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CHANGES IN MICROCLIMATE DUE TO THE PROPERTIES OF LANDSCAPE MATERIALS: A CASE STUDY IN A COASTAL CITY OF A TROPICAL AREA

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ABSTRACT
The objective of this research is to determine the role of landscape materials in microclimate changes within a tropical humid environment, specifically in coastal areas. Landscape materials possess thermophysical properties that can influence microclimate changes. This study focuses on three microclimate variables: surface temperature, air temperature and solar radiation. The landscape materials examined include bricks, dry` soil, paving stones, trees, and a garden pond. A quantitative descriptive analysis method was employed. Thermophysical properties of local materials, such as red bricks and paving blocks, were measured using a calorimeter, infrared thermometer, and thermocouples. Microclimate measurements were conducted in the open space of a commercial zone at coastal area of Manado City, Indonesia. The measurement include solar radiation, air temperature, and surface temperature of various materials. The HEAT2 computer program was used to assist in analyzing changes in surface temperature due to the presence of different landscape materials. The results revealed that at midday, trees could reduce solar radiation by up to 80% under their shade. Conversely, materials like bricks, paving stones, and hard soil, when exposed to direct sunlight, could cause surface temperatures to reach up to 50°C. The surface temperature of the garden pond water could reach 50°C, but at a depth of 50 cm, the temperature dropped to 25°C.

Keyword: ***landscape, tropical, microclimate, heat transfer***

INTRODUCTION

In general, humans engaged in outdoor activities feel physiologically comfortable when they are in environments with temperatures that are neither too hot nor too cold, especially when accompanied by a cool breeze. However, the intense heat of the sun, which can be very hot during the day, causes thermal discomfort, prompting people to seek shelter under shade, such as under trees or other forms of cover. In this context, besides atmospheric climate factors, the morphology and physical anatomy of outdoor architectural spaces also play a role in varying the thermal comfort levels for individuals engaged in activities, both during the day and at night. The physical properties of landscape surface materials can cause changes in microclimates. The surface temperature of materials exposed to direct sunlight during the day can lead to heat radiation from the materials, which also increases the heat load in outdoor spaces. The most influential microclimate variables on the scale of thermal comfort in outdoor spaces are radiation temperature, air temperature, and wind (Givoni, 1998; Sangkertadi, 2013; Sangkertadi & Syafriny, 2016; Aghamolaei et al, 2022).

Landscape morphology, composed of various types of materials, is known to affect microclimate changes, particularly environmental temperature (Thani et al., 2017; Liu S et al, 2021). However, the thermophysical properties of landscape materials are an inseparable part of morphological characteristics. Even water surfaces can influence the microclimate (Lesi, 2017). The thermophysical properties of materials will affect their surface temperature and be radiative when exposed to solar radiation in outdoor spaces (Szokolay, 2010, Zold & Szokolay, 1997; Anand et al, 2022). The physical morphological properties of greenery also significantly affect the filtration of solar heat radiation (Shahidan et al., 2007; Wang K et al, 2022).

In tropical climates, the amount of solar radiation energy is the main source of environmental heat in outdoor spaces. Several studies on heat transfer physics explain that heat energy from solar and sky radiation is partially absorbed by landscape materials, partially reflected, and some is transmitted to the ground (Szokolay, 2010; Zold & Szokolay, 2007; ASHRAE, 2017). After a while, the materials radiate heat into the surrounding environment due to the limited capacity of the material to store heat (Noerwasito, 2020). In this regard, the heat capacity of materials and the emissivity properties of materials are two important parameters to prevent excessive heat emission into the surrounding environment. In addition, the thermal conductivity of materials also affects a material's ability to transfer heat energy to other materials, for example, from the surface of paving to the ground.

Fundamentally, the concept of a microclimate refers to the climate conditions of an area with limited size or function, but whose components are largely the same as those of the macroclimate, including factors such as air temperature, humidity, wind, and solar radiation. Microclimate studies are generally conducted for specific purposes, such as in urban areas, rural areas, or other regions (Lakitan, 2002; Karyati, 2019).

In a limited areas, changes in the microclimate are influenced by the physical elements present in the environment of that specific area. For example, in urban centers, the influence of city architecture or urban landscapes will have a significant impact on the microclimate's components, such as air temperature, humidity, and wind movement (Gaitani et al., 2011; Iek et al., 2014; Yang S et al, 2023).

In the context of architectural science, the thermophysical properties of materials that should be considered include heat capacity, thermal conductivity, emissivity, and density (Szokolay, 2010; Noerwasito, 2020). Solar radiation striking horizontal surfaces in tropical climates can exceed 1000 W/m^2 at midday (Lakitan, 2002). This heat can cause surface temperatures in the environment to reach 40°C on materials such as concrete pavements (Takebayashi & Kyogoku, 2018). The color of the material also plays a role, as it impacts the albedo properties, which in turn affect emissivity and ultimately result in higher radiation or surface temperatures of materials (Lesi, 2017; Joo-Hwa & Lay, 2006).

Understanding the thermophysical characteristics of materials makes it easier to optimize landscape architectural designs to create a comfortable microclimate for users (Choi et al., 2021). Most of the previous studies referred to material data sourced from European and American literature. However, this research uses local materials, whose thermophysical properties are measured first, and then their impact on the thermal response of the environment is examined. Therefore, it is hypothesized that local materials have different thermophysical properties from those found in the literature, which will lead to a different thermal response compared to previous studies.

More specifically, this study aims to gain a deeper understanding of the extent of microclimate variables caused by the application of various types of landscape materials, including surface pavements found at the research location (brick, paving, soil), water, and trees. The microclimate variables in question include material surface temperature, air temperature, and solar radiation penetration. The location of this study is in the commercial beach area of The Mega Mas in Manado City, Indonesia. The landscape formation in this study area consists of paving materials, trees, and a small garden pond (Figure 1). During the day, the outdoor space appears quiet, possibly due to the hot microclimate, but at night, many visitors engage in outdoor activities.

Figure 1. Land situation of the location of the study

METHOD

This research applies a quantitative descriptive method, which includes measurement processes, practical calculations, and computer simulations. The schematic of the research process is shown in Figure 2. The field measurement location is in the Mega Mas beach area, Manado City (Figure 1).

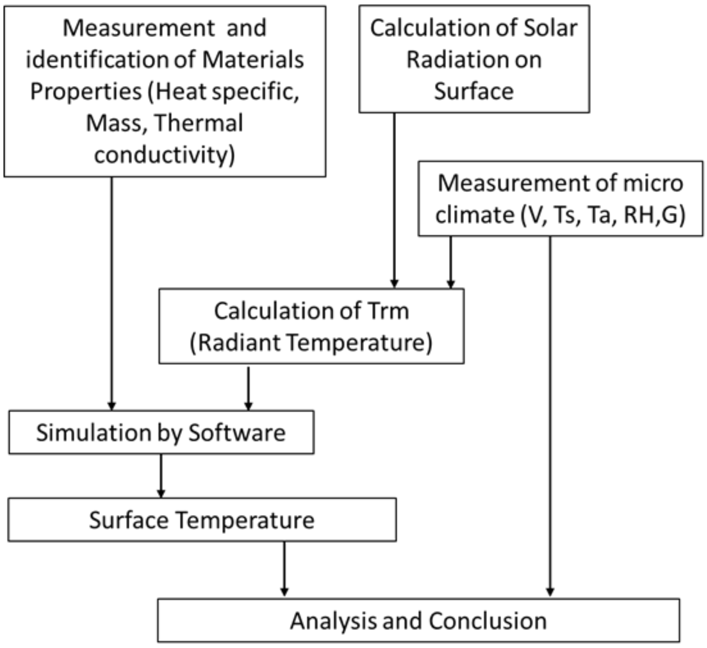

Figure 2. Flow chart of methodology

Measurement and Identification of Material Properties

The materials selected for measuring the thermophysical properties in this study are bricks and paving blocks, which are traditional local products. Laboratory measurements were conducted to determine the heat capacity (c) in Joules/kg°C, thermal conductivity in W/m°C, and density in kg/m^3. The instruments used for these measurements include a Joule calorimeter, thermocouples, and an infrared thermometer. For other materials, such as soil and water, data on heat capacity, density, and thermal conductivity were sourced from various literatures.

Environmental Climate Measurement

Environmental climate measurements include air temperature, material surface temperature, and solar radiation. Measurements were conducted when the sun was not covered by clouds. The equipment used consists of an infrared thermometer (for measuring material surface temperature), a solar power meter (for measuring solar radiation), and a digital thermometer (for measuring air temperature). Surface temperature and radiation measurements were taken at points located under the shade of densely foliaged trees, and those facing the open sky with direct sunlight exposure. Additionally, surface temperature measurements of the garden pond water were taken, as well as the temperature at the bottom of the pond, 50 cm deep. Air temperature measurements were taken at the typical human activity height of 1.5 meters above the material surface.

Computational Simulation and Calculations

The calculation of heat transfer by conduction was performed using the HEAT2 computer program, which is used to determine the material surface temperature caused by radiation penetration from above. The physical and simulation modelling for this are shown in Figure 3. Solar radiation from above subsequently causes the radiation temperature to affect the material, where there is a layer of air above it (a thin air layer that acts as a conductance film in the heat conduction transfer mechanism). By using the HEAT2 software, the solver applied is a transient calculation, with the input boundary (at the top of the material) consisting of temperature values that vary each hour, representing the radiation temperature from the sun. The RAYMAN computer program is used as tool to calculate the average radiation temperature (Trm) due to the effect of solar radiation energy in the outdoor environment. The Trm is also functioned as input for boundary at the top of the material system. The calculation of solar radiation is performed using a general calculation formula as recommended by ASHRAE (Szokolay, 2010), using an MS-Excel spreadsheet. The temperature of the ground at depth is set to a constant 25°C. Based on research results in tropical areas, the ground temperature at a depth of 10 meters remains relatively constant at 20°C (Cui et al., 2011). However, another study by Mukhtar et al. (2017) showed a ground temperature of 28.95°C, is constant at a depth of 10 meters. Therefore, in this study, the median value of 25°C is used.

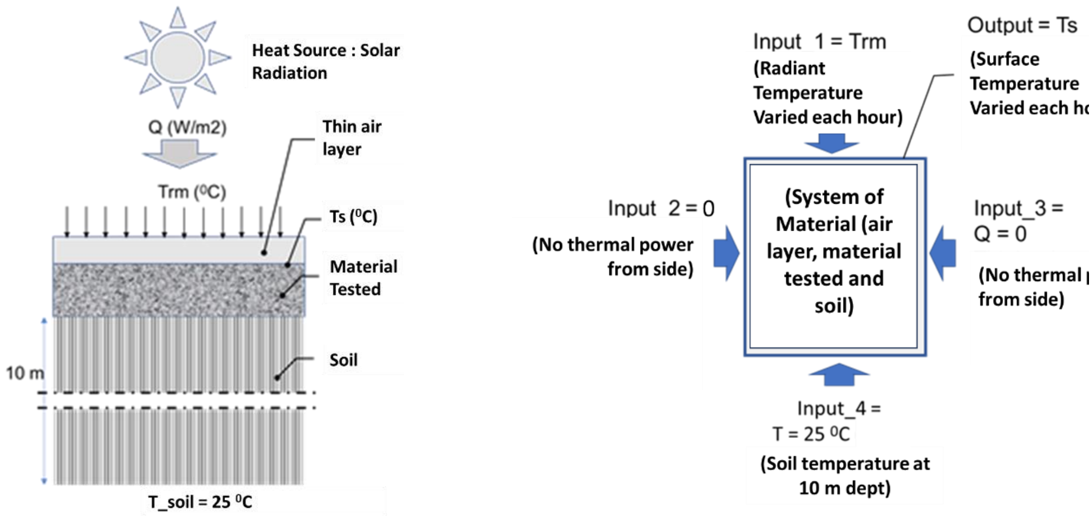

Figure 3. Physical model (left) and Simulation Model (right)

RESULTS AND DISCUSSION

Microclimate in the Coastal Area of Manado City

The results of microclimate measurements in the coastal area of Manado City (1.5°N), specifically in the Mega Mas beach commercial area, on January 10, 2020, are shown in Figure 4 and Table 1. In situations facing direct sunlight, the surface temperature of landscape materials (dry soil) nearly reached 50°C during the peak of midday due to the intense of sunlight. However, when located under the shade of a dense tree (Tanjung tree species), the highest surface temperature of the material only approached 35°C at 1:00 PM, or about 30% lower compared to when exposed to direct sunlight. The surface temperature of the material (soil) in these two situations began to differ after 8:00 AM, when the influence of the sun started to make heat the material. The heat change pattern showed a curve that peaked at midday and decreased in the morning and afternoon. The temperature change pattern of the material surface exhibited a similar trend to the variation in solar radiation measured on the same day and at the same time. The solar radiation reached its peak, almost touching 1050 W/m², at 12:00 PM at the point facing the sky (Figure.4). Conversely, at the point under the tree shade, the highest value at 12:00 PM was only around 150 W/m², a drastic decrease of about 80%. Other researchers have found similar results, such as in Penang, Malaysia, where it was found that due to dense tree canopies, soil surface temperatures could be reduced by up to 17%, and solar radiation could be filtered by around 80% (Tukiran et al., 2016).

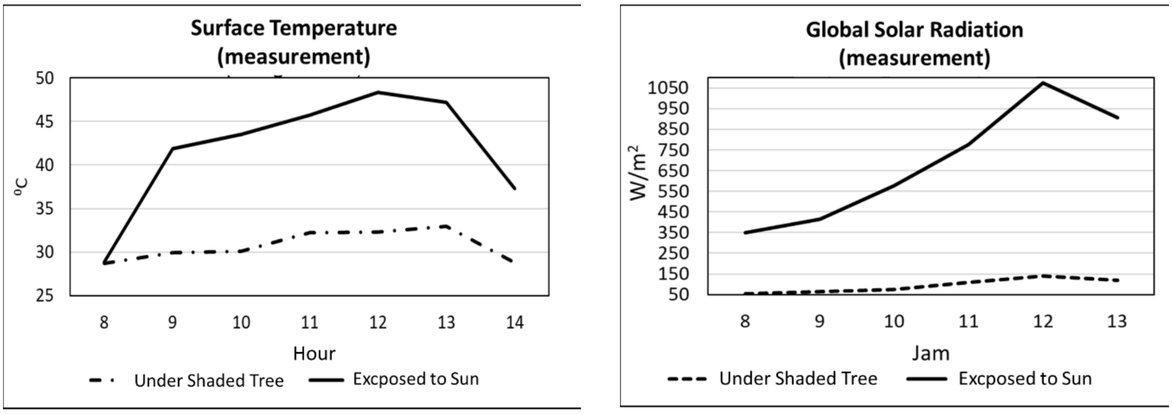

Figure 4. Surface temperature (left). Solar radiation (right)

Table 1. Results of measurement

Hour	Ta	Ts_1	Ts_2	G_1	G_2
	⁰C	⁰C	⁰C	W/m²	W/m²
8	29.7	28.7	28.9	54	350
9	29.2	29.9	41.9	65	416
10	30.9	30.1	43.5	76	575
11	30.4	32.2	45.7	109	775
12	31.2	32.3	48.3	139	1075
13	30;4	33	47.2	118	906
14	28.5	28.8	37.3	NV	NV

Thermophysical Properties of Local Materials

The results of measurements for the heat capacity and thermal conductivity properties of paving stones and bricks show differences compared to the values commonly found in several literatures. The locally made paving stone, after being measured, exhibited thermal conductivity properties with values that differed significantly from those in the literature (Table 2). This may be due to the physical properties of the base materials, which consist of natural stones or gravel that are harder and denser. For the red brick material, the thermophysical property measurements showed values that were close to or within the range typically found in the literature. Information regarding the thermophysical data of materials from the literature can be found on various websites, such as www.engineeringtoolbox.com, among others.

Table 2. Thermal Properties of the materials

Thermophysical Properties	Unit	Pavingstone		Red Brick	
		pengukuran	literatur	pengukuran	literatur
Density	kg/m^3	1947	2000 - 2400	1662	1400 - 2400
Heat Specific	$J/kg\ ^0C$	1423	800 - 1200	1120	800 - 900
Thermal Conductivity	$W/m\ ^0C$	4.1	1 - 2.1	0.9	0.6 - 1

Simulation of Surface Temperature

The computational simulation process using HEAT2 produce outputs in the form of temperatures at specific points on the material at the desired positions, where in this case, at points on the material's surface. As variable inputs for simulation are solar radiation on horizontal surface, air temperature and mean radiant temperature that vary hourly. The solar radiation for this input is obtained by calculation (Figure.5). The mean radiant temperature for input is obtained by using Rayman Software (Figure.5). However the air temperature for input is obtained through measurement (Figure.5). The results of the surface temperature simulation of materials using HEAT2 are shown in Figure 6. The surface temperatures of the landscape materials, including paving stones, hard soil, and red-brick, indicate that at midday, the highest temperatures can reach between 45°C and 50°C, occurring between 1:00 PM and 3:00 PM. There is a delay in the peak temperature compared to the time of the highest solar heat at 12:00 PM. This is due to the material's inertia factor. The heat capacity and thermal conductivity of the material, as well as the heat transfer process into the ground, can also contribute to the shift in the peak heat time by about 1 to 3 hours after the peak solar heat. This phenomenon is also known as the time-lag of the material in response to heat load. For comparison, the surface radiation temperature of paving material reaching a peak of 40°C can also occur in Japan, despite having a different climate from the tropics, as explained by Takebayashi and Kyogoku (Takebayashi and Kyogoku, 2018). Therefore, it is possible for the temperature to peak and approach 50°C. The simulation of water body temperature shows certain characteristics, where temperature changes with water depth. It can be observed through simulation calculations. At the surface, the water temperature can be nearly the same as other solid materials, reaching a peak temperature of 50°C. However, at a depth of 20 cm, the water temperature has already decreased significantly to around 25°C. At a depth of 50 cm, the water temperature remains relatively stable at around 25°C during the period from 7:00 AM to 5:00 PM. Therefore, it is likely that water at a depth of 50 cm, when mixed with surface water, tends to lower the overall water temperature, and this mixing situation has the potential to reduce the microclimate temperature. However, this remains a question for future studies.

The comparison between measurements and simulations is shown in Table 3, where there is no significant difference for both the water case and the solid materials. This demonstrates the validity of the computational simulation results obtained in this study.

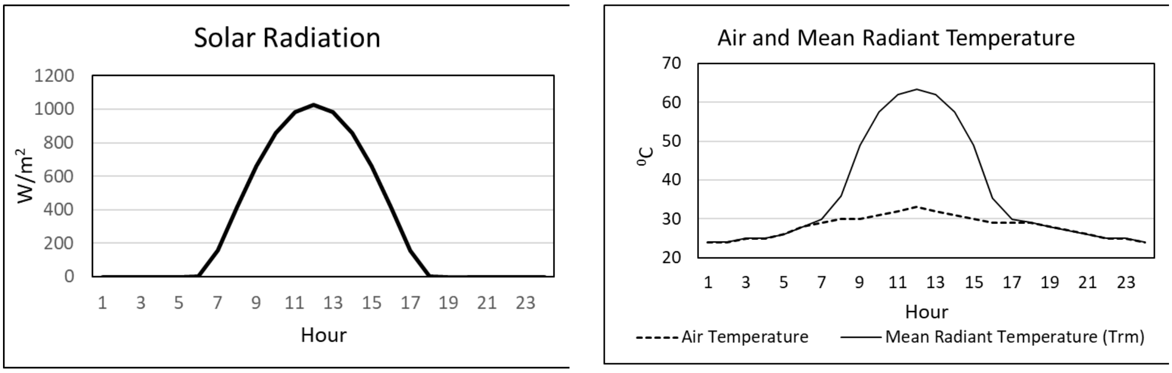

Figure 5. Global solar radiation on a horizontal surface (left). Air and Mean Radiant Temperature (right)

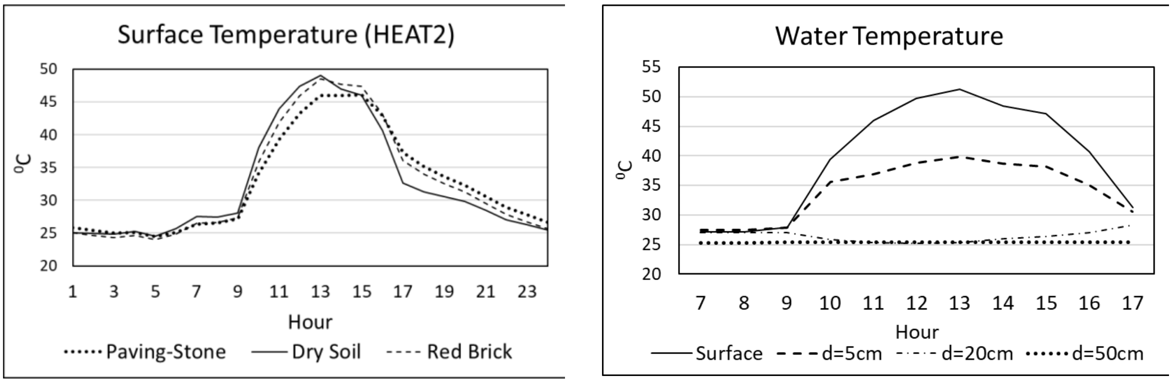

Figure 6. Results of simulation for surface and water temperature

Figure 7. Variation of surface temperature by simulation

Table 3. Comparison between measurement and simulation (^{0}C)

Time (hr)	Water (depth 1 cm)		Paving surface		Dry Soil surface	
	Measurement	simulation	Measurement	simulation	Measurement	simulation
10	33.2	36.55	-	-	39.3	38.09
11	38.4	41.54	45.7	39.31	40.1	43.96
12	38.8	44.4	48.3	43.29	45.1	47.43
13	-	-	47.2	46.01	43	49.08

CONCLUSION

This study concludes that the thermophysical properties of landscape materials significantly influence the surrounding microclimate, particularly the radiation temperature component, as affected by surface temperature. Properties such as heat capacity and thermal conductivity also shift the peak temperature time compared to the highest solar radiation period. Vegetation, especially dense trees, plays a crucial role in reducing solar radiation by up to 80% at midday through shading and can lower the surface temperature of underlying materials by up to 30% when the sun is directly overhead. Computational simulations reveal that the surface temperature of materials like paving stones, bricks, and hard soil can reach nearly 50°C at midday under clear skies, whereas water at a depth of 50 cm maintains a stable temperature of approximately 25°C. This suggests that mixing cooler deep water with surface water may reduce overall water temperature, potentially lowering microclimate temperatures, although further studies are needed to confirm this. The close alignment between measured data and simulation results validates the computational methods used.

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These findings offer valuable insights for landscape architectural design, particularly in tropical climates, to support the creation of more comfortable outdoor environments.

REFERENCES

Aghamolaei R, Azizi MM2, Aminzadeh and O'Donnell J. 2023. A comprehensive review of outdoor thermal comfort in urban areas: Effective parameters and approaches. *Energy & nvironment*. Vol. 34 No.6.

Anand J and Sailor DJ.2022. Role of pavement radiative and thermal properties in reducing excess heat in cities. *Solar Energy*. Vol. 242. August.2022.

Choi GY, Kim AH, Kim H, Lee JS, 2021, How do paving and planting strategies affect microclimate conditions and thermal comfort in apartment complexes? , *International Journal of Climate Change Strategies and Management*, Vol. 13 No. 2, 2021

Cui W, Liao Q, Chang G, Chen G, Peng Q and Jen TC. 2011. Measurement and prediction of undisturbed underground temperature distribution. In: *Proceedings of the ASME 2 international mechanical engineering congress & exposition*, IMECE2011, Denver, CO, USA, January 1 2011.

Gaitani N, Spanou A, Saliari M, Synnefa A, Vassilakopoulou K, Papadopoulou K, Pavlou K, Santamouris M, Papaioannou M, Lagoudaki A, 2011, Improving themicroclimate inurbanareas: acasestudy in the centre of Athens, *Building Serv. Eng. Res. Technology*. Vol 32, No. 1, 2011.

Givoni B, 1998, *Climate Considerations in Building and Urban Design*, New Yoyrk: John Wiley & Sons.

Iek Y, Sangkertadi, Moniaga I, 2014, Kepadatan Bangunan dan Karakteristik Iklim Mikro Kecamatan Weang Kota Manado. *Jurnal Sabua* .Vol,6 No.3.

Joo-Hwa B and Lay OB. 2006. *Tropical Sustainable Architecture. Social and Environmental Dimensions.* London: Architectural Press

Karyati, 2019. *Mikroklimatologi Hutan*, Samarinda: Mulawarman University Press.

Lakitan B, 2002. *Dasar-dasar Klimatologi*, Jakarta: Raja Grafindo Persada.

Lesi M, 2017. *Iklim Mikro di Sekitar Permukaan Air*. Pascasarjana Institut Pertanian Bogor.

Liu S, Zhao J, Xu M and Ahmadian E. 2021. Effects of landscape pattern on the summer microclimate and human comfort inurban squares in China. *Sustainable Cities and Society.* Vol. 73. Oct. 2021. 103099

Mukhtar A, Yusoff MY, Ching NK, 2017, An Empirical Estimation of Underground Thermal Performance for Malaysian Climate, *IOP Conf. Series: Journal of Physics: Conf. Series 949* (2017).

Noerwasito T V, 2020, *Blok Tanah Liat Untuk Arsitektur*, K-Media, Yogyakarta.

Sangkertadi, 2013, *Kenyamanan Termal di Ruang Luar Beriklim Tropis Lembab*, Bandung: Alfabeta.

▪

Sangkertadi & Syafriny R, 2016, Pair influence of wind speed and mean radiant temperature on outdoor thermal comfort of humid tropical environment, *Journal of Urban and Environmental Engineering*, Vol.10 No.2, 2016

Shahidan F M, Salleh E, Mustafa KMS, 2007. Effects of tree canopies on solar radiation filtration in a tropical microclimatic environment. *The 24th Conference on Passive and Low Energy Architecture*, Singapore, 22-24 November 2007.

Szokolay S V. 2010. *Introduction to Architectural Science: The Basis of Sustainable Design*. Oxford: Architectural Press

Takebayashi H dan Kyogoku S. 2018. Thermal Environmental Design in Outdoor Space Focusing on Radiation Environment Influenced by Ground Cover Material and Solar Shading, through the Examination on the Redevelopment Buildings in Front of Central Osaka Station. Japan. *MDPI Sustainability Jurnal*, 2018.

Thani S.K.S.O, dkk. 2013. Outdoor thermal comfort: the effects of urban landscape morphology on microclimatic conditions in a hot-humid city. *WIT Transactions on Ecology and The Environment*, Vol 179, 2013.

Tukiran J Md, Ariffin J, Abdul Ghani, AN, 2016, Cooling Effects of Two Typess of Tree Canopy Shape in Penang Malaysia, *International Journal of Geomate*, Vol. 11, Issue 24.

Wang K, Fang X, Ma Y, Xue S, and Yin S. 2022. Assessing Effects of Urban Greenery on the Regulation Mechanism of Microclimate and Outdoor Thermal Comfort during Winter in China's Cold Region. *Land. 2022*, Vol. 11, 1442.

Yang S, Wang LL, Stathopoulos T and Marey AM. 2023. Urban microclimate and its impact on built environment – a review. *Building and Environment*. Vo. 238. June 2023. 11034

Yang W, Lin Y, Li CQ, 2018. Effects of Landscape Design on Urban Microclimate and Thermal Comfort in Tropical Climate. *Hindawi Advances in Meteorology* Vol.2018, Article ID 2809649.

Zold, A. and Szokolay S,1997. *Thermal Insulation*. PLEA Note 2. PLEA University of Queensland.

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