Net Zero Energy Retrofitting Strategies for Low-Rise Row Housing: The Case of Nashik, India

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Abstract: The implementation of Net Zero Energy Buildings (NZEBs) is progressively vital for sustainable development, particularly in rapidly urbanizing regions such as Nashik, India. This study investigates how building performance simulation can support energy-efficient retrofitting of low-rise row housing to achieve net-zero or energy-positive outcomes. With Nashik experiencing significant urban growth and escalating energy demands, the research evaluates a range of retrofit strategies aimed at optimizing energy consumption and integrating renewable energy systems. Key interventions include passive design measures, high-performance insulation, energy-efficient appliances, and rooftop solar photovoltaic (PV) installations. Simulation results demonstrate that these integrated strategies can collectively reduce energy demand by approximately 47.68%, thereby enabling a transition to NZEBs. The findings highlight the potential for transforming existing housing stock into sustainable, self-sufficient units through a holistic retrofit approach. This research contributes to India's broader objectives of achieving carbon neutrality, ensuring energy security, and promoting resilient urban development.
***Keywords*:** net zero energy buildings, energy retrofit, low-rise housing, energy efficiency, Nashik, India.

1. Introduction

The escalation of global energy consumption has emerged as one of the most pressing challenges confronting contemporary society. This phenomenon is predominantly driven by the rapid expansion of the global population and the concurrent rise in living standards, as noted by the International Energy Agency (Prabhakar, 2025). These trends have intensified fluctuations in energy security and contributed to a series of adverse environmental impacts, particularly in terms of greenhouse gas emissions and climate change. The building industry is a significant contributor to this global issue, accounting for approximately 30% of primary energy consumption and 27% of CO_2 emissions in 2021, according to the International Energy Agency (Santamouriset et al., 2021). These statistics underscore the urgent need for systemic interventions to reduce the energy demand associated with residential and non-residential buildings. Along with retrofitting existing structures, various solutions have been proposed to address this challenge, ranging from the design and construction of new energy-efficient buildings. Given that new buildings characteristically account for less than 5% of the total building stock annually (Li et al., 2022), retrofitting existing buildings presents a practical and cost-effective strategy for significantly reducing total household energy consumption.

Energy retrofitting involves improving building performance by reducing heating and cooling loads, domestic hot water demands, and electricity consumption from electrical appliances (Mukhtar et al., 2021). A study by Kamal et al. have shown reduction in energy consumption through building envelope retrofitting strategies for hospital builsings in India (Kamal et al., 2025). Madadizadehet et al. (2024) highlights energy-saving retrofits as a pivotal measure in the global effort to decarbonizes the built environment. Another study done by Ansari et al. has shown that energy efficiency can be achieved through retrofitting of building envelope in a hospital in Meerut, India (Ansari et al., 2025). Numerous studies have explored this domain. For instance, Hashempouret et al.(2020) emphasized the role of multi-criteria optimization in energy retrofitting, addressing both environmental and economic considerations. Similarly, (Pombo et al., 2016) identified common passive retrofit strategies, such as envelope insulation, window replacement, and air sealing, as highly effective. He et al. (2021) outlined the historic evolution of justifiable building renovation, noting a surge in green building practices since the establishment of the first green building council in 1993 and a marked intensification in scholarly publications since 2015. Additional regional analyses have demonstrated that retrofit strategies must often be tailored to national or local regulatory frameworks. Sesanaet et al. (2018) conducted a comparative study of building retrofits in Belgium, Germany, and France, revealing variations in performance metrics influenced by country-specific directives. Kheiri (2018) argued for the integration of economic and environmental objectives in optimizing building shapes and envelope designs. In contrast Hamid et al. (2018) found that energy considerations dominate retrofit strategies in temperate climates, particularly for multi-family residential buildings. A research has established that the retrofitting strtaegies in buildings as one of the parameters for the transformation of cities into smart cities (Bokhad et al., 2024)

The concept of Net Zero Energy Buildings (NZEBs) has garnered increasing attention, particularly regarding their integration into building retrofits (Harkousset al., 2018). NZEBs are designed to generate an amount of energy equivalent to their annual consumption, typically through a combination of energy efficiency measures and on-site renewable energy generation (Madutaet al., 2025). Importantly, achieving NZEB status does not necessitate complete energy autonomy, but instead requires an annual energy balance that accounts for temporal mismatches between generation and demand (Harkousset al., 2018). The European Union, through its Energy Performance of Buildings Directive (EPBD), has set ambitious long-term goals, aiming to realize NZEB targets by 2050 through comprehensive renovation strategies (D'Agostino et al., 2021).

Various retrofit strategies have been proposed to align existing buildings with NZEB standards. Aksamijaet al. (2020) demonstrated the viability of NZE retrofitting for commercial buildings by enhancing building envelopes and integrating renewable energy systems. Abdooset et al. (2025) evaluated NZE retrofits for educational buildings in Tehran, considering future climate scenarios and recommending double-glazed windows with argon filling and Rockwool insulation to achieve substantial energy savings in both current and projected climates. Mareiet et al. (2024) proposed installing bright windows and increasing wall thickness as measures to enhance thermal efficiency, yielding energy consumption reductions of up to 14.65%.

Further studies have reinforced the effectiveness of envelope and system upgrades. Kitsopoulouet et al. (2024) optimized retrofit solutions for a university building in Greece, emphasizing the importance of improved insulation and reflective coatings. Shin et al. (2019) reported a 37–50% energy savings in a retrofitted office building in Texas, primarily through high-efficiency HVAC systems and advanced insulation. A research on retrofitting strategies in buildings in open high rise residential areas of Delhi has shown reduction in urban heat island effect (Jain et. al., 2025). Other research has highlighted the benefits of double-glazed windows in tropical climates (Soumasundaram et al., 2020), wall insulation (D'Agostino et al., 2022), and double-skin façades with dynamic blinds (Kim et al., 2018), achieving energy savings between 17% and 52%. Among the various residential typologies, low-rise row housing plays a crucial role in Indian urban development, particularly in rapidly growing cities like Nashik. These housing developments, characterized by their compact form and repetitive design, offer an opportunity to implement energy-efficient strategies that can be scaled across similar contexts. However, the challenge lies in optimizing design approaches to achieve net-zero energy performance while maintaining cost-effectiveness and thermal well-being for occupants (Makhloufi et al., 2024).

In a rapidly growing urban center like Nashik, where traditional and modern residential buildings coexist, retrofitting is crucial for fostering a more sustainable and resilient urban environment. As cities worldwide face the dual challenges of rapid urbanization and climate change, retrofitting existing buildings to improve energy efficiency and sustainability has become a crucial strategy for reducing carbon footprints. With many older residential buildings constructed before modern energy standards, Nashik offers a unique opportunity for energy-saving enhancements and the integration of renewable energy technologies. This study investigates retrofitting strategies that could transform Nashik's residential buildings into energy-positive structures, generating more energy than they consume. Achieving Net Zero Energy Consumption Buildings (NZECBs) is generally more straightforward in the context of new construction, where site planning, orientation, and building geometry can be optimized from the outset. However, retrofitting existing buildings presents a viable and impactful pathway to net-zero performance, particularly in the residential sector (Albadry et al., 2017).

This study focuses on retrofitting low-rise residential buildings in Nashik, India, analyzing how various architectural and technological parameters—such as thermal insulation, high-performance building materials, passive design features, and solar photovoltaic (PV) systems—impact overall energy performance. By addressing both existing and future building stock, the research advocates a sustainable development strategy that enables energy-positive outcomes while preserving urban form and enhancing climate resilience. The findings serve to inform scalable retrofit models aligned with India's energy transition and net-zero carbon goals. Energy-positive buildings, also known as net-positive or zero-energy buildings, represent a transformative solution to some of our most pressing environmental challenges as shown in Figure 1. These cutting-edge structures are designed to produce more energy than they utilize, achieving a net-positive energy equilibrium over their entire operational life. The concept of energy-positive buildings emerged from the critical need to reduce greenhouse gas emissions and lessen reliance on non-renewable energy sources. In contrast, traditional buildings have long been significant contributors to excessive energy consumption and environmental damage. Energy-positive buildings offer a sustainable alternative, emphasizing energy efficiency and integrating renewable energy practices (Chen et al., 2024).

At the core of energy-positive structures is minimizing energy requirement through innovative design and construction techniques. These buildings reduce their reliance on active heating, cooling, and lighting systems by employing passive design strategies, including high-performance insulation, optimal building orientation, and natural ventilation. This results in notable energy savings and a reduced carbon footprint (Kumar et al., 2025). The advantage of energy-positive buildings expands beyond just energy efficiency. They help reduce fossil fuel dependence, lessen greenhouse gas emissions, and lessen the implications of climate change (Baniya et al., 2025). Moreover, these structures can reduce energy costs for users and generate revenue by selling excess energy, thereby contributing to energy resilience by providing a reliable power source during grid outages.

The shift toward energy-positive buildings marks a significant milestone in sustainable architecture (Kumar et al., 2025). These structures minimize environmental impact and actively contribute to ecological restoration. By integrating renewable energy practices, applying passive design principles, and fostering interdisciplinary collaboration, energy-positive buildings hold immense potential in advancing the goals of sustainable architecture. They play a crucial role in addressing the need to reduce greenhouse gas emissions and reliance on non-renewable energy sources, helping to create a more sustainable future for the built environment. Amid growing global concerns regarding climate change and environmental sustainability, the architectural and building sectors are under tremendous pressure to develop energy-efficient and environmentally responsible built environments. Addressing the high energy consumption of buildings has become imperative in mitigating the adverse impacts of conventional construction practices. This research aims to examine the integration of energy-efficient design principles into existing low-rise residential buildings as a strategic approach to achieving energy-positive outcomes. The central challenge lies in the immediate need to improve energy performance, lessen greenhouse gas emissions, and transition from traditional energy-intensive structures to energy-efficient, energy-generating residential buildings that promote environmental governance and long-term sustainability.

Despite growing interest in NZEB, a gap remains in research on how building simulation tools can effectively optimize design strategies for row housing in India's tropical hot and dry climate. Existing studies on NZEB primarily focus on commercial and high-rise buildings, with limited exploration of low-rise residential developments. Furthermore, traditional design approaches often overlook the potential of simulation-driven decision-making, resulting in suboptimal energy performance and higher operational costs (Chaturvedi et al., 2024). This study aims to fill this gap by examining how building simulation contributes to NZEB for low-rise row housing in a hot and dry climatic zone in Nashik, India. The specific research objectives are to examine the energy performance of conventional low-rise row housing in Nashik, identify key inefficiencies, and develop a simulation-based framework for designing NZEB-compliant row housing that can be adapted to similar climatic regions.

This paper argues that building a simulation is pivotal in achieving Net Zero Energy Buildings for low-rise row housing in Nashik, India. By integrating passive design strategies with renewable energy systems, energy simulation enables informed decision-making, leading to more sustainable and climate-responsive housing solutions. The study demonstrates that a simulation-based approach can serve as a replicable framework for NZEB design in similar climatic and urban contexts, contributing to India's sustainable development goals. The paper is organized as follows: The next section reviews the applicable literature on NZEB principles, energy simulation tools, and sustainable housing strategies. The following section outlines the research methodology, detailing the simulation tools and performance metrics used in the study. The key findings are highlighted in the next section. These include outcomes related to reducing energy requirement and integrating renewable energy. The following section explores the implications of the results in the detailed context of sustainable urban development. Finally, the last section concludes the paper by summing up key takeaways and providing suggestions for future research directions and policy implications.

2. Literature Review

The National Renewable Energy Laboratory (NREL) defines zero-energy buildings as those that generate as much energy as they utilize annually by integrating energy-efficient systems and renewable sources (Karim et al., 2022). The Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report and the United Nations Framework Convention on Climate Change (UNFCCC) Structured Expert Dialogue emphasized the concept of net-zero, which significantly influenced the development of Article 4 of the 2015 Paris Agreement (Joshi et al., 2023).

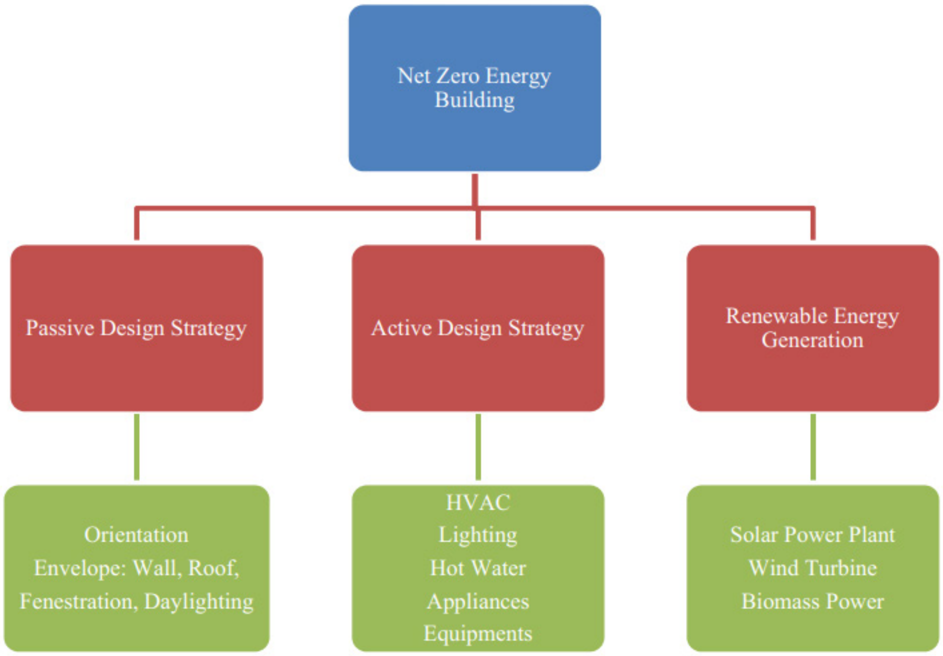

Figure 1. Net Zero Energy Building in India.

Due to the rapid development of the Net Zero Energy Building (NZEB) concept and the intensification of related research efforts, there is currently a lack of uniformity in key definitions and terminology. This inconsistency underscores the pressing need for a transparent and standardized conceptual framework. According to the Intergovernmental Panel on Climate Change (IPCC), the term net zero refers to the equilibrium between anthropogenic greenhouse gas (GHG) emissions and removals achieved over a specific time frame. In the reference of the built environment, this involves ensuring that the emissions generated by a building—such as a NZEB—are effectively neutralized through on-site or external mitigation measures (Noh et al., 2024). The historical development of Zero Energy Buildings (ZEBs) can be traced back to the energy crisis of the 1970s, which prompted initial efforts to conserve energy in buildings (Kim et al., 2018). However, the explicit goal of achieving a net-zero energy equilibrium has acquired considerable impetus in recent decades, driven by technological advancements in renewable energy (RE) systems and an increased focus on sustainable development within architectural practice (Lu et al., 2017).

Various terms are currently in use, including net-zero building, net-zero energy building, zero carbon building, and net-zero emissions building. These terms are sometimes used interchangeably, leading to confusion, particularly in the context of concepts like green buildings. While green buildings focus on minimizing the environmental impact during design, construction, and operation—addressing factors such as water use, indoor air quality, and material sustainability—a NZEB specifically targets energy performance. NZEBs aim to strike a balance between annual energy consumption and renewable energy generation, taking into account both on-site production and grid interactions (Economidou et al., 2020). Given the complexity of energy flows in the built environment, it is crucial that each country or region tailors the NZEB definition to its local energy infrastructure, resource availability, architectural traditions, and climatic conditions (Abdooset al., 2025). This localized approach ensures that NZEBs are both technically feasible and contextually appropriate. The building shell is crucial to energy efficiency in both new and retrofitted NZEBs. Key components—such as thermal insulation, glazing, building orientation, ventilation, and solar shading—are commonly addressed during retrofitting processes (Kim et al., 2024). Aruta et al.(2023) identifies retrofitting as one of the most crucial pathways to achieving global energy transition goals. Hashempour et al.(2020) analyzed multiple retrofit case studies, highlighting the value of multi-criteria decision-making models that assess both environmental and economic performance. The increasing body of empirical research demonstrates the tangible benefits of retrofitting existing buildings to meet Net Zero Energy (NZE) standards. These studies provide valuable data on energy consumption reductions and design interventions that optimize building performance. As urbanization accelerates across India, low-rise residential housing in Tier-2 cities, such as Nashik, is under increasing scrutiny for energy performance improvements. Given Nashik's hot, dry climate and high solar potential, NZEB-aligned retrofitting strategies are not only feasible but also essential to meet India's sustainability goals.

Ansari et al.(2023) Employed a Life Cycle Assessment (LCA) to assess the outcomes of retrofitting in tropical climates, demonstrating that envelope upgrades and efficient appliances yield the highest environmental benefits during the operational phase. These insights affirm the technical and environmental feasibility of large-scale retrofitting in Nashik. The Government of India is actively promoting NZEBs as part of its broader climate goals, including the commitment to attain net-zero emissions by 2070. The Bureau of Energy Efficiency (BEE), set up in 2002 under the Energy Conservation Act (ECA) of 2001, is responsible for promoting energy conservation and efficiency throughout India (Nainwal et al., 2025). One of BEE's key roles is to set energy performance standards and label appliances, ensuring that only energy-efficient products are available to consumers (de Ayala et al., 2022). BEE implements the Energy Conservation Building Code (ECBC) in the building sector, which sets the least energy efficiency benchmark for new commercial buildings (Saini et al., 2022). With the updated ECBC 2017, India aims to cut energy consumption in commercial buildings by up to 50% by 2030 (Saini et al., 2022). The Buildings Energy Efficiency Program (BEEP), launched in 2017, further supports this goal by targeting the retrofit of over 10,000 commercial buildings with modern energy-efficient systems and appliances by 2020.

The state governments can adapt the ECBC 2017 to reflect local climate conditions (Saini et al., 2022). Until 2018, ECBC guidelines applied solely to commercial buildings, with no formal framework for the residential sector (Nainwal et al., 2025). This changed with the introduction of the ECBC for residential buildings in 2018, known as Eco-Niwas Samhita (Ghosh et al., 2021), followed by the launch of a residential energy labeling system in 2019. Since then, multiple states have begun implementing these standards, emphasizing occupant thermal comfort and passive design approaches to improve energy efficiency (Citaristi, 2022). The Government of India has launched a range of policies. It aims to encourage the development of energy-efficient buildings, accelerate the adoption of renewable energy, and support the transition to net-zero energy buildings. Key national strategies include the National Mission for Enhanced Energy Efficiency stated Sambasivam and Sarma (2024), the Jawaharlal Nehru National Solar Mission mentioned Shrimali and Rohra (2012), the National Mission for Sustainable Habitat, and the National Mission for a Green India. Additionally, various states have introduced localized policies directed at addressing climate change and promoting sustainable construction practices.

A significant milestone was achieved in 2019 when India became the first country to implement the Indian Cooling Action Plan (ICAP), designed to reduce cooling demand and enhance energy efficiency in the cooling sector (Jeyasingh, 2025). By 2018, India's investments in solar energy exceeded its investments in nonrenewable sources, marking a significant shift toward clean energy (Dubey et al., 2023). Aligned with the Energy Conservation Building Code (ECBC) and green building rating systems such as LEED, the Indian Green Building Council, and the Green Rating for Integrated Habitat Assessment (GRIHA), India has so far developed many buildings that are either net-zero or nearly zero-energy, showcasing the country's progress in sustainable construction. The Government of India has established a robust policy framework to verify the adoption of Net Zero Energy Buildings, aligning with its climate commitments and fostering sustainable urban development.

3. Research Methodology

This study engages a structured methodological framework to investigate the role of building performance simulation in facilitating energy-efficient retrofitting of low-rise row housing, aiming to achieve net-zero or energy-positive outcomes. The research specifically focuses on the hot and dry climatic zone of India, assessing and optimizing retrofit strategies for existing residential typologies through simulation-driven analyses. The research began with a comprehensive review of existing literature to develop a robust conceptual framework for Net Zero Energy Buildings (NZEBs) and the associated retrofit strategies. This review aimed to elucidate the core principles, potential benefits, and inherent challenges related to energy-positive building designs. Furthermore, it sought to identify critical gaps in the current body of research, particularly in the context of residential building retrofits. To ensure consistency with national standards, the study analyzed the Energy Conservation Building Code (ECBC) 2017 and Eco Niwas Sanhita. This step provided essential benchmarks for energy-efficient design and informed the selection of performance parameters for simulation and evaluation.

A case study methodology was employed, focusing on existing row housing typologies in Nashik, India. This building was selected for its relevance to the context of affordable housing. Data was collected on:

Building geometry and orientation

Electricity consumption patterns

Occupancy schedules

Technical specifications of renewable energy systems.

This real-world data enabled a contextual understanding of the feasibility of Net Zero retrofits. Advanced energy simulation models were developed using Design-Builder software, integrating:

Climatic conditions (hot and dry zone)

Building envelope and material properties

Lighting systems
Occupancy and usage schedules
Renewable energy generation systems

The simulation was designed to assess energy demand, consumption, and savings under various retrofit scenarios. Simulation outputs were analyzed to estimate the effects of different Net Zero design parameters on energy performance. Key metrics included:

Total energy consumption (kWh/year)
Energy savings potential
Renewable energy contribution

The results were benchmarked against ECBC 2017 and Eco Niwas Samhita 2024 standards to evaluate compliance and effectiveness. A schematic representation of the research process, including data collection, simulation, and analysis phases, is provided in Figure 2.

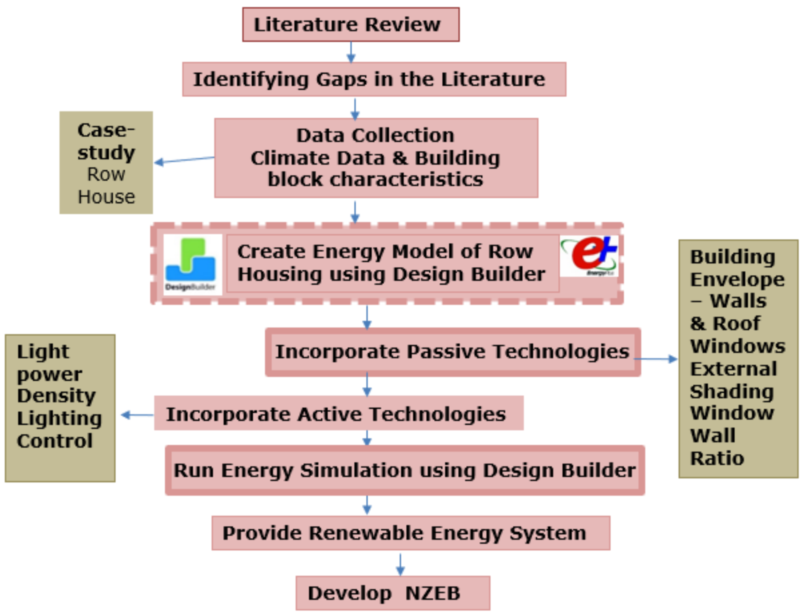

Figure 2. The Research Methodology Flow Chart.

3.1 Design parameters

Net-zero architecture embodies a forward-looking and integrative model of sustainable building design that transcends traditional environmental strategies by contributing to ecological regeneration and long-term sustainability. This architectural paradigm is fundamentally concerned with minimizing environmental impacts while enhancing energy efficiency, reducing carbon emissions, and promoting the health and welfare of building users as well as the broader ecosystem. Central to net-zero architecture is a suite of critical design parameters that aim to optimize energy performance and environmental responsiveness. Foremost among these is the building envelope, including roofs and external walls, which is engineered with high-performance, energy-efficient materials and advanced insulation techniques to reduce thermal transfer and overall energy demand.

Glazing systems are meticulously specified based on their thermal and optical characteristics—such as glass type, pane configuration, and solar heat gain coefficients—to optimize daylight penetration, reduce cooling loads, and maintain high indoor environmental quality. The Window-to-Wall Ratio (WWR) is deliberately optimized to strike a balance between natural daylighting and thermal performance, ensuring that energy savings do not compromise occupant comfort. External shading devices, such as overhangs, are integrated into the building façade to control solar radiation and support passive cooling strategies. These elements are particularly critical in climates with high solar exposure, where they contribute significantly to indoor thermal comfort and energy reduction. The lighting design incorporates low Lighting Power Density (LPD) fixtures alongside advanced control systems, such as occupancy sensors and daylight illumination mechanisms, to reduce artificial lighting demands and optimize energy use throughout the building's operational lifecycle.

A defining feature of net-zero design is the incorporation of renewable energy systems, particularly photovoltaic (PV) panels, which capture solar energy to meet or exceed the building's operational energy requirements. These systems are fundamental to achieving net-zero performance, as they enable on-site energy generation that offsets consumption and aligns with broader sustainability goals. The integration of these design strategies, as detailed in Table 1, enables buildings to transition beyond energy efficiency toward active environmental stewardship. Collectively, these parameters foster the development of resilient and sustainable built environments that contribute to local and global ecological well-being.

Table 1. Design Parameters

S. No.	Parameters	Net Zero Design
1	Parameter 1(P1)	Base Case
2	Parameter 2(P2)	Envelope properties (Roof Wall)
3	Parameter 3(P3)	Fenestration
4	Parameter 4(P4)	Window Wall Ratio
5	Parameter 5(P5)	External Shading
6	Parameter 6(P6)	Lighting Controls
7	Parameter 7(P7)	Light Power Density
8	Parameter 8(P8)	Photovoltaic panels on the Roof

Numerous studies have confirmed the accuracy and applicability of Design-Builder for energy modeling in buildings (Leng et al., 2020). While this study employs Design-Builder, several other simulation platforms are also commonly used within the field of building performance analysis (Nowak et al., 2013).

3.2 Criteria for Choosing the Design Builder Software

The Design-Builder is preferred over other energy simulation tools due to its seamless integration with Energy-Plus, a powerful and validated simulation engine known for its precision in modeling building energy performance. The Design-Builder streamlines the complex input structure of Energy-Plus by providing an intuitive graphical user interface (GUI), thereby minimizing the need for extensive coding and making energy modeling more accessible and user-friendly. The software offers a comprehensive platform for 3D modeling, daylight analysis, HVAC simulation, and evaluation of building envelope performance. A significant advantage of the Design-Builder approach lies in its capability to conduct detailed zone-by-zone energy analyses, which is particularly valuable for evaluating retrofit strategies with precision. Unlike tools like e-QUEST and Open-Studio, Design-Builder features a more intuitive, visually oriented, and streamlined workflow that significantly improves modeling efficiency and the overall user experience. Design-Builder enables the simulation of passive systems (such as insulation, glazing, and shading) and active systems (including lighting controls and Lighting power density), as well as renewable technologies. This functionality optimizes critical parameters, including the window-to-wall ratio (WWR), thermal insulation, and air tightness.

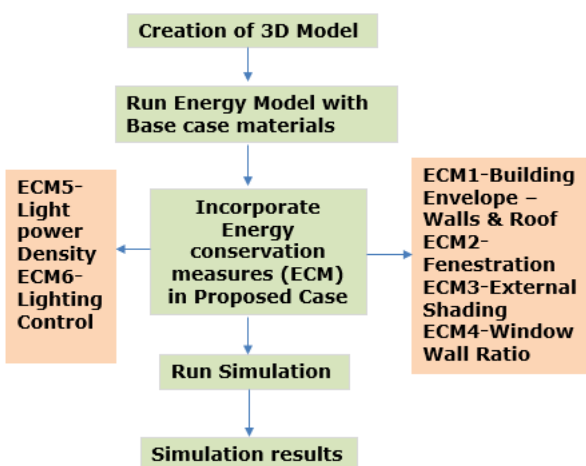

Figure 3. Energy Process Simulation Diagram

Beyond energy simulations, Design-Builder also provides performance metrics, cost analysis, and life cycle assessments (LCA), making it a comprehensive and valuable tool for informed decision-making in Net Zero Energy Building (NZEB) retrofits. It also facilitates compliance with international standards such as LEED, BREEAM, and ASHRAE. For this study, a one-year simulation was conducted using Design-Builder version 7.0, as illustrated in Figure 3, which explains the Energy simulation process diagram. The subsequent sections detail the input parameters used in the simulation. Refer to Table 2 for details of input parameters used in the simulation.

4. Case Study: The City of Nashik, India

The city of Nashik is situated in the northwest region of Maharashtra. It is located on the banks of the Godavari River, with Latitude coordinates ranging from 19° 58’59” N to 20° 04’30” N and Longitude coordinates from 73° 41’30” E to 73° 52’0” E. Nashik is Maharashtra’s fourth most populous city. This study focuses on a whole-building simulation approach for a row housing Typology (refer to Figure 4) constructed by the Maharashtra Housing and Area Development Authority (MHADA) under the Pradhan Mantri Awas Yojana in Nashik, which experiences a hot and dry climate.

Figure 4. Site Plan for Row Housing, Nashik, India.

The base case simulation model depicts a row housing configuration comprising eight residential units, each with a total area of 64 square meters distributed across the ground floor, first floor, and terrace as shown in Figure 5. The model provides a detailed representation of the building’s physical attributes, including its dimensions, spatial orientation, architectural form, and internal floor plan layout, as illustrated in Figure 6.

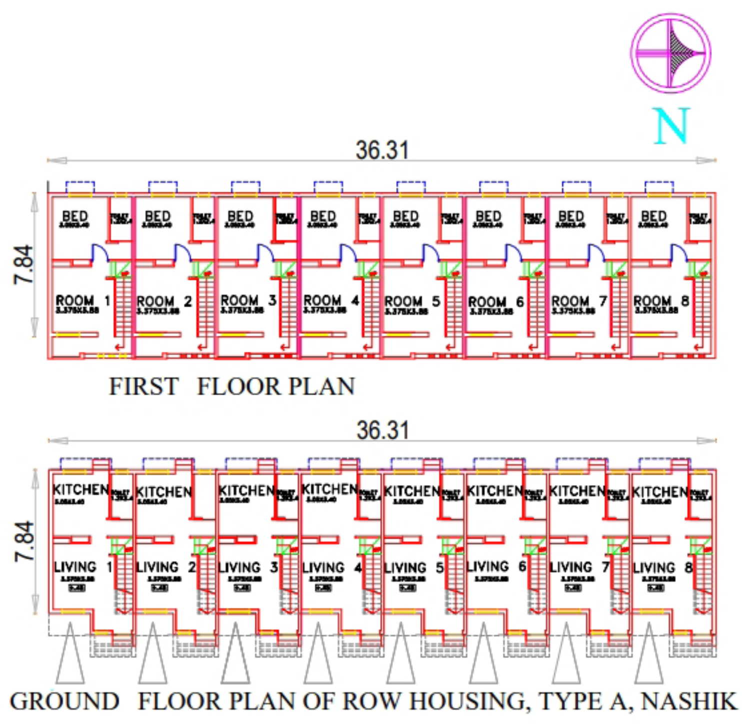

Figure 5. Ground Floor Plan of Row Housing at Nashik, India.

One of the initial steps involved collecting detailed information on the building's envelope components, including walls, roof, windows, and associated mechanical equipment. This data was subsequently entered into the Design-Builder software to conduct load analysis and assess the impact of various power-saving strategies. The primary input parameters included the building typology, geographic location, corresponding climatic data, overall building dimensions, specific measurements, and spatial orientation.

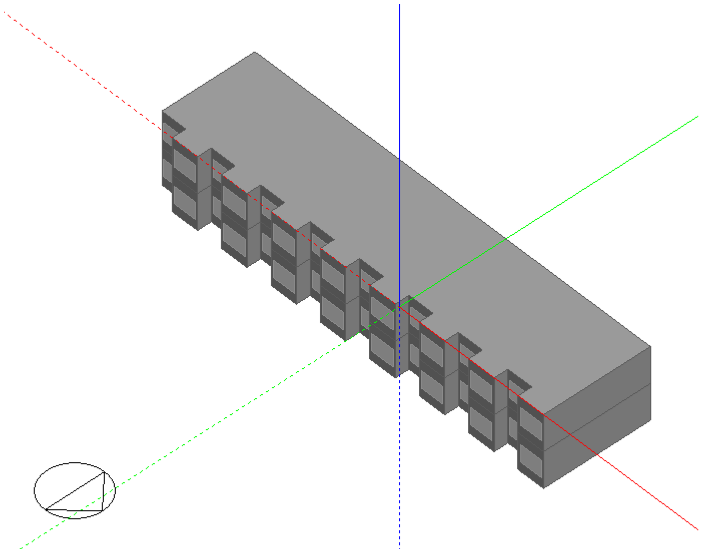

Figure 6. Simulation Model of Row Housing at Nashik, India.

4.1 Baseline Model

The baseline model's building envelope serves as the foundational framework for assessing energy performance. It encompasses the thermal and physical characteristics of key components, including exterior walls, roof assemblies, glazing systems, and fenestration details. These elements were defined by standard construction practices for row housing structures, aligned with regional climatic conditions, and in accordance with applicable code requirements. The envelope configuration was modeled to reflect typical material properties and construction assemblies, thereby establishing a benchmark for assessing the validity of subsequent energy efficiency interventions. The baseline model configuration represents a row housing typology comprising a ground floor, first floor, and terrace level. The construction features include externally finished fire-kiln brick walls, a reinforced cement concrete (R.C.C.) slab roof, single-glazed windows, internal partition walls made of brick, and a concrete ground slab. The building is oriented along the North-South axis, with a 0° deviation, ensuring alignment with cardinal directions. Refer to Table 3 for specifications related to the base case and Table 4 for the simulation model of Row Housing, Type A, MHADA, Nashik. Lighting systems within the model were configured using a predefined schedule, maintaining an illumination level of 300 lux. Additional input parameters, such as domestic occupancy schedules and appliance power consumption, were derived from the Design-Builder 7.0 object library. Furthermore, a standard natural ventilation rate of 0.5 air changes per hour (ACH) was adopted throughout the simulation, reflecting the intentional operation of window openings in accordance with recommended usage protocols.

Table 2. Details of input parameters used in the simulation

S. No.	Details	Description
1	Housing Typology	Row Housing (8 nos.)
2	Levels above ground	G+1
3	Location	Nashik
4	Area of each flat	64 sq. m
5	Total No. of tenements	8
6	Floor-to-Floor Height	3.0 M
7	Ventilation	Natural ventilation using operable windows
8	Lighting system	An incandescent lighting system provided

4.2 Energy Conservation Measures

This refers to strategic interventions implemented to improve the energy efficiency of a building while maintaining occupant comfort and functionality. In the context of this study, a range of ECMs were applied to the baseline simulation model to evaluate their effectiveness in reducing total energy consumption. These measures include:

Thermal Insulation Upgrade

Improving the thermal insulation of building envelopes is a crucial energy conservation measure that lessens heat transfer and improves indoor thermal comfort. In retrofit applications, insulation is typically applied to walls and roofs to minimize heat infiltration and loss, thereby reducing the building's dependence on mechanical heating and cooling systems. In this study, Expanded Polystyrene (EPS) insulation was employed as part of the retrofit strategy. An 80 mm thick EPS layer was applied to the external walls, while the roof was insulated with a 100 mm thick EPS layer. The selected insulation material possesses a thermal transmittance (U-value) of 0.038 W/m²K, indicating high resistance to heat flow. These modifications were incorporated into the simulation model to evaluate their effect on overall energy consumption and indoor thermal performance.

High-Performance Glazing:

Upgrading window systems to high-performance glazing is a key energy conservation strategy aimed at reducing unwanted heat gains and losses through fenestration. In this retrofit scenario, the original single-glazed windows were replaced with spectrally selective low-emissivity (low-E) double-glazed units. These advanced glazing systems feature a green-tinted coating designed to selectively filter solar radiation, thereby enhancing thermal performance while maintaining high visible light transmission. The double-glazed units incorporate an inert argon gas spacer between the panes, which further improves insulation by reducing convective heat transfer. Additionally, the windows are framed with un-plasticized polyvinyl chloride (uPVC), a material known for its low thermal conductivity and high durability. Together, these components significantly enhance the building envelope's thermal resistance, contributing to reduce energy demand for both heating and cooling in the simulation analysis.

Efficient Lighting Systems:

Incorporated LED lighting and optimized lighting schedules to achieve targeted illuminance levels with reduced energy input.

Natural Ventilation Optimization:

Enhancing airflow by modifying window operation schedules and opening areas to reduce dependence on mechanical cooling. The window-to-wall ratio was changed from 27% to 20%.

Solar Reflective Roofing:

Applying reflective coatings or materials to the roof surface to reduce solar heat gain.

Occupant Behavior Adjustment:

Modifying usage patterns of lighting and equipment systems to align with energy-saving best practices.

Use of Passive Design Strategies:

Implementing 0.5m external shading, daylighting, and thermal mass utilization to regulate indoor temperatures passively.

Solar rooftop photovoltaic panels

Following the retrofitting process, the building's residual energy demand will be met through the integration of rooftop solar photovoltaic (PV) modules. A grid-connected solar energy system will be deployed to facilitate on-site electricity generation. Surplus electricity generated beyond the building's consumption requirements will be exported to the utility grid, thereby enabling bidirectional energy flow. This configuration not only ensures that the facility fulfills its energy needs through renewable sources but also contributes to the broader power network. Additionally, the export of excess energy may qualify the building for net metering benefits or financial compensation, further enhancing the economic viability of the system. Overall, this strategy promotes the adoption of renewable energy technologies while simultaneously reducing operational energy expenditures. These ECMs were individually and collectively assessed using simulation outputs from Design-Builder to determine their impact on annual energy demand. The findings inform decision-making for retrofitting existing row housing buildings.

Table 3. Material description for base case with u Values

S. No.	Base Case Materials	Row Housing	U Value W/m^2.K
1	Building Envelope External Walls	Paint + 15mm External Cement Plaster + Fire burnt bricks + 15mm Internal Cement Plaster + paint	2.00
2	Windows	Single-glazed (0.006) clear glass with Aluminum frame	5.778
3	WWR	27 %	
4	Roof Slab	Finishing Tiles + Concrete laid to slope (min. 50mm) + waterproofing (bitumen)+ 125mm R.C.C Slab + 15mm cement plaster + paint	2.534

Table 4. Material description for the Proposed case with U-values.

S. No.	Proposed Materials	Row Housing	U Value W/m^2. K
1	Building Envelope: External Walls	External Reflective paint + 15mm thick. Gypsum Plaster + 80mm XPS Extruded Polystyrene Insulation + 200mm thick. AAC Block + 12mm thick. Gypsum Plaster + Internal paint.	0.22
2	Fenestrations/ Windows	Spectrally selective low-e with green tint double-glazed, with argon spacer + with UPVC frame	1.338
3	Window-to-wall ratio	20 %	
4	Roof Slab	Clay Roofing Tiles + 50mm concrete screed +. XPS Expanded Polystyrene 100mm+ Bitumen + 150mm Aerated Concrete slab +12mm Gypsum plaster + paint	0.20
5	Shading	0.5 M overhang	

4.3. Simulation Results

The simulation outcomes derived from the application of energy-saving strategies to row housing typologies demonstrate significant improvements in energy performance. By incorporating a combination of passive and active energy conservation measures, including enhanced thermal insulation, optimized natural ventilation, LED lighting, and rooftop photovoltaic integration, noticeable decreases in total energy usage and peak requirement were observed. Comparative analyses between the pre- and post-intervention models indicate a substantial decrease in annual energy usage, accompanied by corresponding reductions in greenhouse gas emissions and operational costs. These findings validate the technical feasibility and environmental benefits of retrofitting energy-efficient systems in row housing developments, supporting broader objectives of sustainable urban residential planning.

Table 5. Energy utilization for the base case and the proposed case

	Area	Energy consumption	
		Base case	Proposed case
1	Total Energy (kWh)	37636.36	25228.43
2	Energy per Total Building Area (kWh/m^2)	61.96	41.53

5. Results and Discussion

5.1 Energy Performance of Design Interventions

This study assesses the cumulative and individual effects of various architectural and technological design interventions on the energy performance of residential row housing (G+1) in Nashik, India. Using a standardized Base Case (BC) as a reference model—characterized by average building envelope properties and conventional energy usage profiles—the research systematically introduced Net Zero Energy Building (NZEB) strategies to measure a decrease in energy utilization and improvements in the Energy Performance Index (EPI), expressed in kWh/m²/year.

5.2 Sequential Integration of Design Parameter

The design parameters evaluated included enhancements to the building envelope, improved glazing and window-to-wall ratios (WWR), the application of external shading devices, a reduction in lighting power density (LPD), the implementation of advanced lighting controls, and finally, the integration of a rooftop photovoltaic (PV) system. Table 6 summarizes the progressive reduction in energy consumption with each intervention.

Table 6. Design Parameters and Energy Consumption

Parameters	Building Description	Design Parameters	Energy Consumption (KWH)
P1	Row Housing	Base Case	61.96
P2	Row Housing	Building Envelope Properties (Roof + Wall)	60.19
P3	Row Housing	Building Envelope Properties + Glass	55.72
P4	Row Housing	Building Envelope Properties + Glass + W.W.R @20%	54.04
P5	Row Housing	Building Envelope Properties + Glass + W.W.R + External Shading (0.5 m Overhang)	52.99
P6	Row Housing	Building Envelope Properties + Glass + W.W.R + External Shading + Lighting Control	45.43
P7	Row Housing	Building Envelope Properties + Glass + W.W.R + External Shading + Lighting Control +L.P.D	41.53
P8	Row Housing	Building Envelope Properties + Glass + W.W.R + External Shading + Lighting Control + L.P.D + P.V- Roof	0

5.3 Renewable Energy Integration Strategies

A photovoltaic (PV) system is installed to generate electricity, reducing reliance on conventional grid power. The building is strategically oriented to maximize solar exposure, optimizing renewable energy capture. The unobstructed terrace is ideal for solar panel installation, ensuring maximum energy efficiency throughout the year. For detailed technical specifications of each measure, refer to Table 2. Solar Panel Design Specifications: Orientation: Panels will be installed facing south, which is the optimal direction for solar gain in the Northern Hemisphere. Refer to Table 7 for Details on Solar Panel Specifications.

Panel Type: Mono bifacial photovoltaic panels have been selected due to their high efficiency and ability to capture reflected sunlight from both sides—an advantage under Indian climatic conditions. This system is designed to reduce the building's dependency on standard electricity sources and contribute to its Net Zero Energy goals.

Table 7. Details of the solar panels

S. No.	Details	Case Study
1	The panels' inclination angle	19 degrees.
2	Type of panels	mono bi-facial
3	Power Generation per panel	288 watts/ hour
4	Generation time	6 am to 6 pm
5	Peak generation time	9 am to 4 pm
6	The daily average energy requirement of a building	4 kWh
7	The maximum energy requirement of the building	5 kWh
8	Number of solar panels needed to satisfy the maximum energy demand	24 solar panels

Table 8. Details showing the total capacity of PV panels

S. No.	Details	Value
1	Annual energy needed	25,228.43 kWh
2	Average Solar Irradiance (Nashik)	5.5kWh/m²/day of solar insolation
3	Solar generation per kW/year (Nashik)	2,007.5 kWh
4	Total capacity required	12.57 kW
5	Panel capacity used	540W
	Total panels needed	24 panels

The energy performance of the building was evaluated through a series of incremental design enhancements, with the Energy Performance Index (EPI) serving as the primary metric for comparison. The Base Case exhibited an EPI of 61.96 kWh/m²/year, which is indicative of typical construction and mechanical system standards, as mentioned in Table 5. The first stage of improvement involved upgrading the building envelope properties (roof and wall insulation), which resulted in a noticeable reduction of the EPI to 60.19 kWh/m²/year. Subsequent enhancement of glazing properties further reduced the EPI to 55.72 kWh/m²/year, highlighting the significant role of window performance in thermal energy gains and losses.

When the Window-to-Wall Ratio (WWR) was optimized to 20%, the EPI decreased further to 54.04 kWh/m²/year. The addition of external solar shading devices (0.5 m overhangs) contributed to a modest yet meaningful reduction, lowering the EPI to 52.99 kWh/m²/year. A more substantial performance improvement was observed upon the introduction of advanced lighting controls, which brought the EPI down to 45.43 kWh/m²/year. Incorporating lighting power density (LPD) optimization in conjunction with the controls led to a further decrease, reaching 41.54 kWh/m²/year. Finally, the integration of a 13-kW rooftop photovoltaic (PV) system enabled the building to accomplish net-zero energy status, effectively reducing the EPI to 0 kWh/m²/year. This final step underscores the transformative potential of combining passive design strategies with active renewable energy practices.

5.4 Building Envelope and Passive Design Improvements

Roof Insulation Strategy: Thermal performance enhancements began with modifications to the roof assembly. The revised composition included layers of 100 mm Extruded Polystyrene (XPS) insulation, 50 mm screed, 15 mm Gypsum Plaster, 150 mm aerated concrete slab, and 30 mm roofing clay tiles. These layers were selected to optimize thermal resistance and increase the building's overall thermal mass. XPS, known for its low thermal conductivity, played a pivotal role in reducing heat gain through the roof. High-performance glazing and WWR Optimization in Window systems were also optimized to minimize thermal losses and solar heat gains. The window assembly utilized:

Spectrally selective Double-glazed low-emissivity glass (6 mm thickness) with a green tint

Argon gas spacer (13 mm)

UPVC window frames

Adjustments to the Window-to-Wall Ratio (WWR), capped at 20%, ensured a balance between natural lighting and minimized solar heat gain, aligning with the Energy Conservation Building Code (ECBC) recommendations.

Integration of Renewable Energy Systems

The final intervention involved the deployment of a rooftop photovoltaic system to offset the remaining energy demand, as shown in Table VII. The system specifications included:

Installed capacity: 12.57 kW (24 panels × 560 W). Solar panel size: 2.28 m × 1.14 m (2.60 m² per panel). Solar generation per kW/year (Nashik) 2,007.5 kWh as indicated in Table VIII. Effective roof area utilization: ~45 m² (considering installation gaps and mounting structures). Total estimated annual energy generation from solar panels: 25,228.43 kWh/year. This configuration successfully met the building's energy requirements, enabling it to transition into a Net Zero Energy Building (NZEB).

6. Key Findings

The Results confirm that the combination of passive architectural strategies and active technological interventions can dramatically reduce operational energy consumption in residential mid-rise housing. The initial energy demand of 61.96 kWh/m²/year was reduced to zero with a well-designed package of envelope enhancements, lighting system optimizations, and renewable energy systems. Envelope improvements had a moderate but foundational impact. Lighting systems, both in terms of LPD reduction and intelligent control integration, offered the highest individual gains in efficiency. Photovoltaic deployment was essential to offset remaining loads, enabling NZEB compliance. The insights from this study emphasize the importance of a holistic, sequential approach to NZEB design for residential buildings in warm climates, such as Nashik, where passive cooling, daylighting control, and solar integration are vital.

6.1 Dynamic Façade and Smart Shading System

Future work should explore adaptive façade technologies, such as operable louvers or electro-chromic glazing, which respond in real-time to environmental conditions, further reducing cooling loads and enhancing occupant comfort. Daylighting and Occupancy-Based Control Strategies: Integrating daylighting sensors and occupant-based lighting controls can further reduce artificial lighting demand, particularly in commercial or mixed-use buildings.

6.2 Thermal Comfort and Indoor Environmental Quality (IEQ)

While energy reduction is critical, future design iterations should simultaneously evaluate thermal comfort, daylight autonomy, and indoor air quality to ensure holistic building performance. Performance Monitoring and Post-Occupancy Evaluation (POE): Real-world validation through smart metering and post-occupancy evaluations will be crucial to ensure that modeled performance aligns with actual building operation, enabling further calibration. Integration with Grid-Interactive

Efficient Buildings (GEB): Future iterations could consider how the building can participate in demand response programs or utilize battery systems to store surplus PV generation, thereby increasing grid resilience.

7. Conclusions

This study demonstrated the effectiveness of a sequential, performance-driven design approach in significantly improving building energy efficiency. Starting from a design base case EPI of 61.96 kWh/m²/year, each successive enhancement—ranging from enhanced envelope properties and optimized glazing to lighting strategies and renewable integration—yielded measurable energy savings. The combined effect of passive architectural measures and active system optimizations resulted in a final net-zero energy performance, with the EPI reaching 0 kWh/m²/year through the incorporation of a 13kW rooftop photovoltaic system. The results validate the importance of an integrative design methodology in building energy modeling, where even minor architectural decisions (e.g., window-to-wall ratio and shading devices) can collectively lead to substantial performance gains. Notably, lighting controls and LPD optimization emerged as high-impact measures in the latter stages of energy reduction, demonstrating the value of operational and system-level interventions in conjunction with the envelope.

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