Evaluasi Kenyamanan Termal di Iklim Tropis: Studi Parametrik tentang Morfologi Perkotaan Hipotetis di Jakarta

Evaluating Thermal Comfort in Tropical Environments: A Parametric Study of Hypothetical Urban Morphology in Jakarta

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Abstrak

Pertumbuhan kota yang pesat telah membuat lebih dari setengah populasi dunia tinggal di perkotaan, dan urbanisasi diperkirakan mencapai 68% pada tahun 2050. Namun, pertumbuhan ini juga menyebabkan Urban Heat Island (UHI), yang berdampak negatif pada kenyamanan termal penduduk di lingkungan luar. Penelitian ini bertujuan untuk menemukan hubungan antara *urban morphology* dan kenyamanan ruang luar pada iklim tropis di Jakarta menggunakan indeks kenyamanan termal Universal Thermal Climate Index (UTCI). Metode penelitian menggunakan metode komputasi yang menggunakan bantuin *software* Rhinoceros 7 dan plugin Grasshoper untuk analisis simulasi. Desain parametrik dilakukan dengan parameter-parameter seperti *Building Site Coverage* (BSC), *Floor Area Ratio* (FAR), luas lapak, serta jumlah lantai dan tinggi bangunan. Objek penelitian ini adalah sebuah lahan bangunan yang direpresentasikan sebagai distrik hipotetis di lingkungan perumahan di Jakarta. Hasil penelitian ditemukan bahwa semakin besar Building Site Coverage maka nilai kenyamanan termal akan lebih baik, begitu juga sebaliknya. Hasil simulasi analisis Outdoor Thermal Comfort menghasilkan persebaran thermal yang dingin di sela-sela bangunan sisi timur dan barat, dibanding sisi utara dan selatan karena faktor radiasi matahari, pola angin, dan sirkulasi udara, pemilihan material juga memainkan peran penting dalam menentukan tingkat kenyamanan termal di dalam area yang diteliti.

Kata kunci: kepadatan; ladybug; morfologi; termal; UTCI

Abstract

The rapid growth of cities has led to over half of the world's population residing in urban areas, with urbanization projected to reach 68% by 2050. However, this growth has also given rise to the Urban Heat Island (UHI) phenomenon, negatively impacting the thermal comfort of inhabitants in outdoor environments. This research aims to explore the relationship between urban morphology and outdoor comfort in the tropical climate of Jakarta, utilizing the Universal Thermal Climate Index (UTCI) as a measure of thermal comfort. Computational methods, employing Rhinoceros 7 software and Grasshopper plugin for simulation analysis, were utilized in this study. Parametric design was conducted, considering parameters such as Building Site Coverage (BSC), Floor Area Ratio (FAR), plot size, number of floors and building height. The research focused on a hypothetical district within residential areas in Jakarta. The findings indicate that higher Building Site Coverage correlates with improved thermal comfort. Simulation results show cooler thermal distribution between buildings on the eastern and western sides compared to the northern and southern sides, influenced by factors such as solar radiation, wind patterns, and air circulation. Additionally, material selection played a significant role in determining the level of thermal comfort within the studied area.

***Keywords**: density; ladybug; morphology; thermal; UTCI*

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Introduction

Cities worldwide continue to grow significantly in size and number, driven by challenging economic conditions and high population pressures. According to the 2018 According to the World Urbanization Prospects report released by the United Nations (UN), more than half of the global populace presently lives in urban settings. It is anticipated that by 2050, the worldwide urbanization rate will climb to 68% (DAES, 2019). The expansion of population and urbanization has resulted several adverse impacts on the urban environment. One of the most concerning negative effects is the Urban Heat Island (UHI). UHI phenomenon arises when urban areas replace substitute indigenous vegetation with surfaces that absorb heat, such as pavements and buildings, leading to higher temperatures in comparison to nearby rural and suburban areas (Cheela et al., 2021). This temperature rise contributes to the broader issue of global warming and represents a substantial human-induced change that impacts Earth's ecosystems. Studies on UHI predominantly utilize air temperatures and land surface temperature (LST) extracted from data obtained through thermal infrared remote sensing (Jabbar et al., 2023).

Consequently, urban areas experience elevated temperatures, resulting in discomfort when outdoors and an increased demand for indoor air conditioning, leading to greater energy consumption for cooling systems. This energy use generates artificial heat, ultimately contributing to global warming in the ambient air. Increasing urban temperatures notably influence the thermal comfort experienced by residents in outdoor settings. Outdoor Thermal Comfort (OTC) refers to a mental state indicating contentment with the thermal conditions in the environment (ASHRAE, 1989), specifically related to outdoor environmental conditions. In humid tropical climates, the influence of the Urban Heat Island is typically twice as pronounced compared to its effects in other geographic regions (Binarti et al., 2019). Outdoor public spaces serve as essential components in the advancement of sustainable cities, facilitating not only daily pedestrian movement and diverse outdoor activities but also significantly enhancing the overall quality of urban life and vitality (Addas, 2023). OTC emerges as a pivotal factor directly impacting the perception of the quality of urban open spaces (Li et al., 2018).

The significant rise in urban air temperature has profound implications for the physiological well-being, thermal satisfaction, and urban livability (Aghamolaei et al., 2023). Research on urban morphology delves into the establishment of human settlements and the dynamics involved in their development and evolution, striving to classify spatial arrangements and characteristics of urban form. Insights into urban morphology are fundamental markers for urban planning, data handling, and endeavors concerning urban climate. With the rapid growth of urbanization, characterized by a significant migration from rural to urban areas, cities are witnessing a transformation towards high-density and three-dimensional urban built environments. This change in urban evolution has transformed the characteristics of urban surfaces and morphology, subsequently influencing the energy equilibrium of urban areas and the thermal satisfaction of inhabitants (Chen et al., 2021).

Urban morphology delves into the tangible manifestations of social and economic dynamics, evaluating the underlying intentions and assumptions shaping the formation and delineation of cities. Elements such as buildings, gardens, streets, parks, and sculptures are regarded as pivotal components of morphological analysis. However, over time, these elements undergo gradual modification and alteration (Moudon, 2022). The configuration of urban form is defined by three fundamental physical components: buildings along with their corresponding open areas, plots or parcels of land, and thoroughfares. This configuration can be comprehended across various levels of granularity, typically categorized into four tiers, encompassing the building/lot, street/block, city, and region.

Understanding urban form necessitates a historical lens, as its constituents undergo continual evolution and substitution over time (Soille, 2003).

According to (Pafka, 2017) the elements of urban morphology have several essential aspects. The four elements of urban morphology as outlined by Dovey consist of Density, Accessibility, Functional Mix, and Urban Interface. Urban morphology has a stronger impact on outdoor thermal comfort during the daytime compared to nighttime. While thermal conditions exhibit minor variations across different scenarios at night, significant differences emerge during the hottest periods. During nighttime, there is a relatively uniform dispersion of Mean Radiant Temperature (MRT) and Predicted Mean Vote (PMV) across the study area. However, during daytime, the thermal conditions display noticeable spatial heterogeneity, largely influenced by solar radiation (Zhang et al., 2022).

Urban morphology exerts a direct influence on thermal comfort by impacting factors such as solar radiation, mean radiant temperature, wind speed, and the configuration of various shading patterns. Considering this, examining the influence of urban morphology on outdoor thermal comfort in tropical climates is crucial for investigation. This study seeks to elucidate the correlation between urban morphology and outdoor thermal comfort in tropical climates, utilizing the Universal Thermal Climate Index (UTCI) as a metric for thermal comfort assessment. The UTCI integrates four outdoor thermal comfort parameters: Wind Speed (Va), Air Temperature (Ta), Humidity (rH, Pa), and Radiation (Tmrt) (Błazejczyk et al., 2013).

The UTCI is represented on a scale comprising ten stress levels, with each level determined by specific UTCI value ranges, represents the physiological burden caused by the human body's physiological response and thermoregulation in reaction to prevailing environmental circumstances (Błazejczyk et al., 2013). As this investigation centers on the summer season, it considers seven stress levels, spanning from moderate cold stress to extreme heat stress.

Xu (Xu et al., 2019) introduced an automated workflow to optimize urban spatial forms, aiming to improve outdoor thermal comfort conditions in Kashgar, China's dry and hot climate. The study focused on various urban block models, considering four parameters: building form, building height, open space layout, and street orientation. However, the research overlooked several influential parameters, such as footprint area and building site coverage. To address this, the author proposed integrating additional factors like building site coverage and gross floor area to better understand outdoor thermal comfort's impact on diverse urban morphologies. Despite unchanged urban block configurations throughout the study, this approach facilitated correlating resulting Universal Thermal Climate Index (UTCI) values with their respective parameters

In Yang research (Yang et al., 2022) the focus was on assessing how building spacing influences thermal conditions in residential areas, utilizing the Predicted Mean Vote (PMV) index. The study combined direct measurements and computational fluid dynamics (CFD) simulations across four case studies, primarily examining surface temperature, wind velocity, and mean radiant temperature (MRT). However, the study's narrow focus solely on actual case data limited parameter variability and trend observation, compounded by the one-day analysis duration, which restricted representation of climatic conditions. To address these limitations, future research aims to integrate hypothetical scenarios, broaden parameter ranges, and extend analysis periods, providing a more comprehensive understanding of thermal comfort trends and outdoor thermal comfort dynamics over time.

Angkasa's study in 2023 (Angkasa et al., 2023) explored the application of passive cooling techniques for Urban Heat Island (UHI) mitigation, employing a systematic literature review approach. While this study provides a comprehensive literature review, it does not delve deeply into the detailed analysis of passive cooling methods. However, the author's subsequent research extends this study, indirectly examining the influence of shading from urban block morphology on outdoor thermal comfort, a passive cooling method. This contributes to understanding how passive cooling strategies, like shading, can alleviate UHI effects, advocating for their integration into urban design and planning practices.

This research offers new perspectives on understanding the influence of urban morphology on outdoor thermal comfort, beginning with the complexity of parameters used. These parameters, including Area, Floor Area Ratio (FAR), Building Site Coverage (BSC), Gross Floor Area, Footprint Area, Floor, and Building Height, intricately interrelate, shaping the thermal environment. The study provides a comprehensive understanding of how surface characteristics, such as concrete, grass, and asphalt, impact outdoor thermal comfort. Conducted in the tropical climate of Jakarta, the research focuses on the hottest period of the year, capturing the peak climatic conditions typical of tropical regions. The Urban Thermal Comfort Index (UTCI) serves as the evaluation metric, reflecting human physiological responses to thermal environments, thereby enhancing insights into the intricate dynamics between ground materials and building plots in shaping outdoor thermal comfort.

Research Method

This research integrates computational simulation methods. Simulation can be defined as an effort to create a replica of real-world conditions (Groat et al., 2013). This research is using the Rhinoceros 7 + Grasshopper plug-in software program for simulation analysis. Grasshopper is a visual programming language as an additional plugin in the Rhino software. Rhino itself is a modeling tool commonly used in the architecture design industry.

Rhinoceros and Grasshopper are used as tools for studying the area's form. Parametric design is conducted with parameters such as Building Site Coverage (BSC), Floor Area Ratio (FAR), Footprint Area, as well as the number of floors and building height. To analyze outdoor thermal comfort, the author used the Ladybug plugin after the area model was formed. Ladybug is a parametric environmental plugin for Grasshopper that assists in visualizing and analyzing climate data, such as sun path, wind rose, psychrometric charts, and more.

This methodology is derived from Xu's research (Xu et al., 2019), which utilized Rhinoceros and Grasshopper to analyze urban morphology in actual case studies with building form, building height, open space layout and street orientation as a urban block design parameters and focusing on climatic output like Mean Radiant Temperature (MRT), average wind speed, and the Universal Thermal Climate Index (UTCI). This adaptation simplifies this approach by omitting the Model Generation process, allowing for a more straightforward analysis.

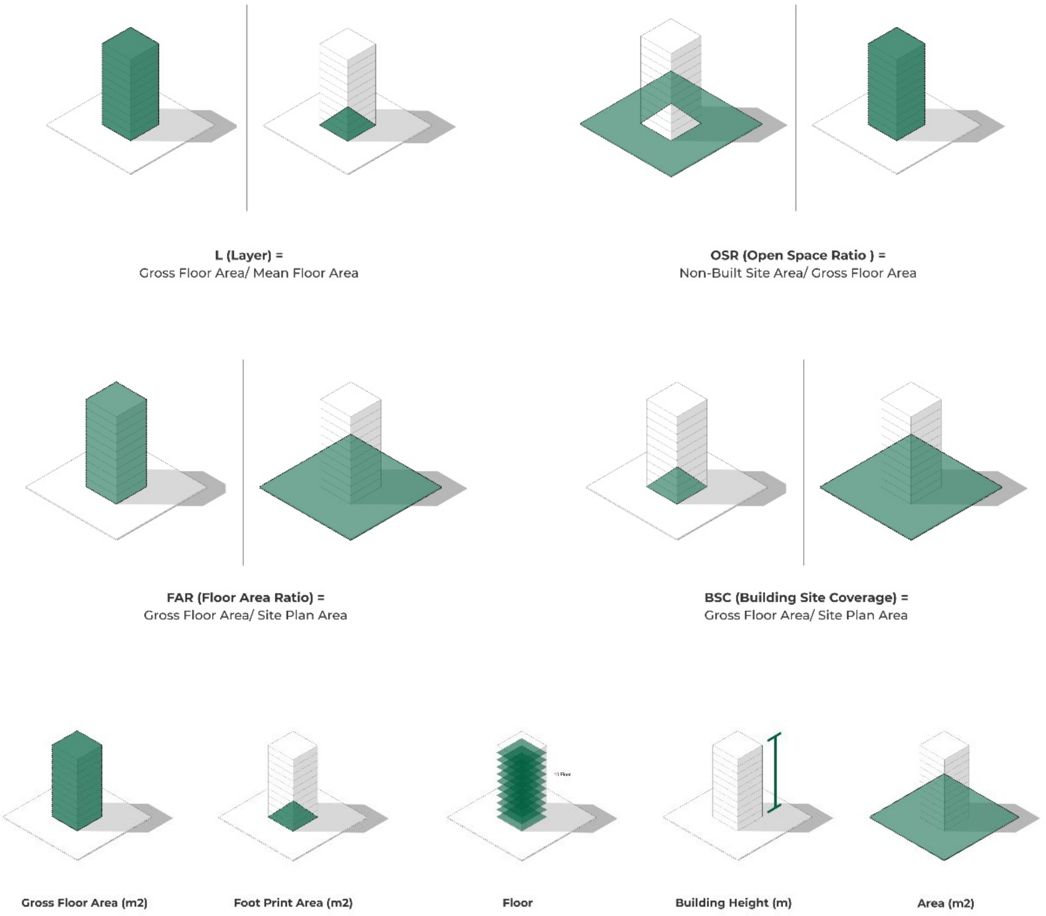


Figure 1. Density Indicators Variables

The density indicators variables were introduced by Pont, M. B. (Pont, 2015) as a comprehensive density indicator to describe urban geometry. These variables include:

- Open Space Ratio (OSR): represents the intensity of non-built land in an area.
- Layer (L): indicates the average number of floors in a building.
- Floor Area Ratio (FAR): describes the intensity of built-up area in a given area.
- Building Site Coverage (BSC): illustrates the proportion of built land in an area.

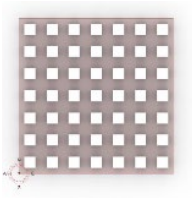
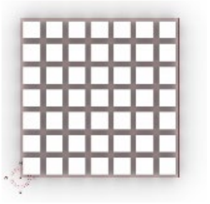
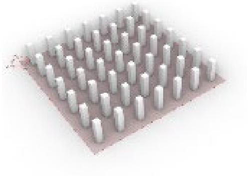
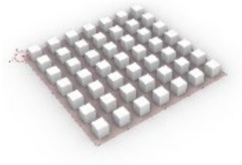
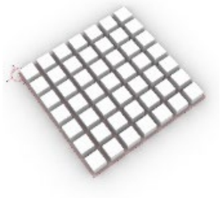
Additionally, in the context of this thesis, "gross floor area" refers to the total built-up area, "footprint area" is the land area occupied by a building, "floor" denotes the number of levels in a building, "building height" is the vertical dimension of a structure, and "Area" denotes the overall land area under study. By understanding and applying these variables, a comprehensive analysis of urban geometry can be conducted.

Tools and Methods

The object of this research is a building plot in the form of a hypothetical district in a residential area. This study defines the physical boundaries of the neighborhood area as 200 x 200 m. Three case studies were selected, distinguished by building density, which was assessed based on Building Site Coverage (BSC) with three different variables: 25%, 50%, and 75%. The selection of these three case studies was done with the aim of representing residential areas with low density on the outskirts of the city, medium density in denser urban areas, and high density in the dense city center.

This approach was adopted from Xu's research (Xu et al., 2019) to acquire a thorough comprehension of the influence of building density on outdoor thermal comfort. The urban configuration variables considered include:

Table 1. Urban Configuration Variable

Urban Block Parameter	**CASE 1**	**CASE 2**	**CASE 3**
2D			
3D			
Area	200 m x 200 m	200 m x 200 m	200 m x 200 m
FAR (Floor Area Ratio)	2	2	2
BSC (Building Site Coverage)	25%	50%	75%
Gross Floor Area (m2)	1632.7 m^2	1632.7 m^2	1632.7 m^2
Foot Print Area	204.1 m^2	408.2 m^2	612.2 m^2
Floor	8	4	3
Building Height	32 m	16 m	12 m

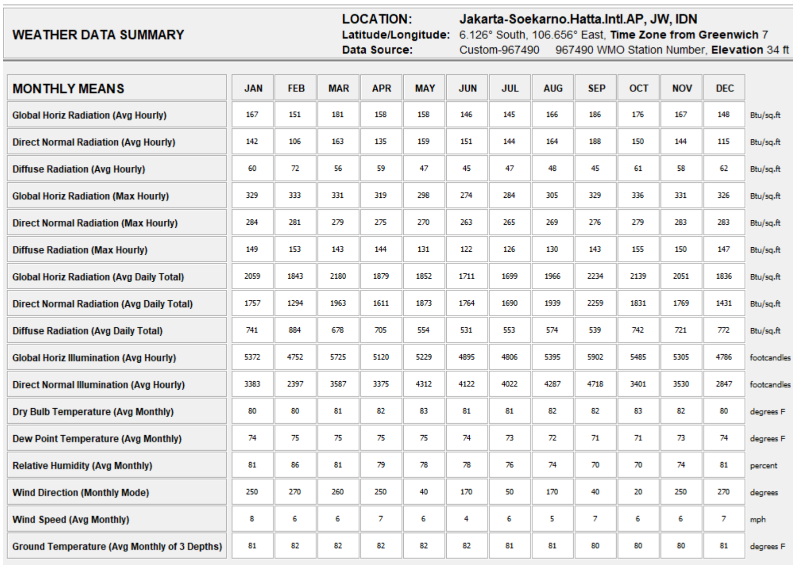
The simulation of outdoor thermal comfort uses ground reflectivity values for asphalt, concrete, and grass on the research object. This aims to examine the influence of differences in ground surface reflectivity on outdoor thermal comfort. By comparing these three materials, this study can provide a better understanding of how ground surface characteristics can affect outdoor thermal comfort.

Table 2. Ground Reflectivity Material

Materials	Ground Reflectivity
Concrete	0.40
Grass	0.25
Asphalt	0.10

Climate Setting

Meteorological data from the city of Jakarta was utilized to establish the climatic parameters for the model. The meteorological data has a latitude/longitude of 6.126° South, 106.656° East, with the following climate data and simulation settings:



WEATHER DATA SUMMARY

LOCATION: Jakarta-Soekarno.Hatta.Intl.AP, JW, IDN
Latitude/Longitude: 6.126° South, 106.656° East, **Time Zone from Greenwich** 7
Data Source: Custom-967490 967490 WMO Station Number, **Elevation** 34 ft

MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	167	151	181	158	158	146	145	166	186	176	167	148	Btu/sq.ft
Direct Normal Radiation (Avg Hourly)	142	106	163	135	159	151	144	164	188	150	144	115	Btu/sq.ft
Diffuse Radiation (Avg Hourly)	60	72	56	59	47	45	47	48	45	61	58	62	Btu/sq.ft
Global Horiz Radiation (Max Hourly)	329	333	331	319	298	274	284	305	329	336	331	326	Btu/sq.ft
Direct Normal Radiation (Max Hourly)	284	281	279	275	270	263	265	269	276	279	283	283	Btu/sq.ft
Diffuse Radiation (Max Hourly)	149	153	143	144	131	122	126	130	143	155	150	147	Btu/sq.ft
Global Horiz Radiation (Avg Daily Total)	2059	1843	2180	1879	1852	1711	1699	1966	2234	2139	2051	1836	Btu/sq.ft
Direct Normal Radiation (Avg Daily Total)	1757	1294	1963	1611	1873	1764	1690	1939	2259	1831	1769	1431	Btu/sq.ft
Diffuse Radiation (Avg Daily Total)	741	884	678	705	554	531	553	574	539	742	721	772	Btu/sq.ft
Global Horiz Illumination (Avg Hourly)	5372	4752	5725	5120	5229	4895	4806	5395	5902	5485	5305	4786	footcandles
Direct Normal Illumination (Avg Hourly)	3383	2397	3587	3375	4312	4122	4022	4287	4718	3401	3530	2847	footcandles
Dry Bulb Temperature (Avg Monthly)	80	80	81	82	83	81	81	82	82	83	82	80	degrees F
Dew Point Temperature (Avg Monthly)	74	75	75	75	75	74	73	72	71	71	73	74	degrees F
Relative Humidity (Avg Monthly)	81	86	81	79	78	78	76	74	70	70	74	81	percent
Wind Direction (Monthly Mode)	250	270	260	250	40	170	50	170	40	20	250	270	degrees
Wind Speed (Avg Monthly)	8	6	6	7	6	4	6	5	7	6	6	7	mph
Ground Temperature (Avg Monthly of 3 Depths)	81	82	82	82	82	82	81	81	80	80	80	81	degrees F

Figure 2. Weather Data Summary (Sources: climate.onebuilding.org)

Table 3. Climate Condition and Simulation Setting

Climate Information of Jakarta-Soekarno Hatta.Intl.AP, JW, IDN	
Location	6.126° S, 106.656° E
Temperature	28.3°C
Relative Humidity	70%
Wind Direction	From North and South
Wind Speed	6 mph
Hottest Period	15 - 21 October
Beginning of the simulation	6 am
End of the simulation	6 pm

The simulation process goes through several stages, starting from literature review, building configuration data, simulation, and generating climate maps. These stages are then elaborated as follows. The first stage involves a literature review of the characteristics of urban morphology forms and their parameters. Second, a 3D model of the area was generated using Rhinoceros 6 + Grasshopper plug-in software, with the case study divided into three segments according to the predetermined building variable configurations. Third, the inclusion of meteorological data in the form of Annual weather data (EPW File) taken from the location in Jakarta, the simulation of outdoor thermal comfort was conducted using the Ladybug plug-in, which was integrated with the preceding algorithm. The simulation outcomes will unveil the impacts of urban morphology on outdoor comfort. To see the simulation process in more detail, the following is the framework diagram of this research process:

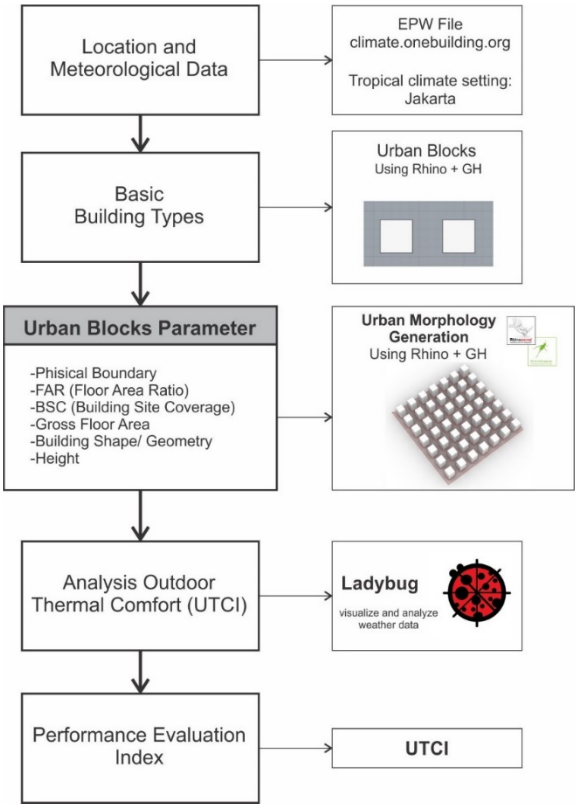


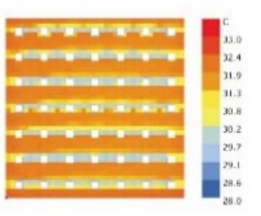
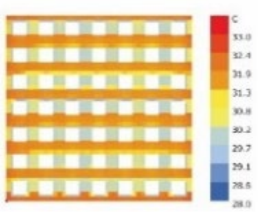
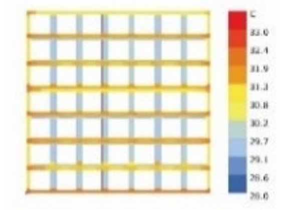
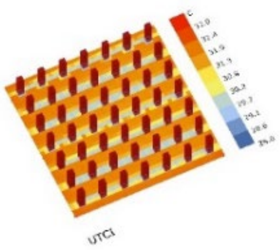
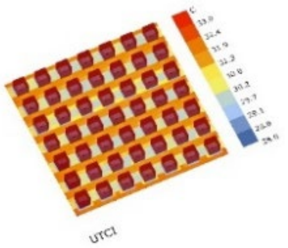
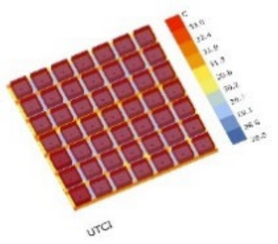
Figure 3. Research Framework

Result and Discussion

The results of the simulations for the three case studies using asphalt ground material depict UTCI conditions around the gaps between buildings on the east and west sides, with temperatures reaching 29.7°C. Meanwhile, on the northern side adjacent to the buildings, the temperature reaches 30.2°C, and on the southern side, further away from the buildings, the temperature reaches 31.3°C. The distribution of areas with a temperature of 29.7°C occurs evenly between the buildings on the east and west sides in each case study. Furthermore, there is a correlation between the Building Site Coverage (BSC) value and thermal distribution, as indicated by the lower UTCI values. The larger the BSC value, the more evident the thermal distribution with lower UTCI values. The UTCI outcomes classify within the moderate heat stress category, indicating that individuals exposed to high environmental temperatures experience some discomfort and moderate heat stress. While the body's thermoregulatory system is still functioning well, there may be a slight increase in skin wetness (Błazejczyk et al., 2013).

Table 4. Simulation Results of Case Studies with Asphalt Ground Material

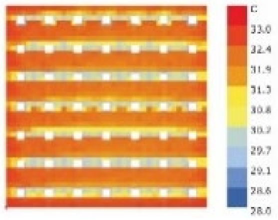
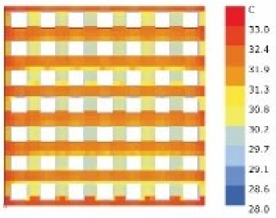
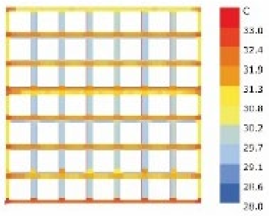
ASPHALT

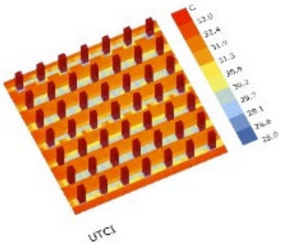
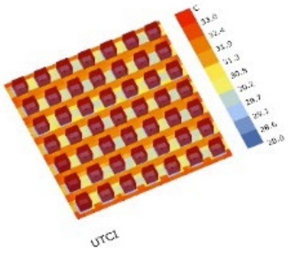
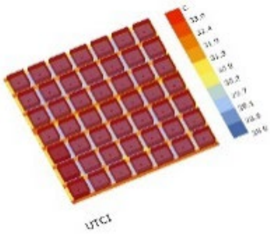
BSC 25%	BSC 50%	BSC 75%
		
		

Results of the simulation for the Grass material in the Case Study depict UTCI conditions dominated by a UTCI value of 31.3°C. Areas with a UTCI of 29.7°C between the space among buildings on the east and west sides have a decreasing and uneven distribution, with smaller Building Site Coverage (BSC) values resulting in a less uniform distribution of the UTCI value of 29.7°C. On the northern side of the buildings adjacent to other buildings, there is a small area with a UTCI range between 30.2 to 30.8°C. Meanwhile, on the southern side of the buildings, a UTCI result of 31.3 to 31.9°C is recorded. The western and southern sides of the neighborhood district are the hottest areas, with UTCI reaching 33.0°C. The UTCI results on the east, west, north, and south sides of the buildings, ranging from 29.1 to 31.9°C, are categorized as experiencing Moderate Heat Stress. The western and southern sides of the neighborhood district, with UTCI ranging from 32.4 to 33.0°C, are classified as experiencing Strong Heat Stress. This means that the body experiences an increase in internal temperature and increased sweating. This makes people in the area feel very hot and lose heat rapidly (Błazejczyk et al., 2013). Strong Heat Stress can even lead to fatigue, dizziness, and muscle cramps.

Table 5. Simulation Results of Case Studies with Grass Ground Material

GRASS

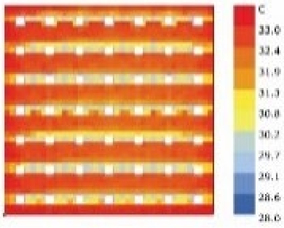
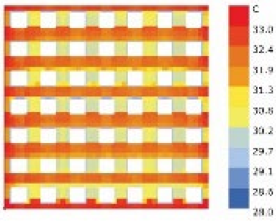
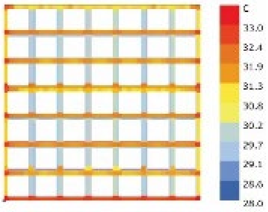
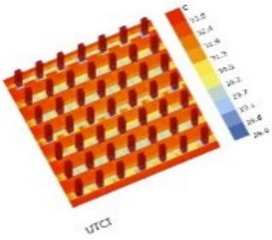
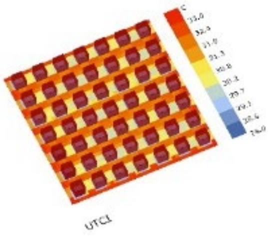
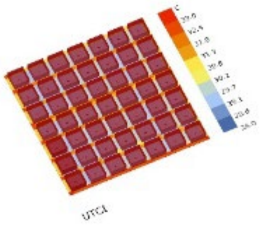
BSC 25%	BSC 50%	BSC 75%
		

GRASS		
BSC 25%	BSC 50%	BSC 75%
		

Results of the simulation for the Concrete material in the Case Study depict the hottest UTCI conditions. The gaps between the buildings on the east and west sides record a temperature of 29.7°C, which has limited distribution, especially at a Building Site Coverage (BSC) value of 25%. Areas with a UTCI result between 30.2 to 30.8°C are located in a small portion on the northern side and are more inclined to be found on the east and west sides. The southern side of the buildings results in a UTCI of up to 32.4°C. The western and southern sides of the neighborhood district are the hottest areas, with UTCI reaching 33.0°C. The UTCI results in the gaps between buildings and a small area to the north have a range of 29.1 to 31.9°C, falling into the category of Moderate Heat Stress. Generally, UTCI results for this material produce temperatures of 32.4 to 33.0°C, especially on the southern side of the buildings and the western side of the neighborhood district, classifying as Strong Heat Stress.

The UTCI outcomes signifies the body's ability to adapt to changes in thermal sensation, such as feeling warmer or cooler in response to environmental conditions, indicating an increase in sweat production that helps regulate body temperature by dissipating heat through evaporation, and reflecting a rise in skin temperature, a physiological response to heat stress (Błazejczyk et al., 2013).

Table 6. Simulation Results of Case Studies with Concrete Ground Material

CONCRETE		
BSC 25%	BSC 50%	BSC 75%
		
		

Here are the average thermal comfort values (UTCI) for each material and Building Site Coverage (BSC):

Table 7. UTCI for each material and Building Site Coverage

Building Site Coverage	**Ground Material**		
	Asphalt	**Grass**	**Concrete**
25%	30.98°C	31.24°C	31.50°C
50%	30.40°C	31.56°C	31.74°C
75%	29.65°C	29.71°C	29.77°C

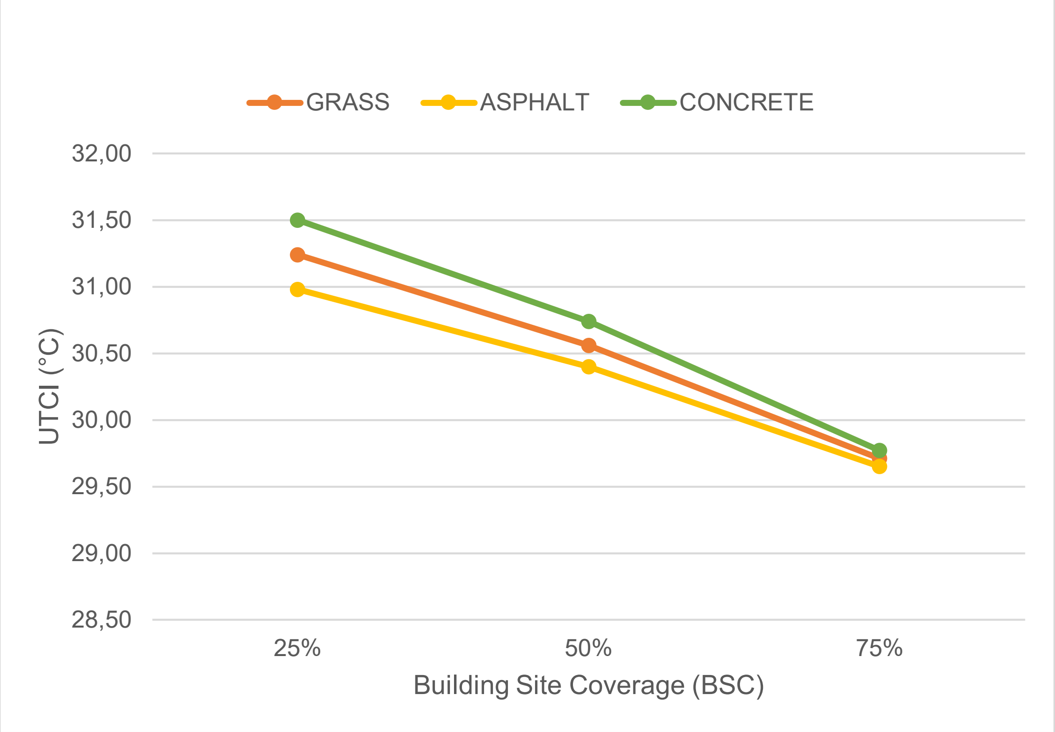


Figure 4. Graph of UTCI Results in Relation to Building Site Coverage

From the simulation results, it was found that the larger the Building Site Coverage (BSC), the lower the thermal comfort values (UTCI), indicating a higher level of thermal comfort, and vice versa. The simulation results of the Outdoor Thermal Comfort analysis showed a cooler thermal distribution among the spaces between buildings on the eastern and western sides, while the north and south sides exhibited a warmer thermal distribution. According to previous research, several factors can explain this phenomenon, including solar orientation. Solar orientation is one of the crucial factors influencing thermal distribution in urban areas (Singh et al., 2023). In this case, the east and west sides of buildings receive direct sunlight from morning until afternoon, causing temperatures on these sides to be lower due to the cooling effect provided by the building's shadows during these times. On the other hand, the north and south sides of the buildings receive sunlight at a smaller angle, resulting in lower solar radiation intensity and minimal shading effects. Furthermore, wind patterns and air circulation also play a significant role in thermal distribution within urban areas (Son et al., 2022). Winds blowing from the north to the south in this location can help reduce temperatures and provide a natural cooling effect, leading to cooler thermal conditions on the eastern and western sides of the buildings. On the northern and southern sides of the buildings, there is a tendency for the formation of stagnant air patterns, where the wind has difficulty moving freely due to building obstructions. This leads to higher temperatures on these sides due to a lack of effective air circulation. In environments with extremely high temperatures, the choice of suitable land cover materials plays a crucial role in determining thermal comfort (Tan et al., 2024).

In this context, ground reflectivity refers to the surface's ability to reflect the incoming solar radiation. In this simulation, concrete, which has a ground reflectivity value of 0.40, exhibited the highest thermal comfort values because it has a greater ability to reflect solar radiation compared to other materials. Meanwhile, the ground reflectivity value of grass is 0.25, indicating that it reflects some of the sunlight that falls on it but not as effectively as concrete, consistent with the findings of the study conducted by Wang (Wang et al., 2021). Wang highlights the cooling effect of lawns and soil through evaporation, noting their significant radiation absorption coefficient, leading to higher local temperatures. The existence of greenery in the vicinity can affect bricked ground and trigger a distinct cooling effect. On the other hand, asphalt has the lowest ground reflectivity value, which is 0.10. This material has limited capacity to reflect solar radiation but is proficient at absorbing sunlight in the morning and afternoon, causing most of the solar energy to be absorbed by its surface. This results in surface heating and lower environmental temperatures during the morning and afternoon simulation period.

This study has several limitations. Firstly, regarding building types, the study aims to extract simplified urban form types, indices, and regular building combination layouts within actual blocks. Secondly, concerning urban scale, the research focuses on how block forms influence climate factors that alter outdoor thermal comfort. This approach simplifies the study of urban forms at the block scale without addressing the effects of landscape elements like vegetation, water, and pavement on comfort. Thirdly, in terms of climate elements, the study concentrates on urban microclimate and does not consider broader climatic conditions. The focus is on extreme seasonal climatic conditions in tropical areas, particularly Jakarta. Additionally, the study does not introduce more indices that should be considered in future research, such as the PMV (Predicted Mean Vote), PPD (Predicted Percentage of Dissatisfied), and the associated energy consumption of buildings.

The findings from this study have significant implications for urban planning and design practices in tropical climates, particularly in cities like Jakarta. The research demonstrates that orientation of buildings, urban density, and material selection significantly affect thermal conditions, with east and west-facing buildings showing cooler UTCI values due to natural shading effects, while north and south sides experience higher temperatures. Lower Building Site Coverage (BSC) leads to greater thermal variation, whereas higher BSC correlates with improved thermal comfort. Additionally, materials with higher ground reflectivity, such as concrete, better reflect solar radiation, enhancing thermal comfort compared to materials like asphalt. These insights emphasize the need for urban planners to integrate strategic building orientations, density management, and material selection into urban design to mitigate heat stress and improve livability in tropical cities.

Conclusion

Through simulation, we studied the relationships between urban morphology and thermal comfort in Jakarta. The conclusions can be summarized as follows:

Firstly, it was found that smaller Building Site Coverage results in greater variations in thermal distribution. This phenomenon suggests a significant interplay between urban morphology and thermal comfort, where the density and spatial configuration of buildings within an area markedly influence the thermal environment. In areas with lower Building Site Coverage, the spaces between buildings are more varied, leading to a wider range of thermal conditions.

Secondly, the study revealed that the spaces between buildings on the east and west sides showed cooler UTCI values, whereas the north and south sides exhibited warmer thermal conditions. This is influenced by several factors, including the direction of the sun and wind patterns. Blocks exposed to the sun from morning to evening tend to have lower thermal conditions due to the cooling effect produced by the building's shadow during those times. Additionally, areas traversed by wind can help reduce temperatures and provide a natural cooling effect, resulting in lower thermal conditions.

Lastly, the choice of materials significantly affects the thermal comfort of the area. The greater the ground reflectivity of a material, the hotter the thermal conditions, and vice versa. This is caused by the ability of surface materials to reflect solar radiation. For instance, concrete, with a higher ground reflectivity, demonstrated better thermal comfort due to its superior ability to reflect solar radiation compared to materials like grass and asphalt, which have lower ground reflectivity and thus absorb more sunlight, leading to higher surface temperatures. These findings emphasize the critical role of urban morphology factors such as building density, orientation, wind patterns, and material selection in enhancing outdoor thermal comfort.

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