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Comparing Building Material & Embodied Energy Consumption Between An Old And A Modern Office Building

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Abstract: *The building sector has witnessed a sea saw change in terms of its looks, design approach, technological interventions and associated limitations. But what has not changed over the period are the core building materials used for construction of the buildings. The four basic building materials extensively used in the building sector are identified as - Bricks, Cement, Steel and Glass today. For buildings, which are around 150 years old and still functional in a city like Kolkata - Only lime was used in place of cement and iron is taken over by steel. The Technopolis, the modern building in study here used all four whereas the KMC, the old building used lime mortar and lime concrete instead of cement and iron instead of steel as its core structural material. What initiated this study is that these building materials are also associated with a high amount of energy consumption in the building sector. And the paper makes a curious attempt in terms of their quantitative use in the two functional buildings of same typology and investigates the embodied energy consumed by these materials. The comparison are based on the embodied energy consumed by these building materials in per square metre area in the two buildings from two different eras and see where the modern building stands wrt the old building and then, if relevant justifications can be made for future buildings.*

Study: *The Kolkata Municipal Corporation Building & The Technopolis Building, Kolkata.*
Key Words: *Building Materials, Embodied Energy, Old & Modern Buildings.*

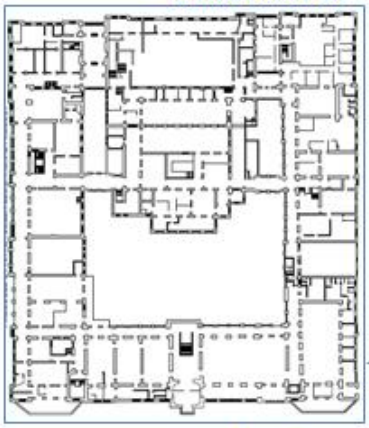
I. Introduction

India is experiencing an unprecedented construction boom. Our country doubled its floors space between 2001 and 2005 and is expected to add 35 billion square metres of new buildings by 2050. Buildings account for 35% of total final energy consumption in India today and building energy use is growing at 8% annually. Studies have shown that carbon policies will have little effect on reducing building energy demand if there are no specific sectoral policies to curb building energy use. Driven by rapid income and population growth, final energy demand of the Indian building sector will grow over five times by the end of this century. The building growth is directly proportional to the increase in consumption of building materials related with building construction. The construction methodology has of course changed with the advent of new technology. The paper identifies four major building materials – bricks, steel, cement and glass in terms of their quantitative use in two functional buildings of same typology but from two different eras and investigates the embodied energy. Embodied Energy refers to the total energy consumed by all of the processes associated with the production and execution of the building material – i.e. from the identification of natural resources to procurement of raw materials, its transportation to industrial process, produce, delivery and installing. The two aspect of embodied energy related with this study are -

- Initial embodied energy - The energy consumed to create the building, including; extraction, processing and manufacturing, transportation and assembling.
- Recurring embodied energy - That is the energy consumed to refurbish and maintain the building during its life.

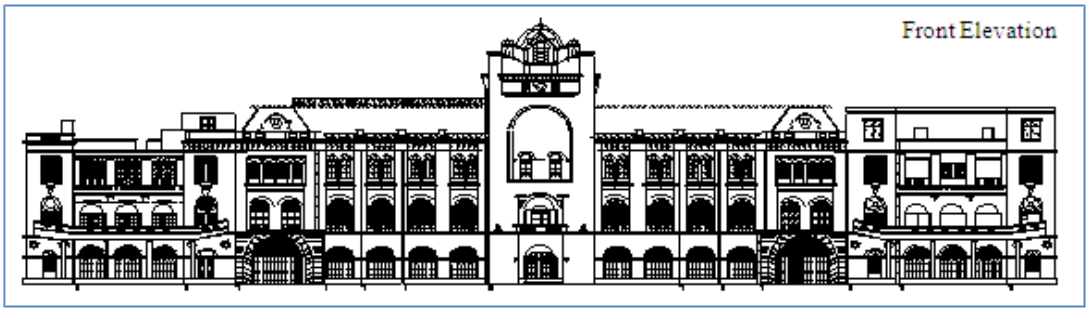
Study: The Kolkata Municipal Corporation Building

Ground Floor Plan



Typical Floor Plan

Area Statement –
- Ground Floor Area – 6870 sqm.
- First & Second Floor Area (Typical) – 15420 sqm.
- Third Floor area – 5020 sqm.
- Total Built up Area – 27310 sqm.



II. Consumption of Building Materials, KMC –

1. Bricks – The total volume of the brick walls were calculated to find the quantities of brick used in the KMC building. The openings in the form of doors, windows and other fenestrations were subtracted from the total wall volume to find the exact areas constructed with bricks.

The following observations were found – Doors and Windows openings -

- Doors - Door openings were found in various sizes, width ranging from 1000mm to 2200mm. An average opening size of 1400mm is opted. The height was also variable. Most of the doors had openings in the form of semi circular ventilators above them. So an average height of 2700mm is opted for. The thickness of the walls was considered as 800mm. Thus, the volume of each door – 1.4 x 2.7 x .8 = 3.02 cum
- Windows - Window openings were also found in various sizes - width ranging from 1000mm to 2400mm. An average opening size of 1500mm is opted. The height was also variable. The windows are there in various shapes along with various openings, jaalis and fenestrations. So an average height of 1800mm is opted for. The thickness of the walls was considered as 800mm. Thus, the volume of each window – 1.5 x 1.8 x .8 = 2.16 cum

	Descriptions	Nos.	Vol. Each (In Cum)	Total Volume (In Cum)	Total Vol. All Floors (in Cum)
Doors	Ground Floor	263	3.02	794.26	2609.28
	First Floor	253	3.02	764.06	
	Second Floor	258	3.02	779.16	
	Third Floor	84	3.02	253.68	
	Roof	06	3.02	18.12	
Windows	Ground Floor	215	2.16	464.4	1658.88
	First Floor	195	2.16	421.2	
	Second Floor	195	2.16	421.2	
	Third Floor	163	2.16	352.08	
	Roof	-	-	-	
Total – (Doors + Windows)					4268.16

Net wall area in all floors –

Sl. No.	Description	Wall Areas (in Sqm)	Volume (in Cum)	Vol-Door (in Cum)	Vol- Win (in Cum)	Net Wall (in Cum)
1.	Ground Floor	1300.7	6503.5	794.26	464.4	5245
2.	First Floor	1298.1	6490.5	764.06	421.2	5305
3.	Second Floor	1298.1	6490.5	779.16	421.2	5290
4.	Third Floor	284.4	1422	253.68	352.08	816
5.	Roof	415	498	18.12	-	480
Total -						17136

So, total number of bricks used = 17136 x 500 = 85,68,000
Note:
* As per CPWD schedule, number of bricks needed for – 1 cum area – 500 nos.
*Floor heights considered - 5m

2. Lime – The usage of lime was seen in the form of 'lime mortar' where lime was mixed with surkhi in 1:3 with water in proportion for brickwork and 'lime concrete' where lime was mixed with sand and surkhi in 1:1:1 with water in proportion for floor slabs and roof slab casting.

Weight of lime = 640 kg/m³

- Lime Mortar: Ratio – 1:3 (Lime – ¼ & Surkhi – ¾)

i. Lime Mortar in Brickwork = .350cum for 9" brick
ii. Lime in Brickwork= 0.350 x 1/4 = 0.0875 cum
iii. So, weight of lime per cum brickwork = 640 x 0.0875 = 56 kg

- Lime Concrete: Ratio – 1:1:1 (Lime – 1/3, sand – 1/3 and surkhi – 1/3)

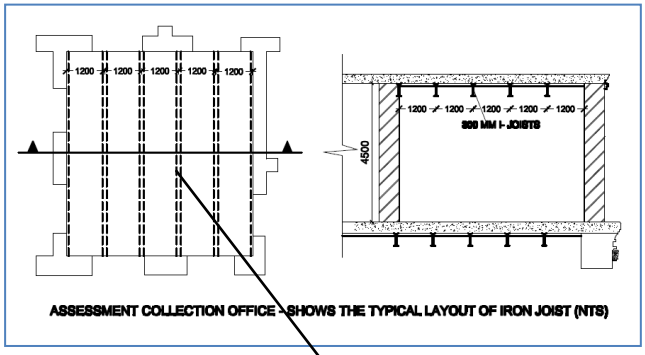
i. Lime in Lime concrete – 0.18cum
ii. Weight of Lime per cum slab area – 640 x 0.18 = 115.2 kg

Roof Slab Areas – 20440 sqm (all floors)
Thickness of Roof Slab – 0.25m
Volume of all floor slabs – 20440 x 0.25 = 5110 cum
So, the usage of lime in KMC –

Sl.No.	Items	Area (in cum)	Lime Consumed (in kg)
1.	Brickwork	17136	17136 x 56 = 959616
2.	Floor Slabs	5110	5110 x 115.2 = 588672
Total			**1548288**

Number of bags – 1548288/30 = 51610 bags

3. Iron Beams – Samples collected from Assessment Collection Office, KMC.
Size of the Room – (6.000 x 6.570)m = 39.42 sqm = 40 sqm = 400 sqft (rounded up) i.e, a 20'0" x 20'0" room (approximately)
Size of the I-Sections = 300mm x 140mm
Spacing between the beams = 1200mm / 4'0"
Length of each Beam –
= (6570 + 300 + 300)mm (300mm is considered to be rested on the load bearing walls on both the side) = 7170 mm = 7.17 m
Unit weight of each Beam = 46kg per meter (standard)
Weight of each beam – 7.17 x 46 = 329.82 kg = 330 kg



ASSESSMENT COLLECTION OFFICE - SHOWS THE TYPICAL LAYOUT OF IRON JOIST (NTS)

There are 5 exposed beams in the 40sqm space of the Assessment Collection Office.
Total weight of the beams = 330 x 5 = 1650 kg (for 40 sqm working space)
Weight per sqm = 1650 / 40 = 41.2 kg.
Total Built up Area of the KMC – 26911.05 sqm.
Hence, quantity of Iron used (approx) –
= 26911.05 x 41.2 = 1125172 kg = **1125 Metric Tonnes.**

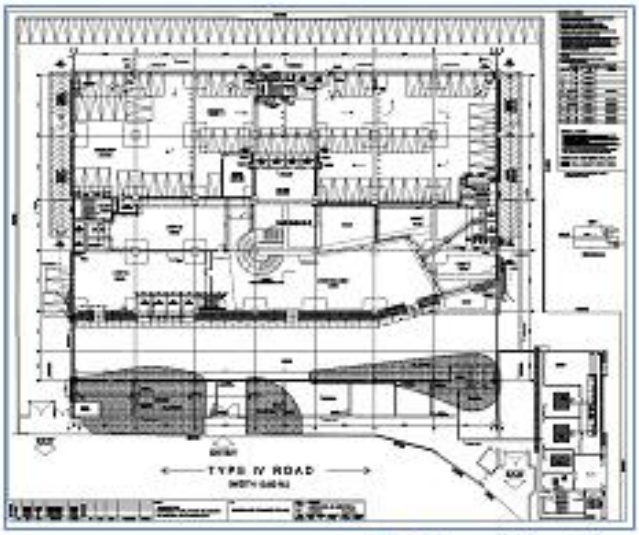
4. Glass – Throughout all the facades, the windows are mostly in 0.5mm clear glass. The window counts were taken from the field study. The sizes and areas were as found from the shapes in the Auto CAD drawings.

Sl. No.	Facades	Ground Floor	First Floor	Second Floor	Third Floor	Glass Use (in Sqm)
1.	East	103.15	118.34	105.74	58.33	385.56
2.	West	127.01	143.87	119.32	51.84	442.04
3.	North	67.58	88.96	72.76	25.92	255.22
4.	South	125.99	131.78	85.7	21.03	364.50
Total						**1447.32**

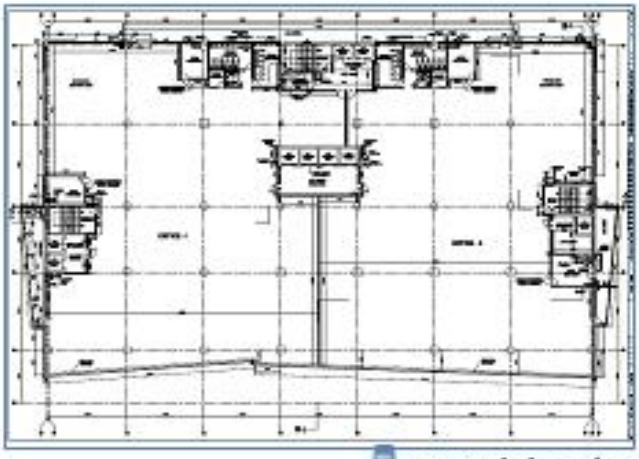
Embodied Energy (EE), KMC –

Sl. No.	Materials	Quantities	Quantities In Kg	EE In Mj/Kg	Total Embodied Energy In Mj
1.	**Bricks(Nos.)**	8568000 Nos.	x 3.5 = 29988000	2.5	**74970000**
2.	**Lime(Dry)**	51610 bags	x 30 = 1548300	5	**7741500**
3.	**Iron (MT)**	1125 MT	x 1000 = 1125000	20	**22500000**
4.	**Glass (Sqm)**	1447.32 Sqm	x 12.5 = 18092	16	**289464**

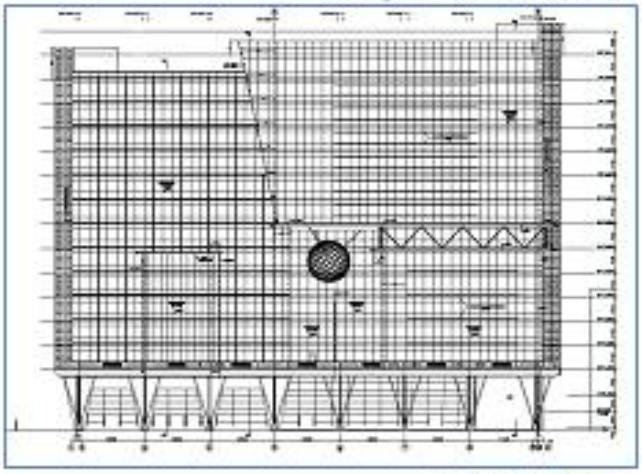
Study: The Technopolis Building –



Ground Floor Plan



Typical Floor Plan



Front Elevation

Area Statement -

- Ground Floor – 5212.65 sqm
- Mezzanine Floor – 2067.49 sqm
- First Floor – 3359.01sqm
- Second, Third & Fourth Floor – 3456.90 sqm (each) (*3)
- Fifth & Sixth Floor – 3527.60 sqm (each) (*2)
- Seventh to Thirteenth Floor – 3754.78 sqm (*7)
- Fourteenth Floor – 2356.73 sqm

30% of area is used as office in G.F. – 5212.65 sqm
10% of area is used as office in Mezzanine – 206.74 sqm
So, Total Built up Area – 51195.63 sqm

Consumption of Building Materials, The Technopolis –

1. Bricks – The pictures are of the superstructure during the construction phase of the building in 2004-05. Shows a minimal requirement of bricks for the building. The following nature of use of brick was found from the BOQ of civil works.

Item	Description	Unit	Area	Numbers
Foundation And Basement	Single Layer Brick Soling	Sqm	3388	169400
	250 mm Brick Wall	Cum	250	125000
	125 mm Brick Wall	Sqm	800	40000
Deck Slab And Super Structure	250 mm Brick Wall	Cum	3200	1600000
	125 mm Brick Wall	Sqm	12000	600000
Total Numbers Of Brick Used -				**25,34,400**

As per CPWD schedule, number of bricks needed for – 1 sqm area – 50 nos. and for 1 cum area – 500 nos.

2. Cement –

Item	Description	Unit	Area	Bags
Foundation & Basement	Single Layer Brick Soling	Sqm	3388	-------
	250 mm Brick Wall	Cum	250	380
	125 mm Brick Wall	Sqm	800	216
	750 mm dia pile	Rmt	700	2542
	500 mm dia pile	Rmt	90	148
	Raft & Beams	Cum	245	2205
	RCC work	Cum	3025	27225
Superstructure	250 mm Brick Wall	Cum	3200	5056
	125 mm Brick Wall	Sqm	12000	3240
	12 mm thick plaster	Sqm	54000	3780
	25 mm thick plaster	Sqm	15000	2025
	RCC work-1	Cum	19500	175500
	RCC work-2	Cum	500	4500
	Total Number of Cement Bags (of 50kg Per Bag)			**226817**

Note -

1. For RCC work-1 & 2, in superstructure - grade of concrete mix used is M25, M30 & M 40, where average kg of cement required per cum area is 422kgs or 9 bags (approx) – referred from chapter 3, Table 1 of CPWD schedule.
2. For Pile work, M25 grade of concrete was used i.e, 410kg per cum. Area is calculated for length 700 rmt & 90 rmt by - $\pi r^2 x\, h$, where r = 375mm & 250mm respectively.
3. Cement in Plaster work is calculated on the average finding of 3bags for 10sqm area.

3. Steel – Steel as a modern structural element was extensively used for construction in Technopolis. The consumption of steel is as found from the BOQ of civil works of the building.

Item	Description	Unit	Area	Metric Tonne
Foundation	750 mm dia pile	Rmt	700	2050
	500 mm dia pile	Rmt	90	
	Raft and Beams	Cum	245	
	RCC work	Cum	3025	
Deck Slab & Column upto Ground Level	RCC work-1 (M40)	Cum	215	230
	RCC work-2 (M35)	Cum	1205	
	Shuttering	Sqm	6800	
Superstructure	RCC work-1 (M40)	Cum	4000	2200
	RCC work-2 (M35)	Cum	7000	
	RCC work-3 (M30)	Cum	8000	
	RCC work-4 (M20)	Cum	500	
	Shuttering	Sqm	110000	
	Total			**4480**

4. Glass – Glass dominates the overall look of Technopolis and one could make out its extensive use. The quantity of glass used is calculated from the drawings and window specifications.

Facade	Description	Unit	Area	Thickness	Area(in sqm)
North	6 mm glazed reflective toughened	sqm	4979	6 mm	29.87
	6 mm plain low e toughened	sqm	5556	6 mm	33.33
South	6 mm glazed reflective toughened	sqm	589	6 mm	3.53
East	6 mm glazed reflective toughened	sqm	680	6 mm	4.08
West	6 mm glazed reflective toughened	sqm	757	6 mm	4.54
Total		**Sqm**	**12561**		**75.35**

Embodied Energy (EE), Technopolis –

Sl. No.	Materials	Quantities	Quantities (in Kg)	EE (in Mj/Kg)	Total Embodied Energy In Mj
1.	**Steel**	4480 MT	x 1000 = 4480000	30	**134400000**
2.	**Cement**	226817 bags	x 50 = 11340850	7	**79385950**
3.	**Brick**	2534400 nos.	x 3.5 = 8870400	2.5	**22176000**
4.	**Glass**	12560 sqm	x 15 = 188400	26	**4898400**

Comparison of Total and Specific Embodied Energy (Sp EE) –

Sl. No.	Materials	EE - KMC (in MJ/kg)	Sp EE - KMC (in MJ/sqm)	EE - Technopolis (in MJ/kg)	Sp EE – Technopolis (in MJ/sqm)
1.	Iron / Steel	22500000	823.87	134400000	2625.22
2.	Lime / Cement	7741500	283.46	79385950	1550.63
3.	Brick	74970000	2745.14	22176000	433.16
4.	Glass	289464	10.59	4898400	95.68
	Total	**105500964**	**3863.08**	**240860350**	**4704.70**

Observations on the proportionate usage of Embodied Energy / sqm of floor area –

Sl. No.	Materials	Comparative Ratio	Observations
1.	**Iron / Steel**	2625.22/823.87= 3.18	**3.18 times more in Technopolis**
2.	**Lime / Cement**	1550.63/283.46 = 5.47	**5.47 times more in Technopolis**
3.	**Brick**	2745.14/433.16 = 6.33	**6.33 times more in KMC**
4.	**Glass**	95.68/10.59 = 9.03	**9.03times more in Technopolis**

III. Conclusions

The consumption as against the floor areas clearly states the pattern of consumption of various building materials in the respective buildings. Knowing how much energy is needed to procure, produce and execute the building materials in a given shape are indicated by the embodied energy. The different eras have dictated the adoption of different construction technology, i.e. the KMC is a load bearing structure where bricks and lime concrete dominated the construction while the Technopolis is frame structure having extensive use of glass. But what needs to be noted is that the KMC building is functional since more than last 140 years now while the projected life spans of a modern building like Technopolis is 40 years. The Technopolis is functional since 2006. From the findings of the study, except for bricks, the Technopolis is clearly ahead in terms of materials

consumption per unit space. Bricks have a low embodied energy. So, a balance needs to be worked out between the embodied energy by optimizing the use of building materials and recommendations may be made for future buildings taking a cue from the old buildings of similar use.

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