

Thermal Comfort Analysis in Urban Area of Penajam Paser Utara Regency: Climate Sensitive Urban Design Approach

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ABSTRACT. The limited availability of vegetation and shading elements contributes to uncomfortable thermal conditions in the urban area of Penajam Paser Utara Regency, particularly during midday. This study aims to analyse microclimatic conditions and outdoor thermal comfort as a basis for developing Climate Sensitive Urban Design (CSUD) recommendations. The study employed a quantitative-descriptive approach supported by spatial analysis and simulation. Measurements were conducted at three observation stations with different physical characteristics at 09:00, 13:00, and 17:00 WITA. The measured parameters included air temperature, relative humidity, and wind speed. Thermal comfort was assessed using the Temperature Humidity Index (THI), while solar movement and shading distribution were simulated using Ecotect Analysis based on a three-dimensional model developed in SketchUp. The results showed that the highest air temperature reached 35.6°C at Station 3 at 13:00 WITA, while shading intensity was only approximately 2% at midday and increased to 55% in the afternoon. The THI values indicated uncomfortable thermal conditions, with the highest average value of 31.47°C at Station 1. By integrating microclimatic conditions, THI, wind speed, and shading patterns, this study developed site-specific CSUD recommendations, including shade vegetation, pedestrian protection, vertical greenery, building solar protection, and optimization of natural ventilation.

Keywords: climate sensitive urban design; humidity; thermal comfort; shadow patterns; air temperature

ABSTRAK. Minimnya vegetasi dan elemen peneduh menyebabkan kawasan perkotaan Kabupaten Penajam Paser Utara mengalami kondisi termal yang kurang nyaman, terutama pada siang hari. Penelitian ini bertujuan untuk menganalisis kondisi iklim mikro dan kenyamanan termal ruang luar sebagai dasar penyusunan rekomendasi *Climate Sensitive Urban Design* (CSUD). Penelitian menggunakan pendekatan kuantitatif-deskriptif yang didukung analisis spasial dan simulasi. Pengukuran dilakukan pada tiga stasiun dengan karakteristik fisik berbeda pada pukul 09.00, 13.00, dan 17.00 WITA. Parameter yang diukur meliputi suhu udara, kelembaban relatif, dan kecepatan angin. Kenyamanan termal dianalisis menggunakan *Temperature Humidity Index* (THI), sedangkan pola pergerakan matahari dan distribusi bayangan disimulasikan menggunakan Ecotect Analysis berdasarkan model tiga dimensi SketchUp. Hasil menunjukkan suhu tertinggi mencapai 35,6°C pada Stasiun 3 pukul 13.00 WITA, sementara intensitas bayangan hanya sekitar 2% pada siang hari dan meningkat hingga 55% pada sore hari. Nilai THI menunjukkan kondisi termal tidak nyaman, dengan nilai rata-rata tertinggi sebesar 31,47°C pada Stasiun 1. Berdasarkan integrasi kondisi iklim mikro, THI, kecepatan angin, dan pola bayangan, penelitian ini menghasilkan rekomendasi CSUD spesifik lokasi berupa vegetasi peneduh, perlindungan jalur pedestrian, penghijauan vertikal, pelindung matahari bangunan, dan optimalisasi ventilasi alami.

Kata kunci: climate sensitive urban design; kelembaban; kenyamanan termal; pola bayangan; suhu udara

INTRODUCTION

The rapid pace of human activity in urban areas often leads to an increase in environmental temperatures compared to surrounding areas. This phenomenon is known as the Urban Heat Island, a condition where urban area temperatures are

higher due to the dominance of built infrastructure and the reduction of green spaces (Yuan et al., 2026). Urban heat islands and climate change occur simultaneously and influence each other (Putra, 2024). The Urban Heat Island effect is a well-documented phenomenon where urban areas experience higher temperatures than their

surroundings due to the prevalence of built structures and reduced green spaces. In understanding ideal urban design, the higher the surface temperature, the more uncomfortable users become with the thermal conditions of the area (Dahrma, Nurudoula, & Romantiaulia, 2019).

Penajam Paser Utara Regency, which directly borders the new capital city, has experienced rapid development in recent years. Penajam Paser Utara Regency has experienced a fairly rapid population growth every year, with an increase of 1.48%. This phenomenon is supposedly influenced by economic developments in the surrounding area, which attract residents from other regions to work and settle there (Syah & Almira, 2025). Land use changes, especially from green space to built-up areas, occur due to the increasing need for infrastructure. This change has a significant impact on increasing environmental temperatures. Based on climate data, the temperature increase in this area indicates the need for mitigation strategies to ensure that the urban environment remains comfortable and sustainable.

One strategy that can be applied to create a more comfortable and sustainable urban environment in Penajam Paser Utara Regency is the redesign of the area with a Climate Sensitive Urban Design approach. This approach emphasizes the importance of urban design that is adaptive to climate change by considering environmental factors such as sunlight, airflow, and temperature on an urban scale. To quantitatively assess the effectiveness of different passive design options, advanced building performance simulation tools will be employed to model the thermal behaviour of various building envelope configurations, allowing for a comprehensive comparison of their respective impacts on indoor thermal comfort (Kolani, Wang, Zhou, Nouyep Tchitchui, & Okolo, 2023). Climate-sensitive urban design concept is expected to create comfortable conditions in outdoor spaces, such as commercial pedestrian blocks (Ma, Fukuda, Zhou, & Wang, 2019). Optimizing the building orientation and spacing, incorporating green infrastructure, and selecting appropriate materials can significantly improve outdoor thermal comfort, encouraging social interaction and economic activity (Elnabawi & Hamza, 2020).

By implementing this concept, environmental quality can be improved so that thermal comfort itself can be measured using the Temperature Humidity Index. The comfort limits are based on (Neuwolt, 1977) The THI values between 21-24°C, where 100% of the population feels comfortable; THI between 25 - 27°C, where only 50% of the population feels comfortable, and at THI > 27°C, 100% of the population feels uncomfortable. Therefore, evaluating thermal comfort is a strategic step in creating a more humane and climate-friendly urban environment.

As a rapidly developing region, Penajam Paser Utara Regency faces challenges in spatial planning management due to increased mobility and the use of building materials such as concrete and asphalt, which exacerbate the increase in surface temperatures. To overcome this, the application of climate-sensitive urban design becomes the main solution in creating a cooler and more comfortable area. By understanding microclimate characteristics, urban design can be directed to be more responsive to environmental conditions and support sustainable development in Penajam Paser Utara Regency as a buffer zone for IKN.

RESEARCH METHODOLOGY

This study employed a quantitative-descriptive approach supported by spatial analysis and simulation to identify microclimatic conditions and thermal comfort levels in the urban area of Penajam Paser Utara Regency. The analysis focused on the relationship between measured microclimatic conditions, thermal comfort levels, and shading availability as a basis for developing *Climate Sensitive Urban Design* (CSUD) recommendations.

The study employed direct field measurements to assess microclimatic conditions at three observation stations representing different physical characteristics of the study area. Air temperature, relative humidity, and wind speed were measured as key parameters for characterizing outdoor microclimatic conditions and thermal comfort (Das & Das, 2020; Jing, Qin, Mu, Ge, & Dong, 2024). Measurements were conducted at 09:00, 13:00,

and 17:00 WITA to capture temporal variations in microclimatic conditions.

The research consisted of four main stages: (1) field measurement of microclimatic conditions, including air temperature, relative humidity, and wind speed; (2) assessment of outdoor thermal comfort using the Temperature Humidity Index (THI); (3) simulation of solar movement and shading distribution based on the physical characteristics of the study area; and (4) integrated analysis of microclimatic conditions, thermal comfort, shading availability, and site characteristics to formulate site-specific Climate Sensitive Urban Design (CSUD) recommendations.

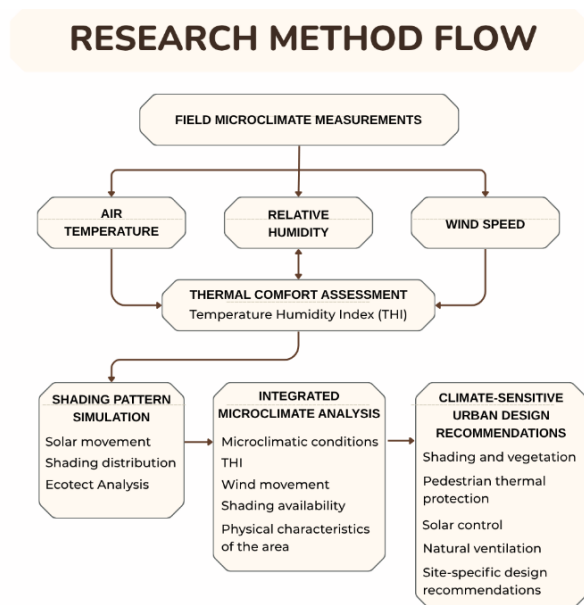


Figure 1. Research Method Flow
Source: Author, 2025

The measured air temperature and relative humidity were subsequently used to assess outdoor thermal comfort using the Temperature Humidity Index (THI). THI combines air temperature and relative humidity to evaluate outdoor thermal comfort conditions (Ardiyansah, Tricahyono, & Dahlia, 2024; Das & Das, 2020). Meanwhile, wind speed was used as a supporting parameter to interpret local air movement and its relationship with the observed thermal conditions (Jing et al., 2024). The THI value was calculated using the following equation (Damayanti, Safe'i, Setiawan, & Yuwono, 2023):

$$THI = 0,8 \times Tr + \left(\frac{RH \times Tr}{500} \right) \quad (1)$$

Information:

THI : Temperature Humidity Index

Tr : Air Temperature (°C)

RH : Relative Humidity (%)

Microclimate Measurement and Calculation

Microclimatic conditions were assessed through direct field measurements at three observation stations representing different physical characteristics of the urban area of Penajam Paser Utara Regency. Air temperature, relative humidity, and wind speed were measured at 09:00, 13:00, and 17:00 WITA to capture temporal variations in local microclimatic conditions. Air temperature and relative humidity were subsequently used to assess outdoor thermal comfort using the Temperature Humidity Index (THI), while wind speed was used as a supporting parameter to interpret local air movement and thermal conditions.

The microclimate and thermal comfort results were integrated with the physical characteristics of the observation sites through a simulation approach. A three-dimensional model was developed using SketchUp, while Ecotect Analysis was used to simulate solar movement and shading distribution at the corresponding observation times. The simulation results were compared with the measured microclimatic conditions and THI values to identify areas with higher solar exposure and limited shading. The integrated results were then used to formulate Climate Sensitive Urban Design (CSUD) recommendations based on the specific conditions of each observation station.

In addition to shading intensity, the degree of sky openness at each observation point was assessed using the Sky View Factor (SVF), generated from the three-dimensional building and street model in Ecotect Analysis. SVF represents the proportion of visible sky from a given point on the ground, ranging from 0 (fully obstructed) to 1 or 100% (fully open); a higher SVF indicates greater exposure to direct solar radiation and, consequently, a higher potential for surface heating. Wind speed data recorded in the field were further classified using

the Beaufort wind force scale to characterize local air movement in descriptive categories (e.g., Light Air, Light Breeze), supporting the interpretation of ventilation conditions at each station.

RESULT AND DISCUSSION

1. Air Temperature

The measurement results show significant temperature variations at each station. In the morning at 09:00 WITA, station 1 recorded a temperature of 33.2°C with a relative humidity of 68.5%, while station 2 was slightly higher with a temperature of 33.7°C and humidity of 72.9%. Station 3 had the lowest temperature among the three, at 32.7°C, but with a higher humidity of 74.1%.

At noon at 13:00 WITA, the temperature increased at all stations. Station 1 reached 35.4°C, while station 2 had a temperature of 34.8°C, slightly lower compared to station 3, which recorded the highest temperature of 35.6°C. The relative humidity across all stations ranged from 61.6% to 62.6%, indicating drier conditions compared to the morning.

Towards the afternoon, at 17:00 WITA, the temperature began to decrease. Station 1 and Station 3 had the same temperature, 32.6°C, with humidity levels of 70.0% and 68.7%, respectively. Station 2 was slightly warmer, with a temperature of 33.2°C and humidity of 71.9%.

The average temperature (T_r) across all points ranged from 33.6°C to 33.9°C, with an average relative humidity (H_r) of 67% – 68.8%. Based on the Temperature Humidity Index values, all points are categorized as uncomfortable, with values of 31.45 – 31.78°C, indicating that the thermal conditions in this area are quite high and require mitigation efforts to improve environmental comfort

2. Humidity

At 09:00 WITA, Station 1 recorded a humidity of 68.5%, which is lower compared to Station 2, which reached 72.9%, while Station 3 recorded the highest humidity with a figure of 74.1%. When it reached 13:00 WITA, all stations experienced a decrease in

humidity. Station 1 was recorded to have a humidity of 62.6%, Station 2 dropped to 61.6%, and Station 3 also experienced the same decrease, which was 61.6%. At 17:00 WITA, the humidity at Station 1 rose again to 70.0%, although it remained lower than that at Station 2, which recorded a humidity of 71.9%. Meanwhile, Station 3 also experienced an increase and was at 68.7%.

3. Thermal Comfort

Thermal comfort levels were measured using an equation that incorporates the previous microclimate values. The results indicate that each station falls into the uncomfortable category. This is due to the relatively high average temperatures, with the highest temperature at 35.6°C across stations and the lowest temperature at 32.6°C across stations. The ideal air temperature for human comfort outdoors is 27°C–28°C, with a comfort range of 21°C–27°C. At Station 1 at 09:00, the recorded temperature was 33.2°C with 68.5% humidity, resulting in a THI value of 31.47°C, which indicates discomfort. At Station 2 and Station 3, the temperature and THI values also indicate similar conditions, reinforcing the conclusion that the thermal comfort conditions at these three stations do not meet the recommended comfort limits.

This finding is consistent with (Das and Das, 2020), who similarly reported that built-up land cover zones in a tropical planning region experienced greater outdoor thermal discomfort than vegetated zones, indicating that the built-density and vegetation-sparse condition of the Penajam urban area contributes directly to its uncomfortable THI category. It also aligns with (Ardiyansah et al., 2024), who found that thermal discomfort in a tropical urban district of Jakarta intensified in dry, low-humidity periods, a pattern comparable to the midday drop in humidity and rise in THI observed at all three stations in this study. This agreement across studies conducted in different tropical Indonesian and South Asian urban contexts strengthens the argument that vegetation- and shading-based CSUD interventions, rather than generic guidelines, are needed to address the specific built-up conditions of the Penajam urban area.

Table 1. Air Temperature in Penajam Urban Area

Location	Time	T °C	Humidity %	Average Tr °C	Average Hr %	Average THI °C	Category
Station 1	09.00 WITA	33,2	68,5	33,7	67	31,47	Uncomfortable
	13.00	35,4	62,6				
	17.00	32,6	70,0				
Station 2	09.00	33,7	72,9	33,9	68,8	31,78	Uncomfortable
	13.00	34,8	61,6				
	17.00	33,2	71,9				
Station 3	09.00	32,7	74,1	33,6	68,1	31,45	Uncomfortable
	13.00	35,6	61,6				
	17.00	32,6	68,7				

Source: Author, 2025

4. The Effect of Wind on Thermal Comfort

The wind speed at each station shows relatively high values compared to the standard wind speed, which is 0.15 - 0.25 m/s. Based on the Beaufort scale classification, the wind speed at Station 1 and Station 2 are categorized as Light Airs, while at Station 3, it falls into the Light Breeze category. At 09:00 WITA, the wind speed at Station 1 was recorded at 1.14 m/s, at Station 2 at 0.57 m/s, and at Station 3 at 0.28 m/s. At 13:00 WITA, the wind speed increased with values of 1.71 m/s at Station 1, 1.64 m/s at Station 2, and 1.46 m/s at Station 3. At 17:00 WITA, the wind speed slightly decreased to 1.46 m/s at Station 1, 1.50 m/s at Station 2, and 1.03 m/s at Station 3.

Table 2. Wind Speed in Penajam Urban Area

Time	Location	Wind Speed (m/s)	Description
09.00	Station 1	1.14	Light Airs
	Station 2	0.57	Light Airs
	Station 3	0.28	Light Breeze
13.00	Station 1	1.71	Light Breeze
	Station 2	1.64	Light Breeze
	Station 3	1.46	Light Breeze
17.00	Station 1	1.46	Light Breeze
	Station 2	1.50	Light Breeze
	Station 3	1.03	Light Breeze

Source: Author, 2025

5. The Effect of Vegetation on Thermal Comfort

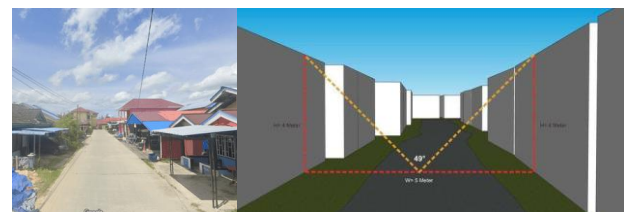
Vegetation plays an important role in reducing air temperature, with the ability to achieve a decrease of about 2°C to 3°C. Buildings exposed to intense sunlight, especially in the afternoon, need to respond with the addition of shading vegetation such as *Mimusops elengi*, *Samanea saman*, *Syzygium myrtifolium* (Putra, Jordan, Dewi, & Edytia, 2024). In this urban area, each station lacks

vegetation that can reduce air temperature because the area is still dominated by built-up areas, causing the air temperature in the urban area to be relatively high.

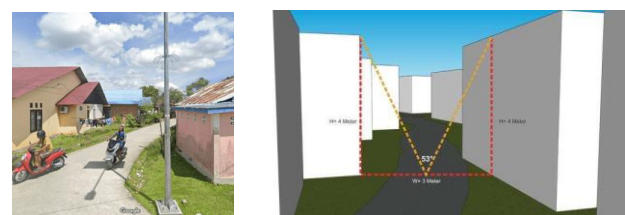
6. Relationship between Microclimate and Urban Design in Penajam Urban Area

The microclimate in the Penajam urban area is influenced by various factors, primarily by the type of land cover material, land use patterns, and the intensity of environmental activities. In general, land cover materials such as vegetation can lower ambient temperatures.

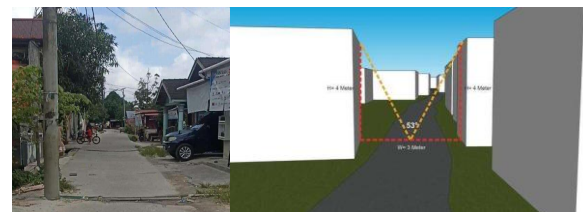
In the Penajam urban area, most of the land is used for settlements with buildings that are generally one to two-story houses, with building materials that tend to use wood and zinc roofs, which are not very effective in absorbing heat. In addition, this area also lacks public facilities and shopping centers, so it lacks in terms of area branding, but this area is quite busy with vehicles, creating excess heat in the area.



(a) Road Geometry at Station 1 Against Buildings



(b) Road Geometry at Station 2 Against Buildings



(c) Road Geometry at Station 3 Against Buildings

Figure 2. Road Geometry at Station 1, 2, and 3 Against Buildings

Source: Author, 2025

Fairly dense human activity, especially in the morning to the afternoon, also contributes to changes in temperature and air quality. As a rapidly developing area, the Penajam urban area also faces challenges in maintaining a balance between infrastructure development and environmental quality. This area has vegetation, but it is sparse; the available vegetation consists of shade trees.

Simulations of thermal comfort, wind patterns, and building layout in the Urban Area show that wind movement patterns vary throughout the day. The regular building layout with a grid pattern makes airflow in this area more stable. The presence of shophouses with rectangular facades and straight roads creates smoother air circulation, both into and out of the area (Ruda Sarria et al., 2024).

The highest temperature was recorded during the day at 13:00 WITA at Station 3 (35.6°C), while the lowest temperature occurred in the morning at Station 3 (32.7°C). Humidity tends to be higher in the morning and evening, while drier conditions occur during the day. Overall, this area is thermally uncomfortable and requires mitigation to improve comfort.

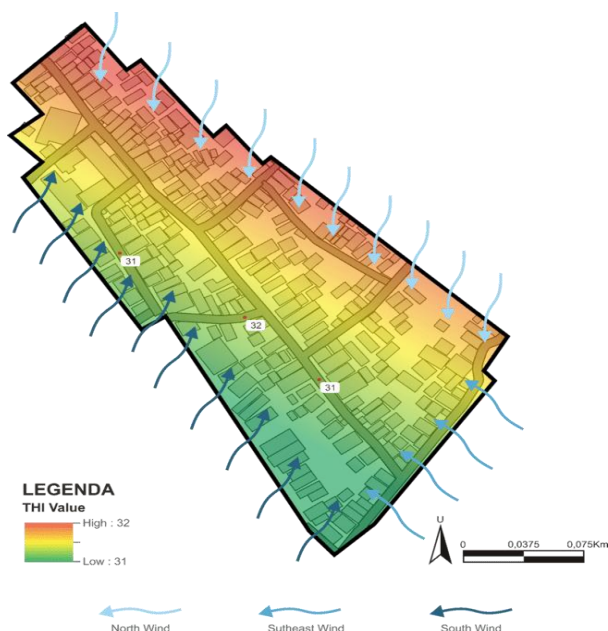


Figure 3. Simulation of THI Values and Wind Direction on Buildings in the Penajam Urban Area
Source: Author, 2025

Ecotect Analysis also shows that shadow patterns in this area influence thermal conditions. In the morning at 09:00 WIB, the average shadow formed reaches 18% as the sun is at a 30° angle from the east. At midday, at 13:00 WIB, when the sun is almost perpendicular in the sky at an 80° angle, the shadow in this area is very minimal, only about 2% or even non-existent (0%). This causes increased exposure to solar radiation and worsens thermal comfort. However, at 17:00 WIB, the intensity of shadows increases significantly, reaching an average of 55%, providing a better protective effect against heat.

Based on the temperature data and shadow patterns obtained, mitigation efforts need to be taken to improve thermal comfort in the Urban Area, such as adding shading elements or vegetation to reduce direct exposure to solar radiation. The most shadows are formed in the morning until late morning and in the afternoon when the sun begins to set. Conversely, during the day, the intensity of shadows is very minimal or even non-existent because the position of the sun is directly overhead, parallel to the earth's surface. In addition, the degree of sky openness or Sky View Factor also affects surface temperature, where the higher the SVF value, the hotter the ambient temperature tends to be. This condition is seen in the Penajam urban area, where the highest SVF was recorded at 13:00 WIB at 52%, which coincided with the maximum temperature based on the thermal comfort analysis.

7. Application of CSUD Concept in Penajam Urban Area

Materials such as asphalt and concrete, which have high thermal properties, increase the 'urban heat island' effect (Ananta, Rayya, & Rehardiyan, 2025). Temperatures in urban areas dominated by asphalt and concrete increase both during the day and at night. Furthermore, it is known that the width of the circulation corridor does not significantly affect wind speed, due to the high density of buildings causing many obstacles. Higher wind speeds tend to be found in corridors adjacent to open spaces, such as roads, parks, green open spaces, and rivers (Syafarina & Felly, 2023). Therefore, to lower the temperature, it is recommended to add vegetation

such as potted plants, vines, and hanging plants. This is done through the effects of shading and evapotranspiration.

In addition, air pollution from motor vehicle emissions in urban areas can cause health problems, global warming, and reduced environmental quality (Ernyasih et al., 2023). Adding vegetation along roads and optimizing pedestrian paths are recommended solutions. These strategies are important to support the mitigation of urban warming, and improving the environmental quality in the Penajam Paser Utara Urban Area can be seen as follows.

Table 3. Selection of Adjustment Recommendations

Category	Recommendation	Environment	Adaptation
Road Dimension	The shoulder of the road is used as a pedestrian walkway	B	B
	Addition of shade in the form of vegetation	B	B
	Adding Potted Vegetation	B	B
Vegetation	Hanging plants in every building	B	B
	Addition of climbing plants to the building walls	B	B
Facade and Interface	Every building uses overhangs	B	B
Natural Ventilation	The building implements cross ventilation	B	B

Information: B (Acceptable), I, (Restricted), T (Unacceptable)

Source: Author, 2025

To enhance thermal comfort in urban areas, several climate-adaptive urban design recommendations can be implemented. One strategy is to utilize road shoulders as comfortable and safe pedestrian paths. By creating these dedicated paths, direct interaction between pedestrians and motor vehicles can be reduced, not only improving comfort but also supporting more environmentally friendly mobility and reducing air and noise pollution in urban areas.

Furthermore, shading elements such as vegetation play a crucial role in lowering high surface temperatures resulting from direct sunlight exposure. Planting trees along roads, in green open spaces, and in city parks can help create a cooler

environment and improve air quality. In addition to vegetation planted in the ground, the use of potted plants and hanging plants around buildings can also provide a natural shading effect. Climbing plants placed on building walls act as natural thermal insulation, reducing the amount of heat absorbed by building materials and increasing humidity in the surrounding air. This aligns with the CSUD approach adopted in this study, which emphasizes how building envelope characteristics, including the use of natural materials, can improve thermal comfort.

From an architectural design perspective, implementing overhangs on building facades is highly recommended to reduce the intensity of direct solar radiation. Well-designed overhangs can create wider shaded areas around buildings, reducing indoor cooling loads. Additionally, implementing cross-ventilation systems is an important element in improving natural air circulation. With properly oriented openings, fresh air can enter and flow optimally inside the room, helping to lower the interior temperature without relying on artificial cooling systems like air conditioning. As shown in this study, the building's capacity to harness natural ventilation is a key factor in thermal comfort.

In addition to these strategies, the use of building materials with reflective properties or low heat absorption is also a crucial factor in creating a more thermally comfortable urban environment. Materials with high albedo, such as white paint or reflective roofing materials, can reduce the heat absorbed by buildings and their surroundings. The implementation of green roofs and green walls is also an increasingly popular innovation for improving thermal efficiency in urban areas.

By implementing these various approaches, urban areas can be designed more sustainably and adaptively to climate change, not only improving thermal comfort but also creating healthier and more liveable environments for the people who live in them.



Figure 4. Recommended Points for North Penajam Paser Urban Area Design
 Source: Author, 2025

Urban areas are dominated by residential buildings with limited open space, making large-scale tree planting infeasible. To overcome this condition, one solution that can be implemented is the use of vertical gardens on building facades. This method allows for greening by utilizing walls as planting areas, thus requiring no additional land.

The application of vertical greenery is particularly suitable for urban areas where existing building density limits the availability of conventional planting areas. By integrating vegetation directly into building facades, this strategy can introduce green elements into spaces that would otherwise remain unused. In addition, vertical greenery can be adapted to different building forms and facade conditions, making it a flexible approach for improving the environmental quality of dense residential areas.

In addition, planting with vertical gardens can reduce temperatures both indoors and outdoors, beautify the environment, create green spaces in limited areas, reduce noise, and increase oxygen levels in the air (Widiastuti & Fauziyah, 2024). By implementing this strategy, it is hoped that urban areas can experience increased thermal comfort without requiring large additional spaces for greening. A vertical garden is a structure that allows

vegetation to spread over a building facade or interior wall. Below is a plan for the placement of vegetation in urban areas, as shown in the figure below.



(a) Existing and Proposed Road Geometry with Vegetation and Ventilation Interventions at Station 1



(b) Existing and Proposed Road Geometry with Vegetation and Ventilation Interventions at Station 2



(c)

Existing and Proposed Road Geometry with Vegetation and Ventilation Interventions at Station 2

Figure 5. Existing and Proposed Road Geometry with Vertical Greenery and Shading Interventions at Station 1, 2, and 3

Source: Author documentation, 2025

8. Urban Design Sketch Recommendations per Station and Proposal to Local Government

The thermal comfort and shading results presented in the previous sections are translated into concrete, station-specific urban design sketches. Thus, the CSUD concept is not only presented as a theoretical approach but also developed into an applicable spatial design solution that responds to the characteristics and problems of each location. Figures 7–9 present the existing conditions and proposed improvements within the same visual frame, allowing the changes and additional design elements to be clearly identified. The existing conditions at each station, characterized by extensive hard paving, limited vegetation, and insufficient shading, are transformed through targeted interventions involving the road shoulder, pedestrian areas, vegetation elements, building facades, and openings to support natural ventilation. Each intervention is developed based on the measured conditions and environmental characteristics of the respective station, ensuring that the proposed solutions are not uniform but responsive to the specific thermal and spatial conditions of each location.

At Station 1, which recorded the highest average THI value (31.47°C), the sketch in Figure 7 proposes converting part of the road shoulder into a shaded pedestrian walkway lined with canopy trees such as *Mimusops elengi*, combined with overhangs on the shophouse facades facing the road. This directly targets the near-zero shading recorded at midday by extending the building's shadow footprint onto the pedestrian zone.



Figure 6. Proposed Climate-Sensitive Shading Design at Station 1

Source: Author documentation, 2025

At Station 2, which showed the highest average temperature and humidity among the three stations, the sketch in Figure 8 emphasizes potted and hanging vegetation along the narrower road corridor, where ground-level planting space is limited, together with cross-ventilation openings on building facades to make use of the relatively higher wind speeds recorded at this station.

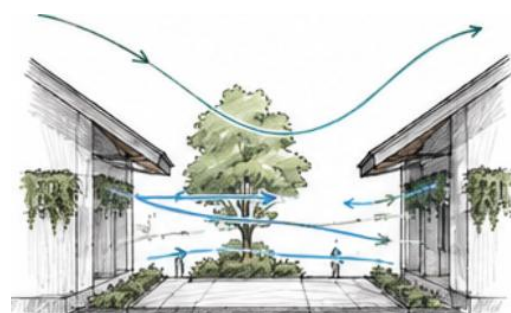


Figure 7. Proposed Climate-Sensitive Natural Ventilation Strategy at Station 2

Source: Author documentation, 2025

At Station 3, which recorded the highest single temperature reading (35.6°C at 13:00 WITA) as well as the highest afternoon shading intensity (55%), the sketch in Figure 9 proposes climbing plants and vertical greenery on building walls to reduce heat absorbed by the facade, positioned to reinforce the afternoon shadow pattern already present at this location while still improving comfort during the unshaded midday period.



Figure 8. Proposed Climate-Sensitive Green Corridor Design at Station 3

Source: Author documentation, 2025

These station-specific sketches, together with the adjustment recommendations summarized in Table 3, are intended to be developed further into a technical design guideline that can be formally proposed to the Penajam Paser Utara Regency Government, particularly the Regional Development Planning Agency (Bappeda) and the Public Works and Spatial Planning Office (Dinas PUPR), as an input for the spatial planning and building code of the regency's urban core. Positioning Penajam Paser Utara as a buffer area for the new national capital, this proposal offers local government a low-cost, incremental pathway, prioritizing vegetation, shading, and passive ventilation, to improve outdoor thermal comfort without requiring large-scale land acquisition or costly mechanical cooling infrastructure.

CONCLUSION AND RECOMMENDATION

As a buffer region for Ibu Kota Nusantara, Penajam Paser Utara Regency faces uncomfortable thermal

conditions due to high air temperatures and a lack of vegetation and shading. Daytime temperatures reach 35.6°C, with relatively high humidity. The lack of shading elements in this area exacerbates exposure to solar radiation, resulting in shadow intensity of only about 2% during the day, increasing to 55% in the afternoon. This condition is amplified by the interaction between building facades and building envelope properties in a high-density urban area, which together restrict natural shading and airflow.

To address this problem, the implementation of Climate Sensitive Urban Design concepts is a recommended solution. This strategy includes increasing vegetation to lower air temperatures and provide natural shade, installing artificial shading elements such as overhangs on buildings, and implementing cross-ventilation to improve natural air circulation. Vertical gardens are also recommended as an effective greening solution in areas with limited open space. By implementing these measures, the area can become more adaptive to climate change and support more sustainable and comfortable development for its residents.

The scientific contribution of this study lies in linking field-measured microclimate data (air temperature, humidity, wind speed, and THI) at station level with Ecotect-based shading simulation and station-specific urban design sketches, so that CSUD recommendations are grounded in local measured conditions rather than generic guidelines. This station-based, sketch-supported approach provides a replicable method for translating microclimate measurement into practical urban design interventions in other IKN buffer areas facing similar rapid urbanization pressures and offers Penajam Paser Utara Regency Government a concrete technical basis for climate-responsive spatial planning.

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