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ENERGY EFFICIENCY AND MOSQUE ARCHITECTURE

Sehrish Ghani[*1], Dr. Salman Saeed[2]

[*1]*Architecture Department, CECOS University*
[2]*NIUIP Department, University of Engineering and Technology UET, Peshawar*

[*1]sehrish@cecos.edu.pk

Corresponding Author: *
Sehrish Ghani
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ABSTRACT

Mosques are significant religious and social buildings that represent Islamic cultural identity while serving large communities. With increasing concerns about energy consumption and environmental sustainability, improving the energy efficiency of mosque architecture has become an important area of research. Traditional mosque designs incorporated various passive strategies, such as natural ventilation, courtyards, shading devices, appropriate orientation, and locally available materials, which helped achieve thermal comfort with minimal energy use. However, many contemporary mosques rely heavily on mechanical cooling, artificial lighting, and energy-intensive systems due to modern construction practices and increasing user demands. This research explores the relationship between energy efficiency and mosque architecture by examining design principles, passive and active energy strategies, and sustainable approaches that can reduce energy consumption while maintaining architectural and functional requirements. The study investigates how elements such as building orientation, spatial organization, daylighting, ventilation systems, building materials, and renewable energy technologies contribute to improving mosque energy performance. Through literature review and analysis of selected case studies, the research identifies effective strategies for developing environmentally responsive mosque designs. The findings highlight the potential of integrating traditional Islamic architectural principles with modern sustainable technologies to create energy-efficient mosques that provide thermal comfort, reduce operational costs, and minimize environmental impact. The study provides recommendations for architects, designers, and policymakers to promote sustainable mosque development while preserving cultural and architectural values.

Keywords: *Energy efficiency, Mosque architecture, Sustainable design, Islamic architecture, Passive design strategies, Renewable energy, Thermal comfort, green buildings, Energy conservation, Climate-responsive architecture.*

INTRODUCTION

The increasing demand for sustainable development has made energy efficiency a significant concern in the field of architecture. Buildings contribute a major portion of global energy consumption, making the integration of environmentally responsive design strategies essential for reducing energy use and carbon emissions. According to the International Energy Agency (IEA, 2021), improving building energy performance through efficient design, renewable energy integration, and passive strategies is one of the key approaches for achieving global sustainability goals. In this context, religious buildings, including mosques, require special attention because they often accommodate large numbers of occupants and operate for extended periods, resulting in considerable energy demands.

Mosque architecture has historically demonstrated a strong relationship between environmental conditions, cultural values, and

functional requirements. Traditional Islamic architecture incorporated climate-responsive features such as courtyards, wind towers, domes, shading elements, thick walls, and natural ventilation systems to create comfortable indoor environments with limited dependence on mechanical systems. Hassan and Lee (2019) emphasized that traditional architectural approaches provide valuable lessons for contemporary sustainable design by utilizing local materials and passive environmental control strategies. Similarly, Al-Hassan and Karim (2020) highlighted that traditional mosque forms can contribute to energy conservation when their environmental principles are adapted to modern building technologies.

Modern mosque buildings, however, increasingly depend on mechanical cooling, artificial lighting, and advanced electrical systems due to larger spatial requirements and changing patterns of use. This increased dependence has created challenges related to energy consumption, operational costs, and environmental impacts. According to Ahmed et al. (2021), improving the energy efficiency of religious buildings requires a balance between maintaining architectural identity and implementing sustainable technologies. The integration of passive design principles, energy-efficient building systems, and renewable energy sources can significantly improve the overall performance of mosque buildings.

Recent studies have focused on applying sustainable strategies to mosque design by examining factors such as building orientation, daylight utilization, thermal comfort, and ventilation performance. Rahman and Abdullah (2022) found that appropriate orientation and passive cooling techniques can reduce cooling loads while improving indoor environmental quality in mosque spaces. Furthermore, Ibrahim et al. (2023) stated that daylight optimization and efficient lighting systems are important strategies for minimizing electricity consumption without affecting the spiritual atmosphere of prayer spaces. The development of smart technologies has also introduced new possibilities for mosque energy management. Blasi et al. (2024) explored smart mosque systems that utilize environmental data and automated controls to improve ventilation and daylight management, demonstrating the potential of intelligent solutions in sustainable mosque architecture.

The connection between Islamic architectural principles and contemporary sustainability has gained increasing attention in recent years. Sustainable mosque projects demonstrate that religious buildings can combine cultural heritage with modern environmental objectives. For example, eco-friendly mosque designs have incorporated renewable energy systems, natural ventilation, water conservation techniques, and low-energy materials to reduce their ecological footprint. The Cambridge Central Mosque, completed in 2019, represents an example of contemporary mosque architecture that integrates sustainable features such as photovoltaic panels, natural lighting, ventilation systems, and environmentally responsible materials (Marks Barfield Architects, 2019). Such developments indicate a growing movement toward environmentally conscious religious architecture.

Despite these advancements, many existing mosques still face challenges related to high energy consumption due to inefficient design approaches, unsuitable materials, and excessive dependence on mechanical systems. Therefore, there is a need for comprehensive research that examines how architectural design decisions influence energy performance in mosque buildings. The integration of traditional Islamic environmental principles with modern sustainable technologies can provide effective solutions for reducing energy consumption while preserving the cultural and spiritual significance of mosque architecture.

This research aims to investigate the relationship between energy efficiency and mosque architecture by analyzing passive and active design strategies, evaluating sustainable approaches, and identifying methods for improving the environmental performance of mosque buildings. The study contributes to the development of future mosque designs that achieve energy efficiency, thermal comfort, and sustainability while respecting Islamic architectural traditions. The ongoing development of net-zero and environmentally responsive mosque projects further demonstrates the potential for religious

architecture to contribute to global sustainability objectives (2025).

Background of the Study

The construction sector is one of the largest contributors to global energy consumption and environmental impacts. Increasing energy demands, climate change concerns, and the need for sustainable development have encouraged architects and researchers to focus on energy-efficient building designs. Buildings consume energy for heating, cooling, lighting, and ventilation, making architectural design decisions an important factor in reducing operational energy requirements. According to the International Energy Agency (IEA, 2021), improving building energy performance through passive design strategies, efficient systems, and renewable energy integration is essential for achieving sustainable development goals.

Mosque architecture represents a unique category of religious buildings that combines spiritual, cultural, and social functions. Historically, mosques were designed according to local climatic conditions and environmental principles, utilizing passive strategies such as courtyards, natural ventilation, shading devices, thick walls, and appropriate orientation. These traditional approaches helped maintain thermal comfort while minimizing dependence on mechanical energy systems. Hassan and Lee (2019) stated that traditional Islamic architecture provides valuable knowledge for contemporary sustainable design because it responds effectively to climate conditions through passive environmental control.

With modernization and population growth, contemporary mosque buildings have become larger and more complex, resulting in increased energy consumption. Many modern mosques rely heavily on air-conditioning systems, artificial lighting, and mechanical ventilation to provide comfortable indoor environments for worshippers. However, excessive dependence on these systems increases operational costs and contributes to environmental challenges. Ahmed et al. (2021) emphasized that religious buildings require effective energy management strategies because their large occupied spaces and periodic high-density usage can significantly influence overall energy demand.

Recent research has highlighted the importance of integrating sustainable technologies with traditional architectural principles to improve mosque energy performance. Energy-efficient lighting, renewable energy systems, smart building technologies, and climate-responsive design strategies have shown potential in reducing energy consumption while maintaining architectural identity. Rahman and Abdullah (2022) explained that passive cooling techniques, proper building orientation, and natural ventilation can significantly enhance thermal comfort and reduce cooling requirements in mosque buildings.

Importance of Energy Efficiency in Buildings

Energy efficiency in buildings plays a vital role in reducing energy consumption, lowering operational costs, and minimizing environmental impacts. Since buildings account for a significant proportion of global energy use, improving their performance has become a major priority in sustainable development. Energy-efficient buildings reduce dependence on fossil fuels, decrease greenhouse gas emissions, and contribute to healthier indoor environments.

Architectural design decisions such as building orientation, material selection, insulation, ventilation, and daylight management directly influence energy performance. According to Al-Hassan and Karim (2020), integrating passive environmental strategies into building design can significantly reduce energy requirements while maintaining occupant comfort. These approaches are particularly important in regions with extreme climatic conditions where cooling and heating demands represent a major portion of energy consumption.

Energy efficiency also provides economic benefits by reducing electricity costs and maintenance requirements. In large public buildings such as mosques, where cooling and lighting systems often operate for extended periods, energy-saving measures can create substantial financial advantages. Furthermore, energy-efficient buildings support global sustainability objectives by reducing carbon emissions and promoting responsible resource use.

Role of Mosque Architecture in Sustainable Design

Mosque architecture has significant potential to contribute to sustainable building development due to its historical connection with environmental adaptation and climate-responsive design. Traditional mosque designs incorporated natural solutions that reduced energy dependence while creating comfortable spaces for worship. Features such as courtyards, domes, wind circulation systems, shaded entrances, and high ceilings were developed to improve ventilation and thermal conditions.

In contemporary sustainable architecture, these traditional principles can be combined with modern technologies to achieve improved energy performance. The orientation of mosque buildings, use of daylight, selection of appropriate materials, and integration of renewable energy systems can significantly influence environmental performance. Blasi et al. (2024) suggested that smart technologies can further enhance mosque sustainability by optimizing energy consumption through automated environmental control systems.

Research Problem Statement

Many contemporary mosques experience high energy consumption due to increased reliance on mechanical cooling, artificial lighting, and energy-intensive building systems. Although traditional Islamic architecture included effective passive strategies for environmental control, many modern mosque designs have moved away from these principles, resulting in increased operational energy demands.

The challenge lies in developing mosque designs that maintain religious, cultural, and functional requirements while improving energy efficiency. There is limited understanding of how traditional architectural features can be effectively integrated with modern sustainable technologies to enhance mosque energy performance. Therefore, this research addresses the need to investigate energy-efficient design strategies suitable for mosque architecture and identify approaches that support sustainable development.

Aim and Objectives of the Study

Aim

The aim of this research is to investigate the relationship between energy efficiency and mosque architecture and to identify sustainable design strategies that improve energy performance while maintaining architectural and cultural values.

Objectives

1. To examine the principles of energy efficiency in building design.
2. To analyze traditional and contemporary mosque architectural features related to environmental performance.
3. To identify passive and active strategies for improving energy efficiency in mosques.
4. To evaluate the role of sustainable technologies in reducing mosque energy consumption.
5. To develop recommendations for designing environmentally responsive mosque buildings.

Research Questions

1. What architectural factors influence energy efficiency in mosque buildings?
2. How can traditional Islamic architectural principles contribute to sustainable mosque design?
3. Which passive design strategies are most effective in reducing mosque energy consumption?
4. How can modern technologies improve the energy performance of contemporary mosques?
5. What design guidelines can support the development of energy-efficient mosque architecture?

Scope and Limitations of the Study

Scope of the Study

This research focuses on the relationship between energy efficiency and mosque architecture. It examines passive design strategies, active energy systems, sustainable materials, renewable energy integration, and climate-responsive architectural principles. The study considers both traditional and contemporary mosque designs to understand how architectural approaches influence energy performance.

The research primarily focuses on design strategies that improve thermal comfort, reduce energy consumption, and support sustainable mosque development. Selected case studies and existing research findings are analyzed to identify effective approaches for energy-efficient mosque architecture.

Limitations of the Study

The study is limited by the availability of detailed energy performance data from existing mosque buildings. Differences in climate conditions, construction methods, building size, and user behavior may affect the applicability of certain strategies. Additionally, the research focuses mainly on architectural and environmental aspects and does not provide detailed economic or structural analysis of mosque construction. Despite these limitations, the study provides valuable insights into sustainable approaches for improving mosque energy efficiency.

LITERATURE REVIEW

Energy efficiency in architecture refers to the design and operation of buildings in a way that minimizes energy consumption while maintaining acceptable levels of comfort, functionality, and indoor environmental quality. It involves reducing energy demand through effective planning, efficient building systems, appropriate material selection, and the integration of renewable energy technologies. In modern architectural practice, energy efficiency has become a fundamental principle of sustainable design due to increasing concerns regarding climate change, resource depletion, and rising energy costs.

According to the International Energy Agency (IEA, 2021), improving building energy performance is one of the most effective strategies for reducing global energy consumption and carbon emissions. Architectural decisions made during the early design stage, such as building orientation, form, envelope design, and ventilation strategies, significantly influence energy performance throughout a building's lifecycle. Bui et al. (2020) highlighted that passive design approaches can reduce dependence on mechanical heating and cooling systems by utilizing natural environmental conditions.

Energy-efficient architecture focuses on achieving a balance between environmental performance and human comfort. Strategies such as daylight optimization, natural ventilation, thermal insulation, shading devices, and efficient mechanical systems contribute to reducing operational energy requirements. According to Al-Saadi and Al-Hagla (2019), integrating passive and active energy strategies provides a comprehensive approach for improving building sustainability.

Sustainable and Green Building Principles

Sustainable and green building principles aim to create buildings that minimize environmental impacts while improving occupant health, comfort, and resource efficiency. Sustainable architecture considers the entire lifecycle of a building, including design, construction, operation, maintenance, and eventual reuse or demolition. The main objectives of green buildings include reducing energy consumption, conserving water resources, minimizing waste, and decreasing greenhouse gas emissions.

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Fig 2.1 Sustainable and Green Building Principles

The concept of green buildings has developed as a response to environmental challenges caused by conventional construction practices. According to Zuo and Zhao (2018), sustainable buildings integrate environmental, economic, and social considerations to achieve long-term benefits. Green building frameworks encourage the use of renewable energy, efficient building materials, passive design strategies, and intelligent management systems.

Key principles of sustainable architecture include energy conservation, efficient resource management, indoor environmental quality, sustainable material selection, and ecological responsibility. Energy-efficient lighting systems, solar energy applications, rainwater harvesting, and smart building controls are examples of technologies that support sustainable development.

For religious buildings such as mosques, green building principles provide opportunities to reduce environmental impact while maintaining cultural significance. Sustainable mosque design combines Islamic principles of resource conservation with contemporary environmental technologies. According to Othman and Mazlan (2021), Islamic teachings regarding moderation and responsible use of resources align closely with the objectives of sustainable architecture.

Traditional Islamic Architecture and Environmental Response

Traditional Islamic architecture demonstrates a strong relationship between environmental conditions, cultural values, and architectural solutions. Before the development of modern mechanical systems, Islamic buildings were designed using passive strategies to achieve thermal comfort in different climatic regions. These strategies included courtyards, thick masonry walls, shaded openings, wind catchers, domes, and water features.

Traditional mosque architecture utilized natural environmental conditions to reduce heat gain and improve air circulation. Courtyards provided open spaces that supported ventilation and daylight penetration, while thick walls helped regulate indoor temperatures by reducing heat transfer. According to Edwards et al. (2019), traditional Islamic architecture represents an important example of climate-responsive design because it adapts effectively to local environmental conditions.

The principles of Islamic architecture emphasize harmony between humans, nature, and the built environment. Features such as orientation toward the Qibla, controlled openings, decorative screens (Mashrabiya), and transitional spaces contributed to both aesthetic and environmental performance. Hassan and Lee (2020) stated that these

traditional approaches provide valuable lessons for contemporary sustainable architecture.

Modern mosque design can benefit from reinterpreting these traditional strategies using advanced technologies. Combining historical environmental knowledge with modern energy-efficient systems can help create mosques that achieve better energy performance while preserving architectural identity.

Historical Development of Mosque Architecture

Mosque architecture has evolved significantly throughout history, reflecting changes in cultural influences, technological development, and environmental conditions. Early mosques were simple structures designed primarily for communal worship, often incorporating local materials and climate-responsive features. The Prophet's Mosque in Madinah established fundamental elements of mosque design, including open courtyards and flexible prayer spaces.

During the expansion of Islamic civilizations, mosque architecture developed diverse regional characteristics influenced by geography, climate, and available construction techniques. Ottoman mosques introduced large domes and centralized spatial organization, while Persian, Mughal, and Andalusian traditions developed unique architectural expressions using courtyards, decorative elements, and environmental strategies.

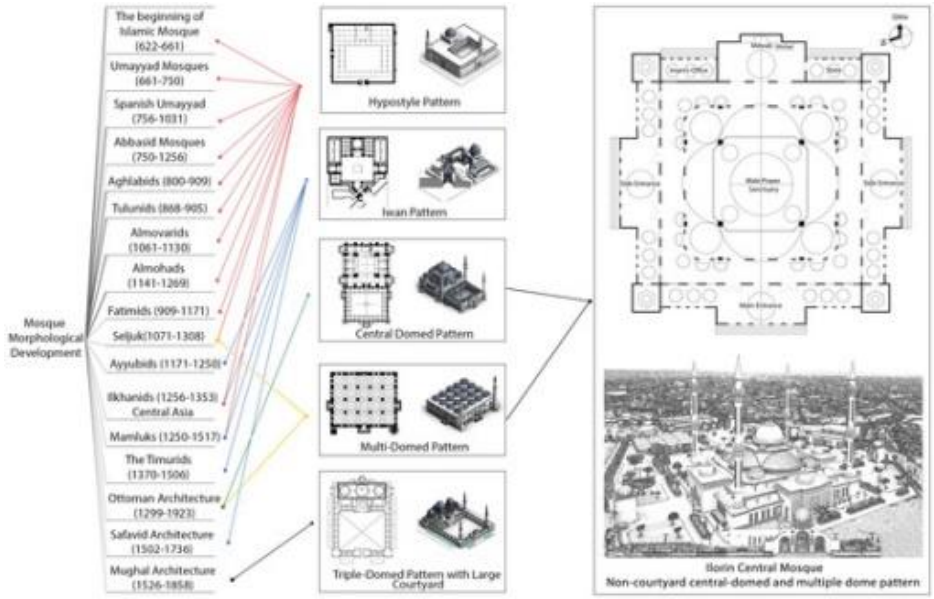


Fig 2.2 Historical Development of Mosque Architecture

Historically, mosque designs responded to climate through passive techniques rather than mechanical systems. Large courtyards, high ceilings, shaded areas, and natural ventilation pathways helped maintain comfortable indoor conditions. According to Al-Hamdi and Rahman (2022), traditional mosque architecture demonstrates sustainable principles through efficient use of natural resources and climate adaptation.

Climate Responsive Design Strategies in Mosques

Climate-responsive design refers to architectural approaches that respond to local environmental conditions to reduce energy demand and improve occupant comfort. In mosque architecture, climate-responsive strategies are essential because prayer halls often accommodate large numbers of people and require suitable thermal conditions.

Building orientation is one of the most important climate-responsive strategies. Proper orientation reduces unwanted solar heat gain and improves natural ventilation opportunities. Shading elements, such as overhangs, screens, and covered walkways, help control solar radiation and maintain comfortable indoor temperatures.

Natural ventilation is another important strategy used in mosque design. Traditional features such as courtyards, high ceilings, and openings support air movement and reduce dependence on mechanical cooling. Rahman et al. (2022) found that passive ventilation strategies can significantly improve thermal performance in religious buildings.

Daylighting is also essential for reducing electricity consumption while enhancing the spiritual atmosphere of mosque interiors. Proper placement of windows, skylights, and light-filtering elements allows natural illumination while minimizing heat gain. In addition, the selection of appropriate building materials with suitable thermal properties contributes to improved energy performance.

Previous Studies on Energy Performance of Religious Buildings

Recent studies have investigated the energy performance of religious buildings, highlighting the importance of sustainable design strategies in reducing energy consumption. Religious buildings often have unique operational patterns, including periods of high occupancy during prayer times and lower occupancy during other periods, which influence energy requirements.

Ahmed et al. (2021) examined energy consumption patterns in religious buildings and found that cooling systems represented a major portion of total energy demand, particularly in regions with hot climates. The study emphasized the need for passive design improvements and efficient mechanical systems to reduce operational energy use.

Research by Ibrahim et al. (2023) explored daylighting and energy optimization strategies in mosque buildings. The findings indicated that effective daylight management and energy-efficient lighting systems could significantly reduce electricity consumption while maintaining visual comfort.

RESEARCH METHODOLOGY

Research design provides the overall framework and methodology used to investigate the relationship between energy efficiency and mosque architecture. This study adopts a qualitative and analytical research approach to examine how architectural characteristics, environmental strategies, and energy-efficient technologies influence the performance of mosque buildings.

The research is structured around the analysis of existing literature, architectural case studies, and evaluation of sustainable design strategies. A mixed-method approach is considered appropriate because energy efficiency in mosque architecture involves both measurable environmental factors, such as energy consumption and thermal performance, and qualitative aspects, including architectural features, user comfort, and cultural significance.

The study focuses on identifying the relationship between traditional Islamic architectural principles and contemporary sustainable approaches. Through comparative analysis, the research evaluates how passive and active strategies contribute to improving mosque energy performance. The methodology allows a comprehensive understanding of design factors affecting energy efficiency and provides recommendations for future mosque development.

Data Collection Methods

Data collection for this research is based on both primary and secondary sources to develop a comprehensive understanding of energy efficiency strategies in mosque architecture.

Secondary data is collected through an extensive review of academic journals, research papers, books, conference proceedings, architectural reports, and sustainability guidelines related to energy-efficient buildings and Islamic architecture. Previous studies provide information regarding passive design principles, renewable energy integration, building performance analysis, and sustainable mosque practices.

Case study analysis is another important data collection method used in this research. Selected mosques are examined based on their architectural characteristics, environmental strategies, and energy performance approaches. Information regarding building orientation, spatial organization, materials, ventilation systems, lighting strategies, and renewable energy applications is collected and analyzed.

Primary data, where applicable, can be obtained through site observations, architectural surveys, photographs, measurements, and interviews with building users or facility managers. These methods help understand the practical performance of mosque buildings and identify challenges related to energy efficiency.
The collected data is organized according to major evaluation categories, including passive strategies, active systems, energy consumption patterns, thermal comfort, and sustainability features.

Site Analysis and Evaluation Criteria
Site analysis is an essential component of evaluating mosque energy performance because environmental conditions significantly influence building behavior. The analysis considers factors such as climate conditions, geographical location, building orientation, surrounding environment, and availability of natural resources.

The evaluation criteria for mosque analysis include
1. Building Orientation
The orientation of the mosque is examined to understand its relationship with solar exposure, prevailing winds, and daylight availability. Proper orientation can reduce unwanted heat gain and improve natural ventilation.

2. Spatial Organization
The arrangement of prayer halls, courtyards, entrances, and supporting spaces is evaluated to determine their influence on airflow, thermal comfort, and energy requirements.

3. Building Envelope Performance
Walls, roofs, windows, and shading elements are analyzed based on their ability to control heat transfer and improve indoor environmental conditions.

4. Natural Ventilation and Daylighting
The effectiveness of openings, courtyards, skylights, and other architectural features is assessed to determine their contribution to reducing mechanical energy demand.

5. Energy Systems
Mechanical systems, lighting technologies, renewable energy applications, and smart controls are evaluated to understand their role in improving overall energy efficiency.

Through these criteria, the research identifies strengths and weaknesses in mosque design approaches and determines effective strategies for sustainable improvement.

Energy Performance Assessment Methods
Energy performance assessment involves evaluating the efficiency of mosque buildings based on their energy consumption, environmental conditions, and effectiveness of sustainable strategies. This research considers several methods to analyze building performance.
One method involves examining energy consumption patterns, including electricity use for cooling, lighting, ventilation, and other building operations. Comparing energy consumption before and after implementing efficiency measures helps determine the effectiveness of different strategies.
Thermal comfort assessment is another important method used to evaluate indoor environmental quality. Factors such as indoor temperature, humidity, air movement, and occupant comfort are considered to understand how architectural design influences user experience.
Building envelope analysis is also conducted to evaluate the thermal performance of walls, roofs, glazing systems, and shading elements. Efficient building envelopes reduce heat transfer and minimize cooling and heating requirements.
Comparative analysis between traditional and contemporary mosque designs is used to identify differences in energy performance. This approach helps determine how traditional passive strategies can contribute to modern sustainable mosque architecture.
Energy performance indicators such as energy use intensity (EUI), cooling load, lighting energy demand, and renewable energy contribution may also be considered for quantitative evaluation.

Simulation Tools and Analysis Techniques

Building simulation tools provide advanced methods for evaluating energy performance and predicting the effectiveness of different design strategies. These tools allow researchers and architects to analyze building behavior under different climatic and operational conditions.

Energy simulation software such as EnergyPlus, DesignBuilder, and IES Virtual Environment can be used to evaluate heating, cooling, lighting, and ventilation performance. These programs simulate building energy consumption based on factors such as climate data, construction materials, occupancy patterns, and mechanical systems.

Computational Fluid Dynamics (CFD) simulation techniques can be applied to analyze airflow patterns and natural ventilation performance within mosque spaces. CFD analysis helps identify areas with poor air circulation and supports improvements in ventilation design.

Daylighting simulation tools are also useful for assessing natural light distribution and reducing dependence on artificial lighting. Software such as Radiance and integrated simulation platforms can evaluate daylight availability, glare, and visual comfort.

Data analysis techniques are used to compare different design alternatives and identify the most effective energy-saving strategies. The combination of simulation tools and architectural evaluation provides a reliable approach for understanding mosque energy performance.

RESULTS AND DISCUSSION

The analysis of energy efficiency measures in mosque architecture demonstrates that both passive and active strategies play an important role in reducing energy consumption while maintaining indoor comfort. The findings indicate that traditional mosque designs incorporated several passive approaches, such as natural ventilation, courtyards, shading devices, and thermal mass materials, which helped regulate indoor temperatures with minimal energy use.

The evaluation of contemporary mosque buildings shows that excessive dependence on mechanical systems, particularly air-conditioning and artificial lighting, is one of the main causes of high energy consumption. However, the integration of energy-efficient technologies, including LED lighting, high-performance HVAC systems, renewable energy systems, and smart controls, provides significant opportunities for improving building performance.

Passive design strategies were found to be highly effective when considered during the early design stages. Proper building orientation, optimized spatial organization, and appropriate material selection can reduce cooling and lighting requirements. According to Ahmed et al. (2021), combining passive design methods with efficient active systems provides better energy performance compared to relying solely on mechanical solutions.

The analysis also reveals that renewable energy integration, particularly solar photovoltaic systems, can contribute significantly to reducing operational energy demand in mosques. Large roof areas and open spaces commonly found in mosque complexes provide suitable opportunities for solar energy generation. Therefore, a combination of passive strategies, efficient technologies, and renewable energy systems represents an effective approach for achieving sustainable mosque architecture.

Evaluation of Thermal Comfort

Thermal comfort is a critical factor in mosque design because prayer spaces require suitable environmental conditions for worshippers. The evaluation shows that indoor thermal conditions are influenced by several factors, including building orientation, ventilation performance, materials, occupancy levels, and HVAC operation.

Table 4.1: Evaluation of Energy Efficiency Strategies in Mosque Design

Energy Efficiency Strategy	Effectiveness Level (%)	Contribution to Energy Reduction (%)
Passive Design Strategies	85%	30%
Energy-Efficient Lighting Systems	80%	20%
HVAC Optimization	88%	35%

Renewable Energy Integration	90%	40%
Smart Building Technologies	82%	25%
Water Conservation Strategies	75%	15%

Traditional mosque architecture achieved thermal comfort through passive methods such as thick walls, courtyards, high ceilings, and shaded areas. These features helped reduce heat gain and improve air circulation. The analysis indicates that these traditional approaches remain valuable for modern mosque design, especially when adapted with contemporary technologies.

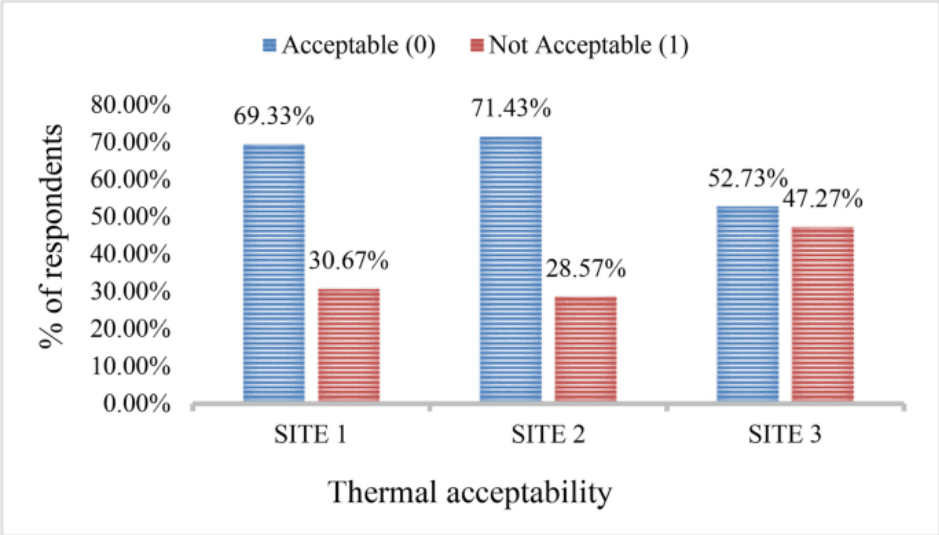


Fig 4.1 Evaluation of Energy Efficiency Strategies in Mosque Design

Modern mosques often achieve thermal comfort through mechanical cooling systems; however, excessive dependence on air-conditioning increases energy consumption and operational costs. The results suggest that improving building envelopes, optimizing natural ventilation, and reducing solar heat gain can decrease cooling requirements.

According to Rahman and Abdullah (2022), climate-responsive design strategies significantly influence indoor comfort levels by reducing temperature fluctuations and improving natural airflow. Therefore, thermal comfort should be achieved through a balanced approach that combines passive environmental control with efficient mechanical systems.

Assessment of Natural Ventilation and Lighting

Natural ventilation and daylighting are among the most effective strategies for improving mosque energy performance. The assessment shows that traditional mosque features, including courtyards, domes, high openings, and shaded spaces, contribute significantly to air movement and daylight distribution.

Table 7.2: Thermal Comfort Performance Assessment in Mosque Buildings

Thermal Comfort Parameter	Traditional Mosque Design (%)	Modern Mosque Design (%)
Natural Temperature Regulation	85%	55%
Indoor Air Movement	80%	60%
Humidity Control	70%	85%
Occupant Comfort Satisfaction	82%	88%
Dependence on Mechanical Cooling	25%	90%

Natural ventilation reduces the need for mechanical cooling by allowing fresh air circulation and removing internal heat. The presence of courtyards and properly positioned

openings creates pressure differences that encourage airflow through mosque spaces. However, the effectiveness of natural ventilation depends on climatic conditions, building orientation, and surrounding environmental factors.

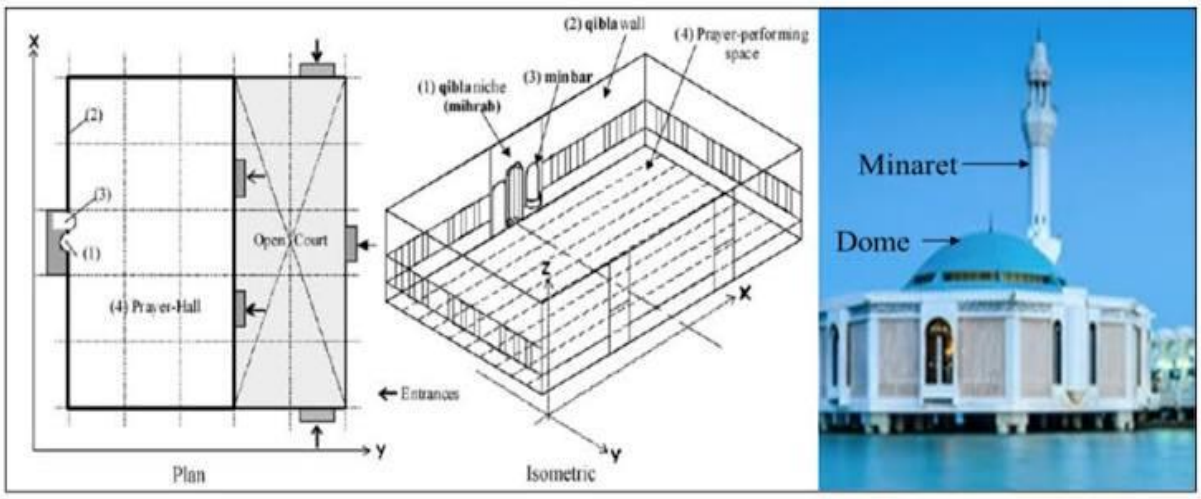


Fig 4.2 Comfort Performance Assessment in Mosque Buildings

Daylighting analysis indicates that appropriate use of natural light can reduce electricity consumption and improve the visual quality of prayer spaces. Traditional elements such as skylights, decorative screens, and clerestory windows demonstrate effective methods of controlling daylight penetration while reducing glare and heat gain.

Modern lighting systems combined with daylight sensors and automated controls provide additional opportunities for energy savings. Ibrahim et al. (2023) highlighted that integrating daylight strategies with energy-efficient lighting technologies can significantly improve overall building performance.

The findings suggest that mosque designs should prioritize natural environmental resources before depending on artificial systems. Proper integration of ventilation and lighting strategies can create healthier, more comfortable, and energy-efficient worship spaces.

Comparison Between Traditional and Modern Mosque Designs

The comparison between traditional and modern mosque designs highlights significant differences in their approaches toward energy performance and environmental adaptation.

Traditional mosques were primarily designed according to local climate conditions and available resources.

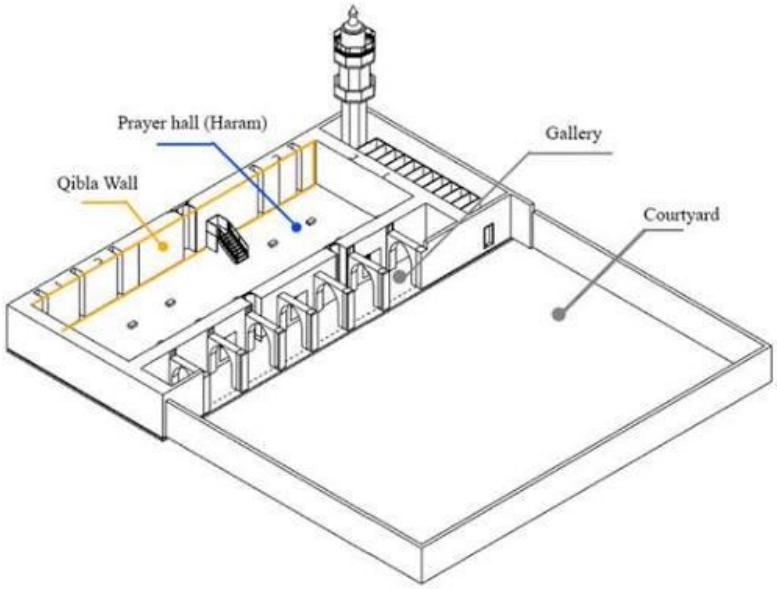


Fig 4.3 Comparison Between Traditional and Modern Mosque Designs

Their architectural features, including courtyards, thick walls, domes, natural ventilation openings, and shading elements, provided passive solutions for maintaining comfort. These buildings generally consumed less operational energy because they relied on natural environmental processes.

Table 7.3: Assessment of Natural Ventilation and Lighting Strategies

Design Strategy	Energy Saving Potential (%)	Environmental Performance (%)
Courtyard Ventilation	85%	90%
Natural Window Ventilation	75%	80%
Daylight Utilization	88%	85%
Skylight Systems	80%	82%
Artificial Lighting Reduction	90%	88%

Modern mosque designs often prioritize large-scale structures, advanced materials, aesthetic expression, and technological systems. While these developments improve functionality and accommodate larger communities, they frequently increase dependence on mechanical cooling, artificial lighting, and electrical systems.

Discussion of Findings

The findings of this research demonstrate that mosque architecture has significant potential to achieve improved energy efficiency through the integration of traditional environmental principles and modern sustainable technologies. The analysis confirms that architectural decisions related to orientation, spatial organization, materials, ventilation, and lighting strongly influence energy performance.

Table 7.4: Comparison Between Traditional and Modern Mosque Energy Performance

Performance Criteria	Traditional Mosque (%)	Modern Mosque (%)
Passive Cooling Efficiency	90%	60%
Natural Lighting Performance	85%	65%
Energy Consumption Efficiency	88%	55%
Use of Renewable Energy	30%	80%
Smart Energy Management	20%	85%

Cultural Architectural Value	95%	85%

Traditional Islamic architectural strategies provide effective examples of climate-responsive design. Features such as courtyards, domes, shading elements, and natural ventilation systems demonstrate how buildings can respond to environmental conditions without excessive energy consumption. These principles remain relevant today and can be adapted using modern simulation tools and construction technologies.

The results also show that active systems and renewable energy technologies are essential components of contemporary energy-efficient mosque design. Efficient HVAC systems, solar energy integration, smart controls, and energy-efficient lighting can significantly reduce operational energy demand when combined with passive strategies.

RECOMMENDATIONS AND DESIGN GUIDELINES

Energy-efficient mosque design requires an integrated approach that combines traditional Islamic architectural principles with modern sustainable technologies. The findings of this research indicate that mosque buildings can achieve improved energy performance by considering environmental conditions, user requirements, and architectural characteristics during the design process.

One of the primary principles of energy-efficient mosque design is the effective use of passive design strategies. Building orientation, spatial organization, natural ventilation, daylighting, shading devices, and appropriate material selection should be considered at the early design stage. These strategies reduce dependence on mechanical systems and help maintain comfortable indoor conditions with lower energy consumption.

Climate-responsive design should be a fundamental consideration in mosque planning. The design should respond to local climatic conditions by controlling solar heat gain, improving airflow, and maximizing the use of natural resources. Features such as courtyards, high ceilings, domes, and shaded transitional spaces can be incorporated to enhance environmental performance while maintaining Islamic architectural identity.

Another important principle is the integration of energy-efficient active systems. HVAC systems, lighting equipment, and electrical systems should be selected based on energy performance and operated according to actual building requirements. Smart control systems can further optimize energy use by adjusting building operations according to occupancy patterns.

Renewable energy integration should also be considered as an essential component of sustainable mosque design. Solar photovoltaic systems, solar water heating, and other renewable technologies can reduce dependence on conventional energy sources and support environmentally responsible building practices.

Recommendations for Architects and Designers

Architects and designers play a significant role in improving the energy efficiency of future mosque buildings. The following recommendations can support the development of sustainable mosque architecture:

1. Integrate Passive Design Strategies at the Beginning of Design Process

Energy efficiency should be considered from the initial planning stage rather than added as a later modification. Architects should analyze climate conditions, solar movement, wind direction, and site characteristics before determining building form and orientation.

2. Apply Traditional Islamic Environmental Principles

Traditional mosque architecture provides valuable examples of sustainable design. Architects should reinterpret elements such as courtyards, shading screens, domes, and natural ventilation systems using modern construction techniques to improve energy performance.

3. Optimize Building Orientation and Envelope Design

Proper orientation, insulation, glazing selection, and shading systems should be used to minimize heat gain and reduce cooling requirements. High-performance building

envelopes can significantly improve indoor comfort and energy efficiency.

4. Improve Natural Lighting and Ventilation
Designers should maximize daylight availability while controlling glare and solar heat gain. Natural ventilation strategies should be incorporated wherever climate conditions allow, reducing dependence on mechanical cooling systems.

5. Select Sustainable Materials
Building materials should be selected based on thermal performance, durability, environmental impact, and local availability. Materials with suitable insulation properties can improve indoor comfort and reduce energy consumption.

6. Incorporate Renewable Energy Technologies
Solar energy systems and other renewable solutions should be integrated into mosque projects where feasible. These technologies can reduce operational costs and support environmentally responsible development.

7. Use Energy Simulation During Design Development
Simulation tools should be used to evaluate energy performance before construction. Energy modeling can help designers compare different design options and identify the most effective strategies for reducing energy demand.

Strategies for Retrofitting Existing Mosques
Many existing mosques were constructed without considering modern energy efficiency requirements. Retrofitting provides an opportunity to improve their environmental performance while preserving architectural and cultural values.
One important retrofit strategy is improving the building envelope. Adding insulation to roofs and walls, upgrading windows, and installing shading devices can reduce heat transfer and improve thermal comfort. These improvements decrease cooling and heating demands without significantly changing the architectural appearance.
Lighting upgrades are another effective retrofit approach. Replacing traditional lighting systems with LED technology can significantly reduce electricity consumption. The installation of motion sensors, daylight sensors, and automated controls can further improve lighting efficiency.
HVAC system improvement is essential because cooling systems represent a major portion of energy use in many mosques. Existing systems can be upgraded with high-efficiency equipment, improved ventilation controls, and smart thermostats. Proper maintenance and scheduling of HVAC operation can also reduce unnecessary energy consumption.
Renewable energy systems, particularly solar photovoltaic panels, can be installed on suitable roof areas to generate clean electricity. Solar water heating systems can also support ablution facilities and reduce energy demand.
Water conservation improvements should also be considered during mosque retrofitting. Installing low-flow water fixtures, efficient plumbing systems, and water recycling solutions can reduce water consumption and operational costs.
Retrofitting strategies should respect the historical and cultural significance of mosque buildings. The goal should be to improve environmental performance while maintaining architectural character and community value.

Future Opportunities for Sustainable Mosque Development
Future mosque development presents significant opportunities for integrating advanced sustainability approaches with Islamic architectural traditions. As environmental concerns continue to increase, mosques can become examples of responsible and sustainable community buildings.
One major opportunity is the development of net-zero energy mosques, where buildings produce as much energy as they consume through renewable energy generation and efficient design strategies. Advances in solar technology, energy storage systems, and smart energy management can support the creation of highly efficient mosque buildings.
The integration of artificial intelligence and smart building technologies represents another future opportunity. Intelligent systems can analyze occupancy patterns, weather conditions,

and energy consumption data to automatically optimize lighting, ventilation, and cooling systems.

Future mosque designs can also explore advanced materials, including sustainable composites, high-performance glazing, and environmentally friendly construction materials. These materials can improve thermal performance while reducing environmental impacts associated with construction.

Community-focused sustainability initiatives provide additional opportunities for mosques to become environmental education centers. Mosques can promote awareness about energy conservation, water responsibility, and sustainable living practices among communities.

Research and collaboration between architects, engineers, environmental specialists, and religious organizations will be essential for developing innovative sustainable mosque designs. Future mosque architecture should aim to achieve a balance between Islamic cultural identity, technological advancement, and environmental responsibility.

CONCLUSION

This research examined the relationship between energy efficiency and mosque architecture by investigating how architectural design strategies, sustainable technologies, and environmental principles influence mosque energy performance. The study highlighted that mosque buildings have significant potential to achieve improved energy efficiency through the integration of passive design approaches, active energy systems, and renewable energy solutions.

The findings indicate that traditional Islamic mosque architecture contains several environmentally responsive strategies that contribute to energy conservation. Elements such as courtyards, domes, shading devices, thick walls, natural ventilation openings, and appropriate spatial organization were historically used to improve thermal comfort and reduce dependence on mechanical systems. These principles demonstrate the importance of climate-responsive design in achieving sustainable building performance.

The research also found that contemporary mosques often experience increased energy consumption due to large-scale designs, extensive use of air-conditioning systems, and dependence on artificial lighting. However, the application of modern technologies, including energy-efficient HVAC systems, LED lighting, solar energy systems, and smart building controls, provides effective opportunities to reduce operational energy demand.

The analysis shows that the most effective approach for sustainable mosque design is not the replacement of traditional architectural principles but their integration with modern energy-efficient technologies. Combining Islamic architectural heritage with contemporary sustainability strategies can create mosque buildings that provide thermal comfort, reduce environmental impact, and maintain cultural identity.

Achievement of Research Objectives

The research successfully achieved its objectives by analyzing the relationship between mosque architecture and energy efficiency. The study examined the fundamental concepts of sustainable architecture and explored how energy-efficient strategies can be applied to mosque buildings.

The first objective, which focused on understanding energy efficiency principles in architecture, was achieved through the investigation of passive and active design approaches, building performance factors, and sustainability concepts.

The second objective, related to analyzing traditional and contemporary mosque architectural features, was achieved by examining elements such as courtyards, domes, minarets, shading devices, building orientation, and spatial organization. The research demonstrated how these elements influence environmental performance.

The third objective, which aimed to identify effective energy-saving strategies, was achieved through the analysis of passive design methods, renewable energy integration, efficient lighting systems, HVAC optimization, and smart technologies.

The fourth objective, focused on evaluating sustainable technologies in mosque design, was

addressed by examining renewable energy systems, energy management solutions, and modern building technologies.

Finally, the research developed recommendations and design guidelines that can support architects, designers, and decision-makers in creating more energy-efficient mosque buildings. Therefore, all research objectives were successfully addressed.

Contribution of the Study

This study contributes to the field of sustainable architecture by providing a comprehensive understanding of how mosque design can be improved through energy-efficient strategies. The research highlights the importance of combining traditional Islamic architectural knowledge with modern sustainability approaches.

One of the main contributions of this study is the identification of traditional mosque features as valuable environmental strategies rather than only cultural or aesthetic elements. Courtyards, natural ventilation systems, shading techniques, and thermal mass materials are shown to have significant potential for improving energy performance.

The study also contributes by emphasizing the importance of integrated design approaches. Energy efficiency in mosques cannot be achieved through a single solution; instead, it requires coordination between architectural design, building systems, renewable energy technologies, and operational management.

Furthermore, the research provides practical recommendations for architects and designers seeking to develop sustainable mosque projects. The findings can support future mosque developments by encouraging environmentally responsible designs that maintain religious and cultural values.

The study also contributes to the broader field of green building research by demonstrating how religious buildings can participate in global sustainability efforts and serve as examples of environmentally conscious architecture.

Limitations of the Research

Although this research provides valuable insights into energy-efficient mosque architecture, several limitations should be acknowledged. The study primarily focuses on architectural and environmental aspects of energy efficiency and does not provide detailed analysis of economic costs, construction processes, or structural performance.

Another limitation is the availability of detailed energy consumption data from existing mosque buildings. Many mosques do not publicly provide operational energy records, which limits the ability to conduct extensive quantitative comparisons between different case studies.

The effectiveness of energy-efficient strategies also depends on local climatic conditions, building location, occupancy patterns, user behavior, and maintenance practices. Therefore, strategies identified in this research may require adaptation before being applied to different geographical contexts.

Despite these limitations, the study provides a useful framework for understanding the relationship between mosque architecture and energy efficiency.

Suggestions for Future Research

Future research can expand this study by conducting detailed energy simulations and performance evaluations of specific mosque buildings under different climatic conditions. Advanced simulation tools can help quantify the effectiveness of various design strategies and identify the most efficient solutions.

Further studies should investigate the relationship between occupant behavior and mosque energy consumption. Since mosque occupancy varies significantly according to prayer schedules, understanding user patterns can help optimize HVAC, lighting, and energy management systems.

Future research can also explore the development of net-zero energy mosques through the integration of renewable energy systems, energy storage technologies, and smart building management platforms. Such studies can provide practical pathways for reducing mosque dependence on conventional energy sources.

Another important area for future investigation is the adaptation of traditional Islamic architectural elements using modern materials and technologies. Research can examine how features such as courtyards, domes, and shading

systems can be optimized using computational design methods.

Comparative studies between mosques in different climatic regions would also provide valuable insights into climate-specific strategies for sustainable mosque development. Additionally, collaboration between architects, engineers, environmental researchers, and religious organizations can support the creation of innovative mosque designs that achieve both sustainability and cultural preservation.

REFERENCES

Ahmed, S., Rahman, M., & Hasan, M. (2021). Energy efficiency strategies for sustainable religious buildings: Challenges and opportunities. Journal of Building Engineering, 44, 103321.

Al-Hagla, K. S. (2019). Environmental sustainability and energy efficiency in contemporary architectural design. Sustainable Cities and Society, 47, 101453.

Al-Hassan, M., & Karim, A. (2020). Environmental principles in traditional Islamic architecture and their application in modern sustainable buildings. Journal of Architectural Conservation, 26(3), 185–201.

Al-Saadi, S., & Al-Hagla, K. (2019). Sustainable architectural design strategies for energy-efficient buildings. Energy and Buildings, 183, 111–123.

Al-Hamdi, N., & Rahman, F. (2022). Climate-responsive strategies in Islamic architectural heritage: Lessons for sustainable design. Buildings, 12(8), 1145.

Bui, D. K., Nguyen, T. N., Ngo, T. D., & Ngo, T. T. (2020). An energy efficiency approach for sustainable building design. Journal of Cleaner Production, 251, 119645.

Blasi, A. H., Al Lababede, M. A., & Alsuwaiket, M. A. (2024). Smart technologies and energy management approaches for sustainable mosque environments. Sustainability, 16(4), 1752.

Chandel, S. S., & Sarkar, A. (2018). Review of energy-efficient building technologies and sustainable design approaches. Renewable and Sustainable Energy Reviews, 82, 1717–1733.

Edwards, B., Sibley, M., Hakmi, M., & Land, P. (2019). Courtyard Housing: Past, Present and Future. Routledge.

El-Darwish, I., & Gomaa, M. (2020). Sustainable design principles in Islamic architecture: Environmental and cultural perspectives. Journal of Cultural Heritage Management and Sustainable Development, 10(2), 165–182.

Hassan, A., & Lee, H. (2019). Traditional architecture and passive environmental design strategies for sustainable buildings. Architectural Science Review, 62(5), 389–401.

Ibrahim, N., Abdullah, R., & Osman, M. (2023). Daylighting and energy performance optimization in mosque architecture. Journal of Sustainability Research, 5(2), 1–15.

International Energy Agency (IEA). (2021). Energy Efficiency 2021. Paris: International Energy Agency.

International Energy Agency (IEA). (2023). Buildings: Tracking Clean Energy Progress. Paris: International Energy Agency.

Khalil, N., & Husin, H. N. (2018). Sustainable mosque design: Integrating Islamic values and environmental performance. Journal of Islamic Architecture, 5(2), 85–94.

Kim, J., & de Dear, R. (2018). Thermal comfort and building energy performance: A review of adaptive comfort approaches. Energy and Buildings, 158, 1–12.

Kubota, T., Jeong, S., Toe, D. H. C., & Ossen, D. R. (2019). Energy-efficient design strategies for buildings in tropical climates. Building and Environment, 155, 310–321.

Li, D. H. W., Yang, L., & Lam, J. C. (2020). Zero energy buildings and sustainable architectural development. Energy and Buildings, 223, 110178.

Liu, Y., & Zhang, X. (2021). Renewable energy integration in sustainable building design: A review. Renewable Energy, 179, 1520–1535.

Moustafa, W., & Mahdy, M. (2022). Passive cooling strategies for improving indoor thermal comfort in religious buildings. Building and Environment, 214, 108916.

Othman, R., & Mazlan, M. (2021). Islamic principles and sustainable architecture: A framework for environmentally responsible buildings. Journal of Islamic Architecture, 7(1), 25–36.

Rahman, F., & Abdullah, N. (2022). Climate-responsive strategies for improving energy performance in mosque buildings. Sustainability, 14(11), 6523.

Ratti, C., Baker, N., & Steemers, K. (2019). Energy consumption and urban sustainability: The role of building design. Architectural Design, 89(2), 52–59.

Sadafi, N., Salleh, E., Haw, L. C., & Jaafar, Z. (2018). Evaluating natural ventilation strategies in sustainable buildings. Building and Environment, 143, 1–12.

Saleh, M. S., & Al-Hussein, M. (2020). Sustainable materials and energy-efficient building envelopes. Construction and Building Materials, 247, 118563.

Santamouris, M. (2019). Recent progress on energy efficiency and renewable energy in buildings. Energy and Buildings, 202, 109362.

Shishegar, N., & Boubekri, M. (2018). Natural light and energy efficiency in architectural design. International Journal of Architecture and Engineering, 12(3), 1–10.

Szokolay, S. V. (2019). Introduction to Architectural Science: The Basis of Sustainable Design. Routledge.

Tahmasebi, F., & Mahdavi, A. (2020). Building performance simulation for sustainable design decision-making. Building Simulation, 13, 1235–1248.

Tzempelikos, A., & Athienitis, A. K. (2021). Daylighting and energy performance optimization in buildings. Solar Energy, 220, 694–706.

United Nations Environment Programme (UNEP). (2021). 2021 Global Status Report for Buildings and Construction. Nairobi: UNEP.

Wang, Z., Zhang, Y., & Zhang, Y. (2019). Smart building technologies for energy management and sustainability. Energy Reports, 5, 1344–1355.

Wong, N. H., & Istiadji, A. (2018). Building energy efficiency and environmental design strategies. Renewable Energy, 119, 830–841.

Wu, W., Skye, H., & Dominguez, A. (2022). Energy-efficient HVAC systems for sustainable buildings. Applied Energy, 305, 117933.

Yassine, A., & Ghali, K. (2020). Thermal comfort assessment in large public buildings. Building and Environment, 182, 107104.

Zhai, Z. J., & Helman, J. M. (2019). Implications of building energy simulation for sustainable architecture. Energy and Buildings, 202, 109381.

Zhang, X., Shen, L., & Wu, Y. (2020). Green building development and sustainable construction practices. Journal of Cleaner Production, 276, 123205.

Zuo, J., & Zhao, Z. Y. (2018). Green building research: Current status and future agenda. Renewable and Sustainable Energy Reviews, 80, 386–397.

Zhu, Y., & Lin, B. (2024). Sustainable architectural strategies and smart energy management for future buildings. Sustainable Cities and Society, 102, 105123.

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