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Green Retrofitting of Cultural Heritage Building: A Case Study of Banten Grand Mosque

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Abstract. The Banten Grand Mosque, as one of Indonesia's oldest cultural heritage buildings, is more than just a place of worship; it embodies layers of history, identity, and spiritual significance for the local community. However, in the face of climate change and rising expectations for user comfort, the mosque is challenged to maintain a balance between thermal performance and architectural authenticity. This study aims to explore passive-based green retrofitting strategies that are both environmentally responsive and sensitive to conservation principles. Research was conducted through field observations, documentation, stakeholder interviews, and a review of relevant literature on green building and heritage conservation. The results highlight several thermal comfort problems, including limited cross ventilation, inadequate roof insulation, and high indoor humidity due to the hot-humid tropical climate. These conditions often cause discomfort for worshippers, particularly during peak hours of use. To address these challenges, the study proposes adaptive yet reversible interventions, such as optimizing natural ventilation through additional lattice panels, applying eco-friendly reflective paints, using natural insulation materials like coconut fiber, and introducing vegetation to enhance microclimate quality. These strategies emphasize the principle of non-invasiveness, ensuring that any modification can be removed without damaging the original structure. Through this approach, the Banten Grand Mosque has the potential to remain a living heritage site: conserving its historical and architectural identity while adapting to contemporary needs of energy efficiency and user comfort. The findings not only provide recommendations for this mosque but also contribute to the discourse on sustainable conservation of tropical heritage buildings.

Keywords: green retrofitting; cultural heritage; thermal comfort; Banten Grand Mosque; adaptive conservation

1. Introduction

Cultural heritage buildings are important assets that not only preserve historical value but also serve as a nation's cultural and architectural identity. In Indonesia, historic mosques hold a unique position. In addition to serving as places of worship, these buildings also serve as centers of social activities and symbols of the past glory of Islam. One example is the Grand Mosque of Banten, founded in the 16th century by Sultan Maulana Hasanuddin. The mosque's uniqueness lies in its architectural style, a blend of Javanese, Chinese, Dutch, and Islamic elements, making it a significant icon in the Indonesian architectural landscape.

Over time, historic buildings in tropical regions face increasingly complex challenges. Climate change, urban heat islands, and the increasing need for thermal comfort for worshippers mean that conservation efforts cannot simply focus on physical or aesthetic aspects. This is where the concept of green retrofitting becomes relevant, namely the application of environmentally friendly strategies to improve a building's performance without compromising its authenticity.

The application of environmentally friendly strategies in heritage buildings is becoming increasingly relevant in the context of climate change and the growing demand for user comfort. Globally, the impacts of climate change on cultural heritage areas, including the risks of tidal flooding and other types of flooding, are very real and require adaptation strategies in local conservation practice [1]. Nevertheless, studies on the implementation of green retrofitting in historic buildings in Indonesia remain very limited, particularly in historic mosques that are strongly influenced by tropical climate conditions. Studies on the application of passive architectural strategies to historic buildings in Indonesia are still limited, even though the tropical climate demands an adaptive design approach to maintain thermal comfort [2]. Furthermore, regulations governing the preservation of cultural heritage buildings in Indonesia refer to Undang-Undang (UU) No. 11 Tahun 2010 concerning Cultural Heritage, which emphasizes the principle of reversibility [3]. This means that any intervention undertaken must be able to be restored to its original condition without damaging the original structure. This principle aligns with international conservation theory, which emphasizes the importance of maintaining a building's historical value and authenticity. Therefore, the retrofit strategy implemented must be add-on, non-invasive, and easily removable to avoid damaging the architectural authenticity.

Considering this context, the Grand Mosque of Banten serves as an important case study. The existing condition presents several problems, such as limited ventilation, an uninsulated roof, and high humidity levels due to its coastal location. Congregants complain about hot and stuffy conditions, particularly during the day when the building is in high use. This underscores the urgency of implementing green retrofitting in accordance with conservation principles to maintain the mosque's continued function as both a place of worship and a cultural heritage site.

Research on historic mosques shows that the application of passive cooling strategies can improve thermal comfort without changing the authenticity of the building form [4]. This limitation raises an essential question about the extent to which green retrofitting strategies can be effectively applied to heritage buildings without reducing their authenticity and historical values.

In this context, the principles of reversibility are highly relevant, particularly the principle of reversibility, which emphasizes that any intervention in heritage buildings should be reversible and allow for the possibility of future interventions [5]. This principle provides a conceptual foundation for designing passive retrofitting strategies for the Banten Grand Mosque, ensuring that interventions are sensitive to the historical values and architectural authenticity of the site. In this way, improvements in thermal comfort and energy efficiency can be achieved while preserving the cultural significance embedded in the building.

2. Methods

2.1 Research Design

This research uses a descriptive-qualitative approach to analyze the existing condition of cultural heritage buildings and formulate green retrofitting recommendations based on passive solutions. This approach was chosen because it aligns with the nature of the research object, which emphasizes contextual understanding and conservation values, rather than merely technical measurements.

2.2 Research Location and Object

The object of this research is the Grand Mosque of Banten, located in the Old Banten Grand Mosque complex in Serang City, Banten Province. This mosque was chosen because it is one of the oldest mosques in Indonesia, built in the 16th century, and holds high architectural, historical, and religious value. Furthermore, this building faces significant challenges related to thermal comfort due to the humid tropical climate, making it a relevant case study for adaptive conservation strategies.

2.3 Data Collection Techniques

The research data were obtained through:

a. Field Observation
   Conducted to identify the physical condition of the building, including spatial layout, ventilation, lighting, wall and roof materials, as well as the surrounding environment.
b. Documentation
   Recording was carried out through photographs, sketches, and field notes to support the description of the mosque's existing conditions.
c. Literature Review
   Utilized scientific sources related to heritage building conservation, green retrofitting strategies, and thermal comfort in tropical climates [6]. Passive cooling strategies have also been widely studied in tropical buildings, such as Javanese vernacular houses that use natural ventilation and local materials [7]. This approach aligns with the principles of non-invasive conservation that emphasize long-term sustainability [2]. International review studies also show that energy efficiency and thermal comfort are major challenges in low-cost tropical buildings, necessitating a comprehensive retrofit approach [8].

2.4 Research Variables

The main variables examined include:

a. Thermal Performance: indoor temperature, relative humidity, and ventilation.
b. Retrofitting Strategies: passive ventilation, thermal insulation, and material optimization.
c. Conservation Aspects: the level of building authenticity, preservation of historical value, and user acceptance.

2.5 Data Analysis Techniques

The data were analysed using a descriptive analysis method, which consisted of:

a. Describing the existing thermal comfort conditions of the mosque.
b. Identifying the main issues affecting comfort (e.g., limited ventilation, lack of insulation, high humidity).
c. Formulating green retrofitting recommendations based on passive strategies appropriate to the heritage building context.

3. Results and Discussion

3.1 Existing Condition of Banten Grand Mosque

Observations show that the Grand Mosque of Banten still maintains its original architectural form. The main hall is rectangular with a five-tiered roof, typical of Javanese architecture, supported by four teak pillars. The walls are constructed of thick red brick with lime plaster, which serves to retain external heat while creating a monumental impression.

Figure 1 The Old Banten Grand Mosque That Exists

However, there are several weaknesses in terms of thermal comfort. Ventilation openings are very limited, consisting of only large wooden doors and small windows with plain glass. The openings are not positioned opposite each other, making cross-ventilation difficult. The clay tile roof lacks insulation, allowing heat radiation from the sun to penetrate directly into the interior.

Figure 2 Interior of the Old Grand Mosque of Banten

The main prayer hall of Banten Grand Mosque reflects traditional architectural characteristics with a tiered roof (five levels), thick brick walls, and limited openings. While the tall roof design supports natural air circulation, in practice, airflow is not optimal due to insufficient cross ventilation. Observations also show that the prayer hall has limited openings with sub-optimal natural ventilation. The thick brick walls with lime plaster help resist heat, but indoor humidity remains relatively high, ranging from 70–85%. Daytime indoor temperatures were recorded at 30–32°C, higher than the thermal comfort standard for tropical climates (24–28°C) [9].

The mosque's foyer serves as a transitional space and a shaded area. However, the foyer's floor is made of ceramic, and the paving in the courtyard tends to absorb heat, resulting in relatively high surface temperatures. Similar research on a heritage church in Malang showed that thermal adaptation can be achieved through increased natural ventilation and vegetation planning [10]. This demonstrates that passive design strategies can be integrated into historic buildings in Indonesia.

Furthermore, a study of the design of a language training center in Banda Aceh also confirmed that implementing passive-based thermal comfort concepts can reduce the use of artificial cooling energy [11]. These findings support the recommendation to utilize natural insulation, cross-ventilation, and vegetation in the Grand Mosque of Banten. These findings are in line with international studies that emphasize the importance of passive strategies as a solution in maintaining the thermal comfort of historic buildings[8]. These findings support the recommendation to utilize natural insulation, cross-ventilation, and vegetation at the Grand Mosque of Banten.

This condition causes discomfort among worshipers, especially during midday prayers. As a temporary solution, mosque administrators use portable fans, but this measure is neither sufficient nor energy-efficient.

From observations and interviews, several main issues related to thermal comfort were identified:

a. **Limited ventilation** → air circulation inside the mosque is not optimal, especially during peak congregation times.
b. **Lack of roof insulation** → solar heat penetrates directly through clay roof tiles, making the interior feel hot during the day.
c. **High humidity** → influenced by the humid tropical climate and the mosque's proximity to Banten's northern coastline.
d. **Heat reflection from open courtyard** → paved surfaces around the mosque absorb heat, increasing ambient temperature.

3.2 Thermal Performance Issues

This finding is in line with the emphasis that mosques in hot-humid climates face major challenges in the form of limited ventilation and high humidity, so passive strategies are needed to maintain thermal comfort without increasing energy consumption [12].

Figure 3 Natural lighting of the Old Banten Grand Mosque

Based on observations, the mosque faces several key challenges related to thermal performance:

a. **Limited ventilation:** although there are large window openings, they are insufficient to provide effective cross-ventilation. Window openings are few and misaligned.

Horizontal airflow is suboptimal, trapping hot air.

b. **Uninsulated roofs tend to absorb heat:** causing indoor temperatures to rise during the day. Clay tiles function well to deter rain but fail to reduce radiant heat. Indoor spaces tend to be hotter during the day.
c. **High humidity:** The combined effects of the tropical climate and limited air circulation result in consistently high indoor humidity. The mosque's location on the northern coast of Banten contributes to high natural humidity. Limited air circulation exacerbates the humid conditions.
d. **Insufficient external shading:** The mosque's courtyard is largely paved and open, with no shade trees. Heat is reflected into the building, increasing the thermal load.

These issues reported that colonial heritage houses in Bandung also experienced thermal comfort challenges due to limited natural ventilation in tropical climates [13].

3.3 Comparative References from Other Heritage Cases

Similar phenomena also occur in other heritage buildings in Indonesia and Southeast Asia.

a. Historic mosque in Bandung: research shows that thick brick walls can reduce outside temperatures, but humidity remains high [13].
b. Traditional Javanese house in Gunungkidul: The use of natural cross-ventilation through wooden louvers has been proven effective in reducing room temperatures [7].
c. An old mosque in Melaka, Malaysia: a retrofit strategy involved adding wooden lattices above the windows to enhance airflow without altering the original façade [10].
d. Colonial church in Malang: Conservation focused on adding vegetation and environmentally friendly reflective paint to reduce radiant heat [11].

This comparison demonstrates that passive retrofitting solutions can be contextually adapted, as long as they adhere to conservation principles.

3.4 Recommended Green Retrofitting Strategies

From qualitative analysis, several passive-based green retrofitting strategies can be considered without compromising the building's authenticity:

a. Cross Ventilation
Enhancing airflow through the addition or optimization of openings on opposite sides of the building. This strategy allows air movement across the main prayer hall without altering the mosque's primary facade. Additional openings may take the form of wooden jalousies or lattice vents integrated with traditional aesthetics. Natural roof insulation using eco-friendly materials (such as processed coconut fiber or bladygrass) can also help reduce radiant heat.
b. Eco-Friendly Reflective Paints
Application of reflective coatings on external roof and wall surfaces to minimize heat absorption. Reflective paints applied to roof surfaces or inner ceiling panels can reduce solar heat gain. This technology does not alter the building's original form, thereby preserving the mosque's architectural authenticity.
c. Vegetation for Microclimate Improvement
Planting vegetation around the building to lower the ambient temperature and improve air quality. Shade trees and climbing plants in the mosque's open areas can reduce heat levels while creating a cooler and more comfortable environment. Moreover,

vegetation reinforces the tropical identity of the heritage complex.

d. Natural Insulation Materials
Utilization of natural insulation beneath the roof layer, such as coconut fiber or woven bamboo, to lower indoor temperature without altering the external roof appearance. This strategy aligns with non-invasive principles in heritage building conservation.

This emphasized that mosques in hot-humid climates face major challenges in the form of limited ventilation and high humidity, so passive strategies are needed to maintain thermal comfort without increasing energy consumption [12].

3.5 Adaptive Retrofit Strategies for Interior Ventilation

Although the tiered roof and saka guru structure theoretically support vertical air circulation, the interior still lacks effective cross ventilation. As a result, indoor humidity remains high and thermal comfort is compromised during peak usage.

As a heritage building, however, interventions cannot be implemented arbitrarily. Therefore, retrofit strategies must follow non-invasive and reversible principles. Recommended options include:

- Installing jalousie panels above existing doors and windows.
- Adding bamboo or wooden lattice vents at the upper wall level.
- Introducing concealed roof vents for hot air release.
- Using adaptive bamboo or rattan blinds in semi-open verandas.

These strategies are add-ons that do not damage the authenticity of the building and can be removed if necessary.

3.6 Comparative Analysis

Table 1. Comparative Retrofit Strategies

Location	Main Issue	Retrofit Strategy	Conservation Principle	Reference
Bandung (Indonesia)	High humidity	Vegetation shading, cross-ventilation	Non-invasive	Sumber no [7]
Gunungkidul (Indonesia)	Heat during daytime	Jalousie panels, bamboo lattice	Add-on	Sumber no [10]
Malaka (Indonesia)	Limited ventilation	Wooden lattice panels	Façade harmony	Sumber no [11]
Malang (Indonesia)	Solar heat radiation	Reflective paint, vegetation	Non-permanent	Sumber no [12]
Semarang (Indonesia)	Historic mosque case	Passive design strategies	Contextual retrofit	Sumber no 14
Banten (this study)	Limited ventilation & no insulation	Jalousie, bamboo lattice, natural insulation, adaptive blinds	Reversible	This study

3.7 Discussion

The analysis revealed a dilemma frequently encountered in historic buildings: how to balance the need for thermal comfort with the obligation to maintain architectural authenticity. The Grand Mosque of Banten serves as a prime example of how these two aspects must be carefully managed. On the one hand, users require a comfortable space for worship, especially in a humid and hot tropical climate.

On the other hand, the mosque holds historical value and architectural identity that should not be compromised through permanent changes.

The findings suggest that passive green retrofitting strategies, such as internal insulation and minimally invasive ventilation improvements, can be applied to heritage buildings without disturbing their architectural authenticity. That passive retrofitting significantly improves thermal comfort in heritage buildings in hot climates compared to active mechanical systems [14]. It also aligns with the 3Ts framework (thermal, technical, traditional), which identifies passive strategies as most appropriate for heritage structures [15].

Field observations indicate that both congregants and mosque administrators generally prefer solutions that do not alter the building's original form. This preference underscores the importance of an approach that is not solely technical but also considers sociocultural aspects. Thus, passive green retrofitting serves not only to improve comfort but also as a means of preserving the historical value, architectural identity, and cultural significance of the Grand Mosque of Banten.

The implementation of these strategies has significant potential to maintain the mosque's comfort, reduce reliance on mechanical cooling systems, and maintain its position as a significant icon of Islamic architectural heritage in Indonesia.

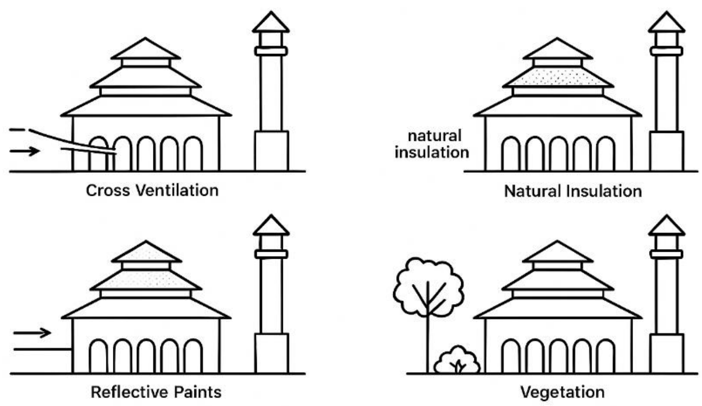

Figure 4 Proposed Green Retrofitting Strategies for the Old Banten Grand Mosque

4. Conclusions

4.1 Conclusion

The results of this study confirm that the Grand Mosque of Banten, as one of the oldest Islamic architectural heritage sites in Indonesia, still exudes the splendor of its historical value. Its original architectural form, with its five-tiered roof, thick brick walls, and teak pillars, remains intact and serves as a powerful symbol of cultural heritage. However, in terms of thermal comfort, the mosque faces significant challenges. Indoor temperatures, recorded at around 30–32°C and high humidity of 70–85%, often make the main hall feel hot and humid. This condition is exacerbated by limited cross-ventilation, minimal roof insulation, and a lack of external shading elements, reducing the comfort of worshippers.

These findings place the Grand Mosque of Banten in a classic dilemma between spatial comfort and historical preservation. However, this study suggests that a green retrofit strategy based on passive design can be an effective compromise. Measures such as the addition of wooden or bamboo latticework, the application of natural insulation made from coconut fiber, palm fiber, or woven bamboo, the use of environmentally friendly reflective paint, and shade vegetation are simple yet significant steps to reduce heat load. This strategy is non-invasive and reversible, thus respecting the principles of heritage building conservation without altering the architectural authenticity. Based on the research findings, it can be concluded that:

1. The Grand Mosque of Banten faces serious thermal comfort challenges due to limited cross-ventilation, minimal roof insulation, high humidity, and ambient heat.
2. A passive green retrofit strategy is the most appropriate approach to address these challenges while maintaining the architectural authenticity.
3. Proposed recommendations include optimizing cross-ventilation, using natural insulation materials, applying environmentally friendly reflective paint, and adding vegetation to support a microclimate.
4. This approach aligns with the principles of non-invasive conservation of heritage buildings and the 3T framework (thermal, technical, traditional).

With the integration of these strategies, the Grand Mosque of Banten can not only function optimally as a place of worship but also serve as a model for adaptive preservation for other historic mosques in Indonesia. This mosque has the potential to continue to be a spiritual symbol and icon of Indonesian Islamic culture, remaining relevant both now and in the future.

4.2 Recommendations

The results of this study confirm that the Grand Mosque of Banten, as one of the oldest Islamic architectural heritage sites in Indonesia, still exudes the splendor of its historical value. Its original architectural form, with its five-tiered roof, thick brick walls, and teak pillars, remains intact and serves as a powerful symbol of cultural heritage. However, in terms of thermal comfort, the mosque faces significant challenges. Indoor temperatures, recorded at around 30–32°C and high humidity of 70–85%, often make the main hall feel hot and humid. This condition is exacerbated by limited cross-ventilation, minimal roof insulation, and a lack of external shading elements, reducing the comfort of worshippers.

These findings place the Grand Mosque of Banten in a classic dilemma between spatial comfort and historical preservation. However, this study suggests that a green retrofit strategy based on passive design can be an effective compromise. Measures such as the addition of wooden or bamboo latticework, the application of natural insulation made from coconut fiber, palm fiber, or woven bamboo, the use of environmentally friendly reflective paint, and the addition of shaded vegetation are simple yet significant steps to reduce heat load. This strategy is non-invasive and reversible, thus respecting the principles of heritage building conservation without altering the architectural authenticity.

Based on the research findings, it can be concluded that:

1. The Grand Mosque of Banten faces serious thermal comfort challenges due to limited cross-sectional measurements, minimal roof layers, high humidity, and ambient heat.
2. A passive green retrofit strategy is the most appropriate approach to address these challenges while maintaining architectural authenticity.
3. Proposed recommendations include optimizing cross-ventilation, using natural insulation materials, implementing environmentally friendly reflective cat litter, and adding vegetation to support a microclimate.
4. This approach aligns with the principles of non-invasive conservation of heritage buildings and the 3T framework (thermal, technical, traditional).

With this integrated strategy, the Grand Mosque of Banten can not only function optimally as a place of worship but also serve as a model for adaptive preservation for other historic mosques in Indonesia. This mosque has the potential to continue to be a spiritual symbol and icon of Indonesian Islamic culture, remaining relevant both now and in the future.

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