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Authors
Kang, Ki-Nam
Song, Doosam
Schiavon, Stefano

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Correlations in thermal comfort and natural wind

Ki-Nam Kang [a], Doosam Song [b,*], Stefano Schiavon [c]

[a] Graduate School, Sungkyunkwan University, 300 Chunchun-dong, Suwon, Gyeonggi 440-746, South Korea
[b] Department of Architectural Engineering, Sungkyunkwan University, 300 Chunchun-dong, Suwon, Gyeonggi 440-746, South Korea
[c] Center for the Built Environment, University of California at Berkeley, 390 Wurster Hall, Berkeley, CA 94720-1839, USA

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ABSTRACT

Many field surveys have shown that naturally ventilated buildings are favorable to human thermal comfort and may allow higher cooling temperatures than air-conditioned buildings. Recreating natural wind characteristics with a mechanical cooling system may diminish the drawbacks of conventional cooling systems such as drafts and high energy demands.Natural wind characteristics (wind velocity, direction, turbulent intensity, temperature and relative humidity) were recorded in a mountain environment and correlated with the human thermal sensation of 48 subjects. Natural wind fluctuation characteristics were analyzed using the Fast Fourier Transform (FFT) analysis. The dynamic characteristics of natural wind were averaged through the power spectrum exponent (β–value), which represents the energy distribution of the turbulent flow of natural wind. The power spectrum exponent (β–value) of the natural wind will decrease when the mean velocity increases, while it will increase when the turbulent intensity increases. The power spectrum exponent (β–value) was correlated (Spearman's rank coefficient=0.56, $p < 0.001$) with thermal comfort. The power spectrum exponent (β-value) for people feeling comfortable has a median value of 1.62 [1.41–1.80 for the first and third quartiles, respectively] and the β–value for people feeling uncomfortable has a median value of 1.10 [0.97–1.25].

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1. Introduction

In naturally ventilated buildings, occupants may accept higher temperatures than in air-conditioned buildings, and natural wind with a relatively high average velocity is more acceptable than mechanical wind (Busch, 1992; Ealiwa et al., 2001; de Dear and Brager, 2002). The occupants of naturally ventilated buildings accept a significantly wider range of temperatures (Busch, 1992; Ealiwa et al., 2001; de Dear and Brager (2002)) that fall out of the standard based on Fanger's thermal comfort model (ISO 7730, 2005). Busch (1992) carried out a field study of thermal comfort in Bangkok, where more than 1,100 office workers responded to a questionnaire while simultaneous physical measurements were taken. In that study, both air-conditioned and naturally ventilated offices were surveyed. The results showed that the upper temperature bound for a Thai comfort standard, instead of the currently accepted level of 26.1 °C, should be as high as 31 °C for office workers who are accustomed to naturally ventilated spaces, and as high as 28 °C for those who are accustomed to air-conditioning. Ealiwa et al. (2001) conducted a field survey of thermal comfort within two types of buildings in Ghadames, an oasis town in Libya, with 24 old buildings that employ natural ventilation systems with courtyards and 27 new buildings that employ air-conditioning systems. Regarding the overall feeling in the summer season, the occupants reported that they are more satisfied and thermally neutral in the old, naturally ventilated buildings than in the new, air-conditioned buildings. In the old buildings, about 54% of the occupants felt neutral and 8% felt hot, compared to only 15% of the occupants that felt neutral and 33% that felt hot in the new, air-conditioned buildings. In addition, de Dear and Brager (2002) analyzed thermal comfort in naturally ventilated buildings using the ASHRAE RP-884 database. They found that the occupants in naturally ventilated buildings preferred a wider range of conditions than those in HVAC buildings, and their indoor thermal comfort temperature ranges more closely reflected the outdoor climate patterns.

People prefer natural wind because it fluctuates following the *1/f* rhythm of the body. The *1/f* fluctuations are ubiquitous in nature and have been identified in biological systems. This type of fluctuation appears to play a crucial role in maintaining life in biological bodies (Musha and Yamamoto, 1997). Shimizu and Hara (1996) and Hara et al. (1997) used power spectral analysis to study outdoor natural wind and found that the fluctuating velocity of natural wind follows the *1/f* function.

Toriumi et al. (2000) measured the characteristics of natural wind in terms of spatial correlation. Hanzawa et al. (1987) and Chow et al. (1997) adopted a stochastic analysis method to study the dynamic characteristics of airflow in air-conditioned and

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[*] Corresponding author. Tel.: +82 31 290 7551; fax: +82 290 7579.
E-mail address: dssong@skku.edu (D. Song).

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mechanically ventilated rooms. The analytical parameters included the turbulence intensity, standard deviation, turbulent integral scale, correlation and spectral characteristics. Similarly, Ouyang et al. (2006) measured and analyzed the spectral characteristics of natural wind and mechanical wind under different conditions using the Fast Fourier Transform (FFT) method. The results showed that, in the frequency region, which is sensitive to human sensation, the spectrum characteristics of natural and mechanical wind in an indoor environment have clear differences. The power spectrum exponent (β-value) of natural wind is between 1.1 and 2.0, falling in the human sensitive frequency region, while the β–value of mechanical wind is between 0 and 0.5 around air supply outlets.

The aim of this study is to independently assess the characteristics of natural wind that cause pleasant or unpleasant thermal sensations for subjects during summer through field measurements. Natural wind characteristics (wind velocity, direction, turbulent intensity, temperature and relative humidity) have been recorded in a mountain environment and have been correlated with the human thermal sensations of 48 subjects. The natural wind fluctuation characteristics were analyzed using the FFT analysis.

2. Methods

2.1. Field measurements and human subject tests

To analyze the characteristics of human thermal comfort perception for natural wind in a hot and humid environment during the summer, field measurements were conducted in the Mt. Seorak area in Korea, where a relatively comfortable wind can be felt in the summer comparable to the wind in urban areas. The measurements were performed from July 21 to 27, 2008. The site for the measurements (Fig. 1) was a cut-grass plain in a valley facing a mountain to the north, which is an open space where few factors affect the wind flow.

As shown in Table 1, the measurement items included the air temperature, relative humidity, air pressure, solar radiation, mean radiant temperature (globe temperature), and three-dimensional (3D) wind velocity/direction to record the micro-climate felt by the subjects in detail. The characteristics of the measuring instruments followed the class C of ISO 7726:2002, which deals with the minimum characteristics of instruments that can be used for the measurement of physical parameters (ISO 7726, 2002). The measurement point for the micro-climate was at a height of 2.3 m åfor the barometric pressure and solar radiation. The air temperature, mean radiant temperature, relative humidity, and air velocity/direction close to the human subject were recorded at a height of 1.1 m according to ISO 7726:2002.

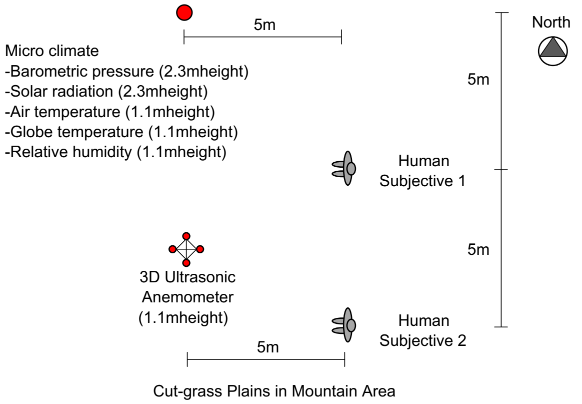

Fig. 1. Measurement setting for natural wind.

The measurement interval was about 30 s for the micro-climate (air temperature, relative humidity, air pressure, horizontal solar radiation and mean radiant temperature) around the subject and 0.1 s (10 Hz) for the 3D wind velocity/direction, due to the need for a detailed analysis of the fluctuation characteristics of natural wind.

To investigate the thermal sensation of a subject exposed to natural wind, questionnaires were given to subjects. In order to minimize variables such as the effect of direct solar radiation on the subject's thermal sensations, a shading device (a parasol) was installed. The reliability of the survey results depends on the quality of the individual responses (Robson, 1993). In this study, 48 subjects, 12 (6 male and 6 female) subjects per day for four days, participated in the survey. Two subjects (one man and one woman) were exposed simultaneously to the same environment. Even though they were exposed to the same environment, they sometimes reported different scores for the thermal sensation and thermal comfort. The data were processed separately by gender. The characteristics of the subjects are shown in Table 2.

The subject questionnaire included two parts: thermal sensation and thermal comfort. Thermal sensations were reported on the ASHRAE 7-point scale (Table 3). The thermal comfort scale was based on the scale developed by Zhang (2003), but the scale at mid-point was modified to “slightly uncomfortable (3)” and “slightly comfortable (4)” to clarify the subject's comfort perception for the natural wind conditions in this study (Table 4). The thermal perception of the subject was recorded once every 30 s. In addition, the background questionnaire was written prior to the experiment and covered demographic data, as well as contextual and psychological factors that may have affected the subject's thermal responses to environments.

The clothing ensembles of the male subjects were 0.4 clo (T-shirt, underwear, short-sleeved shirt, beach shoes and shorts), and those of the female subjects were 0.41 clo (T-shirt, underwear, short-sleeved shirt, brassiere, beach shoes and shorts). The clothing insulation was calculated according to ISO 7730 (2005) and ASHRAE 55 (2004). The metabolic rate of the subject was 1.1 met (sitting), which was calculated according to ASHRAE 55 (2004).

2.2. Power spectral analysis

In order to analyze the fluctuating characteristics of natural wind, the measured data were plotted as a time series and converted to the frequency domain by FFT.

The fluctuating characteristic of natural wind, i.e., turbulence, can be described as the superposition of various periodic motions caused by different sized eddies. The different sized eddies that make up a turbulent motion have a certain kinetic energy, which is determined by their vorticity or by the intensity of the velocity fluctuation of the corresponding frequency. Even though a distinct frequency is not permanently present in real turbulence, it is possible, on average, to allocate a certain amount of the total energy to a distinct frequency by using the following power spectral density $E(f)$, according to Hinze (1975):

$$E(f) = \frac{2h}{N} |X_k|^2 \tag{1}$$

where h is the sampling interval, N is the sample size, and X_k represents the Fourier components via the FFT procedure.

$$X_k = \sqrt{(V_x^2 + V_y^2 + V_z^2)} \tag{2}$$

where V_x is the wind velocity in the x-direction (m/s), V_y is the wind velocity in the y-direction (m/s), and V_z is the wind velocity in the z-direction (m/s).

Table 1
Measurement instruments and specifications.

Instrument	Company	Measurement	Specifications	
Weather station	DAVIS (Vantage Pro2^{TM} Plus-6162)	Barometric pressure	Range	540–1100 hPa/mb
			Accuracy	±1.0 hPa/mb
		Horizontal solar radiation	Resolution	1 W/m^2
			Range	0–1800 W/m^2
			Accuracy	±0.5%
Hygrometer	SATO (SK-L200II)	Relative humidity	Resolution	0.10%
			Range	0–100% RH
			Accuracy	±0.5%
Thermocouple	Omega(K-type)	Mean radiant temperature/air temperature	Range	−200—1370 °C
			Accuracy	±1.0 °C or 0.75%
Data-logger	YOKOKAWA (MX-100-E-1 F)		Resolution	1 μV
			Range	0 to +60 mV
			Accuracy	±0.05%
3D Ultrasonic anemometer	KAIJO (DA-600-3TV)	Wind velocity(x,y and z-axes)	Resolution	0.005 m/s
			Range	0–60 m/s
			Accuracy	±1.0%
		Wind direction	Range	0–540°
			Accuracy	±3.0°

Table 2
Characteristics of subjects.

	Number	Age (mean ± SD)	Height (cm) (mean ± SD)	Weight (kg) (mean ± SD)	Body area (m^2)* (mean)
Male	24	24 ± 2.5	175 ± 1.7	74 ± 3.7	1.88
Female	24	22 ± 2.0	160 ± 5.0	50 ± 1.0	1.49

* Body area = 0.007246 × Weight $^{0.425}$ × Height $^{0.725}$

Table 3
Thermal sensation scale-thermal sensation vote (TSV).

Cold	Cool	Slightly Cool	Neutral	Slightly warm	Warm	Hot
−3	−2	−1	0	1	2	3

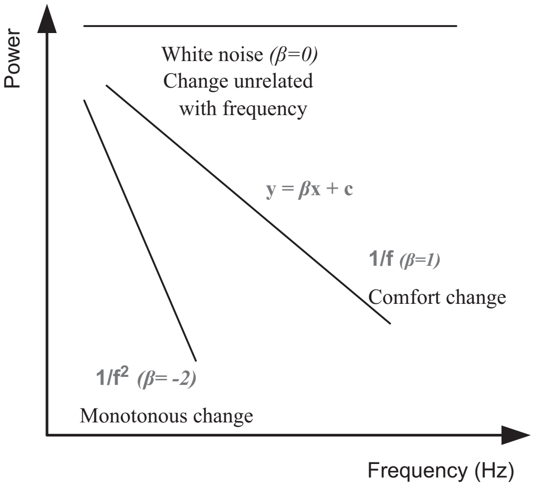

Fig. 2. Power spectral density fluctuations.

The power spectral analysis is one of the most commonly used methods for characterizing the dynamic features of natural wind. The power spectral density (energy or power per Hz) is inversely proportional to the frequency, and is commonly expressed in *1/f* (Bak et al., 1987). Within the scientific literature, the term "*1/f* fluctuation" is sometimes used more loosely to refer to any fluctuation with a power spectral density of the form.

$$E(f) \propto 1/f^{\beta} \tag{3}$$

where f is the frequency and $0 < \beta < 2$, with β usually close to 1. These "*1/f*-like" fluctuations occur widely in nature and are of considerable interest in many fields (Fig. 2).

It is well known that the lower frequency ranges of airflow are particularly important to people's thermal sense. Fanger and Pedersen (1977) verified that air velocity fluctuations and frequencies influence the local thermal sensation and air velocity fluctuations, with frequencies between 0.3 and 0.5 Hz being the most undesirable. Zhou et al. (2002) reported on a study of draught sensations, where the air velocity fluctuations' equivalent frequency, the air velocity and temperature mean values, and air turbulence intensity were considered. They verified that the more sensitive air velocity fluctuations frequencies range between 0.2 and 0.6 Hz. Xia et al. (2000) found that airflow fluctuating in the frequency range of 0.3–0.5 Hz produced the strongest cooling effect and could improve thermal sensations in a warm neutral environment. Ouyang et al. (2006) regarded the low frequency parts as the main factor affecting human sensation, and analyzed the human sense for warm airflow within the low frequency range of 0.01–1.0 Hz.

In accordance with previous research, in this study the measure of natural wind that are closely related to human thermal comfort were analyzed within the frequency range of 0.01– 1.0 Hz. The analysis results were averaged through the power spectrum exponent (β-value), which can simply show the energy distribution of the turbulent flow of natural wind.

2.3. Statistical analysis

The data distributions are reported as frequency histograms and as box-plots. A box-plot is a way of graphically summarizing a data distribution. In a box-plot the thick horizontal line in the box shows the median. The bottom and top of the box show the 25th and 75th percentiles, respectively. The horizontal line joined to the box by the dashed line shows either the maximum or 1.5 times the interquartile range of the data, whichever is smaller. Points beyond these lines may be considered as outliers, and they are plotted as circles in the box-plot graphs. The interquartile range is the difference between the 25th and 75th percentiles (Crawley, 2005). The normal distribution of the data was tested using the Shapiro-Wilk normality test (Shapiro and Wilk, 1965). The correlation between variables is reported with Spearman's rank coefficient

Table 4
Thermal comfort scale-comfort sensation vote (CSV).

Veryuncomfortable	Uncomfortable	Slightlyuncomfortable	Slightly comfortable	Comfortable	Verycomfortable
1	2	3	4	5	6

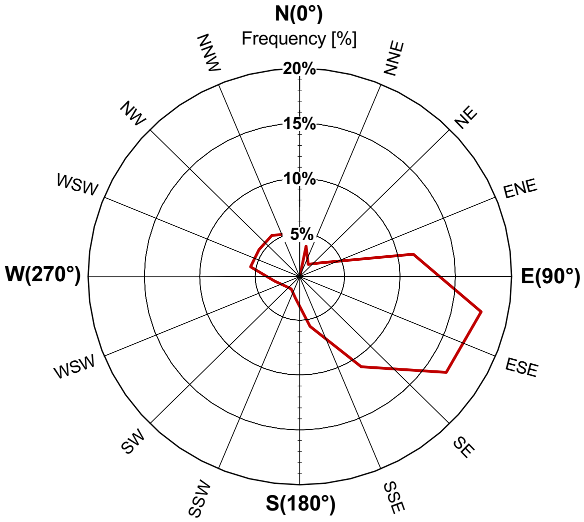

Fig. 3. Distribution of wind direction.

if the variable does not have a normal distribution, and with the Pearson correlation if it has a normal distribution.

The powers of our developed regression models were assessed based on *R*-squared values. *R*-squared value, which is the coefficient of determination of a regression line, is defined as the proportion of the total sample variability as explained by the regression model. A statistical analysis was performed with R version 2.13.1 (http://www.r-project.org).

3. Results and discussion

3.1. Field measurements and human subject tests

As shown in Fig. 3, the wind directions at the measurement site during the measurement period showed a nearly steady distribution, with the southeastern wind having the highest frequency.

As an example of the collected data, Fig. 4 shows the wind velocity in the east–west direction which is the front direction relative to the subject, as well as the outside globe and air temperatures, relative humidity, and thermal sensation and thermal comfort perception of 12 subjects during one day of measurement. The measurement results shown in Fig. 4 are instantaneous values at 30 s intervals.

Table 5 shows the statistical summary of all the measured data. The average wind velocity was 0.82 m/s, and the highest wind velocity was 3.38 m/s. The average outside air temperature was 24.8° C; generally, it was a little lower (roughly 23° C) in the morning and higher (roughly 26° C) in the afternoon. The average globe temperature was 32.8° C. Due to intermittent rains at daybreak during the measurement period; the relative humidity in the morning was high at 70%, but the average humidity during the total experiment period was 54%. The solar radiation was 1,067 W/m^2 at the maximum, and 475.1 W/m^2 on average. The thermal sensation data showed that 29% reported that they were slightly cool, 25% were neutral, 17% were slightly warm and 23% were warm. Also, 43% felt discomfort and 57% were comfortable regarding the thermal comfort perception data.

The Shapiro-Wilk normality test and the visual evaluation of the quantile–quantile plots showed that the globe temperature ($W=0.97$, $p<0.001$), outdoor air temperature ($W=0.93$, $p<0.001$), relative humidity ($W=0.96$, $p<0.001$), and wind velocity ($W=0.98$, $p<0.001$) have non-normal distributions. For globe temperature, relative humidity, and wind velocity, the deviations from the normal distribution are small. A visual evaluation of the relationships between these four parameters and the comfort sensation vote (CSV) showed that the wind velocity is the parameter that most strongly affects the CSV.

Fig. 5 shows a box-plot of the instantaneous wind velocity versus CSV. The subjects felt thermal discomfort in high wind velocities because they felt local coldness on their exposed legs and arms, because they had little clothing and they were seated quietly under the shade of a parasol. They felt thermal comfort when the air velocity was under 1.2 m/s. The highest frequency of feeling comfortable appeared at a wind velocity of around 0.41 m/s.

Table 6 shows the Spearman rank correlation coefficients between the CSV and thermal environment parameters. The wind velocity showed the highest correlation with human thermal comfort with a correlation coefficient of −0.79 ($p<0.001$). This result is in agreement with previous research (Fanger and Pedersen (1977)).

3.2. Power spectral analysis of natural wind and correlations of thermal comfort and natural wind

The frequency and amplitude of air velocity are important factors that influence thermal comfort (Fanger and Pedersen (1977)). To analyze the irregular fluctuation rhythms of natural wind more accurately, power spectral analysis through FFT is required. Therefore, this study analyzed the natural wind measurement data with a focus on the frequency range from 0.01 to 1 Hz, which is sensitive to human sensation. Accordingly, the analysis results were averaged through the power spectrum exponent (β-value), which can simply show the turbulent energy distribution of the turbulent flow of natural wind.

Fig. 6 shows the power spectral analysis results for selected examples of natural wind at a comfortable time (a) and an uncomfortable time (b) based on the analysis results of the measurement data of natural wind versus the power spectral analysis results for mechanical wind (c).

The sampling rate of the wind velocity was 10 Hz, and 512 data were selected for the FFT analysis. The data were selected from conditions in which the air-temperature and thermal sensation vote were in the same range. The analysis results for the mechanical wind were obtained from data measured 2 m away from an inlet of the air flow discharged from a home air-conditioner at a height of 1.1 m and a wind velocity of 2.9 m/s. Comfortable natural wind (a) shows a steeper slope of $1/f$ from low frequency to high frequency. It has high power in the low frequency area, and the power dissipates as it moves towards the high frequency. In contrast, for the uncomfortable natural wind (b) and mechanical wind (c), the power changed less from the low to high frequencies, with a small β-value.

The β-value has a dependence on wind characteristics (wind velocity, turbulent intensity). The relations between the natural

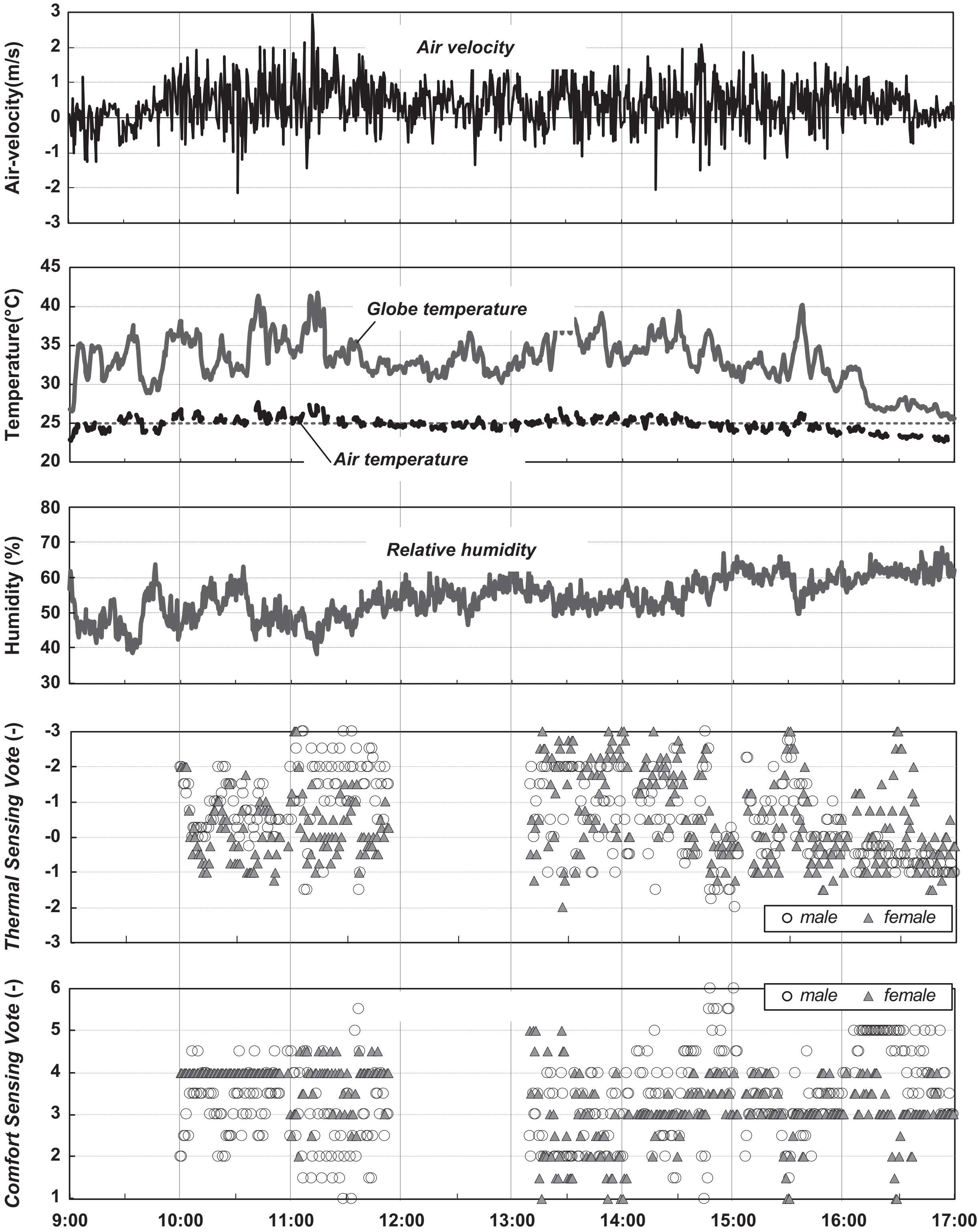

Fig. 4. Measurement data for air-velocity, globe and air temperatures, relative humidity, thermal sensation vote (TSV), and comfort sensation vote (CSV) (July 25).

wind characteristics (wind velocity, turbulent intensity) and β-value were analyzed (Fig. 7 and Fig. 8). This result shows that the β-value becomes smaller when the average wind velocity increases (Spearman's rank coefficient=-0.447, $p < 0.001$) (Fig. 7). In addition, the relations between the turbulent intensity and the β-value were analyzed (Spearman's rank coefficient=0.557, $p < 0.001$) (Fig. 8). The β-value of natural wind increases with the size of the turbulent intensity. This result shows that even though the average wind velocity is the same, the β-value increases with increasing the turbulent intensity. Moreover, the turbulent intensity is inversely proportional to the average wind velocity (Spearman's rank coefficient=−0.505, $p < 0.001$) (Fig. 9).

A linear regression model relating the β-value and wind characteristics (wind velocity, turbulent intensity) has been

Table 5
Statistical summary for all the measured data (July 25).

State variables	Average	Maximum	Minimum	Standard deviation
Wind velocity [m/s]	0.82	3.38	–	0.33
Air temperature [°C]	24.8	27.7	21.9	1.0
Globe temperature [°C]	32.8	41.8	23.8	3.4
Relative humidity [%]	54.8	70.6	38.1	6.1
Horizontal Global solar radiation [W/m^2]	473.7	1067.0	139.0	174.9

Table 6
Correlations between CSV and thermal environment parameters.

	CSV	Relative humidity	Outside air temperature	Globe temperature	Wind velocity
CSV	1.00				
Relative humidity	0.12	1.00			
Outside air temperature	−0.13	−0.67	1.00		
Globe temperature	−0.26	−0.78	0.72	1.00	
Wind velocity	−0.79	−0.10	−0.13	0.25	1.00

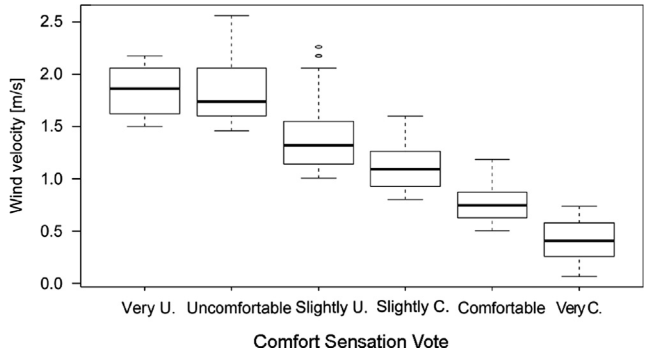

Fig. 5. Box-plot of wind velocity versus comfort sensation vote (CSV).

developed and is as follows:

$$\beta\text{–value} = 1.302 + 1.439Tu - 0.059Vel \quad (R^2 = 0.305, \ p < 0.001) \tag{4}$$

where *Tu* is the turbulent intensity (−), and *Vel* is the average wind velocity (m/s).

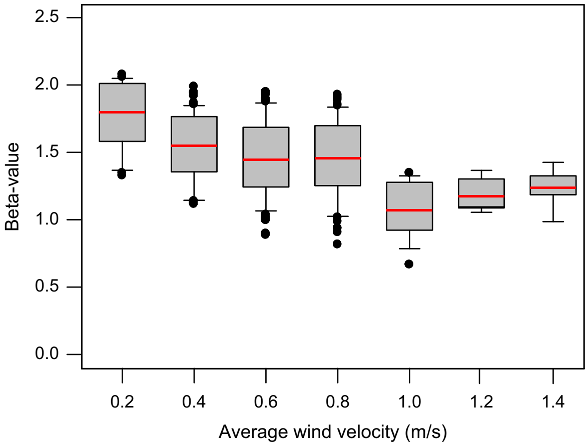

Fig. 7. Relations between the average wind velocity and power spectrum exponent (β-value).

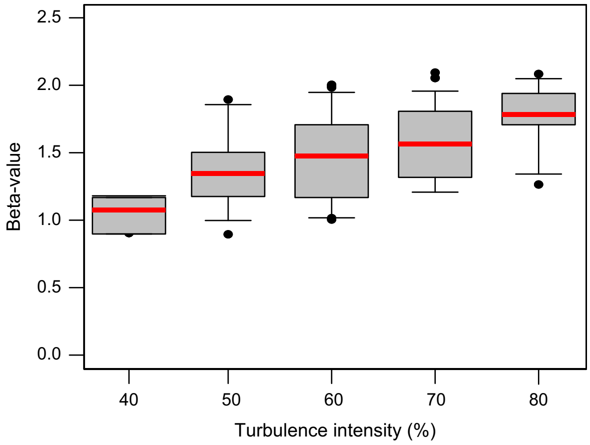

Fig. 8. Relations between the turbulent intensity and β-value.

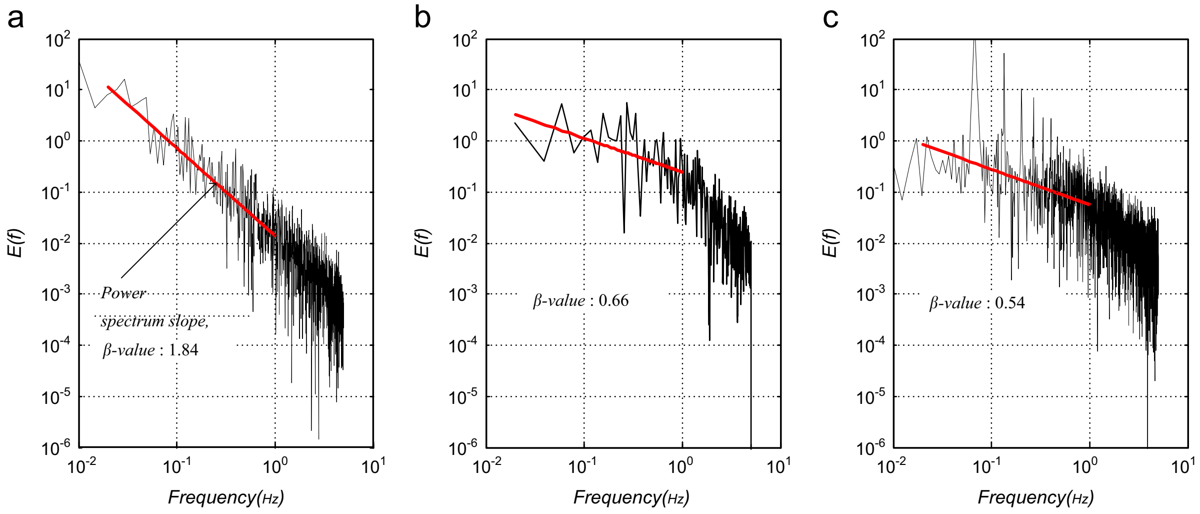

Fig. 6. Example of typical logarithmic power spectrum slopes.(a) Comfortable natural wind, (b) Uncomfortable natural wind and (c) Mechanical wind

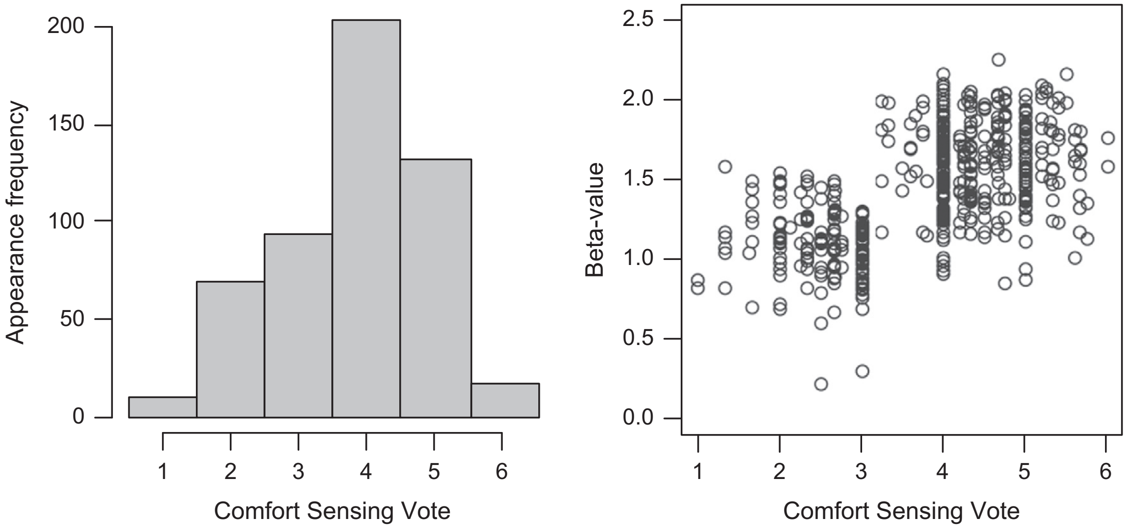

Fig. 10. Appearance frequency distribution of CSV and the scatter-plot of CSV versus β-value.

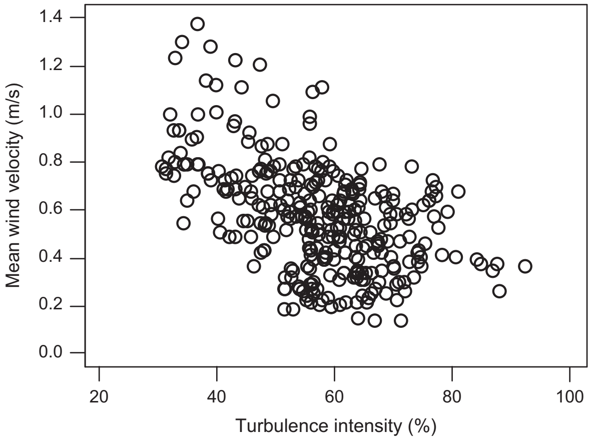

Fig. 9. Relations between the average wind velocity and turbulent intensity.

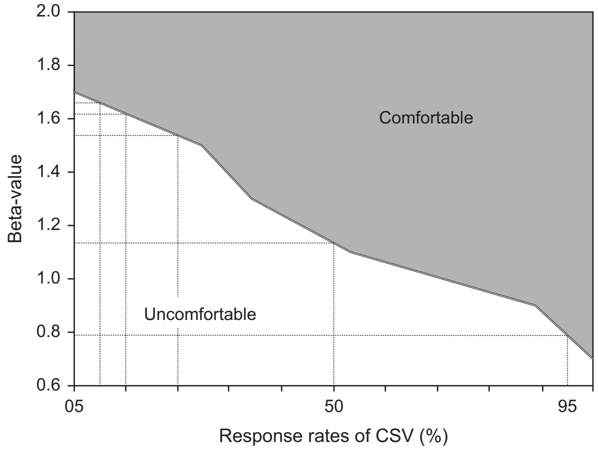

Fig. 11. Appearance frequency distribution of CSV versus β-value.

Fig. 10 shows a histogram of CSV and a scatter-plot of CSV versus β-value. Most of the subjects expressed that they were "slightly comfortable". From the numerical analysis of the histogram, it was found that 50% of the values lay between slightly uncomfortable (3) to comfortable (5). The Shapiro-Wilk normality test ($W = 0.9536$, $p < 0.001$) and the histogram showed that the CSV does not have a normal distribution, even if its deviation is not large. An unreported histogram of the β-values and the Shapiro-Wilk normality test ($W = 0.9859$, $p < 0.001$) showed that the β-value does not have a normal distribution, even if its deviation is not large.

The CSV and β-value are correlated at a statistically significant level (Wilcoxon rank sum test $W = 0.5698$, $p < 0.001$) (Spearman's rank coefficient = 0.56). A linear regression model relating the CSV to the β-value was developed and is reported below.

$$\text{CSV} = 1.333 + 1.777(\beta\text{–value}) \tag{5}$$

where the changes in the outdoor air temperature were small (mean: 23.66 °C ± 1.84 °C).

From the ANOVA analysis of the regression model, it was deduced that the β-value is a significant ($p < 0.001$) independent variable. R-squared is equal to 0.34. A visual evaluation of the plot of the residuals versus the fitted values and of the normal probability plot showed that the residuals have a normal distribution with a mean of zero and that they have the same variance for each fitted value. This means that the hypotheses of the linear regression model are met and thus, the model is valid.

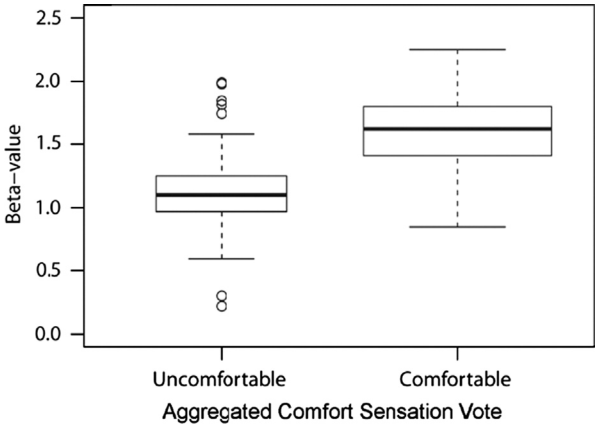

Fig. 12. Box-plot of the β-value versus aggregated CSV.

To simplify the prediction of the β-value, a new index of comfort, called the aggregated CSV was calculated. The aggregated CSV is set to "Uncomfortable" if the CSV is less than 3.5 (the middle point between slightly uncomfortable and slightly comfortable); otherwise, it is set to "Comfortable" when the CSV is greater than or equal to 3.5. In the database, there are 170 points that are rated as "Uncomfortable" and 356 that are rated as "Comfortable". Instead of creating a variable with two levels (uncomfortable and comfortable), it was possible to create a discrete variable with six levels by using a central bin point, and the values are reported in Table 4. It was decided that this was not necessary because the β-value, as shown in the scatter-plot of Fig. 10, was not strongly variable when the CSV was less than 3.5 or higher than 3.5.

Further analysis was carried out based on the results shown in Fig. 10 to determine the CSV frequency according to the β-value. The statistical analysis adopted a Probit analysis (Ballantyne et al., 1977) where the CSV data was classified into β-value bins (0.2 bin). The Probit analysis was performed separately for the "comfortable" and "uncomfortable" CSVs. The number of CSVs was proportionally weighted with the sub total number of votes in each β-value bin. As shown in Fig. 11, the changeover point indicates the β-value at which equal percentages of people who felt "comfortable" and "uncomfortable" were 1.15. When the β-value was under 0.7, all subjects felt "uncomfortable", while all subjects felt "comfortable" when the β-value was over 1.7.

Fig. 12 shows a box-plot of the aggregated CSV versus β-value. From the graph, it can be deduced that the β-value was significantly higher for subjects who were comfortable (expressed by aggregated CSV) than for subjects who were uncomfortable. The box-plot results show that the β-value of the subjects who felt comfortable has a median value of 1.62 [1.41–1.80 are the first and third quartiles, respectively], and that the β-value of the subjects who felt uncomfortable has a median value of 1.10 [0.97–1.25]. These results are close to those reported in the literature (Chow et al., 1997).

4. Conclusions

The main findings of this study are:

(1) Among the measured environmental factors for natural wind (wind velocity, outside air temperature, globe temperature, and relative humidity), wind velocity showed the highest correlation (-0.79, $p<0.001$) with the subject's comfort sensation votes.
(2) The highest frequency of thermal comfort was obtained when the wind velocity was around 0.41 m/s.
(3) Comfortable natural wind has a steeper slope of *1/f* compared to uncomfortable natural wind or mechanical wind.
(4) The analysis results were averaged using the power spectrum exponent (β-value), which can simply show the dynamic characteristics of natural wind. The β-value of natural wind is decreased when the mean velocity increases, while it is increased when the turbulent intensity increases.
(5) The β-value was correlated (Spearman's rank coefficient$=0.56$, $p<0.001$) with thermal comfort.
(6) The β-value for subjects feeling comfortable has a median value of 1.62 [1.41–1.80 are the first and third quartiles, respectively], and the β-value for subjects feeling uncomfortable has a median value of 1.10 [0.97–1.25].

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