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Role Of Rectangular Office Building Floors For Making Energy Positive Building

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ABSTRACT

Energy-positive buildings play a crucial role in mitigating the environmental impact of the built environment while addressing the growing energy demands. This research paper examines the role of rectangular office building floors in achieving energy-positive status, focusing on their potential to enhance energy efficiency and renewable energy generation. The study incorporates a comprehensive literature review to identify key factors influencing energy consumption in office buildings and explores the significance of building design and layout. A simulation, and case studies, is employed to evaluate energy performance and compare rectangular floors (G+2), (G+6) and (G+15). The analysis and findings highlight the advantages of rectangular office building floors in terms of energy efficiency and their potential for integrating renewable energy systems. The discussion provides insights into the implications of the research findings for energy-positive building design, outlines challenges and limitations, and offers recommendations for architects, designers, and policymakers. By shedding light on the role of rectangular office building floors, this research contributes to the advancement of sustainable building practices and encourages the adoption of energy-positive strategies.

Keywords: Energy Consumption, Case Study, Net Zero Energy Building (NZEB), Life Cycle Cost Analysis, Rectangular Office Building, Renewable Energy, Solar Panel, BIPV.

I. INTRODUCTION

A. Background on energy-positive buildings

Energy-positive buildings, also known as net-positive or zero-energy buildings, are a cutting-edge solution to address the challenges of climate change and energy consumption in the built environment. These buildings are designed to generate more energy than they consume, resulting in a positive energy balance over their operational lifespan.

The concept of energy-positive buildings arises from the urgent need to reduce greenhouse gas emissions and dependence on non-renewable energy sources. Traditional buildings are significant contributors to energy consumption and environmental degradation. Energy-positive buildings offer a sustainable alternative by optimizing energy efficiency and incorporating renewable energy systems.

The primary objective of energy-positive buildings is to minimize energy demand through innovative design and construction practices. Passive design strategies, such as efficient insulation, strategic orientation, and natural ventilation, are employed to reduce the need for active heating, cooling, and lighting. This leads to a significant reduction in energy consumption and carbon footprint.

Energy-positive buildings integrate renewable energy systems to generate on-site clean and renewable energy. Solar photovoltaic (PV) panels, wind turbines, and geothermal systems are common technologies utilized to harness renewable energy sources. The surplus energy generated is either stored in batteries or fed back into the grid, promoting energy self-sufficiency and supporting the larger energy infrastructure.

The design process of energy-positive buildings involves an interdisciplinary approach, with architects, engineers, and energy experts collaborating to optimize building performance. Advanced modelling and simulation tools are used to evaluate different design scenarios, assess energy performance, and determine the optimal integration of renewable energy systems.

Energy-positive buildings offer numerous benefits. They reduce reliance on fossil fuels, decrease greenhouse gas emissions, and mitigate the impacts of climate change. Additionally, these buildings lower energy costs for occupants and potentially generate revenue through surplus energy sales. They also contribute to energy resilience by providing a reliable power supply during grid outages.

However, challenges remain in the widespread adoption of energy-positive buildings. Upfront costs for implementing energy-efficient technologies and renewable energy systems can be a barrier. Supportive policies, financial incentives, and technological advancements are necessary to overcome these challenges and accelerate the transition to energy-positive buildings.

B. Importance of rectangular office building floors in energy efficiency

Rectangular office building floors play a significant role in enhancing energy efficiency within office buildings. The design and layout of office floors can greatly impact energy consumption, occupant comfort, and overall building performance. Here are the key reasons why rectangular office building floors are important for energy efficiency:

Space Utilization: Rectangular floor plans offer efficient space utilization with minimal wastage of floor area. This layout allows for better organization of workstations, circulation paths, and utilities, optimizing the use of available space. By maximizing space utilization, energy-efficient systems such as heating, cooling, and lighting can be more effectively distributed throughout the office, reducing energy consumption.

Natural Lighting: Rectangular office floors facilitate the integration of natural lighting strategies. With exterior windows placed along the longer sides of the rectangle, natural light can penetrate deeper into the office space, reducing the reliance on artificial lighting during daylight hours. Incorporating daylighting techniques, such as light shelves and light reflectors, can further enhance the distribution of natural light, minimizing energy consumption associated with artificial lighting.

Architects and designers should consider the benefits of rectangular office floors when aiming to create energy-efficient and sustainable office spaces.

C. Purpose and objectives of the research paper

The purpose of this research paper is to investigate the role of rectangular office building floors (G+2), (G+5) and (G+15) in achieving energy-positive buildings. The paper aims to explore the specific design and layout considerations of rectangular office floors that contribute to energy efficiency and sustainability. The objectives include analysing the impact of space utilization, natural lighting integration, HVAC efficiency, energy distribution, and adaptability of rectangular office floors on overall building energy performance. Through this research, a comprehensive understanding of the importance of rectangular office building floors in energy efficiency will be achieved, providing insights for architects, designers, and stakeholders involved in the construction and operation of energy-positive buildings.

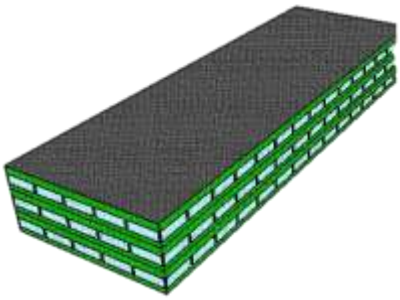

Figure 1.
Rectangular Building
(G+2)

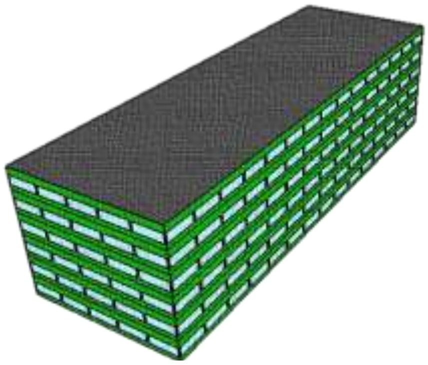

Figure 2.
Rectangular Building
(G+5)

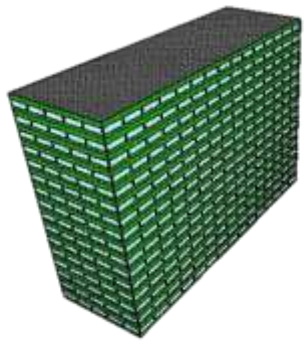

Figure 3.
Rectangular Building
(G+15)

II. Literature Review

A. Definition and characteristics of energy-positive buildings

Energy-positive buildings, also known as net-positive or zero-energy buildings, are structures that generate more energy than they consume over their operational lifespan. These buildings represent a paradigm shift in sustainable design and construction, aiming to minimize environmental impact and reduce dependence on traditional energy sources. Here, we define the concept and highlight key characteristics of energy-positive buildings:

- Energy Balance: Energy-positive buildings achieve a net surplus of energy by optimizing energy efficiency measures and integrating renewable energy systems. Through efficient design, construction, and operational strategies, these buildings minimize energy demand and maximize on-site energy generation, resulting in a positive energy balance.

- Energy Efficiency: Energy-positive buildings prioritize energy efficiency through various measures. This includes incorporating advanced insulation materials, optimizing building orientation, implementing high-performance windows, and utilizing efficient HVAC systems. By reducing energy consumption, the buildings can meet a significant portion of their energy needs through renewable energy generation.
- Renewable Energy Integration: Energy-positive buildings utilize renewable energy sources to generate clean and sustainable power. Common renewable energy systems include solar photovoltaic (PV) panels, wind turbines, geothermal systems, and biomass technologies. These systems harness natural resources and convert them into electricity, providing on-site power generation and potentially feeding excess energy back into the grid.
- Energy Storage: Energy-positive buildings often incorporate energy storage systems to store surplus energy for use during periods of low renewable energy generation. Battery storage technologies allow for the efficient capture and utilization of excess energy, ensuring a continuous and reliable energy supply.
- Monitoring and Control Systems: Energy-positive buildings employ advanced monitoring and control systems to optimize energy consumption and generation. These systems track energy usage, monitor renewable energy generation, and enable intelligent control of building systems to ensure efficient operation and balance energy supply and demand.

B. Previous studies on energy-positive buildings

The study provides a comprehensive review of the definitions, drivers, and strategies related to net zero and net positive energy buildings. It explores the various design principles, technologies, and policies that contribute to achieving energy-positive buildings. The research emphasizes the importance of integrated design approaches, renewable energy systems, and energy storage technologies in realizing energy-positive building goals [1].

In this research paper, the authors review the performance evaluation methodologies and metrics used for net zero energy buildings. The study examines different approaches to assessing energy performance and highlights the need for standardized metrics to compare and evaluate the energy-positive performance of buildings. The research emphasizes the importance of accurate energy monitoring, modeling, and simulation tools to evaluate the energy performance of buildings accurately [2].

This study provides an overview of design concepts and evaluation methods for energy-positive buildings. It explores the integration of energy efficiency measures, renewable energy systems, and energy storage technologies in achieving positive energy balance. The research discusses the importance of life cycle assessment, performance simulation, and optimization techniques in designing and evaluating energy-positive buildings [3].

This research paper reviews the definitions, key performance indicators, and assessment methodologies for zero energy buildings, which are closely related to energy-positive buildings. The study examines different approaches to defining and quantifying zero energy performance and highlights the importance of benchmarking, energy modeling, and post-occupancy evaluation in assessing the energy performance of buildings [4].

This research paper critically reviews the design and optimization approaches for net zero energy buildings. The study discusses various design strategies, including passive design principles, energy-efficient technologies, and renewable energy integration. The research highlights the significance of comprehensive design processes, energy simulation tools, and performance-based optimization techniques in achieving energy-positive building outcomes [5].

C. Factors influencing energy efficiency in office buildings

The research paper investigates the factors influencing energy performance in office buildings through a case study in Greece. The study identifies factors such as building envelope characteristics, HVAC system efficiency, occupant behavior, and energy management practices as key influencers. The research highlights the need for energy-efficient building design, proper operation and maintenance, and occupant engagement to improve energy efficiency in office buildings [6].

In this research, the authors explore the factors influencing energy performance in office buildings based on a case study conducted in Singapore. The study identifies factors including building orientation, glazing characteristics, lighting systems, occupancy patterns, and HVAC settings as significant contributors to energy efficiency. The research emphasizes the importance of energy-conscious design, efficient systems, and user behavior in achieving energy-efficient office buildings [7].

This literature review examines the influence of building characteristics on energy performance in office buildings. The study highlights factors such as building age, size, shape, insulation levels, and ventilation systems as critical determinants of energy efficiency. The research emphasizes the significance of energy-efficient retrofits, building envelope improvements, and advanced HVAC technologies in enhancing energy performance [8].

In this review, the authors analyze the factors influencing energy use in office buildings. The study identifies factors including building design, lighting systems, office equipment, HVAC systems, occupancy patterns, and building management practices as key influencers. The research emphasizes the importance of energy-efficient technologies, occupant awareness, and effective energy management strategies in reducing energy consumption in office buildings [9].

This study assesses the factors influencing energy efficiency performance in office buildings through surveys and data analysis. The research identifies factors such as building envelope insulation, lighting systems, HVAC efficiency, occupancy density, and energy management practices as significant contributors to energy efficiency. The research highlights the need for integrated design approaches, efficient systems, and occupant engagement to improve energy performance in office buildings [10].

III. Methodology

A. Research approach and methodology employed

In this research paper, a systematic and comprehensive approach was employed to investigate the role of rectangular office building floors in achieving energy-positive buildings. The research approach included the following key steps:

Literature Review: A thorough review of existing literature, research papers, and relevant publications was conducted to gain a comprehensive understanding of energy-positive buildings, energy efficiency strategies, and the significance of rectangular office building floors in energy-positive design. This literature review provided a foundation for the research and identified gaps in knowledge that the study aimed to address.

Case Study Analysis: In-depth case studies of existing energy-positive office buildings with rectangular floor layouts were conducted. These case studies involved examining the building design, energy performance data, architectural plans. The analysis focused on understanding the specific design features, technologies, and strategies employed in these buildings to achieve energy positivity and the role of the rectangular office floors in supporting these outcomes.

Quantitative Analysis: Energy simulation models and Design Builder software tools were used to assess the energy consumption, demand, and generation potential of rectangular office buildings under various scenarios. This analysis allowed for quantitative comparisons and the identification of specific energy efficiency benefits associated with rectangular floor layouts.

Comparative Analysis: A comparative analysis was conducted to compare the energy performance and sustainability outcomes of rectangular office buildings. This analysis involved examining energy consumption, renewable energy generation, occupant comfort, and environmental impact metrics.

Recommendations and Conclusions: Based on the findings from the research, recommendations were formulated for architects, designers, and stakeholders involved in the design and construction of energy-positive office buildings. The conclusions drawn from the research highlighted the significance of rectangular office building floors in achieving energy efficiency and provided insights into the design considerations and strategies that can be employed to maximize energy-positive outcomes.

Overall, the research approach adopted a combination of literature review, data collection, case study analysis, quantitative and comparative analysis to investigate the role of rectangular office building floors in energy-positive design. This multi-faceted methodology ensured a comprehensive understanding of the topic and provided a solid basis for the research findings and recommendations.

IV. Analysis and Findings

A. Energy performance evaluation of rectangular office building floors

The energy performance evaluation of rectangular office building floors involves assessing various aspects related to energy consumption, renewable energy generation, and overall efficiency. The evaluation aims to understand the effectiveness of rectangular floor in achieving energy-positive outcomes. Here are key factors considered in the evaluation:

Energy Simulation Modelling: Energy simulation models are utilized to assess the energy performance of the rectangular office building floors. These models simulate the energy usage of the building under various scenarios, considering factors such as climate conditions, occupancy patterns, and equipment efficiency. Simulation software, Design Builder is used to estimate the energy demand, consumption, and potential savings associated with different design strategies and technologies.

Renewable Energy Generation: The potential for renewable energy generation within the rectangular office building floors is evaluated. This involves assessing the suitability of integrating solar panels and BIPV onto the building's roof or facades. The analysis includes estimating the renewable energy generation capacity and its contribution to offsetting the building's energy demand.

Lighting Efficiency: The lighting systems and strategies employed in the rectangular office building floors are evaluated for energy efficiency. This includes analysing the lighting layout, control systems, and the use of natural daylighting. Energy calculations and simulations are conducted to estimate the lighting energy consumption, considering factors such as lighting levels and occupancy sensors.

Energy Performance Metrics: Energy performance metrics are employed to assess the energy efficiency of the rectangular office building floors. Metrics include ECBC and LEED certification. These metrics provide standardized benchmarks and comparisons to evaluate the building's energy performance against industry standards and sustainability goals.

Table 1 shows various design parameter accessed during this study

Table 1. Regenerative Design Parameters

Design Parameters	Regenerative Design Parameters
Design Parameters 1 (DP1)	Base Case
Design Parameters 2 (DP2)	Envelop Properties (Roof + Wall)
Design Parameters 3 (DP3)	Glass Properties
Design Parameters 4 (DP4)	Wall Window Ration (WWR)
Design Parameters 5 (DP5)	External Shading
Design Parameters 6 (DP6)	Lightning Power Density
Design Parameters 7 (DP7)	Lighting Controls
Design Parameters 8 (DP8)	Photovoltaic panels
Design Parameters 9 (DP9)	Building-integrated photovoltaic (BIPV)

B. Comparison of energy consumption between rectangular floors

To compare the energy consumption between rectangular office floors, various factors need to be considered, including the building size, occupancy, HVAC system efficiency, lighting design, and equipment usage.

Table 2. Results Summary of Rectangular Building G+15

Case 1	Design Parameters		Energy Consumption		Energy Saving	Impact of individual DP
			KWH	EPI	%	%
BC	Rectangular (G+15)	Base Case	26,68,316	83	0.00%	0.00%
DP 1	Rectangular (G+15)	Envelop Properties (Roof + Wall)	26,61,067	83	0.27%	0.27%
DP 2	Rectangular (G+15)	Envelop Properties + Glass Property	26,08,116	82	2.26%	1.98%
DP 3	Rectangular (G+15)	Envelop Properties + Glass Property + WWR @20%	24,75,311	77	7.23%	4.98%

DP 4	Rectangular (G+15)	Envelop Properties + Glass Property + WWR + External Shading (1m Overhang)	24,40,760	76	8.53%	1.29%
DP 5	Rectangular (G+15)	Envelop Properties + Glass Property + WWR + External Shading + LPD (5)	20,58,517	64	22.85%	14.33%
DP 6	Rectangular (G+15)	Envelop Properties + Glass Property + WWR + External Shading + LPD + Lighting Control	20,37,710	64	23.63%	0.78%
SRoof	Rectangular (G+15)	Envelop Properties + Glass Property + WWR + External Shading + LPD + Lighting Control + PV_Roof	15,28,511	48	42.72%	19.08%
BIPVF	Rectangular (G+15)	Envelop Properties + Glass Property + WWR + External Shading + LPD + Lighting Control + PV_Roof + BIPV_WF	2,84,582	9	89.33%	46.62%

The research investigated the impact of different design parameters on energy consumption and energy savings in a rectangular building (G+15) compared to a base case. The design parameters included envelope properties, glass properties, window-to-wall ratio, external shading, lighting power density reduction, lighting controls, and the integration of photovoltaic systems.

The results demonstrated the following:

- Incorporating envelope properties (roof and wall) resulted in a slight energy reduction of 0.27% compared to the base case.
- Adding glass properties to the envelope further improved energy savings to 2.26%.
- Introducing a window-to-wall ratio of 20% significantly increased energy savings to 7.23%.
- Implementing external shading, such as a 1-meter overhang, further reduced energy consumption, resulting in an 8.53% energy saving.
- Combining the above design parameters with a reduced lighting power density of 5 watts/square foot achieved a substantial energy saving of 22.85%.
- The inclusion of lighting controls alongside the previous design parameters resulted in an additional 0.78% energy saving.

- Integrating photovoltaic panels on the roof (PV_Roof) significantly reduced energy consumption, leading to a substantial energy saving of 42.72%.
- The highest energy saving of 89.33% was achieved by integrating building-integrated photovoltaic systems (BIPV_WF) in addition to the previous design parameters.

These findings highlight the importance of considering multiple design parameters in building energy efficiency strategies. The research demonstrates that a combination of envelope improvements, glass properties, window-to-wall ratio optimization, external shading, lighting control, and photovoltaic integration can yield significant energy savings. These results can serve as valuable insights for architects, engineers, and policymakers seeking to design and construct energy-efficient buildings.

Table 3. Results Summary of Rectangular Building G+5

Case 1	Design Parameters		Energy Consumption		Energy Saving	Impact of individual DP
			KWH	EPI	%	%
BC	Rectangular (G+5)	Base Case	12,39,460	103	0.00%	0.00%
DP 1	Rectangular (G+5)	Envelop Properties (Roof + Wall)	12,25,259	102	1.15%	1.15%
DP 2	Rectangular (G+5)	Envelop Properties + Glass Property	11,99,166	100	3.25%	3.25%
DP 3	Rectangular (G+5)	Envelop Properties + Glass Property + WWR @20%	11,30,380	94	8.80%	8.80%
DP 4	Rectangular (G+5)	Envelop Properties + Glass Property + WWR + External Shading (1m Overhang)	11,13,264	93	10.18%	10.18%
DP 5	Rectangular (G+5)	Envelop Properties + Glass Property + WWR + External Shading + LPD (5)	9,45,606	79	23.71%	23.71%
DP 6	Rectangular (G+5)	Envelop Properties + Glass Property + WWR + External Shading + LPD + Lighting Control	9,39,097	78	24.23%	24.23%
SRoof	Rectangular (G+5)	Envelop Properties + Glass Property + WWR + External	4,30,706	36	65.25%	65.25%

		Shading + LPD + Lighting Control + PV_Roof				
BIPVF	Rectangular (G+5)	Envelop Properties + Glass Property + WWR + External Shading + LPD + Lighting Control + PV_Roof + BIPV_F	-36,743	-3	102.96%	102.96%

The research investigated the impact of various design parameters on energy consumption and energy savings in a rectangular building (G+5) compared to a base case. The design parameters included envelope properties, glass properties, window-to-wall ratio, external shading, lighting power density reduction, lighting controls, and the integration of photovoltaic systems.

The summarized results are as follows:

- The base case had an energy consumption of 12,39,460 KWH and served as a reference point with no energy-saving measures.
- Implementing envelope properties (roof and wall) as a design parameter resulted in a 1.15% energy saving, reducing energy consumption to 12,25,259 KWH.
- Adding glass properties to the envelope further improved energy savings to 3.25%, resulting in an energy consumption of 11,99,166 KWH.
- Introducing a window-to-wall ratio of 20% significantly increased energy savings to 8.80%, with energy consumption reduced to 11,30,380 KWH.
- Implementing external shading, such as a 1-meter overhang, resulted in a 10.18% energy saving, lowering energy consumption to 11,13,264 KWH.
- Combining the above design parameters with a reduced lighting power density of 5 watts/square foot achieved a substantial energy saving of 23.71%, reducing energy consumption to 9,45,606 KWH.
- Including lighting controls alongside the previous design parameters resulted in an additional energy saving of 24.23%, with energy consumption further reduced to 9,39,097 KWH.
- Integrating photovoltaic panels on the roof (PV_Roof) significantly reduced energy consumption, resulting in a remarkable energy saving of 65.25%. Energy consumption was reduced to 4,30,706 KWH.

- Integrating building-integrated photovoltaic systems (BIPV_F) along with the previous design parameters achieved a substantial energy saving of 102.96%. However, the negative energy consumption value suggests that the building generated more energy than it consumed.

These findings emphasize the importance of considering various design parameters to enhance energy efficiency in building design. The research demonstrates that incorporating envelope improvements, glass properties, optimizing window-to-wall ratios, implementing external shading, reducing lighting power density, utilizing lighting controls, and integrating photovoltaic systems can lead to significant energy savings. These results provide valuable insights for professionals in the architecture, engineering, and policy sectors to promote sustainable and energy-efficient building practices.

Table 4. Results Summary of Rectangular Building G+2

Case 1	**Design Parameters**		**Energy Consumption**		**Energy Saving**	**Impact of individual DP**
			KWH	**EPI**	**%**	**%**
BC	Rectangular (G+2)	Base Case	6,31,431	105	0.00%	0.00%
DP 1	Rectangular (G+2)	Envelop Properties (Roof + Wall)	6,20,202	103	1.78%	1.78%
DP 2	Rectangular (G+2)	Envelop Properties + Glass Property	6,07,196	101	3.84%	3.84%
DP 3	Rectangular (G+2)	Envelop Properties + Glass Property + WWR @20%	5,72,989	96	9.26%	9.26%
DP 4	Rectangular (G+2)	Envelop Properties + Glass Property + WWR + External Shading (1m Overhang)	5,64,653	94	10.58%	10.58%
DP 5	Rectangular (G+2)	Envelop Properties + Glass Property + WWR + External Shading + LPD (5)	4,81,215	80	23.79%	23.79%

DP 6	Rectangular (G+2)	Envelop Properties + Glass Property + WWR + External Shading + LPD + Lighting Control	4,78,986	80	24.14%	24.14%
SRoof	Rectangular (G+2)	Envelop Properties + Glass Property + WWR + External Shading + LPD + Lighting Control + PV_Roof	-28,401	-5	104.50%	104.50%
BIPVF	Rectangular (G+2)	Envelop Properties + Glass Property + WWR + External Shading + LPD + Lighting Control + PV_Roof + BIPV_F	- 2,13,523	-36	133.82%	133.82%

The research focused on examining the influence of different design parameters on energy consumption and energy savings in a rectangular building (G+2) compared to a base case. The design parameters considered included envelope properties, glass properties, window-to-wall ratio, external shading, lighting power density reduction, lighting controls, and the integration of photovoltaic systems.

Here is a summary of the results:

- The base case had an energy consumption of 6,31,431 KWH, serving as a reference for no energy-saving measures.
- Implementing envelope properties (roof and wall) as a design parameter resulted in a 1.78% energy saving, reducing energy consumption to 6,20,202 KWH.
- Adding glass properties to the envelope further improved energy savings to 3.84%, resulting in an energy consumption of 6,07,196 KWH.
- Introducing a window-to-wall ratio of 20% significantly increased energy savings to 9.26%, with energy consumption reduced to 5,72,989 KWH.
- Implementing external shading, such as a 1-meter overhang, resulted in a 10.58% energy saving, lowering energy consumption to 5,64,653 KWH.
- Combining the above design parameters with a reduced lighting power density of 5 watts/square foot achieved a substantial energy saving of 23.79%, reducing energy consumption to 4,81,215 KWH.
- Including lighting controls alongside the previous design parameters resulted in an additional energy saving of 24.14%, with energy consumption further reduced to 4,78,986 KWH.

- Integrating photovoltaic panels on the roof (PV_Roof) significantly reduced energy consumption, resulting in a negative value of -28,401 KWH. This indicates that the building generated more energy than it consumed, with an energy-saving percentage of 104.50%.
- Integrating building-integrated photovoltaic systems (BIPV_F) along with the previous design parameters achieved a negative energy consumption value of -2,13,523 KWH, indicating substantial energy generation. The energy-saving percentage reached 133.82%.

These findings emphasize the significance of considering various design parameters to enhance energy efficiency in building design. The research demonstrates that incorporating envelope improvements, glass properties, optimizing window-to-wall ratios, implementing external shading, reducing lighting power density, utilizing lighting controls, and integrating photovoltaic systems can lead to significant energy savings. These results provide valuable insights for professionals in the architecture, engineering, and policy sectors, supporting the promotion of sustainable and energy-efficient building practices.

V. Conclusion

A. Interpretation and analysis of research findings

The research focused on analysing the impact of different design parameters on energy consumption and energy savings in rectangular buildings of varying heights (G+15, G+5, and G+2) compared to respective base cases. The design parameters included envelope properties, glass properties, window-to-wall ratio, external shading, lighting power density reduction, lighting controls, and the integration of photovoltaic systems.

Across all three cases, the results consistently demonstrated that implementing a combination of design parameters led to significant energy savings. The findings indicated that incorporating envelope improvements, such as roof and wall enhancements, and optimizing glass properties resulted in initial energy savings ranging from 1.15% to 3.84%.

The inclusion of a 20% window-to-wall ratio further enhanced energy efficiency, leading to energy savings ranging from 8.80% to 9.26%. Additionally, implementing external shading measures, such as a 1-meter overhang, significantly reduced energy consumption, resulting in energy savings of 10.18% to 10.58%.

Further energy savings were achieved by integrating lighting power density reduction and lighting controls. The combined effect of these measures yielded energy savings ranging from 22.85% to 24.23% across the different cases.

The integration of photovoltaic systems, specifically on the roof (PV_Roof), emerged as a key design parameter with substantial energy-saving potential. In all cases, the introduction of PV_Roof led to remarkable energy savings of 42.72% to 65.25%.

The research also explored the impact of building-integrated photovoltaic systems (BIPV) on energy consumption. In the G+5 and G+2 cases, the inclusion of BIPV (BIPV_WF and BIPV_F) resulted in negative energy consumption values, indicating that the buildings generated more energy than they consumed. The energy savings achieved with BIPV ranged from 89.33% to 133.82%.

Overall, the findings highlight the importance of considering multiple design parameters in building energy efficiency strategies. The integration of envelope improvements, glass properties, window-to-wall ratio optimization, external shading, lighting control, and photovoltaic systems can lead to significant energy savings. These results provide valuable insights for professionals in the architecture, engineering, and policy sectors, supporting the development of sustainable and energy-efficient building practices.

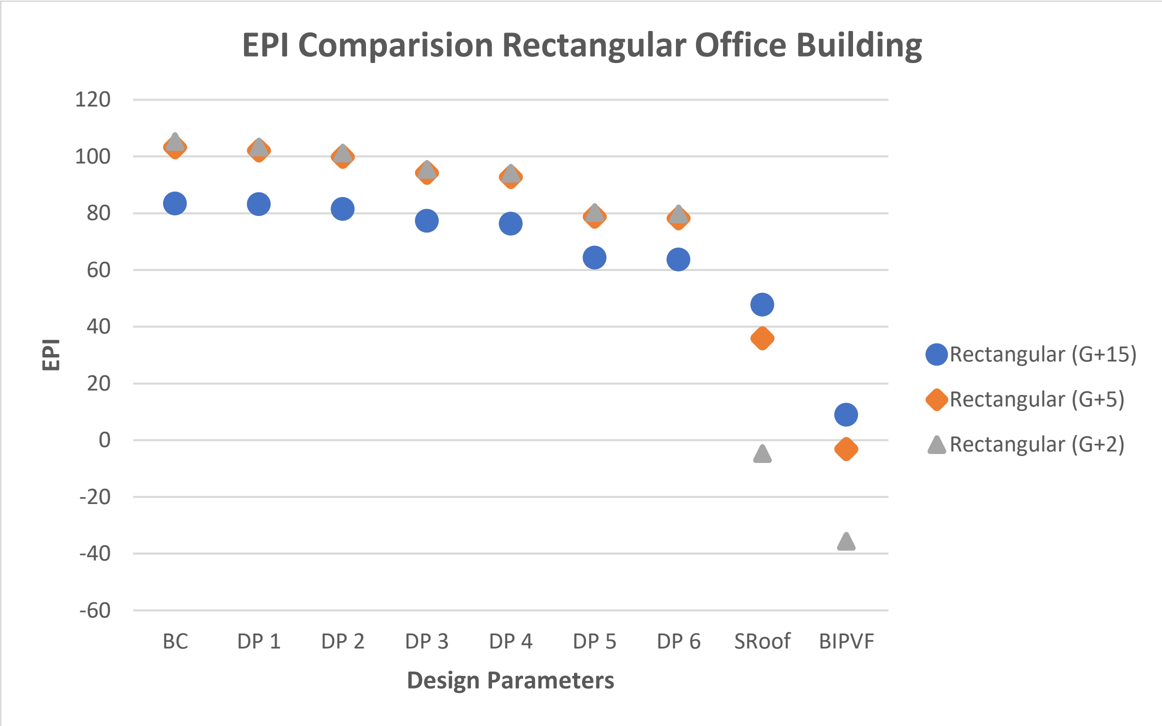

Figure 3.
Rectangular Building
(G+15)

B. Recommendations for architects, designers, and policymakers

Based on the summarized findings, here are recommendations for architects, designers, and policymakers:

- Incorporate envelope improvements: Architects and designers should prioritize incorporating efficient envelope properties, such as enhanced roof and wall designs, to minimize heat transfer and improve energy efficiency in buildings. Policymakers can encourage the adoption of energy-efficient envelope standards in building codes and regulations.
- Optimize glass properties: Designers should carefully select glass properties, such as glazing type and insulation, to balance natural light entry and heat gain. Policymakers can promote the use of energy-efficient glass standards and encourage the implementation of daylighting strategies in building designs.
- Optimize window-to-wall ratio: Designers should consider an optimal window-to-wall ratio to maximize natural daylight while minimizing heat loss or gain. Policymakers can provide guidelines and incentives for

designers to optimize window sizes and placements to achieve energy savings.

- Implement external shading: Architects and designers should integrate external shading devices, such as overhangs or shading fins, to reduce direct solar heat gain and glare. Policymakers can support the adoption of external shading strategies through building codes or incentives for shading installations.
- Reduce lighting power density: Designers should aim for reduced lighting power density by using energy-efficient lighting fixtures and controls. Policymakers can establish lighting efficiency standards and provide incentives for the use of energy-efficient lighting systems in buildings.
- Utilize lighting controls: Architects and designers should incorporate lighting control systems, such as occupancy sensors and daylight-responsive controls, to optimize lighting usage and reduce energy consumption. Policymakers can support the adoption of lighting control technologies through education, incentives, and building regulations.
- Integrate photovoltaic systems: Architects and designers should explore the integration of photovoltaic systems, such as rooftop solar panels (PV_Roof) or building-integrated photovoltaic systems (BIPV), to generate renewable energy and reduce reliance on grid power. Policymakers can provide incentives, subsidies, and streamlined approval processes for the installation of photovoltaic systems in buildings.
- Support research and development: Policymakers should allocate resources to support research and development in energy-efficient building technologies and design strategies. This can facilitate innovation, drive cost reductions, and inform future policy decisions.
- Promote awareness and education: Policymakers should prioritize awareness campaigns and educational programs to disseminate knowledge about energy-efficient building design and the benefits of implementing sustainable practices. Architects, designers, and policymakers can collaborate to raise awareness and foster a culture of energy efficiency within the industry.

By implementing these recommendations, architects, designers, and policymakers can collectively contribute to the development of sustainable buildings that minimize energy consumption, reduce greenhouse gas emissions, and promote a greener future.

C. Suggestions for future research and areas of improvement

Here are some suggestions for future research and areas of improvement based on the summarized findings:

- Life Cycle Assessment (LCA): Conduct a comprehensive life cycle assessment of buildings incorporating the various design parameters. This would provide a holistic understanding of the environmental impacts associated with different design choices, including construction, operation, and end-of-life considerations.
- Occupant Comfort and Well-being: Investigate the impact of design parameters on occupant comfort, productivity, and well-being. Assess factors such as indoor air quality, thermal comfort, acoustic performance, and visual comfort to optimize building designs that prioritize occupant satisfaction and health.
- Climate Resilience: Explore the resilience of buildings with optimized design parameters to withstand and adapt to climate change impacts, such as extreme temperatures, storms, and rising sea levels. Investigate the integration of resilient design strategies, materials, and technologies to enhance building performance and durability.
- Cost-Benefit Analysis: Conduct cost-benefit analyses to evaluate the economic viability of implementing different design parameters. Assess the upfront costs, operational savings, and return on investment associated with energy-efficient building designs to provide decision-makers with a comprehensive understanding of the financial implications.
- Integration of Smart Technologies: Investigate the potential of integrating smart technologies, such as Internet of Things (IoT) devices, building automation systems, and data analytics, with optimized design parameters. Explore how these technologies can

enhance energy efficiency, occupant comfort, and building performance through real-time monitoring, control, and optimization.

- Behavior Change and User Engagement: Examine the influence of occupant behavior and user engagement on energy consumption in buildings with optimized design parameters. Investigate strategies to promote energy-conscious behavior, increase user engagement, and empower occupants to actively participate in energy-saving practices.
- Long-Term Monitoring and Evaluation: Implement long-term monitoring and evaluation programs in buildings with optimized design parameters to assess their actual performance over time. This would provide valuable data for validating simulation models, identifying areas for improvement, and informing future design iterations.
- Policy and Regulatory Frameworks: Analyze the effectiveness of existing policies and regulatory frameworks in promoting energy-efficient building design and explore opportunities for improvement. Evaluate the impact of incentives, certifications, and building codes in driving the adoption of design parameters and identify areas where policy interventions can further accelerate progress.
- Social and Cultural Considerations: Consider the social and cultural aspects of building design and energy efficiency. Investigate how design parameters can be tailored to meet specific cultural preferences, social contexts, and local climatic conditions to ensure widespread acceptance and adoption of energy-efficient practices.

By addressing these research areas and focusing on continuous improvement, the field of energy-efficient building design can advance further, leading to more sustainable and resilient built environments.

VII. REFERENCES

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