

ECO-MOSQUE AND ENVIRONMENTAL SUSTAINABILITY: A SYSTEMATIC REVIEW OF PRACTICE AND APPLICATIONS

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ABSTRACT

Eco-mosque represents an environmental awareness movement in architecture, which has been recognized globally. The design of the eco-mosque contributes to sustainable development, particularly environmental sustainability. This study reviews the eco-mosque practices in both certified and non-certified mosques. Optimizing the PRISMA framework, five articles of 205 initial results, which were published between 2020 and 2025, were included in this study. The data was analyzed by thematic and comparative methods. The results indicate that certified mosque implements integrated advanced technology guided by green building standards, such as energy-efficient materials, renewable energy, and a water recycling system. Meanwhile, non-certified mosques, including traditional ones, highlight the passive approaches such as using local material and natural ventilation, which align with environmental principles. This study emphasizes the need for an inclusive eco-mosque framework that embraces both certified innovations and context-responsive vernacular approaches, offering practical insight for sustainable religious architecture.

Keywords: Eco-mosque, Green building, Environmental sustainability

ABSTRAK

Eko-masjid merepresentasikan gerakan kesadaran lingkungan dalam bidang arsitektur, yang telah direkognisi secara global. Desain eko-masjid berkontribusi terhadap Pembangunan Berkelanjutan, khususnya keberlanjutan lingkungan. Penelitian ini mengkaji praktek eko-masjid, pada masjid bersertifikasi dan tidak bersertifikasi. Dengan mengoptimalkan kerangka PRISMA, lima dari 205 artikel yang dipublikasikan dalam rentang 2020 dan 2025 diikutsertakan dalam studi ini. Data dianalisis menggunakan metode tematik dan perbandingan. Hasil penelitian mengindikasikan masjid bersertifikasi menerapkan teknologi terkini terintegrasi berdasarkan standar bangunan hijau, seperti material yang efisien, energi terbarukan, dan system daur ulang air. Sementara itu, masjid yang tidak bersertifikasi, termasuk masjid tradisional, menekankan pendekatan pasif seperti penggunaan material local dan ventilasi alami yang sesuai dengan prinsip lingkungan. Studi ini menekankan pentingnya kerangka eko-masjid inklusif, yang mengintegrasikan inovasi dan pendekatan tanggap konteks, yang menawarkan ide praktek bagi arsitektur religius berkelanjutan.

Kata kunci: Eko-masjid, Bangunan hijau, Keberlanjutan lingkungan

Introduction

Environmental sustainability, as one of the three pillars of sustainable development alongside economic and social sustainability, emphasizes responsible interaction with the environment to support human life, with little or no negative impact (Wang & Ramakrishnan, 2022). On the other hand, the building and construction sector consumes one-third of global primary energy (Luo et al., 2022), which is used in the construction, operational, maintenance, and demolition stages. It also needs natural resources and water, while simultaneously generating considerable waste (Chen et al., 2023), which could impact biodiversity (Mba et al., 2024). In response to worsening environmental degradation, the building and construction industry has emphasized green building practices to minimize the impact on the natural environment (Chen et al., 2023).

The eco-mosque emerges as a response to the phenomenon of energy use occurring in the mosque. Mosques as religious buildings consume more energy for accommodating the religious, social, and educational activities within (As-Salafiyah et al., 2024; Mat Sobri et al., 2021). The mosque employs mechanical heating, ventilation, and air conditioning (HVAC) for providing indoor thermal comfort (Azmi & Kandar, 2019), and in tropical regions, a significant portion of energy is consumed by air conditioning (Suhono et al., 2020).

An eco-mosque is a mosque that establishes sustainable mutual symbiosis between the building, users, and environment (Hidayat et al., 2018; Prabowo, 2017). Eco-mosque initiatives include sustainable architectural design, renewable energy adoption, rainwater harvesting, natural ventilation and lighting strategies, tree planting, recycling programs, efficient building management systems, and active community participation (Mat Yamin, 2021). Moreover, some interventions could be done in the design process through considering spatial layout and mosque volume, fixed orientation of the prayer hall, occupancy pattern of mosques, user activity level, and clothing type (Azmi & Kandar, 2019). However, previous studies also show a variety of implementations, including technology integrations, depending on the geography, available resources, and historical and cultural contexts (Yu et al., 2025).

As public awareness of eco-mosque has risen in the community and considering the implementation variation, it is important to establish eco-mosque indicators as a design framework across diverse contexts. While prior research (e.g., Mat Sobri et al., 2021) has synthesized conceptual frameworks for sustainable mosque design, there is still a lack of systematic mapping on how these practices are implemented in certified and non-certified eco-mosques, particularly in operational and architectural applications. For that reason, this study aims to find sustainable practices in eco-mosques, both certified and non-certified, and seek the influence of these practices on their design and operations through a systematic literature review.

Methods

This study employs a systematic literature review method that focuses on the eco-mosques' practices both in certified and non-certified mosques in supporting the achievement of environmental sustainability. The methodology follows structured steps based on the PCC framework (Population-Concept-Context), which is widely used in evidence-based reviews in the architecture and environmental design scope.

The PCC framework used to define the scope was: (1) Population: mosque buildings; (2) Concept: implementation of eco-mosque practices; and (3) Context: certified and non-certified mosques globally.

As an access limitation and time constraint, the search was only conducted using Dimensions. It focused on peer-reviewed journal articles that were published between 2020 and 2025. The following search query was applied, namely: ("eco mosque" OR "green mosque" OR "sustainable mosque" OR "environmentally friendly mosque") AND ("sustainability practices" OR "green design" OR "green architecture" OR "energy efficiency" OR "water conservation" OR "environmental management"). Additional filters were applied, namely: (1) Publication type: journal articles; (2) Access type: open access; (3) Subject area: built environment, architecture, building. To ensure relevance and credibility, the screened records were selected based on the inclusion and exclusion criteria, shown in Table 1.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
The article focuses on mosques that apply sustainability principles	Not relevant to the mosque context
Discusses implemented sustainable practices	Does not mention or discuss the actual implementation of sustainability practices
Focuses on actual implementation in mosque design and/or operations	Only discusses theoretical concepts or design recommendations without empirical data or case studies
Peer-reviewed scientific journal articles	The article is not a scientific journal.
Written in English	Written in languages other than English

The search initially collected 205 articles. Using inclusion and exclusion based on titles and abstracts, 10 papers were shortlisted for full-text review. After thorough evaluation, 5 articles were included in the study. The relatively low number of reviewed articles is mainly because of the inclusion criteria based on the research question, which focuses on the actual application of sustainability practices in eco-mosques. A large number of excluded articles were on retrofitted strategies made to improve mosque conditions, but did not discuss the sustainable practices from mosques in buildings themselves. Given that the practical implementation of sustainability is paramount within the context of this review, these were regarded as outside the range of our literature survey. Figure 1 illustrates the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram, which was used to document the screening process systematically.

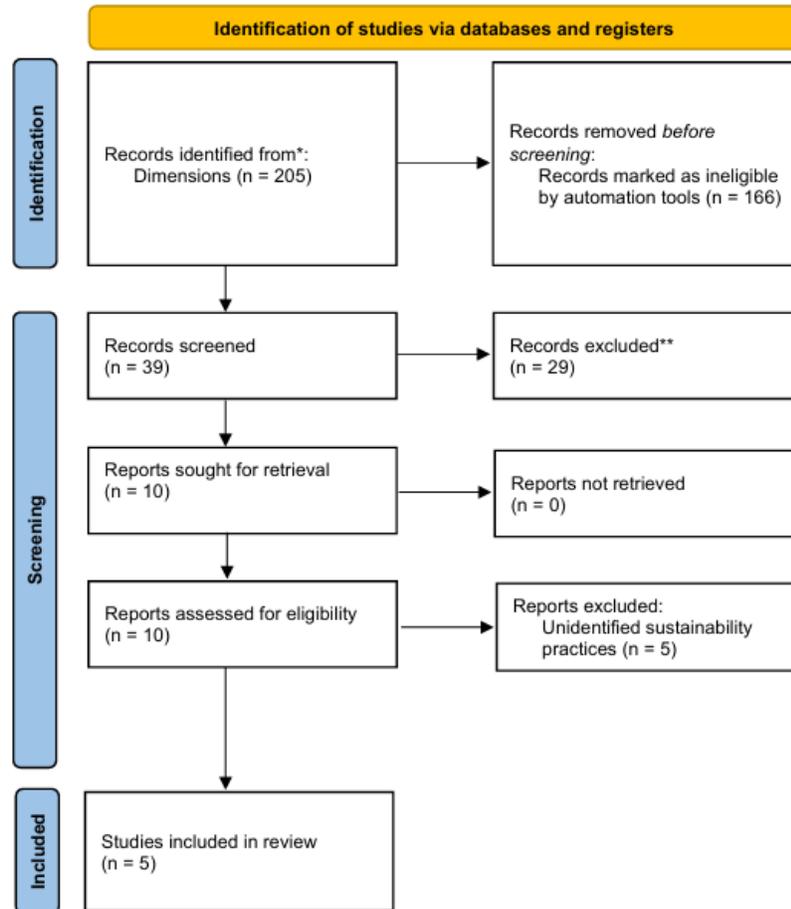


Figure 1. PRISMA diagram

The data was then analyzed using the thematic analysis technique, which enabled the identification and categorization of sustainability practices implemented in the eco-mosque. This approach allowed themes such as energy conservation, water management, materials, green space, and so on to be the indicators of sustainable building practices. The thematic analysis also aligns with the aim of this study, which is to explore actual sustainability practices. Along with that, a comparative analysis was also employed to distinguish the sustainable implementation between certified and non-certified mosques. This dual approach ensures both thematic and contextual contrast and provides a more comprehensive understanding of how sustainability influences mosque design and operations.

Results and Discussion

There are five articles included in this study, with seven mosques discussed as shown in Table 2. The articles encompass different locations, certifications, and types. However, most of the studies are located in Southeast Asia. Unfortunately, only one mosque has been certified, Green Building Index (GBI) Platinum certification, namely Raja Haji Fisabilillah mosque.

Table 2. Included Articles

Researcher	Year of Publication	Mosque, Location	Certification	Mosque Type
Yu, Haoxuan; Zahidi, Izni; Fai, Chow Ming; Madsen, Dag Øivind (Yu et al., 2025)	2025	Raja Haji Fisabilillah Mosque, Cyberjaya, Malaysia	Platinum (GBI)	Modern
Sari, Laina Hilma; Wulandari, Elysa; Idris, Yunita; Kayan, Brit Anak (Sari et al., 2025)	2025	Asal Penampaan Mosque, Tue Kebayakan Mosque, Al Jihad Mosque, Aceh, Indonesia	NA	Traditional
Mochtar, Sahid; Sunartio, Anindhita Nugroho; Lukman, Aldyfra Luhulima; Wirakusumah, Indri Astrina Indrarani; Ramadhan, Adam; Lazuardi, Klarissa; Angeline, Cheryl (Sahid et al., 2024)	2024	Al Ukhuwah Mosque; Istiqamah Mosque, Bandung, Indonesia	NA	Modern
Ismail, Muhammad Azzam; Rashid, Fahanim Abdul (Ismail & Rashid, 2023)	2023	Raja Haji Fisabilillah Mosque, Cyberjaya, Malaysia	Platinum (GBI)	Modern
Rahman, Noor Muhammad Abdul; Abdullah, Muhammad Syukri Imran; Lim, Chin Haw (Abdul Rahman et al., 2021)	2021	Assyafaah Mosque, Singapore	NA	Modern

Materials

The use of sustainable materials in building construction can reduce material extraction from the natural environment. Generally, two approaches can be considered to reduce material consumption, which are (1) reducing new material consumption and (2) reducing embodied energy (Wang & Ramakrishnan, 2022).

Raja Haji Fisabilillah Mosque implements engineered sustainable materials such as the low-emissivity glass, fly-ash concrete, ionized ceiling material, and double-glazed glass for the dome (Danish et al., 2023; Ismail & Rashid, 2023; Yu et al., 2025). Assyafaah Mosque in Singapore applies a white brick wall and reinforced concrete roof slab and structure, clear windows designed with solar shading, and block pavement (Abdul Rahman et al., 2021). Located in a tropical region, the use of advanced green materials aims to achieve energy efficiency and contemporary design standards. The chosen material reflects the mosque image as a modern mosque. In the case of a certified mosque, the material consideration in Raja Haji Fisabilillah Mosque has been embedded in the early stage of design. This is crucial as it will impact the building performance (Feria & Amado, 2019).

On the other hand, a traditional mosque, namely Asal Penampaan in Indonesia, implements local materials such as sago palm leaf roof, stone, and soil wall supported by a wooden structure (Sari et al., 2025). The traditional mosque employs natural, renewable, and low-embodied energy, which can be easily found locally, reflecting the traditional architecture characteristic. This approach, while less

technologically advanced, aligns with the sustainability principles through climatic responsiveness and cultural relevance.

The implementation of green materials in the mosques above has been proven to reduce energy consumption and increase thermal comfort in the building. The low-e glass reduces the heat transfer while allowing natural light to enter and maintains a stable interior temperature and decreases heating and cooling loads compared to the standard glass (Ahmadi, 2025; Shamsudin et al., 2023). Moreover, the use of fly-ash concrete can substitute cement consumption in construction, leading to more environmentally friendly construction (Nayak et al., 2022). The installation of ionized ceiling material could improve indoor air quality as it will release negative ions into the indoor environment, which will neutralize airborne pollutants (Souza, 2025). Another benefit of using ionized material is its ability to affect psychological and cognitive well-being (Souza, 2025). In addition, the use of clear glass windows designed with solar shading can decrease the heat gain during daylight, and the installation of block pavement can lower the water runoff (Abdul Rahman et al., 2021). In the Asal Penampaan mosque, the use of sago palm roofing demonstrates adequate thermal comfort performance, compared to the renovated mosque (Sari et al., 2025).

In eco-architecture perspective, the use of ecological material should consider (1) the amount of energy used in the material exploitation and production, (2) the transformation material ability to be returned to the nature, (3) the pollution level in the process of material exploitation, production, consumption, and maintenance, and (4) local natural sources material (Frick & Suskiyatno, 2006). The main concern is how to reduce the material extraction from the environment, which can be implemented through using recycled, reused, or renewable material, low embodied energy material, or local material. Focusing on these approaches, the building and construction industry will decrease the environmental impacts related to the natural resources reserves, waste generation, and carbon emissions.

Energy Conservation

In terms of energy conservation, Raja Haji Fisabillah Mosque, as a certified mosque, tends to optimize both active and passive approaches. It includes the use of solar energy, LED lighting, passive dome design, cross ventilation (see figure 2), and thermal insulation (Yu et al., 2025). The active approach reflects the advanced technology, which effectively reduces energy consumption, while the use of passive design demonstrates the climate consideration in the design stage.

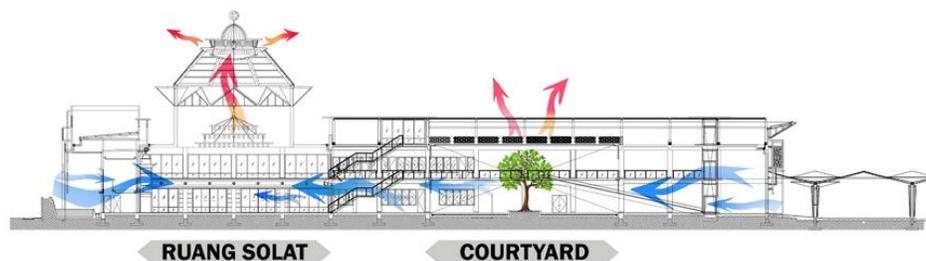


Figure 2. Cross ventilation system in Raja Haji Fisabillah Mosque (Ismail & Rashid, 2023)

Meanwhile, non-certified mosques mainly focus on a passive approach in conserving energy. Al Ukhuwah Mosque and Istiqamah Mosque in Bandung, Indonesia are designed with many openings and transparent walls (Sahid et al., 2024), Asal Penampaan Mosque, Tue Kebayakan Mosque, and Al Jihad Mosque, in Aceh, Indonesia apply ground wall ventilation and clerestory, which is shown in figure 3 (Sari et al., 2024), while Assyafaah Mosque in Singapore employs building orientation principles (longer side facing north), window optimalization at east and north side, cross ventilation in basement construction, and transparent façade (Abdul Rahman et al., 2021). The only active approach in the Assyafaah Mosque is the use of LED at night (Abdul Rahman et al., 2021). As in a non-certified mosque, the advanced technology to conserve energy is barely found.

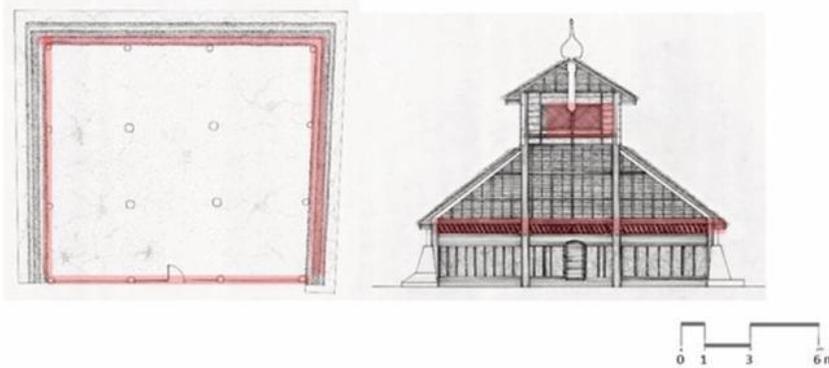


Figure 3. Ventilation and clerestory (highlighted in pink) in Asal Penampaan Mosque (Sari et al., 2025)

Both active and passive approaches contribute to minimum energy consumption in the building. Natural ventilation systems, for example, offer advantages for energy-saving in the building in terms of affordability, durability, lower noise level, and less emission, and well-being in terms of providing adequate indoor thermal comfort and promoting a healthier environment (Zhang et al., 2021). Moreover, providing a transparent façade will allow natural lighting penetration, which impacts the use of artificial lighting.

For active approaches, the installation of solar panels offers multiple advantages, such as providing a renewable and clean energy source, reducing operational costs, and requiring low maintenance procedures (Maka & Alabid, 2022). In addition, the application of LED lighting is more efficient than traditional bulbs, as it converts more energy into light and has a longer lifespan (Palacios-Intriago et al., 2024). As a consequence, less energy is needed to illuminate the building's interior.

Many strategies can be implemented to enhance energy efficiency in buildings, such as optimizing passive design, implementing energy-efficient building systems, and developing an intelligent energy consumption monitoring system (Farghali et al., 2023). The passive design should be considered and implemented during the early design stage, as it is related to site conditions and building

orientation. Meanwhile, the active approach employs technological tools that facilitate the energy-saving process. Recently, active systems have integrated Internet of Things (IoT) technology to control and monitor energy systems in the building. The combination of active technologies with a passive strategy will offer significant energy savings.

Water Management

There are three main practices of reducing water consumption as follow: (1) using water-saving devices, including low-flow fixtures (toilet, urinals, faucets and shower-heads), no-flow fixtures (waterless urinals and composting toilets), and controls (infrared sensors); (2) using rainwater, including collection, storage, and treatment if necessary; (3) reusing or recycling of greywater, which include reuse of domestic sewage effluents or municipal wastewater or recycle water form bathroom, laundry effluent, domestic sewage stream, or municipal wastewater (Wang & Ramakrishnan, 2022).

In Raja Haji Fisabillah mosque, the ablution and toilet fittings are water-saving taps to reduce water consumption (Ismail & Rashid, 2023; Yu et al., 2025). Moreover, rainwater and greywater were treated to be used for toilet flushing and landscape irrigation (Danish et al., 2023), which reduces the water demand. To support the rainwater harvesting system, the mosque is supported with syfon system roof drainage technology, which improves the flow efficiency and ensures reliable water transport to the collection or reuse system (Danish et al., 2023). On the other hand, water management implementation cannot be observed in other non-certified mosques.

The implementation of water conservation in a certified mosque shows integrated and advanced water sustainability practices. The absence in the non-certified mosque demonstrates a sustainable design paradigm gap. As not planned since the beginning, some of the non-certified mosques often prioritize basic functional needs, with limited integration of (advanced) environmental engineering, such as a water system. However, a low-tech rainwater harvesting system has been found in a traditional mosque (Bakri, 2018), showing its response to the climate and resource surroundings.

Green Open Space

The existence of green space supports the achievement of environmental sustainability. For humans, it benefits public health, extending life expectancy, and increasing the quality of life (Mostafa & Alshahrani, 2024). In addition, ecologically it also contributes to the urban heat island effect, supports biodiversity, improves air quality, contributes to ecosystem revitalization, and maintains the balance of urban ecology (Mostafa & Alshahrani, 2024).

Particularly in the Raja Haji Fisabillah mosque, green open space is supported by a green roof. The outdoor area is planted with various vegetation, which creates a tropical ambience (Danish et al., 2023). A study by Yu et al (2025) shows the commitment of the building contractor to ensure the availability of green areas around the Raja Haji Fisabillah mosque. In addition, the green rooftop in the Raja Haji Fisabillah mosque uses synthetic grass, benefiting from collecting rainwater and

decreasing the building's heat (Danish et al., 2023). Meanwhile, Al Ukhuwah Mosque and Istiqamah Mosque have less space for greenery (Sahid et al., 2024). However, the trees planted on the side of the road provide shading (Sahid et al., 2024), which contributes to reducing micro temperature

The effort to providing green space in the mosques indicates the environmental awareness of the architects. Green space in any form not only fulfils an aesthetic purpose. It goes further, maintaining the richness of biodiversity. Gardens, parks, or inner courtyards are habitats for living things, which at the same time are valuable for human well-being.

Certified and Non-Certified Mosque Practices

The review demonstrates the distinct implementation of the eco-mosque in certified and non-certified mosques. The certified mosque tends to be the latest building, thus more aware of the sustainability issue. Therefore, the eco-mosque principles have been embedded since the early design stage. It employs the green regulation, or even certification indicators, as its design guideline. Eco-mosque becomes a paradigm, which influences the decision-making, while a certification indicator becomes a driver, which ensures the green implementation. The review in the certified mosque also shows the use of advanced technology in material, energy conservation, or water management aspects.

In contrast, some of the modern non-certified mosques indicate the lack of green consideration in the early design phase. Conventional design guidelines led to minimal eco-mosque implementations. Some retrofitting strategies are needed to improve the building condition, particularly in the energy and water conservation aspects. Meanwhile, the traditional non-certified mosques demonstrate traditional architectural practice that aligns with sustainability principles. Although it only covers some indicators, the implementation contributes to energy consumption and thermal comfort. Interestingly, these practices only employ traditional knowledge (of adapting to climate, topography, and geography), not the green regulation/certification as their design guideline.

Conclusion

According to the systematic review, the eco-mosque practice is a model of environmental sustainability, and its practices manifest in two distinct trajectories: one is based on a formal certification system, while the other is based on informal, adaptable methods. Certified mosque demonstrates integrated green strategies, which are reflected in advanced material, water management, and green open space to support energy efficiency. On the other hand, non-certified mosques, which are frequently traditional or modern, represent passive, and locally adapted practices. However, it demonstrates ecological potential, particularly when it is tailored to the climate and culture. This duality highlights the need to understand the eco-mosque, one that values innovation and tradition.

As for ensuring environmental sustainability, the implementation of an eco-mosque must meet the core concepts, which are reducing ecological footprint, conserving natural resources, decreasing the production of waste, and conserving the

land and water. Thereby, the varied practices are embraced, based on the contextuality.

This study contributes to an understanding of how eco-mosque practices are applied in certified and non-certified mosques. However, it is limited to the Southeast Asia region and one database. Further research should expand the diverse climate, cultural, and institutional conditions and combine more databases for more comprehensive results.

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