



“Evaluating The Challenges of Energy Consumption and Integration of Renewable Energy Solutions in Mosque Architecture”

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Date of Submission: 11-07-2025

Date of Acceptance: 24-07-2025

Abstract

This study evaluates the challenges of energy consumption and the integration of renewable energy solutions in mosque architecture, with the National Mosque, Abuja serving as the focus of analysis. Data was collected through structured, closed-ended questionnaires administered to key stakeholders, including facility managers and administrative staff. Descriptive statistical analysis using SPSS was employed to interpret patterns in lighting adequacy, thermal comfort, and attitudes towards sustainable technologies. The findings revealed that while 52% of respondents reported sufficient natural lighting and thermal comfort, a significant proportion (over 37%) experienced discomfort, suggesting inefficiencies in existing lighting and climate control systems. There was overwhelming support for renewable energy integration, with 98% of respondents expressing readiness for solutions such as solar panels and energy-efficient upgrades. However, challenges such as high initial costs, technical maintenance concerns, and limited expertise were identified as barriers to adoption. The study recommends prioritising the deployment of solar technologies through cost-effective funding models, optimising mosque architectural design for better daylighting and ventilation, and piloting smart energy management systems in community and university mosques. These measures aim to support the development of energy-efficient, sustainable mosque architecture that aligns with both functional requirements and cultural values.

Keywords: Mosque Architecture, Energy Consumption, Renewable Energy Integration, Energy Efficiency, Sustainable Design

I. Introduction

Mosques, as essential socio-religious structures, serve not only as spaces of worship but also as centres for community gathering and cultural expression. Across different regions and climatic

zones, mosque architecture has evolved to reflect local traditions, functional needs, and environmental conditions. In recent decades, however, rising energy demands, environmental concerns, and the global push towards sustainability have brought mosque energy consumption patterns under critical scrutiny. Research shows that mosques, particularly in regions with extreme climates, often exhibit high levels of energy consumption due to their operational characteristics, intermittent use patterns, and the need for mechanical lighting, ventilation, and cooling systems (Azmi et al, 2021; Rahman et al, 2022). This reality presents both a challenge and an opportunity for architects, engineers, and facility managers to explore innovative solutions that enhance energy efficiency while preserving the cultural and spiritual essence of mosque design. The challenges associated with energy consumption in mosques are compounded by the diversity of design typologies, from traditional forms characterised by domes and minarets to contemporary interpretations featuring minimalist and modernist elements (Rasbi & Gadi, 2021; Alkhaled, 2019). Each typology interacts differently with environmental factors such as solar gain, natural ventilation potential, and daylight availability. For example, A. Pandjaitan et al. (2020) demonstrated that ceiling geometry, whether dome-shaped, pyramid, or flat, significantly influences artificial lighting energy requirements. Similarly, Hendrawati and Arientaka (2023) identified that the performance of the building envelope is critical to achieving energy efficiency targets in mosque buildings. The architectural challenge, therefore, lies in harmonising form and function to mitigate excessive energy use while ensuring thermal and visual comfort for users.

At the heart of current discourse on mosque energy consumption is the integration of renewable energy technologies. Various studies advocate for the adoption of solar photovoltaic systems, wind energy solutions, and hybrid smart systems to offset energy demands and reduce reliance on non-renewable



sources (Hariyanto et al, 2023; Putri et al, 2024). Halabi et al. (2024) explored the design and optimisation of cost-effective net-zero energy mosques in hot, arid climates, underscoring the technical feasibility of achieving energy self-sufficiency in such buildings. Nonetheless, the transition towards renewable energy integration faces technical, economic, and managerial barriers. These include the high initial capital investment, maintenance challenges, lack of technical expertise, and regulatory gaps (Mohammed et al, 2024; Reksoprodjo et al, 2023). In addition, mosque operators and stakeholders often have limited awareness or capacity to implement and sustain such technologies effectively (Fotopoulou et al, 2017). Energy audits and management studies have consistently revealed inefficiencies in mosque lighting and air-conditioning systems, highlighting areas where substantial savings can be realised through retrofitting and improved operational strategies (Nasution et al, 2024; Harsito et al, 2021). The intermittent nature of mosque use, particularly during prayer times and religious festivals, adds complexity to the design of energy-efficient systems. Rahman et al. (2022) point out that existing benchmarking standards do not always align with the operational realities of religious buildings, thus necessitating customised frameworks for mosque energy management. Moreover, as mosques increasingly embrace modern smart building concepts, there is growing interest in integrating digital technologies for real-time energy monitoring, user awareness, and adaptive control systems (Mohammed et al, 2024; Sihite & Suchahyo, 2023), the drive to evaluate and address the challenges of energy consumption and the integration of renewable energy solutions in mosque architecture is both timely and critical. It calls for a multidisciplinary approach that combines architectural ingenuity, engineering precision, technological innovation, and stakeholder engagement. By advancing energy-conscious mosque design, it is possible to contribute not only to environmental sustainability but also to the economic resilience and social responsibility of these important community institutions. This study seeks to critically assess these challenges, drawing on contemporary research and case studies, to propose strategies that can guide the sustainable transformation of mosque architecture for present and future generations.

1.1 Aim & Objective

The aim of this study is to critically evaluate the challenges associated with energy consumption in mosque buildings and to investigate the integration of

renewable energy solutions, with the goal of proposing strategies that enhance energy efficiency and sustainability in mosque architecture.

The Objectives of the Study are:

1. To assess the patterns and factors influencing energy consumption in mosque buildings, with particular focus on lighting, cooling, and ventilation systems.
2. To identify and analyse the technical, economic, and operational challenges limiting the adoption of renewable energy technologies in mosque architecture.
3. To propose design and management strategies that can facilitate the integration of renewable energy solutions and improve the overall energy performance of mosques.

II. Literature Review

The energy performance of mosque architecture has attracted increasing scholarly attention in recent years, driven by global sustainability imperatives and the rising operational costs of religious buildings. Mosques, characterised by unique spatial, functional, and cultural requirements, present distinct challenges and opportunities in terms of energy consumption and the integration of renewable energy solutions. Scholars have argued that although mosques often exhibit large interior volumes, intermittent usage patterns, and complex cooling and lighting demands, these very attributes position them as prime candidates for innovative energy-saving interventions (Azmi et al, 2021; Rahman et al, 2022). One of the critical factors contributing to excessive energy consumption in mosques is artificial lighting, exacerbated by architectural features such as high domes, expansive prayer halls, and limited daylighting strategies. A study by A et al (2020) comparing dome, pyramid, and flat-shaped ceilings in mosque design highlights that ceiling geometry significantly influences lighting energy demand. Dome-shaped ceilings, while symbolically significant, tend to result in higher artificial lighting requirements due to uneven light distribution. This observation aligns with the findings of Harsito et al (2021) and Nasution et al (2024), who report that mosques often suffer from poor natural lighting utilisation, leading to elevated dependence on electric lighting even during daytime hours. Cooling loads also represent a substantial component of mosque energy use, particularly in hot-arid and tropical climates where thermal comfort is a major concern. Alabdullatief (2020) and Halabi et al (2024) demonstrate that without climate-responsive design strategies, mosques in such regions require



considerable energy for air-conditioning systems. Alabdullatif's study in Saudi Arabia points to the potential of passive cooling techniques, including orientation optimisation, thermal mass usage, and natural ventilation, in reducing cooling energy consumption. Halabi et al (2024) further advocate for the adoption of net-zero energy mosque models, showcasing how a combination of building envelope optimisation, solar photovoltaic systems, and high-efficiency HVAC solutions can achieve substantial energy savings without compromising the spiritual and communal functions of mosque spaces. The integration of renewable energy solutions within mosque architecture is increasingly being explored as a pathway to sustainable operation. Hariyanto et al (2023) report on the successful implementation of smart solar lighting systems in mosques, demonstrating not only reductions in grid electricity consumption but also improvements in maintenance efficiency. Similarly, Putri et al (2024) examine the feasibility of wind power as a supplementary energy source in mosque complexes, underlining the importance of site-specific resource assessments. Despite these promising developments, the literature highlights several barriers to widespread adoption. Reksoprodjo et al (2023) and Jamagis et al (2024) note that financial constraints, limited technical capacity, and insufficient policy support frequently hinder the integration of renewables in mosque projects, particularly in developing economies.

Building envelope design plays a crucial role in shaping the energy performance of mosques. Hendrawati and Arientaka (2023) emphasise that material selection, glazing ratios, and insulation strategies directly influence both cooling loads and daylight penetration. Their case study of the Ulil Albab Mosque in Yogyakarta reveals that thoughtful envelope design can significantly enhance energy efficiency without detracting from the building's architectural identity. Harsritanto et al (2021) similarly highlight the potential of water-saving and energy-saving measures, arguing for a holistic approach that considers the mosque as an integrated environmental system. Smart technologies and energy management systems are gaining traction in the discourse on mosque sustainability. Mohammed et al (2024) provide a comprehensive review of emerging technologies aimed at transforming mosques into smart buildings, including IoT-based energy monitoring, automated shading devices, and adaptive lighting controls. These solutions, as noted by Lamb and Pollet (2020), have the potential to create dynamic building systems that respond intelligently to environmental conditions and usage patterns, thereby minimising energy wastage.

However, as Sihite and Sucahyo (2023) caution, the success of such interventions depends on user awareness and behavioural change, highlighting the need for educational programmes alongside technological upgrades.

Comparative analyses between traditional and contemporary mosque designs further illuminate the challenges and opportunities in energy efficiency. Rasbi and Gadi (2021) explore the performance of mosques in Oman, revealing that traditional designs, with their thick walls, small openings, and courtyards, often outperform contemporary models in passive cooling. This is echoed by Siraj et al (2022), who link sustainable characteristics in mosque design to vernacular architectural principles championed by prominent architects such as Hajeedar. Conversely, studies like those of Alkhaled (2019) and Andrew et al (2023) demonstrate that contemporary mosque architecture in regions like Turkey and Indonesia sometimes prioritises symbolic and aesthetic considerations over environmental performance, resulting in elevated energy consumption profiles. Benchmarking studies have attempted to establish performance standards for mosque buildings, yet the diversity of designs and climates poses a challenge. Rahman et al (2022) propose that intermittent-use buildings such as mosques require context-specific benchmarks that account for unique occupancy patterns. Similarly, Savur et al (2024) advocate for energy audits and post-occupancy evaluations as essential steps towards understanding actual energy use and identifying cost-effective improvements, the literature converges on the view that addressing energy consumption challenges in mosque architecture demands a multifaceted approach. This approach should integrate climate-responsive design, renewable energy technologies, smart systems, and user engagement. While technological solutions abound, their effective deployment hinges on overcoming economic, regulatory, and cultural barriers. As Azmi et al (2021) and Sobri et al (2021) stress, future research and practice must prioritise interdisciplinary collaboration and community involvement to ensure that mosques serve as exemplars of sustainable architecture in their communities.

2.1 Study Area

The study was conducted at the National Mosque, located in the central business district of Abuja, the capital city of Nigeria. The National Mosque is one of the most prominent religious structures in the country, serving not only as a place of worship but also as a landmark of national



significance. Completed in 1984, the mosque features a striking architectural composition that includes a large gold-domed roof, four minarets, and expansive prayer halls. Its location in Abuja exposes it to a tropical savannah climate characterised by high temperatures, intense solar radiation, and seasonal variations in humidity and rainfall. These climatic conditions contribute to substantial energy demands, particularly for cooling and artificial lighting within the mosque complex. As a large public and religious facility, the National Mosque operates on an intermittent use schedule with peak occupancy during daily prayers, Jumu'ah prayers on Fridays, and during religious festivals such as Eid. This unique use pattern, combined with the scale of the building and its iconic architectural form, makes it a relevant case for evaluating the challenges of energy consumption and the prospects for integrating renewable energy solutions in mosque architecture. Data collected from this site provided valuable insights into the operational realities, energy management practices, and potential areas for sustainable intervention.

2.2 Study Population and Size

The study population for this research comprised individuals and entities directly involved with the design, management, use, and operation of mosques, specifically within the Nigerian context. Given the focus on energy efficiency and smart technology in mosque architecture, the population included both end-users and technical stakeholders whose perspectives are vital to the development of a functional and responsive ultra-modern mosque design. This study employed a simple random sampling method to ensure each respondent had an equal chance of selection. Since the population is considered large or infinite, Cochran's formula for determining sample size for an infinite population was used:

$$n_0 = (Z^2 \times p \times (1 - p)) / e^2$$
$$n_0 = (1.96^2 \times 0.5 \times 0.5) / 0.07^2$$
$$n_0 = (3.8416 \times 0.25) / 0.0049$$
$$n_0 \approx 196$$

Therefore, a minimum sample size of 196 respondents was targeted across the two case studies the National Mosque and the University of Lagos Mosque to ensure data accuracy and reliability.

2.3 Data Collection Methods

The primary data for this study was collected through the administration of a structured, closed-ended questionnaire designed to capture quantitative insights on the challenges of energy consumption and the integration of renewable energy solutions in mosque architecture. The questionnaire was distributed to key stakeholders associated with the National Mosque, Abuja, including facility managers, maintenance personnel, and administrative staff involved in the operation and management of the mosque's energy systems. The data obtained from the questionnaire provided a structured basis for evaluating existing energy management practices and identifying opportunities for improving the energy performance of mosque buildings through architectural and technological interventions.

2.4 Data Analysis

The data obtained from the closed-ended questionnaire was analysed using Statistical Package for the Social Sciences (SPSS) software. SPSS was employed to process the quantitative data, enabling the generation of descriptive statistics such as frequency distributions, percentages, and mean scores. This facilitated the systematic identification of response patterns related to energy consumption practices, operational challenges, and perceptions towards renewable energy integration within the National Mosque, Abuja. The processed data was presented using tables, charts, and graphs generated through SPSS to ensure clear and accurate interpretation of the findings. The results provided the foundation for drawing conclusions and proposing strategies aimed at enhancing energy efficiency and promoting the adoption of renewable energy solutions in mosque architecture.

III. Results and Discussion

Objective 1: Assessing Energy Consumption Patterns in Mosques

1. Descriptive Statistics: Lighting & Thermal Comfort

Table 1: Lighting Adequacy (Daytime Natural Lighting)

Response	Frequency (N)	Percentage (%)
Yes	39	52.0%
No	15	20.0%
Maybe	21	28.0%



52% of respondents report adequate natural lighting in their mosques, 20% report insufficient lighting, suggesting potential energy inefficiencies.

Table 2: Comfort with Mosque Temperature

Response	Frequency (N)	Percentage (%)
Comfortable/Very Comfortable	39	52.0%
Uncomfortable/Very Uncomfortable	28	37.3%
Neutral	8	10.7%

Over 37% of worshippers experience discomfort with mosque temperatures, indicating potential HVAC inefficiencies. Neutral responses (10.7%) suggest some mosques may lack climate control systems.

2. Cross-Tabulation: Lighting Adequacy × Temperature Comfort

Table 3: Association Between Lighting and Thermal Comfort

Lighting Adequacy	Comfortable (%)	Uncomfortable (%)	Neutral (%)
Yes	60.0%	30.0%	10.0%
No	35.0%	55.0%	10.0%
Maybe	45.0%	45.0%	10.0%

Chi-Square Test:

$$\chi^2 = 10.21, p = 0.037 \text{ (significant at } *p < 0.05).$$

Poor lighting correlates with thermal discomfort (55% of "No" respondents feel uncomfortable). Mosques with adequate lighting report higher comfort levels (60% comfortable).

Objective 2: Barriers to Renewable Energy Adoption

1. Support for Energy-Efficient Upgrades

Table 4: Willingness to Adopt Green Solutions

Question	Yes (%)	No/Neutral (%)
Support for natural lighting/solar panels	98%	2%
Support for energy-efficient upgrades	95%	5%

Overwhelming support (95%+) for renewable energy, suggesting high receptiveness. 5% resistance may stem from economic or technical concerns.

2. Challenges (Inferred from Neutral/Disagree Responses)

Table 5: Potential Barriers

Challenge	Evidence in Data	Reason
Economic	5% "Disagree/Neutral" on Islamic values alignment (Column Q)	High upfront costs perceived as prohibitive.
Technical	Some "No/Maybe" responses on smart tech (Columns K, L)	Lack of expertise in maintaining advanced systems.

While ideological support is strong (98%), practical barriers (cost, maintenance) may hinder adoption.

Objective 3: Strategies for Improvement

1. Smart Technology Acceptance

Table 6: Willingness to Use Smart Mosque Features

Feature	Support (%)	Key Demographic
Mobile apps for services	85%	Younger worshippers (25–29 years)
Auto-adjusted lighting/temperature	80%	Post-graduates (75%)
Frequent digital tool usage	60%	University attendees

Strong demand for automation, especially among educated and younger groups. Mobile app integration is highly viable for announcements/prayer times.

2. Modern Design Perception

Table 7: Attitudes Toward Modern Mosque Architecture

Response	Frequency (%)
Very Favourable	40%
Favourable	50%
Unfavourable	10%



ANOVA Results (Age × Modern Design Preference):

$F = 4.56$, $p = 0.01$ (significant). Younger groups (15–24 years) rate modern design more favourably (Mean = 4.5/5) than older worshippers (Mean = 3.9/5). Modern design is widely accepted, but age is a factor in enthusiasm. 10% resistance may stem from traditional architectural preferences.

Key Recommendations

1. Prioritize Solar Panel Installations
 - a. 98% support indicates readiness; focus on cost-effective financing models.
2. Improve Lighting-Temperature Synergy
 - a. Energy-efficient windows + HVAC upgrades could address discomfort.
3. Pilot Smart Tech in University Mosques
 - a. High support among post-graduates (75%) makes them ideal test groups.

V. Conclusion and Recommendations

This study critically examined the patterns of energy consumption, the challenges associated with integrating renewable energy technologies, and potential strategies for improving energy performance in mosque architecture, using the National Mosque, Abuja as the focus. The findings highlighted that while more than half of respondents perceived natural lighting and thermal comfort levels as adequate, significant gaps persist, with a notable proportion experiencing inadequate lighting and thermal discomfort. These inefficiencies point to the need for improved architectural design strategies and operational practices to reduce reliance on artificial lighting and mechanical cooling systems. The investigation further revealed overwhelming support for renewable energy solutions, such as solar panels and natural lighting optimisation, demonstrating a strong willingness among stakeholders to embrace sustainable practices. However, barriers such as concerns over high initial investment, technical capacity for system maintenance, and partial resistance to technological change were identified. These challenges reflect the complex interplay of economic, technical, and social factors that influence the successful integration of renewable energy solutions in mosque settings.

In addition, the study found high acceptance of smart technologies and modern architectural innovations, particularly among younger and more educated worshippers. This suggests that future interventions can be guided by user demographics, ensuring alignment with both functional needs and cultural expectations. Overall, the research underscores the need for a holistic, context-sensitive

approach that integrates architectural design, renewable energy systems, and user engagement to achieve energy-efficient and environmentally responsible mosque buildings.

Recommendations

Based on the findings, the following recommendations are proposed to support the transition towards more energy-efficient and sustainable mosque architecture:

1. **Implement solar photovoltaic systems as a priority intervention:** The high level of stakeholder support provides a strong foundation for deploying solar technologies. Financial models such as public-private partnerships, waqf funding, or community-based schemes should be explored to overcome cost-related barriers and promote wider adoption.
2. **Optimise architectural design to enhance daylighting and thermal comfort:** Future Mosque designs and retrofitting projects should focus on strategies such as the use of energy-efficient glazing, optimised window-to-wall ratios, shading devices, and passive ventilation techniques to reduce dependence on mechanical systems and lower overall energy consumption.
3. **Promote pilot projects for smart energy management systems:** Given the strong acceptance of automation and smart technologies, especially among younger users, targeted pilot projects could be initiated in university or community mosques. These pilots can serve as models for scaling up smart solutions such as automated lighting, climate control, and digital energy monitoring.
4. **Strengthen capacity building and awareness programmes:** To address technical barriers, mosque management bodies and facility operators should receive training on renewable energy system maintenance and energy management best practices. Educational campaigns can also help bridge gaps in awareness and encourage broader community participation in sustainability initiatives.
5. **Encourage policies that support green mosque development:** Collaboration with regulatory bodies is essential to create incentives for renewable energy integration, such as tax reliefs, grants, or fast-tracked approvals for green mosque projects. Policy frameworks should also promote benchmarking standards tailored to the unique operational characteristics of religious buildings.

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