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COMPARATIVE ANALYSIS OF A CONVENTIONAL AND A GREEN SUSTAINABLE OFFICE BUILDING

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ABSTRACT:

This paper carries out a detailed comparison between a sustainable office building and a conventional one. Since, Buildings are very energy intensive and contribute largely to the ongoing climate crisis, it is necessary to construct them in an eco-friendly and sustainable manner. The embodied carbon, cost benefit analysis and operational energy of two theoretical models of conventional and sustainable buildings are discussed in this paper. This paper concludes by giving point to point comparison for a clearer understanding. The findings of this article can be helpful to green building planners, designers, and developers.

KEYWORDS: Green Building, Sustainable Offices, Energy Efficiency, Cost comparison, Composite Materials, Embodied carbon.

INTRODUCTION:

The idea of sustainability is being increasingly adopted by various industries but there is a visible and substantial lag in the construction Industry. According to the Global Status report (2017) building and construction are responsible for 39% of all carbon emissions in the world. Operational emissions account for 28% while embodied carbon emissions associated with the materials and construction processes account for the remaining 11%. There is a need for sustainability in all stages of the life cycle of a building which is inclusive of the design of the building or the structure, production of raw materials and their transportation, various construction processes and finally the operation of the structure.

With the recent IT boom in Bangalore, there has been a sudden surge in the construction of office buildings. These building are often very energy intensive, tend to have a large carbon footprint and also contribute significantly to the urban heat island effect. Our project strives to comparatively analyse a sustainable office building over a conventional one and to show case the benefits of the former.

Through a methodical review of other studies undertaken in this field, we have been able to conceptualize a method to calculate the embodied carbon footprint of various materials, the operational energy and the capital required for a sustainable building. We have taken into reference buildings which fall under the gold standard of LEED certification for our model.

LEED or leadership in energy and environmental design provides a framework for healthy, efficient, carbon and cost-saving green buildings. LEED certification is a globally recognized symbol of sustainability achievement and leadership developed by the USGBC (U.S. Green Building Council).[1]

We hope to showcase the potential of construction of sustainable buildings in India by providing a simplistic point to point comparison, which will help gauge the benefits of a sustainable workspace over a conventional one.

OBJECTIVES:

- To make a comparative analysis of a sustainable office building and a conventional one.
- To investigate the energy consumption and carbon footprint after adoption of green technology.
- To examine the cost benefit perspectives of sustainable buildings.
- To showcase the potential of construction of sustainable office buildings in India.

METHODOLOGY:

The goal of the project is to make a simple point to point comparative analysis between a conventional office building and a green sustainable one. In order to achieve this, we created theoretical models of both conventional and sustainable buildings of similar size and use, to get a fair result.

The embodied carbon was calculated using ICE database. For the ease of calculations, only the major construction materials were considered. Cost analysis was done using current market rates in India for the materials. The operational electricity usage was calculated assuming the energy performance index of the buildings. This was calculated for a timeframe of 1 year, 5 years, 10 years and 25 years.

Software used – AutoCAD 2021 and SketchUp for rendering the design of the building models. STACK (Take-off and cost estimation) software was used for quantity and cost estimation.

The location for the models was chosen to be Bengaluru, India. With a usable floor area of 100,000sq. ft, for 500 employees. After various site visits to traditional office buildings in the city, a simple common design was chosen for our conventional building model.

For the conventional office model, a G+3 rectangular building was considered. Each floor with 25,000sq. ft. For the sustainable building model, a G+4 “L” shaped building was considered. With an individual floor area of 21,500sq. ft.

After designing both models, Quantity estimation using the STACK software was performed. Using the data from the quantity sheets, Calculations of embodied carbon and construction cost was calculated.

The formula used to calculate embodied carbon: Quantity (kg) x Carbon Factor (kgCO_2e/kg). The caron factor values were sourced from the ICE database.

For the operational energy usage calculations, the Energy Performance Index (EPI) of building was assumed. The national benchmark for EPI for office/commercial building in India is 180kWh/m^2/year.[2] For the sustainable building, EPI of 100kWh/m^2/year was assumed, since that was the target, we wanted to achieve. The cost of electricity per unit was derived from the local municipality, Bangalore Electricity Supply Company Limited (BESCOM).

Solar power system considered for the sustainable building:

Panel: 375W Solar Panels (6ft x 3ft), 750 total Units.

Orientation: South facing, Tilt: 12 degrees from the ground.

Generation: (375 x 6.4 x 0.77) x 750 = 1350kWh/day*

**Note: 6.4hrs = Average peak sunshine time in Bengaluru per day.*

0.77 = Overall efficiency of solar power system.

Sustainable features used in the green office building:

1. **Design:**
   The north-south oriented building was made thinner with large full-length windows to allow maximum light and air inside the building.
2. **Thermal insulation:**
   Double glazed window panels were used to provide thermal insulation. The solar panels on the roof provide a cooling effect on the roof as well.
3. **Powered by renewable energy:**
   With the help of solar power system, we aimed to provide more than 50% of required energy through renewable source. [3]
4. **Usage of energy efficient systems:**
   Energy-efficient systems should be used to supplement the passive systems of heating, ventilation, cooling, water management, etc.[4]
5. **Use of Local Materials & Materials with low embodied energy:**
   Using local materials reduces the energy consumed in their transportation to the site. Traditional building materials can be substituted with alternatives that have low embodied energy.
6. **Rain water harvesting:**
   Harvested rainwater in a building can be used for non-potable purposes in the building. Rainwater Harvesting Capacity: 900mm x 2000m^2 = 18,00,000 lts annually.
7. **Waste Management System:**
   Organic waste can be composted on-site, which can feed into green spaces as compost. Recycled greywater can be used in certain places, such as for flushing in bathrooms.
8. **Increase Green area:**
   Have sufficient green coverage with trees, lawn, vertical gardens and indoor plants. This not only improves the environmental quality of the area but also act as psychological betterment catalysts. [5]

CONVENTIONAL BUILDING MODEL:

SUSTAINABLE BUILDING MODEL:

RESULTS

Embodied Carbon –

Conventional Building:

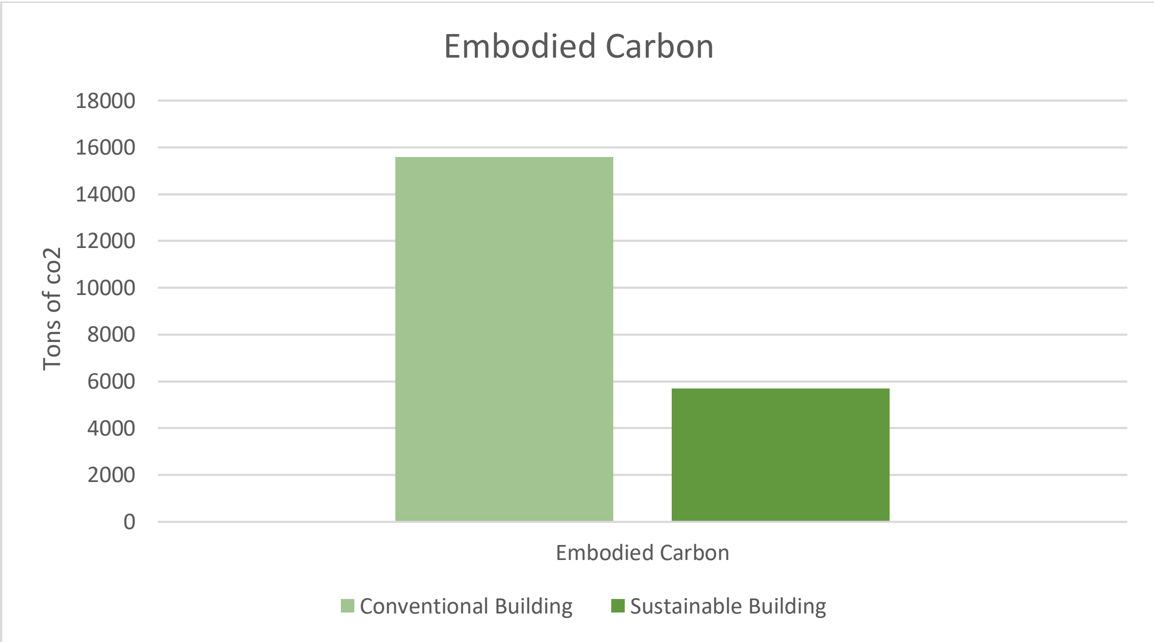
Sl. No.	Item	Quantity	Unit	Embodied Carbon contribution per Kg	Total (Kg)	Total (Tonne)
1	Portland Cement	22,50,000	Kg	0.958	2155500	2155.5
2	Sand	1,13,60,000	Kg	0.25	2840000	2840
3	Aggregate	1,07,58,750	Kg	0.7	7531125	7531.125
4	Cement Blocks	49,37,500	Kg	0.368	1817000	1817
5	Reinforcement Steel	4,53,600	Kg	2.289	1038290.4	1038.2904
6	Stones	5,80,000	Kg	0.141	81780	81.78
7	Window Glass	16,000	Kg	1.551	24816	24.816
8	Timber - Plywood 100%	54,000	Kg	1.12	60480	60.48
9	Solvent borne paint	6,979	Kg	3.76	26241.04	26.24104
10	Earthwork	7,975	m^3	0.107	853.325	0.853325
11	Asphalt	5,25,600	Kg	0.007	3679.2	3.6792
				Total Embodied Carbon in Metric Tonnes		15579.76497

Sustainable Building:

Sl. No.	Item	Quantity	Unit	Embodied Carbon contribution per Kg	Total (Kg)	Total (Tonne)
1	GGBS	8,52,930	Kg	0.042	35823.06	35.82306
2	Portland Cement	6,82,350	Kg	0.958	653691.3	653.6913
3	Sand	21,90,240	Kg	0.25	547560	547.56
4	Locally sourced aggregate	43,29,936	Kg	0.6	2597961.6	2597.9616
5	Fly ash based plaster & Mortar	1835538	kg	0.04	73421.52	73.42152
6	Brickwork	43,88,050	Kg	0.285	1250594.25	1250.59425
7	Steel - Rebar - 97% recycled	4,38,805	Kg	0.835	366402.175	366.402175
8	Timber - Manufactured structural timber	62,000	Kg	0.432	26784	26.784
9	granite	23,275	Kg	0.141	3281.775	3.281775
10	Double glazed Window Glass	83,600	Kg	1.551	129663.6	129.6636
11	Earthwork	4,212	m^3	0.107	450.684	0.450684
12	Non VOC paint	3,875	Kg	2.54	9842.5	9.8425
13	Permeable Pavement	91,800	Kg	0.007	642.6	0.6426
				Total Embodied Carbon in Metric Tonnes		5696.119064

[6]–[8]

Embodied Energy Comparison chart:



Embodied Carbon Saving = 36.5%

Cost Estimation –

Conventional Building:

Sl. No.	Item	Quantity	Unit	Rate	Unit	Estimate	Note
1	Portland Cement	22,50,000	Kg	350	1 Bag	1,57,50,000	45,000 Bags
2	Sand	1,13,60,000	Kg	650	1 ton	73,84,000	11,360 Tons
3	Aggregate	1,07,58,750	Kg	600	1 ton	64,55,250	10,758.75 Tons
4	Cement Blocks	49,37,500	Kg	52	1 Block	1,02,70,000	1,97,500 units / 8"x8"x12"
5	Reinforcement Steel	4,53,600	Kg	40	Kg	1,81,44,000	
6	Stones	5,80,000	Kg	50	Sq.ft	36,25,000	72,500 Sq. ft
7	Glass	16,000	Kg	85	Sq.ft	11,90,000	14,000 Sq. ft
8	Timber	54,000	Kg	850	Cubic ft	5,10,000	600 Cubic ft
9	Paint	6,979	Kg	250	lt	6,71,100	2,684 lts
10	Earthwork Excavation	7,975	m^3	1400	m^3	1,11,65,000	
11	Asphalt	5,25,600	Kg	25,000	1 ton	1,31,40,000	525.6 Tons
	Total :					8,83,04,350	
12	Electrical Wiring			7%		61,81,500	
13	Water Supply & Sanitation			7%		61,81,500	
14	Labour Charges			15%		1,32,45,650	
15	Scaffolding, Shuttering, etc			15%		1,32,45,650	
16	Consultation & Miscellaneous work			12%		1,05,96,500	
17	Contigencies			5%		44,15,250	
	Grand Total :					14,21,70,400	

Sustainable Building:

Sl. No.	Item	Quantity	Unit	Rate	Unit	Estimate	Note
1	GGBS	8,52,930	Kg	1000	1 ton	8,52,930	852.93 Tons
2	Portland Cement	6,82,350	Kg	350	1 Bag	47,77,500	13,650 Bags
3	Sand	21,90,240	Kg	650	1 ton	14,23,650	2,190.24 Tons
4	Locally sourced aggregate	43,29,936	Kg	700	1 ton	30,30,650	4329.93 Tons
5	Fly ash based plaster & Mortar	849	m^3	2100	m^3	17,83,000	
6	Brickwork	43,88,050	Kg	3	1 unit	42,46,500	14,15,500 standard brick units
7	Recycled Steel	4,38,805	Kg	80	Kg	3,51,04,400	
8	Reclaimed hardwood	62,000	Kg	1200	Cubic ft	8,28,000	690 Cubic ft
9	Linoleum	23,275	Kg	200	m^2	16,05,200	8,026 m^2
10	Window Glass	83,600	Kg	7,500	m^2	3,15,00,000	4,200 m^2
11	Earthwork Excavation	4,212	m^3	1400	m^3	58,96,800	
12	Non VOC Paint	3,875	Kg	370	lt	5,51,300	1,490 lts
13	Permeable Pavement	91,800	Kg	2400	Sq. ft	1,44,00,000	6000 Sq.ft
14	Local STP	7500	lts/day	66,000	1 KLD	5,00,000	500 No. Staff/ 15lt per staff
15	Solar Power System	750	Units	21,500	Unit	1,60,50,000	375W Solar panel unit*
16	Rainwater Harvesting System	2100	m^2	66	m^2	1,40,000	
	Total :					12,26,89,930	
17	Electrical Wiring			10%		1,22,69,000	
18	Water Supply & Sanitation			10%		1,22,69,000	
19	Labour Charges			15%		1,80,50,000	
20	Scaffolding, Shuttering, etc			15%		1,80,50,000	
21	Consultation & Miscellaneous work			12%		1,44,40,000	
22	Contigencies			5%		60,16,000	
	Grand Total :					20,37,83,930	

[9]–[12]

Cost Estimation chart:

Excess cost for sustainable building = 6,16,13,530Rs = 43.3%

Operational Life Electricity usage overview:

Conventional Building:

Timeframe	1 Year		5 Years		10 Years		25 Years	
	Usage(kWh)	Cost (Rs)	Usage(kWh)	Cost (Rs)	Usage(kWh)	Cost (Rs)	Usage(kWh)	Cost (Rs)
Electricity consumed	16,72,200	1,36,28,430	83,61,000	6,81,42,150	1,67,22,000	13,62,84,300	4,18,05,000	34,07,10,750
CO_2 Released (Tons)	**1,421**		**7,105**		**14,213**		**35,534**	

Sustainable Building:

Timeframe	1 Year		5 Years		10 Years		25 Years	
	Usage(kWh)	Cost (Rs)	Usage(kWh)	Cost (Rs)	Usage(kWh)	Cost (Rs)	Usage(kWh)	Cost (Rs)
Electricity consumed	9,29,000	75,71,350	46,45,000	3,78,56,750	92,90,000	7,57,13,500	2,32,25,000	18,92,83,750
Electricity generated	4,92,750	40,15,913	24,63,750	2,00,79,563	49,27,500	4,01,59,125	1,23,18,750	10,03,97,813
Total -	**4,36,250**	**35,55,438**	**21,81,250**	**1,77,77,188**	**43,62,500**	**3,55,54,375**	**1,09,06,250**	**8,88,85,938**
CO_2 Released (Tons)	**371**		**1,854**		**3,708**		**9,270**	

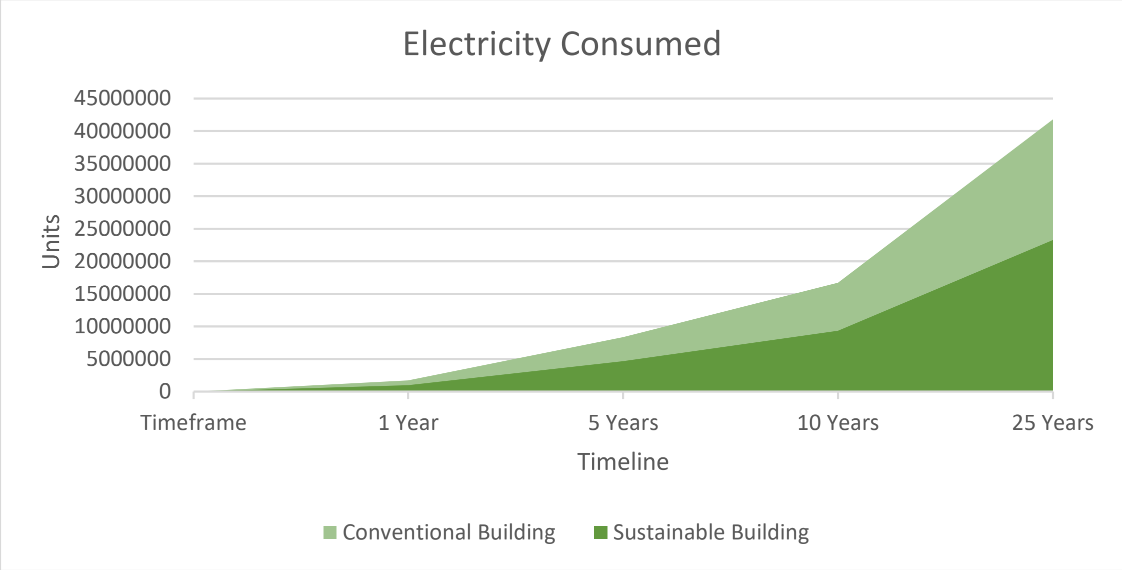
**Note: 1kWh = 1 Unit; 1 Unit = 8.15Rs; CO_2 released = kWh/year x 0.85 (ISO 14064)*

Conventional Building EPI = 180kWh/m^2/year; Sustainable Building EPI = 100kWh/m^2/year[2], [13], [14]

Total saved in sustainable building over time:

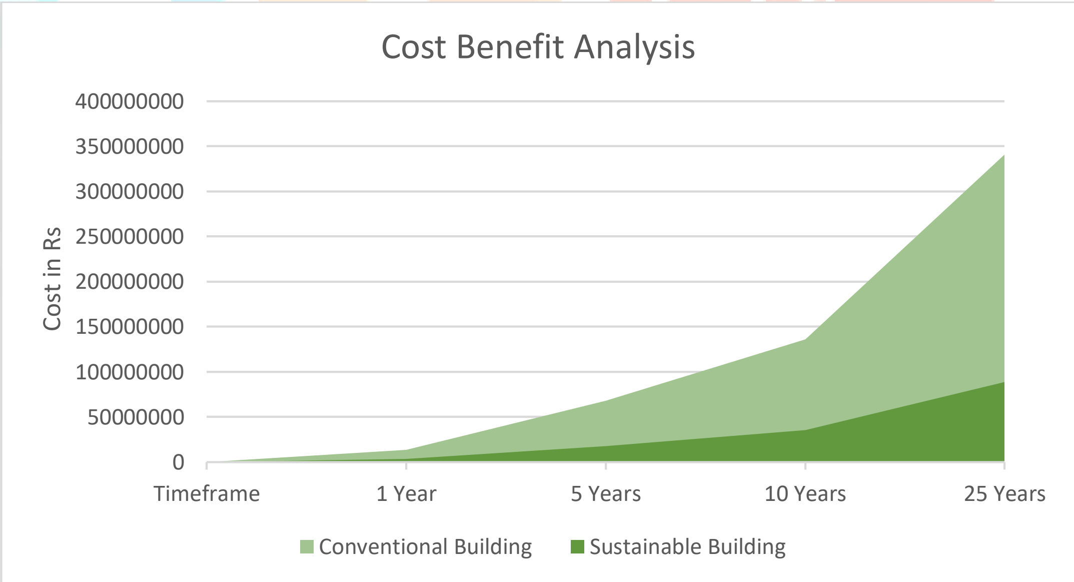
Timeframe	1 Year	5 Years	10 Years	25 Years
Electricity (kWh)	7,43,200	37,16,000	74,32,000	1,85,80,000
Cost (Rs)	1,00,72,993	5,03,64,963	10,07,29,925	25,18,24,813
CO_2 Released (Tons)	**1,050**	**5,251**	**10,505**	**26,264**

Operational Life Electricity usage comparison charts:



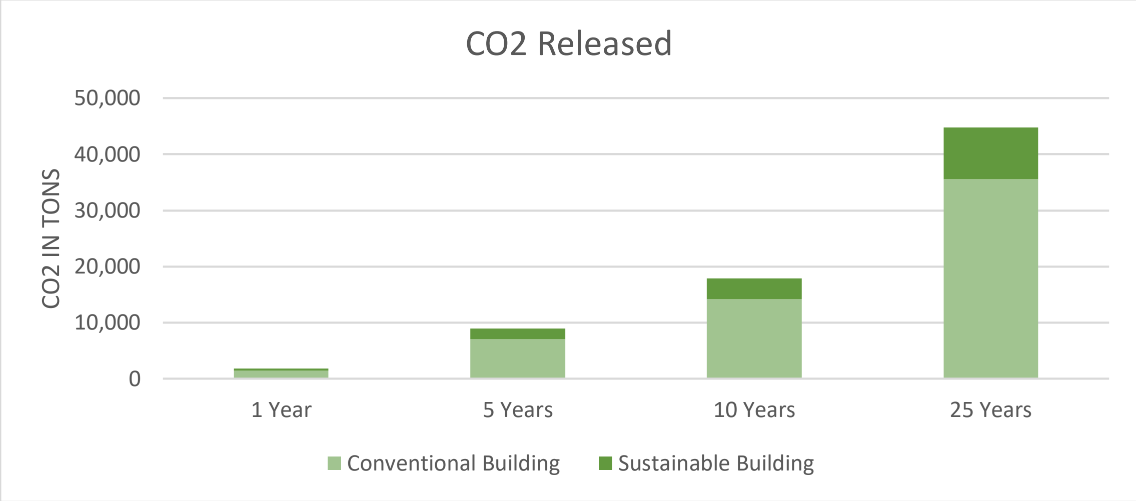
Timeframe	1 Year	5 Years	10 Years	25 Years
Conventional Building	16,72,200	83,61,000	1,67,22,000	4,18,05,000
Sustainable Building	9,29,000	46,45,000	92,90,000	2,32,25,000
Savings - (kWh)	7,43,200	37,16,000	74,32,000	1,85,80,000

Savings = 44.4% /year



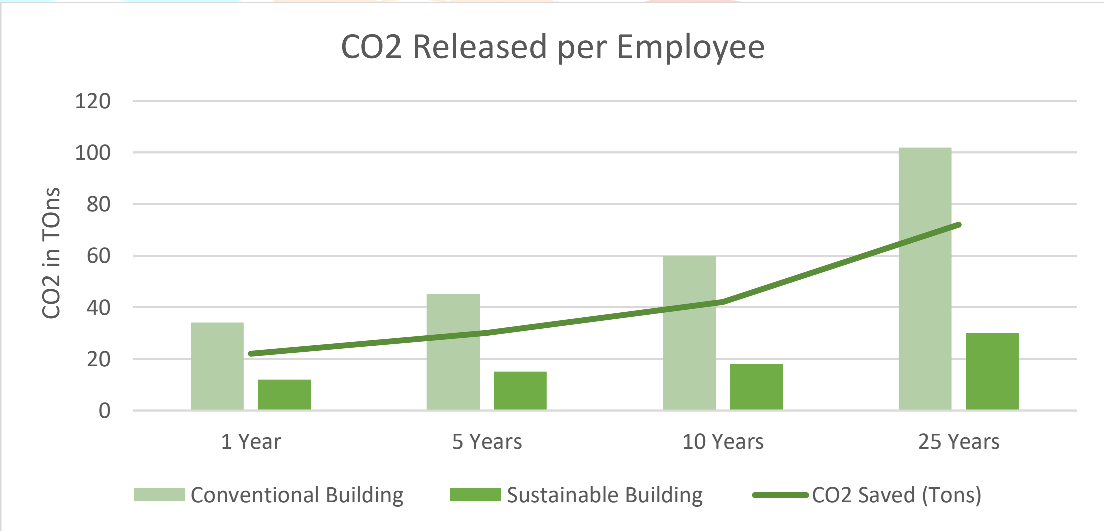
Timeframe	1 Year	5 Years	10 Years	25 Years
Conventional Building	1,36,28,430	6,81,42,150	13,62,84,300	34,07,10,750
Sustainable Building	35,55,438	1,77,77,188	3,55,54,375	8,88,85,938
Savings - (Rs)	1,00,72,993	5,03,64,963	10,07,29,925	25,18,24,813

Savings on Electricity Bill = 73.9% /year



Timeframe	1 Year	5 Years	10 Years	25 Years
Conventional Building	1,421	7,105	14,213	35,534
Sustainable Building	371	1,854	3,708	9,270
CO_2 Saved (Tons)	1,050	5,251	10,505	26,264

CO_2 Saved = 73.8% /year



Timeframe	1 Year	5 Years	10 Years	25 Years
Conventional Building	34	45	60	102
Sustainable Building	12	15	18	30
CO_2 Saved (Tons)	22	30	42	72

CO_2 Saved per employee = 64.7% /year

**Note: Embodied Carbon per employee: Conventional Building = 31 Tons; Sustainable Building = 11 Tons*

Breakeven Period for Sustainable Building = 6 years

Rainwater Harvesting Capacity: 900mm x 2000m^2 = 18,00,000 lts annually.

CONCLUSION

The results computed give an easy understanding about the differences, benefits and a basic comparison between a conventional office building and a green sustainable one.

The embodied carbon calculation showed that our sustainable building model has a potential of savings of up-to 36.5% annually. This will help greatly reduce the environmental impact of the construction of the building. Using locally sourced materials also help boost local economy.

The results show that since, the sustainable building comes with a solar power system, rainwater harvesting, usage of alternative building materials and so on, the cost of building a sustainable building is 43.3% higher than that of a conventional building. Although the initial cost is higher, due to reduced cost in operations, the breakeven period for the building is 6 years.

The electricity consumption is drastically reduced for the sustainable building. It was calculated that 44.4% is saved annually. This combined with solar power generation, results in a 73.9% savings in the electricity bill annually.

The CO_2 released due to operational usage drops by about 73.8% annually for the sustainable building in comparison to the conventional office building. The CO_2 released per employee is also down by 64.7% annually.

This project clearly highlights the benefits of constructing a sustainable office building in India. For a rapidly developing country which is witnessing a boom in the construction industry, this paper showcases the potential and advantages for approaching construction with sustainability in mind.

These types of constructions will not only lower the burden on the national grid and have a lower carbon footprint impact, these will also in the long-term work out economically for the builder as well as the client.

Therefore, this project will help spread awareness in the country and motivate developers, consumers and architects to move towards greener sustainable building design and construction.

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