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# ASSESSING OUTDOOR THERMAL COMFORT IN HIGH-DENSITY URBAN KAMPUNGS IN TAMANSARI, BANDUNG: A MICROCLIMATE SIMULATION STUDY

# EVALUACIÓN DEL CONFORT TÉRMICO EXTERIOR EN KAMPUNGS URBANOS DE ALTA DENSIDAD EN TAMANSARI, BANDUNG: UN ESTUDIO DE SIMULACIÓN DEL MICROCLIMA

# AVALIAÇÃO DO CONFORTO TÉRMICO AO AR LIVRE EM KAMPUNGS URBANOS DE ALTA DENSIDADE EM TAMANSARI, BANDUNG: UM ESTUDO DE SIMULAÇÃO DO MICROCLIMA

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# ABSTRACT

Urban kampungs, characterized by dense, organically developed settlements, present unique challenges in outdoor thermal comfort. This study investigates how key physical variables—building arrangement, surface materials, and vegetation—impact the microclimate of outdoor spaces in Tamansari, Bandung, using ENVI-met 4 simulations. The findings reveal that material reflectivity significantly influences air temperature, with lower-albedo paving proving more effective in reducing heat accumulation. Compact building arrangements with a high height-to-width ratio provide essential shading, mitigating heat stress, while strategically placed vegetation enhances shading and wind flow, contributing to improved thermal comfort. These insights offer valuable guidelines for architects and urban planners designing climate-responsive, high-density urban environments. The study underscores the importance of integrating passive cooling strategies to improve outdoor livability in urban kampungs, especially in tropical climates.



Keywords
urban kampung, outdoor thermal comfort, performance simulation, ENVI-met, high-density settlement



# RESUMEN

Los asentamientos urbanos, caracterizados por asentamientos densos y desarrollados orgánicamente, presentan desafíos únicos para lograr el confort térmico al aire libre. Este estudio investiga cómo las variables físicas clave (disposición de los edificios, materiales de la superficie y vegetación) afectan el microclima de los espacios al aire libre en Tamansari, Bandung, utilizando simulaciones ENVI-met 4. Los hallazgos revelan que la reflectividad del material influye significativamente en la temperatura del aire, y que los pavimentos con un albedo más bajo resultan más efectivos para reducir la acumulación de calor. Las disposiciones de edificios compactos con una alta relación altura-ancho brindan un sombreado esencial, mitigando el estrés térmico, mientras que la vegetación ubicada estratégicamente mejora tanto el sombreado como el flujo del viento, lo que contribuye a mejorar el confort térmico. Estos conocimientos ofrecen pautas valiosas para los arquitectos y planificadores urbanos que buscan diseñar entornos urbanos de alta densidad que respondan al clima. El estudio resalta la importancia de integrar estrategias de refrigeración pasiva para mejorar la habitabilidad al aire libre en los kampungs urbanos, particularmente en climas tropicales.



Palabras clave
asentamiento urbano, confort térmico al aire libre, simulación de rendimiento, ENVI-met, asentamiento de alta densidad



# RESUMO

Os assentamentos urbanos, caracterizados por assentamentos densos e desenvolvidos organicamente, apresentam desafios únicos em termos de conforto térmico ao ar livre. Este estudo investiga como variáveis físicas importantes — disposição dos edifícios, materiais de superfície e vegetação — afetam o microclima dos espaços ao ar livre em Tamansari, Bandung, utilizando simulações ENVI-met 4. Os resultados revelam que a refletividade dos materiais influencia significativamente a temperatura do ar, com pavimentos de baixo albedo se mostrando mais eficazes na redução do acúmulo de calor. O arranjo compacto dos edifícios, com uma alta relação altura/largura, proporciona sombreamento essencial, mitigando o estresse térmico, enquanto a vegetação estrategicamente posicionada aumenta o sombreamento e o fluxo de vento, contribuindo para melhorar o conforto térmico. Essas informações oferecem diretrizes valiosas para arquitetos e urbanistas que projetam ambientes urbanos de alta densidade e que respondem às mudanças climáticas. O estudo ressalta a importância de integrar estratégias de resfriamento passivo para melhorar a habitabilidade ao ar livre em kampungs urbanos, especialmente em climas tropicais.



Palavras-chave:
assentamentos urbano, conforto térmico ao ar livre, simulação de desempenho, ENVI-met, assentamento de alta densidade

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# INTRODUCTION

Architects and city planners, to face the population's concerns regarding the environment and climate change, are now considering the urban micro-climate in their planning constraints, especially the intervention of outdoor spaces. In urban areas, particularly in Urban Kampungs, outdoor spaces are essential for sustaining habitats because they accommodate pedestrians, cyclists, and varied outdoor activities to contribute to urban livability (Johansson & Emmanuel, 2006). Studies have demonstrated that urban morphology, including street orientation and building configuration, directly impacts outdoor thermal comfort by regulating solar radiation exposure and wind circulation (Taleghani et al., 2014).

Urban kampungs are settlements that existed long before formal urban planning emerged. Developed informally, they are characterized by traditional features and irregular structures, while small building coverage, dense massing arrangement, narrow alleys, and organic development are features of urban Kampung houses. The concept of kampungs arose because of family growth in an area with limited land and economic issues (Asriana et al., 2024; Hamidah et al., 2017; Rochmania & Sukmawati, 2024). They are common in most developed Southeast Asian cities, such as Jakarta, Bandung, Bangkok, and Manila. Initial observations in the case studied here, the Tamansari Urban Kampung, Bandung, show many social activities within closely spaced houses, with children playing in the street and small squares around the houses. In a setting of tight spaces, outdoor typology, narrow streets, and small squares, intimate outdoor activity between inhabitants is escalated. This sense of community is a valuable social aspect of urban kampung settlements, contributing to social resilience in the city. Hence, improving outdoor communal spaces would support social cohesion and elevate the overall habitability of the urban kampung.

The time inhabitants spend in outdoor spaces often reflects their subjective satisfaction with the thermal comfort level. People's perception of comfort is not solely driven by physical measurements such as temperature and humidity, but also by physiological and cultural factors (Nikolopoulou & Steemers, 2003). For instance, in urban kampung settlements, the acceptance of varying thermal conditions might be higher due to the social acceptance of outdoor living. So, this study explores how shaded areas, natural ventilation, and green elements can significantly enhance the inhabitants' perceived thermal comfort and encourage more outdoor activity even in warm climates.

People expect different thermal comfort experiences in indoor and outdoor spaces. Their expectations vary depending on exposure circumstances, such as sun and shade variants, wind speed and direction, changes in humidity rate, direct and indirect radiation, etc. (Givoni et al., 2003; Wang & Su, 2025). The external environment significantly affects how people live, and it is determined by natural conditions, anthropogenic factors, the density of urban construction, the size of vegetation areas, etc. (Klemm, 2007). Enhancing outdoor thermal comfort can also impact health and well-being, promote physical activities, and increase social interactions (Abaas, 2020; van den Bosch & Ode Sang, 2017).

Researchers have extensively studied thermal comfort conditions in urban environments. Liu found that in the last 23 years, there have been 632 articles in the Web of Science and Scopus using a similar keyword (Liu et al., 2023; Mandić et al., 2024). However, limited attention has been given to informal, high-density settlements characterized by urban kampungs. This study seeks to address this gap by simulating outdoor thermal comfort in urban kampungs and defining the role of their unique physical conditions. By modeling the site with an understanding of existing building arrangements, surface material, and vegetation, this study aims to provide insights into optimizing outdoor spaces in high-density settlements. The findings could offer valuable guidelines for urban planners to create better thermal comfort and well-being in urban kampungs.

## MICROCLIMATE THERMAL COMFORT

This section outlines the approach to improving outdoor thermal comfort conditions in urban environments. The physical parameters include environmental factors such as the mean radiant temperature (MRT), air temperature, wind speed, and relative humidity. Recent studies emphasize that, in high-density urban settlements, MRT plays a critical role in determining thermal sensation compared to air temperature alone. In compact environments like urban kampungs, narrow streets, dense building masses, and limited vegetation amplify solar radiation, increasing MRT and causing greater heat stress even with moderate air temperatures. Moreover, research by Gallardo et al. (2016) highlights that even small increases in natural ventilation can significantly enhance perceived thermal comfort in warm, humid climates. Wind speeds of merely 0.3-1.0 m/s also improve comfort perception when combined with shading or surface cooling strategies. Research has proven that physical intervention affects urban microclimates and that these changes in the urban environment result in thermal comfort. To improve thermal comfort, inhabitants can adjust physical factors like building arrangement, materials, vegetation, and water features (Cheng et al., 2022; Liao et al., 2024; Pamungkas et al., 2024; Rodriguez et al., 2025; Uno et al., 2018; Zhang et al., 2025). The following section explains how this factor decreases inhabitants' heat stress in microclimates.

## BUILDING ARRANGEMENT

In blocks of buildings, alley surfaces receive solar radiation, which influences outdoor thermal atmospheres and

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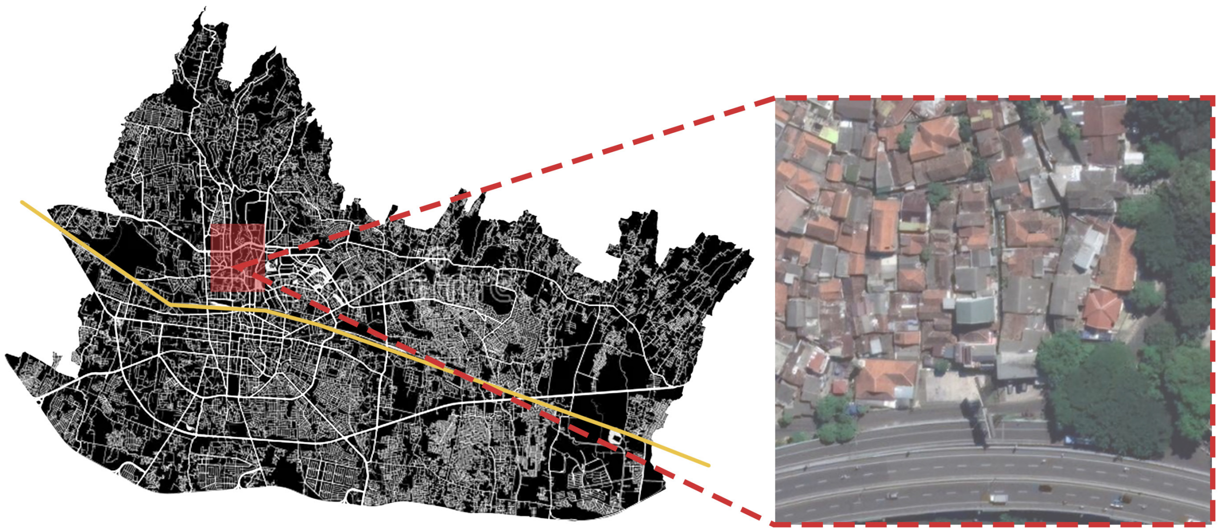
Figure 1. Assessment location, Kampung Tamansari, Bandung. Sources: Google Earth, modified by the Authors

affects an alley's thermal sensitivities. However, there are significant differences between human thermal comfort sensation values in sunny and shaded areas due to the solar radiation (Aleksandrowicz & Pearlmutter, 2023; Kim et al., 2024; Murakami, 2006).

Shashua-Bar and Hoffman (2000) introduced the "spacing ratio" (buildings' distance parallel to street/building length parallel to street orientation) to quantify the separated form. This follows the basic street form pattern and morphological indicators. Studies have addressed the solar access index of street canyons, such as in the urban kampung's negative space, using H/W ratios in variable values with E-W and N-S street orientation (Arnfield, 1990). These fundamental indicators were used to set up the case study with H/ W of 0.5, 1, 2, 4, and E-W, N-S, NE-SW, and NW-SE orientations (Ali-Toudert & Mayer, 2006).

Wind-induced pressure distributions are another aspect of building arrangement. These depend on many factors in the urban environment, such as the condition of the approach flow, the wind direction, the urban structure's geometry, and the urban surroundings (Montazeri & Blocken, 2013; Setaih et al., 2013).

**Surface material**

Using less absorptive (high albedo) materials is a practical, promising technique to reduce the thermal environment's effect on pedestrian comfort. High albedo surfaces reflect a greater portion of incoming solar radiation, thereby reducing the amount absorbed and stored as heat in urban environments. It is characterized by the ability of environmental surfaces to absorb incoming solar radiation in urban environments (Akbari et al., 1992; Baniassadi et al., 2018; Fintikakis et al., 2011). On the other hand, white and lighter-color surfaces can enhance thermal comfort by reducing ambient temperature. Research evidence has indicated that increasing the solar reflectance of materials by 0.25 significantly reduces the material's temperature by 10°C, as it keeps the structural surfaces cooler under the sun, thus reducing heat convection from the material to the ambient air (Akbari et al., 2001; Setaih et al., 2013; Synnefa et al., 2011). While the principle remains valid in tropical regions like Bandung, empirical studies suggest that temperature reductions due to albedo improvements may be slightly moderated due to consistently high baseline humidity and diffuse radiation effects (Benrazavi et al., 2016; Liu et al., 2023).

**Vegetation**

One of the most common and effective methods of improving outdoor pedestrian thermal comfort in urban spaces is planting vegetation and trees in available open spaces. Such an intervention can lessen the sun's heat gain, providing cooling through both shading and evapotranspiration (Dimoudi & Nikolopoulou, 2003). Empirical studies have demonstrated the strong role of vegetation in modifying urban microclimates. For instance, Picot (2004) observed that urban parks in hot climates reduce local air temperatures by up to 2- 3 °C compared to adjacent built-up areas. Similarly, Mahmoud (2011) reported that shaded areas under tree canopies exhibited a lower mean radiant temperature (MRT) than unshaded spaces.

The great advantage of tree cover is the cooling effect from the joint impact of evapotranspiration (ET) and canopy shading (Kim & Lee, 2024; Kim et al., 2024; Shashua-Bar & Hoffman, 2000). Beyond its aesthetic role and pleasant natural perception, increasing greenery in urban areas represents a significant mitigation technique as it helps reduce heat stress, blocks out noise, improves air quality, and protects people from the wind, making it an essential component of climate-resilient urban design

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Figure 2. Current Situation in Kampung Tamansari. This shows typical building height and street width. The settlement (top) inside has a high H/W ratio, and the perimeter (bottom) has a low H/W ratio. Sources: Photographs taken by the Authors.

(Fintikakis et al., 2011; Liu et al., 2023). Recent simulation studies reveal that vegetation cooling's effectiveness is highly dependent on corridor geometry. In canyons with higher H/W ratios, trees' shading impact becomes more pronounced, enhancing reductions in both air temperature and MRT. In their simulation, vegetation is more effective for corridors with a W-E orientation than other orientations (Liu et al., 2023; Suryantara et al., 2019).

## METHODOLOGY

The case study was conducted in Tamansari (Figure 1), an urban kampung located in Bandung, Indonesia (6°53›50.5»S 107°36›31.2» E). Bandung covers a total area of 16.729,65 hectares and has a population of 2,579,837 people in 2023, making it one of the most densely populated cities in Indonesia with a density of 15,051 people/km$^2$. Tamansari exemplifies the morphological characteristics of urban kampungs in Southeast Asia, where outdoor spaces undeniably express diverse social interactions (Figure 2).

The effect of outdoor features on thermal comfort is analyzed through microclimate simulation using ENVI-met 4 software. It is important to note that this study did not use a calibrated model. No field-measured data were incorporated for calibration or validation purposes. Instead, the simulation model uses constant meteorological conditions set manually based on local climatology data.

The selected simulation domain is 60 m (x) x 60 m (y) x 15 m (z) with a spatial resolution of 1m per grid. Default environmental parameters are used, but because the study location is not available in the software, the longitude and latitude of the location are set manually. Due to the location, some location-dependent physical parameters such as temperature, humidity, and wind speed are set based on data from BMKG Indonesia (Badan Meteorologi, Klimatologi dan Geofisika) or the Indonesian Agency for Meteorology, Climatology and Geophysics. The environmental parameters used were air temperature (23°C-33°C, average 27°C), relative humidity (47-89%, average 48%), and wind speed was set at 1 m/s from east to west. The simulation was run for 18 hours, from 4:00 until 22:00. Because the location is in the southern hemisphere, the day chosen for the calculation is the summer solstice for the southern hemisphere, which is on December 21$^{st}$, the hottest day of the year.

The base model used existing concrete paving with an albedo of 0.25, representing standard grey surfaces under real conditions. These values were applied across ground surfaces, including streets, pavement, and communal spaces. Vegetation was modeled as three-dimensional volumetric objects, as in its real-life condition, accounting for leaf area density (LAD), tree height, and crown shape. ENVI-met simulates vegetation as dynamic microclimate agents that influence solar shading, evapotranspiration, and wind flow. As Bruse & Fleer (1998) suggested, these parameters allow the model to simulate the vegetation's effect on temperature and airflow more realistically. The existing vegetation on-site, mostly medium-sized trees with broad canopies, was integrated into the simulation, and additional greening scenarios were explored to assess their impact on outdoor thermal conditions.

The simulation aimed to isolate and compare the effects of building configuration (H/W ratios and orientation), surface material (albedo variation), and vegetation patterns on outdoor microclimate conditions. The simulation evaluates diffuse, direct, and reflected shortwave (SW) radiation, wind speed, and the mean radiant temperature (MRT). These parameters are crucial for understanding thermal comfort. Diffuse SW Radiation contributes to the radiant heat load even in shaded conditions. Direct SW

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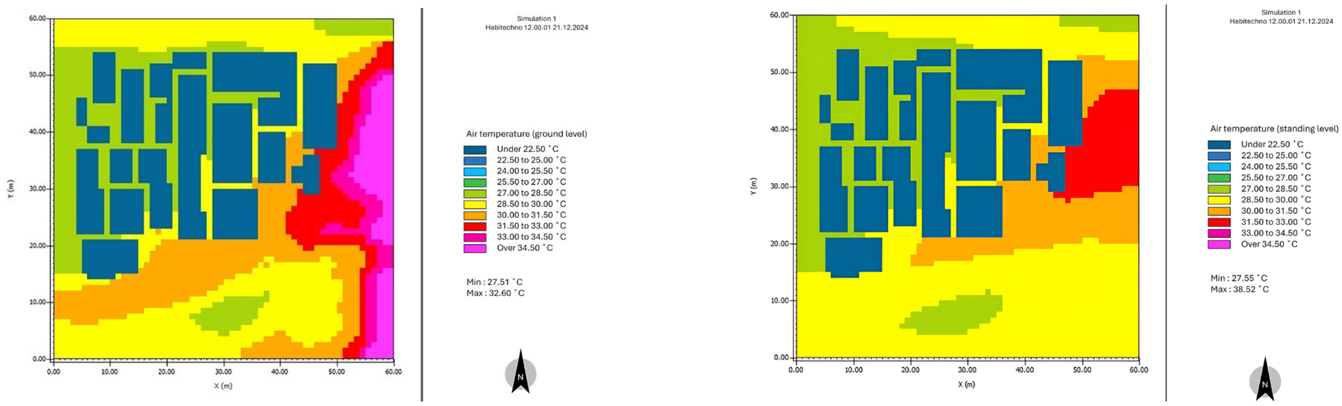


Figure 3. (A) Reflected Radiation at Ground Level; (B) Reflected Radiation at a Standing Level. Sources: Prepared by the Authors.

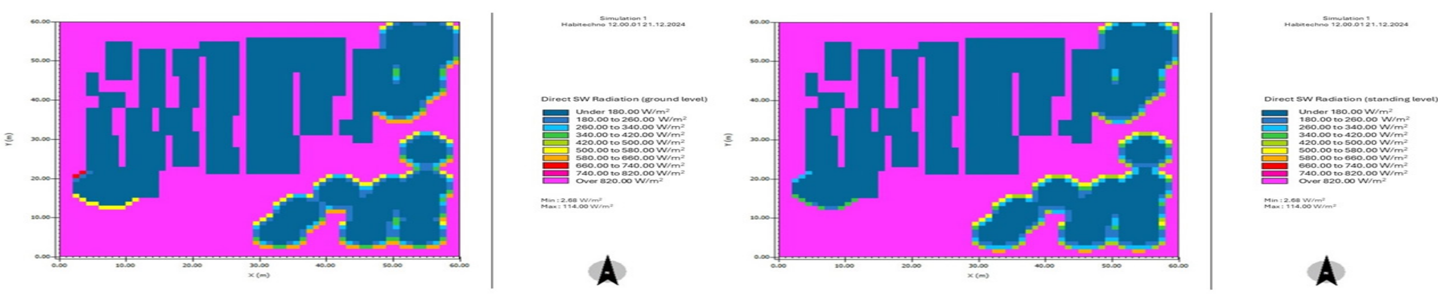


Figure 4. (A) Direct SW Radiation at Ground Level. (B) Direct SW Radiation at a Standing Level. Sources: Preparation by the Authors.

radiation can significantly increase surface temperatures. Reflective SW radiation measures the portion of solar radiation reflected from the urban surface. Wind speed influences convective cooling and air circulation. The results provided insights into temperature distribution, mean radiant temperature (MRT), and wind speed, which are crucial contributors to perceived outdoor thermal comfort. MRT represents the combined effect of all radiation sources on human thermal perception.

The simulation compared temperature variations at both ground (0.5 m) and standing level (1.5m). Ground level provides insights into the thermal environment by seating children and accumulating ground-surface heat. Standing level represents the average height of an adult pedestrian and critical thermal exposure during typical outdoor activities. Evaluating both ensures a comprehensive understanding of the key factors for outdoor thermal comfort and leads to more precise and context-sensitive urban design recommendations.

# RESULTS AND DISCUSSION

## TEMPERATURE DISTRIBUTION AND SURFACE MATERIALS

Air temperature analysis reveals a significant difference between ground level and standing level. Figure 3 shows that the temperature near the ground is consistently higher than 1.5 meters above ground level. This variation is primarily attributed to surface materials' reflectivity (albedo). In this simulation, the surface covering material used for the corridor is concrete with high albedo, as in the real-life scenario. High-albedo materials increase heat accumulation in urban areas, exacerbating thermal stress (Synnefa et al., 2007).

Further examination of solar radiation (Figure 3 and Figure 4) indicates that direct and diffuse radiation do not significantly differ between the two heights. There are differences between radiation values in areas with a <1 H/W ratio at a standing and a ground level, as shown in the highlighted rectangular area (Figure 3). Reflected shortwave (SW) radiation (Figure 5) shows a noticeable ground-level increase. Since there is no specific standard number for this radiation, this study examines the values at different height levels. This result indicates that the dependence between the floor surface and the H/W ratio contributes to elevated ambient temperatures.

### Effects on Building Arrangement

An E-W street orientation gains 30-36 °C at ground level and 33-39°C at standing level on >1 H/W ratio, and a N-S street orientation has a 42- 48°C MRT range at ground

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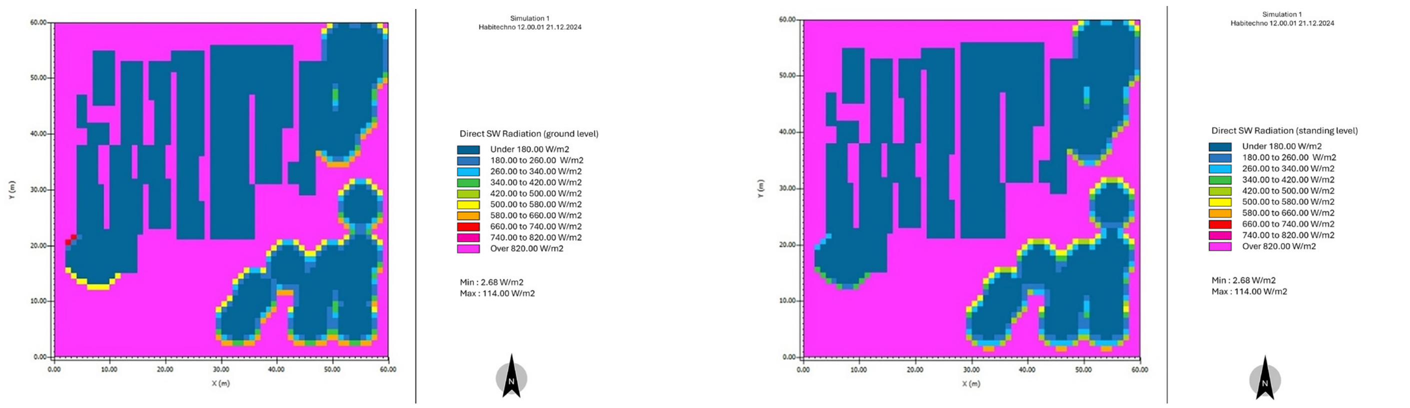


Figure 5. (A) Reflected SW Radiation at Ground Level. (B) Reflected SW Radiation at a Standing Level. Sources: Preparation by the Authors.

Table 1. Values of different H/W ratios and MRT ranges. Sources: Preparation by the Authors.

| H/W Ratio | Street orientation | MRT range ground level (°C) | MRT range standing level (°C) |
|---|---|---|---|
| 0.83 | E-W | 48-51 | 51-54 |
| 1.66 | E-W | 33-36 | 36-39 |
| 2.5 | E-W | 30-33 | 33-36 |
| 5 | E-W | 30-33 | 33-39 |
| 1.25 | N-S | 45-48 | 51-54 |
| 2.5 | N-S | 45-48 | 51-54 |
| 5 | N-S | 42-45 | 51-54 |

level and 51-54°C at standing level (Table 1). Normal MRT should be less than 40°C (Nikolopoulou & Steemers, 2003; Pamungkas et al., 2024), which makes E-W street orientation more comfortable than N-W. This result differs from other previous studies where E-W street orientation creates a more uncomfortable thermal condition than N-E.

This result shows that building arrangement and H/W ratio are critical in modifying thermal conditions through shading. The simulation results confirm that the streets' height-to-width (H/W) ratio influences shading efficiency. In this case study, the sun's path is slightly above the equator, so the sunlight falling on the building mass north of the road casts shadows on the E-W street. Moreover, N-S streets with an H/W ratio of>1 provide more shading, effectively reducing MRT on the ground and standing level (Figure 5). Building arrangements also significantly influence shading efficiency. Previous studies indicate that an H/W ratio >1 provides effective shading, minimizing direct solar radiation exposure (Taleghani et al., 2014; Ali-Toudert & Mayer, 2006).

Furthermore, street orientation affects solar access on the street corridor. As a previous study suggests (Ali-Toudert & Mayer, 2006), East-West orientations prove more effective in providing shade and enhancing thermal comfort. This orientation creates more expansive shaded areas throughout the day, reducing heat exposure to pedestrian paths and public spaces. Studies in tropical cities, such as those conducted by Johansson and Emmanuel (2006), confirm that suitable urban layouts can significantly mitigate heat stress, particularly when integrated with vegetation and built-form shading.

## Vegetation and Wind Flow

This simulation shows differences in wind speed at ground and standing level in the settlement's perimeter and interior outdoor areas. The perimeter has a wide main road, an H/W ratio <1, and contains a group of trembesi trees, while the interior outdoor has an H/W ratio >1. In areas with an H/W ratio >1, wind speed remains stable at 0.15-0.45 m/s, whereas in areas with an H/W ratio <1, wind speed varies between 0.3-1.2 m/s at both ground level and standing level (Figure 6).

Vegetation contributes to both shading and wind flow regulation. This simulation reveals that wind speed is generally higher at the standing level than at the ground

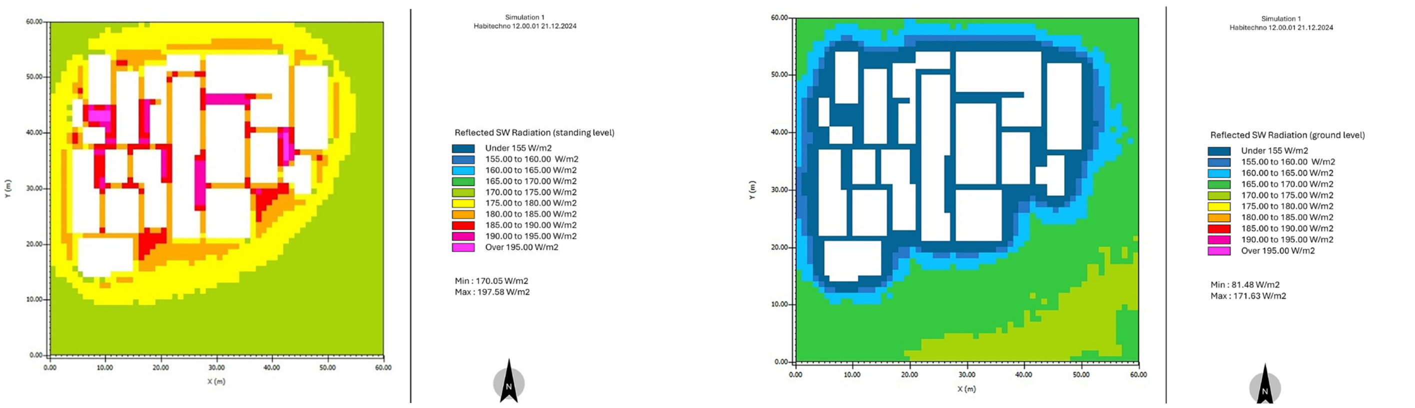


Figure 6. (A) MRT at Ground Level. (B) MRT at a Standing Level. Sources: Preparation by the Authors.

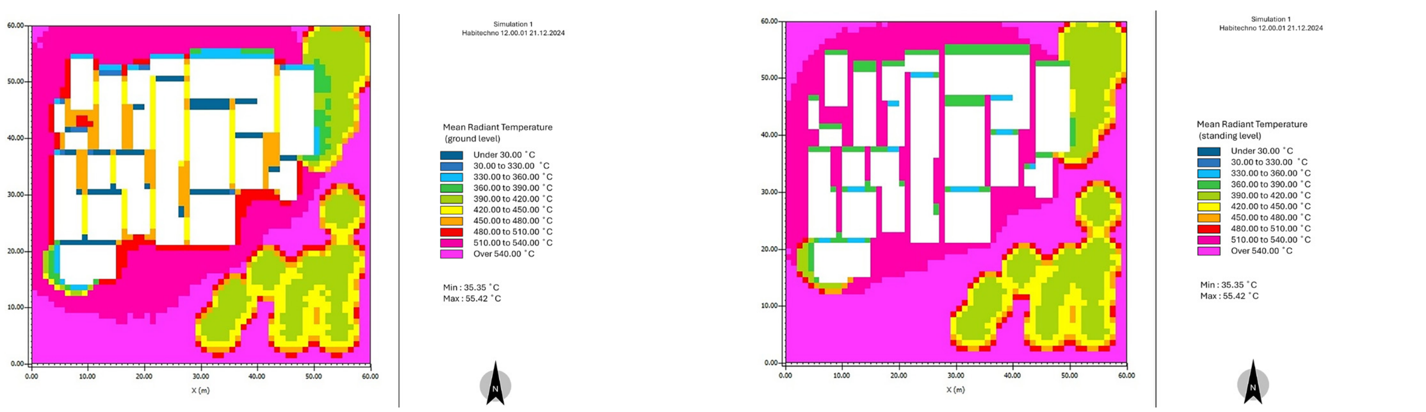


Figure 7. (A) Wind Speed at Standing Level. (B) Wind Speed at Standing Level. Sources: Preparation by the Authors.

level at the settlement's perimeter (Figure 7), indicating disruption caused by surface friction. This also indicates that air movement is quite comfortable with <2.5 m/s for the inhabitants for frequent outdoor sitting activities. On the other hand, this study shows that vegetation does not play an active role in high H/W ratio areas and organic regional morphology, in contrast to several previous studies (Liu et al., 2023; Rodriguez et al., 2025; Suryantara et al., 2019).

However, open spaces with vegetation demonstrate increased wind speed, suggesting that strategically placed greenery can enhance natural ventilation while simultaneously reducing thermal stress. In this case, the vegetation in the eastern area is a trembesi tree (*Samanea saman*) with a big trunk and a wide canopy. So, the air at ground and standing level is ventilated well across its area. Other researchers have also demonstrated that strategically placed vegetation can reduce urban temperatures by up to 5˚C, significantly enhancing microclimatic conditions (Dimoudi & Nikolopoulou, 2003; Shashua-Bar & Hoffman, 2000).

Additionally, tree shading provides several cooling effects through solar radiation buffers and evapotranspiration, reinforcing vegetation's role in improving microclimatic conditions. These findings align with previous studies emphasizing the importance of integrating vegetation into settlements for thermal comfort optimization. Moreover, Bowler et al. (2010) highlighted that vegetation can contribute to long-term cooling effects, reducing the intensity of urban heat islands. Recent studies have shown that combining tree canopies with permeable ground surfaces can amplify cooling effects (Morakinyo et al., 2017), reinforcing the importance of integrating urban greening strategies. A strategy that can be a viable option for narrow alleys is a vertical garden and potted plants. Furthermore, trees contribute to airflow regulation by increasing wind speed in open spaces, further promoting cooling effects, as demonstrated in studies across dense urban settlements in Asia (Ng et al., 2011).

**Implications for urban planning**

The results highlight the importance of holistic urban design strategies integrating building arrangement, material selection, and vegetation to create thermally comfortable outdoor environments. The strategic placement of vegetation, particularly in open spaces along the W-E corridor axis, is essential. Studies confirm that shading reduces direct radiation on surfaces while keeping wind corridors unobstructed (Shashua-Bar & Hoffman, 2000). As seen in Figure 6, the MRT on the W-E corridor is higher than the N-S corridor at similar altitude coordinates. The placement, including rooftop gardens and terrace vegetation on the second or third floors, can promote evapotranspiration and improve thermal comfort at higher levels, especially in an H/W ratio >1 (Morakinyo et al., 2017; Perini & Magliocco, 2014). This strategy also becomes even more crucial for a W-E H/W ratio <1 corridor, since it controls wind speed. Vertical gardens, such as green walls and facade planting, also help regulate building temperatures while improving air quality.

Light-colored pavements and facades can reflect more sunlight and absorb less heat, making them suitable for open areas (Synnefa et al., 2007; Santamouris, 2013). However, excessive reflectivity may trap heat within confined spaces in narrow alleys with closely packed buildings, leading to unintended warming effects. Future studies should explore combinations of optimal existing high-albedo and permeable materials to ensure balanced heat mitigation.

This study demonstrates that albedo floor surfaces in outdoor areas can elevate pedestrians' heat stress in urban kampungs with narrow spaces flanked by tight two—to three-story buildings. The increased reflectivity leads to higher radiant heat exposure, which offsets the benefits of reduced air temperatures. As a result, pedestrians may experience heightened thermal discomfort despite cooler ambient conditions. This study highlights the importance of considering broader climatic interaction when applying such materials for paving, instead of concrete.

Compact settlement design in high-density areas requires careful planning to integrate ventilation corridors and adjust the composition of buildings' H/W ratios and street orientations. Gaps between buildings along the north-south axis enhance airflow, while vegetation buffers on the east-west side are thermal regulators. These buffers reduce radiation exposure and filter pollutants effectively.

Semi-open spaces and shaded communal areas within dense settlements can enhance social and environmental resilience by reducing heat stress and promoting public well-being. These strategies are practical guidelines for urban planners and architects designing high-density kampung settlements in tropical climates.

Improving thermal comfort in narrow alleys within high-density settlements requires a multifaceted approach that considers spatial constraints, private spatial needs, and climatic conditions. Urban planners need to engage with local communities and authorities to implement designs and policies for this area with organic development. Regional planning requires a community-driven approach that can synergize the implementation of ideas and policies in public areas, the domain of planner design, and the implementation of ideas on building surfaces, which are the domain of private design. In implementing the policy in private areas, urban planners should encourage the integration of sustainable building materials essential for long-term thermal comfort improvements.

# CONCLUSIONS

This study examines the influence of surface materials, building arrangement, and vegetation on outdoor thermal comfort in urban kampungs. Each factor plays a crucial role in modifying the microclimate of outdoor spaces, with significant implications for urban design and planning. Addressing these factors holistically can foster healthier and more livable high-density urban environments.

The study reveals that high-albedo surface materials tend to elevate air temperatures due to their reflective properties, particularly ground surfaces. Lower albedo paving materials are preferred to mitigate heat accumulation. Building arrangements with a high height-to-width (H/W) ratio provide effective shading, minimizing direct solar radiation and reducing mean radiant temperature (MRT). An east-west building orientation is more effective in creating shaded outdoor areas. Vegetation improves thermal comfort by providing shade and ET, which helps dissipate heat. This study reveals that it has a lower impact on increasing wind flow on >1 H/W ratio corridors and organic structures than <1, since building mass reduces wind speed. To maximize its benefits, vegetation should be strategically placed around open spaces to optimize airflow.

This research enriches the understanding of outdoor thermal comfort in high-density urban kampungs, which can be a foundation in urban planners' decision-making. The findings serve as a valuable reference for urban planners, architects, and policymakers aiming to design sustainable, thermally comfortable urban kampungs or high-density settlements. However, effective implementation will require collaboration with local communities, as private building surfaces largely determine outdoor thermal conditions.

Overall, the study significantly contributes to the discourse on outdoor thermal comfort in dense urban kampungs. It emphasizes the necessity of addressing microclimatic variables through a holistic design approach. Future research should incorporate thermal comfort validation, simulate the effect of designer adjustments, conduct long-term monitoring, and explore additional environmental factors such as humidity control and water features. Comparative studies across multiple urban kampungs could further enhance the applicability of these findings.

## AUTHOR CONTRIBUTION CRediT

Conceptualization, R.P., S., D.K; Data Curation, R.P., S., D.K; Formal Analysis, R.P., S.; Funding Acquisition, R.P., S., D.K.; Research, Acronym; Methodology, R.P., S.; Project Management, D.K; Resources, R.P., S., D.K; Software. S.; Supervision, D.S; Validation, R.P., S.; Visualization, R.P., S.; Writing - original draft, R.P.; Writing - review and editing, R.P., S.; Writing - revision and editing, R.P., S.

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