

Criterion for wind environment assessment based on the percentage of people dissatisfied with strong winds

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SUMMARY:

The criterion for wind environment assessment proposed by Wind Engineering Institute Co., Ltd. (WEI) have often been used in Japan. This criterion is based on the relationship between the mean wind speeds at cumulative frequencies of 55 and 95% and the surrounding terrain conditions. In a wind environment assessment, it is important to consider the human sensation of wind. In addition, the criterion should be easier for the public to understand. Therefore, the present study proposes a new criterion which is based on the Percentage of People Dissatisfied with strong Winds (PPDW). PPDW is defined as the exceedance probability of an effective wind speed of 6.5 m/s. Referring to the thresholds of Predicted Percentage of Dissatisfied (PPD) specified in ISO-17772-1, the thresholds of PPDW are defined as 5, 10, and 15%. The wind environment where PPDW is $\leq 5\%$ approximately corresponds to Comfort Level 4, which is specified in the guidelines of the Alan G. Davenport Wind Engineering Group. According to the criteria proposed by Hunt, Penwarden, and Gandemer, the wind environment where PPDW is $\leq 10\%$ is generally considered 'tolerable'. Moreover, the 15% PPDW corresponds to the threshold of Area D of WEI criterion, which represents a strong-wind area.

Keywords: criterion for wind environment assessment, percentage of people dissatisfied with strong winds

1. INTRODUCTION

The criterion for wind environment assessment, which was proposed by Wind Engineering Institute Co., Ltd. (WEI) and is shown in Table 1, has often been used for the wind environment assessments in Japan. This criterion is based on the relationship between the mean wind speeds at cumulative frequencies of 55 and 95% and the surrounding terrain conditions.

Table 1. WEI wind environment assessment criterion (Nakamura et al., 1986)

Rank	Terrain condition	Mean wind speeds at cumulative frequencies of 55 and 95%	
		55%	95%
Area A	Residential area	≤ 1.2 m/s	≤ 2.9 m/s
Area B	Middle- and low-rise urban areas	≤ 1.8 m/s	≤ 4.3 m/s
Area C	Middle- and high-rise urban areas	≤ 2.3 m/s	≤ 5.6 m/s
Area D	Strong wind area	> 2.3 m/s	> 5.6 m/s

The relationship between this criterion and human sensation of wind strength had not yet been clarified. In our previous study (Akahoshi et al., 2019), the effective wind speed U_e defined by

Eq. (1) correlated well with the human sensation of wind strength according to the results of field observations, a wind tunnel experiment, and a questionnaire survey done in Kamiosaki, Shinagawa-ku, Tokyo, Japan.

$$U_e = U(1 + kI_u) \quad (1)$$

where U is the mean wind speed, k is the weight coefficient, and I_u is the turbulence intensity. In this study, $k = 3$. Table 2 shows the relationship between U_e and human sensation of wind strength. Based on this relationship, a new criterion was proposed using the effective wind speed. However, it is desirable that the criterion be easily understood by the public. In practice, the effective wind speeds are not widely available. Therefore, this study proposes a new criterion based on the percentage of people dissatisfied with strong winds. In addition, the correspondence of the new criterion with those proposed by other researchers is discussed.

Table 2. Relationship between human sensation of wind strength and the effective wind speed.

Effective wind speed	Human sensation of wind strength
$U_e \leq 6.5$ m/s	I: "calm"
6.5 m/s < $U_e \leq 9$ m/s	II: "slightly strong"
9 m/s < $U_e \leq 15$ m/s	III: "strong and uncomfortable"
$U_e > 15$ m/s	IV: "dangerous"

2. DEFINITION OF THE PERCENTAGE OF PEOPLE DISSATISFIED WITH STRONG WINDS

It is difficult to strictly define the Percentage of People Dissatisfied with strong Winds (PPDW) in an outdoor wind environment because both wind conditions and the flow of people change constantly. In the present study, PPDW is conveniently defined as follows. First, the threshold of the effective wind speed U_{et} that makes people feel uncomfortable is defined. Second, it is assumed that when $P\%$ of winds in a year makes people uncomfortable at a place, $P\%$ of people feel uncomfortable at that place in a year. Based on this assumption, the exceedance probability of U_{et} is defined as PPDW. The value of U_{et} is determined as follows. Figure 1 shows the relationship between U_e and the relative frequency F_r of respondents who replied that the wind they experienced was uncomfortable or strong in the Kamiosaki questionnaire survey. Based on this relationship and the wind observation data obtained at 55 points in Tokyo, Figure 2 shows the relationship between the annual integrated value of F_r and the exceedance probability of $U_e = 4, 6.5,$ and 9 m/s. The exceedance probability of $U_e = 6.5$ m/s, which corresponds to Sensation I (calm) in Table 2, has the highest correlation with F_r . Thus, $U_e = 6.5$ m/s is defined as U_{et} .

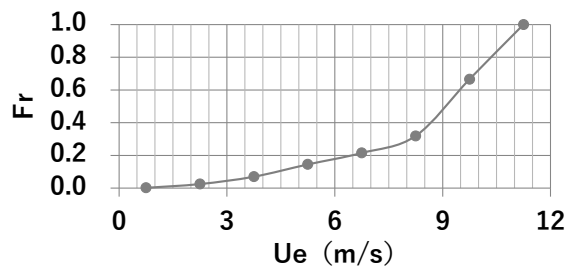


Figure 1. Relationship between U_e and F_r .

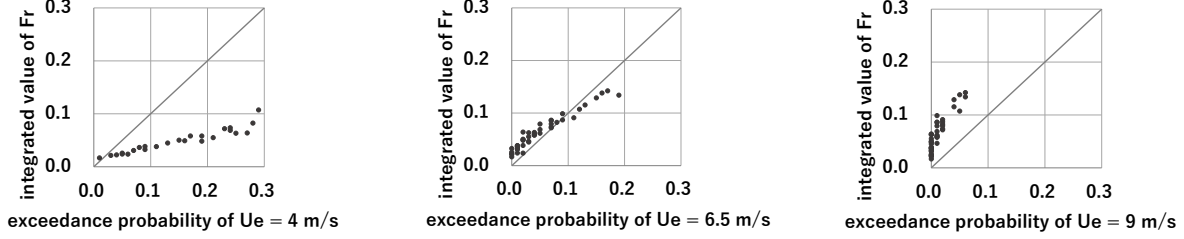


Figure 2. Relationship between annual integrated value of F_r and the exceedance probability of U_e .

3. THRESHOLD OF PPDW

To propose a new criterion based on PPDW, the threshold of PPDW is defined based on the threshold of PPD (Predicted percentage of dissatisfied), which is specified in ISO-17772-1 (ISO, 2017). The ISO standard shows the relationship between PPD and the expected indoor environmental quality as shown in Table 3. The ISO standard recommends that the PPD should be $< 10\%$. Although PPD is discussed in the indoor thermal environment, the relationship between PPD and the expected environmental quality can be applied to outdoor wind environment. Referring to Table 3, the thresholds of PPDW are defined as 5, 10, and 15% in the present study. Depending on these thresholds, categories of wind environments are classified into zones 1 – 4, as shown in Figure 3.

Table 3. Categories of indoor environmental quality and PPD recommendations specified by ISO-17772-1.

Category	PPD	Expected environmental quality
I	$< 6\%$	High
II	$< 10\%$	Medium
III	$< 15\%$	Moderate
IV	$< 25\%$	Low

4. RELATIONSHIP BETWEEN THE NEW CRITERION AND OTHER CRITERIA

Figure 3 shows the relationship between the new criterion based on PPDW and other criteria proposed by WEI (1986), Alan G. Davenport Wind Engineering Group (2007), Hunt et al. (1976), Penwarden et al. (1975), and Gandemer et al. (1978). The relationship between the new criterion and WEI criterion is given by Eq. (2), as proposed in our previous study (Akahoshi et al., 2019).

$$P_e = \exp\left(-\left(\frac{U_{95}}{10.2}\right)^{2.94}\right) \quad (2)$$

where P_e is the exceedance probability of $U_e = 6.5$ m/s and U_{95} is the mean wind speed at a cumulative frequency of 95%. Comparing the new criterion with WEI criterion, 5% PPDW roughly corresponds to the medium point of Area B, and 10% PPDW roughly corresponds to one-third point of Area C. Moreover, 15% PPDW corresponds to the threshold of Area D. Comparing the new criterion with that proposed by Davenport Wind Engineering Group (2007), 5% PPDW approximately corresponds to Comfort Level 4. In addition, 10% PPDW corresponds to a wind environment that is generally considered ‘tolerable’ by other researchers. Hunt et al. (1976) showed that the threshold of U_e for ‘comfortable’ and ‘little effect on performance’ is 6 m/s, and suggested that the exceedance probability of $U_e = 6$ m/s for ‘very little discomfort’ is \leq

10%. Furthermore, Penwarden et al. (1975) showed that people feel ‘satisfactory’ when the exceedance probability of $U = 5$ m/s is $\leq 10\%$. Gandemer et al. (1978) showed that the wind environment corresponds to a ‘suitable degree of comfort’ for a brief stay without walking if the exceedance probability of $U_e = (5 + k)$ m/s is $\leq 10\%$, where the weight coefficient k is 1–3.

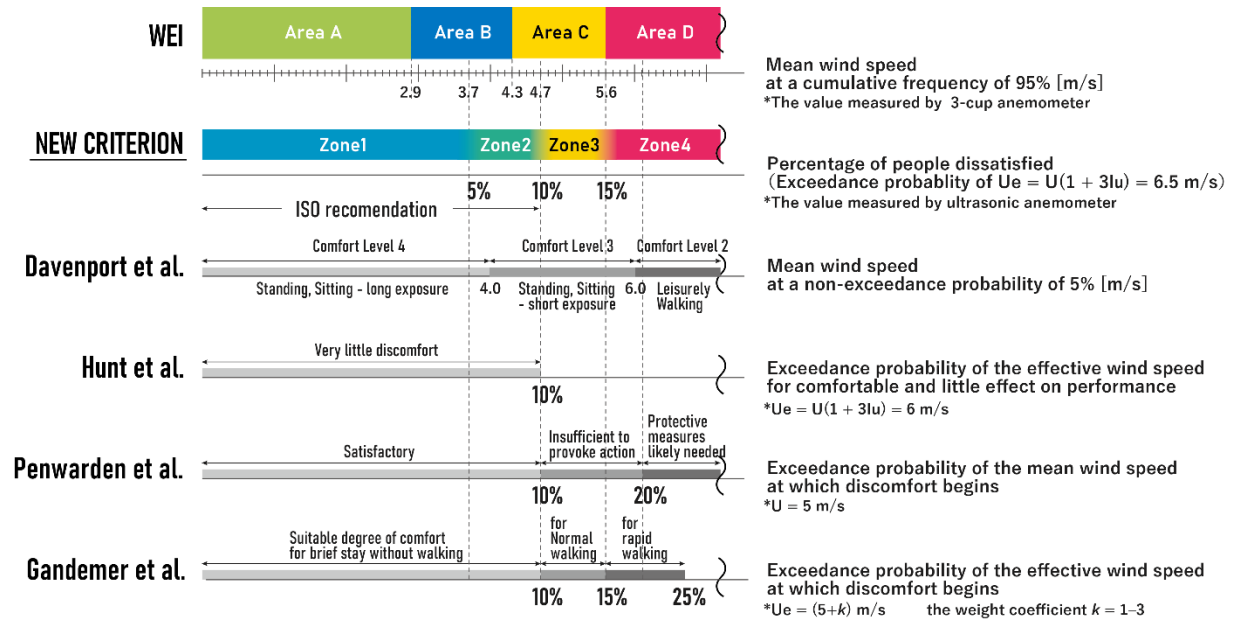


Figure 3. Relationship between the new criterion for wind environment assessment and other criteria.

5. CONCLUSION

A new criterion for the wind environment around high-rise buildings was proposed based on the PPDW, which is defined as an exceedance probability of the effective wind speed of 6.5 m/s. Comparing the new criterion with the existing one proposed by WEI, it is shown that 15% PPDW corresponds to the threshold of Area D of the WEI criterion representing a strong-wind area. In addition, 5% PPDW corresponds to Comfort Level 4, as proposed by Davenport Wind Engineering Group (2007). Finally, compared to the criteria proposed by Hunt et al. (1976), Penwarden et al. (1975), and Gandemer et al. (1978), the wind environment where PPDW is $\leq 10\%$ is considered ‘tolerable’, which also corresponds to the recommended value of PPD by ISO.

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