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Energy Performance and Optimization of Commercial Building under Composite Climate using BIM

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***Abstract:** The use of BIM REVIT for Energy Performance and Optimisation of Buildings (EPOBs) has been shown in this research to be a sustainable and energy-efficient response to the problems posed by climate change and growing energy expenses. These buildings are made to produce as much energy as they consume, ensuring that their net energy consumption is zero. The paper explores the evolution of energy performance and optimisation of buildings and the latest emerging technologies that are enabling their development, comprising innovative sensors, lightweight insulation panels, energy-efficient lighting and HVAC systems, building integrated photovoltaic (BIPV) systems, and smart building automation systems. The effectiveness of these strategies is analysed using Autodesk insights and Revit software. In order to ascertain the effectiveness of energy-efficient and renewable energy strategies, the article also compares energy use intensity (EUI) before and after implementation. The proposed building achieved a significant 44.3% reduction in energy consumption after implementing various energy performance and Optimization strategies for commercial building design, resulting in a mean EUI value of -33.1 kWh/sq. m/year. The analysis was conducted using Autodesk Insights and Revit software, utilising the Building Information Modelling (BIM) approach for building design. This paper concludes with a discussion on the future of energy performance and optimisation and how they are an important step towards achieving sustainable and efficient energy use in the building sector, resulting in cost savings and reducing carbon emissions.*
***Keywords:** Energy Performance and Optimization of Buildings (EPOBs), BIPV, HVAC, energy use intensity (EUI), BIM, Revit, Autodesk Insights, sustainability, Energy analysis, energy efficiency, Energy Performance and Optimization of Buildings (EPOBs).*

I. INTRODUCTION

In 2019, the energy landscape of the United States witnessed a substantial impact from the energy consumption of residential and commercial buildings, accounting for over 39.2% of the nation's total energy and a significant 71.1% of electrical energy[1]. According to the International Energy Outlook 2023 worldwide energy consumption in the building sector will increase by an average of 1.5% per year between 2012 and 2040[1] . A Global Pathway to Keep the 1.5 °C Goal in Reach, the IEA update to the landmark Net Zero by 2050 Roadmap, was published in September 2023 (IEA, 2023b)[1]–[4]. The updated Net Zero Emissions by 2050 (NZE) Scenario is incorporated in full in this Outlook[5]. It reached the conclusion that the pathway to net zero emissions by 2050 has narrowed since the first version published in 2021, but that it remains feasible[2], [6]. In this section, we highlight four reasons why this pathway remains open and look at four areas that require urgent attention if the promise of a 1.5 °C limit on global warming is to be realised[7]. This underscored the imperative to address energy use intensity, leading to the development of emerging technologies. These encompassed various sectors, including HVAC systems, water heating, appliances, windows, solid-state lighting, grid-interactive buildings, sensors, controls, and building energy modelling, all aimed at reducing energy consumption and enhancing efficiency[2], [8]. The conventional approach to evaluating energy performance faced significant challenges, characterized by manual simulations that often resulted in error-prone data duplication, leaks, and redundant data processing and storage[9]–[11]. The introduction of Building Information Modelling (BIM) emerged as a transformative solution. BIM operates as a dynamic data model, seamlessly integrating 3D digital techniques with diverse information throughout a building's life cycle[12]. This integration facilitates swift energy model generation by capitalizing on existing data, eliminating the pitfalls of traditional approaches[13]. Moreover, the parametric nature of BIM enables the efficient incorporation of suggested changes to the energy model, providing a dynamic and adaptable platform for continuous energy performance measurement. Shifting the focus to Iran, a considerable amount of energy is annually consumed in the household, public, and commercial sectors, with buildings contributing to 34% of total energy consumption in 2016[2], [14], [15].

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The need to optimize energy consumption in Iran has emphasized the role of BIM in providing accurate analyses of thermal and cooling loads during the design phase. Despite various research initiatives on BIM adoption for energy efficiency, there remains a research gap in simultaneously evaluating building components through BIM technology, especially during the conceptual design phase[16]. In India, recent data reveals a total installed capacity of 152.31 Million Tonne per year in coal washeries as of March 31, 2022, comprising 37.18 MTY in coking and 115.13 MTY in Non-Coking Coal Washeries. The refining sector, with a capacity of 2,51,216 TMTPA, experienced a notable 9% increase in production during 2021-22[17]. Public sector refineries dominate, displaying a robust capacity utilization increase to 96.99%[17]. The emphasis on increasing electricity generation capacity aligns with global commitments to sustainability and the growing energy demands in densely populated regions[2], [8], [15]. The chapter underscores the global commitment to sustainable energy services, as reflected in the Sustainable Development Goals (SDG Target 7.B). India's policy planning revolves around generating reliable power sustainably, with a thrust to increase installed generating capacity while decreasing reliance on primary fossil fuels. It is crucial to note the nuances of capacity translating into actual power generation, emphasizing the significance of sustainable practices and the adoption of clean energy systems in the broader context of global energy challenges[6], [15].

II. METHODOLOGY

The Energy Performance and Optimization of Commercial Buildings (EPOCBs) aims to attain a balance between energy consumption and energy generation, resulting in zero net energy consumption. This is accomplished by utilising renewable energy sources, energy-efficient design concepts, and the most recent, innovative energy-efficiency technologies[18]–[20].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.

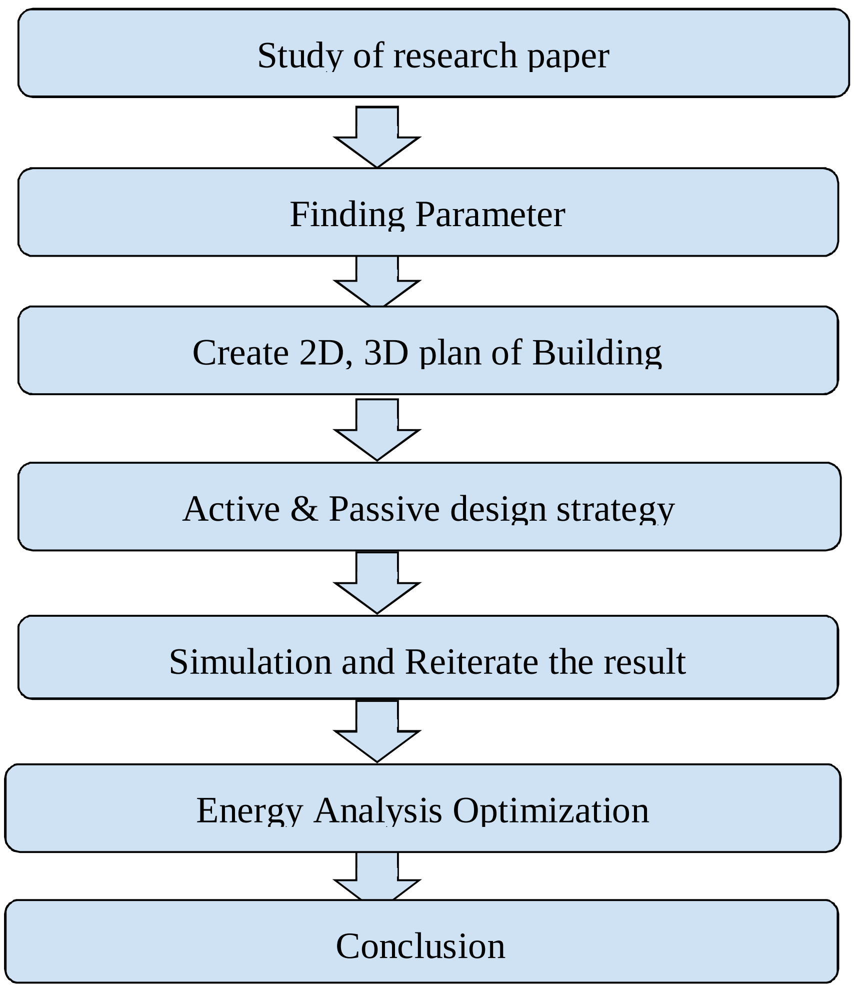

Fig. 1. METHODOLOGY

Following are the design strategies we have applied for Energy Performance and Optimization of Proposed Buildings (EPOBs):

1) *Passive Design Strategy:* The goal of passive design principles is to use passive methods to lower a building's consumption of energy[16]. 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 required to heat, cool, and light the building, passive design strategies can significantly reduce the energy consumption of a building[21].
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 concentrate on the production, allocation, and management of energy throughout the building[22]. Examples of active design strategies include geothermal heating and cooling systems, CTMA3 (Dexa Cetyltrimethylammonium Chloride) Technology 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) *Renewable Energy Design Strategy:* Energy Performance and Optimization of Commercial Buildings (EPOCBs**)** 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 [10]. The solar modules mounted on the building capture solar energy at converting it into electricity

Notes: CTMA3: Introducing the advanced CTMA3 Air purification technology that purifies your living spaces, while killing any germs and viruses from the environment, giving you pure air to breathe, and clean surfaces to live at. Natural biological proteins collagen hydrolysate acts as dielectric material due to the presence of hydroxyl groups. Cationic surfactant hexadecyltrimethylammonium chloride (CTMA) is added into collagen hydrolysate to form a dielectric layer in a bio thin film transistor (BioTFT) device. Experimental results highlight that the collagen-CTMA mixture at 3 wt% (Col-CTMA3) has shown an average mobility of 3.36 × 10−2 cm2V−1s−1 and an on/off ratio up to 2.7 × 106.1-aminopyrene is embedded into Col-CTMA3 mixture to form Col-CTMA3-1-aminopyrene (Col-CTMA3-AP) mixture to fabricate bio field-effect transistor (BioFET) type memory device. Furthermore, the optimized addition of 1-aminopyrene in the Col-CTMA3-AP mixture for memory device has provided enhanced performances associated to an average mobility of 1.23 × 10−2 cm2V−1s−1, an on/off ratio up to 5.22 × 105 and a memory window of 13.6 V, as the proportion of 1-aminopyrene increased, the charge-trapping ability of collagen strengthened. Studies on the effects of the environment have revealed that BioFET memory devices submerged in water emphasise the importance of the hydroxyl group in enhancing BioFET performance.

A. Building Details

Table .1. Building Details

General detail	Value
Building Type	Commercial Building
Total floor area	397.56m^2
No. of floor	G+4
Building Shedule	24/7
floor height	4200mm
Weather File	New Delhi Safdarjung
Latitude [deg]	28.59
Longitude [deg]	77.21
Elevation [m]	214.90
Time Zone	5.50
North Axis Angle [deg]	0.00
Orientation	15-degree East of south
Hours Simulated [hrs]	35/60

B. 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. 2D PLAN) while Autodesk Revit software was used for developing a 3D model (Fig.3. 3D PLAN) of the building[23]. 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[23]–[25].

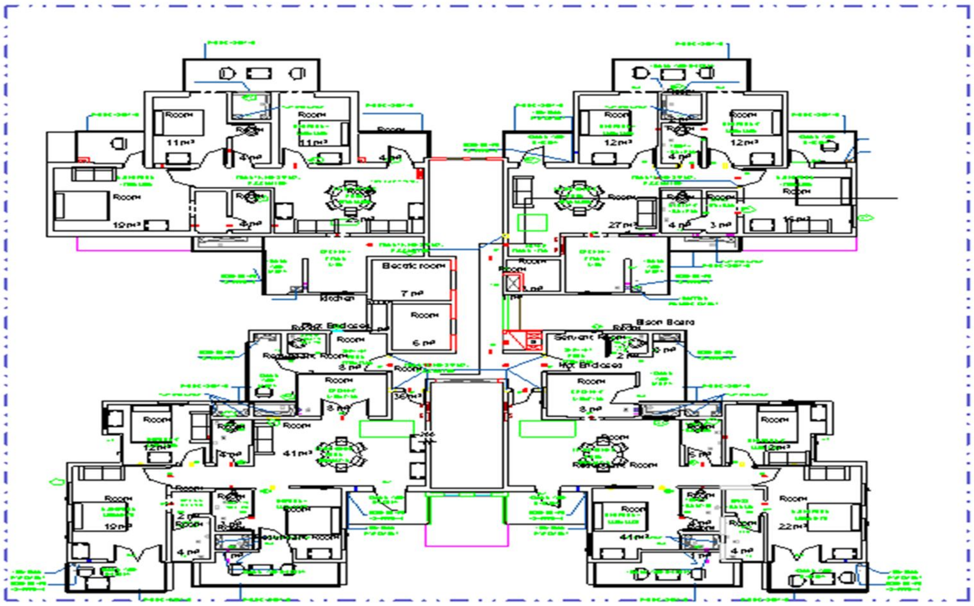

Fig.2. 2D PLAN

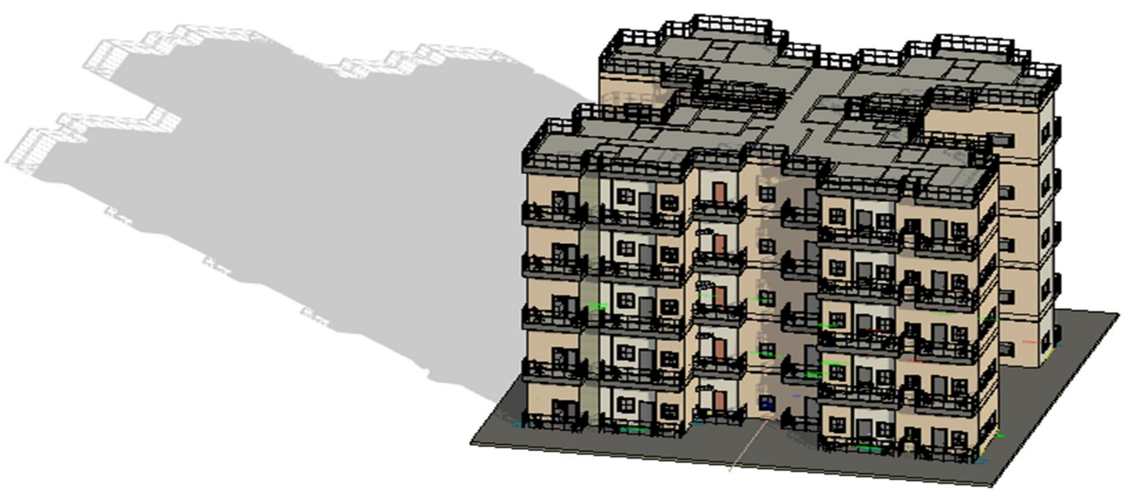

Fig.3. 3D PLAN

C. Effective Parameter used in Building Simulation

In the context of building simulation, various parameters play a crucial role in creating an effective simulation model[18]. These parameters help in accurately representing and analyzing the behaviour of a building or system. Here are some key parameters used in building simulation like Geometry and Layout(Building Shape and Size, Room Layout), Thermal Properties(Material Properties, Insulation Values, Window Properties), Climate Data(Weather Conditions, Location-specific Data), Occupancy and Usage Patterns, HVAC Systems, Control Strategies, Internal Loads(Lighting, Appliances), Ventilation and Infiltration, Simulation Time Steps, Simulation Software Settings, Validation and Calibration Data(Real Data Comparison, Calibration Parameters)[26]–[28].

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Table 2. Building component and material used in building

S.no.	Component	Material used
1.	Wall Construction	Fiber glass 20mm, Concrete mass 100mm, ICF (Insulated Concrete Form).
2.	HVAC System	ASHARE package terminal heat pump & High Efficiency VAV.
3.	Operating Schedule	12/6-12/5
4.	Plug load Efficiency	7.53-3.23W/m^2
5.	Day lighting & Occupancy Controls	Only Daylight Control
6.	Roof construction	R60 & 0.17ACH (Air change per hour)
7.	Window glass WWR	Dbl LoE & Dbl clr
8.	WWR (Window to Wall Ratio)	40-15%(BIM)
9.	Window Shade	1/3-2/3 of Window height

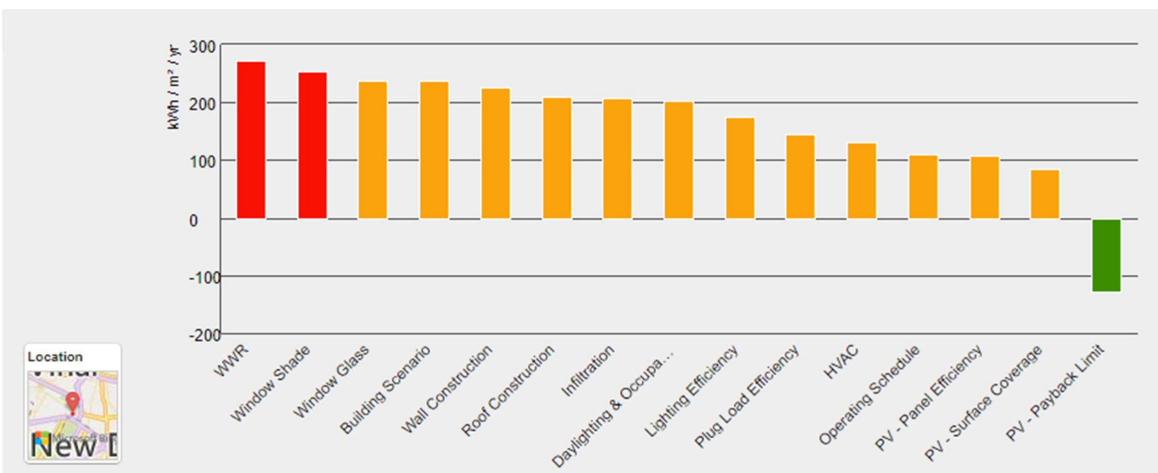

Fig.4. Rank of Selecting Parameter

Note: A). According to given Fig.4 rank is gives in decreasing order in such a way that Energy consumption decreasing and get to optimize building.

Rank order: Payback limit> HVAC>Window shade>Window Glass>Plug load Efficiency>Day lighting & Occupancy Controls>WWR (Window To Wall Ratio)

III. ANALYSIS RESULTS

1) *Monthly Temperature:* According to the given fig.5. Average Monthly temperature slope varies in order from January 14.5°C to Peak Average Monthly temperature of month May 33.9°C then slope will decrease May to December 15.5°C.
2) *Windrose Speed:* According to the Annual windrose diagram (Fig.6.) weather Station WNW 1.7Km away from the location of the building. Maximum Speed in WNW is 16kmph up to 10% with 2% Frequency and 12kmph with frequency 6.5%.

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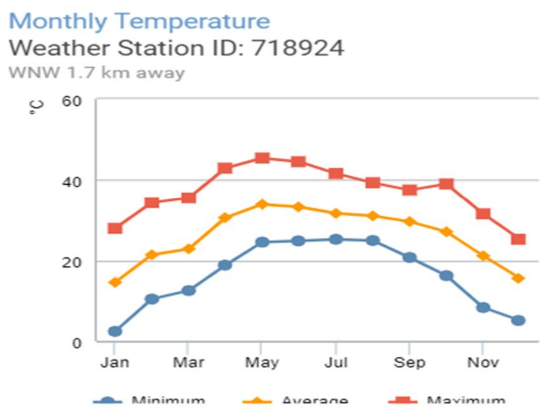

Fig.5. Monthly Temperature

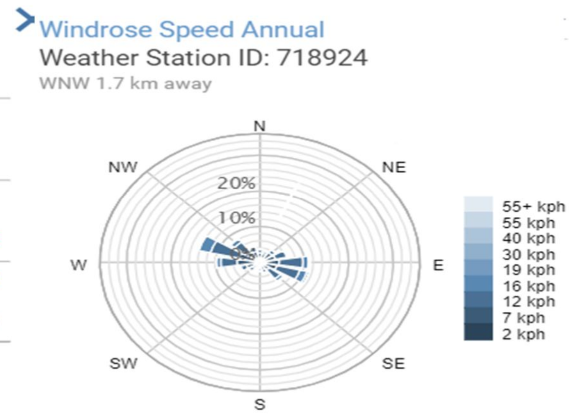

Fig.6. Windrose Diagram

3) *Solar Radiation:* This study investigates how solar radiation on building surfaces. After setting parameters such as project location, date, time, and time interval, will be obtained a graphical presentation of solar radiation (Fig. 7). The results indicated that block A (located on the western side of the site) with the most sunlight received during a day, had a better position compared to other blocks.

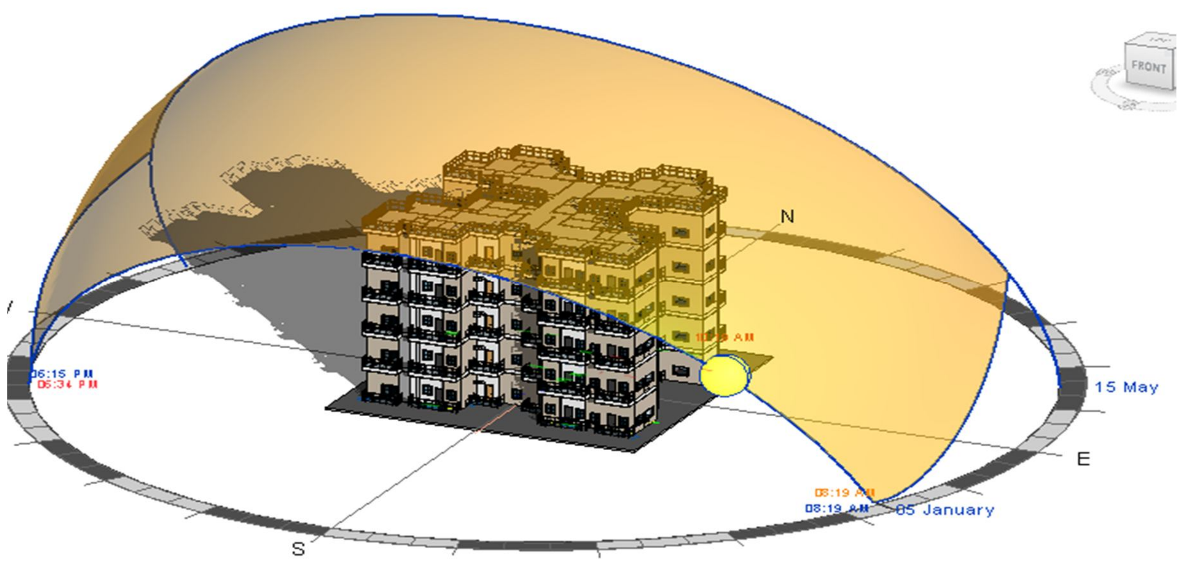

Fig.7. Solar radiation

4) *Energy Optimisation*

Energy Optimization for Revit is a fast, reliable, and scalable tool for better building energy performance.

Analyze tab ➤ Energy Optimization panel ➤

- (Location)
- (Create Energy Model)
- (Generate)
- (Optimize)
- (Energy Setting)

According to this analysis, ventilation fans and space cooling have the largest share compared to other parameters affecting energy consumption. The maximum energy use intensity in block A is observed in January Obviously, space heat and ventilation fans have the highest share among other parameters. Accordingly, the highest level of energy consumption based on energy cost is seen in July and August, and based on energy use intensity is seen in January and December. The schematic diagrams of energy consumption for blocks B, C, D, and the middle-lobby are similar.

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IV. BUILDING SIMULATION

1) The results of this analysis show that block A has the lowest energy consumption, among other blocks. The cost of energy consumption based on parameters is 237kwh/m2/year, as shown in Table 2. This value for blocks B, C, D, and the middle-lobby is equal to 13, 13.6, 14.1, and 14.1, respectively. Accordingly, the energy use intensity for blocks A-D and the middle-lobby would be equal to 112, 119, 126, 119, and 191 kWh/m2/year, respectively.
2) The building orientation, in this case, is based on the geographical north. Thus, the angle of the building is automatically determined by the software, based on the building form and the project geographic coordinates.
3) The windows ratios to the northern, southern, eastern, and western walls are 16%, 20%, 7%, and 5%, respectively.
4) The shades of all windows were considered by default. Therefore, the windows installed on the terraces would use their overhead ceiling as a shade.
5) The walls and roof materials are shown in Tables 3 and 6.
6) The values of the building infiltration rate, lighting efficiency, plug load efficiency, operating schedule, and building's HVAC system were adjusted according to the BIM parameter (as shown in Table 2).
7) After adjusting the parameters affecting energy consumption, according to Table 2.

A. Energy using Intensity

Upon completion of the requisite energy consumption analyses, as outlined in the methodology, and in light of the outcomes attained a significant reduction in EUI.

This reduction is indicative of the building's energy utilization levels.

Note: There are two cases are generated:

- First rank given to HVAC and Passive energy parameters.
- First rank given to Payback limit up to 30 years energy parameter.

B. Sample of Room - Area Report for Ground Floor

This area calculation proof is generated by computing a signed area under every boundary curve of a room and summing them together (computing an integral around a closed contour). Room boundaries are traversed so that a room is always on the left-hand side of a boundary.

The top portion of the boundary contributes positive area under the top of the boundary while bottom portion contributes negative value subtracting area under the bottom.

- For linear segments signed areas are calculated as-

$$\frac{1}{2} * (x_0 - x_1) * (y_0 + y_1), \qquad \text{equation-(i)}$$

- For arc segments signed areas are calculated as

$R * y_c * (\cos a_0 - \cos a_1) + \frac{1}{2} * R^2 * (a_1 - a_0 + \frac{1}{2} * (\sin 2a_0 - \sin 2a_1))$,

where $\mathbf{y_c}$ is the **y**-coordinate of the center of the arc, **R** is the radius of the segment and $\mathbf{a_0}$ and $\mathbf{a_1}$ are start and stop angles of the arc respectively.

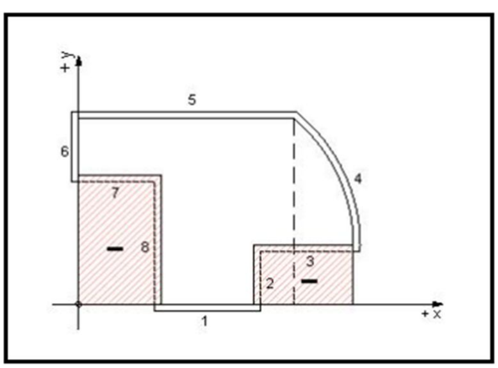

Fig.8. Area Calculation model

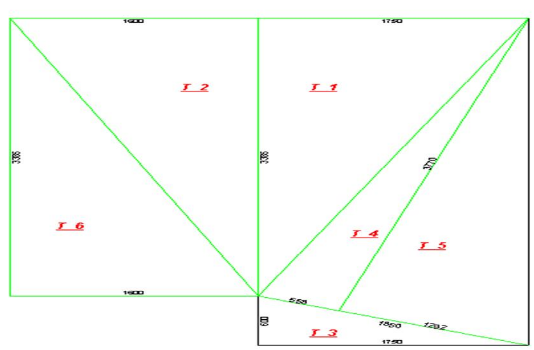

Fig.9. office Room - Room Number 32

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Table 3. Area calculation for office Room - Room Number 32

	Segment Type	Sub-Area	x_0	y_0	x_1	y_1	y_c	R	a_0	a_1
1	Linear	0 m²	0	1450	0	600	.	.	.	.
2	Linear	-1 m²	0	600	1600	600	.	.	.	.
3	Linear	0 m²	1600	600	1600	0	.	.	.	.
4	Linear	0 m²	1600	0	3350	0	.	.	.	.
5	Linear	0 m²	3350	0	3350	3985	.	.	.	.
6	Linear	13 m²	3350	3985	0	3985	.	.	.	.
7	Linear	0 m²	0	3985	0	1450	.	.	.	.

Total Room Area : 12 m²

Total Windows Area : 1 m²

Hence, We get net maximum EUI value of the building using formula Given in Table no. 4 and 5.

$$EUI = \frac{\text{Total Annual Energy Use}}{\text{Total Gross Square Footage}}$$

1) *CASE 1:* According to given figure 8,9 and table 3. Net Reduction of upto EUI 44.3%

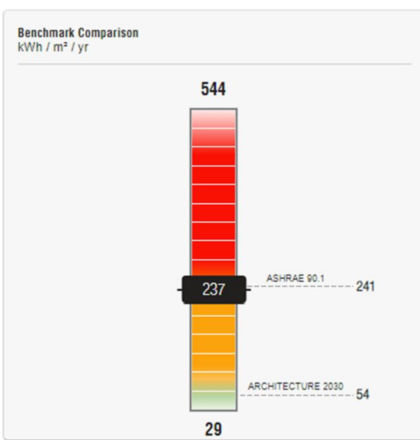

Fig.10. Initial Benchmark Comparison

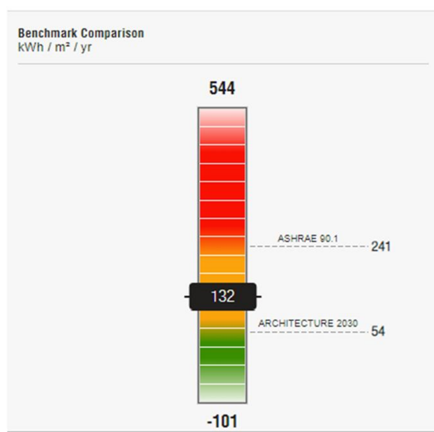

Fig.11. Final Benchmark Comparison

Table 4. Energy using Intensity

EUI Max (kWh / m² / yr)	544	544
EUI Mean (kWh / m² / yr)	237	132
EUI Min (kWh / m² / yr)	29	-101
Net EUI reduced (in kWh/m2/yr.)	105	

2) *CASE II:* When we apply Payback limit up to 30 years then followed by CASE I and Hence we get Green Building(Fig .11.)

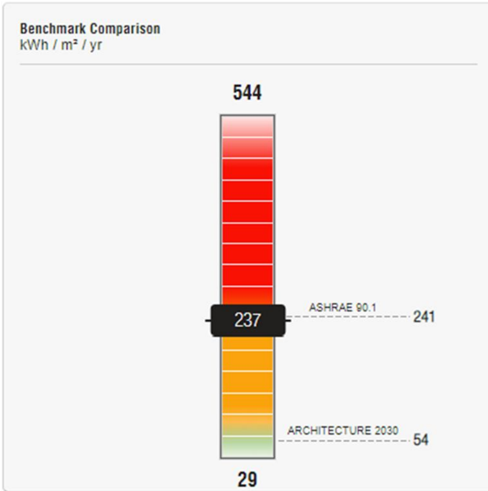

Fig.11. Initial Benchmark Comparison

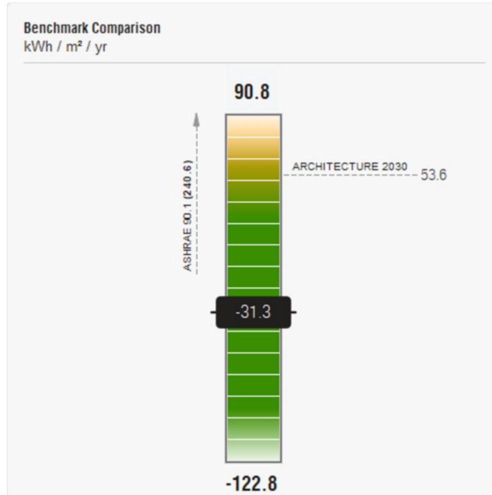

Fig.12. Final Benchmark Comparison

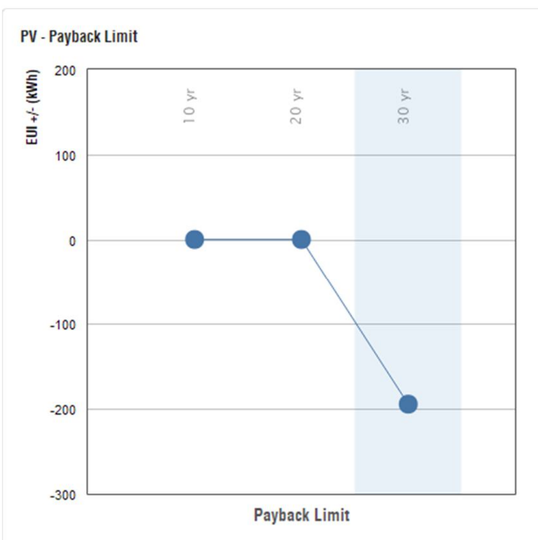

Fig.13. Payback Limit

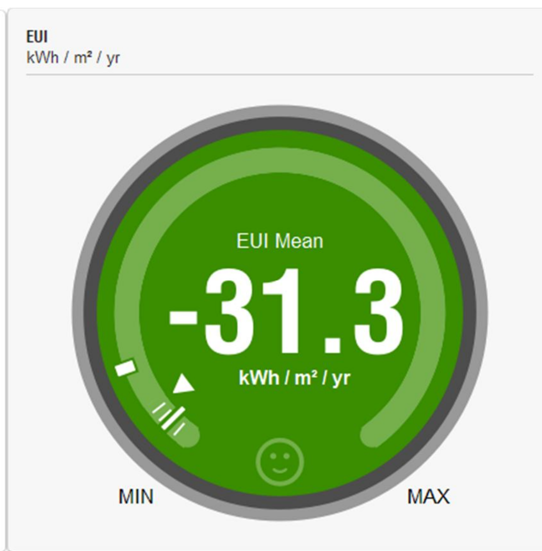

Fig.14. Energy cost

Table 5. Energy using Intensity

EUI Max (kWh / m² / yr)	544	90.8
EUI Mean (kWh / m² / yr)	237	-31.3
EUI Min (kWh / m² / yr)	29	-122.8
Net EUI reduced (in kWh/m2/yr.)	-31.3	

V. CONCLUSION

By utilising several tactics including building orientation, WWR, etc., this study seeks to identify the most effective design strategies for lowering cooling demand, refrigerant demand, and energy consumption in office buildings in diverse regions.

1) By applying the first example, it was discovered that the building performance in New Delhi Safdarjung had improved by 44.3%. A 30-year repayment restriction is applied in Cases 1 and 2, respectively. We obtain a mean EUI score of -31.3%, indicating net zero energy construction.
2) In New Delhi Safdarjung, optimising the building orientation, WWR, window shades and glazing, and roof characteristics produced the greatest impact.
3) On the other hand, New Delhi's maximum energy consumption decrease of 40.86% was made possible by optimising lighting efficiency and management.
4) In office buildings across various temperature zones, the average reduction in EUI, annual energy consumption, and annual energy peak demand is determined to be -31.3 kWh/m2/yr,0 kWh/m2/yr and 90.8 kWh/m2/yr respectively.

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