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Simulation-Based Study on Nearly Zero Energy Building Design

Roshan Kunwar[1], Roshan Shahi[2], Varsha R[3], W. Kritivash Singh[4]
[1,2,3,4]Undergraduate Student, Civil Engineering, Bangalore Technological Institute, Bangalore, Karnataka, India.
Emails: *rk9825663747@gmail.com[1], shahiroshan5007@gmail.com[2], varsharvarsha123@gmail.com[3], kritivaswahengbam@gmail.com[4]*

Abstract
This study presents a comprehensive simulation-based approach for the design and evaluation of a Nearly Zero Energy Building (NZEB), focusing on achieving optimal energy performance through both passive and active design strategies. Energy modeling tools were utilized to analyze the impact of factors such as building orientation, insulation materials, window-to-wall ratios, shading devices, and natural daylighting on overall energy efficiency. Additionally, the study incorporated renewable energy systems, including solar photovoltaic panels and energy-efficient HVAC systems, to further reduce dependence on conventional energy sources. Through iterative simulations, the research optimized the building's design to balance thermal comfort, indoor air quality, and energy consumption.

Keywords: *Nearly Zero Energy Building (NZEB), Energy Simulation, Passive and Active Design Strategies, Energy Efficiency.*

1. Introduction

Buildings are among the highest consumers of energy globally, and with rapid urbanization and rising living standards, electricity demand in residential and commercial structures continues to increase. A significant portion of this energy is used for heating, cooling, lighting, and operating appliances, leading to high carbon emissions and environmental degradation. In response to these challenges, the concept of Nearly Zero Energy Buildings (NZEB) has emerged as a promising solution. An NZEB is designed to consume very low energy through efficient architectural strategies while generating most of its required energy from renewable sources, thereby reducing operational costs and supporting environmental sustainability. Energy-efficient building design has become a priority in engineering and policy frameworks, with governments promoting green standards to minimize energy consumption and improve indoor comfort. However, achieving an effective NZEB is complex and requires an integrated approach involving passive design strategies, advanced materials, optimized mechanical systems, and renewable technologies. Design parameters such as building orientation, glazing type, insulation level, shading devices, and window-to-wall ratios significantly influence performance and must be evaluated accurately. Traditional design methods often depend on assumptions, limiting their ability to predict real energy behavior. Modern simulation tools, such as Design Builder and EnergyPlus, enable detailed analysis of energy consumption, thermal comfort, daylighting, and HVAC performance. By assessing multiple scenarios virtually, designers can identify the most efficient configurations and reduce overall energy demand. As a result, simulation-based design has become fundamental in developing realistic, high-performance NZEB solutions. This study Focus on a simulation-based design approach for an NZEB, analysing various design configurations and assessing their impact on building energy performance. The goal is to explore how optimized architectural features and renewable energy systems contribute to minimizing energy demand, thereby supporting sustainable development [1].

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1.1. Methods of NZEB Design

1.1.1. Site Location

- **Coordinates:** 28°36′15.4″N,81°03′14E
- **Nearby Feature:** River (east side of the site)
- **Context:** Agricultural land with scattered rural settlement

1.1.2. Site Surroundings

- **North:** Agricultural fields & road connection
- **East:** River (important for microclimate & flood consideration)
- **South:** Settlements and farmland
- **West:** Road networks and fields

1.1.3. Climate Consideration

- Located at an elevation of 600.95 meters (1971.62 feet) above sea level, Kailali has a Temperate highland tropical climate with dry winters climate (Classification: CWB). Kailali (Tikapur) experiences a climate that shifts from cool and mild winters around 14–17 °C to very hot summers reaching up to 30 °C in June and July.
- Most of the year remains warm to hot, especially from March to September, where temperatures stay above 21 °C.
- The hottest months are June and July, while January and December are the coolest [2].
- Overall, Tikapur has a warm tropical climate with long hot periods and short mild winters.

1.2. Materials used

Compressed Earthen Blocks (CEB): Compressed Earthen Blocks (CEB/CSEB) are eco-friendly building materials made by compacting a mixture of soil, sand, stabilizers, and water in a mechanical press. The primary ingredient is sandy soil, containing the right balance of sand, silt, and clay for strength. Sand improves stability and reduces cracking, while stabilizers such as cement (5–10%), lime, fly ash, or GGBS increase durability and water resistance, making blocks suitable for G+2 structures. A small amount of clean water binds the mix during compression. Optional natural fibers like coir or sisal may be added for extra tensile strength and crack control.

- **Cool rooftop tiles:** Cool roof tiles are special roofing materials designed to reflect more sunlight and absorb less heat than traditional tiles. Made using high-reflective coatings or light-colored ceramics, lower roof temperature, reduce indoor heat gain, and decrease the need for air-conditioning. These tiles improve comfort, save energy, and help reduce the urban heat-island effect.
- **Terrazzo:** Terrazzo is a durable, eco-friendly flooring material made from a mix of marble chips, quartz, granite, glass pieces, or other recycled aggregates bound together with cement or epoxy resin. After curing, the surface is polished to a smooth, glossy finish. Terrazzo is long-lasting, low-maintenance, and ideal for sustainable building applications.
- **Double-glazing Low-E glass:** Double-glazing Low-E glass consists of two glass panes separated by an air or gas-filled gap, coated with a low-emissivity (Low-E) layer that reflects heat while allowing light to pass through. This reduces heat transfer, improves insulation, lowers energy consumption for cooling or heating, and enhances indoor comfort in modern buildings.

1.3. Simulation Tools:

- Revit for 3D model preparation.
- AutoCAD for final 2D documentation.
- Design Builder (Energy Plus) for energy simulation [3].

2. Methodology

The research objective is to prepare a detail methodology for simulation and design of Simulation based study on nearly zero energy building design and the process is as below Shown in Figure 1,

Figure 1 Lifecycle of Sustainable Green Building Development

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Page No: 3442 - 3446

- Conduct site assessment to analysed soil, climate, sun path, and wind for sustainable planning.
- Use low-carbon construction materials like earthen blocks, recycled steel, terrazzo, and Low-E double-glazed glass.
- Apply passive design techniques such as natural ventilation, daylighting, and thermal insulation.
- Install renewable energy systems, especially a solar PV setup with batteries or hybrid inverter for full energy independence.
- Adopt eco-friendly construction practices like minimizing waste, reusing materials, and reducing water usage during construction.
- Ensure energy-efficient operation by using LED appliances, waste reduction practices, and continuous monitoring of carbon footprint [4].

2.1.AutoCAD 2D

The typical building plan is prepared and the same has been drawn using AutoCAD Software shown below Shown in Figure 2 - 4.

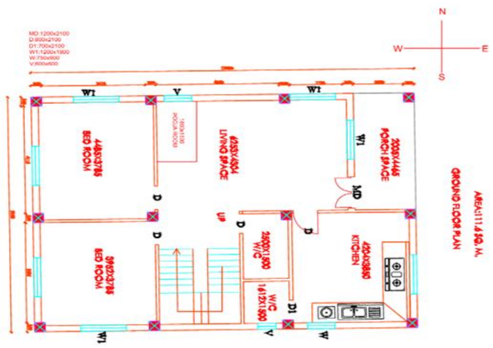

Figure 2 Ground Floor

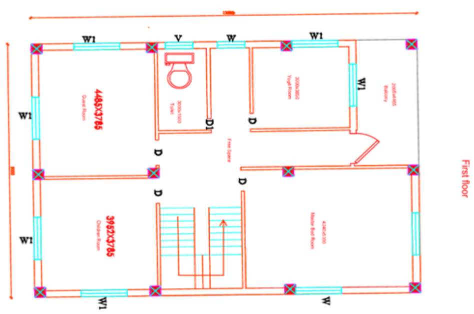

Figure 3 First Floor

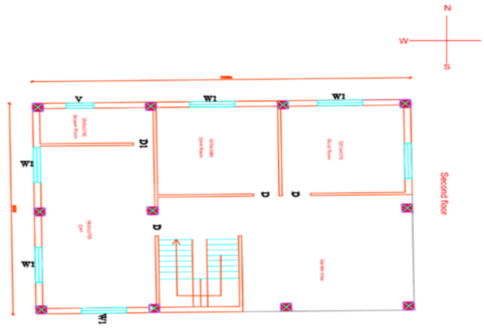

Figure 4 Second Floor

2.2.REVIT 3D Modelling

3D Perspective models are prepared using the Autodesk Revit [5]. Materials are individually added with the data required for energy analysis. Location data assumed orientation details are all clearly specified. Fig 2.6 shows a 3D perspective view of the building Shown in Figure 5 and 6.

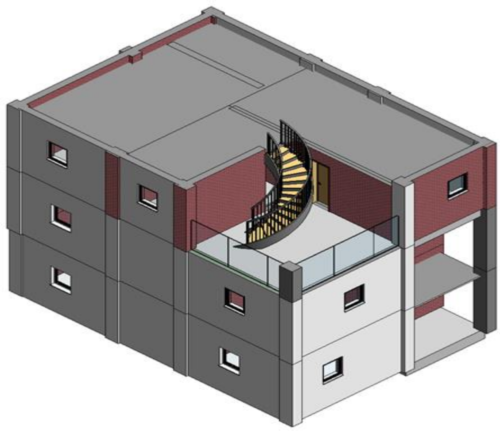

Figure 5 Revit Work 3D Design

Figure 6 Front Face

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2.3.Design Builder

Design Builder is a building simulation software used to analyze energy performance, daylight, HVAC, and carbon emissions. It helps create 3D models, run thermal simulations, estimate solar gains, and optimize building design. Engineers use it to improve efficiency, reduce energy consumption, and choose sustainable materials and systems for better building performance Shown in Figure 7 and 8.

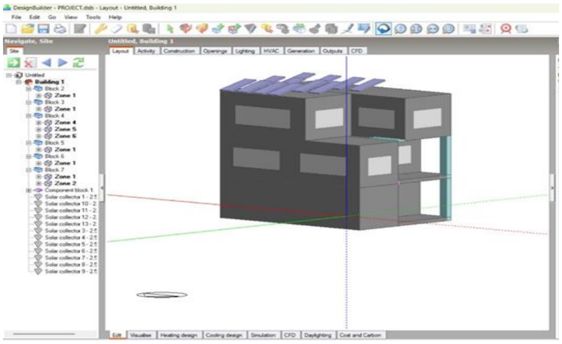

Figure 7 Design Builder Software

Appliance	Power (W)	Realistic Daily Use (kWh)
LED Bulb (10 units)	10 W each	0.60 kWh
Ceiling Fans (8 units)	65 W each	3.20 kWh
Television (1 unit)	100 W	0.60 kWh
Laptops (2 units)	60 W each	0.80 kWh
WiFi Router	12 W	0.07 kWh
Refrigerator (runs in cycles)	150 W avg	1.10 kWh
Water Pump (750 W)	750 W	0.60 kWh
Washing Machine	500 W	0.40 kWh
Rice Cooker	700 W	0.35 kWh
Induction Cooker	2000 W	1.20 kWh
Electric Kettle	1500 W	0.20 kWh
CCTV System	50 W	0.30 kWh
Air Conditioners (2 units, 1.5 ton)	1600 W each	20.00 kWh

Figure 8 Total Realistic Daily Energy Consumption: 29.42 kWh/day

2.4.Design of panel and battery

Peak Sun Hours (Charge Hours): 6 hours.
Individual Solar Panel Wattage: 550 W.

Total Array Wattage

$$=\frac{Daily\ wh\ required \times reserve\ factor}{charge\ hour}$$

$$=\frac{29.15\times1.26}{6}=\mathbf{6.121\ Kwh}$$

Total Watt/550Watt solar pane= $\frac{6121W}{550W}$

$$=\mathbf{11.13\ no.'s}$$

Provide 12 No - 550 W panels.

2.5.Number of Batteries

This calculates the total Ah required to store the daily energy and determines the number of batteries.

- **Panel Current Output (from example):** 550 W panels produce 13 Amps per hour.

Total Charging Current: 12 No.'s×13 Amp=156A
Total Daily Amp-hour Generation (for 6 hours): 156A×6 hour=936Ah

- **Assumed Battery:** 208 Ah batteries.

Maximum Depth of Discharge (DOD): 50%
Usable Ah per Battery: (208Ah×50%) = 104 Ah
Now

$$\textbf{No of batteries} = \frac{Total\ Daily\ Ah\ requirement}{usable\ Ah\ per\ day}$$

$$=\frac{936}{104} = 9\ \text{no's}$$

9 batteries of 208 Ah are required

3. Result and Discussion

3.1.Results

The simulation-based design of the Nearly Zero Energy Building (NZEB) successfully demonstrated a significant reduction in overall energy demand through optimized passive and active strategies. Using Design Builder (Energy Plus), the building's orientation, material selection such as CEB blocks, Low-E double-glazed windows, cool roof tiles, and terrazzo flooring showed improved thermal performance. Renewable energy integration with a 12-panel (550 W each) solar PV system provides sufficient energy generation to meet daily electrical requirements of approximately 6.121 Kwh, supporting near-zero operational consumption [6].

3.2.Discussion

The results highlight that simulation tools are essential in evaluating multiple design scenarios and identifying the most energy-efficient combination. Passive features such as shading devices, proper orientation, natural ventilation, and insulation contributed to reducing heating and cooling loads. The choice of materials—Compressed Earthen Blocks (CEB), Low-E glass, and cool roof tiles—further enhanced thermal comfort and minimized heat transfer. Active strategies, including solar PV installation and energy-efficient appliances, reduce dependency on grid electricity. The detailed 3D modeling in Revit and 2D plans in AutoCAD ensured accurate building geometry for energy simulation. Design builders enabled precise assessment of daylighting, HVAC loads, and energy consumption, which helped refine

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Page No: 3442 - 3446

the design iteratively. Overall, integrating passive design, efficient materials, and renewable systems proved crucial in meeting NZEB performance goals.

Conclusions

The study concludes that a simulation-based design approach is highly effective for developing Nearly Zero Energy Buildings. By combining optimized passive architecture, sustainable materials, and renewable energy technologies, the building model achieved low energy consumption and near-self-sufficiency. The integration of solar photovoltaic systems further enhanced sustainability by offsetting most operational energy needs. This approach demonstrates a practical and environmentally responsible framework for future residential and institutional building projects, contributing significantly to long-term energy efficiency and carbon emission reduction.

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