The Impact of Sky View Factor on Pedestrian Thermal Comfort in Tropical Context: A Case of Jakarta Sidewalk

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Abstract Rapid increase of high Urban Heat Island (UHI) intensity, as one of the main contributors to climate change, is an urgent environmental issue in high dense cities today. The development of outdoor environment influences the pattern and behavior of city dwellers. Climate and physical features parameters affect the thermal comfort of humans doing their outdoor activities, such as walking. However, climate factors in identifying the success of an outdoor design is not frequently discussed especially in the tropical context. This study aims to determine the effect of microclimate on the sidewalk in Sudirman and Thamrin Street with spatial variations on thermal comfort by using Envi-met and Rayman simulation to determine the effect of thermal comfort on the comfort of walking activities in outdoor space. The level of walking comfort was analyzed using the correlation model of Outdoor Thermal Comfort (OTC). This study pinpoints that Sky View Factor (SVF) significantly correlated to thermal comfort (T_{mrt} and PET). This study also reported that 5 pm is the most comfortable time for walking while the least comfortable is at 1 pm in less and moderate shaded areas.

Keywords Microclimate · Thermal comfort · Walking comfort · Jakarta sidewalk · Tropical context

1 Introduction

Increase of Urban Heat Island (UHI) intensity is currently an ongoing issue that occurs in high-density cities as one of the impacts of rapid urbanization. Urban development significantly modified the meteorological conditions of the surrounding area [1] and have an impact on the urban microclimate especially the rising of air temperatures [2]. There are two substantial scales to measure the urban heat islands, which are urban boundary layer (UBL) and the urban canopy layer

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(UCL) [3]. UBL is the scale above the building roughness level, while UCL is the scale roughly between the ground and the roof level of the building known as a micro-scale. In this study, thermal comfort condition was considered as the UHI at the UCL scale.

Outdoor thermal comfort is predominantly and tacitly associated with the UHI phenomenon [4]. Thermal comfort is defined as level of human satisfaction based on a combined effect of the physical and climatic parameters [5]. Human thermal comfort sensation is influenced by four factors, namely air temperature, radiation temperature, humidity, and wind speed [6] as well as individual factors including clothing and activities [7]. In tropical climates, humans are more likely to look for places with cooler temperatures [8]. Poor thermal comfort in public spaces causes a low public interest in carrying out outdoor activities in public spaces, one of which is walking. Studies shown that there is a strong correlation between walkability and city sustainability. UHI that is not mitigated properly will cause a significant increase of household energy demand [9]. By this, walkability has been seen as the main basis for urban sustainability [10].

As the biggest metropolis in Indonesia, Jakarta continues to grow and develop rapidly especially in the central of Jakarta. UHI in Jakarta could be seen by the increasing of air temperature in 2014 up to 2–3 °C higher compared to 2001 [11]. The main issue on this study is the high-density environment and pedestrians in the central of Jakarta. Sudirman and Thamrin Street is the main road of the city center, and currently completed the government's master plan project to design a comprehensive and integrated transportation system, including the pedestrian networks. In order to evaluate the Sudirman and Thamrin sidewalk, this study aims to investigate the pedestrian in Sudirman and Thamrin sidewalk through spatial, microclimate and thermal comfort variables by using simulation. This study also analyses the effect of thermal comfort on the comfort of walking activities in outdoor spaces by using the Outdoor Thermal Comfort (OTC) correlation model.

2 Methods

This study was situated at Sudirman and Thamrin Street, the main roads of Jakarta city center. Jakarta has a tropical climate that is hot and humid. Along the Sudirman and Thamrin sidewalk, six points have been selected as case study. In this study, the location of the receptor points was chosen based on the function and character of the surrounding area which affects the activity of pedestrian and the spatial character such as closed, shaded and open areas to develop various possible conditions of thermal comfort.

This study uses two simulation models, namely Envi-met and RayMan. Envi-met simulation is used to calculate the microclimate data and value of mean radian temperature (T_{mrt}). Meanwhile, RayMan simulation is used to calculate the sky view factor (SVF) and calculating Physiologically Equivalent Temperature (PET). The simulation conducted on May, 1st 2020, during 12 h from 6 am to

6 pm. Configuration used in Envi-met model is a 10 × 10 m limitation and a 20 × 20 × 20 grid. Due to the limitations in the process of taking direct meteorological data during the COVID-19 pandemic in 2020, the microclimate data from Envi-met simulation are used in RayMan simulation. Subjects in the Rayman simulation used personal data as users and receptors (150 cm height, 50 kg body weight, and 25 years of age). The RayMan simulation is calculated at 3 different times: (1) morning at 7.00 WIB; (2) during the day at 13.00 WIB; (3) afternoon at 17.00 WIB. These times reflected typical times of morning and evening commutes, and time close to the midday when the radiation is the highest.

Statistical analysis was used to determine the effect of microclimate variables on thermal comfort on the Sudirman and Thamrin sidewalk. The correlation test is used to show a relationship between each variable. The variables analysed were T_{mrt}, Air Temperature (T_a), SVF, Wind Speed (v), and Relative Humidity (RH). Correlation analysis using Bivariate Pearson correlation with SPSS program. The data used were Envi-met model data which had previously been validated. Through this study, it would be known the impact of SVF, to microclimate and thermal comfort (T_{mrt} and PET) and how important of its impact on outdoor thermal comfort consequently.

3 Results and Discussion

In this analysis, we focused on the correlation of SVF with microclimate and thermal comfort based on simulation that have been performed using Envi-met and RayMan. Figure 1 shows the Sky View Factor (SVF) value calculated using the RayMan application to show conditions at the receptor point.

Based on Rayman simulations, point A and point F has the lowest SVF value of 0.136 and 0.393, therefore these two points are categorized as highly shaded area. As seen, point A has lowest exposure to the sky caused by building and vegetation. Meanwhile, Point C and D are categorized as moderate shaded area. Point B and point E are categorized as less shaded area. Comparing SVF maps of each points shown in Fig. 1.

Figure 2 shows the T_{mrt} distribution maps at 13.00 (maximum solar radiation). The colors indicate the mean radiant temperature within the area. The highest T_{mrt} is concentrated on the main road with T_{mrt} values is up to 15 °C higher than shadowing areas due to the direct solar radiation. The model in Point A and F perform better than other points. While, Point E has the highest T_{mrt} value on most of its surface. Table 1 shows the SVF value as environment variables and climatic variables in Sudirman and Thamrin Street.

The results indicate the correlation between the SVF value shown in Fig. 2. Distribution of mean radian temperature (T_{mrt}) at 13.00 in six receptor points where in those particular points have lower SVF value. This is rational because when there is no radiation, the heat released and reflected between surfaces in the

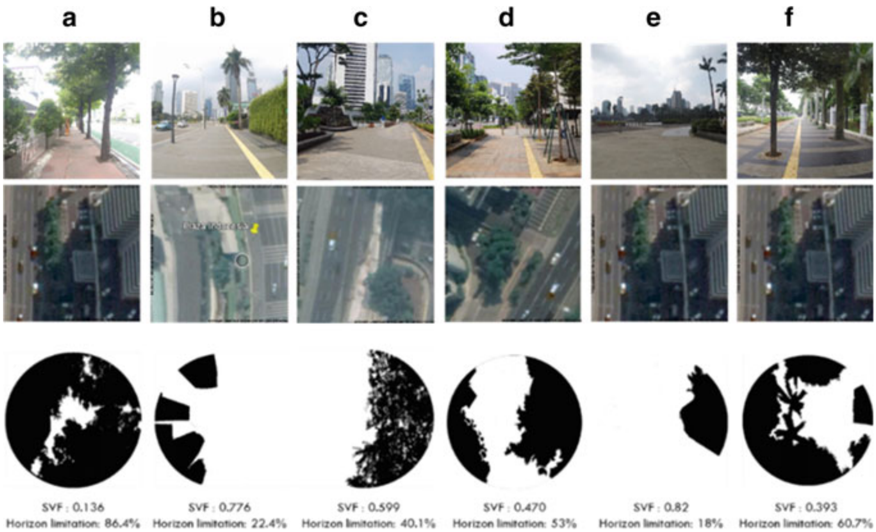

Fig. 1 Sky view factor calculations at 6 receptor locations using RayMan's simulations

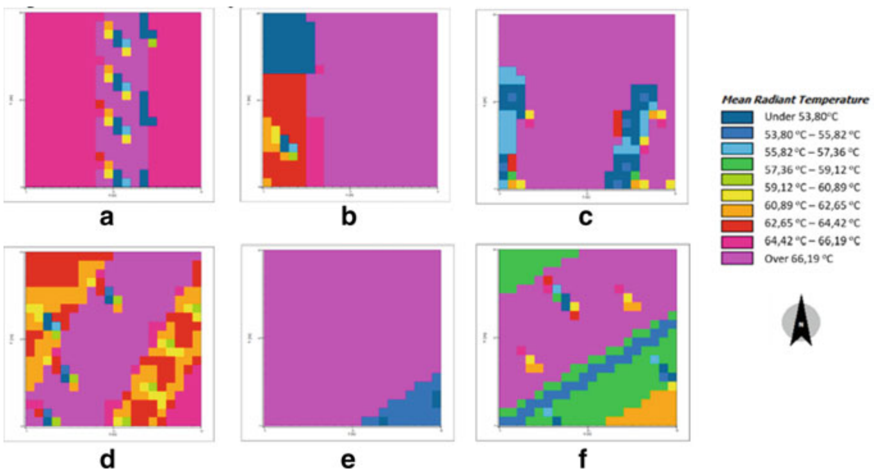

Fig. 2 Distribution of mean radian temperature (T_{mrt}) at 13.00 on six receptor points

form of long-wave radiation. To determine how far the sky view factor affects the thermal comfort, a correlation analysis is needed. The result is shown on Table 2.

Results quantitatively show that SVF is significantly correlated with SVF, while T_a, T_{mrt}, and PET with the value 0.905, 0.750, and 0.748. Based on the correlation results, SVF affects T_{mrt}, and PET in Jalan Sudirman and Thamrin. Thermal comfort will increase as the SVF value increasing. Correlation SVF and thermal

Table 1 Value of SVF, microclimate variables, and thermal comfort

Receptor points	SVF	T_a (°C)	RH (%)	v (m/s)	T_{mrt} (°C)	PET (°C)
A	0.136	25.23	94.55	2.14	55.05	23.50
B	0.776	25.38	93.32	2.07	58.75	29.87
C	0.599	25.36	94.38	2.01	58.77	30.00
D	0.470	25.34	94.43	1.93	55.98	29.93
E	0.820	25.49	93.13	1.94	58.83	30.10
F	0.393	25.24	96.05	1.87	58.84	30.20

Table 2 Pearson correlation coefficients between SVF and the microclimate and thermal comfort indices for all six points using Envi-met simulations

	SVF
T_a	0.905
RH	−0.689
v	−0.266
T_{mrt}	0.750
PET	0.748

comfort prove that the location in the less shaded area is much more get the sun penetration and will be hotter than the location in the shaded area. Different with negative value of correlation between SVF and relative humidity. This means that increasing of SVF will decreasing the humidity.

Using the model of Outdoor Thermal Comfort on walking (OTCw), the walking comfort value is estimated. The walking comfort is calculated at three different times and divided into three categories based on SVF value. Table 3 illustrates the results of walking comfort simulation at 7:00, 13:00, and 17:00. Based on simulation results, it is known that the highest discomfort on walking experience occur in moderate and less shaded area at 13.00 with the OTCw value is 5.1. Meanwhile, a more comfortable time on three locations achieved at 17.00 in the afternoon with OTCw value is 1.7 or the perception of warm.

In the walking comfort, it is indicated that the role of T_{mrt} and T_a are more dominant than the influence of wind speed. In this study it can be seen the

Table 3 The simulation results of walking comfort

Time	Highly shaded		Moderate shaded		Less shaded	
	OTCw	Preception	OTCw	Preception	OTCw	Preception
7:00	2.2	Hot/ uncomfortable	2.2	Hot/ uncomfortable	2.2	Hot/ uncomfortable
13:00	3.5	Very hot/very uncomfortable	5.1	Very very hot/ very very uncomfortable	5.1	Very very hot/ very very uncomfortable
17:00	1.7	Warm/slightly uncomfortable	1.7	Warm/slightly uncomfortable	1.7	Warm/slightly uncomfortable

significant effect of SVF on walking comfort. Receptor points with high shaded area have a better walking comfort level than the moderate and less shaded area. This shown at 13.00 when the solar radiation reaches its peak and causing OTCw value on moderate and shaded area increased up to 5.1 while the high shaded area only increased to 3.5. The lowest OTCw value occurs at 17.00 in three areas. This indicates that apart from SVF, the values of T_{mrt} and T_a are very influential on walking comfort level. Meanwhile, wind speed and humidity variables did not significantly affect walking comfort.

4 Conclusions

This research found that environmental parameters in the form of SVF have a significant correlation with thermal comfort. The result show that in Jakarta context, the exposure of area to solar radiation indicates higher air temperature (T_a), mean radiant temperature (T_{mrt}) and Physiologically Equivalent Temperature (PET). This also related to walking comfort that mostly effected by thermal comfort. Receptor points with high shaded areas have a better comfort level than moderate and less shaded areas, especially at 13.00 when the highest radiation occurs.

This research is based on the simulation data analysis and discussions. Using Envi-met and RayMan allow us to determine the environmental impact of the SVF. This also allowing us to have a better understanding on the experience of thermal comfort in existing city area. Further researches could include comparison between specified urban geometry changes, varied urban vegetation volumes, measurement on people experiences with different activities, and the impacts of different building surface coatings and ground surface materials. This analysis contributes to planning policies development with environmental strategies.

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