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Evaluating the Effectiveness of Energy-Efficient Design Strategies in Achieving Net Zero Energy Building through Reduced Energy Consumption

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Abstract: Net zero energy buildings (NZEBs) have emerged as a sustainable and energy-efficient solution to the challenges of climate change and rising energy costs. These buildings are designed to generate as much energy as they consume, resulting in zero net energy consumption. The paper explores the evolution of NZEBs and the latest emerging technologies that are enabling their development, including smart building automation systems, energy-efficient lighting and HVAC systems, vacuum insulation panels, Building Integrated Photovoltaic (BIPV) systems, and advanced sensors. The effectiveness of these strategies is analyzed using Autodesk insights and Revit software. The paper also discusses the comparison of Energy Use Intensity (EUI) before and after implementing energy-efficient and renewable energy techniques, which is crucial in determining their effectiveness. The proposed building achieved a significant 57.3% reduction in energy consumption after implementing various NZEB design strategies, resulting in a mean EUI value of 99.8 kWh/sq. m/year. The analysis was conducted using Autodesk Insights and Revit software, utilizing the Building Information Modeling (BIM) approach for building design. This paper concludes with a discussion on the future of NZEBs and how they are an important step towards achieving sustainable and efficient energy use in the building sector, resulting in cost savings and reduced carbon emissions.
Keywords: Net zero energy buildings (NZEBs), BIPV, HVAC, energy use intensity (EUI), BIM, Revit, Autodesk Insights, sustainability, Energy analysis, energy efficiency, NZEB design strategies.

I. INTRODUCTION

In today's fast-paced world, energy consumption has reached alarming levels across all sectors. However, there is one industry that stands out as the largest consumer of energy, and that is the building sector. Shockingly, this sector alone accounts for a whopping 40% of the world's total energy consumption, with a significant portion of it coming from non-renewable sources such as coal and oil [1]. Unfortunately, this high level of energy consumption is depleting the world's fossil fuel reserves at an unprecedented rate.

The production of energy is primarily fueled by the burning of fossil fuels, which is then used to power essential building appliances such as air conditioning and refrigeration. This reliance on non-renewable energy sources has led to the emission of harmful gases like CO_2, nitrogen oxide, and sulfur oxide into the environment, contributing significantly to global warming and climate change. Shockingly, the building sector alone accounts for a staggering 39% of total CO_2 emissions [5].

However, there is hope on the horizon. By constructing buildings that rely solely on renewable energy sources, we can significantly reduce our carbon footprint and pave the way for a greener, more sustainable future. Net zero energy buildings are the answer to this problem - structures that consume no more energy than they produce, making them a game-changer in the fight against climate change [1,8]. Designing net zero energy buildings has become an increasingly important topic in the field of engineering and sustainable development. As the world continues to face the impacts of climate change and dwindling fossil fuel resources, the need for buildings that consume little to no energy from non-renewable sources has become imperative. A net zero energy building is defined as a structure that produces as much renewable energy as it consumes over a given period, typically a year. This requires a holistic approach to building design that prioritizes energy efficiency, renewable energy generation, and energy storage.

Net Zero Energy Buildings (NZEBs) are not only environmentally friendly, but they also provide various advantages. Firstly, NZEBs use less energy than conventional buildings, resulting in significant energy savings. This reduced energy consumption leads to lower energy bills, which translates into significant cost savings over time. Additionally, NZEBs reduce greenhouse gas emissions and contribute to mitigating climate change [3].

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While the benefits of designing net zero energy buildings are clear, there are still significant challenges that must be overcome to make this approach to building design more widespread. These challenges include the need for more rigorous building codes and standards, the development of cost-effective renewable energy technologies, and the integration of renewable energy systems into existing building stock. However, with continued research, innovation, and collaboration across the design and construction industries, the goal of net zero energy buildings can become a reality, paving the way for a more sustainable and resilient built environment.

Therefore, the research paper aims to propose a design for a net zero energy building using the latest technology and strategies available. The paper will also analyze emerging technologies in building design to identify the most promising technologies to achieve net zero energy status. Additionally, the research paper will focus on building an optimized building suitable for all climatic zones of India by taking into account the diverse climatic conditions of the country. The ultimate goal is to showcase the potential of net zero energy building design and contribute to achieving a sustainable and resilient built environment in India.

This research paper explores the use of Building Information Modeling (BIM) technology and energy evaluation tools in designing a net zero energy building. BIM technology has revolutionized the construction industry by offering benefits such as time savings, improved accuracy, and rigorous designs. By integrating energy evaluation tools with BIM, engineers can predict a building's environmental performance and select low-impact materials and components that minimize energy usage. The paper showcases the use of BIM software, specifically Revit, in the design process of a net zero energy building, highlighting the benefits and challenges of this approach. The results demonstrate the potential of BIM and energy evaluation tools in creating sustainable buildings that meet functional and financial needs while minimizing environmental impact [10].

II. METHODOLOGY

The design of Net Zero Energy Buildings (NZEBs) aims to attain a balance between energy consumption and energy generation, resulting in zero net energy consumption [7]. This is achieved through the use of energy-efficient design principles, renewable energy sources, and the latest emerging technologies for energy efficiency. A comprehensive analysis of the building's various aspects was conducted and compared with other emerging technologies to ensure maximum optimization. This research outlines the process undertaken to design the net zero energy building, which is illustrated in the accompanying figure 1.

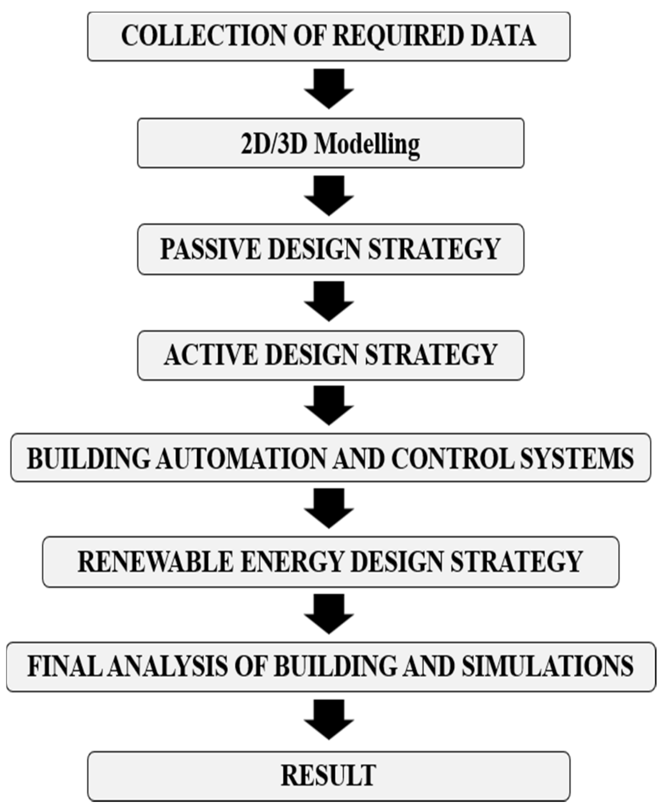

Figure 1 Flow Chart

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Following are the design strategies we have applied for achieving net zero energy consumption in a building:

1) *Passive Design Strategy:* Passive design principles focus on reducing the energy consumption of buildings through the use of passive strategies. These strategies include optimizing the building's orientation, using shading devices to control solar gain, maximizing natural daylight, and minimizing air leakage. By minimizing the energy re- quired to heat, cool, and light the building, passive design strategies can significantly reduce the energy consumption of a building.
2) *Active Design Strategies:* Active design strategies are design strategies that rely on the use of active systems and technologies to achieve net zero energy consumption in buildings. These strategies focus on the generation, distribution, and management of energy within the building. Examples of active design strategies include geothermal heating and cooling systems, efficient lighting systems, efficient HVAC systems, and building automation and control systems. These strategies are critical to achieving net zero energy consumption and reducing the environmental impact of buildings.
3) *Building Automation and Control Systems:* Building automation and control systems are used to optimize the operation of the building and its systems. These systems include sensors, controls, and software that monitor and control HVAC systems, lighting systems, and other building systems to minimize energy consumption.
4) *Renewable Energy Design Strategy:* The performance of Net Zero Energy Building depends upon the effectiveness of the Renewable Energy System Design Strategy. The size of a Solar Photovoltaic Power Plant is calculated depending upon the requirement of power and availability of shadow-free roof area. The solar modules mounted on the building capture solar energy at converting it into electricity.

A. *Building Details*

1) *Building Description*

Table 1: Building specifications

Particular	Specification Location of building	Delhi, India
Building type	Commercial-Office Building	
Build-up area	35,772m2	
Plot area	10342 m2	
No. of floors	G+12	
No. of basements	2	
No. of staircase	3	
No. of elevator	7	
Orientation of building	South-East facing	

2) *2D and 3D Modelling*

The design of a Net Zero Energy Building involves the use of advanced software tools for optimizing energy efficiency. AutoCAD was used for the 2D design (fig. 2) while Autodesk Revit software was used for developing a 3D model (fig. 3) of the building. We also used Autodesk Insights to analyze the building's energy consumption, ensuring that the building was optimized for energy efficiency and capable of achieving Net Zero Energy status. By utilizing these advanced software tools, the team was able to create an energy-efficient and sustainable building.

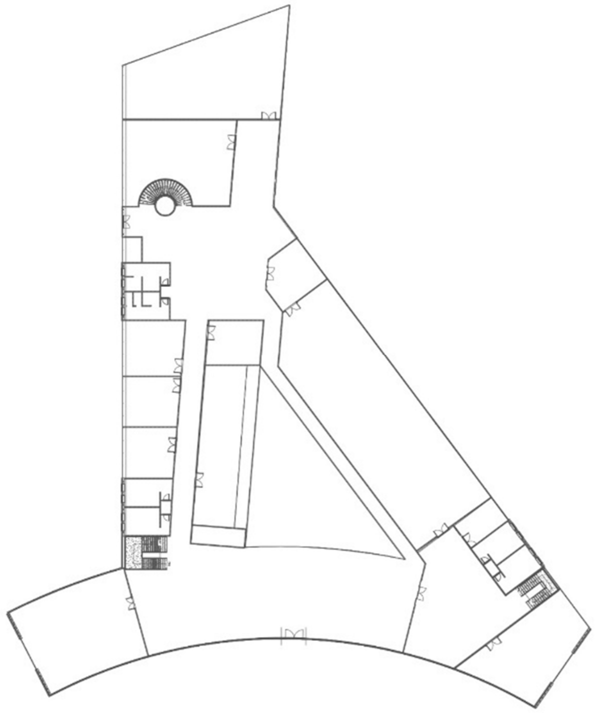

Figure 2 2D Model

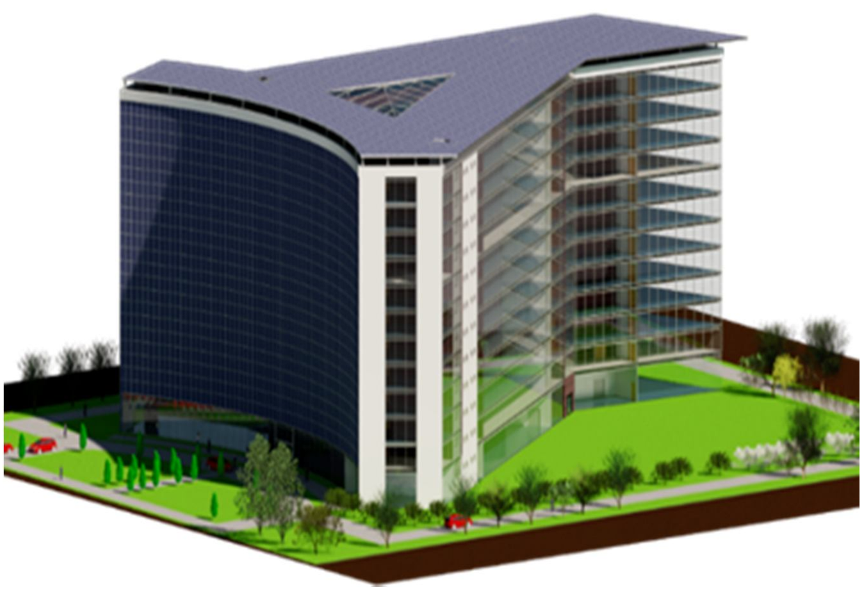

Figure 3 3D model

B. Passive Design Strategy

Passive design principles focus on reducing the energy consumption of buildings through the use of passive strategies. These strategies include optimizing the building's orientation, using shading devices to control solar gain, and maximizing natural daylight. By minimizing the energy required to heat, cool, and light the building, passive design strategies can significantly reduce the energy consumption of a building [15].

1) Building Orientation

When it comes to a building's solar gains, orientation is a key factor [13]. The ideal solar orientation for a building maximizes solar gains in winter while minimizing them in summer.

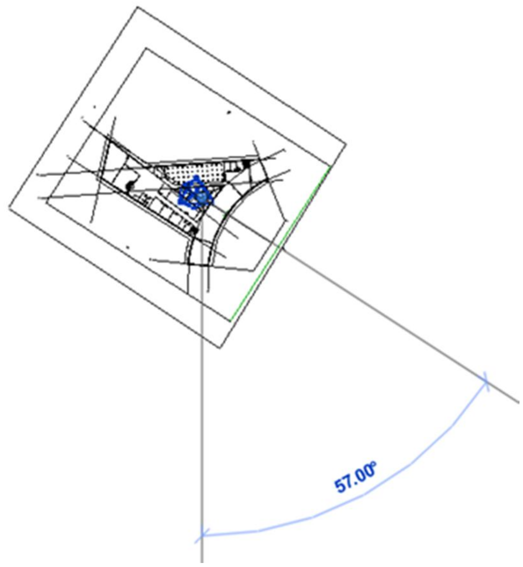

Figure 4 orientation of the building

To enhance the utilization of solar radiation for renewable energy generation and curtail energy consumption, the orientation of the building has been fine-tuned. Although a southern orientation was initially deemed as the best, further studies revealed that an eastward shift of 57 degrees from the south (fig. 4), corresponding to 123 degrees from the north, would yield the highest energy output. By making this adjustment, the building is expected to generate a remarkable 1379.9 MWh/year (table 2).

Table 1: shows PV energy production at different orientations

Orientation	PV Energy Production (MWh/year)	Payback year
North	896.4	21.1
South	1214.1	20.1
South-East	1379.9	16.6
East	1347.6	17.2
West	940.7	24.7

According to the data presented in Table 2, the solar energy production of a building depends on its orientation. When the orientation is north-facing, the solar energy production will be 896.4 MWh/year, with a payback period of 21.1 years. However, if the building is oriented towards the south, east, or west, it will produce 1214.1, 1347.6, and 940.7 MWh/year of solar energy, respectively. Based on the analysis (fig. 5), it was determined that the building should be oriented towards the southeast to maximize solar energy production, which will be 1379.9 MWh/year.

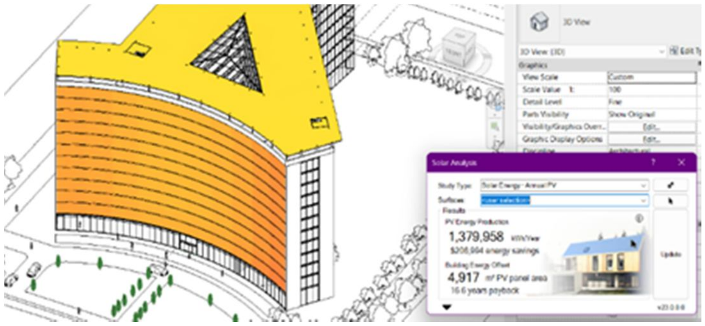

Figure 5: solar energy analysis

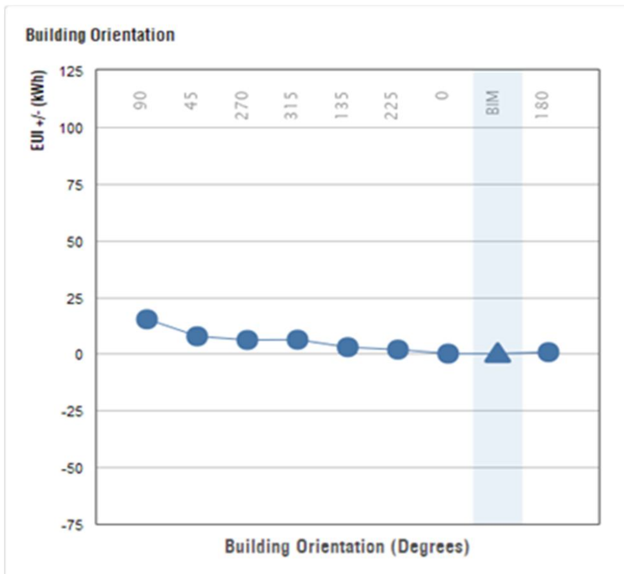

Figure 6: Optimizing the building orientation towards the South-East direction at an angle of 123 degrees from the North can result in reduced energy consumption.

According to the findings, positioning the proposed building at an angle of 123 degrees from the North in a South-East direction has proven to be beneficial, as it not only decreases energy usage (as indicated in fig. 6) but also yields the most advantageous outcome (as depicted in table 2).

2) Skylight

Natural sunlight entering a building through skylights can have positive effects on employee well-being, productivity, stress levels, and mental functioning. Insulated skylights can prevent excess heat from entering the building, maintaining a positive work environment and enhancing the building's appearance.

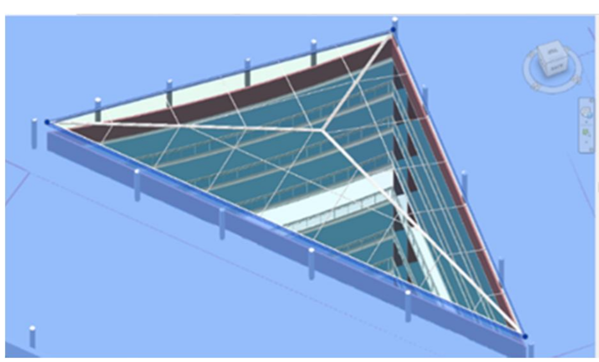

Figure 7 skylight

A large space (fig. 7) is provided at the top of the building for the skylight. And to prevent excess solar heat gain in building monochromatic technology is used in skylight glass panels.

3) Landscaping:

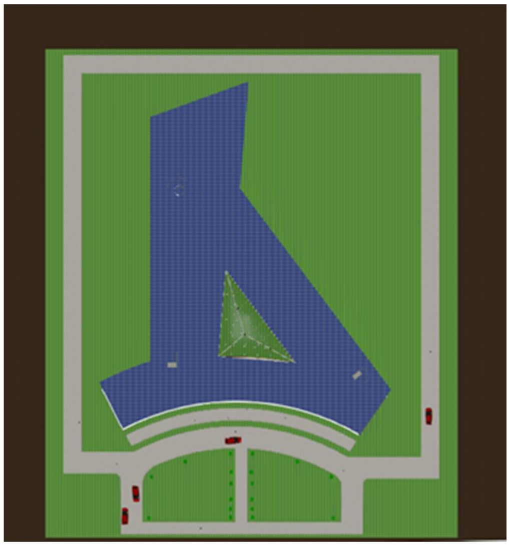

Figure 8: Landscaping

Landscaping in net-zero energy building design can contribute to energy efficiency and reduce the carbon footprint. It provides shading, cools the surrounding area, and enhances rainwater harvesting and water quality. The use of native plants and low-maintenance techniques can help reduce water usage [2]. The green color in the image (fig. 8) denotes the landscaping area around the building.

4) Insulation

Insulation is crucial in Net Zero Energy Buildings (NZEBs) to minimize heat loss during winter and heat gain during summer, ensure comfortable indoor temperatures with minimal energy consumption, and reduce the building's carbon footprint. By using high-quality insulation materials and techniques, NZEBs can significantly reduce their energy consumption and maintain consistent indoor temperatures year-round.

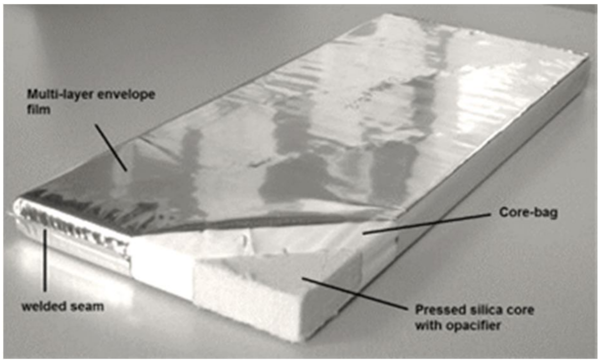

Figure 9: vacuum insulation panel

Vacuum insulation panels (fig. 9) are high-performance insulation materials composed of a porous core enclosed by a sealed envelope with several layers of materials, such as PET, PE, and Al [12,17]. The core has open nanopores with a diameter of up to 200 nm and is almost vacuumed. The envelope is waterproof and airproof, and it protects the core from mechanical damage. Vacuum insulation panels cannot be modified to maintain the inner vacuum state, and they have a compression strength of 0.14-0.25 MPa and a density of 240-250 kg/m3.

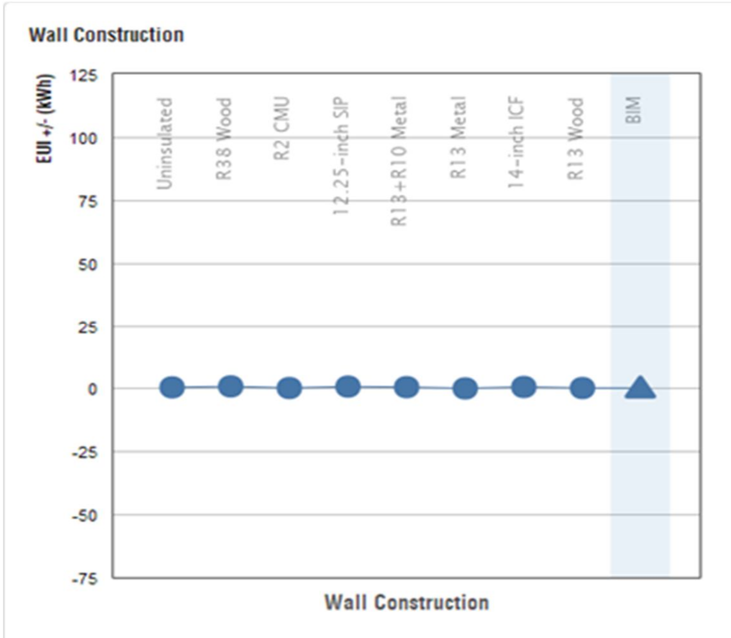

Figure 10: Wall construction represents the overall ability of wall construction to resist heat losses and gains.

C. Active Design Strategy

Heating, ventilation, and air conditioning (HVAC) systems account for a significant portion of a building's energy consumption. In NZEBs, energy-efficient HVAC systems are used to minimize energy consumption. These systems include ground-source heat pumps, air-source heat pumps, and energy recovery ventilators that recover heat from exhaust air and use it to preheat incoming fresh air.

1) Heating, ventilation, and air distribution system (HVAC)

Proper HVAC design considers all interrelated building systems while managing indoor air quality, energy consumption, and thermal comfort in Net Zero Energy Buildings (NZEBs) [16]. Ventilation is crucial for an NZEB because of its airtight envelope, and the mechanical ventilation system needs to create cross ventilation. To minimize energy usage through an all-encompassing building strategy, HVAC experts must tackle these concerns during the schematic design phase and consistently refine their choices in the design development process.

UFAD has been found to be more effective than traditional overhead HVAC systems.

Building Data	
Building Type	Office
Building Operating Schedule	12/6 Facility
HVAC System	Underfloor Air Distribution
Outdoor Air Information	Edit...

Figure 11: Implementation of the UFAD system in building performance analysis.

Underfloor air distribution (UFAD): Underfloor air distribution (UFAD) is an innovative technology that supplies conditioned air through raised floor plenums in commercial buildings [11]. It provides improved thermal comfort, ventilation efficiency, and indoor air quality while reducing energy use and floor-to-floor height. However, it requires careful design to avoid cold feet and noise near occupants.

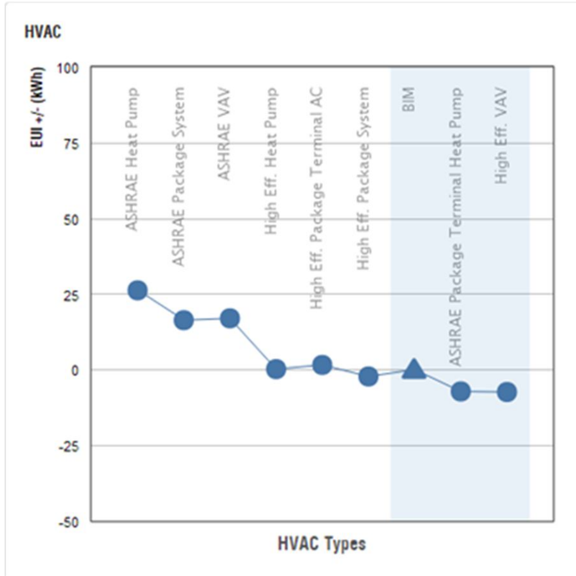

Figure 12:Represents a range of HVAC system efficiency which will vary based on location and building size, after applying the HVAC system (UFAD) it gives 7.28 kWh/m2/yr.

2) Earth Air Tunnel System

The Earth Air Tunnel System is a type of HVAC system that uses underground tunnels to pre-condition the air before it enters a building [16]. The system consists of a network of buried pipes or ducts that draw in fresh air from outside, where it is naturally cooled or warmed by the earth, depending on the season. The pre-conditioned air is then delivered into the building through a ventilation system. This approach can help reduce the energy consumption required for heating and cooling, leading to lower operating costs and environmental impact. However, it requires careful design and installation to ensure proper ventilation and air quality, and may not be suitable for all buildings or climates.

D. Renewable Energy Design Strategy

Renewable energy design is vital in achieving net-zero energy buildings that produce as much energy as they consume annually. renewable energy design can significantly reduce a building's carbon footprint and contribute to a sustainable future. The latest technology of renewable energy is BIPV [4,6]. And this technology is implemented in the building.

Building-integrated photovoltaics (BIPV) is a relatively new technology that integrates solar panels into a building's design, replacing traditional building materials. BIPV offers several advantages, including improved aesthetics, space-saving, potential cost savings, and improved energy efficiency. While the technology is still developing, BIPV has the potential to revolutionize the way we generate and use renewable energy in our built environment.

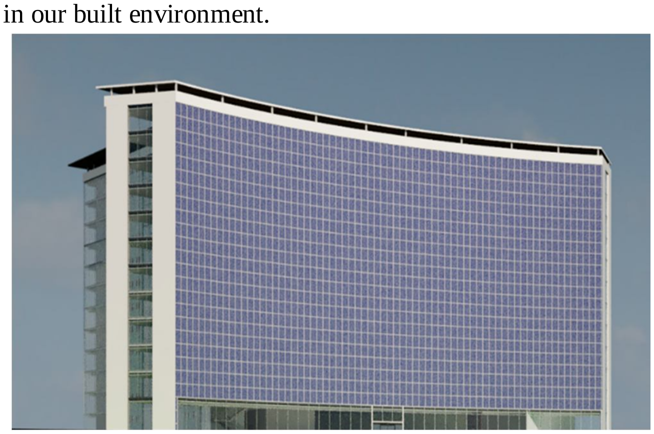

Figure 13:The front wall has a solar system installed.

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Opting for Building Integrated Photovoltaic (BIPV) systems instead of conventional solar panels can result in a larger coverage of the building's surface area. This increase in coverage allows for the installation of more solar cells and consequently, greater production of solar energy. BIPV systems can be installed on the facade of the building as well as the roof surface (as in fig. 14). The combined surface area of the roof and front facade of the building that can be covered by BIPV is 4916 sq. m. (fig. 15) After conducting multiple solar analyses, it was found that this surface area can generate 1380.8 MWh/year of solar energy, with a payback period of 16.6 years (fig. 15).

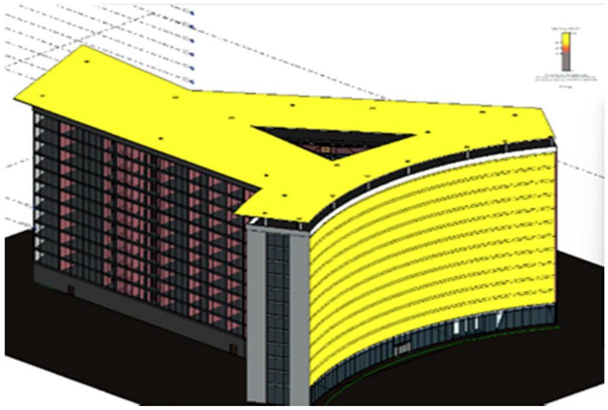

Figure 14: BIPV is installed on the roof and front facade of the building as indicated in yellow colour.

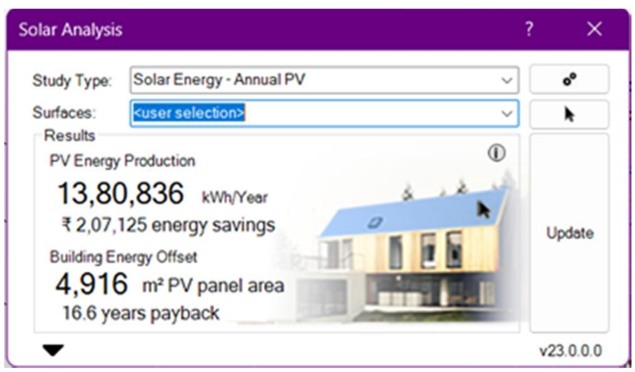

Figure 15:solar analysis of the combined area of the roof and front wall of the building as in fig. 13.

PV-Surface coverage (fig. 16) area refers to the total area of the photovoltaic (PV) used in a solar energy system. The surface area of a solar PV system depends on several factors, such as the size and efficiency of the panels used, the orientation and tilt of the panels, and the available space for installation. The total surface area of a solar PV system is an important consideration for determining its energy output and overall efficiency, as more surface area typically means more electricity generation capacity.

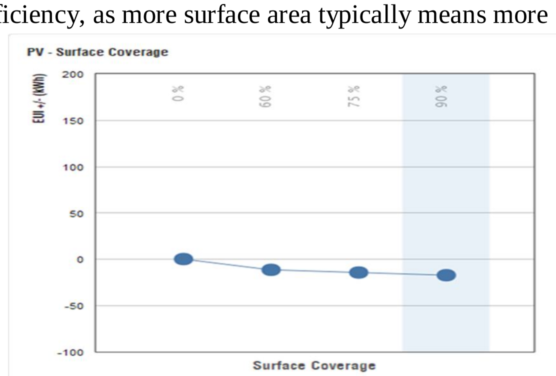

Figure 16: This parameter specifies the amount of roof space available for PV, maintenance access, rooftop equipment, and system infrastructure is crucial for the proper installation and upkeep of solar systems. At present, the setting for this metric stands at 90% and above.

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Panel efficiency (fig. 17) refers to the percentage of solar energy that is converted into AC (alternating current) energy by the solar panel. The statement suggests that panel efficiency is a crucial factor to consider when evaluating solar panels because it directly impacts the amount of energy that can be generated from a given surface area of solar panels. Panels with higher efficiency can convert a greater proportion of the available solar energy into usable AC energy, resulting in more energy generation from a given area of solar panels. current panel efficiency is set at 20.4% (fig. 17).

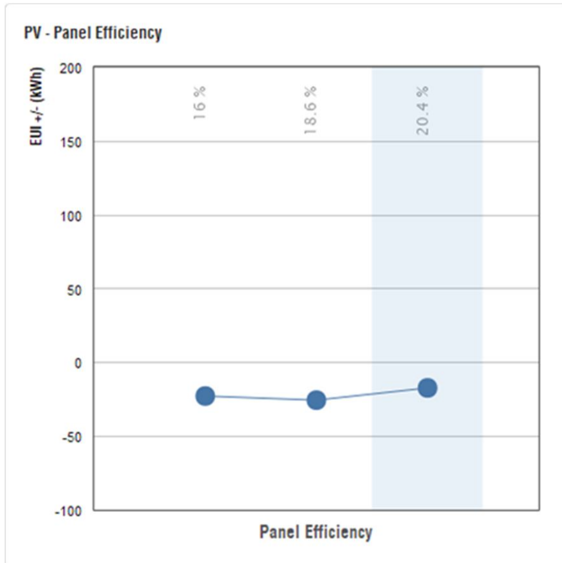

Figure 17: Panel efficiency

E. *Building Automation and Control Systems*

Building automation and control systems are used to optimize the operation of the building and its systems. These systems include sensors, controls, and software that monitor and control HVAC systems, lighting systems, and other building systems to minimize energy consumption.

1) *Advanced Window Control System:* Smart glasses use electrochromic technology to change their color or transparency when an electrical voltage is applied. This technology helps to tint the window, reflecting heat radiation from the sun and preventing rooms from overheating. Smart glasses can be controlled by sensors that measure factors such as brightness and temperature, triggering the window to darken gradually. This technology reduces the need for air conditioning and provides anti-glare protection on sunny days. On cloudy days and in the evening, the windows remain in a bright state
2) *Smart Lighting Systems:* Smart lighting systems optimize critical lighting metrics beyond illuminance for greater control over light output. Current LED smart lighting systems only optimize illuminance, but with advancements in LED technology, mixed color systems are becoming more viable and will allow for greater control over color temperature and chromaticity.
3) *Occupancy Sensing Technology:* Occupancy sensing is a popular energy-saving technique due to its ease of implementation and effectiveness. In fact, occupancy sensing technologies have been heavily promoted in North American and European building codes, standards, and recommended practice documents. The integration of implementing occupancy sensors can potentially result in 3 - 60% energy savings, depending on occupant usage patterns. Occupancy sensing systems utilize occupancy sensors to detect motion or human presence within a specific environment. The information gathered from these sensors is then employed to regulate the lighting state for the corresponding area. [16].

Smart lighting control systems (daylighting) and occupancy control sensors utilizing AI and IoT technologies have led to a reduction in EUI of 9.60 kWh/sq. m/yr. (fig. 20), resulting in more efficient and sustainable energy use, and significant cost savings. The control systems adjust lighting levels based on natural light availability and occupancy, and occupancy control sensors detect people in a space to adjust lighting or temperature levels accordingly. The use of AI and IoT technologies has enabled more sophisticated and effective control systems, leading to a reduction in EUI and cost savings. This implementation represents a significant step forward in sustainable and efficient energy use and is likely to be a key area of focus for future developments.

III. ANALYSIS RESULTS

A comprehensive analysis of various aspects of the building was conducted and compared with emerging technologies to attain optimal optimization. The utilization of Autodesk Insights (Fig. 18) enabled the analysis of the building's energy consumption, ensuring its energy efficiency was optimized through the application of diverse energy consumption scenarios and available technology alternatives aimed at reducing energy consumption.

Figure 18: analysing energy consumption of the building in Autodesk Insight by Appling different scenarios of energy consumption.

Passive design strategies focused on reducing the building's energy consumption through the optimization of the building's orientation, using shading devices to control solar gain (fig.19), and maximizing natural daylight.

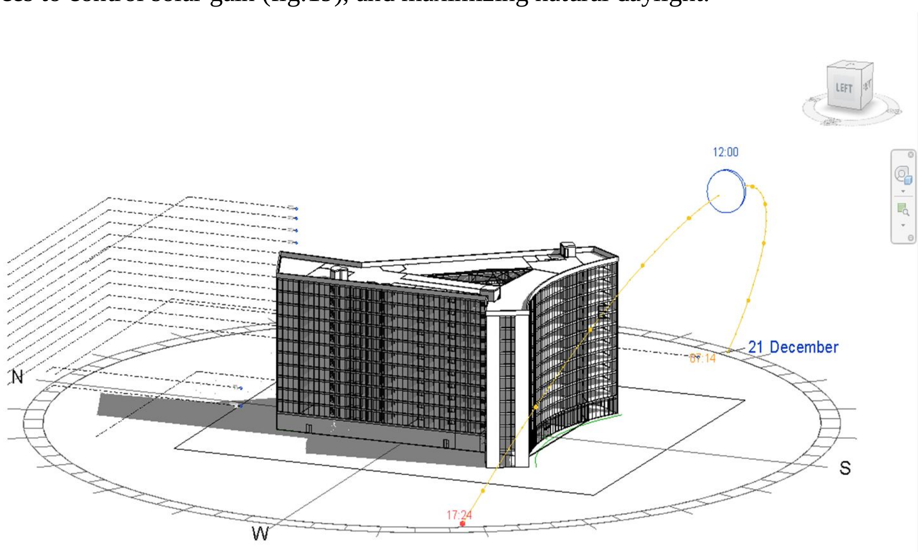

Figure 19: solar analysis of building

The building's orientation was determined to be crucial in maximizing solar gains and minimizing energy consumption. The analysis (as shown in table 1) revealed that the building's orientation towards the southeast (as illustrated in fig. 4) would yield the highest solar energy production of 1379.9 MWh/year. Furthermore, the use of skylights (fig. 7) was also incorporated into the building's design to optimize natural daylight, positively affecting employee well-being, productivity, stress levels, and mental functioning.
Building automation and control systems were used to optimize the operation of the building and its systems. These systems included sensors, controls, and software that monitored and controlled HVAC systems, lighting systems, and other building systems to minimize energy consumption.

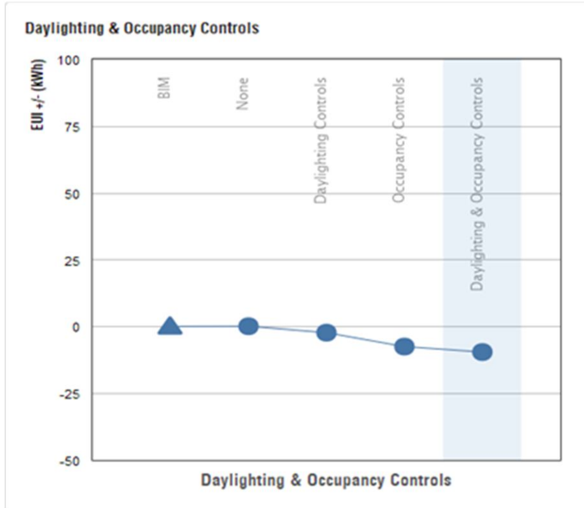

Figure 20: daylight and occupancy control analysis

Upon completion of the requisite energy consumption analyses, as outlined in the methodology, and in light of the outcomes attained (refer to figures 6, 10, 12, 16, 17, 20), a significant reduction in EUI was achieved, amounting to 57.3%. This reduction is indicative of the building's energy utilization levels.

Assessing the effectiveness of energy-efficient and renewable energy techniques involves comparing a building's mean Energy Use Intensity (EUI) before and after their implementation. In the present study, prior to the adoption of any energy-efficient technologies, the building's EUI was recorded at 234 kWh/sq. m/yr (refer to fig. 21), as depicted by a red bar in figure 21.

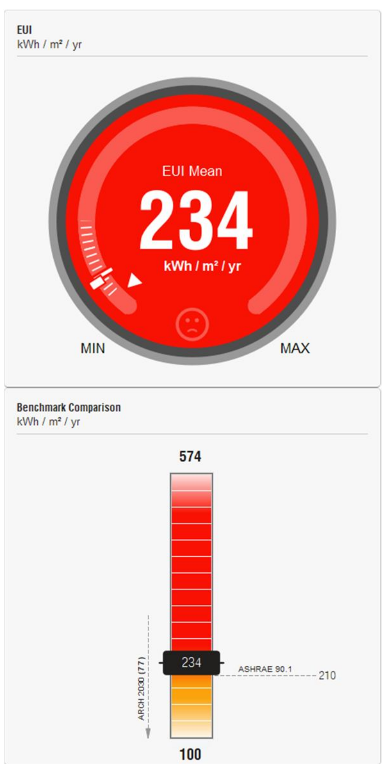

Figure 21: EUI value before implementing any strategy and energy efficiency technology

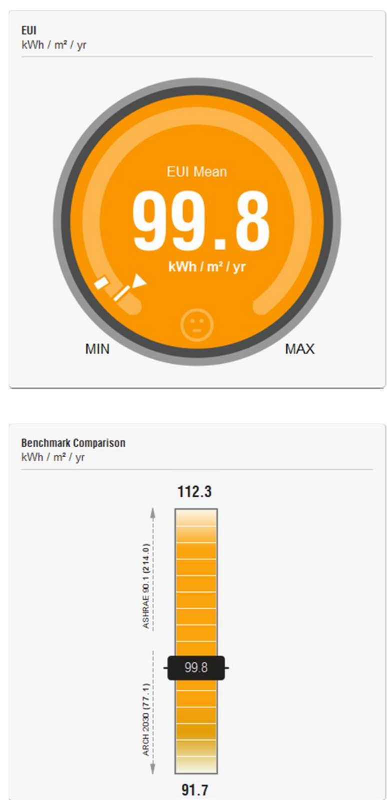

Figure 22: This represents the EUI value after implementing different strategies and technology

The notable high value of the building's EUI prior to the implementation of energy-efficient and renewable energy measures, as evidenced by fig. 21, signified the building's excessive and potentially unsustainable energy consumption, accompanied by considerable costs. However, through the adoption of diverse NZEB design strategies, inclusive of passive and active measures, the proposed building achieved a mean EUI of 99.8 kWh/sq. m/yr (refer to fig. 22), demonstrating a noteworthy 57.3% reduction in energy utilization, indicative of the efficacy of the implemented energy optimization methods.
This reduction in energy consumption is a result of a combination of strategies, incorporating passive techniques such as building orientation, insulation, glazing, and natural ventilation, alongside active measures such as the utilization of solar panels, energy-efficient lighting, and efficient HVAC systems. The benefits of this energy-saving outcome extend beyond cost savings, encompassing the reduction of carbon emissions, supporting the development of sustainable energy practices, and promoting environmental conservation.

IV. CONCLUSION

In conclusion, this research Evaluated the Effectiveness of Energy-Efficient Design Strategies to Achieving Net Zero Energy Building design through Reducing Energy Consumption and producing solar energy. The study successfully employed various design strategies to design a Net Zero Energy Building, resulting in zero net energy The study highlights the use of energy-efficient design principles, renewable energy sources, passive and active design strategies, and the latest emerging technologies for energy efficiency. The study also found that building automation and control systems and renewable energy design strategies played a significant role in achieving net zero energy building. Through comprehensive analysis and comparison of the building's various aspects. The use of passive design strategies, such as building orientation, skylights, insulation, and landscaping, helped to significantly reduce the building's energy consumption. Additionally, the use of energy-efficient HVAC systems helped to minimize energy consumption while ensuring thermal comfort and indoor air quality. By integrating these strategies, the proposed building is expected to generate a remarkable 1379.9 MWh/year of solar energy, resulting in zero net energy consumption. The study demonstrates that the application of emerging technologies and design principles can help to achieve sustainable and energy-efficient buildings, which will be beneficial for the environment and society.

Conflict of interest
The authors declared that there is no conflict of interest.

REFERENCES

[1] Torcellini, P., Pless, S. & Deru, M. (2006). Zero Energy Buildings: A Critical Look at the Definition. National Renewable Energy Laboratory (NREL), USA
[2] Saitoh, T (1984). Natural energy autonomous house with underground water reservoir. Bulletin of the JSME Vol. 27
[3] Kilkis, S.(2007). A new metric for net-zero carbon buildings. Proceedings of ES2007. Energy Sustainability 2007
[4] Mertz, G.A., Raffio, G.S. & Kissock, K. (2007). Cost optimization of net-zeroenergy house. Proceedings of ES2007. Energy Sustainability 2007
[5] Griffith, B., Torcellini, P. & Long, N. (2006). Assessment of the Technical Potential for Achieving Zero-Energy Commercial Buildings. National Renewable Energy Laboratory (NREL), USA
[6] Iqbal, M.T. (2003). A feasibility study of a zero-energy home inNewfoundland. Renewable Energy
[7] The Potential Impact of Zero Energy Homes" (2006). Developed by the NAHB Re- search Center, the U.S. Department of Energy, and the National Renewable Energy Laboratory (NREL)
[8] Torcellini,P.&Crawley,D.*(2006).UnderstandingZero-EnergyBuildings. ASHRAE Journal September 2006,
[9] Parker, D.S., Thomas, M. & Merrigan, T. (2001). On the path to Zero Energy Homes. Produced for the U.S. Department of Energy by the National Renewable Energy Lab- oratory, and DOE national laboratory
[10] Noguchi, M., Athienitis, A., Delisle, V., Ayoub, J. & Berneche, B. (2008). Net Zero Energy Homes of the Future: A Case Study of the ÉcoTerraTM House in Canada. Presented at the Renewable Energy Congress, Glasgow, Scotland, July 2008
[11] ROUSSEAU, RAYMOND J. COLE & DAVID. (1992), "Environmental Auditing for Building". Energy and Air Pollution Indices for building materials, pp. 8.
[12] Torben V. Esbensen, Vagn Korsgaard, (1977) 'Performance of the zero-energy house in Denmark', Thermal Insulation Laboratory, Technical University ofDenmark.
[13] Varun, Aashish Sharma, Venu Shree, Himanshu Nautiyal. (2012), "Life cycle environmental assessment of an educational building in Northern India", Sustainable Cities and Society, p p. 7.
[14] Chrysi K. Metallidou, et, al. (2020) Energy Efficiency in Smart Buildings: using IoT Approaches
[15] Sourena Sami et al. 2022. Design and optimization of a CCHDP system integrated with NZEB
[16] Jennifer King and Christopher Perry, 2017, Smart Building technologies and sensors.
[17] Ligia Moga, et al. (2018) Nano insulation materials for application in NZEB