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Thermal mitigation through landscaping in tropical buildings
Case study of Sheikh Zayed Mosque Surakarta

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ABSTRACT

The rapid expansion of urban development in tropical regions has substantially increased local microclimate temperatures, primarily as a consequence of the urban heat island (UHI) phenomenon. Landscape design is widely acknowledged as an effective passive strategy for mitigating these adverse thermal conditions. This study aims to assess the effectiveness of landscape layout and design at the Sheikh Zayed Mosque in Surakarta in reducing both surface and ambient air temperatures within the surrounding neighborhood. The research adopts a quantitative methodological approach that integrates systematic temperature measurements, direct field observations, and an in-depth review of relevant literature. The investigation was carried out through the combined use of satellite imagery, in situ surface temperature measurements, and spatial analysis focusing on the distribution of vegetation, water ponds, and shading elements. The findings demonstrate that the strategic placement of vegetation and water features is capable of reducing surface temperatures by up to 5°C during daylight hours. These results underscore the critical role of landscape design as a climate-adaptive component in public building environments, particularly within tropical contexts. Moreover, the research provides a meaningful contribution to the development of tropical climate-responsive landscape design strategies aimed at enhancing building thermal comfort and supporting the realization of sustainable development in religious public spaces.

Introduction

Global climate change has intensified the challenges associated with maintaining thermal comfort in buildings, particularly in tropical regions characterized by high temperatures and elevated humidity levels (Pradono 2019; Nugroho 2020; Imran, Shamin, and As'Adiyah 2020). In parallel with the continuously rising energy demand for mechanical cooling systems, passive strategies, such as the utilization of landscape elements, are increasingly recognized as environmentally responsible and sustainable solutions. Among public building typologies, mosques hold a significant social and cultural position, functioning not only as places of worship but also as centers for community activities (Shahridzal 2024; Huldiansyah and Subroto 2020). Therefore, ensuring adequate thermal comfort in mosque buildings is essential

to effectively support the activities and well-being of worshippers (Sahid et al. 2024).

At the same time, rapid urbanization in tropical cities has substantially contributed to increasing ambient temperatures through the urban heat island (UHI) effect. This phenomenon is primarily driven by the extensive use of impervious surfaces such as concrete and asphalt, the reduction of vegetative cover, and diminished natural air circulation (Gaitani et al. 2017; Foustalieraki et al. 2017). Within this context, passive architectural approaches become increasingly critical, including landscape design, which serves not only an aesthetic function but also plays a vital role in enhancing thermal comfort.

Well-conceived landscape design has the capacity to modify local microclimatic conditions through mechanisms such as evapotranspiration, the provision of shading, and the reduction of thermal radiation. Numerous previous studies have demonstrated that landscape elements including trees, ground vegetation, and water features can significantly lower surface temperatures (Toparlar et al. 2015; Sakenova et al. 2024; Schettini et al. 2016; Brown and Lundholm 2015; Koc, Osmond, and Peters 2016; López-Cabeza et al. 2018).

This research focuses on the Sheikh Zayed Mosque in Surakarta, a relatively new public building that adopts a contemporary landscape design approach. The Sheikh Zayed Mosque in Surakarta, which resembles the renowned mosque in Abu Dhabi, represents a compelling case study due to its monumental architectural character and distinctive integration of landscape elements. Accordingly, this study aims to evaluate the extent to which the landscape design of the mosque complex contributes to the reduction of ambient temperatures and the thermal conditions of the building environment.

Landscape design plays a critical role in microclimate regulation within tropical climates (Kurniati et al. 2023), primarily through natural processes such as evapotranspiration and the creation of shaded areas. Vegetated surfaces tend to absorb less heat than hard, impervious materials, resulting in cooler surface temperatures and more thermally favorable environments (Littlefair et al. 2000; Salata et al. 2016; Castaldo et al. 2018).

Assessments of the thermal performance of landscape configurations commonly employ parameters such as land surface temperature (LST), air temperature, and thermal comfort indices. The technologies frequently applied in such evaluations include satellite-based thermal imaging, infrared cameras, and in situ digital thermometers (Castaldo et al. 2018; Yuliani et al. 2021; Enggarsiwi, Yuliani, and Winarto 2024).

Mosques are also distinguished by their architectural characteristics and operational performance. In this regard, research has examined how various retrofitting strategies contribute to enhancing the operational efficiency of Al-Imam Al-Hussein Mosque, one of the largest historic mosques in Cairo. The evaluation conducted by Mohamed Marzouk et al. considered aspects of energy efficiency, thermal comfort, and daylighting performance. The results were substantial, indicating a 23% reduction in annual energy consumption, a 30% decrease in visual discomfort, and a 65% improvement in thermal comfort for worshippers (Marzouk et al. 2024). In relation to building energy efficiency, further studies on mosque architecture in Egypt have been carried out by Amr Sayed Hassan Abdallah et al. (Abdallah et al. 2025; Mohamed and Mohammad Yusof 2023).

Research undertaken by Nur Athirah et al. on the Kampung Laut Mosque in Malaysia (binti Khalit et al. 2023) demonstrates that the average indoor air temperature remains within an acceptable comfort range, indicating that the mosque adapts effectively to its local climatic conditions. Nevertheless, the study suggests that increasing airflow velocity from 0.4 m/s to 1.2 m/s could further enhance indoor thermal comfort. Another investigation focusing on the Raja Fi Sabilillah Mosque in Cyberjaya, Malaysia, examined green building principles and aimed to identify sustainable architectural elements that could be replicated in other mosque designs. Overall, these case studies illustrate that a green architecture approach can contribute to the sustainability of mosques and be broadly applicable for community benefit (Mochtar et al. 2024; Purba et al. 2024).

In terms of mosque revitalization, Mohd Farid Mohamed et al. investigated mosques in Malaysia and found that community participation plays a decisive role in determining the efficiency of funding for building maintenance and operations. The study recommends prioritizing fundamental facility upgrades, particularly those that directly address primary user needs and support core activities (Mohamed and Mohammad Yusof 2023; Purba et al. 2024).

A number of previous studies on mosque architecture emphasize that this category of public buildings requires careful consideration in the implementation of green building principles, including site management, energy efficiency, spatial quality, occupant comfort, and micro-environmental support. The application of green building concepts extends beyond the architectural envelope to encompass the entire site, including the surrounding landscape. Optimizing landscape design as a contributor to microclimate formation can play a significant role in reducing ambient temperatures and lowering overall energy consumption. However, research examining the influence of landscape design on mosque architecture in Indonesia remains limited, and studies addressing the application of green building principles in mosque design are still relatively scarce. In particular, architectural investigations of the Sheikh Zayed Mosque as a case study have not been extensively explored. Therefore, this study is expected to contribute to the advancement of architectural knowledge related to green building implementation in public religious buildings, especially mosques. The findings propose a strategic framework for landscape design development within mosque complexes through the integrated use of plazas, shaded pedestrian pathways, water ponds, lawns, and peripheral green belts.

Methods

Research location

Sheikh Zayed Mosque Surakarta was selected as the case study due to its integration of modern Islamic architectural expression with a tropical landscape design approach, as illustrated in Fig. 1. The Sheikh Zayed Mosque complex occupies a land area of approximately 3 hectares, with a total building footprint of around 10,200 square meters and a capacity exceeding 10,000 worshippers. The site is characterized by an open courtyard configuration, extensive vegetated areas, a central fountain, tree-shaded pedestrian pathways, water pools, and perimeter green belts. In accordance with applicable regulations, buildings of this scale are required to comply with established green building criteria (Wali Kota Surakarta 2024; Menteri Pekerjaan Umum dan Perumahan Rakyat Republik Indonesia 2021).

Figure 1. Sheikh Zayed Mosque Surakarta

Data collection technique

This study employed a quantitative mixed-method approach combining spatial observation and on-site environmental measurements. Data were collected through the following methods:

a. Satellite Imagery: Analysis of land surface temperatures derived from Landsat 8 satellite imagery using the thermal infrared band.
b. Field Measurements: Measurements of air temperature and surface temperature were conducted using digital thermometers and infrared thermal cameras across five distinct landscape zones.
c. Observation Time: Measurements were carried out in the morning (07:00), midday (13:00), and late afternoon (17:00) during the period of May–June 2025.

Analysis zone

For the purpose of thermal analysis, the mosque site was systematically divided into five landscape zones, as outlined below:

a. Lawn: A green open space functioning as both a cooling buffer and an aesthetic element.
b. Pedestrian path with tree shade: Circulation routes lined with trees that provide continuous natural shading.
c. Plazas with hard surfaces: Open paved or concrete areas that tend to absorb and retain heat, resulting in localized thermal hotspots.
d. Pool/fountain area: Water features that contribute to microclimate cooling through evaporative processes and localized humidity enhancement.
e. Green belt on the perimeter side: Vegetated boundary areas surrounding the mosque site that function as natural wind buffers and shading elements.

The spatial grouping shown in figure 2 visualizes the proportional relationship between building mass and landscaped areas. Measurement points were established within each outdoor space that forms part of the landscape system, corresponding to the defined analysis zones. The total site area of the Sheikh Zayed Grand Mosque in Solo is approximately 26,581 square meters, with a mosque building area of 7,814 square meters.

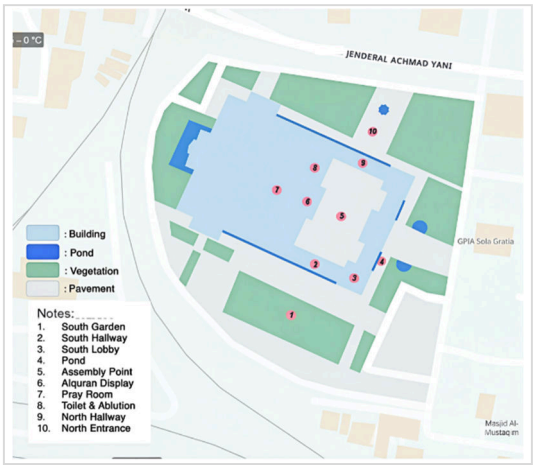

Figure 2. Visualization of the division of building and landscaping areas

Results and discussion

The measurement results reveal clear and significant temperature variations among the different landscape zones. Areas dominated by hard surfaces, particularly plazas, record the highest surface temperatures, whereas zones incorporating vegetation and water elements exhibit the lowest temperatures. For analytical clarity, landscape measurements are classified into five components: plaza/pavement, tree-shaded paths, lawns, fountain pools, and perimeter green belts, as summarized in table 1.

Table 1. Surface temperature data of landscaping areas

Landscaping Zone	Average Temperature (°C)	Decrease compared to plaza (°C)
Plaza/pavement	46.2	0
Tree shade paths	41.4	4.8
Lawn	42.7	3.5
Fountain pool	41.2	5
Perimeter green belt	44.5	1.7

Three distinct pond typologies are incorporated within the mosque landscape. The first, located on the front or southern side of the building, takes the form of a star-shaped water pool, as shown in figure 3. The second type consists of elongated water features positioned along the southern and eastern sides of the mosque building. Vegetation types across the site range from shrubs to medium-height and tall trees, including calathea, palm species, plants from the tea family, canna lilies, and Madagascar almond (Terminalia mantaly), commonly known as ketapang kencana, as illustrated in figure 4 and 5. The third pond typology is located within the perimeter zone and functions as a cooling enhancer along the green belt, as shown in figure 7.

The landscape design of the Sheikh Zayed Mosque complex also integrates alternative energy solutions, particularly through the installation of solar-powered lighting systems for nighttime illumination around the site, as depicted in figure 5 and 6. The findings indicate that the incorporation of such sustainable landscape components represents a tangible effort toward energy-efficient design and constitutes an integral element of green building implementation. By harnessing solar energy, the mosque reduces reliance on conventional electrical power sources, leading to lower energy consumption and operational costs. Furthermore, the integration of renewable energy technologies within the landscape demonstrates a strong commitment to environmental responsibility and enhances the overall sustainability performance of the site. Beyond energy efficiency considerations, these design strategies also improve the visual quality, safety, and functionality of outdoor spaces, creating a more comfortable environment for visitors during evening hours. This approach exemplifies how innovative landscape planning combined with renewable energy applications can support sustainable development, reinforce climate-responsive design principles, and serve as a reference model for other public buildings in tropical urban contexts. The design strategy aligns closely with the findings and recommendations of previous studies (Marzouk et al. 2024; Ismail and Abdul Rashid 2023; Mohamed and Mohammad Yusof 2023; Abdallah et al. 2025; Purba et al. 2024).

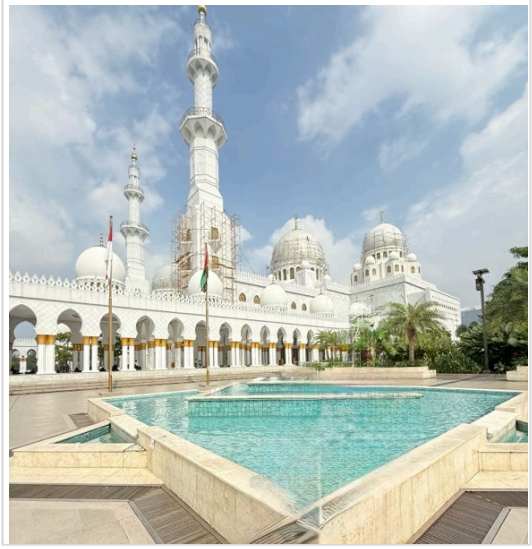

Figure 3. Ponds as a component of landscaping

Figure 4. Types of plants on the perimeter belt

Figure 5. Use of solar panel lights, tree shade and perimeter belts

Figure 6. Ablution water and solar panel lamps in the landscaping area

Figure 7. Water pools in the perimeter belt area

Consistent with previous research, the integration of climate-responsive design strategies, energy-efficient technologies, and sustainable landscaping within religious buildings not only enhances thermal comfort and user experience but also contributes to broader environmental and energy conservation objectives. The design approach implemented at this mosque illustrates how the thoughtful integration of these strategies can create a more comfortable and sustainable built environment while simultaneously respecting architectural identity and cultural values. By adhering to principles supported by prior scholarly research, this design offers a practical reference for other mosque buildings in tropical and urban settings, demonstrating that environmentally conscious planning can significantly enhance both functional performance and long-term sustainability. Overall, the design highlights the importance of evidence-based architectural approaches, showing that alignment with established research strengthens the effectiveness and relevance of contemporary mosque design.

The most pronounced temperature differences were observed during the early afternoon period between 12:00 and 14:00, indicating that the cooling effectiveness of landscape elements is maximized under conditions of peak solar radiation. The cooling influence of landscaping was found to persist into the later afternoon. Notably, outdoor thermal conditions differ markedly between the northern and southern areas of the mosque complex. The northern zone recorded higher temperatures, reaching up to 36.7 °C, whereas the southern outdoor areas exhibited a distinct thermal character, despite having relatively similar landscape treatments. In the southern zone, ambient temperatures were lower due to reduced direct solar exposure from building shading and the presence of prevailing breezes with average wind speeds of approximately 1.5 m/s under clear weather conditions. Even at this relatively low wind speed, a measurable cooling effect was achieved, consistent with the findings of Nur Athirah et al. (binti Khalit et al. 2023). The measurement results further indicate that variations in ambient temperature are strongly influenced by the intensity and duration of solar radiation. In tropical regions, where buildings are exposed to high levels of solar radiation throughout the year, careful consideration of microclimatic conditions is therefore essential. The implementation of supportive microclimate strategies such as the incorporation of vegetation, shading structures, and water features can play a significant role in moderating indoor and outdoor thermal environments. Through these measures, buildings can maintain lower internal temperatures, improve occupant comfort, and reduce dependence on mechanical cooling systems, thereby supporting more sustainable and energy-efficient performance in consistently sunny tropical climates. For this reason, the southern area of the mosque site would benefit from further expansion of landscape interventions. The reduction of ambient temperatures through landscape elements is highly advantageous in the successful application of green building principles, in agreement with previous studies (Gaitani et al. 2017; Foustalieraki et al. 2017; Toparlar et al. 2015; Sakenova et al. 2024; Schettini et al. 2016; Brown and Lundholm 2015).

Based on the outdoor thermal measurements presented in Table 1, the highest recorded surface temperature occurs in the plaza area at 46.2°C, while the lowest surface temperature is observed in the water pool zone at 41.2°C. The average outdoor ambient temperature in the central plaza area reaches 35.5°C, whereas the tree-shaded pedestrian paths provide substantially improved thermal comfort, with temperatures of approximately 32°C. This condition is particularly relevant for religious activities that are frequently conducted outdoors during Islamic holidays. Within the prayer hall, indoor

temperatures are maintained within a range of 27.8–29.6°C, which is perceived as relatively comfortable. Thermal visualization of the Sheikh Zayed Mosque complex, as shown in figure 7, indicates that the highest temperatures are concentrated in the front and central plaza areas where vegetation is minimal. The front of the building is flanked by two water pools adjacent to the plaza and building façade, while vegetation is predominantly arranged along the perimeter zones and on the eastern and western sides of the plaza. In the inner plaza area, although water features are absent, eight medium-sized Madagascar almond trees are positioned at distances of approximately 3–5 meters, contributing to partial shading and localized thermal mitigation.

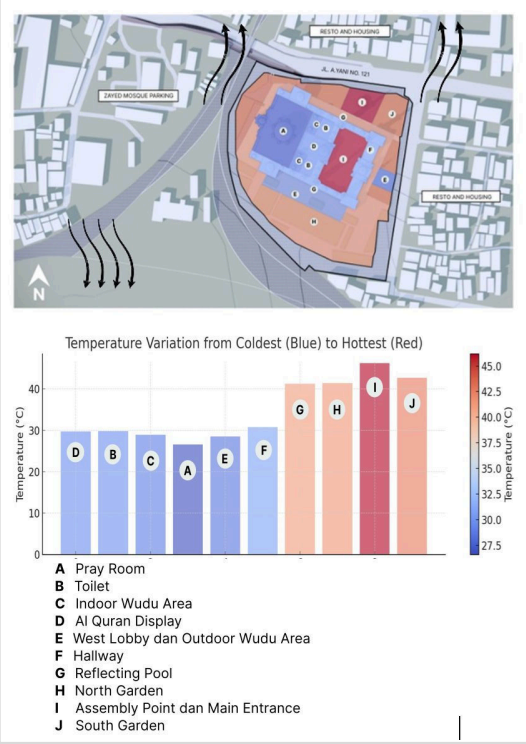

Figure 8. Thermal visualization of Sheikh Zayed Mosque

The presence of landscaping in outdoor areas has the potential to function as an effective component in reducing floor surface temperatures through the use of vegetation and water ponds; however, in the case of this building, its performance has not yet reached an optimal level. This finding is consistent with previous studies indicating that the selection and configuration of outdoor materials significantly influence microclimatic quality, which in turn supports building thermal comfort and energy efficiency (Purba et al. 2024; Marzouk et al. 2024; Mochtar et al. 2024). Considerations related to the implementation of green building principles are therefore essential, as certain strategies can generate benefits not only for the building itself but also for the surrounding environment, as demonstrated by research conducted by Sahid et al. (Mochtar et al. 2024).

The landscape configuration and overall landscape design of this mosque adopt a minimalist concept, which is organized into five primary components: the linear placement of trees along circulation paths; a central fountain pool serving as the main cooling feature; the distribution of grasses and shrubs along the building perimeter; and a green belt encircling the mosque complex. Despite these features, several limitations are evident, particularly the presence of an extensive plaza area that lacks adequate shading elements. To address these shortcomings, several improvement strategies are recommended, including the addition of shade-providing vegetation, the replacement of existing pavement materials with more permeable surfaces, and the introduction of vertical green structures to enhance shading and thermal performance.

Conclusions

Landscape design has been demonstrated to play a significant role in reducing ambient temperatures in public buildings, particularly within tropical climatic contexts. This study reveals that the landscaping implemented at the Sheikh Zayed Mosque is capable of reducing local temperatures by up to 5°C when compared to areas devoid of vegetation or water features. The strategic arrangement of trees, shrubs, and water ponds contributes substantially to surface shading, evaporative cooling processes, and improved airflow across the site. Beyond measurable temperature reductions, the integration of well-designed landscape elements enhances overall user comfort by creating cooler and more pleasant microclimates within outdoor and semi-outdoor spaces. Furthermore, this approach aligns closely with broader green building strategies by supporting energy

efficiency, climate responsiveness, and sustainable development objectives. Through the integration of environmental, social, and architectural values, the mosque's landscape design serves as a relevant example of how urban and religious public spaces in tropical regions can be adapted to mitigate heat and support long-term sustainability goals.

The key recommendations derived from this study emphasize the critical importance of landscape design in improving thermal comfort and advancing sustainable development. First, the addition of vegetative shading along primary circulation routes is strongly recommended to reduce direct solar exposure and lower both surface and ambient temperatures for pedestrians. Second, the strategic incorporation of water features, such as ponds and fountains, should be pursued as passive cooling elements that enhance evaporative cooling and improve local microclimatic conditions. Third, minimizing the extent of heat-absorbing pavement surfaces can significantly reduce thermal energy accumulation and mitigate the urban heat island effect. Fourth, reinforcing perimeter vegetation around the site can function as a natural climatic buffer by moderating wind flow, providing shade, and creating more comfortable outdoor environments. Finally, the integration of additional water features throughout the site not only contributes to thermal regulation but also improves the aesthetic and environmental quality of the landscape. Collectively, these strategies demonstrate how thoughtful and evidence-based landscape planning can effectively reduce temperatures, enhance user comfort, and support climate-responsive and sustainable design approaches for public buildings, particularly in tropical urban settings. In addition, this study is recommended to be further developed across different building types and locations in order to assess the consistency and broader applicability of landscape-driven thermal temperature reduction in tropical environments.

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References

Abdallah, Amr Sayed Hassan, Randa Mohamed Ahmed Mahmoud, Mohamed Hssan Hassan Abdelhafez, and Mohammed A. Aloshan. 2025. "Assessing Mosque Energy Efficiency Using Smart Occupancy Sensors to Mitigate Climate Change in Hot Regions." *Buildings* 15 (6): 935. https://doi.org/10.3390/buildings15060935.

binti Khalit, Nur Athirah, Zuraini binti Denan, Aliyah Nur Zafirah binti Sanusi, and Norwina binti Mohd Nawawi. 2023. "Assessment of Indoor Thermal Condition on Traditional Vernacular Masjid: A Case Study on Masjid Kampung Laut, Malaysia." *Jurnal Kejuruteraan* 35 (3): 647–55. https://doi.org/10.17576/jkukm-2023-35(3)-12.

Brown, Charlotte, and Jeremy Lundholm. 2015. "Microclimate and Substrate Depth Influence Green Roof Plant Community Dynamics." *Landscape and Urban Planning* 143 (November):134–42. https://doi.org/10.1016/j.landurbplan.2015.07.009.

Castaldo, Veronica Lucia, Anna Laura Pisello, Cristina Piselli, Claudia Fabiani, Franco Cotana, and Mattheos Santamouris. 2018. "How Outdoor Microclimate Mitigation Affects Building Thermal-Energy Performance: A New Design-Stage Method for Energy Saving in Residential near-Zero Energy Settlements in Italy." *Renewable Energy* 127 (November):920–35. https://doi.org/10.1016/j.renene.2018.04.090.

Enggarsiwi, Astri Resmi, Sri Yuliani, and Yosafat Winarto. 2024. "Thermal Performance of Tall Building Envelope Design in Tropical Urban Region." *IOP Conference Series: Earth and Environmental Science* 1361 (1): 012018. https://doi.org/10.1088/1755-1315/1361/1/012018.

Foustalieraki, M., M.N. Assimakopoulos, M. Santamouris, and H. Pangalou. 2017. "Energy Performance of a Medium Scale Green Roof

System Installed on a Commercial Building Using Numerical and Experimental Data Recorded during the Cold Period of the Year." *Energy and Buildings* 135 (January):33–38. https://doi.org/10.1016/j.enbuild.2016.10.056.

Gaitani, Niki, Ingunn Burud, Thomas Thiis, and Mat Santamouris. 2017. "High-Resolution Spectral Mapping of Urban Thermal Properties with Unmanned Aerial Vehicles." *Building and Environment* 121 (August):215–24. https://doi.org/10.1016/j.buildenv.2017.05.027.

Huldiansyah, Denny, and Tarcicius Yoyok Wahyu Subroto. 2020. 'Konsistensi Ruang Pangimaman, Liwan, Dan Pawestren Di Masjid Pathok Negara Ad-Darojat Babadan, Bantul, Yogyakarta (1970-2019)'. *ARTEKS : Jurnal Teknik Arsitektur* 5 (2). https://doi.org/10.30822/arteks.v5i2.248.

Imran, Mohammad, Novita Shamin, and Rahmi Budi As'Adiyah. 2020. 'The Utilization of Paving Blocks as Environmental Heat Reduction Materials'. *ARTEKS : Jurnal Teknik Arsitektur* 5 (3). https://doi.org/https://doi.org/10.30822/arteks.v5i3.564.

Ismail, Muhammad Azzam, and Fahanim Abdul Rashid. 2023. "Green Architecture Approach Toward Sustainable Mosques in Malaysia." *Jurnal Kejuruteraan* 35 (3): 693–98. https://doi.org/10.17576/jkukm-2023-35(3)-17.

Koc, Carlos Bartesaghi, Paul Osmond, and Alan Peters. 2016. "A Green Infrastructure Typology Matrix to Support Urban Microclimate Studies." *Procedia Engineering* 169:183–90. https://doi.org/10.1016/j.proeng.2016.10.022.

Kurniati, Rina, Wakhidah Kurniawati, Diah Intan Kusumo Dewi, and Endah Kartika Syahri. 2023. "Climate Sensitive Urban Design in Cultural Landscape." *ARTEKS : Jurnal Teknik Arsitektur* 8 (3): 343–56. https://doi.org/10.30822/arteks.v8i3.2181.

Littlefair, P. J., Mat Santamouris, Servando Álvarez, and A Dupagne. 2000. *Environmental Site Layout Planning: Solar Access, Microclimate and Passive Cooling in Urban Areas*. BRE Publications.

López-Cabeza, V.P., C. Galán-Marín, C. Rivera-Gómez, and J. Roa-Fernández. 2018. "Courtyard Microclimate ENVI-Met Outputs Deviation from the Experimental Data." *Building and Environment* 144 (October):129–41. https://doi.org/10.1016/j.buildenv.2018.08.013.

Marzouk, Mohamed, Maryam El-Maraghy, Ahmed El-Shihy, and Mahmoud Metawie. 2024. "Evaluating Energy Retrofit Strategies in Enhancing Operational Performance of Mosques: A Case Study of Al-Imam Al-Hussein Mosque." *Cleaner Energy Systems* 9 (December):100144. https://doi.org/10.1016/j.cles.2024.100144.

Menteri Pekerjaan Umum dan Perumahan Rakyat Republik Indonesia. 2021. *Peraturan Menteri Pekerjaan Umum Dan Perumahan Rakyat Republik Indonesia No 21 Tahun 2021 Tentang Penilaian Kinerja Bangunan Gedung Hijau*. Indonesia.

Mochtar, Sahid, Anindhita Nugroho Sunartio, Aldyfra Luhulima Lukman, Indri Astrina Indrarani Wirakusumah, Adam Ramadhan, Klarissa Lazuardi, and Cheryl Angeline. 2024. "Challenges of Implementing the Green Building Concept in Mosques." *ARTEKS : Jurnal Teknik Arsitektur* 9 (1): 99–108. https://doi.org/10.30822/arteks.v9i1.2956.

Mohamed, Mohd Farid, and Wardah Fatimah Mohammad Yusof. 2023. "Potential Strategies for Revitalizing UKM Mosque in Enhancing Community Engagement." *Jurnal Kejuruteraan* si6 (1): 325–38. https://doi.org/10.17576/jkukm-2023-si6(1)-28.

Nugroho, Agung Murti. 2020. 'The Effect of Vertical Gardens on Temperature and CO2 Levels in Urban Housing'. *ARTEKS : Jurnal Teknik Arsitektur* 5 (3): 401–8. https://doi.org/10.30822/arteks.v5i3.551.

Pradono, Budi. 2019. 'The Interiority of Proximity between Nature and Arhitecture in Contemporary and Tropically Context with Cases Studies'. *ARTEKS : Jurnal Teknik Arsitektur* 3 (2). https://doi.org/https://doi.org/10.30822/arteks.v3i2.63.

Purba, Agnes, Yusuf Latief, Bernadette Detty Kussumardianadewi, and Bambang Trigunarsyah. 2024. "The Application of Life Cycle Cost Analysis Method for Green Retrofitting of Mosque Building to Improve Investment Performance." *Civil Engineering*

and Architecture 12 (5): 3254–66. https://doi.org/10.13189/cea.2024.120511.

Sahid, Anindhita Nugroho Sunartio, Aldyfra Luhulima Lukman, Indri Astrina Indrarani Wirakusumah, Adam Ramadhan, Klarissa Lazuardi, and Cheryl Angeline. 2024. 'Challenges of Implementing the Green Building Concept in Mosques'. *ARTEKS : Jurnal Teknik Arsitektur* 9 (1). https://doi.org/https://doi.org/10.30822/arteks.v9i1.2956.

Sakenova, Saya, Usama Konbr, Tatyana Kisselyova, Zaure Aimagambetova, Gulnar Mugzhanova, and Dina Amandykova. 2024. "Conformation Factors of Building Bioclimatic Microclimate." *Civil Engineering and Architecture* 12 (1): 350–60. https://doi.org/10.13189/cea.2024.120126.

Salata, Ferdinando, Iacopo Golasi, Roberto de Lieto Vollaro, and Andrea de Lieto Vollaro. 2016. "Urban Microclimate and Outdoor Thermal Comfort. A Proper Procedure to Fit ENVI-Met Simulation Outputs to Experimental Data." *Sustainable Cities and Society* 26 (October):318–43. https://doi.org/10.1016/j.scs.2016.07.005.

Schettini, Evelia, Ileana Blanco, Carlo Alberto Campiotti, Carlo Bibbiani, Fabio Fantozzi, and Giuliano Vox. 2016. "Green Control of Microclimate in Buildings." *Agriculture and Agricultural Science Procedia* 8:576–82. https://doi.org/10.1016/j.aaspro.2016.02.078.

Shahridzal, Nuralyia Natasha binti. 2024. 'Analyzing Architectural and Cultural Elements of Masjid Jamek Sultan Ibrahim, Muar, Johor'. *ARTEKS : Jurnal Teknik Arsitektur* 9 (1). https://doi.org/https://doi.org/10.30822/arteks.v9i1.2493.

Toparlar, Y., B. Blocken, P. Vos, G.J.F. van Heijst, W.D. Janssen, T. van Hooff, H. Montazeri, and H.J.P. Timmermans. 2015. "CFD Simulation and Validation of Urban Microclimate: A Case Study for Bergpolder Zuid, Rotterdam." *Building and Environment* 83 (January):79–90. https://doi.org/10.1016/j.buildenv.2014.08.004.

Wali Kota Surakarta. 2024. *Peraturan Daerah Kota Surakarta Tentang Penyelenggaraan Bangunan Gedung*. Surakarta.

Yuliani, Sri, Gagoek Hardiman, Erni Setyowati, Wiwik Setyaningsih, and Yosafat Winarto. 2021. "Thermal Behaviour of Concrete and Corrugated Zinc Green Roofs on Low-Rise Housing in the Humid Tropics." *Architectural Science Review* 64 (3): 247–61. https://doi.org/10.1080/00038628.2020.1751054.

Author(s) contribution

Sri Yuliani contributed to the research topic, methodologies, data analysis, articles drafting and revisions.

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