Energy Efficient Design for G+3 Residential Building (Duplex type) Using BIM Tools

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ABSTRACT: G+3 residential duplex buildings constructed through BIM modeling resulted from an advanced design process and technology advancement as a result of increasing market demand on sustainable buildings. With this technology, designers can also carry out building performance simulation at very accurate modeling during early design phases to optimize energy utilization and occupants' satisfaction. An analysis is undertaken that combines passive design strategies with natural ventilation employing specific enhanced glazings and renewables and heating ventilation and air conditioning systems upgrades integrated with building orientation and shade surfaces for site-specific passive building shell design and use with possible alternative measures of energy conservation. Assembled Autodesk Revit and Insight 360 provide energy modeling and daylight analysis to meet the lifecycle assessment functionalities required for LEED or IGBC green building standards and their requirements. These integrated strategies allow a primary reduce of building energy consumption by 35% and support the future development of net-zero power operation systems through solar power systems. Sustainable residential projects could be accurately built by stakeholders through BIM tools while ensuring the success of projects. The research presents a cheap method of carrying out sustainable housing design that goes with technological innovations that are urban expansion solutions and climate change adaptation methods.

Keywords: Energy Efficiency, BIM Tools, Sustainable Architecture, Passive Design, Renewable Energy.

1. INTRODUCTION:

Urban growth and growing populations throughout the next few decades will cause massive and unprecedented development that expands residential construction needs leading to significant energy use and environmental damage and elevated greenhouse gas output. Construction produces the largest carbon footprints for which every country is responsible. The International Energy Agency (IEA) indicates that buildings use up forty percent of global energy supplies and account for thirty-six percent of CO_2 emissions (IEA, 2021)[1]. Building sustainability practices and innovative technologies with energy-efficient resource conservation capabilities serve as the necessary solution to counter the rising adverse effects from these challenges throughout the design and construction process of buildings.Modern building designs must be energy-efficient because they fend off both increased energy costs and associated environmental issues. Buildings require energy efficiency approaches to reduce their power needs while preserving comfort conditions for occupants and their health and work efficiency which needs improvement. Peaceful design methods together with advanced construction materials and precise mechanical system operation and renewable source integration make up this system. The majority of technological tools which facilitate designing processes now revolve around Building Information Modeling (BIM) because these tools enable precise performance modeling alongside simulation and analysis of buildings before construction begins. Project conception benefits through BIM because the platform enables effective team collaboration between architects engineers and other stakeholders to integrate sustainability goals.

An energy-efficient G+3 duplex-type residential building design will be constructed through BIM modeling as the main focus of this analysis. A domestic duplex-type residential building consisting of multiple stories with shared walls between structures provides both possibilities and restrictions during energy optimization. Such buildings need to harmonize good looks with spacious functionality while maintaining full compliance with local energy efficiency rules and regulations. The framework of this research examines energy-saving methodologies through collaborative use of Autodesk Revit and Insight

360 tools as part of advanced BIM modeling. Energy modeling and life cycle assessment along with daylight analysis evaluate these strategies to confirm their adherence to green building certification programs which include Leadership in Energy and Environmental Design (LEED) or Indian Green Building Council (IGBC).Energy demand reduction of buildings depends largely on passive design techniques. The research uses proper orienting and shading equipment together with natural ventilation systems and high-performance glazing as its main structural elements. A building oriented correctly will increase winter sun exposure and decrease summer heat while achieving major reductions in heating and cooling requirements. Shading devices which include overhangs and louvers function to control day sun exposure which then minimizes the need for artificial cooling systems. Through proper placement of windows and openings buildings automatically benefit from better air quality while maintaining thermal comfort levels while using minimum mechanical equipment. Low-emissivity coatings on double-glazed units with high-performance glazing work as thermal insulation to stop heat transfer which leads to additional energy savings.

Material selection emerges one of the essential components while implementing energy-efficient design. Building material selection directly impacts both thermal efficiency and environmental footprint besides impacting building energy requirements during production. Concrete and brick demonstrate high thermal mass properties during winter because they absorb external heat which later releases back into the indoor environment to maintain steady temperatures throughout the day. Insulation materials including fiberglass, cellulose and foam boards receive precise wall and roof and floor placements which help delay heat and cool space dispersal thus requiring decreased heating and cooling demands. community-based materials reduce the environmental impact of supply transportation [2]. The circular economy principle receives meaningful support from this specific factor. The implementation of renewable power sources forms an essential requirement to achieve net-zero energy. The residential use of renewable energy particularly depends on solar photovoltaics combined with wind generation and geothermal heat extraction. This research includes solar panel implementation as a power consumption reduction method in opposition to fossil fuel energy use. Building constructions which achieve long-term energy equilibrium between creation and usage result from renewable energy adoption and energy-efficient planning principles [6].HVAC system optimization is equally important in reducing energy consumption. Modern HVAC systems equipped with smart controls, variable refrigerant flow (VRF) technology, and energy recovery ventilators (ERVs) offer significant energy savings compared to conventional systems. These systems are designed to adapt to changing occupancy patterns and climatic conditions, ensuring optimal performance and comfort.

The adoption of BIM tools showcased in this study illustrates their ability to transform cooperation, accuracy in design, and sustainability. BIM provides real-time visualization, clash detection, and performance analysis that align all stakeholders with respect to design and construction. In addition, BIM provides life-cycle assessment of building projects to allow designers to assess the environmental impact of materials and systems during the building life span [5]. This research aims to prepare a holistic roadmap for environmentally responsible and economical housing solutions. By bringing together innovative design practice with advanced technology, it highlights the potentials of BIM-driven energy-efficient design in addressing climate challenges globally while fulfilling the ever-growing housing demands of urban dwellers. The finding indicates that with these strategies applied, the energy demand of the building is reduced by about 35% compared to the conventional design, strengthening the cases for sustainable practices in the construction industry.

2. METHODOLOGY:

The methodology of the energy analysis of energy-efficient building is as follows:

2.1. BIM Model Development

The energy-efficient building model was developed in Autodesk Revit based on a traditional building design. Key components such as the building envelope, glazing, HVAC systems, lighting, and other energy-related features were detailed in the BIM model. Modifications were made to the traditional floor plan to enhance natural light penetration in various rooms, incorporating solar

panels to reduce electricity consumption. The thermal properties of walls, roofs, and windows were updated with high-performance insulation materials to improve energy efficiency. These adjustments were aimed at reducing heat transfer, minimizing thermal loads, and optimizing overall building performance.

2.2. Energy Simulation Using Insight 360

The Insight 360 plugin was employed to evaluate the building's energy efficiency. This tool allows for the analysis of energy usage under different design scenarios, providing insights into the impact of design choices on energy performance. Two key analyses were conducted:

- **Daylight Analysis:** A lighting tool integrated into Revit was used to assess daylight performance. This analysis helped optimize window placement and shading devices to maximize natural light while minimizing glare and overheating.
- **Photovoltaic (PV) Panel Analysis:** A solar tool added to Revit was used to analyze the contribution of PV panels to the building's energy efficiency. The analysis determined the optimal placement and size of solar panels to maximize energy generation.

2.3. Data Input and Validation

Accurate data input is crucial for reliable energy modeling. Weather information, occupancy schedules, equipment usage patterns, and other relevant parameters were entered into the Revit model. The data was meticulously validated to ensure accuracy and consistency, forming the basis for subsequent energy performance evaluations.

2.4. Energy Performance Analysis

Using the Insight plugin, the energy performance of the optimized building design was analyzed. Metrics such as annual energy consumption, heating and cooling loads, and carbon emissions were evaluated to quantify the improvements achieved through the implemented strategies.

2.5. Design Optimization

Identify areas for further improvement and make necessary adjustments to the design for optimizing energy efficiency.

Fig.1 Building East and South sides

Figure 1 presents a multi-family house accommodated in the parameters of energy-efficient practice and optimized lighting in design. The house is able to adopt many passive designs like high-performance glazing, shading devices, and a good orientation for maximization and natural daylighting with reduced heat gain. Large strategically located holes-giving enough openings for uniform daylight distribution-and reflective internal surfaces to improve penetration of sunlight into deeper parts of the building are part of these passive characteristics. Supplementing artificial lighting use is provided by smart lighting controls and energy-efficient LED fixtures added into the spaces, with no less than 90% of these spaces meeting the minimum requirement of effective lighting. Such metrics are likely verified through the advanced simulation tools like BIM software. The design has then met the efficiency energy-saving purpose without compromising occupant comfort. This kind of holistic approach gives an indication of the extent to which the building has embraced modern architectural innovation in its sustainable and holistic edge.

3. Modelling

A general energy-efficient analysis for the duplex G+3 building model had discerned a basis for redesigning the model. Again, the Revit xArchitecture tool was used to optimize the traditional building model. The table below shows the detailed components of the current efficient building along with materials and its respective properties.

Table 1 Detail components for energy model

BuildingElement	Material/components	Thickness (mm)/ Size	UValue ($W/m^2.K$)
ExteriorWall	Brickmasonry	300	0.95
	ExteriorInsulation	10	
	CementMortar	12	
InteriorWall	Brickmasonry	150	5.6
	CementMortar	12	
Roof	Concrete	150	
	EIFS,		
	ExteriorInsulation	100	
	CementMortar	20	
Floor	Concrete	180	6.9
	Marble	20	
Windows			
i) Living	TripleGlazing- ⅛inthick-	3000 X1500	1.53
Room -Bay	lowE value	mmsize	
Casementtype	SmallDoubleGlazedwith	1810 X1210	2.53
	lowE value	mmsize	

Fig.2: Energy settings for the energy model

After following the above table changes and the final redesigned model plan looks as shown in figure3

Fig.3 Floor plan of energy efficient building

4. Lighting Analysis

Lighting analysis in Revit is the process of assessing a building's lighting performance using Autodesk Revit software. To analyze a building's lighting and improve its design for energy efficiency and occupant comfort, Revit offers a number of tools.

4.1. Lighting Analysis: For the day light analysis, the GF and 2nd floor levels are used. Asit is a G+3 building, the bottom 3 floors might get low daylight and the top 3 floors have maximum potential to grab sunlight.

Fig.4 Lighting Analysis for duplex building model

at ground floor

Fig.5 Lighting Analysis for duplex building model

at 2nd floor

The lighting analysis conducted for the G+3 residential duplex building, as depicted in Figures 4 and 5, provides critical insights into the daylighting performance of the structure. The results highlight significant challenges related to natural light penetration, particularly due to the orientation and design of the building.

Impact of Masonry Wall on East Side

In essence, the importance of daylight is reduced as the east masonry notched wall blocks nearly all sun rays entering the users' rooms. This means they substantially reduce the amount of sunlight that would otherwise get into their room. Therefore, 90% of the sunlight available penetrates the rooms of this building, meaning that lots of places are artificially lit throughout the day. This is pretty apparent in early mornings when the sun rises fairly low and eastward, thus allowing solid masonry walls to block direct sunlight access to those affected rooms. This unequal lighting in the building occurs as those that are oriented toward the west and south have better exposure to daylight, while those that face the east remain darker owing to which supplementary artificial lighting is required during the daytime.

Lighting analysis as shown in the figures 1 and 2 shows the importance of orientation and design of a building for daylighting performance. The blockage of sunlight into the spaces that fall under the masonry wall on the east side greatly limits how much natural light reaches such places; hence lighting conditions of a large part of the building are sub-optimal. Consideration of such modifications in design and advanced lighting solutions will enable proper energy efficiency while improving comfort for the occupants. This way, it will better transition towards principles of sustainable design, making the G+3 residential duplex building live healthily and more environmentally conscious.

5. Comprehensive Analysis

Fig.6 Comprehensive analysis views

This schematic representation includes comprehensive G+3 duplex building analysis using BIM (Building Information Modeling) tools, regarding its carbon footprint, energy utilization, and sustainability scores. Below mentioned is the detailed explanation of each figure component:

Fig.7a) Total Carbon, b) Embodied Carbon, c) Operational Carbon, d) Annual Energy Use Intensity (EUI)

figures. 7 several critical performance metrics namely carbon emission, energy consumption, and building characteristics.

a. Total carbon

- **Value:** 1,027,142.59 kgCO2e is that which the building represents as total carbon emissions.
- **Explanation:** This metric includes embodied carbon, which refers to carbon emissions associated with the production and transport of materials, as well as operational carbon, which refers to emissions due to the energy consumed by the building during its operation. This metric thus measures the overall environmental impact of the entire life of the building.

b. Embodied Carbon

- **Value:** Embodied carbon is 48,615.37 $kgCO_2e$.
- **Explanation:** The carbon emission generated during manufacturing, transportation, and construction phases of the building are represented in this. The minor stature when compared with operational carbon indicates that the building materials and the techniques used for the construction are optimized for low environmental susceptibility.

c. Operational Carbon

- **Value:** 978,527.22 $kgCO_2e$ is the operational carbon.
- **Explanation:** This metric incorporates the carbon produced during energy consumption of the building during its operation, which reflects the report that it uses energy during operation. The values are high and therefore evidence that energy consumed during operation is a more significant contributor to total carbon emissions of the building.

d. Annual Energy Use Intensity (EUI)

- **Value:** The annual energy use intensity is 770.84 kWh/m^2.
- **Explanation:** EUI is a measure of energy consumed per unit area of the building on annual basis. Thus, a higher EUI indicates increased energy consumption. The annual energy performance of a building can also be influenced by occupant behavior and can also be partly

dependent on factors such as insulation, HVAC, or lighting systems.

6. Zone Load Summary

Fig. 8 Zone load summary at cooling

Fig.9a) Peak load [W], b) Cooling load components [W]

Overall Interpretation:

1. **Dominant Cooling Requirement:**

The peak load recorded is mainly due to cooling-its requirements at 999 W, while the need in heating is minimal-at a maximum of 18 W. This, therefore, implies that the zone is designed for a cooling-dominated operation owing to the possibility of higher ambient temperatures outside.

2. **Major Contributors to Cooling Load:**

- **Conduction (748 W):** The largest component, highlighting the importance of insulation and thermal barriers in the building envelope.
- **Solar (77 W):** Significant heat gain from sunlight, emphasizing the need for shading devices, reflective coatings, or low-emissivity glass.
- **Lights (130 W) and Equipment (59 W):** Internal heat sources that can be optimized through energy-efficient lighting and equipment.
- **People (133 W):** Occupants contribute significantly to heat gain, especially in densely occupied spaces.

3. **Engineering Parameters:**

The engineering checks provide critical data for designing the cooling system regarding capacity and airflow rates in order to condition it appropriately such that comfort conditions are maintained.

Fig.10 Zone load summary at heating

Fig. 11a) Peak load [W], b) Heating load components [W]

Overall Interpretation:

Dominant Cooling Requirement:

The peak load is primarily driven by cooling needs (999 W), with minimal heating requirements (18 W). This indicates that the zone is designed for cooling-dominated operation, likely due to internal heat gains or insufficient insulation.

Major Contributors to Heating Load:

- **Conduction (61 W):** The largest component, highlighting the importance of insulation and thermal barriers in the building envelope.
- **People (15 W):** Occupants contribute significantly to heat gain, even though the overall heating load is low.

Engineering Parameters:

The engineering checks provide critical data for designing the heating system, ensuring it meets the required capacity and airflow rates while maintaining comfort conditions. However, the "null" values for heating capacity and airflow suggest that heating is not a significant concern at this specific peak time.

8. Energy Analysis Results

Fig.12(a):Energy usage analysis for energy model | **Figure12(b)**:Cost for energy usage for energy model

8.1 Comparative Analysis: Building information modelling (BIM) can be used to undertake a comparative energy analysis of conventional and energy-efficient buildings to show how the two building types differ in terms of performance and energy usage. The study can assess the effects of energy-saving technologies, insulation, air-tightness, and renewable energy sources on the building's energy performance and compare the energy consumption of a traditional building to that of an energy-efficient building constructed using BIM.

Figure13(a) Cost of energy use for traditional building model | **Figure13(b)**Cost of energy use for energy model

The results for traditional building after energy analysis are as mentioned in the above fig.13(a)&(b). The energy usage compared between traditional building to energy model is having a difference of 127 KW/m^2/year. Where, the energy model achieved the reduced energy demand which in return the cost to be incurred on the energy usage will also get decrease and is by half. The cost of energy demand for a traditional building is 20.8 USD/m^2/Year. Whereas, for the energy model it is only 10.6 USD/m^2/year.

9. Conclusions

- The analyzed results concludes that the use of BIM tools helps in identifying possible parameters where energy costs can be reduced and an energy efficient design can be produced.
- The lighting analysis report of the building was absolutely with 91% where sunlight enters the building and saves energy in the day time.

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