ESTIMATION OF GREEN BUILDING OVER CONVENTIONAL BUILDING

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ABSTRACT

This report investigates the comparative costs and benefits of green building versus conventional building practices. By integrating five advanced techniques: Biophilic Design, Passive House Design Strategies, Digital Twin Technology, Net Zero Energy Techniques, and Water Harvesting System into the construction of a conventional building, we transformed it into a green building at an additional cost of approximately ₹6,72,420. The total cost for constructing the green building amounted to ₹24,23,876.78, inclusive of the base cost of a conventional building.

The study outlines a comprehensive methodological approach, which includes creating theoretical models, conducting cost analyses using current market rates in India, and evaluating environmental impacts through carbon emissions calculations. The findings reveal that although the initial costs for green buildings are higher, they offer substantial long-term benefits, including reduced operational expenses, improved occupant health, and minimized environmental footprints.

Green buildings are designed to maximize resource efficiency, enhance indoor air quality, and utilize renewable energy sources, resulting in significant energy savings and reduced carbon emissions. This investment in sustainable construction practices not only promotes environmental stewardship but also ensures economic viability through long-term savings and improved occupant well-being. The transition to green buildings is a crucial step towards addressing climate change and fostering sustainable development for future generations.

This report underscores the importance of adopting green building techniques and demonstrates that the benefits far outweigh the initial financial outlay, making green buildings a worthwhile investment for a sustainable future.

CHAPTER 1

1.1. INTRODUCTION

The construction industry plays a significant role in shaping our environment, economy, and society. While it offers employment opportunities and essential infrastructure, it also contributes to issues like noise pollution, waste disposal, and resource depletion. With the global population on the rise and advancements in technology, there's an urgent need to address these challenges while meeting the growing demand for infrastructure. In India, the booming real estate sector presents both opportunities and challenges, particularly considering projected GDP growth and population expansion. Sustainability has become paramount, driven by concerns over energy shortages and environmental degradation. The inception of the green building movement in 2001 marked a pivotal moment in promoting eco-friendly construction practices in India, with various rating systems such as LEED NC-USA and GRIHA leading the way in sustainable building design. Cities like Mumbai, Pune, and Bangalore have emerged as frontrunners in adopting green building principles, especially in the commercial sector, where businesses are reaping benefits like employee retention, cost reduction, and enhanced market image.

Green Building designed to minimize their environmental footprint by reducing reliance on non-renewable resources and maximizing utilization efficiency through strategies like reuse, recycling, and the use of renewable energy sources such as solar, wind, and water. By prioritizing the efficient use of resources and incorporating recycled, eco-friendly, and reusable materials, green buildings aim to sustain the natural environment and promote human health and well-being. In recent years, the importance of green building has grown significantly, driven by its ability to mitigate climate change, reduce waste generation, and offer cost-effective solutions for environmental, economic, and social challenges.

Green buildings embody principles of energy efficiency and environmental responsibility, striving to minimize reliance on external energy sources while harnessing renewable energy to meet operational needs. Drawing inspiration from nature's efficiency, these buildings emulate the symbiotic relationship found in ecosystems, where resources are utilized harmoniously. Key to green building design is the conscientious management of natural resources, aiming to minimize depletion during both construction and operation phases. This involves not only reducing demand for non-renewable resources but also maximizing their utilization efficiency. Additionally, green buildings prioritize the adoption of renewable resources and emphasize strategies for waste reduction, recycling, and repurposing materials, thereby minimizing environmental impact throughout their lifecycle.

Green building design represents a beacon of hope for a sustainable future, where buildings serve as catalysts for environmental stewardship and resilience. Through the adoption of eco-conscious construction practices, India can address pressing challenges such as energy shortages, climate change, and resource depletion while promoting economic growth and social well-being. By embracing green building principles and incorporating sustainable design features, we can pave the way for a more sustainable and resilient built environment for generations to come.

Conventional Building methods represent the traditional approach to construction, involving on-site assembly of materials such as steel, brick, and cement through welding and cutting processes. This approach has been widely employed in the construction industry for decades, but it comes with inherent challenges and limitations.

The design phase of a conventional building project requires intricate planning and detailing to ensure structural integrity and adherence to building codes and regulations. This often necessitates the involvement of various consultants, including architects, structural engineers, and MEP (mechanical, electrical, plumbing) specialists. The complexity of this phase can lead to delays and increased project costs if not managed efficiently.

Construction progresses incrementally in conventional building projects, typically starting with excavation and foundation work, followed by structural assembly, interior finishing, and exterior cladding. Each step in the process must be completed before moving on to the next, which can lead to potential delays, especially in projects with complex designs or site conditions. This sequential approach can also increase the overall project timeline and costs.

Conventional construction methods are often labour-intensive, requiring skilled workers for tasks such as bricklaying, welding, and concrete pouring. The reliance on manual labour can lead to higher labour costs, as well as increased risks of accidents and injuries on construction sites. Moreover, the availability of skilled labour can be limited, further exacerbating project delays and cost overruns.

The production waste generated during conventional construction, including excess materials, packaging, and demolition debris, poses environmental hazards. Many of these materials contain toxic substances, such as heavy metals and harmful chemicals, which can leach into the soil and waterways, posing risks to human health and ecosystems. Disposal of this waste can be costly and often involves transportation to landfill sites, contributing to carbon emissions and environmental degradation.

Despite its widespread use, the conventional approach to construction lacks the efficiency and sustainability inherent in modern building practices. As concerns about climate change, resource depletion, and environmental pollution continue to grow, there is a pressing need for alternative, greener building methodologies. Embracing innovative construction techniques, such as prefabrication, modular construction, and the use of sustainable materials, can help reduce environmental impact, increase efficiency, and create healthier, more resilient buildings for the future. By transitioning away from conventional building methods and embracing greener alternatives, the construction industry can play a significant role in addressing global sustainability challenges and creating a more sustainable built environment. In conclusion, while conventional building methods have served as the backbone of the construction industry for decades, their limitations in terms of efficiency, sustainability, and environmental impact are increasingly evident. As we look to the future of construction, it's clear that embracing alternative, greener building methodologies is not only necessary but essential for creating a more resilient and sustainable built environment for generations to come.

1.2. OBJECTIVE OF THE WORK

1. **Compare the Initial Cost:** Evaluate the upfront financial investment required for conventional and green building construction, considering factors such as materials, technology, and design. To compare the initial cost, operational cost, maintenance cost, and life cycle cost of conventional and green buildings.
2. **Analyse Operational Cost:** Assess the ongoing operational expenses associated with conventional and green buildings, including energy consumption, water usage, and maintenance.
3. **Examine Maintenance Cost:** Investigate the long-term maintenance expenses of conventional and green buildings, considering factors such as repairs, upgrades, and replacements.

4. **Evaluate Life Cycle Cost:** Calculate the total cost incurred throughout the lifespan of conventional and green buildings, integrating initial, operational, and maintenance expenses.
5. **Assess Energy Consumption:** Compare the energy usage patterns of conventional and green buildings, including heating, cooling, lighting, and appliances, to determine efficiency and environmental impact.
6. **Measure Carbon Emissions:** Quantify the carbon footprint generated by conventional and green buildings, considering emissions from energy consumption, materials production, and transportation.
7. **Evaluate Water Usage:** Compare the water consumption rates of conventional and green buildings, including indoor usage, landscaping, and wastewater management.
8. **Examine Indoor Air Quality:** Evaluate the indoor air quality of conventional and green buildings, considering factors such as ventilation, pollutant levels, and occupant health outcomes.
9. **Assess Occupant Comfort:** Measure the comfort levels experienced by occupants in conventional and green buildings, considering factors such as temperature control, lighting quality, and acoustics.
10. **Measure Occupant Productivity:** Assess the effect of building design and environmental factors on occupant productivity levels in conventional and green buildings, considering factors such as air quality, lighting, and ergonomics.
11. **Examine Social Responsibility:** Analyze the social impact of conventional and green building practices on local communities, including aspects such as job creation, community engagement, and equity considerations.
12. **Achieve LEED Gold Rating:** Aim to attain a LEED Gold certification for the green building under consideration, with a target score ranging from 60 to 79 points, reflecting excellence in sustainability and environmental performance.

1.3. METHODOLOGICAL APPROACH

1. This project involved creating theoretical models of both conventional and sustainable green buildings, with similar size and usage parameters, to enable a fair comparative analysis.
2. To facilitate cost analysis, various techniques were implemented to minimize the initial expenses associated with the green building. This included exploring alternative construction methods and utilizing cost-effective sustainable materials where possible.
3. For accurate assessment of environmental impact, carbon emissions of different construction materials were calculated, focusing primarily on major components.
4. The cost analysis aspect utilized current market rates in India for construction materials to ensure realistic estimates.
5. Operational electricity usage was determined based on the energy performance index of the buildings, allowing for comparisons over different timeframes, including 1 year, 5 years, 10 years, and 20 years.
6. Additionally, the project aimed to achieve LEED Gold rating, necessitating adherence to specific sustainability criteria and performance benchmarks. Through this comprehensive methodology, the project aimed to provide a robust point-to-point comparative analysis between conventional and sustainable green buildings, considering factors such as cost, environmental impact, and energy efficiency.

CHAPTER 2

2.1. DESIGN OF CONVENTIONAL BUILDING

A design of conventional building in 2D on AutoCAD of area **13.4112 m x 7.3152 m (98.1056 m^2) or 44 ft x 24 ft (1056 sq. ft).** It is a 2-bedroom house, with a toilet, bathroom, kitchen, living room on the ground floor and gardening facilities on the terrace with some open area for balcony. The walls provided are of brick masonry 230 mm thick, where an over-head tank is also provided. Sump and a septic tank are also provided in underground.

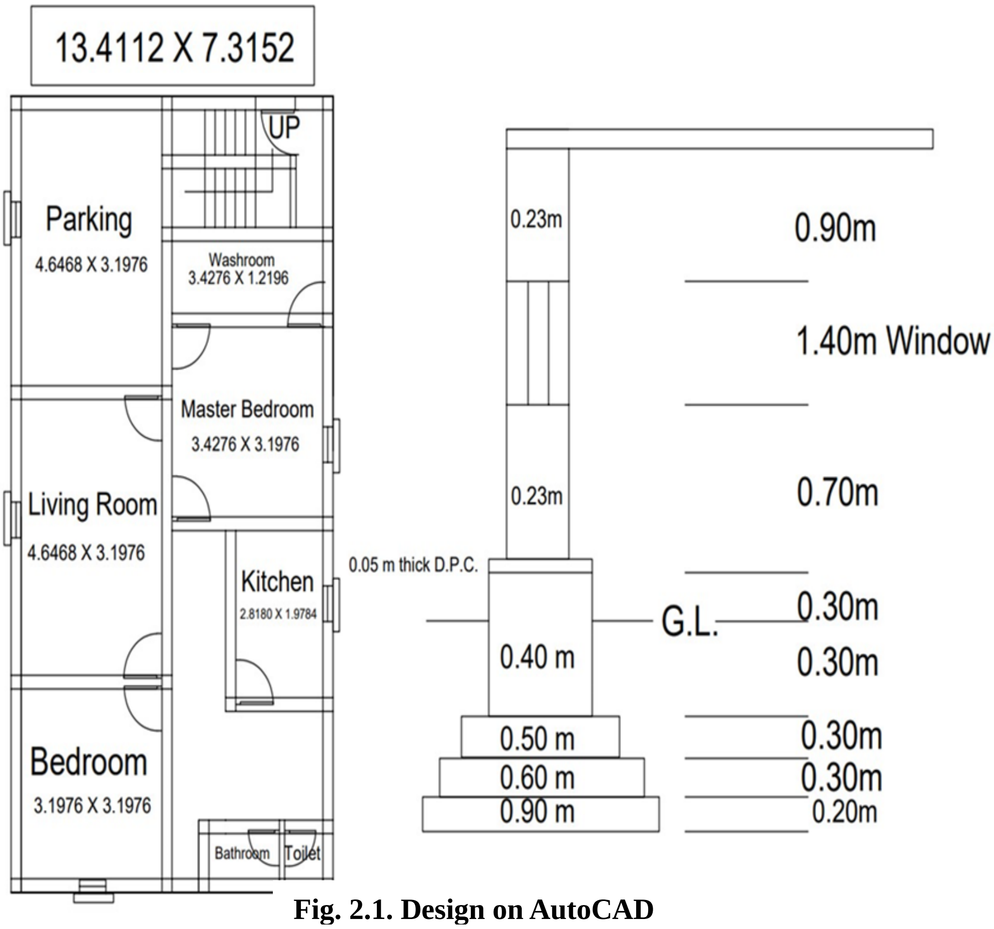


Fig. 2.1. Design on AutoCAD

A single-family residence type building consists of different sections:

1. **Parking (4.6468 m x 3.1976 m):** The parking area is typically designed to accommodate vehicles for the occupants of the building. It can be open-air or enclosed, depending on the design and location of the building.
2. **Living Room (4.6468 m x 3.1976 m):** The living room is a space where occupants relax, entertain guests, and engage in various activities. It is usually one of the central gathering areas of a home.
3. **Bedroom (3.1976 m x 3.1976 m):** Bedrooms are private spaces designed for sleeping and resting. They often include a bed, storage for clothing and personal items, and may have additional features like a desk or seating area.
4. **Kitchen (2.8180 m x 1.9784 m):** The kitchen is a functional area for preparing meals, cooking, and sometimes dining. It includes appliances, cabinets, countertops, and storage space for cookware and utensils.
5. **Washroom (3.4276 m x 1.2196 m):** The washroom typically refers to a room with a sink and facilities for washing hands and sometimes face. It can also include basic storage for toiletries.
6. **Bathroom (1.5988 m x 0.7592 m):** Bathrooms are designed for personal hygiene activities such as bathing and using the toilet. They often include a shower or bathtub, toilet, sink, and storage for toiletries and towels.
7. **Toilet (0.8692 m x 0.7592 m):** Toilets are essential sanitation areas designed for urination and defecation. They typically include a toilet fixture and may have a sink for handwashing.

8. **Staircase Area (1.9780 m x 3.4276 m):** Staircases can be constructed using various materials such as wood, metal, concrete, or a combination of these materials. They typically include steps (treads) for walking on, risers that provide support between steps, a handrail for safety and support, and sometimes a landing for resting or changing direction.
9. **Hall Area (10.5875 m^2):** The design and layout of a hall area are influenced by factors such as building function, user needs, safety requirements, and architectural style. Hall areas are essential components of building design, providing circulation, access, and social interaction within the built environment.
10. **Master Bedroom (3.4276 m x 3.1976 m):** The master bedroom serves as a private retreat and sanctuary within the home, offering comfort, luxury, and privacy for the homeowners or occupants to relax, unwind, and recharge.
11. **Window:** A window is an opening in a wall or roof of a building that is fitted with glass or other transparent material to allow light to enter and to enable occupants to see outside. Windows play a crucial role in building design and function, providing natural light, ventilation, views, and other benefits to occupants while contributing to the visual character of the building.
12. **Door:** A door is a movable barrier that can be opened or closed to allow access to or block entry into a room, building, or other enclosed space. Doors are essential components of building design and function, providing access, privacy, security, and other benefits to occupants while contributing to the architectural character of the space.
13. **Flooring:** Flooring refers to the surface material that covers the floor of a room or building. Flooring serves both functional and aesthetic purposes, providing a durable and stable surface for walking, standing, and other activities, while also contributing to the overall look and feel of a space.

2.2. ESTIMATING MATERIALS USED IN CONSTRUCTION

To estimate the materials used in the construction of a residential building, we need to consider various components such as concrete, steel, bricks, cement, sand, aggregate, wood, etc.

1. Cement: Hydraulic cementitious material used as a binder in concrete and mortar.

- Type: Ordinary Portland Cement (OPC).
- Unit Weight: Approximately 1440 kg/m^3.
- Strength: Strength varies depending on the grade of cement (e.g., 33, 43, 53).
- Price: Varies by brand and quantity, typically priced per 50 kg bag (50 kg for Rs.400).

2. Sand: Granular material composed of finely divided particles, used as a key ingredient in concrete, mortar, and plaster.

- Type: Fine aggregate.
- Density: Typically, around 1600 to 2000 kg/m^3.
- Price: Varies by source and quality, typically priced per cubic meter or cubic yard.

3. Aggregate: Granular material consisting of particles larger than sand but smaller than 75 mm (3 inches), used in concrete mixes for strength and volume stability.

- Type: Coarse aggregate (gravel or crushed stone).
- Density: Typically, around 1600 to 2000 kg/m³.
- Price: Varies by type, size, and quality, typically priced per cubic meter or cubic yard.

4. Steel: High-strength steel bars or mesh used to reinforce concrete in structural elements such as beams, columns, and slabs.

- Type: Mild steel reinforcement bars (rebars).
- Strength: Varies depending on the grade (e.g., Fe415, Fe500).
- Price: Varies by type, size, and grade, typically priced per kilogram or ton.

5. Concrete: Mixture of cement, sand, aggregate, and water, used as a construction material for foundations, slabs, walls, and other structural elements.

- Type: Ready-mix concrete.
- Strength: Specified compressive strength (e.g., 20 MPa, 30 MPa).
- Price: Varies by mix design and supplier, typically priced per cubic meter.

6. Bricks: Rectangular blocks made from clay or concrete, used in masonry construction for walls, partitions, and facades.

- Type: Clay bricks or concrete bricks.
- Unit Weight: Varies by type and size, typically around 1600 to 2000 kg/m³.
- Price: Varies by type, size, and quality, typically priced per thousand bricks.

7. Wood: Natural material derived from trees, used for framing, flooring, doors, windows, and finishing work.

- Type: Lumber (e.g., pine, cedar, oak).
- Density: Varies by species, typically around 500 to 700 kg/m³.
- Price: Varies by species, grade, and size, typically priced per board foot or cubic meter.

8. Concrete:

- Estimate the volume of concrete needed for foundations, columns, slabs, etc.
- Calculate the quantities of cement, sand, and aggregate required based on the mix design (e.g., 1:2:4 for Cement:Sand:Aggregate).
- Multiply the volume of concrete by the proportions of each material in the mix to determine the quantities needed.
- Calculate the total cost of cement, sand, and aggregate based on their respective prices per unit.

9. Mortar (for Brickwork and Masonry):

- Estimate the volume of mortar needed for brickwork, blockwork, etc.
- Calculate the quantities of cement and sand required based on the mix ratio (e.g., 1:4 for Cement:Sand).
- Multiply the volume of mortar by the proportions of cement and sand to determine the quantities needed.

- Calculate the total cost of cement and sand based on their respective prices per unit.

10. Foundation Bedding:

- Estimate the volume of sand or aggregate needed for foundation bedding.
- Calculate the quantities required based on the thickness and area of the foundation.
- Multiply the volume by the density of sand or aggregate to determine the quantities needed.
- Calculate the total cost based on the price per unit.

11. Glass: Glass is a transparent material used in windows, doors, facades, and decorative elements in buildings.

12. Asphalt: Asphalt is a viscous, petroleum-based material used in road construction for paving surfaces, as well as in roofing for waterproofing.

13. Gypsum: Gypsum is a mineral used to manufacture drywall (plasterboard), ceiling tiles, and other interior finishes.

Note: These are general estimates and prices can vary significantly depending on factors such as location, market conditions, supplier rates, and project specifications.

Table 2.1. Estimation of Conventional Building

S.No.	Description of Item	No.	Length (m)	Breadth (m)	Height (m)	Quantity (m3/m2)	Cost Per Item(₹)	Total Cost(₹)
1	Excavation for Foundation	1	68.55	1.1	1.1	82.94	150.00	12441.5346
2	P.C.C(1:4:8)	1	70.05	0.9	0.2	12.61	3396.00	42819.18595
3	Brickwork in Foundation							
	1st Step	1	72.30	0.6	0.3	13.01	...	63672.6
	2nd Step	1	73.05	0.5	0.3	10.96	...	53897.376
	3rd Step upto Plinth Level	1	73.80	0.4	0.85	25.09	...	123034.776
4	D.P.C at Plinth Level(50mm)	1	73.80	0.4	...	29.52	58.00	1712.12288
5	Cost of Column	14	...	...	...	...	2935.00	41090
6	Cost of Beam	...	...	...	...	10.68	3800.00	40584
7	Cost of Superstructure							
	Brick	25461	0.19	0.09	0.09	0.001539	7.00	178227
	Mortar(1:4)	1	...	...	...	11.737	...	70966.8704
8	Cost of Staircase	...	...	...	...	...	...	73513.65
9	Slab							
	Steel	...	...	...	...	1502.64 kg	50000 per tonne	75132.00
	Concrete(1:1:2)	1	13.4112	7.3152	0.15	14.71584154	5859.15	86222.32
10	Plaster							
	Internal Plaster(1:5)	1	113.5898	0.12	3	40.892328	6792.75	277771.36
	External Plaster(1:3)	1	41.4528	0.2	3	24.87168	7634.00	189870.41
11	Cost of Paint	...	...	...	...	...	...	26764
	Calculations						Total	1357719.21
	Length = Centre Line - (Width/2) x No. of T-Junction					Sanitary fixtures(10%)		135771.921
	Number of T- Junction = 15					Electrical fixtures(8%)		108617.5368
	Sand = ₹1750 per Tonne					Contingency(3%)		40731.57629
	Brick = ₹7 per Brick					Supervision(8%)		108617.5368
	Cement = ₹400 per 50 Kg Bag						**Net Total**	**1751457.78**
	Aggregate = ₹300 per Tonne							

The cost of a residential building, totalling Rs. 17,51,457.78(approx.) may extend to approximately Rs. 20,00,000 or less. It's important to note that this figure excludes the price of the land itself.

Adopting a load-bearing structure approach for the entire building, the **Centre Line Method** is utilized to determine the dimensions of the structure. These dimensions are subsequently employed to calculate the required amount and cost of materials.

Total Area: The overall dimension of the plan is **13.4112 X 7.3152 meters**, which is approximately **98.11 square meters** or **1056 square feet**.

Construction Cost: The average construction cost ranges from ₹800 to ₹5,000 per square foot.

For a basic construction quality, multiplying 1055.77 sq. ft by ₹800 gives **₹844,616**. For a high-end construction, multiplying by ₹5,000 gives **₹5,278,850**. This is a rough estimate and the actual cost may vary based on the quality of materials, labour charges, design complexity, and other factors.

2.3. ENERGY CONSUMPTION

Energy consumption for a conventional building in India can vary based on factors such as building design, construction materials, climate conditions, occupancy patterns, and the availability of energy-efficient technologies. However, to provide a general estimation, we can consider some typical energy consumption figures for residential buildings in India:

1. **Heating and Cooling**: In most parts of India, space heating is not a significant energy demand due to the predominantly warm climate. Air conditioning systems contribute significantly to energy consumption, especially during hot and humid summer months. The energy consumption for cooling can vary based on the size and efficiency of the air conditioning units, insulation levels, and occupant behaviour.
2. **Lighting**: Lighting fixtures and bulbs contribute to electricity consumption. Energy-efficient lighting solutions such as LED bulbs are increasingly being adopted to reduce energy consumption.
3. **Appliances and Electronics**: Energy usage from appliances such as refrigerators, fans, TVs, washing machines, and other electronic devices can be significant. Energy-efficient appliances and smart home technologies can help reduce energy consumption.
4. **Hot Water**: Water heating consumes energy, especially if conventional water heaters powered by electricity or gas are used. Solar water heaters are becoming more popular in India as a sustainable and energy-efficient alternative.
5. **Ventilation**: Ventilation systems, including fans and exhaust systems, are used to maintain indoor air quality and comfort. Energy-efficient ventilation solutions can help reduce energy consumption.
6. **Building Envelope**: The quality of insulation, windows, doors, and roofing materials affects heating and cooling loads, impacting energy consumption. Proper insulation and shading can help reduce energy demand for cooling.
7. **Occupant Behaviour**: Energy consumption is influenced by occupant behaviour, including thermostat settings, lighting usage, appliance usage, and awareness of energy-saving practices.

While specific energy consumption figures can vary widely depending on the factors mentioned above, a typical residential building in India might consume anywhere from 80 to 200 kWh per square meter per year (24 to 60 kWh per square foot per year) for electricity, and additional energy for other fuel sources such as cooking gas or biomass. These are rough estimates, and actual energy consumption can vary based on the specific characteristics of the building, location, and occupants' behaviour. Conducting an energy audit or using energy modelling software can provide more accurate estimates tailored to a particular building in India.

In India, various technologies have been successfully trailed to mitigate building energy consumption. These include the implementation of both active and passive solar technologies like flat plate and transpired solar collectors. Additionally, recuperative heat wheels are employed to recover and reuse waste heat, enhancing overall energy efficiency. Integrating energy-efficient equipment within buildings, coupled with advanced feedback control sensors, contributes to optimizing energy usage and reducing environmental impact.

These innovative technologies not only aid in lowering energy consumption but also promote sustainable practices in the construction and operation of buildings. Through continued research, development, and adoption of such solutions, India and other nations aim to elevate energy efficiency standards, mitigate environmental consequences, and advance towards a greener and more sustainable future in the realm of building construction and management.

Table 2.2. Break Up Energy and Power Demand

S. No.	Parameters	Residential	
		Energy %	Power %
1	Lighting	20 - 40	10 - 15
2	Fans	10 - 15	4 - 6
3	Electric Heaters to Solar Water Heaters	0 - 20	20 - 30
4	Water Pumps	5 - 8	5 - 10
5	Equipment not Related to Building Energy	50 - 70	50 - 70

A green building integrates energy-conscious practices not only during its construction but throughout its operational life span. During the construction phase, such a building is characterized by the following features:

- Smart building methodologies are employed to optimize performance.
- Use of minimal non-renewable resources to reduce environmental impact.
- Mitigation of pollution during the construction process.
- Prioritization of the comfort, health, and safety of occupants.

Throughout its operational life, a green building emphasizes the following principles:

- Conservation of resources and energy.
- Utilization of renewable energy sources to reduce reliance on non-renewable alternatives.

- Implementation of water harvesting and recycling systems.
- Adoption of energy recycling practices for sustainability.

In essence, a green building considers sustainability across its entire life cycle, encompassing construction, usage, and maintenance stages.

CHAPTER 3

3.1. GREEN BUILDING OBJECTIVES

Through a holistic approach, our green building objectives aim to integrate with nature, conserve the natural environment, optimize material use, enhance energy, and water efficiency, manage waste effectively, prioritize societal well-being, promote occupant health, and ensure economic sustainability. The green building objectives can be defined as follows:

1. **Integration with Nature:** The idea that buildings should emulate natural systems, where waste is minimized and resources are recycled, is crucial. Mimicking natural cycles can help reduce environmental impact and improve functionality.
2. **Conservation of Natural Environment:** Recognizing the impact of construction on ecosystems and striving to minimize disruption is essential for maintaining biodiversity and ecosystem health.
3. **Optimum Use of Building Materials**: Prioritizing sustainable and locally sourced materials can reduce environmental degradation associated with extraction, processing, and transportation.
4. **Energy Efficiency:** Buildings consume a significant portion of global energy, mostly from non-renewable sources. Designing energy-efficient buildings can lower overall energy demand and reduce greenhouse gas emissions.
5. **Water Efficiency:** Given the increasing scarcity of fresh water, efficient water use and management in buildings are crucial for preserving this vital resource.
6. **Waste Management:** Minimizing waste generation and implementing recycling practices can reduce environmental burden and promote circularity in resource use.
7. **Society and Human Experience:** Buildings impact the wellbeing of occupants and communities. Designing spaces that prioritize human dignity, safety, and community values can foster sustainable and thriving societies.
8. **Health:** Sustainable buildings promote occupant health by providing a conducive indoor environment with good air quality, lighting, acoustics, and temperature control.
9. **Economic Sustainability:** Financial sustainability is integral to overall sustainability. Efficient buildings can reduce operational costs, making them more accessible and beneficial for society at large.

This comprehensive approach emphasizes the interconnectedness of environmental, social, and economic factors in achieving sustainability in the built environment. By addressing these aspects holistically, we can create spaces that not only minimize negative impacts but also enhance human wellbeing and promote long-term resilience.

3.2. GREEN BUILDING DESIGN

Green building design, also known as sustainable building design, involves the creation of structures that minimize negative environmental impacts while maximizing benefits for both people and the planet. Here are some key aspects of green building design:

Program Planning and Site Selection:

- Set Preliminary Environmental Perform.
- Research Funding Opportunities.
- Reuse Existing Buildings.
- Start Early to Source Salvaged Materials.
- Select Appropriate Land.

Stage in the Process Selection of Design Team:

- Select a Design Team with Experience or Interest in Green and Integrated Design.
- Select Appropriate Professionals for the Expanded Design Team.
- Set Environmental Performance Targets.

Site Design:

- Protect or Enhance Site's Ecological Integrity and Biodiversity.
- Reduce or Eliminate Disturbance to Water System.
- Prevent or Reduce the Use of Potable Water for Irrigation.
- Reduce Urban Heat Islands.
- Design Infrastructure to Support Alternative Transportation.

Building Orientation and Configuration:

- Use Site Resources to Reduce Building Loads and Enhance Indoor Environmental Quality.
- Develop a Project Specific Building Form and Massing.
- Configure Internal Layout to reduce Loads and Enhance Indoor Environmental Quality.
- Select Best Concept Design.
- Finalize All Non-Energy Performance Targets.

Building Systems Design:

- Design and Select All Building Systems to Meet Energy Targets.
- Choose Environment Ally Sensitive Structural Materials.
- Design for Reuse.
- Design Envelope to Reduce Heating, Cooling, Lighting, and Ventilation Load.
- Optimizes Indoor Environmental Quality.
- Reduce Ventilation Loads.
- Provide Users Comfort and Control.
- Provide Adequate Fresh Air.
- Select Water Efficient Fixture.
- Reduce Water-Related Energy Use.
- Reduce Lighting Load.
- Maximize Daylight and Views.

Interior Finishes and Appliances Selection:

- Reduce Internal Loads.
- Reduce Disposal of Waste Materials to Landfills.
- Ensure Indoor Air is Free of Pollution.

Specifications/ Construction Drawings:

- Specify the Overall Environmental Intent of the Project.
- Specify Energy Efficient Systems and Products.
- Specify Green Products and Materials.

Construction and Commissioning:

- Prevent Erosion During Construction.
- Ensure Protection of Site Ecosystem.
- Minimize the Disposal of Construction Waste.
- Commission All Major Systems.
- Protect and Conserve Topsoil.

3.3 RATING SYSTEMS FOR SUSTAINABLE BUILDINGS

Rating systems have been developed to assess the sustainability of green buildings and facilitate achieving the highest certification standards. These systems establish benchmarks for certifying the design, construction, and operation of sustainable buildings. These criteria encompass aspects such as energy efficiency, sustainable site development, human and environmental health, water conservation, material selection, indoor environmental quality, social considerations, and economic viability. This holistic approach enables stakeholders to measure and enhance the sustainability of their buildings effectively.

Table 3.1. Comparison of Different Rating Systems for Sustainable Buildings

System (Country of origin)	DGNB (Germany)	BREEAM (Great Britain)	LEED (USA)	Green Star (Australia)	CASBEE (Japan)	Minergie (Switzerland)
Initiation	2007	1990	1998	2003	2001	1998
Key Aspects of Assessment & Versions	- Ecological Quality - Economical Quality - Social Quality - Technical Quality - Process Quality - Site Quality Purpose of the DGNB Certificate: Application for buildings of any kind (Office high-rises, detached residential homes, infrastructure buildings etc.) DGNB for: - Offices - Existing Buildings - Retail - Industrial - Portfolios - Schools	- Management - Health & Well-being - Energy - Water - Material - Site Ecology - Pollution - Transport - Land consumption BREEAM for: Courts, EcoHomes, Education, Industrial, Healthcare, Multi-Residential, Offices, Prisons, Retail	- Sustainable Sites - Water Efficiency - Energy & Atmos-phere - Material & Resources - Indoor Air Quality - Innovation & Design LEED for: New Construction, Existing Buildings, Commercial Interiors, Core and Shell, Homes, Neighbor-hood Development, School, Retail	- Management - Indoor Comfort - Energy - Transport - Water - Material - Land Consumption & Ecology - Emissions - Innovations Green Star for: - Office – Existing Buildings - Office – Interior Design - Office – Design	Certification on the basis of "building-environment efficiency factor" BEE=Q/L Q … Quality (Ecological Quality of buildings) Q1 - Interior space Q2 - Operation Q3 - Environment L … Loadings (Ecological effects on buildings) L1 - Energy L2 - Resources L3 - Material Main Criteria: (1) Energy Efficiency (2) Resource Con-sumption Efficiency (3) Building Environment (4) Building Interior	4 Building standards are available: (1) Minergie - Dense building envelope - Efficient heating system - Comfort ventilation (2) Minergie-P additional criteria to (1): - Airtightness of building envelope - Efficiency of household applicances (3) Minergie-Eco additional criteria to (1): - Healthy ecological manner of construction (optimized daylight conditions, low emissions of noise and pollutants) (4) Minergie-P-Eco Adherence to criteria of Minergie-P and Minergie-Eco
Level of Certification	Bronze Silver Gold	Pass Good Very good Excellent Outstanding	LEED Certified LEED Silver LEED Gold LEED Platinum	4 Stars: ‚Best Practice' 5 Stars: ‚Australien Excellence' 6 Stars: ‚World Leadership'	C (poor) B B+ A S (excellent)	Minergie Minergie-P Minergie-Eco Minergie-P-Eco

3.3.1. LEED (Leadership in Energy and Environmental Design): LEED stands for Leadership in Energy and Environmental Design. It's a widely used rating system globally for the design, construction, operation, and maintenance of green buildings and communities. Developed by the U.S. Green Building Council (USGBC), LEED provides a framework for building owners and operators to create environmentally responsible and resource-efficient structures. Here's a breakdown of how the LEED rating system works:

1. LEED certification is based on various categories of environmental performance. These categories include Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, Indoor Environmental Quality, and Innovation.

2. Within each category, there are specific criteria and prerequisites that a building project must meet to earn points, known as credits. These credits are awarded based on the degree of sustainability achieved in each category.

3. The total number of points a project earns determines its level of LEED certification. There are four levels of certification: Certified, Silver, Gold, and Platinum. The higher the certification level, the more environmentally friendly the building is to be considered.

4. To achieve LEED certification, a project team must register the building with the USGBC and submit documentation demonstrating compliance with the LEED requirements. This documentation includes design plans, construction records, and performance data.

5. LEED certification offers numerous benefits, including lower operating costs, increased property value, healthier indoor environments, and reduced environmental impact. It also demonstrates a commitment to sustainability and can enhance a building's marketability and reputation.

6. LEED is a dynamic system that evolves over time to reflect advances in sustainable building practices and technologies. The USGBC regularly updates the rating system to ensure its relevance and effectiveness in promoting green building practices.

Overall, the LEED rating system provides a comprehensive framework for designing and constructing buildings that are environmentally responsible, resource-efficient, and healthy for occupants. It has become a globally recognized standard for sustainable building design and construction.

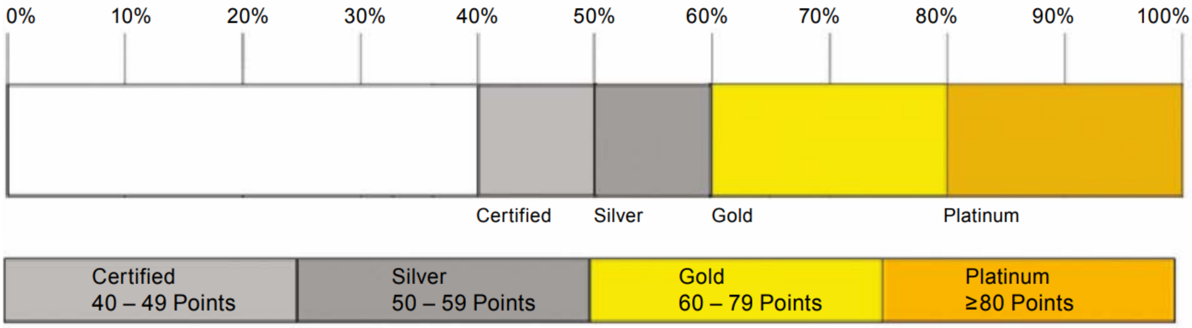


Fig. 3.1. LEED Certification

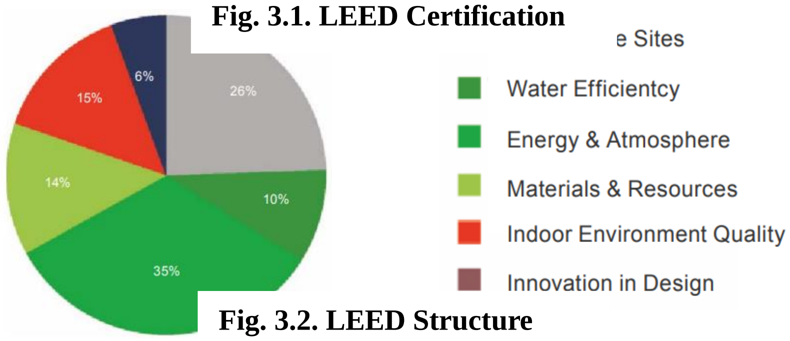


Fig. 3.2. LEED Structure

3.3.2. BREEAM (Building Research Establishment Environmental Assessment Method): BREEAM is another widely used rating system for assessing the sustainability of buildings. Developed by the Building Research Establishment (BRE) in the United Kingdom, BREEAM evaluates the environmental performance of buildings across various categories and provides a rating based on their overall sustainability. Here's an overview of how the BREEAM rating system works:

1. BREEAM assesses buildings across multiple categories. These categories typically include Management, Health & Wellbeing, Energy, Transport, Water, Materials, Waste, Land Use & Ecology, and Pollution.
2. Within each category, specific assessment criteria are used to evaluate the environmental performance of the building. These criteria cover aspects such as energy efficiency, water usage, materials selection, ecological impact, and indoor environmental quality.
3. Like LEED, BREEAM awards credits based on the degree to which a building meets the assessment criteria in each category. The total number of credits earned determines the final BREEAM rating of the building.
4. BREEAM offers several certification levels, including Pass, Good, Very Good, Excellent, and Outstanding. The level achieved depends on the number of credits earned relative to the total possible credits.
5. To obtain BREEAM certification, a building project must undergo an assessment process conducted by qualified BREEAM assessors. The assessors evaluate the building's design, construction, and operation to determine its compliance with the BREEAM criteria.
6. BREEAM certification provides numerous benefits, including reduced environmental impact, lower operating costs, improved occupant health and wellbeing, and enhanced marketability. It demonstrates a commitment to sustainability and can help buildings stand out in the marketplace.
7. BREEAM is continuously updated to reflect advances in sustainable building practices and technologies. The BRE regularly reviews and updates the assessment criteria to ensure that BREEAM remains a relevant and effective tool for promoting sustainable development.

Overall, BREEAM is a comprehensive rating system that assesses the environmental performance of buildings and promotes sustainable design, construction, and operation practices. It is widely recognized internationally and has been used to evaluate thousands of buildings across the globe.

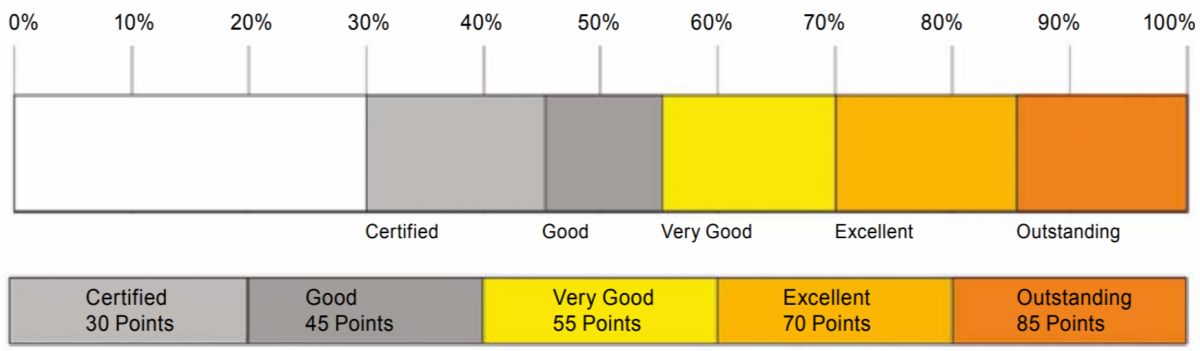


Fig. 3.3. BREEAM Certification

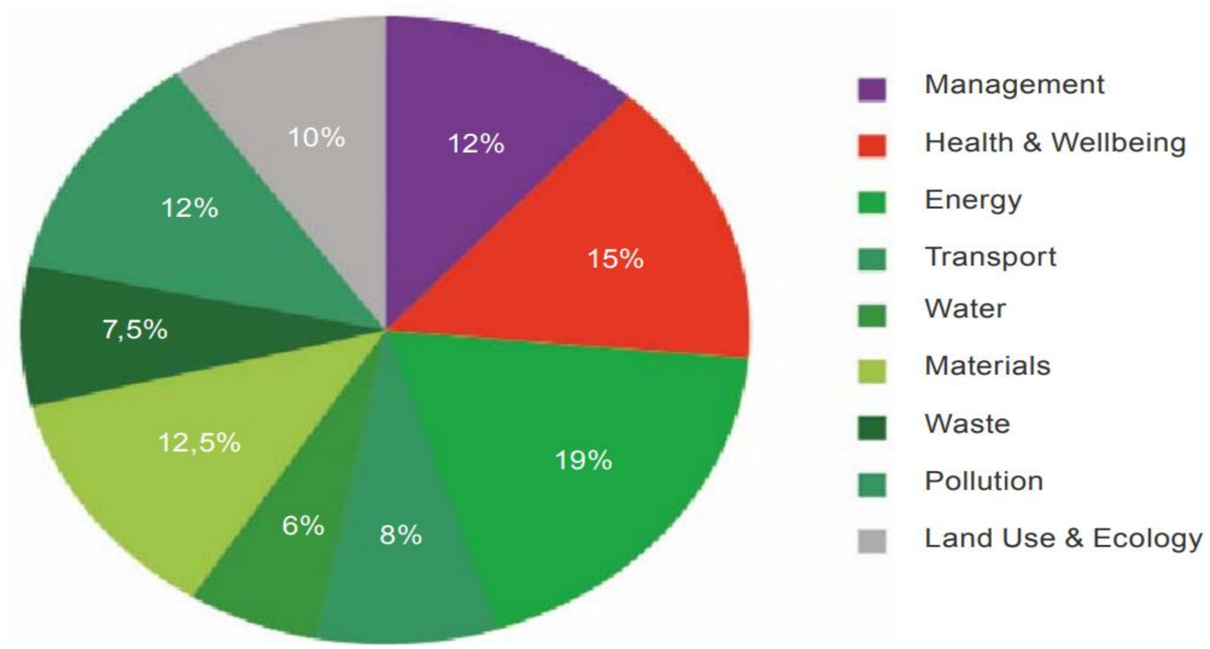


Fig. 3.4. BREEAM Structure

3.3.3. The DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen): The DGNB certification system, also known as the German Sustainable Building Certificate (GeSBC), is a comprehensive sustainability assessment method primarily used in Germany for evaluating the environmental performance of buildings. It was developed by the DGNB organization, which is a non-profit association dedicated to promoting sustainable building practices. Here's an overview of how the DGNB rating system works:

1. The DGNB certification assesses buildings based on a wide range of sustainability criteria, covering aspects such as environmental quality, economic viability, sociocultural and functional aspects, technical quality, and processes involved in the planning, construction, and operation phases.
2. The certification process involves a comprehensive evaluation of a building project by DGNB auditors. The assessment considers various factors, including site selection, energy efficiency, resource use, indoor environment quality, life cycle assessment, and innovation.
3. Buildings are rated on a scale of Platinum, Gold, Silver, and Bronze based on their overall sustainability performance. The rating is determined by the number of points earned across different categories and criteria. A higher number of points corresponds to a higher certification level.
4. One notable aspect of the DGNB system is its flexibility and adaptability to different building types, contexts, and project goals. It allows for customized assessments tailored to the specific needs and priorities of each project.
5. DGNB places significant emphasis on considering the entire life cycle of a building, from planning and construction to operation and eventual demolition or reuse. This holistic approach ensures that sustainability considerations are integrated at every stage of the building's life.
6. DGNB certification offers various benefits to building owners, occupants, and the environment. These include reduced environmental impact, improved energy efficiency, lower operating costs, enhanced occupant comfort and well-being, and increased market value and competitiveness.

7. While initially developed in Germany, DGNB certification has gained recognition internationally and is increasingly used in other countries as well. Its rigorous assessment methodology and holistic approach make it a valuable tool for promoting sustainable building practices worldwide.

Overall, the DGNB certification system provides a robust framework for assessing and promoting sustainable building practices, fostering the development of environmentally responsible and resource-efficient buildings.

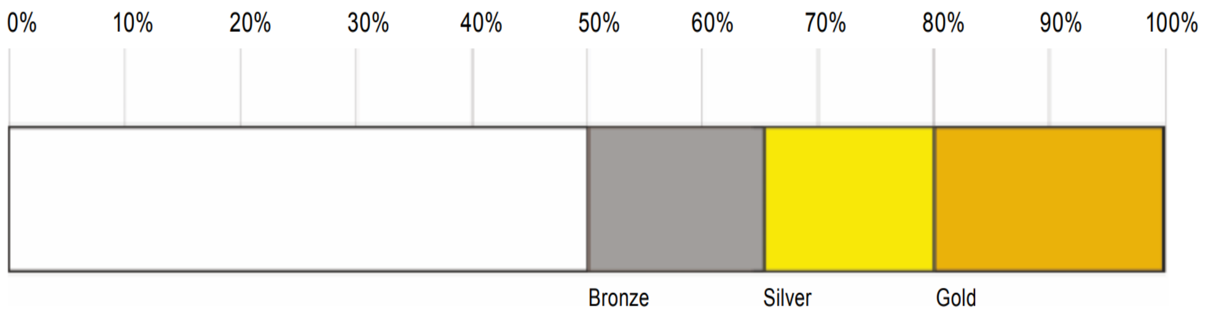


Fig. 3.5. DGNB Certification

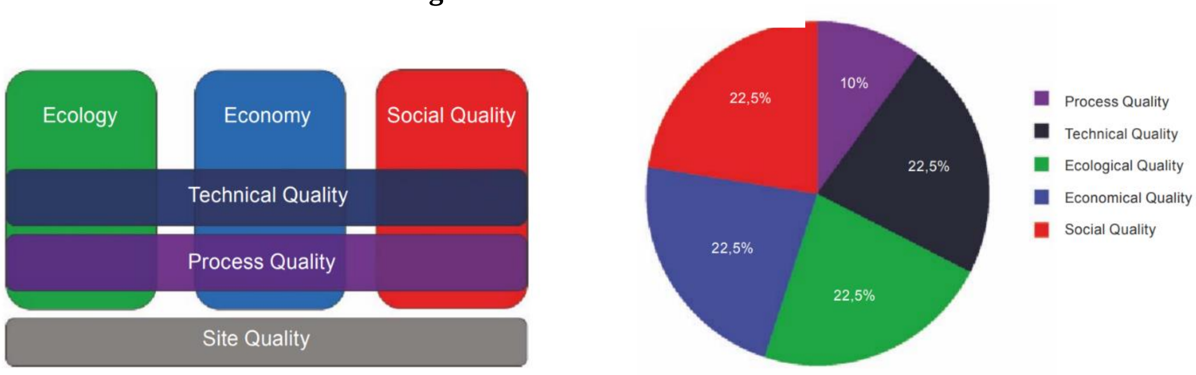


Fig. 3.6. DGNB Structure

3.3.4. MINERGIE: MINERGIE is a Swiss-based sustainability standard and certification system for buildings, focusing primarily on energy efficiency and indoor comfort. It aims to promote low-energy and environmentally friendly building practices while ensuring high-quality indoor environments for occupants. Here's an overview of the MINERGIE rating system:

1. The primary focus of MINERGIE is on reducing energy consumption in buildings. It sets stringent requirements for energy performance, including limits on energy use for heating, cooling, ventilation, and lighting. Buildings seeking MINERGIE certification must meet these requirements to demonstrate their commitment to energy efficiency.

2. In addition to energy efficiency, MINERGIE places a strong emphasis on indoor comfort and quality of life for occupants. This includes factors such as thermal comfort, air quality, daylighting, acoustics, and ergonomic design. Buildings must meet specific criteria related to indoor comfort to qualify for MINERGIE certification.

3. MINERGIE offers several certification levels based on the energy performance and indoor comfort of a building. These levels include MINERGIE, MINERGIE-P, MINERGIE-A, and MINERGIE-ECO. Each

level has different requirements and standards, with MINERGIE-ECO being the most stringent and comprehensive.

4. MINERGIE certification is available for various types of buildings, including residential, commercial, industrial, and institutional buildings. There are specific criteria and guidelines tailored to each building type to ensure that the certification requirements are appropriate and achievable.
5. In addition to new construction, MINERGIE offers certification options for renovation and retrofitting projects. This allows existing buildings to improve their energy performance and indoor comfort through upgrades and modifications while achieving MINERGIE certification.
6. MINERGIE certification offers several benefits to building owners, occupants, and society. These include reduced energy bills, improved indoor comfort and health, increased property value, environmental sustainability, and compliance with regulatory requirements and market expectations.
7. MINERGIE is well recognized and respected in Switzerland and is increasingly gaining recognition internationally as well. It provides a reliable benchmark for sustainable building performance and helps differentiate certified buildings in the marketplace.

Overall, MINERGIE is a comprehensive and rigorous certification system that promotes energy-efficient and comfortable buildings. It plays a crucial role in advancing sustainable building practices and contributing to the transition to a low-carbon built environment.

3.3.5. CASBEE (Comprehensive Assessment System for Built Environment Efficiency): CASBEE is a sustainability assessment method and certification system used primarily in Japan to evaluate the environmental performance of buildings and urban developments. Developed by the Japan Sustainable Building Consortium (JSBC), CASBEE provides a comprehensive framework for assessing the sustainability of the built environment. Here's an overview of how the CASBEE rating system works:

1. CASBEE evaluates the environmental performance of buildings and urban developments across various aspects, including energy efficiency, resource conservation, environmental impact, and quality of life for occupants.
2. CASBEE assesses buildings and urban developments based on multiple categories, which may include energy efficiency, indoor environment quality, resource efficiency, site ecology, and socio-economic aspects. These categories are tailored to address the specific environmental and social impacts of the built environment.
3. Within each category, CASBEE uses specific assessment criteria to evaluate the environmental performance of buildings and urban developments. These criteria may include energy consumption, water usage, waste generation, indoor air quality, biodiversity, and social equity, among others.
4. CASBEE uses a scoring system to quantify the environmental performance of buildings and urban developments. Points are awarded based on the degree to which they meet the assessment criteria within each category. The total number of points earned determines the final CASBEE rating.
5. CASBEE offers several certification levels based on the environmental performance of buildings and urban developments. These levels may include S (for Superior), A (for Excellent), B (for Very Good), and C (for Good), among others. Each level corresponds to a specific range of points earned in the assessment.

6. To obtain CASBEE certification, building projects or urban development's undergo a comprehensive assessment conducted by qualified assessors. The assessment process involves collecting data, analysing performance, and documenting compliance with CASBEE criteria.
7. CASBEE certification offers various benefits to building owners, developers, and occupants. These include reduced environmental impact, lower operating costs, improved indoor comfort and health, increased property value, and compliance with regulatory requirements and market expectations.
8. CASBEE is continuously updated and refined to reflect advances in sustainable building practices, technologies, and societal priorities. The JSBC regularly reviews and updates the assessment criteria to ensure that CASBEE remains relevant and effective in promoting sustainable development.

Overall, CASBEE provides a robust framework for assessing and promoting the environmental performance of buildings and urban developments in Japan and beyond. It plays a vital role in advancing sustainable building practices and contributing to the creation of more environmentally friendly and liveable communities.

3.4. INDIAN GREEN BUILDING RATING SYSTEMS

3.4.1. GRIHA (Green Rating for Integrated Habitat Assessment): GRIHA, India's National Rating System for green buildings developed by TERI and approved by MNRE, aligns with the 'Five Rs' philosophy: Refuse, Reduce, Reuse, Recycle, and Reinvent. It aims to quantify and manage aspects such as energy and water consumption, waste generation, and renewable energy integration to enhance sustainability.

GRIHA evaluates a building's performance over its entire lifecycle, from pre-construction through operation and maintenance. Its key stages include pre-construction, building planning and construction, and building operation and maintenance.

Benefits of GRIHA include reducing greenhouse gas emissions, energy consumption, and reliance on natural resources. Green buildings offer advantages such as decreased energy usage while maintaining comfort levels, preservation of natural habitats and biodiversity, reduced air and water pollution, lower water consumption, and minimized waste generation through recycling and reuse.

The criteria for evaluating buildings under GRIHA encompass various sustainability aspects, promoting environmental responsibility and resource efficiency. List of criteria and points for GRIHA are given below:

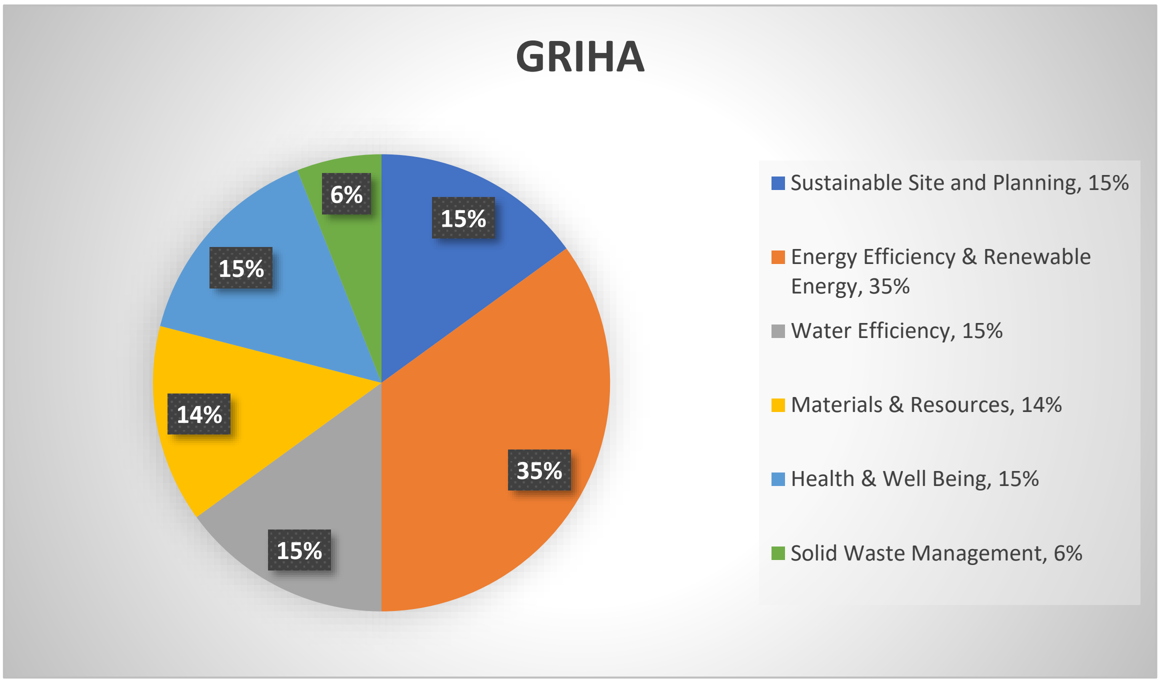
Table 3.2. Threshold Criteria for GRIHA Certification

Sl. No.	Criteria	Points		Sl. No.	Criteria	Points
1	Site Selection	1		**19**	Renewable energy based hot water system	3
2	Preserve and protect landscape during construction/compensatory depository forestation	5		**20**	Waste water treatment	2
3	Soil conservation (post	4		**21**	Water recycle and reuse	5

	construction)				(including rainwater)	
4	Design to include existing site features	2		**22**	Reduction in waste during construction	2
5	Reduce hard paving on-site	2		**23**	Efficient waste segregation	2
6	Enhance outdoor lighting system efficiency and use renewable energy system for meeting outdoor lighting requirement	3		**24**	Storage and disposal of waste	2
7	Plan utilities efficiently and optimize on-site circulation efficiency	3		**25**	Resource recovery from waste	2
8	Provide at least minimum level of sanitation/safety facilities for construction workers	2		**26**	Use of low VOC paints/adhesives/ sealants	4
9	Reduce air pollution during construction	2		**27**	Minimize ozone depleting substances	3
10	Reduce landscape water requirement	3		**28**	Ensure water quality	2
11	Reduce building water use	2		**29**	Acceptable outdoor and indoor noise levels	2
12	Efficient water uses during construction	1		**30**	Tobacco and smoke control	1
13	Optimize building design to reduce conventional energy demand	6		**31**	Universal Accessibility	1
14	Optimize energy performance of building within specified comfort	12		**32**	Energy audit and validation	
15	Utilization of fly ash in building structure	6		**33**	Operations and maintenance protocol for electrical and mechanical equipment	2
16	Reduce volume, weight, and time of construction by adopting efficient technology (such as pre-caste systems, ready-mix concrete)	4			Total score	100
17	Use low-energy material in interiors	4		**34**	Innovation (beyond 100)	4
18	Renewable energy utilization	5			**Total points**	**104**

Table 3.3. Points Achieved for GRIHA Rating

Certification Levels	Points
1 STAR	25-30
2 STAR	31-35
3 STAR	36-40
4 STAR	41-45
5 STAR	46-50



3.4.2. IGBC (Indian Green Building Council): The IGBC Green New Buildings rating system is a voluntary and consensus-driven program developed to leverage current materials and technologies for sustainable construction. It aims to foster environmentally friendly buildings by integrating architectural design, water efficiency, waste management, energy efficiency, and occupant well-being.

This rating system employs both prescriptive and performance-based approaches to evaluate mandatory requirements and credit points. It's designed to be comprehensive yet user-friendly, focusing on national priorities and enhancing occupants' quality of life.

Key features of this rating system include recognition of architectural excellence through integrated design, passive architectural features, and optimization of structural design concerning steel and cement. Projects are encouraged to contribute to the development of baselines for future use in these areas.

Additionally, there's emphasis on reducing water use during construction, with opportunities for projects to receive developmental credits. IGBC Counsellors are also available to provide guidance and support throughout the project journey, enhancing the program's effectiveness and impact.

Table 3.4. Threshold Criteria for IGBC Certification

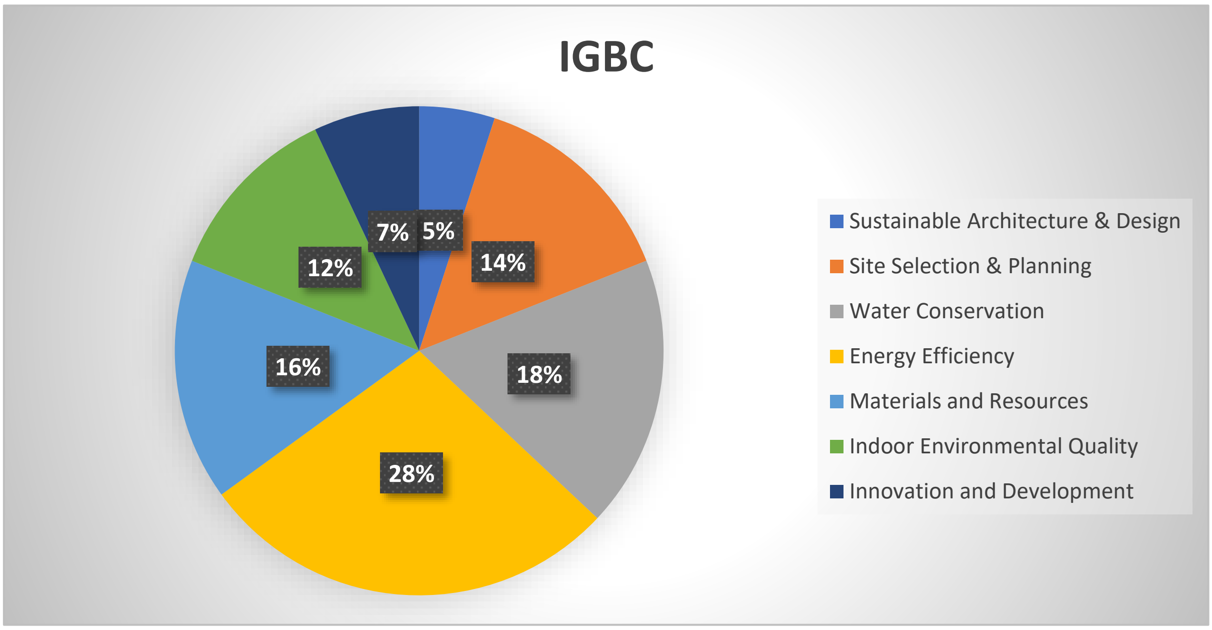
IGBC Green New Buildings Rating System Checklist		**Points Available**	
		Owner-Occupied Building	**Tenant - Occupied Building**
Modules		**100**	**100**
Sustainable Architecture and Design		**5**	**5**
SA Credit 1	Integrated Design Approach	1	1
SA Credit 2	Site Preservation	2	2
SA Credit 3	Passive Architecture	2	2
Site Selection and Planning		**14**	**14**
SSP Mandatory Requirement 1	Local building regulations	Required	Required
SSP Mandatory Requirement 2	Soil Erosion Control	Required	Required
SSP Credit 1	Basic Amenities	1	1
SSP Credit 2	Proximity to public transport	1	1
SSP Credit 3	Low-emitting vehicles	1	1
SSP Credit 4	Natural topography or vegetation	2	2
SSP Credit 5	Preservation or Transplantation of trees	1	1
SSP Credit 6	Heat island reduction, non - roof	2	2
SSP Credit 7	Heat island reduction, roof	2	2
SSP Credit 8	Outdoor light pollution reduction	1	1
SSP Credit 9	Universal Design	1	1
SSP Credit 10	Basic facilities for construction workforce	1	1
SSP Credit 11	Green building guidelines	1	1
Water Conservation		**18**	**19**
WC Mandatory Requirement 1	Rainwater harvesting, Roof, and Non-Roof	Required	Required
WC Mandatory Requirement 2	Water efficient plumbing fixtures	Required	Required
WC Credit 1	Landscape Design	2	2
WC Credit 2	Management of	1	1

	irrigation systems		
WC Credit 3	Rainwater harvesting, Roof and Non - roof	4	4
WC Credit 4	Water efficient plumbing fixtures	5	5
WC Credit 5	Wastewater Treatment and Reuse	5	5
WC Credit 6	Water Metering	1	2
Energy Efficiency		**28**	**28**
EE Mandatory Requirement 1	Ozone depleting substances	Required	Required
EE Mandatory Requirement 2	Minimum energy efficiency	Required	Required
EE Mandatory	Commissioning plan for building equipment and systems	Required	Required
EE Credit 1	Eco-friendly refrigerants	1	1
EE Credit 2	Enhanced energy efficiency	15	15
EE Credit 3	On-site renewable energy	6	6
EE Credit 4	Off-site renewable energy	2	2
EE Credit 5	Commissioning, Post-installation of Equipment and Systems	2	2
EE Credit 6	Energy metering and management	2	2
Building Materials and Resources		**16**	**16**
BMR Mandatory Requirement 1	Segregation of waste, post-occupancy	Required	Required
BMR Credit 1	Sustainable building materials	8	8
BMR Credit 2	Organic waste management, post-occupancy	2	2
BMR Credit 3	Handling of waste materials, During construction	1	1
BMR Credit 4	Use of certified green building materials, equipment	5	5
Indoor Environmental Quality		**12**	**11**

IEQ Mandatory Requirement 1	Minimum fresh air ventilation	Required	Required
IEQ Mandatory Requirement 2	Tobacco smoke control	Required	Required
IEQ Credit 1	CO_2 Monitoring	1	1
IEQ Credit 2	Day lighting	2	2
IEQ Credit 3	Outdoor views	1	1
IEQ Credit 4	Minimize indoor and outdoor pollutants	1	1
IEQ Credit 5	Low emitting materials	3	3
IEQ Credit 6	Occupant well-being facilities	1	-
IEQ Credit 7	Indoor air quality testing, after construction & before occupancy	2	2
IEQ Credit 8	Indoor air quality management, During construction	1	1
Innovation and Development		**7**	**7**
ID Credit 1	Innovation in Design Process	4	4
ID Credit 2	Optimization in structural design	1	1
ID Credit 3	Wastewater Reuse, During Construction	1	1
ID Credit 4	IGBC Accredited Professional	1	1

Table 3.5. Points Achieved for IGBC Rating

Certification Levels	**Points**
Certified	50-59
Silver	60-69
Gold	70-79
Platinum	80-89
Super Platinum	90-100



3.4.3. LEED (Leadership in Energy and Environmental Design): LEED, short for Leadership in Energy and Environmental Design, is a classification system developed by the US Green Building Council (USGBC) to assess and recognize the environmental performance of buildings, promoting the transition towards sustainable design. This credit-based system allows projects to earn points for environmentally friendly practices employed during construction and building operation.

The primary goal of LEED is to establish a consensus-driven, market-oriented scoring system that accelerates the adoption of sustainable building practices. Unlike rigid frameworks, LEED offers flexibility, allowing projects to tailor their strategies to meet specific environmental objectives.

LEED encompasses various product categories, including New Construction and Major Renovations, Homes, Core and Shell, Existing Buildings: Operations and Maintenance, Commercial Interiors, Schools, Retail spaces, Healthcare facilities, and Neighborhood Development. Each category addresses unique aspects of sustainability to promote holistic environmental stewardship.

Table 3.6. Threshold Criteria for LEED Certification

LEED India NC Project Checklist		**Points Available**
Sustainable Sites (max 13 points)		
Prerequisite 1	**Erosion & Sedimentation Control**	**Required**
Credit 1	Site Selection	1
Credit 2	Development Density & Community Connectivity	1
Credit 3	Brownfield Redevelopment	1
Credit 4.1	Alternative Transportation, Public Transportation Access	1
Credit 4.2	Alternative Transportation, Low Emission & Alternative	1

	Fuel Refueling Stations	
Credit 4.3	Alternative Transportation, Parking Capacity	1
Credit 5.1	Reduce Site Disturbance, Protect or Restore Habitat	1
Credit 5.2	Reduce Site Disturbance, Development Footprint	1
Credit 6.1	Stormwater Design, Quantity Control	1
Credit 6.2	Stormwater Design, Quality Control	1
Credit 7.1	Heat Islands Effect, nonroof	1
Credit 7.2	Heat Islands Effect, roof	1
Credit 8	Light Pollution Reduction	1
		13
Water Efficiency (max 6 points)		
Credit 1.1	Water Efficient Landscaping, Reduce by 50%	1
Credit 1.2	Water Efficient Landscaping, No potable use, or No irrigation	1
Credit 2	Water Efficiency in Air conditioning System, Reduce by 50%	1
Credit 3	Innovative Wastewater Technologies	1
Credit 4.1	Water Use Reduction, 20% Reduction	1
Credit 4.2	Water Use Reduction, 30% Reduction	1
		6
Energy & Atmosphere (max 17 points)		
Prerequisite 1	**Fundamental Building Systems Commissioning**	**Required**
Prerequisite 2	**Minimum Energy Performance**	**Required**
Prerequisite 3	**Fundamental Refrigerant Management**	**Required**
Credit 1	Optimise Energy Performance	10
Credit 2	Onsite Renewable Energy, 2.5%, 5%, 7.5%	3
Credit 3	Additional Commissioning	1
Credit 4	Ozone Depletion	1
Credit 5	Measurement & Verification	1
Credit 6	Green Power, 50%	1

		17
Materials & Resources (max 13 points)		
Prerequisite 1	**Storage and Collection of Recyclables**	**Required**
Credit 1.1	Building Reuse, Maintain 75% of Existing Walls, Floors, and Roof	1
Credit 1.2	Building Reuse, Maintain 100% of Existing Walls, Floors, and Roof	1
Credit 1.3	Building Reuse, Maintain 100% shell + 50% non-shell	1
Credit 2.1	Construction Waste Management, Divert 50% from Disposal	1
Credit 2.2	Construction Waste Management, Divert 75% from Disposal	1
Credit 3.1	Resource Reuse, 5%	1
Credit 3.2	Resource Reuse, 10%	1
Credit 4.1	Recycled Content, 5%	1
Credit 4.2	Recycled Content, 10%	1
Credit 5.1	Regional +%	1
Credit 5.2	Regional Materials, 50%	1
Credit 6	Rapidly Renewable Materials, 5% of Building Materials	1
Credit 7	Certified Wood, 50% of Wood-based Materials	1
		13
Indoor Environmental Quality (max 15 points)		
Prerequisite 1	**Minimum IAQ Performance**	**Required**
Prerequisite 2	**Environmental Tobacco Smoke Control**	**Required**
Credit 1	Outdoor Air Delivery Monitoring	1
Credit 2	Increased Ventilation, 30% above ASHRAE 62.1 requirements	1
Credit 3.1	Construction IAQ Management Plan, During Construction	1
Credit 3.2	Construction IAQ Management Plan, Before Occupancy	1
Credit 4.1	Low Emitting Materials, Adhesives & Sealants	1
Credit 4.2	Low Emitting Materials, Paints	1

Credit 4.3	Low Emitting Materials, Carpet	1
Credit 4.4	Low Emitting Materials, Composite Wood & Agri fibre Products	1
Credit 5	Indoor Chemical & Pollutant Source Control	1
Credit 6.1	Controllability of Systems, Lighting	1
Credit 6.2	Controllability of Systems, Thermal Comfort	1
Credit 7.1	Thermal Comfort, Design	1
Credit 7.2	Thermal Comfort, Verification	1
Credit 8.1	Daylight and Views, Daylight 75% of spaces	1
Credit 8.2	Daylight and Views, View 90% of Spaces	1
		15
Innovation & Design Process (max 5 points)		
Credit 1	Innovation in Design	4
Credit 2	LEED Accredited Professional	1
		5
Total Maximum Points		**69**

Table 3.7. Four Levels of LEED Rating

Certification	Points
Certified	40-49
Silver	50-59
Gold	60-79
Platinum	80 points and above

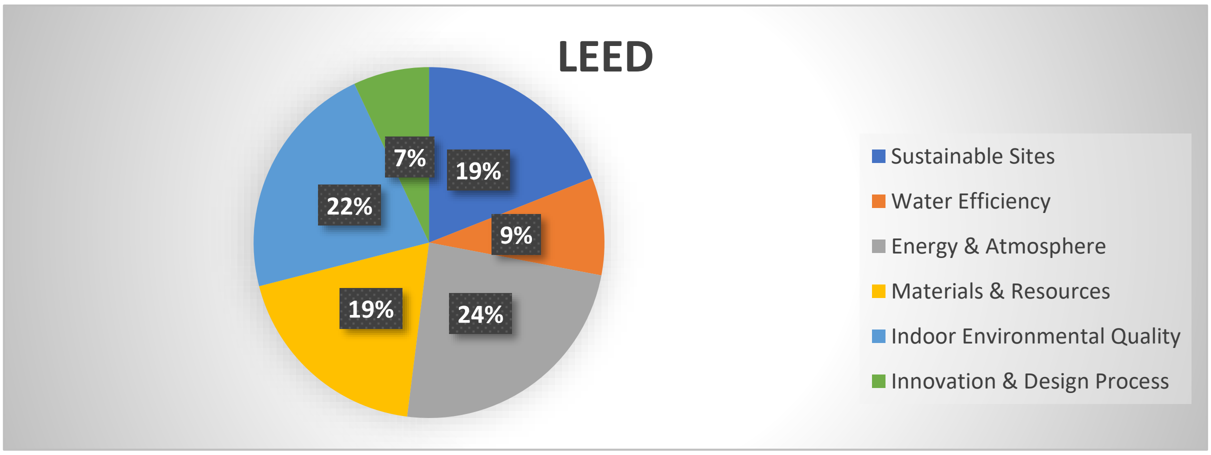


Fig. 3.9. LEED Evaluation Criteria

CHAPTER 4

4.1. SUSTAINABLE OR ECO-FRIENDLY MATERIALS THAT CAN BE USED AS A BUILDING MATERIAL

1. Autoclaved Aerated Concrete Blocks (AAC): AAC blocks are a precast, foam concrete, sustainable construction material made from aggregates of quartz sand, calcined gypsum, lime, Portland cement, water, and aluminum powder. After mixing and molding, the concrete is autoclaved under heat and pressure and it thus gains its distinctive properties. AAC bricks are in high demand, owing to their high strength, load-bearing and thermal insulation properties. Manufacturers of autoclaved aerated concrete produce AAC blocks ranging in varied sizes and strengths. The AAC block price for rectangular AAC bricks having size (length X height X width) of 600mm x 200mm x 250mm can range between Rs 2,000 and Rs 3,500 per cubic meter. The AAC blocks sizes and prices differ, depending on the manufacturer.

The Components of AAC Blocks are Aggregates of Quartz sand, calcined gypsum, lime, Portland, cement, water, and aluminum powder.

The benefits of AAC block are better workability and faster construction, Earthquake resistant, thermal insulation and energy efficiency, fire resistant, sustainable, and affordable, high compressive strength, pest resistant, soundproof, moisture proof.

2. Plastic Brick: Plastic bricks are a type of construction material made from recycled plastic. They are an innovative solution to address plastic pollution while also providing an eco-friendly alternative to traditional bricks made from clay or concrete.

The process of making plastic bricks usually involves melting down plastic waste and then moulding it into brick shapes. These bricks can be used for various construction purposes, including building homes, schools, and other structures.

The advantages of plastic bricks include their environmental benefits, as they help reduce the amount of plastic waste that ends up in landfills or oceans. They are also lightweight, durable, and resistant to weathering, making them a practical choice for construction projects.

The composition of plastic bricks typically involves a combination of recycled plastic materials and additives to enhance their properties:

- **Recycled Plastic**: The primary component of plastic bricks is recycled plastic waste. This can include various types of plastic, such as polyethylene (PE), polypropylene (PP), polystyrene (PS), and others. The plastic is usually collected from sources like plastic bottles, containers, packaging, and other discarded items.
- **Binding Agents**: Binding agents are often added to the plastic mixture to help hold the materials together and improve cohesion. These agents may include resins, adhesives, or other chemical compounds that facilitate the bonding of plastic particles during the manufacturing process.
- **Fillers**: Fillers such as sand, gravel, or other aggregates may be included in the mixture to enhance the strength, stability, and density of the plastic bricks. These fillers help improve the structural integrity of the bricks and reduce the amount of plastic needed in the mixture.

- **Pigments or Colorants**: Depending on the desired appearance, pigments or colorants may be added to the plastic mixture to give the bricks a specific color or texture. This can help enhance the aesthetic appeal of the bricks and make them more visually appealing for construction projects.
- **Stabilizers and Additives**: Stabilizers and other additives may be incorporated into the plastic mixture to improve the performance and durability of the bricks. These additives can help enhance resistance to factors such as UV radiation, weathering, heat, and chemical degradation, ensuring that the plastic bricks maintain their structural integrity over time.

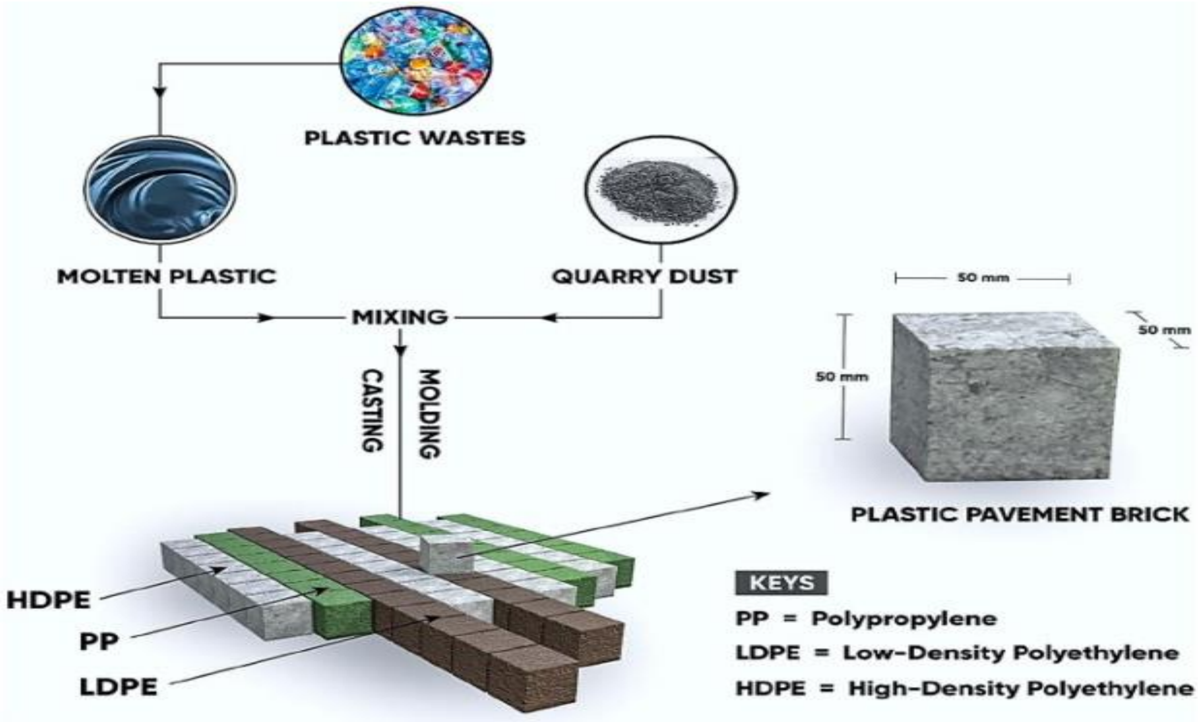


Fig. 4.1. Plastic Brick

3. Bamboo: Bamboo as a raw resource in structural & non-structural works can emerge as one of the most eco-friendly as well as most effective construction modes in recent times. The various components of a building where Bamboo can be used as an alternative to conventional building materials are trusses/roof structure, wall framing, flooring, siding/cladding, interior finishes, and furniture & fixtures. Bamboo is functional for various intentions at different stages:

- Less than 30 days is fit for consumption.
- Between 6 and 9 months for weaving baskets.
- 2 to 3 years for making ply boards or lamination.
- 3 to 6 years for use in construction works.
- Greater than 6 years bamboo slowly lacks its strength up till 12 years old.

Bamboo emerges as a premier crop for agriculture due to its remarkable adaptability to diverse climates and rainfall patterns. With a short growth cycle, bamboo outpaces traditional wood species in speed while consuming less water, making it a sustainable choice for resource-conscious farming practices. Its suitability extends beyond agriculture, as bamboo boasts durability surpassing even that of mild steel. This inherent strength positions bamboo as a leading naturally engineered material globally, particularly significant in earthquake-prone regions where its resilience is invaluable for construction projects seeking stability and safety.

4. Hempcrete: Hempcrete stands out as a groundbreaking bio-aggregate concrete, blending hemp shives small wood pieces from the plant's stalk with lime or mud cement to craft a robust, eco-friendly building material. While lightweight and non-structural, hempcrete seamlessly integrates with traditional construction methods. It can be cast-in-place or prefabricated into versatile components like blocks or sheets.

Harnessing the high silica content inherent in hemp's woody parts, hempcrete forms a strong bond with lime. The lime, in the form of calcium hydroxide, initiates a process of carbon absorption from the atmosphere, transforming into calcium carbonate or limestone. This unique trait renders hempcrete not just durable but actively carbon negative. Moreover, during curing, hempcrete requires notably less water than conventional cement, aiding in the conservation of this vital resource.

From cultivation to eventual reuse or recycling, hempcrete's entire life cycle champions environmental sustainability. Hemp cultivation demands minimal water, pesticides, and fertilizers compared to other crops. With its rapid growth rate and biannual harvests, hemp flourishes in diverse climates, sequestering CO_2, combating erosion, and enriching soil health. Post-harvest, it decomposes into the soil, enriching it with nutrients and positioning hemp as an appealing rotation crop for farmers.

Even after transformation into hempcrete, its benefits endure. In the event of fire, the lime coating furnishes ample fire-resistance, affording occupants crucial time for evacuation. Furthermore, it curtails fire spread and smoke inhalation risks, burning locally and smoke-free. Hempcrete ensures a safe indoor environment, free from skin or respiratory issues, while its vapor-permeability enhances air quality. Its lightweight nature, coupled with air pockets among particles, renders hempcrete both earthquake-resistant and an efficient thermal insulator, exemplifying its multifaceted utility in modern construction.

Fig. 4.2. Hempcrete

5. Green Concrete: "Green concrete" y approach to concrete production, characterized by the environmentally responsible recycling of concrete debris. This innovative material is defined by its ability to consume less energy and emit lower levels of carbon dioxide throughout its manufacturing process compared to conventional concrete.

Often synonymous with resource-saving construction practices, green concrete exemplifies a commitment to reducing environmental impact by conserving energy, minimizing carbon dioxide emissions, and mitigating wastewater generation. Its emergence marks a groundbreaking development in the concrete industry, reflecting a shift towards sustainable building solutions.

Concrete wastes such as slag, power plant residues, recycled concrete, mining and quarrying by-products, waste glass, incinerator residues, red mud, burnt clay, sawdust, combustor ash, and foundry sand serve as prime examples of materials utilized in green concrete production.

Distinct from conventional concrete, green concrete undergoes additional processes during mix design and installation to ensure the creation of structures that are sustainable, possess a long-life cycle, and require minimal maintenance. This holistic approach to concrete construction is championed by the Centre for Green Concrete, dedicated to mitigating the environmental impact of concrete and advancing new technologies to achieve this goal.

Central to the concept of green concrete is its consideration of all stages in the concrete construction life cycle, encompassing structural design, specification, manufacturing, and maintenance. Notably, green concrete significantly reduces emissions of carbon dioxide compared to traditional production methods. By utilizing powdered limestone, clay, and sand to create cement, green concrete production emits 5% to 8% less carbon dioxide, contributing to a substantial reduction in environmental harm. In fact, the production of green concrete can yield up to an 80% decrease in carbon dioxide emissions when compared to traditional methods, making it a pivotal component in global efforts to combat climate change. Embracing environmentally friendly concrete as the norm in building construction represents a significant stride towards achieving emissions reduction targets on a global scale.

The types of green concrete are:

- **Magnesium Oxychloride Cement:** This type of concrete comprises magnesium oxide powder and a concentrated solution of magnesium chloride as the primary components.
- **Ferrocrete:** This is the type of green cement made by mixing silica and iron.
- **Geopolymer Cement:** Also referred to as alkali-activated cement, this type of cement is manufactured using aluminosilicates.
- **Calcium Sulfoaluminate Cement:** Calcium Sulfoaluminate Cement is a type of green cement can reduce energy consumption by 25% and carbon emission by 20%.

6. 3D Printing: 3D printing, also known as additive manufacturing, has emerged as a promising technology in green building construction due to its ability to reduce material waste, energy consumption, and carbon emissions. 3D printing is utilized in green building construction by:

1. **Customization and Optimization**: 3D printing enables the creation of complex and customized architectural designs with precision, allowing for optimized material usage and reduced waste. This customization capability ensures that only the necessary amount of material is used, minimizing construction waste and environmental impact.

2. **Use of Sustainable Materials**: In green building construction, sustainable and eco-friendly materials are often preferred. Many 3D printing technologies allow for the use of recycled materials, such as recycled plastics or bio-based polymers, further reducing the environmental footprint of construction projects.

3. **On-Site Construction**: 3D printing can be used for on-site construction, eliminating the need for transporting prefabricated building components, which reduces transportation-related emissions. Additionally, on-site 3D printing can streamline the construction process, leading to faster build times and reduced energy consumption.

4. **Energy Efficiency**: Certain 3D printing technologies, such as robotic arm-based printing, consume less energy compared to traditional construction methods. This energy efficiency contributes to the overall sustainability of the construction process.

Regarding materials used in 3D printing for green building construction, several options are available:

- **Recycled Plastics**: Recycled plastics, such as PET (polyethylene terephthalate) or ABS (Acrylonitrile Butadiene Styrene), can be used as feedstock for 3D printing. These materials are derived from post-consumer or post-industrial waste, making them environmentally friendly choices.
- **Biodegradable Polymers**: Bio-based or biodegradable polymers, such as PLA (polylactic acid) derived from renewable resources like corn starch or sugarcane, are commonly used in 3D printing for green building construction. These materials offer the advantage of being compostable or biodegradable at the end of their life cycle.
- **Natural Fibers**: Some 3D printing technologies allow for the incorporation of natural fibers, such as bamboo or hemp fibers, into the printing process. These fibers enhance the mechanical properties of printed objects and offer a sustainable alternative to traditional materials.

The latest technologies that can be used to develop green buildings are:

- Biophilic Design
- Passive Design Strategies
- Digital Twin Technology
- Net Zero Energy Building Techniques
- Rainwater Harvesting System

All these technologies involving a variety of materials will be used to develop a greener structure than a conventional building.

4.2. BIOPHILIC DESIGN

Biophilic design is a design philosophy that seeks to reconnect people with nature by integrating natural elements, materials, and forms into the built environment. It encompasses strategies such as incorporating natural light, views of nature, indoor plants, natural materials like wood and stone, and designs inspired by natural patterns and processes. The goal of biophilic design is to create spaces that enhance human health, well-being, and productivity by fostering a deeper connection to the natural world.

Biophilic Design, rooted in the concept of fostering strong connections between nature and the built environment, holds significant promise for enhancing human health and well-being. Coined from the Greek roots meaning "love of nature," the term "Biophilia" gained prominence through the pioneering work of social psychologist Erich Fromm. However, it was American biologist Edward O. Wilson who propelled Biophilia into mainstream discourse in the 1980s. Wilson's seminal book, "Biophilia," published in 1984, not only introduced the term but also laid the groundwork for a new paradigm emphasizing the innate human need to reconnect with nature.

Wilson's definition of Biophilia as "the connections that human beings subconsciously seek with the rest of Life" underscores the profound psychological and physiological benefits associated with engaging with natural environments. This recognition spurred a shift in architectural and interior design paradigms towards integrating natural elements, such as vegetation, natural light, and biomimetic design principles, into urban spaces and buildings.

Studies have consistently demonstrated the positive impacts of Biophilic Design on various aspects of human health and well-being. Access to nature, whether through views of greenery, indoor plants, or natural materials, has been linked to reduced stress levels, improved cognitive function, and enhanced emotional well-being. Moreover, Biophilic Design strategies contribute to environmental sustainability by promoting energy efficiency and fostering a deeper appreciation for the natural world.

By prioritizing Biophilic Design principles in architectural projects, designers and planners can create environments that not only support human flourishing but also foster a harmonious relationship between the built environment and the ecosystems it inhabits. This holistic approach to design holds the potential to address pressing challenges facing urban populations, from mitigating the negative effects of urbanization to promoting resilience in the face of climate change.

4.2.1 Materials

The materials that can be used are: -

1. **Timber:** The benefits of using timber include strength and durability, which leads to long-term value for money, as well as environmental benefits and insulation. Crucially, though, it is a very versatile material that can be used for many purposes while also delivering a wide range of design possibilities.
2. **Areca Palms:** The Areca palm generates more oxygen than other indoor plants. The Areca Palm stands out for its capacity to keep the air pure while removing hazardous substances from the environment. According to NASA, this plant is really one of the greatest air-purifying plants discovered till now. Keep the plant near a curtained window or a place with dim sunlight to get the maximum benefits.
3. **Spider Plant:** The Spider plant is one of the simplest indoor plants to grow. Apart from being an excellent indoor plant for producing the highest levels of oxygen, it is well recognised for its ability to promote happiness and manage levels of stress and anxiety. Spider plants give their best in a study, offices, or any of your working spaces.
4. **Snake Plant:** The Snake plant, also known as the mother-in-law's tongue, is renowned for its night-time oxygen generation and its capacity to filter the air by removing benzene, formaldehyde, trichloroethylene, xylene, and toluene. Not only does this come under the category of the highest oxygen-producing plant, but is also considered the fastest oxygen-generating indoor plant.
5. **Money Plant:** The money plant has effective air-purifying qualities that can remove chemicals and other air pollutants with ease. And like the snake plant, the money plant also produces oxygen even at night, thus making it one of the best plants to keep inside. Moreover, the Money plant also emits positive energies which can help enhance your lifestyle from a spiritual perspective.
6. **Gerbera Daisy:** The Gerbera daisy is a flowering plant that contains more than just colour and looks. It is one of the highest oxygen-producing indoor plants which also shows its magic at night. And unlike the other selections on the list, the plant is just perfect to make your indoor settings look more colourful, attractive, and wholesome.
7. **Aloe Vera:** Aloe vera not only purifies the air by removing formaldehyde and benzene but also has healing properties for minor burns and skin irritations.
8. **Small Flower Pot**: Small flower pots typically have diameters ranging from 4 to 6 inches (10 to 15 centimetres) and are suitable for small plants like herbs, succulents, or seedlings. These pots are commonly used for indoor gardening or as decorative accents on windowsills or shelves.
9. **Medium Flower Pot**: Medium-sized flower pots usually have diameters ranging from 8 to 12 inches (20 to 30 centimetres) and are suitable for medium-sized plants such as flowering perennials, small shrubs, or houseplants. These pots are versatile and can be used indoors or outdoors, either as standalone containers or as part of a larger garden arrangement.

Table 4.1. Biophilic Design

S. No.	Materials	Quantity or Volume	Price of Material	Cost
1.	Teak Wood Timber (40mm)	138.58 cu. Ft.	₹1600/cu. Ft.	₹221,728
2.	Areca Palms	5 pieces	₹900/piece	₹4500
3.	Spider Plant	5 pieces	₹500/piece	₹2500
4.	Snake Plant	5 pieces	₹120/piece	₹600
5.	Money Plant	5 pieces	₹140/piece	₹700
6.	Aloe Vera Plant	5 pieces	₹75/piece	₹375
7.	Gerbera Daisy	5 pieces	₹70/piece	₹350
8.	Flower Seeds	5 pieces	₹50/piece	₹250
9.	Small Flower Pots	15 pieces	₹100/piece	₹1500
10.	Medium Flower Pots	20 pieces	₹150/piece	₹3000
			Total	**₹235503**

4.2.2. Biophilic Smart City

Biophilic smart city design is a visionary approach to urban planning, aimed at seamlessly integrating the natural environment into the fabric of cities. By embracing this concept, cities can harness a multitude of benefits, ranging from improved air quality and reduced carbon emissions to enhanced microclimates and better flood control. Take Singapore, for instance, a shining example of a biophilic city, where a concerted effort to develop green areas and eco-friendly buildings has revitalized the city's natural systems, fostering an urban ecosystem reminiscent of its original state.

To achieve this transformative vision, several guiding principles come into play:

- Embracing green roofs and walls adorned with vegetation, including vines and trellises.
- Prioritizing efficient road networks for commuting, ensuring smooth traffic flow while minimizing environmental impact.
- Promoting the cultivation of vegetable gardens and communal green spaces, fostering community engagement and local food production.
- Integrating plants and greenery within buildings and parks, connected by wildlife corridors to promote biodiversity.
- Implementing urban constructed wetlands for stormwater and wastewater management, enhancing water quality and conservation efforts.
- Employing shade plantings strategically to reduce internal building temperatures during hot summers.

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- Maximizing natural light and ventilation in building designs to minimize reliance on artificial resources.
- Embracing green sidewalks over traditional pavement, enhancing pedestrian experience, and promoting sustainable urban infrastructure.
- Fostering connectivity within green spaces and greenways, creating networks that promote recreation, biodiversity, and overall well-being.

By adhering to these guidelines, cities can not only mitigate environmental challenges but also cultivate vibrant, liveable spaces that harmonize with nature, benefiting both current and future generations.

4.3. PASSIVE HOUSE DESIGN STRATEGIES

Passive House Design is an architectural approach that collaborates with the local climate to maintain a comfortable indoor temperature. Originating in Germany in 1996, it was developed by Dr. Wolfgang Feist. The core principle is to create buildings that are extremely energy-efficient and comfortable to live in, using minimal energy for heating and cooling.

The passive house design strategies are: -

1. **Orientation & Siting:** The house is positioned with its longer axis running east-west to maximize solar access and cooling breezes. The optimal direction for installing solar panels depends on the geographical location of the installation site and the specific solar energy goals of the system. In the northern hemisphere, solar panels typically generate the most electricity when they face south, while in the southern hemisphere, they are typically oriented north.

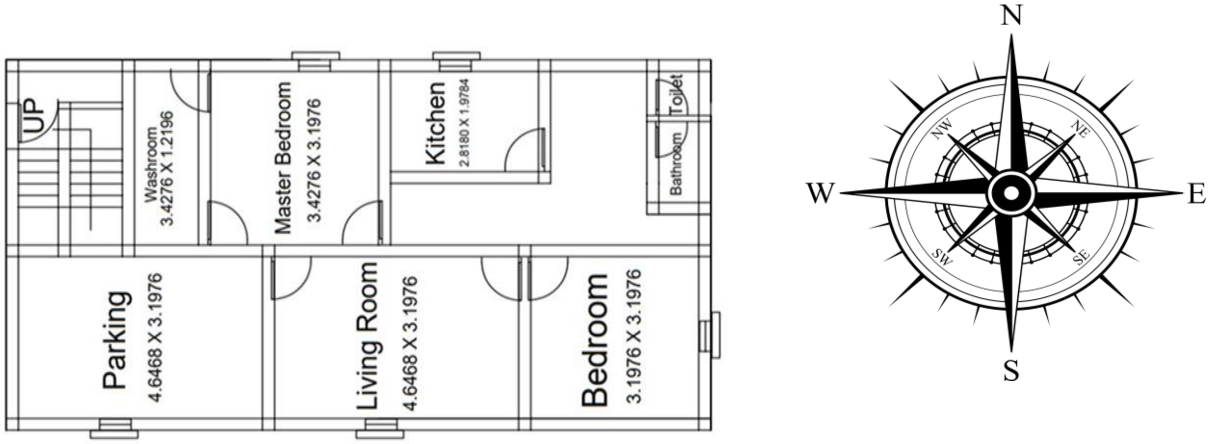


Fig. 4.3. House Direction

2. **Super Insulation:** High insulation values are specified, ensuring minimal thermal breaks and proper installation to maintain a continuous thermal envelope.
3. **Thermal Mass:** A 100 mm thick concrete floor slab serves as thermal mass, well-placed for winter sun and insulated from the outside.
4. **Window Specification:** Double glazing with thermally broken aluminium frames and low-E coating on the inner pane to reduce heat transfer.

Passive house design achieves significant reductions in energy consumption for heating and cooling, often by up to 90% compared to traditional buildings. This not only lowers energy bills but also reduces the building's carbon footprint, contributing to environmental sustainability.

Passive house design is becoming increasingly popular in both residential and commercial buildings worldwide as awareness of energy efficiency and sustainability grows.

4.3.1 Materials

The materials that can be used are: -

1. **Electrochromic Smart Glasses:** Electrochromic smart glasses are an innovative solution for residential and commercial buildings that allow windows to change their tint automatically in response to sunlight. This technology helps to control glare, manage indoor temperatures, and enhance energy efficiency by reducing the need for artificial cooling and lighting. The glass can be controlled manually or automatically through a control system that adjusts the tint based on weather conditions and sunlight intensity. Electrochromic glass is beneficial in reducing HVAC costs and providing a modern, sleek aesthetic to buildings. It is especially useful in areas with high sunlight exposure, as it helps to maintain indoor comfort without the need for blinds or curtains.
2. **Low VOC Paints:** Low VOC paints are paints that contain fewer volatile organic compounds (VOCs) than traditional paints. VOCs are harmful chemicals that can cause health problems like headaches, dizziness, and cancer. Low VOC paints are safer and more environmentally friendly than traditional paints because they release fewer pollutants into the air. They also have a reduced environmental footprint.
3. **Green Roofs:** Green roofs are a passive thermal comfort strategy that can help buildings achieve Passive House-level energy efficiency. Green roofs can reduce a building's surface temperature by 30 to 40% compared to conventional roofs, and can act as insulation to reduce the energy needed for heating and cooling.
4. **Terracotta Air Conditioner:** The Terracotta-based air cooler system is an innovative and sustainable solution for cooling indoor spaces. It utilizes the natural properties of terracotta, a porous clay material, to provide effective and energy-efficient cooling. The system consists of a terracotta body with a water reservoir, an air inlet, and an exhaust. As hot air passes through the wet terracotta, it undergoes evaporative cooling, resulting in a pleasant and refreshing indoor environment. The terracotta's porous structure facilitates the evaporation process, and the system operates without the need for harmful refrigerants or high energy consumption. With its eco-friendly design and ability to provide affordable cooling, the terracotta-based air cooler system is a sustainable alternative to traditional cooling methods.

Fig. 4.4. Terracotta Air Conditioner

Table 4.2. Passive Design Strategies

S. No.	Materials	Quantity or Area	Price of Material	Cost
1.	Electrochromic Smart Glasses	6 pieces	₹4000/piece	₹24000
2.	Eco-Friendly Primer Paint	12 pieces	₹2500/20 litre	₹30000
3.	Dulux Acrylatex Low VOC Paint	20 pieces	₹350/litre	₹7000
4.	Green Roof	1056 sq. ft.	₹100/sq. ft.	₹105600
5.	Terracotta Air Conditioner	3 pieces	₹3000/piece	₹9000
			Total	**₹175600**

4.4. DIGITAL TWIN TECHNOLOGY

Digital twin technology is transforming green building by enabling more sustainable design, efficient construction, and optimal operation. By leveraging real-time data and advanced simulations, digital twins help reduce the environmental impact of buildings while enhancing their performance and occupant comfort. This technology is a key component in the push towards more sustainable and resilient urban environments.

4.4.1. What is Digital Twin Technology?

A digital twin is a virtual model of a physical object, system, or process that is updated in real-time based on data collected from its real-world counterpart. In the context of buildings, a digital twin replicates the physical structure, including its systems and operations, allowing for continuous monitoring and simulation.

4.4.1.1. Application in Green Building

1. **Design Optimization**:
    - *Simulation and Analysis:* During the design phase, digital twins allow architects and engineers to simulate various building scenarios. They can analyze the impact of different materials, layouts, and energy systems on the building's environmental footprint.
    - *Energy Modelling:* By using digital twins, designers can model energy consumption patterns and optimize the design to minimize energy use. This includes optimizing natural lighting, heating, ventilation, and air conditioning (HVAC) systems.

2. **Construction Management**:
   - *Resource Efficiency:* Digital twins help in planning and managing resources more efficiently. They can predict material needs accurately, reducing waste and ensuring sustainable procurement.
   - *Construction Monitoring:* Real-time data from the construction site can be fed into the digital twin, allowing project managers to track progress and ensure that sustainable practices are being followed.
3. **Operational Efficiency**:
   - *Energy Management:* Digital twins enable real-time monitoring of energy consumption. Building managers can identify inefficiencies and take corrective actions to reduce energy use and carbon emissions.
   - *Predictive Maintenance:* By analysing data from the building's systems, digital twins can predict when maintenance is needed, preventing failures, and extending the lifespan of building components.
   - *Occupant Comfort and Health:* Digital twins can monitor and adjust indoor air quality, lighting, and temperature, enhancing occupant comfort and well-being while optimizing energy use.

4.4.1.2. Benefits of Digital Twin Technology in Green Buildings

1. Enhanced Sustainability:

- *Reduced Carbon Footprint:* By optimizing energy use and reducing waste, digital twins contribute to a lower carbon footprint.
- *Efficient Resource Use:* Digital twins ensure that materials and resources are used efficiently, minimizing environmental impact.

2. Cost Savings:

- *Operational Efficiency:* Improved energy management and predictive maintenance lead to significant cost savings over the building's lifecycle.
- *Reduced Construction Costs:* Efficient resource planning and reduced waste during construction lower overall costs.

3. Improved Decision-Making:

- *Data-Driven Insights:* Continuous data collection and analysis provide valuable insights for making informed decisions about building operations and maintenance.
- *Scenario Planning:* Digital twins allow for scenario planning and testing, helping stakeholders make decisions that enhance sustainability and efficiency.

4. Compliance and Certification:

- *Green Building Standards:* Digital twins can help buildings meet green building standards and certifications, such as LEED (Leadership in Energy and Environmental Design), by ensuring that all sustainability criteria are met.

4.4.1.3. Real-World Examples

1. The Edge, Amsterdam: Known as one of the greenest buildings in the world, The Edge uses digital twin technology to optimize energy use, lighting, and climate control.

2. Singapore's Smart Nation Initiative: Singapore employs digital twins for urban planning and management, ensuring that buildings and infrastructure are sustainable and efficient.

4.4.2. Materials

The materials that can be used are: -

1. **ESP32 Module:** The ESP32 is a low-cost, high-performance 32-bit microcontroller with built-in Wi-Fi and Bluetooth capabilities. It features a dual-core Tensilica Xtensa LX6 processor, capable of operating at up to 240 MHz. This module includes various internal components such as RF, IR, CAN, Ethernet modules, temperature sensor, hall effect sensor, and touch sensor, making it suitable for IoT and smart home applications.
2. **GP2Y1010AU Dust Sensor:** This is an analog output sensor used for detecting dust particles in the air. It utilizes an infrared light-emitting diode (IRED) and a phototransistor arranged opposite each other. Dust particles entering the sensor's air chamber reflect IR beams, which are detected by the phototransistor, generating a corresponding voltage output.
3. **MH-Z14A CO2 Sensor Module:** This sensor measures CO2 concentration using the non-dispersive infrared (NDIR) principle. It can measure CO2 levels ranging from 0 to 5000 ppm with a resolution of 5 ppm and an accuracy of ±50 ppm. The MH-Z14A provides CO2 concentration outputs in three different modes: Serial output (RS-232), analog output, and pulse width modulation (PWM).
4. **MICS-4514 Gas Sensor:** Primarily used for measuring emissions from automobile exhausts, the MICS-4514 can also detect concentrations of gases such as NO2, CO, and hydrocarbons. It includes a built-in heating element and a micro-sensing diaphragm. This sensor comprises two independent sensor chips with individual heaters; one chip detects oxidizing gases (OX), and the other detects reducing gases (RED).
5. **DHT22 Temperature and Humidity Sensor:** The DHT22 is a combined temperature and humidity sensor with a digital output. It consists of a thermistor temperature sensor and a capacitive humidity sensor, both of which are connected to an 8-bit microcontroller. The DHT22 offers a relative error of ±0.5°C for temperature measurements and ±2% rH for humidity measurements, providing a fast response time and calibrated digital signal output.

These components collectively form an E-Nose System capable of monitoring various air quality parameters such as CO2, CO, PM10, NO2, temperature, and humidity, leveraging the capabilities of the ESP32 module for processing and communication.

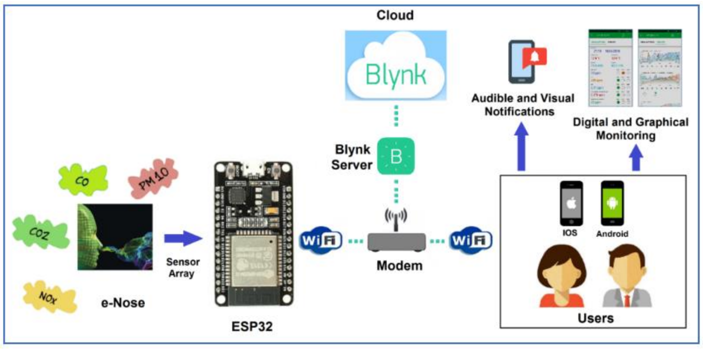


Fig. 4.5. E – Nose System

Table 4.3. Digital Twin Technology

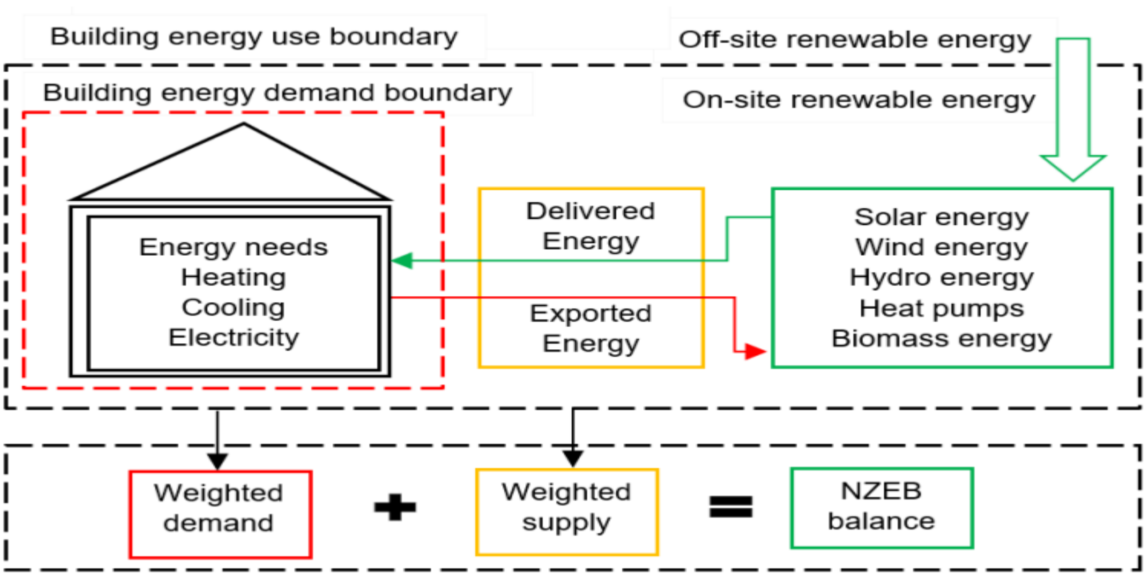
S. No.	Materials	Quantity	Price	Cost
1.	ESP-32 Module	2 pieces	₹400/piece	₹800
2.	GP2Y1010AU Dust Sensor	2 pieces	₹295/piece	₹590
3.	MH-Z14A CO2 Sensor Module	2 pieces	₹3460/piece	₹6920
4.	MICS-4514 Gas Sensor	2 pieces	₹967/piece	₹1934
5.	DHT22 Temperature and Humidity Sensor	2 pieces	₹156/piece	₹312
			Total	**₹10556**

4.5. NET ZERO ENERGY TECHNIQUES

A Net–Zero Energy Building (NZEB) building is a building that produces as much renewable energy as it consumes over the course of a year. This means that the total amount of energy consumed by the building is equal to the amount of energy generated on site through renewable sources such as solar panels or wind turbines. In other words, the building does not rely on fossil fuels for its electricity or other non-renewable sources of energy.

NZEBs are buildings with zero-net energy consumption or zero carbon emissions over a set period. They aim to significantly reduce energy use and increase the share of renewable energy.

NZEBs can be categorized into four models based on energy generation and usage: Net-Zero Site Energy, Net-Zero Emissions, Net-Zero Source Energy, and Net-Zero Cost Energy buildings.



The materials that can be used are:

1. **Solar Panels:** Solar panels, or photovoltaic (PV) panels, form the essential part of any solar power system. They are designed to capture sunlight and convert it into electricity. In India, the market offers several types of solar panels, including Mono PERC, Polycrystalline, and Half Cut panels. Mono PERC panels are known for their high efficiency but tend to be more expensive. Polycrystalline panels are a more cost-effective option, though slightly less efficient. Half Cut panels combine high efficiency with improved performance in shaded conditions.

2. **Inverters:** Inverters are crucial for converting the direct current (DC) electricity generated by solar panels into alternating current (AC), which is suitable for home use. The two main types of inverters are string inverters and microinverters. String inverters are more cost-effective but present a single point of failure. In contrast, microinverters, though more expensive, enhance performance and reliability, especially in areas with partial shading.
3. **Mounting Structures:** Solar panels require a robust and secure mounting structure, which can either be ground-mounted or rooftop-mounted. The choice between these options depends on factors such as available space and local climate conditions. Ground mounts provide flexibility in positioning, while rooftop mounts save space. Adjustable mounts, which can optimize the angle of the panels for maximum sunlight exposure, may add to the overall cost but increase efficiency.
4. **Batteries:** Batteries are an optional component for those looking to store excess energy generated during the day for use at night or during power outages. While they add to the initial installation cost, batteries provide energy independence and resilience against power interruptions.

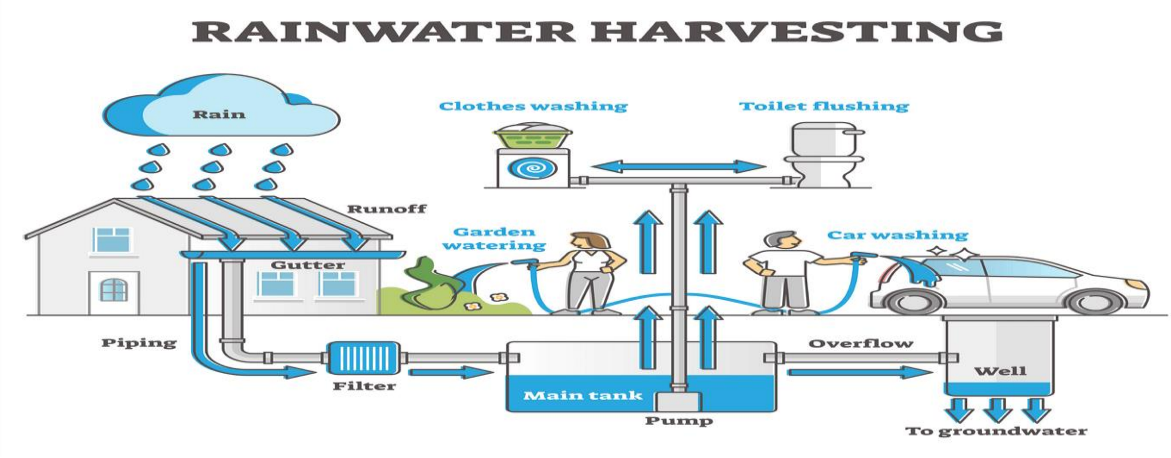
Table 4.4. NZEB Material Cost

S. No.	Materials	Quantity	Price	Cost
1.	250W Solar Panel	5 pieces	₹19000/piece	₹95000
2.	Greenland Off Grid Solar Home Systems (100W)	5 pieces	₹10500/piece	₹52500
3.	Inverter	2 pieces	₹12000/piece	₹24000
4.	Mounting Structures	10 pieces	₹500/piece	₹5000
5.	Battery	2 pieces	₹14000/piece	₹28000
			Total	**₹204500**

4.6. WATER HARVESTING SYTEM

Rainwater harvesting is a sustainable practice that involves collecting, storing, and using rainwater for various purposes such as irrigation, flushing toilets, and even drinking water, depending on the level of treatment. It helps reduce reliance on traditional water sources and minimizes runoff, which can prevent erosion and flooding.

Rainwater harvesting is an effective and environmentally friendly approach to managing water resources. It integrates simple principles with advanced technology to provide sustainable solutions for water use and conservation.



4.6.1. Materials

A rainwater harvesting system consists of several key components, each playing a crucial role in the collection, storage, and utilization of rainwater: -

1. **Catchment Area:** The catchment area is the initial point where rainwater is collected, typically the roof of a building. This area captures rainfall, directing it into the system.
2. **Gutters and Downspouts:** Gutters and downspouts are channels attached to the edges of the roof, designed to transport the collected rainwater from the catchment area to the storage system.
3. **Leaf Screens and First Flush Diverters**: To ensure clean water enters the storage, leaf screens and first flush diverters are used; leaf screens filter out large debris such as leaves and twigs, while first flush diverters discard the initial runoff, which often contains the most contaminants like dust and bird droppings.
4. **Storage Tanks or Cisterns**: Once filtered, the rainwater is directed into storage tanks or cisterns, which are containers designed to hold the collected water. These tanks can be made from materials like plastic, concrete, or metal and may be installed above ground or underground, depending on space and design considerations.
5. **Filtration System:** To ensure the water remains clean and usable, a filtration system is employed, which can include sand filters, activated carbon filters, and UV purification systems to remove finer particles and pathogens.
6. **Pumping System:** When the stored water needs to be used, a pumping system is often required to transport it from the storage tanks to the points of use. This system ensures adequate water pressure and flow, making the water accessible for irrigation, flushing toilets, or other applications.
7. **Distribution System:** Finally, the water is distributed through a distribution system consisting of pipes and valves that direct the water to various usage points efficiently.
8. **Monitoring and Control System:** To maintain the system's efficiency and monitor water usage and quality, a monitoring and control system is often implemented. This system includes sensors and automated controls that manage water levels, operate pumps, and ensure the water quality remains high.

Together, these components create an effective rainwater harvesting system that promotes water conservation and sustainable use of natural resources.

Table 4.5. Installation Cost of Rainwater Harvesting System

S. No.	Materials	Quantity	Price	Cost
1.	Catchment Area	352 sq. ft.	₹25/sq. ft.	₹8800
2.	Gutters and Downspouts	42 metres	₹130/metre	₹5460
3.	Leaf Screens and First Flush Diverters	1 piece	₹1000/piece	₹1000
4.	Storage Tanks or Cisterns (10000 litres)	1 piece	₹10000/piece	₹10000
5.	Pumping System	1 piece	₹7000/piece	₹7000
6.	Distribution System	20 metres	₹200/metre	₹4000
7.	Monitoring and Control System	1 piece	₹10000/piece	₹10000
			Total	**₹46260**

CHAPTER 5

5.1. THE BENEFITS OF GREEN BUILDING FOR SUSTAINABLE CONSTRUCTION

Green building represents the pinnacle of sustainable practices within the construction industry, providing significant social and economic benefits. This approach not only reduces long-term costs but also minimizes the environmental impact by lowering carbon dioxide and greenhouse gas emissions. Below are key aspects highlighting the advantages of green building over conventional building design:

5.1.1. Comparison of Conventional and Green Building Designs

1. **Lighting and Ventilation:** Conventional buildings typically rely heavily on artificial lighting and ventilation systems. In contrast, green building designs prioritize daylighting, shading, and natural ventilation from the design stage. This focus enhances indoor air quality and promotes the health and well-being of occupants.
2. **Daylighting:** Studies have shown that green buildings provide better access to natural light compared to conventional buildings. Improved daylighting reduces the need for artificial lighting, leading to significant energy savings.
3. **Indoor Air Quality:** By utilizing natural ventilation and low-emitting materials, green buildings ensure superior indoor air quality, which has been linked to better health outcomes for occupants.

5.1.2. Material Efficiency and Cost

1. **Long-term Cost Benefits:** Although the initial costs of materials for green buildings may be higher, they offer substantial savings over time. Green building materials, often made from recycled and eco-friendly sources, have lower embodied energy, and reduce environmental impact.
2. **Environmental Impact:** Green building materials are designed to be sustainable, often incorporating recycled content and requiring less energy to produce. This results in a reduced environmental footprint and helps conserve natural resources.

5.1.3. Energy Efficiency

1. **Appliance Efficiency:** Traditional electrical appliances consume more energy compared to Energy Star-rated appliances. Energy Star appliances are designed to use less power while delivering the same performance, leading to lower energy consumption and cost savings.
2. **Overall Energy Savings:** Green buildings are equipped with energy-efficient systems and technologies that significantly reduce energy consumption. This includes advanced HVAC systems, energy-efficient windows, and high-performance insulation materials.

5.2. COST ANALYSIS OF GREEN BUILDING

The initial cost of green building may be higher, but its benefits for both humans and the environment are substantial and enduring. By incorporating five advanced techniques, we can transform a conventional building into a green building for an additional cost of approximately ₹ 6,72,420. This investment, when added to the base cost of a conventional building, results in a sustainable, energy-efficient structure that offers significant long-term savings.

Table 5.1. Green Building Cost

S. No.	Techniques	Cost
1.	Biophilic Design	₹235503
2.	Passive House Design Strategies	₹175600
3.	Digital Twin Technology	₹10556
4.	Net Zero Energy Techniques	₹204500
5.	Water Harvesting System	₹46260
Total		**₹672419**
Conventional Building Cost		**₹1751457.78**
Net Total		**₹2423876.78**

5.3 RESULT

Green Building utilize innovative strategies such as solar panels, rainwater harvesting, energy-efficient windows, sustainable building materials, and advanced insulation techniques. These features not only reduce the environmental footprint but also enhance the well-being of occupants by providing better air quality and natural lighting.

In the long run, the reduced operational costs, improved health benefits, and positive environmental impact make the initial investment in green building highly worthwhile. This commitment to sustainability reflects a proactive approach to addressing climate change and conserving natural resources, ensuring a better future for the next generations. The value added by transforming a conventional building into a green building is immeasurable, as it contributes to a healthier, more sustainable world.

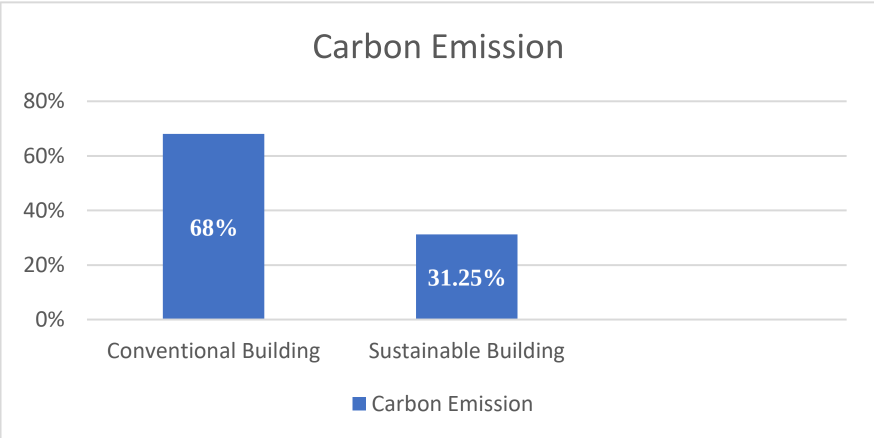


Fig. 5.1. Carbon Emission Comparison

Table 5.2. Operational Life Electricity Usage

Conventional Building								
Timeframe	**1 Year**		**5 Year**		**10 Year**		**20 Year**	
	Usage (kWh)	**Cost (₹)**	**Usage (kWh)**	**Cost (₹)**	**Usage (kWh)**	**Cost (₹)**	**Usage (kWh)**	**Cost (₹)**
Electricity Consumed	4800	34800	24000	174000	48000	348000	96000	696000
Carbon Emitted (Tons)	4.080		20.400		40.800		81.600	
Note: 1kWh = 1 Unit; 1 Unit = 7.25Rs; CO2 released = kWh/year x 0.85 (ISO 14064) Conventional Building EPI = 180kWh/m2 /year; Sustainable Building EPI = 100kWh/m2 /year Energy Performance Index (EPI)								
Sustainable Building								
Timeframe	**1 Year**		**5 Year**		**10 Year**		**20 Year**	
	Usage (kWh)	**Cost (₹)**	**Usage (kWh)**	**Cost (₹)**	**Usage (kWh)**	**Cost (₹)**	**Usage (kWh)**	**Cost (₹)**
Electricity Consumed	4800	34800	24000	174000	48000	348000	96000	696000
Electricity Generated	2555	18520	12775	92600	25550	185200	51100	370400
Total	2245	16280	11225	81400	22450	162800	44900	325600
Carbon Emitted (Tons)	1.90		9.54		19.08		38.16	
Note: 7.3hrs = Average peak sunshine time in per day. 0.77 = Overall efficiency of solar power system. Generation: (250W x 7.3 x 0.77) x 5 unit = 7kWh/day								

5.4. CONCLUSION

This project has demonstrated the significant benefits of transforming conventional buildings into green buildings through the incorporation of advanced sustainable techniques. Despite the higher initial costs, the long-term advantages for both human well-being and the environment are substantial and enduring. The additional investment of approximately ₹672,420 in sustainable design elements, when added to the base cost of a conventional building, results in a structure that is not only energy-efficient but also promotes better indoor air quality and natural lighting.

Green buildings employ innovative strategies such as biophilic design, passive house design strategies, digital twin technology, net-zero energy techniques, and water harvesting systems. These features not only reduce the environmental footprint but also enhance the health and comfort of occupants. The reduced operational costs, improved health outcomes, and positive environmental impact make the initial investment in green building highly worthwhile.

The commitment to sustainability reflected in this project represents a proactive approach to addressing climate change and conserving natural resources. By adopting green building practices, we can create healthier, more sustainable living and working environments. The transformation from conventional to green building practices is not just an investment in the present but a crucial step towards ensuring a sustainable future for the next generations.

In conclusion, this project underscores the necessity and value of green buildings. The integration of sustainable techniques into building design and construction can lead to significant environmental, economic, and health benefits, making green buildings an essential component of modern architecture and urban planning.

5.5. FUTURE SCOPE

The transition from conventional to green buildings, as demonstrated in this project, opens numerous avenues for future research and development. The future scope of green building technology can be expanded in the following ways:

1. **Advanced Material Research**: Further exploration of innovative and sustainable building materials can enhance the efficiency and reduce the costs associated with green buildings. Research into materials with better insulation properties, lower carbon footprints, and longer lifespans will be crucial.
2. **Smart Building Technologies**: The integration of IoT and AI in building management systems can significantly optimize energy consumption, improve indoor environmental quality, and enhance occupant comfort. Future projects could focus on developing more advanced and affordable smart systems.
3. **Renewable Energy Integration**: Expanding the use of renewable energy sources, such as solar, wind, and geothermal, in building designs can further reduce dependency on non-renewable energy. Research into more efficient and cost-effective renewable energy systems will be beneficial.
4. **Water Conservation Techniques**: Developing advanced water management systems that recycle and reduce water usage within buildings can address water scarcity issues. Future studies could explore innovative rainwater harvesting, greywater recycling, and water-efficient landscaping solutions.
5. **Biophilic Design**: Incorporating more natural elements into building design, such as green walls, rooftop gardens, and natural lighting, can improve the mental and physical health of occupants. Research into cost-effective biophilic design elements and their benefits can encourage widespread adoption.
6. **Policy and Regulation Development**: Advocating for stronger government policies and regulations that support green building practices can drive industry-wide changes. Future work could involve policy analysis and development to create incentives for green building adoption.
7. **Community Engagement and Education**: Increasing awareness and education about the benefits of green buildings among stakeholders, including builders, occupants, and policymakers, can facilitate the transition to sustainable practices. Future projects could focus on community outreach and educational programs.
8. **Lifecycle Assessment and Optimization**: Conducting comprehensive lifecycle assessments of green buildings to evaluate their long-term environmental and economic impacts can provide valuable insights for future projects. Research into optimization techniques to further reduce lifecycle costs and environmental impact will be critical.

9. **Scalability and Cost Reduction**: Exploring methods to scale green building technologies for widespread use, especially in developing regions, can help address global environmental challenges. Future research could focus on reducing the costs of green building technologies to make them more accessible.

By addressing these areas, the future development of green buildings can lead to more sustainable, efficient, and healthier living environments, contributing significantly to global efforts in combating climate change and promoting sustainable development.

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CERTIFICATE OF COMPLIANCE WITH UNITED NATIONS SUSTAINABLE DEVELOPMENT GOAL

This is to certify that the project titled, **"Estimation of Green Building Over Conventional Building"**, submitted by **Shashank Garg, Abhijeet Yadav, Shreeya Mishra, Aditya Chaurasiya, Ritanshu Singh and Rahul**, final year students of the Bachelor of Technology in **Civil Engineering** program at **Ajay Kumar Garg Engineering College, Ghaziabad,** have been reviewed and found to be in alignment with the following **United Nations Sustainable Development Goals (SDGs).** Details regarding the justification of the same are provided in **Chapter 5.**

SDG No.	SDG Name	Relevance	SDG No.	SDG Name	Relevance
1	No Poverty	☐	**10**	Reduced Inequalities	☐
2	Zero Hunger	☐	**11**	Sustainable Cities and Communities	☐
3	Good Health and Well-Being	☐	**12**	Responsible Consumption and Production	☐
4	Quality Education	☐	**13**	Climate Action	☐
5	Gender Equality	☐	**14**	Life Below Water	☐
6	Clean Water and Sanitation	☐	**15**	Life on Land	☐
7	Affordable and Clean Energy	☐	**16**	Peace, Justice, and Strong Institutions	☐
8	Decent Work and Economic Growth	☐	**17**	Partnerships for the Goals	☐
9	Industry, Innovation, and Infrastructure	☐			

Signature of the Students

Shashank Garg

Abhijeet Yadav

Shreeya Mishra

Aditya Chaurasiya

Ritanshu Singh

Rahul

Signature of the Supervisor

Ms. Kshama Shukla