Ash Bricks	M80 – M60 with NS Walls	M60 – M40 with NS Walls
Carbon Footprints of Internal Plaster (A1 To A3)	21558	21558	21558	21558	0	0
Carbon Footprints of Internal Plaster (A1 To A3) with 2% Wastage (A13)	431	431	431	431	0	0
Carbon Footprints of Transportation (A4)	642	642	642	642	0	0
Carbon Footprints of wasted Internal Plaster Transportation(2% of total) (A4-W)	13	13	13	13	0	0
Total Quantity in kgs	128318	128318	128318	128318	0	0
2% wastage in quantity in kgs	2566	2566	2566	2566	0	0
C2 Transporting Wasted material away from site @ 2% (C2),0.005$kgCO_{2e}$	13	13	13	13	0	0
C34, Carbon Footprints for processing of wastage of Internal Plaster @ 0.013 (C34)	33	33	33	33	0	0
A5W = (A13+A4W+C2+C34)	490	490	490	490	0	0

Gypsum Plaster						
	Alt. 1 & 2	Alt. 3 & 4	Alt. 5 & 6	Alt. 7 & 8	Alt. 9 & 10	Alt. 11 & 12
	M80 – M60 with AAC	M60 – M40 with AAC	M80 – M60 with Fly Ash Bricks	M60 – M40 with Fly Ash Bricks	M80 – M60 with NS Walls	M60 – M40 with NS Walls
Carbon Footprints of Gypsum Plaster (A1 To A3)	37680	37680	37680	37680	37680	37680
Carbon Footprints of Gypsum Plaster (A1 To A3) with 10% Wastage (A13)	3768	3768	3768	3768	3768	3768
Total Quantity in kgs	380610	380610	380610	380610	380610	380610
10% wastage in quantity in kgs	38061	38061	38061	38061	38061	38061
Carbon Footprints of Transportation (A4)	1903	1903	1903	1903	1903	1903
Carbon Footprints of wasted Gypsum Plaster Transportation (2% of total) (A4-W)	190	190	190	190	190	190
C2 Transporting Wasted material away from site @ 2% (C2)	190	190	190	190	190	190
C34, Carbon Footprints for processing of wastage of Gypsum Plaster @ 0.013 (C34)	495	495	495	495	495	495
A5W = (A13+A4W+C2+C34)	4643	4643	4643	4643	4643	4643

Annexure 6 N : Summary of Carbon Emission due to Wastage of all Materials

	Alternative 01 & 02		Alternative 03 & 04		Alternative 05 & 06		Alternative 07 & 08		Alternative 09 & 10		Alternative 11 & 12	
	M80 – M60 with AAC		M60 – M40 with AAC		M80 – M60 with Fly Ash Bricks		M60 – M40 with Fly Ash Bricks		M80 – M60 with NS Walls		M60 – M40 with NS Walls	
	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)	OPC + GGBS (+MS for HSC)	OPC + FA (+MS for HSC)
Annexure 6 J : Carbon Emission due to Wastage of Concrete (A5c)	76523	95222	66948	89971	76379	94964	65970	88669	88106	111281	77435	104616
Annexure 6 K : Carbon Emission due to Wastage of Steel (A5s)	112361	112361	132092	132092	113897	113897	129492	129492	134100	134100	150523	150523
Annexure 6 L : Carbon Emission due to Wastage of Walling Materials (A5w)	13179	13179	12638	12638	16739	16739	16885	16885	0	0	0	0
Annexure 6 M : Carbon emission due to wastage of External plaster	3975	3975	3975	3975	3975	3975	3975	3975	0	0	0	0
Annexure 6 M : Carbon Emission due to wastage of Internal Plaster	490	490	490	490	490	490	490	490	0	0	0	0
Annexure 6 M : Carbon Emission due to wastage of Gypsum Plaster	4643	4643	4643	4643	4643	4643	4643	4643	4643	4643	4643	4643
Total	211170	229869	220786	243809	216122	234707	221456	244155	226850	250025	232602	259783
Total Carbon Emission	6696005.92	7576935.67	6720817.11	7872172.75	6977349.59	7909306.59	6777610.29	7912546.54	7161111.75	8321220.68	6957041.06	8314810.05
% of total	3.15	3.03	3.29	3.10	3.10	2.97	3.27	3.09	3.17	3.00	3.34	3.12

Annexure 6 O = Estimation of GWP of Typical Masonry and Plaster

Let's consider AAC Block masonry having following features

- Size: 600mm x 200mm x 150 mm
- Assumed density of block = 500 kg/m^3
- GWP of AAC Blcok = 0.5 $kgCO_{2e}$ (as per IFC data base)

Finding out No of block required per m^3

Assuming gap of 10 mm gap between the masonry units

Volume	= 0.61 × 0.21 × 0.16 = 0.0205 m^3
No of blocks required per m^3	= 1/0.0205
	= 48.79 nos
Add 5% wastage	= 02.44 nos
Total blocks per m^3	= 51.23 nos.
Quantity of blockwork	= 51.23 × 0.6 × 0.2 × 0.15
	= 0.922 m^3
Volume of mortar	= 0.078m^3
Quantity of blocks in kg	= 0.922 × 500 = 461.066 kg
GWP of blockwork per m^3	= 461.066 × 0.5
	= 230.533 $kgCO_{2e}$
Density of cement mortar	= 2200 kg/m^3
Quantity of mortar m^3	= 0.078 × 2200 = 171.311 kg/m^3
Cement mortar GWP	= 0.14 $kgCO_{2e}$
GWP of mortar/m^3	= 171.311 × 0.14 = 23.98
Total GWP of AAC Block work	= 230.533 + 23.98 = 254.52 $kgCO_{2e}$

GWP of 1:4 Plaster

Ingredients

- Cement = 330 kg
- Fly ash = 110 kg
- Sand = 1320 kg

GWP of plaster

Cement	330 × 0.91	= 300.3 $kgCO_{2e}$
Fly ash	110 × 0.064	= 7.04 $kgCO_{2e}$
Sand	1320 × 0.009	= 11.88 $kgCO_{2e}$
Total		= 319.22 $kgCO_{2e}$

CHAPTER 7 : ANNEXURES

Annexure 7 – (a) for Alternative 1 B – Conventional frame model: Walling with AAC block

Sr. No.	Thresholds specified in IS code		Conventional frame with AAC Block Wall, mm			
1	Displacement For EQ = 54mm For Wind =27 mm	EQX	14.757			
		EQY	10.748			
		WX	2.838			
		WY	2.64			
2	Storey Drift (should not exceed 0.004 x H = 12mm)	EQX	0.001366			
		EQY	0.001038			
		SPECX	0.001526			
		SPECY	0.001274			
3	Torsional Irregularity Check (Max/Avg ratio should be less than 1.2)		**Max**	**Avg**	**Max/Avg**	
		EQX	14.757	14.7475	1.00	
		EQY	10.748	10.748	1.00	
4	Modal Mass Participating Ratios (shall be greater than 0.65 for UX, UY and RZ)		Time Period	UX	UY	RZ
		1	0.933	0.8249	0	0
		2	0.808	0	0.8484	0
		3	0.795	0	0	0.8302
5	Soft Storey Check		No Soft Storey			

Annexure 7 – (b) : Alternative 1C – Conventional frame model: Walling with EPS Panels

Sr. No.	Thresholds specified in IS code		Conventional frame with EPS Panels			
1	Displacement For EQ = 54 mm For Wind = 27 mm	EQX	14.561			
		EQY	11.283			
		WX	0.568			
		WY	0.601			
2	Storey Drift (should not exceed 0.004 x H = 12mm)	EQX	0.001329			
		EQY	0.00108			
		SPECX	0.000792			
		SPECY	0.000694			
3	Torsional Irregularity Check (Max/Avg ratio should be less than 1.2)		**Max**	**Avg**	**Max/Avg**	
		EQX	14.561	14.537	1.00	
		EQY	11.283	11.26	1.00	
4	Modal Mass Participating Ratios (shall be greater than 0.65 for UX, UY and RZ)		**Time Period**	**UX**	**UY**	**RZ**
		1	0.933	0.8364	0	0
		2	0.835	0	0.8568	0
		3	0.819	0	0	0.839
5	Soft Storey Check		No Soft Storey			

Annexure 7 – (c) : Alternative 1D – Conventional frame model : Walling with fly ash bricks

Sr. No.	Thresholds specified in IS code		Conventional frame with fly ash bricks			
1	Displacement For EQ = 54mm For Wind = 27mm	EQX	23.069			
		EQY	16.610			
		WX	2.77			
		WY	2.216			
2	Storey Drift (should not exceed 0.004 x H = 12mm)	EQX	0.002132			
		EQY	0.001595			
		SPECX	0.001876			
		SPECY	0.001562			
3	Torsional Irregularity Check (Max/Avg ratio should be less than 1.2)		**Max**	**Avg**	**Max/Avg**	
		EQX	23.069	23.059	1.00	
		EQY	16.610	16.510	1.00	
4	Modal Mass Participating Ratios (shall be greater than 0.65 for UX, UY and RZ)		**Time Period**	**UX**	**UY**	**RZ**
		1	1.16	0.8152	0	0
		2	0.999	0	0.8396	0
		3	0.979	0	0	0.8217
5	Soft Storey Check		No Soft Storey			

Annexure 7 – (d) : Alternative 2A – Conventional frame-shear wall model: Walling burnt clay bricks

Sr. No.	Thresholds specified in IS code		Conventional frame with shear wall and burnt clay brick walls			
1	Displacement For EQ = 54 mm For Wind = 27 mm	EQX	21.363			
		EQY	3.108			
		WX	2.528			
		WY	0.461			
2	Storey Drift (should not exceed 0.004 x H = 12mm)	EQX	0.001963			
		EQY	0.000305			
		SPECX	0.001739			
		SPECY	0.000467			
3	Torsional Irregularity Check (Max/Avg ratio should be less than 1.2)		**Max**	**Avg**	**Max/Avg**	
		EQX	21.363	21.31	1.002	
		EQY	3.108	3.10	1.002	
4	Modal Mass Participating Ratios (shall be greater than 0.65 for UX, UY and RZ)		**Time Period**	**UX**	**UY**	**RZ**
		1	1.051	0.7434	0	0
		2	0.396	0	0.7237	0
		3	0.339	0	0	0.726
5	Soft Storey Check		No Soft Storey			

Annexure 7 – (e) : Alternative 2B- – Conventional frame with shear wall model: Walling with AAC blocks

Sr. No.	Thresholds specified in IS code		Conventional frame with shear wall with AAC Blocks			
1	Displacement For EQ = 54mm For Wind =27 mm	EQX	9.707			
		EQY	1.979			
		WX	1.814			
		WY	0.46			
2	Storey Drift (should not exceed 0.004 x H = 12mm)	EQX	0.000861			
		EQY	0.000195			
		SPECX	0.001182			
		SPECY	0.000202			
3	Torsional Irregularity Check (Max/Avg ratio should be less than 1.2)		**Max**	**Avg**	**Max/Avg**	
		EQX	9.707	9.69	1.00	
		EQY	1.979	1.97	1.00	
4	Modal Mass Participating Ratios (shall be greater than 0.65 for UX, UY and RZ)		**Time Period**	**UX**	**UY**	**RZ**
		1	0.719	0.768	0	0
		2	0.316	0	0.7313	0
		3	0.268	0	0	0.7351
5	Soft Storey Check		No Soft Storey			

Annexure 7 – (f) : Alternative 2C- Conventional frame with shear wall : Walling with EPS sandwich Panels

Sr. No.	**Thresholds specified in IS code**		**Conventional frame with shear wall with EPS Panels**			
1	Displacement For EQ = 54 mm For Wind = 27 mm	EQX	11.974			
		EQY	1.391			
		WX	3.338			
		WY	0.488			
2	Storey Drift (should not exceed 0.004 x H = 12mm)	EQX	0.00112			
		EQY	0.000137			
		SPECX	0.001347			
		SPECY	0.000216			
3	Torsional Irregularity Check (Max/Avg ratio should be less than 1.2)		**Max**	**Avg**	**Max/Avg**	
		EQX	11.974	11.96	1.00	
		EQY	1.391	1.391	1.00	
4	Modal Mass Participating Ratios (shall be greater than 0.65 for UX, UY and RZ)		**Time Period**	**UX**	**UY**	**RZ**
		1	0.79	0.755	0	0
		2	0.267	0	0.7435	0
		3	0.234	0	0	0.7427
5	Soft Storey Check		No Soft Storey			

Annexure 7 (g) Alternative 2D – Conventional frame with shear wall : Walling with fly ash bricks

Sr. No.	Thresholds specified in IS code		Conventional frame with shear wall with fly ash bricks			
1	Displacement For EQ = 54mm For Wind = 27mm	EQX	20.819			
		EQY	3.029			
		WX	2.528			
		WY	2.022			
2	Storey Drift (should not exceed 0.004 x H = 12mm)	EQX	0.001914			
		EQY	0.000297			
		SPECX	0.001716			
		SPECY	0.000457			
3	Torsional Irregularity Check (Max/Avg ratio should be less than 1.2)		**Max**	**Avg**	**Max/Avg**	
		EQX	20.819	20.812	1.00	
		EQY	3.029	3.015	1.00	
4	Modal Mass Participating Ratios (shall be greater than 0.65 for UX, UY and RZ)		**Time Period**	**UX**	**UY**	**RZ**
		1	1.04	0.7456	0	0
		2	0.392	0	0.7259	0
		3	0.335	0	0	0.7279
5	Soft Storey Check		No Soft Storey			

CHAPTER 8: ANNEXURES

ALTERNATIVE: 1

Annexure 8 – 1T (i) : Carbon Emission During Transportation of Concrete

	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
M30 Grade of Concrete	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Concrete Quantity, m^3	391.42	391.42	391.42	385.78	385.78	385.78	326.67	326.67	326.67	388.90	388.90	388.90
Density, kg/m^3	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
Total Quantity, kg	939408	939408	939408	925872	925872	925872	784008	784008	784008	933360	933360	933360
Carbon Emission of Material Transported, $kgCO_{2e}/kg$	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011
Emission during Transportation (A4), $kgCO_{2e}$	1033	1033	1033	1018	1018	1018	862	862	862	1027	1027	1027

Annexure 8 – 1T (ii) : Carbon Emission During Transportation of Steel

	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
M30 Grade of Concrete	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Reinforcement, kgs	49330	49330	49330	48030	48030	48030	39080	39080	39080	48920	48920	48920
Carbon Emission of Material Transported, $kgCO_{2e}/kg$	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
Emission during Transportation (A4), $kgCO_{2e}$	1579	1579	1579	1537	1537	1537	1251	1251	1251	1565	1565	1565

Annexure 8 – 1T (iii) : Carbon Emission during transportation of Walling Material

	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
M30 Grade of Concrete	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Concrete Quantity, m^3	208.95	208.95	208.95	208.95	208.95	208.95	94.72	94.72	94.72	208.95	208.95	208.95
Density, kg/m^3	1900	1900	1900	500	500	500	15	15	15	1760	1760	1760
Total Quantity, kg	397005	397005	397005	104475	104475	104475	1421	1421	1421	367752	367752	367752
Carbon Emission of Material Transported, $kgCO_{2e}/kg$	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Emission during Transportation (A4), $kgCO_{2e}$	1985	1985	1985	522	522	522	7	7	7	1839	1839	1839

Annexure 8 – 1T (iv) : Carbon Emission during Transportation of Formwork

	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
M30 Grade of Concrete	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Plywood Quantity, m^2	480.70	480.70	480.70	453.70	453.70	453.70	371.10	371.10	371.10	456.66	456.66	456.66
Plywood Quantity, m^3, 0.012m	5.77	5.77	5.77	5.44	5.44	5.44	4.45	4.45	4.45	5.48	5.48	5.48
Density, kg/m^3	600	600	600	600	600	600	600	600	600	600	600	600
Total Quantity, kg	3461.04	3461.04	3461.04	3266.64	3266.64	3266.64	2671.92	2671.92	2671.92	3287.952	3287.952	3287.952
Carbon Emission of Material Transported, $kgCO_{2e}$/kg	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Emission during Transportation (A4), $kgCO_{2e}$	17	17	17	16	16	16	13	13	13	16	16	16
Timber Quantity For Scaffolding	6320	6320	6320	6050	6050	6050	5220	5220	5220	6320	6320	6320
Carbon Emission of Material Transported, $kgCO_{2e}$/kg	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Emission during Transportation (A4), $kgCO_{2e}$	32	32	32	30	30	30	26	26	26	32	32	32
Total Quantity, kgs	9781	9781	9781	9317	9317	9317	7892	7892	7892	9608	9608	9608
Total Emission during Transportation (A4), $kgCO_{2e}$	49	49	49	47	47	47	39	39	39	48	48	48

Annexure 8 – 1T (v) : Carbon Emission During Transportation of External Plaster

	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
M30 Grade of Concrete	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Concrete Quantity, m^3	49.45	49.45	49.45	49.45	49.45	49.45	45.20	45.20	45.20	49.45	49.45	49.45
Density, kg/m^3	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Total Quantity, kg	93955	93955	93955	93955	93955	93955	85880	85880	85880	93955	93955	93955
Carbon Emission of Material Transported, $kgCO_{2e}$/kg	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Emission during Transportation (A4) , $kgCO_{2e}$	470	470	470	470	470	470	429	429	429	470	470	470

Annexure 8 – 1T (vi) : Carbon Emission During Transportation of Internal Plaster

	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
M30 Grade of Concrete	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Concrete Quantity, m^3	37.43	37.43	37.43	37.43	37.43	37.43	79.53	79.53	79.53	37.43	37.43	37.43
Density, kg/m^3	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Total Quantity, kg	71117	71117	71117	71117	71117	71117	151107	151107	151107	71117	71117	71117
Carbon Emission of Material Transported, $kgCO_{2e}/kg$	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Emission during Transportation (A4), $kgCO_{2e}$	356	356	356	356	356	356	756	756	756	356	356	356

Annexure 8 – 1T (vii) : Carbon Emission during Transportation of Internal Gypsum Plaster

	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
M30 Grade of Concrete	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Quantity ,m^3	31.19	31.19	31.19	31.19	31.19	31.19	26.51	26.51	26.51	31.19	31.19	31.19
Density, kg/m^3	750	750	750	750	750	750	750	750	750	750	750	750
Total Quantity , kg	23393	23393	23393	23393	23393	23393	19883	19883	19883	23393	23393	23393
Carbon Emission of Material Transported, $kgCO_{2e}/kg$	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Emission during Transportation (A4), $kgCO_{2e}$	117	117	117	117	117	117	99	99	99	117	117	117

Annexure 8 – 1T (viii) : Summary of Carbon Emission due to Transportation of Materials In Alternative 1

	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Annexure 8 – 1T (i) : Carbon Emission During Transportation of Concrete	1033	1033	1033	1018	1018	1018	862	862	862	1027	1027	1027
Annexure 8 – 1T (ii) : Carbon Emission During Transportation of Steel	1579	1579	1579	1537	1537	1537	1251	1251	1251	1565	1565	1565
Annexure 8 – 1T (iii) : Carbon Emission during transportation of Walling Material	1985	1985	1985	522	522	522	7	7	7	1839	1839	1839
Annexure 8 – 1T (iv) : Carbon Emission during Transportation of Formwork	49	49	49	47	47	47	39	39	39	48	48	48
Annexure 8 – 1T (v) : Carbon Emission During Transportation of External Plaster	470	470	470	470	470	470	429	429	429	470	470	470
Annexure 8 – 1T (vi) : Carbon Emission During Transportation of Internal Plaster	356	356	356	356	356	356	756	756	756	356	356	356
Annexure 8 – 1T (vii) : Carbon Emission during Transportation of Internal Gypsum Plaster	117	117	117	117	117	117	99	99	99	117	117	117
Total Emission During A4	5588	5588	5588	4067	4067	4067	3444	3444	3444	5421	5421	5421
Total Sum of Carbon Footprints (A1 To A3)	365030	345972	309499	337442	318659	282712	268683	252778	222339	357572	338636	302399
% of Carbon Foot-prints due to transportation out of total	1.53	1.62	1.81	1.21	1.28	1.44	1.28	1.36	1.55	1.52	1.60	1.79

Annexure 8 – 1W (i) : Carbon Emission due to Wastage of Concrete

Embodied Carbon Calculation	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Carbon Footprints of Concrete, (A1-A3)	142179	123121	86649	140131	121347	85400	118660	102754	72315	141264	122328	86091
Carbon Footprints of Concrete, (A1 to A3) with 2% wastage (A13)	2844	2462	1733	2803	2427	1708	2373	2055	1446	2825	2447	1722
Total Quantity in kgs	939408	939408	939408	925872	925872	925872	784008	784008	784008	933360	933360	933360
Wastage of Concrete (A4), 2%, kgs	18788	18788	18788	18517	18517	18517	15680	15680	15680	18667	18667	18667
Carbon Footprints of Wasted Concrete during Transportation (A4-W), 0.005kgCO_{2e}	94	94	94	93	93	93	78	78	78	93	93	93
C2 Carbon Footprinting Transporting wasted material away from site (0.005kgCO_{2e})	94	94	94	93	93	93	78	78	78	93	93	93
Carbon Footprinting for Processing of Waste Material (0.013kgCO_{2e}), C34	244	244	244	241	241	241	204	204	204	243	243	243
Total Wastage (A13+ A4-W+C34+C2)	3276	2895	2165	3229	2853	2134	2734	2416	1807	3255	2876	2151

Annexure 8 – 1W (ii) : Carbon Emission due to Wastage of Steel

Embodied Carbon Calculation	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Carbon Footprint of Reinforcement (A1-A3)	115432	115432	115432	112390	112390	112390	91447	91447	91447	114473	114473	114473
Carbon Footprint of Reinforcement (A1-A3) with 5% wastage (A13)	5772	5772	5772	5620	5620	5620	4572	4572	4572	5724	5724	5724
Total Quantity, kgs	49330	49330	49330	48030	48030	48030	39080	39080	39080	48920	48920	48920
Wastage of Steel (A4), 5%, kgs	2467	2467	2467	2402	2402	2402	1954	1954	1954	2446	2446	2446
Carbon Footprints of Wasted Steel during Transportation (A4-W), 0.005 $kgCO_{2e}$	12	12	12	12	12	12	10	10	10	12	12	12
C2 Transporting Wasted Material Away from site (0.005 $kgCO_{2e}$)	12	12	12	12	12	12	10	10	10	12	12	12
Carbon Footprint for processing wasted material (0.013 $kgCO_{2e}$), (C34)	32	32	32	31	31	31	25	25	25	32	32	32
Total Wastage (A13+ A4-W +C34+C2)	5828	5828	5828	5675	5675	5675	4617	4617	4617	5780	5780	5780

Annexure 8 – 1W (iii) : Carbon Emission due to Wastage of Walling Materials

Embodied Carbon Calculation	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Carbon Footprint of Walling Materials (A1-A3)	75590	75590	75590	53182	53182	53182	15345	15345	15345	70023	70023	70023
Carbon Footprints of Walling Materials (A1-A3) with 2% wastage (A13)	1512	1512	1512	1064	1064	1064	307	307	307	1400	1400	1400
Total Quantity, kgs	397005	397005	397005	104475	104475	104475	1421	1421	1421	367752	367752	367752
Wastage of Walling Materials (A4), 2%, kg	7940	7940	7940	2090	2090	2090	28	28	28	7355	7355	7355
Carbon Footprints of wasted Walling Materials Transporation, (A4-W), 0.005 $kgCO_{2e}$	40	40	40	10	10	10	0.14	0.14	0.14	37	37	37
C2 Transporting wasted Walling Materials from site (C2), 0.005$kgCO_{2e}$	40	40	40	10	10	10	0.14	0.14	0.14	37	37	37
C34, Processing of wasted Walling Materials from site @ 0.013	103	103	103	27	27	27	0.37	0.37	0.37	96	96	96
Total Wastage (A13+ A4-W +C34+C2)	1694	1694	1694	1112	1112	1112	308	308	308	1570	1570	1570

Annexure 8 – 1W (iv) : Carbon Emission due to Wastage of Formwork

Embodied Carbon Calculation	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Carbon Footprint of Timber (A1-A3)	1662	1662	1662	1591	1591	1591	1373	1373	1373	1662	1662	1662
Carbon Footprint of Plywood (A1-A3)	327	327	327	309	309	309	253	253	253	311	311	311
Total Carbon Footprint of Timber & Plywood (A1-A3)	1990	1990	1990	1900	1900	1900	1626	1626	1626	1973	1973	1973
Carbon Footprints of Timber & Plywood (A1-A3) with 5% wastage (A13)	99	99	99	95	95	95	81	81	81	99	99	99
Total Quantity of Plywood and Timber, kg	9781	9781	9781	9317	9317	9317	7892	7892	7892	9608	9608	9608
Wastage of Formwork (A4), 5%, kgs	489.05	489.05	489.05	465.83	465.83	465.83	394.60	394.60	394.60	480.40	480.40	480.40
Carbon Footprints of wasted Formwork Transporation, (A4-W), 0.005kgCO_{2e}	2.45	2.45	2.45	2.33	2.33	2.33	1.97	1.97	1.97	2.40	2.40	2.40
C2 Transporting wasted Formwork from site, (C2), 0.005kgCO_{2e}	2.45	2.45	2.45	2.33	2.33	2.33	1.97	1.97	1.97	2.40	2.40	2.40
C34, Processing of wasted Formwork from site @ 1.77 KgCO_{2e}	865.62	865.62	865.62	824.52	824.52	824.52	698.43	698.43	698.43	850.30	850.30	850.30
Total Wastage (A13+ A4-W +C34+C2)	970	970	970	924	924	924	784	784	784	954	954	954

Annexure 8 – 1W (v) : Carbon Emission due to Wastage of External Plaster

Embodied Carbon Calculation	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Carbon Footprints of External Plaster (A1-A3)	15785	15785	15785	15785	15785	15785	14429	14429	14429	15785	15785	15785
Carbon Footprints of External Plaster (A1-A3) with 2% wastage (A13)	316	316	316	316	316	316	289	289	289	316	316	316
Total Quantity, kgs	93955	93955	93955	93955	93955	93955	85880	85880	85880	93955	93955	93955
Wastage of External Plaster (A4) , 2%, kgs	1879	1879	1879	1879	1879	1879	1718	1718	1718	1879	1879	1879
Carbon Footprints of Wasted External Plaster during Transportation (A4-W) , 0.005 $kgCO_{2e}$	9	9	9	9	9	9	9	9	9	9	9	9
C2 Transporting wasted External Plaster from site (C2), 0.005$kgCO_{2e}$	9	9	9	9	9	9	9	9	9	9	9	9
C34, Processing of wasted external plaster from site @0.013	24	24	24	24	24	24	22	22	22	24	24	24
Total Wastage (A13+ A4-W +C34+C2)	359	359	359	359	359	359	328	328	328	359	359	359

Annexure 8 – 1W (vi) : Carbon Emission Due to Wastage of Internal Plaster

Embodied Carbon Calculation	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Carbon Footprints of Internal Plaster (A1-A3)	11948	11948	11948	11948	11948	11948	25388	25388	25388	11948	11948	11948
Carbon Footprints of Internal Plaster (A1-A3) with 2% wastage (A13)	239	239	239	239	239	239	508	508	508	239	239	239
Total Quantity, kgs	71117	71117	71117	71117	71117	71117	151107	151107	151107	71117	71117	71117
Wastage of Internal Plaster (A4), 2%, kgs	1422	1422	1422	1422	1422	1422	3022	3022	3022	1422	1422	1422
Carbon Footprints of Wasted Internal Plaster during Transportation (A4-W), 0.005 $kgCO_{2e}$	7	7	7	7	7	7	15	15	15	7	7	7
C2 Transporting wasted Internal Plaster from site (C2), 0.005$kgCO_{2e}$	7	7	7	7	7	7	15	15	15	7	7	7
C34, Processing of wasted Internal plaster from site @ 0.013	18	18	18	18	18	18	39	39	39	18	18	18
Total Wastage (A13+ A4-W +C34+C2)	272	272	272	272	272	272	577	577	577	272	272	272

Annexure 8 – 1W (vii): Carbon Emission due to Wastage of Gypsum Plaster

Embodied Carbon Calculation	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Carbon Footprints of Gypsum Plaster (A1-A3)	2105	2105	2105	2105	2105	2105	1789	1789	1789	2105	2105	2105
Carbon Footprints of gypsum Plaster (A1-A3) with 10% wastage (A13)	210.53	210.53	210.53	210.53	210.53	210.53	178.94	178.94	178.94	210.53	210.53	210.53
Total Quantity, kgs	23393	23393	23393	23393	23393	23393	19883	19883	19883	23393	23393	23393
Wastage of Gypsum Plaster (A4) , 10%, kgs	2339	2339	2339	2339	2339	2339	1988	1988	1988	2339	2339	2339
Carbon Footprints of wasted Gypsum Plaster Transporation , (A4-W), 0.005 $kgCO_{2e}$	12	12	12	12	12	12	10	10	10	12	12	12
C2 Transporting wasted Gypsum Plaster from site (C2), 0.005$kgCO_{2e}$	12	12	12	12	12	12	10	10	10	12	12	12
C34, Processing of wasted Gypsum Plaster from site @ 0.013	30	30	30	30	30	30	26	26	26	30	30	30
Total Wastage (A13+ A4-W +C34+C2)	264	264	264	264	264	264	225	225	225	264	264	264

Annexure 8 – 1W (viii) : Summary of Carbon Emission due to Wastage of Materials In Alternative 1

	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block			Alternative 1-C EPS PANEL			Alternative 1-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Annexure 8 -1W (i) : Carbon Emission due to Wastage of Concrete	3276	2895	2165	3229	2853	2134	2734	2416	1807	3255	2876	2151
Annexure 8 -1W (ii) : Carbon Emission due to Wastage of Steel	5828	5828	5828	5675	5675	5675	4617	4617	4617	5780	5780	5780
Annexure 8 -1W (iii) : Carbon Emission due to Wastage of Walling Materials	1694	1694	1694	1112	1112	1112	308	308	308	1570	1570	1570
Annexure 8 -1W (iv) : Carbon Emission due to Wastage of Formwork	970	970	970	924	924	924	784	784	784	954	954	954
Annexure 8 -1W (v) : Carbon Emission due to Wastage of External Plaster	359	359	359	359	359	359	328	328	328	359	359	359
Annexure 8 -1W (vi) : Carbon Emission Due to Wastage of Internal Plaster	272	272	272	272	272	272	577	577	577	272	272	272
Annexure 8 -1W (vii): Carbon Emission due to Wastage of Gypsum Plaster	264	264	264	264	264	264	225	225	225	264	264	264
Total Wastage	12663	12282	11553	11834	11458	10739	9572	9254	8645	12453	12074	11349
Total Sum of Carbon Footprints (A1 To A3)	365030	345972	309499	337442	318659	282712	268683	252778	222339	357572	338636	302399
% of Carbon Footprints due to wastage out of total	3.47	3.55	3.73	3.51	3.60	3.80	3.56	3.66	3.89	3.48	3.57	3.75

ALTERNATIVE: 2

Annexure 8 – 2T (i) : Carbon Emission during Transportation of Concrete

	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS Panel			Alternative 2-D Fly Ash Brick		
M30 Grade of Concrete	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Concrete Quantity, m^3	443.00	443.00	443.00	439.48	439.48	439.48	381.13	381.13	381.13	442.36	442.36	442.36
Density, kg/m^3	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
Total Quantity, kg	1063200	1063200	1063200	1054752	1054752	1054752	914712	914712	914712	1061664	1061664	1061664
Carbon Emission of Material Transported, $kgCO_{2e}/kg$	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011
Emission during Transportation (A4) , $kgCO_{2e}$	1170	1170	1170	1160	1160	1160	1006	1006	1006	1168	1168	1168

Annexure 8 – 2T (ii) : Carbon Emission During Transportation of Steel

	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS Panel			Alternative 2-D Fly Ash Brick		
M30 Grade of Concrete	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Reinforcement, kgs	39060	39060	39060	36390	36390	36390	29880	29880	29880	38350	38350	38350
Carbon Emission of Material Transported, $kgCO_{2e}/kg$	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032	0.032
Emission during Transportation (A4), $kgCO_{2e}$	1250	1250	1250	1164	1164	1164	956	956	956	1227	1227	1227

Annexure 8 – 2T (iii) : Carbon Emission during Transportation of Walling Material

	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS Panel			Alternative 2-D Fly Ash Brick		
M30 Grade of Concrete	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Quantity, m^3	153.15	153.15	153.15	153.15	153.15	153.15	94.72	94.72	94.72	153.15	153.15	153.15
Density, kg/m^3	1900	1900	1900	500	500	500	15	15	15	1760	1760	1760
Total Quantity, kg	290985	290985	290985	76575	76575	76575	1421	1421	1421	269544	269544	269544
Carbon Emission of Material Transported, $kgCO_{2e}/kg$	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Emission during Transportation (A4), $kgCO_{2e}$	1455	1455	1455	383	383	383	7	7	7	1348	1348	1348

Annexure 8 – 2T (iv) : Carbon Emission during transportation of Formwork

	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS Panel			Alternative 2-D Fly Ash Brick		
M30 Grade of Concrete	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Plywood Quantity, m^2	396.62	396.62	396.62	383.06	383.06	383.06	437.57	437.57	437.57	376.78	376.78	376.78
Plywood Quantity, m^3, 0.012m	4.76	4.76	4.76	4.60	4.60	4.60	5.25	5.25	5.25	4.52	4.52	4.52
Density, kg/m^3	600	600	600	600	600	600	600	600	600	600	600	600
Total Quantity, kg	2855.66	2855.66	2855.66	2758.03	2758.03	2758.03	3150.50	3150.50	3150.50	2712.82	2712.82	2712.82
Carbon Emission of Material Transported, $kgCO_{2e}$/kg	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Emission during Transportation (A4), $kgCO_{2e}$	14	14	14	14	14	14	16	16	16	14	14	14
Timber Quantity For Scaffolding	5470	5470	5470	5340	5340	5340	5880	5880	5880	5470	5470	5470
Carbon Emission of Material Transported	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Emission during Transportation (A4), $kgCO_{2e}$	27	27	27	27	27	27	29	29	29	27	27	27
Total Emission during Transportation (A4), $kgCO_{2e}$	42	42	42	40	40	40	45	45	45	41	41	41
Total Quantity, kg	8326	8326	8326	8098	8098	8098	9031	9031	9031	8183	8183	8183

Annexure 8 – 2T (v) : Carbon Emission During Transportation of External Plaster

	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS Panel			Alternative 2-D Fly Ash Brick		
M30 Grade of Concrete	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Quantity, m^3	49.45	49.45	49.45	49.45	49.45	49.45	45.20	45.20	45.20	49.45	49.45	49.45
Density, kg/m^3	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Total Quantity, kg	93955	93955	93955	93955	93955	93955	85880	85880	85880	93955	93955	93955
Carbon Emission of Material Transported, $kgCO_{2e}$/kg	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Emission during Transportation (A4), $kgCO_{2e}$	470	470	470	470	470	470	429	429	429	470	470	470

Annexure 8 – 2T (vi) : Carbon Emission During Transportation of Internal Plaster

	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS Panel			Alternative 2-D Fly Ash Brick		
M30 Grade of Concrete	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Concrete Quantity, m^3	37.43	37.43	37.43	37.43	37.43	37.43	79.53	79.53	79.53	37.43	37.43	37.43
Density, kg/m^3	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Total Quantity, kg	71113	71113	71113	71113	71113	71113	151107	151107	151107	71113	71113	71113
Carbon Emission of Material Transported, $kgCO_{2e}/kg$	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Emission during Transportation (A4) , $kgCO_{2e}$	356	356	356	356	356	356	756	756	756	356	356	356

Annexure 8 – 2T (vii) : Carbon Emission during Transportation of Internal Gypsum Plaster

	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS Panel			Alternative 2-D Fly Ash Brick		
M30 Grade of Concrete	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Total Quantity, m^3	31.19	31.19	31.19	31.19	31.19	31.19	26.51	26.51	26.51	31.19	31.19	31.19
Density, kg/m^3	750	750	750	750	750	750	750	750	750	750	750	750
Total Quantity, kg	23393	23393	23393	23393	23393	23393	19883	19883	19883	23393	23393	23393
Carbon Emission of Material Transported, $kgCO_{2e}/kg$	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Emission during Transportation (A4), $kgCO_{2e}$	117	117	117	117	117	117	99	99	99	117	117	117

Annexure 8 – 2T (viii) : Summary of Carbon Emission due to Transportation of Materials In Alternative 2

	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS Panel			Alternative 2-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Annexure 8 – 2T (i) : Carbon Emission During Transportation of Concrete	1170	1170	1170	1160	1160	1160	1006	1006	1006	1168	1168	1168
Annexure 8 – 2T (ii) : Carbon Emission During Transportation of Steel	1250	1250	1250	1164	1164	1164	956	956	956	1227	1227	1227
Annexure 8 – 2T (iii) : Carbon Emission during transportation of Walling Material	1455	1455	1455	383	383	383	7	7	7	1348	1348	1348
Annexure 8 – 2T (iv) : Carbon Emission during Transportation of Formwork	42	42	42	40	40	40	45	45	45	41	41	41
Annexure 8 – 2T (v) : Carbon Emission During Transportation of External Plaster	470	470	470	470	470	470	429	429	429	470	470	470
Annexure 8 – 2T (vi) : Carbon Emission During Transportation of Internal Plaster	356	356	356	356	356	356	756	756	756	356	356	356
Annexure 8 – 2T (vii) : Carbon Emission during Transportation of Internal Gypsum Plaster	117	117	117	117	117	117	99	99	99	117	117	117
Total Emission During A4	4858	4858	4858	3690	3690	3690	3299	3299	3299	4726	4726	4726
Total Sum of Carbon Footprints (A1 To A3)	339266	317697	276418	315273	293875	252924	267156	248599	213085	333279	311741	270522
% of Carbon Footprints due to transportation out of total	1.43	1.53	1.76	1.17	1.26	1.46	1.23	1.33	1.55	1.42	1.52	1.75

Annexure 8 – 2W (i) : Carbon Emission due to Wastage of Concrete

Embodied Carbon Calculation	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS PANEL			Alternative 2-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Carbon Footprints of Concrete, (A1-A3)	160915	139346	98067	159637	138238	97288	138442	119884	84371	160683	139144	97925
Carbon Footprints of Concrete, (A1-A3) with 2% wastage (A13)	3218	2787	1961	3193	2765	1946	2769	2398	1687	3214	2783	1959
Total Quantity in kg	1063200	1063200	1063200	1054752	1054752	1054752	914712	914712	914712	1061664	1061664	1061664
Wastage of Concrete (A4), 2%, kgs	21264	21264	21264	21095	21095	21095	18294	18294	18294	21233	21233	21233
Carbon Footprints of Wasted Concrete during Transportation (A4-W) , 0.005kgCO_{2e}	106	106	106	105	105	105	91	91	91	106	106	106
Transporting wasted material away from site (0.005kgCO_{2e}), C2	106	106	106	105	105	105	91	91	91	106	106	106
Carbon Footprint for Processing of Waste Material (0.013kgCO_{2e}), C34	276	276	276	274	274	274	238	238	238	276	276	276
Total Wastage (A13+A4-W+C34+C2)	3707	3276	2450	3678	3250	2431	3190	2818	2108	3702	3271	2447

Annexure 8 – 2W (ii) : Carbon Emission due to Wastage of Steel

Embodied Carbon Calculation	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS PANEL			Alternative 2-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Carbon Footprint of Reinforcement (A1-A3)	91400	91400	91400	85153	85153	85153	69919	69919	69919	89739	89739	89739
Carbon Footprint of Reinforcement (A1-A3) with 5% wastage, (A13)	4570	4570	4570	4258	4258	4258	3496	3496	3496	4487	4487	4487
Total Quantity in kgs	39060	39060	39060	36390	36390	36390	29880	29880	29880	38350	38350	38350
Wastage of Steel (A4), 5%, kgs	1953	1953	1953	1820	1820	1820	1494	1494	1494	1918	1918	1918
Carbon Footprints of Wasted reinforcement Tranportation(A4-W), 0.005kgCO_{2e}	10	10	10	9	9	9	7	7	7	10	10	10
C2 Transporting Wasted Material Away from site (0.005 kgCO_{2e})	10	10	10	9	9	9	7	7	7	10	10	10
Carbon Footprint for processing wasted material (0.013 kgCO_{2e}), (C34)	25	25	25	24	24	24	19	19	19	25	25	25
Total Wastage (A13+A4-W+C34+C2)	4615	4615	4615	4299	4299	4299	3530	3530	3530	4531	4531	4531

Annexure 8 – 2W (iii) : Carbon Emission due to Wastage of Walling Materials

Embodied Carbon Calculation	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS PANEL			Alternative 2-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Carbon Footprint of Walling Materials (A1-A3)	55404	55404	55404	38980	38980	38980	15345	15345	15345	51324	51324	51324
Carbon Footprints of Walling Materials (A1-A3) with 2% wastage (A13)	1108	1108	1108	780	780	780	307	307	307	1026	1026	1026
Total Quantity, kgs	290985	290985	290985	76575	76575	76575	1420.8	1420.8	1420.8	269544	269544	269544
Wastage of Walling Materials (A4), 2%, kgs	5819.7	5819.7	5819.7	1531.5	1531.5	1531.5	28.416	28.416	28.416	5390.88	5390.88	5390.88
Carbon Footprints of wasted Walling Materials Transporation, (A4-W), 0.005kgCO_{2e}	29.10	29.10	29.10	7.66	7.66	7.66	0.14	0.14	0.14	26.95	26.95	26.95
C2 Transporting wasted Walling Materials from site (C2), 0.005kgCO_{2e}	29.10	29.10	29.10	7.66	7.66	7.66	0.14	0.14	0.14	26.95	26.95	26.95
C34, Processing of wasted Walling Materials from site @ 0.013	75.66	75.66	75.66	19.91	19.91	19.91	0.37	0.37	0.37	70.08	70.08	70.08
Total Wastage (A13+A4-W+C34+C2)	1242	1242	1242	815	815	815	308	308	308	1150	1150	1150

Annexure 8 – 2W (iv) : Carbon Emission due to Wastage of Formwork

Embodied Carbon Calculation	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS PANEL			Alternative 2-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Carbon Footprint of Timber (A1-A3)	1439	1439	1439	1404	1404	1404	1546	1546	1546	1439	1439	1439
Carbon Footprint of Plywood (A1-A3)	270	270	270	261	261	261	298	298	298	257	257	257
Total Carbon Footprint of Timber & Plywood (A1-A3)	1709	1709	1709	1665	1665	1665	1844	1844	1844	1695	1695	1695
Carbon Footprints of Timber & Plywood (A1-A3) with 5% wastage (A13)	85.44	85.44	85.44	83.26	83.26	83.26	92.22	92.22	92.22	84.76	84.76	84.76
Total Quantity, kgs	8326	8326	8326	8098	8098	8098	9031	9031	9031	8183	8183	8183
Wastage of Formwork (A4), 5%, kgs	416.28	416.28	416.28	404.90	404.90	404.90	451.53	451.53	451.53	409.14	409.14	409.14
Carbon Footprints of wasted Form-work Transporation, (A4-W), 0.005kgCO_{2e}	2.08	2.08	2.08	2.02	2.02	2.02	2.26	2.26	2.26	2.05	2.05	2.05
C2 Transporting wasted Formwork from site (C2), 0.005kgCO_{2e}	2.08	2.08	2.08	2.02	2.02	2.02	2.26	2.26	2.26	2.05	2.05	2.05
C34, Processing of wasted Formwork from site @ 1.77	736.82	736.82	736.82	716.68	716.68	716.68	799.20	799.20	799.20	724.18	724.18	724.18
Total Wastage (A13+A4-W+C34+C2)	826	826	826	804	804	804	896	896	896	813	813	813

Annexure 8 – 2W (v) : Carbon Emission due to Wastage of External Plaster

Embodied Carbon Calculation	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS PANEL			Alternative 2-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Carbon Footprints of External Plaster (A1-A3)	15785	15785	15785	15785	15785	15785	14429	14429	14429	15785	15785	15785
Carbon Footprints of External Plaster (A1-A3) with 2% wastage (A13)	316	316	316	316	316	316	289	289	289	316	316	316
Total Quantity, kgs	93955	93955	93955	93955	93955	93955	85880	85880	85880	93955	93955	93955
Wastage of External Plaster (A4), 2%, kgs	1879	1879	1879	1879	1879	1879	1718	1718	1718	1879	1879	1879
Carbon Footprints of wasted External Plaster Transporation, (A4-W), 0.005kgCO_{2e}	9	9	9	9	9	9	9	9	9	9	9	9
C2 Transporting wasted External Plaster from site (C2), 0.005kgCO_{2e}	9	9	9	9	9	9	9	9	9	9	9	9
C34, Processing of wasted external plaster from site @ 0.013	24	24	24	24	24	24	22	22	22	24	24	24
Total Wastage (A13+A4-W+C34+C2)	359	359	359	359	359	359	328	328	328	359	359	359

Annexure 8 – 2W (vi) : Carbon Emission Due to Wastage of Internal Plaster

Embodied Carbon Calculation	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS PANEL			Alternative 2-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Carbon Footprints of Internal Plaster (A1-A3)	11948	11948	11948	11948	11948	11948	25388	25388	25388	11948	11948	11948
Carbon Footprints of Internal Plaster (A1-A3) with 2% wastage (A13)	239	239	239	239	239	239	508	508	508	239	239	239
Total Quantity, kgs	71113	71113	71113	71113	71113	71113	151107	151107	151107	71113	71113	71113
Wastage of Plaster (A4), 2%, kgs	1422	1422	1422	1422	1422	1422	3022	3022	3022	1422	1422	1422
Carbon Footprints of wasted Internal Plaster Transporation, (A4-W), 0.005kgCO_{2e}	7	7	7	7	7	7	15	15	15	7	7	7
C2 Transporting wasted Internal Plaster from site (C2), 0.005kgCO_{2e}	7	7	7	7	7	7	15	15	15	7	7	7
C34, Processing of wasted Internal plaster from site @0.013	18	18	18	18	18	18	39	39	39	18	18	18
Total Wastage (A13+A4-W+C34+C2)	272	272	272	272	272	272	577	577	577	272	272	272

Annexure 8 – 2W (vii): Carbon Emission due to Wastage of Gypsum Plaster

Embodied Carbon Calculation	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS PANEL			Alternative 2-D Fly Ash Brick		
	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix	OPC Mix	PPC Mix	PSC Mix
Carbon Footprints of Gypsum Plaster (A1-A3)	2105	2105	2105	2105	2105	2105	1789	1789	1789	2105	2105	2105
Carbon Footprints of gypsum (A1-A3) with 10% wastage (A13)	210.53	210.53	210.53	210.53	210.53	210.53	178.94	178.94	178.94	210.53	210.53	210.53
Total Quantity, kgs	23393	23393	23393	23393	23393	23393	19883	19883	19883	23393	23393	23393
Wastage of Gypsum Plaster(A4), 10%, kgs	2339.25	2339.25	2339.25	2339.25	2339.25	2339.25	1988.25	1988.25	1988.25	2339.25	2339.25	2339.25
Carbon Footprints of wasted gypsum Transporation, (A4-W), 0.005kgCO_{2e}	11.70	11.70	11.70	11.70	11.70	11.70	9.94	9.94	9.94	11.70	11.70	11.70
C2 Transporting wasted gypsum from site (C2), 0.005kg$C0_{2e}$	11.70	11.70	11.70	11.70	11.70	11.70	9.94	9.94	9.94	11.70	11.70	11.70
C34, Processing of wasted gypsum from site @0.013	30.41	30.41	30.41	30.41	30.41	30.41	25.85	25.85	25.85	30.41	30.41	30.41
Total Wastage (A13+A4-W+C34+C2)	264	264	264	264	264	264	225	225	225	264	264	264

Annexure 8 – 2W (viii) : Summary of Carbon Emission due to Wastage of Materials In Alternative 2

	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block			Alternative 2-C EPS PANEL			Alternative 2-D Fly Ash Brick		
	OPCMix	PPC Mix	PSC Mix	OPCMix	PPC Mix	PSC Mix	OPCMix	PPC Mix	PSC Mix	OPCMix	PPC Mix	PSC Mix
Annexure 8 – 2W (i) : Carbon Emission due to Wastage of Concrete	3707	3276	2450	3678	3250	2431	3190	2818	2108	3702	3271	2447
Annexure 8 – 2W (ii) : Carbon Emission due to Wastage of Steel	4615	4615	4615	4299	4299	4299	3530	3530	3530	4531	4531	4531
Annexure 8 -2W (iii) : Carbon Emission due to Wastage of Walling Materials	1242	1242	1242	815	815	815	308	308	308	1150	1150	1150
Annexure 8 -2W (iv) : Carbon Emission due to Wastage of Formwork	826	826	826	804	804	804	896	896	896	813	813	813
Annexure 8 -2W (v) : Carbon Emission due to Wastage of External Plaster	359	359	359	359	359	359	328	328	328	359	359	359
Annexure 8 -2W (vi) : Carbon Emission Due to Wastage of Internal Plaster	272	272	272	272	272	272	577	577	577	272	272	272
Annexure 8 -2W (vii): Carbon Emission due to Wastage of Gypsum Plaster	264	264	264	264	264	264	225	225	225	264	264	264
Total Wastage	11286	10854	10029	10491	10063	9244	9053	8682	7972	11091	10661	9836
Total Sum of Carbon Footprints (A1 To A3)	339266	317697	276418	315273	293875	252924	267156	248599	213085	333279	311741	270522
% of Carbon Footprints due to Wastage out of total	3.33	3.42	3.63	3.33	3.42	3.65	3.39	3.49	3.74	3.33	3.42	3.64

Annexure 8 – 3C : Cost Estimation for Alternatives 1-A & 1-B

	Alternative 1-A Fire Clay Brick			Alternative 1-B AAC Block		
M30 Grade concrete, m^3	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX
Total concrete quantity, m^3	391.42	391.42	391.42	385.78	385.78	385.78
Per m^3	5,859.00	5,511.00	5,730.00	5,859.00	5,511.00	5,730.00
Cost of Concrete	22,93,329.78	21,57,115.62	22,42,836.60	22,60,285.02	21,26,033.58	22,10,519.40
Reinforcement quantity (tonne)	49.33	49.33	49.33	48.03	48.03	48.03
Per tonne	70,000.00	70,000.00	70,000.00	70,000.00	70,000.00	70,000.00
Cost of Reinforcement	34,53,100.00	34,53,100.00	34,53,100.00	33,62,100.00	33,62,100.00	33,62,100.00
Formwork (m^2)						
12 mm Plywood	480.70	480.70	480.70	453.70	453.70	453.70
Per m^3	1,614.00	1,614.00	1,614.00	1,614.00	1,614.00	1,614.00
Cost of Plywood	7,75,849.80	7,75,849.80	7,75,849.80	7,32,271.80	7,32,271.80	7,32,271.80
Timber	6.32	6.32	6.32	6.05	6.05	6.05
Per m^3	70,000.00	70,000.00	70,000.00	70,000.00	70,000.00	70,000.00
Cost of Timber	4,42,400.00	4,42,400.00	4,42,400.00	4,23,500.00	4,23,500.00	4,23,500.00
Walling (m^3)						
150/80 mm thick	208.95	208.95	208.95	208.95	208.95	208.95
Per m^3	7,928.00	7,928.00	7,928.00	7,000.00	7,000.00	7,000.00
Cost of Walling	16,56,555.60	16,56,555.60	16,56,555.60	14,62,650.00	14,62,650.00	14,62,650.00
Plaster						
External Sand Plaster	1978	1978	1978	1978	1978	1978
Per m^2	1,100.00	1,100.00	1,100.00	1,100.00	1,100.00	1,100.00
Cost of External Plaster	21,75,800.00	21,75,800.00	21,75,800.00	21,75,800.00	21,75,800.00	21,75,800.00
Internal Sand Plaster	3119	3119	3119	3119	3119	3119
Per m^2	800.00	800.00	800.00	800.00	800.00	800.00
Cost of Internal Plaster	24,95,200.00	24,95.200.00	24,95,200.00	24,95.200.00	24,95,200.00	24,95.200.00
Internal Gypsum Plaster	3119	3119	3119	3119	3119	3119
Per m^2	300.00	300.00	300.00	300.00	300.00	300.00
Cost of Gypsum Plaster	9,35,700.00	9,35,700.00	9,35,700.00	9,35,700.00	9,35,700.00	9,35,700.00
Total Cost	1,42,27,935	1,40,91,721	1,41,77,442	1,38,47,507	1,37,13,255	1,37,97,741

Annexure 8 – 3C : Cost Estimation for Alternatives 1-C & 1-D

	Alternative 1-C EPS Panel			Alternative 1-D Fly Ash Brick		
M30 Grade concrete, m^3	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX
Total concrete quantity, m^3	326.67	326.67	326.67	388.90	388.90	388.90
Per m^3	5,859.00	5,511.00	5,730.00	5,859.00	5,511.00	5,730.00
Cost of Concrete	19,13,959.53	18,00,278.37	18,71,819.10	22,78,565.10	21,43,227.90	22,28,397.00
Reinforcement quantity (tonne)	39.08	39.08	39.08	48.92	48.92	48.92
Per tonne	70,000.00	70,000.00	70,000.00	70,000.00	70,000.00	70,000.00
Cost of Reinforcement	27,35,600.00	27,35,600.00	27,35,600.00	34,24,400.00	34,24,400.00	34,24,400.00
Formwork (m^2)						
12 mm Plywood	371.10	371.10	371.10	456.66	456.66	456.66
Per m^3	1,614.00	1,614.00	1,614.00	1,614.00	1,614.00	1,614.00
Cost of Plywood	5,98,955.40	5,98,955.40	5,98,955.40	7,37,049.24	7,37,049.24	7,37,049.24
Timber	5.22	5.22	5.22	6.32	6.32	6.32
Per m^3	70,000.00	70,000.00	70,000.00	70,000.00	70,000.00	70,000.00
Cost of Timber	3,65,400.00	3,65,400.00	3,65,400.00	4,42,400.00	4,42,400.00	4,42,400.00
Walling (m^3)						
150/80 mm thick	94.72	94.72	94.72	208.95	208.95	208.95
Per m^3	827.00	827.00	827.00	7,500.00	7,500.00	7,500.00
Cost of Walling	78,336.75	78,336.75	78,336.75	15,67,125.00	15,67,125.00	15,67,125.00
Plaster						
External Sand Plaster	1506.69	1506.69	1506.69	1978.00	1978.00	1978.00
Per m^2	1,100.00	1,100.00	1,100.00	1,100.00	1,100.00	1,100.00
Cost of External Plaster	16,57,359.00	16,57,359.00	16,57,359.00	21,75,800.00	21,75,800.00	21,75,800.00
Internal Sand Plaster	2651.15	2651.15	2651.15	3119.00	3119.00	3119.00
Per m^2	800.00	800.00	800.00	800.00	800.00	800.00
Cost of Internal Plaster	21,20,920.00	21,20,920.00	21,20,920.00	24,95,200.00	24,95,200.00	24,95,200.00
Internal Gypsum Plaster	2651.15	2651.15	2651.15	3119.00	3119.00	3119.00
Per m^2	300.00	300.00	300.00	300.00	300.00	300.00
Cost of Gypsum Plaster	7,95,345.00	7,95,345.00	7,95,345.00	9,35,700.00	9,35,700.00	9,35,700.00
Total Cost	1,02,65,876	1,01,52,195	1,02,23,735	1,40,56,239	1,39,20,902	1,40,06,071

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Annexure 8 – 4C : Cost Estimation for Alternatives 2-A & 2-B

	Alternative 2-A Fire Clay Brick			Alternative 2-B AAC Block		
M30 Grade concrete, m³	**OPC MIX**	**PPC MIX**	**PSC MIX**	**OPC MIX**	**PPC MIX**	**PSC MIX**
Total concrete quantity, m³	443.00	443.00	443.00	439.48	439.48	439.48
Per m³	5,859.00	5,511.00	5,730.00	5,859.00	5,511.00	5,730.00
Cost of Concrete	25,95,537.00	24,41,373.00	25,38,390.00	25,74,913.32	24,21,974.28	25,18,220.40
Reinforcement quantity (tonne)	39.06	39.06	39.06	36.39	36.39	36.39
Per tonne	70,000.00	70,000.00	70,000.00	70,000.00	70,000.00	70,000.00
Cost of Reinforcement	27,34,200.00	27,34,200.00	27,34,200.00	25,47,300.00	25,47,300.00	25,47,300.00
Formwork (m²)						
12 mm Plywood	396.62	396.62	396.62	383.06	383.06	383.06
Per m³	1,614.00	1,614.00	1,614.00	1,614.00	1,614.00	1,614.00
Cost of Plywood	6,40,144.68	6,40,144.68	6,40,144.68	6,18,258.84	6,18,258.84	6,18,258.84
Timber	5.47	5.47	5.47	5.34	5.34	5.34
Per m³	70,000.00	70,000.00	70,000.00	70,000.00	70,000.00	70,000.00
Cost of Timber	3,82,900.00	3,82,900.00	3,82,900.00	3,73,800.00	3,73,800.00	3,73,800.00
Walling (m³)						
150/80 mm thick	153.15	153.15	153.15	153.15	153.15	153.15
Per m³	7,928.00	7,928.00	7,928.00	7,000.00	7,000.00	7,000.00
Cost of Walling	12,14,173.20	12,14,173.20	12,14,173.20	10,72,050.00	10,72,050.00	10,72,050.00
Plaster						
External Sand Plaster	1,978.00	1,978.00	1,978.00	1,978.00	1,978.00	1,978.00
Per m²	1,100.00	1,100.00	1,100.00	1,100.00	1,100.00	1,100.00
Cost of External Plaster	21,75,800.00	21,75,800.00	21,75,800.00	21,75,800.00	21,75,800.00	21,75,800.00
Internal Sand Plaster	3,119.00	3,119.00	3,119.00	3,119.00	3,119.00	3,119.00
Per m²	800.00	800.00	800.00	800.00	800.00	800.00
Cost of Internal Plaster	24,95,200.00	24,95,200.00	24,95,200.00	24,95,200.00	24,95,200.00	24,95,200.00
Internal Gypsum Plaster	3,119.00	3,119.00	3,119.00	3,119.00	3,119.00	3,119.00
Per m²	300.00	300.00	300.00	300.00	300.00	300.00
Cost of Gypsum Plaster	9,35,700.00	9,35,700.00	9,35,700.00	9,35,700.00	9,35,700.00	9,35,700.00
Total Cost	1,31,73,655	1,30,19,491	1,31,16,508	1,27,93,022	1,26,40,083	1,27,36,329

Annexure 8 – 4C : Cost Estimation for Alternatives 2-C & 2-D

	Alternative 2-C EPS Panel			Alternative 2-D Fly Ash Brick		
M30 Grade concrete, m^3	OPC MIX	PPC MIX	PSC MIX	OPC MIX	PPC MIX	PSC MIX
Total concrete quantity, m^3	381.13	381.13	381.13	442.36	442.36	442.36
Per m^3	5,859.00	5,511.00	5,730.00	5,859.00	5,511.00	5,730.00
Cost of Concrete	22,33,040.67	21,00,407.43	21,83,874.90	25,91,787.24	24,37,845.96	25,34,722.80
Reinforcement quantity (tonne)	29.88	29.88	29.88	38.35	38.35	38.35
Per tonne	70,000.00	70,000.00	70,000.00	70,000.00	70,000.00	70,000.00
Cost of Reinforcement	20,91,600.00	20,91,600.00	20,91,600.00	26,84,500.00	26,84,500.00	26,84,500.00
Formwork (m^2)						
12 mm Plywood	437.57	437.57	437.57	376.78	376.78	376.78
Per m^3	1,614.00	1,614.00	1,614.00	1,614.00	1,614.00	1,614.00
Cost of Plywood	7,06,237.98	7,06,237.98	7,06,237.98	6,08,122.92	6,08,122.92	6,08,122.92
Timber	5.88	5.88	5.88	5.47	5.47	5.47
Per m^3	70,000.00	70,000.00	70,000.00	70,000.00	70,000.00	70,000.00
Cost of Timber	4,11,600.00	4,11,600.00	4,11,600.00	3,82,900.00	3,82,900.00	3,82,900.00
Walling (m^3)						
150/80 mm thick	94.72	94.72	94.72	153.15	153.15	153.15
Per m^3	827.00	827.00	827.00	7,500.00	7,500.00	7,500.00
Cost of Walling	78,336.75	78,336.75	78,336.75	11,48,625.00	11,48,625.00	11,48,625.00
Plaster						
External Sand Plaster	1,506.69	1,506.69	1,506.69	1,978.00	1,978.00	1,978.00
Per m^2	1,100.00	1,100.00	1,100.00	1,100.00	1,100.00	1,100.00
Cost of External Plaster	16,57,359.00	16,57,359.00	16,57,359.00	21,75,800.00	21,75,800.00	21,75,800.00
Internal Sand Plaster	2,651.15	2,651.15	2,651.15	3,119.00	3,119.00	3,119.00
Per m^2	800.00	800.00	800.00	800.00	800.00	800.00
Cost of Internal Plaster	21,20,920.00	21,20,920.00	21,20,920.00	24,95,200.00	24,95,200.00	24,95,200.00
Internal Gypsum Plaster	2,651.15	2,651.15	2,651.15	3,119.00	3,119.00	3,119.00
Per m^2	300.00	300.00	300.00	300.00	300.00	300.00
Cost of Gypsum Plaster	7,95,345.00	7,95,345.00	7,95,345.00	9,35,700.00	9,35,700.00	9,35,700.00
Total Cost	1,00,94,439	99,61,806	1,00,45,274	1,30,22,635	1,28,68,694	1,29,65,571

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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Aditya Birla UltraTech
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India Cements (The India Cements Limited, A subsidiary of UltraTech Cement Limited)
JSW Cement
JKcement
JK Lakshmi Cement Ltd.
Kamal Cement
MP Birla Group
Maha Cement
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Orient Cement
The Ramco Cements Limited
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