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ENERGY MANAGEMENT OF BUILDINGS THROUGH SUSTAINABLE DESIGN

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ABSTRACT

Urbanization is gradually becoming a worldwide phenomenon since there is a colossal growth in population around the world. There is an emergent demand of housing around the world and hence construction sector is the booming sector all over the world. This accounts for extreme energy consumption and leading to GHG emissions which contribute to phenomenon of global warming.CO_2 is the major gas contributing to GHG emissions. Concrete is the vital building material used in construction. The production of concrete is responsible for emission of CO_2 gas. Thus, main aim of energy management of buildings is to propose a sustainable approach in conventional design method which can be introduced during conceptual design stage. This paper enumerates the quantification of the CO_2 emission of construction material especially concrete. All construction materials endure through various stages right from raw material extraction, transportation, manufacturing till demolition and waste processing. These stages are called system boundary. The system boundary for present study is manufacturing of concrete which is responsible for emission of CO_2 gas. Manufacturing of concrete requires energy consumption in many ways.Power sector in the form of electricity is one of the pathways of energy consumption responsible for CO_2 emission. The study involves comparative analysis and design of G+4 RCC building with structural components especially slab and columns as variable parameters. Based on the final design, the quantification of CO_2 emission for concrete is accomplished. Available data of energy consumption required for manufacturing process of concrete and integration of emission factor with energy consumption leads to quantification of CO_2 emission. The conclusion demonstrate that with variation in design of structural components, a considerable amount of quantity of CO_2 emission can be controlled, rather than concentrating on design and analysis of low carbon material, which requires lot of time and cost.

Key words: Carbon dioxide (CO_2), Greenhouse Gas (GHG), Reinforced Cement Concrete (RCC), System Boundary, and Energy Consumption.

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1. INTRODUCTION

Use of global energy is the major sphere in today's scenario. It is directly related to emission of greenhouse gases (GHG) in atmosphere. Sector which is majorly responsible for GHG emissions to annual global emissions leading to global warming is the construction sector. Construction sector is one of the most important sectors. The construction industry not only helps in meeting the housing demand, but provides employment on enormous scale. It has major impact on GDP of country, but need always comes with a challenge. The boom in construction sector is having impact on environmental condition. Construction industry contributes part in global warming due to greenhouse gas emission The global warming is basically the slow heating up of lower atmosphere of earth due to increase in intensity of greenhouse gases, especially CO2 (Spencer 2007). Life on earth will be in danger if there is excess of CO2 emission which will result in the earth's temperature to rise According to United Nations Environment programme, the building sector is responsible for 40% of the global energy consumption and one third of the GHG emissions. In future, growth in population will lead to rapid growth in building sector which will lead to increase in CO2 emissions thus effecting global warming. Electricity is one form of energy which is used in construction industry accounting for more than 42 % of fuel emission worldwide alone (IEA2016). Thus, energy management becomes an important aspect for building sector considering power sector as one of the driving factor of CO2 emission. One of the reasons for CO2 emission in building sector is manufacturing process and transportation of various construction materials, consequences of subsequence use of energy in form of electricity. Thus, from building design point of view, structural engineers and architects should go for energy management through sustainable design. This can be done by including strategies during early design stage which includes bringing down the CO2 emission due to energy consumption.

This study mainly focuses on energy management of buildings through sustainable approach by mainly concentrating on driving factors of CO2 emission of construction material especially concrete based on conventional design method.

Based on the above results obtained, comparative study of the CO2 emission for conventional design method is performed This study will further help the concern designers and policy makers in rearranging the strategies of conceptual design phase of building project for quantification of CO2 emission of concrete material. This will help in reducing negative impact of building industry on environment.

1.1. CO2 emission in Power Sector

Energy utilization for obtaining, fabricating, conveying, assembling, substitution, dismantlement and retrofitting of construction materials results in CO_2 emissions. CO_2 accounts for about 76 percent of total greenhouse gas emissions (IPCC (2014)), as shown in Figure 1. India is third largest country amongst world's 20 largest carbon emitting countries as shown in Figure 2.

Emission of CO_2 can take place from areas which are divided into two parts

1) Direct emissions: Here emission takes place during production
2) Indirect emissions: Result from consumption of energy in the form of electricity.

Other greenhouse gases are methane and nitrous oxide, articulated as CO2e or CO2 equivalent, which is an evaluation way to convey the emissions from the above-mentioned gases influenced by their global warming potential. The Global Warming Potential of a structure (GWP, expressed in kgCO2e/m^2 when normalized by floor area) can be calculated by multiplying these two key variables, as illustrated in Equation no. 1. (Source Catherine De Wolf, 2017).

$$GWP = SMQi \times ECCi \qquad \text{Equation no. 1}$$

Where: i is a particular material in building structure

GWP Global Warming Potential ($kgCO2e/m^2$)

SMQi Structural Material Quantities (kgm/m^2)

ECCi Embodied Carbon Coefficients (kgCO2e/kg)

The scope of CO2 calculation is called the system boundary. Stages of system boundary are as follows: cradle-to-gate, cradle-to-site, and cradle-to-end of construction, cradle-to grave or even cradle-to cradle (EN151515978:2011).

CO2 emission from power sector i.e. electricity is usually expressed in kg CO2/MWh, which consumed during manufacturing of construction material.

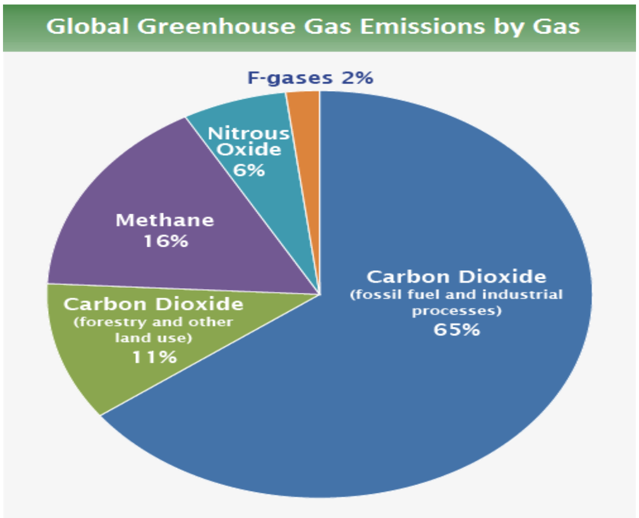

Figure 1 Global Greenhouse gas emission data (Source: IPCC (2014)

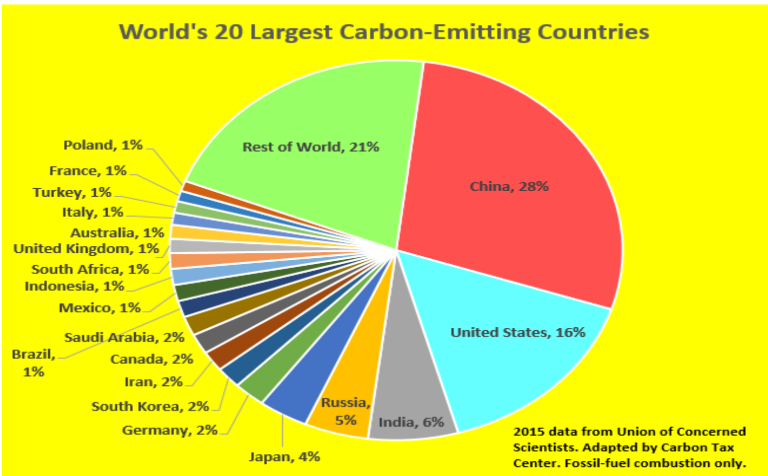

Figure 2 World's 20 largest carbon Emitting Countries

(Source: 2015 Data from Union concerned scientist)

1.2. System boundary

The scope of the CO2 calculation is called the system boundary.

For energy management of buildings through sustainable design, system boundary is requisite. It includes complete life cycle of buildings and products right from the material extraction to end-of-life. Segregation of a system (Life cycle stage) under investigation is system boundary as shown in Figure 3. It is necessary to define the system boundary of the analysis to understand which materials and processes need to be considered.

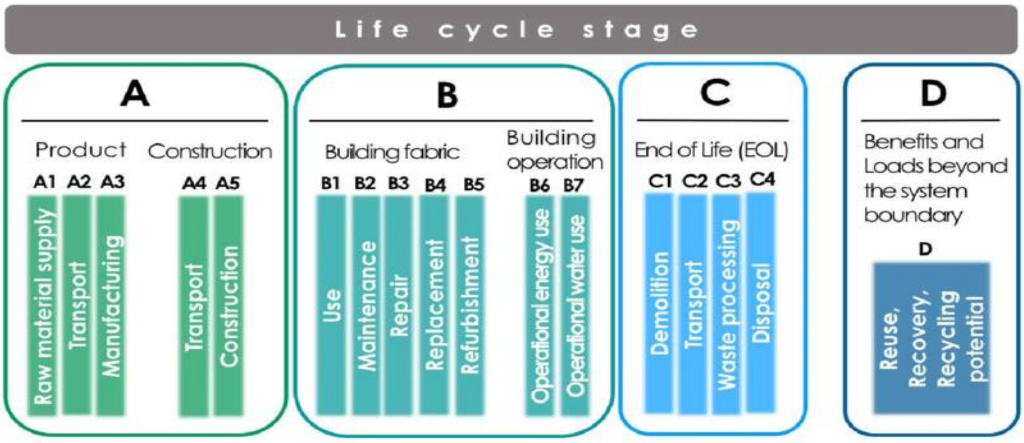

Figure 3 Building life cycle stages (Source: adapted from EN151515978:2011)

1.3. Sustainable Design

Sustainable design endeavour to lessen the adverse impacts on the environment, and the health and comfort of building inhabitants, thereby improving building performance. The elementary objective of sustainability is to reduce depletion of non-renewable resources, abate waste, and create healthy, productive environments. Here sustainable design for energy management is implemented by bringing down the CO_2 emission through energy consumption in buildings through analysis and design of RCC structure. This opportunity will not only help to minimize the total cost or total weight of a structure but also to minimize energy consumption and carbon emission.

Sustainable design acts as an associate of smart solution for smart cities.

2. METHODOLOGY

Research design includes the comparative analysis of G+4 structure using Staad pro software. Further design of structure is carried out using conventional design method, the result of which can be effectively integrated with different data of energy consumed for the manufacturing of concrete and refining them to produce finished product which results in CO_2 emission. The methodology is shown in the form of flow chart in Figure 4.

2.1. Data collcetion

In order to estimate the CO_2 emission of the building constuction material ,the data collection should be very precise.In this research, data is placed in two broad forms.The first form of data includes design parameters required for the analysis and design of RCC structure.The second form of data is external data . This includes energy consumption during manufacturing of building material.Here the source of data for energy consumed is the RMC plant ,including weighted average emission factor expressed in units $kgCO_2/MWh$.

2.2. Data Analysis

Analysis of the structure is carried out on following design basis assumptions.

Design philosophy for RCC framed structure

- Lateral force resisting system shall consist mainly of columns. The columns along with the floor slab acting as floor diaphragm (there by acting as tie between columns) shall form the lateral load resisting system.
- The whole structure is idealized in Staad pro software as a space frame and each beam and column in the structure is modelled as a line member element.
- RC Columns and Beams are designed using Limit State Method of design as per IS 456.
- Boundary Conditions: Base of the structure is considered as fixed for superstructure analysis.
- Effects due to non-structural components such as block walls, stairs, parapet walls, glass/stone cladding etc. are accounted appropriately in static loading and lumped mass calculations.

Following are the load combinations used for analysis and design of RCC structure as per codal reference.
i) 1.5DL+1.5 LL, ii) 1.2DL+1.2LL+1.2WL (+-X), iii) 1.2DL+1.2LL+1.2WL (+-Z),
iv) 1.5DL+1.5WL (+-X) , v) 1.5DL+1.5WL(+-Z), vi) 0.9DL+1.5WL(+-X),
vii) 0.9DL+1.5WL (+-Z), viii) 1.2DL+1.2LL+1.2EL (+-X),
ix) 1.2DL+1.2LL+1.2EL (+-Z), x) 1.5DL+1.5EL (+-X)
xi) 1.5DL+1.5EL (+-Z), xii) 0.9DL+1.5EL (+-X), xiii) 0.9DL+1.5EL (+-Z),
xiv) 1.5DL+1.5 EL(+-X), xv) 1.5DL+1.2 EL(+-Z)

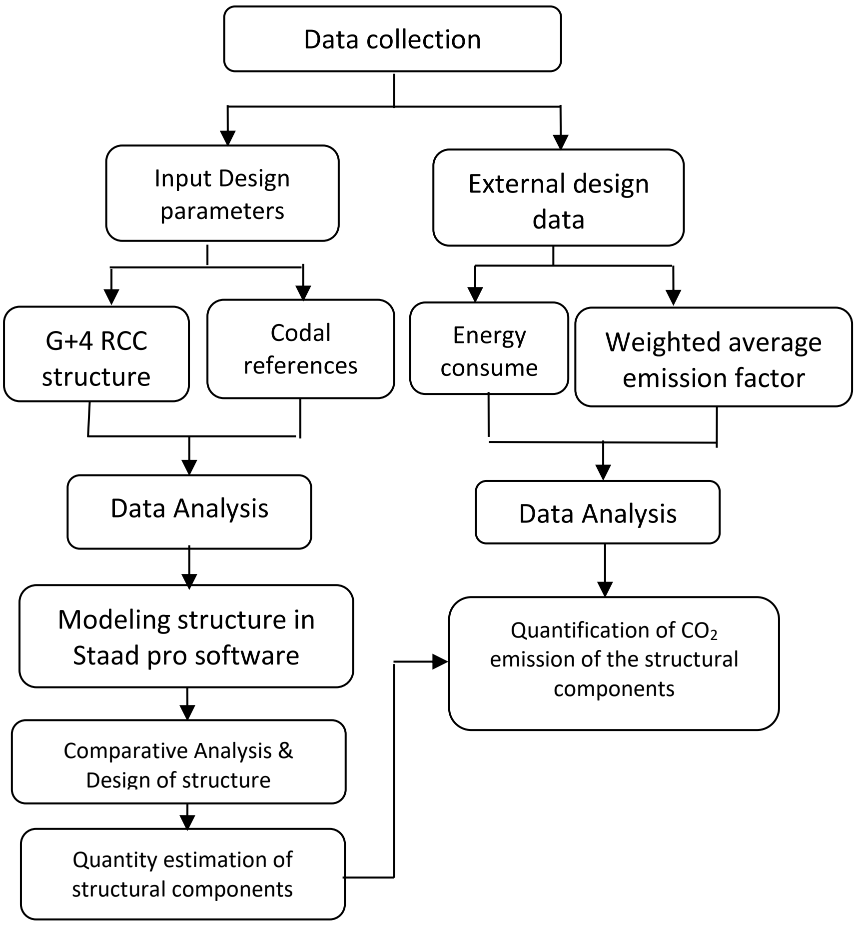

Figure 4 Flow chart illustrating the Quantification of CO_2 emission

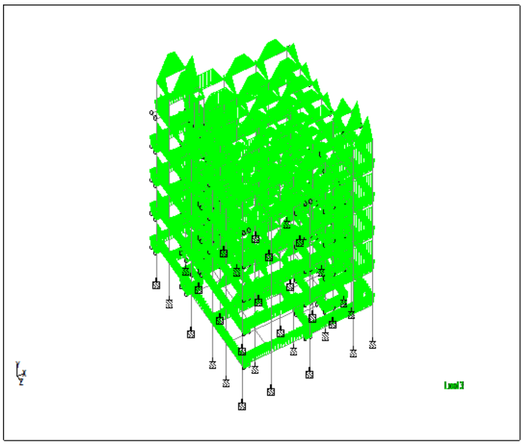

Figure 5 Staad pro model depicting vertical loads

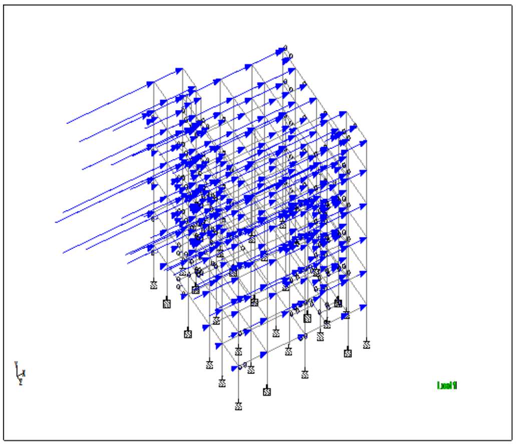

Figure 6 Staad pro depicting lateral loads

2.3. Analysis in Staad

Analysis in Staad pro software is implemented by applying design loads which includes vertical and lateral loads to the 3D model as shown in Figure 5 and Figure 6. Based on these load application further analysis is accomplished for design of structural components.

3. RESULTS AND DISCUSSION

This section presents the results of quantification of CO_2 emission of slab and column components of RCC structure based on energy consumption during manufacturing of building construction material especially concrete. Table 1 to 8 represents the quantification of construction material for structural components and corresponding CO_2 emission.

3.1. Quantification of structural component (slab and Column).

Table 1 Quantity of Typical floor for 150 mm thick

Sr. No.	Material	Unit	Quantity
1	Concrete M25	(cuM)	65.69
	Sub Total		65.69
2	Steel T8 (Fe 500)	kg	3526.2
3	Steel T10 (Fe 500)	kg	331.59
4	Steel T12 (Fe 500)	kg	66.82
	Subtotal		3924.61

Table2 CO_2 emission for typical floor slab of 150 mm thick.

Specific CO_2 emitted**	4.23 kg CO_2/m^3 concrete
Total CO_2 emitted**	277.867 kg CO_2

** CO_2 emitted during manufacturing of concrete

Table 3 Quantity of Typical floor for 115 mm thick

Sr. No.	Material	Unit	Quantity
1	Concrete M25	(cuM)	50.84
	Sub Total		50.84
2	Steel T8 (Fe 500)	kg	3432.27
3	Steel T10 (Fe 500)	kg	648.76
4	Steel T12 (Fe 500)	kg	307.36
	Subtotal		4388.39

Table 4 CO_2 emission for typical floor slab of 115 mm

Specific CO_2 emitted**	4.23 kg CO_2/m^3concrete
Total CO_2 emitted**	215.05 kg CO_2

*** CO_2 emitted during manufacturing of concrete*

Percentage decrease in CO_2 emission due to change in thickness of typical floor slab from 150 mm to 115mm =29%

Percentage increase in steel due to change in thickness of slab from 150mm to 115 mm typical floor slab =12%

Table 5 Quantity of Columns for G+4 structure *

Sr. No.	Material	Unit	Quantity
1	Concrete M25	(cuM)	118.47
	Sub Total		118.47
2	Steel T10 (Fe 500)	kg	10816.48
3	Steel T12 (Fe 500)	kg	4513.24
4	Steel T16 (Fe 500)	kg	7371.02
5	Steel T20 (Fe 500)	kg	49.82
6	Steel T25 (Fe 500)	kg	87.28
	Subtotal		22837.83

*considering slab thickness 150 mm

Table 6 CO_2 emission for entire columns of building

Specific CO_2 emitted**	4.23 kg CO_2/m^3 concrete
Total CO_2 emitted**	501.1281 kg CO_2

** CO_2 emitted during manufacturing of concrete

Table 7 Quantity of columns for G+ 4 structures*

Sr. No.	Material	Unit	Quantity
1	Concrete M25	(cuM)	83.59
	Sub Total		83.59
2	Steel T8 (Fe 500)	kg	4330.69
3	Steel T12 (Fe 500)	kg	3890.38
4	Steel T16 (Fe 500)	kg	4380.53
5	Steel T20 (Fe 500)	kg	1935.43
6	Steel T25 (Fe 500)	kg	978.37
	Subtotal		15515.4

**considering slab thickness 115mm*

Table 8 CO_2 emission for entire columns of building

Specific CO_2 emitted**	4.23 kg CO_2/m^3 concrete
Total CO_2 emitted**	353.585 kg CO_2

** CO_2 emitted during manufacturing of concrete

Percentage decrease inCO_2 emission due to change in column deign for reduced slab thickness of typical floor slab=41%

5. CONCLUSION

This research presents the design method of building structure for optimizing the material quantity in such a way that variation in material quantity will have direct impact on CO_2 emission. The study focuses on analysis and design of G+4 RCC structure within the constraints of design codes. The analysis and design was conducted using slab and column components as variable parameter. Keeping slab thickness and column sizes as per architectural requirements, analysis and design of RCC structure is implemented. The structure is reanalyzed and designed for the change in slab thickness Following are the conclusions drawn based on the above analysis:

1) The quantification of reinforcement for the above slab design has impact on CO_2 emission. Due to variation in slab thickness from 150 mm to 115 mm, the reduction in quantity of CO_2 emission of typical floor slab is 29%.
2) The percentage decrease in quantity of CO_2 emission due to change in column design for reduced slab thickness of typical floor slab is 41%.
3) The increase of steel reinforcement increases the total cost of structural component, but it can have some positive effect on the global warming issues as there is reduction of concrete use.
4) Thus, increase in percentage of reinforcement for conventional structure within the constraints of structural design code, CO_2 emission of the construction materials can be reduced with sustainable design approach.
5) With variation in design of structural components, a considerable amount of quantity of CO_2 emission can be controlled, rather than concentrating on design and analysis of low carbon material, which requires lot of time and cost.

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