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A Study on Analysis and Performance Evaluation of a Net Zero Carbon Building

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NITTTR, Chandigarh

Abstract: ***Thebuildingsectorsignificantlycontributestoglobalenergyconsumptionandcarbon emissions, highlighting the need for energy-efficient and low-carbon buildings. This study focuses on the analysis and performance evaluation of a Net-Zero Carbon Building by examining energy consumption, building envelope performance, HVAC and lighting loads, thermal comfort, renewable energy generation, and carbon emissions. Passive design strategies and energy-efficient systems are evaluated for their effectiveness in reducing energy demand, while renewable energy integration is assessed for offsetting operational energy consumption.***

KeyperformanceindicatorssuchasEnergyUseIntensity(EUI),annualenergyconsumption, renewable energy contribution, and carbon emissions are analyzed. The study identifies opportunities for improving building efficiency and reducing carbon impact, while providing practical strategies for achieving net-zero performance and guiding sustainable practices in future building construction.

Keywords: ***Net-ZeroCarbonBuilding,BuildingEnergyPerformance,EnergyEfficiency,Carbon Emissions, Renewable Energy, Passive Design Strategies, Solar Photovoltaic (PV), Sustainable Building, Carbon Footprint, Green Building, Thermal Comfort, HVAC Efficiency, Sustainable Construction.***

I. INTRODUCTION

The construction sector is increasingly required to reduce energy consumption and greenhouse-gas emissions while maintaining acceptable occupant comfort. Buildings in the Chandigarh–Mohali region experience hot summers, monsoon conditions and cool winters, resulting in significant seasonal cooling and heating requirements. Chandigarh's official climate information reports mean summer maximum temperatures around 42°C and winter minimum temperatures around 3.6°C, while historical IMD climatological datashowsubstantialseasonalvariation.Consequently,buildingenvelopecharacteristics, solar heat gain, glazing, shading, HVAC efficiency, lighting loads and renewable-energy generation can have a significant effect on annual building performance.

Theresearchproblemcanthereforebeframedas:Howcananappropriatelydesigned building in the Chandigarh–Mohali region minimize its operational energy demand and associated carbon emissions, and to what extent can energy-efficient design strategies combined with renewable energy generation achieve net-zero carbon performance?

The increasing impacts of climate change, depletion of natural resources, rising energy demandandurbanizationhavecreatedaneedforatransitionfromconventionalbuildings towards high-performance, low-energy and low-carbon buildings.

Oneoftheimportantapproachestowardssustainabledevelopmentisthedevelopmentof net-zero buildings. These buildings are designed to reduce energy consumption and carbonemissionsthroughefficientplanning,passivedesignstrategies,efficientbuilding services and integration of renewable energy systems. After reducing energy demand through efficient design and systems, Renewable Energy technologies can be incorporated to meet a portion or, where feasible, the remaining energy requirement.

Solar Photovoltaic (PV) systems are particularly relevant because they can generate electricity on-site and reduce dependence on grid-supplied energy. The relationship betweenenergyconsumptionandrenewableenergygenerationisthereforeanimportant consideration in evaluating whether a building can approach or achieve net-zero operational carbon performance.

Thefundamentalprinciple is:

Reduceenergydemandfirst,improveefficiencysecond,andmeettheremaining demand through renewable energy.

Foranet-zerocarbonbuilding,theobjectiveextendsbeyondenergybalanceandfocuseson reducing and offsetting carbon emissions associated with the building.

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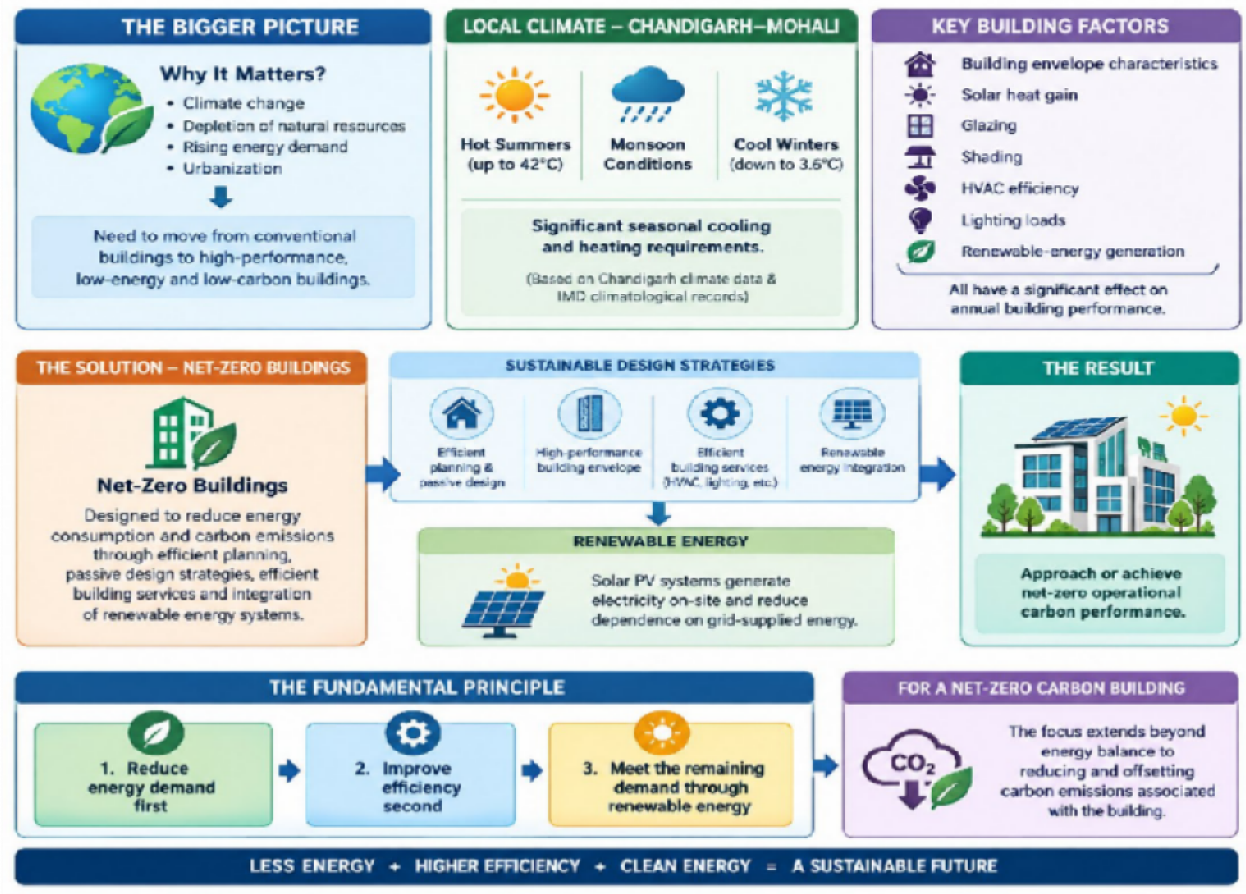


Figure1:VariousAspectsPlayingaPivotalRoleInanAchievementofaNetZeroCarbon Building

II. CHALLENGES OF THE PRESENTERA

The transition towards net-zero carbon buildings is becoming increasingly important becauseofrapidurbanization, risingenergydemand,climatechange,resourcedepletion and increasing construction activity. However, achieving true net-zero carbon performance is technically, economically and operationally challenging. Despite the increasing adoption of sustainable building practices, achieving net-zero carbon performance remains challenging due to technical, economic, environmental and operational constraints. High initial construction costs, increasing building energy demand, intermittent renewable-energy generation, and limited space for on-site generation, embodied carbon from construction materials, uncertainty in energy modelling, occupant behavior and the performance gap between predicted and actual energy consumption are major barriers. Furthermore, climate change and urban heat-islandeffectscanincreasecoolingdemand,whiletheavailabilityofreliablelow-carbon materials and accurate carbon-emission data remains a concern. In the Indian context, these challenges are further influenced by regional climatic conditions, electricity-grid characteristics, material availability, building practices and maintenance conditions.

Therefore, achieving net-zero carbon performance requires an integrated approach combiningpassivedesign, energyefficiency,renewableenergy,low-carbonmaterials, intelligent controls, life-cycle assessment and continuous performance monitoring.

Intruesensecreatinganetzerocarbonbuildingrightnowisamythforusaswecreatea building with a foot print and we try to offset it by adopting various measures.

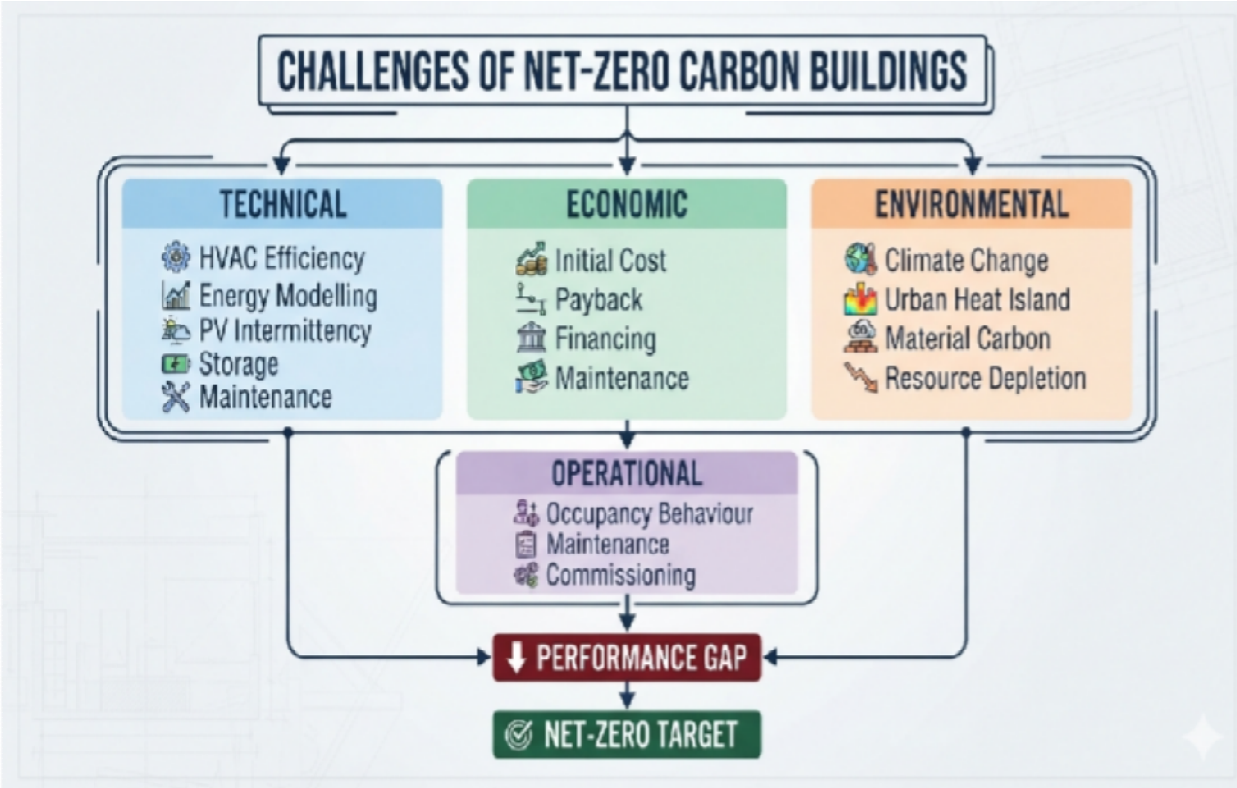


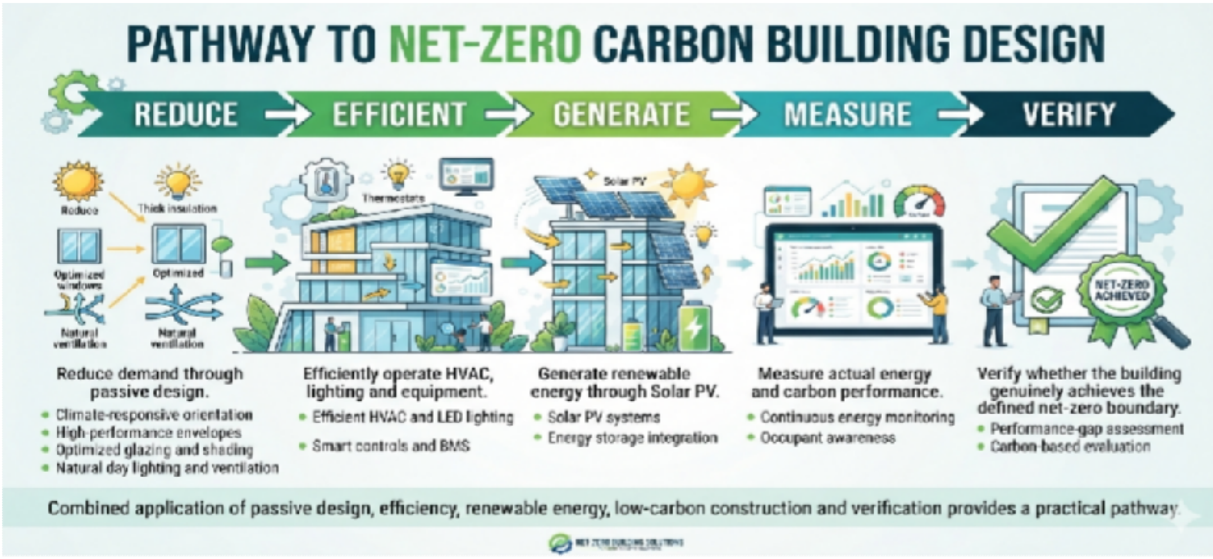
Figure2VariousChallengesinsuccessfullyachievinganetzerocarbonbuilding.

III. THE WAY AHEAD AND DISCUSSION

A building cannot realistically eliminate all environmental impacts associated with its constructionandoperation.Therefore,thepracticalobjectiveofnet-zerocarbonbuilding design is to minimize energy demand and embodied emissions at source, maximize energy efficiency, generate renewable energy, and compensate for the remaining emissions through credible and measurable mechanisms.

REDUCE→EFFICIENT→GENERATE→MEASURE→VERIFY

- Reducedemandthroughpassive design.
- EfficientlyoperateHVAC,lightingand equipment.
- GeneraterenewableenergythroughSolarPV.
- Measureactualenergyandcarbonperformance.
- Verify whether the building genuinely achieves the defined net-zero boundary. Achieving net-zero carbon performance requires an integrated approach focused on reducing energy demand, improving efficiency, generating renewable energy, and minimizing embodied carbon. Climate-responsive orientation, high-performance envelopes, optimized glazing and shading, natural day lighting and ventilation, efficient HVAC and LED lighting, smart controls and Building Management Systems can significantly reduce energy consumption. Appropriately sized **Solar PV systems**, supported by energy storage where required, can meet a substantial portion of the remaining energy demand and reduce grid dependence. Low-carbon materials, construction-waste reduction, water-efficient systems and life-cycle assessment can further minimize environmental impacts. Continuous energy monitoring, occupant awareness, performance-gap assessment and carbon-based evaluation are essential for verifying actual building performance. Overall, the combined application of passive design, energy efficiency, renewable energy, low-carbon construction and continuous performanceverificationprovidesapracticalpathwaytowardsachievingnet-zerocarbon performance.



IV. CONCLUSIONS

1) Net-zerocarbonbuildingsrequireanintegrateddesignapproachratherthanrelianceona single technology or strategy. Building planning, envelope design, HVAC, lighting, renewable energy and operational practices must work together.
2) Reducing energy demand is the first priority in achieving net-zero performance. Passive strategiessuchasclimate-responsiveorientation,appropriateshading,naturalventilation, day lighting and optimized building form can substantially reduce cooling, heating and lighting requirements.
3) Thebuildingenvelopeplaysacriticalroleinenergyperformance.Properinsulation, suitableglazing,controlledwindow-to-wallratiosandeffectiveexternalshadingcan reduce unwanted solar heat gain and improve indoor thermal comfort.
4) HVACsystemsrepresentasignificantcomponentofbuildingenergyconsumption, particularly under the climatic conditions of the Chandigarh–Mohali region. High-efficiencyHVACequipment,appropriatesizing,zoningandintelligentcontrolsare therefore essential for reducing operational energy demand.
5) Lightingandelectricalloadsshouldbeminimizedthroughenergy-efficientsystems.LED lighting, daylight utilization, occupancy controls and efficient equipment can reduce unnecessary electricity consumption without compromising occupant comfort.
6) Renewable energy, particularly Solar PV, is an important component of the net-zero pathway.Afterreducingthebuilding'senergydemand,appropriatelysizedPVsystems can offset a significant portion of the remaining electricity requirement and reduce dependence on grid electricity.
7) Net-zerocarbonperformanceshouldnotbeevaluatedsolelythroughenergygeneration. Theassessmentshouldconsiderenergyconsumption,renewable-energygenerationand the associated carbon emissions within a clearly defined system boundary.
8) EnergyUseIntensity(EUI)isanimportantperformanceindicatorforcomparingbuilding energy performance. Annual energy consumption, peak loads, renewable-energy contribution and carbon emissions should also be evaluated to obtain a comprehensive performance assessment.
9) Embodied carbon must be considered alongside operational carbon. Materials, constructionprocesses,transportation,replacementandend-of-lifeimpactscancontribute significantly to the overall carbon footprint of a building.
10) TheChandigarh–Mohaliclimatecreatesspecificdesignchallenges.Hotsummerscan increase cooling demand, monsoon conditions influence ventilation and moisture considerations, while cool winters create seasonal heating requirements. Therefore, climate-responsive strategies should be incorporated into the building design.
11) There can be a significant performance gap between predicted and actual building performance.Energymodellingalonecannotestablishwhetherabuildingisgenuinely achievingitsintendedperformance;actualenergyconsumptionmustbemonitoredand compared with predicted results.

12) Occupantbehaviourandbuildingoperationsignificantlyinfluenceenergyperformance. User awareness, thermostat settings, equipment usage, operating schedules and maintenance practices can alter actual energy consumption.
13) Thehighinitialcostofenergy-efficienttechnologiesremainsamajorbarrier.However, the evaluation of a net-zero building should consider long-term energy savings, operationalbenefitsandlife-cycleimpactsratherthanfocusingonlyoninitial construction cost.
14) Continuousmonitoringandverificationareessentialforcrediblenet-zeroclaims.Smart meters, Building Management Systems and regular performance assessments can help identify deviations from predicted performance and support corrective actions.
15) The concept of net-zero carbon should therefore be understood as a measurable performanceobjectiveratherthanmerelytheinstallationofrenewable-energysystems.A building should demonstrate that its defined energy and carbon balance is achieved within a clearly established assessment boundary.
16) The key conclusion of the literature review is that achieving net-zero carbon performance is technically possible only through the combined application of passive design, energy efficiency, renewable energy, low-carbon materials and continuous performancemonitoring.Noindividualinterventionissufficienttoachievethedesired outcome.
17) Therefore,theproposedstudyshouldevaluatethebuildingholistically,consideringthe interaction between climate, envelope, HVAC, lighting, occupant comfort, energy consumption, renewable-energy generation and carbon emissions.

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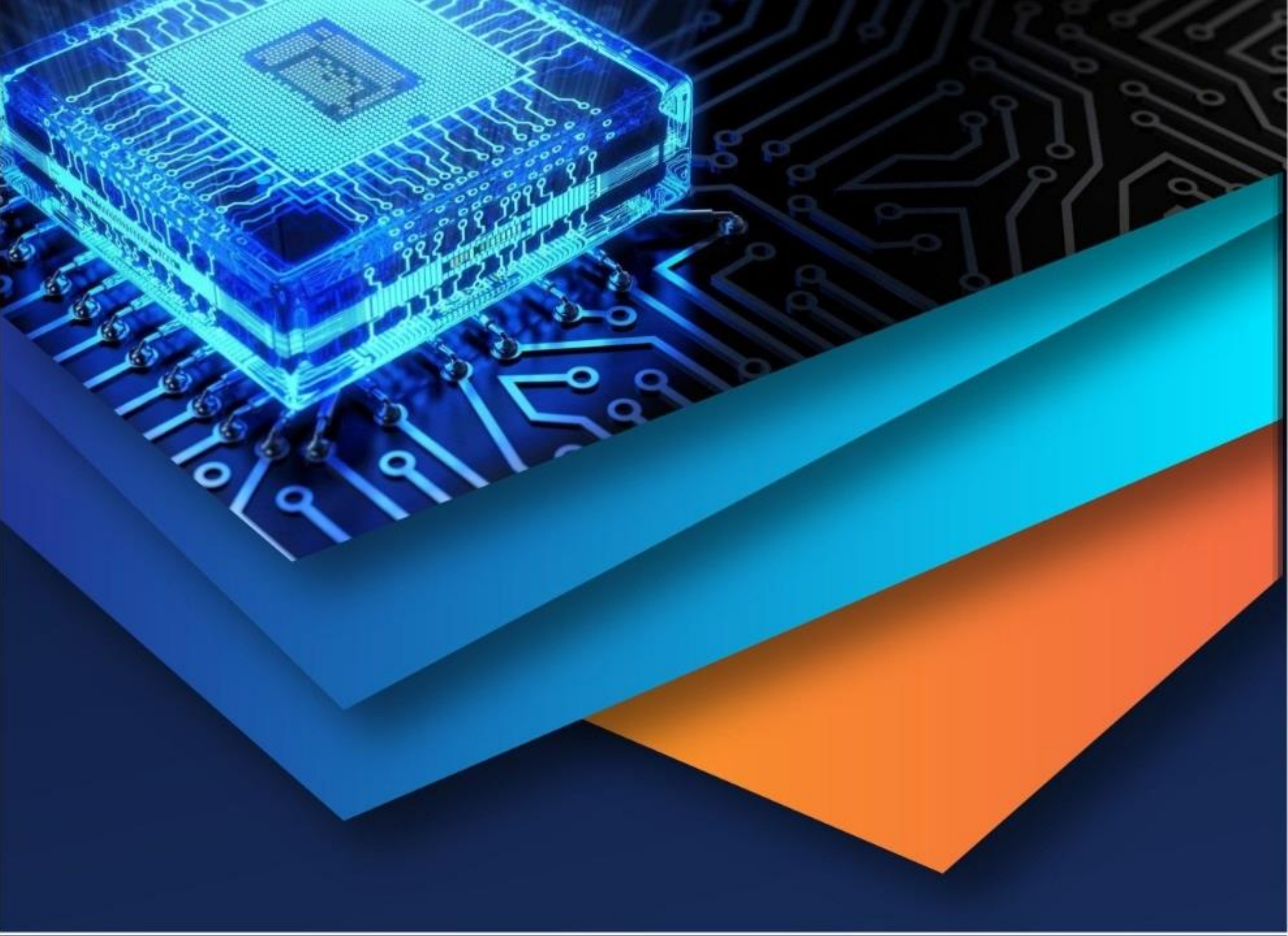

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