CPWD

Reducing Carbon Footprint in Buildings

राजेश कुमार कौशल
महानिदेशक

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MESSAGE

The construction and building sector in India stand at a critical juncture in its evolution. As the nation strides forward in its development journey, the imperative to address carbon emissions within this sector has become increasingly urgent.

The book 'Reducing Carbon Footprint in Buildings 2024' marks a pivotal contribution to the discourse on reducing carbon emissions in India's construction sector. It delves deep into the complexities and challenges of transitioning towards sustainable building practices, offering a comprehensive analysis of strategies, technologies, and policies that can catalyse meaningful change.

Through the compelling case studies of 40 projects / buildings, ranging from 11,840 sq. mtr. to 1,80,000 sq. mtr., it is established that average CO2 embedding is approximately one ton per sq. mtr built-up area. Further, a case study of 65 buildings reveals that average CO2 embedding during 50 years of operation and maintenance is almost six times the construction phase. This highlights the importance of sustainable practices not only in construction, but also in the ongoing maintenance of buildings.

This book not only highlights the pressing need for action but also provides actionable pathways for stakeholders to reduce their carbon footprint effectively. It underscores the transformative potential of collaboration and innovation in achieving ambitious sustainability goals, paving the way for a more resilient and environmentally conscious built environment.

As we navigate the complexities of climate change and sustainable development, this book serves as a catalyst for informed decision-making and transformative action. It empowers readers with the knowledge, tools, and inspiration to drive positive change in reducing carbon emissions across India's construction and building sector.

Let us embark on this journey towards a future where sustainable construction practices not only mitigate environmental impact but also foster inclusive growth and resilience for generations to come.

I would like to extend my heartfelt congratulations to Sh. Ujjwal Mitra, ADG (Training & Research), Sh. Naimuddin, ADG (Tech), and Sh. Devendra Kumar Sachan, Director (Tech & PR), along with their dedicated team, for successfully bringing out this book on such short notice.

New Delhi
July, 2024

Rajesh Kumar Kaushal

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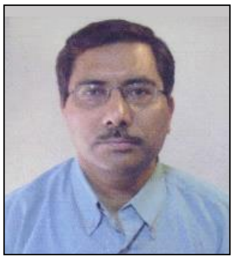

FOREWORD

CPWD has served as a torchbearer in adopting green building guidelines and implementing energy efficiency measures in the construction and maintenance of public infrastructure. India has set the following ambitious goals for reducing carbon emissions as part of its climate action commitment to:

1. Reduce the total projected carbon emissions by 1 billion metric tons by 2030.
2. Achieve 500 GW Non-Fossil based electricity generation capacity by 2030.
3. Achieve the target of net zero by 2070.

Reducing carbon emissions is vital for safeguarding the planet's ecosystems, protecting human health, enhancing energy security, and promoting global cooperation in addressing climate change. Assessing carbon emissions from the construction sector is essential for mitigating climate change, making policy decisions, meeting sustainability goals, and fostering innovation in building practices and technologies. Hence, the analysis presented in this report is a critical step towards achieving a low-carbon future in the built environment.

For the first time, a sincere effort has been made in this regard to derive the carbon factor of building construction. As of today, the available facts & figures available on the internet are not accurate. Thus, special efforts were made to search & collect authentic data. The whole exercise of analysing this data shows that there is massive potential to reduce the carbon emissions, much beyond the national commitments made by India. This report is the result of a process which has evolved continuously over the past few months. By integrating the recommendations suggested in this book, into its operations & projects, CPWD has the potential to make a significant contribution towards reducing carbon emissions in construction sector, thereby advancing national climate goals & promoting sustainable development.

I would like to acknowledge DG, CPWD Sh. Rajesh Kumar Kaushal, for his guidance, Sh. Naimuddin, ADG (Tech) for his continuous and persuasive motivation, and members of the committee: Sh. R.R. Meena, CE (CSQ)(E), Sh. Prem Mohan, CE (CSQ)(C), Sh. D.K. Ujjania, SE (TAS)(C), Sh. R.P. Gupta, SE (TAS)(E&M), Sh. Devendra Kumar Sachan, Director (Tech & PR) for his huge contribution in collecting pan-India data with his personal persuasion & Sh. Pradeep Kumar, SE (Kolkata) for valuable inputs on one of the projects. Also, I must acknowledge the dedicated efforts of Sh. Vivek Bansal, CE (NCA), Sh. R P Singh, SE (NCA), Ms. Ashu Chaudhary, Sh. Kartikay Kaushik, AEE (Civil), Sh. K.K. Mishra, AE (NCA), Sh. Kamal Passi, Asstt. Architect and Sh. Bruj Bhanu, Asstt. Architect, all of whom have provided their valuable inputs in preparing this report.

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Place: New Delhi
Dated: 09.07.2024

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Introduction

Reducing CO_2 Emissions by One Billion Tonnes

Global warming is now the most evident and undisputed concern by its effect on climate change and changes seen in ecological balance and environment. Extensive research has been done on Global warming, its causes, its effects as climate changes and is being continuously carried out by hundreds of dedicated institutes, scientists, researchers internationally and in our country.

The energy received from the Sun annually is approximately **8000** times of the current energy being used in any form, globally. Under steady state conditions, this heat energy coming from the sun in radiation form, is radiated back into the outer atmosphere and the average steady state temperature of earth remains approximately 15^{o}C. Here, it is pertinent to mention that some of the Greenhouse Gases (GHGs) have been present in our atmosphere and stratosphere for millions of years. Major GHGs are CO_2, CH_4, and N_2O. These GHGs play an instrumental role in maintaining a habitable temperature for biological entities and human beings to survive on the surface of earth as the average temperature of Earth would have dropped to -15 degrees in its absence.

The GHGs are signified by their Global Warming Potential (GWP) which is a measure of the quantum of solar radiations being trapped by a particular GHG. Thus, GWP of a GHG is directly related to its potency to increase the temperature of Earth. For example the GWP of CO_2 is assumed as 1 whereas for other gases it may vary from 1 to 350 per unit weight / volume of the gas. GHGs such as CH_4 and N_2O have many times of GWP as compared to CO_2. This means that they have a much stronger capability of trapping the radiated heat and preventing it from escaping to outer space, thereby, causing the atmospheric temperature to rise. Additionally, all GHGs have different retention periods in earth's atmosphere after emission during which they actively cause the greenhouse effect. To bring all these GHGs (with different GWPs & retention periods) on a common platform, they are expressed as CO_2-equivalent (CO_2e) by converting amounts of other gases to the equivalent amount of CO_2 with the same global warming effect. This conversion factor accounts for both the potential to restrict reflected solar radiations as well as the retention period in atmosphere and stratosphere. The total tonnage of carbon footprint is therefore expressed in terms of CO_2e of GHG.

Due to several developmental activities being undertaken by various countries across the globe, huge amounts of GHGs are being emitted. Various COPs (Conference of Parties) held under UNFCCC (United Nations Framework Convention on Climate

Change) and Assessment Reports of Intergovernmental Panel on Climate Change (IPCC) have concluded that the GHG emission in CO_2-e terms, has to be limited to such an extent that from 1901 to 2101, i.e. during these 200 years, the net rise in temperature should not exceed 2°C. The result of a 2°C rise in the average temperature of earth has been methodically calculated by various organizations working on climate change. By 2024, it has been estimated that the temperature would increase by 1.2°C from the reference level of 1901. The detailed supporting data for total CO_2e emission per annum by various countries for the last several decades is available. The present and cumulative GHG emission in terms of CO_2e is given in Annexure 1.

The current CO_2e globally is 56 billion Tonnes, in which 38 BT is contributed from CO_2. In India, CO_2e emission is 3.8 BT and the corresponding CO_2 emission is 2.8 BT (as of the year 2022). These emission values have a natural growth rate in absolute terms which is directly linked to economic growth. Our Goal is to reduce CO_2e emission by 1 BT by 2030.

A Committee for the following topic was constituted vide letter No. 26(2) CE CSQ(E)/BEE/E-9150712/2024/92/Hindi dated 07.02.2024:

"To provide inputs for 1 billion tonnes of CO_2 emission reduction."

This was done with reference to the fourth meeting of Inter-Ministerial Committee held on 8th June 2022 regarding the implementation of the road map on energy efficiency and one billion tonne of CO_2 emission reduction by 2030 with due focus on sectors with high emission intensity vide OM No. 8/8/2022-EC-Part II dated 30.01.2024. The Minutes of Meeting of 08.06.2022 were circulated by the Office of Director, Ministry of Power, with targets for various Ministries. Shri Abhay Bapre, Director General, Bureau of Energy Efficiency (BEE) coordinated the meeting under the Chairmanship of Secretary, Ministry of Power, in which it was emphasized that the Ministries may map the respective proposed programmes/activities with their respective agencies to achieve the required emission reduction and subsequent CO_2 emission reduction by 2030. Representatives from National Institution for Transforming India (NITI) Aayog, Adviser (Energy) mentioned that NITI Aayog is in agreement with the macro assumptions for achieving targets announced at the UN Climate Change Conference in Glasgow (COP26).

Regarding emission reduction targets in the steel sector, the Additional Industrial Adviser, Ministry of Steel, mentioned that hydrogen-based technologies will be available only after 2026 and that its full impact may not be visible till 2030. He requested BEE to share the basis of emission reduction targets of 144 MT CO_2 assigned to the steel sector. Representative from MNRE, Senior Director, invited attention towards the impact of the green hydrogen mission and the mandates for use of green hydrogen in industry sectors such as steel. Regarding the discussion on achieving emission reduction targets in the building sector, representative from Ministry of Housing and Urban Affairs, Ms. D. Thara, Additional Secretary, mentioned that MoHUA will issue advisory to States for adoption of Energy Conservation Building Code (ECBC) in their respective bye-laws. Other Ministries like Chemical and Petrochemicals, Road Transport and Highways, Railways, Ministry of Shipping and Waterways, Ministry of Petroleum and Natural Gas, Ministry of Mines (especially for aluminum sector), Micro Small and Medium Enterprises (MSME), Ministry of Environment , Forest and Climate Change, Ministry of New and Renewable Energy, and Department of Heavy Industry were also present and suggested methods and programmes.

Indicative activities to be undertaken by various Ministries/Departments related to MoHUA are as follows:

1. **Ministry of Housing and Urban Affairs:**

   Direct States/ULBs to adopt ECBC in building byelaws, Municipality to promote use of energy efficient pumps and street lights, Central Public Works Department (CPWD) to aggressively take up electric cooking in office canteens.

2. **Ministry of Steel:**

   As per National Steel Policy (NSP) 2017, the Ministry of Steel has the target to reduce CO_2 emission intensity from 3.1T CO_2 per ton of steel to 2.4T CO_2 per ton of steel by 2030 from 2005 level.

3. **Ministry of New and Renewable Energy:**

   Support in uptake of solar thermal technologies in industries.

4. **CMD National Thermal Power Corporation (NTPC)** mentioned that the use of fly ash as an option for reducing carbon emissions must be included in this framework for achieving COP26 targets.

The main action-point related to MoHUA as directed by the Chair is as follows: the basis for estimated high penetration of ECBC in the commercial building sector to be mentioned in the draft note of Committee of Secretaries.

To start the whole process, the calculation for the carbon footprint per sq. mtr. of building construction is based on actual data from project sites, which has been gathered from pan-india projects, being executed by CPWD. To obtain this data, field units were requested to furnish several details related to the projects being executed by them vide OM No. 26(2) CE CSQ(E)/BEE/E-9150712/2024/91/Hindi (Annexure B) dated 07.02.2024. Based on the raw data collected, certain calculations have been done to arrive at a figure of carbon footprint of construction of residential and non-residential sectors in tonnes of CO_2 per sq. mtr.. Based on the analysis and various calculations, some important conclusions have been drawn to reduce the carbon footprints on part of the construction sector.

Simultaneously, data on **Energy Performance Index (EPI)** i.e. annual KWh (unit) per sq. mtr. of buildings, was also collected from pan-india projects being maintained by CPWD. Study of collection data revealed following facts:

1) The CO_2 embedding of 40 buildings (for an area ranging from 11,840 sq. mtr. to 1,80,000 sq. mtr.) totaling to 15,43,812 sq. mtr., the gross average of CO_2 footprint is approximately 0.99 ton per sq. mtr. of CO_2. Individually, this figure of CO_2 embedding per sq. mtr. varies from 0.49 to 1.65. Few buildings have this figure of CO_2 embedding per sq. mtr. as very high which may be an aberration in data collected. It is observed that in all the above 40 buildings, 85-90% contribution of CO_2 emission comes from cement, steel, and masonry items, bifurcated below:

   a) CO_2 emission on account of cement ≈ 30%
   b) CO_2 emission on account of steel ≈ 48%
   c) CO_2 emission on account of masonry ≈ 11%

2) From EPI data, it has been found that the EPI of a building on an average is 168 units. Considering the operational life of a particular building as fifty years, the total consumption during fifty years per sq. mtr. comes out to be 8400 units. Assuming 0.71 (kg CO_2 per unit of power) as the gross average on the Indian electric energy presently, the CO_2 emission due to operational Electrical energy usage is 5.96 tonnes per sq. mtr. Compared to the gross average of approximately 0.99 ton per sq. mtr. of CO_2 (discussed in previous point) this stands out to be 5.96/0.99 = 6 times. Therefore, it can be concluded that the operational energy usage of 50 years has almost six times CO_2 emissions when compared to the embedded CO_2 emissions during construction.

3) From the above, it can be concluded that the importance of carbon footprint for energy usage i.e. EPI during the lifecycle is certainly very high compared to CO_2 embedding during original construction. Hence, there is a high necessity of bringing improvements. In this light, a 2-step approach has been proposed .

The first approach to reducing the carbon footprint during construction focuses on minimizing carbon emissions, which account for 14% (1/7) of the total lifecycle carbon footprint. To achieve this, it is essential to use materials like steel and cement that are less CO_2-intensive. Details on these materials are provided in the subsequent chapters.

Key strategies include:

1. **Procurement Adjustments**: Implement changes in procurement methods with specific criteria, such as the amount of CO_2 per ton of steel and CO_2 per ton of cement.
2. **Autoclaved Aerated Concrete (AAC) Blocks**: Increase the use of AAC blocks instead of burnt clay bricks due to their numerous advantages:

   The weight of the building comes down drastically, having cascading impact on the design parameters and quantum usage of the steel, cement in the building, the impact of which is extremely high in reducing CO_2 emission per sqm.

- The R-value of AAC is far better as compared to burnt clay bricks which further reduces heat gain of the building thereby reducing the air conditioning load which is the primary component of total EPI which as above has been explained as the primary weightage of 85.7% (6/7) of the total life cycle CO_2 emission.
- The absolute value of carbon embedding / footprint of AAC (volumetric) is far less compared to burnt clay.

The second approach focuses on reducing the CO_2 footprint during the operational phase, which accounts for 86% (6/7) of the total lifecycle carbon footprint. The primary goal is to reduce the air conditioning load through demand-side management. This can be achieved by:

1. **Using Highly Energy-Efficient Equipment**: Ensure that air conditioning machines are highly energy-efficient to minimize energy consumption.
2. **Reducing Building Heat Gain**: Drastically increase the R-value of walls and roofs to improve insulation and reduce heat gain.

The most significant factor contributing to heat gain is the Solar Heat Gain Coefficient (SHGC) of glass, which has a greater impact compared to heat gain from roofs and walls.

These points have been covered in detail in respective chapters. This write-up has been prepared in 3 chapters and 12 annexure which are as follows:

1. Chapter 1 examines the carbon footprint of the Indian Construction industry, carbon life cycle of a building and carbon footprint of transportation.
2. Chapter 2 elaborates on CO_2 emission relating to one-time construction (part A) and electrical energy consumption during lifetime (part B). It also provides details on embodied carbon in major components such as Steel, cement and Masonry (burnt clay to AAC).

3. Chapter 3 provides recommendations for Reducing CO_2 emission both during the initial construction stage and lifetime CO_2 emissions.

The chapters are followed by twelve detailed annexures which provide a comprehensive overview of the key aspects of reducing CO_2 emissions, beginning with an analysis of global and cumulative emissions and a sector-wise breakdown of greenhouse gas contributions. Major greenhouse gases and their global warming potentials, along with the life-cycle emissions of various electrical energy sources and their respective global warming potentials have been examined. Insights from the IPCC 6th Assessment Report 2022 are incorporated, alongside critical facts, figures, and expert commentary. The annexures also delves into the embedded carbon and embodied energy of construction materials, the R-Factor of insulating and other construction materials, and compares the carbon impact of different energy sources for present and future scenarios. Lastly, they contrast the conventional building standards with energy-efficient codes like ECBC, ECBC Plus, and ECBC Super, highlighting their potential in mitigating carbon emissions.

Chapter 1

Carbon Footprint of Buildings

CARBON ACCOUNTING

Carbon accounting (or GHG accounting) refers to the process of measuring the total amount of GHGs emitted from an activity, project, industry, or organization i.e. their carbon footprint. Carbon footprints are reported as Global Warming Potential (GWP) and are measured relative to the impact of one molecule of CO_2, usually over a 100-year time-frame. For example, 1 Kg of methane is equivalent to approximately 28 kgs of CO_2.

A need for carbon accounting exists for several reasons. With ambitious targets set by the industry to become carbon Net Zero, the requirement to track carbon at all stages of the supply chain is vital. For example: India has promised to achieve net zero emissions by 2070. Calculating carbon footprint will allow meaningful comparisons to be made between structural schemes, building materials and MEP services. This can help CPWD officers to understand the climate risk associated with each item, thereby facilitating selection of environment friendly items while preparing detailed estimates.

In the Indian construction industry, about 39% of the carbon footprint is generated by construction of buildings and their operations together due to processes like lighting, cooling, and heating (figure 1). As per today's scenario, there is not even 1% of the total buildings that can help in achieving net zero emissions. This fact highlights the need of carbon accounting in construction projects.

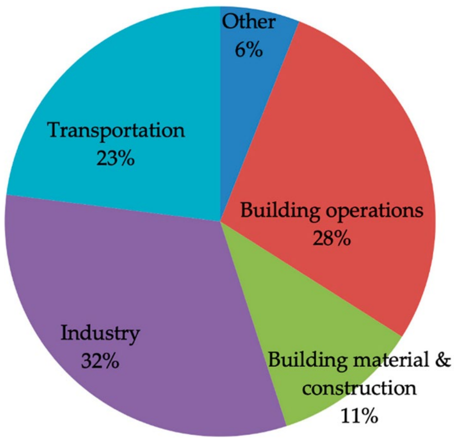


Figure 2. Carbon life cycle of a building.

ESTIMATING CARBON FOOTPRINT: A LIFE CYCLE APPROACH

The carbon life cycle of a building consists of different stages of a building's life over which the emission of carbon occurs. Embodied carbon, operational carbon, and End of Life (EOL) carbon make up the whole carbon life cycle of a building, as demonstrated by Figure 2.

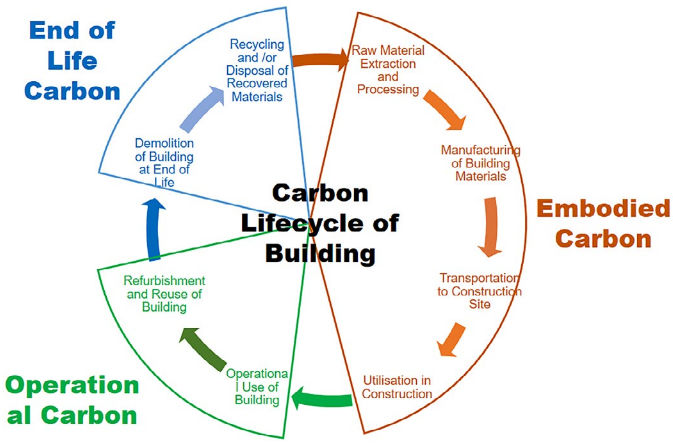
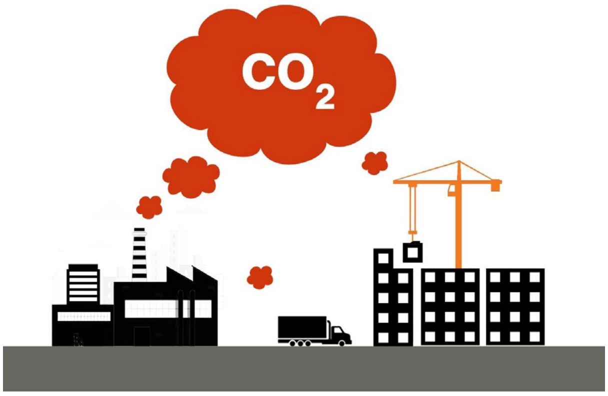


Figure 2. Carbon life cycle of a building.

For calculating the carbon footprint of a building or a project, a cradle-to-grave approach has to be adopted. This means that all activities from the origin i.e., the extraction of raw materials, to the end i.e., the demolition of the building and disposal of Construction and demolition (C&D) waste, needs to be considered.

EMBODIED CARBON

Embodied carbon includes GHGs produced during the extraction, transportation, and fabrication of building materials, as well as the transportation of those items to the project site and the construction methods utilized. Simply put, embedded carbon refers to a building's or infrastructure project's carbon footprint before its completion. The following activities are considered while estimating the embodied carbon of a building or project: extraction of raw materials, transportation to manufacturing facility, manufacturing of building material, transportation of building material to project site, and execution of the project. The fundamental principle of an embodied carbon calculation is to multiply the quantity of each material by a carbon factor for the life cycle modules being considered:



Embodied Carbon
Manufacture, Transport and Installation of Construction Materials

Embodied carbon (kg CO_2e) = Material quantity (kg) × Carbon factor (kg CO_2e/kg)

Material quantities can be calculated in a number of different ways, depending on the stage of design and the tools available, including: Manual calculations, BIM models, structural analysis models, and previous project experiences.

CARBON FACTOR CONCEPT

The carbon factor is expressed in a kilogram of CO_2 equivalent per kg of material. The embodied carbon is calculated by piecing together existing evidence on CO_2 emitted across the broad areas of a building's life cycle. For estimating CO_2 emissions, the carbon factors have been derived from the following sources:

- International Environmental Product Declarations (EPD) system library: The EPD presents transparent, verified and comparable information about the life-cycle environmental impact of products and services.
- India construction materials database: prepared by International Finance corporation, a World Bank group, for their green rating system called EDGE.

CALCULATING CARBON FOOTPRINT OF TRANSPORTATION

Transportation during the construction process involves transport of materials or products from the factory gate to the construction site, and the transport of construction equipment (cranes, scaffolding, etc.) to and from the site. The carbon emission due to transportation of each material to site can be estimated as:

Transportation emission (kg CO_2e) = Σ ($TD_{mode} \times TEF_{mode}$)

Where, for a particular mode of transport:

TD_{mode} = transport distance for each transport mode considered (km).

TEF_{mode} = transport emission factor for each transport mode considered (kg CO_2e/km).

The calculated transport emission factor for each mode of transport (road, air, and rail) have been provided in Table 1. For road transport, this has been categorized by light, medium, and heavy duty vehicles.

Mode	Category	TEF (kg CO_2e/km)
Road Transport	LDV (<3.5T)	0.3070
	MDV (<12T)	0.5928
	HDV (>12T)	0.7375
Air Transport	Freight flight	1.58 per Ton
Rail Transport	Freight train	0.00996 per Ton

Table 1. transport emission factor for each transport mode

OPERATIONAL CARBON

Operational carbon is the carbon emitted only while the building is being used — which includes the energy needed for lighting, ventilation, temperature regulation, and electricity. The following activities are considered while estimating the operational carbon of a building or project: operational energy use, operational water use, building maintenance and repair, and solid waste generated by building users.

Operational Carbon
Building Energy Consumption

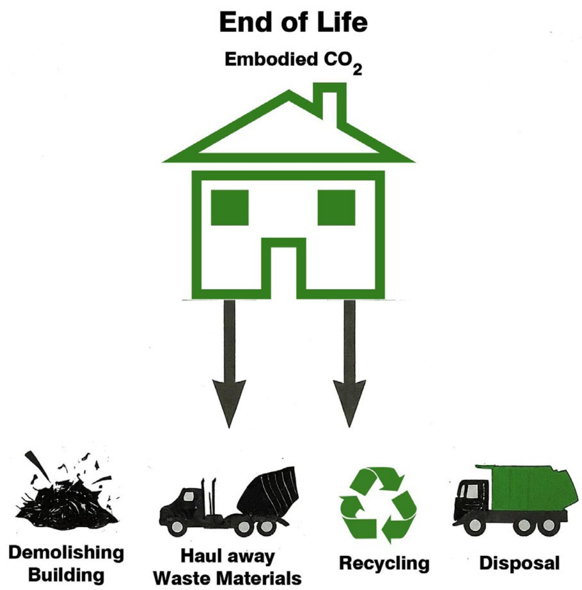
Since there is no data available for the carbon emissions due to maintenance, repair of buildings, water use and solid waste generated by users, we can calculate operational carbon as the sum of carbon emissions due to energy used over the life of building.

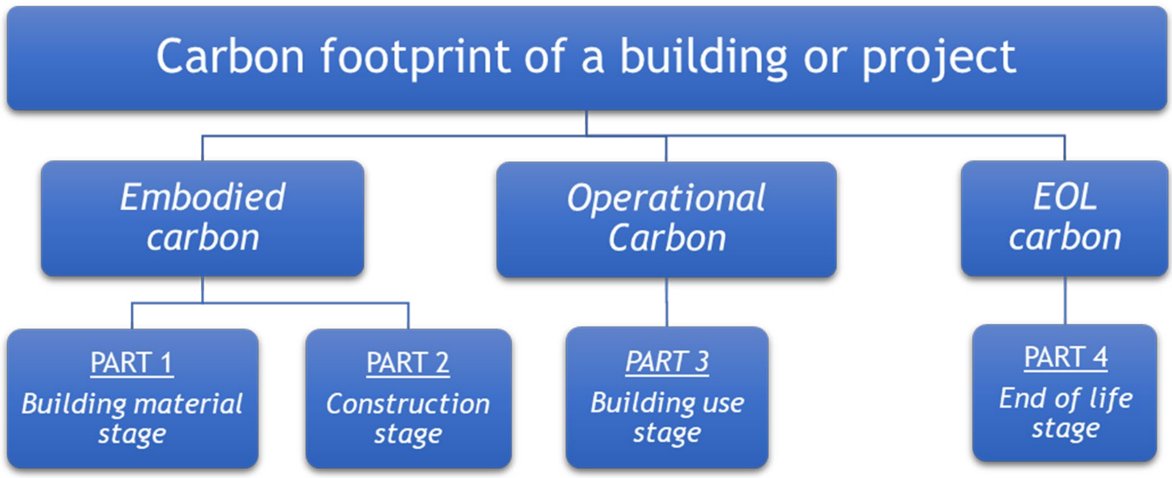
As per Central Electricity Authority (CEA), the emissions per unit of electricity are estimated to be 0.71 kg/kWh for CO_2 (including renewable energy sources). This can be used to calculate operational carbon emission due to electricity use (kg CO_2e) as:

EPI(kWh/m²/year) × Building life(years) × Build-up area(m²) × 0.71(kg CO_2e/kWh)

END OF LIFE (EOL) CARBON

EOL carbon is the carbon emitted after the building has served its design life. It includes emissions during the demolition or deconstruction of the building. Further, it also considers the carbon emissions due to transportation of C&D waste along with its treatment & disposal by C&D plants. The following activities are considered while estimating the EOL carbon of a building or project: demolition or deconstruction, transportation of C&D waste, waste processing, and waste disposal.





Vide Annexure-12 & 13, raw data, used for calculating embodied CO_2 and EPI, has been provided. This data was obtained from various CPWD projects recently executed across India.

Carbon Factor data used for calculating the Embodied CO_2

DATA ON CARBON FACTORS					
S. No.	MATERIAL	CARBON FACTOR (in kg CO_2e/kg)	CARBON FACTOR (in kg CO_2e/CUM)	BULK DENSITY (in kg/CUM)	REMARKS
1	Portland Pozzolana Cement (PPC)	0.760	1094	1,440	30% fly ash content; EPD of Ambuja
2	Steel Rebars	3.450	27083	7,850	EPD by Jindal Steel
3	Burnt Clay bricks	0.320	563	1,760	Bull's Trench kiln; Size: 230x110x70
4	AAC blocks	0.500	275	550	Size: 600x200x100
5	Glass	1.290	3225	2,500	6mm float glass
6	Vitrified ceramic floor tile	0.680	1496	2,200	11 mm thickness
7	Stone floor tile	0.056	146	2,600	Kota stone; 20 mm thickness
8	Aluminium window frame	26.000	70460	2,710	
9	Copper sheet	7.400	66304	8,960	
10	Sand	0.009	14.85	1,650	River sand
11	Aggregate	0.009	13.95	1,550	Crushed stone aggregate
12	Steel	2.100	16485	7,850	Calculated using weighted average of 3 steel making techniques: (a) BOF, (b) DRI, (c) EAF
13	Bitumen	1.370	1397	1,020	Cutback bitumen (i/c operational carbon)
14	Diesel	2.680	2680	850	Carbon factor in kg per liter; includes CO_2 emission due to combustion only

DATA ON TRANSPORT EMISSION FACTORS			
MODE	CATEGORY	UNIT	TRANSPORT EMISSION FACTOR (TEF)
Road transport	LDV (<3.5T)	kg CO_2e/km	0.30700
	MDV (<12T)	kg CO_2e/km	0.59280
	HDV (>12T)	kg CO_2e/km	0.73750
Air transport	Freight flight	kg CO_2e/ton	1.58000
Rail transport	Freight train	kg CO_2e/ton	0.00996

Some examples demonstrating analysis of data & calculations for Embodied CO_2

P5 (Non-residential building: College)

Name of work: Construction of New Academic Complex – II at IIT Madras, Chennai-36.					
S. No.	**MATERIAL**	**UNIT**	**QUANTITY**	**CO_2e EMISSION (in kg CO_2e)**	**% of total embodied carbon (III)**
1	Portland Pozzolana Cement (PPC)	MT	10,340	7,858,400	28.81
2	Steel	MT	3,940	13,592,310	49.82
3	Burnt Clay bricks masonary	CUM	7,998	3,792,919	13.90
4	AAC blocks masonary	CUM	0	0	0.00
5	Glass	CUM	25	80,249	0.29
6	Vitrified ceramic floor tile	CUM	285	425,634	1.56
7	Stone floor tile	CUM	312	45,362	0.17
8	Aluminium window frame	MT	32	819,0000	3.00
9	Bitumen	MT	46	63,623	0.23
10	Diesel	KL	45	120,600	0.44
11	Sand	CUM	21,931	325,676	1.19
12	Aggregates	CUM	2,085	29,083	0.11
(I) TOTAL OF CIVIL COMPONENT =				**27,152,856**	**99.53**
1	Weight of Civil & Electrical component	MT	69,350	127,864	0.47
(II) TOTAL OF TRANSPORTATION COMPONENT =				**127,864**	**0.47**
(III) aTOTAL EMBODIED CARBON (I + II) =				**27,280,719**	

Plinth area = 30,896 sq. mtr.

Carbon emission per unit area = 0.88 tonne per sq. mtr.

P11 (Residential & Non-residential building: College)

Name of work: C/o Academic and Residential Complexes under Phase-II for campus of IIT Patna					
S. No.	**MATERIAL**	**UNIT**	**QUANTITY**	**CO_2e EMISSION (in kg CO_2e)**	**% of total embodied carbon (III)**
1	Portland Pozzolana Cement (PPC)	MT	36,625	27,835,000	23.01
2	Steel	MT	12,500	43,125,000	35.66
3	Burnt Clay bricks masonary	CUM	26,689	12,656,991	10.47
4	AAC blocks masonary	CUM	0	0	0.00
5	Glass	CUM	816	2,631,600	2.18
6	Vitrified ceramic floor tile	CUM	383	572,968	0.47
7	Stone floor tile	CUM	1,080	157,248	0.13
8	Aluminium window frame	MT	818	21,268,000	17.59
9	Bitumen	MT	72	98,640	0.08
10	Diesel	KL	159	426,120	0.35
11	Sand	CUM	607,888	9,027,137	7.46
12	Aggregates	CUM	65,824	918,245	0.76
(I) TOTAL OF CIVIL COMPONENT =				118,716,949	98.16
1	Weight of Civil & Electrical component	MT	1,207,721	2,226,735	1.84
(II) TOTAL OF TRANSPORTATION COMPONENT =				**2,226,735**	**1.84**
(III) TOTAL EMBODIED CARBON (I + II + III) =				**120,943,684**	

Plinth area = 92,000 sq. mtr.

Carbon emission per unit area = 1.31 tonne per sq. mtr.

P21 (Non-residential building: College)

Name of work: Construction of New Administrative Building (S+8) at AIIMS, Bhubaneswar					
S. No.	**MATERIAL**	**UNIT**	**QUANTITY**	**CO_2e EMISSION (in kg CO_2e)**	**% of total embodied carbon (III)**
1	Portland Pozzolana Cement (PPC)	MT	9,000	6,840,000	24.49
2	Steel	MT	4,350	15,007,500	53.72
3	Burnt Clay bricks masonary	CUM	6,000	2,845,440	10.19
4	AAC blocks masonary	CUM	1,800	457,380	1.64
5	Glass	CUM	24	77,400	0.28
6	Vitrified ceramic floor tile	CUM	297	444,312	1.59
7	Stone floor tile	CUM	120	17,472	0.06
8	Aluminium window frame	MT	60	1,560,000	5.58
9	Bitumen	MT	0	0	0.00
10	Diesel	KL	15	40,200	0.14
11	Sand	CUM	16,500	245,025	0.88
12	Aggregates	CUM	18,000	251,100	0.90
(I) TOTAL OF CIVIL COMPONENT =				**27,785,829**	**99.46**
1	Weight of Civil & Electrical component	MT	81,110	149,547	0.54
(II) TOTAL OF TRANSPORTATION COMPONENT =				**149,547**	**0.54**
(III) TOTAL EMBODIED CARBON (I + II + III) =				**27,935,376**	

Plinth area = 26,898 sq. mtr.

Carbon emission per unit area = 1.04 tonne per sq. mtr.

P38 (Non-residential building: College)

S. No.	MATERIAL	UNIT	QUANTITY	CO_2e EMISSION (in kg CO_2e)	% of total embodied carbon (II)
Name of work: Construction of Permanent Campus of IIT Bhilai at Kuthelabhata, Durg Chattisgarh, Phase I stage I					
1	Portland Pozzolana Cement (PPC)	MT	60,000	45,600,000	33.12
2	Steel	MT	16,600	57,270,000	41.60
3	Burnt Clay bricks masonary	CUM	35,000	16,598,400	12.06
4	AAC blocks masonary	CUM	14,500	3,684,450	2.68
5	Glass	CUM	93	299,925	0.22
6	Vitrified ceramic floor tile	CUM	880	1,316,480	0.96
7	Stone floor tile	CUM	8	1,164	0.00
8	Aluminium window frame	MT	200	5,200,000	3.78
9	Bitumen	MT	220	301,400	0.22
10	Diesel	KL	940	2,519,200	1.83
11	Sand	CUM	138,000	2,049,300	1.49
12	Aggregates	CUM	127,500	1,778,625	1.29
(I) TOTAL OF CIVIL COMPONENT =				**136,618,945**	**99.23**
1	Weight of Civil & Electrical component	MT	574,109	1,058,514.02	0.77
(II) TOTAL OF TRANSPORTATION COMPONENT =				**1,058,514**	**0.77**
(III) TOTAL EMBODIED CARBON (I + II + III) =				**137,677,459**	

Plinth area = 1,65,000 sq. mtr.

Carbon emission per unit area = 0.83 tonne per sq. mtr.

Summary of analysis for Embodied CO_2
Table 1

GRAND SUMMARY OF CO_2 EMISSION PER UNIT AREA								
PROJECT	BUILT-UP AREA (in SQM)	CONSUMPTION OF MATERIAL (in kg per SQM)		TOTAL CO_2 EMISSION (in Tonnes)	% CONTRIBUTION OF MATERIAL IN EMBODIED CARBON			CO_2 EMISSION PER UNIT AREA (Tonnes per sqm)
		CEMENT	STEEL		CEMENT	STEEL	MASONRY	
P1	26,000	668	140	29,867	44.18	42.16	2.22	1.15
P2	14,200	580	97	13,080	47.88	36.32	3.43	0.92
P3	38,400	490	131	51,829	27.61	33.44	13.98	1.35
P4	138,600	334	125	184,053	19.11	32.48	33.31	1.33
P5	30,896	335	128	27,281	28.81	49.82	13.90	0.88
P6	23,620	216	79	12,446	31.14	51.59	10.01	0.53
P7	21,800	371	105	17,869	34.35	44.19	15.52	0.82
P8	12,844	24	184	10,385	2.21	78.53	9.56	0.81
P9	70,000	368	100	59,272	33.02	40.74	18.82	0.85
P10	36,000	353	101	37,066	26.07	33.86	17.68	1.03
P11	92,000	398	136	120,944	23.01	35.66	10.47	1.31
P12	23,600	346	104	20,452	30.34	41.55	11.27	0.87
P13	27,200	588	213	37,165	32.70	53.88	4.45	1.37
P14	27,708	314	72	16,774	39.42	41.13	11.31	0.61
P15	22,256	468	772	68,905	11.50	86.08	0.34	3.10
P16	20,000	220	75	33,064	30.34	46.95	16.03	1.65
P17	29,000	489	164	40,916	26.34	40.08	29.27	1.41
P18	31,800	502	226	45,382	26.76	54.71	13.23	1.43
P19	24,220	379	72	14,356	48.65	41.61	1.45	0.59
P20	16,800	339	85	13,352	32.40	36.88	18.44	0.79
P21	26,898	335	162	27,935	24.49	53.72	11.82	1.04
P22	26,550	269	87	16,816	32.31	47.21	11.41	0.63
P23	43,000	504	151	45,468	36.22	49.11	3.37	1.06
P24	28,860	540	137	30,341	39.07	45.10	6.47	1.05
P25	30,000	300	70	16,640	41.11	43.54	8.65	0.55
P26	69,000	319	78	54,755	30.54	34.02	28.12	0.79
P27	14,264	450	128	12,676	38.46	49.57	3.46	0.89
P28	15,000	525	154	17,429	34.31	45.73	11.70	1.16
P29	12,700	9	106	7,185	1.22	64.82	18.53	0.57
P30	11,840	313	127	10,128	27.84	51.32	7.34	0.86
P31	14,970	474	164	16,643	32.42	50.99	8.43	1.11
P32	13,840	258	115	11,355	23.93	48.52	8.03	0.82
P33	18,534	380	163	18,009	29.71	57.89	2.01	0.97
P34	21,298	199	82	10,330	31.21	58.46	4.72	0.49
P35	180,000	250	111	120,916	28.28	57.06	4.90	0.67
P36	50,000	319	143	48,669	24.91	50.77	11.38	0.97
P37	23,200	385	143	21,579	31.45	53.16	4.98	0.93
P38	165,000	364	101	137,677	33.12	41.60	14.73	0.83
P39	37,120	296	113	27,630	30.26	52.44	0.33	0.74
P40	14,794	394	149	15,460.55	28.65	49.18	9.12	1.05
GRAND TOTAL / GRAND AVERAGE	15,43,812	364	131	15,22,101	30	48	11	0.99

Table 2

PERCENTAGE CONTRIBUTION OF EACH MATERIAL TOWARDS CO_2 EMISSION (P1 to P11)												
S. No.	**MATERIALS**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**
1	Portland Pozzolana Cement (PPC)	44.18	47.88	27.61	19.11	28.81	31.14	34.35	2.21	33.02	26.07	23.01
2	Steel	42.16	36.32	33.44	32.48	49.82	51.59	44.19	78.53	40.74	33.86	35.66
3	Burnt Clay bricks masonary	2.22	3.42	13.55	5.52	13.90	0.48	15.52	9.56	13.12	17.68	10.47
4	AAC blocks masonary	0.00	0.01	0.43	27.79	0.00	9.53	0.00	0.00	5.70	0.00	0.00
5	Glass	3.40	0.02	0.30	0.05	0.29	0.60	0.14	0.47	0.26	0.13	2.18
6	Vitrified ceramic floor tile	2.00	0.26	18.22	4.55	1.56	2.47	1.07	3.60	1.67	1.21	0.47
7	Stone floor tile	0.00	0.00	0.10	0.10	0.17	0.00	0.00	0.10	0.00	0.01	0.13
8	Aluminium window frame	0.30	0.15	5.21	1.70	3.00	0.07	2.82	0.00	0.56	0.60	17.59
9	Bitumen	0.87	0.00	0.00	4.19	0.23	0.00	0.00	0.00	0.01	0.00	0.08
10	Diesel	1.70	4.02	0.17	1.52	0.44	0.41	0.19	0.00	1.88	18.08	0.35
11	Sand	0.89	2.20	0.48	1.32	1.19	1.44	0.76	2.07	0.45	0.90	7.46
12	Aggregates	1.59	4.25	0.12	0.97	0.11	1.52	0.47	2.42	1.88	0.88	0.76
13	**Total of Cement & Steel (1+2)**	**86.34**	**84.20**	**61.05**	**51.59**	**78.63**	**82.73**	**78.55**	**80.74**	**73.76**	**59.93**	**58.67**
14	**Total of Bricks & AAC Blocks (3+4)**	**2.22**	**3.43**	**13.98**	**33.31**	**13.90**	**10.01**	**15.52**	**9.56**	**18.82**	**17.68**	**10.47**
15	**Total of Cement, Steel, Bricks & blocks (13+14)**	**88.57**	**87.63**	**75.03**	**84.90**	**92.53**	**92.74**	**94.06**	**90.30**	**92.58**	**77.61**	**69.14**

Table 3

PERCENTAGE CONTRIBUTION OF EACH MATERIAL TOWARDS CO_2 EMISSION (P12-P22)												
S. No.	**MATERIALS**	**P12**	**P13**	**P14**	**P15**	**P16**	**P17**	**P18**	**P19**	**P20**	**P21**	**P22**
1	Portland Pozzolana Cement (PPC)	30.34	32.70	39.42	11.50	30.34	26.34	26.76	48.65	32.40	24.49	32.31
2	Steel	41.55	53.88	41.13	86.08	46.95	40.08	54.71	41.61	36.88	53.72	47.21
3	Burnt Clay bricks masonary	4.75	4.45	11.31	0.20	15.95	29.27	13.23	0.03	18.44	10.19	11.41
4	AAC blocks masonary	6.52	0.00	0.00	0.14	0.08	0.00	0.00	1.42	0.00	1.64	0.00
5	Glass	0.17	0.19	0.29	0.08	0.20	0.10	0.17	1.09	0.30	0.28	0.23
6	Vitrified ceramic floor tile	5.41	1.62	1.43	0.73	0.41	1.33	1.39	2.42	2.00	1.59	1.42
7	Stone floor tile	0.21	0.00	0.08	0.02	1.23	0.10	0.00	0.28	0.13	0.06	0.15
8	Aluminium window frame	7.02	4.20	1.55	0.20	1.10	0.13	0.63	0.00	6.39	5.58	3.09
9	Bitumen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Diesel	1.53	1.08	1.92	0.19	2.03	0.43	0.59	1.31	0.00	0.14	0.96
11	Sand	0.78	0.64	0.97	0.26	0.52	0.71	1.11	0.99	1.14	0.88	1.34
12	Aggregates	1.15	0.81	1.25	0.38	0.70	0.90	0.82	1.52	1.53	0.90	1.17
13	**Total of Cement & Steel (1+2)**	**71.89**	**86.58**	**80.55**	**97.57**	**77.30**	**66.41**	**81.47**	**90.26**	**69.28**	**78.21**	**79.52**
14	**Total of Bricks & AAC Blocks (3+4)**	**11.27**	**4.45**	**11.31**	**0.34**	**16.03**	**29.27**	**13.23**	**1.45**	**18.44**	**11.82**	**11.41**
15	**Total of Cement, Steel, Bricks & blocks (13+14)**	**83.16**	**91.03**	**91.86**	**97.91**	**93.33**	**95.68**	**94.70**	**91.71**	**87.72**	**90.03**	**90.93**

Table 4

S. No.	MATERIALS	P23	P24	P25	P26	P27	P28	P29	P30	P31	P32
PERCENTAGE CONTRIBUTION OF EACH MATERIAL TOWARDS CO_2 EMISSION (P23-P32)											
1	Portland Pozzolana Cement (PPC)	36.22	39.07	41.11	30.54	38.46	34.31	1.22	27.84	32.42	23.93
2	Steel	49.11	45.10	43.54	34.02	49.57	45.73	64.82	51.32	50.99	48.52
3	Burnt Clay bricks masonary	2.39	6.23	7.13	0.27	0.65	11.70	7.92	2.12	1.63	1.32
4	AAC blocks masonary	0.98	0.24	1.53	27.84	2.81	0.00	10.61	5.21	6.80	6.71
5	Glass	0.13	0.29	0.29	0.19	0.16	0.35	0.85	0.81	0.54	0.40
6	Vitrified ceramic floor tile	2.13	0.64	1.44	2.19	3.22	2.11	2.19	1.22	2.76	3.16
7	Stone floor tile	1.16	0.01	0.08	0.01	0.09	0.00	0.00	0.14	0.06	0.06
8	Aluminium window frame	0.09	5.23	0.00	0.00	2.19	2.16	5.07	7.57	3.12	12.82
9	Bitumen	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
10	Diesel	1.83	0.18	2.01	1.71	0.60	0.23	1.86	1.46	0.66	1.18
11	Sand	2.24	0.96	0.94	1.08	0.71	1.18	2.14	0.82	0.34	0.65
12	Aggregates	2.56	1.41	1.30	1.41	1.03	1.48	2.28	0.97	0.38	0.81
13	**Total of Cement & Steel (1+2)**	**85.33**	**84.17**	**84.65**	**64.56**	**88.04**	**80.04**	**66.03**	**79.16**	**83.41**	**72.45**
14	**Total of Bricks & AAC Blocks (3+4)**	**3.37**	**6.47**	**8.65**	**28.12**	**3.46**	**11.70**	**18.53**	**7.34**	**8.43**	**8.03**
15	**Total of Cement, Steel, Bricks & blocks (13+14)**	**88.70**	**90.64**	**93.30**	**92.68**	**91.49**	**91.74**	**84.56**	**86.50**	**91.84**	**80.48**

Table 5

PERCENTAGE CONTRIBUTION OF EACH MATERIAL TOWARDS CO_2 EMISSION (P33 to P39)										
S. No.	**MATERIALS**	**P33**	**P34**	**P35**	**P36**	**P37**	**P38**	**P39**	**P40**	**AVERAGE**
1	Portland Pozzolana Cement (PPC)	29.71	31.21	28.28	24.91	31.45	33.12	30.26	28.65	29.92
2	Steel	57.89	58.46	57.06	50.77	53.16	41.60	52.44	49.18	48.12
3	Burnt Clay bricks masonary	0.34	0.09	0.27	11.38	4.98	12.06	0.33	7.24	7.58
4	AAC blocks masonary	1.67	4.63	4.62	0.00	0.00	2.68	0.00	1.88	3.32
5	Glass	0.99	0.76	0.36	0.30	0.33	0.22	0.48	4.26	0.47
6	Vitrified ceramic floor tile	0.52	1.64	2.04	1.13	1.34	0.96	1.76	0.54	2.24
7	Stone floor tile	0.06	0.07	0.28	0.04	0.00	0.00	0.15	0.01	0.13
8	Aluminium window frame	4.87	1.41	2.15	8.71	6.02	3.78	10.35	3.05	3.52
9	Bitumen	0.00	0.00	0.00	0.00	0.02	0.22	0.00	0.00	0.14
10	Diesel	1.49	0.00	2.22	0.28	0.16	1.83	0.00	3.59	1.45
11	Sand	0.74	0.46	0.98	0.97	1.88	1.49	1.29	0.27	1.22
12	Aggregates	1.20	0.87	1.15	0.94	0.11	1.29	2.12	0.93	1.22
13	**Total of Cement & Steel (1+2)**	**87.60**	**89.67**	**85.35**	**75.69**	**84.61**	**74.72**	**82.70**	**77.83**	**78.04**
14	**Total of Bricks & AAC Blocks (3+4)**	**2.01**	**4.72**	**4.90**	**11.38**	**4.98**	**14.73**	**0.33**	**9.12**	**10.90**
15	**Total of Cement, Steel, Bricks & blocks (13+14)**	**89.62**	**94.39**	**90.25**	**87.07**	**89.58**	**89.45**	**83.03**	**86.95**	**88.93**

Chapter 2

Building Life Cycle CO_2 emission

It has been explained in the introduction part above that the CO_2 emission related to the construction sector is mainly divided in two parts: one time construction (**Part A**) and electrical energy consumption during lifetime (herein we have assumed fifty years) (**Part B).** The impact of Part A to B is almost 1 : 6 units with the following information:

- The value of 40 Buildings (Annexure-12) in respect of consumption of steel, cement, masonry, glass, aluminum, and all other material, all electrical and mechanical equipment and their CO_2 emission,
- The value of 10 Buildings (Annexure-13) in respect of EPI means the annual energy in kWh (unit of electric power) per unit sq. mtr. plinth area,
- Life of building assumed is 50 yrs,
- The CO_2 in Kg per kWh of electricity being 0.71 Kg (which will come down with time as the percentage of renewable energy goes up in India).

Part A: Dealing major components Steel, Cement, Masonry (burnt clay to AAC)

The construction sector in India emits about 37% of the total annual emission of CO_2 (including energy used during lifetime) resulting from the Indian economy. Of the emissions from the construction sector, 85-90% are from the products/industrial processes of three energy intensive building materials: steel, cement, and bricks (burnt clay) / AAC.

For each of the three building materials, there exists a technology spread characterized by widely varying levels of energy and material consumption within each sector. A study conducted by Development Alternatives (world's first social enterprise dedicated to sustainable development) discussed the increasing demand for building materials in the construction sector as a direct outcome of the galloping demand for housing on a continuing growth. The housing gap which is currently 45.8 million houses will be steadily cleared by 2030. The summary of the total energy and emissions for the three materials derived through the Development Alternatives study has been presented in Table 2.

The energy and emissions have been computed using specific energy consumption and carbon emission factors. Although steel and cement together constitute more than three fourth of the net contribution, these are sectors that are showing positive signs of adopting Carbon and energy efficiency measures.

Embodied carbon in construction

The World Green Building Council aims for new buildings to reduce embodied carbon by at least 40%. A life-cycle assessment calculates embodied carbon emissions across a building's lifespan, including construction, use, maintenance, and demolition. Re-use is vital because existing buildings generally emit less carbon than new constructions, especially as energy efficiency improves and renewable energy becomes more common.

To reduce embodied carbon, two main strategies are used: reducing construction material mass (reduce the quantity of construction material) and substituting lower-carbon alternatives. Structural design changes, like reducing beam or slab spans and increasing column density, can significantly cut emissions.

Material substitution is supported by Environmental Product Declarations (EPDs) from manufacturers of materials like steel rebar, glulam, and precast concrete, which certify the carbon impact of their products. Databases compile embodied carbon values from EPDs and academic studies, though comparing these values can be challenging due to various calculation methods.

Reducing carbon-intensive materials involves selecting lower-carbon versions of products like glass and steel and using materials produced with low-emissions energy. In concrete construction, Portland cement alternatives, such as ground granulated blast-furnace slag, recycled aggregates, and industry by-products, help lower embodied carbon. Carbon-neutral, carbon-positive, and carbon-storing materials include bio-based options like timber, bamboo, hemp fiber, hempcrete, wool, dense-pack cellulose insulation, and cork.

A 2021 study on "carbon-intensive hotspot materials" in light industrial buildings estimated that a 60% reduction in embodied carbon is achievable within two to three years by widely adopting readily available low-carbon materials (Julie Kriegh, 2021).

Rapid urbanization and population growth in developing economies have spurred a construction boom. In India, the buildings and construction sector accounts for approximately one-third of the nation's energy consumption and associated CO_2 emissions. Projections suggest that by 2050, as India aims to add 21.5 billion square meters of building space by 2040, primarily residential, energy consumption could nearly triple and emissions quadruple. This scenario underscores the urgency of making informed choices to avoid significant carbon commitments.

Decarbonization strategies must encompass both operational and embodied energy considerations through an integrated ecosystem approach. While India has made strides in addressing operational energy through renewable offsets and standards such as the Energy Conservation Building Code 2017 and Eco Niwas Samhita 2018, efforts to reduce embodied energy and carbon are gaining momentum. Initiatives like the compendium of indigenous materials and technologies released by the Building Material and Technology Promotion Council mark initial steps towards mainstreaming sustainable materials.

Steel

As per NSP 2017, the Ministry of Steel has the target to reduce CO_2 emission intensity from 3.1 TCO_2 / TCS (tonnes of CO_2 per tonne of crude steel produced) to 2.4 TCO_2/ TCS by 2030 from 2005 level. Therefore, the steel industry is at a pivotal juncture, needing to lower its carbon footprint while meeting the rising global demand for steel. As a major industrial emitter, responsible for around 7-9% of global CO_2 emissions, the steel sector is crucial in combating climate change.

India targets net zero emissions by 2070. The domestic steel industry, according to India's steel ministry, emits 2.2-2.7 TCO_2/TCS, compared to the global average of 1.8-2 TCO_2/TCS. As the second-largest crude steel producer, with 161 million tonnes of installed capacity and 140 million tonnes of annual production in 2023, India faces significant challenges.

Technological advancements offer hope for reducing steel production emissions. However, current solutions are either in early development stages or face challenges needing substantial investment and collaboration between government and industry. Green hydrogen shows promise but is currently too costly for Indian steel companies, requiring prices around $1-2/kg to be competitive. Additionally, only up to 15% of coking coal in blast furnaces can be replaced by green hydrogen, and integrating hydrogen injection systems into older blast furnaces poses engineering challenges.

Interest in carbon capture, utilization, and storage (CCUS) has grown. The World Steel Association suggests CCUS technologies can retrofit existing systems to cut emissions, projected to reach 8 billion tonnes by 2050. For example, Tata Steel has commissioned a 5-tonne-per-day carbon capture plant in Jamshedpur in collaboration with a UK-based startup. However, high costs and issues with post-capture utilization, like low carbon uptake in mineralization and the need for green hydrogen in ethanol and methanol conversion, pose challenges. Economically viable storage requires specific geological conditions, and sea basin storage is not feasible for all companies.

Steel manufacturers are exploring coke oven gas, with Germany's SMS group's EasyMelt technology utilizing blast furnace top gas recycling for syngas production by reforming coke oven gas. However, scalability remains a challenge since only about 15% of coal used to generate coke is released as coke oven gas.

In Europe, China, and India, stamped charging of coals allows using highly volatile poor coking coals without impairing coke quality. Polymerization technology can increase non-coking coals in steelmaking by about 10%, while the shear crushing method enhances the use of cheaper coals. Microwave coke oven technology can potentially produce coke entirely from non-coking coals.

The Japanese steel industry has made advancements with the Super COURSE 50 technique, which uses heated hydrogen to reduce blast furnace CO_2 emissions by up to 30%. It uses by-product gas generated in integrated steel mills that are currently used in furnaces. The SCOPE 21 (Super Coke Oven for Productivity and Environment Enhancement toward the 21st Century), also developed by the Japanese steel industry, process uses up to 50% semi-soft, weak, and non-coking coals, aiming to replace aging coke ovens.

Indian steelmakers are incorporating electric arc furnaces (EAF) into their production, though the main challenge is the availability of low-cost green electricity and steel scrap. Tata Steel is building its first EAF-based low-emissions steel plant in Ludhiana and has signed a 25-year agreement with Tata Power for renewable power, potentially reducing emissions by 50 million tonnes.

The steel industry needs a range of solutions to transform itself. Through advanced technology, emissions can be reduced, efficiency improved, and sustainability promoted. Collaboration is essential, and by working together, a clear path toward a bright, resilient future can be charted. Embracing innovation and collective efforts can build a greener, more sustainable steel industry for future generations (*Rajiv Mangal, 2024*).

Autoclaved Aerated Concrete (AAC)

Traditionally, in RCC framed structures, burnt clay bricks have been used for brick masonry work. Now, let us imagine a framed structure where the burnt clay bricks have been completely replaced by AAC blocks for brick masonry work. The benefits achieved in terms of reducing carbon emissions are listed below:

1. Reducing embodied CO_2 emission:
    a. AAC blocks have lower Carbon factor per m^3 of brick masonry.
        i. Carbon factor for AAC blocks = 275 kg CO_2 per m^3 of masonry.
        ii. Carbon factor for burnt clay bricks = 563.2 kg CO_2 per m^3 of masonry.

    Thus, it can be concluded that substituting burnt clay bricks with AAC blocks can reduce the embodied CO_2 emission by 5.1% (weightage of masonry in embodied carbon is about 10%)

    b. AAC blocks are lighter in weight. Thus, during an earthquake, AAC blocks will attract lower seismic forces. Also, they significantly reduce the Dead Load on a building and reduce transportation emissions. Saving in cement is mainly due to less consumption of mortar for joining & plastering. These factors result in steel saving up to 15% and cement saving up to 10% approximately. Thus, it can be concluded that substituting burnt clay bricks with AAC blocks can reduce the embodied CO_2 emission by another 9.8%.

   c. Thus, combined savings of approximately 15% in the embodied CO_2 emissions can be achieved.

2. Reducing operational CO_2 emission:

   a. The thermal transmittance of AAC blocks is much lower than burnt clay bricks. This fact can be supported by the data as follows:

      i. U-value of AAC blocks = 0.8 W/(m^2.K)

      ii. U-value of Burnt clay bricks = 2.0 W/(m^2.K)

      This means that substituting the burnt clay bricks with AAC blocks can reduce the thermal transmittance of walls by approximately 60%.

   b. This means that AAC blocks have a very high thermal insulation index which means that the ambient temperature within these structures doesn't change rapidly with the external temperature. To demonstrate the positive effect of lower U-value we have the following assumptions:

      i. 50% of the operational CO_2 emission is due to Air conditioning.

      ii. 64% of the Air conditioning load is due to heat gain through the building envelope.

      iii. 40% of the heat gained by the building envelope is due to walls.

   c. Considering the assumptions mentioned above, approximately 7.7% savings in the operational CO_2 emissions can be achieved.

Note: For analysis, a typical rectangular building (G+4) with built-up area of 10,000 sq. mtr., length as 50 mtr., width as 40 mtr. with floor height as 3.5 mtr. has been assumed.

Part B: Electrical Energy in Life cycle , reducing Air Conditioning, R factor, special role of glass in building envelope It has been calculated above that the impact of Part A to B is almost 1 : 6 with the following information achieved and assumption

1. The value of 40 Buildings in respect of consumption of Steel, Cement, Masonry, Glass, Aluminum, and all other material, all electrical and mechanical equipment and their CO_2 emission.

2. The value of 10 Buildings in respect of EPI means the annual energy in kWh (unit of electricity) per unit sq. mtr plinth area.
3. Life of the building is 50 yrs yrs,
4. The CO_2 in Kg per KWH of Electrical power being 0.71 Kg.

From the above, it can be concluded that the sensitivity of the Energy Performance Index (EPI) is six times higher. Therefore, extreme sensitivity should be exercised in designing buildings, strictly following ECBC guidelines and ensuring that CPWD buildings meet at least the ECBC Plus standards. In addition to meeting the ECBC Plus criteria, the following highly sensitive factors can be further improved:

- **Improvement of R-Value**: Substantially enhance the R-value of roofs and walls to improve insulation.
- **Minimizing Glass Use**: Drastically reduce the use of glass by lowering the window-to-wall ratio to the minimum required to meet various bylaws, while maintaining daylight criteria.
- **Optimizing Window Placement**: Position windows primarily on the south side of buildings to maximize energy efficiency.
- **Using AAC Blocks**: Implement the use of AAC blocks as wall material to further reduce the carbon footprint.

From the various data received from field units regarding electrical energy consumption in different buildings, it is found that the annual electricity consumption is divided as follows:

- Lighting, fans, computers, other equipment like lifts, pumps (water supply and firefighting), compound lighting, and 16-amp power loads together account for 50%.
- Air conditioning load accounts for the remaining 50%.

This proportion of air conditioning to other electrical loads is corroborated by data received from across India.

Further analysis of air conditioning heat load calculation reveals that:

- **60% of the air conditioning tonnage** is due to building envelope heat gain.
- **40% of the air conditioning tonnage** is due to heat gain from electrical equipment (lighting, fans, computers, other equipment), human heat load, and infiltration load.

This means that the building envelope is responsible for controlling approximately 60% of the air conditioning load, which in turn represents 30% of the total electrical load. Therefore, the building envelope influences about 60% x 50% = 30% of the total electricity bill.

Out of this total building envelope heat load gain, it is found that on average, the heat load gained varies according to the following tables for three types of ECBC-compliant buildings and one conventional building, each with Window-to-Wall Ratios (WWR) of 10%, 15%, 20%, 30%, and 40%.

Assumptions:

1. Delhi solar heat gain from 6 AM to 6 PM direction wise average is as per following table. Solar heat gain of grand average 8 direction as per distribution of use glass is 182 watts per sq. mtr. (10% North south combined, 25% South, 15% North, 12.5% each in NE, SE, NW, and SW)
2. Typical area of wall, roof, glass has been taken from a few projects converted to a standardized area. For analysis, a typical rectangular building (G+4) with built-up area of 10,000 sq. mtr., length as 50 mtr., width as 40 mtr. with floor height as 3.5 mtr. has been considered. This assumption is valid for all heat gain calculations in the book.
3. Building is ECBC compliant.
4. Grand average as calculated below the solar heat gain.
5. Temp difference in respect of wall and glass is 15^0C.
6. Temp difference in respect of Roof is 25^0C.
7. Location is Delhi.
8. Total carbon factor during one time construction is roughly 0.9 tonne/sq. mtr.
9. Total carbon factor during lifetime (EPI) energy uses assuming 140 EPI-140 and carbon factor of present energy generation as 0.71 tonnes/kWh and adjusted with future increase of renewable components of next 50 to 70 years and average value as 0.40 tonnes/kWh and assuming the life of building as 60 years the net tonnage/sq. mtr. for energy use is: **140 kWh/sq. mtr. x 60 years x 0.4 Kg/kWh = 3.36 Tonnes / sq. mtr.**
10. 3.36 tonne life time considering future lowering of carbon factor of energy with substantial increase of Non renewable energy.

Direction	Average of 12 hours in a year (W/sq.mtr.)	Remarks
N	148	Less preferable to provide glass
S	103	Most preferable to provide glass
E	291	Least preferable to provide glass
W	291	Least preferable to provide glass
NE	210	Very less preferable preferable to provide glass
NW	210	Very less preferable to provide glass
SE	210	Very less preferable to provide glass
SW	210	Very less preferable to provide glass

Grand average	182.5	10 % North south combined 25 % South 15% North 12.5 % each in NE, SE, NW, and SW

Assumed U values and SHGC				
Compliance	**Roof U value**	**Wall U value**	**Glass U value**	**SHGC**
Non ECBC	1.8	2.4	5	0.80
ECBC basic	0.33	0.4	2	0.27
ECBC Plus	0.20	0.34	1.5	0.25
ECBC Super	0.20	0.22	1	0.20

Typical cross section of wall to achieve desired U-value as per ECBC Super compliance

S. No.	Layer type	Material used	Thickness (in mm)	Thermal conductivity (in W/m.K)	R-value (in m^2.K/W)	U-factor (in W/m^2.K)
1	2	3	4	5	6	7
					Col.(4)/Col.(5)	1/Sum(R-values)
L1	Surface air film	Outer surface				0.22
L2	External finish	Cement plaster	15	1.208	0.012	
L3	Mass	AAC block	200	0.184	1.088	
L4	Insulation	Extruded Polystyrene (XPS)	75	0.032	2.336	
L5	Mass	AAC block	200	0.184	1.088	
L6	Internal finish	Cement plaster	15	1.208	0.012	
L7	Surface air film	Inner surface				
		Total thickness =	**505**		**4.536**	

Typical cross section of Roof to achieve desired U-value as per ECBC Super compliance

S. No.	Layer type	Material used	Thickness (in mm)	Thermal conductivity (in W/m.K)	R-value (in sqm.K/W)	U-factor (in W/ sqm.K)
1	2	3	4	5	6	7
					Col.(4)/Col.(5)	1/Sum(R-values)
L1	Surface air film	Outer surface				0.20
L2	Flooring	Ceramic tiles	10	1.600	0.006	
L3		Mortar	20	1.208	0.017	
L3	Brick bat coba	Cement plaster	20	1.208	0.017	
		Brickbats	70	1.273	0.055	
		Cement plaster	20	1.208	0.017	
L4	Insulation	Extruded Polystyrene (XPS)	150	0.032	4.673	
L5	Slab	RCC	150	1.208	0.124	
L6	Internal finish	Cement plaster	20	1.208	0.017	
L7	Surface air film	Inner surface				
		Total thickness =	**460**		**4.925**	

ECBC Basic (for typical WWR = 20%)						
Type of Envelope	U value in W/Sq.mtr./^{0}C (SHGC in case of glass)	Temp difference in ^{0}C (Solar heat gain in case of glass)	W/Sq.mtr.	Rough Area in sq.mtr.	Net heat gain In Watts	Net % of contribution
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Col.(2) x Col.(3)		Col.(4) x Col.(5)	
Roof	0.33	25	8.25	2000	16,500	20.2
Wall	0.4	15	6	2520	15,120	18.6
Glass U value gain	2	15	30	630	18,900	23.2
Glass SHGC	0.27	182	49.14	630	30,958	38
Total					**81,478**	**100**

ECBC Plus (for typical WWR = 20%)						
Type of Envelope	U value in W/Sq.mtr./^{0}C (SHGC in case of glass)	Temp difference in ^{0}C (Solar heat gain in case of glass)	W/Sq.mtr.	Rough Area in sq.mtr.	Net heat gain In Watts	Net % of contribution
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Col.(2) x Col.(3)		Col.(4) x Col.(5)	
Roof	0.2	25	5	2000	10,000	15.2
Wall	0.34	15	5.1	2520	12,852	19.6
Glass U value gain	1.5	15	22.5	630	14,175	21.6
Glass SHGC	0.25	182	45.5	630	28,665	43.6
Total					**65,692**	**100**

ECBC Super (for typical WWR = 20%)						
Type of Envelope	U value in W/Sq.mtr./^{0}C (SHGC in case of glass)	Temp difference in ^{0}C (Solar heat gain in case of glass)	W/Sq.mtr.	Rough Area in sq.mtr.	Net heat gain In Watts	Net % of contribution
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Col.(2) x Col.(3)		Col.(4) x Col.(5)	
Roof	0.2	25	5	2000	10,000	19.7
Wall	0.22	15	3.3	2520	8,316	16.4
Glass U value gain	1	15	15	630	9,450	18.6
Glass SHGC	0.2	182	36.4	630	22,932	45.3
Total					**50,698**	**100**

Non ECBC Compliant Conventional Building (for typical WWR = 20%)						
Type of Envelope	U value in W/Sq.mtr./^{0}C (SHGC in case of glass)	Temp difference in ^{0}C (Solar heat gain in case of glass)	W/Sq.mtr.	Rough Area in sq.mtr.	Net heat gain In Watts	Net % of contribution
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Col.(2) x Col.(3)		Col.(4) x Col.(5)	
Roof	1.8	25	45	2000	90,000	28.1
Wall	2.4	15	36	2520	90,720	28.4
Glass U value gain	5	15	75	630	47,250	14.8
Glass SHGC	0.8	182	145.6	630	91,728	28.7
Total					3,19,698	100

For other WWR like 10%, 15%, 30%, and 40% calculation: 16 numbers of tables are provided in Annexure 11.

Result of increasing R-value of <u>Roof by and wall by 4 times even in a non compliant building</u>: Presently the buildings designed by CPWD the R value generally varies from 0.6 to 0.75 in normal practice. But there is huge scope of increasing this to minimum 4 times in respect of roof and wall then there will be total electricity saving of 14 % combined.

(R value for roof varies from 3-5 ECBC compliant, 4-5 for ECBC plus and 5 for ECBC super building).

So only if ECBC/plus/super is followed strictly, will result in 14% total electrical energy over lifetime and approximately 23% of air conditioning design rating. Since EPI or electricity consumption is having 6 times impacts of original construction carbon footprint (assuming a life time of 50 years) in energy carbon footprint so overall the impact will be as follows in carbon footprint reduction.

A further chart of effect of variation of total heat gain with respect to variation in window to wall ratio in four different ECBC non compliant , ECBC basic, ECBC Plus and ECBC Super is tabulated below **for a 10000 sq. mtr. building.**

Summary of building envelope heat gain with varying ECBC compliances and WWR					
	WWR = 10%	WWR = 15%	WWR = 20%	WWR = 30%	WWR = 40%
ECBC Super (in KW)	36	43	51	66	81
ECBC Plus (in KW)	46	56	66	85	105
ECBC Basic (in KW)	58	70	82	105	128
Non ECBC (in KW)	261	291	320	378	436

So it is evident that if we simply comply mandatorily it will be yeoman service to the cause of energy saving, carbon emission reduction.

So in a typical Air conditioned building where out of total approximately 250 TR the contribution of Building envelope is 140 TR and others load like light and fan, Computers, small power point load, human load, infiltration load, server are cumulatively 110 TR there is scope of reducing the above 140 TR to as less as 28 TR by suitably controlling WWR and making it ECBC super compliant.. Any such extra cost will always pay back the environmental and economic future cost adjustment.

Vide Annexure-10, a calculation on the lifetime energy cost saving on compliances of ECBC compared to non-ECBC conventional building in Rs. per sq. mtr. basis has been done to indicate that actually net impact of ECBC compliance expenditure is balanced out with the savings in Energy cost.

Glass use impacts on building

The following analysis pertains to air-conditioned buildings (fully or predominantly) and the use of glass in fenestration or structural glazing. Glass is used for the building's outer envelope for three primary reasons, outlined below.

A) Daylight: This is mandatory according to existing bye-laws and as per ECBC by mandatory provision, Chapter 4.2. The ECBC's daylighting criterion aims to reduce reliance on artificial lighting. However, in practice, this reduction is not fully achieved. Light fixtures are often needed during evenings and nights, and empirical surveys of existing commercial and office buildings show that even during the day, lights near windows are often on. This is due to the prevalent summer-like conditions in most parts of India, which last for the majority of the year, which often leads to curtains being drawn and consequent dependence on artificial light. During the brief winter period (2-2.5 months), daylight is allowed in, but with sufficient solar heat gain, lights near windows remain on. Therefore, the basic criterion for providing sufficient natural daylight as per bye-laws and otherwise is defeated. This point is emphasized as the corresponding heat gain due increase in fenestration (or at least the minimum glass to be used for natural daylight) increases the AC load (which 50% accountable to EPI) by at least 50% from best case scenario (super ECBC with less WWR) to worst case scenario (non-ECBC with high WWR).

B) Fresh air-flow: This criterion is largely defeated in fully or predominantly air-conditioned buildings because the glass fenestration is non-operable. Fresh air is introduced through forced ventilation or fresh air induction for the air conditioning system. Additionally, with the increasing impacts of global warming and climate change, the number of fully or mostly air-conditioned buildings is expected to rise dramatically in the coming years and decades.

C) Psychological reason: Fenestration and windows provide a sense of connection with the outside world. However, in office buildings, curtains are often drawn to mitigate heat gain, reducing this psychological benefit. The corresponding heat gain is too high if curtains are not drawn.

The above reasons increase EPI dramatically; hence, present percentage of fenestration should be reduced.

Location of glass use: Glass is used invariably in building design and construction. The use of glass can be divided into two major categories:

1. For fenestration or structural façade and other openings, such as main doors, that are part of the building's exterior envelope.
2. For internal applications, including railings, partition walls, table tops, and other aesthetic enhancements within rooms, corridors, and common areas, limited to the building's interior.

As explained above, the carbon footprint of glass is high, and its SHGC is significantly greater compared to the conduction heat gain through the roof and walls. Consequently, the impact of CO_2 reduction can be divided into two parts: one time construction and lifetime energy use (with a ratio of 1 : 6 or 1 : 8).

The use of glass, both internally and on the building's exterior envelope, has the following impacts:

1. Increasing the use of glass for **internal aesthetics and architectural design** has a high one-time carbon footprint due to the glass itself. However, since this accounts for only 14.3% (1/7) of the building's lifetime carbon emissions, glass usage should be judiciously balanced with carbon reduction as one of the design considerations. Analyzing data from 40 constructed buildings shows that the CO_2 contribution from glass is relatively small compared to other materials like steel, cement, masonry, and aluminum. Therefore, increasing the use of glass can be acceptable as long as its proportion of the total building's carbon footprint remains low.

2. Glass used for fenestration and on the outer façade for windows or glass openings has two main impacts:

   a. **Construction CO_2 factor**: This is the same as explained above, where the one-time carbon footprint of glass is significant but limited to the initial construction phase.

   b. **Lifetime CO_2 factor**: Glass used as doors and windows has a dramatic impact on air conditioning tonnage increase. Approximately 80% (4/5) of a building's total lifetime CO_2 emissions are due to electrical energy use. In fully air-conditioned buildings, around 55% of the CO_2 emissions are attributable to air conditioning. Further, the envelope heat gain load accounts for roughly 60-65% of the total air conditioning load and glass contributes to 74% of the envelope's heat gain, assuming typical compliance with ECBC standards. The following basic assumption of a typical building are outlined below:

- Wall temperature difference 15°C and U value 0.33 W/sq.mtr./°C.
- Roof temperature difference 25°C and U value 0.33 W/sq.mtr./°C.
- Glass U value gain, temperature difference 15°C and U value 2 W/sq.mtr./°C.
- SHGC = 0.5 and solar gain = 350 watts/sq. mtr. Which is the yearly average of eight directions (N, S, E, W, NE, NW, SE, SW) taken from the condition of Delhi.
- Window to wall ratio as 20%.

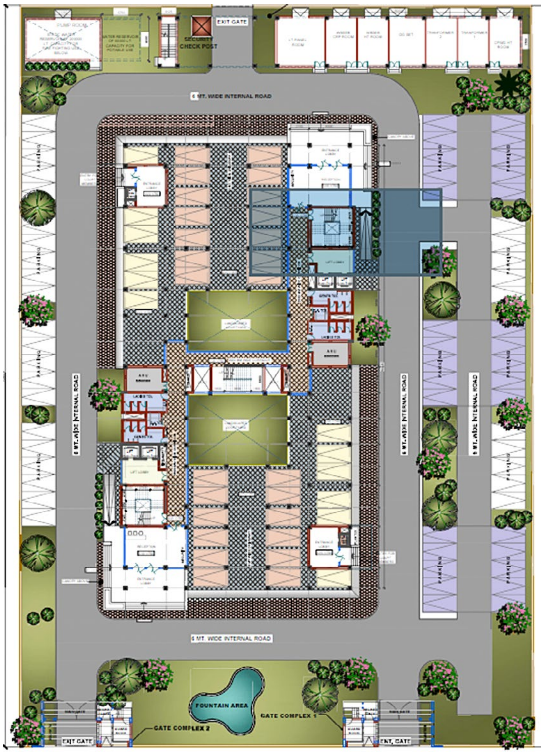
It is evident that glass use in air-conditioned buildings contributes significantly to lifetime CO_2 emissions, with approximately 19.5 CO_2 units per 100 units attributed to glass. Detailed tables and annexures provide absolute CO_2 values in tonnes per square meter, correlating WWR with varying levels of ECBC compliance. Notably, the one-time construction CO_2 emissions alone account for 20%, suggesting a potential 10% reduction in lifetime emissions through strategic reductions in WWR and strict adherence to ECBC super/Plus compliance.

Therefore, it is crucial to strictly limit glass use for fenestration to the minimum values specified by bylaws. CPWD should engage with various ministries to establish new lower limits for WWR. As emphasized earlier, reducing glass usage, especially in air-conditioned buildings, is justified. Given that future institutional and office buildings will predominantly be air-conditioned, minimizing glass usage should be a standard practice across all new constructions.

3. **Glass used for structural glazing**: As previously mentioned, structural glazing is highly undesirable due to both the one-time construction CO_2 emissions and the substantial increase in lifetime energy use. The high WWR in structural glazing significantly increases the design and operational load of air conditioning systems.

Case Study: Corporate Bhawan(G+7)

Location of the building:City- Kolkata ; Lat-22.32 deg. North ; Altitude- 6 Mtr.



A. Energy Saving

- 60 KWp building integrated photovoltaic system
- East west orientation to reduce light power density
- Sensor based automation in light system
- VFD chiller and AHU to reduce Energy demand.

B. Water Saving

- Low Flow fixture to reduce water demand.
- Local and drought tolerant species in landscape.
- Rainwater storage and its re-use.

C. Waste recycling

- Dual plumbing system to reuse waste water.
- Verme-composter to reduce biodegradable waste
- Fly-ash & AAC bricks to reduce embodied energy
- Use of fly ash in cement to recycle waste.

D. Occupants wellbeing

- Maximum use of daylight with central atrium and DGU on external façade.
- Use of low VOC paints to ensure good indoor air quality.
- By using high value of Solar Reflective Index (SRI) paint on the terrace to reduce
- heat transmission within the building.
- CO_2 sensors in AHU to ensure good indoor air quality.
- Landscape on terrace

	Roof	External wall	Glass	Glass SHGC
U-Value (in W/m².K)	0.68	2	3	0.36
Area (sq. mtr.)	2144	2830	4757	4757

3 Star TERI-GRIHA Rating

Plinth area = 14,794 sq. mtr.

Embedded Carbon during construction : 1.05 tonne per sq. mtr.

Heat gain of Corporate Bhavan through building envelope (at present)						
Type of Envelope	U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)	Temp difference in ^{0}C (Solar heat gain in case of glass)	W / Sq.mtr.	Rough Area in sq.mtr.	Net heat gain In Watts	Net % of contribution
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Col.(2)xCol.(3)		Col.(4)xCol.(5)	
Roof	0.68	25	17	2144	36,448	5.6%
Wall	2	15	30	2830	84,900	13.1%
Glass U value gain	3	15	45	4757	2,14,065	33%
Glass SHGC	0.36	182	66	4757	3,13,962	48.3%
Total					**6,49,375**	**100**

Heat gain through building envelope if designed as ECBC Super (WWR = 20%)						
Type of Envelope	U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)	Temp difference in ^{0}C (Solar heat gain in case of glass)	W / Sq.mtr.	Rough Area in sq.mtr.	Net heat gain In Watts	Net % of contribution
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Col.(2)xCol.(3)		Col.(4)xCol.(5)	
Roof	0.2	25	5	2144	10,720	9.9%
Wall	0.22	15	3.3	6070	20,031	18.4%
Glass U value gain	1	15	15	1517	22,755	20.9%
Glass SHGC	0.2	182	36.4	1517	55,219	50.8%
Total					**1,08,725**	**100**

Heat gain and reduction in CO_2 emissions due to building envelope of Corporate Bhawan, Kolkata with varying levels of ECBC compliance					
Level of ECBC compliance	**Heat gain (in kW)**	**Tonnage of AC required (in TR)**	**Power used during lifetime (in units)**	**Lifetime CO_2 emissions due to building envelope heat gain (in tonnes)**	**Lifetime savings in CO_2 emission by compiling with ECBC norms**
Current status (Non-ECBC)	649	185	1,31,06,284	5,046	
ECBC Basic (WWR=20%)	173	49	34,71,394	1,336	3,710 tonnes (73.3%)
ECBC Plus (WWR=20%)	145	41	29,04,636	1,118	3,928 tonnes (77.7%)
ECBC Super (WWR=20%)	109	31	21,96,188	846	4,200 tonnes (83.2%)

Assumptions for the above table are:

1. Energy Efficiency Ratio (EER) for the AC system = 6.7
2. The AC system is operational for 10 hours per day for 270 days in a year.
3. Operational life of building = 50 years.

Conclusion: Lifetime CO_2 emissions of Corporate Bhavan building during its operational life is very high mainly due to the following factors:

- Non-compliance of ECBC norms.
- High U-factor of Wall, Roof & Glass used in building envelope.
- High SHGC of glass used as glazing.
- High WWR

There is a tremendous scope of reducing the Carbon emissions by simply limiting the WWR value and reducing the U-factor of elements used in the building envelope. From the above table, it is evident that CO_2 emissions can be reduced by as high as 4200 tonnes during its 50 year operational life if the building would have complied with ECBC super criterion. In addition to reducing the carbon emissions, there are great financial benefits as the electricity bill will reduce significantly owing to reduced power consumption. Therefore, following the ECBC norms is a must to improve the Energy performance of the building & reducing the Carbon emissions due to the construction sector in India.

Summary Table for glass use from Carbon emission reduction point of view:		
	One time construction CO_2 emission increase impact	**Lifetime CO_2 emission increase impact due to increased EPI in air conditioned building**
Glass used internally	Can be taken up to a limit and for strictly for minimum compliance of bye Laws	Not applicable
Glass used in outer envelope for fenestration	As low as possible	Extremely high impact
Glass used in outer envelope for structural purpose	Not to be preferred at all	Still more impact from the no. 2 point above

<table>
<tr><th colspan="8">A typical absolute & percentage CO_2 calculation (in tonnes per sq. mtr.) based on 49 building reports made available:</th></tr>
<tr><td rowspan="7">Total lifetime carbon factor including construction</td><td rowspan="7">6.93 (100%)</td><td rowspan="4">One time construction carbon factor</td><td rowspan="4">0.99 (14.3%)</td><td>Steel</td><td>0.48</td><td colspan="2" rowspan="4"></td></tr>
<tr><td>Cement</td><td>0.30</td></tr>
<tr><td>Masonry</td><td>0.11</td></tr>
<tr><td>Other</td><td>0.11</td></tr>
<tr><td rowspan="3">Lifetime carbon factor for energy use (due to EPI)</td><td rowspan="3">5.94 (85.7%)</td><td>Due to energy uses other than air conditioning</td><td>3.27 (47%)</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Due to energy used for air conditioning</td><td rowspan="2">2.67 (38.5%)</td><td>Due to human heat load, computer and server load, light and fan picture load, infiltration load, other light power loads</td><td>1.07 (15.4%)</td></tr>
<tr><td>Due to building envelope</td><td>1.6 (23%)</td></tr>
</table>

Chapter 3

Recommendations for Reducing CO_2 emission

A. During initial construction Stage (weightage of 14.3% i.e. 1/7)

1. Considering that steel and cement contribute approximately 75-80% of the environmental impact in construction, CPWD should mandate carbon factor declaration through Environmental Product Declarations (EPDs) from manufacturers.

2. Efforts should be made to reduce carbon emissions from steel, aiming for a target carbon factor of 2 - 2.4 kg CO_2 per kg of steel. It is recommended to arrange a meeting with steel manufacturers to discuss and collaborate on achieving this goal.

3. Substituting burnt clay bricks with Autoclaved Aerated Concrete (AAC) blocks significantly reduces carbon emissions, as previously explained..

4. Based on the analysis of received data covering 15 lakh square meters, it is evident that aluminum contributes approximately 3.9% on average. Given that aluminum has a high carbon factor of 30, even slight adjustments in its usage can significantly impact total emissions. Therefore, efforts should be made to minimize the use of aluminum wherever possible to reduce carbon emissions effectively..

5. Based on the analysis of 40 buildings, it has been found that glass used for internal aesthetic and design purposes accounts for approximately 0.47% of the total. Therefore, there are no significant environmental concerns associated with its current usage for these purposes.

6. The use of glass in fenestration and structural glazing can have detrimental effects, especially in terms of the window to wall ratio and compliance with ECBC (Energy Conservation Building Code). These factors become crucial determinants in air-conditioned buildings, overshadowing other considerations..

B. Reducing Lifetime CO_2 emission (weightage of 85.7% i.e. 6/7)

1. Based on the significant impact observed from reducing Energy Performance Index (EPI) over a building's lifetime, implementing two controls is essential.

   a. ECBC compliance should be mandatory for every building.having window to wall ratio up to 20%.

b. ECBC Plus compliance should be mandatory for every building.having window to wall ratio 20%-40%.

c. ECBC Super compliance should be mandatory for every building having window to wall ratio more than 40%.

Figure—-Optimised WWR , Proposed Lecture Hall Complex JNU Campus, New Delhi

d. In exceptional circumstances where client departments specifically request a window to wall ratio exceeding 40%, efforts should be made to inform them about the potential disadvantages, including increased carbon emissions. Additionally, in such cases, the Solar Heat Gain Coefficient (SHGC) of the windows should be less than 0.20 (compared to ECBC's standard of 0.25), achieved through appropriate selection of shading factors and designing necessary projections.

   Suitable glasses meeting these specifications are currently available in the market.

e. Also Annexure-10 provides Saving in lifetime energy cost per sq. mtr if we convert a non ECBC to ECBC , Plus and super.

f. ECO Niwas Samhita should be made mandatory in respect of Residential buildings

g. It should be mandatory to cover the maximum part of roofs with solar panels, particularly promoting Building Integrated Solar Photovoltaic (BIPV) systems in accordance with government policies.

Figure—Building Integrated Solar Photovoltaic (BIPV) systems-Proposed Lecture Hall Complex, IIT Mandi

h. ECBC compliance should be removed from the GHAR (CPWD own rating system) compliance and ECBC compliance and certification should be done exclusively.

Assorted Recommendations

1. Geopolymer concrete offers significant environmental benefits compared to Portland concrete. It can reduce CO_2 emissions by approximately 25%, from 362 kg CO_2 per cubic meter for Portland concrete to 272 kg CO_2 per cubic meter for Geopolymer concrete. Additionally, the embedded energy in Geopolymer concrete is about 13% lower, decreasing from 1821 MJ per cubic meter in Portland concrete to 1592 MJ per cubic meter in Geopolymer concrete.

2. Sand procurement should be local.

3. It is crucial to assess the carbon emissions associated with fast-paced or emerging technologies before their adoption. A separate analysis should be conducted to evaluate the environmental impact, particularly focusing on CO_2-intensive aspects.

4. It is imperative to replace raw materials with recycled materials wherever feasible in construction projects. Construction and Demolition (C&D) plants offer a variety of recycled products such as paver blocks, Recycled Concrete Aggregates (RCA), Recycled Aggregates (RA), and Manufactured Sand (M-sand).

   To effectively utilize these materials, it is essential to analyze the economics and challenges associated with recycled C&D waste materials.

5. It is crucial to adopt a carbon-sensitive mindset from the planning stage of each project.. Carbon factors should be prioritized as essential parameters when evaluating building materials and construction technologies. An abstract detailing carbon emissions should be prepared and included in the Detailed Estimate or Detailed Project Report.

6. It should be mandatory for manufacturers, particularly in industries producing building materials such as cement and steel, to publish Environmental Product Declarations (EPDs). These documents would detail the embodied carbon emissions and other environmental impacts of their products. Manufacturers should be encouraged to prominently display EPDs on their products, especially for materials like steel and cement, which have significant contributions to embodied carbon emissions.

7. We may include carbon calculation in EPC.

8. Mandate steel use with minimum CO_2 criteria kg/kg.

9. It should be mandatory to implement roof gardening or cool roofs, covering a certain minimum percentage of rooftops. These initiatives aim to enhance energy efficiency, reduce urban heat island effects, and promote sustainable building practices.

10. Use of deciduous trees for shading on a large scale wherever possible.

11. The State Electrical Distribution Services Limited (SEDSL) plays a crucial role in incentivizing energy efficiency in large buildings. One of their initiatives is to link electricity charges to the actual achieved Energy Performance Index (EPI) for buildings exceeding 5000 square meters.

    Energy bill rebates are provided based on achieving lower EPIs, encouraging energy-efficient practices. This approach introduces a slab-based electricity billing system, similar to the existing models for unit consumption or improving power factor in installations. This system ensures that buildings with better energy performance benefit from reduced electricity rates, thus promoting sustainable energy use.

12. All projects should mandatorily integrate renewable energy sources, such as solar power, beyond merely fulfilling the Energy Conservation Building Code (ECBC) requirements. It is recommended to establish a dedicated committee to determine the extent to which each project should increase the installation of solar or other renewable energy systems.

    The committee would also be responsible for defining a minimum percentage of renewable energy that must be incorporated into each project. This initiative aims to enhance the overall proportion of renewable energy in the total electrical energy mix. By doing so, it will contribute to reducing the current CO_2 emission value of 0.71 kg per unit of electrical power, leading to a gradual decrease in overall emissions.

13. Use of biodiesel in DG sets up to a certain %.

14. A new initiative should mandate that every existing building above a certain plinth area, whether residential or non-residential, must comply with the Energy Conservation Building Code (ECBC). This drive includes retrofitting existing buildings to enhance energy efficiency by upgrading all electrical fittings, fixtures, appliances, especially air conditioning equipment, and increasing the insulation of building envelopes.

    To oversee this initiative, a dedicated committee should be established to specifically determine the requirements and guidelines for retrofitting existing buildings to meet ECBC standards.

15. Winter indoor heating and water heating should mandatorily be done using heat pumps, either completely or up to a specified minimum percentage. This requirement aims to enhance energy efficiency and reduce reliance on traditional heating methods.

16. There is significant potential for reducing construction mass through optimized structural design. Measures such as reducing beam or slab spans and increasing column density can result in substantial carbon savings.

17. Competent authority may take decision for Implementation of Work from home for all Govt and private jobs excluding the jobs requiring physical work. This will reduce the requirement of office buildings, heavy traffic, road infra etc.

18. Competent authority may take decision for Restrictions on use of Air-conditioning.

19. Encourage the use of ETAC (Evaporation type air cooling) rather making it a must for North India is desirable. This will drastically reduce the power consumption, environmental impact and enhance indoor air quality, subsequently improving human health.

20. Competent authority may take decision for Restrictions on meat production especially for export purposes.

21. Pedestrian and cycle friendly Roads to encourage use of cycle for short distance.

22. Improve the public transport system and reward the public transport users.

23. Competent authority may take decision for heavy restrictions on VIP culture and luxury life.

24. Restrictions on non-productive activities during night.

25. ECBC compliance should be a must for private constructions as well.

26. Restrictions on use of Glazing as facade rather than making compulsory the use of horticulture facade.

The following Recommendations were already sent earlier By MoHUA:

a. Direct States/ULBs to adopt ECBC in building byelaws,

b. Municipality to promote use of energy efficient pumps and street lights,

c. CPWD to aggressively take up electric cooking in office canteens.

The Point no a) and b) is already detailed above. The point no. c) is analyzed below:

1) To promote energy efficiency, the use of electric and induction cooking in canteens should be increased. Induction cookers are more than twice as energy-efficient as traditional electric cooking methods and significantly more efficient than gas cooking.

2) Cooking on an induction cooktop offers numerous benefits, primarily due to its energy efficiency. Induction cooktops require significantly less energy to heat as they transfer heat directly to the cookware, minimizing energy loss during the cooking process. By some estimates, induction cooktops can deliver up to 90% of the electromagnetic energy generated to the food in the pan, compared to as little as 38% for gas ranges.

3) Another advantage of induction cooktops is their speedy cooking times. Induction surfaces can boil water in about half the time it takes for gas, allowing meals to be prepared more quickly and efficiently.

4) Additionally, because induction cooktops transfer heat directly to the cookware, the surface itself does not get hot. This means if you touch it, you won't get burned. Any spills won't cook on the stovetop, making cleanup easier and safer.

5) Electric cooktops, often referred to as skillets, come with special equipment that includes electrical plugs and wires. While they offer convenience, their prices are relatively high compared to other cooking alternatives. One drawback is that electric cooktops can retain residual heat even after being turned off, which can be a consideration for safety and energy use..

Annexure 1

Global cumulative emissions and country-wise emissions

Country wise cumulative emission	
Country	**Cumulative emissions from 1850 to 2021 (in billion tonnes)**
USA	510
China	280
Russia	150
Brazil	120
Indonesia	100
Germany	90
India	60
UK, Japan, Canada	70 x 3 = 210
10 others	35 x 10 = 350
180 others	180 x 3 = 540
Grand total	2410

Temperature rise 1.09°C: Range 0.95 to 1.20°C from 1850-1900 (industrial period) to 2020

Country wise current emission yearly (out of total 58 BT CO_2e)		
Country	**Percentage contribution to CO_2e emission**	**Absolute contribution to CO_2e emission in Billion Tonnes**
China 2022	26%	15.1
US	12%	7.0
India	7%	4.1
EU	7%	4.1
Russia	4%	2.3
Brazil	3%	1.7
Japan	2%	1.2
Rest of World	37%	21.5
Total World	100%	57

Global emission year wise (in Billion Tonnes)	
Year	**Emissions (in billion tonnes)**
2030 (Anticipated)	62
2022	58
2021	40.8
2020	50.1
2019	52.4
2018	48.9
2017	32.5
2016	49.3
2015	47.0
2014	32.5
2013	35.3
2012	34
2011	33.1
2010	30.6
2000	25.2

Annexure 2

Sector Wise Global Greenhouse Gas emission

Globally, we emit around 56 billion tonnes of greenhouse gases each year from the World Research Institute. based on explanations provided in the IPCC's Fifth Assessment Report AR5) and a methodology paper published by the World Resources Institute.

Almost three-quarters of emissions come from energy use; almost one-fifth from agriculture and land use and the remaining 8% from industry and waste.Emissions come from many sectors: we need many solutions to decarbonize the economy. It is clear from this breakdown that a range of sectors and processes contribute to global emissions. This means there is no single or simple solution to tackle climate change. Focusing on electricity, or transport, or food, or deforestation alone is insufficient.

Even within the energy sector – which accounts for almost three-quarters of emissions – there is no simple fix. Even if we could fully decarbonize our electricity supply, we would also need to electrify all of our heating and road transport. And we'd still have emissions from shipping and aviation – which we do not yet have low-carbon technologies for – to deal with.

1.0. Energy (electricity, heat and transport): 73.2%

1.1. Energy use in industry: 24.2%

1.1.1. Iron and Steel (7.2%): energy-related emissions from the manufacturing of iron and steel.

1.1.2. Chemical & petrochemical (3.6%): energy-related emissions from the manufacturing of fertilizers, pharmaceuticals, refrigerants, oil and gas extraction, etc.

1.1.3.Food and tobacco (1%): energy-related emissions from the manufacturing of tobacco products and food processing (the conversion of raw agricultural products into their final products, such as the conversion of wheat into bread).

1.1.4. Non-ferrous metals: 0.7%: Non-ferrous metals are metals which contain very little iron: this includes aluminium, copper, lead, nickel, tin, titanium and zinc, and alloys such as brass. The manufacturing of these metals requires energy which results in emissions.

1.1.5. Paper & pulp (0.6%): energy-related emissions from the conversion of wood into paper and pulp.

1.1.6. Machinery (0.5%): energy-related emissions from the production of machinery.

1.1.7. Other industry (10.6%): energy-related emissions from manufacturing in other industries including mining and quarrying, construction, textiles, wood products, and transport equipment (such as car manufacturing).

1.2. Transport: 16.2%

This includes a small amount of electricity (indirect emissions) as well as all direct emissions from burning fossil fuels to power transport activities. These figures do not include emissions from the manufacturing of motor vehicles or other transport equipment – this is included in the previous point 'Energy use in Industry'.

1.2.1. Road transport (11.9%): emissions from the burning of petrol and diesel from all forms of road transport which includes cars, trucks, lorries, motorcycles and buses. Sixty percent of road transport emissions come from passenger travel (cars, motorcycles and buses); and the remaining forty percent from road freight (lorries and trucks). This means that, if we could electrify the whole road transport sector, and transition to a fully decarbonized electricity mix, we could feasibly reduce global emissions by 11.9%.

1.2.2. Aviation (1.9%): emissions from passenger travel and freight, and domestic and international aviation. 81% of aviation emissions come from passenger travel; and 19% from freight. From passenger aviation, 60% of emissions come from international travel, and 40% from domestic.

1.2.3. Shipping (1.7%): emissions from the burning of petrol or diesel on boats. This includes both passenger and freight maritime trips.

1.2.4. Rail (0.4%): emissions from passenger and freight rail travel.

1.2.5. Pipeline (0.3%): fuels and commodities (e.g. oil, gas, water or steam) often need to be transported (either within or between countries) via pipelines. This requires energy inputs, which results in emissions. Poorly constructed pipelines can also leak, leading to direct emissions of methane to the atmosphere – however, this aspect is captured in the category 'Fugitive emissions from energy production'.

1.3. Energy use in buildings: 17.5%

1.3.1. Residential buildings (10.9%): energy-related emissions from the generation of electricity for lighting, appliances, cooking etc. and heating at home.

1.3.2. Commercial buildings (6.6%): energy-related emissions from the generation of electricity for lighting, appliances, etc. and heating in commercial buildings such as offices, restaurants, and shops.

1.4. Unallocated fuel combustion (7.8%)

Energy-related emissions from the production of energy from other fuels including electricity and heat from biomass; on-site heat sources; combined heat and power (CHP); nuclear industry; and pumped hydroelectric storage.

1.5. Fugitive emissions from energy production: 5.8%

1.5.1. Fugitive emissions from oil and gas (3.9%): fugitive emissions are the often-accidental leakage of methane to the atmosphere during oil and gas extraction and transportation, from damaged or poorly maintained pipes. This also includes flaring – the intentional burning of gas at oil facilities. Oil wells can release gases, including methane, during extraction – producers often don't have an existing network of pipelines to transport it, or it wouldn't make economic sense to provide the infrastructure needed to effectively capture and transport it. But under environmental regulations they need to deal with it somehow: intentionally burning it is often a cheap way to do so.

1.5.2. Fugitive emissions from coal (1.9%): fugitive emissions are the accidental leakage of methane during coal mining.

1.6. Energy use in agriculture and fishing (1.7%)

Energy-related emissions from the use of machinery in agriculture and fishing, such as fuel for farm machinery and fishing vessels.

2.0. Direct Industrial Processes: 5.2%

2.1. Cement (3%)

Carbon dioxide is produced as a byproduct of a chemical conversion process used in the production of clinker, a component of cement. In this reaction, limestone ($CaCO_3$) is converted to lime (CaO), and produces CO_2 as a byproduct. Cement production also produces emissions from energy inputs – these related emissions are included in 'Energy Use in Industry'.

2.2. Chemicals & petrochemicals (2.2%)

Greenhouse gases can be produced as a byproduct from chemical processes – for example, CO_2 can be emitted during the production of ammonia, which is used for purifying water supplies, cleaning products, and as a refrigerant, and used in the production of many materials, including plastic, fertilizers, pesticides, and textiles. Chemical and petrochemical manufacturing also produces emissions from energy inputs – these related emissions are included in 'Energy Use in Industry'.

3.0. Waste: 3.2%

3.1. Wastewater (1.3%)

Organic matter and residues from animals, plants, humans and their waste products can collect in wastewater systems. When this organic matter decomposes it produces methane and nitrous oxide.

3.2. Landfills (1.9%)

Landfills are often low-oxygen environments. In these environments, organic matter is converted to methane when it decomposes.

4.0. Agriculture, Forestry and Land Use: 18.4%

Agriculture, Forestry and Land Use directly accounts for 18.4% of greenhouse gas emissions. The food system as a whole – including refrigeration, food processing, packaging, and transport – accounts for around one-quarter of greenhouse gas emissions. We look at this in detail here.

4.1. Grassland (0.1%)

When grassland becomes degraded, these soils can lose carbon, converting to carbon dioxide in the process. Conversely, when grassland is restored (for example, from cropland), carbon can be sequestered. Emissions here therefore refer to the net balance of these carbon losses and gains from grassland biomass and soils.

4.2. Cropland (1.4%)

Depending on the management practices used on croplands, carbon can be lost or sequestered into soils and biomass. This affects the balance of carbon dioxide emissions: CO_2 can be emitted when croplands are degraded; or sequestered when they are restored. The net change in carbon stocks is captured in emissions of carbon dioxide. This does not include grazing lands for livestock.

4.3. Deforestation (2.2%)

Net emissions of carbon dioxide from changes in forestry cover. This means reforestation is counted as 'negative emissions' and deforestation as 'positive emissions'. Net forestry change is therefore the difference between forestry loss and gain. Emissions are based on lost carbon stores from forests and changes in carbon stores in forest soils.

4.4. Crop burning (3.5%)

The burning of agricultural residues – leftover vegetation from crops such as rice, wheat, sugar cane, and other crops – releases carbon dioxide, nitrous oxide and methane. Farmers often burn crop residues after harvest to prepare land for the resowing of crops.

4.5. Rice cultivation (1.3%)

Flooded paddy fields produce methane through a process called ‘anaerobic digestion’. Organic matter in the soil is converted to methane due to the low-oxygen environment of water-logged rice fields. 1.3% seems substantial, but it’s important to put this into context: rice accounts for around one-fifth of the world’s supply of calories, and is a staple crop for billions of people globally.

4.6. Agricultural soils (4.1%)

Nitrous oxide – a strong greenhouse gas – is produced when synthetic nitrogen fertilizers are applied to soils. This includes emissions from agricultural soils for all agricultural products – including food for direct human consumption, animal feed, biofuels and other non-food crops (such as tobacco and cotton).

4.7. Livestock & manure (5.8%)

Animals (mainly ruminants, such as cattle and sheep) produce greenhouse gases through a process called ‘enteric fermentation’ – when microbes in their digestive systems break down food, they produce methane as a by-product. This means beef and lamb tend to have a high carbon footprint, and eating less is an effective way to reduce the emissions of your diet.

Nitrous oxide and methane can be produced from the decomposition of animal manures under low oxygen conditions. This often occurs when large numbers of animals are managed in a confined area (such as dairy farms, beef feedlots, and swine and poultry farms), where manure is typically stored in large piles or disposed of in lagoons and other types of manure management systems ‘Livestock’ emissions here include direct emissions from livestock only – they do not consider impacts of land use change for pasture or animal feed.

Classification 1: Summary of the above data (Sector Wise)

S. No.	Sector	%	Sub-sector	%		%
1	Energy	73.2	Energy use in Industry	24.2	Iron and steel	7.2
					Non-ferrous metals	0.7
					Chemical & Petrochemical	3.6
					Food & tobacco	1
					Paper & pulp	0.6
					Machinery	0.5
					Other industry	10.6
			Transport	16.2	Road Transport	11.9
					Aviation	1.9
					Shipping	1.7
					Rail	0.4
					Pipeline	0.3
			Energy use in buildings	17.5	Residential buildings	10.9
					Commercial	6.6
			Unallocated fuel combustion	7.8		
			Fugitive emissions from energy production	5.8		
			Energy in Agriculture & Fishing	1.7		
2	Industry	5.2	Cement	3		
			Chemicals	2.2		
3	Waste	3.2	Wastewater	1.3		
			Landfills	1.9		
4	Agriculture, Forestry & Land Use	18.4	Grassland	0.1		
			Cropland	1.4		
			Deforestation	2.2		
			Crop burning	3.5		
			Rice cultivation	1.3		
			Agricultural soils	4.1		
			Livestock & manure	5.8		
	Grand Total	**100**	**Grand Total**	**100**		

Classification 2: Type of end use wise		
S. No.	**Final use**	**%**
1	El./Heat	32%
2	Manufacturing & Constn.	13%
3	Industry	6%
4	Fugitive emission	5%
5	Water	3%
6	Transport	15%
7	Agriculture	11%
8	Other	9%
9	LU & Forestry	6%
10	Grand Total	100%

Classification 3 : Sub sector wise				
S. No.	**Sector**	**%**	**Sub-sector**	**%**
1	Industry	29	Oil & Gas	6
			Iron & Steel	5
			Cement	5
			Chemicals	4
			Coal mining	2
			Refinery	1
			Other industries	6
2	Electricity	29	Coal	21
			Natural Gas	7
			Oil	1
3	Agriculture Land Use & Wastes	20	Live stock	7
			Crops	6
			Landfills & waste	4
			LU & Forests	2
			Agricultural fuel combustion	1
4	Transport	15	Roads	12
			Ships	2
			Aviation	1
5	Buildings	7	Residential	4
			Refrigerants	2
			Commercial	1
	Grand total	**100**	**Grand total**	**100**

Annexure 3

Major Gases and their Global Warming Potential

Major Gases of GHG and GWP

Major Long –Lived Greenhouse Gases and Their Characteristics are listed in the table below:

Greenhouse Gas	How it's produced	Average lifetime in the atmosphere	100-year global warming potential
Carbon Dioxide	Emitted primarily through the burning of fossil fuels (oil, natural gas, and coal), solid waste and trees and wood products. Changes in land use also play a role. Deforestation and soil degradation add carbon dioxide to the atmosphere, while forest regrowth takes it out of the atmosphere.	See below	1
Methane	Emitted during the production and transport of oil and natural gas as well as coal. Methane emissions also result from livestock and agricultural practices and from the anaerobic decay of organic waste in municipal solid waste landfills.	12.4 years	28-36
Nitrous Oxide	Emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste.	121 years	265-298
Fluorinated gases	A group of gases that contain fluorine, including hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride among other chemicals. These gases are emitted from a variety of industrial processes and commercial and household uses and do not occur naturally. Sometimes used as substitutes for ozone-depleting substances such as chlorofluorocarbons.	A few weeks to thousand of years	Varies (the highest is sulfur hexafluoride at 23,500)

This table shows 100-year global warming potentials which describe the effects that occur over a period of 100 years after a particular mass of a gas is emitted. Global warming potentials and lifetimes come from Table 8.A.1 of the intergovernmental Panel on Climate Change's Fifth Assessment Report, Working Group contribution.

*Carbon dioxide's lifetime cannot be represented with a single value because the gas is not destroyed over time, but instead moves among different parts of the ocean-atmosphere-land system. Some of the excess carbon dioxide is absorbed quickly (for example by the ocean surface) but some will remain in the atmosphere for thousands of years due in part to the very slow process by which carbon is transferred to ocean sediments.

** The lifetimes shown for methane and nitrous oxide are perturbation lifetimes which have been used to calculate the global warming potentials shown here.

In contrast, a molecule of water vapor stays in the atmosphere just nine days, on average. It then gets recycled as rain or snow. Its amounts don't accumulate.

Global warming potential

Global warming potential (GWP) is the heat absorbed by any greenhouse gas in the atmosphere, as a multiple of the heat that would be absorbed by the same mass of carbon dioxide (CO_2). GWP is 1 for CO_2. For other gases it depends on the gas and the time frame.

Carbon dioxide equivalent (CO_2 eq or CO_2-e) is calculated from GWP. For any gas, it is the mass of CO_2 that would warm the earth as much as the mass of that gas. Thus it provides a common scale for measuring the climate effects of different gases. It is calculated as GWP times the mass of the other gas.

Methane has GWP (over 100 years) of 27.9 meaning that, for example, a leak of a tonne of methane is equivalent to emitting 27.9 tonnes of carbon dioxide. Similarly a tonne of nitrous oxide, from manure for example is equivalent to 273 tonnes of carbon dioxide.

Value

Carbon dioxide is the reference. It has a GWP of 1 regardless of the time period used. CO_2 emissions cause increases in atmospheric concentrations of Cos that will last thousands of years. Estimates of GWP values over 20, 100 and 500 years are periodically compiled and reviewed in reports from the Intergovernmental Panel on Climate Change:

1. SAR (1995)
2. TAR (2001)
3. AR4 (2007)
4. AR5 (2013)
5. AR6 (2021)

Though recent reports reflect more scientific accuracy, countries and companies continue to use SAR and AR4 values for reasons of comparison in their emission reports. AR5 has skipped 500 year values but introduced GWP estimations including the climate-carbon feedback with a large amount of uncertainty.

GWP	Lifetime (years)	Global warming potential, GWP		
		20 years	100 years	500 years
Carbon tetrafluoride (CF_4 / PFC-14)	50,000	4,880	6,630	11,200
CFC-11 (chlorofluorocarbon)	52.0	6,900	4,660	1,620
HFC-23 (hydrofluorocarbon)	222	12,000	14,800	12,200
HFC-134a (hydrofluorocarbon)	14.0	3,710	1,300	435
Hydrogen (H_2)	4–7	33 (20-44)	11 (6–16)	-
Methane (CH_4)	11.8	56	21	6.5
Nitrous oxide (N_2O)	109	280	310	170
Sulfur hexafluoride (SF_6)	3,200	16,300	22,800	32,600

The IPCC lists many other substances not shown here. Some have high GWP but only a low concentration in the atmosphere. The values given in the table assume the same mass of compound is analyzed; different ratios will result from the conversion of one substance to another. For instance, burning methane to carbon dioxide would reduce the global warming impact, but by a smaller factor than 25:1 because the mass of methane burned is less than the mass of carbon dioxide released (ratio 1:2.74). For a starting amount of 1 tonne of methane, which has a GWP of 25, after combustion there would be 2.74 tonnes of CO_2, each tonne of which has a GWP of 1. This is a net reduction of 22.26 tonnes of GWP, reducing the global warming effect by a ratio of 25:2.74 (approximately 9 times).

Importance of time horizon

A substance's GWP depends on the number of years (denoted by a subscript) over which the potential is calculated. A gas which is quickly removed from the atmosphere may initially have a large effect, but for longer time periods, as it has been removed, it becomes less important. Thus methane has a potential of 25 over 100 years (GWP_{100} = 25) but 86 over 20 years (GWP_{20} = 86); conversely sulfur hexafluoride has a GWP of 22,800 over 100 years but 16,300 over 20 years (IPCC Third Assessment Report). The GWP value depends on how the gas concentration decays over time in the atmosphere. This is often not precisely known and hence the values should not be considered exact. For this reason when quoting a GWP it is important to give a reference to the calculation.

The GWP for a mixture of gases can be obtained from the mass-fraction-weighted average of the GWPs of the individual gases. Commonly, a time horizon of 100 years is used by regulators.

Water vapour

Water vapour does contribute to anthropogenic global warming, but as the GWP is defined, it is negligible for H_2O: an estimate gives a 100-year GWP between -0.001 and 0.0005.

H_2O can function as a greenhouse gas because it has a profound infrared absorption spectrum with more and broader absorption bands than CO_2. Its concentration in the atmosphere is limited by air temperature, so that radiative forcing by water vapour increases with global warming (positive feedback). But the GWP definition excludes indirect effects. GWP definition is also based on emissions, and anthropogenic emissions of water vapour (cooling towers, irrigation) are removed via precipitation within weeks, so its GWP is negligible.

Carbon dioxide equivalent

Carbon dioxide equivalent (CO_2e or CO_2eq or CO_2-e) of a quantity of gas is calculated from its GWP. For any gas, it is the mass of CO_2 which would warm the earth as much as the mass of that gas. Thus it provides a common scale for measuring the climate effects of different gases. It is calculated as GWP multiplied by the mass of the other gas. For example, if a gas has GWP of 100, two tonnes of the gas have CO_2e of 200 tonnes, and 9 tonnes of the gas has CO_2e of 900 tonnes.

On a global scale, the warming effects of one or more greenhouse gases in the atmosphere can also be expressed as an equivalent atmospheric concentration of CO_2. CO_2e can then be the atmospheric concentration of CO_2 which would warm the earth as much as a particular concentration of some other gas or of all gases and aerosols in the atmosphere. For example, CO_2e of 500 parts per million would reflect a mix of atmospheric gases which warm the earth as much as 500 parts per million of CO_2 would warm it. Calculation of the equivalent atmospheric concentration of CO_2 of an atmospheric greenhouse gas or aerosol is more complex and involves the atmospheric concentrations of those gases, their GWPs, and the ratios of their molar masses to the molar mass of CO_2.

CO_2e calculations depend on the time-scale chosen, typically 100 years or 20 years since gases decay in the atmosphere or are absorbed naturally, at different rates.

Annexure 4

Life-cycle greenhouse gas emissions of Electrical Energy Sources

Greenhouse gas emissions are one of the environmental impacts of electricity generation. Measurement of life-cycle greenhouse gas emissions involves calculating the global warming potential of energy sources through life-cycle assessment. These are usually sources of only electrical energy but sometimes sources of heat are evaluated. The findings are presented in units of global warming potential per unit of electrical energy generated by that source. The scale uses the global warming potential unit, the carbon dioxide equivalent (CO_2e), and the unit of electrical energy, the kilowatt hour (kWh). The goal of such assessments is to cover the full life of the source, from material and fuel mining through construction to operation and waste management.

In 2014, the Intergovernmental Panel on Climate Change harmonized the carbon dioxide equivalent (CO_2e) findings of the major electricity generating sources in use worldwide. This was done by analyzing the findings of hundreds of individual scientific papers assessing each energy source. Coal is by far the worst emitter, followed by natural gas, with solar, wind and nuclear all low-carbon. Hydropower, biomass, geothermal and ocean power may generally be low-carbon, but poor design or other factors could result in higher emissions from individual power stations.

For all technologies, advances in efficiency, and therefore reductions in CO_2e since the time of publication, have not been included. For example, the total life cycle emissions from wind power may have lessened since publication. Similarly, due to the time frame over which the studies were conducted, nuclear Generation II reactor's CO_2e results are presented and not the global warming potential of Generation III reactors. Other limitations of the data include: a) missing life cycle phases, and, b) uncertainty as to where to define the cut-off point in the global warming potential of an energy source. The latter is important in assessing a combined electrical grid in the real world, rather than the established practice of simply assessing the energy source in isolation.

Annexure 5

Global Warming Potential of Selected Electricity Sources

Life-cycle greenhouse gas emissions of electricity supply technologies, median values calculated by IPCC.

Life cycle CO_2 equivalent (including albedo effect) from selected electricity supply technologies according to IPCC 2014. Arranged by decreasing median (gCO_2eq/kWh) values.

Technology	Min.	Median	Max.
Currently commercially available technologies			
Coal – PC	740	820	910
Gas – combined cycle	410	490	650
Biomass – Dedicated	130	230	420
Solar PV – Utility scale	18	48	180
Solar PV – rooftop	26	41	60
Geothermal	6.0	38	79
Concentrated solar power	8.8	27	63
Hydropower	1.0	24	2200[1]
Wind Offshore	8.0	12	35
Nuclear	3.7	12	110
Wind Onshore	7.0	11	56
Pre-commercial technologies			
Ocean (Tidal and wave)	5.6	17	28

Annexure 6

IPCC 6th Assessment Report 2022

- Paris temp goal was 1.5^0C till 2100.
- Current store is 3000 – 4000 BT of Carbon
- Chances of 4^0C increase by 2100 are 50 – 70%.
- Potentially releasing 11 – 200 BT of carbon from Arctic alone (MC)
- From Scenarios
  - Very likely to be exceeded → High GHG
  - Very likely to be exceeded → Intermediate to High
  - More likely than not to be exceeded → low GHG
  - More likely than not to be reached on very low GHG.
- RFC = Reason for concern
- MC = Medium confidence
- SRM = Solar Radiation Modification
- With very low GHG it is likely global surface temp would decline back to below $1\text{-}5^0$C toward and of 21^{st} century with temporary overshoot of 0.1^0C
- 8 lakh years B.C. we have CO_2 data but before it is just an educated guess.
- Venus has 96% of carbon in its air so steady state temp is 500^0C and Mars 95% but a very thin layer with -60^0C Steady state because of its distance.
- Air – 78% N, 21% O_2 , 0.95% Argon.

Kyoto Protocol and UNFCCC

Under the Kyoto Protocol, in 1997 the Conference of the Parties standardized international reporting, by deciding that the values of GWP calculated for the IPCC Second Assessment Report were to be used for converting the various greenhouse gas emissions into comparable CO_2 equivalents. After some intermediate updates, in 2013 this standard was updated by the Warsaw meeting of the UN Framework Convention on Climate Change (UNFCCC, decision number 24/CP.19) to require using a new set of 100-year GWP values. They published these values in Annex III, and they took them from the IPCC Fourth Assessment Report, which had been published in 2007. Those 2007 estimates are still used for international comparisons through 2020, although the latest research on warming effects has found other values, as shown in the tables above. Though recent reports reflect more scientific accuracy, countries and companies continue to use the IPCC Second Assessment Report (SAR) and IPCC Fourth Assessment Report values for reasons of comparison in their emission reports. The IPCC Fifth Assessment Report has skipped the 500-year values but introduced GWP estimations including the climate-carbon feedback (f) with a large amount of uncertainty.

Annexure 7

Important facts, Figures and Comments

- In order to limit climate change below 2°C, following is the Global CO_2 budget along with its respective likelihood of achieving success:
  - 1150 bn tonnes with 50% likelihood
  - 950 bn tonnes with 67% likelihood
  - 800 bn tonnes with 83% likelihood
- In 2022, 54.6 bn tonnes of GHGs (CO_2e) were released on planet Earth. Following is the contribution of top 3 GHG emitters in the world:
  - China: 13.7 bn tonnes
  - USA: 5.9 bn tonnes
  - India: 3.9 bn tonnes
- In FY22, according to National Accounts Statistics published by the Ministry of Statistics and Program Implementation (MOSPI), the contribution of the construction sector to India's GDP was 8.2%. (7.9% in FY20)
- According to India's Third National Communications to the United Nations Framework Convention on Climate Change (UNFCCC), India's buildings and construction sector contributed to about 17% of the nation's total GHG emissions in 2019, where:
  - 10% was the contribution of operational carbon emitted by residential and commercial buildings.
  - And the remaining 7% was the contribution of embodied carbon.
- Therefore, it can be inferred that the yearly contribution of **embodied** and **operational** carbon in the GHG emissions by buildings and construction sector is 40% and 60% respectively.

Indian Construction (Residential and Non-residential Scenario)

1.	Total construction per annum	800 million sq. mtr.
2.	Average carbon factor	350 gm per sq. mtr.
3.	Total Carbon emission	240 million tonnes (7% of total 3900 MT)
4.	Total current Asset	8208 million sq. mtr
5.	Gross average EPI	67 Unit (kWh) per sq. mtr.
6.	Total energy used	8.208 x 67 = 550 Billion units (33% of 1620 billion unit)
7.	Total Carbon emission	390 million tonnes (10% of total 3900 MT)

Factors for Complete lifecycle of building

1. Raw material extraction and procession
2. Manufacture of building materials
3. Transport to construction site
4. Utilization in construction of building
5. Operational use of building
6. Refurbishment & reuse of building
7. Demolition at the end of life
8. Recycling and demolition of recovered materials

Air constituents

N	81%	CH_4	1.8 ppm
O	21%	Krypton	1.1 ppm
Argon	0.93%	N_2O	0.3 ppm
CO_2	400 ppm	H_2	0.5 ppm
Neon	18 ppm	Ozone	0.01 ppm
He	5.2 ppm		

Emission by Gas, 2010

a) CO_2 65% (fossil fuel and industrial processing)

b) CO_2 11% (forestry and other LU)

c) CO_2 16%

d) NO_2 6%

e) F-gases 2%
(Fluorinated Greenhouse gases)

Note: Solar power generation / rooftop solar whatever be the method the main purpose has to be to reduce the primary energy demand like if one building is designed and operated at 180 EPI and solar power generation is say 90 units per sq. mtr. Per year, then it is better to design and operate same building which is 120 EPI and 30 EPI solar power as in both the cases the money paid for electricity by owner of building will be for 90 EPI but environmentally 60 extra EPI energy shall be produced and with CO_2 generation of 0.71 kg / unit of electrical power, for 10,000 sq. mtr. building for 50 years of life the difference of CO_2 would be (60 x 10 x 0.77 x 50 yrs / tonne) **(23100 tonnes)** over life cycle.

Annexure 8

Embedded Carbon and Embodied Energy of Construction Material

Material	Energy MJ/kg	Carbon factor kg of CO_2/kg	Material density in kg/m^3
Aggregate	0.083	0.0048	2240
Concrete (1:1.5:3)	1.11	0.159	2400
Bricks (common)	3	0.24	1700
Concrete block (Medium density)	0.67	0.073	1450
Aerated block	3.5	0.3	750
Limestone block	0.85		2180
Marble	2	0.116	2500
Cement mortar (1:3)	1.33	0.208	
Steel (general, av. recycled content)	20.1	1.37	7800
Stainless steel	56.7	6.15	7850
Timber (general, excludes sequestration)	8.5	0.46	480–720
Glue laminated timber	12	0.87	
Cellulose insulation (loose fill)	0.94–3.3		43
Cork insulation	26		160
Glass fiber insulation (glass wool)	28	1.35	12
Flax insulation	39.5	1.7	30
Rockwool (slab)	16.8	1.05	24
Expanded Polystyrene insulation	88.6	2.55	15–30
Polyurethane insulation (rigid foam)	101.5	3.48	30
Wool (recycled) insulation	20.9		25
Straw bale	0.91		100–110
Mineral fiber roofing tile	37	2.7	1850
Slate	0.1–1.0	0.006–0.058	1600
Clay tile	6.5	0.45	1900

Aluminium (general & incl 33% recycled)	155	8.24	2700
Bitumen (general)	51	0.38–0.43	
Medium-density fibreboard	11	0.72	680–760
Plywood	15	1.07	540–700
Plasterboard	6.75	0.38	800
Gypsum plaster	1.8	0.12	1120
Glass	15	0.85	2500
PVC (general)	77.2	2.41	1380
Vinyl flooring	65.64	2.92	1200
Terrazzo tiles	1.4	0.12	1750
Ceramic tiles	12	0.74	2000
Wool carpet	106	5.53	
Wallpaper	36.4	1.93	
Vitrified clay pipe (DN 500)	7.9	0.52	
Iron (general)	25	1.91	7870
Copper (average incl. 37% recycled)	42	2.6	8600
Lead (incl 61% recycled)	25.21	1.57	11340
Ceramic sanitary ware	29	1.51	
Paint - Water-borne	59	2.12	
Paint - Solvent-borne	97	3.13	

Photovoltaic (PV) Cells Type	Energy MJ per m^2	Energy kWh per m^2	Carbon kg CO_2 per m^2
Monocrystalline (average)	**4750**	**1319.5**	**242**
Polycrystalline (average)	**4070**	**1130.5**	**208**
Thin film (average)	**1305**	**362.5**	**67**

Annexure 9

R-Factor of Insulating and other Construction Material

R-Value (I/U) of Building Materials		
Material	**R/Inch**	**R/Thickness**
Insulation Materials		
Fiberglass Batt	3.14	
Rock Wool Batt	3.14	
Air entrained Concrete	3.90	
Urea terpolymer foam	4.48	
Rigid fiberglass (>4 lb/ft^2)	4.00	
Expanded Polystyrene (beadboard)	4.00	
Extruded Polystyrene	5.00	
Polyurethane (foamed-in-place)	6.25	
Polyisocyanurate (foil-faced)	7.20	
Construction Materials		
Concrete Block 8 inch		1.11
Brick 4 inch common		0.80
Brick 4 inch face		0.44
Cedar Logs and Lumber	1.33	
Sheathing Materials		
Plywood	1.25	
1/2 inch		0.63
3/4 inch		0.94
Fiberboard	2.64	
1/2 inch		1.32
Fiberglass (3/4 inch)		3.00
(1 inch)		4.00
(1 1/2 inch)		6.00
Extruded Polystyrene (3/4 inch)		3.75
(1 inch)		5.00
Foil-faced Polyisocyanurate (3/4 inch)		5.40
(1 inch)		7.20
Siding Materials		
Hardboard (1/2 inch)		0.34

Plywood (5/8 inch)		0.77
Brick 4 inch		0.44
Interior Finish Materials		
Gypsum Board (drywall 1/2 inch)		0.45
Paneling (3/8 inch)		0.47
Flooring Materials		
Plywood	1.25	
Particle Board (underlayment)	1.31	
Hardwood Flooring	0.91	
Tile, Linoleum		0.05
Carpet (fibrous pad)		2.08
(rubber pad)		1.23
Roofing Materials		
Asphalt Shingles		0.44
Wood Shingles		0.97
Windows		
Single Glass		0.91
w/storm		2.00
Double insulating glass (3/16 inch) air space		1.61
(1/4 inch air space)		1.69
(1/2 inch air space)		2.04
(w/suspended film)		2.77
(w/suspended film and low-E)		4.05
Triple insulating glass (1/4 inch air spaces)		2.56
(1/2 inch air spaces)		3.23
Addition for tight fitting drapes or shades, or closed blinds		0.29
Doors		
Wood Hollow Core Flush (1 3/4 inch)		2.17
Solid Core Flush (1 3/4 inch)		3.03
Solid Core Flush (2 1/4 inch)		3.70
Panel Door w/ 7/16 inch Panels (1 3/4 inch)		1.85
Metal insulating (2 inch w/ urethane)		15.00
Air Films		
Interior Ceiling		0.61
Interior Wall		0.68
Exterior		0.17
Air Spaces		
1/2 inch to 4 inch approximately		1.00

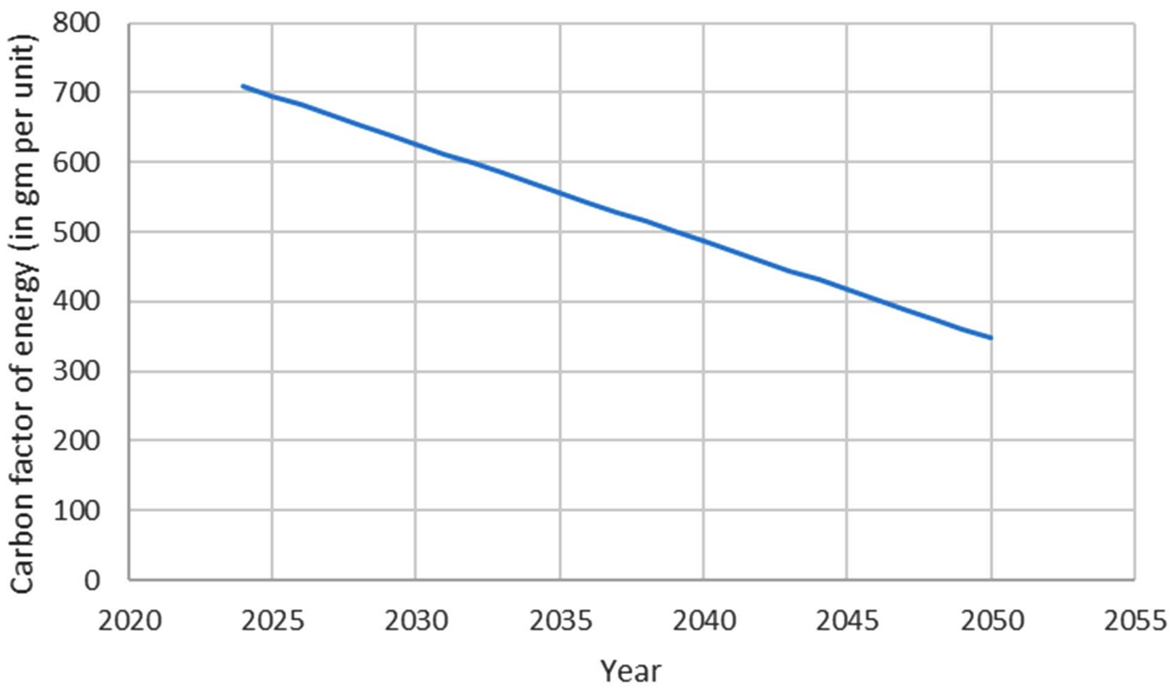
Annexure 10

Calculated Energy Sources Distribution and their Carbon Impact for Present and Future

Source		Assumed U/KW	CO_2 emitted (in gm/unit)	Calculations for the year 2024					Calculations for the year 2050				
Category	Sub-category			Installed capacity (in MW)	Calculated power (in Million unit)	Total CO_2 emitted (in kg)	% of total power	% of total Energy	Installed capacity (in MW)	Calculated power (in Million unit)	Total CO_2 emitted (in kg)	% of total power	% of total Energy
1	2	3	4	5	6	7	8	9	10	11	12	13	14
					Col.(3)xCol.(5)	Col.(4)xCol.(6)				Col.(3)xCol.(10)	Col.(4)xCol.(11)		
Fossil	Coal	5,600	1050	212000	1187200	1246560	51	67	225000	1260000	1323000	13.02	28
	Gas	4,000	490	24,824	99296	48655	6	6	50000	200000	98000	2.89	4
	Diesel	2,000	1400	589	1178	1649	0	0	600	1200	1680	0.03	0
Hydro	Hydro	3,460	20	46,850	162101	3242	11	9	70000	242200	4844	4.05	5
Renewable	Wind	3,500	15	42,600	149100	2236	10	8	400000	1400000	21000	23.15	31
	Solar	1,250	100	66,780	83475	8347	16	5	900000	1125000	112500	52.1	25
	Bio-Power-Cogen	2,000	230	10,248	20496	4714	2	1	30000	60000	13800	1.74	1
	Waste to Energy	2,000	200	554	1108	222	0	0	2000	4000	800	0.12	0
	Small Hydro	3,000	24	4,944	14832	356	1	1	10000	30000	720	0.58	1
Nuclear	Nuclear	6,000	20	6,780	40680	814	2	2	40000	240000	4800	2.32	5
Grand Total		**32,810**		**416169**	**1759466**	**1316795**	**99**	**99**	**1727600**	**4562400**	**1581144**	**100**	**100**

Year	Assumed carbon factor of energy
2024	710
2030	626
2035	556
2040	487
2045	417
2050	347
Average 2024 to 2050	528.5

Assumed variation of Carbon factor of energy from 2024 to 2050



Saving in lifetime energy cost per sq. mtr. if we convert a non ECBC to ECBC basic, ECBC Plus and ECBC super

The following Table shows the life time saving in four cases: ECBC non-compliant, ECBC basic, ECBC Plus and ECBC Super. Basic assumptions are 10,000 sq. mtr. of area, cost as Rs. 40,000 per sq. mtr., WWR = 20% and life of building as 60 years.

Fixed AC Load (in TR)	WWR (in %)	ECBC Compliance	Building Envelope Heat Gain (in kW)	Building Envelope Tonnage (in TR)	Total Tonnage (in TR)	A.C. Units used per year (in kWh)	Fixed Non AC Energy per year (in kWh)	Total Energy per year (in kWh)	Effective EPI (in kWh/ sq.mtr. per annum)	Total units consumed in 60 years	Total cost in 60 years (in Crores)	Total El. Cost for 60 years (in Rs. per sq.mtr.)
1	2	3	4	5	6	7	8	9	10	11	12	13
					Col.(1)+Col.(5)	Col.(6)x1440		Col.(7)+Col.(8)	Col.(9)/10000	Col.(9)x60	Col.(11)x8	Col.(12)x1000
121	10	ECBC Super	36	10.29	131.29	189051.4	382277.3	571328.7	57.13	34279721	27.42	27423
121	10	ECBC Plus	46	13.14	134.14	193165.7	382277.3	575443	57.54	34526578	27.62	27621
121	10	ECBC Basic	58	16.57	137.57	198102.9	382277.3	580380.1	58.03	34822807	27.85	27858
121	10	Non ECBC	261	74.57	195.57	281622.9	382277.3	663900.1	66.39	39834007	31.86	31867
121	15	ECBC Super	43	12.29	133.29	191931.4	382277.3	574208.7	57.42	34452521	27.56	27562
121	15	ECBC Plus	56	16.00	137.00	197280	382277.3	579557.3	57.95	34773436	27.81	27818
121	15	ECBC Basic	70	20.00	141.00	203040	382277.3	585317.3	58.53	35119036	28.09	28095
121	15	Non ECBC	291	83.14	204.14	293965.7	382277.3	676243	67.62	40574578	32.45	32459
121	20	ECBC Super	51	14.57	135.57	195222.9	382277.3	577500.1	57.75	34650007	27.72	27720
121	20	ECBC Plus	66	18.86	139.86	201394.3	382277.3	583671.5	58.36	35020293	28.01	28016

121	20	ECBC Basic	82	23.43	144.43	207977.1	382277.3	590254.4	59.02	35415264	28.33	28332
121	20	Non ECBC	320	91.43	212.43	305897.1	382277.3	688174.4	68.81	41290464	33.03	33032
121	30	ECBC Super	66	18.86	139.86	201394.3	382277.3	583671.5	58.36	35020293	28.01	28016
121	30	ECBC Plus	85	24.29	145.29	209211.4	382277.3	591488.7	59.14	35489321	28.39	28391
121	30	ECBC Basic	105	30.00	151.00	217440	382277.3	599717.3	59.97	35983036	28.78	28786
121	30	Non ECBC	378	108.00	229.00	329760	382277.3	712037.3	71.20	42722236	34.17	34177
121	40	ECBC Super	81	23.14	144.14	207565.7	382277.3	589843	58.98	35390578	28.31	28312
121	40	ECBC Plus	105	30.00	151.00	217440	382277.3	599717.3	59.97	35983036	28.78	28786
121	40	ECBC Basic	128	36.57	157.57	226902.9	382277.3	609180.1	60.91	36550807	29.24	29240
121	40	Non ECBC	436	124.57	245.57	353622.9	382277.3	735900.1	73.51	44154007	35.32	35323.21

So it may be concluded that

1. There is a saving in designing the building as ECBC compliant vs ECBC non compliant by a margin of roughly 6000 rs per sq. mtr. over lifetime assumption of 60yrs

Annexure 11

Conventional vs ECBC, ECBC Plus & ECBC Super

ECBC Basic (for typical WWR = 10%)						
Type of Envelope	U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)	Temp difference in ^{0}C (Solar heat gain in case of glass)	W/Sq.mtr.	Rough Area in sq.mtr.	Net heat gain In Watts	Net % of contribution
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Col.(2) x Col.(3)		Col.(4) x Col.(5)	
Roof	0.33	25	8.25	2000	16,500	28.2
Wall	0.4	15	6	2835	17,010	29.1
Glass U value gain	2	15	30	315	9,450	16.2
Glass SHGC	0.27	182	49.14	315	15,479.1	26.5
Total					**58,439.1**	**100**

ECBC Plus (for typical WWR = 10%)						
Type of Envelope	U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)	Temp difference in ^{0}C (Solar heat gain in case of glass)	W/Sq.mtr.	Rough Area in sq.mtr.	Net heat gain In Watts	Net % of contribution
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Col.(2) x Col.(3)		Col.(4) x Col.(5)	
Roof	0.2	25	5	2000	10,000	21.8
Wall	0.34	15	5.1	2835	14,458.5	31.5
Glass U value gain	1.5	15	22.5	315	7,087.5	15.5
Glass SHGC	0.25	182	45.5	315	14,332.5	31.2
Total					**45,878.5**	**100**

ECBC Super (for typical WWR = 10%)						
Type of Envelope	U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)	Temp difference in ^{0}C (Solar heat gain in case of glass)	W/Sq.mtr.	Rough Area in sq.mtr.	Net heat gain In Watts	Net % of contribution
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Col.(2) x Col.(3)		Col.(4) x Col.(5)	
Roof	0.2	25	5	2000	10,000	28.1
Wall	0.22	15	3.3	2835	9,355.5	26.3
Glass U value gain	1	15	15	315	4,725	13.3
Glass SHGC	0.2	182	36.4	315	11,466	32.3
Total					35,546.5	100

Non ECBC Compliant Conventional Building (for typical WWR = 10%)						
Type of Envelope	**U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)**	**Temp difference in ^{0}C (Solar heat gain in case of glass)**	**W/Sq.mtr.**	**Rough Area in sq.mtr.**	**Net heat gain In Watts**	**Net % of contribution**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
			Col.(2) x Col.(3)		**Col.(4) x Col.(5)**	
Roof	1.8	25	45	2000	90,000	34.4
Wall	2.4	15	36	2835	1,02,060	39.0
Glass U value gain	5	15	75	315	23,625	9.0
Glass SHGC	0.8	182	145.6	315	45,864	17.5
Total					**2,61,549**	**100**

ECBC Basic (for typical WWR = 15%)						
Type of Envelope	**U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)**	**Temp difference in ^{0}C (Solar heat gain in case of glass)**	**W/Sq.mtr.**	**Rough Area in sq.mtr.**	**Net heat gain In Watts**	**Net % of contribution**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
			Col.(2) x Col.(3)		**Col.(4) x Col.(5)**	
Roof	0.33	25	8.25	2000	16,500	23.5
Wall	0.4	15	6	2675	16,050	22.9
Glass U value gain	2	15	30	475	14,250	20.3
Glass SHGC	0.27	182	49.14	475	23,341.5	33.3
Total					**70,141.5**	**100**

ECBC Plus (for typical WWR = 15%)						
Type of Envelope	**U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)**	**Temp difference in ^{0}C (Solar heat gain in case of glass)**	**W/Sq.mtr.**	**Rough Area in sq.mtr.**	**Net heat gain In Watts**	**Net % of contribution**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
			Col.(2) x Col.(3)		**Col.(4) x Col.(5)**	
Roof	0.2	25	5	2000	10,000	17.9
Wall	0.34	15	5.1	2675	13,642.5	24.4
Glass U value gain	1.5	15	22.5	475	10,687.5	19.1
Glass SHGC	0.25	182	45.5	475	21,612.5	38.6
Total					**55,942.5**	**100**

ECBC Super (for typical WWR = 15%)						
Type of Envelope	**U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)**	**Temp difference in ^{0}C (Solar heat gain in case of glass)**	**W/Sq.mtr.**	**Rough Area in sq.mtr.**	**Net heat gain In Watts**	**Net % of contribution**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
			Col.(2) x Col.(3)		**Col.(4) x Col.(5)**	
Roof	0.2	25	5	2000	10,000	23.1
Wall	0.22	15	3.3	2675	8,827.5	20.4
Glass U value gain	1	15	15	475	7,125	16.5
Glass SHGC	0.2	182	36.4	475	17,290	40.0
Total					**43,242.5**	**100**

Non ECBC Compliant Conventional Building (for typical WWR = 15%)						
Type of Envelope	**U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)**	**Temp difference in ^{0}C (Solar heat gain in case of glass)**	**W/Sq.mtr.**	**Rough Area in sq.mtr.**	**Net heat gain In Watts**	**Net % of contribution**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
			Col.(2) x Col.(3)		**Col.(4) x Col.(5)**	
Roof	1.8	25	45	2000	90,000	31.0
Wall	2.4	15	36	2675	96,300	33.0
Glass U value gain	5	15	75	475	35,625	12.2
Glass SHGC	0.8	182	145.6	475	69,160	23.8
Total					**2,91,085**	**100**

ECBC Basic (for typical WWR = 30%)						
Type of Envelope	**U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)**	**Temp difference in ^{0}C (Solar heat gain in case of glass)**	**W/Sq.mtr.**	**Rough Area in sq.mtr.**	**Net heat gain In Watts**	**Net % of contribution**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
			Col.(2) x Col.(3)		**Col.(4) x Col.(5)**	
Roof	0.33	25	8.25	2000	16,500	15.8
Wall	0.4	15	6	2205	13,230	12.7
Glass U value gain	2	15	30	945	28,350	27.1
Glass SHGC	0.27	182	49.14	945	46,437.3	44.4
Total					**1,04,517.3**	**100**

ECBC Plus (for typical WWR = 30%)						
Type of Envelope	**U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)**	**Temp difference in ^{0}C (Solar heat gain in case of glass)**	**W/Sq.mtr.**	**Rough Area in sq.mtr.**	**Net heat gain In Watts**	**Net % of contribution**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
			Col.(2) x Col.(3)		**Col.(4) x Col.(5)**	
Roof	0.2	25	5	2000	10,000	11.7
Wall	0.34	15	5.1	2205	11,245.5	13.2
Glass U value gain	1.5	15	22.5	945	21,262.5	24.8
Glass SHGC	0.25	182	45.5	945	42,997.5	50.3
Total					**85,505.5**	**100**

ECBC Super (for typical WWR = 30%)						
Type of Envelope	**U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)**	**Temp difference in ^{0}C (Solar heat gain in case of glass)**	**W/Sq.mtr.**	**Rough Area in sq.mtr.**	**Net heat gain In Watts**	**Net % of contribution**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
			Col.(2) x Col.(3)		**Col.(4) x Col.(5)**	
Roof	0.2	25	5	2000	10,000	15.2
Wall	0.22	15	3.3	2205	7,276.5	11.1
Glass U value gain	1	15	15	945	14,175	21.5
Glass SHGC	0.2	182	36.4	945	34,398	52.2
Total					**65,849.5**	**100**

Non ECBC Compliant Conventional Building (for typical WWR = 30%)						
Type of Envelope	**U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)**	**Temp difference in ^{0}C (Solar heat gain in case of glass)**	**W/Sq.mtr.**	**Rough Area in sq.mtr.**	**Net heat gain In Watts**	**Net % of contribution**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
			Col.(2) x Col.(3)		**Col.(4) x Col.(5)**	
Roof	1.8	25	45	2000	90,000	24.0
Wall	2.4	15	36	2205	79,380	21.0
Glass U value gain	5	15	75	945	70,875	18.6
Glass SHGC	0.8	182	145.6	945	1,37,592	36.4
Total					**3,77,847**	**100**

ECBC Basic (for typical WWR = 40%)						
Type of Envelope	**U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)**	**Temp difference in ^{0}C (Solar heat gain in case of glass)**	**W/Sq.mtr.**	**Rough Area in sq.mtr.**	**Net heat gain In Watts**	**Net % of contribution**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
			Col.(2) x Col.(3)		**Col.(4) x Col.(5)**	
Roof	0.33	25	8.25	2000	16,500	12.9
Wall	0.4	15	6	1890	11,340	8.9
Glass U value gain	2	15	30	1260	37,800	29.6
Glass SHGC	0.27	182	49.14	1260	61,916.4	48.5
Total					**1,27,556.4**	**100**

ECBC Plus (for typical WWR = 40%)						
Type of Envelope	**U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)**	**Temp difference in ^{0}C (Solar heat gain in case of glass)**	**W/Sq.mtr.**	**Rough Area in sq.mtr.**	**Net heat gain In Watts**	**Net % of contribution**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
			Col.(2) x Col.(3)		**Col.(4) x Col.(5)**	
Roof	0.2	25	5	2000	10,000	9.5
Wall	0.34	15	5.1	1890	9,639	9.1
Glass U value gain	1.5	15	22.5	1260	28,350	27.0
Glass SHGC	0.25	182	45.5	1260	57,330	54.4
Total					**1,05,319**	**100**

ECBC Super (for typical WWR = 40%)						
Type of Envelope	**U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)**	**Temp difference in ^{0}C (Solar heat gain in case of glass)**	**W/Sq.mtr.**	**Rough Area in sq.mtr.**	**Net heat gain In Watts**	**Net % of contribution**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
			Col.(2) x Col.(3)		**Col.(4) x Col.(5)**	
Roof	0.2	25	5	2000	10,000	12.4
Wall	0.22	15	3.3	1890	6,237	7.7
Glass U value gain	1	15	15	1260	18,900	23.3
Glass SHGC	0.2	182	36.4	1260	45,864	56.6
Total					**81,001**	**100**

Non ECBC Compliant Conventional Building (for typical WWR = 40%)						
Type of Envelope	**U value in W/ Sq.mtr./^{0}C (SHGC in case of glass)**	**Temp difference in ^{0}C (Solar heat gain in case of glass)**	**W/Sq.mtr.**	**Rough Area in sq.mtr.**	**Net heat gain In Watts**	**Net % of contribution**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
			Col.(2) x Col.(3)		**Col.(4) x Col.(5)**	
Roof	1.8	25	45	2000	90,000	20.6
Wall	2.4	15	36	1890	68,040	15.6
Glass U value gain	5	15	75	1260	94,500	21.8
Glass SHGC	0.8	182	145.6	1260	1,83,456	42.0
Total					**4,35,996**	**100**

Annexure 12

Raw data obtained from projects for calculating embodied CO_2

Raw data obtained for calculating Embodied CO_2

S. No.	Name of Project	Cost of completion (in Rs. Crores)	Built-up area (in SQM)	CONSUMPTION OF MATERIALS											
				Cement (in Metric Tons)	Steel i.e. Reinforcement bars, MS & SS Steel works (in Metric Tons)	Aluminum (in Metric Tons)	Glass (in CUM)	Tiles (floor & wall) (in CUM)	Marble (floor & wall) (in CUM)	Burnt Clay/ Fly Ash / Bricks (in CUM)	AAC Blocks (in CUM)	Coarse aggregate (in CUM)	Fine aggregate (in CUM)	Bitumen (in Metric Tons)	Diesel in work (in Kilolitres)
P1	Construction of Various Infrastructure at GC, CRPF, Chandauli (U.P.)	130.00	26000	17363	3650	3.50	315.00	400	0	1400	0	34000	18000	190	190
P2	Construction of Various industrial Building for new Helicopter Manufacturing Facility for HAL at Biderahalla Kaval, Gubbi Taluk, Tumkur district under Phase-I Stage-III	71.00	14200	8240	1377	0.73	0.83	23	1	944	5	39829	19367	0	196
P3	Construction of Type-A-240 Nos, Type-B-240 Nos, Type-C-80 Nos & Type-D-24 nos quarters (phase - III) for HAL, Bangalore	192.00	38400	18830	5024	103.91	48.42	6314	358	14811	873	4558	16816	0	32
P4	Construction of Permanent Campus for IIT Tirupati, at Merlapaka Village, Yerpedu Mandal, Chittoor Dist., A.P. Phase-1 (Stage-1C)	693.00	138600	46280	17325	120.00	27.00	5604	1285	21440	201295	127917	163633	5623	1046
P5	Construction of New Academic Complex-II at IIT Madras, Chennai-36	154.48	30896	10340	3940	31.50	24.88	285	312	7998	0	2085	21931	46	45
P6	Construction of Medical College Building and associated development works at Academic Campus for JIPMER, Karaikal	118.10	23620	5100	1861	0.32	23.08	205	0	127	4668	13542	12039	0	19
P7	Up-gradation of Jawahar Lal Nehru Medical College & Hospital, Bhagalpur under PMSSY (Phase-IV)	109.00	21800	8077	2289	19.40	7.86	128	0	5847	0	6060	9165	0	13

S. No.	Name of Project	Cost of completion (in Rs. Crores)	Built-up area (in SQM)	CONSUMPTION OF MATERIALS											
				Cement (in Metric Tons)	Steel i.e. Reinforcement bars, MS & SS Steel works (in Metric Tons)	Aluminum (in Metric Tons)	Glass (in CUM)	Tiles (floor & wall) (in CUM)	Marble (floor & wall) (in CUM)	Burnt Clay/ Fly Ash / Bricks (in CUM)	AAC Blocks (in CUM)	Coarse aggregate (in CUM)	Fine aggregate (in CUM)	Bitumen (in Metric Tons)	Diesel in work (in Kilolitres)
P8	C/o 72 Nos. T-5 and 27 nos T-6 Qtrs at AIIMS, Rishikesh	64.22	12844	302	2364	0.00	15.00	250	70	2093	0	17993	14500	0	0
P9	Construction of Permanent Campus of Indian Institute of Management (IIM) Bodhgaya, Bodhgaya, Bihar, Phase-I	350.00	70000	25750	7000	12.85	48.50	660	2	16400	13298	80000	18000	4	416
P10	Construction of 480 nos. type-II(G+3) storeyed, 24 nos. type-III (G+3) storeyed, 12 nos. type- IV(G+3) storeyed and 04 nos. type-V (Duplex) Qtrs. for G.C., CRPF at Musabani, Jamshedpur (Jharkhand)	92.00	36000	12715	3638	8.60	15.00	300	33	13815	0	23500	22500	0	2500
P11	C/o Academic and Residential Complexes for campus of IIT Patna	460.00	92000	36625	12500	818.00	816.00	383	1080	26689	0	65824	607888	72	159
P12	C/o 1 No. Academic Building-I (G+3), Faculty Residential Apartments, 1 No. Students Hostel (G+7), Academic Block-I Vertical extension from (G+3) to (G+5) at IISER, Bhopal(MP)	118.00	23600	8165	2463	55.19	10.77	740	298	2048	5245	16807	10811	0	117
P13	C/o 314 Nos. GPRA Quarters (G+10) at Digha Patna, Bihar	136.00	27200	15991	5804	60.00	22.00	403	0	3486	0	21471	15935	0	150
P14	C/o 100 bedded ESIC Hospital at Tuticorin, Tamil Nadu	138.54	27708	8700	2000	10.00	15.00	160	90	4000	0	15000	11000	0	120
P15	Construction of New 88 Nos. Type-V qtrs at AIIMS Jodhpur	111.28	22256	10422	17192	5.38	17.24	338	93	284	385	19011	12254	1	49
P16	Construction of VPE at New Delhi	300.00	60000	13200	4500	14.00	20.00	90	2784	11120	105	16500	11650	0	250
P17	Construction Of Type-V Qtrs and Type VI Qtrs at IIT (ISM) Dhanbad	145.00	29000	14178	4753	2.00	13.00	365	267	25254	0	26476	19495	0	65
P18	C/o 1000 Rooms (2000 Seats) Boys Hostel (G+10) for ISMU at Dhanbad	159.00	31800	15978	7197	11.00	24.00	423	0	12663	0	26670	33800	1	100

S. No.	Name of Project	Cost of completion (in Rs. Crores)	Built-up area (in SQM)	CONSUMPTION OF MATERIALS											
				Cement (in Metric Tons)	Steel i.e. Reinforcement bars, MS & SS Steel works (in Metric Tons)	Aluminum (in Metric Tons)	Glass (in CUM)	Tiles (floor & wall) (in CUM)	Marble (floor & wall) (in CUM)	Burnt Clay/ Fly Ash / Bricks (in CUM)	AAC Blocks (in CUM)	Coarse aggregate (in CUM)	Fine aggregate (in CUM)	Bitumen (in Metric Tons)	Diesel in work (in Kilolitres)
P19	Construction of 3 Nos. (G+3) Students Hostels for IIT Jodhpur at Karwar, NH-65 Jodhpur, Rajasthan	121.10	24220	9190	1732	0.00	48.45	232	277	10	800	15600	9600	0	70
P20	Construction of Super Specialty Hospital Block (G+4) at Patliputra Medical College & Hospital, Dhanbad under PMSSY Phase – III at Dhanbad	84.00	16800	5692	1427	32.81	12.61	178	119	5192	0	14684	10288	0	0
P21	Construction of New Administrative Building (S+8) at AIIMS, Bhubaneswar	134.49	26898	9000	4350	60.00	24.00	297	120	6000	1800	18000	16500	0	15
P22	Construction of a 150 bedded Critical Care (S+5) building at AIIMS Campus for AIIMS,Bhubaneswar	132.75	26550	7150	2301	20.00	12.00	160	178	4045	0	14100	15200	0	60
P23	Construction of 120 nos. GPRA Type-VII flats at DDU Marg, New Delhi	215.00	43000	21670	6472	1.65	18.15	647	3611	2289	1752	83500	68700	0	310
P24	Construction of permanent campus of IIT Gandhinagar at Palaj, Gandhinagar	144.30	28860	15597	3966	61.00	27.00	130	29	3988	287	30605	19577	0	20
P25	Construction of office buildings and residential quarters at NACP Okha in package 1	150.00	30000	9000	2100	0.00	15.00	160	90	2500	1000	15500	10500	0	125
P26	C/o of Permanent Campus of NIT at Cuncolim Salcete Taluka Goa.	345.00	69000	22000	5400	0.00	32.40	800	24	315	60000	55400	40000	3	350
P27	C/o New Boys Hostel for 300 Students & Girls Hostel for 362 Students at AIIMS Jodhpur	71.32	14264	6415	1821	10.68	6.32	273	80	172	1402	9345	6043	0	28
P28	C/o 100 Bedded ESIC Hospital with 32 Nos. Residential quarters for ESIC Hospital at Raigarh (CG).	75.00	15000	7869	2310	14.45	19.10	246	0	4300	0	18550	13900	0	15

S. No.	Name of Project	Cost of completion (in Rs. Crores)	Built-up area (in SQM)	CONSUMPTION OF MATERIALS											
				Cement (in Metric Tons)	Steel i.e. Reinforcement bars, MS & SS Steel works (in Metric Tons)	Aluminum (in Metric Tons)	Glass (in CUM)	Tiles (floor & wall) (in CUM)	Marble (floor & wall) (in CUM)	Burnt Clay/ Fly Ash / Bricks (in CUM)	AAC Blocks (in CUM)	Coarse aggregate (in CUM)	Fine aggregate (in CUM)	Bitumen (in Metric Tons)	Diesel in work (in Kilolitres)
P29	C/o (Administrative cum Academic block, Development & Horticulture work) at IIIT Kota at Kota, Rajasthan	63.50	12700	115	1350	14.00	19.00	105	0	1200	3000	11740	10370	0	50
P30	Construction of Central Research Laboratory Building(G+10) Utkarsh Bhawan at NIT Durgapur, West Bengal	59.20	11840	3710	1507	29.50	25.42	83	99	454	2077	7033	5600	0	55
P31	C/o Hostel No. 17 (G+9 storeys) at IITB Bombay, Powai, Mumbai.	74.85	14970	7099	2460	20.00	28.00	307	70	572	4452	4530	3778	0	41
P32	Construction of 78 Nos Type B Quarter at IIT Bombay Powai, Mumbai.	69.20	13840	3575	1597	56.00	14.00	240	47	315	3000	6598	5004	0	50
P33	C/o of ECGC office at plot situated at M.V. road Andheri (East), Mumbai.	92.67	18534	7041	3022	33.70	55.31	63	78	131	1181	15501	9000	0	100
P34	Construction of office building for Income Tax Department at Nariman Point, Mumbai (B+G+13)	106.49	21298	4242	1750	5.60	24.24	113	47	20	1881	6443	3221	0	0
P35	Construction of Permanent Campus for IIT, Dharwad (Phase-1A)	900.00	180000	45000	20000	100.00	135.00	1650	2300	700	22000	100000	80000	0	1000
P36	Construction of Engineering Block 99B & 99C at IIT Delhi	250.00	50000	15955	7162	162.98	44.72	369	130	11682	0	32887	31930	0	50
P37	C/o Boys Hostel 'E' at IIT Delhi	116.00	23200	8929	3325	50.00	22.36	193	0	2265	0	1625	27254	4	13
P38	Construction of Permanent Campus of IIT Bhilai at Kutelabhata, Durg Chattisgarh, Phase I stage I	825.00	165000	60000	16600	200.00	93.00	880	8	35000	14500	127500	138000	220	940
P39	Construction of 76 nos. Multi Storied Flats (Basement+Stilt+13 floors) for Hon'ble MP's of Lok Sabha at Dr. B.D. Marg, New Delhi	185.60	37120	11000	4200	110.00	41.00	325	288	195	0	42000	24000	0	0
P40	C/o Corporate Bhawan, Kolkata	101.10	14,794	5829	2204	18.11	204	55.77	14.04	2359	1145	10285	2810	0	207

Annexure 13

Raw data obtained from projects for calculating operational EPI

Raw data obtained for calculating EPI

Name of Building i/c address	Annual electricity consumption		Annual Diesel consumption for DG set & Diesel Fire Engine (FY 2023-24) (in KL)	Total Plinth Area of the Building (in Sq. Mtr)	Total Air Conditioned Space (approx. in Sq. Mtr)	Details of Air Conditioning Systems (Approx. Total Tonnage Refrigeration and Quantity of each type like WTAC, STAC, VRV, Central Plant etc)	Annual Water Consumption (approx. in KL) (FY 2023-24)
	in KVAH (FY 2023-24)	in KWH (FY 2023-24)					
GPOA Rajaji Bhawan, Besant Nagar, Chennai-600090	11431	6036832	5.46	36000	25200	700 TR STAC (425 Nos) and 530 HP VRV (30 Nos) (Approximately)	
GPOA Shastri bhavan ,Haddows road, Chennai, Tamil Nadu 600006	1930280	1865166.2	1	45278.6	31695.02	VRF AC -437 TR, SPLIT TYPE- 750 TR	26280
JIPMER Campus, Dhanvantri Nagar, Puducherry 605 006	10670	27592000	4800	121000	28000	WTAC Units - Nil, STAC (including cassette type) Units (1.5 TR - 152 nos. & 2.0 TR - 223 nos., Fan Coil Units - 251 nos., VRV AC Units - 342 HP, Central AC Plant - 2030 TR	1525000
Income tax Building ,Nungambakkam, Chennai-06	10884	2218640	0.96	37802.61	30250	1518 TR (Split type/Cassette type 1.5 TR - 156 Nos , Split type/ Cassette type 2 TR- 628 Nos , Tower ac units 4 TR - 7 Nos)	36500 Kilo liters
KENDRIYA SADAN KORAMANGALA BANGALORE	817.89	727.45	10.797	25936	4185.28	312 TR, STAC 1.5/2 TR -84 NOS., VRV-72 HP, PRECISION AC 8.5 TR-6 Nos., TOWER AC 4.5 TR-9 Nos., CASSETTE AC 1.5 TR-28 Nos	45685 KL
CISF 10th RB Dabaspet Bangalore	451391	437844					
Old & New CGO complex, NH-IV, Faridabad	25560	582768	12	30171	120681	WTAC approx. 103 and STAC approx. 52. No VRV & Central Plant	13500 KL approx.
ICMR-NIRCMD (Desert Medicine Research Centre, Pali Rd, Bhagat Ki Kothi, Jodhpur, Rajasthan 342005	270780	284731	5	7000	6500	474	600
West Zone Regional Training Centre of the Intelligence Bureau (IB), in Jodhpur, Rajasthan	343136	361196	1.5	5000	130	130, STAC X 72 nos	1200

Name of Building i/c address	Annual electricity consumption		Annual Diesel consumption for DG set & Diesel Fire Engine (FY 2023-24) (in KL)	Total Plinth Area of the Building (in Sq. Mtr)	Total Air Conditioned Space (approx. in Sq. Mtr)	Details of Air Conditioning Systems (Approx. Total Tonnage Refrigeration and Quantity of each type like WTAC, STAC, VRV, Central Plant etc)	Annual Water Consumption (approx. in KL) (FY 2023-24)
	in KVAH (FY 2023-24)	in KWH (FY 2023-24)					
CISF 10th Reserve Battalion,Lakkur Village ,Dabaspet, Karnataka	451386	437808	1.458	46748	1000	1.5 TR Split AC-21Nos,2 TR Split AC-11 Nos. ,60HP VRV system-1No	21900KL
Audit building, Gwalior		1093536		35580			Not known
GPOA Building at Naya Raipur CG	754713	679242	3	11449.82	8730	854 HP VRV	9000
East Block -1 to 10	16440	4742868	8	38000	25000	1600 approx. 900 WTAC/STAC mostly 1.5Tr. , 34TR. Package Plant	N.A.
Central Revenue Building, Queen's Road, Bangalore - 560001	225	222	3	18769	12000	550 TR (Approx)	16500 KL
Central Revenue Building, Queen's Road, Bangalore -560001	4038	912000	3	18769	11261	550 TR	15650 KL
Audit building,AG, Gwalior		1979936	1.2	35580	3500	484 hp	NA
CGO-1 COMPLEX, HAPUR CHUNGI GHAZIABAD U.P.	3000	360000	4	2145	NIL	AC 45 X 1.5 = 75	50 KL
CGO COMPLEX-2 HAPUR CHUNGI GHAZIABAD.	3000	240000	2.5	1860	NI	AC 40 X 1.5 = 60	50 KL
CBI ACADEMY, KAMLA NEHRU NAGAR GHAZIABAD U.P.	300	840000	10	4285	1400	AC 225 X 1.5 = 337.5, VRV 148 HP / 0.80 = 310, AC PLANT 48 X3 = 144	1.5 KL
NATIONAL CPWD ACADEMY, KAMLA NEHRU NAGAR GHAZIABAD U.P.	200X12	600000	6	3570	1800	AC 209 X 1.5= 313, AC PLANT 48 X 3 = 144, 40 /0.8 = 50	100 KL
GPRA COLONY, KAMLA NEHRU NAGAR, GHAZIABAD. U.P.	141X12	36000X12	1	7140	NIL	NIL	300 KL
AYKAR BHAWAN VAISHALI SECTOR-4 GHAZIABAD.	1462X12	1344000	10	1200	50000	AC 55 X 1282.5, 3 X 200= 600	2000 KL
PCIM AND H BUILDING, KAMLA NEHRU NAGAR, GHAZIABAD U.P.	401.5X12	324000	5.5	1715	1600	AC 95 X 1.5 = 142.5, AC PLANT = 75	300 KL
Permanent campus of IIT Bhilai at Kutelabhata Durg Chhattisgarh	4487835	3378120	4870	142000	70835	VRV 524 HP, Central AC Plant 3 x 800 TR (2 working + 1 Standby)	74000 KL

Name of Building i/c address	Annual electricity consumption		Annual Diesel consumption for DG set & Diesel Fire Engine (FY 2023-24) (in KL)	Total Plinth Area of the Building (in Sq. Mtr)	Total Air Conditioned Space (approx. in Sq. Mtr)	Details of Air Conditioning Systems (Approx. Total Tonnage Refrigeration and Quantity of each type like WTAC, STAC, VRV, Central Plant etc)	Annual Water Consumption (approx. in KL) (FY 2023-24)
	in KVAH (FY 2023-24)	in KWH (FY 2023-24)					
CIP, Kanke, Ranchi	6652.8	2644920	16659.7		3715	STAC (2 ton- 40 Nos., 1.5 ton- 94 Nos.)	146000
INCOME TAX OFFICE UDAIPUR RAJASTHAN	227895	216500	20	5110.57	4600	336, HP, 21 OUTDOOR UNIT EACH 16 HP	550
Karpoori Thakur Sadan,Ashiyana Digha Road,Patna	8122	6498	4100	22712	18170	WTAC-1.5TRx145nos.+STAC-1.5TRx127nos.+VRV--212TR=620TR	....
Lokpal Building & IIAC Building, Plot No. 6 Plot No. 6, Vasant Kunj, Institutional Area, New Delhi-110070.	100	720000	1000	2740	5760	3 x 90 TR & 2 x 110 TR Chiller Plant	4500 KL
Sewa Bhawan, West Block-1 & 2, R.K. Puram, New Delhi-110066	20940	16752	3.00	69715.84	14467	2 TR STAC- 3 Nos. 1.5 TR STAC- 39 Nos. 2 TR WTAC- 5 Nos. 1.5 TR WTAC- 20 Nos. Hot & Cold PTAC Plant 16.5 TR- 24 Nos.	-NA-
West Block-3,4,5,6,7 & 8, R.K.Puram, New Delhi-110066	21120	16896	7.00	78947.52	51316	1.5/2.0 TR WTAC- 129 Nos. 1.5/2.0 TR STAC-255 Nos. 1.5/2.0 TR Cassette- 68 Nos. VRV-133 Nos. PTAC Plant 2X17 TR. PTAC Plant 3X17 TR PTAC Plant 3X17 TR	-NA-
AG Office, Bhubaneswar	791000	767200	0.5	14000	4500	1.5 TR STAC-300 Nos	8500
WZRTC, Intelligence Bureau (MHA) Old SSB Complex, Bhadwasiya Road Jodhpur 342006	271179	244311	1.2	8923.60	1350	Total tonnage: 135 TR (2 ton split AC 60 Nos, 1.5 Ton Split AC 10 Nos,)	18000 KL
Income tax Office Udaipur, Rajasthan	293334	280350	1.343	5802	4600	336 HP (21 Outdoor unit each unit 16 HP)	550 KL
GPOA, Rajaji Bhawan,Besant Nagar,Chennai-90	3964556	3936832	6.3	35,000	24,500	950 ton (approx) Split AC 620 ton,VRF AC 330 ton.	......
North Block		7440995	9.6	102000	51000	2902 Tr	
ICMR-NIRCMD (Desert Medicine Research Centre, Pali Road, Bhagat Ki kothi Jodhpur (Raj.) 342005	418814	351770	2.4	9800	4420	Rooftop Package 30 Tr 2 Nos, 10 TR 8 Nos, 20 TR 5 Nos, 25 TR 2 Nos, 18 TR 1 Nos, 15 TR 1 Nos, 3 TR 3 Nos, 2 TR 1 Nos and VRV 20 TR 4 Nos and guest house Split AC 2 ton 15, Total ton : 442	36000 KL

Name of Building i/c address	Annual electricity consumption		Annual Diesel consumption for DG set & Diesel Fire Engine (FY 2023-24) (in KL)	Total Plinth Area of the Building (in Sq. Mtr)	Total Air Conditioned Space (approx. in Sq. Mtr)	Details of Air Conditioning Systems (Approx. Total Tonnage Refrigeration and Quantity of each type like WTAC, STAC, VRV, Central Plant etc)	Annual Water Consumption (approx. in KL) (FY 2023-24)
	in KVAH (FY 2023-24)	in KWH (FY 2023-24)					
GPOA, Shree Visvesvaraya Kendriya Bhavan, Domlur, Bangalore	981810	980561	8	18505	12953	755 TR(VRV/VRF Air conditioning,32 HP-1 No,44 HP-13 Nos)	10955 KL
Central Revenue Building, Queen's Road, Bangalore 560001	1021914	1012320	3	18769	11261	557 TR (1.5 TR Split AC - 210 Nos, 2 TR Split AC - 35 Nos, VRV/ VRF - 22HP -9 Nos, 18 HP - 1 No)	15650 KL
Atal Akshaya Urja Bhawan, Opp. CGO Complex, Lodhi Road, New Delhi	1287500	1236000	1.2	55233	14405	Central AC 430 TR (Conventional 215 TR, Radiant 215TR) & VRV 37TR	64 KL
Vayu Bhawan, Airforce Headquarters, Motilal Nehru Marg, New Delhi	5595840	5595840	16	50866	30500	2200 TR	
West wing South Block, New Delhi		2066745	2	6560	3860	803 HP VRV, 112 TR (STAC)	
East wing Sub Station South Block , New Delhi		5975880	3.5	67115	40269	2888 HP VRV, 700 TR (STAC)	
Sardar Petal Bhawan , New Delhi		1867340	4.5	15504	7005	716 HP VRV, 192 TR (STAC)	
GPOA, Pushpa Bhawan, New Delhi-110062	1170741	1123940		9850		Complete Details not available	18250 Approx as per civil
Karpoori Tahkur Sadan, Ashiana Digha Road Patna.	2260691	1808553	4.1	22712	18170	WTAC - 1.5 TR x 145 Nos. = 217.5 TR, STAC - 1.5 TR x 127 Nos. = 190.5 TR, VRV - 212 TR, Total = 620 TR	-------------------------
Survey of India,Bhubaneswar	27427	24933	1.2	1113	950	WTAC-11 Nos,STAC-39Nos.	25
New AG Office Building, Kesharinagar, Bhubaneswar	260160	259536	0.5	6200	4800	480 TR(384HP VRV type)	8500
Vayu Bhawan, New Delhi	5595840	5595840	1.6	18,623	10,000	2250 TR	110 KL
Shastri bhawan, New Delhi	4328358	4025373	4.5	68231			
Udyog Bhawan, New Delhi	3186560	2963501	2.5				
Sewa Bhawan & West Block-1 & 2, R.K.Puram, New Delhi	6459	5167	3.00	69716	45315.3	1711 TR Approx. (PTAC Plant -576 TR, VRV AC=280 TR, 2 TR WT/ ST/CT AC= 248, 1.5 TR WT/ST=239)	NA

Name of Building i/c address	Annual electricity consumption		Annual Diesel consumption for DG set & Diesel Fire Engine (FY 2023-24) (in KL)	Total Plinth Area of the Building (in Sq. Mtr)	Total Air Conditioned Space (approx. in Sq. Mtr)	Details of Air Conditioning Systems (Approx. Total Tonnage Refrigeration and Quantity of each type like WTAC, STAC, VRV, Central Plant etc)	Annual Water Consumption (approx. in KL) (FY 2023-24)
	in KVAH (FY 2023-24)	in KWH (FY 2023-24)					
West Block-3,4,5,7 & 8, R.K.Puram, New Delhi	5349	4279	6.20	65790	42763.24	2200 TR Approx.(1.5TR WT/ST AC=610, 2 TR WT/ST AC= 510, PTAC Plant=254)	NA
West Block-6, R.K.Puram, New Delhi	2351	1881	1.2	13158	8552.65	611 TR Approx. (1.50 ST/WT AC =93,2.0 ST/WT AC=92, VRV=288 TR)	NA
Panchsheel bhawan, Block A, Siri Fort Institutional Area, Siri Fort, New Delhi, Delhi 110049	278653	264720	0.3	2322	1857	WTAC-1.5TRx09nos.+STAC-1.5TRx41nos.+Central AC--116TR=744.5TR	3817
Old JNU Campus, Munirka, New Delhi, Delhi	2769977	2659178	11	39226	13821	Central AC Plant - 45 TR, Ductable AC- 44TR, 1.5 TR (348 Nos.) & 2 TR (20 Nos.)	49275
NATIONAL CPWD ACADEMY HAPUR ROAD, KAMLA NEHRU NAGAR GHAZIABAD U.P.	440000	400000	10	4285	1400	750	150
CGO COMPLEX-1 HAPUR CHUNGI GHAZIABAD U.P.	235000	230000	4	2145	NIL	75	50
CGO-2 HAPUR CHUNGI GHAZIABAD	186000	184000	2.5	1860	NIL	75	50
PCIM AND H BUILDING KAMLA NEHRU NAGAR GHAZIABAD	333300	330000	5.5	1715	1600	215	100
CBI ACADEMY, KAMLA NEHRU NAGAR, GHAZIABAD U.P.	605000	550000	10	4285	1400	750	150
AAYAKAR BHAWAN KAUSHAMBI, VAISHALI GHAZIABAD	1307950	129500	10	1200	6000	600	200
GPRA COLONY, KAMLA NEHRU NAGAR, GHAZIABAD	326028	322800	1	7140	NIL	NIL	300
Air Force Station Hindan	21374600	21713400	96	2988349	89505	Total TR= 3192 TR WATC-270 (405 TR), STAC-758 (1137 TR), VRV-3 (25 TR), Central AC Plant-4 (1625 TR)	800000 KL
Corporate Bhawan, Kolkata	2851200	253400	5200	14794	10436	300 X 3 TR Super ECVC Compliant.Central Ac plant (2 working + 1 Standby).2x11 TR VRF AC Unit (1 Working + 1 Standby). 3x2 TR Dx unit	51 KL

List of Abbreviations

1. **AAC** - Autoclaved Aerated Concrete
2. **AR** - Assessment Report
3. **ADG** - Additional Director General
4. **BEE** - Bureau of Energy Efficiency
5. **BIM** - Building Information Modelling
6. **BT** - Billion Tonnes
7. **CEA** - Central Electricity Authority
8. **COP** - Conference of Parties
9. **CPWD** - Central Public Works Department
10. **C&D waste** - Construction and Demolition waste
11. **DG set** - Diesel Generator set
12. **ECBC** - Energy Conservation Building Code
13. **EDGE** - Excellence in Design for Greater Efficiencies
14. **EOL carbon** - End of Life carbon
15. **EPD** - Environmental Product Declarations
16. **EPI** - Energy performance indicator
17. **GWP** - Global Warming Potential
18. **GHAR** - Green Habitat Accomplished Rating
19. **GHGs** - Greenhouse Gases
20. **IPCC** - Intergovernmental Panel on Climate Change
21. **MEP** - Mechanical, Electrical & Plumbing
22. **MNRE** - Ministry of New and Renewable Energy
23. **MoHUA** - Ministry of Housing and Urban Affairs
24. **M-Sand** - Manufactured Sand

25. **MSME** - Micro, Small and Medium Enterprises

26. **MT** - Million Tonnes

27. **NSP** - National Steel Policy

28. **NITI** - National Institution for Transforming India

29. **NTPC** - National Thermal Power Corporation

30. **RA** - Recycled Aggregate

31. **RCA** - Recycled Concrete Aggregate

32. **SAR** - Second Assessment Report

33. **SDG** - Special Director General

34. **SHGC** - Solar Heat Gain Coefficient

35. **TAR** - Third Assessment Report

36. **TCS -** Tonnes of CO_2 per tonne of Crude Steel produced

37. **TEF** - Transport Emission Factor

38. **TR** - Ton of Refrigeration

39. **ULB** - Urban Local Bodies

40. **UNFCCC** - United Nations Framework Convention on Climate Change

41. **WWR** - Window to Wall Ratio

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