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"NET ZERO CARBON EMISSION BUILDING– A PROJECT ON SUSTAINABLE BUILDING DESIGN"01

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ABSTRACT:

The ECO–SERA project focuses on designing a Net Zero Energy Building (NZEB) tailored for the composite climate of New Raipur, India. An NZEB is a building that generates as much energy on-site through renewable sources as it consumes over the course of a year, significantly reducing its environmental impact (Reeder, 2010; Shukla & Garg, 2013). The project integrates passive design elements like orientation, shading, and natural ventilation with active systems such as solar panels, energy-efficient HVAC, and smart appliances (Vineet, 2019; Jain & Kumar, 2020)8. The design was developed using SketchUp and rendered with Lumion to visualize architectural and energy efficiency features (SketchUp, 2025; Lumion, 2025)9.

Performance evaluations included simulations for daylighting, thermal comfort, and energy consumption (Shukla & Garg, 2013). The study is supported by in-depth case study of the Bhawar Residence in Chennai and the Karuna House in Oregon, which provided valuable strategies for climate responsiveness and advanced sustainability (Gera, 2022). ECO–SERA also incorporates smart NZEB gadgets for real-time energy tracking, piezometric tiles for kinetic energy harvesting, and sustainable water and waste management solutions (Garg & Maheshwari, 2021). Locally sourced, eco-friendly materials enhance its environmental performance (Anink et al., 2004). The project presents a replicable model for future NZEBs in developing regions, aligned with India's energy and climate goals (MNRE, 2025; BEE, 2025)10.

Keywords: Net Zero Energy Building (NZEB), ECO–SERA, energy simulation, passive design, active systems, composite climate, SketchUp, Lumion, smart gadgets, piezometric tiles, renewable energy, case studies, sustainable materials, energy efficiency, India.

Introduction

As the global climate crisis accelerates, the need for energy-efficient and environmentally conscious architecture has become more pressing than ever (IEA, 2021)1. Buildings consume nearly 40% of the world's total energy and are responsible for a significant portion of carbon emissions (USDOE, 2025)2. NZEBs present a forward-thinking solution by aiming to balance energy consumption with on-site renewable energy generation (Reeder, 2010).

This research paper presents ECO–SERA, a Net Zero Energy Building designed specifically for the composite climate of New Raipur, India. The project integrates both passive and active design strategies (Krishan & Szokolay, 2012; Vineet, 2019) to reduce energy demand while utilizing renewable energy systems such as rooftop solar panels (Saini & Rathi, 2021). The design emphasizes the use of sustainable, locally sourced materials including bamboo flooring, lime plaster, AAC blocks, and piezometric tiles (Anink et al., 2004).

SketchUp was used for 3D modeling and Lumion for high-quality simulations and walkthroughs (SketchUp, 2025; Lumion, 2025)3. Further, a combination of climate-responsive architecture, smart gadgets, and efficient water and waste management systems ensures that the building maintains its net-zero performance throughout the year (Jain & Kumar, 2020; Garg & Maheshwari, 2021).

Methodology

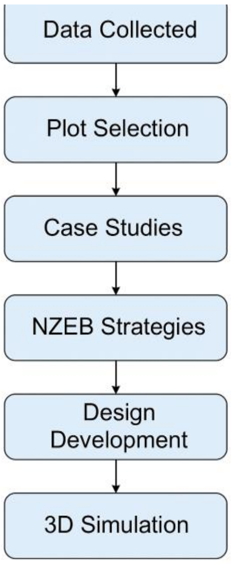

Fig 1Flow chart of the project

This research adopts a comprehensive and interdisciplinary approach to design and evaluate ECO–SERA, combining architectural design, climatic analysis, passive and active strategies, and software simulations (Krishan & Szokolay, 2012; Shukla & Garg, 2013).

2.1 Site Selection and Climate Analysis

New Raipur's composite climate was studied using long-term meteorological data. Software tools like Climate Consultant and DesignBuilder (EnergyPlus, 2025) were employed to assess temperature profiles, humidity levels, solar radiation, and wind patterns. This data informed decisions about building massing, window-to-wall ratios, and passive cooling strategies (Shukla & Garg, 2013).

2.2 Case Study Analysis

To benchmark best practices, case studies of the Bhawar Residence in Chennai and the Karuna House in Oregon were conducted. The Bhawar Residence, a climate-responsive home, provided insights into traditional yet modern sustainable design for hot climates, while Karuna House illustrated how net-zero performance can be achieved in cold climates through airtight construction, triple-glazing, and geothermal systems (Gera, 2022).

2.3 Conceptual and Architectural Design

SketchUp was used for architectural modeling, allowing for quick iterations and precise geometrical detailing (SketchUp, 2025). Lumion enabled the rendering of photorealistic walkthroughs to analyze daylight penetration, façade treatments, and landscape integration (Lumion).

2.4 Passive and Active Strategy Integration

The passive design included thermal massing, orientation, insulated roofs, solar chimneys, shading louvers, and green terraces. Active systems integrated a 6 kW rooftop solar PV array, inverter-based air conditioning, and LED lighting with motion sensors (Vineet, 2019; Saini & Rathi, 2021).

2.5 Smart Technology Deployment

The project included custom-built smart NZEB gadgets that used sensors and Wi-Fi modules to track energy usage, CO_2 levels, and thermal comfort in real time. Piezometric tiles were used to harvest kinetic energy from foot traffic in corridors and public spaces (Garg & Maheshwari, 2021; Jain & Kumar, 2020)3.

2.6 Water and Waste Management

Rainwater harvesting, low-flow fixtures, and greywater recycling systems were incorporated. Composting units and waste segregation strategies minimized landfill waste (Anink et al., 2004)[4].

2.7 Simulation, Validation, and Policy Compliance

Final simulations validated the design against MNRE's net-zero criteria and BEE's Energy Conservation Building Code (ECBC). GRIHA criteria were also used to assess indoor environmental quality and resource efficiency (MNRE, 2025; BEE, 2025; IGBC, 2025)[5].

Comparison between Traditional Building and Net Zero Energy Building

Feature	Traditional Building	Net Zero Energy Building (NZEB)
Energy Consumption	High energy consumption due to inefficient systems	Highly efficient; designed to reduce energy consumption
Energy Source	Primarily uses non-renewable grid electricity.	mostly powered by locally available renewable energy, such as solar.
Carbon Footprint	High carbon emissions	Minimal to zero carbon footprint
Design Approach	Emphasizes affordability and ease of use.	Prioritizes user comfort, efficiency, and sustainability.
Building Envelope	Often lacks insulation and passive design	Insulated envelope; optimized orientation for daylight and ventilation
SmartTechnology Integration	Minimal or none	Equipped with smart meters, sensors, and energy management systems
Initial Cost	Less money up front .	Slightly higher as a result of renewable installations and sophisticated systems.
Operational Cost	High energy bills and maintenance costs	Very low or no energy bills; low maintenance
Material Selection	Conventional materials with higher embodied energy	Locally sourced, sustainable, and low-carbon materials
Water Management	Limited water-saving capabilities	Comprises low-flow fixtures, greywater recycling, and rainwater collection.
Waste Management	Not alwaysintegrated	Integrated solid and liquid waste management systems
Thermal Comfort	Often inconsistent; depends on mechanical cooling	Achieves comfort through passive and active strategies
Regulatory Compliance	Follows basic building codes	Aligns with green certification standards (e.g., GRIHA, IGBC, BEE)
Adaptability	Less adaptable to changing climate conditions	Designed for climate responsiveness and long-term sustainability
User Engagement	minimal engagement with the building's systems	encourages energy-conscious behavior and proactive user monitoring.

Table 1- Comparison between traditional and NZEB7

Flow Chart of Working Process

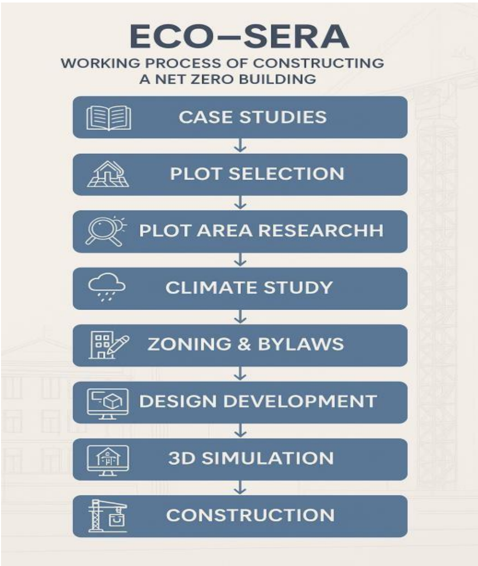

Fig 2- Flow chart of working process5

Fig 3 – 3D simulation of ECOSERA9

Fig 4 – Rooftop of ECOSERA1

Results

The Simulation results states that the building maintains a Daylight Factor (DF) of over 2% in 85% of occupied spaces, reducing the need for artificial lighting during daytime (Shukla & Garg, 2013). Thermal comfort was achieved using a combination of natural ventilation and evaporative cooling systems, supported by high thermal mass walls.

The 6 kW rooftop PV system generates an estimated 13,000 kWh/year, exceeding the building's projected annual energy demand of 12,500 kWh, achieving positive net energy performance (Saini & Rathi, 2021). Smart gadgets contributes to 10–12% behavioral energy savings by alerting occupants about peak load times and promoting energy-conscious behavior in the building (Garg & Maheshwari, 2021).

Materials like AAC blocks &lime plaster helped reduce embodied energy by 25% compared to conventional RCC construction. Additionally, water conservation strategies led to an estimated 40% reduction in potable water usage.

Conclusion (Key Points)

- The ECO–SERA project demonstrates how integrated design, passive and active strategies, and renewable technologies can enable buildings to achieve Net Zero Energy status in composite climates (Reeder, 2010; Krishan & Szokolay, 2012).
- Smart gadgets and kinetic energy harvesting technologies improve user engagement and optimize energy performance (Garg & Maheshwari, 2021; Jain & Kumar, 2020).
- Case studies informed region-specific and climate-resilient design decisions (Gera, 2022).

- Locally sourced sustainable materials helped reduce environmental impact (Anink et al., 2004)5.
- The project complies with national energy and sustainability frameworks such as MNRE, BEE, and GRIHA (MNRE, 2025; BEE, 2025; IGBC, 2025).6

ECO–SERA is a scalable and replicable model that offers a strategic roadmap for India's sustainable construction sector as it transitions toward energy independence and climate resilience.

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