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Evaluating The Influence of Building Typologies and Attributes on Outdoor Thermal Comfort in Urban Environments

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Abstract—The variation in urban microclimate is closely related to the building's physical attributes, including building height, material composition, building condition, building size, building morphology, and building type. Changes in microclimate due to the continuous expansion of urban buildings have a significant impact on the health and comfort level of urban residents. Thus, it is necessary to understand the influence of built environment factors towards outdoor thermal comfort, particularly in tropical cities like Kuching, Sarawak. This study investigates the interplay between building typologies and microclimatic factors in Kuching, Sarawak, focusing on residential, commercial, office and educational buildings. Field measurements of air temperature, relative humidity, wind speed, and heat index were conducted over more than seven consecutive days in April 2024 using handheld environmental meters. The measurement was recorded every two hours per day at sixteen (16) static points across different types of buildings. The data were collected manually with the sensor positioned at a height of approximately 1.5 m above ground level, taking into account the average breathing zone height of a standing adult. Additional data, including human activities around each study area, were also recorded to account for the influence of these factors on the microclimate. Following the confirmation of non-normality in the dataset through a Kolmogorov-Smirnov test, a Kruskal-Wallis test was performed. The results reveal that wind speed and relative humidity vary significantly among building types ($p < 0.05$), whereas air temperature and heat index show a consistent statistical pattern. In the analysis, commercial areas showed the

highest wind speeds, while residential areas recorded the highest relative humidity. Therefore, the result clearly underscored that the importance of building types, spatial design, materials, and methods influences outdoor thermal comfort.

Keywords—Building heat indicators, Building typologies, Microclimatic conditions, Outdoor thermal comfort, Sarawak.

I. INTRODUCTION

Thermal comfort is now a more important factor because it directly impacts people's health, safety, and well-being, especially for city inhabitants. Due to the fast growth of the built environment and rising anthropogenic heat emissions, cities are facing serious issues with outdoor thermal comfort as urbanization expands. The main result of this is the emergence of the urban heat island (UHI) phenomenon, which affects the climate of cities. According to Ramly *et al.* [1], the increase in temperature within urban areas relative to their surrounding regions is referred to as the urban heat island phenomenon. This phenomenon can arise from several factors, including heightened human activities that result in increased carbon dioxide emissions, unsustainable building practices, and expanded land use, among others. These factors can lead to various environmental impacts, significantly affecting human health. Outdoor thermal comfort (OTC) is an essential aspect of improving the

quality of human life in urban spaces [2]. Urban design and planning studies are consequently confronted with a growing challenge as they strive to enhance Outdoor Thermal Comfort (OTC) and the microclimate conditions of urban settings. The analysis of OTC presents greater difficulties in comparison to indoor thermal comfort due to the broader array [3].

Urban and building typologies significantly impact the urban climate and largely determine the magnitude of urban overheating and heat island intensity. A study by Kolokotsa *et al.* [4] shows that a higher aspect ratio of the precinct results in lower cooling potential. It is also observed that the higher the built-area ratio of the precincts, the lower the cooling contribution of the mitigation measures. Besides the typology of buildings in urban areas, the surface of buildings that receive and release heat to the surroundings might influence the growth of urban heat island effects. A study conducted by Wonorahardjo *et al.* [5] shows different façade systems of buildings significantly affect both the indoor and outdoor environments where the brick wall emits thermal energy compared to the aluminum composite panels (ACP) and low emissivity (Low-E) glass by having the highest surface temperature (28.6 °C) is registered for the low-E glass as while the lowest temperature (24.5 °C) is measured for the brick wall. Besides, the temperature fluctuations are also found to be lower in the brick wall, compared to the others, since it can store a higher amount of thermal energy during solar exposure and release that energy during the afternoon [5]. Heavily populated areas typically generate more heat. When houses, shops, and industrial buildings are built close together, it can create urban canyons that block natural wind flow to cool the city [6].

This study was conducted to investigate how four different building types (residential, educational, commercial, and office) affect outdoor thermal comfort conditions based on microclimatic measurements and physical building characteristics. The study only focuses on the outdoor thermal attributes resulting from the building activities of four different types of buildings in Kuching, Sarawak.

II. LITERATURE REVIEW

Thermal comfort is commonly referred to as a psychological condition in which an individual feels satisfied with the surrounding thermal environment [7]. As such, it is influenced by psychological and behavioral factors in addition to the physical condition of outdoor spaces [8, 9]. In this regard, there are two primary categories of assessment for outdoor thermal comfort (OTC): the first category presents the physical parameters related to urban morphology and landscape design, while the second category adopts a human-based approach, emphasizing the physiological responses and social characteristics of people [3]. Unlike indoor thermal comfort, where thermal conditions can be actively managed and controlled.

The most popular approaches to evaluating OTC in urban planning studies focus on physical parameters, primarily the features of the built environment.

As examined in various studies across multiple scales, such as streets, urban open spaces, neighborhoods, districts, and city scale, the geometrical and morphological characteristics of urban areas are significant contributors to OTC [3]. These characteristics of built environments, such as building height, façade material, orientation, density, and building setback, can alter local temperature distributions, including wind flow, solar exposure, and sky view factor (SVF) [10, 11]. For example, Wang *et al.* [12] and Chen *et al.* [13] noted that high-rise buildings amplify wind turbulence but reduce solar exposure at street level, creating variable comfort zones. Meanwhile, narrow building setbacks with low-rise buildings tend to trap heat due to restricted airflow, which elevates the ambient air temperature and often exhibits "urban canyon" effects [11]. Material characteristics also influence thermal conditions, especially low-albedo materials such as dark asphalt or concrete that absorb high amounts of solar radiation, leading to an increase in surface and surrounding air temperature [14]. In contrast, reflective or porous building materials can help dissipate heat efficiently.

Furthermore, the integration of vegetation into building design and its surroundings plays a major role in regulating surface temperature through evapotranspiration [15], enhancing comfort for individuals in urban open spaces [16]. Figure 1 shows how the balance between heat gain, heat loss, and anthropogenic heat emission influences outdoor thermal comfort. These factors all affect outdoor temperature and eventually contribute to the urban heat island (UHI) effect. The diagram also demonstrates how both internal building operations and external sources collectively affect outdoor thermal conditions.

Building typology refers to their function and type, which includes variations in scale, design intent, land use density, landscape integration, and operational characteristics. Many comparative studies have been conducted on how these different building types exhibit environmental impacts on their surroundings. For instance, residential areas characterized by low-rise and low-density often allow greater wind penetration and provide thermal relief compared to high-density apartment complexes, which can create urban canyon effects that trap heat and limit airflow [17].

Besides, commercial and office buildings typically feature larger footprints, more impervious surfaces, and higher energy consumption due to their operational characteristics and human density. A study conducted by Jo *et al.* [18] reported that the Universal Thermal Climate Index (UTCI) value varies by up to 6 °C across Local Climate Zones (LZCs) representing different urban typologies, confirming that commercial and compact built-up areas tend to

experience greater heat stress levels than residential zones. Hong *et al.* [19] also noted that the energy performance of commercial and office structures is primarily from lighting, equipment usage, HVAC operations, and occupant-related activities. These

factors are also correlated with the type of material used for building façades and the height of the office building, which influence wind flow and shading factors [20].

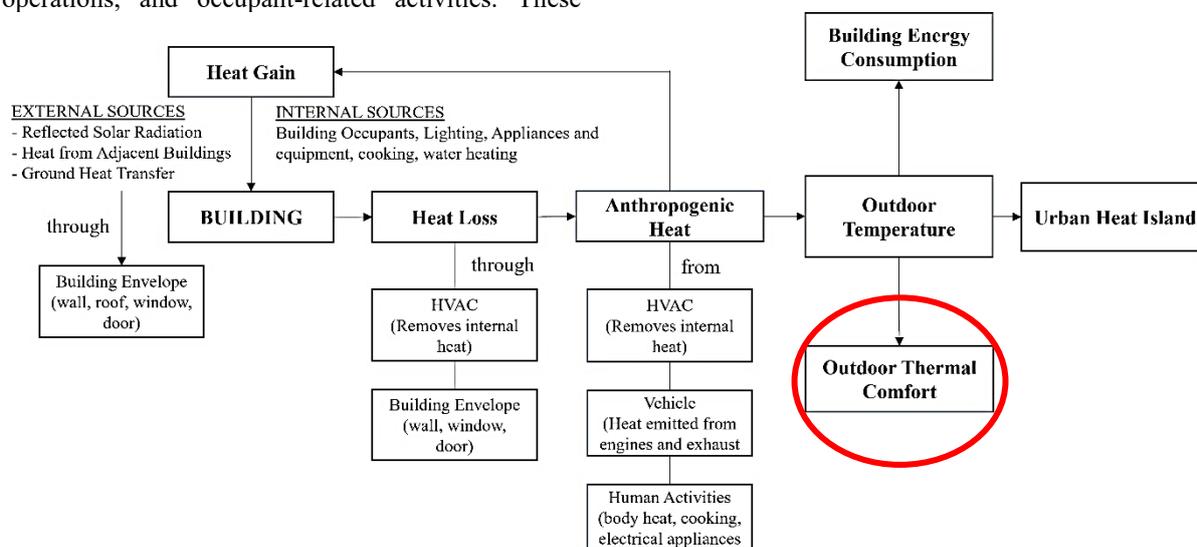


Fig. 1. Conceptual framework of the interaction between building heat indicators and microclimate toward outdoor thermal comfort.

This is different from educational buildings, where the architectural layouts are mostly open and low-density, featuring courtyards, green infrastructure, and the integration of sustainable design principles, making this building more favourable for outdoor microclimates [13]. Besides, educational institutions nowadays increasingly implement sustainable campus strategies, including net-zero campuses. This comprehensive approach involves maximizing energy efficiency, exploiting renewable energy technologies, and encouraging sustainable practice within the campus community [21].

III. METHODOLOGY

A. Study Area

This research was conducted at four different types of buildings: educational (university), residential (terraced houses and apartments), mixed-use (ground-floor retail with high rise office tower), and commercial (retail shops), as shown in Fig. 2. The selected buildings are located within the urban area of

Simpang Tiga, Kuching, Sarawak, Malaysia. This location was strategically selected to represent a diverse range of urban environments, reflecting the functional and spatial traits characteristic of their specific land-use categories. The selection sought to capture and understand how the function and form of buildings which representing over 70% of building count, along with their functional and morphological characteristics (footprint, height, ground surface), impact the local microclimate. An analysis was conducted on each building type in relation to its architectural layout, envelope materials, surrounding surface characteristics, and the density of land use. These elements are acknowledged as the main factors that influence outdoor thermal conditions. This approach allowed the research to account for the outdoor thermal comfort effects of various building functions and design attributes while conducting on-site microclimate observations.

Educational Building (Swinburne University)



Front



Rear



Right side



Left side

Swinburne University Sarawak was selected as the educational building for this study which is located in Simpang Tiga, Kuching. It consists of several mid-rise blocks interspersed with open areas. The building features a façade composed of concrete walls and large glass windows, complemented by surrounding elements such as trees, walkways, and parking areas.

Residential Building



Front



Rear



Right side



Left side

This residential area is located within a low-density housing area in Simpang Tiga, Kuching. The area consists of landed double-story terrace houses with moderate spacing between units and limited vertical shading. The surroundings include paved roads, a small landscaped garden, and open grassy areas at the rear.

High-rise Office Tower



Front



Rear



Right side



Left side

Kumpulan Wang Simpanan Pekerja (KWSP) Tower was selected as the office building for this study. It is a modern high-rise office structure with a glass and metal façade. The building is surrounded by paved surfaces and limited vegetation, with nearby construction and commercial activity influencing its immediate environment.

Commercial Building



Front



Rear



Right side



Left side

This commercial building is a low-rise shop lot with narrow frontages and limited open space. These buildings typically house ground-floor businesses such as retail stores, eateries and services, with upper floors used for offices or storage. The surrounding environment features fully paved surfaces, dense building arrangements, minimal greenery and constant vehicular and pedestrian traffic.

Fig. 2. Photographic views and description of each building type.

B. Field Measurement

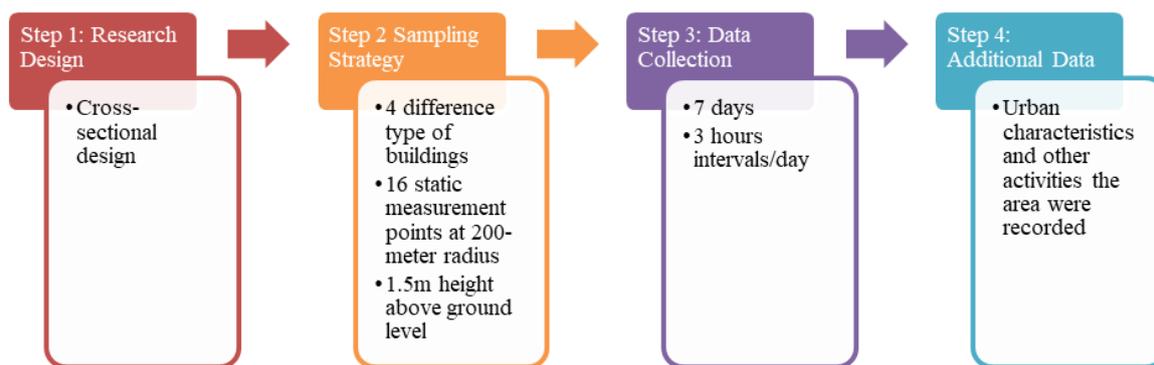


Fig. 3. Research design.

A cross-sectional research design has been adopted in this research to assess microclimatic conditions across different building typologies, as shown in Fig. 3. The field measurement involved in-situ manual collection using a handheld environmental meter sensor, which measured key variations in outdoor environmental parameters, including air temperature, relative humidity, heat index, and air velocity. These parameters aim to represent the thermal comfort conditions surrounding different types of buildings. A total of 16 static measurement points across four different building typologies with four different point at each typology were identified. The data were collected manually within a 200-meter radius from a central reference location with the sensor positioned approximately 1.5 m above the ground level. This height corresponds to the average breathing zone of a

standing adult and is commonly used in the thermal comfort assessment to capture microclimatic conditions experienced at the pedestrian level.

The field measurements were carried out for seven consecutive days in April 2024, and data were recorded every three hours daily, resulting in a temporal snapshot of microclimatic variation in real-world conditions. In addition to environmental data, urban characteristics and activities around each study area were recorded and documented to account for the influence of these factors on the outdoor thermal environment. The specifications of the environmental meter used in this research are summarized in Table I, including model, type, setting, and measurement accuracy.

Table I. Instrument specifications of the KESTREL 3000 environmental meter.

Data logger	Model	Climatic Variables	Instruments Accuracy	Measurement Range
Environmental Meter	Kestrel 3000	Wind Speed	± 3% FS	0.4 – 40 m/s
		Heat Index	± 3%	-29 to +70°C
		Humidity	± 3%	5 – 95%
		Temperature	± 2°C	-29 to +70°C

IV. RESULT AND ANALYSIS

This research aimed to investigate whether various types of buildings, specifically commercial, office, academic and residential, have statistically significant effects on outdoor thermal comfort parameters, including wind speed, air temperature, relative humidity, and heat index. These four measurements were tested using statistical techniques to determine if

there is a significant difference of each condition between types of building. It is essential to assess the data distribution before choosing the statistical method used in the analysis. Therefore, the Kolmogorov–Smirnov test was applied to evaluate the data normality, as shown in Table II to determine the distribution of the data.

Table II. Test of normality.

Condition	Kolmogorov -Smirnov Z	p-value	Conclusion
Wind speed	4.442	< 0.00	Data is not normally distributed
Air temperature	6.340	< 0.00	Data is not normally distributed
Relative humidity	6.284	< 0.00	Data is not normally distributed
Heat index	5.829	< 0.00	Data is not normally distributed

The result of the Kolmogorov-Smirnov test is significant ($p < 0.05$) for all four conditions, indicating that the data are not normally distributed. Hence, the non-parametric test i.e Kruskal-Wallis test is carried out to test the following null hypotheses;

- i. There is no significant difference of wind speed between commercial, office, academic and residential buildings.
- ii. There is no significant difference of air temperature between commercial, office, academic and residential buildings.

- iii. There is no significant difference of relative humidity between commercial, office, academic and residential buildings.
- iv. There is no significant difference in the heat index between commercial, office, academic, and residential buildings.

Table III. Kruskal-Wallis Test.

Condition	Type of building	Mean rank	Chi-Square	<i>p</i> -value
Wind speed	Commercial	539.36	95.75	< 0.00*
	Office	504.60		
	Academic	430.67		
	Residential	319.37		
Air temperature	Commercial	475.67	6.01	0.111
	Office	424.94		
	Academic	462.46		
	Residential	430.93		
Relative humidity	Commercial	464.39	15.06	< 0.00*
	Office	444.42		
	Academic	396.96		
	Residential	488.23		
Heat index	Commercial	473.9	6.22	0.102
	Office	419.11		
	Academic	437.44		
	Residential	463.56		

*Significant at 0.05 significance level.

The results of the Kruskal-Wallis test, summarized in Table III, indicate a statistically significant difference in wind speed and relative humidity across the building typologies, with *p*-values less than 0.05. Based on the mean rank, the highest wind speed was observed in the commercial building, followed by the office, academic, and residential buildings. On the contrary, relative humidity in residential buildings is significantly higher than in other type of building. Nonetheless, the Kruskal-Wallis test also revealed that there is no significant difference in air temperature and heat index between commercial, office, academic, and residential buildings. This indicates that these two parameters remain relatively consistent among the different building types within the scope and conditions of this research.

Thus, these findings highlight that building typology plays a critical role in shaping specific yet vital elements of the urban microclimate, particularly the pattern of wind flow and humidity regulation, which are both key determinants of human outdoor thermal comfort. The notable differences in wind speed underscore how design elements, such as street width, the ratios of building height to width, and the

distribution of open spaces, influence airflow [22, 23]. Meanwhile, the differences in humidity draw attention to the importance of surface features and vegetation. This diversity necessitates typology-responsive design strategies to address microclimate dynamics.

V. CONCLUSION

This research empirically quantifies the significant influence of building typologies on the key outdoor microclimatic parameters, wind speed, air temperature, relative humidity and heat index, within the tropical urban context of Simpang Tiga, Kuching, Sarawak. Field data were collected over seven days using an environmental meter at 16 static points across the four different types of buildings. Following a normality check was conducted with Kolmogorov-Smirnov test, and the data were then analysed through the Kruskal-Wallis test, a non-parametric statistical method appropriate for comparing several independent groups of variables. The results revealed that wind speed and relative humidity varied significantly among different building types ($p < 0.05$), whereas air temperature and heat index showed no so significant differences. Commercial buildings

experience the highest wind speeds, probably because of the street layouts that enhance ventilation. Conversely, residential areas showed the highest levels of relative humidity, likely attributable to the presence of vegetation and lower impervious surfaces. Although air temperature and heat index showed no significant differences, these results may reflect external climatic consistency or limitations related to short-term measurement.

Although our four typologies cover the most common urban forms within the study area, we acknowledge that other land-use categories, such as industrial, religious, and institutional buildings like hospitals and government offices, possess unique morphologies and operational attributes that could influence the outdoor thermal environment differently. Thus, future research should widen the typology spectrum to include these categories and evaluate how their distinct building uses can influence the outdoor thermal comfort index.

From a practical standpoint, this research compellingly argues for embedding climate-responsive design principles at the early stage of urban planning and architectural practice. Understanding and utilizing typology-specific microclimatic interactions provides a robust foundation for creating smarter, healthier and more resilient urban environments in tropical regions.

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AUTHOR CONTRIBUTIONS

Amira Shazlin Adnan: Conceptualization, Research Design, Methodology Development, Testing, Data Analysis, Validation, Writing – Original Draft Preparation, Review & Editing, Manuscript Refinement;

Adi Irfan Che Ani: Conceptualization, Supervision, Methodological Guidance, Validation, Data analysis;

Mohamad Ezad Hafez Mohd Pahroraji: Data collection and Data analysis;

Noraziah Wahi: Writing – Review & Editing, Language Refinement and Manuscript Structuring;

Mohd Asraf Ayob: Data collection, Fieldwork Coordination and Preliminary Data Processing.

CONFLICT OF INTERESTS

No conflict of interests was disclosed.

ETHICS STATEMENTS

Our publication ethics follow The Committee of Publication Ethics (COPE) guideline. <https://publicationethics.org/>

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