

Impact of Green Building Design on Energy Efficiency

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Abstract

The building sector is a major consumer of energy and an important source of greenhouse gas emissions. Green building design seeks to reduce energy demand while maintaining thermal comfort, indoor environmental quality, and functional performance. This paper examines the impact of green building design on energy efficiency, focusing on passive design, building envelopes, daylighting, natural ventilation, heating and cooling systems, lighting, renewable energy, smart controls, and building performance evaluation. Evidence from systematic reviews indicates that energy efficiency in sustainable buildings depends on an integrated combination of architectural design, efficient technologies, renewable energy, and effective operation. Greenery systems can reduce solar radiation and heat transfer through building envelopes in suitable climates, while building energy-efficiency strategies can lower energy demand through improved envelopes, efficient equipment, and control systems. The paper argues that the greatest benefits are achieved when energy performance is addressed from the earliest design stage rather than through isolated technological additions. At the same time, actual performance can differ from predicted performance because of occupant behaviour, maintenance, commissioning, and operational practices. Green building design should therefore be understood as a whole-building strategy supported by simulation, monitoring, post-occupancy evaluation, and appropriate energy-performance standards.

Keywords

Green Buildings; Energy Efficiency; Sustainable Architecture; Passive Design; Building Envelope; HVAC; Renewable Energy; Smart Building Systems

Introduction

Energy efficiency has become a central objective of contemporary building design because buildings require energy for heating, cooling, ventilation, lighting, appliances, and other services. The environmental implications of this demand are significant. The United Nations Environment Programme reported that buildings and construction accounted for 32% of global energy use and 34% of global carbon dioxide emissions in its 2024–2025 global status report. [\[cite turn0search3\]](#)

Green building design responds to this challenge by integrating energy-conscious architectural decisions with efficient mechanical and electrical systems. Instead of treating energy efficiency as an equipment-selection issue, green design considers site

orientation, building form, envelope performance, daylight, natural ventilation, thermal comfort, efficient systems, renewable energy, controls, and occupant behaviour.

A systematic review of energy efficiency in sustainable buildings identifies energy-efficient design and technologies as a broad research field involving building envelopes, renewable energy, energy management, modelling, and operational strategies.

□cite□turn0search4□ The International Energy Agency also identifies buildings as an important sector for energy-efficiency improvements and tracks developments in building efficiency, electrification, and related technologies. □cite□turn0search6□

This paper examines how green building design influences energy efficiency and discusses major architectural and technological strategies, performance measurement, economic considerations, barriers, and future directions.

1. Concept of Green Building Design

Green building design refers to an integrated approach to planning, designing, constructing, and operating buildings with the objective of reducing environmental impacts and improving resource efficiency. Energy efficiency is one of its central components, but green buildings may also address water, materials, waste, site ecology, indoor environmental quality, and occupant health.

From an energy perspective, green design aims to reduce unnecessary demand before adding mechanical or renewable systems. This principle is important because a building with a low energy requirement is generally easier and less expensive to operate efficiently.

2. Passive Design and Building Orientation

Passive design uses climate and site conditions to reduce the need for mechanical heating and cooling. Building orientation, form, shading, window placement, thermal mass, insulation, and natural ventilation can influence solar heat gain, heat loss, daylight availability, and indoor comfort.

Orientation should respond to local climate rather than following a universal formula. In hot climates, minimizing unwanted solar heat gain and promoting ventilation may be priorities, whereas in colder climates, solar access and heat retention may be more important.

Effective passive design can reduce the load placed on HVAC systems and can therefore improve the efficiency of the entire building system.

3. Building Envelope and Thermal Performance

The building envelope separates indoor and outdoor environments and strongly influences heating and cooling demand. Walls, roofs, floors, windows, shading devices, insulation, air sealing, and glazing characteristics determine how heat moves through the building.

A high-performance envelope reduces unwanted heat transfer and can stabilize indoor temperatures. Appropriate glazing and external shading can also reduce solar heat gain while preserving useful daylight.

Greenery systems can provide additional shading and thermal effects. A systematic review of 56 studies found that green roofs, façades, and walls can reduce solar radiation and heat transfer through building envelopes, although performance varies according to climate, vegetation characteristics, and building conditions. [\[cite turn0search0\]](#)

4. Daylighting and Natural Ventilation

Daylighting can reduce dependence on artificial lighting when it is carefully designed to avoid excessive glare and solar heat gain. Window size, orientation, shading, light shelves, interior surface reflectance, and room depth all influence daylight performance.

Natural ventilation can reduce mechanical cooling and ventilation demand when outdoor conditions are suitable. Cross-ventilation, stack effects, operable windows, courtyards, and appropriately designed openings can support passive cooling.

These strategies must be climate-responsive. Poorly designed glazing or ventilation openings can increase cooling demand or compromise thermal comfort, demonstrating why passive strategies should be evaluated through integrated building-performance analysis.

5. Energy-Efficient HVAC and Lighting Systems

Heating, ventilation, and air-conditioning systems can account for a substantial share of building energy use. Green building design therefore combines reduced thermal loads with efficient equipment, appropriate system sizing, variable-speed drives, heat recovery, efficient heat pumps, and effective controls.

Lighting efficiency can be improved through LED technology, occupancy sensors, daylight-responsive controls, and appropriate lighting design. Reducing unnecessary lighting also reduces internal heat gains, which can further lower cooling demand in warm climates.

The IEA's Energy Efficiency 2024 report emphasizes the importance of improving energy efficiency across sectors and highlights building-related opportunities associated with efficiency, electrification, and investment. [\[cite turn0search6\]](#)

6. Renewable Energy Integration

Renewable energy can complement energy-efficient building design by supplying a portion of the building's remaining energy demand. Photovoltaic systems are particularly suitable for many buildings because roof and façade areas can provide space for on-site generation.

However, renewable energy should generally follow demand reduction. Passive design, efficient envelopes, and efficient systems can reduce the amount of energy that must be generated, making renewable systems more effective.

Integration also requires attention to roof orientation, shading, structural capacity, storage, grid connection, maintenance, and local regulations.

7. Smart Controls and Building Energy Management

Building energy management systems can monitor and control lighting, HVAC, ventilation, and other energy-consuming systems. Sensors can detect occupancy, temperature, daylight, and other conditions and adjust building services accordingly.

Smart controls can reduce energy wasted through simultaneous heating and cooling, unnecessary lighting, excessive ventilation, or operation during unoccupied periods. However, technology alone does not guarantee savings. Effective commissioning, appropriate control logic, maintenance, and user understanding are necessary.

Recent systematic research on green buildings also identifies efficient technologies, renewable energy, and performance indicators such as energy intensity as important components of sustainable building performance. □cite□turn0search2□

8. Measurement of Energy Efficiency and Economic Benefits

Energy efficiency should be evaluated using measurable indicators such as annual energy use, energy-use intensity, peak demand, energy cost, carbon emissions, and thermal comfort. Building energy simulation can estimate performance during design, while meters and building-management systems can provide operational data after occupation.

Green building investments may involve higher initial costs for insulation, high-performance windows, efficient systems, controls, or renewable technologies. However, lower energy consumption can reduce operating costs over the building's service life. Life-cycle assessment and life-cycle cost analysis can help decision-makers evaluate these trade-offs.

Post-occupancy evaluation is particularly important because actual energy performance can differ from design predictions. Monitoring can identify commissioning problems, equipment faults, unexpected occupant behaviour, or control issues.

9. Challenges and Future Directions

Despite the potential benefits, green building design faces challenges including higher initial investment, limited technical expertise, fragmented project decision-making, inadequate commissioning, inconsistent maintenance, and uncertainty about long-term energy savings.

Another challenge is the performance gap between predicted and actual energy use. Building models depend on assumptions about weather, occupancy, equipment, and operation, while real buildings are affected by changing occupant behaviour and maintenance conditions.

Future green buildings should therefore use integrated design, reliable energy simulation, performance-based targets, renewable energy, efficient electrification, smart controls, and continuous monitoring. Greater emphasis should also be placed on retrofitting existing

buildings because improving the performance of the existing building stock is essential for reducing overall energy demand.

Conceptual Framework

The following framework summarizes the relationship between green building design strategies and energy efficiency. Climate, occupancy, operation, maintenance, and technology selection can influence the final performance of a green building.

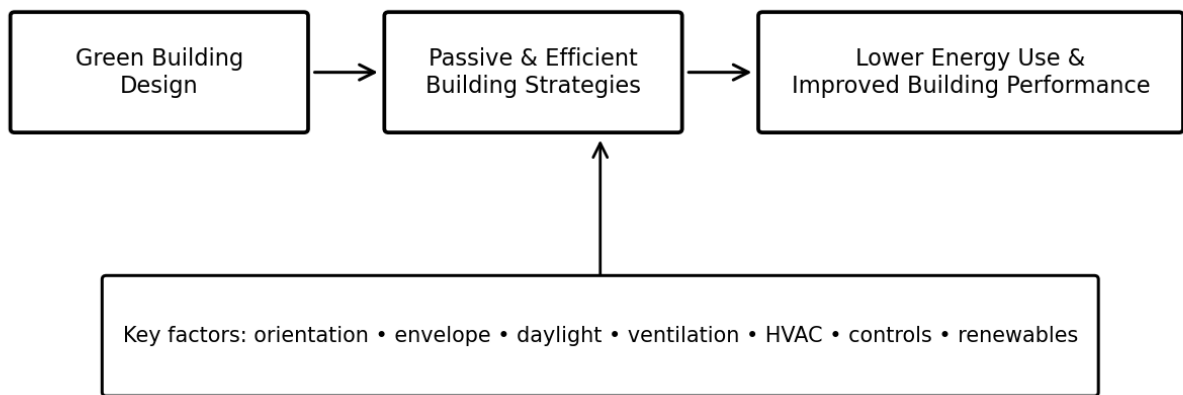


Figure 1. Conceptual framework showing how green building design can influence energy efficiency.

Conclusion

Green building design can significantly contribute to energy efficiency by reducing building energy demand and improving the performance of energy-consuming systems. Passive design, high-performance envelopes, daylighting, natural ventilation, efficient HVAC and lighting, renewable energy, and smart controls can work together to reduce energy consumption.

The evidence indicates that no single technology is sufficient for optimal performance. Green building design is most effective when energy efficiency is considered from the earliest stages of planning and integrated with climate-responsive architecture, efficient systems, and appropriate operation. Systematic reviews also indicate that building greenery and other sustainable technologies can contribute to energy performance under suitable conditions. □cite□turn0search0□turn0search4□

Ultimately, energy efficiency should be measured through actual building performance rather than design intentions alone. Continued monitoring, commissioning, maintenance, occupant engagement, and post-occupancy evaluation are essential for achieving long-

term energy savings. Green building design therefore represents not simply a design style, but an integrated strategy for creating lower-energy, more resilient, and environmentally responsible buildings.

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