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The Primacy of Microclimate and Thermal Comfort in a Walkability Study in the Tropics: A Review

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ABSTRACT

One of the urgent environmental issues that are encountered by densely populated cities today is climate change and Urban Heat Island (UHI) which are increasing significantly. In the development of outdoor spaces or urban public spaces, there are environmental issues that affect the comfort of human activities. Meteorological, physiological, and psychological parameters affect the thermal comfort of humans doing their activities outdoors. Walking as one of the outdoor activities, in terms of urban design, there is not much mention of climate factors in identifying the success of outdoor space design. Walkability, the comfort level of walking is one of the parameters that many researchers discuss in the context of activity studies related to outdoor activities. This study aims to further review the development of literature relating to the urban microclimate, thermal comfort to walkability, especially in high-density tropical cities.

Keywords: microclimate, thermal comfort, walkability, and tropical region.

1. Introduction

Urban Heat Island (UHI) is currently an issue that occurs in urban areas with high density. As one of the effects of urbanization, UHI has increased significantly along with rapid urban development. Urban development significantly modify the meteorological conditions of the surrounding area (Landsberg, 1981) and have an impact on the urban microclimate. Massive high rise construction and growth of the human population cause an imbalance of ecosystems that triggers microclimate changes that are characterized by rising air temperatures. Koerniawan and Gao (2015) stated that high rise buildings disturb thermal comfort in the surrounding environment and cause heat radiation from the sun trapped from day to night. The sensation of human thermal comfort is influenced by four factors, including air temperature, radiation temperature, humidity, and wind speed as well as individual factors including clothing and activity (ISO 7730, 1994).

In tropical climates, humans will be more likely to find places with cooler temperatures. This is in line with research by Zacharias et al. (2001) who found that the use of public space decreased significantly when the temperature increased. Poor thermal comfort in public spaces is one of the issues that cause low public interest in conducting activities in open

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spaces or public spaces. Nouri (2017) stated that climate change, user aspects, and urban design are related to the success of public spaces. One of them is activities related to pedestrians. Pedestrians are one of the important focuses on implementing the concept of a smart city on a sustainable city agenda. According to Michael Southworth (2005) walkability is the main basis for city sustainability. Untermann, Ricahrd K (1984) emphasized that walkability is shaped by comfort, safety, and access to pedestrian environments.

So far, walkability studies have generally been discussed in the study of microclimate and thermal comfort in a separate discussion, while the two variables are very closely related in creating good walkability. Therefore, this study discusses the literature review on the influence of microclimate and thermal comfort on the walkability of urban space. In responding to this influence, urban climate studies have been developed through various forms of approaches and methods in the context of the city. Previous research (Yola, 2017) emphasizes that the development of the city climate study continues to be carried out by researchers to obtain a more comprehensive analysis and more precise results. Specifically, this study aims to carefully review the development of literature relating to the urban microclimate, thermal comfort, and walkability, especially in high-density tropical cities.

2. Previous Studies on Microclimate, Thermal Comfort, and Walkability

2.1 Microclimate

Climate is a long-term condition of an environment in a particular region that has specific features such as temperature, pressure, wind, rainfall, clouds, and humidity. In urban areas, the scale of climate based on time and space in an area refers to the extent of the atmospheric region covered (Erell, 2012). Microclimate according to Valsson (2008) is a climate pattern in a relatively small region. Meanwhile, according to Erell in the book *Urban Microclimate: Designing the space between buildings*, microclimates are factors of climate conditions specific to the local area that provide a direct influence on enjoyment (physical) and comfort (taste) in smaller places (Erell, 2012).

A microclimate is influenced by climate variables such as light radiation, temperature, wind speed, humidity, wind direction, season, time, and physical characteristics of the region. The local factors that influence climate in the air layer near the surface of the earth include the characteristics of vegetation, small bodies of water, and human activities that can change the

purity of the microclimate (Frick, 1998). The existence of locality factors causes each environment in a region to create a unique local climate (Mahgoub, 2013).

Based on theory and practice, urban microclimate depends on the type of city in terms of size, geographical location, population size, and density, and land use in addition to road design features along with building height, road width, orientation and mass distribution of buildings, etc. (Koerniawan, 2014). Some researchers explain that the microclimate conditions in cities are influenced by the climate and the built environment (Landsberg 1981; Eliasson 2000; Okay 1984, 2006). The artificial environment accelerates heat absorption during the day and slows to release heat at night. This formation is known as Urban Heat Island where the hot region is surrounded by areas adjacent to the cooler.

2.2 Thermal Comfort

Thermal comfort is defined as a state of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation (ASHRAE Standard 55, 2010). Fanger (1970) states that thermal comfort is defined as a state of mind that states the level of human satisfaction with the thermal conditions of the environment. Sometimes, the thermal environment that is occupied does not provide the expected conditions. Therefore, humans make efforts to achieve the conditions they want. The role of psychology in assessing thermal comfort becomes an important aspect, which includes the function of biophysical parameters (such as skin temperature and sweat) as well as individual preferences that may be related to cultural context and thermal expectations (Okay, 2017).

Humans are warm-blooded living things that undergo metabolic processes. This metabolic process produces energy for the human body and also produces heat. The heat is produced to maintain body temperature in ideal conditions in the range of 36.5-37 °C (Koch-Nielsen, 2002). Naturally, the human body has a low tolerance range for temperature changes. Therefore, in reaching the ideal temperature, humans make various efforts.

According to Oke (2017), six variables govern the balance of human energy. Environmental variables consist of wind speed, air temperature, relative humidity, and radiation. These variables are then summarized into the average radiation temperature (T_{MRT}), which expresses the short and long wave radiation absorbed on the outside surface of the body.

According to Hoppe (2002), there are three approaches in the assessment of thermal comfort, namely psychological approaches, thermophysiological approaches, and approaches to human body heat balance. The psychological approach to thermal comfort is assessed based on human perception. In the thermophysiological approach, the thermal comfort assessment is based on individual data such as age, gender, activity, and clothing used at the time. Both of these approaches were obtained through interview data which was conducted at one time. While the heat balance is an assessment of the balance of the body's thermal conditions and environmental conditions.

Thermal comfort in the outdoor space is different from the thermal comfort in the indoor room. The indoor space environment tends to have a relatively stable, static, and controlled microclimate, while the outdoor space environment has a more complex microclimate (Oke, 2017). The thermal comfort of outdoor space is not only influenced by the physiological response of the microclimate, but rather the psychological and cultural adaptations that regulate various stimuli from the environment to avoid thermal fluctuations and discomfort.

There is an index of assessment of human thermal comfort developed by previous researchers. The index assumes human thermal comfort over the microclimate over time which enables humans to achieve equilibrium. In a previous study of comfort in an outdoor environment conducted by Thom, EC, 1959; Steadman, RG, 1971; J. Unger, 1999; Matzarakis, A. et al. 2004, focusing on the bioclimatic index (the Discomfort Index, thermohygrometric index (THI), this study only considers a few meteorological parameters. Then the new model is based on research on the equation of human energy balance by Fanger, PO 1972; Jendritzky, G. et al. 1990; Hoppe, PR, 1993, 1999; Matzarakis, A. et al. 1999; Nikolopoulos, 2002, produced what is called the thermal comfort index which results in an assessment of outdoor thermal comfort, such as Predicted Mean Vote (PMV), Physiological Equivalent Temperature (PET). Table 1 presents a comparison of PET and PMV characters.

Table 1. Comparison of PET and PMV Thermal Comfort Assessment Index

	PET	PMV
Scale	4 °C = very cold, 8 °C = cold, 13 °C = cool, 18 °C = rather cool, 23 °C = comfortable, 29 °C = rather warm, 35 °C = hot, 41 °C = very hot.	+3 = hot, +2 = warm, +1 = a little warm, 0 = neutral, -1 = a little cold. -2 = cold, -3 = very cold.

	PET	PMV
Function	The use of physiological aspects in evaluating thermal conditions.	An index developed for thermal comfort in terms of microclimate, psychological, and physiological climate of the user.
Variables	Meteorology (air temperature, humidity, wind speed, solar radiation), heat resistance from clothing movement (clo value), and internal heat production (Value Met).	Air temperature, average radiation, wind speed, humidity, clothing endurance, and activity level.
The use of indices in the assessment of thermal comfort	<ul style="list-style-type: none"> • PET makes it possible to compare the integrative effects of complex thermal conditions in the outdoor environment with spaces inside buildings. • PET can be used throughout the year and in various climates. • Use a scale in the form of °C so that the results are easy to understand. 	<ul style="list-style-type: none"> • PMV makes it possible to know the relationship between the influences of environmental conditions with individual conditions. • PMV can be used throughout the year in various climates.

Thermal comfort that is influenced by climate is influenced by geographically different climate zones. Thermal comfort is influenced by the sensitivity of humans living in certain climates (Koch-Nielsen, 2002). Cities located on the equator receive a lot of sunlight and solar radiation, this affects the movement of cold and hot air (Emmanuel, 2016). According to Bekele et al. (2008), cities that have hot and humid climatic conditions need ventilation in their street-to-canyon to release heat quickly. The study found that buildings oriented at an angle of 45 degrees to the existing wind will create positive and negative air pressure that allows wind to move around the building and increase air circulation at the pedestrian level. To make better wind circulation between buildings, the H/W ratio (ratio between road width and building height) must be 0.7 or less.

Lin and Matzarakis (2008) classify the sensation of outdoor thermal comfort specifically in the tropics. Air temperature, humidity, air velocity, shortwave radiation, longwave heat radiation, ground surface temperature, sky view factor, and the ratio of the angle of the solid surface of green and water in this study were measured. This study states that the shadow area or shade significantly influences the outdoor thermal environment. In achieving maximum exposure, natural elements such as vegetation become very influential in increasing thermal comfort. Table 2 shows the Thermal Scale Classification in the tropics according to Lin and Matzarakis.

Table 2. Classification of Thermal Comfort Sensations in the Tropics

PMV	PET	Thermal Sensation	Heat Release Rate
-3.5	14	Very cold	Extreme cold release
-2.5	18	Cold	Strong cold release
-1.5	22	Cool	Medium cold release
-0.5	26	Rather cool	Light cold release
0		Neutral	There is no heat release
+0.5	30	Rather warm	Light heat release
+1.5	34	Warm	Medium heat release
+2.5	38	Hot	Strong heat release
+3.5	42	Very hot	Extreme heat release

Source: (Lin dan Matzarakis, 2008)

Yola and Siong (2016) in their research showed that in the context of the tropics, with the influence of weak wind speeds, solar radiation has a significant impact on thermal comfort. Previous research (Yola, 2020) also emphasized that the configuration of the city greatly influences the modification of the microclimate which is the main determinant of the outdoor comfort level.

2.3 *Walkability*

Speck (2012) in the book *Walkable City* states that most studies related to walkability are part of the study of urban transportation systems, which often focus exclusively on car travel and transit, but neglect pedestrian travel. As a result, they do not place walkability as a vital form of urban transportation.

Jacobs (1961) in his book *The Death and Life of Great American Cities* states that the core of the urban spirit is walkability, where there is a mixture of urban functions such as short blocks, population density, diversity and mixed users, and the type and age of buildings that all play a role in their role. Social interaction in the city is the main asset of the city that can be inhabited, namely when people from various jobs, goods, services, and locations of the city are of business value. A more comfortable and lively place to walk is a place with various services and destinations that are close to each other.

Urban design researchers have investigated that well-connected roads affect human comfort when walking. In urban design theory, the basic building blocks of a walkable environment are defined as the area covered by a 5-minute walk (about 400 meters). Handy (2005) found that the artificial environment caused some measure of physical activity. The main role of

placing high-density housing, commercial buildings, and transit connectivity contribute to making walking a more efficient form of transportation and enabling individuals to complete their daily activities without the need for motorized vehicles.

Carvaro et al., (2003) stated that outdoor activities such as walking and using public transportation naturally require interaction with the natural environment. Exposure to extreme heat, humidity, and rainfall conditions are considered as significant barriers in outdoor activities.

3. A Balance between Microclimate, Thermal Comfort, and Walkability in the City's Outdoor Spaces

The relationship between open space users and thermal comfort is stated by several studies (Nikolopolou et al., 2001; Thorsson, 2004; Zacharias et al., 2004; Nikolopolou et al., 2006; Lin, 2009). Outdoor thermal comfort is one of the most important, direct, and recognizable impacts that is affected by the artificial environment. Most of the literature found related to the influence of climate on walkability in urban environments comes from the field of public health. O'Hare (2006) notes about active transportation and recognizes that walking, part of physical activity, is an innate component of transit use. Buys and Miller (2010) find that walking is more difficult in climatic conditions in Brisbane, Australia. Merrill et al. (2003) found physical activity has been influenced by seasons and climate for adults in the United States. Psychological factors play an important role in how people perceive weather and climate, stated by Hoppe (1999); Nikolopoulo (2001); and Ahmed (2003).

Studies on climate impacts on walkability in pedestrians are still limited. However, from literature studies on thermal comfort, it was found that biometeorological variables can be used to calculate walkability. How far can a person walk before experiencing discomfort in open space/outdoor space. Mileage physiological response to the body to be able to walk while maintaining thermal comfort is included in one study investigation; or also called comfort shed (DeVau, 2011).

Thermal comfort and its effects on pedestrians are revealed in the study of Nikolopoulou et al. (2019) conducted for three years on variations in perceptions of thermo-spatial conditions and the comfort of moving pedestrians between interconnected spaces. This study shows that sequential space does not significantly affect microclimate variations but has a large impact

on the dynamic thermal perception of pedestrians. High-density interconnected spaces produce differentiation of thermal pleasure between the road and the square.

Research related to microclimate and thermal comfort, especially in the tropics, was carried out by several researchers, Koerniawan and Gao (2014); Lin and Siong (2016); Makaremi et al (2012); Lin and Matzarakis (2008). Lin and Matzarakis's research (2008) was conducted in Taiwan with a focus on modifying PET that is suitable for tropical and subtropical climate conditions. Walking, as one of the human activities in outer space, cannot be separated from the presence of meteorological factors. Thus, investigations of the relationship of microclimate and thermal comfort, especially in hot and humid conditions, to walking comfort with meteorological, physiological, and psychological parameters are needed.

4. Conclusions

Based on literature studies, microclimate, and thermal comfort in terms of walkability in urban studies, especially in the tropics, is topics that require further investigation. The development of research related to the topic of microclimate and thermal comfort is still limited to areas with a moderate climate. As for research conducted concerning the quality of outdoor space or walking, climate factors are not a significant theme. Some literature describes the activity of walking in detail but does not use climate as one of the factors.

To determine thermal comfort, two parameters are taken into account, namely: 1) Meteorological parameters. Calculation of thermal comfort is measured by field measurements in micro spaces, meteorological parameters such as radiation, temperature, wind speed, and humidity, and landscape elements such as vegetation and water bodies, need to be investigated in measuring thermal comfort. 2) The involvement of psychological and physiological parameters to determine the condition of the individual in the use of outdoor space. This study concludes the need for a comprehensive study of the two variables, namely microclimate and thermal comfort in realizing the concept of good walkability in the outer space of tropical cities whose outdoor activities are strongly influenced by the influence of microclimates which are relatively hot and extreme and do not provide comfort.

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