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Innovative Strategies and Technologies for Sustainable Renewable Energy and Low-Carbon Development
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Energy efficient green building design utlilising renewable energy and low-carbon development technologies

Sagar, Yogendra Arya*, and Poonam Singhal

Department of Electrical Engineering, J.C. Bose University of Science and Technology, YMCA, Faridabad, Haryana, 121006, India

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Abstract. The core issue these days is to reduce carbon dioxide (CO_2) emission and prevent the hole in the ozone layer. Numerous emerging environmental crises successfully tackled by coordinated global efforts in the past few years. Despite this, the present climate emergency is a much more serious threat than anything we have ever encountered and requires much more action consequently. Today, more attention is paid on green buildings in the society, which will make use of the sustainable and energy-efficient buildings a necessity for future generations. Hence, this paper proposes a novel design model of an energy-efficient residential green building with low carbon emission to maintain the health and enhances the productivity and living standards of inhabitants. Green building technology is utilised to enhance energy efficiency and lower carbon emission. This design considers green, recyclable, and eco-friendly building materials, which are beneficial for human health and comply with relevant Indian standards and building codes. This building design proposes Renewable Energy Sources (RES) integrated with the power grid, although RES powers most of the load of the proposed green building. The suggested green building design shows effective results, *i.e.*, building energy consumption has reduced by 50.54%, total energy consumption cost has reduced by 57.41%, and CO_2 emission per month has reduced by 50.54%. In addition, stormwater-harvesting system is proposed to collect 54,322.23 L of rainwater annually, which helps in water conservation and contributes to improve the groundwater level. The proposed solid waste management plan has contributed to the achievement of regional and national Sustainable Development Goals (SDGs). Finally, there are some suggestions to promote the use of green buildings for sustainable development.

Keywords: Green building, Sustainable development, Green material, Green building technologies, Stormwater-harvesting.

1 Introduction

1.1 Background

In today's world, residential buildings have always been associated with comfort, human health, and convenience. The building industry is experiencing an accelerated growth by investing the maximum amount of global infrastructure resources. It is now crucial to build energy-efficient green buildings that prioritise the health of all occupants and are environmentally friendly. In addition, the Indian government has taken steps to promote and disseminate knowledge about sustainable built environments using a near-zero energy approach. In order to design green buildings, it is important to use green materials, green technologies, reduce waste production, and minimise energy consumption. The green building design also includes water conservation through better utilisation and reduction of greenhouse gas emissions. The material used to construct energy-efficient green buildings has a direct or indirect impact on the improvement of human life. Green energy is more effective in meeting basic energy requirements and preserving natural resources in the realm of modern green technologies. The continuous development of green building technology contributes to energy conservation and the design of eco-friendly structures for buildings.

1.2 Literature review and gaps

For the advancement in the design of green building, a green performance base policy helps to improve building energy efficiency. It is important to consider the entire process of design, construction, and maintenance in the future development of building energy conservation.

* Corresponding author: mr.y.arya@gmail.com

It has become necessary to create a system to evaluate the data of building energy consumption and pursue energy-efficiency retrofitting [1]. The utilisation of green buildings should be considered to minimize energy consumption, and renewable energy sources should be employed for the electricity consumption of the building [2]. Green buildings have several advantages compared with ordinary buildings in all aspects. The design of green buildings should create a healthy environment, less illness, and reduce absenteeism [3].

Green building material is composed of marble powder proved very effective in assuring very good cohesiveness of mortar and concrete. The ratio of water to cement decreases significantly when paired with a superplastic mixture [4, 5]. Microsilica in cement reduces air pollution and makes concrete more sustainable. There is no significant impact on the strength of concrete when fine aggregates are replaced with demolished brick waste. Concrete is more economical than conventional concrete because the overall cost is reduced [6]. Green concrete has a higher resistance to sulphate than conventional concrete [7]. Utilisation of alkali solution and steam curing raises the compressive strength of the green concrete [8]. The presence of an alkaline solution enhances green concrete's compressive strength, and the solution's strength can be achieved by imparting binding properties to it through steam curing. It is important to pre-treat demolished waste to restore concrete's strength and mechanical properties like concrete and brick debris [9]. Buildings made up of mud bricks are the best energy efficient for the inner heat gain of the building at all windows-to-wall ratios, and the utilisation of reflective glass in windows reduces cooling loads in buildings [10]. Increment in the utilisation of recycling green building materials leads to a reduction in construction waste and CO_2 emission [11]. Recycling materials can meet CO_2 emission reduction and waste reduction indicators. It has the potential to lessen the environmental burden caused by the accumulation of waste and the expenses associated with developing new resources [12].

To achieve sustainable development, it is necessary to deal with environmental protection, resource conservation, and other socioeconomic aspects. The high economic growth rates are required to meet essential needs by adopting green initiatives for resource conservation and environmental protection [13]. Environmental pollution due to marble sludge powder may be substantial and so, it should be prevented. Marble dust powder can be a cost-effective option for construction, due to its treatment as waste and cheap availability in certain areas. Concrete is able to achieve greater strength and durability while reducing its environmental impact [5].

The ongoing and futile task of building connections to make the interactive design and analysis process seamless and effective in Virtual Reality/Augmented Reality (VR/AR) remains unresolved [14]. Comfort conditions in the building can be maintained using the heat pump and the heat accumulator. Furthermore, the average cost of electricity is significantly lower than that of standard split-system AC units [15]. Reducing excessive heat during summer is beneficial by achieving effective results, which will consequently reduce energy consumption and make the building more energy-efficient [16]. Green buildings have specific environmental benefits, such as promoting natural resource conservation and improving the environment [17]. It is impossible to carry out any further economic activity without renewable energy sources, making them a strategic commodity [18]. Implementing a green roof is the primary way to reduce energy consumption [19]. The reduction of CO_2 emissions and greenhouse gases can be achieved using RES [20]. By appropriate design and evaluation of a building, energy consumption can be reduced [21]. Green materials can be utilised to reduce energy consumption [22]. The key features of green building development include the substantial reduction of non-renewable energy consumption and the achievement of building energy conservation [23]. Compared to conventional buildings, energy supply systems that utilise RES display improved environmental performance and a reduction in CO_2 emissions [24]. In order to promote the widespread use of green construction methods and increase awareness of their benefits, it is necessary to have more education and outreach [25].

Organic fertilizer can be obtained from the slurry that is generated during the process of producing biogas [26]. The interior design of green buildings can be improved by using image-processing technology to enhance indoor scenes [27]. Designing appropriate green buildings can be made easier by using data mining algorithms [28]. Green building materials have a higher energy efficiency and low carbon footprint than conventional building materials [29]. Adopting green building practices can lead to sustainable development [30]. Optimising design options and employing renewable energy systems can increase energy efficiency, reduce costs, and contribute to sustainable development in the built environment [31].

It is concluded from the literature that to construct green buildings, it is necessary to include more green features, components, and designs. Improper design of the building structure, including not considering green materials, RES, waste management, rainwater harvesting etc. are the reasons for the inaccuracy in the design of green buildings. Hence, in this paper, we present a design model for a residential green building that incorporates green technologies, green materials, and is highly powered by renewable energy. By considering all parameters, green material has been proposed that can be characterized by its physical and chemical properties. The high fineness of the proposed green material is the reason for its excellent cohesive strength, as indicated by the test results. By utilising RES, the proposed green building can meet its maximum electrical energy demand and reduce its burden on the power grid. Water consumption in and around the building is made possible by the proposed building's rainwater harvesting system, which treats the rainwater and allows it to be utilised. Waste management system is used, with waste materials being reused by multiple recycling manufacturing processes, and waste management plans. Additionally, the proposed green building is compared with an ordinary green building, the result depicted that the proposed green building is self-sufficient and has strategies for achieving net zero energy.

1.3 Objectives of the research

Health factors of the occupants require a significant amount of attention; hence, it has become necessary to develop green residential buildings by incorporating RES, green materials, and residential building operation planning. In view of foregoing, following are the main objectives of the designed model of the residential green building:

- Maintaining the health of the inhabitants.
- Boosting the productivity and living standards of residents.
- Optimising the efficiency of energy, water, and other resources.
- Minimising the environmental impact.
- Achieving optimum environmental and economic performance.
- Improving the water ground level.
- Reducing carbon emissions and other harmful gases within the building.
- Maintaining an uninterrupted and economical power supply for 24 h.
- Enhancing the societal benefits and reducing the overall cost.

1.4 Contribution of the paper

A concept for a residential green building that utilises green technologies and largely powered by green energy is proposed. Taking into account all aspects, a green material is proposed that can be explained through its physical and chemical properties. The high fineness of the proposed green material, as indicated by the test results, makes it has excellent cohesive strength. The proposed green building is capable of meeting its maximum electrical energy demand and reducing its burden on the power grid by utilising RES. The rainwater harvesting system treats rainwater and makes it possible to consume water in and around the building. In waste management system, waste materials are reused through multiple recycling manufacturing processes. This work contributes to the reduction of costs by using green materials and various elements such as electrical-thermal energy storages, PV panels, and typical appliances used in houses by considering proper operation planning of the proposed green building. Green material contributed towards the reduction in carbon emission and the heating and cooling things inside the building. Following are the contributions of the work:

- Improvement in the indoor air quality and occupant health.
- Improvement in the quality of life of the occupant.
- Conservation of energy, water and other resources.
- CO_2 emission reduced.
- Heating and cooling inside the building maintained.
- Clean energy and 24-hour uninterrupted power supply maintained.
- Overall cost decreased.

1.5 Organisation of the paper

The paper is structured as follows. In Section 2, the methodology adopted outlines the proposed green building materials, architectural design, stormwater-harvesting system, waste management system, and building management planning. Section 3 presents the discussion and testing results. In Section 4, the conclusions and recommendations for future work are provided.

2 Methodology

The methodology began with a research gap framework derived from the literature review related to green buildings. The research methodology process of this research is depicted in Figure 1. Firstly, raw data is collected from various previous researches, field surveys, benchmarking, etc. Accordingly proposed design model of residential green building is prepared in Autodesk Revit, Autodesk 3d Max, and AutoCAD software. The energy consumption and other parameters are analysed by demonstrating the energy model of the proposed green building. The proposed composition of green materials used for the construction of green buildings is analysed and tested in the laboratory. The parameters of the selected green materials are compared with the IS code and other researches.

2.1 Proposed green material for green building modeling and implementation

It is crucial to consider the quality of the building materials used in the proposed green building system, advancing the well-being of individuals, improving their quality of life, and conserving the ecological environment. The proposed green Building Management System (BMS) is intended to efficiently reduce the health risk factors of people and create a sustainable building. Different factors are taken into account when selecting materials for green buildings to ensure environmental protection, such as reducing the use of heavy metals, asbestos, and radioactive materials to protect the environment [12]. Green building assessment is influenced by factors such as production, utilisation, demolition, and recycling. For the examination of the environmental impact of energy-efficient green buildings, we need to think of its four life cycle stages, as depicted in Figure 2. The first stage involves the raw materials that are used to construct the building, such as cement, fine and coarse aggregates, waste paper pulp, quarry dust, fly ash, and marble powder. In the second stage, *i.e.*, production stage, this involves renewable energy sources, HVAC systems, BMS systems, green technologies, and green materials develop green building. In the third stage, *i.e.*, utilisation stage, renewable energy sources have the potential to reduce energy consumption. Indoor air quality improves through the HVAC system, which also decreases the health risk factors of inhabitants. The fourth stage involves the demolition of buildings after the completion of their life cycle. After demolition of green building in fourth stage, waste

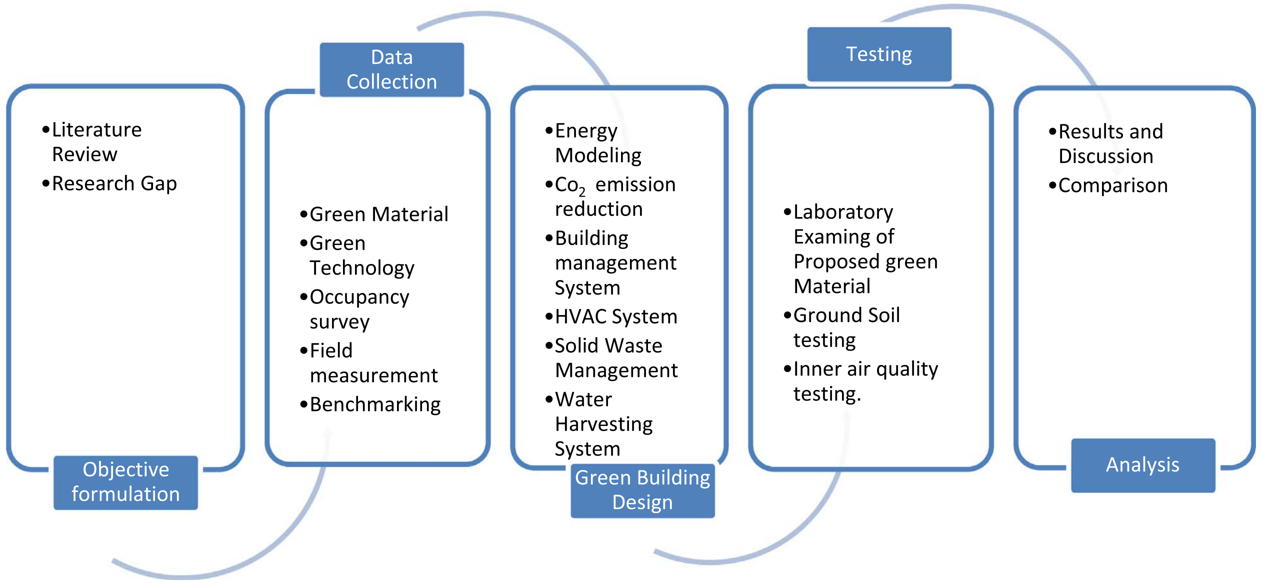


Fig. 1. Research methodology process.

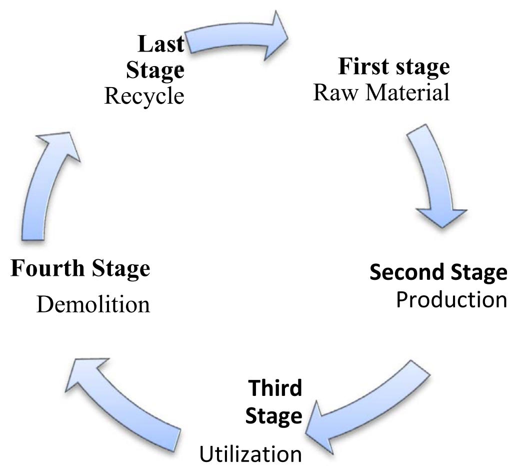


Fig. 2. Life cycle of a green building.

materials are recycled to produce raw material for other buildings. Each stage is managed independently and a lot of data and information collected from various resources are analysed.

2.2 Ecological green building material

In order to consider ecological green building materials, the materials must satisfy basic needs, utilise RES, be energy-efficient, and be recyclable [13]. The main concept of green building is from nature's return to nature [12]. As shown in Figure 3, it starts from the raw material, and the first stage is the production or process; building materials produced from raw materials have irreversible effects on the environment. Some specific criteria are used to identify green materials, *i.e.*, local availability, embodied energy, percentage of recycled or waste materials, renewable materials, contribution to energy efficiency, and durability. In the second stage, green buildings is used and several factors related to human health risk are considered. In the third stage, water conservation, innovative reduction water technology, and waste management systems are considered, and in the final stage, recycling of green material, renewable material, resources reuse, and the environmental impact of material are depicted.

2.3 Healthy green building material

Methanol and Volatile Organic Compounds (VOCs) are used in the making of interior building materials of green building. In conditions such as high temperature and humidity, harmful gases discharged automatically into the air may have adverse effects on indoor air quality and human health. Therefore, the proposed system is designed in such a manner that the building management system and control prevent the harmful gases. All the testing of the proposed green materials complies with the IS codes.

2.4 Recycling green building material

The proposed system is designed in such a way that the green building materials reduce construction waste and can recycle the materials during the demolition of the building. The 3R (reduce, reuse, and recycle) concept is used during the design of green building. Its main goal is to reduce the waste material of the green building and use green technologies to recycle the materials. The evaluation and assessment involve the type and percentage of recycled materials. All materials are as per IS standards.

2.5 Proposed green building material

Following are green building materials proposed for the construction of green building:

Fig. 3. Process for evaluation of green building material.

Fig. 4. Proposed exterior design of a residential green building.

Table 1. Comparison of the proposed green building.

S. No.	Description	Ordinary building [16] (°C)	Green building [16] (°C)	Green building this paper (°C)	Remarks
1	Normal room temperature	31.4	29.3	28.1	Proposed green building in this paper provide more cooling effect as compared to the reference building given at [16].
2	After the increase in room temperature by the lighting effect	34.9	30.1	29.3	

Cement: Ordinary Portland cement is used.

Fine and Coarse Aggregate: The durability, strength, workability, and ability to receive finishes are the primary criteria for selecting aggregates in concrete mixes [7]. The best aggregates for cement paste bonding are gravel or broken stone aggregates with a rough and non-glassy texture [5]. After submerging coarse aggregates in water for 24 h, it is important to limit their moisture absorption to less than 10% of their weight. The total quantity of aggregates should not exceed 40% when it comes to flaky and elongated particles.

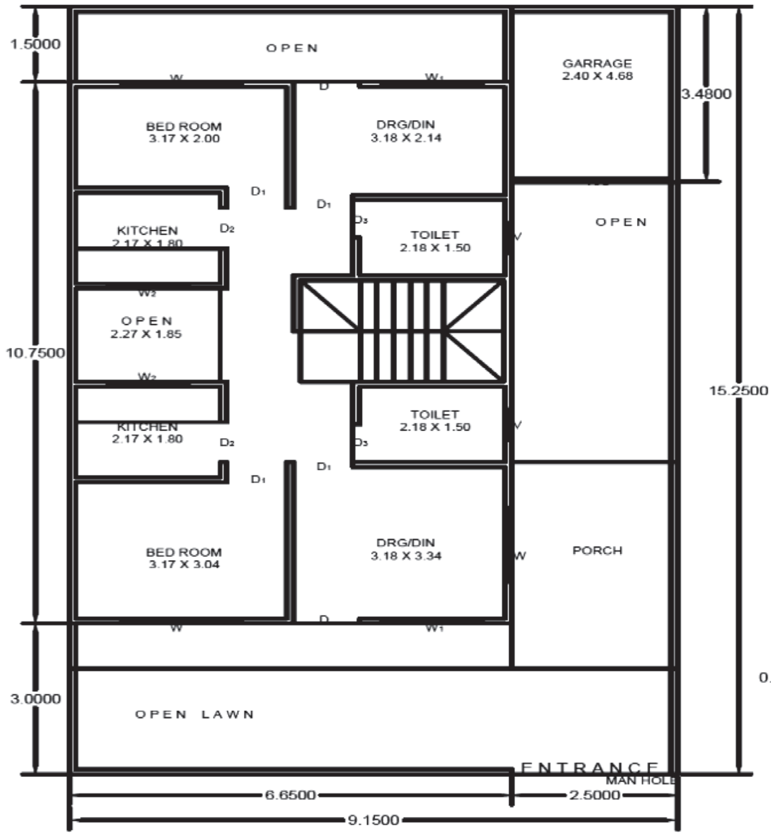
Water: Tap water or waste water can be used to manufacture green concrete.

Waste paper pulp, quarry dust, and marble powder: Marble powder and quarry dust from mining industries are used along with paper pulp from the paper industry and artistic items made of marble in green concrete [7].

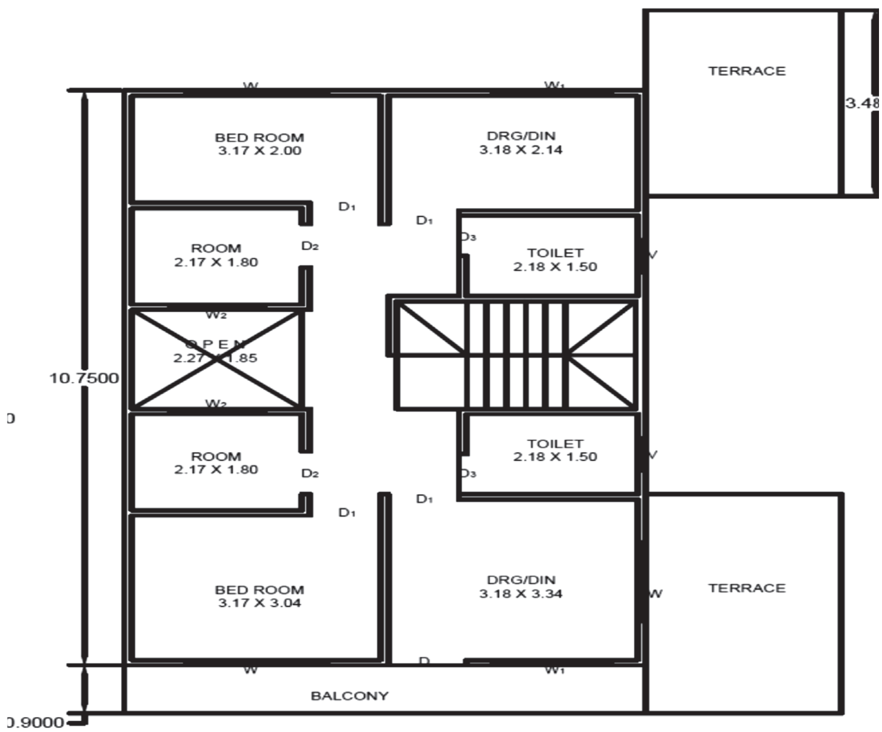
Fly Ash: Modern power stations in India produce fly ash of good quality with low sulphur and very low unburned carbon. At the outset, fly ash lacks binding properties that hold aggregates in place. Alkali solutions are employed to generate binding properties in fly ash, *i.e.*, at different molarities, fly ash receives a mixture of sodium hydroxide and sodium silicate [7].

2.6 Proposed architecture of a residential green building

The proposed architectural design of residential buildings is based on green technologies and green materials. In the architectural design, incorporative approach and joined concepts are considered. All physical and chemical parameters are considered during the design of the structure of the building. The design architecture is developed



(a)



(b)

Figure 5. Proposed layout of green building: (a) Ground floor, (b) First floor, and (c) Second floor.

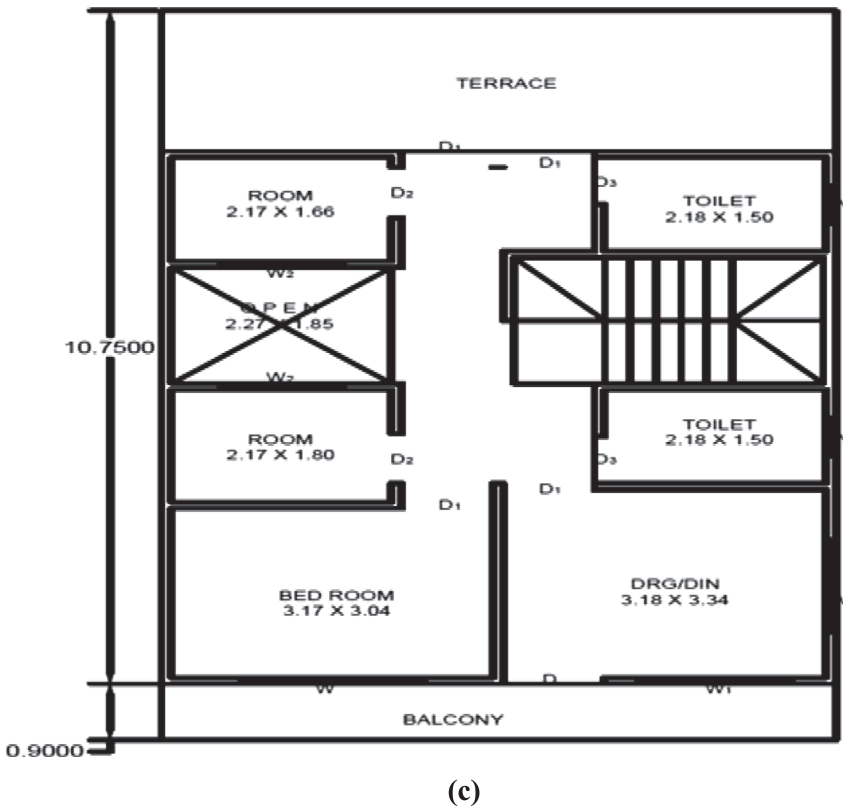


Fig. 5. Continued.

Fig. 6. Proposed inner room air quality.

in Autodesk Revit, AutoCAD software and Autodesk 3ds Max software.

In green buildings, green is associated with ecology, in which high-performance energy conservation techniques are considered [14]. Some important factors that are necessary for the designing of the green building are ecologically identical without much altering from existing by using clean materials, natural water resources, ecological conversion, maximum utilisation of renewable resources, and rainwater harvesting system [15]. Figure 4 shows the exterior design of the proposed green building. The carpet area of the proposed green building is 770 square feet and the total covered area is 1500 square feet. The ventilation system is designed in such a manner that all harmful gases are automatically diluted. The window-to-wall ratio is selected based on the maximum utilisation of daylight inside the building.

The renewable energy sources are considered for the fulfilment of energy demand. Figure 4 is also compared with the other building [16], as given in Table 1.

Figure 5 shows the layout and architectural drawing of the proposed three-storey green building. The proposed design is based on energy-saving design standards; the building faces north as building orientation has an impact on energy efficiency. All dimensions are taken as per standard norms. Building energy consumption, carbon emissions, and indoor thermal environment is also depending on the design of the building.

2.7 Design strategy of proposed green building

The proposed design of green building with consideration of several conditions explained in earlier sections that affect various processes are shown in Figure 6. The proposed structure involves those components that specify and highlight the concept and features of green building. Indoor air quality depends on sustainable design, maintenance, ventilation systems of the interior building, moisture level, humidity level, and end-user thoughts and sensitivity [17, 18]. For controlling the indoor air quality in the proposed green building, three main strategies are considered. First, removing pollutants by isolating them from the occupants through physical barriers or by air pressure. Second, through ventilation, removing or dilution of pollutants. Third, by installing an air filtration machine to remove the pollutants from the air. In Figure 6, all installed furniture is considered to be certified by Indian Green Building Council (IGBC) or Green Rating for Integrated Habitat Assessment (GRIHA).

The proposed interior air quality improvement strategies may have a beneficial impact on the atmosphere. In Figure 7, wind stream circulation strategies inside and outside of the building are depicted. Privilege is given for natural ventilation to exhaust the interior pollutants and exchange the fresh air. In the proposed green building, the interaction between renewable sources and their high penetration is also taken into consideration. The design involves a significant amount of ecological energy conversion.

The arrangement of maximum natural wind circulation inside and outside of the building is shown in Figures 7 and 8. Wind pressure is exerted on the surface of the building and slows down the flow of wind, and flows upward and sideways and forms shape like vortex and enters inside the building. In Figure 8, the window-to-wall ratio is proposed in such a way that maximum utilisation of daylight can be achieved.

2.8 Stormwater-harvesting system for proposed building

In the area of water conservation, the proposed green building design is based on a rainwater harvesting system, as shown in Figure 9. Stormwater is collected in a chamber, and with the help of a Granular Activated Carbon (GAC) filter, unwanted chemicals are removed from the stormwater and then clarified water is fed to a water storage tank for further processing. Similarly, rainwater from the roof of the green building is collected and fed to the storage tank for further processing.

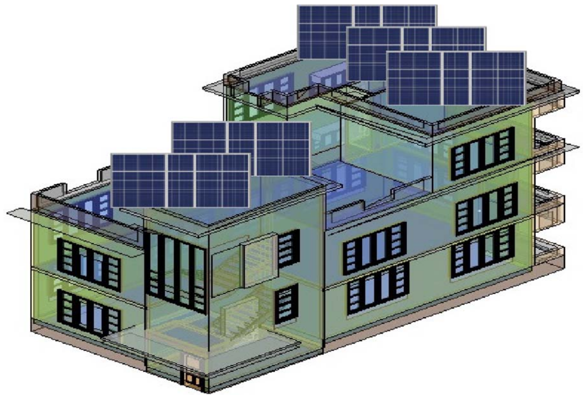


Fig. 7. Wind stream circulation inside and outside of building.

The proposed strategy is based on clean natural sources and on their protection against pollution from water. The interactivity of stormwater and soil waste and the interactivity of land and greenery is an important segment for the design of green buildings.

Design parameter of rainwater harvesting system

Average rainfall in Haryana = 617 mm = 0.617 m.
Area of catchment or rooftop = $10.75 \times 9.1 = 97.825$ m^2.
Total rainfall = area × average rainfall = $97.825 \times 0.617 = 60.358$ m^3.
Collected rainwater in liters = annual rainfall in mm × area in m^2 × runoff factor = $617 \times 97.825 \times 0.9 = 54{,}322.23$ L. Runoff coefficient = 0.9.

2.9 Solid waste management system

In order to build sustainable and livable residential building, it is essential to have proper waste management. The technical challenges involved in managing solid waste are complex. There are many administrative, economic, and social challenges that need to be addressed and resolved. The disposal of organic waste can lead to its use as manure or bio-gas production. Non-organic waste is capable of being processed and used as raw materials or recycled. Figure 10 shows the block diagram of plan for the solid waste management system of proposed green building.

The total waste per person is 0.6 kg/day as per the report of Ministry of Housing and Urban affairs, Government of India [32]. The following calculations have been performed assuming that there are six members of a family living in the proposed green building.

Total waste generated per day = $0.6 \times 6 = 3.6$ kg.
1 kg/hr = 0.00059 cfm.
Required capacity of vacuum pump = $3.6 \times 0.00059/0.33 = 0.0064$ cfm.
Average biogas generation from 1 kg of organic waste = 0.3 m^3 [26].
Total biogas production rate per day for proposed green building = $3.6 \times 0.3 = 1.08$ m^3/day.

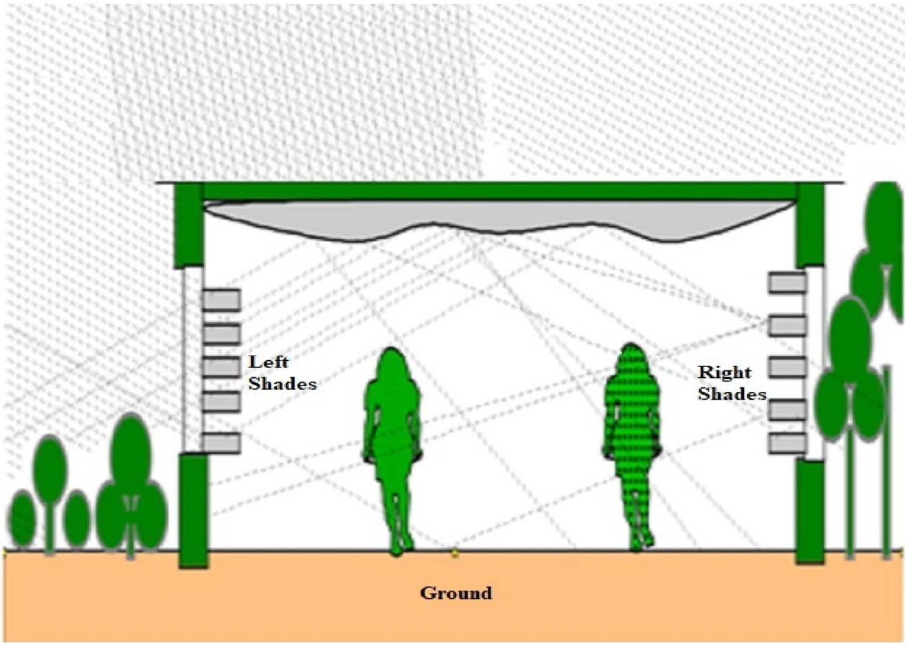


Fig. 8. Provision of maximum utilisation of day light inside the building.

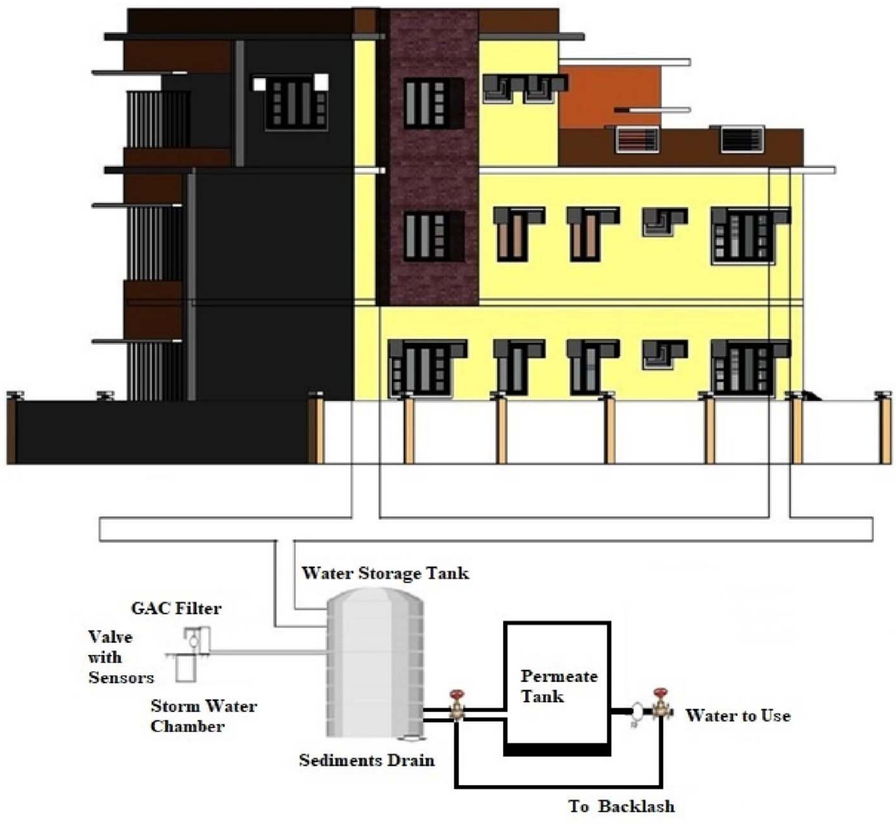


Fig. 9. Stormwater-harvesting system of proposed green building.

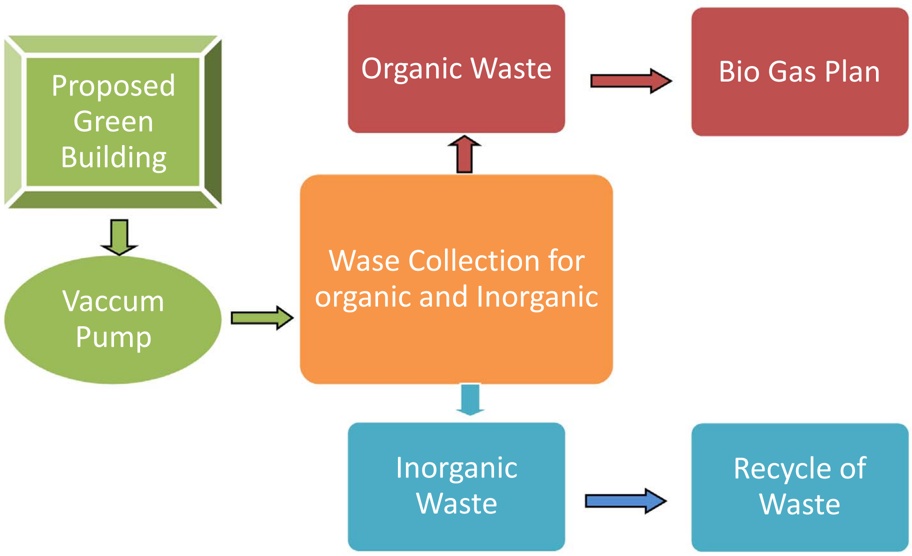


Fig. 10. Block diagram of solid waste management plan.

2.10 Lightning surge protection using rolling sphere method

The external part of the system is designed to prevent lightning surges, conduct surges safely, and make sure that the lightning current is able to flow to the earth by providing a passage. In the worst-case scenario of lightning strike, the Rolling Sphere Lightning Protection scheme takes into account the exact amount of spikes required. The area to be protected depend on the radius of sphere. The sphere is able to roll up and down on power masts, shielding wires, and other metal objects that are grounded and can protect from lightning.

3 Results and discussions

The results are of great importance because this kind of innovative design and green material enhances the quality of green buildings. Following are the analyses of the proposed green building:

3.1 Energy calculation analysis

The typical load profile is given for ordinary building and proposed building in Tables 2 and 3, respectively. Energy consumption and power generation from solar are analysed for the proposed green building in Table 3. For the analysis, weather of Haryana in 2024 is considered. From Table 3, it is observed that the power demand of the building is entirely fulfilled by solar panels installed on the rooftop of the building. A Battery Energy Storage (BES) system is also used to store the extra power of the solar system for further utilisation. Figure 11 shows the single-line diagram of the lighting and power supply system of the proposed three-storey building.

Proposed green material due to the high fineness of the green concrete mixture, provided very good cohesive strength. It is observed that the water absorption in the proposed mixture of green concrete is more than in ordinary concrete. From this study, it is concluded that green concrete provides self-compacting and higher workability. The test detail of green concrete is given in the following subsection.

3.2 Tests and methodologies

Design parameters

Grade of concrete: M-30, Slump: 75–100 mm

Test parameters for cement

Type of cement: PPC of TOPCEM brand cement as per IS: 1489, Cement's specific gravity: 2.91, Coarse aggregate's specific gravity: 2.72, Fine aggregate's specific gravity: 2.61, Absorbing water from Coarse Aggregate: 0.73%, Absorbing water of fine aggregate: 1.40%.

Aggregate 20 mm and 10 mm are mixed in proportion of 60:40 by weight as mentioned in Tables 4 and 5. In Tables 4 and 5, crushed granite stones are used as coarse aggregate. The gradation of the coarse aggregate is determined by sieve analysis, as per IS-383 (1970). In Table 6, river sand is used as fine aggregate. The gradation of the fine aggregate is determined by sieve analysis, as per IS-383 (1970).

The desired strength of concrete

As per IS 10262: Target mean strength $(f'_{sk}) = f_{sk} + T \times s = 30 + 1.65 \times 5 = 38.25$ N/mm^2. Where f_{sk} = characteristic compressive strength, $T = 1.65$ from IS 10262:2009, s = standard deviation (Table 1 of IS 10262:2009).

Water cement ratio

The maximum water cement ratio is 0.45, as per Table 5 of IS 456, according to the standards. Water cement ratio for

Table 2. Load profile of ordinary building.

S. No.	Home appliances	Rated power (W)	Quantity	Operational period (Hrs)	Daily energy demand (kWh)
1	LED light	20	14	8	2.240
2	Ceiling fan	75	5	8	3
3	Microwave oven	1100	1	0.25	0.275
4	TV	100	2	5	1
5	Coffee maker	900	1	0.25	0.225
6	Computer	90	1	2	0.180
7	Water motor	370	1	0.5	0.185
8	Iron	750	1	0.25	0.187
9	Mixer	750	1	0.15	0.112
10	Air conditioners	2000	1	6	12
11	20 L geezer	2000	1	4	8
12	Washing machine	–	1	2	0.1
13	Refrigerator	–	1	14	2
	Total				29.504

Table 3. Load profile of the proposed green building.

S. No.	Home appliances	Rated power (W)	Quantity	Operational period (Hrs)	Daily energy demand (kWh)
1	LED light	20	14	6	1.680
2	Ceiling fan	75	5	6	2.250
3	Microwave oven	1100	1	0.25	0.275
4	TV	100	2	5	1
5	Coffee maker	900	1	0.25	0.225
6	Computer	90	1	2	0.180
7	Motor	370	1	0.5	0.185
8	Iron	750	1	0.25	0.187
9	Mixer	750	1	0.15	0.112
10	Air conditioners	2000	1	3	6
11	Washing machine	–	1	2	0.1
12	Refrigerator	–	1	14	2
13	Solar water eater	200	1	2	0.4
	Total				14.59
	Solar panel installed capacity at roof of the building (500 W × 6)	500	6	Availability only at day time (5 Hrs)	18.00

proposed building material = 0.42. 0.42 < 0.45, hence, the ratio is good for compressive strength of material.

Water contents

From Table 2 of IS 10262:2009, maximum water content for 20 mm aggregate 186 L (for 25–50 mm slump) [Ref. IS 10262:2009, Cl 4.2, pp. 2–3].

Estimated water content for 75–100 mm slump = 186 + 6/100 × 186 = 197.16 L.

The water content can be reduced up to 20% and above when the super plasticizer is used, based on the trail that shows a 19% reduction in admixture water content. Hence, the water contents in the proposed material = 197.16 × 0.81 = 159.7 L.

Cement content

Water cement ratio = 0.42, Cement content = 159.7/0.42 = 380 kg/m^3.

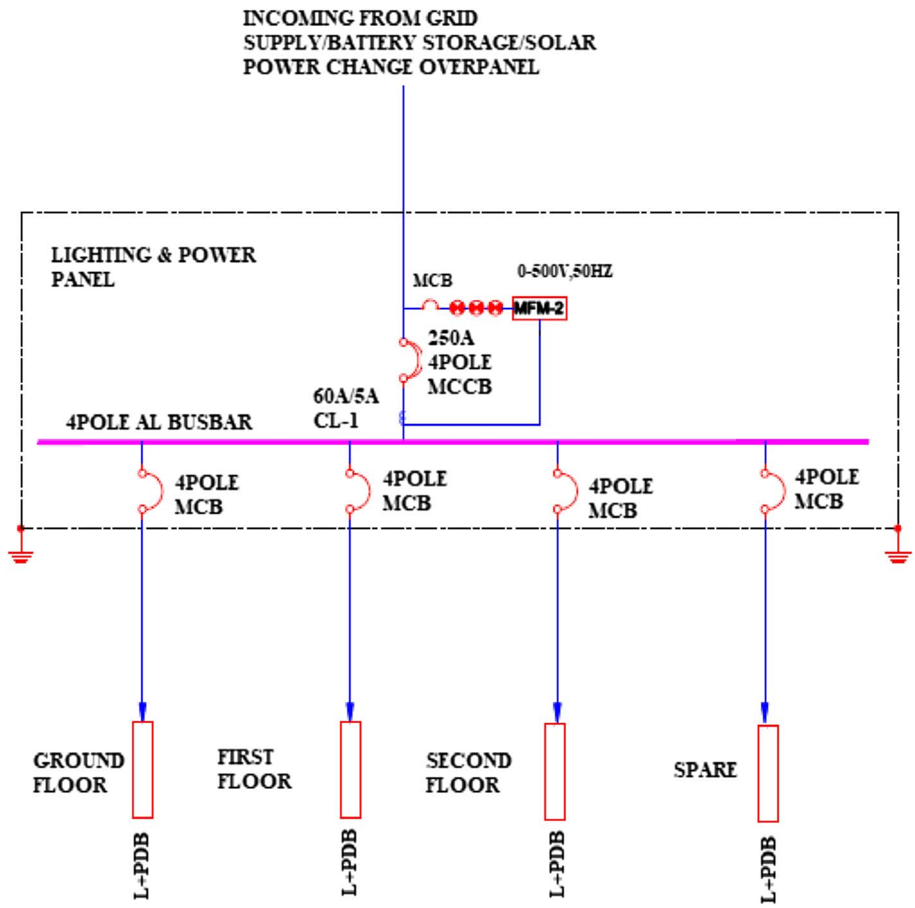


Fig. 11. Single-line diagram of power distribution in proposed green building.

Table 4. Grading of coarse aggregate 20 mm.

Sieve size (mm)	(% Finer)	Permissible limit (%)	Remarks
40	100	100	Confirms to IS: 383:1970 [33]
20	90.26	85–100	
10	12.63	0–20	
4.75	1.21	0–5	

Table 5. Grading of coarse aggregate 10 mm.

Sieve size (mm)	(% Finer)	Permissible limit (%)	Remarks
12.5	100	100	Confirms to IS: 383:1970 [33]
10	91.76	85–100	
4.75	14.12	0–20	
2.36	2.54	0–5	

Table 6. Grading of fine aggregate.

Sieve size (mm)	(% Finer)	Permissible limit (%)	Remarks
10	100	100	Confirms to Grading Zone II of IS: 383:1970 [33]
4.75	96.44	90–100	
2.36	88.22	75–100	
1.18	79.41	55–90	
0.60	48.16	35–59	
0.30	18.51	8–30	
0.15	1.70	0–10	

Table 7. Trial mix.

Trial No.	Average 7 days' cube compressive strength (MPa)	Average 28 days' cube compressive strength (MPa)	Slump (mm)
I (W/C = 0.40)	28.93	46.54	95
II (W/C = 0.44)	25.57	45.49	100
III (W/C = 0.36)	29.20	47.28	80

Table 8. Comparison of proposed green building with other buildings in winter [3].

S. No.	Description	Time	Conventional building [3]	Average of green building 1, 2, 3 & 4 [3]	Proposed green building in this paper	%age Improved in this paper as compared with average of Green Building 1, 2, 3 & 4 [3]
1	Air contaminants (ppm)	Morning	4.23	0.64	0.4	37%
		Afternoon	4.48	1.19	1.19	0%
		Evening	4.67	1.28	1	22%
2	Humidity (%)	Morning	58	51.80	47	9%
		Afternoon	57	51.25	45	12%
		Evening	54.6	52.63	46	13%
3	Lighting (Lux)	Morning	226	853.33	890	4%
		Afternoon	245	907.23	985.2	9%
		Evening	237	859.25	912	6%
4	Temperature (°C)	Morning	12.26	19.53	19.4	1%
		Afternoon	12.28	21.68	21.1	3%
		Evening	11.3	19.98	19.7	1%
5	Noise(dB)	Morning	43	45.62	42.3	7%
		Afternoon	41	45.33	44.5	2%
		Evening	44.66	45.77	45	2%

According to Table 5 of IS 456, it is necessary to have 320 kg/m^3 cement content under severe exposure conditions. In the proposed green material, cement content = 380 kg/m^3 > 320 kg/m^3. Hence, compressive strength of material is good.

Mix calculation for trial mix

Cement: 380 kg/m^3.

Sand, waste paper pulp, quarry dust and marble powder: 775.01 kg/m^3, stone chips 20 mm = 669.21 kg/m^3, Stone chip 10 mm = 446.15 kg/m^3, water = 159.7 kg/m^3, admixture = 2.28 kg/m^3. Result of trial mix is given in Table 7.

Two more trials were carried out having variation of ±10% of water cement ratio in the laboratory. However, durability requirement shall be meet.

Results pertaining to the assessment of the proposed green building and comparison with other buildings are given in Table 1. We have considered five parameters in terms of indoor air quality, *i.e.*, air contaminants, humidity, lighting, temperature and noise level. The proposed green

Table 9. Comparison of proposed green building with other buildings in summer [3].

S. No.	Description	Time	Conventional building [3]	Average of green building 1, 2, 3 & 4 [3]	Proposed green building this paper	%age Improved in this paper as compared with average of green building 1, 2, 3 & 4 [3]
1	Air contaminants morning (ppm)	Morning	6.64	1.30	1.21	7%
		Afternoon	6.68	1.59	1.42	11%
		Evening	6.38	1.30	0.9	31%
2	Humidity (%)	Morning	74	55.50	49	12%
		Afternoon	79	57.25	51	11%
		Evening	78	55.58	50	10%
3	Lighting (Lux)	Morning	346	1078.32	1295	20%
		Afternoon	368	1258.75	1535	22%
		Evening	366	1068.25	1350	26%
4	Temperature (°C)	Morning	42.66	26.08	21	19%
		Afternoon	48.66	28.29	24.2	14%
		Evening	45	26.00	23.1	11%
5	Noise (dB)	Morning	64.33	51.09	40	22%
		Afternoon	68	53.73	45.3	16%
		Evening	64.45	50.90	48.1	5%

Table 10. Comparison for the energy consumption and cost of proposed green building with ordinary building.

Description	Ordinary building	Proposed green building	% age saving in the proposed green building with respect to ordinary building
Daily energy consumption	29.504 kWh	14.59 kWh	50.54%
Monthly energy consumption	885.12 kWh	437.7 kWh	50.54%
Monthly tariff 0–150 unit @ Rs. 2.75/unit	Rs. 412.5	Rs. 412.5	–
Monthly tariff 151–250 unit @ Rs. 5.25/unit	Rs. 525	Rs. 525	–
Monthly tariff 251–500 unit @ Rs. 6.30/unit	Rs. 1575	Rs. 1182.51	–
Monthly tariff 501–800 and above unit @ Rs. 7.10/unit	Rs. 2734.352	–	–
Fixed charges	Rs. 200	Rs. 200	–
Total cost/month	Rs. 5446.852	Rs. 2320.01	57.41%

building design is simulated in Revit simulation software by considering Haryana weather for both summer and winter seasons. Detailed analysis is presented for both winter and summer seasons in Tables 8 and 9, respectively.

From Tables 8 and 9, it is inferred that the proposed green building is far better than conventional buildings and other existing buildings, as given in Table 1. The green building creates a healthier environment and reduces illness. So, more and more residential buildings must be promoted to green buildings and must contribute towards sustainable development. As a result, our planet will become pollution-free and help to reduce global warming.

Energy consumption and energy cost

The energy consumption of the proposed building has been calculated based on the tariff plan issued by Uttar Haryana Bijli Vitran Nigam as per sales circular No. U-08/2024 [34]. The typical load profile for both the ordinary building and the proposed green building has been considered the same. However, the proposed green building has limited requirement of several electrical appliances per day due to its design and use of green materials. The comparison of energy consumption and cost of the proposed green building with ordinary building is shown in Table 10.

Further, the proposed green building is completely powered by renewable energy sources. The dependency of the proposed green building on grid is limited and grid is used only during non-availability of solar radiations.

Carbon emission

Carbon emission of a building is calculated by taking the ratio of average energy cost (avgEP) over the month and

Table 11. CO_2 emission/month.

Parameter	Ordinary building	Proposed green building	Difference %
CO_2 emission/month	1236.20	611.31	50.54% reduced

the price per kWh (η) multiplied by the weighted emissions factor (γ) and the number of months (m): $CO_2 = \frac{\text{avgEP}}{\eta \times \gamma \times m}$. Where, weighted average emission factor (γ) = 0.716 tCo_2/MWh as per CERC, GoI report [35]. The comparison of carbon emission of the proposed green building with ordinary building is shown in Table 11. Table 11 indicates improved performance of green building compared to ordinary building.

4 Conclusion

The proposed design model for a residential green building is examined to determine its impact on eco-friendliness. Using green materials in accordance with the intended composition of cement, fine and coarse aggregate, waste paper pulp, quarry dust, fly ash, and marble powder, it was discovered that all pollutants dilute themselves automatically, leading to the building becoming eco-friendly. Further, the proposed green building has seen a decrease in power consumption from the grid due to the use of renewable energy sources and other green technologies. The proposed green building is very beneficial and produces effective outcomes. Building energy consumption, total energy consumption cost, and CO_2 emission per month are reduced by 50.54%, 57.41%, 50.54%, respectively. Thus reducing energy consumption and making the building more sustainable. Additionally, a proposal has been made to collect 54,322.23 L of rainwater annually through stormwater harvesting, which aids in water conservation and helps to utilise natural energy to reduce the wastage of water and improve groundwater level. The design of the proposed green building is a combination of energy efficiency with its functional, construction, and system design. The proposed green building results indicate that the building is self-sufficient and has strategies for achieving net zero energy. Further enhancement can be achieved in the future by focusing more research on occupant-centered perception, cost reduction, and resource reduction.

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