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Comparative Study of Natural and Artificial Wind for Thermal Comfort Studies

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***Abstract*— Wind speed is widely known factor affecting human thermal perception and comfort. However, little is available about the dynamic characteristics of natural and artificial wind. Currently, some investigators addressed the dynamic aspect of natural and artificial wind speed for thermal comfort according to power spectrum slope. However, there is little information about the dynamic characteristics of wind direction (wind azimuth) and elevation. The aim of this study is to investigate some of the characteristics of natural versus artificial wind at various sampling time. Measurements of natural and artificial wind were made using ultrasonic anemometer. The study location is Kota Kinabalu, Malaysia. Wind speed, wind direction, wind elevation and air temperature are the recorded parameters. In the present case study, the artificial wind is referred to the indoor wind generated by air conditioning and USB fan simultaneously. Several differences were observed between natural and artificial wind at various sampling time. The power spectral slopes of natural wind speed, wind direction, wind elevation and air temperature were higher than the case of artificial wind.**

Keywords*— *Natural Dynamic wind; Artificial wind; Air Temperature; Thermal comfort; Humid tropics; Malaysia

I. INTRODUCTION

The human body is made of several trillions of cells within a three-dimensional matrix [1]. The human body is also exposed to the outer environment. In fact, the human body interacts consciously and unconsciously with the indoor and outdoor environment. The interaction may occur via stimuli. Stimuli may significantly affect the brain without the person's awareness. For instance, infrasound sources from winds can spread for millions of meters [1].

Air temperature and wind are two widely recognized parameters affecting human thermal comfort. However, little information is available about the dynamic characteristics of natural wind in thermal comfort studies. Most of recent studies on this topic were carried out in china [2, 3, 4, 5]. However, this did not reflect the global aspect in terms of scope, external validation and generalization. Further, the complexity of natural wind behavior at various time scale and human response to it remain unresolved. For instance, humans respond to several stimuli differently at various time scales. The response is either conscious or not. This let such interesting topic more fascinating and an unresolved.

This investigation will not certainly solve all the stated issues due to the complexity of the topic. The aim of this study is about investigating similarities and differences of natural and artificial wind. Second, it is important to discuss the impact of the obtained results on thermal comfort prediction under different time scales. In this article, the indoor air movement generated by USB fan and air conditioning is referred to it by artificial wind.

II. METHODOLOGY

The natural wind parameters were recorded at the edge of a tree for 30 Minutes. The indoor artificial wind in a classroom was also recorded for 30 Minutes. The sampling time for both experiments is eight records per second. There were 14400 records in each experiment. In this investigation, ultrasonic anemometer was used to measure the wind speed, azimuth, elevation and air temperature. Figure 1 shows the experiment setup of this study. In this article, the procedure of the experiment is similar to our previous published article on the same topic. Therefore, the reader may refer to the previous study [6].

Figure 1 Experimental Setup of this Study
(1) Artificial Wind; (2) Natural Wind

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III. RESULTS AND DISCUSSION

Several graphs of natural and artificial wind were firstly plotted for an initial observation of the recorded data. In the next step, wind azimuth, wind elevation and wind speed were analyzed and compared. The comparison of natural versus artificial wind was made based on maximum, minimum, average and standard deviation values of the recorded parameters. Finally, power spectrum slops of natural and artificial wind and air temperature were estimated within the frequency range of 0.01 to 1 Hz [6, 7].

A. Some Observations about Time Series Plots of Natural versus Artificial Wind

Time is an important factor affecting human thermal perception and thermal adaptation. Time is also an important factor when considering the dynamic aspect of wind on human thermal comfort. Figure 2 shows time series of natural versus artificial wind speed. The cycles in natural wind are broader when compared with artificial wind. The natural wind range is higher when compared with artificial wind. The artificial wind speed was dominant within the range of 0.3 m/s to 0.4 m/s. It is also apparent that natural wind speed was higher than artificial wind. Visually, it is very possible to identify natural wind speed from artificial wind speed for the case study from time series plots.

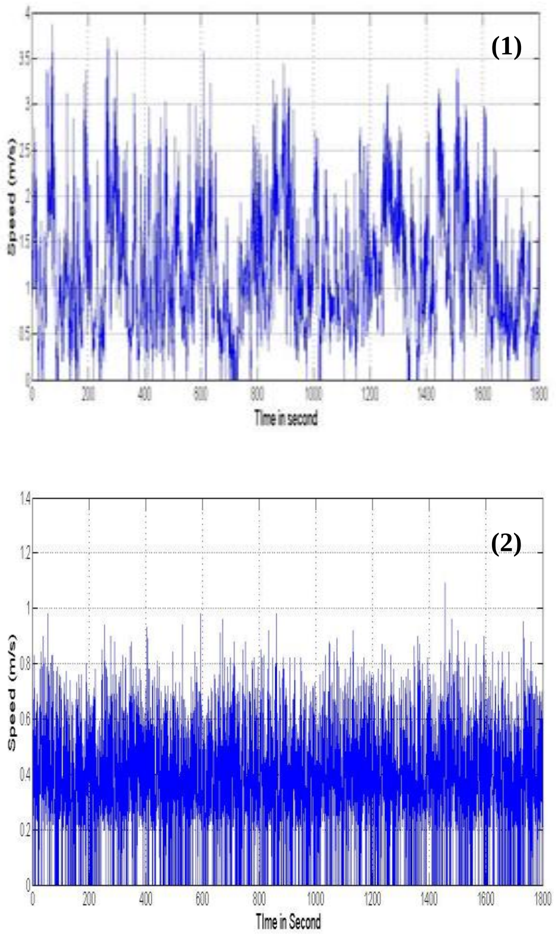
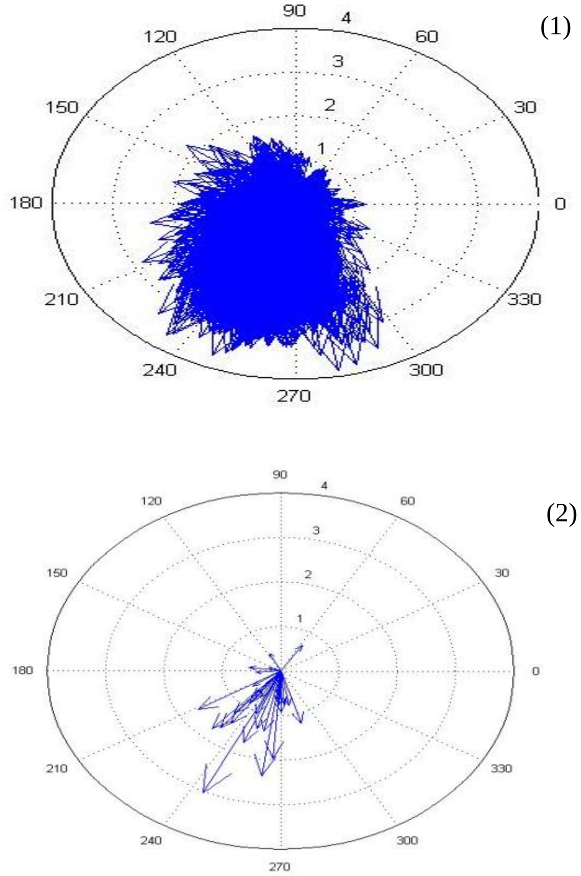


Figure 2 Time Series for Natural versus Artificial Wind Speed (8 records per second)
(1) Natural Wind; (2) Artificial Wind

B. Analysis of Compass Plots of Natural versus Artificial Wind

In this section, compass plot is used to investigate natural and artificial wind direction and wind speed. The selected plot is known by compass plot. Compass plot did not only consider wind azimuth (wind direction) but also wind speed. A compass graph displays wind speed and wind direction in Cartesian coordinates plotted on a circular grid. Four compass plots are displayed in Figure 3. Each arrow's length corresponds to the wind speed records. The first plot is about natural wind. It was produced with a sampling time of eight records per second for thirty minutes duration. It is apparent from the graph that the dominant wind direction for the sampling time of one record per minute (plot (2)) is nearly within the range of 210 to 270. The situation is different for the artificial wind. The artificial wind direction was subjected to wider range for the case of one record per minute. This might occurred due to the interface of air movement generated by air conditioning and USB fan.



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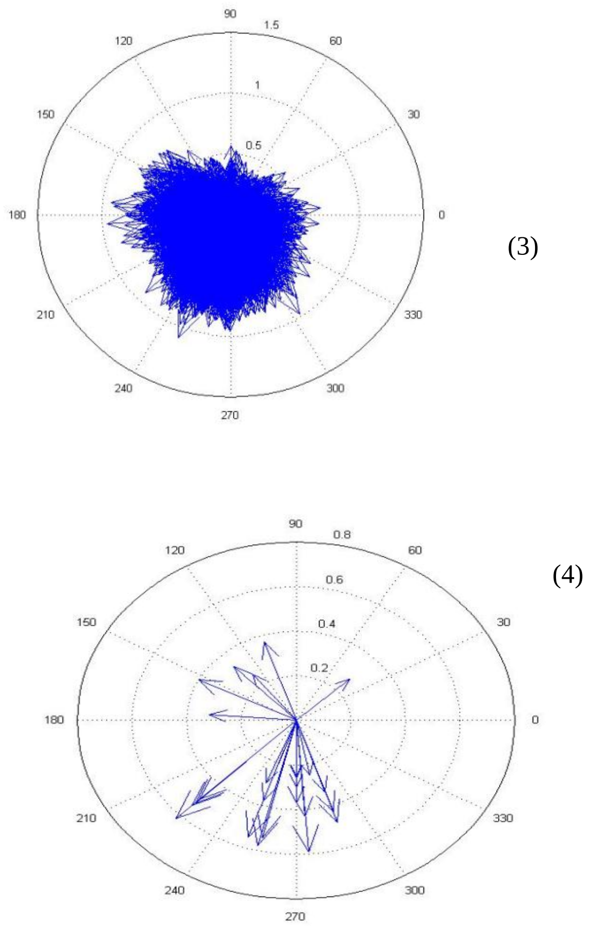
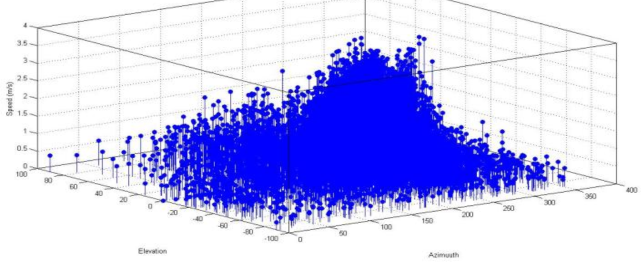


Figure 3 Compass Plots of Natural versus Artificial Wind
(1) and (2) Natural Wind , (3) and (4) Artificial Wind

C. Analysis of 3D Plots of Natural versus Artificial Wind

For further understanding the behavior of natural wind versus artificial wind, three-dimensional plots are generated. The 3D plots shown in Figure 4 represent visual information on natural and artificial wind direction and wind elevation in x-y axis and wind speed in z- axis. The sampling time is eight records per second for the first and the third plots. For the second and the fourth plots, the sampling time is one record per minute. The time duration for all cases is 30 minutes. Briefly, when considering all the records, the natural wind speed has a natural hill shape, whereas artificial wind appears almost flat and was subjected to moderate fluctuation.

(1)



(2)

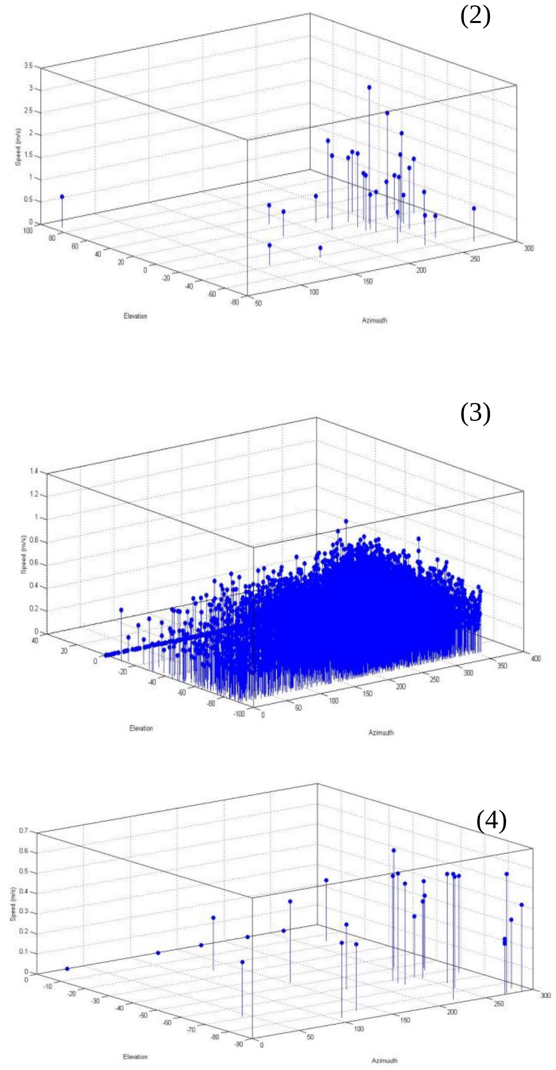


Figure 4 Three-dimensional Plots of Natural versus Artificial Wind
(1) and (2) Natural Wind , (3) and (4) Artificial Wind

D. Comparison of Maximum Records of Natural versus Artificial wind

In this section, the maximum natural wind records of azimuth, elevation and speed are compared with artificial wind speed in Table 1. Three different sampling times were investigated. The purpose of using different sampling times is to address the impact of the selection of sampling time on thermal comfort.

It is apparent from Table 1 that the sampling time affected the results. The difference in the maximum wind speed reached up to 0.83m/s when considering one record per second versus one record per minute. However, the difference is reduced to 0.47 m/s for artificial wind speed. In thermal comfort studies, it is widely accepted that a wind speed above 0.2 m/s affects human thermal perception and thermal comfort. However, wind speed records are generally averaged in thermal comfort field studies. There is no specific standardized sampling time in wind data records for thermal comfort studies.

The natural and artificial wind elevations were also subjected to slight fluctuation regardless of the selected sampling time. The situation is different for wind azimuth when considering sampling time of 1-second record versus 1-minute record.

Table 1 Maximum of Azimuth, Elevation and Speed of Natural and Artificial Wind

Id	Wind	Sampling Time	Azimuth	Elevation	Speed
A	Natural Wind	8-Records per Second	359.60	90	3.87
B		1-Record per Second	355.60	90	3.87
C		1-Record per Minute	287.30	89.10	3.04
D		Range (B-C)	68.3	0.9	0.83
A	Artificial Wind	8-Records per Second	359.10	25.10	1.09
B		1-Record per Second	359.10	0.80	1.09
C		1-Record per Minute	288.40	0	0.62
D		Range (B-C)	70.7	0.8	0.47

E. Comparison of Minimum Records of Natural versus Artificial wind

The minimum wind azimuth, wind elevation and wind speed records of natural wind were compared with artificial wind. The procedure of analysis is similar to the previous section. The results are shown in Table 2.

Table 2 Minimum of Azimuth, Elevation and Speed of Natural and Artificial Wind

Id	Wind	Sampling Time	Azimuth	Elevation	Speed
A	Natural Wind	8-Records per Second	0	-90	0
B		1-Record per Second	0	-90	0
C		1-Record per Minute	57.60	-67	0.21
D		Range (B-C)	57.6	23	0.21
A	Artificial Wind	8-Records per Second	0	-90	0
B		1-Record per Second	0	-90	0
C		1-Record per Minute	32.50	-90	0
D		Range (B-C)	32.5	0	0

Wind azimuth was subjected to more variation when considering different sampling times. Wind azimuth was subjected to more variation when considering different sampling times. For artificial wind speed, there is no difference between results when considering the instantaneous artificial wind (eight records per second) versus one record per second. However, the situation is different for the sampling time of one record per minute. The difference in wind speed of the minimum record reached 0.21 m/s. No difference in wind speed is observed for artificial wind. This means that regression analysis is likely to predict different comfort temperatures when including the wind speed as an independent variable. This is because; wind speed above 0.2 m/s affects human thermal perception and thermal comfort. Additionally, it is apparent that the sampling time and the duration of wind record in thermal comfort studies are important. This is also crucial for making the comparison among thermal comfort studies acceptable when the wind is above 0.2 m/s.

F. Comparison of Mean Records of Natural versus Artificial wind

Mean wind speed is widely used in thermal comfort studies. Table 3 illustrates the mean wind speed for 30 minutes duration. The obtained results showed little fluctuation for the three components of wind speed, wind elevation and wind azimuth. The situation might be different for shorter duration of 15 minutes. Therefore, mean wind speed did not reflect the instantaneous variation of wind speed, which certainly affects human thermal comfort. Additionally, the mean value of wind speed may not be the dominant wind [8].

Table 3 Mean of Azimuth, Elevation and Speed of Natural and Artificial Wind

Id	Wind	Sampling Time	Azimuth	Elevation	Speed
A	Natural Wind	8-Records per Second	232.97	-6.92	1.20
B		1-Record per Second	236.74	-6.68	1.19
C		1-Record per Minute	230.94	-9.34	1.09
D		Range (B-C)	5.8	2.66	0.1
A	Artificial Wind	8-Records per Second	220.01	-58.92	0.37
B		1-Record per Second	219.80	-59.13	0.38
C		1-Record per Minute	216.90	-56.10	0.34
D		Range (B-C)	2.9	3.03	0.04

G. Comparison of Standard Deviation of Natural versus Artificial Wind

The standard deviations for all the selected cases were calculated. The obtained results are illustrated in Table 4. It is apparent from Table 4 that the standard deviation of natural outdoor wind speed was above 0.6 m/s regardless of the selected sampling time. This shows that the standard deviation of natural wind speed was higher than 0.2 m/s. Further analysis was not possible because the mean wind speed may not be the dominant wind speed. The situation probably is different for the indoor natural wind speed.

Table 4 Standard Deviation of Azimuth, Elevation and Speed of Natural and Artificial Wind

Id	Wind	Sampling Time	Azimuth	Elevation	Speed
A	Natural Wind	8-Records per Second	52.561	24.27	0.67
B		1-Record per Second	52.54	24.18	0.67
C		1-Record per Minute	50.31	29.58	0.64
D		Range (B-C)	2.23	5.4	0.03
A	Artificial Wind	8-Records per Second	71.10	24.91	0.18
B		1-Record per Second	71.60	24.41	0.18
C		1-Record per Minute	72.51	31.28	0.19
D		Range (B-C)	0.91	6.87	0.01

H. Comparison of Power Spectrum Slope of Natural versus Artificial Wind

Power spectral analysis is widely used in investigating the dynamic characteristics of airflow. Several thermal comfort investigators used power spectral to analyse the fluctuating characteristics of natural wind speed within the frequency range of 0.01 to 1 Hz. However, little is available about the power spectrum slops of wind azimuth and wind elevation. In this section, the method is used to estimate power spectrum slops of wind azimuth, wind elevation, wind speed, and also for air temperature. Fast Fourier Transform (FTT) was applied. The results are plotted in Table 5. The sampling time is eight records per second. The duration is thirty minutes. The power spectral slopes of natural wind speed, wind azimuth, wind elevation and air temperature were all above 1. The situation is different for the artificial wind and temperature. The power spectral slopes for all those cases were less or equal 0.5.

Table 5 Power Spectral Slope of Natural and Artificial Wind

Sampling Time	Azimuth	Elevation	Speed	Temperature
Natural Wind	1.17	1.06	1.56	1.41
Artificial Wind	0.19	0.31	0.43	0.50

IV. CONCLUSIONS

This study is about investigating similarities and differences of natural versus artificial wind at various time scales. The selected variables are wind speed, wind direction and wind elevation. Air temperature was also included in estimating power spectral slope. The main conclusions are:

- The plotted wind data showed visual distinction between natural versus artificial wind.
- The selected sampling times affected the statistical description of the wind data. Therefore, it is recommended that the sampling time and the exact duration of the wind record to be standardised in thermal comfort field studies. This is important when the wind speed is above 0.2 m/s.
- Power spectral slopes of natural versus artificial wind were estimated within the frequency range of 0.01 to 1 Hz. The slopes of wind azimuth, wind elevation, wind speed and air temperature of natural environment were higher than the case of artificial wind and artificial air temperature.

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