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Embodied Energy Analysis by Data Comparison for Highrise Building

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ABSTRACT: Energy is required in every aspect for the life time of any building. Buildings are evaluated in terms of their energy requirement and eventually their impact on environment to find their sustainability. This assessment of energy is a widely developed topic. This energy in building is divided into two main types based on their functions,

i. Operational Energy
ii. Embodied Energy

The Operational energy is the energy that is required to function the energy, whereas the Embodied energy is the energy that is enveloped in making the building initially. In this study, embodied energy is derived through rigorous exercise of counting the total materials used, their material, transport and different process energy and the total accounted for two different structural systems in high-rise buildings. For which earlier works done in the field is used and help of professionals taken. At the end of the study, it is concluded that the embodied energy for RCC frame building per unit area of that high-rise building is more than the embodied energy of similar scaled Steel composite building. The difference for the case studies used is almost 15%. The percentage figure looks not so significant, however, the total embodied energy difference which is counted in GJ is huge when compared toe to toe. The study thus suggests, that selection of structural system, especially for high-rise buildings with respect to their embodied energy can affect positively on the overall environment impact of the structure.

KEYWORDS: Embodied, Greenhouse, Environment, Recycling, Consumption, Composite

I. INTRODUCTION

Embodied Energy is the total amount of energy required for a product or material to have achieved the current state or properties. This will include the energy used at different stages like extraction, processing, manufacture and transportation. This energy consumption at various stages produces Greenhouse Gases (GHG) like carbon dioxide, which eventually contributes to the greenhouse effect and harms the environment. Reducing Carbon Dioxide (CO^2) emission from buildings and nonrenewable resources consumed during construction is a priority in the fight against global warming (Lam et al, 2010). Thus, embodied energy reflects the overall impact of a material or system on the environment and hence the study on embodied energy is important in general.

Figure 1

Unlike other industries, construction industry has lot many distinctiveness. This is in terms that the final product of construction industry is a building containing numbers of materials and equal numbers of techniques of construction. This vastness of materials and techniques give many alternatives for any single task. Mostly the selection of materials or techniques is done based on their Cost differences, architectural requirements, climate or location based conditions, available resources and time constraints. However, there is one more important aspect, especially neglected in Indian construction industry, their impact on environment. By providing readily available data and spreading awareness on this aspect is a very important measure. As per past research works, using alternative building construction systems, methods and techniques can reduce the overall environmental effect and also reduce embodied energy as well as CO^2 emission in the process. (Balubaid et al, 2014)

However, there is a difference between Embodied energy and the life cycle assessment (LCA), LCA computes all the

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impacts over the complete life of a material or element, while embodied
energy only considers the early aspect of the impact of a building material. It does not include the energy used during the operation or disposal of materials.

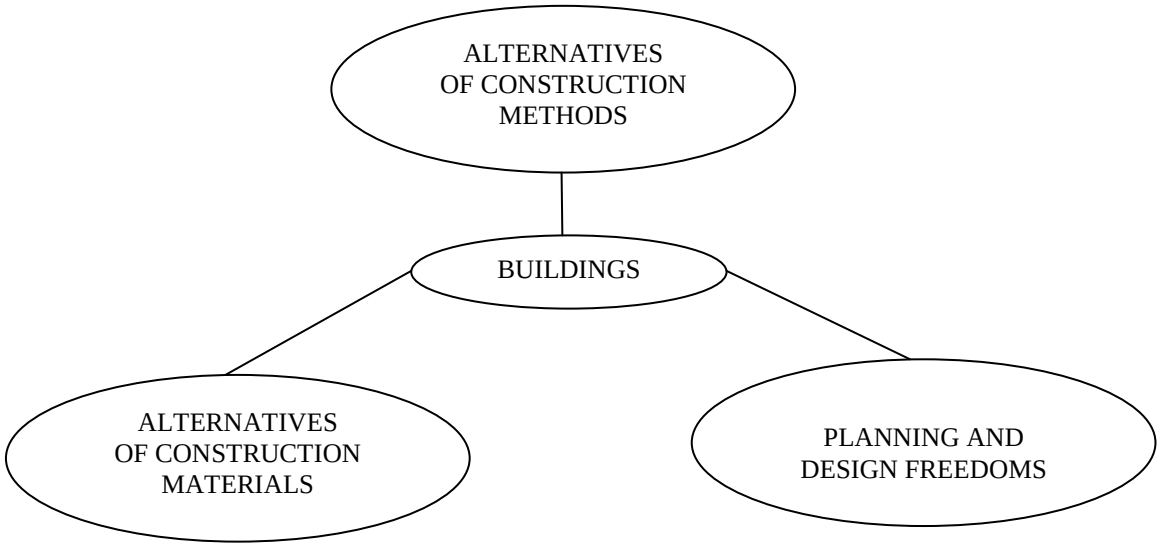

Figure 2

The total energy consumed by the building throughout its life cycle includes embodied energy (EE) and operating energy (OE). Embodied energy is embedded in building materials during all processes of production, on site construction and final demolition and disposal while, operating energy is consumed in operating and maintaining the inside environment (Ding,2004). Also there are two types of embodied energy considered for building materials as per definitions,

i. Initial Embodied energy

ii. Recurring Embodied energy

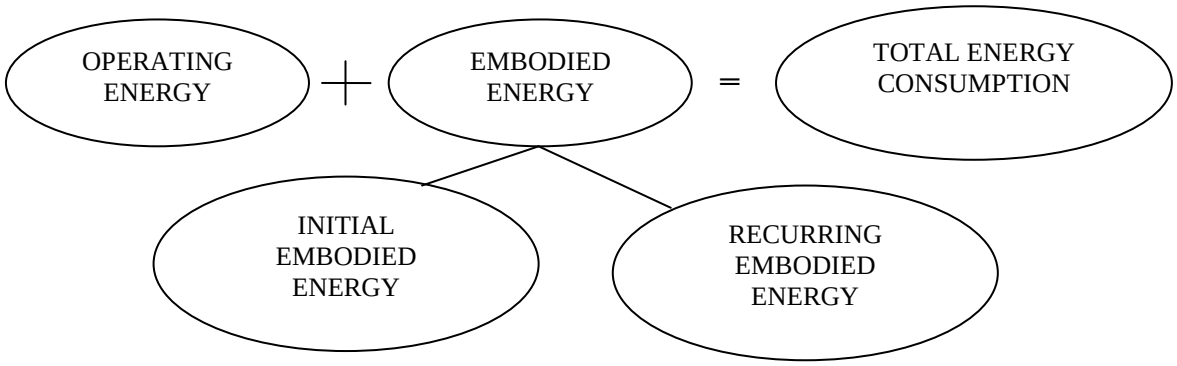

Figure 3

The difference between both the types of embodied energy is that the Initial embodied energy of a particular material is the energy used to produce that material in that state up till their construction phase. While the recurring embodied energy is the energy used after the installation or construction phase to retain that phase of the specific material, or in other words their maintenance. Wherever the word embodied energy is mentioned in the paper, which should be considered as Initial Embodied energy only as the Recurring embodied energy has many unpredictable factors affecting to it, which may be very site specific.In recent past the race to build vertical has been increased day by day, the reasons for which are many and varied; the shortage of suitable land, the increasing land price, the desire to live close to CBDs, builders to gain more profit, vast construction techniques and structural freedom, shortage of housing spaces etc. are the main factors. Although there is no precise definition of high-rise building that is universally accepted, various bodies

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have tried to define what 'high-rise' means, as per NBC any buildings more than 16m high are considered as high- rise buildings. In this study however, we will consider super tall buildings of around 40-50 floors as high-rise, looking at the current trend of development in India that can be viewed as justified. High rise buildings are one of the top most structures in demand in construction world today. In general almost each and every construction companies today are working on it. Analysis of such an apartment building project showed that the material manufacturing stage had the largest amount of energy consumption and GHG emissions (Taehoon Hong et al, 2013). Considering that the amount of materials being used in this kind of structure is very high compared to low and mid-rise structure, they are the prime choice of study in case of embodied energy.

II. LITERATURE SURVEY

Luisa F Cabeza, Camila Barreneche, Laia Miro, Monica Martınez, Ines Fernandez & Diana Urge-Vorsatz (2013). This paper shows that even though there is a lack of research on this topic, embodied energy and carbon are studied in the context of buildings and construction materials

Lu Aye, T. Ngo, R.H. Crawford, R. Gammampila, P. Mendis (2012). The article featured a research that suggested Embodied energy content varies greatly with different construction types

B V Venkatrama, K S Jagdish This paper begins with statements like of considerable amount of energy is spent in the manufacturing processes and transportation of various building materials. It include comparisons of Embodied energy between alternative materials / techniques of concrete work and roofing systems.

S. Balubaid, R. M. Zin, M. Z. Abd Majid, J. S. Hassan, Samihah Mardzuki. This paper aims at confirming the Malaysian common construction systems and compares it with the historical literature while it also explores energy efficiency in building construction.

Daniel Felton, Robert Fuller & Robert H. Crawford (2013). This article investigates the potential of renewable building materials to reduce embodied energy and greenhouse emissions in medium-rise construction by substituting the conventional materials in a commercial building in Melbourne with renewable materials

T.J. Mac Ginley (2005). The book gives in-depth information regarding the steel structures for different building typologies. As mentioned in the book, there are many different structural systems being used for tall structures with help of steel. The book gives basic information of these systems with help of design aspects and sketches which can be referred to for the case study building.

D. R. Panchal and P. M. Marathe.This paper presents work as Comparative study of R.C.C., Steel & Composite building. Hypothetical G+30 storey commercial building, which is situated in earthquake zone IV is considered for comparison. For modeling of Composite, Steel & R.C.C. structures, ETABS software was used and the results were compared.

III. METHODOLOGY

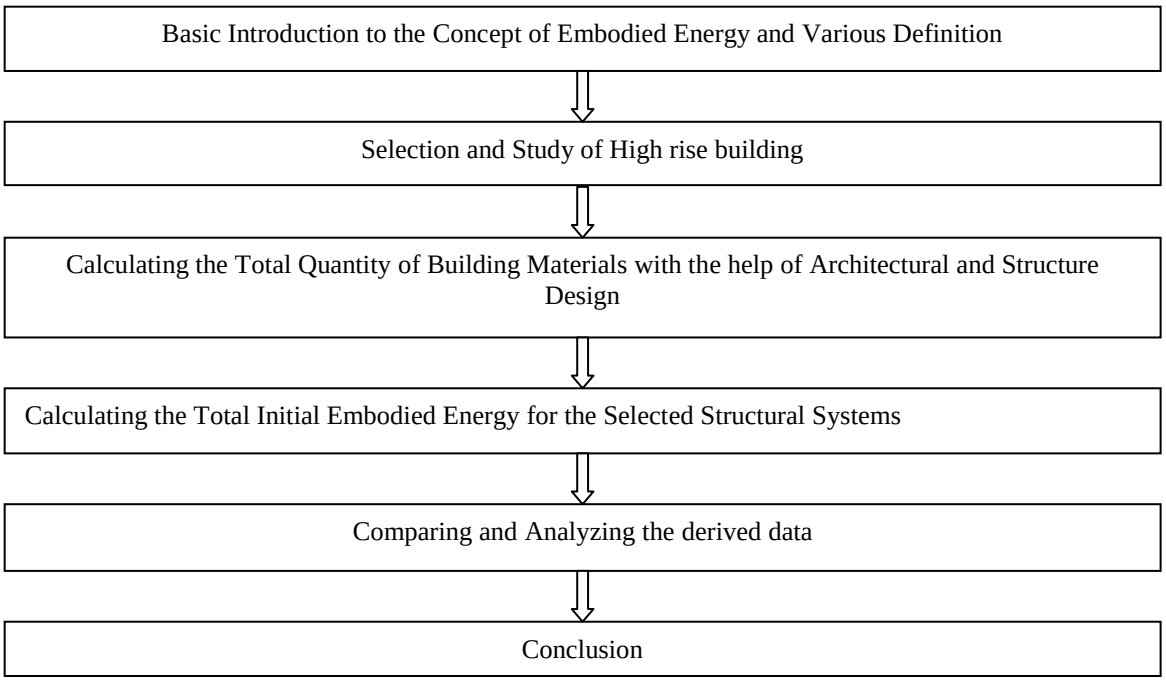

Figure 4

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IV. EXPERIMENTAL RESULTS

ASSUMPTIONS FOR CALCULATIONS

Following assumptions are made while calculating the embodied energy of the structural system, these assumptions are based on the on-site work information received from the architect's team and the field experience of the author,

- Embodied energy for Site-clearing, Earth-work, layout markings etc are not considered for the study, since they are necessary processes and will change little with respect to selection of structural system.
- Steel reinforcement calculations are based on the industry thumb rules, (percentage of volume for each structural member).
- All the materials are calculated based on the latest architectural and structural drawings received from the architect. Wastage quantity is added wherever required and the wastage quantity/proportions are as mentioned in the calculations.
- The EE data for Steel, Concrete, formwork, Machines, processes and other Manual energy are as per the earlier work of department and are crosschecked from the ICE data (University of Bath), which are more or less similar.
- Although the actual site conditions may have required a different strategy, techniques or method of work, it is limited by the scope of this study to consider that these processes are typical.
- The Embodied energy for formwork provided in her Thesis report is as the total embodied energy for the material, however as per the industry rule, steel plates and props are used at least 120-150 times before being discarded and eventually recycled.

Therefore, the unit EE used in this calculation is a division of the total unit EE and their subsequent reuse. Recycling is not considered here, since recycling for steel is proven to be much less energy consuming than mining. Also, it is not possible to track the material to its root for such time bound study. No. of reuse considered here is 150.

- Similarly, the Plywood formwork is supposed to be reused for 15-20 times, the total unit embodied energy provided in her report does not consider this part.

Therefore we shall be using the division of the Unit EE provided in her report by the number of their subsequent reuse. Again recycling/discarding is not considered here. No. of reuse considered here is 20.

- As a common practice, It is considered that 50% of the material is procured from the nearest supplier, remaining is procured from the other sources equally. This is a very site specific and preferential matter to generalize, therefore the decision to divide the procurement is considered.
- The Embodied energy for transportation is taken from the Seminar report of Suniti churiwal (2008), where she has shown the method of calculations as well.
- The mode of transport is considered by road here for distances less than 500Km, since the location of site is well connected through road, it is assumed that the transportation is done by the most common transportation method in shorter distances. For longer distances rail transport is considered.
- The vertical transport is considered for Concrete and steel only, shuttering plates and props etc will not be considered for this transport because they are generally transferred on one after another floor which is a manual labour work too.
- The Labour requirement for the Reinforcement binding and Concrete work is derived from the Delhi Schedule or Rates-2014, IS:7272 and total quantity of work.
- This calculation does not consider any other processes, such as Curing, Finishing etc, since they are either very site specific processes, for which calculating EE is not possible for such time bound study, and also they are comparatively negligible energy consuming activities as compared to the ones which are considered here.

Quantification of materials for calculation is done floor wise and item wise, since even for the same material (i.e. Cement concrete and Steel) the construction processes and vertical transportation data are different. This will make a huge error if considered as one single entity.Any particular assumptions are stated for each calculations as and where made.

Calculation Methodology

Table 1

Methodology of Embodied Energy Calculations for RCC Work				
Embodied Energy of Unit Materials	×	Total quantities of various material in RCC	=	Total EE of Materials

Energy Calculation Case Study I

MATERIAL EE - [C] (RCC Materials)

Location	Item	DATA			EE CALCULATIONS - STEEL					EE CALCULATIONS - CONCRETE				TOTAL EE-RCC
		Height Considered	Area	RCC Volume	% of Steel in Volume	Steel Volume	Steel Qua. (Incl. Wastage)	EE	Total EE	Conc. Quantity (Incl. Wastage)	Concrete Grade	EE	Total EE	
		(m)	(Sqm)	(m3)	(%)	(m3)	(q)	(MJ/Kg)	(MJ)	(m3)		(MJ/m3)	(MJ)	(MJ)
Basement Floor	Foundation	0.85	677.90	550.00	1.00%	5.50	453.34	40	1813350.0	598.95	M20	3276.72	1962591.4	3775941.4
	Columns	3.25	5.60	18.20	2.00%	0.36	30.00		120010.8	19.62	M25	4756.72	93324.9	213335.7
	Retaining Walls	3.25	14.90	48.43	1.50%	0.73	59.87		239485.8	52.47			249577.9	489063.7
	Slabs & Beams	0.15/0.20	499.77	135.69	1.75%	2.37	195.72		782897.4	146.65			697558.6	1480455.9
	Staircase	0.15	15.15	2.84	1.50%	0.04	3.51		14048.3	3.08			14640.3	28688.6
Stilt Floor	Columns	2.90	3.60	10.44	2.00%	0.21	17.21	40	68841.4	11.25	M25	4756.72	53533.6	122375.0
	Shear Walls	2.90	0.90	2.61	1.50%	0.04	3.23		12907.8	2.83			13451.7	26359.4
	Slabs & Beams	0.15	302.08	69.05	1.75%	1.21	99.60		398401.2	74.63			354974.0	753375.2
	Staircase	0.15	32.73	6.14	1.50%	0.09	7.59		30349.9	6.65			31628.9	61978.8
Ground Floor	Columns	3.60	3.60	12.96	2.00%	0.26	21.36	40	85458.2	13.97	M25	4756.72	66455.6	151913.8
	Shear Walls	3.60	0.90	3.24	1.50%	0.05	4.01		16023.4	3.51			16698.7	32722.1
	Slabs & Beams	0.15	302.08	69.05	1.75%	1.21	99.60		398401.2	74.63			354974.0	753375.2
	Staircase	0.15	32.73	6.14	1.50%	0.09	7.59		30349.9	6.65			31628.9	61978.8
First Floor	Columns	3.60	3.60	12.96	2.00%	0.26	21.36	40	85458.2	13.97	M25	4756.72	66455.6	151913.8
	Shear Walls	3.60	0.90	3.24	1.50%	0.05	4.01		16023.4	3.51			16698.7	32722.1
	Slabs & Beams	0.15	302.28	69.05	1.75%	1.21	99.60		398401.2	74.63			354974.0	753375.2
	Staircase	0.15	32.73	6.14	1.50%	0.09	7.59		30349.9	6.65			31628.9	61978.8
Second Floor	Columns	3.60	3.60	12.96	2.00%	0.26	21.36	40	85458.2	13.97	M25	4756.72	66455.6	151913.8
	Shear Walls	3.60	0.90	3.24	1.50%	0.05	4.01		16023.4	3.51			16698.7	32722.1
	Slabs & Beams	0.15	285.40	72.10	1.75%	1.26	104.00		415999.0	77.92			370653.5	786652.5
	Staircase	0.15	32.73	6.14	1.50%	0.09	7.59		30349.9	6.65			31628.9	61978.8
Third Floor	Columns	3.60	3.60	12.96	2.00%	0.26	21.36	40	85458.2	13.97	M25	4756.72	66455.6	151913.8
	Shear Walls	3.60	0.90	3.24	1.50%	0.05	4.01		16023.4	3.51			16698.7	32722.1
	Slabs & Beams	0.15	297.05	69.60	1.75%	1.22	100.39		401574.6	75.22			357801.4	759376.0
	Staircase	0.15	32.73	6.14	1.50%	0.09	7.59		30349.9	6.65			31628.9	61978.8
Fourth Floor	Columns	3.60	3.60	12.96	2.00%	0.26	21.36	40	85458.2	13.97	M25	4756.72	66455.6	151913.8
	Shear Walls	3.60	0.90	3.24	1.50%	0.05	4.01		16023.4	3.51			16698.7	32722.1
	Slabs & Beams	0.15	285.40	72.10	1.75%	1.26	104.00		415999.0	77.92			370653.5	786652.5
	Staircase	0.15	32.73	6.14	1.50%	0.09	7.59		30349.9	6.65			31628.9	61978.8
Fifth Floor	Columns	3.60	3.60	12.96	2.00%	0.26	21.36	40	85458.2	13.97	M25	4756.72	66455.6	151913.8
	Shear Walls	3.60	0.90	3.24	1.50%	0.05	4.01		16023.4	3.51			16698.7	32722.1
	Slabs & Beams	0.15	297.05	69.60	1.75%	1.22	100.39		401574.6	75.22			357801.4	759376.0
	Staircase	0.15	32.73	6.14	1.50%	0.09	7.59		30349.9	6.65			31628.9	61978.8
Sixth Floor	Columns	3.50	3.60	12.60	2.00%	0.25	20.77	40	83084.4	13.58	M25	4756.72	64609.6	147694.0
	Shear Walls	3.50	0.90	3.15	1.50%	0.05	3.89		15578.3	3.41			16234.8	31813.1
	Slabs & Beams	0.15	267.75	72.10	1.75%	1.26	104.00		415999.0	77.92			370653.5	786652.5
	Staircase	0.15	32.73	6.14	1.50%	0.09	7.59		30349.9	6.65			31628.9	61978.8
Terrace Floor	Columns	2.70	3.60	9.72	2.00%	0.19	16.02	40	64093.7	10.48	M25	4756.72	49841.7	113935.4
	Shear Walls	2.70	0.90	2.43	1.50%	0.04	3.00		12017.6	2.63			12524.0	24541.6
	Slabs & Beams	0.15	80.04	17.90	1.75%	0.31	25.82		103278.5	19.35			92020.8	195299.3
Total Values =				1522.95			1856.91		7427633.1	1650.46			6964350.9	14391984.0

Table 2

Energy Calculation Case Study II

Embodied Energy for STRUCTURAL SYSTEM [Residential Apartment at Ashok Vihar]														
MATERIAL EE - [C] (RCC Materials)														
Location	Item	DATA			EE CALCULATIONS - STEEL					EE CALCULATIONS - CONCRETE				TOTAL EE-RCC
		Height Considered	Area	RCC Volume	% of Steel in Volume	Steel Volume	Steel Qua. (Incl. Wastage)	EE	Total EE	Conc. Quantity (Incl. Wastage)	Concrete Grade	EE	Total EE	
		(m)	(Sqm)	(m3)	(%)	(m3)	(q)	(MJ/Kg)	(MJ)	(m3)		(MJ/m3)	(MJ)	(MJ)
Basement-2 Floor	Foundation	0.75	296.99	222.74	1.00%	2.23	183.60	40	734382.0	242.57	M25	4756.72	1153821.3	1888203.3
	Columns	2.55	6.73	17.16	2.00%	0.34	28.29		113162.9	18.50			87999.8	201162.7
	Retaining Walls	2.55	15.02	38.30	1.50%	0.57	47.35		189417.6	41.50			197399.8	386817.4
	Slabs & Beams	0.15	205.27	36.95	1.75%	0.65	53.30		213184.2	39.93			189946.3	403130.5
	Staircase	0.15	4.28	0.80	1.50%	0.01	0.99		3968.8	0.87			4136.0	8104.8
Basement-1 Floor	Columns	2.55	6.73	17.16	2.00%	0.34	28.29	40	113162.9	18.50	M25	4756.72	87999.8	201162.7
	Retaining Walls	2.55	18.42	46.97	1.50%	0.70	58.07		232295.1	50.89			242084.1	474379.2
	Slabs & Beams	0.15	239.56	43.12	1.75%	0.75	62.20		248796.2	46.60			221676.5	470472.7
	Staircase	0.15	12.44	2.33	1.50%	0.03	2.88		11535.4	2.53			12021.5	23556.9
Stilt Floor	Columns	2.40	6.73	16.15	2.00%	0.32	26.63	40	106506.3	17.41	M25	4756.72	82823.3	189329.6
	Shear Walls	2.40	17.59	42.22	1.50%	0.63	52.19		208779.2	45.74			217577.3	426356.5
	Slabs	0.15	207.20	31.08	1.75%	0.54	44.83		179323.8	33.59			159776.8	339100.7
	Staircase	0.15	6.86	1.29	1.50%	0.02	1.59		6361.1	1.39			6629.2	12990.4
Ground Floor	Columns	0.00	0.00	0.00	2.00%	0.00	0.00	40	0.0	0.00	M25	4756.72	0.0	0.0
	Shear Walls	0.00	0.00	0.00	1.50%	0.00	0.00		0.0	0.00			0.0	0.0
	Slabs	0.15	194.36	29.15	1.75%	0.51	42.05		168211.3	31.51			149875.6	318086.9
	Staircase	0.15	6.86	1.29	1.50%	0.02	1.59		6361.1	1.39			6629.2	12990.4
First Floor	Columns	0.00	0.00	0.00	2.00%	0.00	0.00	40	0.0	0.00	M25	4756.72	0.0	0.0
	Shear Walls	0.00	0.00	0.00	1.50%	0.00	0.00		0.0	0.00			0.0	0.0
	Slabs	0.15	212.72	31.91	1.75%	0.56	46.03		184101.2	34.48			164033.4	348134.6
	Staircase	0.15	6.86	1.29	1.50%	0.02	1.59		6361.1	1.39			6629.2	12990.4
Second Floor	Columns	0.00	0.00	0.00	2.00%	0.00	0.00	40	0.0	0.00	M25	4756.72	0.0	0.0
	Shear Walls	0.00	0.00	0.00	1.50%	0.00	0.00		0.0	0.00			0.0	0.0
	Slabs	0.15	223.59	33.54	1.75%	0.59	48.38		193508.8	36.25			172415.6	365924.3
	Staircase	0.15	6.86	1.29	1.50%	0.02	1.59		6361.1	1.39			6629.2	12990.4
Third Floor	Columns	0.00	0.00	0.00	2.00%	0.00	0.00	40	0.0	0.00	M25	4756.72	0.0	0.0
	Shear Walls	0.00	0.00	0.00	1.50%	0.00	0.00		0.0	0.00			0.0	0.0
	Slabs	0.15	223.59	33.54	1.75%	0.59	48.38		193508.8	36.25			172415.6	365924.3
	Staircase	0.15	6.86	1.29	1.50%	0.02	1.59		6361.1	1.39			6629.2	12990.4
Fourth Floor	Columns	0.00	0.00	0.00	2.00%	0.00	0.00	40	0.0	0.00	M25	4756.72	0.0	0.0
	Shear Walls	0.00	0.00	0.00	1.50%	0.00	0.00		0.0	0.00			0.0	0.0
	Slabs	0.15	223.59	33.54	1.75%	0.59	48.38		193508.8	36.25			172415.6	365924.3
	Staircase	0.15	6.86	1.29	1.50%	0.02	1.59		6361.1	1.39			6629.2	12990.4
Fifth Floor	Columns	0.00	0.00	0.00	2.00%	0.00	0.00	40	0.0	0.00	M25	4756.72	0.0	0.0
	Shear Walls	0.00	0.00	0.00	1.50%	0.00	0.00		0.0	0.00			0.0	0.0
	Slabs	0.15	223.59	33.54	1.75%	0.59	48.38		193508.8	36.25			172415.6	365924.3
	Staircase	0.15	6.86	1.29	1.50%	0.02	1.59		6361.1	1.39			6629.2	12990.4
Terrace Floor	Columns	0.00	0.00	0.00	2.00%	0.00	0.00	40	0.0	0.00	M25	4756.72	0.0	0.0
	Shear Walls	0.00	0.00	0.00	1.50%	0.00	0.00		0.0	0.00			0.0	0.0
	Slabs	0.15	13.06	1.96	1.75%	0.03	2.83		11302.9	2.12			10070.9	21373.8
Total Values =				721.17			884.17		3536693.0	781.49			3717309.2	7254002.2

Table 2

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COMPARISIONS AND ANALYSIS OF THE CASE-STUDIES

	TOTAL EE-STEEL	TOTAL EE - CONCRETE	TOTAL EE -RCC
CASE STUDY 1 (RCC FRAMED STUCTURE)	7427633.1	6964350.9	14391984.0
CASE STUDY 2 (COMPOSITE STUCTURE)	3536693.0	3717309.2	7254002.2

Table 3

V. CONCLUSION

After the detailed calculations of embodied energy of RCC Frame structure and Composite structure, it is concluded that the Embodied energy of Composite structure is significantly lesser than the RCC frame structure. Therefore it is safe to say that the Composite structure system is better than the RCC frame structure in High-rise buildings with respect to Embodied Energy.

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