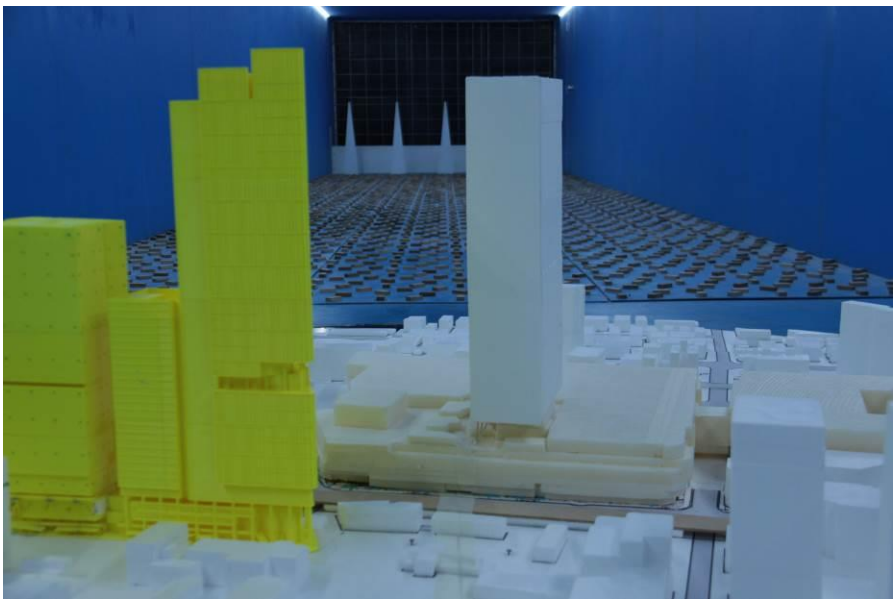

SECTION 75W MODIFICATION (MOD1) TO THE APPROVED COMMERCIAL TOWER BUILDING ENVELOPE CONCEPT APPROVAL MAJOR PROJECT MP10_0068 WESTFIELD SHOPPING CENTRE PARRAMATTA

PEDESTRIAN WIND ENVIRONMENT STUDY

WB400-04F04(REV1)- WE REPORT

MAY 14, 2018

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DOCUMENT CONTROL

Date	Revision History	Issued Revision	Prepared By (initials)	Instructed By (initials)	Reviewed & Authorised by (initials)
May 3, 2018	Initial.	0	AH	AB	BU
May 14, 2018	Report Update	1	AH	AB	BU

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EXECUTIVE SUMMARY

This report presents the results of a detailed investigation into the wind environment impact of the proposed Section 75W Modification (MOD1) to the Approved Commercial Tower Building Envelope Concept Approval Major Project MP10_0068 Westfield Shopping Centre Parramatta. Testing was performed using Windtech's boundary layer wind tunnel, which has a 3.0m wide working section and has a fetch length of 14m. Measurements were made in the wind tunnel at selected critical trafficable outdoor locations within and around the development from 16 wind directions at 22.5 degree increments using a 1:400 scale detailed model based on the architectural drawing package prepared by Woods Bagot, received April 2018. The effects of nearby buildings and land topography have been accounted for through the use of a proximity model, which represents an area with a radius of 500m.

Peak gust and mean wind speeds were measured at selected critical outdoor trafficable locations within and around the subject development. Wind velocity coefficients representing the local wind speeds are derived from the wind tunnel and are combined with a statistical model of the regional wind climate (which accounts for the directional strength and frequency of occurrence of the prevailing regional winds) to provide the equivalent full-scale wind speeds at the site. These wind speed measurements are compared with criteria for pedestrian comfort and safety, based on gust wind speeds and Gust-Equivalent Mean (GEM) wind speeds.

The model of the development was tested in the wind tunnel without the effect of any forms of wind ameliorating devices such as screens, balustrades, etc., which are not already shown in the architectural drawings. The effect of vegetation was also excluded from the testing.

The results of the study indicate that treatments are required for the Level 6 Terrace to achieve the desired wind speed criteria for pedestrian comfort and/or safety. To improve the wind conditions of the development, in-principle ameliorative treatments have been recommended as follows:

- Inclusion of 2m impermeable screening along the northern and eastern perimeter.
- Inclusion of an impermeable awning with a depth of at least 3m along the southern edge of the northern restaurant.
- Inclusion of an impermeable awning with a depth of at least 3m along the eastern edge of the tower slab.

It should be noted that the study has shown that with the addition of the tower, with a 3m set back from Argyle St, the wind conditions at street level will be either equivalent to, or better than, the current conditions experienced along Argyle Street and Marsden Street. Hence from a wind mitigation point of view there is no need to set the tower further back than what has been proposed.

With the inclusion of the abovementioned treatments to the final design, suitable wind conditions are expected to be achieved for all trafficable areas within and around the subject development site. Further wind tunnel testing should be undertaken during the detailed design stage to verify the wind conditions with the implementation of the design treatments.

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1 WIND CLIMATE FOR THE PARRAMATTA REGION

Details of the wind climate of the Parramatta region have been determined from a detailed statistical analysis of measured mean wind speed data from the meteorological observation station located at Bankstown Airport. The data has been collected from this station from 1993 to 2016, and corrected so that it represents winds over standard open terrain at a height of 10m above ground (including correcting for the presence of the nearby north-easterly building). This data is also presented in Table 1. The frequency of occurrence of the regional winds is also shown in Figure 1 for each wind direction. Note that the recurrence intervals examined in this study are for exceedances of 5% for the comfort criteria and annual maximum for any 22.5 degree sector for the Safety Limit.

The data indicates that the south-easterly winds are by far the most frequent winds for the Parramatta region, and are also the strongest. The westerly winds occur most frequently during the winter season for the Parramatta region, and although they are typically not as strong as the south-easterly winds, they are usually a cold wind and hence can be a cause for discomfort for outdoor areas. North-easterly winds occur most frequently occur during the warmer months of the year for the Parramatta region, and hence are usually welcomed within outdoor areas since they are typically not as strong as the south-easterly or westerly winds.

Table 1: Directional Mean and Gust Wind Speeds for the Parramatta Region (referenced to 10m height above ground in standard open terrain)

Wind Direction	Reference Hourly Mean Wind Speeds (m/s)	
	5% Exceedance per 90deg sector	Annual Maximum per 22.5deg sector
N	5.2	9.1
NNE	4.7	7.9
NE	7.0	9.6
ENE	7.1	8.9
E	6.2	8.5
ESE	7.4	9.8
SE	8.2	10.8
SSE	8.5	11.3
S	7.1	11.0
SSW	4.8	9.4
SW	5.8	9.5
WSW	7.0	10.8
W	6.8	11.2
WNW	6.5	11.4
NW	5.2	9.9
NNW	5.4	9.3

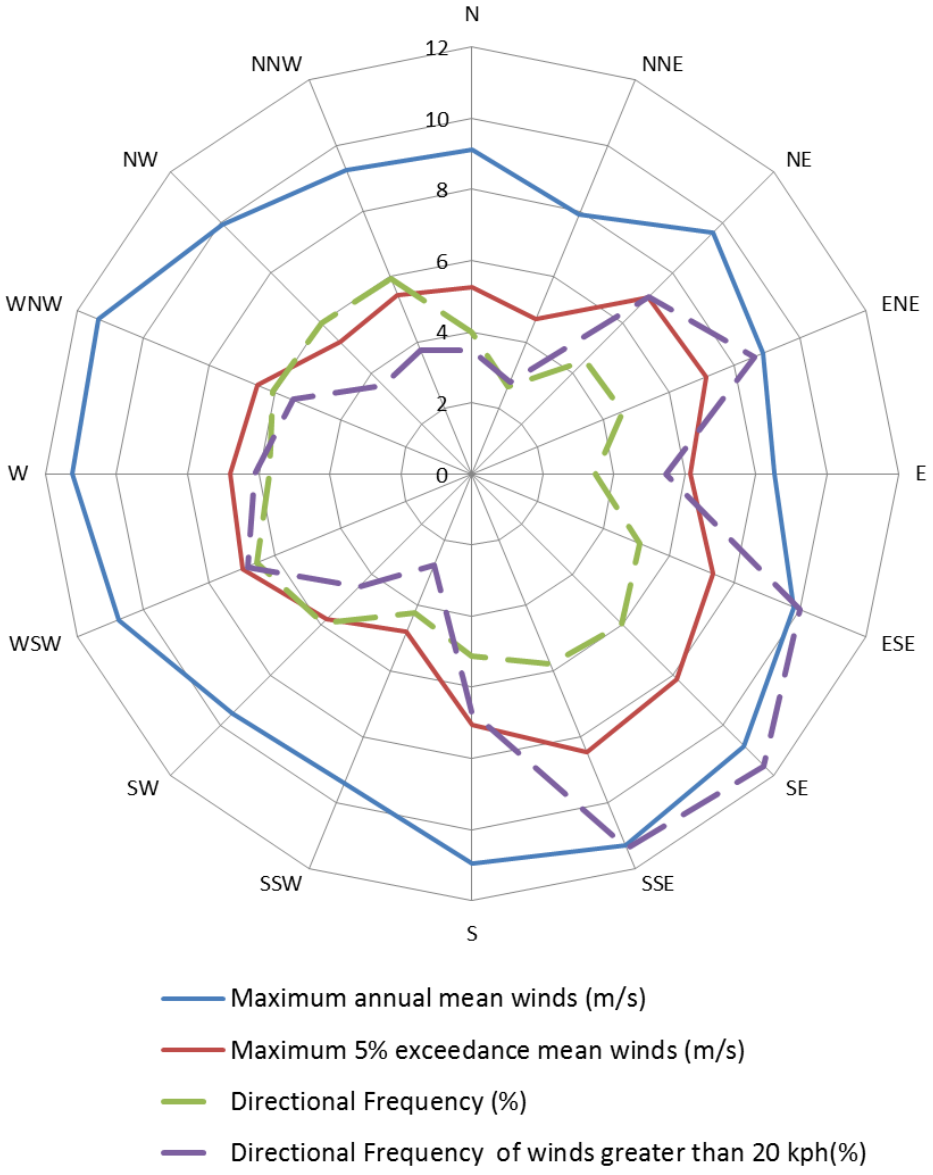


Figure 1: Directional Hourly Mean Wind Speeds, and Frequencies of Occurrence, for the Parramatta Region (for annual and 5% probability exceedance winds, referenced to standard open terrain at a height of 10m above ground)

2 THE WIND TUNNEL MODEL

Wind tunnel testing was undertaken to obtain accurate wind speed measurements at selected critical outdoor locations within and around the development using a 1:400 scale model. The study model incorporates all necessary architectural features on the development to ensure an accurate wind flow is achieved around the model, and has been constructed based on the available architectural drawing package prepared by Woods Bagot, received April 2018.

A proximity model has also been constructed and represents the surrounding buildings and significant topographical effects within a radius of 500m, centred on the development site. Photographs of the wind tunnel model and plan view image of the proximity model are presented in Figures 2a to 2g on the following pages. A map of the proximity model is shown in Figure 2h. Note that the Parramatta Square development is not included in this map figure, but is included on the physical proximity model.

The model was tested in the wind tunnel without the effect of any forms of wind ameliorating devices such as screens, balustrades, etc., which are not already shown in the architectural drawings. The effect of vegetation was also excluded from the testing. If the results of the study indicate that any area is exposed to strong winds, in-principle treatments are recommended. Existing wind conditions have also been tested for the critical trafficable outdoor locations at street level and these results have been compared against the results with the proposed development in-place.

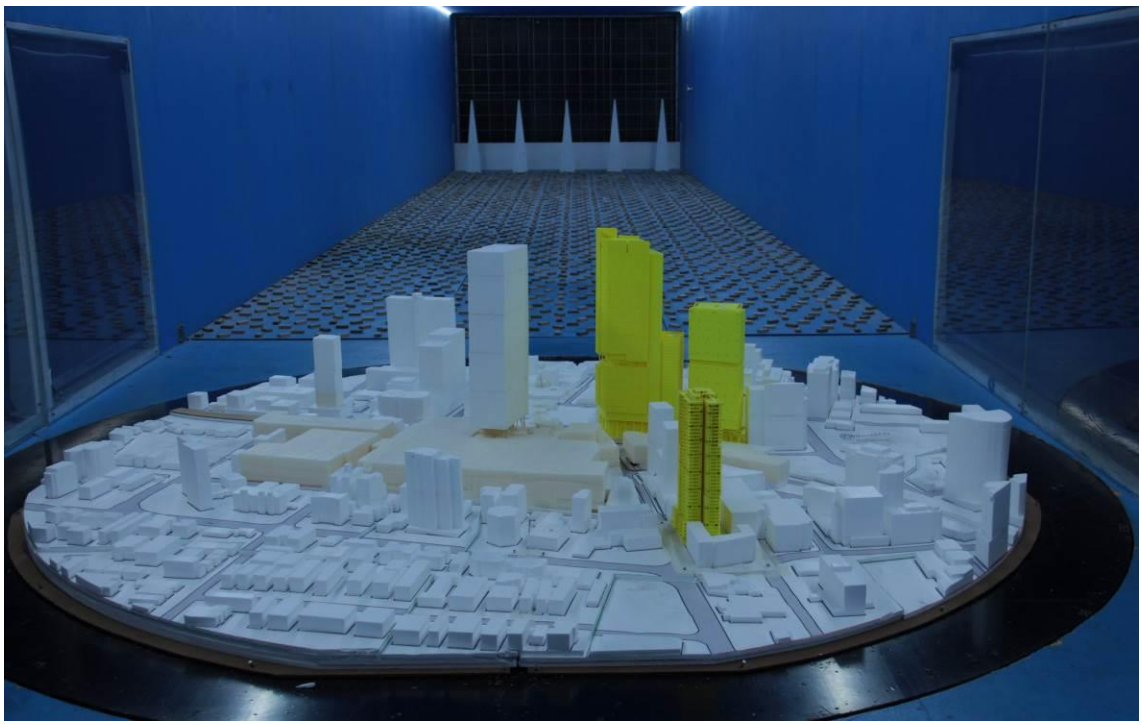


Figure 2a: Photograph of the Wind Tunnel Model – Proposed Scenario (view from the south)

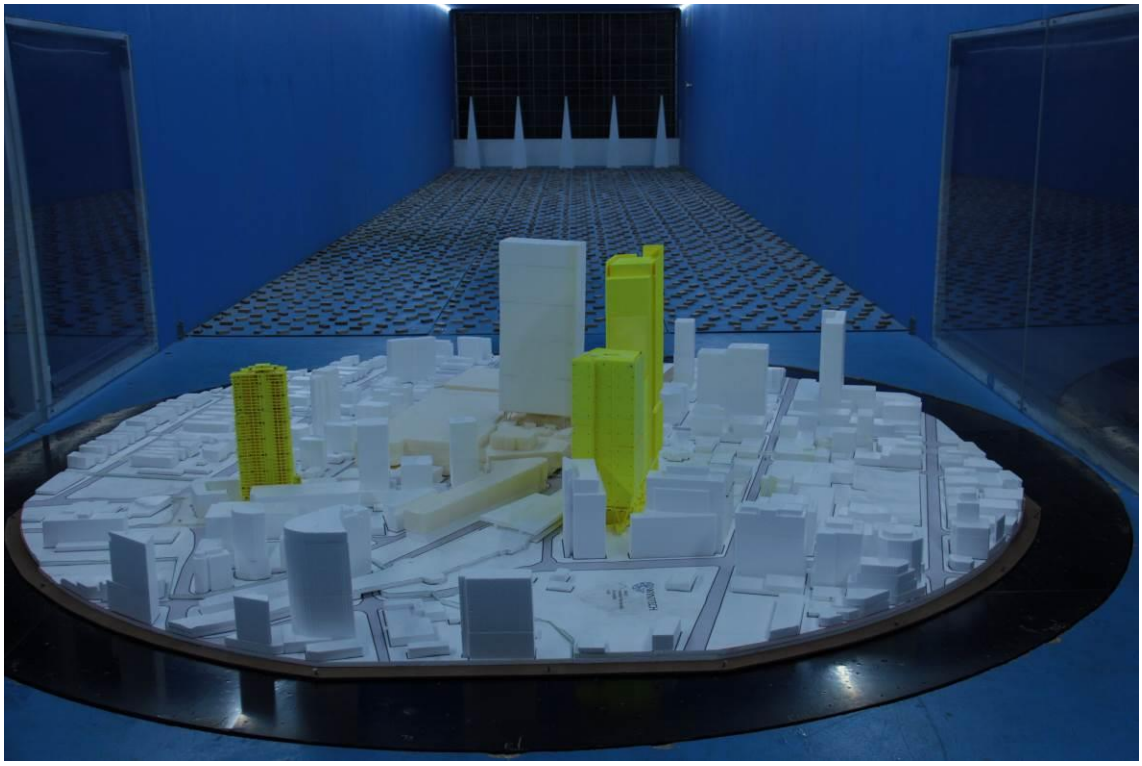


Figure 2b: Photograph of the Wind Tunnel Model – Proposed Scenario (view from the east)

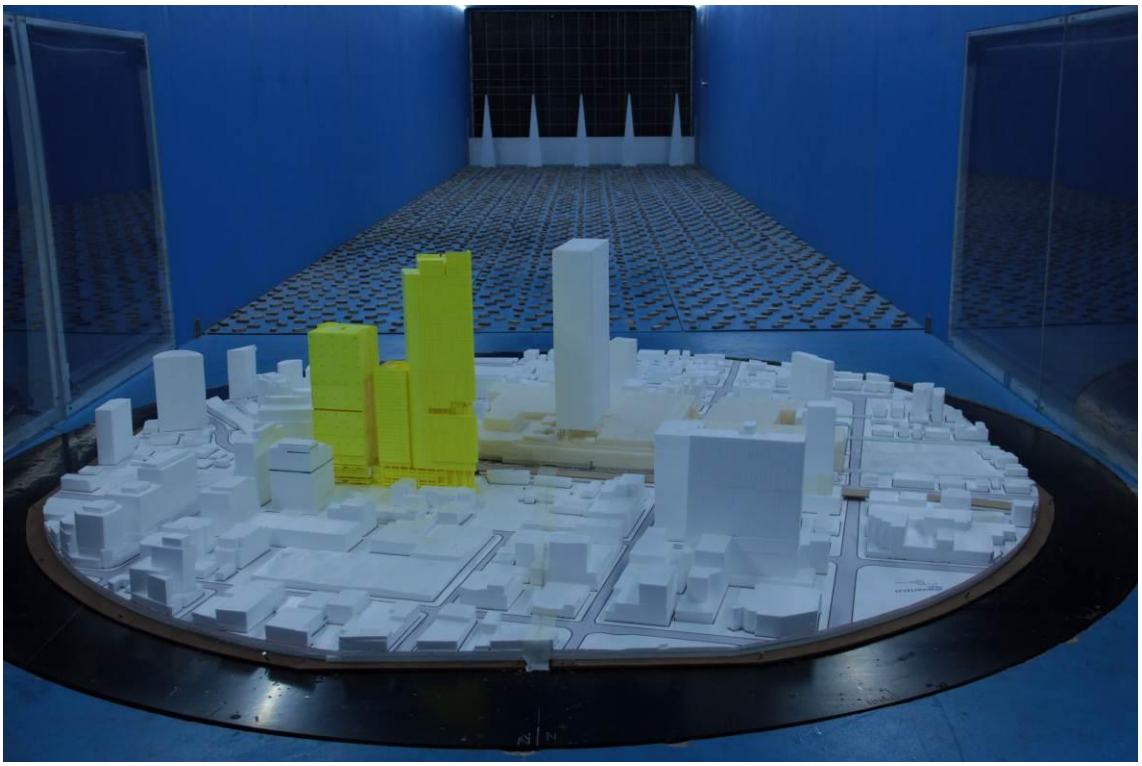


Figure 2c: Photograph of the Wind Tunnel Model – Proposed Scenario (view from the north)

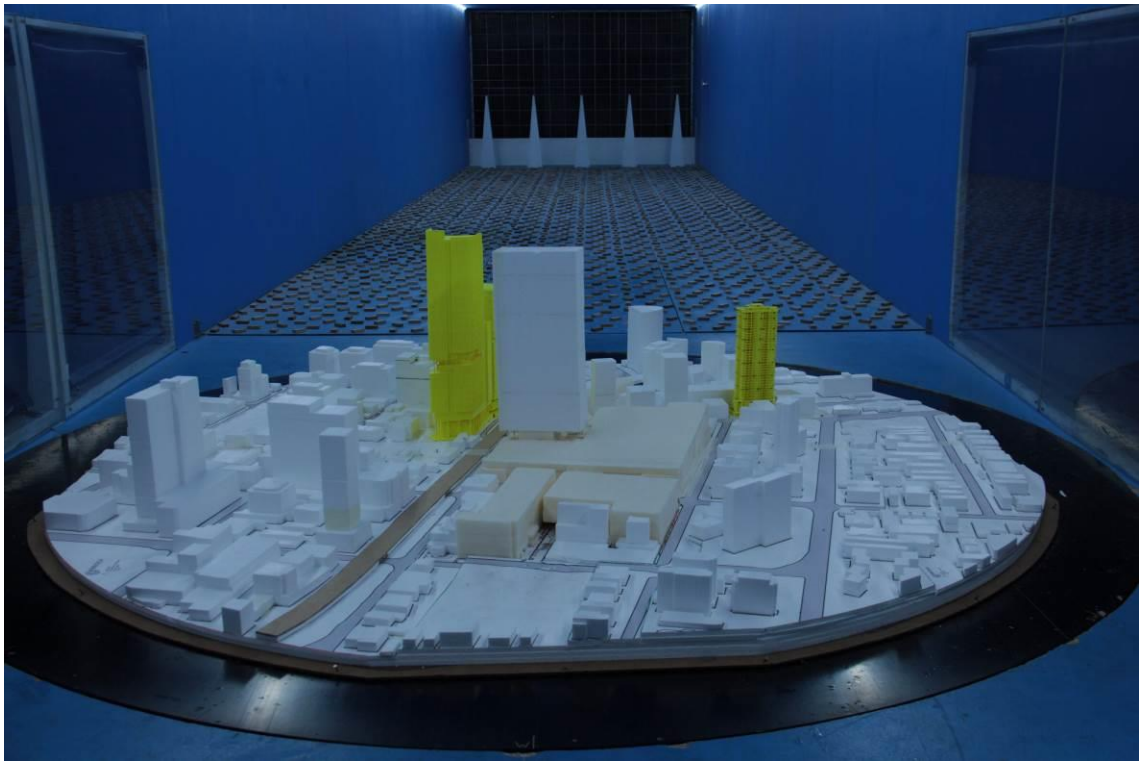


Figure 2d: Photograph of the Wind Tunnel Model – Proposed Scenario (view from the west)

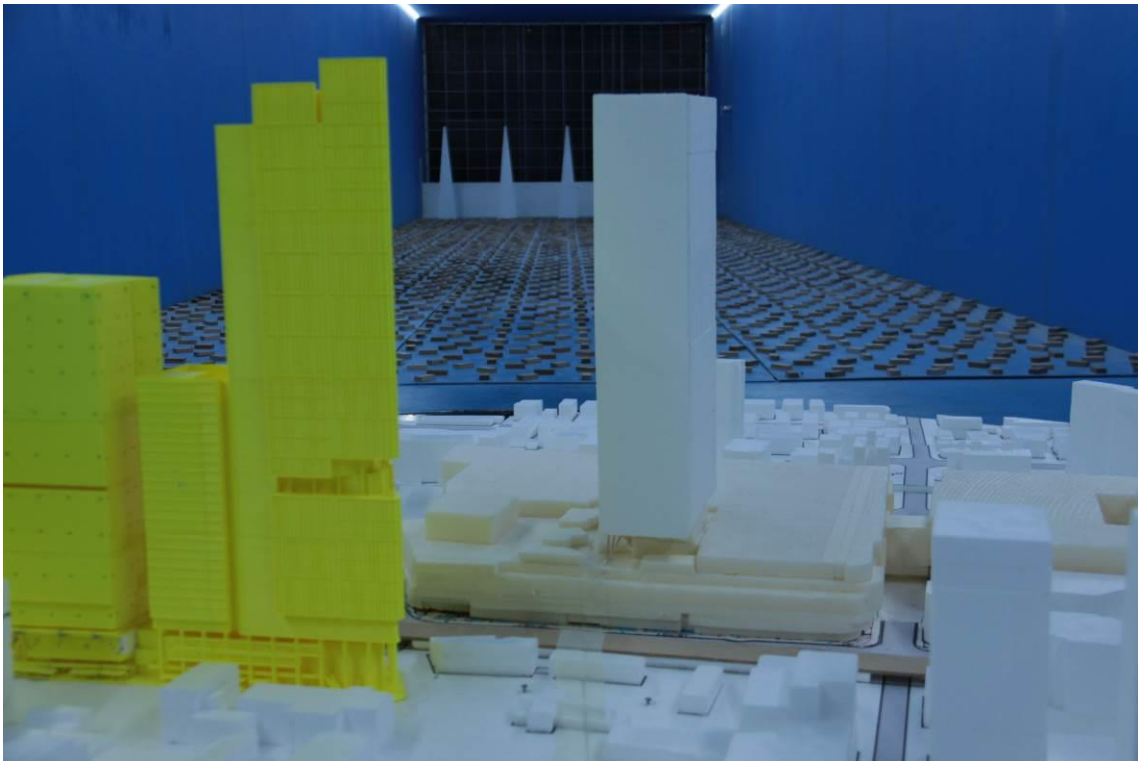


Figure 2e: Photograph of the Wind Tunnel Model – Proposed Scenario (view from the north)

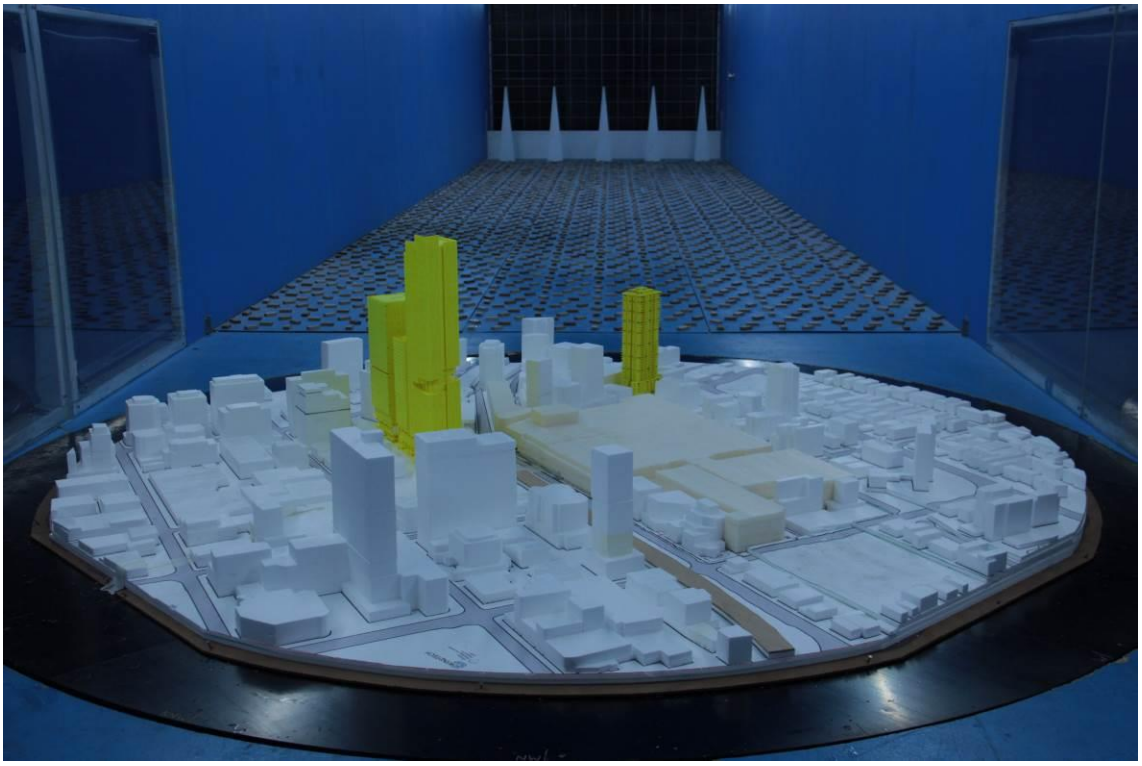


Figure 2f: Photograph of the Wind Tunnel Model – Existing Scenario (view from the north-west)

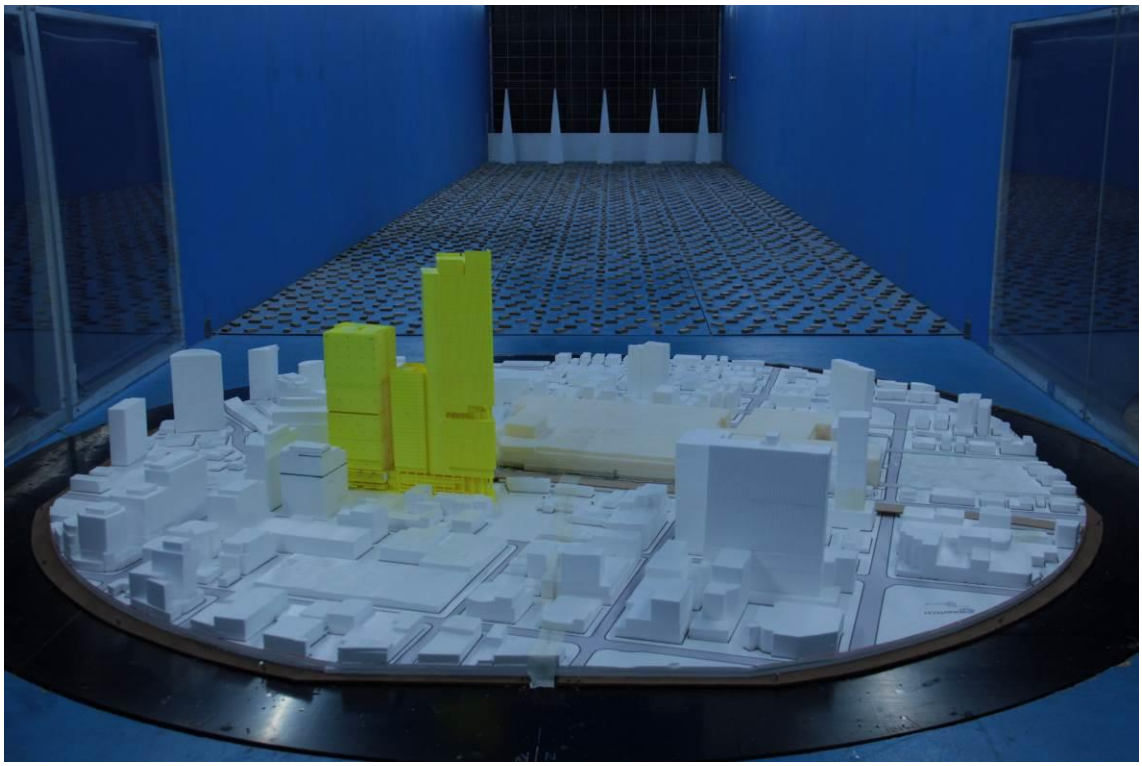


Figure 2g: Photograph of the Wind Tunnel Model – Existing Scenario (view from the north)

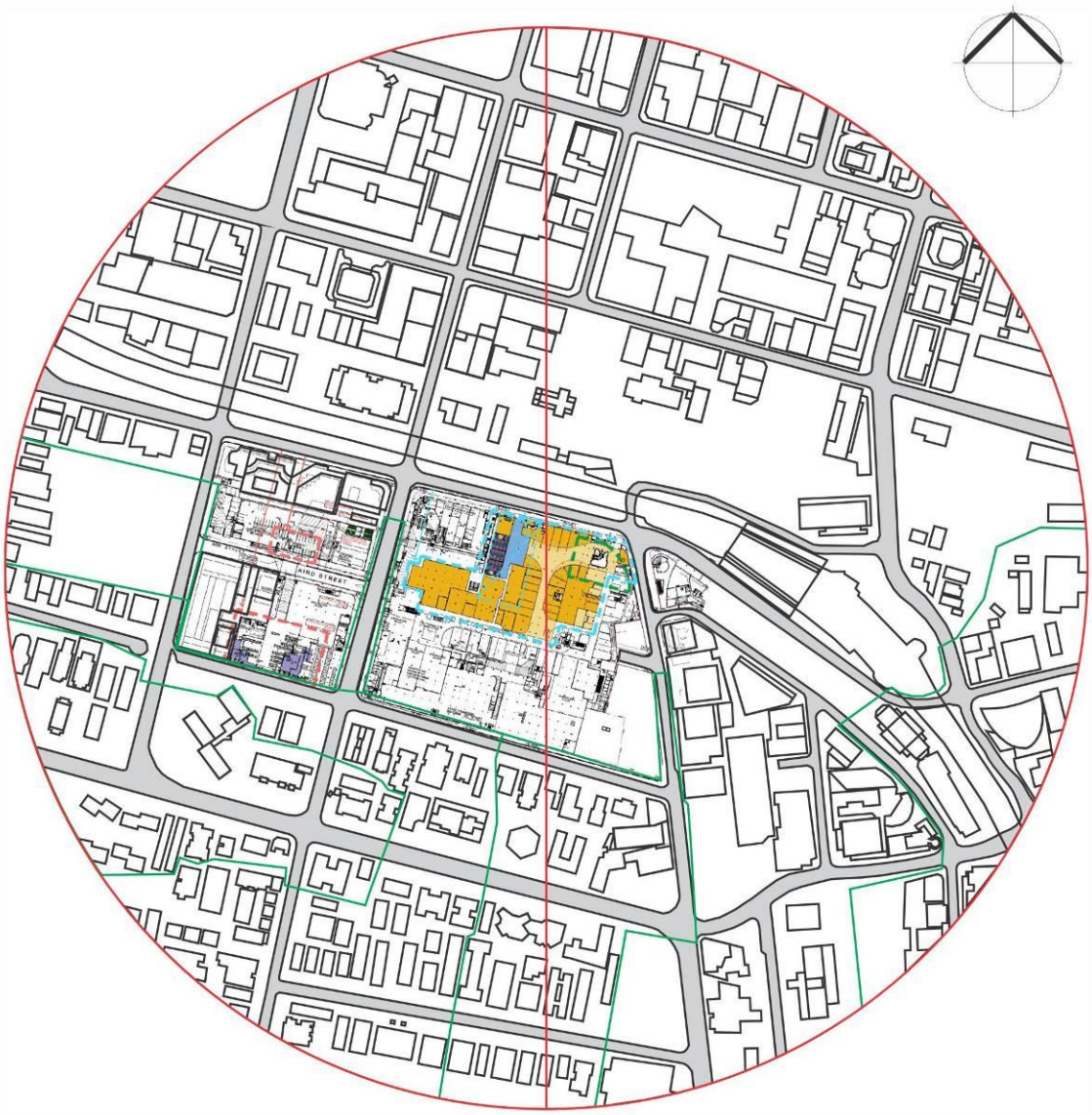


Figure 2h: Image of the Proximity Model – Plan View

3 BOUNDARY LAYER WIND FLOW MODEL

Testing was performed using Windtech's boundary layer wind tunnel, which has a 3.0m wide working section and has a fetch length of 14m. The model was placed in the appropriate standard boundary layer wind flow for each of the prevailing wind directions for the wind tunnel testing. The type of wind flow used in a wind tunnel study is determined by a detailed analysis of the surrounding terrain types around the subject site. Details of the analysis of the surrounding terrain for this study are provided in the following pages of this report.

The roughness of the earth's surface has the effect of slowing down the prevailing wind near the ground. This effect is observed up to what is known as the *boundary layer height*, which can range between 500m to 3km above the earth's surface depending on the roughness of the surface (i.e. oceans, open farmland, dense urban cities, etc.). Within this range, the prevailing wind forms what is known as a *boundary layer wind profile*.

Various wind codes and standards classify various types of boundary layer wind flows depending on the surface roughness. However, it should be noted that the wind profile does not change instantly due to changes in the terrain roughness. It can take many kilometres (at least 100km) of a constant surface roughness for the boundary layer profile to achieve a state of equilibrium. Descriptions of the standard boundary layer profiles for various terrain types are summarised as follows:

- **Terrain Category 1.0:** Extremely flat terrain. Examples include enclosed water bodies such as lakes, dams, rivers, bays, etc.
- **Terrain Category 1.5:** Relatively flat terrain. Examples include the open ocean, deserts, and very flat open plains.
- **Terrain Category 2.0:** Open terrain. Examples include grassy fields and plains and open farmland (without buildings or trees).
- **Terrain Category 2.5:** Relatively open terrain. Examples include farmland with scattered trees and buildings and very low-density suburban areas.
- **Terrain Category 3.0:** Suburban and forest terrain. Examples include suburban areas of towns and areas with dense vegetation such as forests, bushland, etc.
- **Terrain Category 3.5:** Relatively dense suburban terrain. Examples include centres of small cities, industrial parks, etc.
- **Terrain Category 4.0:** Dense urban terrain. Examples include CBD's of large cities with many high-rise towers, and areas with many closely-spaced mid-rise buildings.

For this study, the shape of the boundary layer wind flows over standard terrain types is defined in accordance with Deaves & Harris (1978). These are summarised in Table 2, referenced to the study reference height (approximately half the height of the tower).

Table 2: Terrain and Height Multipliers, Turbulence Intensities, and Corresponding Roughness Lengths, for the Standard Boundary Layer Profiles (at the study reference height)

Terrain Category	Terrain and Height Multipliers			Turbulence Intensity	Roughness Length (m)
	$k_{tr,T=3600s}$ *(hourly)*	$k_{tr,T=600s}$ *(10-minute)*	$k_{tr,T=3s}$ *(3-second)*	I_v	$z_{0,r}$
1.0	1.04	1.07	1.33	0.094	0.003
1.5	0.99	1.02	1.32	0.109	0.01
2.0	0.94	0.97	1.30	0.127	0.03
2.5	0.87	0.91	1.27	0.152	0.1
3.0	0.80	0.84	1.24	0.182	0.3
3.5	0.70	0.75	1.19	0.230	1
4.0	0.60	0.64	1.13	0.298	3

An analysis of the effect of changes in the upwind terrain roughness was carried out for each of the wind directions studied. This has been undertaken based on the method given in AS/NZS1170.2:2011, which uses a "fetch" length of 40 times the study reference height. However, it should be noted that this "fetch" commences *beyond* a "lag distance" area, which has a length of 20 times the study reference height (in accordance with AS/NZS1170.2:2011), so the actual "fetch" of terrain analysed is the area between 20 and 60 times the study reference height away from the site. An aerial image showing the surrounding terrain is presented in Figure 3 for a radius of 6.3km from the edge of the wind tunnel proximity model. The resulting mean and gust terrain and height multipliers at the site location are presented in Table 3, referenced to the study reference height.

Table 3: Terrain and Height Multipliers for Each Directional Sector (at the study reference height)

Wind Sector (degrees)	$k_{tr,T=3600s}$ (hourly mean)	$k_{tr,T=600s}$ (10-minute mean)	$k_{tr,T=3s}$ (3-second gust)
0	0.80	0.84	1.24
30	0.81	0.85	1.24
60	0.80	0.84	1.24
90	0.80	0.84	1.24
120	0.70	0.75	1.19
150	0.80	0.84	1.24
180	0.79	0.83	1.23
210	0.76	0.80	1.22
240	0.76	0.81	1.22
270	0.80	0.84	1.24
300	0.80	0.84	1.24
330	0.80	0.84	1.24

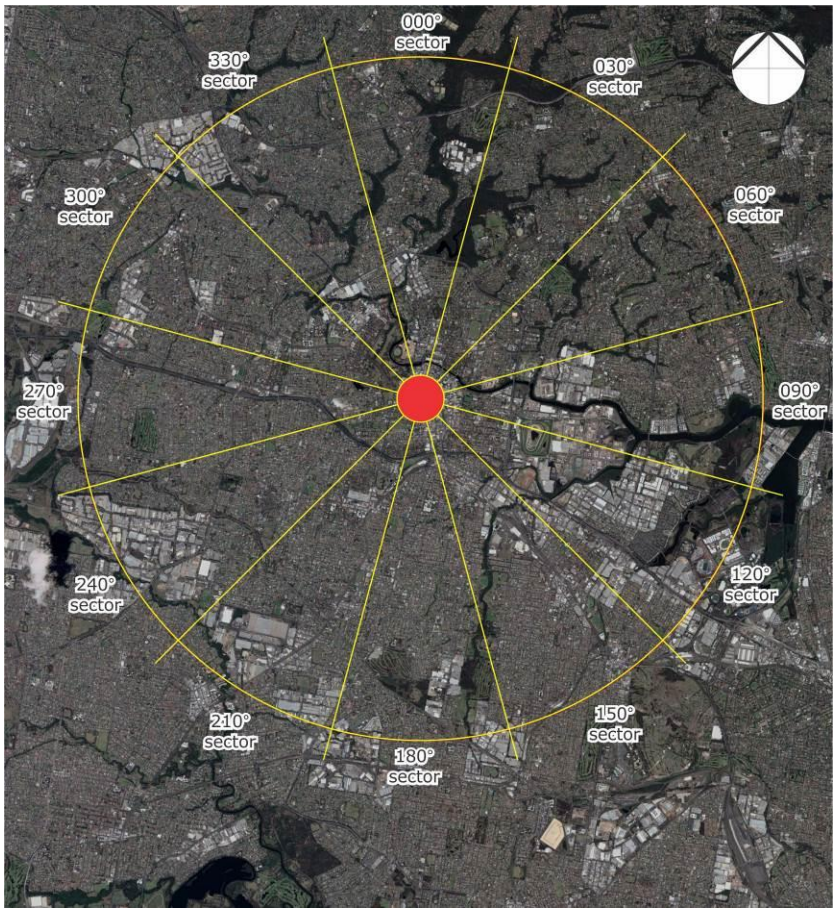


Figure 3: Aerial Image of the Surrounding Terrain (radius of 6.3km from the edge of the proximity model, which is coloured red)

4 ENVIRONMENTAL WIND SPEED CRITERIA

4.1 Wind Effects on People

The acceptability of wind in any area is dependent upon its use. For example, people walking or window-shopping will tolerate higher wind speeds than those seated at an outdoor restaurant. Various other researchers, such as A.G. Davenport, T.V. Lawson, W.H. Melbourne, A.D. Penwarden, etc., have published criteria for pedestrian comfort for pedestrians in outdoor spaces for various types of activities. These are discussed in the following sub-sections of this report.

4.1.1 A.D. Penwarden (1975) Criteria for Gust Wind Speeds

The following table developed by A.D. Penwarden (1975) is a modified version of the Beaufort Scale, and describes the effects of various wind intensities on people. Note that the applicability column related to wind conditions occurring frequently (a probability of exceedance of 5%). Higher ranges of wind speeds can be tolerated for rarer events.

Table 4: Summary of Wind Effects on People (after A.D. Penwarden, 1975)

Type of Winds	Beaufort Number	Mean Wind Speed (m/s)	Effects
Calm, light air	1	0 - 1.5	Calm, no noticeable wind
Light breeze	2	1.6 - 3.3	Wind felt on face
Gentle breeze	3	3.4 - 5.4	Hair is disturbed, Clothing flaps
Moderate breeze	4	5.5 - 7.9	Raises dust, dry soil and loose paper - Hair disarranged
Fresh breeze	5	8.0 – 10.7	Force of wind felt on body
Strong breeze	6	10.8 – 13.8	Umbrellas used with difficulty, Hair blown straight, Difficult to walk steadily, Wind noise on ears unpleasant.
Near gale	7	13.9 – 17.1	Inconvenience felt when walking.
Gale	8	17.2 - 20.7	Generally impedes progress, Great difficulty with balance.
Strong gale	9	20.8 – 24.4	People blown over by gusts.

4.1.2 A.G. Davenport (1972) Criteria for Mean Wind Speeds

A.G. Davenport (1972) had also determined a set of criteria in terms of the Beaufort Scale and for various return periods. The values presented in Table 5 below are based on a probability of exceedance of 5%.

Table 5: Criteria by A.G. Davenport (1972)

Classification	Activities	Maximum Mean (5% exceedance)
Walking Fast	Acceptable for walking, main public accessways.	7.5 m/s < $\overline{V}$ < 10.0 m/s
Strolling, Skating	Slow walking, etc.	5.5 m/s < $\overline{V}$ < 7.5 m/s
Short Exposure Activities	Generally acceptable for walking & short duration stationary activities such as window-shopping, standing or sitting in plazas.	3.5 m/s < $\overline{V}$ < 5.5 m/s
Long Exposure Activities	Generally acceptable for long duration stationary activities such as in outdoor restaurants & theatres and in parks.	$\overline{V}$ < 3.5 m/s

4.1.3 T.V. Lawson (1975) Criteria for Mean Wind Speeds

In 1973, T.V. Lawson quotes that A.D. Penwarden's Beaufort 4 wind speeds (as listed in Table 3) would be acceptable if it is not exceeded for more than 4% of the time; and a Beaufort 6 as being unacceptable if it is exceeded more than 2% of the time. Later, in 1975, T.V. Lawson presented a set of criteria very similar to those of A.G. Davenport's. These are presented in Tables 6 and 7.

Table 6: Safety Criteria by T.V. Lawson (1975)

Classification	Activities	Annual Maximum Mean
Safety (all weather areas)	Accessible by the general public.	15 m/s
Safety (fair weather areas)	Private outdoor areas (balconies, terraces, etc.)	20 m/s

Table 7: Comfort Criteria by T.V. Lawson (1975)

Classification	Activities	95 Percentile Maximum Mean
Business Walking	Objective Walking from A to B.	8 m/s < $\overline{V}$ < 10m/s
Pedestrian Walking	Slow walking, etc.	6 m/s < $\overline{V}$ < 8 m/s
Short Exposure Activities	Pedestrian standing or sitting for short times.	4 m/s < $\overline{V}$ < 6 m/s
Long Exposure Activities	Pedestrian sitting for a long duration.	$\overline{V}$ < 4 m/s

4.1.4 W.H. Melbourne (1978) Criteria for Gust Wind Speeds

W.H. Melbourne (1978) introduced a set of criteria for the assessment of environmental wind conditions, which were developed for a temperature range of 10°C to 30°C and for people suitably dressed for outdoor conditions. These criteria are based on maximum gust wind speeds with an annual probability of exceedance, and are outlined in Table 8 below. It should be noted that this criteria tends to be more conservative than criteria suggested by other researchers.

Table 8: Criteria by W.H. Melbourne (1978)

Classification	Human Activities	Annual Maximum Gust
Limit for safety	Completely unacceptable: people likely to get blown over.	$\hat{V}$ > 23m/s
Marginal	Unacceptable as main public accessways.	23 m/s > $\hat{V}$ > 16 m/s
Comfortable Walking	Acceptable for walking, main public accessways	16 m/s > $\hat{V}$ > 13 m/s
Short Exposure Activities	Generally acceptable for walking & short duration stationary activities such as window-shopping, standing or sitting in plazas.	13 m/s > $\hat{V}$ > 10 m/s
Long Exposure Activities	Generally acceptable for long duration stationary activities such as in outdoor restaurants & theatres and in parks.	10 m/s > $\hat{V}$

4.2 Comparison of the Various Wind Speed Criteria

The criteria by W.H. Melbourne (1978) mentioned in Table 8, and criteria from other researchers, are compared on a probabilistic basis in Figure 4. This indicates that the criteria by W.H. Melbourne (1978) are quite conservative. This was also observed by A.W. Rofail (2007) when undertaking on-site remedial studies, who concluded that the criteria by W.H. Melbourne (1978) generally overstates the wind effects in a typical urban setting, which is caused by the assumption by W.H. Melbourne of a fixed 15% turbulence intensity for all areas. This value tends to be at the lower end of the range of turbulence intensities, and the A.W. Rofail (2007) study found that, in an urban setting, the range of the *minimum* turbulence intensities is typically in the range of 20% to 60%.

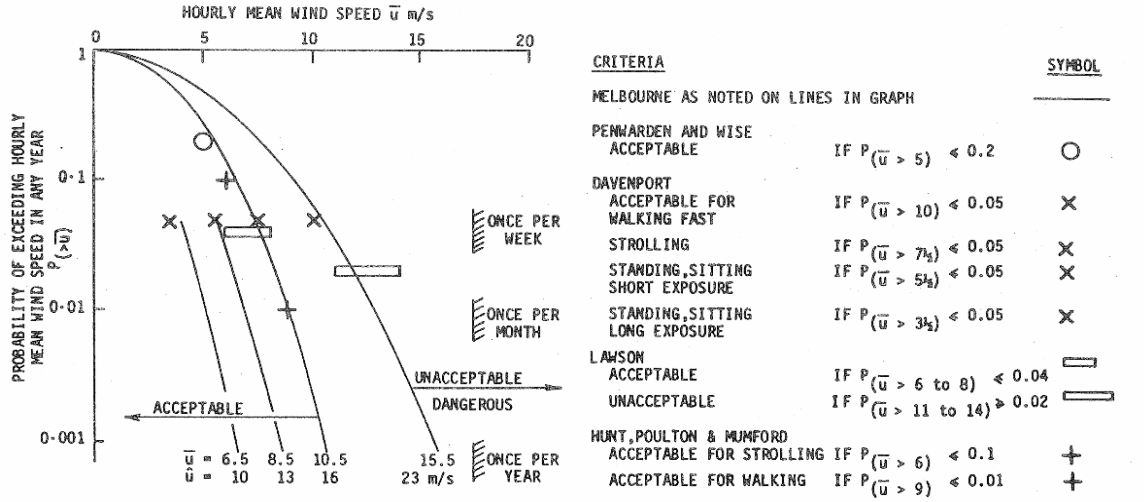


Figure 4: Comparison of Various Mean and Gust Wind Environment Criteria, assuming 15% turbulence and a Gust Factor of 1.5 (after W.H. Melbourne, 1978)

4.3 Wind Speed Criteria Used for This Study

For this study, the measured wind conditions for the various critical outdoor trafficable areas within and around the subject development are compared against two sets of criteria. For comfort, the A.G. Davenport (1972) criteria are used in conjunction with a maximum Gust-Equivalent Mean (GEM) wind speed (defined below). The safety limit criterion by W.H. Melbourne (1978) of 23m/s for the maximum peak gust wind speeds is also used. Note that the A.G. Davenport (1972) criteria, used in conjunction with a GEM wind speed (defined below), has proven over time, and through field observations, to be the most reliable indicator of pedestrian comfort (Rofail, 2007). Note also that the safety limit criterion by W.H. Melbourne (1978) of 23m/s for maximum peak gust wind speeds is also applied to all areas. The basic criteria for a range of outdoor activities are described as follows:

- **Short Exposure:** 5.5m/s maximum GEM wind speeds
- **Comfortable Walking:** 7.5m/s maximum GEM wind speeds
- **Safety Limit:** 23.0m/s maximum gust wind speeds.
- **Existing Site Conditions:** Where relevant, if the existing site conditions exceed the target comfort criterion, then the target wind speed for that area with the inclusion of the proposed development is to at least match the existing site conditions.

The results of the wind tunnel study are summarised in the following section, and presented in the form of directional plots attached in Appendix A of this report. Each study point has 2 plots (one comparing to the modified version of the A.G. Davenport (1972) criteria for the maximum GEM wind speeds and the other comparing to the W.H. Melbourne (1978) criteria for the maximum peak gust wind speeds).

Notes:

- The GEM is defined as the maximum of the mean wind speed and the gust wind speed divided by a gust factor of 1.85.
- The gust wind speed is defined as 3.0 standard deviations from the mean for a 3 second gust duration, or 3.4 standard deviations from the mean for a 0.5-second gust duration.
- Short Exposure applies typically to areas where short duration stationary activities are involved (less than 1 hour). This includes window shopping, waiting areas, etc.
- Comfortable Walking applies typically to areas used mainly for pedestrian thoroughfares. This also includes private swimming pools, communal areas, and private balconies and terraces.
- In all areas, the wind conditions are also checked against the safety limit.

5 TEST PROCEDURE AND METHODOLOGY

5.1 Measurement of the Velocity Coefficients

Testing was performed using Windtech's boundary layer wind tunnel facility, which has a 3.0m wide working section and has a fetch length of 14m. The test procedures followed for the wind tunnel testing performed for this study generally adhere to the guidelines set out in the Australasian Wind Engineering Society Quality Assurance Manual (AWES-QAM-1-2017), ASCE 7-10 (Chapter C31), and CTBUH (2013) guidelines.

The model of the subject development was setup within the wind tunnel, and the wind velocity measurements were monitored using Dantec hot-wire probe anemometers at selected critical outdoor locations at a full-scale height of approximately 1.5m above ground/slab level. The probe support for each study location was mounted such that the probe wire was vertical as much as possible, which ensures that the measured wind speeds are independent of wind direction along the horizontal plane. In addition, care was taken in the alignment of the probe wire and in avoiding wall-heating effects. Wind speed measurements are made in the wind tunnel for 16 wind directions, at 22.5° increments. The output from the hot-wire probes was obtained using a National Instruments 12-bit data acquisition card. A sample rate of 1024Hz was used, which is more than adequate for he given frequency band.

The mean and the maximum peak gust velocity coefficients are derived from the wind tunnel test by the following relation:

$$\hat{C}_V = \overline{C}_V + g.\sigma_V \qquad (5.1)$$

where: $\hat{C}_V$ is the gust velocity coefficient.

$\overline{C}_V$ is the mean velocity coefficient.

g is the gust factor, which is taken to be 3.0 for a 3-second gust duration, or 3.4 for a 0.5-second gust duration.

σ_V is the standard deviation of the velocity measurement.

The mean free-stream wind speed measured in the wind tunnel for this study was approximately 9.0m/s. Note that the measurement location for the mean free-stream wind speed is at a height of 200m at the upwind edge of the proximity model. A sample length of 12 seconds was used for each wind direction tested, which is equivalent to a minimum sample time of approximately 46 minutes in full-scale for the maximum gust wind speeds, which is suitable for this type of study.

5.2 Calculation of the Full-Scale Results

To determine if the wind conditions at each study point location will satisfy the relevant criteria for pedestrian comfort and safety, the measured velocity coefficients need to be combined with information about the local wind climate. The aim of combining the wind tunnel measurements with wind climate information is to determine the probability of exceedance of a given wind speed at the site. The local wind climate is normally described using a statistical model, which relates wind speed to a probability of exceedance. Details of the wind climate model used in this study are outlined in Section 1.

A feature of this process is to include the impact of wind directionality, which includes any local variations in wind speed or frequency with wind direction. This is important as the wind directions that produce the highest wind speed events for a region may not coincide with the most wind exposed direction of the site.

The methodology adopted for the derivation of the full-scale results for the maximum gust and the maximum GEM wind speeds are outlined in the following sub-sections.

5.2.1 Maximum Gust Wind Speeds

The full-scale maximum gust wind speed at each study point location is derived from the measured velocity coefficient using the following relationship:

$$V_{study} = V_{ref,RH}\left(\frac{k_{200m,tr,T=3600s}}{k_{RH,tr,T=3600s}}\right)C_V \qquad (5.2)$$

V_{study} is the full-scale wind velocity at the study point location, in m/s.

$V_{ref,RH}$ is the full-scale reference wind speed at the upwind edge of the proximity model at the study reference height. This value is determined by combining the directional wind speed data for the region (detailed in Section 1) and the upwind terrain and height multipliers for the site (detailed in Section 3).

$k_{200m,tr,T=3600s}$ is the hourly mean terrain and height multiplier at 200m for the standard terrain category setup used in the wind tunnel tests.

$k_{RH,tr,T=3600s}$ is the hourly mean terrain and height multiplier at the study reference height (see Table 3).

C_V is the velocity coefficient measurement obtained from the hot-wire anemometer, which is derived from the following relationship:

$$C_V = \frac{C_{V,study}}{C_{V,200m}} \quad (5.3)$$

$C_{V,study}$ is the velocity coefficient measurement obtained from the hot-wire anemometer at the study point location.

$C_{V,200m}$ is the measurement obtained from the hot-wire anemometer at the free-stream reference location at 200m height upwind of the model in the wind tunnel.

The value of $V_{ref,RH}$ varies with each prevailing wind direction. Wind directions where there is a high probability that a strong wind will occur will have a higher directional wind speed than other directions. To determine the directional wind speeds, a probability level must be assigned for each wind direction. These probability levels are set following the approach used in AS/NZS1170.2:2011, which assumes that the major contributions to the combined probability of exceedance of a typical load effect comes from only two 45 degree sectors.

5.2.2 Maximum Gust-Equivalent Mean Wind Speeds

The contribution to the probability of exceedance of a specified wind speed (i.e. the desired wind speed for pedestrian comfort, as per the criteria) is calculated for each wind direction. These contributions are then combined over all wind directions to calculate the total probability of exceedance of the specified wind speed. To calculate the probability of exceedance for a specified wind speed a statistical wind climate model was used to describe the relationship between directional wind speeds and the probability of exceedance. A detailed description of the methodology is given by Lawson (1980).

The criteria used in this study, is referenced to a probability of exceedance of 5% of a specified wind speed.

5.3 Layout of Study Points

For this study a total of 27 study point locations have been selected for analysis in the wind tunnel. This includes the following:

- 15 study points at Ground Level (Level 2) along the pedestrian footpaths and trafficable areas around the site.
- 8 study points on the Level 6 Terrace.
- 4 study points located in surrounding areas around the proposed development site to determine any impact on the surrounding conditions.

The locations of the various study points tested for this study are presented in Figures 5a to 5c in the form of a marked-up plan drawings, along with the wind criteria each point is required to meet. It should be noted that only the most critical outdoor locations of the development have been selected for analysis.

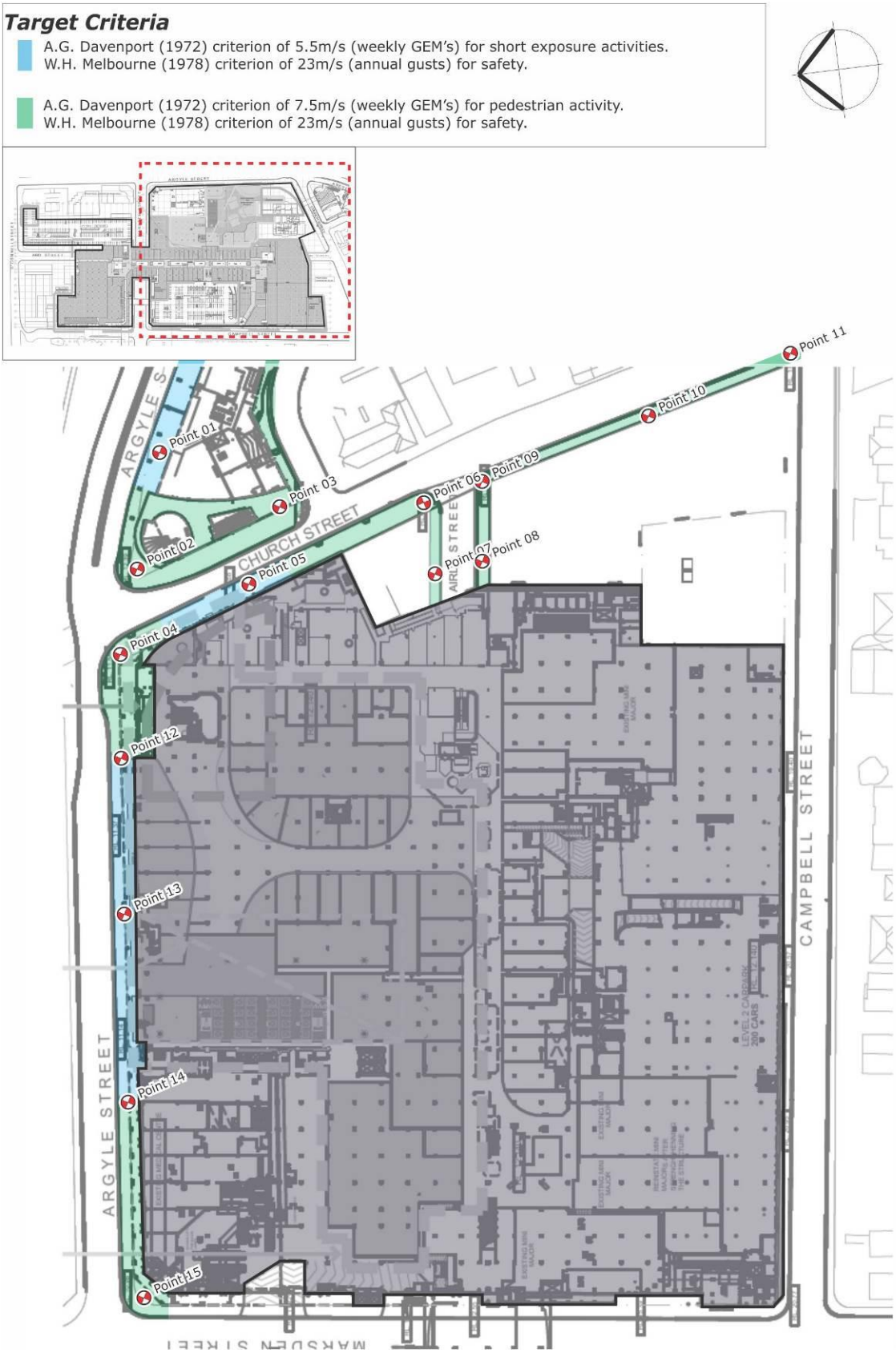


Figure 5a: Study Point Locations and Wind Speed Criteria – Level 2

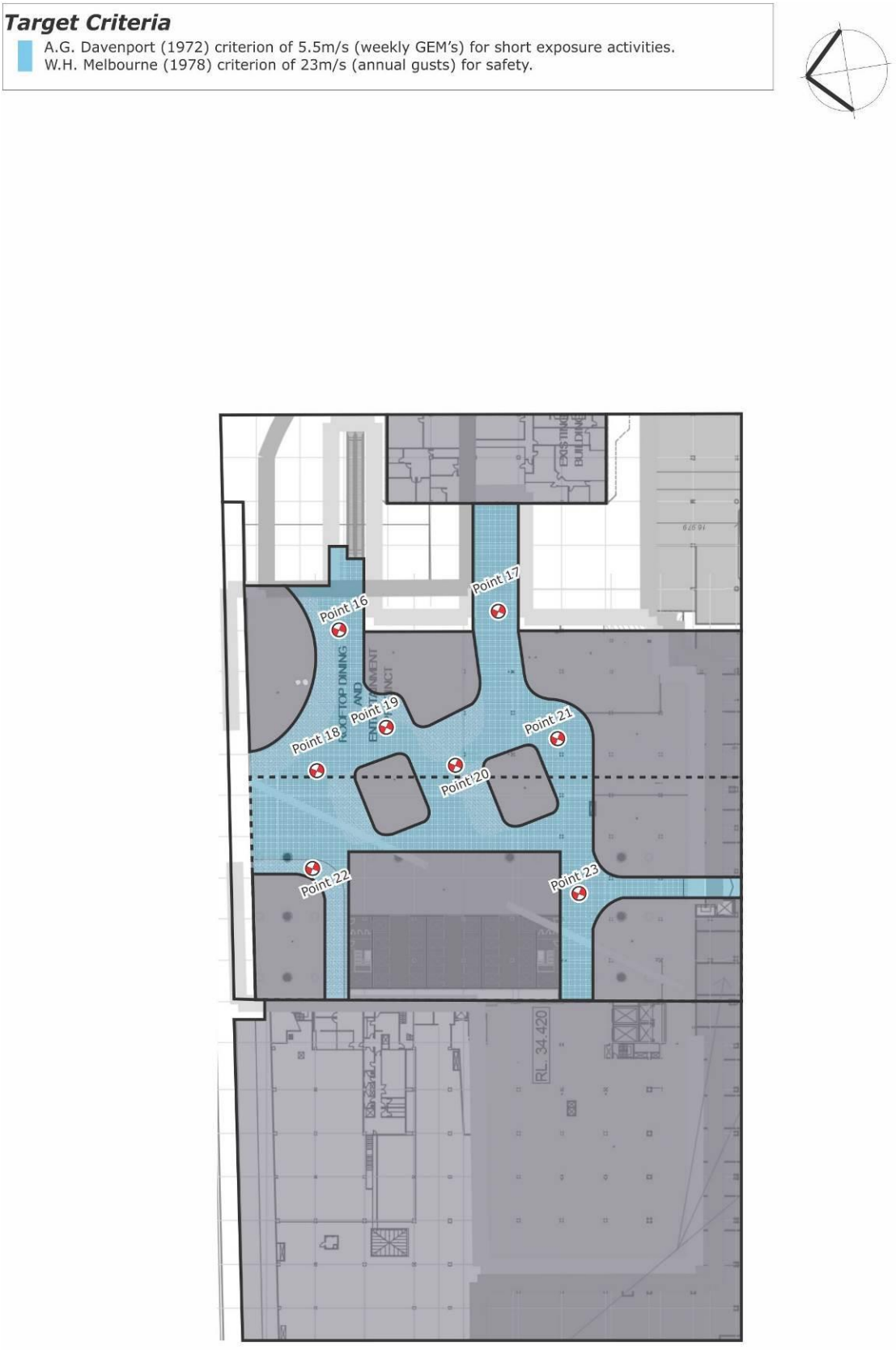


Figure 5b: Study Point Locations and Wind Speed Criteria – Level 6 Terrace

Target Criteria

A.G. Davenport (1972) criterion of 7.5m/s (weekly GEM's) for long exposure activities.
W.H. Melbourne (1978) criterion of 23m/s (annual gusts) for safety.

Figure 5c: Study Point Locations and Wind Speed Criteria – Surrounding Areas

6 RESULTS AND DISCUSSION

The model of the development was tested in the wind tunnel without the effect of any forms of wind ameliorating devices such as screens, balustrades, etc., which are not already shown in the architectural drawings. The effect of vegetation was also excluded from the testing. If the results of the study indicate that any area is exposed to strong winds, in-principle treatments have been recommended.

It should be noted that the proposed development is currently in the concept design stage and further wind tunnel testing will be required once the model has been finalised.

The results for all study point locations are presented in the form of directional plots in Appendix A, and are summarised in Table 9 and also in Figures 6a to 6c. The wind speed criteria that the wind conditions should achieve are also listed in Table 9 for each study point location, as well as in Figures 5a to 5c.

The results of the study indicate that treatments are required for the Level 6 Terrace to achieve the desired wind speed criteria for pedestrian comfort and/or safety. To improve the wind conditions of the development, in-principle ameliorative treatments have been recommended as follows:

- Inclusion of 2m impermeable screening along the northern and eastern perimeter, as indicated in Figure 7.
- Inclusion of an impermeable awning with a depth of at least 3m along the southern edge of the northern restaurant, as indicated in Figure 7.
- Inclusion of an impermeable awning with a depth of at least 3m along the eastern edge of the tower slab, as indicated in Figure 7.

It should be noted that the study has shown that with the addition of the tower, with a 3m set back from Argyle St, the wind conditions at street level will be either equivalent to, or better than, the current conditions experienced along Argyle Street and Marsden Street. Hence from a wind mitigation point of view there is no need to set the tower further back than what has been proposed.

With the inclusion of the abovementioned treatments to the final design, suitable wind conditions are expected to be achieved for all trafficable areas within and around the subject development site. Further wind tunnel testing should be undertaken during the detailed design stage to verify the wind conditions with the implementation of the design treatments.

Table 9a: Wind Tunnel Results Summary

Study Point	Desired Criterion (m/s)		Equivalent to or Better than Existing Site Wind Conditions?	Treatment Necessary to Pass?	Description of Suggested Treatment/ Notes
	GEM 5% exceedance	Safety Limit			
Point 01	5.5	23.0	-	-	-
Point 02	7.5	23.0	-	-	-
Point 03	7.5	23.0	-	-	-
Point 04	7.5	23.0	-	-	-
Point 05	5.5	23.0	-	-	-
Point 06	7.5	23.0	-	-	-
Point 07	7.5	23.0	-	-	-
Point 08	7.5	23.0	-	-	-
Point 09	7.5	23.0	-	-	-
Point 10	7.5	23.0	-	-	-
Point 11	7.5	23.0	-	-	-
Point 12	7.5	23.0	-	-	-
Point 13	5.5	23.0	YES	NO	-
Point 14	7.5	23.0	-	-	-
Point 15	7.5	23.0	YES	NO	-
Point 16	5.5	23.0	-	YES	Refer to Figure 7
Point 17	5.5	23.0	-	YES	Refer to Figure 7
Point 18	5.5	23.0	-	YES	Refer to Figure 7
Point 19	5.5	23.0	-	-	-
Point 20	5.5	23.0	-	-	-
Point 21	5.5	23.0	-	-	-
Point 22	5.5	23.0	-	YES	Refer to Figure 7
Point 23	5.5	23.0	-	-	-
Point 101	7.5	23.0	YES	NO	-
Point 102	7.5	23.0	YES	NO	-
Point 103	7.5	23.0	YES	NO	-
Point 104	7.5	23.0	YES	NO	-

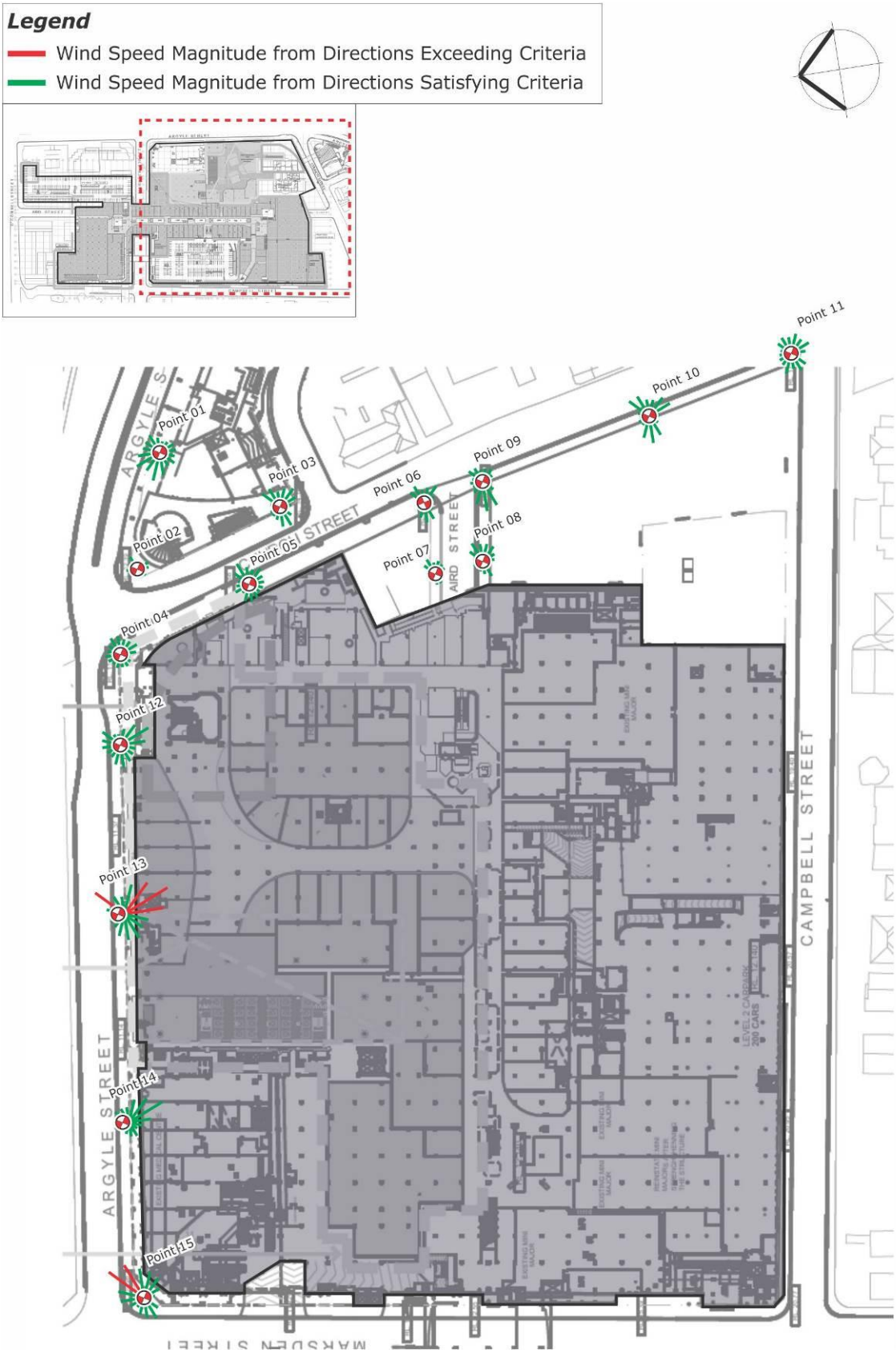


Figure 6a: Wind Directionality Plots – Level 2

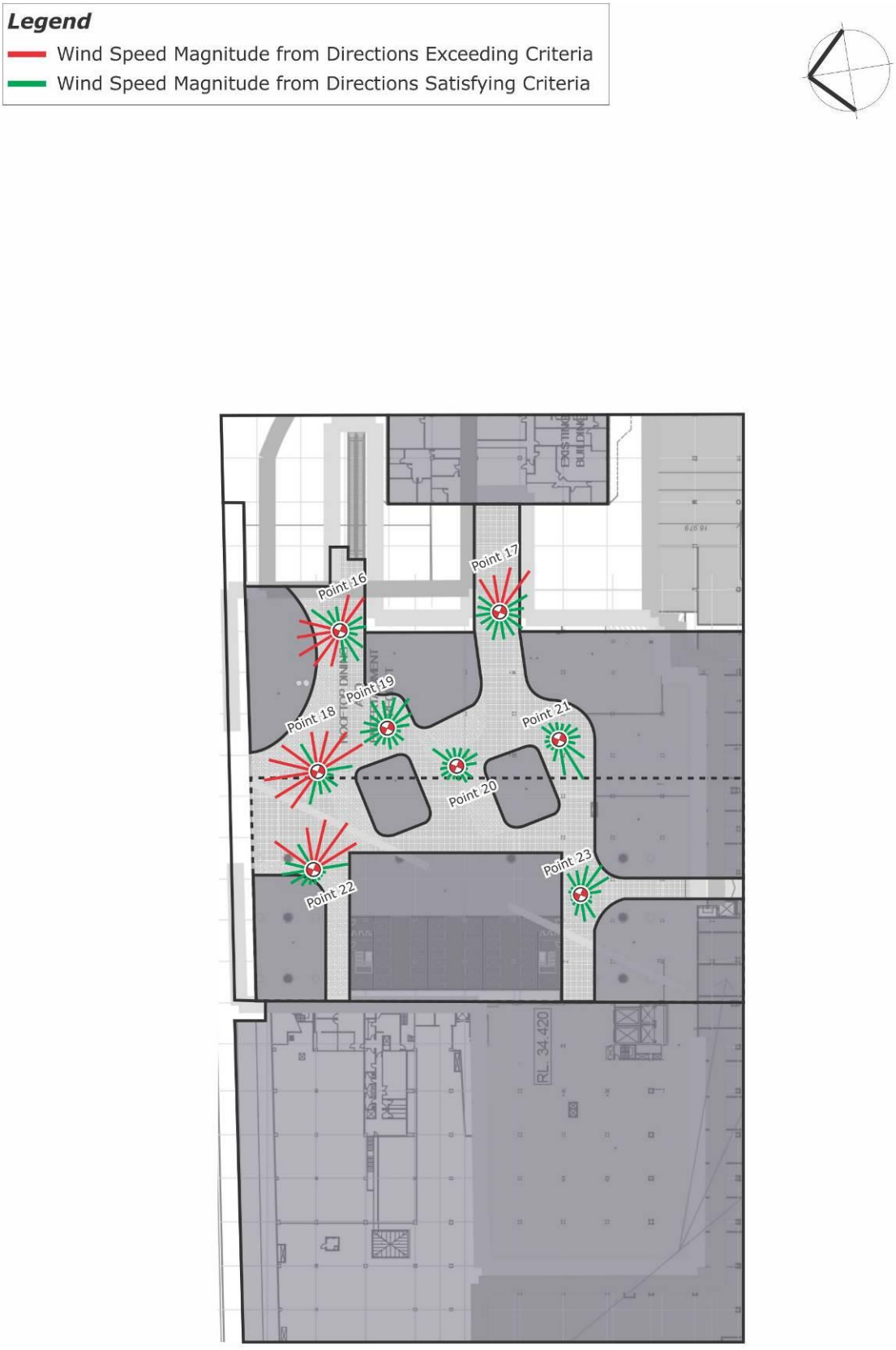


Figure 6b: Wind Directionality Plots – Level 6 Terrace

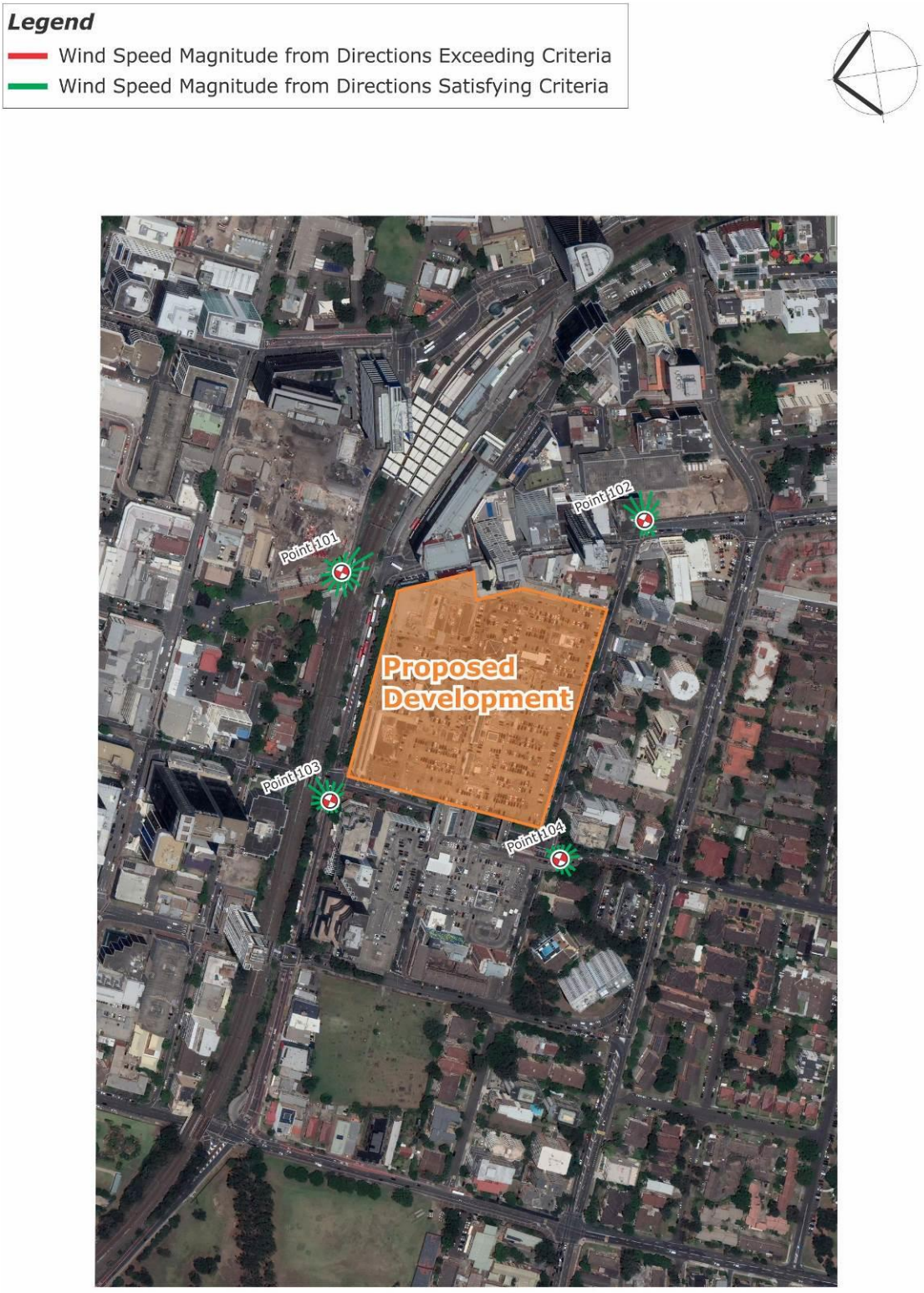


Figure 6c: Wind Directionality Plots – Surrounding Study Points

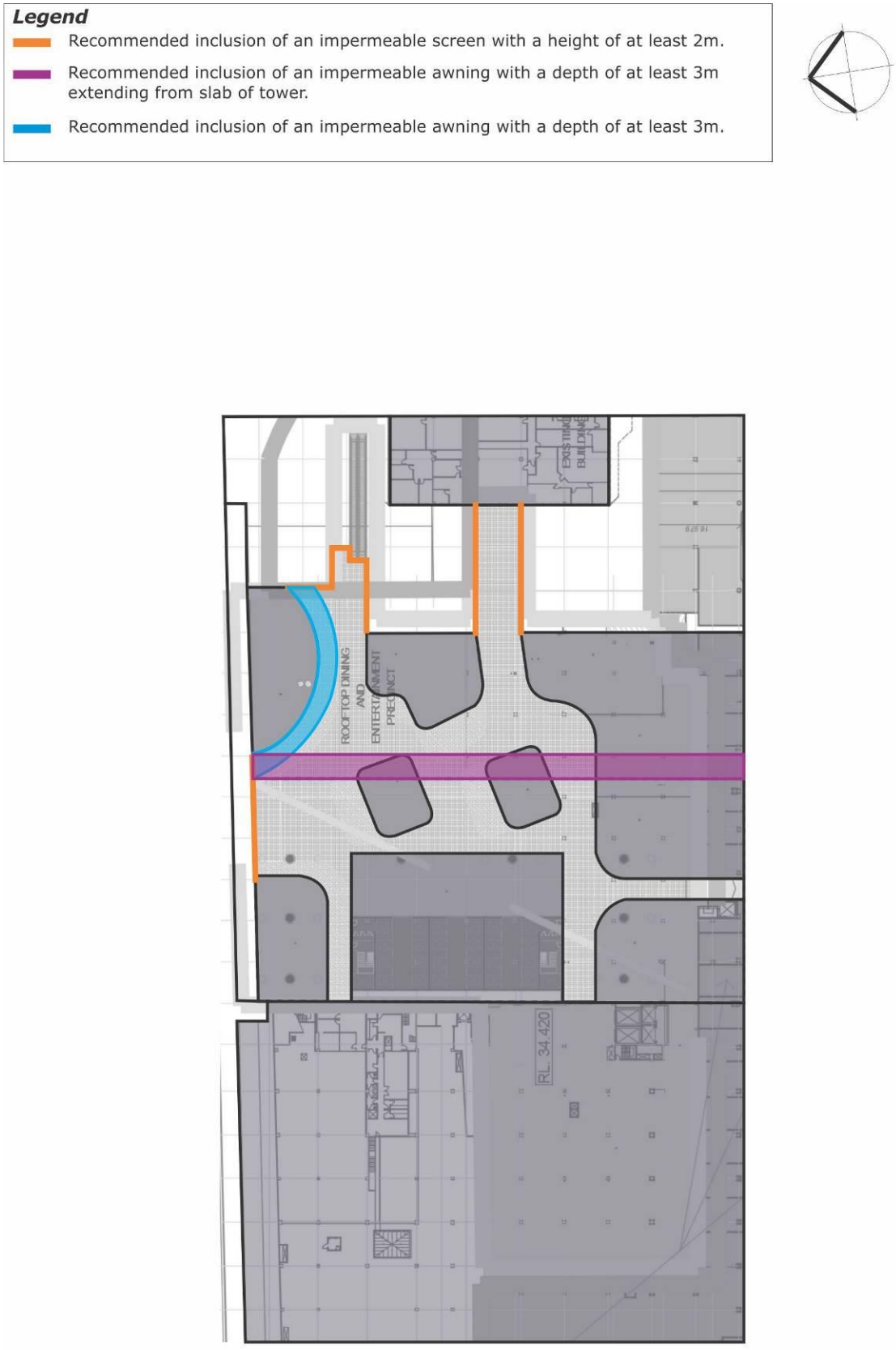


Figure 7: Recommended Treatments – Level 6 Terrace

REFERENCES

American Society of Civil Engineers, ASCE-7-10, 2010, "Minimum Design Loads for Buildings and Other Structures".

Australasian Wind Engineering Society, QAM-1, 2017, "Quality Assurance Manual".

Australasian Wind Engineering Society, 2014, "Guidelines for Pedestrian Wind Effects Criteria"

Aynsley, R.M., Melbourne, W.H., Vickery, B.J., 1977, "Architectural Aerodynamics". Applied Science Publishers.

City of Sydney Council, 2012, "City of Sydney Development Control Plan 2012"

City of Sydney Council, 2016, "City of Sydney Development Control Plan 2012: Central Sydney Planning Strategy Amendment"

Council on Tall Buildings and Urban Habitat (CTBUH), 2013, "Wind tunnel testing of high-rise buildings", CTBUH Technical Guides.

Davenport, A.G., 1972, "An approach to human comfort criteria for environmental conditions". Colloquium on Building Climatology, Stockholm.

Davenport, A.G., 1977, "The prediction of risk under wind loading", 2nd International Conference on Structural Safety and Reliability, Munich, Germany, pp511-538.

Deaves, D.M. and Harris, R.I., 1978, "A mathematical model of the structure of strong winds." Construction Industry and Research Association (U.K), Report 76.

Engineering Science Data Unit, 1982, London, ESDU82026, "Strong Winds in the Atmospheric Boundary Layer, Part 1: Hourly Mean Wind Speeds", with Amendments A to E (issued in 2002).

Engineering Science Data Unit, 1983, London, ESDU83045, "Strong Winds in the Atmospheric Boundary Layer, Part 2: Discrete Gust Speeds", with Amendments A to C (issued in 2002).

International Organisation for Standardisation, ISO4354, 2009, "Wind Actions on Structures".

Lawson, T.V., 1973, "The wind environment of buildings: a logical approach to the establishment of criteria". Bristol University, Department of Aeronautical Engineering.

Lawson, T.V., 1975, "The determination of the wind environment of a building complex before construction". Bristol University, Department of Aeronautical Engineering.

Lawson, T.V., 1980, "Wind Effects on Buildings - Volume 1, Design Applications". Applied Science Publishers Ltd, Ripple Road, Barking, Essex, England.

Melbourne, W.H., 1978, "Criteria for Environmental Wind Conditions". *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 3, pp241-249.

Melbourne, W.H., 1978, "Wind Environment Studies in Australia". *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 3, pp201-214.

Penwarden, A.D., Wise A.F.E., 1975, "Wind Environment around Buildings". Building Research Establishment Report, London.

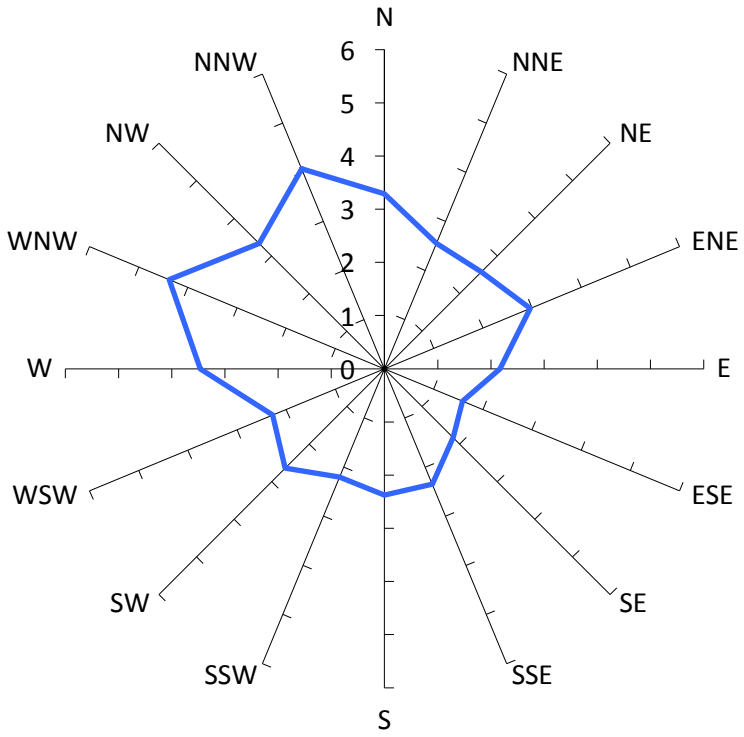
Rofail, A.W., 2007, "Comparison of Wind Environment Criteria against Field Observations". 12th International Conference of Wind Engineering, Cairns, Australia.

Standards Australia and Standards New Zealand, AS/NZS 1170.2, 2011, "SAA Wind Loading Standard, Part 2: Wind Actions".

APPENDIX A - DIRECTIONAL PLOTS OF THE WIND TUNNEL RESULTS

Measured Wind Speeds at Point 01

Weekly Maximum GEM (m/s)



Desired Criterion
5.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
1%

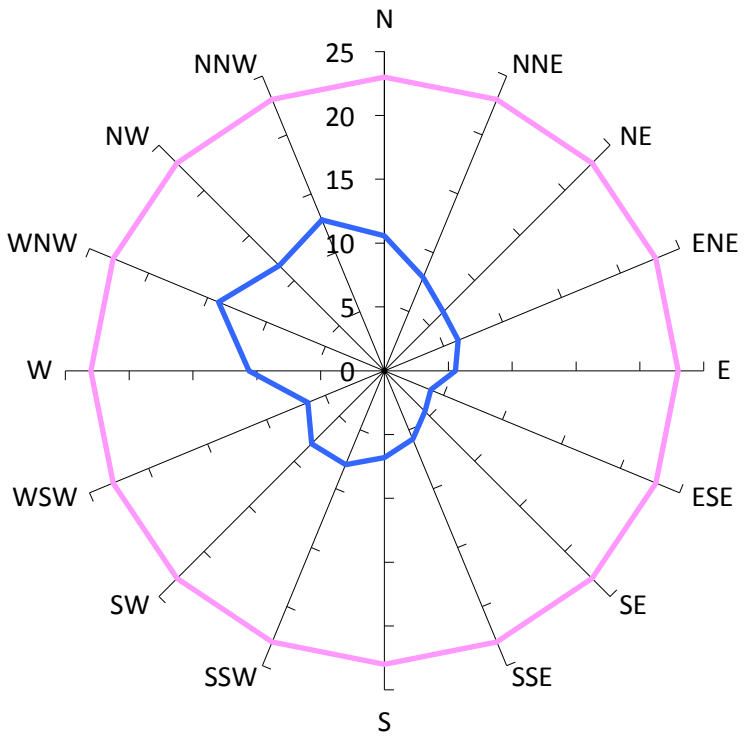
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

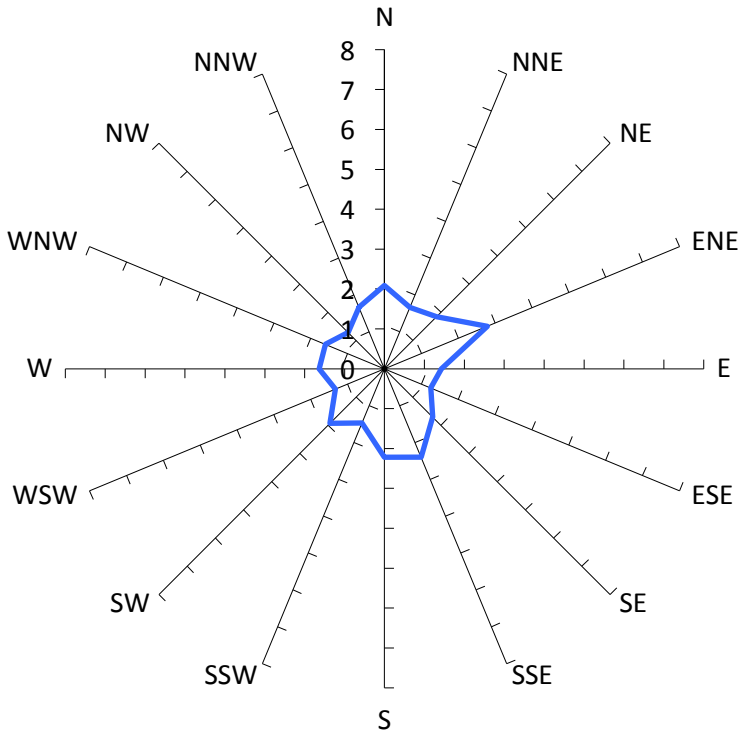
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 02

Weekly Maximum GEM (m/s)



Desired Criterion
7.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
0%

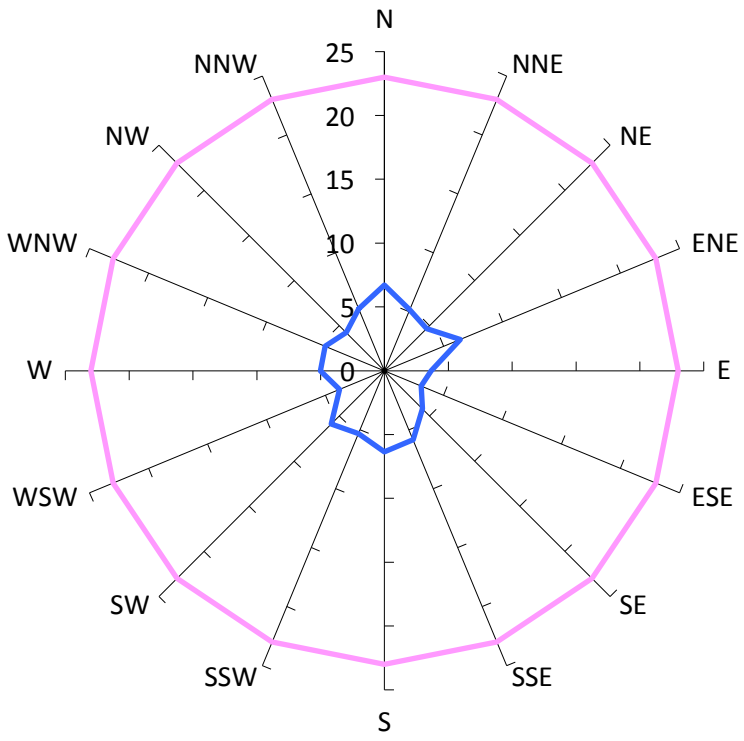
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

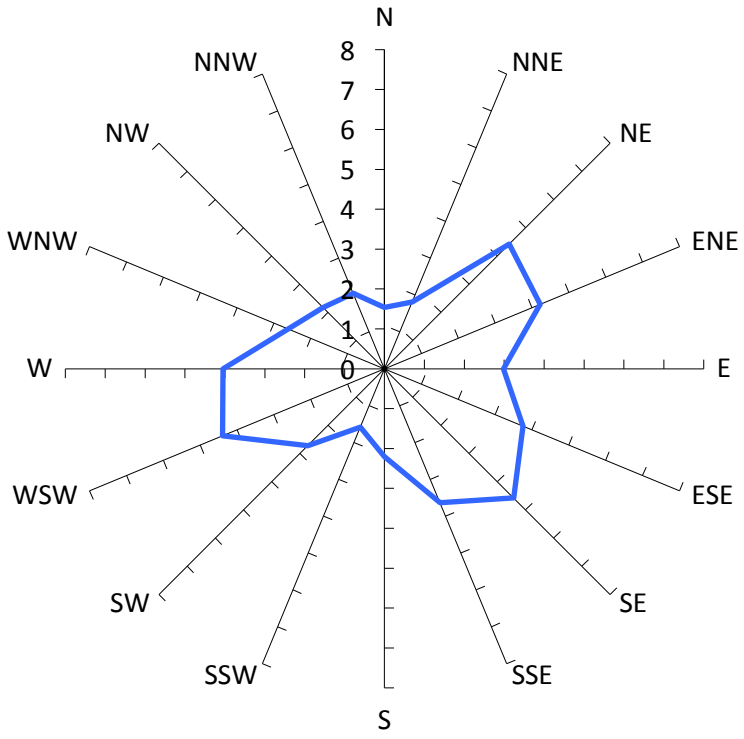
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 03

Weekly Maximum GEM (m/s)



Desired Criterion
7.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
0%

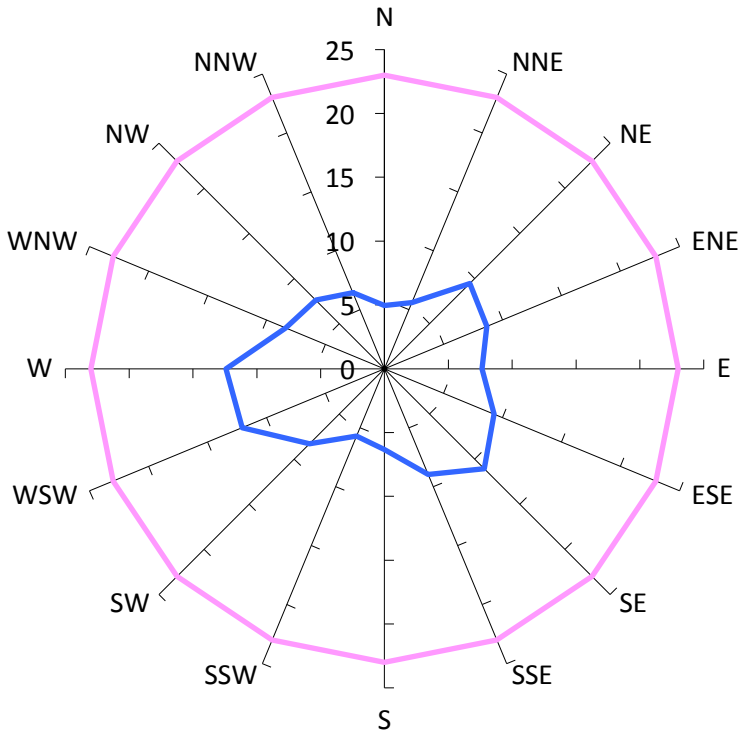
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

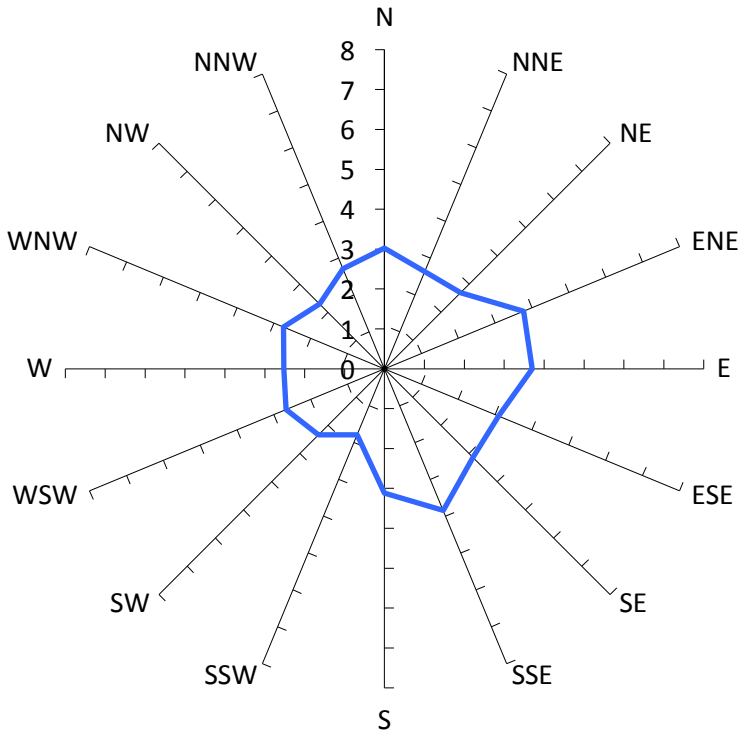
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 04

Weekly Maximum GEM (m/s)



Desired Criterion
7.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
0%

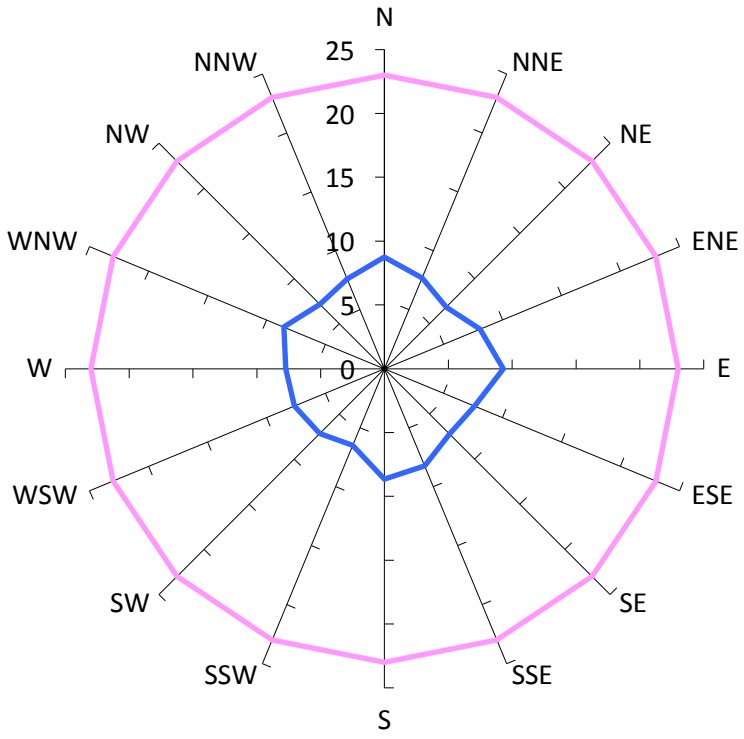
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

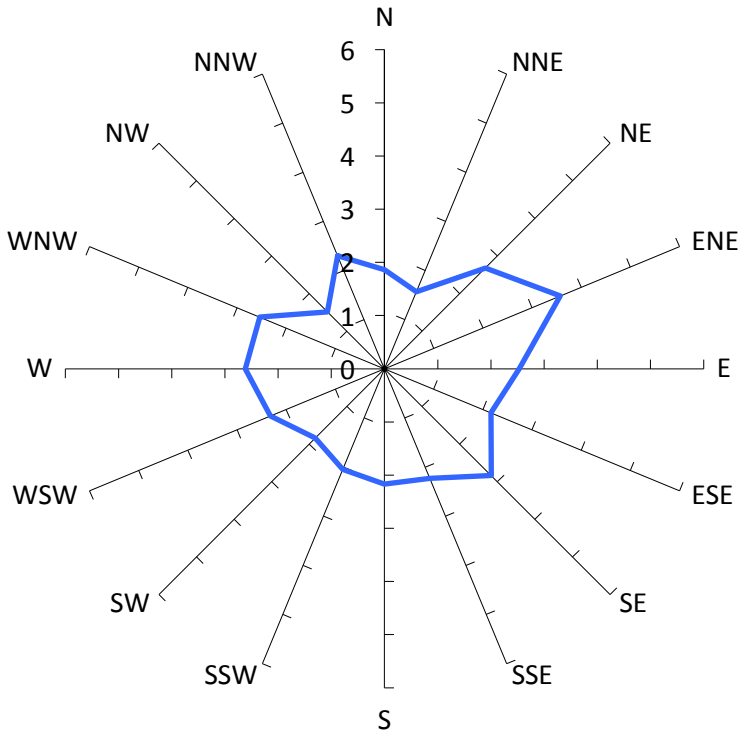
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 05

Weekly Maximum GEM (m/s)



Desired Criterion
5.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
0%

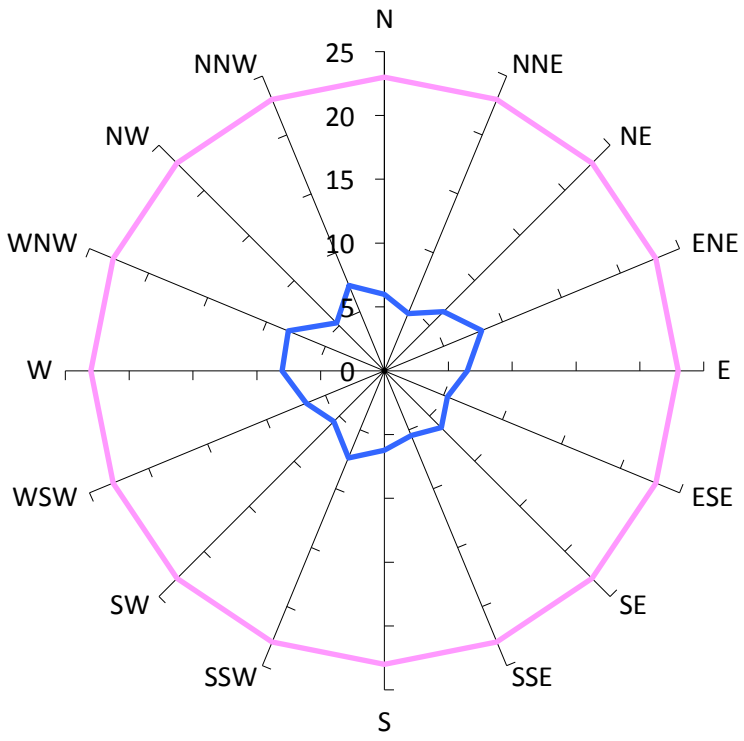
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

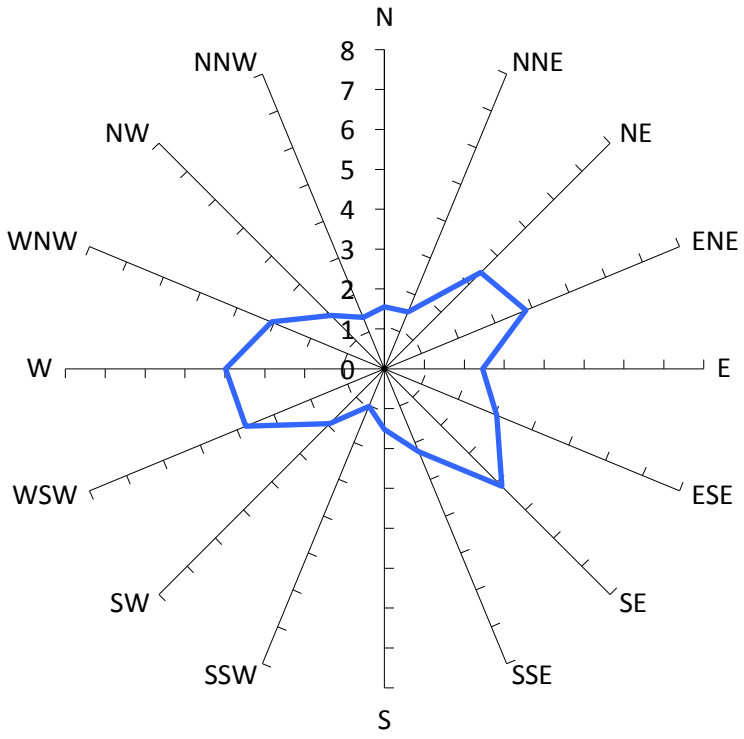
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 06

Weekly Maximum GEM (m/s)



Desired Criterion
7.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
0%

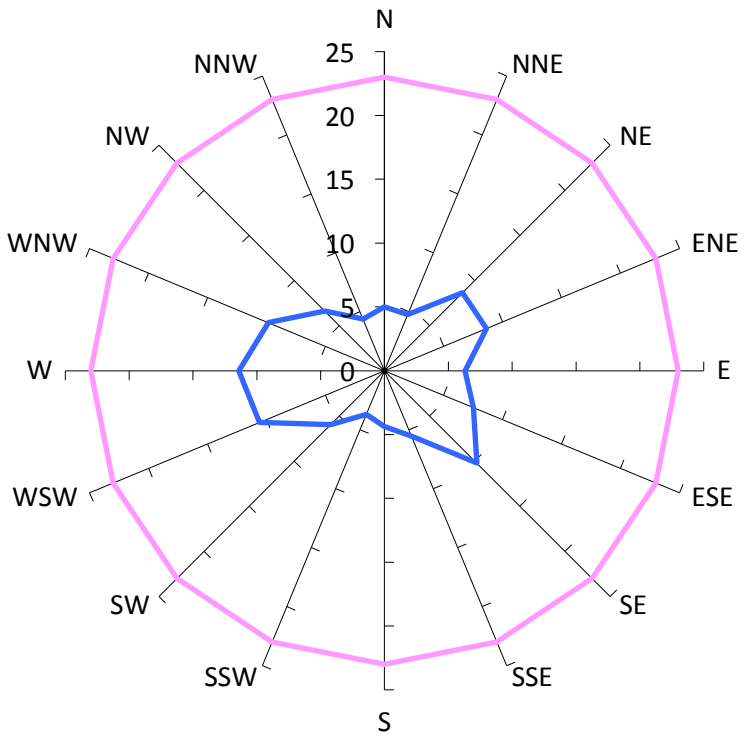
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

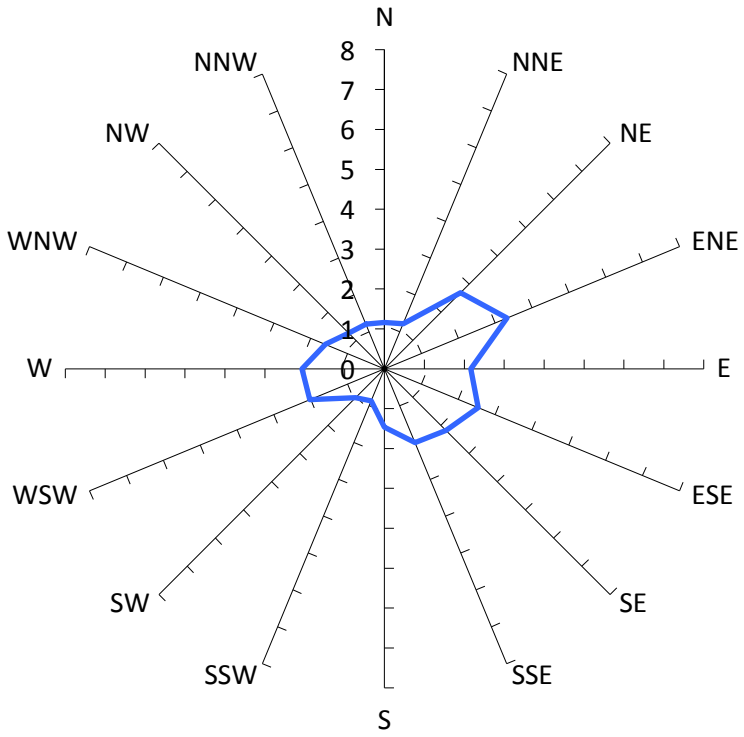
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 07

Weekly Maximum GEM (m/s)



Desired Criterion
7.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
0%

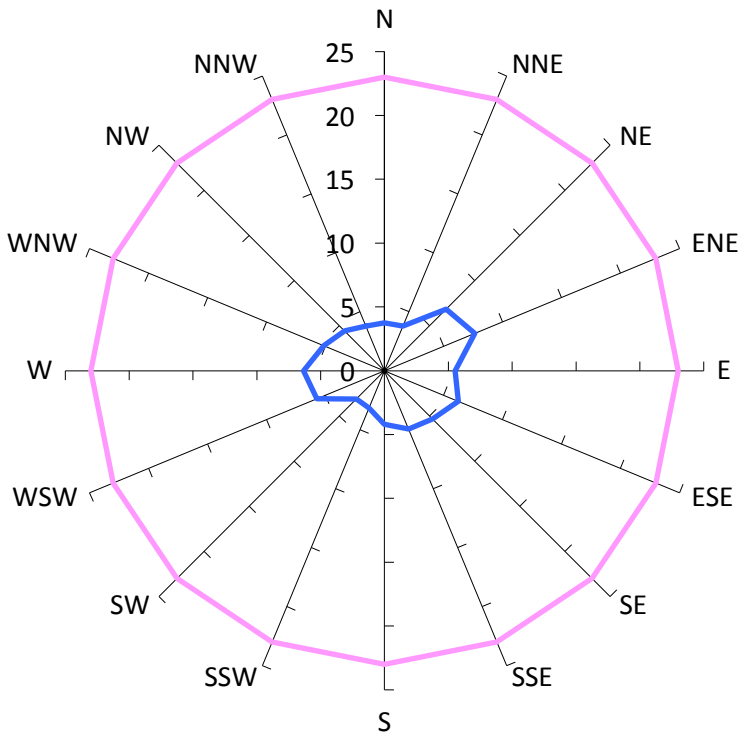
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

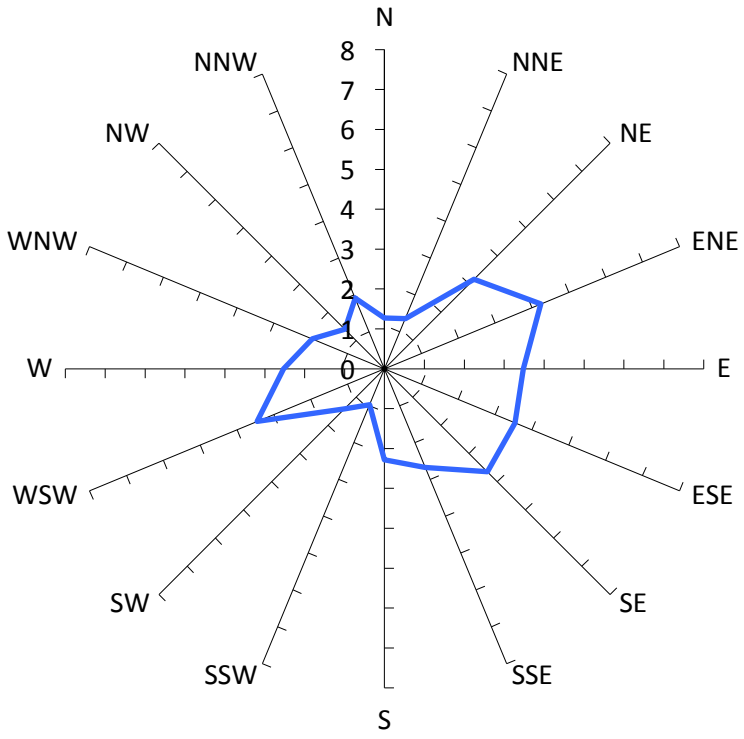
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 08

Weekly Maximum GEM (m/s)



Desired Criterion
7.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
0%

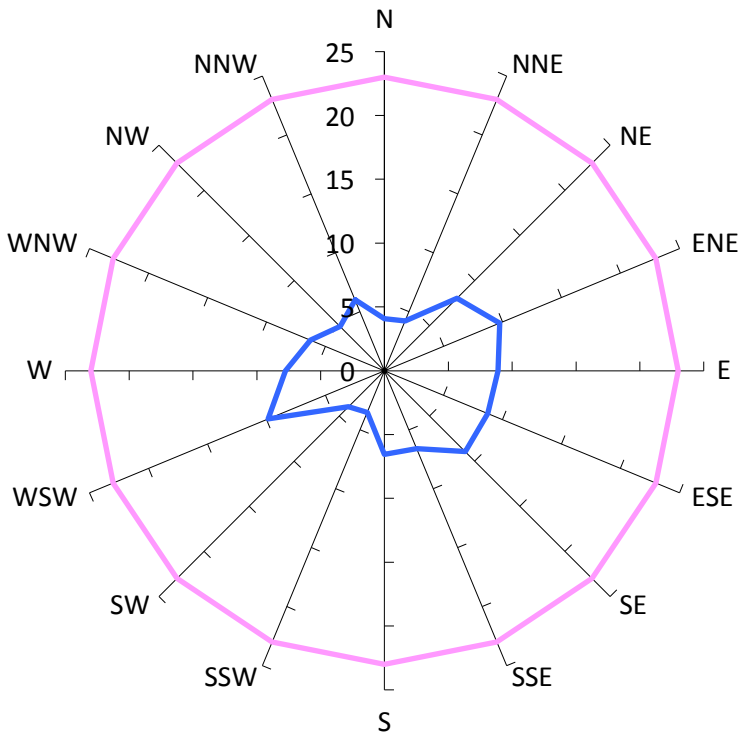
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

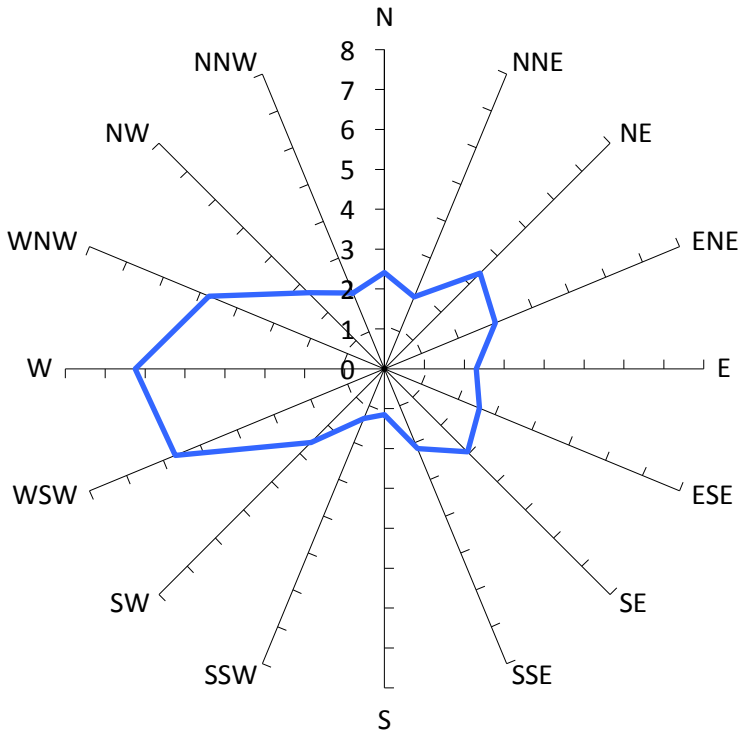
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 09

Weekly Maximum GEM (m/s)



Desired Criterion
7.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
1%

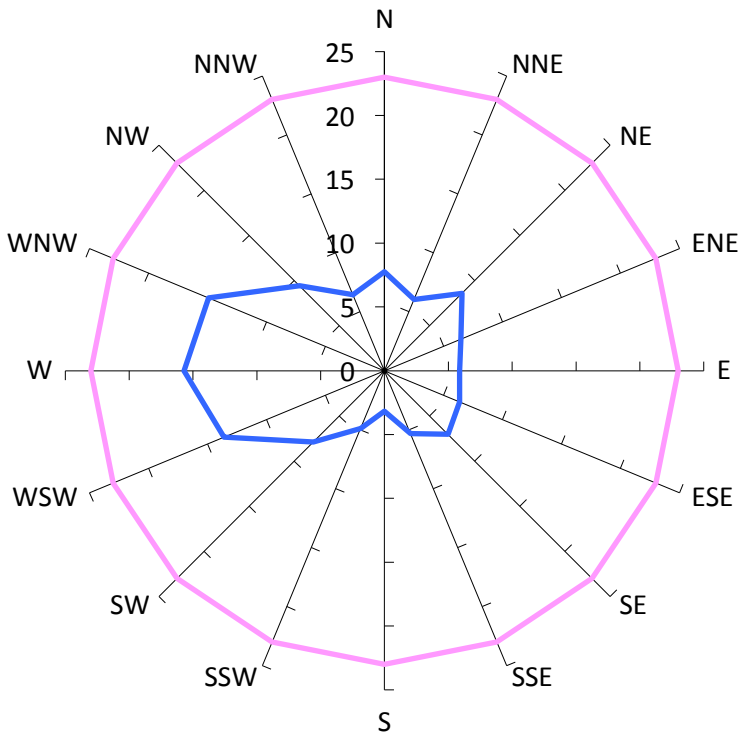
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

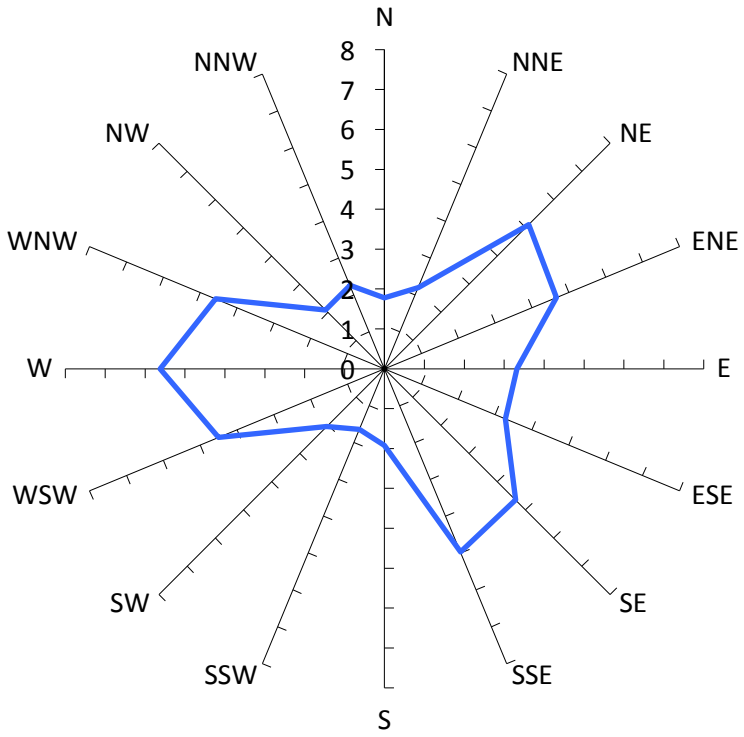
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 10

Weekly Maximum GEM (m/s)



Desired Criterion
7.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
1%

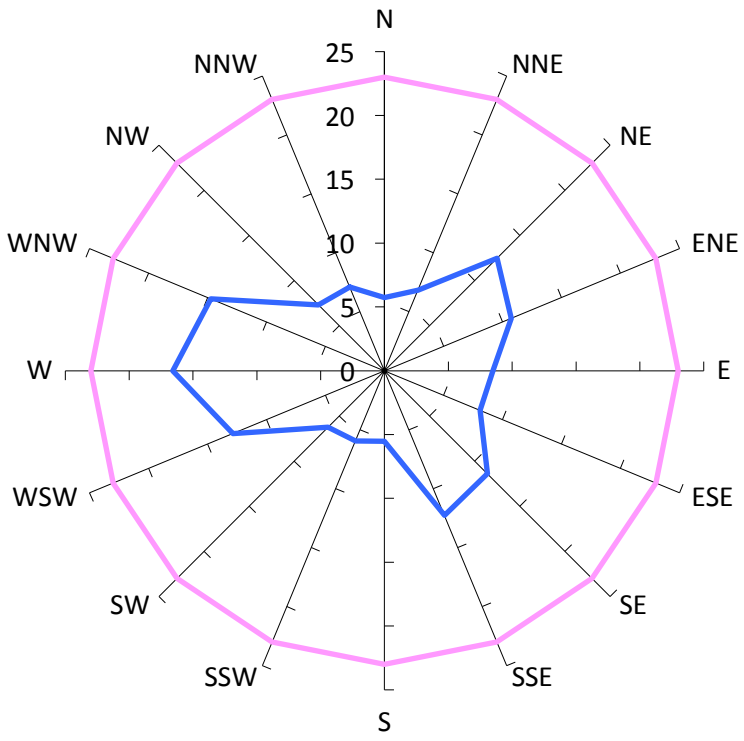
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

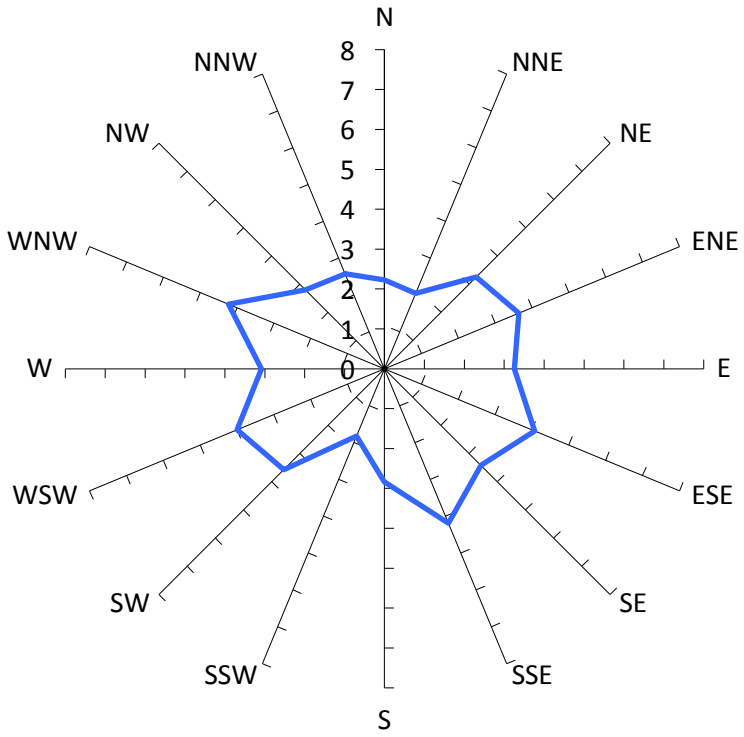
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 11

Weekly Maximum GEM (m/s)



Desired Criterion
7.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
0%

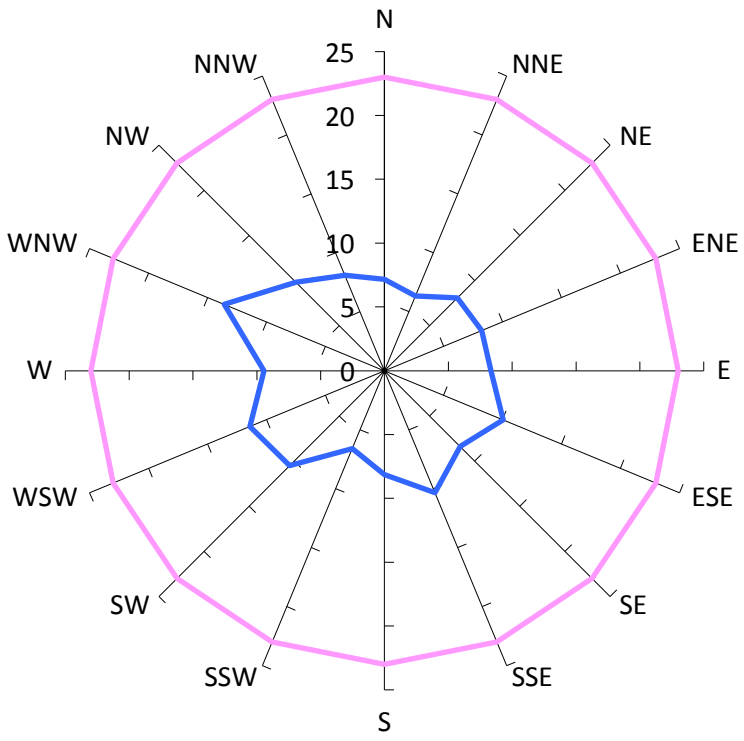
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

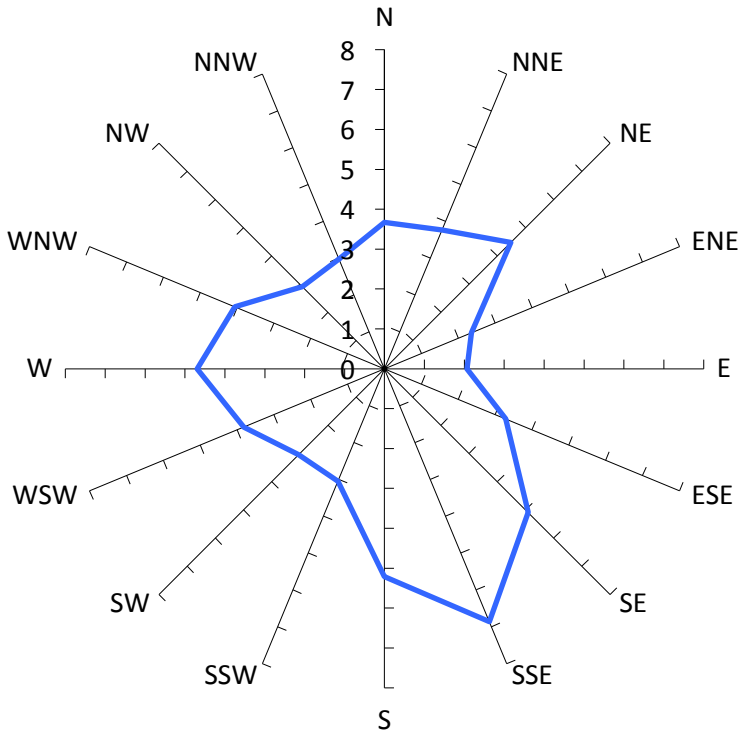
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 12

Weekly Maximum GEM (m/s)



Desired Criterion
7.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
1%

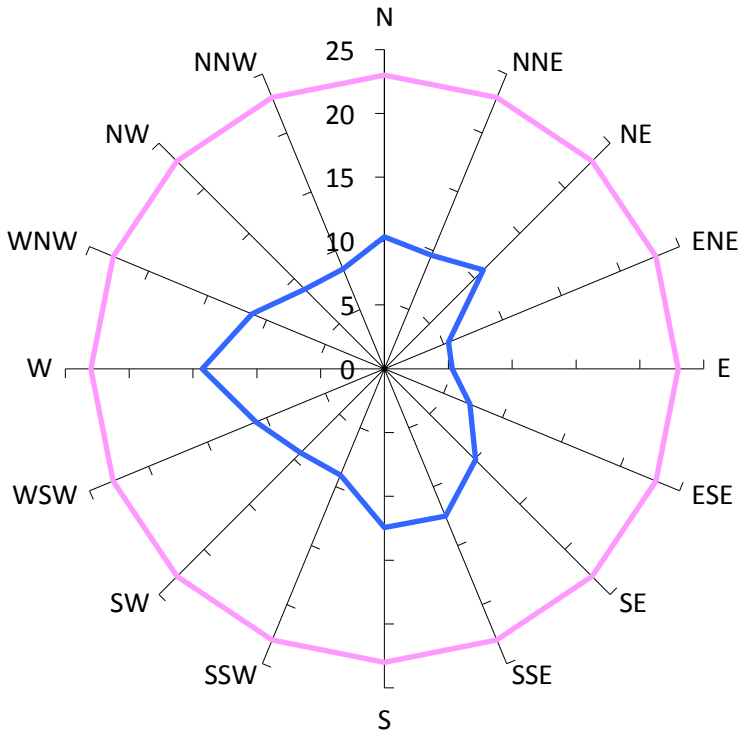
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

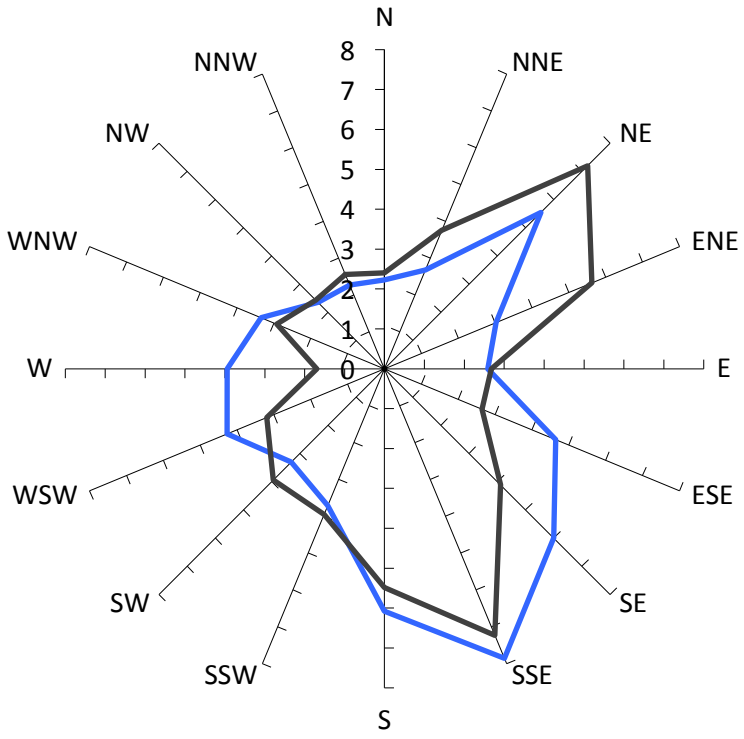
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 13

Weekly Maximum GEM (m/s)



Desired Criterion
5.5m/s

Prob. of Criterion Exceedence (existing site conditions)
11%

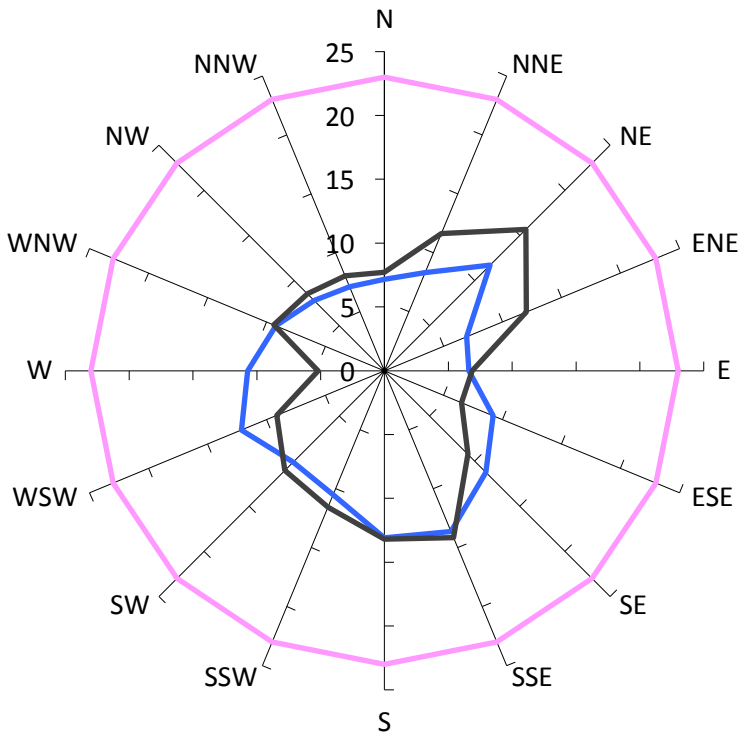
Probability of Criterion Exceedence (initial test)
9%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.
With development "as proposed", no vegetation or other treatments.
Existing site conditions

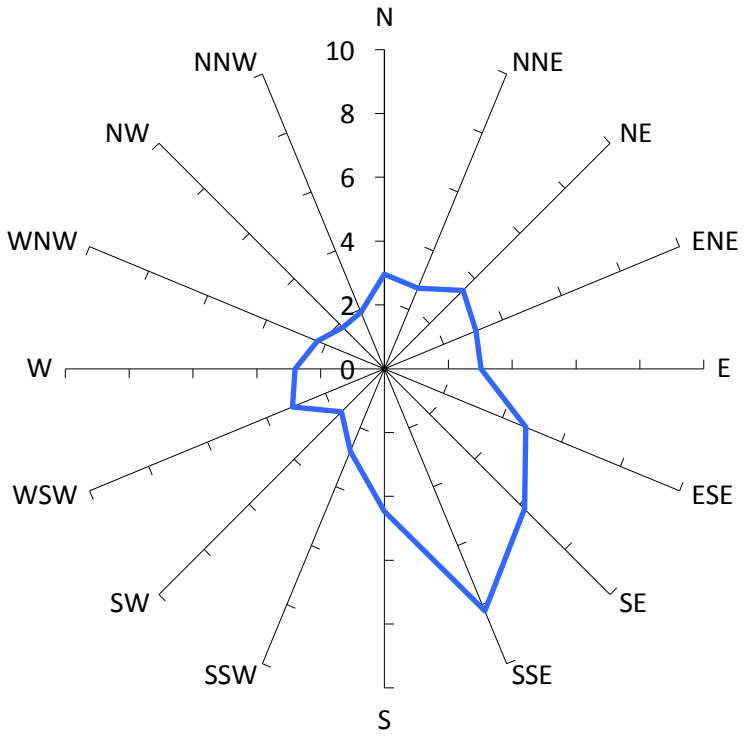
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 14

Weekly Maximum GEM (m/s)



Desired Criterion
7.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
2%

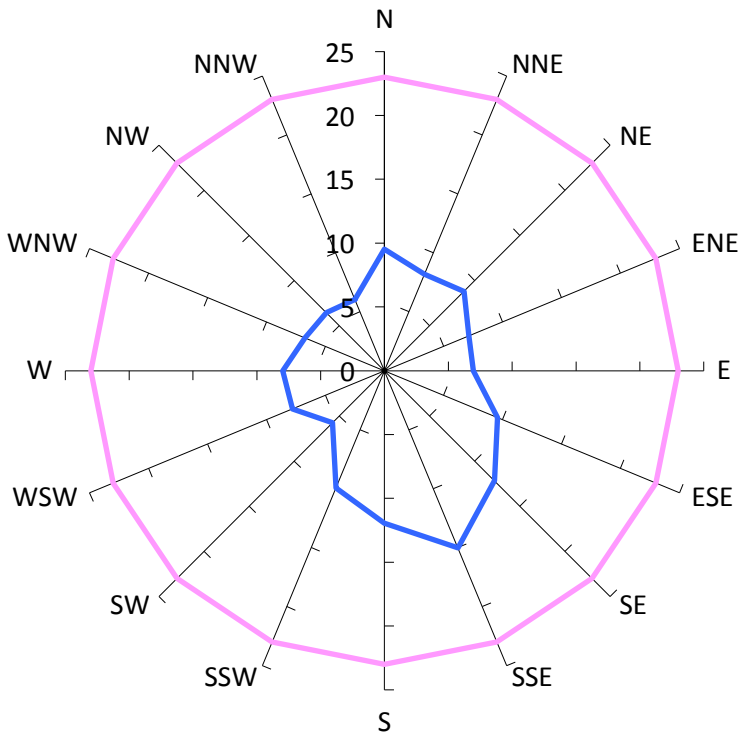
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

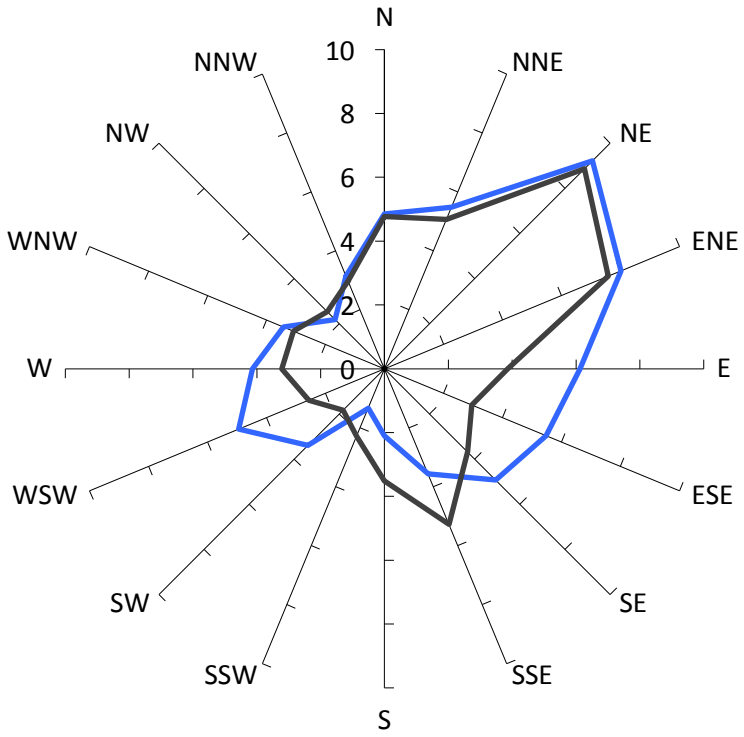
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 15

Weekly Maximum GEM (m/s)



Desired Criterion
7.5m/s

Prob. of Criterion Exceedence (existing site conditions)
5%

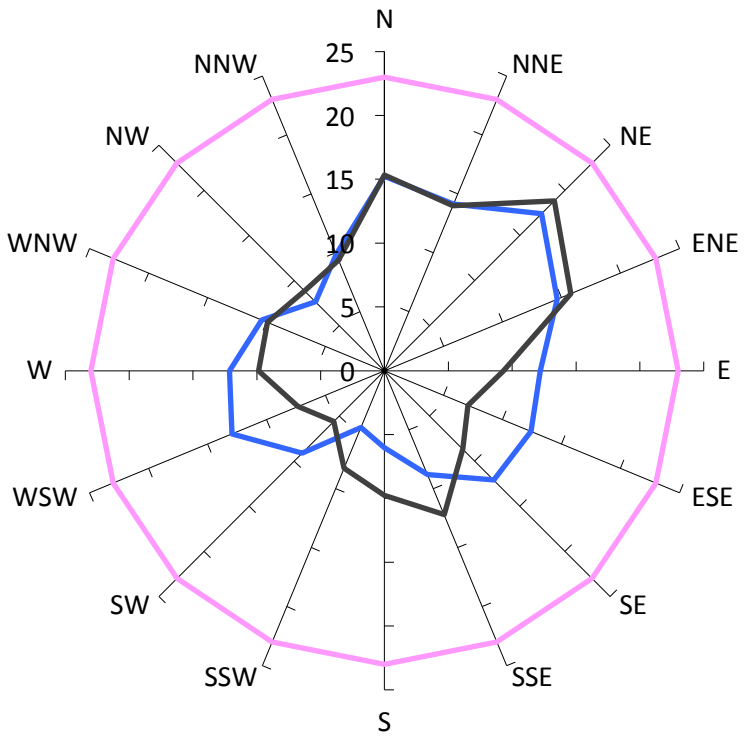
Probability of Criterion Exceedence (initial test)
7%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.
With development "as proposed", no vegetation or other treatments.
Existing site conditions

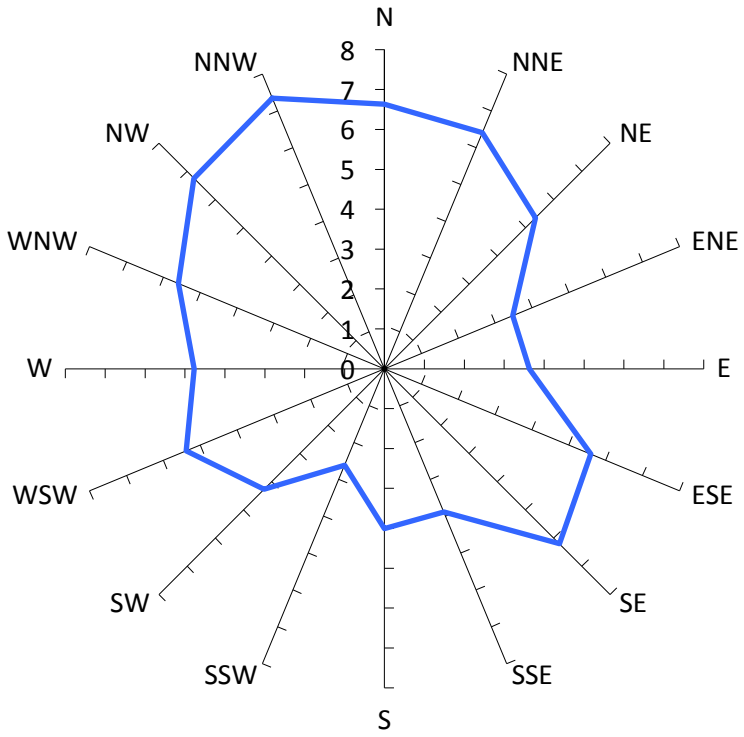
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 16

Weekly Maximum GEM (m/s)



Desired Criterion
5.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
16%

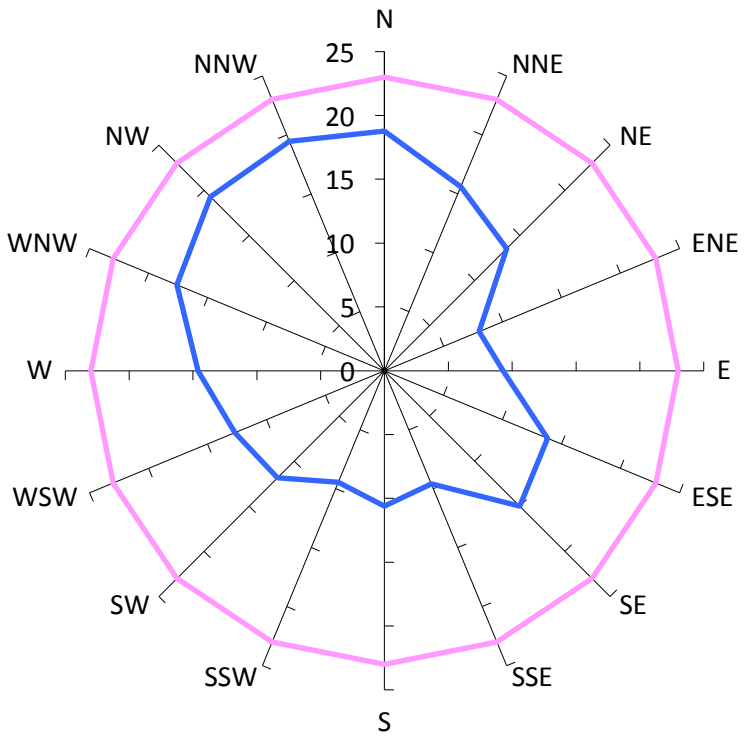
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

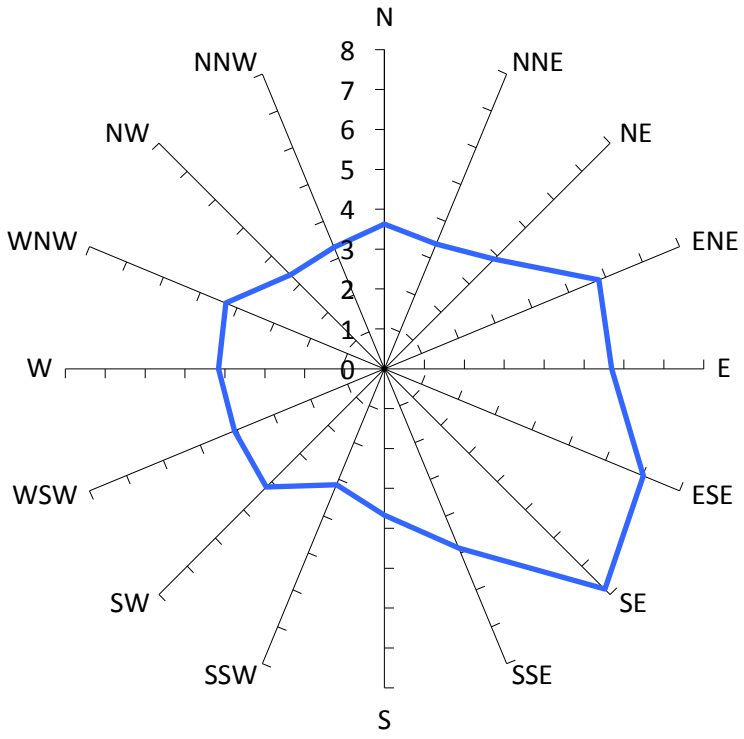
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 17

Weekly Maximum GEM (m/s)



Desired Criterion
5.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
13%

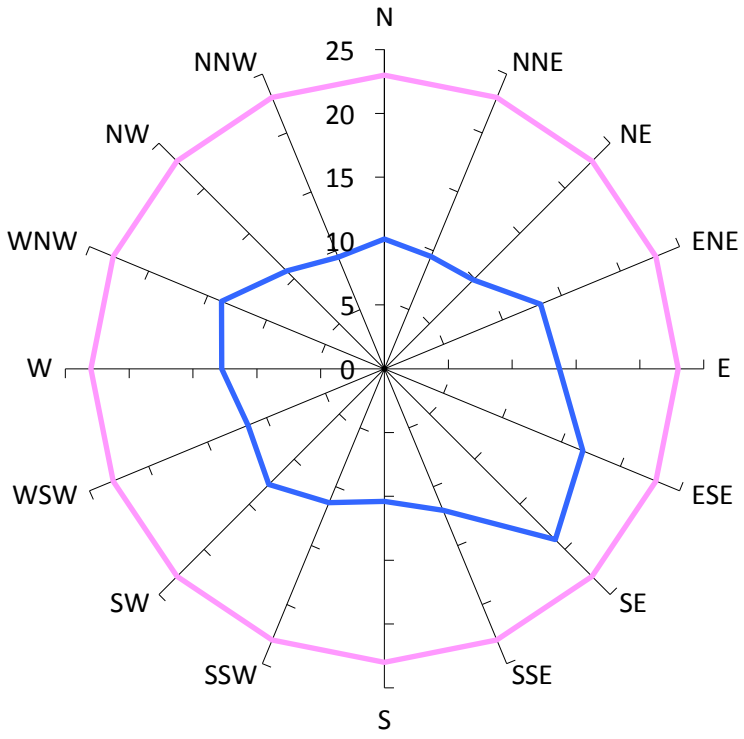
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

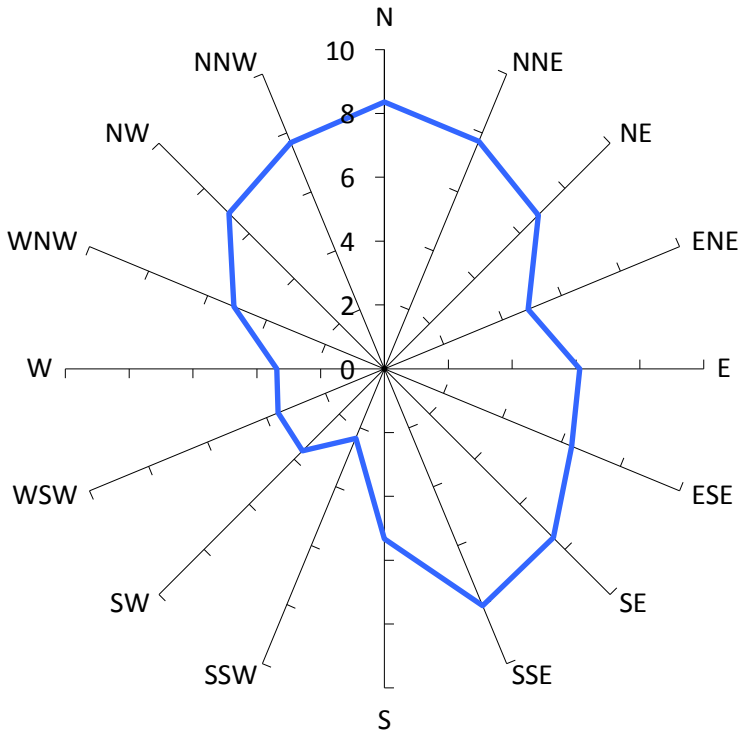
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 18

Weekly Maximum GEM (m/s)



Desired Criterion
5.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
26%

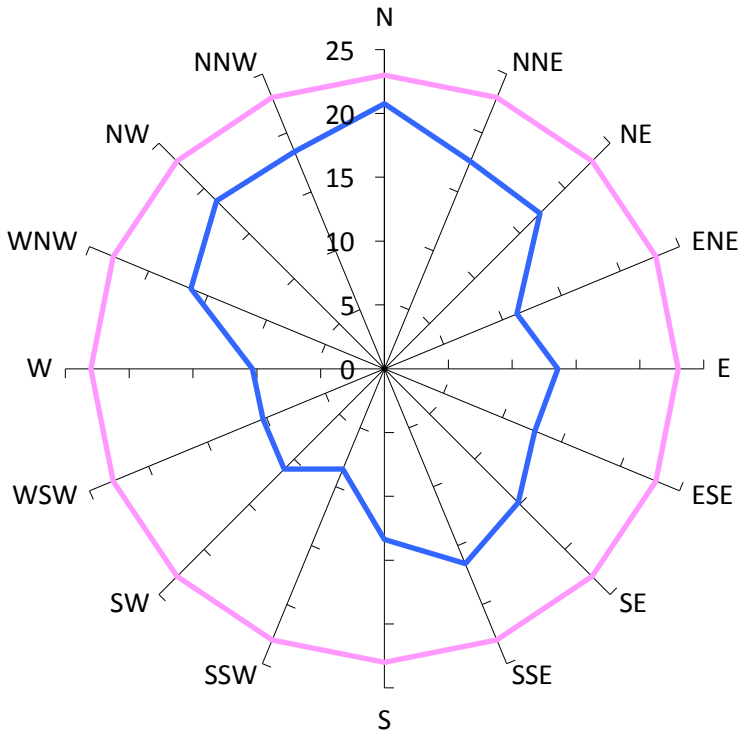
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

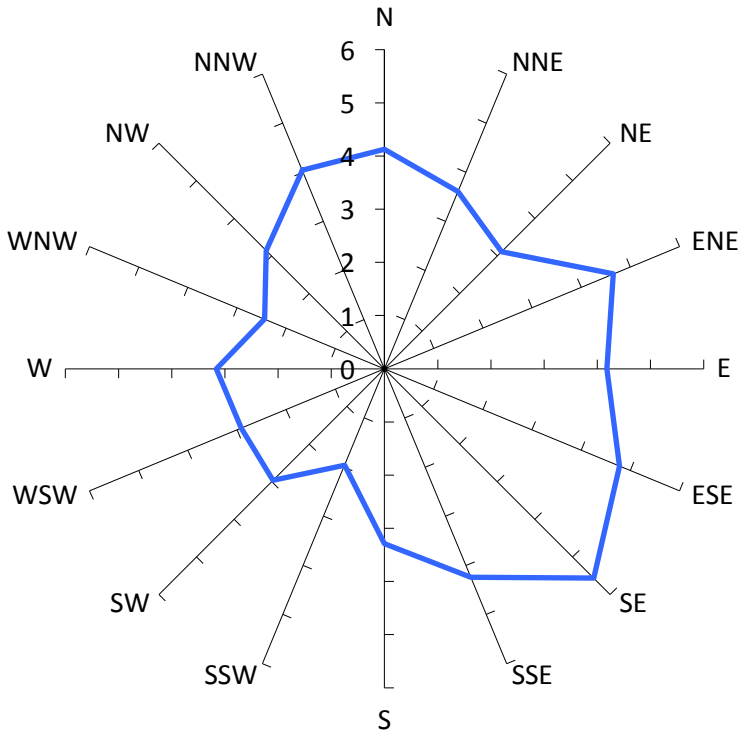
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 19

Weekly Maximum GEM (m/s)



Desired Criterion
5.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
3%

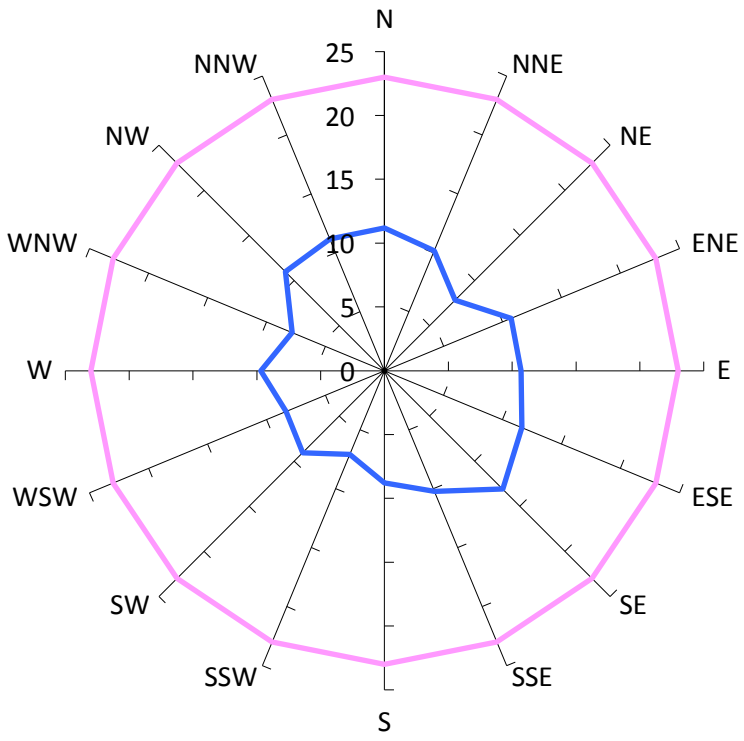
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

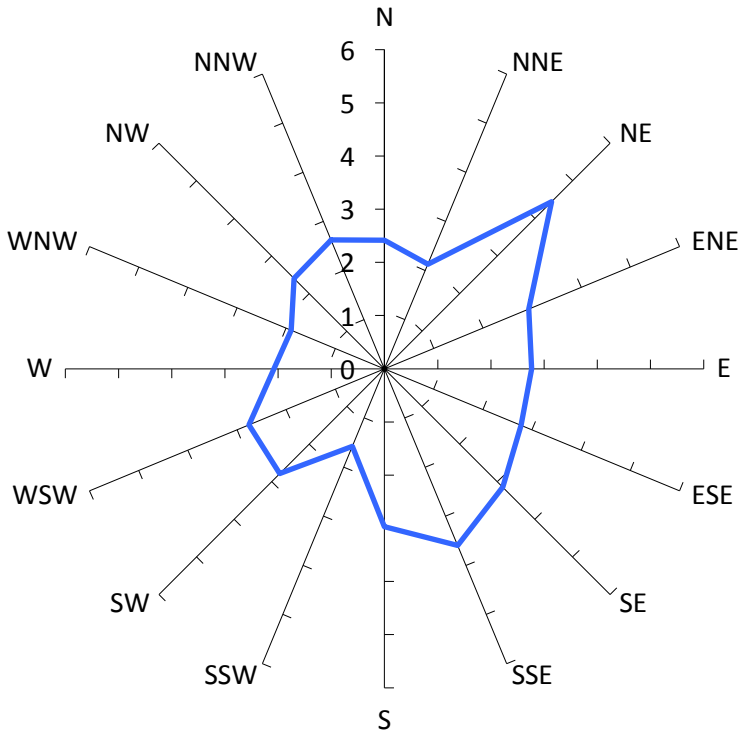
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 20

Weekly Maximum GEM (m/s)



Desired Criterion
5.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
0%

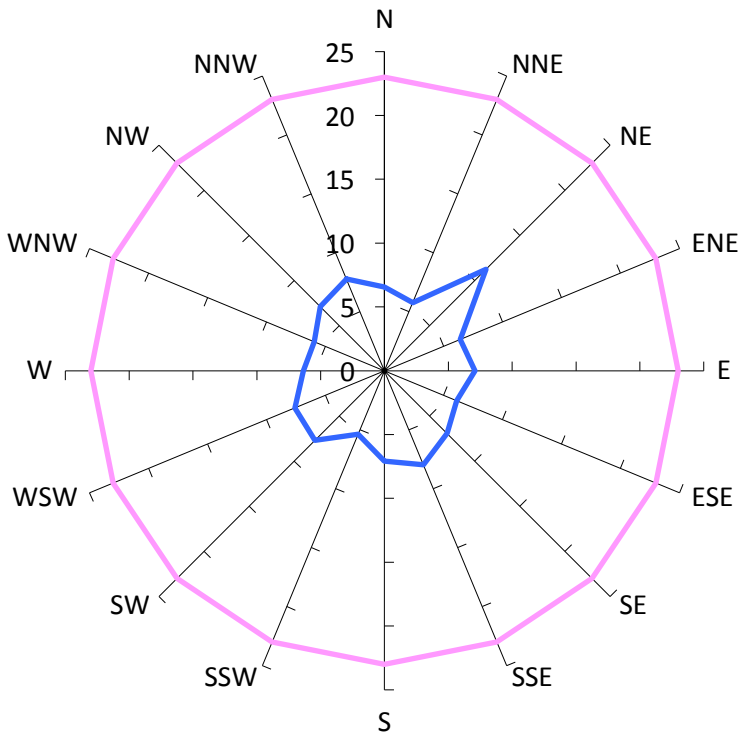
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

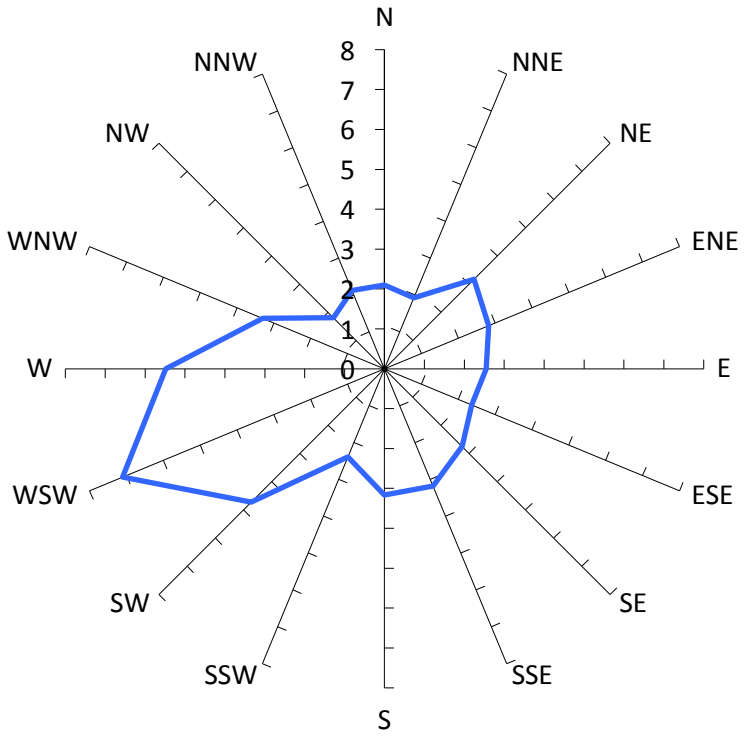
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 21

Weekly Maximum GEM (m/s)



Desired Criterion
5.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
5%

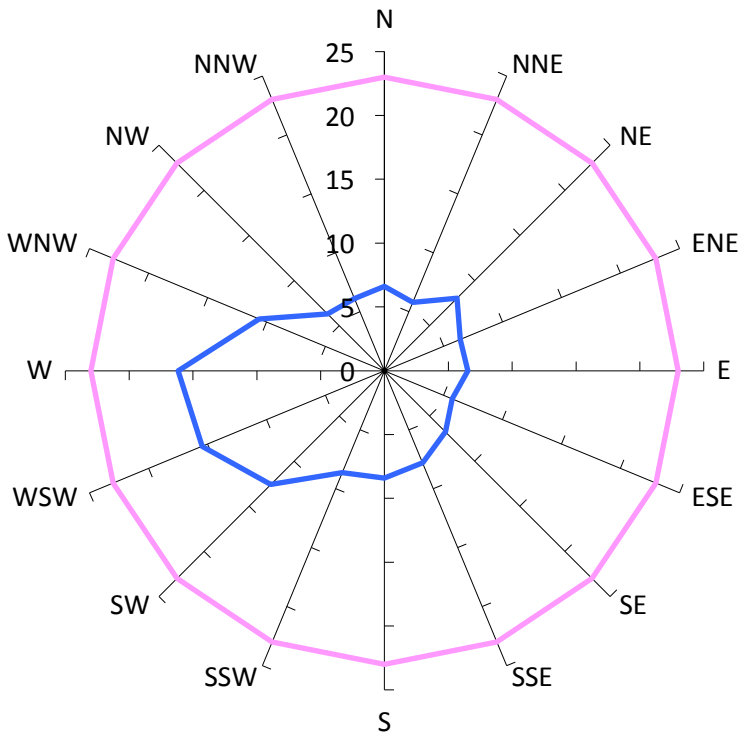
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

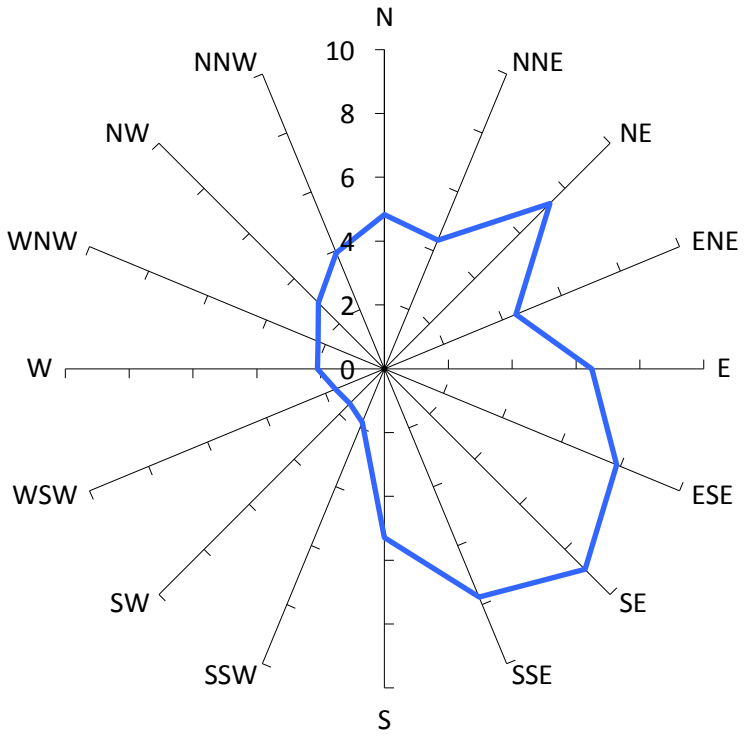
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 22

Weekly Maximum GEM (m/s)



Desired Criterion
5.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
20%

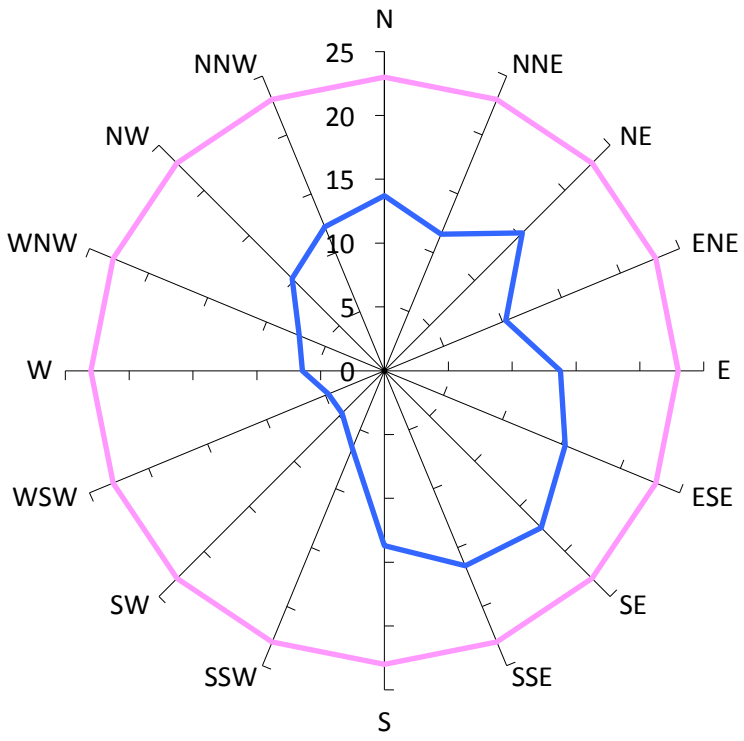
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

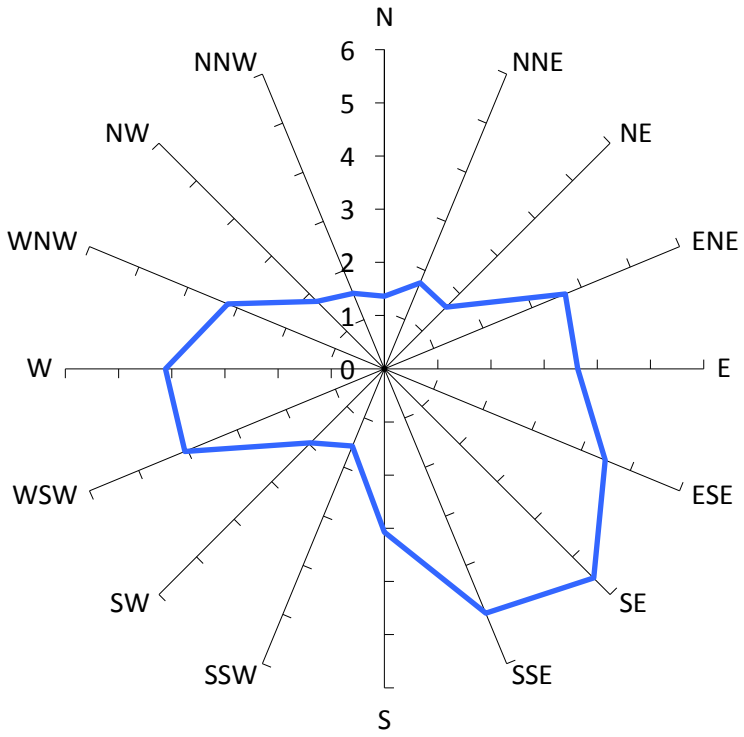
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 23

Weekly Maximum GEM (m/s)



Desired Criterion
5.5m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
2%

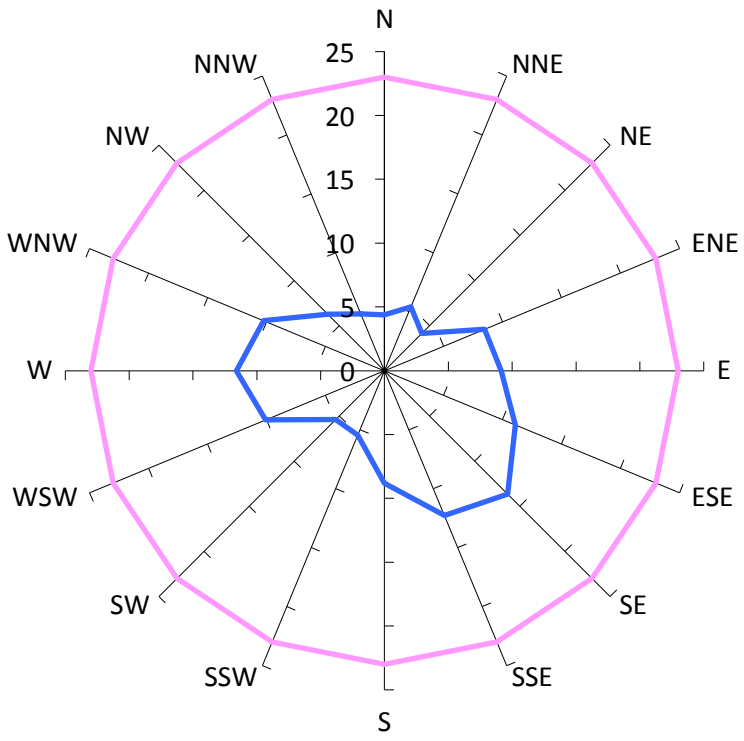
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With development "as proposed", no vegetation or other treatments.

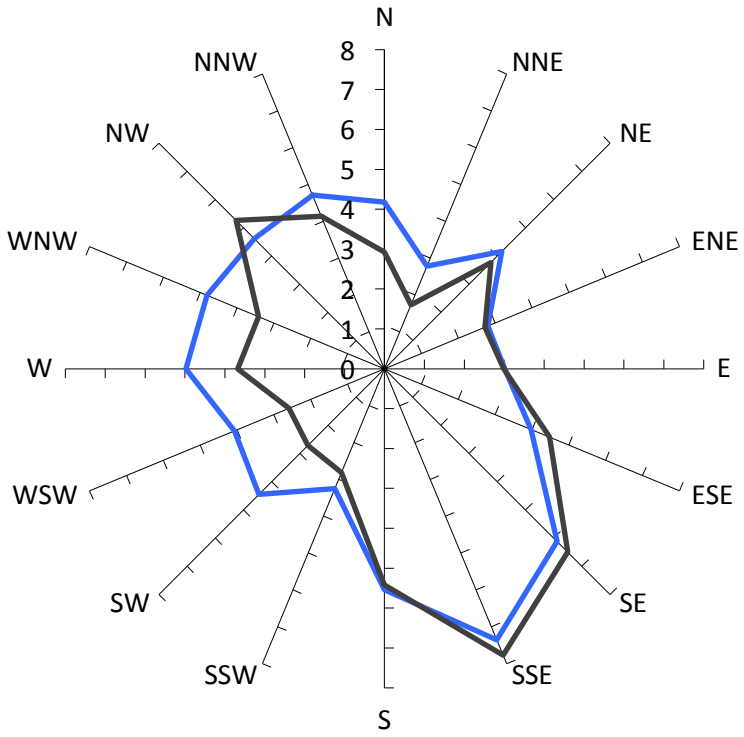
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 101

Weekly Maximum GEM (m/s)



Desired Criterion
7.5m/s

Prob. of Criterion Exceedence (existing site conditions)
2%

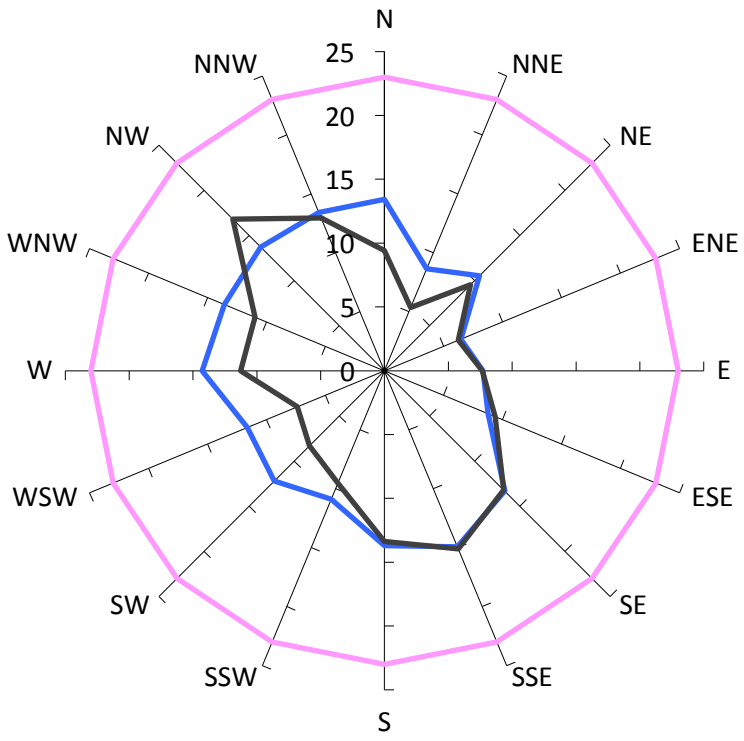
Probability of Criterion Exceedence (initial test)
2%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.
AWES surrounding point
AWES surrounding point - Existing site conditions

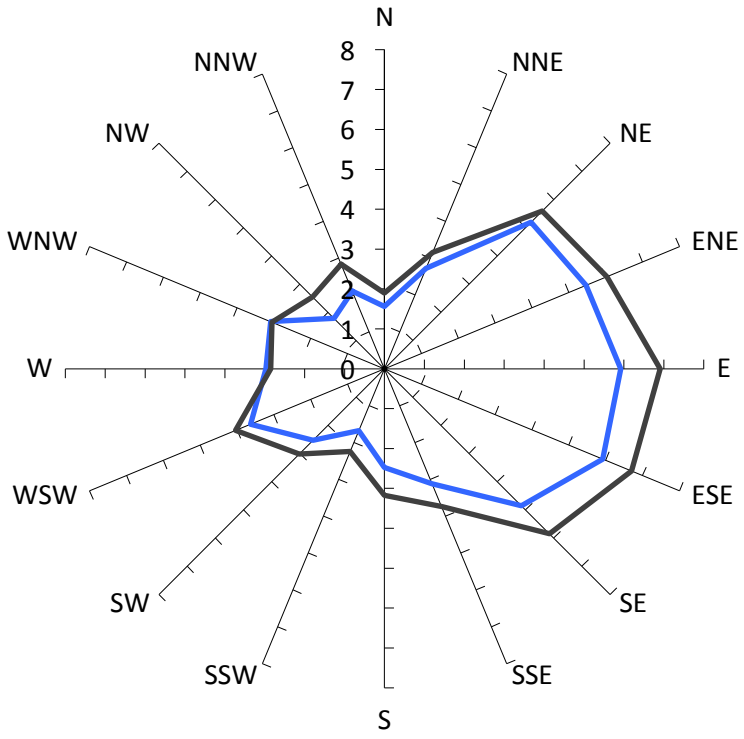
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 102

Weekly Maximum GEM (m/s)



Desired Criterion
7.5m/s

Prob. of Criterion Exceedence (existing site conditions)
1%

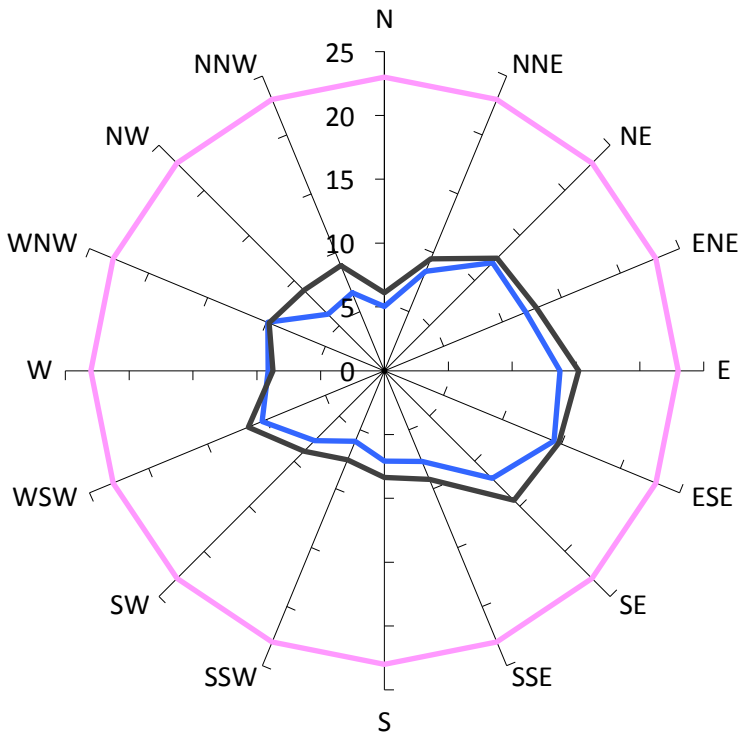
Probability of Criterion Exceedence (initial test)
1%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.
AWES surrounding point
AWES surrounding point - Existing site conditions

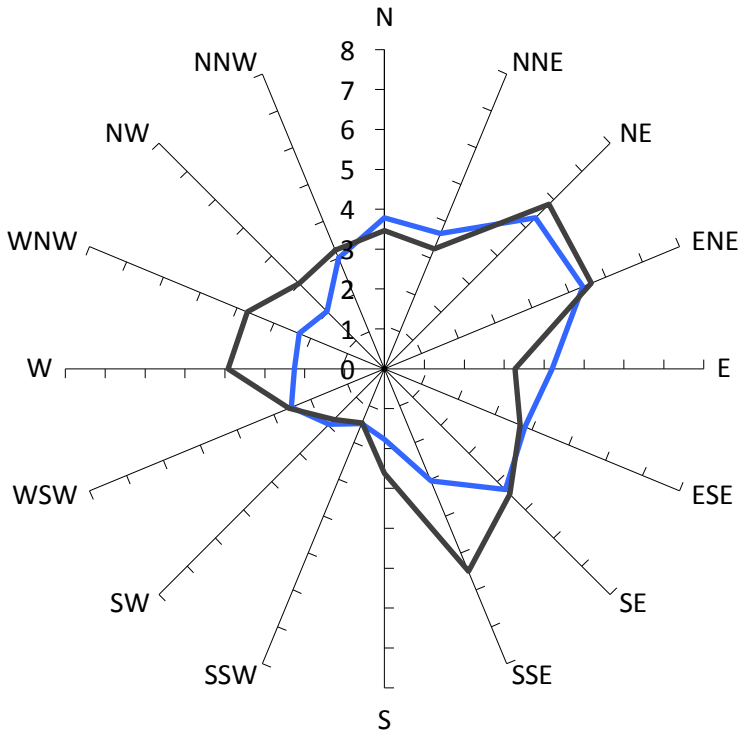
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 103

Weekly Maximum GEM (m/s)



Desired Criterion
7.5m/s

Prob. of Criterion Exceedence (existing site conditions)
0%

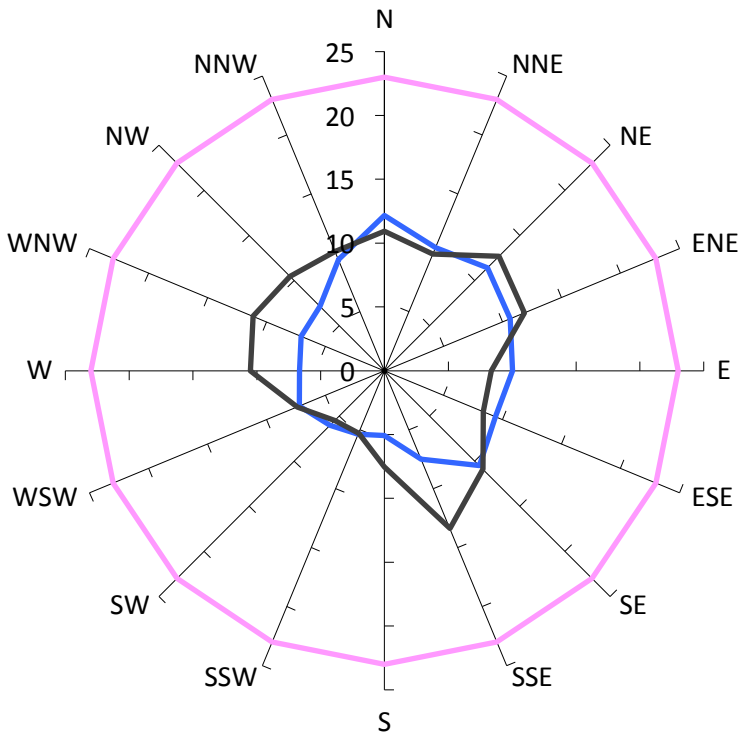
Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.
AWES surrounding point
AWES surrounding point - Existing site conditions

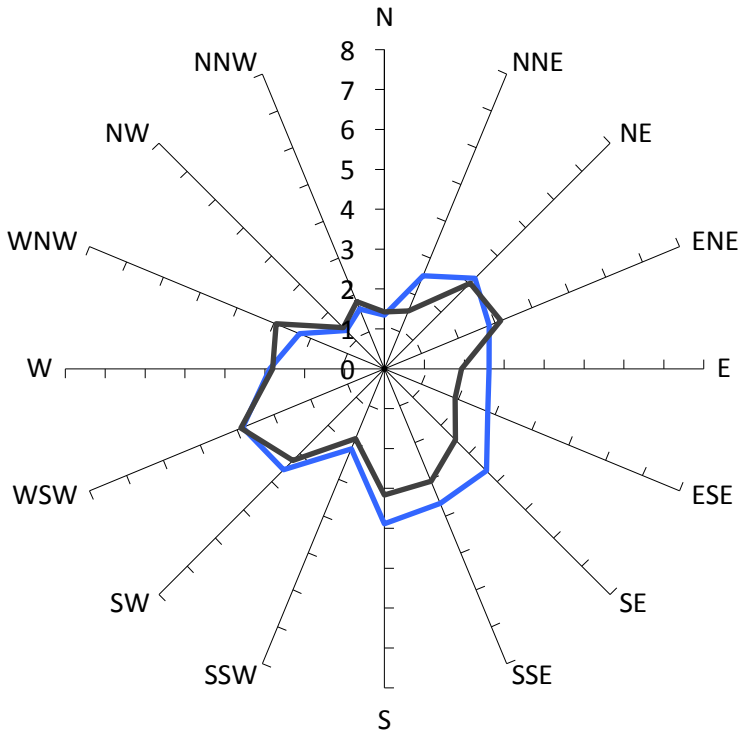
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

Measured Wind Speeds at Point 104

Weekly Maximum GEM (m/s)



Desired Criterion
7.5m/s

Prob. of Criterion Exceedence (existing site conditions)
0%

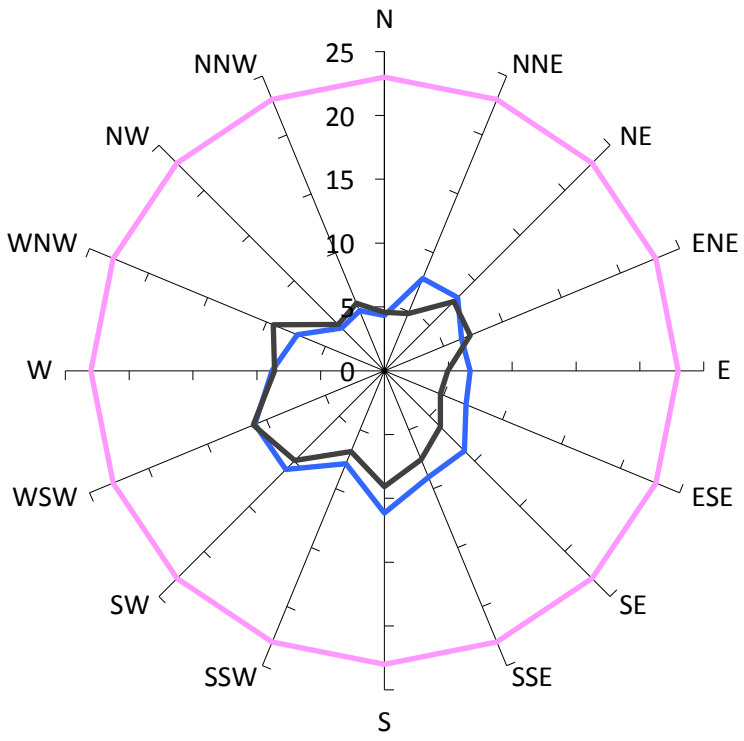
Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

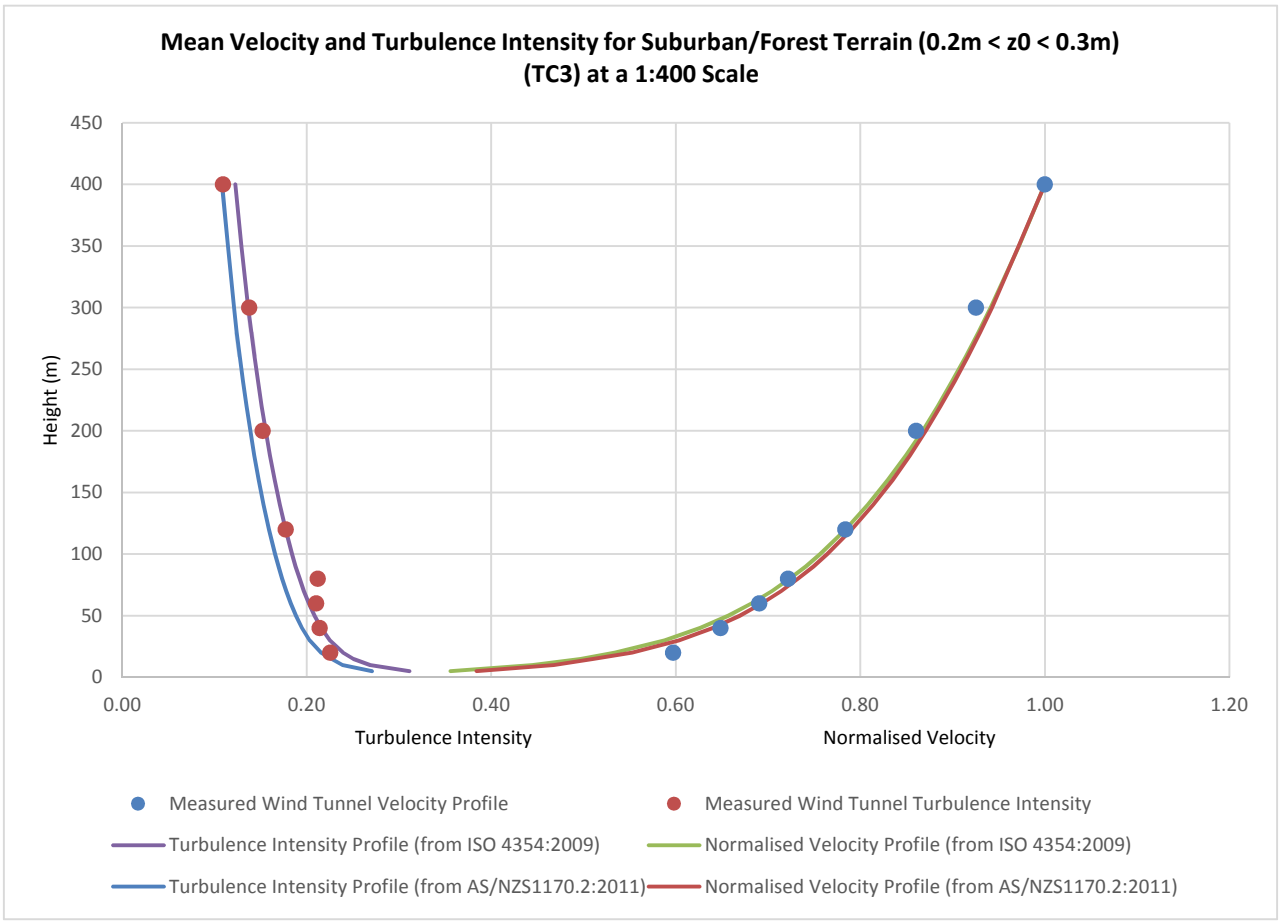
Criterion.
AWES surrounding point
AWES surrounding point - Existing site conditions

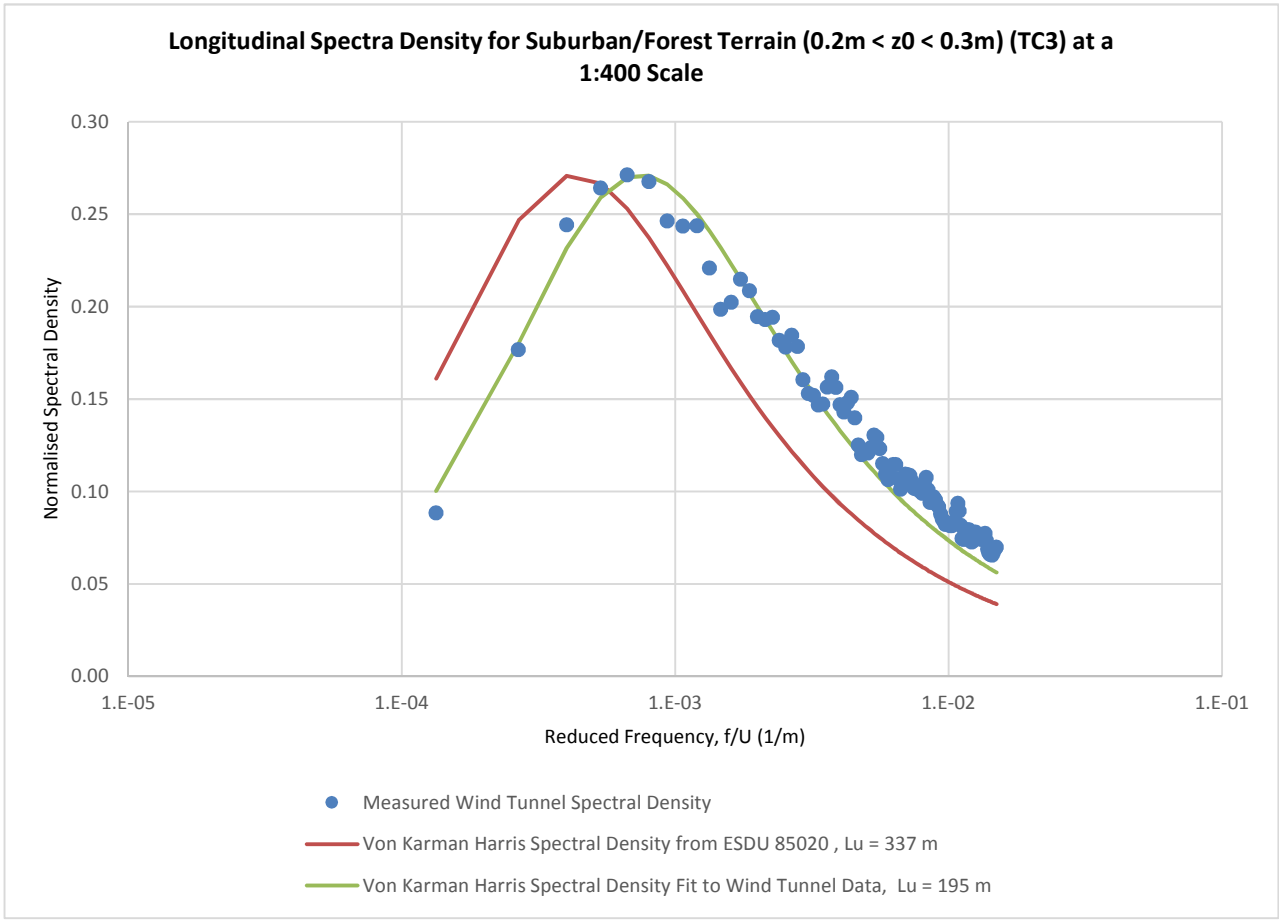
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

APPENDIX B - VELOCITY AND TURBULENCE INTENSITY PROFILES


Mean Velocity and Turbulence Intensity for Suburban/Forest Terrain (0.2m < z0 < 0.3m) (TC3) at a 1:400 Scale
Height (m)
450
400
350
300
250
200
150
100
50
0
0.00
0.20
0.40
0.60
0.80
1.00
1.20
Turbulence Intensity
Normalised Velocity
Measured Wind Tunnel Velocity Profile
Measured Wind Tunnel Turbulence Intensity
Turbulence Intensity Profile (from ISO 4354:2009)
Normalised Velocity Profile (from ISO 4354:2009)
Turbulence Intensity Profile (from AS/NZS1170.2:2011)
Normalised Velocity Profile (from AS/NZS1170.2:2011)


Longitudinal Spectra Density for Suburban/Forest Terrain (0.2m < z0 < 0.3m) (TC3) at a 1:400 Scale
Normalised Spectral Density
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1.E-05
1.E-04
1.E-03
1.E-02
1.E-01
Reduced Frequency, f/U (1/m)
Measured Wind Tunnel Spectral Density
Von Karman Harris Spectral Density from ESDU 85020 , Lu = 337 m
Von Karman Harris Spectral Density Fit to Wind Tunnel Data, Lu = 195 m