



The Influence of Pedestrian Path Pavement Materials on Microclimate in Jalan Tunjungan, Surabaya

Anisa Budiani Arifah¹, I Gusti Ngurah Antaryama², Sri Nastiti N Ekasiwi²

¹ Postgraduate Architecture Program, Department of Architecture, Faculty of Civil, Planning, and Geo Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

² Department of Architecture, Faculty of Civil, Planning, and Geo Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia.

| Received December 12th 2025 | Accepted May 2nd 2026 | Published September 30th 2026 |

| DOI <https://doi.org/10.32315/jlbi.v15i3.649> |

Abstract

Surface materials of pedestrian paths significantly influence microclimatic conditions, although the corridor's spatial configuration moderates these effects. This study assesses the impacts of various pavement materials on the microclimate across seven segments of the pedestrian corridor of Jalan Tunjungan, Surabaya. Field measurements were conducted for three days at 08:00, 13:00, and 18:00 on both sides of the corridor. The results indicate that pavement material has the most significant impact on surface temperature (Ts), which responds directly to incoming solar radiation. Materials such as coral stones, concrete block-style pavements, and ceramic tiles exhibit distinct thermal responses. However, radiation distribution, which is affected by surface area, vegetation, and building density, further modulates heating intensity. On the northeast side of the corridor, increased solar radiation leads to higher surface temperatures, subsequently driving up air temperatures (Ta). This relationship is less linear on the southwest side, where ventilation and broader atmospheric conditions exert a more dominant influence. These findings highlight that microclimate evaluation of tropical pedestrian corridors should consider the interaction between pavement materials and spatial morphology to enhance microclimatic quality and outdoor thermal comfort.

Keywords: urban microclimate, urban heat island, surface temperature, air temperature, pavement material, pedestrian pathway

Pengaruh Material Perkerasan Terhadap Mikroklimat pada Jalur Pedestrian Jalan Tunjungan Surabaya

Abstrak

Material permukaan jalur pedestrian memengaruhi kondisi mikroklimat, namun pengaruhnya dimodifikasi oleh konfigurasi spasial koridor. Penelitian ini bertujuan untuk menganalisis pengaruh material perkerasan terhadap mikroklimat pada tujuh segmen Jalur Pedestrian Jalan Tunjungan di Surabaya. Pengukuran dilakukan selama tiga hari pada pukul 08.00, 13.00, dan 18.00 di kedua sisi koridor. Hasil menunjukkan bahwa pengaruh material paling signifikan terlihat pada suhu permukaan (Ts), yang secara langsung merespons energi radiasi matahari yang diterima. Material seperti koral, motif beton, dan motif keramik menunjukkan respons pemanasan yang berbeda, tetapi intensitasnya dipengaruhi oleh distribusi radiasi akibat luas permukaan, vegetasi, dan kepadatan bangunan. Pada sisi timur laut, peningkatan radiasi dan Ts cenderung diikuti oleh kenaikan Ta, sedangkan pada sisi barat daya hubungan tersebut tidak selalu linier karena dominannya pengaruh ventilasi dan atmosfer umum. Temuan ini menegaskan bahwa evaluasi mikroklimat pedestrian tropis perlu mempertimbangkan interaksi material, jenis perkerasan dan morfologi ruang dalam upaya meningkatkan kualitas mikroklimat dan kenyamanan termal pejalan kaki.

Kata-kunci: mikroklimat perkotaan, urban heat island, suhu permukaan, suhu udara, material perkerasan, jalur pedestrian

*Corresponding Author

E-mail: antaryama@its.ac.id



Copyright ©2026 by the Author(s)

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

Introduction

Outdoor urban microclimate conditions are strongly affected by the thermal characteristics of surface materials. Numerous studies have shown that road and sidewalk surface materials play a major role in raising local temperatures. Materials with high heat capacity and absorptivity—such as asphalt and dark paving—typically store more heat and release it back into the environment, thus contributing to increasing air and surface temperatures [1].

Materials with higher albedo or better thermal properties can lower surface temperatures and reduce local heat levels [2], [3]. Albedo is the ratio of solar radiation reflected by a surface to the total incoming radiation, expressed as a value between 0 and 1. A higher albedo indicates a greater ability of a surface to reflect solar radiation and a lower amount of heat energy absorbed. Meanwhile, emissivity refers to a material's ability to release stored heat back into the environment [4], [5].

The types of landscaping materials used in tropical urban areas greatly influence heat levels and radiation absorption [6]. Using appropriate materials can significantly lower surface temperatures and improve the outdoor thermal environment [7]. Compared to other paving materials such as ceramic, granite, and paving blocks, asphalt has a lower albedo and tends to produce higher air and surface temperatures [8].

Shading conditions, street orientation, and urban canyon geometry also produce different temperature patterns along the pedestrian pathway [9], [10]. Dense urban canyons, such as narrow streets between tall buildings, trap vehicle emissions and heat from materials. This process triggers the Urban Heat Island (UHI) phenomenon, where city temperatures become significantly higher than the surrounding areas [5].

These variations create an uneven distribution of temperature along pedestrian pathways, which in turn affects the thermal experience of outdoor users. Solar radiation, both direct and reflected from surrounding surfaces, plays a significant role in shaping local thermal conditions [11]. Therefore, including radiation variables in microclimate analysis is essential.

In Surabaya, the urban heat island (UHI) phenomenon shows the highest intensity in central areas, which are dominated by dense building configurations and hard surfaces [12]. Jalan Tunjungan, located in central Surabaya, is known as a busy heritage and commercial corridor with high activity density. This area has been

identified as a UHI hotspot. The dominance of asphalt on roadways and the use of low-albedo materials on pedestrian paths in this area potentially exacerbate heat buildup and increase pedestrian exposure to thermal radiation. This signifies the importance of microclimate studies at the pedestrian scale.

Most studies on urban pedestrian paths have primarily focused on visual and physical aspects, including street furniture, aesthetic quality, and spatial comfort [13], [14]. Prior microclimate studies on pedestrian paths have emphasized the influence of pavement materials on surface temperature through experimental and simulation-based approaches, demonstrating that high-albedo materials can reduce surface temperatures. However, most of these studies were conducted under controlled conditions or relied on simulation methods, which did not fully capture the complexity of real-world urban environments [2], [7], [15].

This present study uses on-site measurements in a historic pedestrian area characterized by diverse materials, buildings, and vegetation patterns. Rather than just identifying material types, this study analyzes the total surface area of each material to show its specific impact on the microclimate. This approach provides a better understanding of how materials perform in real-life conditions, where dynamic environmental factors constantly modify their impacts.

This study aims to examine how pavement materials affect microclimatic conditions along the pedestrian paths of Jalan Tunjungan, with a focus on surface temperature, air temperature, and solar radiation. The findings are expected to enrich understanding of the relationship between landscape material characteristics and the thermal behavior of outdoor spaces in tropical environments, as well as to provide design recommendations that are more responsive to pedestrian thermal comfort.

Methods

This study adopts a positivist approach, using direct field measurements for data collection [16]. The observed microclimatic variables are air temperature, surface temperature, and solar radiation. The collected data were analyzed to identify patterns and relationships between the pavement materials and the microclimate variables.

Data Collection Methods

Data collection employed direct observation and in situ field measurements. The study area was divided into seven segments, each approximately 100 meters in length, corresponding to the representative horizontal scale of microclimatic conditions [17]. A total of 14 measurement points were established across the study area, as shown in Figure 1.



Figure 1. Study Area Segmentation and Measurement Points on Jalan Tunjungan [24]

Table 1. Microclimate Variables and Measurement Instruments

Microclimate Variables	Measuring Instruments
Air Temperature and Humidity	 - Instrument: Hygro-Thermometer Sd Logger Extech - Accuracy: $\pm 3\%RH$ (humidity), $\pm 1.8^{\circ}F$ (temperature)
Surface Temperature	 - Instrument: Extech IR Thermometer - Accuracy: Surface applications (90%)
Solar Radiation	 - Instrument: Solar Power Meter, Tes - Accuracy: Angular error $< 5\%$ at incidence angles $< 60^{\circ}$

Measurements at each segment were conducted for 5 minutes, with a 10-second recording interval, over a seven-day period. Three days with clear sky conditions were selected for analysis to avoid cloud cover interference. Data were collected at 08.00,

13.00, and 18.00 to represent morning, midday, and afternoon. To ensure consistency, all tools listed in Table 1 were placed on a single tripod at a height of 1.5 meters on both sides of the pedestrian paths.

Table 2. Physical Environmental Parameters

Data Type	Data Collection Method
Pavement Material and Albedo	Field observation and literature review
Building Dimensions and Height	Direct measurement (laser meter) and estimation from imagery
Road and Pedestrian Path Width	Direct measurement (laser meter)
Existing Vegetation	Field observation

Table 2 presents the specific variables contributing to the microclimatic conditions of the study area. These factors shape the urban canyon and its shading patterns, which directly impact heat levels, surface temperatures, and the distribution of solar radiation [15], [18], [19]. Meanwhile, the various materials of pedestrian paths and roads in the study area are shown in Table 3. Materials with higher albedo values, such as ceramic, typically absorb less heat by reflecting solar radiation. Furthermore, all materials in this study have similar emissivity. This indicates a similar ability to release absorbed heat back to the environment.

Table 3. Albedo and Emissivity Values of Existing Materials

Material Type	Albedo	Emissivity	Source
Ceramic/Granite Tile	0.4	0.90	[20], [21]
Grass	0.2	0.97	[20], [21]
Coral (red)	0.32	0.90	[22], [23]
Concrete block-style pavement	0.31	0.90	[23]

Data Analysis Methods

- Descriptive Statistical Analysis**
This approach calculates the mean, minimum, and maximum values, and the distribution of air temperature, surface temperature, and solar radiation. It provides a comprehensive overview of the microclimatic profile for each segment and identifies temporal variations across the three measurement periods (08.00, 13.00, and 18.00) over the three-day observation.
- Local Comparative Analysis**
Comparative assessments were conducted across segments 1–7 and between both sides of the pedestrian paths. This analysis evaluates localized microclimate fluctuations and identifies locations with the best thermal conditions.

Study Area

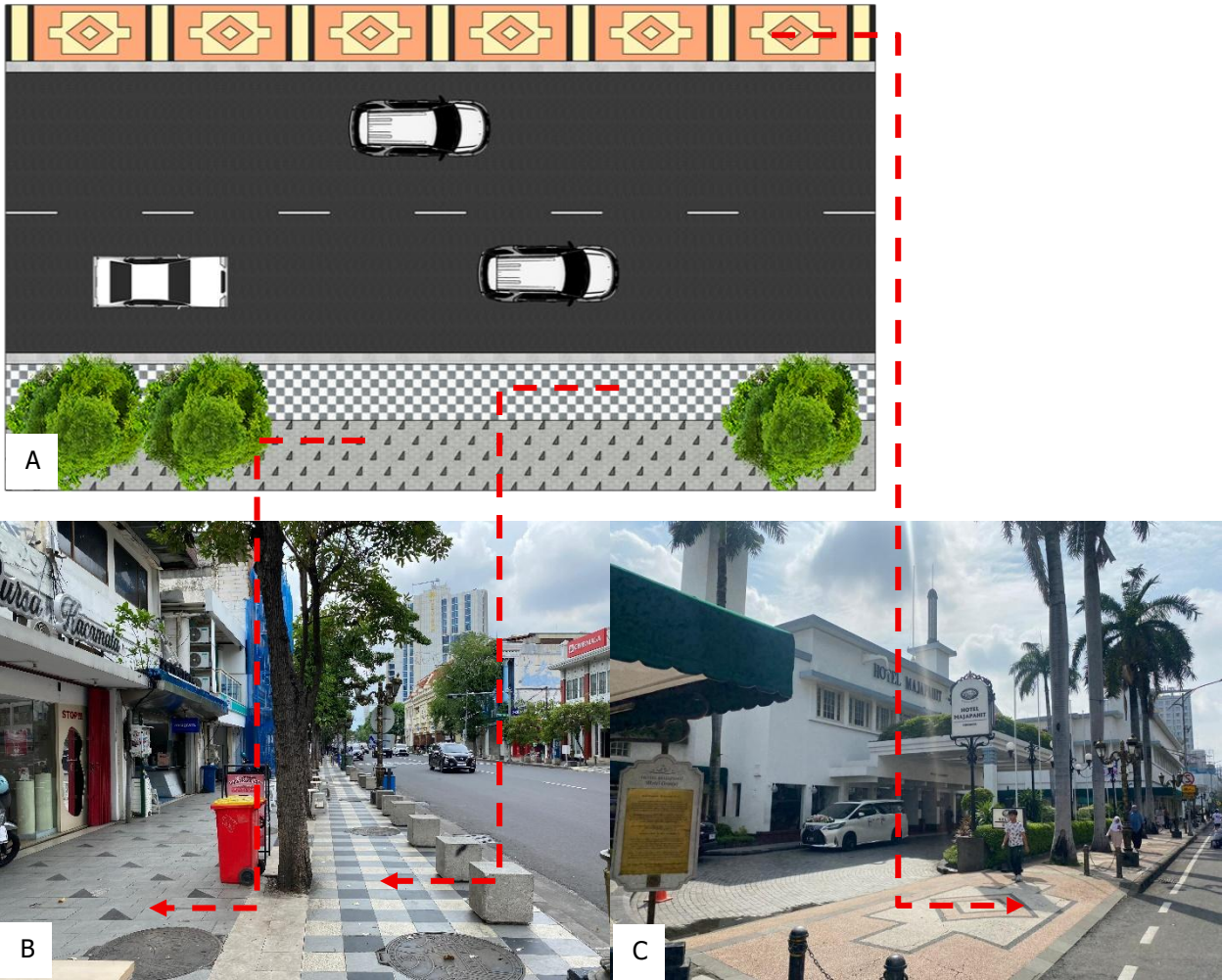


Figure 2. Pavement Material Variation of Pedestrian Paths in Jalan Tunjungan, Surabaya, (A) Top View (B) Concrete Block-Style Pavement and Ceramics, (C) Coral

This study focuses on the pedestrian paths of Jalan Tunjungan in Surabaya’s Central Business District. As a primary heritage corridor, Jalan Tunjungan has significant historical and architectural values, with colonial and modern-style buildings along its length. The buildings and the tree density create different levels of solar radiation exposure and ventilation throughout the corridor.

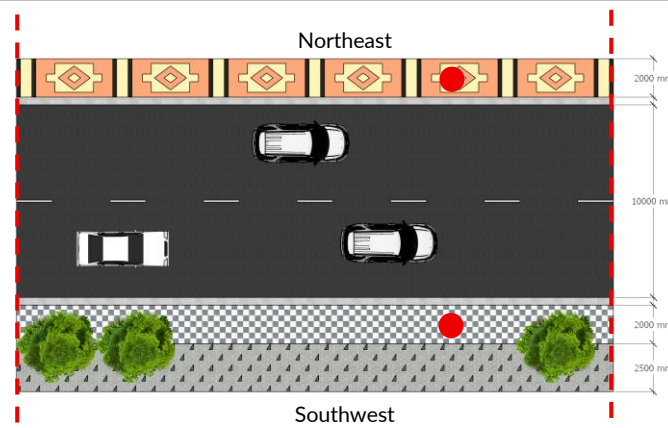
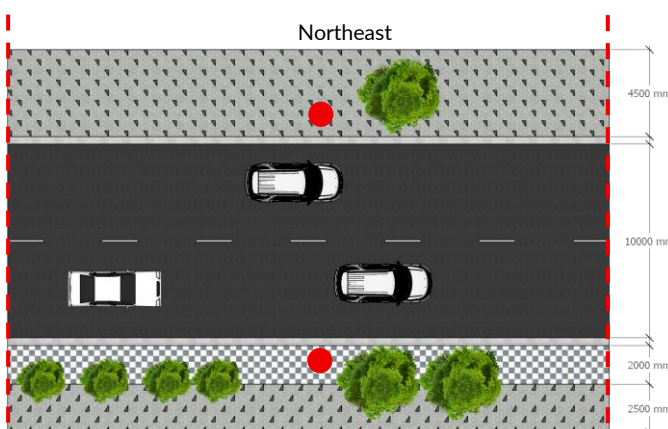
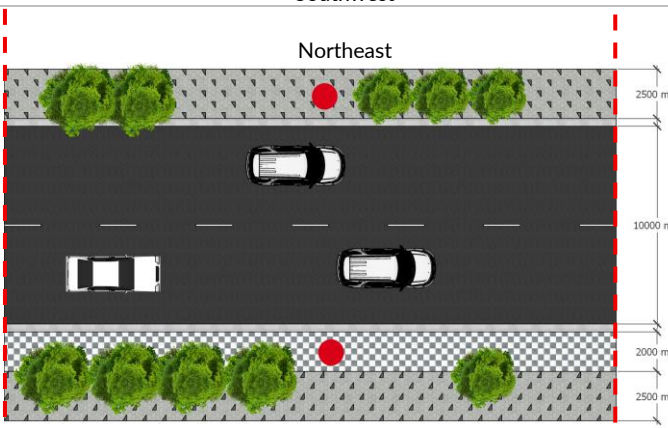
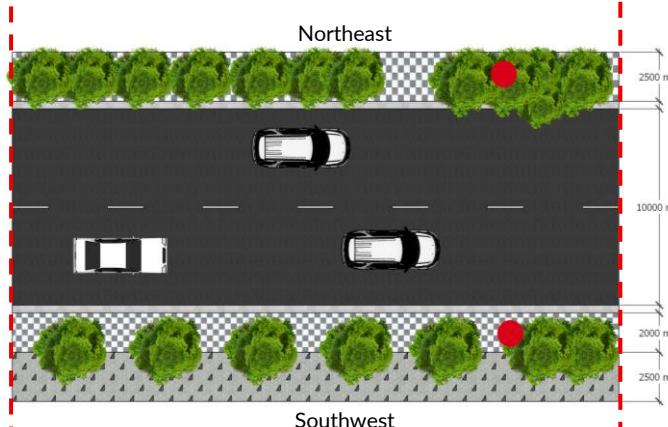
Field observations show that the pedestrian paths of Jalan Tunjungan use concrete block paving, ceramics, and coral stones. Most sections on both the southwest and northeast sides use a grey concrete-ceramic combination, as illustrated in Figure 2. Coral stone is used in specific areas: Segment 1 (northeast) and Segment 7 (southwest). Typically, surface temperature follows the material’s physical properties, particularly under high sunlight. By calculating the exact area of each material, the contribution of each pavement type to the overall surface heat can be determined. Therefore, this analysis includes a

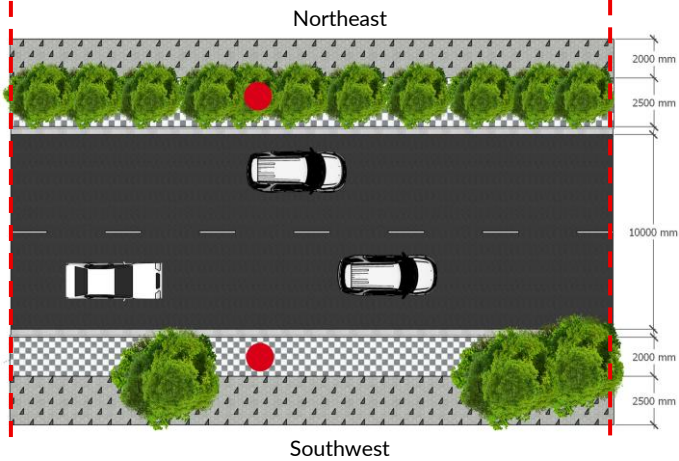
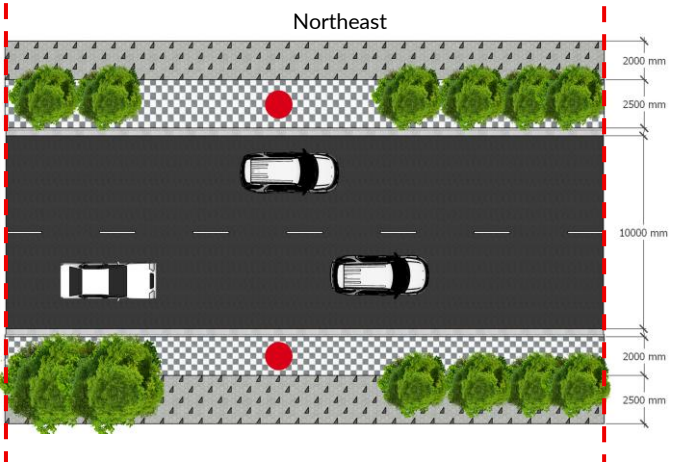
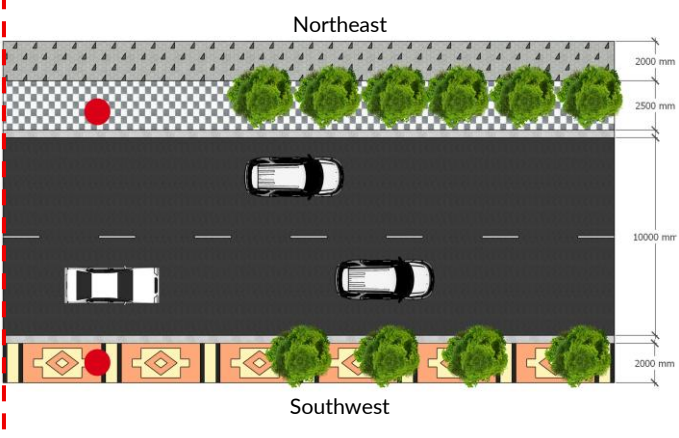
quantitative examination of material distribution. The results are shown in Table 4.

Table 4. Surface Area of Pedestrian Pavement Materials

Segment	Northeast		
	Concrete block-style pavement (m ²)	Coral (m ²)	Ceramic (m ²)
1		134	
2	360		
3	245		52.15
4			277.5
5	140		175
6	146		182.5
7	130		162.5
Segment	Southwest		
	Concrete block-style pavement (m ²)	Coral (m ²)	Ceramic (m ²)
1	167.5		134
2	200		160
3	245		196
4	277.5		222
5	175		140
6	182.5		146
7		130	

Tabel 5. Measurement Points and Material Layout

Segments	Measurement Points and Material Layout	Description
1		- On the northeast side, the pedestrian path is finished with coral stone pavement, with an approximate width of 2.0 m. This area is directly adjacent to the roadway and lacks vegetation, resulting in greater exposure to solar radiation and minimal shading. - On the southwest side, the pedestrian path consists of a combination of concrete block style and ceramic paving materials, with a total width of approximately 4.5 m, divided into a ceramic pavement zone (2.0 m) and a concrete block style pavement zone (2.5 m).
2		- On the northeast side, the pedestrian path is finished with concrete block style pavement, with an approximate width of 4.5 m. With limited vegetation, this area tends to result in great exposure to solar radiation because of minimal shading. - On the southwest side, the pedestrian path consists of a combination of concrete block style and ceramic paving materials, with a total width of approximately 4.5 m, divided into ceramic (2.0 m) and concrete block style pavement (2.5 m). With denser vegetation (street trees), this area provides greater shading than the northeast side.
3		- On the northeast side, the pedestrian path consists of a concrete block style pavement with an approximate width of 2.5 m. With denser vegetation, this area tends to provide more shade than the northeast side of segments 1 and 2. - The southwest side features a combination of ceramic with a width of 2 m and a concrete block style pavement of 2.5 m. This area also has denser vegetation, resulting in more extensive shading coverage.
4		- On the northeast side, the pedestrian path consists of a ceramic pavement of approximately 2.5 m wide. This area is characterized by dense street trees that provide significant shading. - The southwest side consists of a combination of a ceramic pavement of approximately 2 m wide and a 2.5 m concrete block style pavement. This area also has vegetation, but it is less dense compared to the northeast side.

5	 Northeast Southwest	• The northeast side consists of a combination of a ceramic pavement of approximately 2.5 m wide and a concrete block style pavement with 2 m wide. With the presence of continuous vegetation (street trees), this area provides extensive shading along the pedestrian paths, thereby reducing greater solar radiation than the southwest side. • The southwest side features a combination of ceramics with 2 m wide and a concrete block style pavement with 2.5 m wide. This area provides less dense and more discontinuous vegetation, resulting in great exposure to solar radiation.
6	 Northeast Southwest	• The northeast side consists of a combination of ceramic with 2.5 m wide and concrete block style pavement with 2 m wide. This area has moderate vegetation that gives partial shading. • The southwest side features a similar combination of ceramic (2.0 m) and concrete block style pavement (2.5 m), with a comparable level of vegetation, providing relatively similar shading conditions.
7	 Northeast Southwest	• The northeast side consists of a combination of ceramic with 2.5 m wide and concrete block style pavement with 2 m wide, with continuous vegetation (street trees). • The southwest side features coral stone pavement with 2.5 m wide, accompanied by vegetation. However, the measurement points (red dots) are located in unshaded areas which are not directly covered by vegetation.

The observed segments have varying pavement materials and vegetation density along the pedestrian corridor, as illustrated in Table 4. This results in different levels of solar exposure and shading. The corridor is flanked by rows of buildings on both sides, forming a street canyon condition that influences solar access and heat retention.

Segments with minimal vegetation, such as Segment 1, are characterized by higher exposure to direct solar

radiation. Meanwhile, segments with denser or more continuous vegetation, such as Segments 4 and 5, provide greater shading potential. In several cases, similar pavement materials are found on both sides of the corridor, yet differences in vegetation distribution create distinct microclimatic conditions.

Result and Discussion

Air Temperature (Ta)

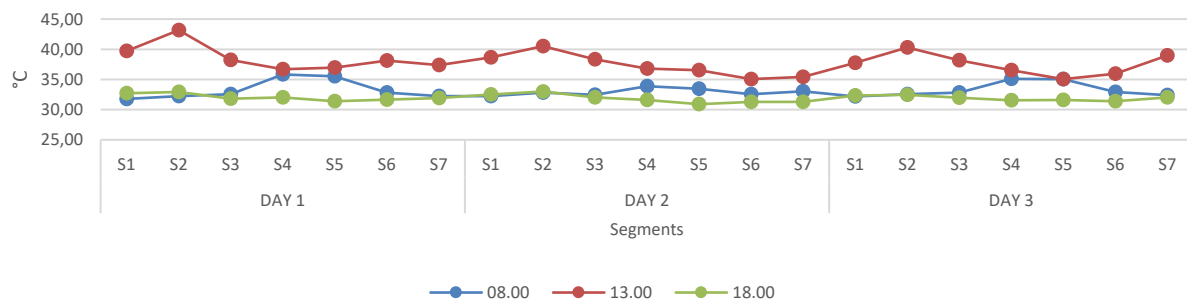


Figure 3. Average air temperature on the northeast side (day 1, day 2, and day 3)

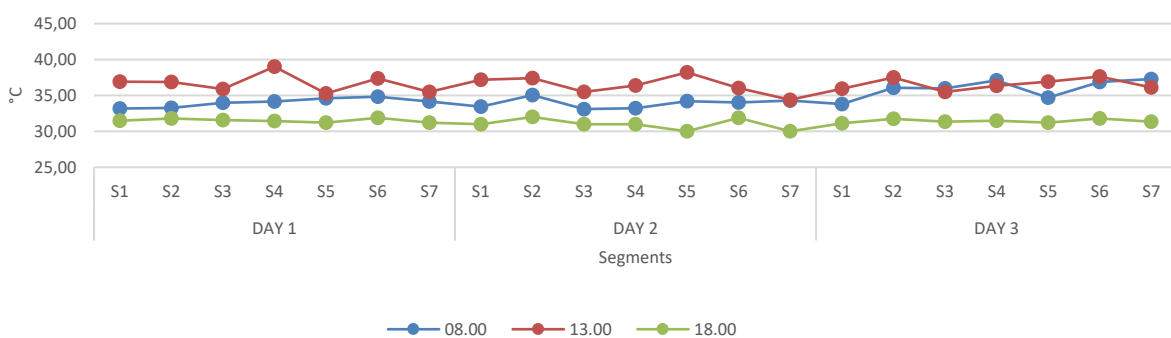


Figure 4. Average air temperature on the southwest side (day 1, day 2, and day 3)

As illustrated in Figure 3, Segment 2 of the northeast side exhibited the highest air temperature at 13:00, indicating peak thermal conditions during the period of maximum solar exposure. This condition is primarily associated with the dominance of concrete block-style pavement (360 m²), which has a higher capacity to absorb and store heat compared to other materials. In addition, the limited presence of vegetation in Segment 2 results in minimal shading, allowing the surface to receive direct solar radiation throughout the day.

In contrast, Segments 4 to 7 showed lower air temperatures, despite similar material compositions. This reduction is associated with a higher proportion of ceramic pavement (higher albedo), denser vegetation, and more shade from buildings, which reduce solar exposure. These findings align with previous studies indicating that high-albedo materials and urban shading can effectively lower microclimatic temperatures [25], [26]. This implies that, in tropical urban canyons, the combined effect of material and shading is more influential than material alone.

In contrast to the northeast side, the southwest side exhibits more variable air temperature fluctuations, particularly during the daytime, as shown in Figure 4. The pedestrian path on this side is predominantly composed of a combination of ceramics and concrete block-style pavement in Segments 1–6, and coral pavement in Segment 7. Despite this relatively homogeneous material composition, the observed temperature variation suggests that additional factors, such as average building height, surface area ratio, sky view factor, and building density, play a significant role in influencing local microclimatic conditions [26].

Previous studies comparing cool and standard pavements have reported relatively small air temperature differences (0.1–0.8°C) during daytime [7], indicating a limited direct effect of material properties—such as albedo—on air temperature. Instead, urban morphology and radiative processes play a more dominant role in shaping temperature variability within street canyons. Therefore, albedo and emissivity influence air temperature indirectly, with stronger effects on surface temperature and radiation, which subsequently impact pedestrian thermal comfort.

Surface Temperature (Ts)

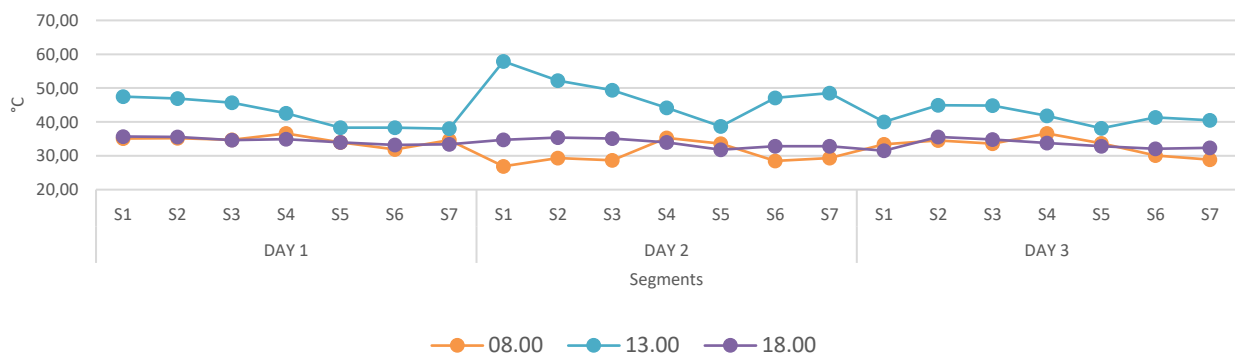


Figure 5. Average surface temperature on the northeast side (day 1, day 2, and day 3)

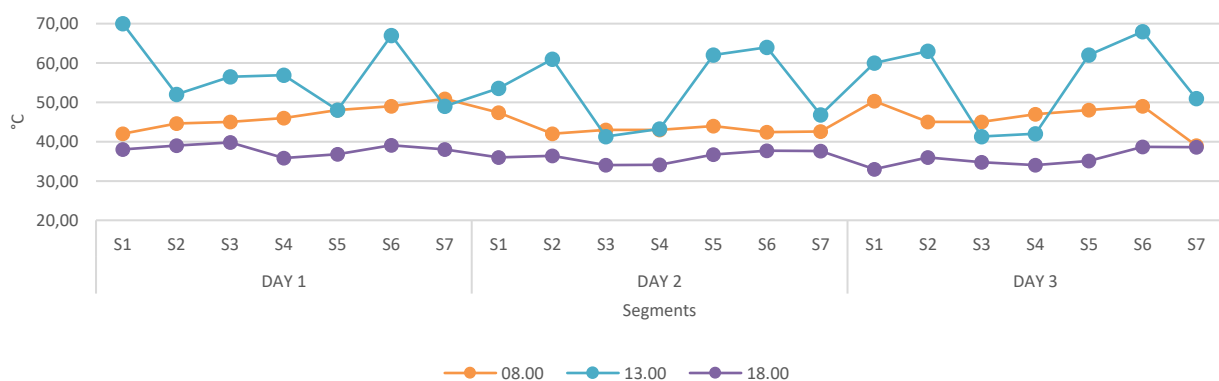


Figure 6. Average surface temperature on the southwest side (day 1, day 2, and day 3)

On the northeast side, Segments 1–3 recorded the highest surface temperatures (60–65°C) at 13.00, as shown in Figure 5. This condition is primarily associated with the dominance of low-albedo materials (coral and concrete) and limited vegetation, which allow direct solar exposure. Concrete block-style pavement in Segment 2 has relatively large coverage (360 m²).

Segments 4–5 showed a substantial decrease in surface temperature (41–50°C). This can be attributed to the greater proportion of ceramic pavement (higher albedo) and the presence of dense vegetation, which reduce solar exposure. However, in Segments 6 and 7, surface temperatures increased once again (58–63°C), despite the dominance of ceramic material and partial shading from buildings. This condition is influenced by sparser vegetation and a more open spatial configuration, which allow solar radiation to dominate. These findings are consistent with previous studies indicating that low-albedo materials tend to absorb more solar radiation—leading to higher surface temperatures—while high-albedo

materials and vegetation can reduce heat buildup through reflection and shading effects [25], [26].

On the southwest side, the most pronounced surface temperature variations were observed in Segments 3, 4, and 7 (See Figure 6). Generally, Segments 1–6 on this side are dominated by a combination of concrete block-style and ceramic pavement, while Segment 7 uses coral material. Segments 3 and 4 have lower surface temperatures due to the presence of denser vegetation. This finding confirms those of previous studies that a higher Leaf Area Index (LAI) enhances vegetation's ability to intercept and absorb solar radiation, thereby significantly lowering surface temperature [27]. Conversely, Segment 7—which is located in a more open area—also exhibits reduced surface temperature. This is likely due to better air circulation that limits heat accumulation [28], [29]. These findings suggest that, beyond material properties, vegetation density and airflow conditions play a critical role in influencing surface temperature in pedestrian corridors.

Solar Radiation

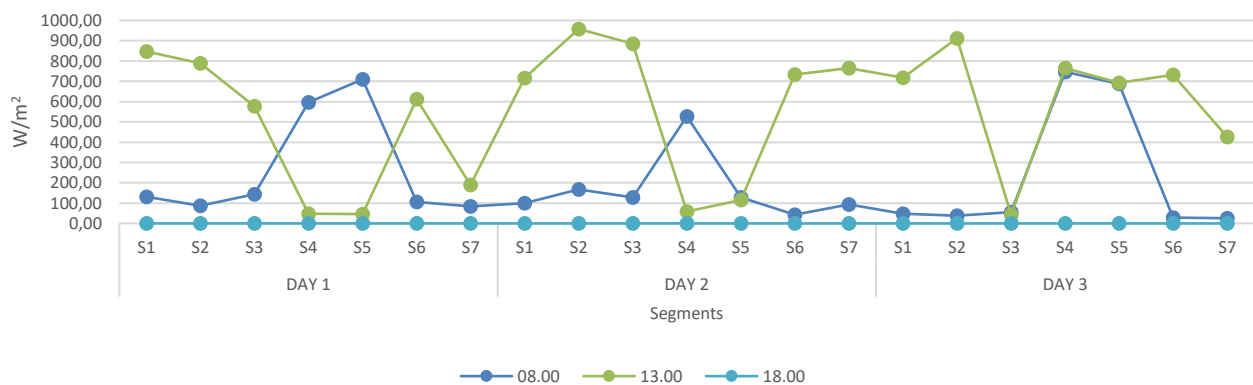


Figure 7. Average solar radiation on the northeast side (day 1, day 2, and day 3)

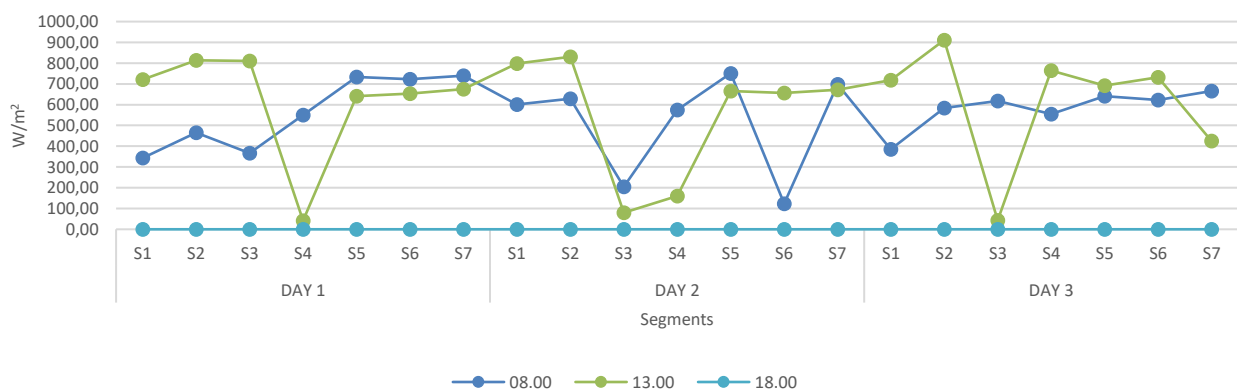


Figure 8. Average solar radiation on the southwest side (day 1, day 2, and day 3)

On the northeast side, solar radiation varies clearly across all segments during the three observation days, with a peak at 13:00 reaching up to 950 W/m² (See Figure 7). This pattern corresponds closely with surface temperature distribution, where segments receiving higher radiation tend to have higher surface temperatures. The reduction of radiation is most evident in Segments 4 and 5, which have denser vegetation and a higher proportion of ceramic pavement, both of which limit direct solar exposure and reduce heat accumulation.

A notable case occurs in Segment 3 on the third day, where a significant drop in radiation due to cloud cover is followed by a corresponding decrease in surface temperature, indicating a strong relationship between the two parameters.

In contrast to the northeast side, radiation patterns on the southwest side fluctuate more and are not always followed by consistent surface temperature responses, as shown in Figure 8. In some segments, surface temperatures remain relatively low despite high radiation levels. This suggests the influence of

additional factors, including vegetation and air circulation, which can modify the thermal response of surfaces. These findings agree with previous studies indicating that while solar radiation is a primary driver of surface temperature, its impact can be amplified or mitigated by corridor spatial conditions, such as shading and ventilation [21].

Comparative Analysis

On the northeast side, segments dominated by low-albedo materials, such as coral (Segment 1) and concrete block-style pavement (Segments 2 and 3), exhibit higher surface temperatures, which are further intensified by their relatively large coverage areas. However, despite similar material compositions, surface temperatures decrease in Segments 4 and 5. This indicates that the influence of path materials is not independent; rather, it is strongly conditioned by surrounding spatial factors. In Segments 4 and 5, dense vegetation effectively reduces incoming solar radiation, resulting in relatively cooler conditions.

Conversely, Segments 6 and 7 do not show the expected reduction in surface temperature, even though ceramic pavement with higher albedo is more dominant. Interestingly, air temperature in these segments tends to decrease, suggesting that higher surface temperature does not necessarily translate directly into higher air temperature. This phenomenon can be explained by the more open spatial configuration, which allows greater air movement and enhances natural ventilation as an uncontrollable variable [30].

Air temperature fluctuates more on the southwest side, despite relatively homogeneous material composition. This further emphasizes the limitation of material as a single controlling factor. Segments 3 and 4 exhibit lower temperatures, associated with shading from vegetation and adjacent buildings, whereas segments with limited vegetation (Segments 1 and 2) show higher temperatures. Meanwhile, Segment 7, which has a more open space, demonstrates reduced heat accumulation due to improved ventilation, despite the use of coral pavement.

Conclusion

This study examines the influence of pedestrian pavement materials on microclimatic conditions in an urban corridor, specifically in Jalan Tunjungan, Surabaya. The findings indicate that while pavement materials—particularly their albedo and emissivity—do affect microclimatic parameters such as surface temperature and solar radiation, their direct impact on air temperature is relatively limited. Spatial factors, including vegetation density, shading from buildings, and urban canyon geometry, play a more dominant role in shaping the thermal environment.

The results suggest that pedestrian microclimate is shaped by the interaction between material properties and urban morphology, rather than by material alone. While high-albedo materials can reduce surface temperature, their effectiveness depends on vegetation and shading. This highlights the multifactorial nature of thermal conditions in tropical environments. Theoretically, this study emphasizes the indirect role of material properties and the stronger influence of spatial configuration. Practically, it suggests that improving thermal comfort requires an integrated approach that combines materials, vegetation, and urban form, rather than relying solely on material substitution.

Despite its valuable implications, this study still has several limitations. In this study, the albedo values are

not measured directly but are inferred from literature. This may not fully represent actual surface conditions. In addition, the study relies solely on field measurements without simulation-based scenario testing, thus limiting its ability to explore alternative design interventions.

Therefore, to improve accuracy, future studies are strongly recommended to incorporate in situ measurement of material properties, particularly albedo and emissivity. Furthermore, integrating field data with simulation approaches (e.g., scenario-based modeling) would allow a more comprehensive evaluation of design strategies, especially in optimizing the combined effects of materials, vegetation, and urban form on pedestrian thermal comfort.

Acknowledgements

The author would like to express sincere gratitude to the Laboratory of Architectural Science and Technology, Institut Teknologi Sepuluh Nopember (ITS), for providing the measurement instruments and technical support during the fieldwork. Their contribution has been invaluable to the successful completion of this study.

References

- [1] R. S. Benrazavi, K. Binti Dola, N. Ujang, and N. Sadat Benrazavi, "Effect of pavement materials on surface temperatures in tropical environment," *Sustain. Cities Soc.*, vol. 22, pp. 94–103, Apr. 2016, doi: 10.1016/j.scs.2016.01.011.
- [2] K. Seifeddine, S. Amziane, E. Toussaint, and S. E. Ouldboukhithine, "Review on thermal behavior of cool pavements," Sep. 01, 2023, *Elsevier B.V.* doi: 10.1016/j.uclim.2023.101667.
- [3] M. Santamouris, "Using cool pavements as a mitigation strategy to fight urban heat island - A review of the actual developments," 2013. doi: 10.1016/j.rser.2013.05.047.
- [4] R. Paolini and M. Santamouris, *Urban Climate Change and Heat Islands : Characterization, Impacts and Mitigation*. Candice Janco, 2023.
- [5] I. D. Stewart and G. Mills, *The Urban Heat Island*. 2021. doi: 10.1016/c2017-0-02872-0.
- [6] S. Sangkertadi, R. Syafriny, C. E. V. Wuisang, and Z. Zahra, "Influence of landscape material properties on microclimate change in a tropical area with a case in Manado City," in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing

- Ltd, Apr. 2022. doi: 10.1088/1755-1315/1007/1/012006.
- [7] H. Elmagri, T. M. Kamel, and H. Ozer, "Assessment of the effectiveness of cool pavements on outdoor thermal environment in urban areas," *Build. Environ.*, vol. 266, Dec. 2024, doi: 10.1016/j.buildenv.2024.112095.
- [8] S. J. Jung, "Pedestrian-path pavement materials to improve microclimate and air quality on current pedestrian paths," *Urban Clim.*, vol. 55, no. January, p. 101973, 2024, doi: 10.1016/j.uclim.2024.101973.
- [9] E. Morini *et al.*, "Experimental analysis of the effect of geometry and façade materials on urban district's equivalent albedo," *Sustainability (Switzerland)*, vol. 9, no. 7, Jul. 2017, doi: 10.3390/su9071245.
- [10] K. Ornam, S. Wonorahardjo, and S. Triyadi, "Several façade types for mitigating urban heat island intensity," *Build. Environ.*, vol. 248, Jan. 2024, doi: 10.1016/j.buildenv.2023.111031.
- [11] B. Shu, H. T. Chang, and Y. X. Chen, "Influence of the thermal environment of urban sidewalks under green shading from a human scale," *All Earth*, vol. 36, no. 1, pp. 1–17, 2024, doi: 10.1080/27669645.2024.2327253.
- [12] A. Y. Pratiwi and L. M. Jaelani, "Analisis Perubahan Distribusi Urban Heat Island (UHI) di Kota Surabaya Menggunakan Citra Satelit Landsat Multitemporal," *Jurnal Teknik ITS*, vol. 9, no. 2, 2021, doi: 10.12962/j23373539.v9i2.53982.
- [13] K. Iffiyah, B. Soemardiono, and D. Septanti, "Aspek Fasad Bangunan Cagar Budaya Yang Mempengaruhi Minat Masyarakat," *Jurnal Arsitektur ARCADE*, vol. 6, no. 3, p. 354, 2022, doi: 10.31848/arcade.v6i3.1047.
- [14] K. Iffiyah, E. B. Santoso, and R. P. Setiawan, "The Quality of Pedestrian Based on Pedestrian Environment Quality Index (PEQI) Standards in the Cultural Heritage Area of Tunjungan Street Surabaya," *BERKALA SAINSTEK*, vol. 10, no. 2, p. 101, Jun. 2022, doi: 10.19184/bst.v10i2.28408.
- [15] T. Zhang *et al.*, "Optimizing pedestrian thermal comfort in urban street canyons for summer and winter: Tree planting or low-albedo pavements?," *Sustain. Cities Soc.*, vol. 120, no. September 2024, 2025, doi: 10.1016/j.scs.2025.106143.
- [16] Groat, Linda N., Wang, and David, "Architectural Research Methods."
- [17] T. R. Oke, G. Mills, A. Christen, and J. A. Voogt, *Urban Climates*. 2017.
- [18] Z. Li, H. Zhang, C. Y. Wen, A. S. Yang, and Y. H. Juan, "Effects of height-asymmetric street canyon configurations on outdoor air temperature and air quality," *Build. Environ.*, vol. 183, no. August, 2020, doi: 10.1016/j.buildenv.2020.107195.
- [19] T. Haeri, N. Hassan, and A. Ghaffarianhoseini, "Evaluation of microclimate mitigation strategies in a heterogeneous street canyon in Kuala Lumpur from an outdoor thermal comfort perspective using Envi-met," *Urban Clim.*, vol. 52, Nov. 2023, doi: 10.1016/j.uclim.2023.101719.
- [20] D. Elgendy, O. Tolba, and T. Kamel, "The impact of increasing urban surface albedo on outdoor air and surface temperatures during summer in newly developed areas," *Sci. Rep.*, vol. 15, no. 1, Dec. 2025, doi: 10.1038/s41598-025-08574-2.
- [21] A. Salvati, M. Kolokotroni, A. Kotopouleas, R. Watkins, R. Giridharan, and M. Nikolopoulou, "Impact of reflective materials on urban canyon albedo, outdoor and indoor microclimates," *Build. Environ.*, vol. 207, no. August 2021, 2022, doi: 10.1016/j.buildenv.2021.108459.
- [22] A. Salvati and M. Kolokotroni, "Microclimate data for building energy modelling: Study on ENVI-met forcing data," in *Building Simulation Conference Proceedings*, International Building Performance Simulation Association, 2019, pp. 3361–3368. doi: 10.26868/25222708.2019.210544.
- [23] P. A. Tirel, A. Perrot, R. Baudet, and D. Rangeard, "Field and laboratory characterization of the albedo of asphalt and horizontal surfaces," *Materials and Structures/Materiaux et Constructions*, vol. 58, no. 8, Oct. 2025, doi: 10.1617/s11527-025-02787-7.
- [24] J. F. Marbun and H. H. Handayani, *Analisis Pola Angin Dengan Model 3 Dimensi Dan Hubungannya Dengan Mikroiklim Di Koridor Pedestrian Jalan Tunjungan*. 2026.
- [25] E. Erell, D. Pearlmutter, and T. Williamson, *Urban Microclimate Designing: Designing the Spaces Between Buildings*. 2018.
- [26] N. V. S. K. Manapragada and J. Natanian, "Urban Microclimate and Energy Modeling: A Review of Integration Approaches," *Sustainability (Switzerland)*, vol. 17, no. 7, 2025, doi: 10.3390/su17073025.
- [27] T. Zhang *et al.*, "Effects of tree density variations on outdoor heritage conservation: Numerical study

of an ancient brick city wall with four orientations," *Build. Environ.*, vol. 254, Apr. 2024, doi: 10.1016/j.buildenv.2024.111392.

- [28] Y. Liu *et al.*, "Impacts of high-albedo urban surfaces on outdoor thermal environment across morphological contexts: A case of Tianjin, China," *Sustain. Cities Soc.*, vol. 100, no. April 2023, 2024, doi: 10.1016/j.scs.2023.105038.
- [29] D. Elgendy, O. Tolba, and T. Kamel, "The impact of increasing urban surface albedo on outdoor air and surface temperatures during summer in newly developed areas," *Sci. Rep.*, vol. 15, no. 1, pp. 1–24, 2025, doi: 10.1038/s41598-025-08574-2.
- [30] E. Bahadori, F. Rezaei, B. J. He, M. Heiranipour, and S. Attia, "Evaluating urban heat island mitigation strategies through coupled UHI and building energy modeling," *Build. Environ.*, vol. 280, no. March, 2025, doi: 10.1016/j.buildenv.2025.113111.