Urban Canyon Configurations for Sustainable Tropical Cities: A Simulation for Design Practice

Wasiska Iyati*[1], Andika Citraningrum[2], Jono Wardoyo[3]
[1-3] Department of Architecture, Universitas Brawijaya, Jl. MT Haryono 167 Malang, East Java, Indonesia

Article Info

Article history:

Received: Oct 2, 2025
Revised: Nov 5, 2025
Accepted: Dec 18, 2025

Keywords:

Daylight potential;
Simulation;
Surface temperature;
Tropical cities;
Urban canyon configuration.

ABSTRACT

Urban overheating and limited daylight access are persistent challenges in rapidly densifying tropical cities. This study examines the influence of urban canyon geometry—including building width-to-length ratio, corridor width, and lateral spacing—on surface temperature dynamics and daylight performance. Using Autodesk Forma, 27 building massing configurations were simulated under standardized conditions with a fixed building height of 30 meters and a footprint of 900 m². Surface temperatures were measured at corridor and rear façade points at 10:00 a.m. and 2:00 p.m., while daylight performance was assessed using sun hours and daylight potential indicators. The results indicate that compact building forms with minimal spacing exacerbate heat accumulation and restrict daylight access, whereas configurations with greater spatial permeability enhance both thermal and lighting performance. The optimal configuration featured an elongated building ratio of 1:3, a narrow corridor width of 15 meters, and wide lateral spacing of 30 meters, achieving corridor surface temperatures as low as 33°C and daylight performance values of up to 66%. Beyond its analytical findings, this study highlights the practical applicability of Autodesk Forma as an accessible and user-friendly tool for early-stage massing studies. Compared to more complex simulation platforms such as ENVI-met or CFD, Autodesk Forma enables architects and designers to conduct simple yet effective climate-responsive analyses during the initial phases of building and site design, thereby supporting sustainable urban development in tropical contexts.

Corresponding Author:

Wasiska Iyati
Department of Architecture, Faculty of Engineering, Universitas Brawijaya
Jl. MT Haryono 167, Malang, East Java, Indonesia 65145
Email: wasiska.iyati@ub.ac.id

1. INTRODUCTION

The geometric configuration of urban environments plays a pivotal role in determining microclimatic conditions, particularly in tropical humid cities where elevated moisture levels exacerbate heat stress. Among the most influential urban form parameters are building aspect ratio (height-to-width ratio of an urban canyon), canyon width, and the spacing between buildings. These factors collectively shape airflow, solar exposure, and heat accumulation. High aspect ratios reduce the sky view factor, limiting both longwave radiation loss and air circulation, thereby intensifying the urban heat island (UHI) effect and increasing near-surface air temperatures [1], [2] In narrow canyons, inadequate ventilation hampers convective heat dissipation and traps anthropogenic heat, which raises cooling energy demand and reduces outdoor thermal comfort [3], [4].

Canyon width has a dual role in thermal performance. Narrow corridors enhance shading, reducing direct solar radiation on buildings and pedestrian areas, which in turn lowers cooling loads [1], [5]. However, excessive narrowness impedes air circulation and prevents heat dissipation, especially in humid tropical climates where latent cooling is already limited [4] [2]. Consequently, urban designers must consider not only geometrical proportions but also supplemental cooling strategies, such as the integration of vegetation and water elements, which can alter wind dynamics and improve the surface energy balance [6]. Similarly, the spacing between buildings significantly affects urban thermal dynamics. Wider spacing facilitates airflow and reduces heat buildup, but it also exposes surfaces to greater solar radiation, potentially increasing surface temperatures [1] [2]. Conversely, compact arrangements increase shading and reduce radiative gain but may restrict ventilation, causing stagnant heat zones [4], [5]. This underscores the necessity for balanced spatial arrangements in tropical design, optimizing both shading and ventilation to mitigate thermal discomfort [3] [6].

Urban densification is widely acknowledged as a major contributor to elevated surface temperatures and the intensification of UHI effects. High-density development, characterized by extensive impervious surfaces and minimal green cover, limits natural cooling mechanisms and increases heat retention. These changes in land use and surface material explain why rapidly growing urban centers often experience significantly higher land surface temperatures than adjacent rural areas [7]. In metropolitan cores, reduced vegetation and increased thermal mass exacerbate these effects [8]. Furthermore, building height, particularly in high-rise environments, interacts with form and material to shape energy flows and thermal storage. While density influences daytime heating, building height governs nighttime heat retention [9]. Effective thermal management in such contexts requires height-sensitive solutions, such as reflective materials, shading devices, and ventilation corridors. Urban design should respond to the thermal contributions of high-rise structures through sustainable material selection and energy-efficient configurations [10].

Remote sensing studies provide robust evidence supporting the link between urban geometry and microclimatic outcomes. Gerçek et al. demonstrate that compact urban forms with limited vegetation and high impermeability strongly correlate with increased UHI intensity [11]. Similarly, Ridwan et al., using Landsat data, show that the spatial concentration and morphology of built environments significantly affect thermal retention, with denser areas showing more pronounced UHI effects [12]. These findings reinforce the need for urban form reconfiguration as a complementary strategy to vegetation-based cooling. Morphological studies further highlight how building layout, orientation, and block positioning affect ventilation and convective heat transfer. Rana et al. found that the spatial arrangement of buildings influences airflow paths and thus the effectiveness of outdoor cooling [13]. Yang et al. add that urban expansion and densification contribute to global warming through the reinforcement of UHI [14]. Braun et al. argue that deliberate management of building density and integration of green infrastructure are essential to reduce urban heat and achieve spatial efficiency [15]. Despite growing literature in this field, there remains a lack of studies exploring the simultaneous effects of aspect ratio, canyon width, and spacing on thermal performance in tropical cities. This study aims to address that gap by assessing the combined influence of these geometric variables on surface temperature in humid environments.

The hypothesis guides the present research that optimal combinations of building form and spacing can effectively lower surface temperatures and enhance microclimatic comfort, even within dense urban configurations. While previous studies often examine individual parameters in isolation, this study employs a combinatorial approach that reflects the complexity of real urban conditions. By simulating different urban geometries, the study seeks to generate empirical evidence supporting climate-responsive urban design. To achieve this objective, the research employs a combination of parametric modeling and performance-based environmental simulation. Unlike conventional studies that focus on isolated variables, this approach integrates multiple geometrical dimensions in assessing their thermal effects. The focus on high-rise configurations typical of tropical urban centers ensures the study's relevance to cities undergoing rapid densification, such as those in Indonesia. The integration of architectural form with environmental data contributes to a broader sustainability agenda by providing design recommendations that reduce UHI and energy use. This study highlights how accessible digital tools support data-driven early design and foster collaboration for climate-responsive urban planning.

This study employs Autodesk Forma, a cloud-based platform enhanced with artificial intelligence, to simulate surface temperature, daylight potential, and sun hours under diverse urban canyon configurations. Models were standardized with a 30-meter building height and a 900 m² footprint, while corridor widths (15 m, 30 m, 45 m) and side spacing (0 m, 15 m, 30 m) were systematically varied. Simulations at 10:00 a.m. and 2:00 p.m. captured diurnal solar exposure. Although previous studies have explored individual parameters such as aspect ratio, orientation, or canyon width, few have investigated their combined effects in tropical high-density contexts. Moreover, most existing analyses employ advanced tools like ENVI-met or CFD, which remain complex and less accessible to practitioners, leaving a gap in early-stage design applications. Addressing this gap, the present study demonstrates how integrated geometric variations, specifically width-to-length ratio, corridor width, and side spacing, shape both thermal and daylight performance. The findings aim to provide architects, planners, and policymakers with evidence-based strategies for climate-responsive urban design, while contributing to the broader discourse on environmental resilience. This approach simplifies early-stage design by linking microclimate data with spatial logic, enabling practical decisions without advanced technical tools. It bridges academic insights and professional workflows to support livable tropical cities.

2. METHOD

The influence of building geometry, orientation, and distance on the urban thermal climate is gaining attention in architectural and environmental research. Simulation methods such as parametric modeling and CFD are important for understanding the interaction between building form and microclimate behavior. These approaches allow researchers to explore the impacts of urban form on environmental parameters such as solar radiation, airflow, and thermal comfort [16], [17], [18]. To initiate a consistent simulation framework, parametric urban configurations must be developed. Variations in height-to-width (H/W) ratios, spatial layouts, and orientations are systematically modeled using simulation tools such as ENVI-met and CFD-based platforms [19], [20]. These configurations are evaluated using standardized thermal comfort indices, including the Physiologically Equivalent Temperature (PET), Universal Thermal Climate Index (UTCI), and Predicted Mean Vote (PMV) [17], [21], [22]. By examining diverse morphological typologies such as linear blocks, courtyards, and dispersed forms, researchers can identify how combinations of design parameters influence microclimatic conditions.

A critical component of simulation-based research is model calibration and validation. To ensure analytical accuracy, simulated outputs, such as surface temperatures and wind velocities, must be validated against empirical field data. Several studies have achieved such validation through in-situ measurements within urban canyons or along pavements [18], [23], confirming the reliability of simulation tools for informing architectural decision-making. Recent advancements integrate machine learning algorithms to capture non-linear dynamics between urban form and thermal behavior, further refining model accuracy and interpretability [24], [25]. These techniques facilitate a nuanced understanding of how urban geometry affects pedestrian-level sun exposure and ventilation [16], [26].

Contemporary research has moved beyond single-variable studies toward multidimensional analyses that reflect the interaction of multiple urban design factors. By embedding meteorological data into three-dimensional parametric models, simulations can replicate real-time thermal environments across diverse urban morphologies, from dense commercial zones to low-rise residential areas [27]. This allows for dual-scale evaluations, for example, assessing the cooling benefits of courtyards in winter or the advantages of larger setbacks during summer. These methods emphasize the integration of thermal comfort considerations into early urban design processes, linking spatial planning with environmental performance and energy efficiency [6].

This study adopts Autodesk Forma as the primary simulation platform. As a cloud-based, AI-supported design environment, Autodesk Forma enables early-stage environmental assessments and spatial planning within a Building Information Modeling (BIM) framework. Its application in architectural research has grown, especially for analyzing how modifications in form and layout impact urban microclimates.

In their work on Local Climate Zones and morphological thresholds, Silva & Ferraz (2024) employed Autodesk Forma to simulate various land-use patterns, showing how spatial and vegetative interventions can significantly reduce air temperatures [28]. Similarly, Kurniawan et al. demonstrated how Autodesk Forma was used in an integrated design approach for the IKN Nusantara project, allowing designers to visualize and assess multiple design strategies rapidly [29]. By enabling precise modeling of massing and façade characteristics, Autodesk Forma facilitated iterative evaluation of energy and thermal performance.

One of Autodesk Forma's strengths lies in its ability to simulate complex urban conditions, including solar radiation, wind dynamics, and heat retention. This capability allows designers to explore and optimize various geometric configurations, such as building orientation and spacing, for improved outdoor thermal comfort. When used alongside parametric tools or machine learning algorithms, simulation data from Forma can support high-resolution urban-scale thermal analyses.

This study used three massing models to represent different building width-to-length ratios: Model A (1:1), Model B (1:2), and Model C (1:3), as shown in Figure 1. Each model maintained a consistent building height of 30 meters (equivalent to five stories) and a footprint of 900 m². The models were differentiated by variations in frontal and lateral spacing, 15 m, 30 m, and 45 m for the former; 0 m, 15 m, and 30 m for the latter, resulting in configurations resembling urban canyons. Orientation was inherently addressed through corridor alignment.

The simulation examined surface temperature, sun hours, and daylight potential as key dependent variables, representing environmental performance and outdoor thermal comfort. These metrics were evaluated under the specific climatic conditions of central Malang, East Java, Indonesia. Simulations were conducted for two distinct time intervals 10:00 a.m. and 2:00 p.m. to account for diurnal temperature fluctuations and pedestrian-level microclimatic dynamics.

A descriptive comparative method was employed to analyze and contrast results across all simulation scenarios. The output was visualized using Autodesk Forma's built-in tools, including heat maps and tabular data, to illustrate the spatial distribution of thermal variables. These visualizations facilitated the identification of thermal performance trends under different morphological configurations, particularly within a tropical humid context.

This study employs Autodesk Forma not only for its capacity to simulate solar exposure and thermal conditions but also to demonstrate its practical applicability for architects and designers during early massing studies. Unlike advanced research-oriented tools such as ENVI-met or CFD, which are often complex and primarily used in academic contexts, Autodesk Forma is freely accessible and user-friendly, making it suitable for practitioners. By utilizing this platform, the study highlights how simple simulations can guide architects toward climate-responsive design decisions at the initial stages of building and site planning.

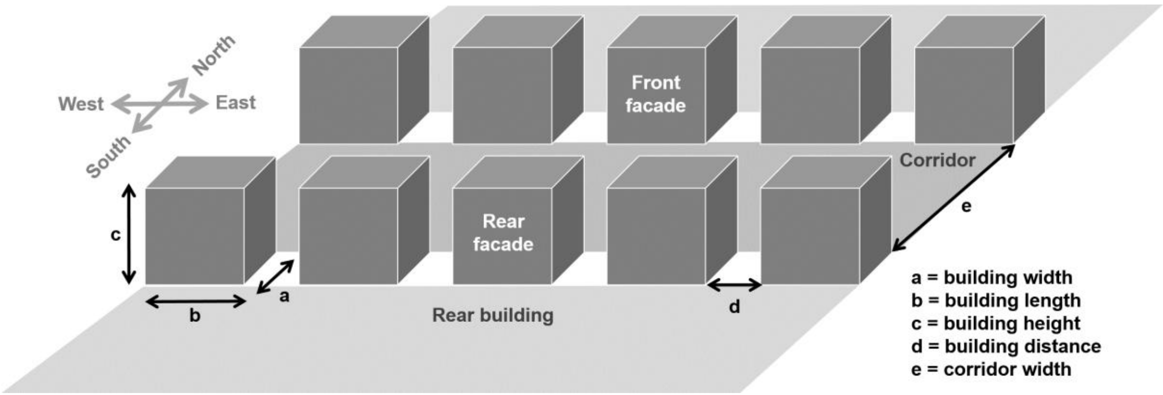

Figure 1. Urban Canyon and Building Configuration Simulation Model

3. RESULTS

This study investigates the microclimatic performance of various building configurations by simulating 27 combinations of width-to-length ratios, corridor widths, and side spacings using Autodesk Forma. These configurations were evaluated under tropical conditions for their influence on surface temperature, solar exposure, and daylight potential. Results were obtained through standardized simulations at two time points: 10:00 a.m. and 2:00 p.m. (Figure 2), representing morning and afternoon peak heating periods. This section presents key findings structured into five themes. Together, these findings aim to inform passive design strategies that enhance urban livability in dense tropical environments.

3.1. Impact of Building Width-to-Length Ratio

The ratio between a building's width and length substantially affects how sunlight is distributed across urban canyon surfaces. Models with elongated proportions (1:3) recorded lower surface temperatures, especially during the morning period. For instance, Model C3.1, with a 1:3 ratio, showed corridor temperatures of 33°C at 10:00 a.m., while a compact 1:1 configuration like Model A1.1 maintained higher readings at 34°C. Elongated buildings offer longer façades and deeper canyons that enable solar exposure to be staggered throughout the day, reducing radiant concentration. This phenomenon has been recognized in previous studies emphasizing that form influences solar irradiance and air ventilation within canyons [22]. More rectangular layouts allow for improved airflow, especially when combined with effective corridor spacing, which helps dissipate accumulated heat. Conversely, compact forms (1:1) create tightly enclosed spaces that retain more heat, particularly during afternoon hours.

3.2. Influence of Corridor Width and Side Spacing

Corridor width and building side spacing are significant modifiers of thermal performance. Narrow corridors (15 m) provided enhanced shading from adjacent buildings, reducing direct solar penetration and contributing to lower corridor temperatures. For example, Models with 15 m corridors and 30 m spacing (e.g., C3.1) consistently produced morning temperatures 1°C cooler than their 45 m counterparts (e.g., C3.3). This finding supports previous claims that while wider corridors can facilitate airflow, they also expose more surfaces to sunlight, especially when paired with minimal side spacing [30], [31]. In terms of side spacing, configurations with 30 m gaps yielded rear façade temperatures 1°C lower than zero-spacing cases. This effect stems from enhanced air movement and reduced surface-to-surface radiant exchange, as supported by [32], [33].

3.3. Diurnal Variations in Surface Temperature

A consistent trend across all configurations was a rise in surface temperature from morning to afternoon. Rear façade temperatures often increased slightly more than those of the corridor, indicating differential heat retention. For example, Model C2.1 showed an increase from 33°C to 34°C in corridor temperature and from 35°C to 36°C in rear façade temperature between 10:00 a.m. and 2:00 p.m. These diurnal dynamics underscore the importance of building geometry and orientation. Although orientation was held constant in this study, geometric variation alone created notable differences in thermal behavior. Prior research emphasizes that urban blocks with reduced sky view factors (SVF) tend to trap heat more intensely, particularly in the afternoon [34], [35].

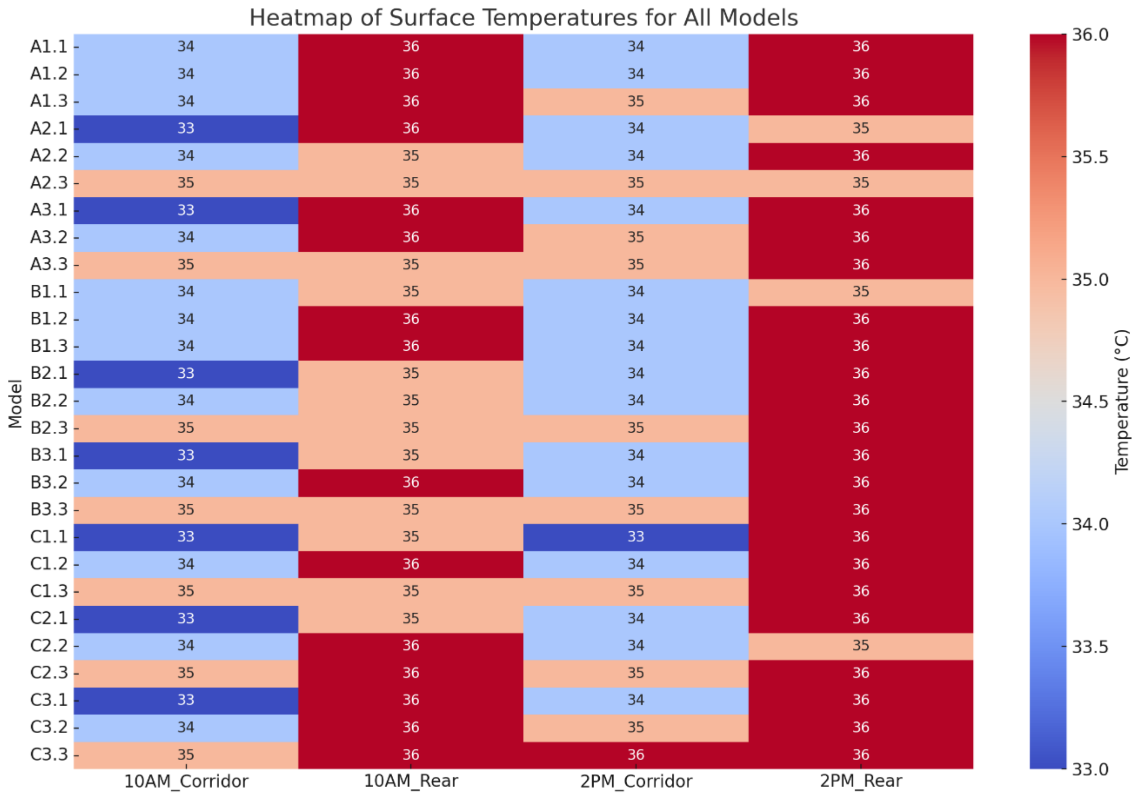

Figure 2. Surface Temperature for All Models at 10:00 a.m. and 02:00 p.m.

3.4. Identification of Optimal Configuration

Among all models, C3.1, combining an elongated form (1:3), narrow corridor (15 m), and wide side spacing (30 m) delivered the most balanced thermal performance. This model achieved 33°C in the morning and only 34°C in the afternoon in corridor zones, with rear façades peaking at 36°C. The cooling efficiency of this configuration lies in its spatial porosity and vertical shading. Narrow corridors maximize shadowing, while wide lateral gaps enhance airflow. These findings reinforce recommendations from previous studies suggesting that integrated manipulation of width-to-length ratios and spacing yields the best thermal outcomes [22], [36].

3.5. Daylight Potential and Sun Hours Analysis

Daylight simulations highlighted the trade-off between spatial compactness and solar access (Figure 3). Compact configurations (e.g., Model A1) yielded the highest daylight performance, with over 60% of surfaces scoring above 37 in daylight potential. However, they also exhibited extreme sun hour polarization, with a large share of surfaces receiving either minimal or excessive sunlight. To visualize these differences, Figure 4 presents the total surface area exposed to various durations of direct sunlight, revealing the dominance of either very short or very long exposure in compact models. Figure 5 complements this by showing the percentage distribution of sun exposure per model, helping identify configurations that achieve more even sunlight access. Finally, Figure 6 compares the performance of all models across three key exposure categories:

low (0–1 hours), optimal (3–6 hours), and high (9+ hours), offering a clear benchmark for evaluating sunlight accessibility. Models such as B2 and C2, which featured moderate corridor width (30 m) and side spacing (15 m), demonstrated more balanced solar exposure profiles. These results align with research by [2], who found that geometric moderation improves daylight quality while avoiding overheating. Furthermore, Huang et al. (2021) stress that an optimal corridor width provides a beneficial compromise between shading and visibility of the sky dome [25]. Across all models, configurations with greater spacing generally shifted sunlight exposure towards intermediate durations, improving daylight quality without compromising thermal comfort. Models B3 and C3 confirmed this by achieving consistent daylight scores and avoiding extremes seen in more compact alternatives.

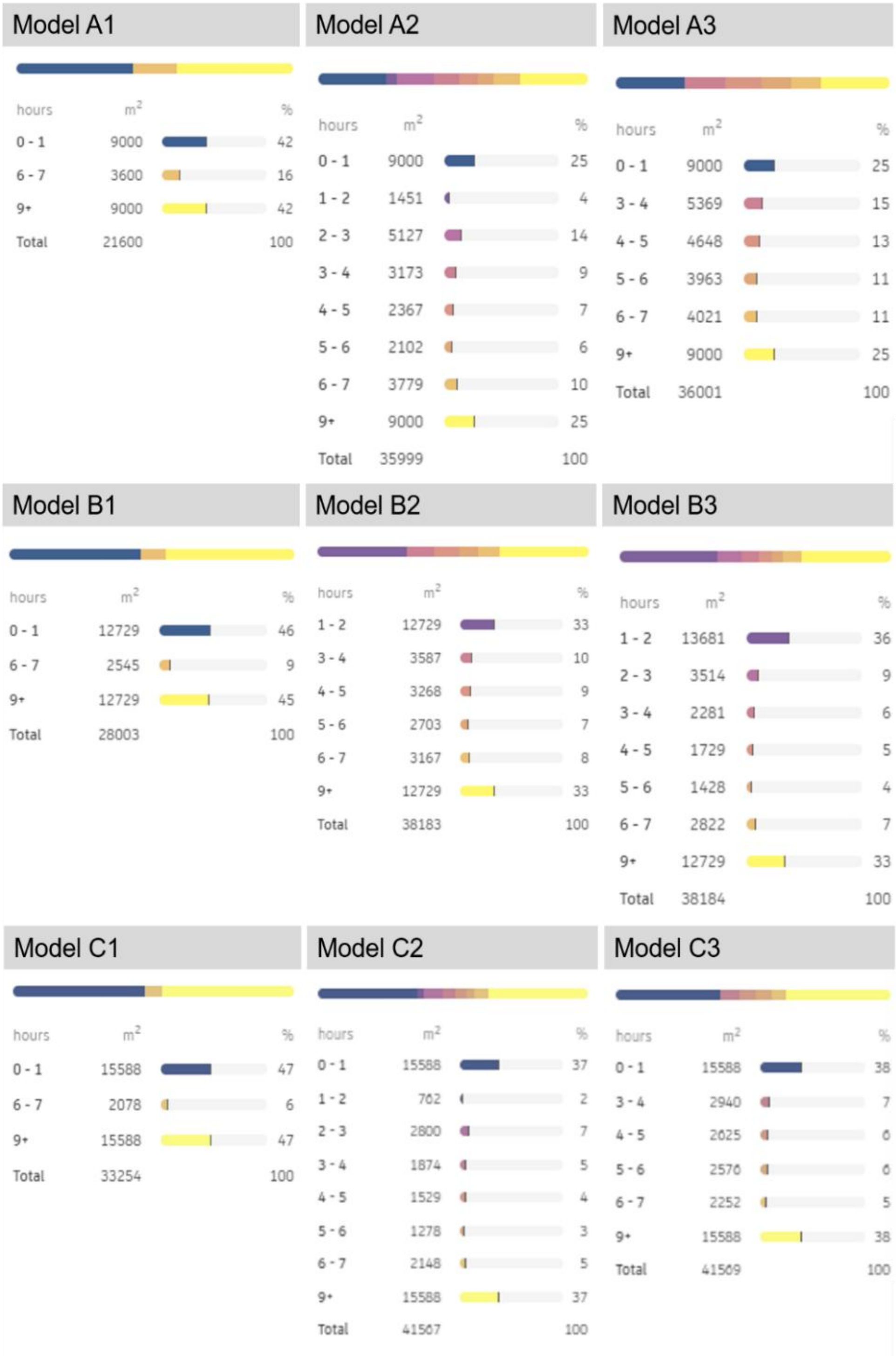

Figure 3. Sun Hours Simulation Results

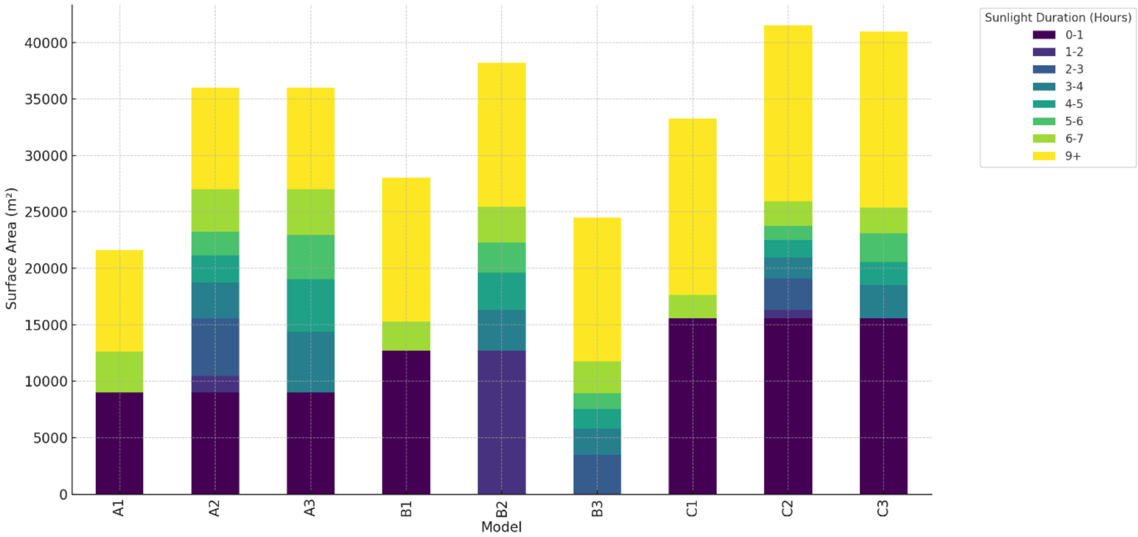

Figure 4. Distribution of Sunlight Duration Across Building Models

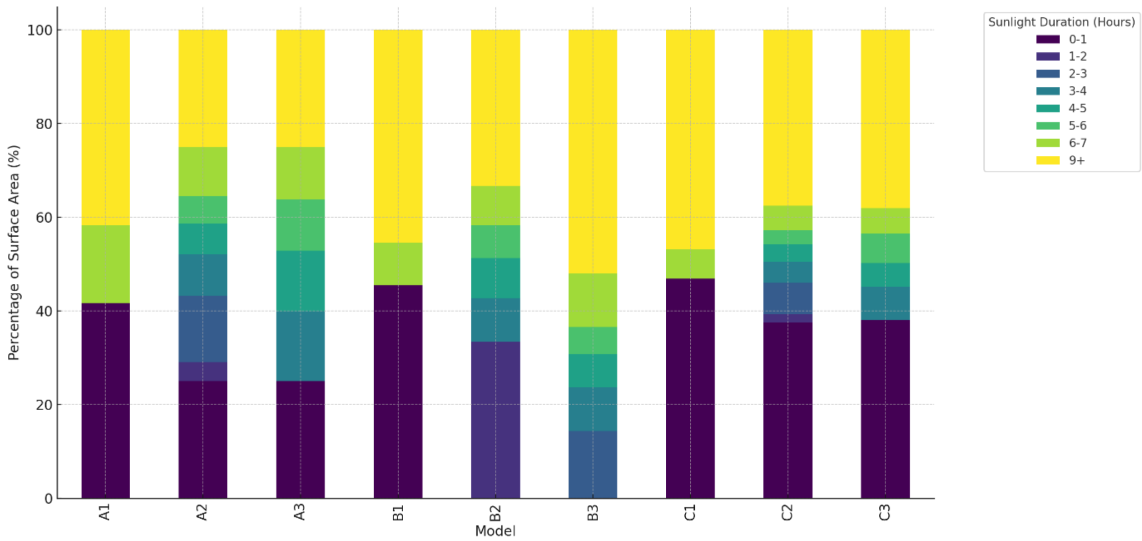

Figure 5. Percentage Distribution of Sunlight Duration per Model

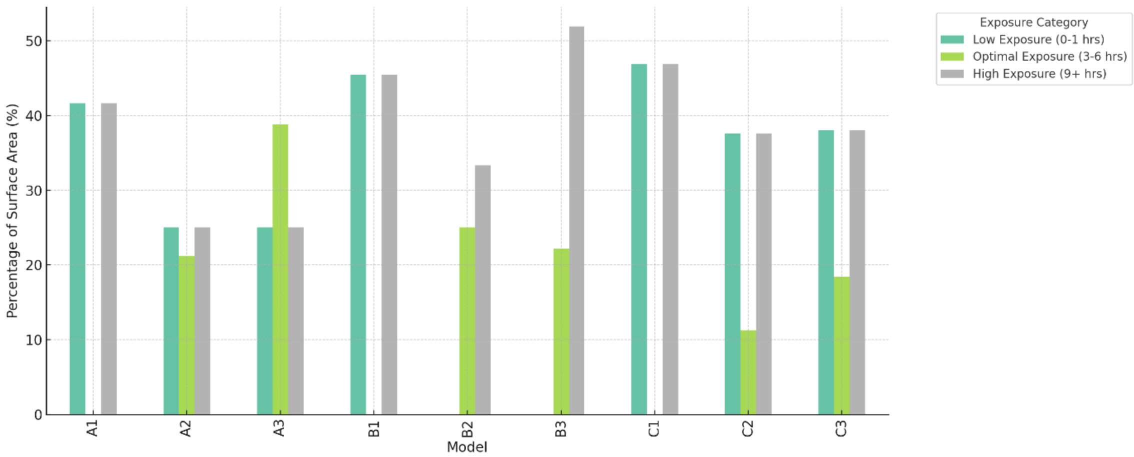

Figure 6. Sunlight Exposure Performance Comparison Across Models

This analysis confirms that geometry alone, even without material or vegetation interventions, has a significant influence on urban canyon microclimates. Key takeaways include:

1. Elongated buildings perform better in dissipating heat.
2. Narrow corridors enhance shading but must be paired with lateral spacing for ventilation.
3. Spatial permeability improves both thermal and daylight performance.
4. Model C3.1 offers the best overall configuration for hot, humid urban contexts.

These results form the empirical basis for the subsequent discussion, which will explore the theoretical, practical, and policy implications of these findings.

4. DISCUSSION

This study set out to explore how variations in urban canyon configurations influence microclimatic performance in dense tropical environments. By simulating 27 geometric arrangements using Autodesk Forma, the research offers evidence-based insights into how building form, corridor width, and side spacing interact to shape surface temperatures and daylight access. As reflected in the article's objectives, this discussion highlights the simulation's role in informing design strategies that contribute to thermal comfort and urban sustainability.

4.1. Geometrical Influence on Microclimatic Dynamics

Urban canyons are defined by the spatial interplay between buildings and the voids they frame. The results demonstrated that elongated building forms (1:3 width-to-length ratio) consistently achieved better thermal outcomes than compact (1:1) forms. These configurations distribute solar exposure across longer façades, reducing localized heat accumulation and enhancing airflow, both of which are critical for tropical cities where overheating is prevalent [22]. The thermal efficiency of elongated forms affirms that sustainable urban design is not solely dependent on materiality or vegetation, but can also be achieved through deliberate shaping of built form. This supports the broader agenda of urban sustainability by promoting passive cooling solutions that reduce energy demand for mechanical ventilation [37].

4.2. The Role of Corridor Width and Side Spacing in Urban Canyon Design

Corridor width and side spacing emerged as key spatial parameters with direct influence on thermal behavior. Narrow corridors (15 m), especially when paired with 30 m side spacing, yielded the lowest surface temperatures during morning and afternoon simulations. These findings counter conventional assumptions that wider spaces always improve ventilation and comfort [30]. Instead, the interaction of narrow, shaded corridors and well-ventilated lateral gaps proved most effective. As highlighted by [31], building shade can be just as crucial as air movement in mitigating heat. Additionally, studies by [32], [33] confirm that increased spacing improves the SVF, facilitating radiative cooling and better convective airflow. These findings have major implications for early-stage design in tropical cities, where land pressure often encourages compactness at the expense of thermal comfort.

4.3. Heat Retention and Temporal Microclimate Dynamics

The consistent increase in surface temperatures from 10:00 a.m. to 2:00 p.m. across all models illustrates typical diurnal heat accumulation patterns in urban environments. However, the rate of increase varied significantly by configuration. Models with greater spatial permeability, especially Model C3.1 which exhibited more moderate thermal fluctuations. In contrast, compact, tightly spaced models retained more heat, particularly at rear façades. This aligns with findings by Bajšanski et al. (2019) and Roslan et al. (2018), who reported that low SVF and restricted airflow limit the ability of surfaces to release absorbed heat [34], [35]. These temporal behaviors reinforce the need for designers to anticipate not just peak-hour conditions, but the thermal lag and retention characteristics of different urban canyon forms. Such insights are critical for sustainable tropical urbanism, where 24-hour comfort can reduce the need for energy-intensive cooling systems and improve livability. Incorporating these principles during the design phase contributes directly to the sustainability goals outlined in the article's title.

4.4. Thermal and Daylight Trade-offs in Canyon Configurations

A central tension in urban canyon design is balancing shading (which reduces heat) with daylighting (which reduces energy use for lighting). The study found that compact forms like Model A1 delivered high daylight scores but also experienced extreme sunlight exposure disparities. Conversely, configurations like B2 and C2 showed more balanced solar exposure without substantial losses in daylight potential. These results echo the observations of Wu and Liu (2023), who noted that daylight access and thermal comfort are often in conflict within dense urban morphology [2]. Huang et al. further emphasized that corridor width modulates both sun hours and daylight scores [25]. As such, designers must calibrate massing and spacing to mediate these competing priorities. In the context of *design practice*, this trade-off becomes a crucial parameter. Instead of relying on aesthetic or density-driven templates, simulation tools like Autodesk Forma enable data-informed decisions that harmonize light, heat, and space, which are key features of sustainable tropical design.

4.5. Performance Validation of the Optimal Scenario (Model C3.1)

An elongated block with 15 m corridor width and 30 m side spacing of model C3.1 emerged as the most efficient configuration in balancing thermal and daylight performance. Its ability to maintain corridor temperatures of 33–34°C while achieving moderate daylight levels makes it a compelling model for tropical cities aiming to reduce energy use without compromising comfort. This finding validates theoretical frameworks that advocate for integrated form-based solutions. Studies by Khraiwesh & Genovese (2023), Devi et al. (2023), and Xu et al. (2019) argue that geometry can serve as a passive regulatory mechanism in climate-responsive urbanism [22][36][38]. By aligning these findings with practical simulation outputs, the research bridges theoretical knowledge with design application.

4.6. Implications for Design Practice Using Autodesk Forma

The integration of Autodesk Forma in this study exemplifies how simulation tools can inform early design decisions. Compared to more complex and time-consuming platforms like ENVI-met or CFD software, Forma offers a balance of usability and environmental accuracy, suitable for iterative design evaluations. Rodrigues Silva & Barbosa Ferraz (2024) and Kurniawan et al. (2024) highlight the role of such platforms in democratizing environmental modeling, especially for practitioners without access to high-performance computing [28], [29] In this study, Forma was used to visualize and quantify subtle differences in thermal behavior and lighting exposure across building layouts, enabling designers to explore "what-if" scenarios before physical construction begins. This approach directly supports the article's objective of using simulation for design practice, and positions Forma as a practical tool for architects and planners addressing urban heat in tropical regions.

4.7. Contribution to Sustainable Tropical Urbanism

By demonstrating how basic form manipulation can significantly alter microclimatic outcomes, this study offers a scalable, cost-effective strategy for tropical urban sustainability. Rather than relying on post-occupancy solutions (e.g., mechanical cooling or retrofitted shading), the research advocates for proactive geometric calibration in the planning phase. This aligns with the broader literature that calls for climate-responsive planning rooted in morphological logic [18], [37]. As cities in the tropics grow denser and hotter, the need for integrated, low-tech solutions becomes ever more urgent. Moreover, the emphasis on configuration over construction materials allows these insights to be applied in resource-constrained settings, making the research both globally relevant and locally actionable.

4.8. Limitations and Directions for Further Research

While the study successfully isolates geometric influences, it does not account for material reflectivity, wind dynamics, or vegetation, which also shape microclimates. Future research should include these variables and test configurations in multiple tropical cities with varying urban densities and cultural contexts. Field validation through in-situ data collection could further strengthen the applicability of these findings. Additionally, integrating human comfort indices such as PET or UTCI would extend the environmental data into experiential metrics.

This discussion reinforces the core message of the article: urban canyon configurations are a vital determinant of environmental quality in tropical cities. Through simulation-driven design practice, designers can optimize building forms not just for density or aesthetics, but for thermal comfort, daylighting, and sustainability. The results affirm that sustainable tropical urbanism can be achieved through spatial intelligence, particularly when tools like Autodesk Forma are embedded early in the design process. As exemplified by Model C3.1, small adjustments in geometry yield significant benefits, providing a replicable strategy for cities facing the compounded challenges of heat, density, and limited resources.

5. CONCLUSION

This study aimed to examine how variations in urban canyon geometry namely building width-to-length ratio, corridor width, and side spacing, which affect surface temperature and daylight potential in tropical urban settings. Simulation results revealed that the most thermally comfortable configuration featured an elongated building form (1:3), a narrow corridor (15 m), and wide lateral spacing (30 m), achieving corridor surface temperatures as low as 33°C and daylight scores up to 66% in the highest category. Conversely, dense layouts with minimal spacing produced higher surface temperatures, up to 36°C, and reduced daylight performance. Models such as C3.1 consistently demonstrated superior microclimatic outcomes across both thermal and lighting metrics. These findings underscore the critical role of spatial permeability and form orientation in enhancing urban environmental quality. The study's use of 27 massing configurations enabled a comprehensive evaluation of interaction effects between massing and spacing, offering a robust comparative framework. Importantly, Autodesk Forma was employed not only for its capacity to simulate solar exposure and thermal conditions but also to demonstrate its practical applicability for architects and designers during early massing studies. Unlike complex research-oriented tools such as ENVI-met or CFD, Autodesk Forma is free, accessible, and user-friendly, making it suitable for practitioners. By leveraging this platform, the study highlights how simple simulations can guide architects toward climate-responsive design decisions at the initial stages of building and site planning.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude for the financial support provided by the Faculty of Engineering, Universitas Brawijaya, through the DIPA funding scheme in 2024, which made this research possible.

REFERENCES

[1] N. Nasrollahi, Y. Namazi, and M. Taleghani, "The Effect of Urban Shading and Canyon Geometry on Outdoor Thermal Comfort in Hot Climates: A Case Study of Ahvaz, Iran," *Sustain. Cities Soc.*, 2021, doi: 10.1016/j.scs.2020.102638.

[2] P. Wu and Y. Liu, "Impact of Urban Form at the Block Scale on Renewable Energy Application and Building Energy Efficiency," *Sustainability*, 2023, doi: 10.3390/su151411062.

[3] C.-H. Huang, H.-H. Tsai, and H. Chen, "Influence of Weather Factors on Thermal Comfort in Subtropical Urban Environments," *Sustainability*, 2020, doi: 10.3390/su12052001.

[4] Y. Mohammed and A. Salman, "Effect of urban geometry and green area on the formation of the urban heat island in Baghdad city," *MATEC Web Conf.*, vol. 162, pp. 1–9, 2018, doi: 10.1051/matecconf/201816205025.

[5] Y.-J. Chen, R. H. Matsuoka, and T.-M. Liang, "Urban Form, Building Characteristics, and Residential Electricity Consumption: A Case Study in Tainan City," *Environ. Plan. B Urban Anal. City Sci.*, 2017, doi: 10.1177/2399808317690150.

[6] P. Lin, Z. Gou, S. S. Lau, and H. Qin, "The Impact of Urban Design Descriptors on Outdoor Thermal Environment: A Literature Review," *Energies*, 2017, doi: 10.3390/en10122151.

[7] P. Iamtrakul, A. Padon, and S. Chayphong, "Quantifying the Impact of Urban Growth on Urban Surface Heat Islands in the Bangkok Metropolitan Region, Thailand," *Atmosphere (Basel).*, 2024, doi: 10.3390/atmos15010100.

[8] K. Rastogi and S. K. Sharma, "Spatio-Temporal Relation of Urban Density and Surface Urban Heat Island Index," *J. Geomatics*, 2024, doi: 10.58825/jog.2024.18.1.133.

[9] T. Wei, W. Li, and J. Tang, "Decoding Tianjin: How Does Urban Form Shape the Diurnal Cycle of Surface Temperature?," *Sustainability*, 2024, doi: 10.3390/su162310241.

[10] P. C. Alexandra and Y. Philip, "Assessing the Vulnerability of Urban Areas to the Urban Heat Island Phenomenon: Strategies for Effective Mitigation and Sustainable Urban Planning," *JPSTD*, 2025, doi: 10.61511/jpstd.v2i2.2025.1487.

[11] D. Gerçek, İ. T. Güven, and İ. Ç. Oktay, "Analysis of the Intra-City Variation of Urban Heat Island and Its Relation to Land Surface/Cover Parameters," *Isprs Ann. Photogramm. Remote Sens. Spat. Inf. Sci.*, 2016, doi: 10.5194/isprs-annals-iii-8-123-2016.

[12] R. Ridwan *et al.*, "Assessment of the Relationship Between Building Density and Urban Heat Island Using Landsat Images in Makassar City," *Iop Conf. Ser. Earth Environ. Sci.*, 2021, doi: 10.1088/1755-1315/802/1/012042.

[13] D. P. Rana, A. Tripathi, S. S. Siddiqui, S. Sabahat, R. Chattopadhaya, and S. Munshi, "Exploring the Interplay Between Urban Morphology and Microclimate in Urban Heat Island Formation," *Int Res J Adv Engg MGT*, 2025, doi: 10.47392/irjaem.2025.0033.

[14] J. Yang, K. M. Alahmadi, and S. Shirowzhan, "The Impact of Urban Expansion in Beijing and Metropolitan Area Urban Heat Island From 1999 to 2019," *Appl. Math. Nonlinear Sci.*, 2021, doi: 10.2478/amns.2021.1.00104.

[15] A. Braun, C. E. Duffy, G. Warth, and V. Hochschild, “Relationship of Urban Heat With Building Density and Green Spaces - A Remote Sensing-Based Study Across Vietnam’s Metropolitan Areas,” *Vietnam J. Sci. Technol.*, 2023, doi: 10.15625/2525-2518/16435.

[16] S. Sedira and S. Mazouz, “The Effect of Urban Geometry on Outdoor Thermal Comfort. Application of the UTCI Index in Hot and Arid Climates.,” *Tech. Rom. J. Appl. Sci. Technol.*, 2023, doi: 10.47577/technium.v2021i.8140.

[17] C. Y. Wai, M. A. Ur Tariq, H.-W. Chau, N. Muttil, and E. Jamei, “A Simulation-Based Study on the Impact of Parametric Design on Outdoor Thermal Comfort and Urban Overheating,” *Land*, 2024, doi: 10.3390/land13060829.

[18] J. Wu, H. Chang, and S.-H. Yoon, “Numerical Study on Microclimate and Outdoor Thermal Comfort of Street Canyon Typology in Extremely Hot Weather—A Case Study of Busan, South Korea,” *Atmosphere (Basel).*, 2022, doi: 10.3390/atmos13020307.

[19] H. Huo *et al.*, “Simulation of the Urban Space Thermal Environment Based on Computational Fluid Dynamics: A Comprehensive Review,” *Sensors*, 2021, doi: 10.3390/s21206898.

[20] J. Yang, B. Shi, G. Xia, X. Qin, and S.-J. Cao, “Impacts of Urban Form on Thermal Environment Near the Surface Region at Pedestrian Height: A Case Study Based on High-Density Built-Up Areas of Nanjing City in China,” *Sustainability*, 2020, doi: 10.3390/su12051737.

[21] Y. Ibrahim, T. Kershaw, P. Shepherd, and D. Coley, “On the Optimisation of Urban Form Design, Energy Consumption and Outdoor Thermal Comfort Using a Parametric Workflow in a Hot Arid Zone,” *Energies*, 2021, doi: 10.3390/en14134026.

[22] M. M. Khraiwesh and P. V. Genovese, “Outdoor Thermal Comfort Integrated With Energy Consumption for Urban Block Design Optimization: A Study of the Hot-Summer Mediterranean City of Irbid, Jordan,” *Sustainability*, 2023, doi: 10.3390/su15108412.

[23] X. Song, G. Wang, Q. Deng, S. Wang, and C. Jiao, “The Influence of Residential Block Form on Summer Thermal Comfort of Street Canyons in the Warm Temperate Zone of China,” *Buildings*, 2023, doi: 10.3390/buildings13071627.

[24] K. B. Bedra, B. Zheng, J. Li, and X. Luo, “A Parametric-Simulation Method to Study the Interconnections Between Urban-Street-Morphology Indicators and Their Effects on Pedestrian Thermal Comfort in Tropical Summer,” *Sustainability*, 2023, doi: 10.3390/su15118902.

[25] X. Huang, C. Li, and Z. Zhuang, “Analysis of Height-to-Width Ratio of Commercial Streets With Arcades Based on Sunshine Hours and Street Orientation,” *Appl. Sci.*, 2021, doi: 10.3390/app11041706.

[26] J.-M. Huang and L.-C. Chen, “Synergistic Effects of Roadside Trees and Spatial Geometry on Thermal Environment in Urban Streets: A Case Study in Tropical, Medium-Sized City, Taiwan,” *Buildings*, 2023, doi: 10.3390/buildings13082092.

[27] H. Mahmoud, “Effect of Urban Form on Outdoor Thermal Comfort of Governmental Residential Buildings: New Aswan as a Case Study, Egypt,” *Jes J. Eng. Sci.*, 2019, doi: 10.21608/jesaun.2019.115472.

[28] P. D. Rodrigues Silva and M. E. Barbosa Ferraz, “Estudo Para Melhoria Do Conforto Térmico E Diminuição Da Formação De Ilhas De Calor Urbana No Centro De Recife, PE,” *Periódico Técnico E Científico Cid. Verdes*, 2024, doi: 10.17271/23178604123820245440.

[29] A. Kurniawan, V. C. Saragih, A. Wiranti, D. Rahmadi, and H. W. Poerbo, “Revealing the Future of Urban Design: Exploring Human and Artificial Intelligence Collaboration in Planning and Design for the Sustainable Built Environment (Case Study: IKN Nusantara),” *Iop Conf. Ser. Earth Environ. Sci.*, 2024, doi: 10.1088/1755-1315/1394/1/012032.

[30] S. Xie, P. Martínez-Vázquez, and C. Baniotopoulos, “Wind Flow Characteristics on a Vertical Farm With Potential Use of Energy Harvesting,” *Buildings*, 2024, doi: 10.3390/buildings14051278.

[31] Y. Jiang, J. Huang, T. Shi, and X. Li, “Cooling Island Effect of Blue-Green Corridors: Quantitative Comparison of Morphological Impacts,” *Int. J. Environ. Res. Public Health*, 2021, doi: 10.3390/ijerph182211917.

[32] D. Liu *et al.*, “Research on the Planning of an Urban Ventilation Corridor Based on the Urban Underlying Surface Taking Kaifeng City as an Example,” *Land*, 2022, doi: 10.3390/land11020206.

[33] W. Xu, L. Zhao, Y. Zhang, and Z. Gu, “Investigation on Air Ventilation Within Idealised Urban Wind Corridors and the Influence of Structural Factors With Numerical Simulations,” *Sustainability*, 2023, doi: 10.3390/su151813817.

[34] I. Bajšanski, V. Stojaković, and D. Milošević, “Optimizing Trees Distances in Urban Streets for Insolation Mitigation,” *Geogr. Pannonica*, vol. 23, no. 4, pp. 329–336, 2019, doi: 10.5937/gp23-24242.

[35] N. H. Roslan and M. R. Ismail, “Influence of Building Shapes on Thermal and Energy Performances

in Glass Façade High-Rise Buildings: A Review," *Matec Web Conf.*, 2018, doi: 10.1051/matecconf/201825006006.

[36] S. Devi, E. Horrison, and S. Amraotkar, "Evaluating the Impact of Transition Spaces on the Indoor Comfort Conditions of a Naturally Ventilated Institution Building," *Iop Conf. Ser. Earth Environ. Sci.*, 2023, doi: 10.1088/1755-1315/1210/1/012014.

[37] W. Maneechote, J. Liu, and D. Jareemit, "Cool Facades and Pavements: Mitigating Heat Stress and Improving Urban Thermal Conditions in Affordable Housing Project – A Case Study in Thailand," *Futur. Cities Environ.*, 2024, doi: 10.5334/fce.219.

[38] X. Xu, C. Yin, W. Wang, N. Xu, T. Hong, and Q. Li, "Revealing Urban Morphology and Outdoor Comfort Through Genetic Algorithm-Driven Urban Block Design in Dry and Hot Regions of China," *Sustainability*, 2019, doi: 10.3390/su11133683.

Notes on contributors

Wasiska Iyati is a Lecturer at the Department of Architecture, Faculty of Engineering, Universitas Brawijaya. She earned her Bachelor of Engineering from Universitas Brawijaya in 2009 and a Master of Architecture from Institut Teknologi Bandung in 2012. Her research focuses on building science and technology, particularly building physics, green building, and smart building. She can be contacted at email: wasiska.iyati@ub.ac.id

Andika Citraningrum is a Lecturer at the Department of Architecture, Faculty of Engineering, Universitas Brawijaya. She holds a bachelor's degree from Universitas Brawijaya (2009) and a double-degree master's from Universitas Brawijaya and National Central University, Taiwan (2011). Her expertise lies in sustainable architecture. She can be contacted at email: andikacitra@ub.ac.id

Jono Wardoyo is a Lecturer at the Department of Architecture, Faculty of Engineering, Universitas Brawijaya. He is a Doctoral Candidate in Environmental Science Universitas Brawijaya. His research focuses on the thermal comfort studies in urban environments. He can be contacted at email: jono_arch@ub.ac.id