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A Comparison of Pedestrian Wind Comfort and Safety Criteria

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Abstract

A comparison of two widely-used pedestrian wind comfort and safety criteria is presented and the results critically discussed, with wind data from the Adelaide area used for the examples.

The two criteria are by Melbourne (1978) and University of Western Ontario Boundary Layer Wind Tunnel Laboratory (BLWTL, 2007).

Introduction

Wind records from Adelaide Airport have been analysed to produce the statistics of 10-minute mean wind speeds, for varying wind directions . These wind speeds have been converted to equivalent pedestrian-height wind speeds in Terrain Categories 1 to 4 in accordance with AS/NZS 1170.2 (Standards Australia 2011).

The resulting annual probability pedestrian-height wind speeds have been compared with criteria for acceptability for walking and safety developed by Melbourne (1978), and the safety criterion developed by BLWTL (2007). The resulting wind speeds, with 5% probability of exceedence, have been compared with the criteria for acceptability for walking developed by BLWTL (2007).

Wind Climate Analyses

Wind records of 10-minute averaged wind speeds and directions, recorded continuously at half-hourly intervals from 1985 to 2011 at Adelaide Airport, at the standard height of 10 metres, were analysed to give annual maximum values as a function of wind direction, as shown in Figure 1.

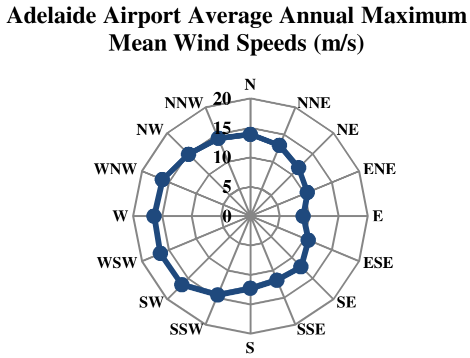

Figure 1. Adelaide Airport directional distribution of average annual maximum 10 minute mean wind speeds at 10m height.

Table 1 shows the expected annual maximum, for all wind directions, obtained by averaging the recorded maxima from each of the 27 years of data.

Table 1 also shows the wind speed with 5% probability of exceedence, obtained by fitting the data with a Weibull distribution, for which the parameters obtained were: shape factor, k, 2.05; and scale factor, 5.82 m/s.

Probability	All-directions Mean Wind Speed
Annual	18.2 m.s^{-1}
0.05	9.9 m.s^{-1}

Table 1. All-directions wind speeds for Adelaide Airport.

Pedestrian Wind Speeds in Terrain Categories 1 to 4

The maximum all-directions wind speeds at 10m height in Terrain Category 2 have been converted to mean and gust wind speeds, at 2m height, in Terrain Categories 1 to 4, using the terrain-height multipliers and turbulence intensities in AS/NZS 1170.2, taking M_d, M_s and M_t as 1.0 and using an assumed peak factor (g) of 3.15, i.e. $\hat{V} = \bar{V}(1 + g.I_z)$.

	Annual probability all directions wind speeds		0.05 probability all directions wind speeds
Terrain category	$\bar{V}_{2m}$ (ms^{-1})	$\hat{V}_{2m}$ (ms^{-1})	$\bar{V}_{2m}$ (ms^{-1})
1	19	29	10
2	16	26	9
3	12	23	7
4	10	21	5

Table 2. All-directions Adelaide wind speeds in Terrain Categories 1 to 4.

The peak factor, g, was taken as 3.5 by Melbourne (1978), however, in ESDU 83045 (ESDU International,2002) this would correspond to a gust wind speed averaged over a 0.5 second duration. Melbourne indicated his criteria were based on a gust duration of 2 seconds which corresponds approximately to g=3.15, according to ESDU 83045. Hence, a value of g of 3.15 has been used to predict peak gusts in this comparative study. Note for the widely used 3 second gust, g≅2.9.

Description of the Wind Criteria

The Melbourne (1978) and BLWTL (2007) pedestrian wind criteria for safety and walking are summarized in the following table. The long and short exposure criteria were not compared in this study and have not been presented here.

Condition	Criteria Set	
	Melbourne	BLWTL
Safety	$\hat{V}_{2sec} > 23ms^{-1}$ not more than once per year	$\bar{V}_{10min} > 15ms^{-1}$ not more than once per year
Walking	$\hat{V}_{2sec} > 16ms^{-1}$ not more than once per year	$\bar{V}_{10min} > 10ms^{-1}$ not more than 5% of the time

Table 3. The two pedestrian wind criteria compared in this study

Comparison of Pedestrian Wind Speeds with Safety Criteria in the Adelaide Region

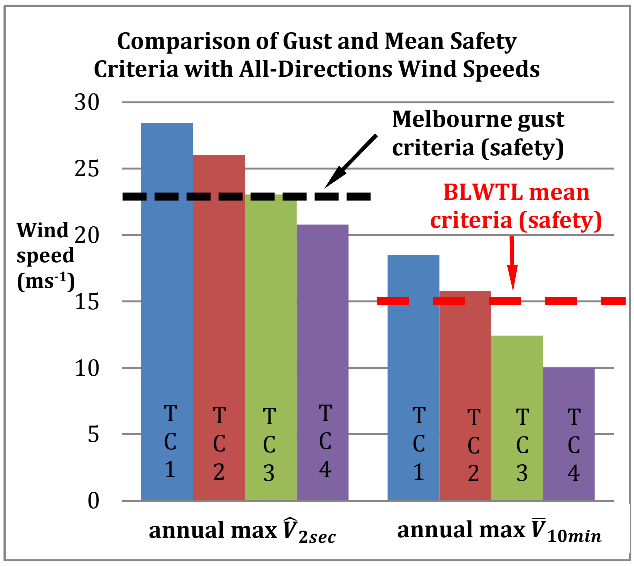

Figure 2. Adelaide Airport annual maximum all-directions wind speed data converted to 2s peak gusts and 10 minute means at 2m height in Terrain Categories 1 to 4 and plotted against Melbourne (1978) and BLWTL (2007) safety criteria.

TC	Comparison with Melbourne safety criteria ($\hat{V}_{2s}/23ms^{-1}$) ×100 (1)	Comparison with BLWTL safety criteria ($\bar{V}/15ms^{-1}$) ×100 (2)	Agreement between Melbourne and BLWTL criteria (2)/(1) × 100
1	124%, i.e. exceeds safety by 24%	123%, i.e. exceeds safety by 23%	100%
2	Exceeds by 13%	Exceeds by 5%	93%
3	Exceeds by <1%	Meets by 17%	83%
4	Meets by 10%	Meets by 33%	74%

Table 4. All-directions annual maximum wind speeds for Adelaide at 2m height in Terrain Categories 1 to 4 compared to BLWTL and Melbourne criteria.

Comparison of Pedestrian Wind Speeds with Walking Criteria in the Adelaide Region

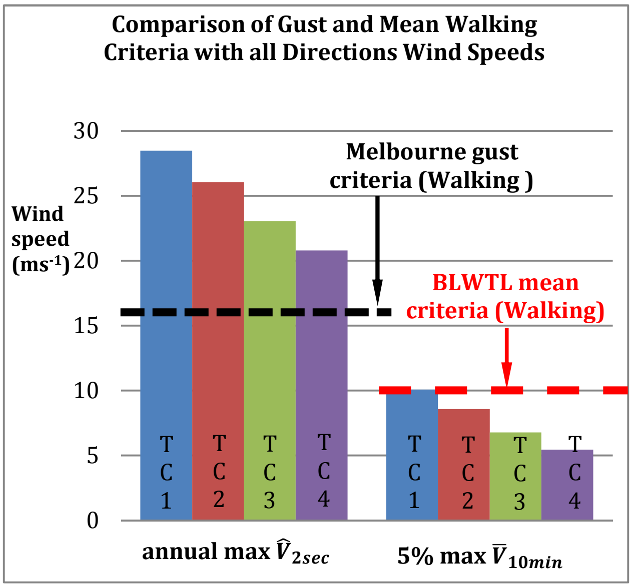

Figure 3. Adelaide Airport annual maximum all-directions 2s peak gust wind speed, and 5% probability mean wind speed data, converted to 2m height in Terrain Categories 1 to 4, and plotted against Melbourne (1978) and BLWTL (2007) criteria for acceptability for walking.

TC	Comparison to Melbourne walking criteria ($\hat{V}_{2s}/16ms^{-1}$) ×100 (1)	Comparison to BLWTL walking criteria ($\bar{V}/10ms^{-1}$) ×100 (2)	Agreement between Melbourne and BLWTL criteria (2)/(1) × 100
1	Exceeds by 78%	Exceeds by <1%	57%
2	Exceeds by 63%	Meets by 14%	53%
3	Exceeds by 44%	Meets by 32%	47%
4	Exceeds by 30%	Meets by 46%	42%

Table 5. Annual maximum all-directions 2s peak gust wind speed and 5% probability mean wind speeds for Adelaide at 2m height in Terrain Categories 1 to 4 compared with Melbourne and BLWTL criteria for acceptability for walking.

Results

The Adelaide wind climate has been converted to pedestrian height in Terrain Categories 1 to 4, and compared graphically with the Melbourne (1978) and BLWTL (2007) criteria in Figures 2 and 3. The comparison of the wind climate at pedestrian height and the criteria is presented in Tables 4 and 5 in terms of percentages by which the relevant wind speed (peak gust or mean) meets or exceeds the relevant criteria (Melbourne or BLWTL), and the percentage by which the criteria agree with each other.

From Figure 2 and Table 4, it can be seen that in Terrain Categories 1 and 2 the agreement between the two sets of criteria for safety is good – i.e. within 10%.

In Terrain Category 3 the agreement between the two sets of criteria is poor, with conditions slightly exceeding the Melbourne criterion for safety, and comfortably meeting the BLWTL criterion for safety. The trend continues in Terrain Category 4 where agreement between the two safety criteria is reduced again. In Terrain Category 4 I_z=0.342 and $\hat{V}_{2m}$=2.1$\bar{V}_{2m}$. In this case, if we convert the Melbourne safety criteria to an equivalent mean then $\bar{V}_{2m}$=11ms^{-1} once per year, some 27% lower in wind speed than the BLWTL safety criterion and some 46% lower in resultant wind force perceived by pedestrians.

From Figure 3 and Table 5 it can be seen that agreement between the Melbourne and BLWTL walking criteria is poor irrespective of Terrain Category. An example of the poor agreement between the two criteria is as follows: the Melbourne criteria for acceptability for walking of $\hat{V}_{2m}$>16ms^{-1} not more than once per year would typically correspond to $\bar{V}_{2m}$> *8ms^{-1} not more than once per year* in Terrain Category 3. Compare this to the BLWTL criteria for acceptability for fast walking $\bar{V}_{2m}$> *10ms^{-1} not more than once per week.*

Discussion

Gust Versus Mean Criteria

Melbourne observed younger, able-bodied adults (i.e. university students) being blown over by wind gusts of approximately 23m/s. There seems no reason to dispute that gusts of 23m/s are capable of blowing people over and could be classified as dangerous, particularly for frail members of the public. Furthermore, it is difficult to dispute Melbourne's argument that "it is the peak gust wind speeds…which people feel most…" particularly in Terrain Categories 3 and 4 where the dynamic pressure of a peak gust would typically be 3 to 4 times higher than mean dynamic pressures.

Melbourne's criteria, particularly the comfort criteria, have been regarded by some as tending to be relatively stringent. The comparison in this study may go some way to explaining this opinion.

However, if we accept Melbourne's argument in favour of a gust-based approach and we accept that, in built-up areas, turbulence intensities are relatively high (e.g. Ratcliff and Peterka (1990) found the average turbulence intensity measured at 246 locations in 9 proposed building projects was 45%), and means tend to be low, hence it is difficult to justify the sole application of mean wind speed criteria in Terrain Categories 3 and 4. Whilst some may consider the Melbourne criteria overly stringent, it seems reasonable to say that the risk in solely applying the BLWTL mean criteria in such cases is that an area may be deemed "safe", whilst experiencing gust wind speeds well in excess of Melbourne's observed safety limits quite often.

Furthermore, the ability of wind tunnel instrumentation, such as hotwires and Irwin sensors, to accurately measure mean wind speeds in flows with turbulence intensities in excess of 25% is questioned. The ability of the same instruments to accurately measure gust wind speeds is not disputed. For this reason alone it would seem futile to try to broadly apply mean wind speed criteria to most urban environments since accurate data for comparison with the criteria is often not available.

Frequency of Winds

One of the limitations of criteria based solely on annual maxima, such as that of Melbourne, is that, depending on the nature of the wind climate in question, annual maxima may be inaccurate descriptors of more frequently occurring winds which dominate the perception of comfort for outdoor areas. Some wind climates may have smaller ratios between annual and 5% maxima than the Adelaide wind climate used in this comparison. In this type of wind climate, the observed discrepancy between criteria based on annual maxima and those based on more frequent winds is reduced.

One of the problems in applying the BLWTL criteria is how to reconcile an exceedence of the safety criterion based on annual maxima, whilst simultaneously readily meeting comfort criteria based on 5% probability winds (compare Figs 2 and 3, Terrain Category 2). In this case, it may be that, despite meeting suitable comfort criteria, building geometry modifications are required due to the hazards posed by the exceedence of the safety criteria. Given this possibility for somewhat contradictory results possible from the BLWTL criteria due to the use of two probability levels, when reporting in accordance with BLWTL's criteria both the annual and 5% maxima must be presented in order for the results to be properly assessed.

Developments in Wind Tunnel Instrumentation

Both sets of criteria were developed at a time when wind tunnel instrumentation and data acquisition were not digital and significant simplifications in approaches to measuring and assessing wind speeds were necessary. For example, Melbourne notes in his 1978 paper that the "windiest areas have the highest means". This statement appears to have been made in support of the simplification of ignoring wind speeds in highly turbulent wake flow areas as follows: "This means that wind tunnel investigations…can often be reasonably based on very simple and inexpensive model measurements of mean wind speed." Such an approach may be justified given the instrumentation available at that time and may be acceptable for assessment of safety. However, designers are often interested in making good use of all available areas adjacent to developments and we cannot reasonably confine our attentions to the windiest areas. For example, there is now significant interest in where low wind speed areas are to locate outdoor retail and dining businesses which have expanded dramatically in the last two decades.

Making broad assumptions about turbulence intensities and the need to only assess means or peaks is unnecessary now with modern instrumentation and data analysis techniques. It is quite possible to set up an analysis system which assesses measured mean wind speeds against mean criteria when I_z<15% and measured peak gusts against gust criteria when I_z>15% for example.

Classifications of Comfort and Safety

The definition of the criterion for safety is broadly understood (and thankfully so as it is the most important) however it would seem the community would be well served by wind engineers if a standard set of comfort criteria descriptors could be agreed upon. In many cases researchers have developed their own criteria descriptors. Terms such as "comfortable", "tolerable", "acceptable" may superficially appear synonymous as might "unpleasant" and "unacceptable", however, they are ambiguous and almost certainly increase confusion.

For example, the BLWTL (2007) "standing, sitting long exposure" criterion is clearly equivalent in definition to the Melbourne (1978) "stationary long exposure" criterion. Similarly the BLWTL "standing, sitting short exposure" is equivalent in definition to the Melbourne "stationary short exposure". However, Melbourne has only a single criterion for walking, defined as "generally acceptable" whereas BLWTL expands on the criteria for walking by defining 2 criteria, "leisurely walking" and "fast walking". Presumably the former infers comfortable conditions and the latter is just acceptable. It is not immediately obvious which of the BLWTL criteria are most equivalent in definition to the Melbourne acceptable for walking criteria. However, for the comparison in this study, the higher of the two BLWTL walking criteria was assumed to be equivalent in meaning to the Melbourne walking criteria.

Areas with annual maximum gusts exceeding $23ms^{-1}$ are defined by Melbourne as "completely unacceptable" and areas with annual maximum gusts less than $16ms^{-1}$ are defined as "generally acceptable". We can infer from these definitions that areas with wind conditions in between these 2 criteria are neither "completely unacceptable", nor are they "generally acceptable". We may assume such areas are safe but quite unpleasant and can perhaps infer they may be tolerated if the area is not intended for wind sensitive usage. This further illustrates the ambiguity of the criteria definitions.

Definition of Gust Duration

If gust criteria are to be used it is important to clearly state and adhere to a standard gust duration. Presently there appears to be some lack of consistency on this point as a number of researchers nominate the 3 second gust duration but use a peak factor applicable to a 0.5 second duration. AS/NZS 1170.2 (Standards Australia ,2011) will shortly re-define the peak gust as a 0.2 second duration gust and, for this reason alone, it may be advisable to define gust criteria for pedestrian winds using this standard duration.

Conclusions

Comparing the criteria developed by two well-known researchers suggests both sets of criteria have significant limitations.

It would seem arguments in favour of solely using mean wind speed criteria in highly turbulent flows such as ground level areas in Terrain Categories 3 and 4 are not sustained. In these highly turbulent flows the means are often "meaningless" and a gust based approach should be applied.

Where instrumentation such as hotwires and Irwin sensors can measure both reasonable means (I_z<20%) and peaks this data should be compared to mean and peak criteria. When I_z is too high to measure accurate mean wind speeds (>20%), the gusts are likely to dominate peoples' perception and only the gusts need to be compared to gust criteria. Attempting to measure and report on mean wind speeds in relation to mean criteria in these cases appears likely to result in misleading conclusions.

Arguably the BLWTL (2007) criteria are too lenient in urban areas. In areas of high speed, high turbulence flows, comparison with mean criteria alone could lead to dangerous wind conditions going undetected.

The limitations of criteria based solely on annual maxima are that this approach makes broad assumptions about the nature of the wind climate in question. In some cases, annual maxima may be poor descriptors for frequently occurring winds which dominate the perception of outdoor comfort.

Gust criteria require clear definition and consistent application of the gust duration. Alignment with the AS/NZS 1170.2 gust duration is suggested.

The first author has learnt, through his own experience, that a significant error which may be made in the assessment of pedestrian level wind conditions is the rigid adherence to either of these sets of criteria irrespective of the nature of the wind flows in question.

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