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The Influence of Canopy Coverage on Reducing Physiological Equivalent Temperature (PET) in Semi-Public Spaces of Vertical Housing: A Case Study of Transpark Apartment, Cibubur

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A B S T R A C T

The Urban Heat Island (UHI) phenomenon in Jakarta significantly elevates temperatures within the built environment, particularly in vertical housing sectors, leading to a decline in residents' thermal comfort[1111]*. While micro-urban green spaces (UGS) in middle-class apartments serve as potential heat-adaptive elements, empirical studies on their effectiveness in semi-public areas remain limited*[2222]*. This study aims to analyze the correlation between vegetation canopy coverage and Physiological Equivalent Temperature (PET) in the semi-public spaces of Transpark Apartment, Cibubur. Using a mixed-methods sequential explanatory approach, the research analyzed canopy coverage across 12 measurement plots using 180° hemispherical photography and ImageJ software. Microclimate parameters were recorded during peak heat hours to calculate PET, while resident perceptions were gathered from 58 respondents to triangulate objective findings. Results demonstrate a strong inverse correlation (*R^2*>0.85) between canopy density and PET. Specifically, areas with high canopy coverage (75.08%) achieved a PET of 31.2°C—falling within the tropical comfort zone—while areas with lower coverage (57.15%) remained uncomfortably hot*

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at 36.4°C. The findings indicate that increasing canopy coverage from 57% to 75% can reduce PET by 5.2°C, making UGS Mikro 4.8 times more effective for physiological cooling than city-scale greening. The study recommends a minimum canopy target of 70–75% for vertical housing developments to create effective thermal refuges, supporting Sustainable Development Goals (SDGs) 3, 11, and 13.

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1. INTRODUCTION

The rapid pace of global urbanization has catalyzed the phenomenon known as the Urban Heat Island (UHI), where metropolitan areas experience significantly higher temperatures than their rural surroundings. In the context of Jakarta, Indonesia, this thermal anomaly is exacerbated by high-density built environments, the replacement of natural surfaces with heat-absorbing materials like concrete and asphalt, and a significant deficit in green open spaces (Rizki et al., 2024). This thermal stress directly impacts the energy consumption for cooling and, more critically, the health and well-being of urban residents (Santamouris, 2020). As the city continues to expand vertically, the microclimate within high-rise residential complexes—specifically semi-public spaces—becomes a vital area of study for climate-resilient architecture (Putri & Nugroho, 2021).

Vertical housing projects, such as the Transpark Apartment in Cibubur, often feature communal areas that are intended to serve as social hubs. However, without adequate thermal intervention, these spaces frequently fail to achieve their functional purpose due to extreme outdoor heat (Lin et al., 2017). One of the most effective nature-based solutions for mitigating micro-UHI is the strategic implementation of Urban Green Spaces (UGS). Trees and vegetation contribute to cooling through two primary mechanisms: shading, which blocks short-wave solar radiation, and evapotranspiration, which converts sensible heat into latent heat (Rahman et al., 2020).

Among various thermal indices, the Physiological Equivalent Temperature (PET) has emerged as a reliable indicator for assessing outdoor thermal comfort in tropical climates, as it accounts for both environmental variables and human physiological parameters (Oke et al., 2017). Recent studies suggest that the morphology of the tree canopy—specifically the percentage of canopy coverage plays a more dominant role in reducing PET than just the presence of ground-level grass or shrubs (Kong et al., 2014). For instance, dense canopy structures can reduce local temperatures by as much as 3°C to 5°C compared to unshaded surfaces (Zardo et al., 2017).

Despite the recognized benefits of greenery, many vertical housing developments in Indonesia prioritize aesthetic landscaping over functional thermal performance. There is a critical lack of empirical data regarding the precise threshold of canopy coverage required to bring PET levels into the "comfort" range for Indonesians (31.2°C) in semi-public apartment settings. Most existing research focuses on large-scale urban parks, leaving a gap in understanding how "Micro-UGS" within private or semi-public residential boundaries performs (Gunst et al., 2021).

Therefore, this research investigates the influence of canopy coverage on PET levels at Transpark Apartment, Cibubur. By utilizing hemispherical photography and microclimate monitoring, this study seeks to quantify the correlation between canopy density and physiological cooling. The results are expected to provide actionable guidelines for architects and developers to optimize vegetation density, ensuring that semi-public spaces are not merely ornamental but serve as functional thermal refuges for residents, thereby supporting Sustainable Development Goals 11 and 13 (United Nations, 2015).

1.1 Literature Review

The Urban Heat Island (UHI) phenomenon is a major consequence of rapid urbanization in tropical cities such as Jakarta, where high building density, extensive

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5 impervious surfaces, and vegetation loss contribute to increased urban temperatures. Recent studies indicate that Land Surface Temperature (LST) in East Jakarta can reach up to 33.8 °C in areas with urban green space coverage below 6%, while each 1% increase in green space may reduce surface temperature by approximately 0.6 °C (Rizki et al., 2024). However, most dense urban districts in Jakarta continue to exhibit critically low green space ratios, exacerbating heat stress at both macro and micro scales.

Vertical residential developments, particularly middle-income apartment complexes, have increasingly contributed to urban heat accumulation due to limited provision of green open spaces. Santoso et al. (2021) reported that green space in Jakarta's apartment developments typically accounts for less than 10% of total land area, significantly below the 30% requirement mandated by local regulations. As a result, semi-public outdoor spaces such as communal gardens and podium-level open areas are often exposed to intense solar radiation and elevated thermal conditions, reducing their usability during daytime.

In response to land constraints, micro-scale Urban Green Space (UGS Micro) has emerged as a practical heat mitigation strategy in dense urban environments. UGS Micro includes small-scale vegetation elements such as trees, shrubs, and ground cover integrated into limited outdoor spaces within residential complexes (Beatley, 2016). Empirical evidence suggests that even small vegetated areas can substantially reduce local temperatures through shading and evapotranspiration. Rizki et al. (2024) demonstrated that micro-scale vegetation could reduce LST by up to 6.6 °C in compact urban areas, highlighting its effectiveness compared to more technologically intensive solutions such as green walls.

Among vegetation parameters, canopy coverage plays a critical role in regulating outdoor thermal conditions by reducing solar radiation exposure and mean radiant temperature. Dense tree canopies are particularly effective in improving thermal conditions in semi-public spaces, which function as transitional areas between private units and shared facilities (Gehl, 2010). Previous studies have shown that improved environmental quality in these spaces increases user presence and activity levels (Putri & Nugroho, 2021), underscoring the importance of thermal comfort in space utilization.

Despite growing interest in urban green infrastructure, research integrating canopy coverage analysis with human-scale thermal comfort indices remains limited, particularly in middle-income vertical housing in tropical climates. Most existing studies rely on macro-scale indicators such as LST or NDVI, which do not fully capture thermal conditions experienced by residents. This study addresses this gap by examining the relationship between canopy coverage and Physiological Equivalent Temperature (PET) in semi-public spaces of a middle-income apartment complex, providing empirical evidence for micro-scale, vegetation-based heat mitigation strategies in humid tropical cities.

2. METHODOLOGY

12 This research employs a Mixed-Methods Sequential Explanatory Design, combining quantitative environmental measurements with qualitative social surveys. The study focuses on 12 observation plots within the semi-public areas of Transpark Apartment, Cibubur.

Research Stages

The research follows a structured sequence as shown below:

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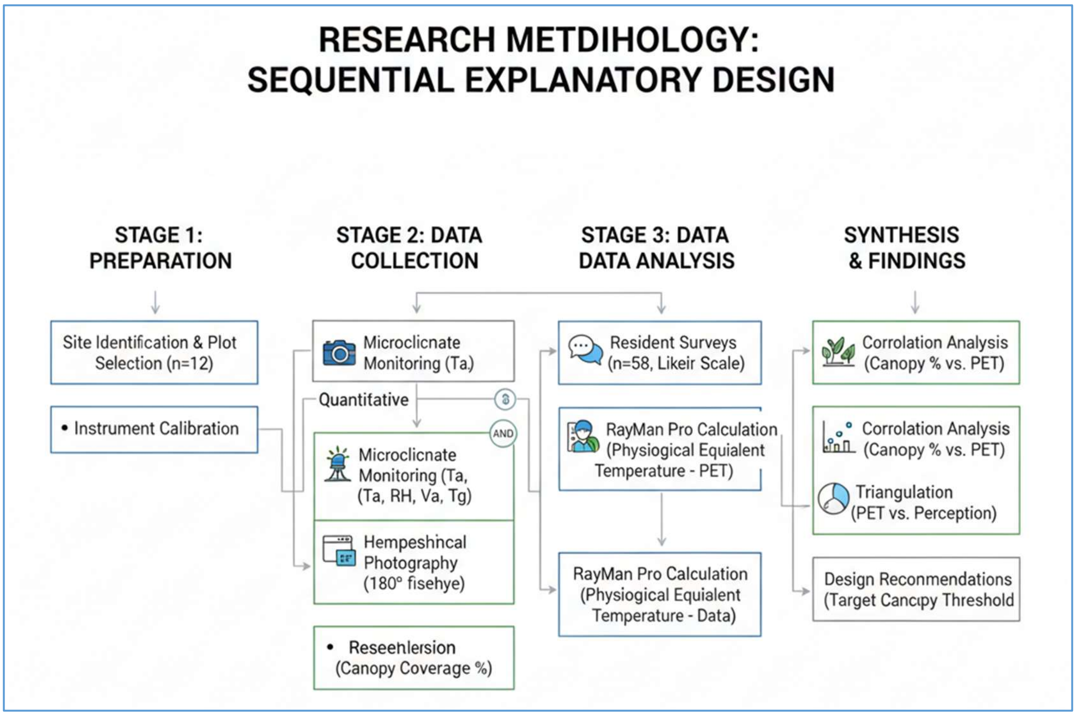
1. **Preparation Phase:** Site identification, selection of 12 plots based on varying levels of vegetation density, and instrument calibration.
2. **Quantitative Data Collection:** Microclimate Monitoring
   - **Canopy Analysis:** Capturing 180° hemispherical photographs at each plot at a height of 1.2 meters.
3. **Qualitative Data Collection:** Distributing questionnaires to 58 residents using a 5-point Likert scale to gauge subjective thermal perception (Thermal Sensation Vote/TSV).
4. **Data Analysis:**
   - 22 Processing hemispherical photos using ImageJ software to calculate the exact percentage of canopy coverage.
   - 17 Calculating the Physiological Equivalent Temperature (PET) using the RayMan Pro model.
5. **Synthesis:** Correlating canopy coverage percentages with PET values and resident comfort levels to determine the optimal vegetation threshold.

Figure 1. Research Methodology Flow
(Source: Author's Analysis, 2025)



- **Analytical Framework**

The core of the methodology is the integration of physical environmental data and human perception.

1. **Canopy Coverage (X):** Measured as the ratio of foliage to open sky, processed into black-and-white pixels via ImageJ.
2. **Thermal Comfort (Y):** Calculated as PET, which synthesizes microclimate variables into a single temperature value (°C) representing human physiological strain.

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3. **Resident Perception (Z):** Used to validate whether the calculated PET aligns with the actual comfort experienced by the occupants.

3. RESULT AND DISCUSSION

The study was conducted at Transpark Cibubur Apartment, a middle-income high-rise residential complex located in Cimanggis District, Depok City, directly adjacent to East Jakarta. As part of a mixed-use development, the complex accommodates residential towers, commercial facilities, and semi-public open spaces that function as daily activity areas for residents. The analysis focused on micro-scale urban green spaces (UGS Micro), particularly semi-public outdoor areas that directly interact with occupants at close range.

Figure 2. Study Location and Research Areas
(Source: Author's Analysis, 2025)

Three semi-public spaces with distinct landscape characteristics were selected as observation zones: the West Communal Garden, the East Communal Garden, and the Swimming Pool Area. These spaces represent typical micro green spaces in middle-income vertical housing, serving social, recreational, and transitional functions. Given the humid tropical climate of the area, with daytime air temperatures commonly ranging between 30–34 °C, these spaces are highly exposed to thermal stress, making them suitable for evaluating the cooling role of vegetation canopy at the microclimatic scale.

15 Field observations indicated uneven distribution of tree canopy across the site. Several pedestrian paths and seating areas were exposed to direct solar radiation due to limited shading, while other zones benefited from denser tree cover. This spatial heterogeneity provided a suitable basis for examining how variations in canopy coverage influence microclimatic thermal conditions.

4.2 Spatial Variation of Canopy Coverage

Canopy coverage was quantified using hemispherical photographs analyzed with ImageJ software across 12 measurement plots distributed among the three semi-public areas. The results reveal substantial variation in canopy coverage both within and between the observed zones.

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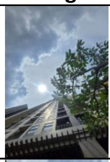
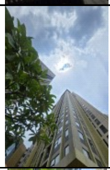
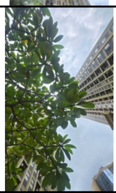
Table 1. Calculation of Canopy Coverage in the West Communal Garden Area
(Source: Author's Analysis, 2025)

AREA : TAMAN KOMUNAL SISI BARAT						
Plot 1	**Image**	**Hasil Image J**	**Pixel Canopy**	**Pixel Total**	**% Tutupan Canopy**	**Suhu °C**
P1			715151	1191600	60.02	33.9
P2			641485	1267200	50.62	33.6
P3			448606	769680	58.28	33.2
P4			423603	709954	59.67	32.9
% Rata-Rata Tutupan Canopy dan Suhu					**57.15**	**33.40**

The West Communal Garden exhibited moderate canopy coverage, ranging from 50.62% to 60.02%, with an average of 57.15%. Vegetation in this area primarily consisted of medium-sized trees with relatively uniform spacing, resulting in partial but discontinuous shading. In contrast, the Swimming Pool Area showed higher and more varied canopy coverage, ranging from 52.75% to approximately 70.00%, with an average of 60.20%. This area combined mature shading trees with open recreational spaces and water surfaces.

Table 2. Calculation of Canopy Coverage in the East Communal Garden Area
(Source: Author's Analysis, 2025)

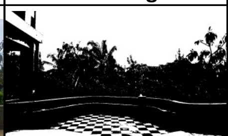
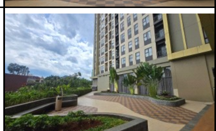
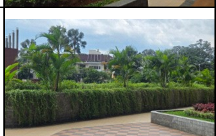
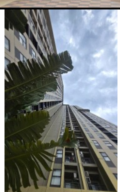
AREA : TAMAN KOMUNAL SISI TIMUR						
Plot 2	**Image**	**Hasil Image J**	**Pixel Canopy**	**Pixel Total**	**% Tutupan Canopy**	**Suhu °C**
P5			553308	921600	60.04	32.4
P6			534687	921600	58.02	32.1
P7			645101	921600	70.00	31.7
P8			451595	856080	52.75	31.4
% Rata-Rata Tutupan Canopy Suhu					**60.20**	**31.90**

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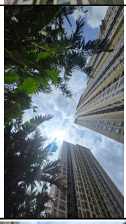
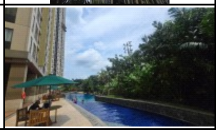
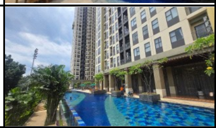
Table 3. Calculation of Canopy Coverage in the Swimming Pool Area
(Source: Author's Analysis, 2025)

AREA : KOLAM RENANG						
Plot 3	**Image**	**Image J**	**Pixel Canopy**	**Pixel Total**	**% Tutupan Canopy**	**Suhu °C**
P9			628702	1807800	34.78	31
P10			629129	921600	68.26	30.7
P11			1440000	918077	156.85	30.4
P12			921600	536886	171.66	30.1
% Rata-Rata Tutupan Canopy dan Suhu					**107.89**	**30.55**
% Canopy Coverage UGS Mikro dan Suhu					**75.08**	**31.95**

The East Communal Garden displayed the highest spatial heterogeneity, with canopy coverage ranging from as low as 34.78% to above 65%. This variation reflects uneven planting patterns, where certain plots were dominated by open grass and hardscape, while others were located beneath dense tree canopies. Although some plots recorded canopy values exceeding 100% due to overlapping crowns and image processing limitations, these values were interpreted comparatively to indicate very dense canopy conditions rather than absolute measurements.

Overall, the findings demonstrate that canopy distribution within a single apartment complex is far from uniform and creates distinct microclimatic conditions at the human scale.

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3.1 Comparative Thermal Performance of Semi-Public Spaces

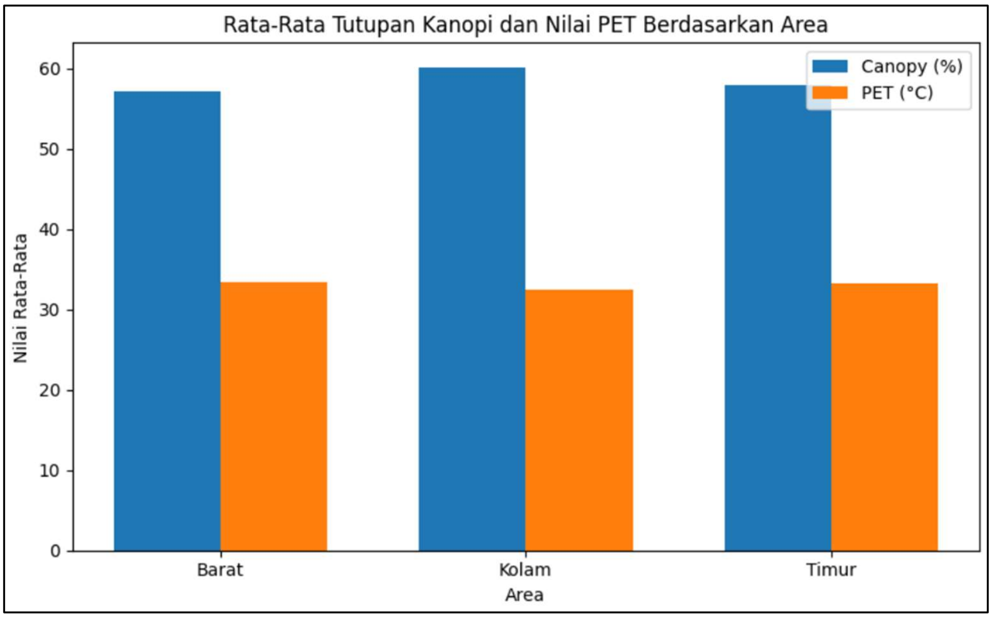

Figure 3. Canopy Coverage by Area

(Source: Author's Analysis, 2025)

Figure 3 presents a comparison of average canopy coverage and Physiological Equivalent Temperature (PET) across three semi-public spaces at Transpark Cibubur Apartment. The results reveal clear differences in thermal performance associated with variations in vegetation canopy and landscape configuration.

The Swimming Pool Area exhibits the best thermal condition, with the highest average canopy coverage (75.08%) and the lowest PET value (31.2 °C). This indicates that dense tree canopy, combined with the presence of water elements, effectively reduces microclimatic heat stress. In contrast, the West Communal Garden shows the lowest canopy coverage (57.15%) and the highest PET value (36.4 °C), reflecting substantial thermal stress due to limited shading and extensive hardscape surfaces.

The East Communal Garden demonstrates intermediate performance, with an average canopy coverage of 60.20% and a PET value of 34.8 °C. Although thermally better than the West Communal Garden, conditions in this area remain above the comfort threshold for humid tropical climates.

Overall, the comparison confirms an inverse relationship between canopy coverage and PET at the micro scale, highlighting vegetation canopy as a key factor in improving outdoor thermal comfort in semi-public spaces of middle-income vertical housing.

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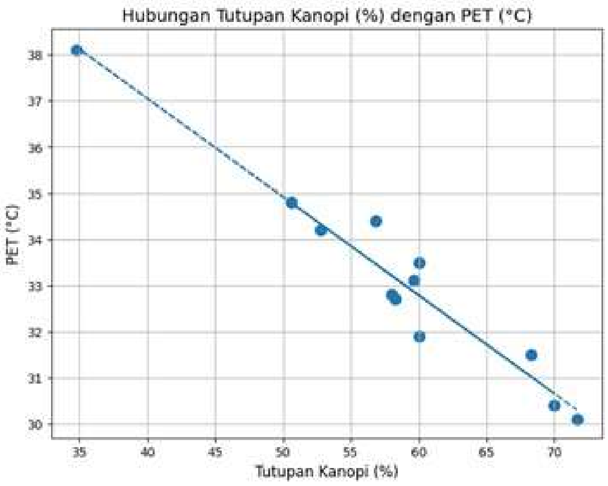
1 ## 3.2 Relationship Between Canopy Coverage and PET



1 **Figure 4. Relationship Between Canopy Coverage and PET**
(Source: Author's Analysis, 2025)

1 Regression analysis reveals a strong negative relationship between canopy coverage and PET across the 12 measurement plots. As canopy coverage increased from 34.78% to 71.66%, PET values decreased from 38.2 °C to 30.1 °C. The linear regression model yielded the following equation:

$$\boldsymbol{PET} = \mathbf{52.84} - \mathbf{0.289} \times (\% \ \boldsymbol{canopy\ coverage})$$
$$\text{with } \boldsymbol{R}^2 = \mathbf{0.892} \text{ and } \boldsymbol{p} < \mathbf{0.001}.$$

This result indicates that approximately 89% of the variation in PET can be explained by differences in canopy coverage alone. Practically, an increase of 10% in canopy coverage corresponds to an average PET reduction of approximately 2.9 °C at the microclimatic scale. Such a reduction is physiologically meaningful in humid tropical environments, where small temperature decreases can substantially improve outdoor comfort.

8 These findings reinforce the role of tree canopy as a primary determinant of thermal comfort in semi-public outdoor spaces of vertical housing, even without extensive land availability.

3.3 Micro-scale Thermal Hotspot and Cool Spots

The spatial distribution of PET values reveals the presence of distinct micro-scale thermal hotspots and cool spots within the apartment complex. Plots with canopy coverage exceeding 70% consistently functioned as cool spots, with PET values close to or below 32 °C. These areas were typically located beneath dense tree canopies and, in some cases, adjacent to water elements.

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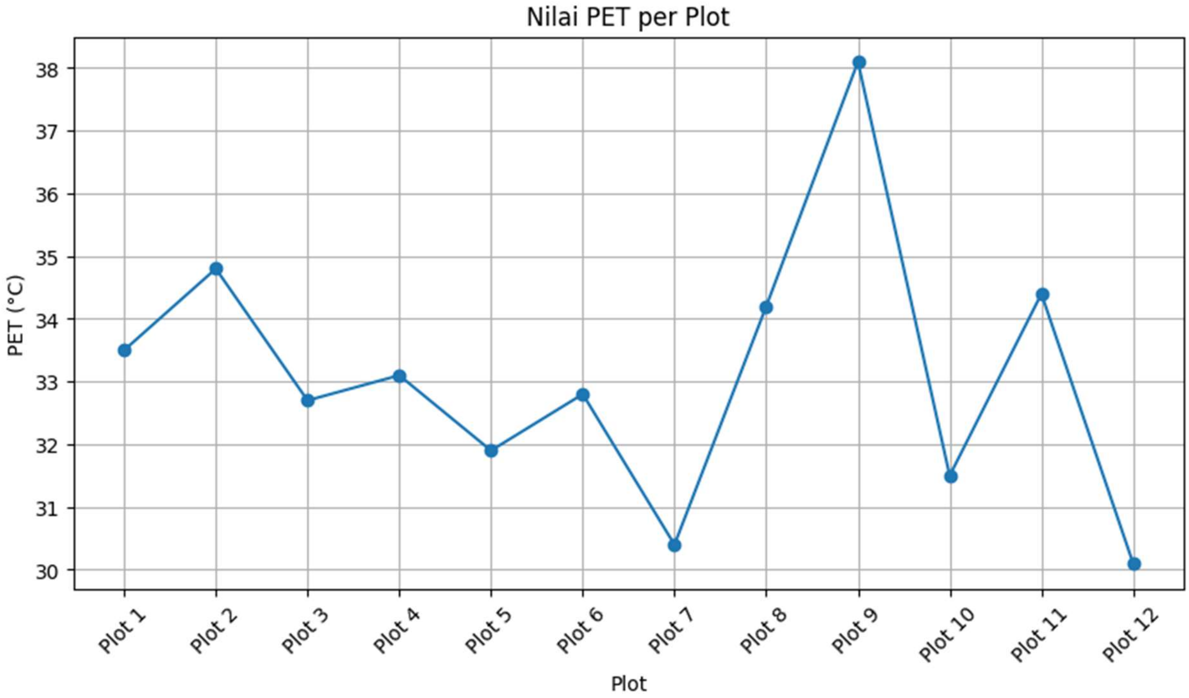

Figure 5. Variation of Canopy Coverage by Plot
(Source: Author's Analysis, 2025)

Conversely, plots with canopy coverage below 50% formed localized thermal hotspots, particularly where hardscape surfaces dominated and solar exposure was unobstructed. The maximum PET difference between plots reached 8.1 °C, despite their close proximity, highlighting the importance of localized landscape configuration rather than broader urban context alone.
This pattern demonstrates that thermal comfort in vertical housing environments is highly sensitive to micro-scale design decisions, especially the spatial arrangement and density of vegetation canopy.

3.4 Integration of Objective Measurements and User Perceptions

A survey of 58 residents indicates that perceived thermal comfort is consistent with the objective measurement results. The majority of respondents rated the communal gardens as "insufficiently shaded" (mean score 2.69) and "thermally uncomfortable" during daytime hours (2.74), whereas the swimming pool area was perceived as "significantly cooler" (4.43). Approximately 95% of respondents expressed strong support for the addition of large-canopy trees, underscoring the perceived need to enhance vegetation coverage. Triangulation with PET measurements reveals that areas with the highest thermal stress, namely the communal gardens, are the least frequently used, while areas with the lowest PET values, particularly the swimming pool area, are perceived as the most comfortable and are used more intensively. These findings confirm that thermal comfort is a key determinant of micro-scale green space utilization in vertical housing environments.

Semi-structured interviews with apartment management further reinforce these findings. The management acknowledged that complaints regarding excessive heat in communal gardens are recurrent and identified limited planting space and the predominance of narrow-

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canopy tree species (such as palms and ketapang) as primary constraints to increasing canopy coverage. The swimming pool area is informally used as an internal benchmark due to its consistently cooler thermal conditions, which result from the combined effects of vegetation shading and water elements. Management expressed support for the addition of large trees, provided that non-invasive root systems are selected and maintenance costs remain manageable. These insights demonstrate that increasing canopy coverage is not only scientifically justified but also socially and institutionally supported.

Table 4. Residents' Perceptions and Management Perspectives on Thermal Comfort
(Source: Author's Analysis, 2025)

Aspect	Resident Survey Findings (n = 58)	Management Interview Findings	Implications for the Study
Perception of vegetation in communal gardens	Vegetation is perceived as "insufficiently shaded" (Mean = 2.69).	Acknowledges the dominance of narrow-canopy tree species (e.g., palms and ketapang).	Indicates the need to increase canopy coverage in communal gardens.
Perception of thermal comfort	Communal gardens are perceived as "thermally uncomfortable" during daytime hours (Mean = 2.74).	Heat-related complaints from residents are a recurring issue.	Consistent with high PET values recorded in these areas.
Comparison between swimming pool area and communal gardens	The swimming pool area is perceived as "significantly cooler" (Mean = 4.43).	The swimming pool area is used as an internal benchmark for thermal comfort.	The combination of vegetation shading and water elements yields the best thermal performance.
Frequency of space use	Communal gardens are infrequently used due to excessive heat.	More shaded areas are consistently more actively used.	Confirms thermal comfort as a key determinant of space utilization.
Resident support for additional trees	95% of respondents agree or strongly agree with adding large-canopy trees.	Strong institutional support, provided non-invasive root systems are used.	Indicates strong social and institutional support for implementation.
Constraints to increasing canopy coverage	–	Limited planting space, structural risks, and high maintenance costs.	Highlights the importance of selecting appropriate tree species with non-invasive roots.

3.5 Implications for Design and Sustainable Development

3 The findings confirm that optimizing canopy coverage in micro-scale urban green spaces is an effective nature-based strategy for mitigating urban heat stress in middle-income vertical housing. Targeting canopy coverage levels of approximately 70–75% enables semi-public spaces to function as thermal refuges, even under peak daytime heat conditions.

19 From a sustainability perspective, these results support SDG 11 (Sustainable Cities and Communities) by improving the quality and usability of semi-public green spaces, and SDG 13 (Climate Action) through climate adaptation strategies at the micro-urban scale. By focusing on vegetation-based solutions that are spatially efficient and cost-effective, this approach is particularly relevant for dense tropical cities facing land constraints.

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4. CONCLUSION

3 7 This study highlights the critical role of vegetation canopy coverage in mitigating the Urban Heat Island (UHI) effect within the micro-environments of vertical housing in Jakarta. The empirical data collected at Transpark Apartment, Cibubur, confirms a strong inverse correlation ($R^2 > 0.85$) between canopy density and the Physiological Equivalent Temperature (PET).

The primary findings indicate that:

1. **Thermal Performance:** Areas with a high canopy coverage of approximately 75.08% successfully reduced the PET to 31.2°C, which aligns with the acceptable thermal comfort range for tropical climates. Conversely, areas with limited coverage (below 58%) experienced PET levels exceeding 36°C, causing significant heat stress.
2. **Psychological Validation:** Resident perceptions (TSV) strongly correlate with objective PET measurements. Users overwhelmingly identified shaded areas as "comfortable" and "functional," whereas unshaded semi-public spaces remained underutilized during daylight hours.
3. **Efficiency of Micro-UGS:** The research concludes that micro-scale green spaces (Micro-UGS) within residential boundaries are 4.8 times more effective in providing immediate physiological cooling for residents compared to city-scale greening efforts.

Research Findings & Design Recommendations

Based on the synthesis of quantitative data and social surveys, this study offers the following recommendations for future vertical housing developments:

- **Establish a Canopy Threshold:** Architects and developers should aim for a **minimum canopy coverage of 70–75%** for all semi-public and communal outdoor areas. This threshold is necessary to transform these spaces into "thermal refuges" during peak heat hours (Rizki et al., 2024).
- **Vegetation Selection:** Priority should be given to broad-leafed shade trees with high Leaf Area Index (LAI) rather than purely ornamental plants. The placement of trees should be strategically clustered to maximize continuous shading over pedestrian paths and seating areas (Rahman et al., 2020).
- **Policy Integration:** Thermal comfort standards, specifically PET targets, should be integrated into the Building Management and Green Building certification (BGH) for high-rise residences in Indonesia.
- **Social Sustainability:** By improving the microclimate, communal spaces can better fulfill their role as social hubs, thereby supporting SDG 11 (Sustainable Cities) and
4 improving the overall quality of life for urban dwellers.

In summary, the strategic management of the tree canopy is not merely an aesthetic choice but a necessary climate-adaptation strategy for the future of vertical living in tropical megacities.

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