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A Review-Zero Energy Building

VinayakPavate[1],Pranita More[2],Pratik Naik[3],Bhakati Galatage[4],Sakashi Khot[5]
[1]*Assistant Professor,* [2, 3,4,5]*Student, Departmentof CivilEngineering,SanjayGhodawatInstitute,Atigre,India*

Abstract: The concept of net zero energy building has attracted many attentions and controversies since it was put forward. Many scholars have analyzed its configuration, technology, modelling approach and feasibility of application. However, there are still few studies focus on the application of net zero buildings considering future energy development. Based on the current energy situation and the development trend of energy technology, this paper analyzed the technical feasibility of net zero energy building. The Indira ParyavaranBhawan it's indeed a remarkable example of sustainable architecture, being India's first net zero energy building. By incorporating green building features and minimizing its impact on the surrounding environment, this building serves as a model for environmentally responsible construction. The project's objective is to create a Net Zero Energy Building (NZEB) for The Ministry of Environment and Forest (MOEF) infrastructure expansion drives national progress. Construction activities, factories, and industries pollute the environment construction sector contributes 40% Of air pollution. co 2 emissions harm the ozone layer, causing global warming, Adopt green building construction, eco-friendly materials, Balancing infrastructure growth with environmental concerns is crucial. Sustainable practices, like green buildings and eco-friendly materials, offer a feasible solution to mitigate pollution and environmental harm infrastructure growth must balance development with Environmental conservation. The construction industry contributes significantly to environmental pollution (40% of air pollution). Cement and steel production are primary sources of Co2 emissions (8-10% and 510% respectively). Zero energy building offer a sustainable solution, minimizing environmental impacts and Promoting occupant health. The construction industry's environmental impact can be mitigated through sustainable practices, such as zero energy buildings, to balance development with environmental conservation it is reported that 30% to 40% of all the primary energy used worldwide is used in building. It is necessary to take steps to make the more environmentally sustainable. The Zero Energy Building uses natural energy sources to meet the energy requirements of the building. Now a day, the energy which is created produced 36% of co2 emission. The building consumes zero or very little energy and is built on renewable energy sources. We have carried out a studied in this work to analyse the performance of a zero-energy building, also studied the various parameters of ZEB and found such building is possible. In India it emphasis the integration of Building Information Modelling (BIM) energy analysis and practical construction method to optimize design for enhanced energy efficiency. Additionally, the study searching into combining local bio -based construction materials with PHOTHO VOLTAIC (PV) system for sustainable rural housing solution in developing nations ultimately, these covers the way towards a more sustainable and energy – efficient future by promoting innovative solutions and practices in building design and construction.

Keywords: Environment sustainable, Energy crisis, technical feasibility, Mitigate, resiliency, spectrum, multifaceted, environmental deterioration, subtropical climate, summation, re-acquaint, prototype.

I. INTRODUCTION

India's energy challenges, the need for sustainable building solutions, and the concept of Net Zero Energy Buildings (NZEBs). India faces significant energy challenges due to its growing population and economy. The country's primary energy supply needs to grow by 3-4 times, and electricity generation capacity by 5-6 times, compared to 2003-04. India currently faces an electricity shortage of 9.9% and a peak demand shortage of 16.6%. nZEBs are highly energy-efficient buildings that use renewable energy technology to produce the same amount of energy they consume over a year. NZEBs aim to reduce energy consumption, operating costs, and carbon footprint. Indira ParyavaranBhawan in New Delhi is India's first zero net energy building, featuring passive solar power generation and energy-efficient design. Energy-efficient architectural, structural, material, electrical, and air-conditioning design.Optimum building orientation for solar access and shading.Use of renewable energy technologies, such as solar power.Reduced energy consumption and carbon footprint. Zero energy building combine energy efficiency and renewable energy generation to consume only as much as energy can be produced on site through renewable resources. It is a combination of energy efficiency and renewable energy to produce as much energy as they use over the throughout year. By Creating their own renewable energy, zero energy buildings lower operating and maintenance cost helps environment and increases resiliency during power outages.

Global environment problems such as climate change, depletion of non – renewable energy sources, and lack of drinking water are the significant effects to the environment. The covid 19 pandemic, war, population growth and global energy demand contribute to an impending energy crisis. Therefore, Energy is the heart of the solution to the climate change.

The building and construction industry is a significant contributor to environmental deterioration responsible for considerable share of global energy consumption and carbon emissions. Building account for approximately 40 % of the world 's annual energy consumption,55% of electrical consumption. The building and construction sector contributes around 37% of total global CO2 emissions. It is predicated that the building energy demand will be increased by 32% by 2050 while global temperature will be increased by 1.5 degree Celsius. The Zero Energy Building concept strives to reduce energy consumption by improving energy efficiency within the building and construction sector. This promotes the use of sustainable and clean energy sources to fulfil energy demands which leads to reliance on fossil fuels. The main reason why the building and construction sector is considered one of the essential topics for achieving sustainable development Goals.

The Zero Energy Building (ZEB) concept which includes such as NZEB (Net zero energy building) it is a solution which reduce energy and mitigate CO2 emissions in construction sector. This improves the aspects of the building i.e from site selection to design, construction, operation and renovation .The multifaceted structure of the ZEB concept makes it challenging to conduct through examination, as it encompasses a vast spectrum of disciplines. A clear understanding of the characteristics and goals of a crucial. Thus, it is essential to have a clear grasp of the ZEB concept, which can be serving as a roadmap for designers to achieve this Goals.

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II. LITERATURE REVIEW

Mohammad Reza Bahrami et al (1) ZEBs are designed to consume approximately zero net energy annually by generating renewable energy on-site. They play a crucial role in reducing reliance on non-renewable resources like coal and contribute to sustainability and energy security. Different definitions exist, including Net Zero Energy Buildings (NZEBs) and Nearly Zero Energy Buildings, varying by region and policy frameworks. Various definitions and policies across different countries. The Methods to optimize building energy performance, Use of renewable energy sources, battery storage, and energy-efficient materials. The Economic feasibility and optimization strategies, How ZEBs interact with the energy grid to ensure stability. The ZEBs require significant initial investment, but policy incentives and economic models can encourage adoption. Some studies focus on carbon emissions rather than energy use to measure sustainability. Essential for load balancing and energy storage in ZEBs, particularly in regions with variable renewable energy generation. Energy management methodologies focus on maximizing self-consumption of renewable energy. The Countries like Germany and Australia promote self-consumption and grid interaction strategies. Microgrids allow buildings to operate independently or in coordination with the main grid. Smart grids improve energy distribution and efficiency, with new concepts like Zero Grid Impact Buildings (ZGIBs) emerging. Technologies like Semi-Transparent Photovoltaic (STPV) have been studied for their role in energy efficiency and lighting needs. Battery and thermal storage systems help regulate energy consumption effectively. Various studies discuss control strategies, such as Building Energy Management Systems (BEMS) and Technical Building Systems (TBS), to optimize energy use. ZEBs represent a promising solution for sustainable buildings, but their widespread adoption requires technological advancements, economic incentives, and policy support. Future research should focus on cost reduction, energy storage, and grid integration for enhanced feasibility.

Zalamea-León et al. (2) Building Energy Modelling (BEM) & Building Information Modelling (BIM): integrated BEM into BIM, allowing renewable energy simulations and a full Life Cycle Assessment (LCA) from construction to demolition. This section discusses analytical models and simulation methods used to optimize building designs for energy efficiency and sustainability. Grazieschi et al. studied how integrating renewable energy affects energy demand across a building's life cycle, identifying the optimal balance between operational and embodied energy.

Riel Miller et al. (3) studied structural design, comparing beam and slab, flat slab, and flat plate systems while evaluating conventional and post-tensioned (PT) construction methods. PT methods significantly reduced concrete volume, steel mass, and overall building weight, leading to material savings and lower embodied emissions. Similarly, Volf et al. assessed the environmental impact of curtain walls, developing a system using natural materials. Experimental testing confirmed that this system met technical standards and had the potential to reduce embodied environmental impact. Efficient structural and material design plays a crucial role in minimizing environmental burdens.

Daniela Besana et al. (4) studied the reuse and retrofitting of an abandoned office building in Milan to achieve net-zero carbon status. Using a Whole Life Carbon Assessment (WLCA), they evaluated retrofit strategies, materials, and carbon emissions. By incorporating bio-based materials and efficient design, embodied carbon was reduced by 91% compared to standard new construction.

Additionally, a life cycle assessment (LCA) of a net-zero energy building in India quantified emissions across construction, use, end-of-life, and recycling phases. This analysis aimed to distinguish between net-zero energy and net-zero carbon goals. Kristjansdottir et al. analyzed greenhouse gas (GHG) emissions and payback times of photovoltaic (PV) systems in Norwegian Zero Emission Pilot Buildings. Their study found that embodied emissions per square meter of PV modules ranged from 150 to 350 kg CO_2 EQ/m², with variations depending on mounting system materials. The research emphasized how system design choices significantly impact overall emissions and greenhouse gas emission payback times (GPBT).

Also he examined whether net-zero energy buildings (nZEBS) could balance operational and embodied emissions with on-site renewable energy. Their study found that while PV systems generated more energy than needed, embodied emissions—mainly from PV panels, external walls, and foundations—remained significant contributors to overall CO_2 emissions. Similarly, Kneifel et al. used a life-cycle assessment (LCA) to analyzecostoptimal energy efficiency. They discovered that achieving net-zero energy performance increased embodied emissions by over 40%, potentially offsetting operational energy savings. Cusenza et al. analyzed four design scenarios combining two insulation materials—extruded expanded polystyrene (XPS) and cellulose fibers (CF)— with two photovoltaic (PV) system configurations, with and without battery storage. Their study assessed energy needs, primary energy consumption, and environmental impacts.

Zhou et al. (5) examined the economic and energy viability of solar energy systems in a multi-story apartment, comparing Life Cycle Zero-Energy Buildings (LCZEBs)—which offset total lifetime energy use—with nZEBs, which balance energy through on-site renewables and grid interaction. Economic feasibility was evaluated using Net Present Value (NPV) and solar energy utilization. Tumminia et al. compared standalone PV systems with integrated designs that include batteries and fuel cells. They found that adding a 20kWh battery to a 4.56 kW PV system could reduce greenhouse gas emissions by 50.4%. Fuel cells improved load matching and efficiency but had higher CO_2 emissions. The study emphasized the importance of balancing storage capacity, system size, and fuel cell use for optimal energy performance. The studies discussed examine the economic and energy viability of different energy systems in buildings. Zhou et al. analyzed a solar energy system for multi-story apartments in a temperate climate, comparing Life Cycle Zero-Energy Buildings (LCZEBs) and nZEBs. LCZEBs offset all energy used over a building's lifespan, while nZEBs balance energy use with on-site renewables and grid interaction. Economic viability was assessed using Net Present Value (NPV) and solar energy utilization.

VinayakPavate et al. (6) it discusses sustainable construction practices that reduce environmental harm and encourage energy efficiency. Construction causes 40% of air pollution and CO2 emissions, which contribute to global warming. Green building practices can lessen this impact by utilizing eco-friendly and recycled materials. Key concepts include focusing on energy efficiency, water conservation, and waste reduction through methods like passive solar design, photovoltaic panels, green roofs, and sustainable landscaping. Biophilic design is also included to enhance the connection between humans and nature. Sustainable materials such as fly ash, hempcrete, and ashcrete are highlighted, along with technologies like energy-efficient windows, solar energy, and rainwater harvesting systems. However, there are challenges to adopting these practices, including a lack of awareness, high initial costs, the need for skilled labor, and complex approval processes for certifications like LEED. The case study of the ITC Green Centre shows successful green building practices, achieving 53% energy savings, rainwater harvesting, and solar energy use. In conclusion, green building is vital for sustainable development. It aims to create energy-efficient, cost-effective, and eco-friendly structures while enhancing human well-being.

Taherahmadi et al. (7) reviewed and synthesized definitions of net-zero energy buildings (nZEBs) to propose a comprehensive definition for standardizing communication among energy planners and policymakers. Torcellini et al. identified four main perspectives on nZEBs: The building produces as much energy on-site as it consumes annually. The building consumes as much energy as calculated from the energy source, including generation and delivery processes. The building's annual energy costs are neutral, with earnings from exporting energy balancing the cost of consumed energy. The building's renewable energy production offsets emissions from non-renewable energy sources. Li et al. proposed four scenarios of residential energy use in inner Melbourne to predict future energy consumption: high carbon, business-as-usual, accelerated policy, and net-zero emissions. The study identified effective strategies for reducing energy use, including improving building envelope efficiency, upgrading heating and hot water systems, and incorporating renewable energy. These strategies are aimed at supporting informed policy-making for energy conservation.

Loli et al. (8) (GHG Emissions Assessment) studied the embodied greenhouse gas (GHG) emissions for constructing the Zero-Emission Building (ZEB) Laboratory in Norway. They found significant differences in GHG emissions calculations between data from Environmental Product Declarations (EPDs) and generic data from the ecoinvent database. The building achieves net-zero emissions by offsetting emissions with on-site renewable energy.

De Masi et al. explored the environmental impact of increased insulation and photovoltaic system integration in nearly zero-energy buildings (nZEBs). They concluded that the most energy-efficient solutions do not always provide the best environmental outcomes, highlighting the importance of case-specific assessments.

Grazieschi et al. (9) found that low-energy design solutions outperformed nZEBs from a life cycle energy perspective. For example, increasing insulation and maximizing photovoltaic power without battery storage reduced life cycle energy demand, while nZEBs showed better economic feasibility than Life Cycle Zero-Energy Buildings (LCZEBs). Moazzen et al. analyzed school buildings across Turkey's mild-humid, hot-humid, and cold zones, showing that energy consumption, environmental impact, and cost-effectiveness depend on the climate. This emphasized the need for climate-specific assessments. Green Building Codes (GBCs) were critiqued for not accounting for actual occupancy patterns, which affect energy usage. The building energy rating system in Australia does not consider embodied energy, and improvements to energy efficiency can lead to a significant increase in embodied emissions. It was suggested that embodied emissions should be regulated.

Li et al. (10) studied nZEB development in the top three carbon-emitting countries—China, India, and the U.S noting a development gap. The U.S. had an earlier start with more collaboration, while China and India began later, driven primarily by government initiatives. This highlighted the need for broader policy frameworks and collaboration. Studies by Davidson and others examined the role of stakeholder attitudes and occupant behavior in energy efficiency. They found that behavior changes in existing homes, followed by improvements to building envelopes, are the most effective ways to reduce energy use, emphasizing the importance of social acceptability for sustainable goals. Various definitions of net-zero energy buildings (NZEB) have been proposed by different researchers. Iqbal et al, described NZEBs as buildings that use renewable energy technologies and energy-efficient construction methods, without consuming fossil fuels. Kilkis et al, defined NZEBs as buildings with zero energy transfer over a specific time period, accounting for all energy flows. Laustsen characterized NZEBs as buildings that rely entirely on solar and other renewable energy sources, without using fossil fuels. Noguchi et al. defined an NZEB as a building that consumes as much energy as it produces over a certain period.

Brahme et al. (11) discussed modeling a single-family residence to demonstrate common strategies used in the NZEB design process, highlighting the ease of using various modeling tools and the importance of quality control for inputs and outputs. Hernandez and Kenny et al explored renewable energy evaluation and the concept of 'net energy' from ecological economics, which considers energy used during the manufacturing phase of a commodity. They introduced a model for Life Cycle Zero Energy Building (LC-ZEB), which defines it as a structure whose primary energy consumption during its service life is equal to or less than the energy produced by renewable systems plus the energy embodied in the building materials and systems over its lifetime. Charron et al defined net-zero energy solar homes (ZESH) as homes that use solar thermal and solar PV technologies to generate as much energy as they consume annually. According to ASHRAE Kilkis et al a Zero Energy Building (ZEB) is one that uses no more energy than it generates through on-site renewable energy sources on an annual basis. While biomass and wind energy are also considered potential renewable energy sources for ZEBs, solar energy remains the most common choice. Importance of Design is the most crucial and cost-effective factor in achieving Zero Energy. Strategic planning in site selection, solar orientation, and roofing for solar panels enhances performance without extra cost. Poor design choices can be costly to fix later. Setting Energy Goals ZEB design sets goals beyond aesthetics and liveable space, focusing on energy efficiency. Homeowners can target full Zero Energy, partial solar reliance, or specific energy ratings. Without clear energy goals, buildings may only meet minimum code requirements. Site Selection A site impacts construction costs, material choices, house layout, passive solar design, ventilation, indoor-outdoor connectivity, and overall comfort. Lighting &Daylighting Lighting is a major energy consumer. ZEBs use natural light, sensor-based lighting, CFL/LED bulbs, and automated systems to reduce artificial lighting needs. Low Consumption Technology & Appliances Energy-efficient appliances and office equipment contribute to lower energy use. Many rating systems help consumers select sustainable products. Material Selection Key material considerations include resource efficiency, health impacts, durability, and recyclability to minimize waste and environmental harm. Comfort ZEBA comfortable living space is a priority. Comfort is influenced by factors like temperature, humidity, airspeed, and clothing level, which can be optimized through good design.

III. CONCLUSION

Its analysis and examines the viability of Net-Zero Energy Buildings (NZEBs) as a sustainable alternative to conventional buildings. NZEBs generate their own energy, reducing both energy crises and environmental emissions. The study explores strategies for achieving net-zero energy in existing buildings, reviewing policies, on-site energy generation, and the role of solar PV in balancing energy demand and supply. Amid change and energy scarcity, energy efficiency and smart system applications are highlighted. The study also emphasizes the significance of embodied carbon in building life cycle assessments.

Technological advancements, innovative materials, and modelling techniques are discussed for cost-effective, climate-responsive designs. The selection of energy systems and the environmental impact of renewable sources are also considered. Its finds to suggest that addressing inconsistencies in greenhouse gas (GHG) assessments, balancing energy efficiency with sustainability, and refining climate-dependent designs are crucial. Public awareness, emerging technologies, financial incentives, and policy support are essential for expanding NZEB adoption. Investment in scientific research and technological advancements is recommended to drive NZEB development.

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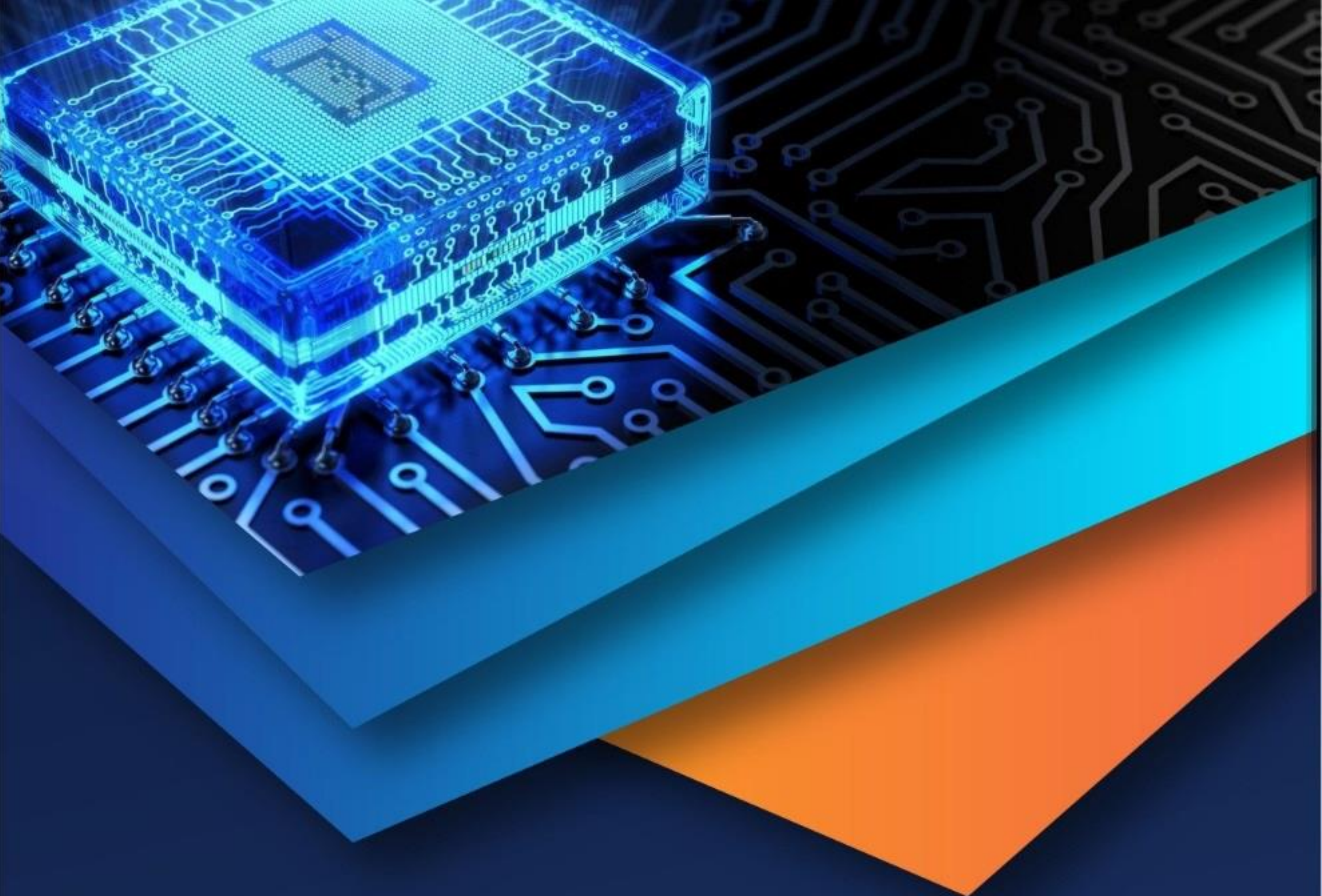

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