FIELD STUDY FOR PEDESTRIAN WIND COMFORT CRITERIA ON THE UNIVERSITI TEKNOLOGI MALAYSIA KUALA LUMPUR CAMPUS

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ABSTRACT

Emerging tropical countries, such as Malaysia, are not an exception when it comes to pedestrian wind comfort issues resulting from rapid urbanization. Kuala Lumpur, in particular, is still experiencing density growth in its centre with high-rise, skyscrapers continuing to be built. It is assumed that wind flow is deflected and disturbed due to new development. Thus, our goal is to assess the wind comfort in this urban area after being impacted by rapid development. The Universiti Teknologi Malaysia, Kuala Lumpur campus was chosen to represent an urban area for the purpose of identifying pedestrian wind comfort conditions. This paper presents our findings on pedestrian wind comfort parameters in terms of meteorological statistics and comfort criteria. The meteorological data was collected using two weather stations installed at the pedestrian level at 3.5 m off the ground. While, the Beaufort scale was used to measure the comfort criteria. Additionally, the reference weather station was placed on a rooftop at 53 m off of the ground. Based on the observation, our case study areas is fall within the calm wind comfort condition category at a range of less than 1 m/s in conformity with the Beaufort wind force scale. Moreover, pedestrian wind comfort is also influenced by several building morphology factors such as building height, orientation, and aspect ratio of studied areas. This study is still in the preliminary stage and it is expected to provide insight into understanding prevailing wind conditions within the study area. Based on this, we are optimistic in projecting the factors that contribute towards the desirability of the wind comfort conditions and can be applied in enhancing the quality of the outdoor life within urban contexts.

Keywords: Wind comfort, Wind environment, Tropical regions, Urban area.

Introduction

In recent years, most of the emerging tropical countries have become more focused toward economic development due to large growing populations. As a result, many environmental issues such as poor pedestrian wind comfort, dispersion of pollutants, and urban heat islands need to be addressed. Most of these aforementioned urban environmental issues have attracted significant interest in temperate-subarctic developed countries. In contrast, these issues have been left relatively understudied in tropical countries, thus resulting in the reliance on temperate region standard, criteria, or guidelines. Pedestrian wind comfort, however, is a growing problem in most cities, due to rapid urbanization. Kuala Lumpur, as the capital of Malaysia, continues to be developed with high-rise residential and commercial buildings, becoming increasingly dense over days. Due to wind flow being deflected and disturbed, comfort conditions are also altered due to this vigorous urban growth. Thus, we wish to assess the wind comfort in this urban area. The health and comfort level of pedestrians are mostly affected by the mechanical influences of wind movement in relation to human beings (Ghasemi, Esfahani, & Bisadi, 2015). Normally, wind impacts are based on the comfort level, safety, distribution of heat, dispersion of excessive humidity, spreading of traffic, and ventilation of buildings. High wind speed events near high-rise buildings might cause an uncomfortable and hazardous experience for pedestrians.

Nowadays, many municipal authorities encounter the importance of providing guidelines for wind comfort and wind safety regarding pedestrians. This awareness results in the encouragement of designers, architects and urban planners to conduct preliminary studies regarding wind comfort prior to the construction stage (Ghasemi et al., 2015; Lin, 2009). Moreover, there are several approaches used to conduct wind comfort studies such as wind tunnel experiments, computational fluid dynamics (CFD) simulation, and field measurements. For a real measurement, the data required for estimating wind comfort consists of wind statistics from local meteorological data, aerodynamic information, and wind comfort criteria (Bert Blocken, Roels, & Carmeliet, 2004). A minimum of 30 years of hourly wind data collected from a meteorological station should be used for estimating pedestrian wind comfort (B Blocken, Janssen, & van Hooff, 2012). In addition, the aerodynamic condition of wind comfort is influenced by design-related contributions that cause changes in the wind statistics due to high-rise and low-rise building configurations. The wind amplification factor was used to evaluate local wind conditions for the investigated area.

Present assessments of wind comfort are based on several existing guidelines such as the Beaufort wind scale, Isyumov and Davenport (Isyumov & Davenport, 1975), Melbourne (Melbourne 1978), Lawson (Lawson TW,1978), Bottema (Bottema, 2000), and Dutch Wind Nuisance Standard, NEN 8100 (NEN, 2006). In fact, each comfort criterion could lead to a different conclusion regarding the wind comfort situation depending on various complex urban conditions (Janssen et al., 2013). The comfort criteria are based on the combination of a threshold wind speed and a maximum allowed exceedance probability of this threshold value (Blocken & Persoon, 2009; Shi, Zhu, Duan, Shao, & Wang, 2015). Most past studies were conducted in temperate regions with only a few studies conducted in tropical regions, which might be due to typically weak wind characteristics in tropical microclimates. Recent rapid urbanization with high-rise buildings in tropical regions, however, has consequently caused the presence of strong winds at the pedestrian level. Hence, one related study conducted at the tropical region for determining the pedestrian wind environment at four major areas in the Klang Valley reported that building morphology, such as height, orientation, array, and aspect ratio, contributed significant impacts on wind comfort criteria (Razak, Rodzi, Jumali, & Zaki, 2015).

Therefore, it is important to conduct in-depth studies on the effect of pedestrian wind comfort in conjunction to rapid urbanization for tropical microclimates. The aim of this study is to analyse wind statistics in measuring the pedestrian wind comfort based on the Beaufort wind scale that is mostly used by meteorological offices for regular weather forecasting and assess what is an acceptable urban wind environment from two weather station locations installed on the Universiti Teknologi Malaysia campus.

Outline Of Methodology

Climate

Geographically, Malaysia consists of two parts: 1) Peninsular Malaysia bordered by Singapore, Thailand, and Indonesia; and 2) East Malaysia, formerly known as Malaysia Borneo, bordered by Brunei, Indonesia, and Philippines. Malaysia's latitude and longitude is at 2° 30' N and 112° 30' E (Malaysia, 2016). In terms of microclimate, Malaysia experiences warm, hot, and humid conditions and is located within tropical and rainforest regions. Its high annual mean temperature is approximately 26.4 °C with daily maximum and minimum temperatures up to 34 °C and 23 °C, respectively. While the annual relative humidity values are within 74%-86%, skies are clear between 3.7 hours and 8.7 hours per day, with six hours of sunshine daily (Jamaludin, Mohammed, Khamidi, & Wahab, 2015).

Site Description

This study is conducted in Kuala Lumpur campus at the Universiti Teknologi Malaysia, which is located in the city of Kuala Lumpur's centre at latitude of 3°10′21.43″ N, longitude 101°43′10.54″ E, formerly known as the fastest growing region in Malaysia. This study area represents the perspective urban area's morphology of low- and high-rise buildings located within or surrounding the urban areas of Kuala Lumpur. These low- and high-rise buildings are typically 3 m to 84 m, respectively. The highest building is the Razak Tower (84 m), followed by the Malaysia-Japan International Institute of Technology (MJIIT) building standing at a height of 53 m. Indeed, the recent development of several high-rise buildings and continued rapid development of the UTM campus has changed the physical environmental condition and thus wind comfort. Under these circumstances, strong winds, which may be uncomfortable for pedestrians, may have developed. Thus, with this intention, this paper assesses and quantifies the wind generated around. Figure 1 illustrates the field measurement weather station locations.

Figure 1: Weather station location, Universiti Teknologi Malaysia, Kuala Lumpur

In-Situ Measurement

The statistical meteorological data used for this study was collected between March 2014 and February 2015. The meteorological data measured using an anemometer for the Watchdog 8705 weather station (WS1) placed behind the MJIIT building, the Watchdog 8704 weather station (WS2) was located at the main entrance gate of the UTM, and the cup anemometer wind sentry (Campbell CR1000) was placed on a rooftop with the coordinate location of Nº10´22.8, E 101º43´14.88 as the reference weather station (WS3). The Watchdog weather station was placed above pedestrian level at 3.5 m high off the ground.

Statistical Meteorological Data

The meteorological data is categorised according to month for all environment factors, as illustrated in Table 1.

Table 1: Meteorological data for WS1 and WS2

Month		Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14	Jan-15	Feb-15
AIR TEMPERATURE													
WS1	T-Max	36.00	35.11	34.89	35.55	34.49	33.66	34.58	34.33	34.43	33.45	34.23	34.87
	T-Min	25.06	24.11	24.53	26.31	25.70	24.54	24.49	24.28	24.09	24.50	24.49	24.85
	T-Ave	29.15	27.81	28.33	30.39	29.51	28.36	28.26	27.97	27.39	27.46	27.87	28.61
WS2	T-Max	35.87	34.81	34.73	34.93	34.20	33.66	34.42	33.85	34.12	32.90	33.94	34.79
	T-Min	25.08	24.20	24.58	26.05	25.92	24.66	24.51	24.36	24.33	24.56	24.44	24.76
	T-Ave	29.34	27.86	28.31	29.93	29.64	28.34	28.26	28.03	27.57	27.50	28.05	28.85
RELATIVE HUMIDITY													
WS1	RH-Max	83.74	94.26	94.80	78.56	80.14	86.12	87.21	87.86	92.73	91.27	83.84	77.14
	RH-Min	33.37	44.94	44.08	37.50	38.48	41.47	38.55	39.06	43.21	44.77	35.65	33.30
	RH-Ave	64.38	76.75	76.80	64.11	62.87	68.46	68.84	70.12	76.13	75.48	65.34	58.70
WS2	RH-Max	84.61	95.27	96.83	82.38	81.15	87.55	88.75	91.05	93.71	92.37	85.60	79.39
	RH-Min	34.94	45.76	46.68	42.36	41.24	44.77	41.48	42.20	46.03	46.85	38.88	34.96
	RH-Ave	62.83	76.42	75.24	59.41	61.36	66.43	67.69	68.69	75.81	74.14	63.82	57.69
SOLAR RADIATION													
WS1	SR-Max	1035.65	933.68	844.85	802.29	748.47	844.19	876.60	776.67	865.94	814.08	884.63	970.79
	SR-Ave	178.41	151.89	135.00	148.33	134.61	140.18	138.44	119.87	116.47	105.79	132.32	146.50
WS2	SR-Max	1049.87	946.68	841.33	769.83	712.16	818.52	815.53	706.92	739.83	684.54	781.60	884.25
	SR-Ave	195.21	150.14	130.10	130.20	119.60	128.76	133.14	109.03	109.07	93.80	126.62	153.67
WIND SPEED													
WS1	WS-Max	9.04	3.48	3.20	3.67	0.94	3.40	3.36	0.35	1.34	6.43	6.47	12.96
	WS-Ave	1.77	0.66	0.62	1.11	0.24	0.79	0.77	0.08	0.32	1.39	0.76	2.97
WS2	WS-Max	2.81	2.33	1.97	3.36	2.90	3.25	2.98	2.88	2.19	1.79	3.36	4.32
	WS-Ave	1.25	0.63	0.58	0.94	0.30	0.89	0.58	0.51	1.33	1.03	1.50	3.84

All of the data from the two studied weather stations (WS1 and WS2) is then compared with that from the reference weather station (WS3). The purpose of this comparison is to clarify the effect of air temperature, solar radiation, relative humidity, and wind flow with the reference weather station. This reference station is located at an area with free wind flow and direct to sun penetration without obstacles and shadow effects but is also different in terms of altitude of the weather station, as shown in Figures 2 and 3.

The correlation graph shows that there are similarities regarding air temperature, solar radiation, and relative humidity at different weather station altitudes and locations. Whereas for the wind speed, it shown significant differences and uneven data correlations between each weather station, and the presence of wind might be influenced by several factors of building morphology such as building height, orientation, aspect ratio, and arrangement of the case study area. Moreover, WS1 wind speed is slightly lower than WS2; this might be due to the position of WS1 which being installed too near to the building compared to WS2, where it was placed in an open public space. This placement meant that WS1 caused blockage or deviation in the wind penetration regarding the pedestrian area.

Figure 2: Correlation of WS1/WS3 for a) air temperature, b) relative humidity, c) solar radiation, and d) wind speed

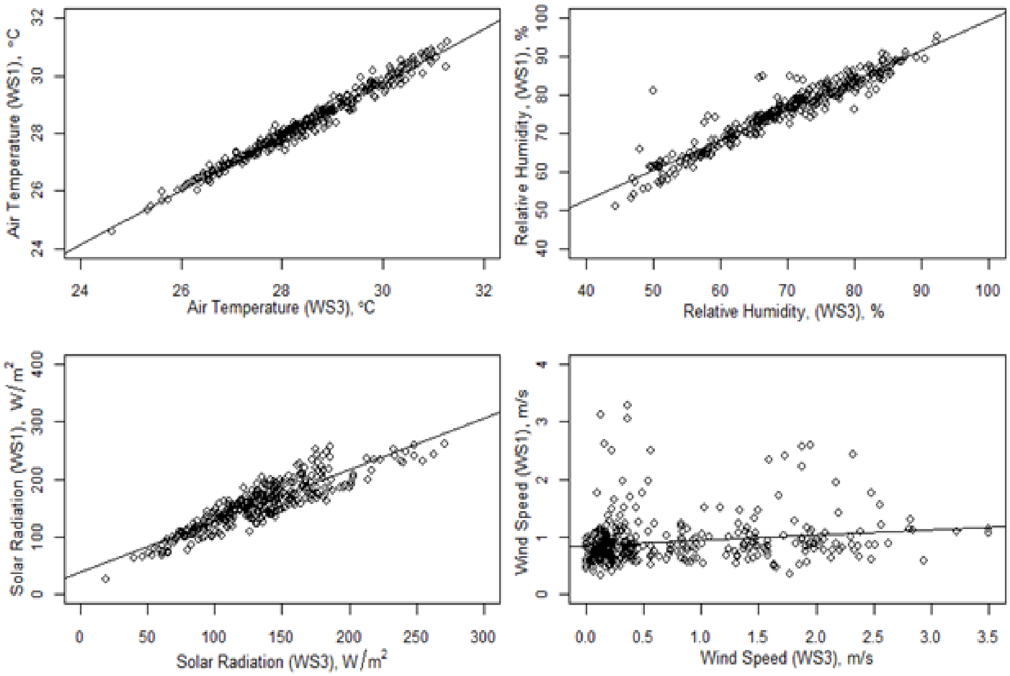
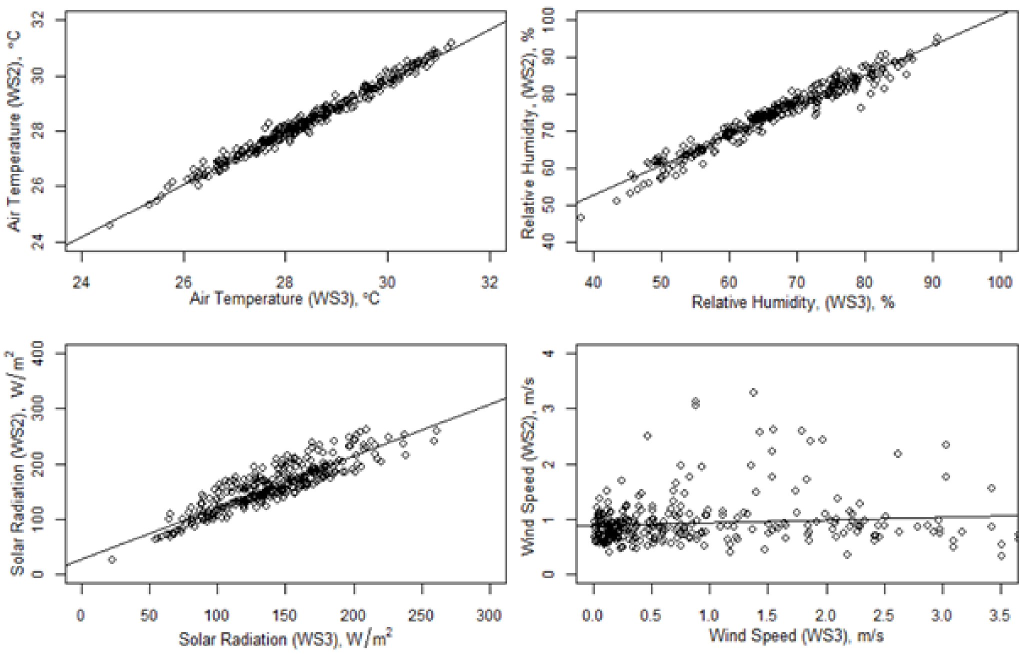


Figure 3: Correlation of WS2/WS3 for a) air temperature, b) relative humidity, c) solar radiation, and d) wind speed



Wind Comfort Criteria

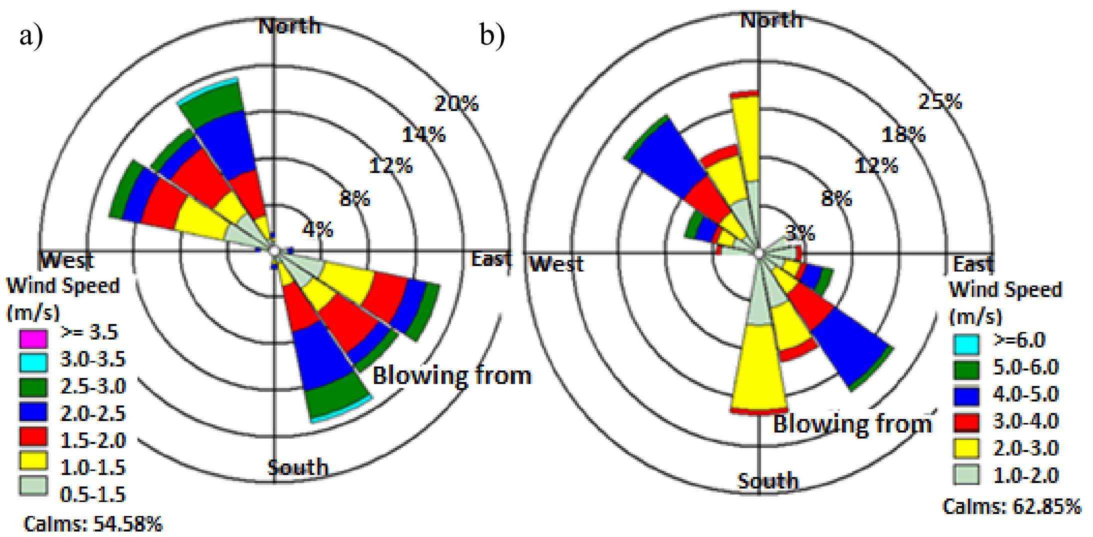
Based on the meteorological data collected from March 2014 to February 2015, the objective of this paper is to define the wind comfort conditions of the field study area by referring to the Beaufort scale as shown in Table 2.

Table 2: Beaufort scale

Beaufort wind scale	Mean wind speed (m/s)	Limit wind speed (m/s)	Wind descriptive terms	Description on land
0	0	<1	Calm	Smoke rises vertically
1	1	1-2	Light air	Wind felt on face; leaves rustle; ordinary vanes moved by wind
2	3	2-3	Light Breeze	
3	5	4-6	Gentle Breeze	
4	7	6-8	Moderate Breeze	Raises dust and loose paper; small branches are moved
5	10	9-11	Fresh Breeze	Small trees in leaf begin to sway; crested wavelets from on inland waters
6	12	11-13	Strong Breeze	Large branches in motion; whistling heard in telephone wires; umbrella used with difficulties
7	15	14-16	Near Gale	Whole trees in motion; inconvenience felt when walking against wind
8	19	17-20	Gale	Twigs break off trees; progress generally impeded
9	23	21-24	Strong Gale	Slightly damage to structures occurs-roofing dislodged; larger branches break off
10	27	25-28	Storm	Seldom experienced inland; trees uprooted; considerable structural damage
11	31	29-32	Violet Storm	Very rarely experienced-widespread damage
+12		33+	Hurricane	Very rarely experienced-widespread damage

A compilation of the wind speed and wind direction data is then configured with WR plot software in identifying the wind comfort criteria and wind direction, as shown below. Figure 4 illustrates the wind patterns of weather stations 1 and 2 (WS1 and WS2). In general, the wind blows from the southeast to northeast region. However, the reference weather station (WS3) shows a different pattern where the wind from northeast to southeast region. This might, under contrasting circumstances to the reference weather station (WS3), be due to the altitude where the measurement is placed where wind can freely blows without obstacles. Whereas, the others two weather stations were placed within obstacles, altering wind flow conditions.

Figure 4: Wind direction for a) WS1 and b) WS2



Additionally, the data is then analysed according to wind comfort conditions as per the Beaufort scale. Figure 5 illustrates weather station 1 (WS1), with a wind comfort percentage of 54.6%, 33.8%, and 11.6% for calm, light air, and a light breeze, respectively. Conversely, there is an increment to the calm condition percentages for weather station 2 (WS2) recorded at 62.8%, as shown in Figure 6. While, the light air and light breeze are at 15.6% and 15.4%, respectively. Moreover, from the annual data statistics, 6.2% of wind speed in the studied area falls within the range of 4.0 to 6.0 m/s, which is categorized as gentle breeze, according to the Beaufort Wind Scale that occurred suddenly. The presence of strong wind might be influenced by the weather station's surrounding environment given that it is located to the open public urban environmental conditions.

Figure 5: Wind comfort criteria for WS1

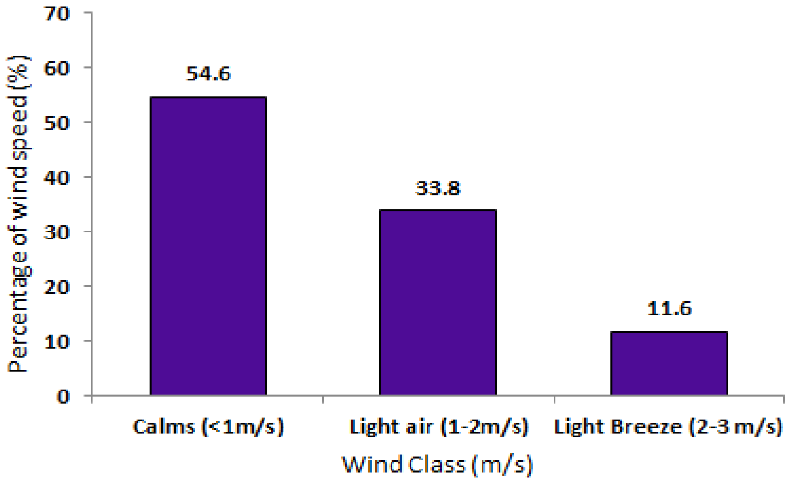
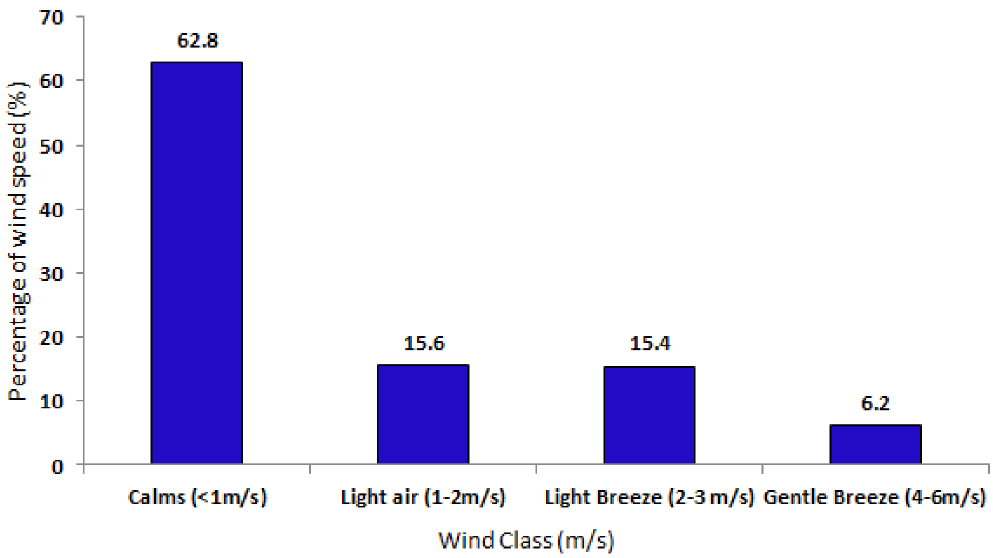
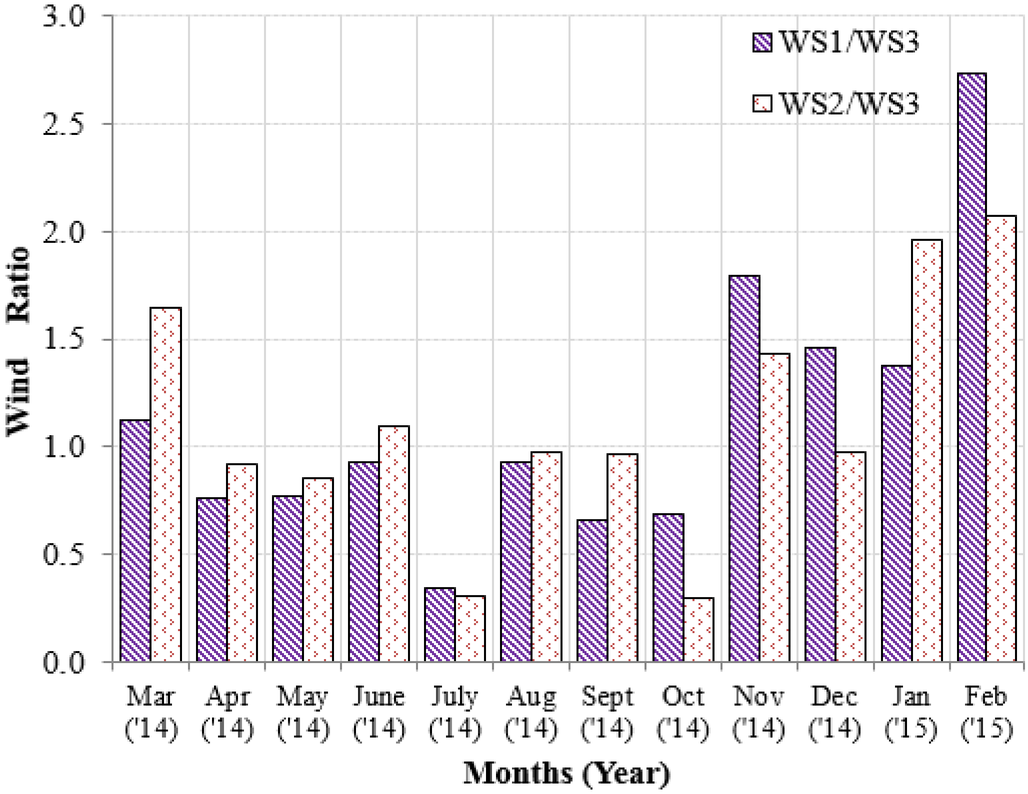


Figure 6: Wind comfort criteria for WS2



In summary, the wind speed ratio values for weather station 2 (WS2) are slightly higher than those of weather station 3 (reference station) and relatively lower than those of weather station 1 (WS1), as illustrated in Figure 7.

Figure 7: Wind speed ratio WS1/WS3 and WS2/WS3



Conclusions

This paper presented the results of wind comfort criteria for a tropical region based on the Beaufort comfort criteria using meteorological data measured between March 2014 and February 2015. Throughout the data analysis, it was found that the wind velocity for the case study area was categorized within calm conditions. However, while being a tropical microclimate, the country's wind flow regimes are also now influenced by several building morphology factors such as building height, orientation, and aspect ratio. Nevertheless, with limitations to our weather station instruments, measurements could only be conducted at two points; this could be improved by adding more measurement points for the future. Therefore, for future work, field measurements should take those building morphology factors into consideration in order to improve the outdoor environmental conditions in tropical regions. Moreover, this can also provide an important reference for urban planning, in terms of building arrangement and landscaping, in order to accommodate better wind comfort for pedestrians.

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