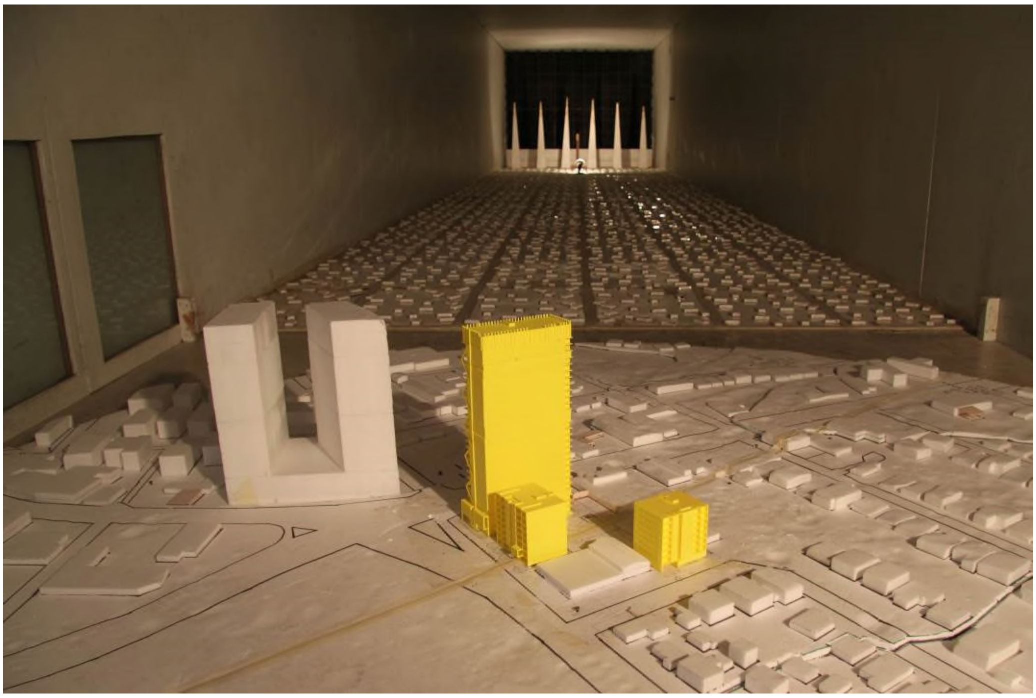

311 HUME HIGHWAY, LIVERPOOL

PEDESTRIAN WIND ENVIRONMENT STUDY

WC178-02F03(REV0)- WE REPORT

6 JULY 2015

Prepared for:

Hume Developments Pty. Ltd.

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DOCUMENT CONTROL

Date	Revision History	Non-Issued Revision	Issued Revision	Prepared By (initials)	Instructed By (initials)	Reviewed & Authorised by (initials)
06/07/2015	Update of previous report (Windtech Reference WC178-01F03(rev0)), Tower height increased to 33 Levels.	-	0	TH	AB	TH

The work presented in this document was carried out in accordance with the Windtech Consultants Quality Assurance System, which is based on International Standard ISO 9001.

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EXECUTIVE SUMMARY

This report presents the results of a detailed investigation into the wind environment impact of the development located at 311 Hume Highway, Liverpool. Testing was performed using Windtech's boundary layer wind tunnel, which has a 2.6m wide working section and has a fetch length of 14m. Measurements were carried out using a 1:300 scale detailed model of the redevelopment, other significant surrounding buildings, and land topography effects, for a diameter of approximately 750m, centred on the subject redevelopment site. Measurements were made in the wind tunnel from 16 wind directions at 22.5 degree increments.

Peak gust and mean wind speeds were measured at selected critical outdoor trafficable locations within and around the subject redevelopment. 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 which are representative of an annual recurrence, and Gust-Equivalent Mean (GEM) wind speeds which are representative of approximately a weekly recurrence.

The model was tested in the wind tunnel without the effect of any forms of wind ameliorating devices, which are not already shown in the architectural drawings. If the results of the study indicate that any area is exposed to strong winds, in-principle recommendations for treatment have been suggested. These treatments could be in the form of vegetation that is already proposed for the site, and/or additional trees, shrubs, screens, awnings, etc.

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

- The inclusion strategic planting in the form of densely foliating trees on the north western and south western corners of Building A, the north eastern and south western corners of the Tower and the south western corner of Building B. Trees should be evergreen and capable of growing to a height of at least 5 to 6m with a 4 to 5m wide canopy.

- The inclusion of an impermeable screen approximately 3m in height on the south eastern Ground Level corner of the Tower.

- The implementation of either of the following:

    - Further strategic planting on the northern end of the development and around the south western corner of the Tower and Building B; OR

- Inclusion of a wraparound awning above the ground level of the Towers South Western corner as well as an extension to the canopy on the northern end of the development.

- The inclusion of full height impermeable screens along the corner balconies of the Tower.

With the inclusion of the above mentioned in-principle treatments to the final design, the results of this study indicate that wind conditions for all outdoor trafficable areas within and around the proposed development will be suitable for their intended uses.

Furthermore, the use of loose glass-tops, light-weight sheets or covers (including loose BBQ lids) is not appropriate on the higher level private balconies. Lightweight furniture is not recommended unless it is securely attached to the balcony floor slab.

CONTENTS

1 WIND CLIMATE FOR THE SYDNEY REGION

The Sydney region is governed by three principle wind directions, and these can potentially affect the subject development. These winds prevail from the north-east, south and west. A summary of the principal time of occurrence of these winds throughout the year is presented in Table 1 below. This summary is based on a detailed analysis undertaken by Windtech Consultants of recorded directional wind speeds obtained at the meteorological station located at Kingsford Smith Airport by the Bureau of Meteorology (recorded from 1939 to 2008). The data was corrected to represent winds in standard open terrain at a height of 10m above ground. From this analysis, directional plots of the 10-minute mean winds for the Sydney region is also determined (as shown in Figure 1), which are representative of approximately the weekly and annual recurrences. The frequency of occurrence of these winds is also shown in Figure 1.

As shown in Figure 1, the southerly winds are by far the most frequent wind for the Sydney region, and are also the strongest. As indicated in Table 1, the westerly winds occur most frequently during the winter season for the Sydney region, and although they are typically not as strong as the southerly winds, they are usually a cold wind since they occur during the winter and hence can be a cause for discomfort for outdoor areas. North-easterly winds occur most frequently during the warmer months of the year for the Sydney region, and hence are usually welcomed within outdoor areas since they are typically not as strong as the southerly or westerly winds.

Table 1: Principle Time of Occurrence of Winds for Sydney

Month	Wind Direction		
	North-Easterly	Southerly	Westerly
January	X	X	
February	X	X	
March	X	X	
April		X	X
May			X
June			X
July			X
August			X
September		X	X
October	X	X	
November	X	X	
December	X	X	

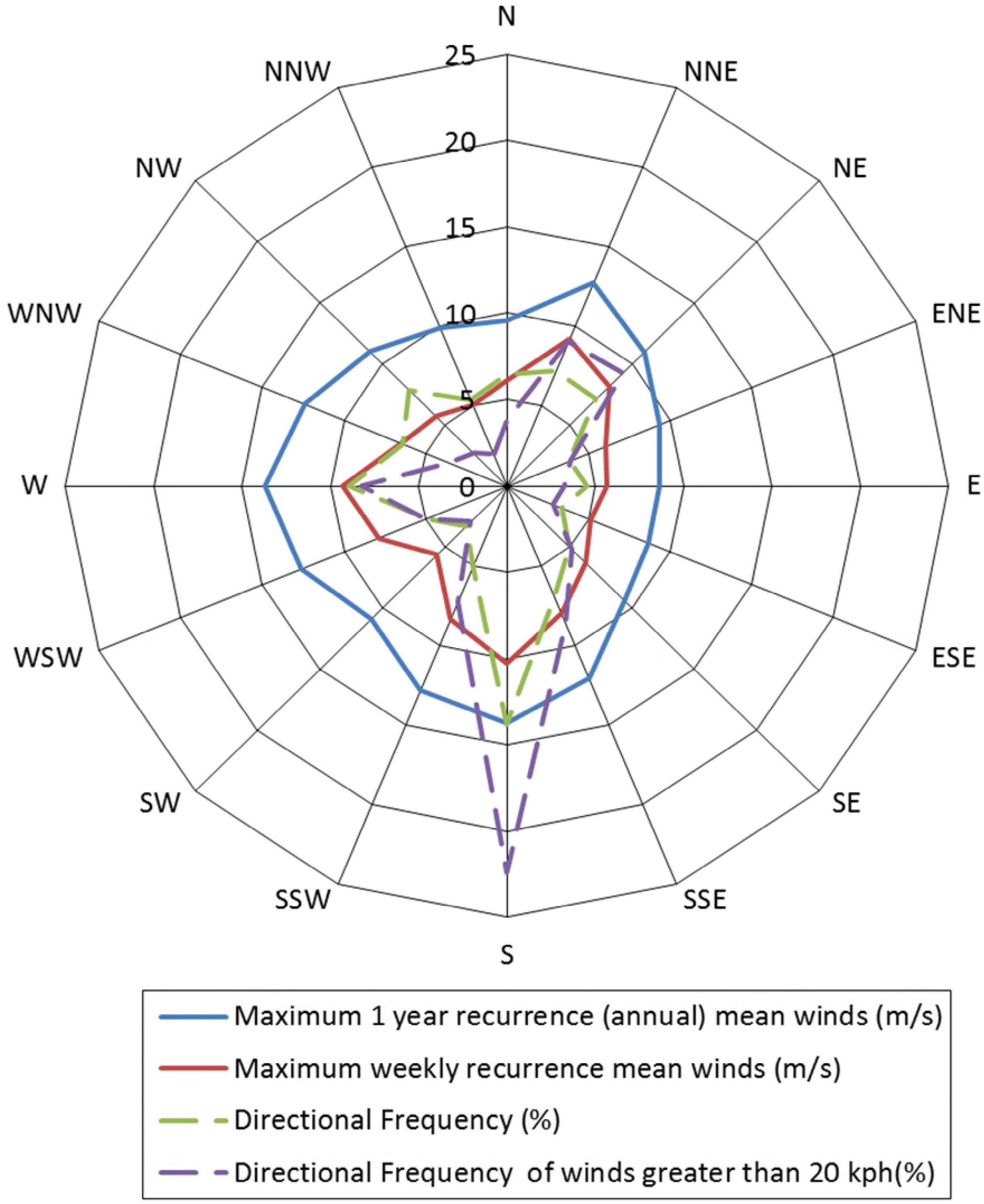

Figure 1: Annual and Weekly Recurrence Mean Wind Speeds, and Frequencies of Occurrence, for the Sydney Region (based on 10-minute mean observations from Kingsford Smith Airport from 1939 to 2008, corrected to open terrain at 10m)

2 THE WIND TUNNEL MODEL

Wind tunnel testing was undertaken to obtain accurate wind speed measurements at selected locations within and around the redevelopment using a 1:300 scale model. The study model incorporates all necessary architectural features on the façade to ensure an accurate wind flow is achieved around the model, and was constructed using a Computer Aided Manufacturing (CAM) process to ensure that a high level of detail and accuracy is achieved. The effect of nearby buildings and land topography has been accounted for through the use of a proximity model, which represents an area with a diameter of 750m, centred on the redevelopment site. Photographs of the wind tunnel model are presented in Figures 2a to 2g.

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 have been recommended. These treatments could be in the form of vegetation that is already proposed for the site, and/or additional trees, shrubs, screens, awnings, etc.

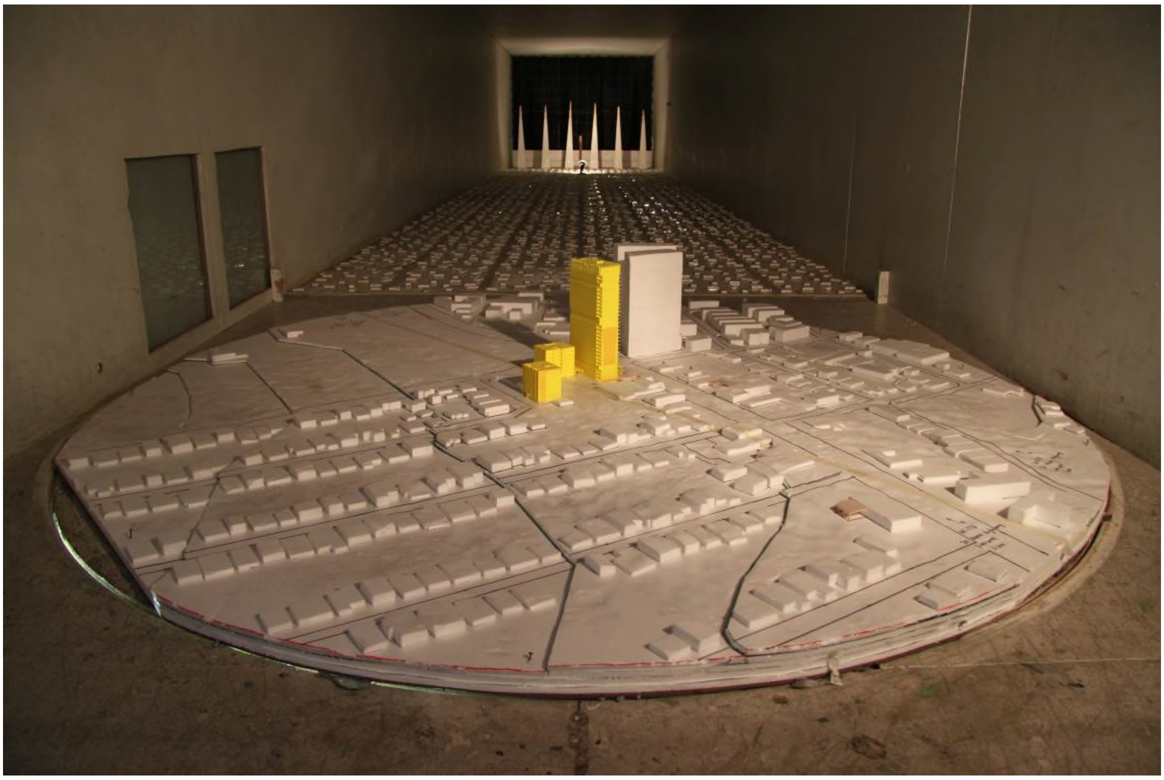

Figure 2a: Photograph of the Wind Tunnel Model – view from the south west

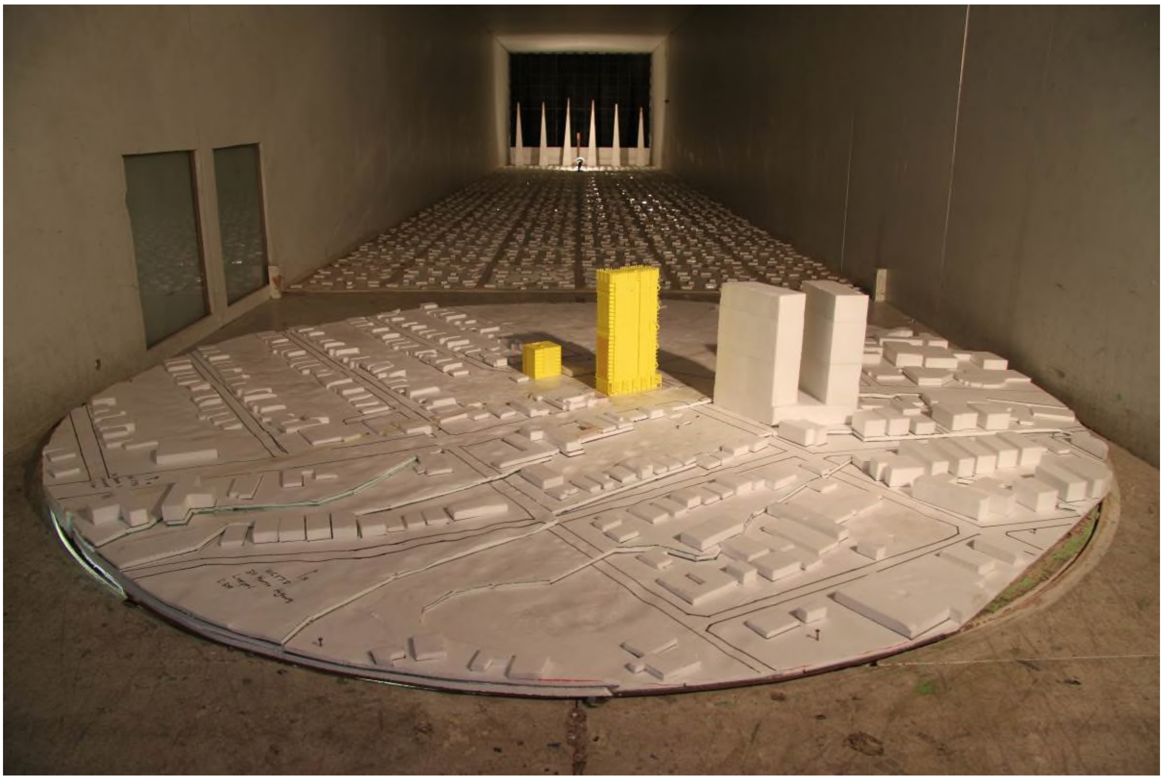

Figure 2b: Photograph of the Wind Tunnel Model – view from the south east

Figure 2c: Photograph of the Wind Tunnel Model – View from the north west

Figure 2d: Photograph of the Wind Tunnel Model – View from the north east

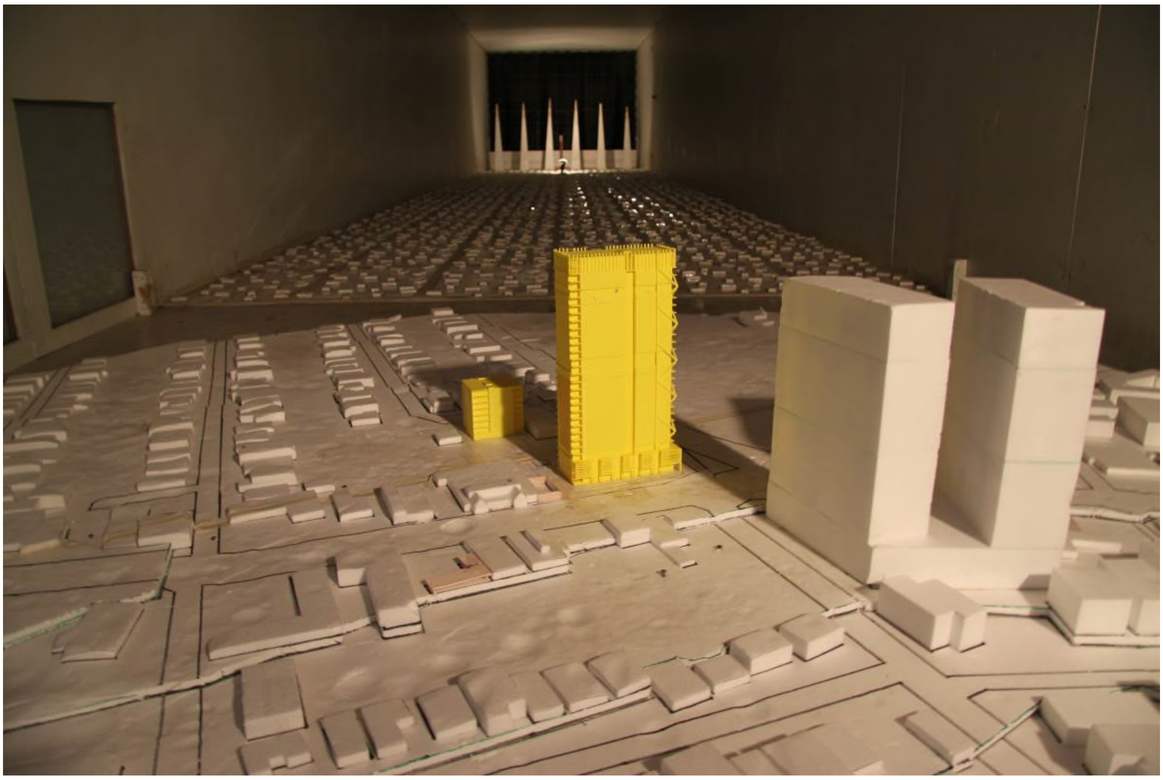

Figure 2e: Photograph of the Wind Tunnel Model – View from the east

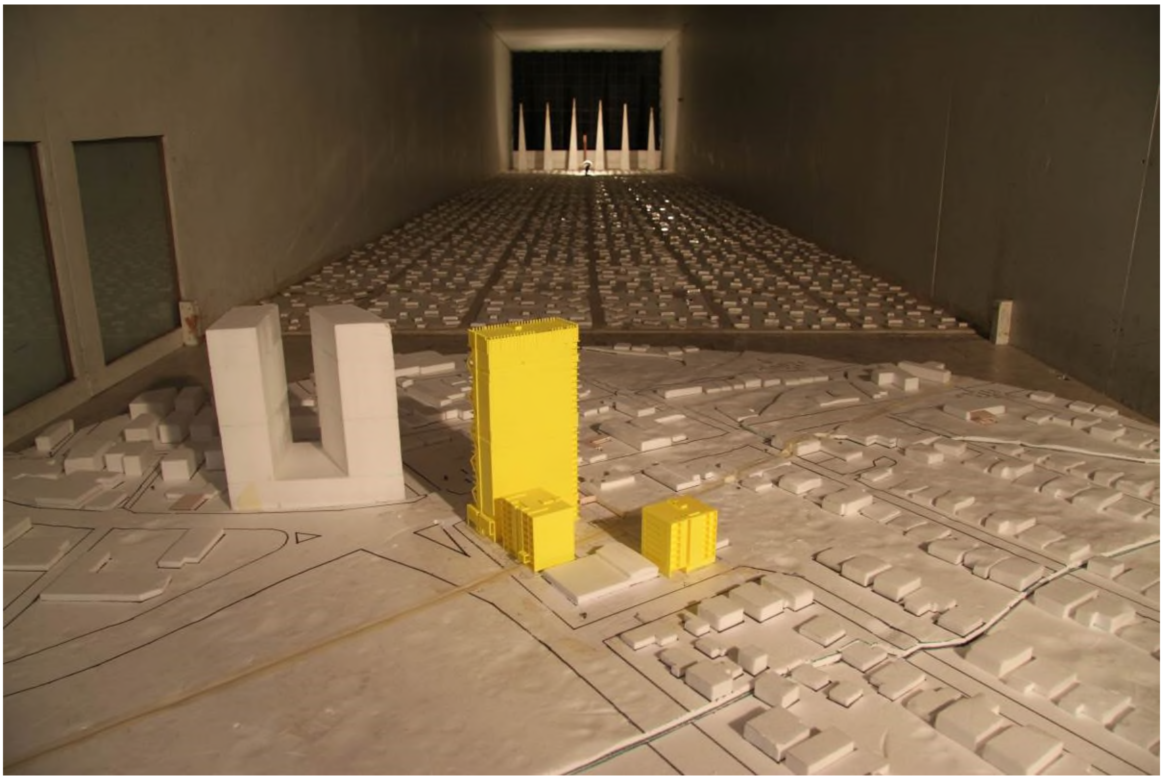

Figure 2f: Photograph of the Wind Tunnel Model – View from the north west

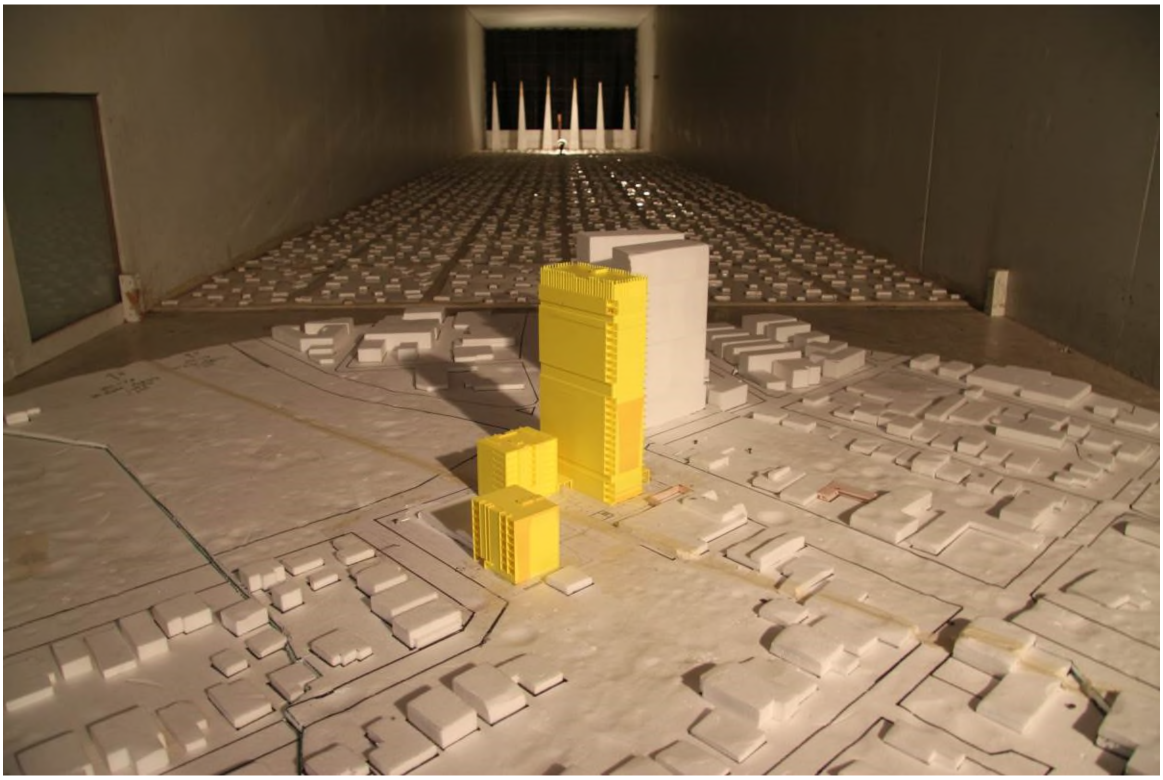

Figure 2g: Photograph of the Wind Tunnel Model – View from the south west

3 BOUNDARY LAYER WIND FLOW MODEL

Testing was performed using Windtech's boundary layer wind tunnel, which has a 2.6m 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 (ie: 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 (as per the definitions in AS/NZS1170.2:2011):

- **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 as per ISO4354:2009. These are summarised in Table 2, referenced to the study reference height of 50m above ground.

Table 2: Terrain and Height Multipliers, Turbulence Intensities, and Corresponding Roughness Lengths, for the Standard ISO4354:2009 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	0.96	0.99	1.28	0.112	0.003
1.5	0.90	0.93	1.25	0.128	0.01
2.0	0.84	0.88	1.21	0.147	0.03
2.5	0.77	0.81	1.17	0.174	0.1
3.0	0.69	0.73	1.12	0.208	0.3
3.5	0.58	0.62	1.04	0.265	1
4.0	0.46	0.51	0.96	0.355	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 60 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 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.

For each of the 16 wind directions tested in this study, the approaching boundary layer wind profiles modelled in the wind tunnel matched the model scale and the overall surrounding terrain characteristics beyond the 375m radius of the proximity model. Plots of the wind tunnel boundary layer wind profiles are presented in Appendix B of this report.

Table 3: Directional Terrain and Height Multipliers at the Site (at the study reference height, as per the AS/NZS1170.2:2011 boundary layer transition methodology)

Wind Sector (degrees)	$k_{tr,T=3s}$ *(3-second gust)*	$k_{tr,T=600s}$ *(10-minute mean)*	$k_{tr,T=3600s}$ *(hourly mean)*
0	1.13	0.75	0.71
30	1.14	0.76	0.72
60	1.14	0.76	0.72
90	1.14	0.76	0.72
120	1.12	0.73	0.69
150	1.15	0.78	0.74
180	1.17	0.81	0.77
210	1.12	0.73	0.69
240	1.13	0.74	0.70
270	1.12	0.73	0.69
300	1.14	0.76	0.72
330	1.14	0.76	0.72

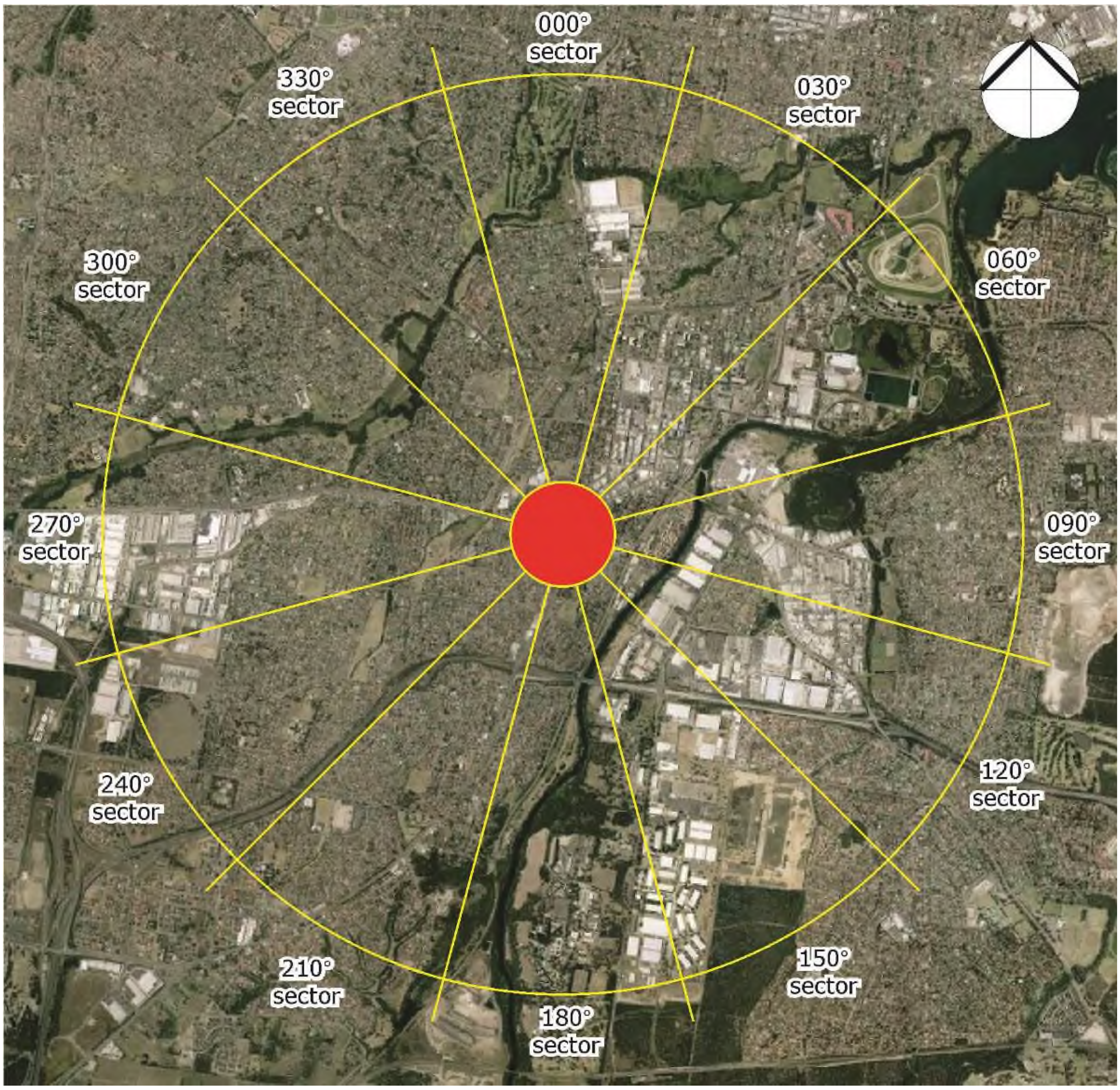

Figure 3: Aerial Image of the Surrounding Terrain
(radius of 3.0km from the edge of the proximity model, which is coloured red)

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 Davenport, Lawson, Melbourne, 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 Penwarden (1975) Criteria for Gust Wind Speeds

The following table developed by 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 (approximately once per week on average). Higher ranges of wind speeds can be tolerated for rarer events.

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

Type of Winds	Beaufort Number	Gust 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 Davenport (1972) Criteria for Mean Wind Speeds

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 frequency of exceedance of approximately once per week (a probability of exceedance of 5%).

Table 5: Criteria by Davenport (1972)

Classification	Activities	95 Percentile Maximum Mean (approximately once per week)
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 Lawson (1975) Criteria for Mean Wind Speeds

In 1973, Lawson quotes that Penwarden's Beaufort 4 wind speeds (as listed in Table 4) 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, Lawson presented a set of criteria very similar to those of Davenport's. These are presented in Tables 6 and 7.

Table 6: Safety Criteria by 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 Lawson (1975)

Classification	Activities	95 Percentile Maximum Mean (approximately once per week)
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 Melbourne (1978) Criteria for Gust Wind Speeds

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 peak annual maximum gust wind speeds, 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 Melbourne (1978)

Classification	Human Activities	Annual Maximum Gust
Limit for safety	Completely unacceptable: people likely to get blown over.	$\hat{V} > 23$m/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 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 Melbourne (1978) are quite conservative. This was also observed by Rofail (2007) when undertaking on-site remedial studies, who concluded that the criteria by Melbourne (1978) generally overstates the wind effects in a typical urban setting, which is caused by Melbourne's assumption 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 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%.

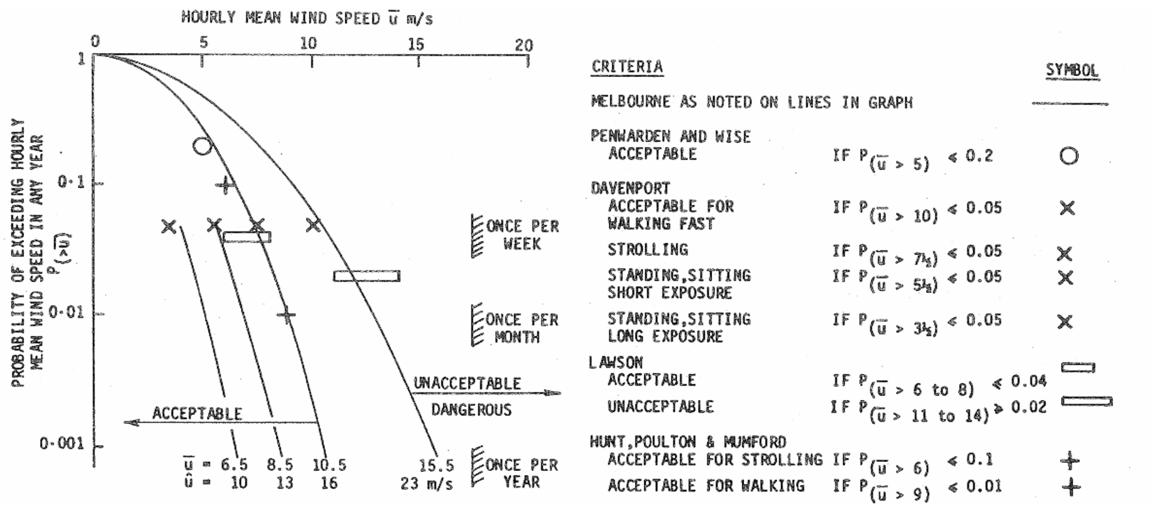

Figure 4: Comparison of Various Mean and Gust Wind Environment Criteria, assuming 15% turbulence and a Gust Factor of 1.5 (after Melbourne, 1978)

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 Davenport (1972) criteria are used in conjunction with a maximum Gust-Equivalent Mean (GEM) wind speed (defined below), which are representative of approximately a weekly recurrence. The safety limit criterion by Melbourne (1978) of 23 m/s for the annual maximum peak gust wind speeds is also used. Note that the 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 Melbourne (1978) of 23 m/s for annual maximum peak gust wind speeds is also applied to all areas.

The basic criteria for a range of outdoor activities are described as follows:

- **Long Exposure:** 3.5 m/s maximum GEM wind speeds (representative of approximately a weekly recurrence).
- **Short Exposure:** 5.5 m/s maximum GEM wind speeds (representative of approximately a weekly recurrence).
- **Comfortable Walking:** 7.5 m/s maximum GEM wind speeds (representative of approximately a weekly recurrence).
- **Safety Limit:** 23.0 m/s annual maximum gust wind speeds.

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 of the external study point has 2 plots (one comparing to the modified version of the Davenport (1972) criteria for the maximum GEM wind speeds (which are representative of approximately a weekly recurrence), and the other comparing to the Melbourne (1978) criteria for the annual 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 3.5 standard deviations from the mean.
- Long Exposure applies typically to outdoor fine dining, amphitheatres, etc.
- 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 and communal areas.
- In all areas, the wind conditions are also checked against the safety limit.

5 LOCAL WIND SPEED 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-1-2001), ASCE-7-10 (Chapter C31), and CTBUH 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 1,024Hz was used, which is more than adequate for he given frequency band. The signal was low pass filtered at 32Hz, which results in the peak gust being the equivalent of a 2 to 3 second gust (which is what the criteria for pedestrian comfort and safety are based upon).

The mean and the maximum 3-second duration peak gust velocity coefficients are derived from the wind tunnel test by the following relation:

$$\hat{C}_V = \overline{C}_V + g.\sigma_V \qquad (4.1)$$

where: $\hat{C}_V$ is the 3-second gust velocity coefficient.

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

g is the gust factor, which is taken to be 3.5.

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 10.8m/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 13 seconds was used for each wind direction tested, which is equivalent to a minimum sample time of approximately 34 minutes in full-scale for the annual 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 which produce the highest wind speed events for a region may not coincided with the most wind exposed direction at the site.

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

5.2.1 Annual Maximum Gust Wind Speeds

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

$$V_{study} = V_{ref,RH}\left(\frac{k_{200m,tr,T=3600s}}{k_{RH,tr,T=3600s}}\right)C_V \tag{4.2}$$

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:

$$C_V = \frac{C_{V,study}}{C_{V,200m}} \tag{4.3}$$

$C_{V,study}$ 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 Weekly Maximum Gust-Equivalent Mean Wind Speeds

The contribution to the probability of exceedance of a specified wind speed (ie: 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 of Davenport (1972), which are used in this study, are referenced to a probability of exceedance of 5% of a specified wind speed and is representative of approximately a weekly recurrence interval.

5.3 Layout of Study Points

For this study a total of 30 study point locations have been selected for analysis in the wind tunnel. This includes the following:

- 24 study points on the Ground Level within and around the site
- 6 study points on the Tower Corner Balconies

The locations of the various study points tested for this study are presented in Figures 6a and 6c in the form of a marked-up plan drawings. It should be noted that only the most critical outdoor locations of the redevelopment have been selected for analysis.

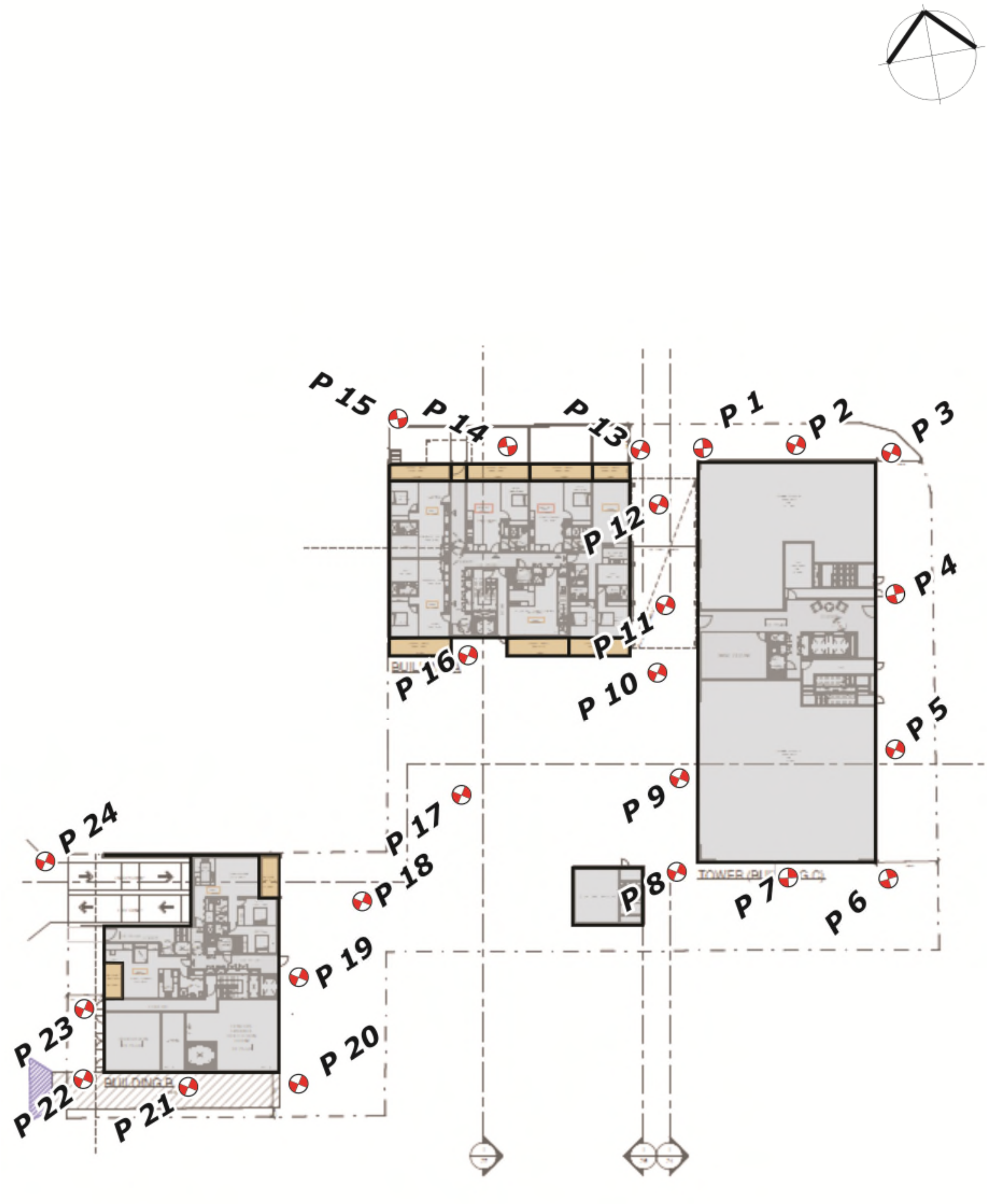

Figure 5a: Study Point Locations – Street Level Plan

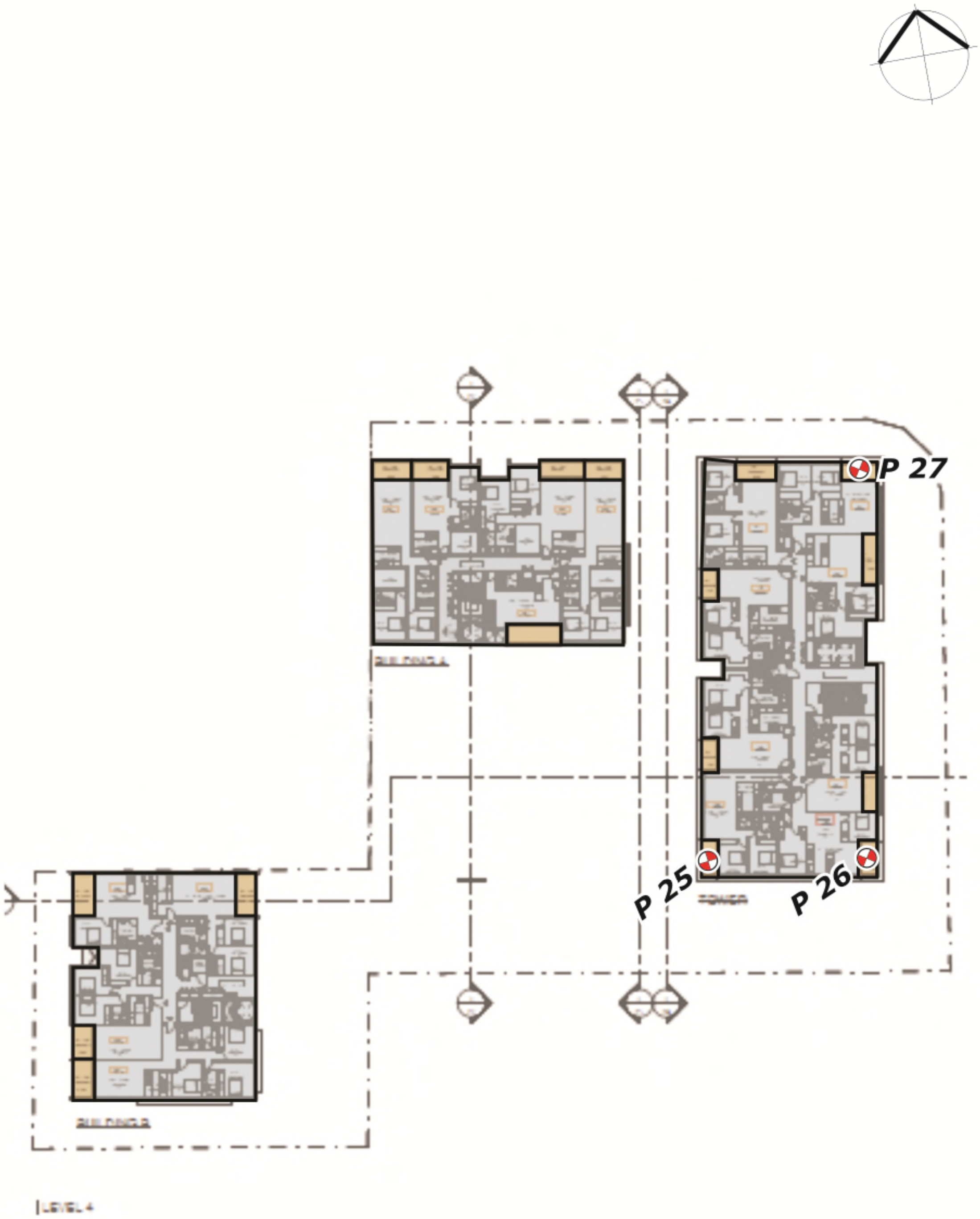

Figure 5b Study Point Locations – Lower Level Balconies on the Tower (Level 4)

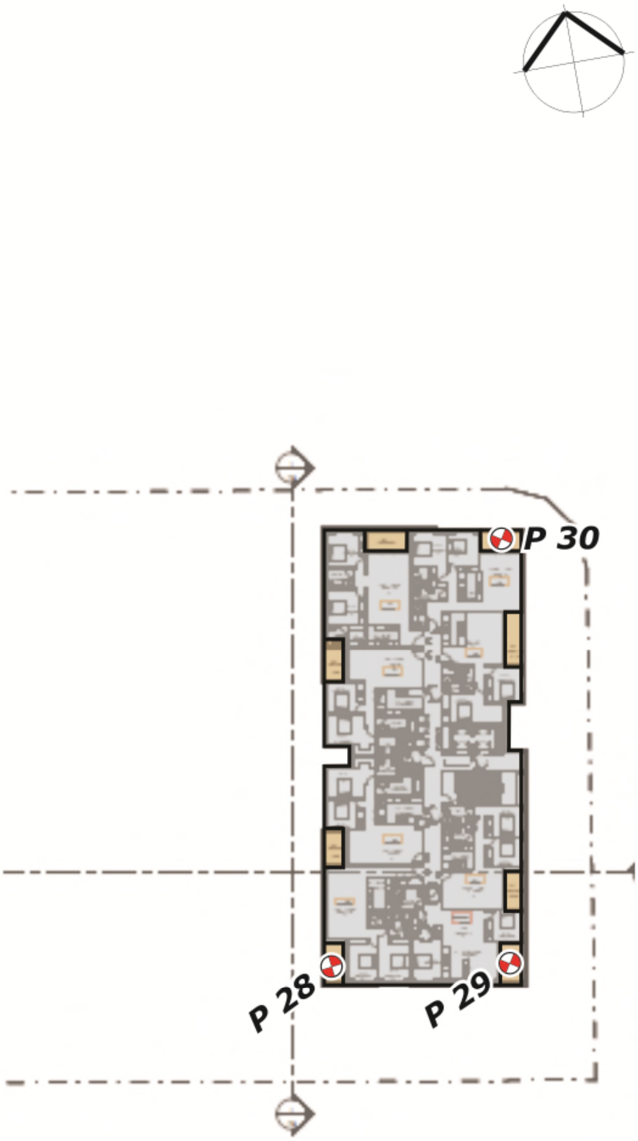

Figure 6c: Study Point Locations – – Upper Level Balconies on the Tower (Level 29)

6 RESULTS AND DISCUSSION

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, treatments have been devised and tested in the wind tunnel to verify their effectiveness. These treatments could be in the form of vegetation that is already proposed for the side, and/or additional trees, shrubs, screens, awnings, etc. Furthermore, "existing" site conditions at selected locations were also tested.

The results of the study are summarised in Table 9 below. The wind speed criteria that the wind conditions should achieve re also listed in Table 9 for each study point location. The results of the study indicate that treatments are required for certain locations to achieve the desired criteria for pedestrian comfort and safety. To improve wind conditions of the development, in-principle ameliorative treatments have been recommended as follows:

- The inclusion strategic planting in the form of densely foliating trees on the north western and south western corners of Building A, the north eastern and south western corners of the Tower and the south western corner of Building B As indicated in Figures 5a and/or 5b. Trees should be evergreen and capable of growing to a height of at least 5 to 6m with a 4 to 5m wide canopy.
- The inclusion of a screen approximately 3m in height on the south eastern Ground Level corner of the Tower and Building B, as indicated in Figure 5a and/or 5b.
- The implementation of either of the following:
  - o Further strategic planting on the northern end of the development and around the south western corner of the Tower as indicated in Figure 5a; OR
  - o Inclusion of a wraparound awning above the ground level of the Towers South Western corner as well as an extension to the canopy on the northern end of the development, as indicated in Figure 5b.
- The inclusion of full height impermeable screens along the corner balconies of the Tower, as indicated in Figure 5c.

With the inclusion of the above mentioned in-principle treatments to the final design, the results of this study indicate that wind conditions for all outdoor trafficable areas within and around the proposed development will be suitable for their intended uses.

Furthermore, the use of loose glass-tops, light-weight sheets or covers (including loose BBQ lids) is not appropriate on the higher level private balconies. Lightweight furniture is not recommended unless it is securely attached to the balcony floor slab.

Table 9: Results Summary

Study Point	Desired Criterion (m/s)		Treatment Necessary to Pass?	Description of Suggested Treatment
	Weekly GEM	Annual Peak		
Point 01	7.5	23.0	NO	
Point 02	7.5	23.0	NO	
Point 03	7.5	23.0	YES	With the inclusion of densely foliating trees as per Figures 5a and 5b
Point 04	7.5	23.0	NO	
Point 05	7.5	23.0	NO	
Point 06	7.5	23.0	YES	Inclusion of a 3m high impermeable screen and trees as per Figures 5a and 5b
Point 07	7.5	23.0	NO	
Point 08	7.5	23.0	YES	Inclusion of awning or additional trees as per Figures 5a and 5b
Point 09	7.5	23.0	NO	
Point 10	7.5	23.0	NO	
Point 11	7.5	23.0	YES	Inclusion of canopy extension or additional trees as per Figures 5a and 5b
Point 12	7.5	23.0	YES	Inclusion of canopy extension or additional trees as per Figures 5a and 5b
Point 13	7.5	23.0	NO	
Point 14	7.5	23.0	NO	
Point 15	7.5	23.0	YES	Inclusion of densely foliating trees as per Figures 5a and 5b
Point 16	7.5	23.0	YES	Inclusion of densely foliating trees as per Figures 5a and 5b
Point 17	7.5	23.0	NO	
Point 18	7.5	23.0	NO	
Point 19	7.5	23.0	NO	
Point 20	7.5	23.0	NO	
Point 21	7.5	23.0	NO	
Point 22	7.5	23.0	YES	Inclusion of densely foliating trees as per Figures 5a and 5b
Point 23	7.5	23.0	NO	
Point 24	7.5	23.0	NO	
Point 25		23.0	YES	Full height impermeable screen as per Figure 5c
Point 26		23.0	YES	Full height impermeable screen as per Figure 5c
Point 27		23.0	YES	Full height impermeable screen as per Figure 5c
Point 28		23.0	YES	Full height impermeable screen as per Figure 5c
Point 29		23.0	YES	Full height impermeable screen as per Figure 5c
Point 30		23.0	NO	

Legend

3m high impermeable screen

Treatments Legend

Proposed trees (already indicated in drawings).
These should be evergreen, densely foliating, and capable of growing to a minimum height of 5 to 6m with a 4 to 5m wide canopy which has a low end canopy height of approximately 2m to 2.5m

Recommended tree locations. These trees should be evergreen and capable of growing to a height of at least 5 to 6m, with the canopy height starting at approximately 2m to 2.5m above the ground, with a densely foliating interlocking canopy with a diameter ranging from approximately 4m to 5m.

Figure 5a Option 1 Treatments for Ground Level (Additional Planting)

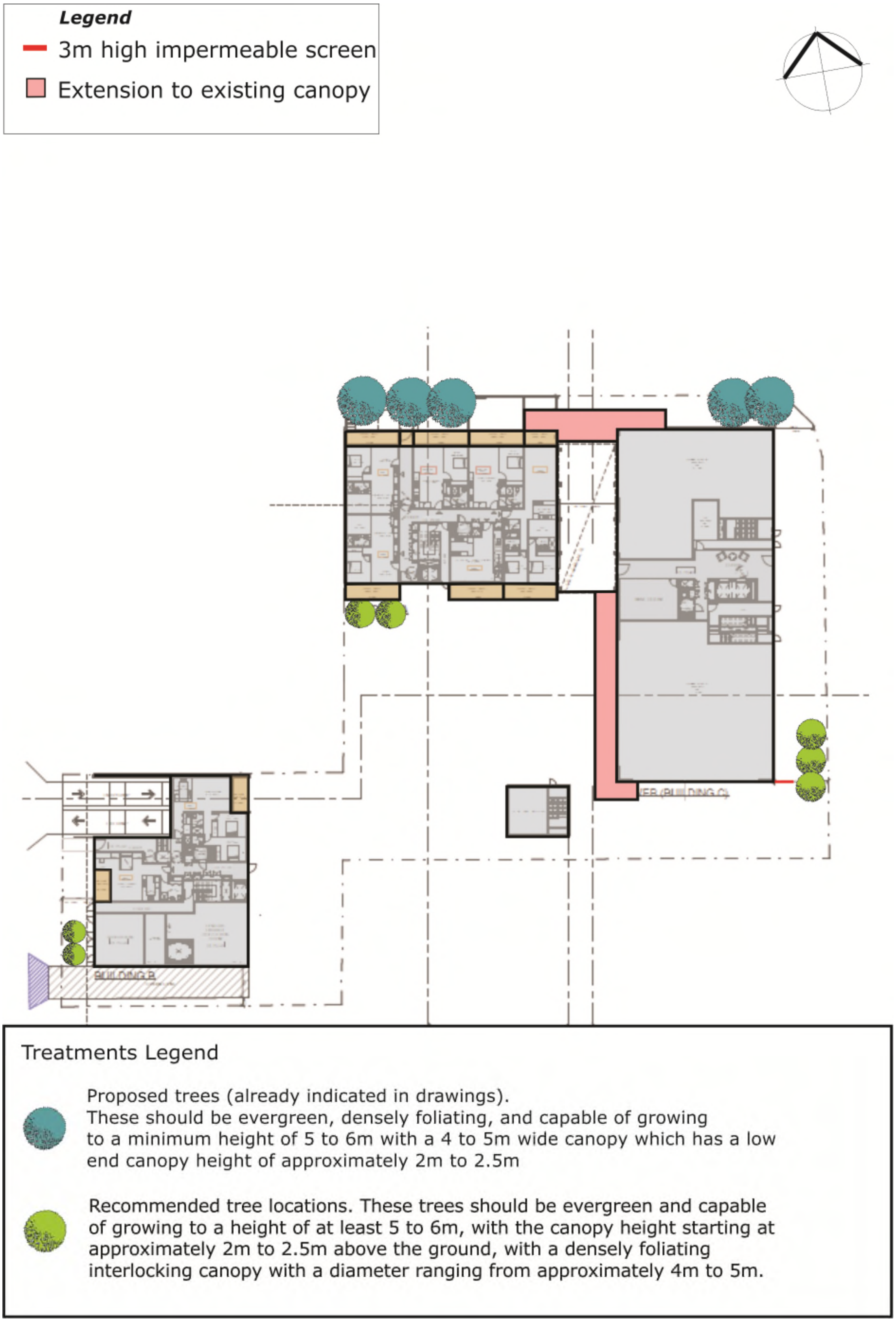

Figure 5b Option 2 Treatments for Ground Level (Extended canopy and awnings)

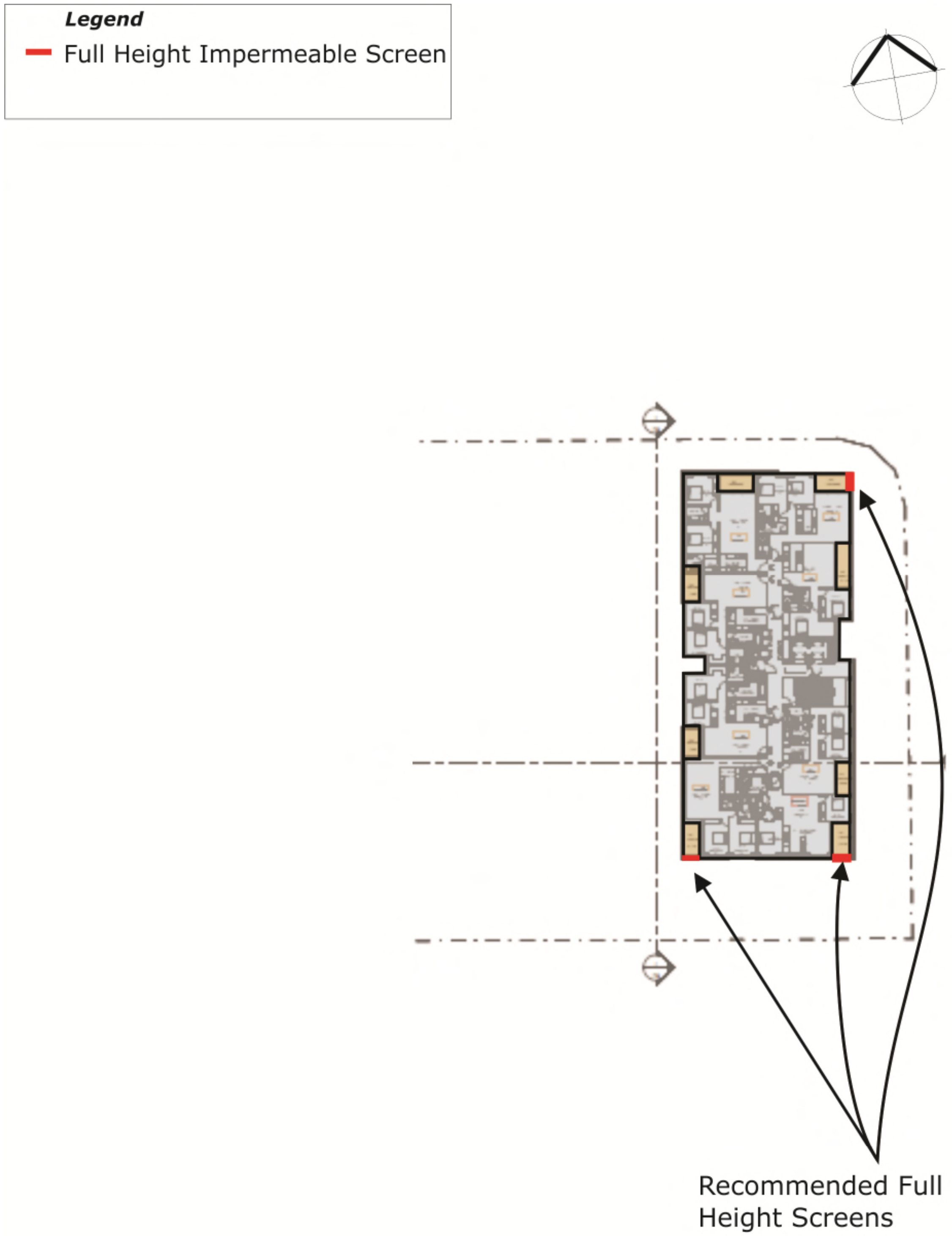

Figure 5c Tower Balcony Treatments

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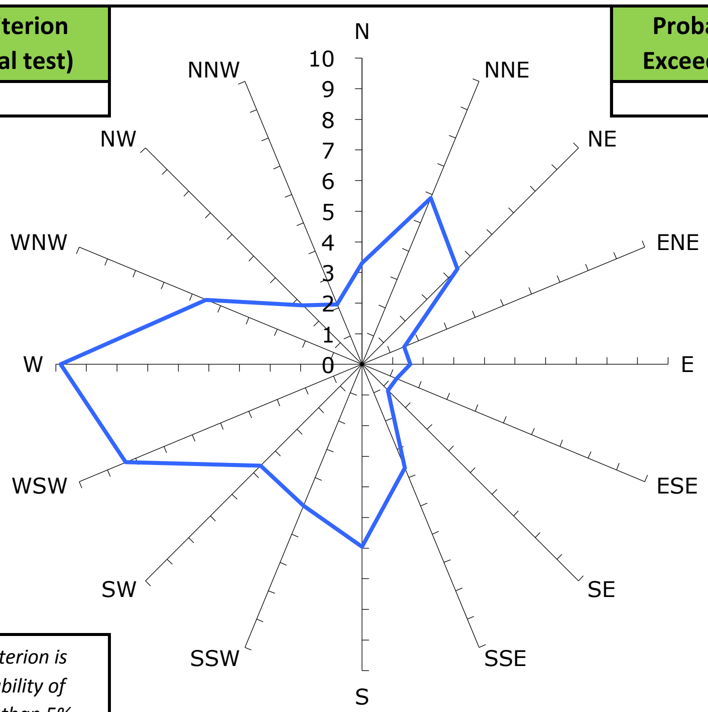
APPENDIX A - DIRECTIONAL PLOTS OF THE WIND TUNNEL RESULTS

Measured Wind Speeds at Point 01

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
4%

Probability of Criterion Exceedence (final retest)
N/A

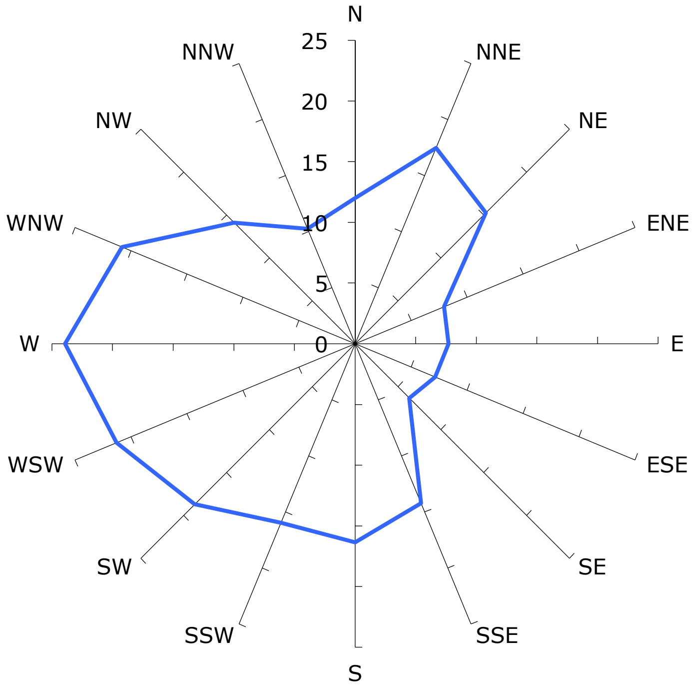


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



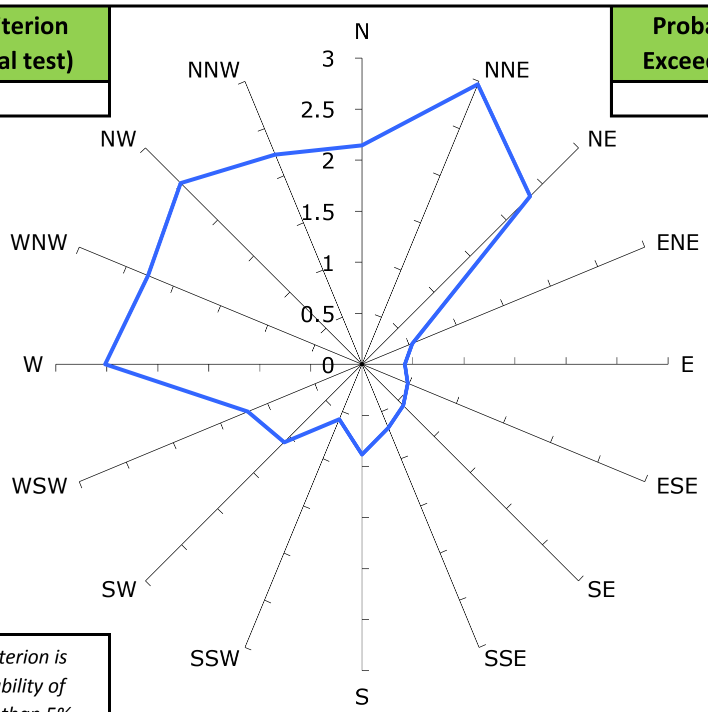
Desired Criterion
23m/s

Measured Wind Speeds at Point 02

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

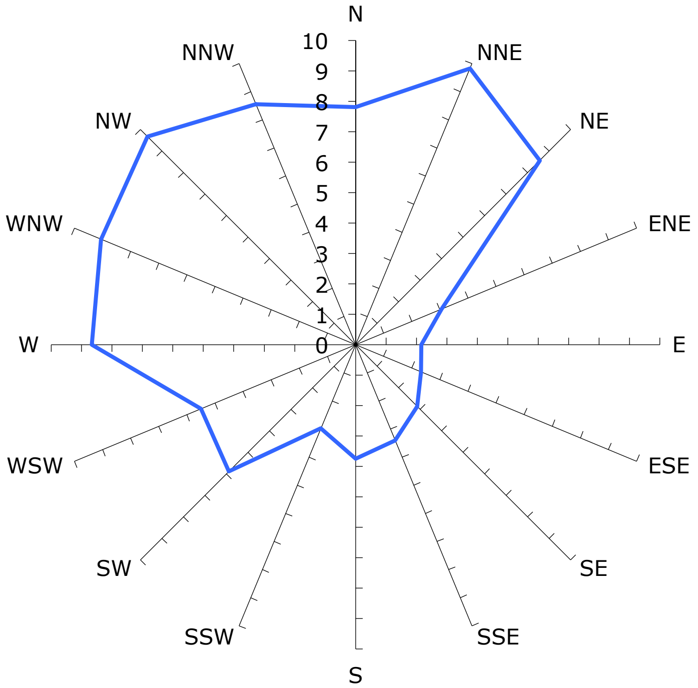


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



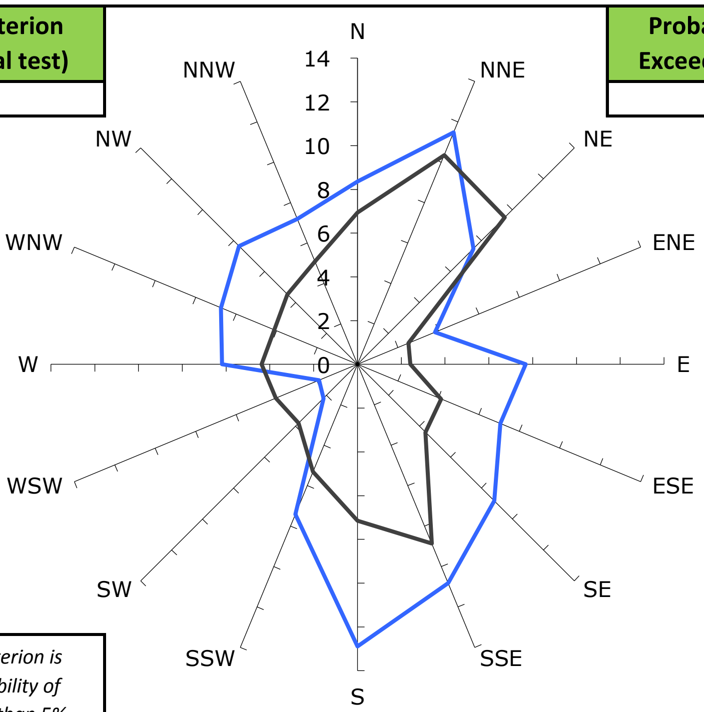
Desired Criterion
23m/s

Measured Wind Speeds at Point 03

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
23%

Probability of Criterion Exceedence (final retest)
N/A



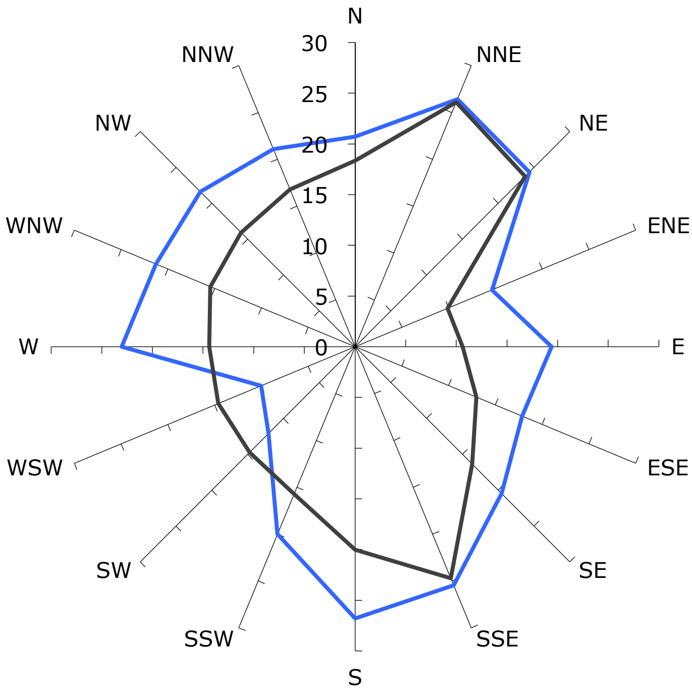
NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Existing site conditions.

Annual Maximum Gust (m/s)



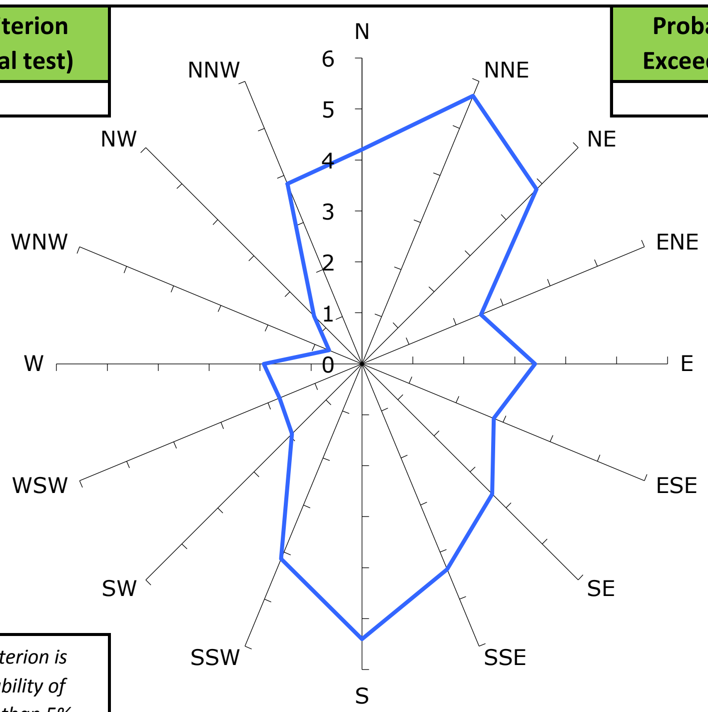
Desired Criterion
23m/s

Measured Wind Speeds at Point 04

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

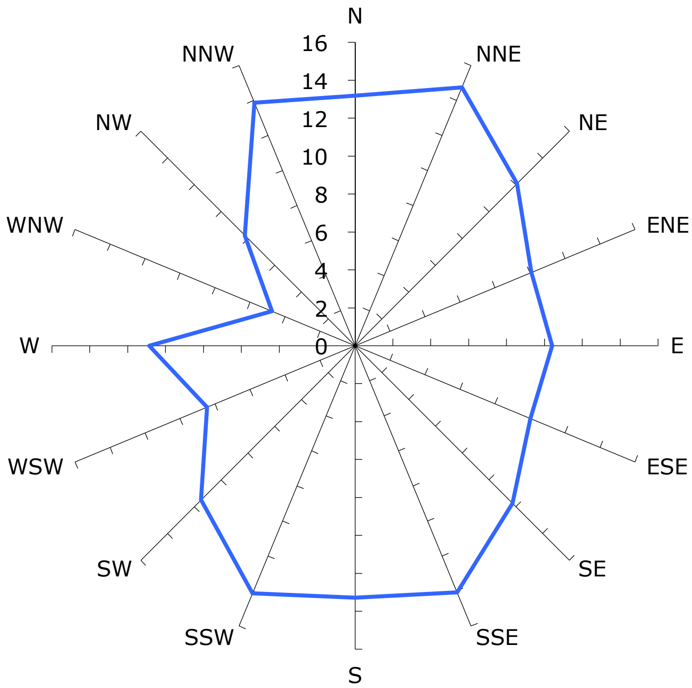


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



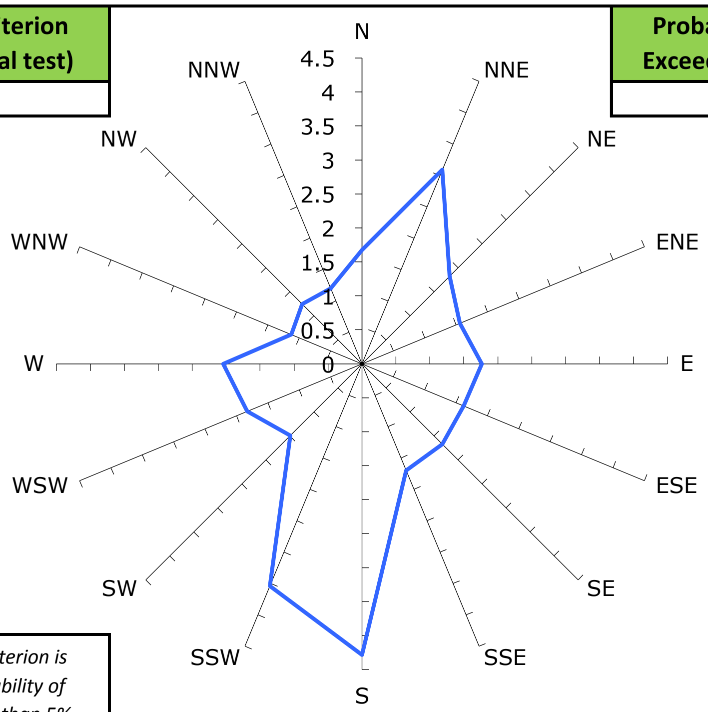
Desired Criterion
23m/s

Measured Wind Speeds at Point 05

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

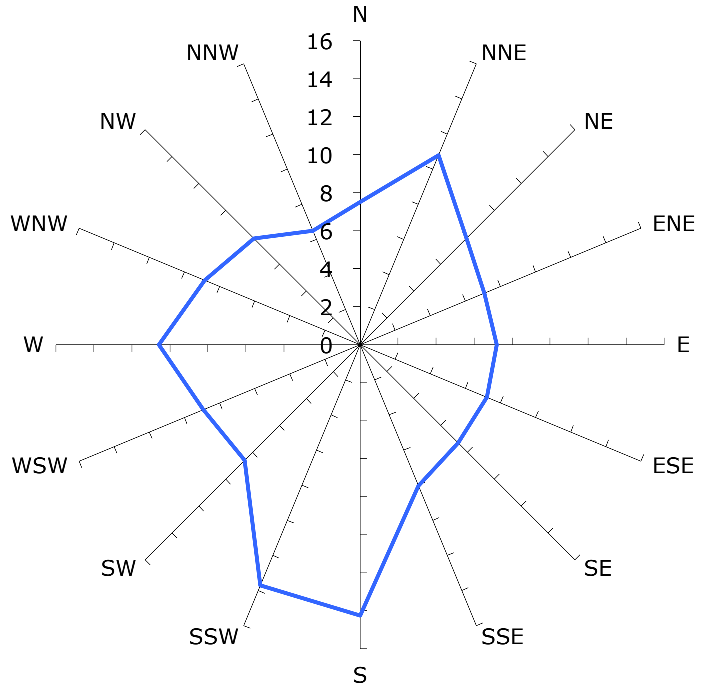


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



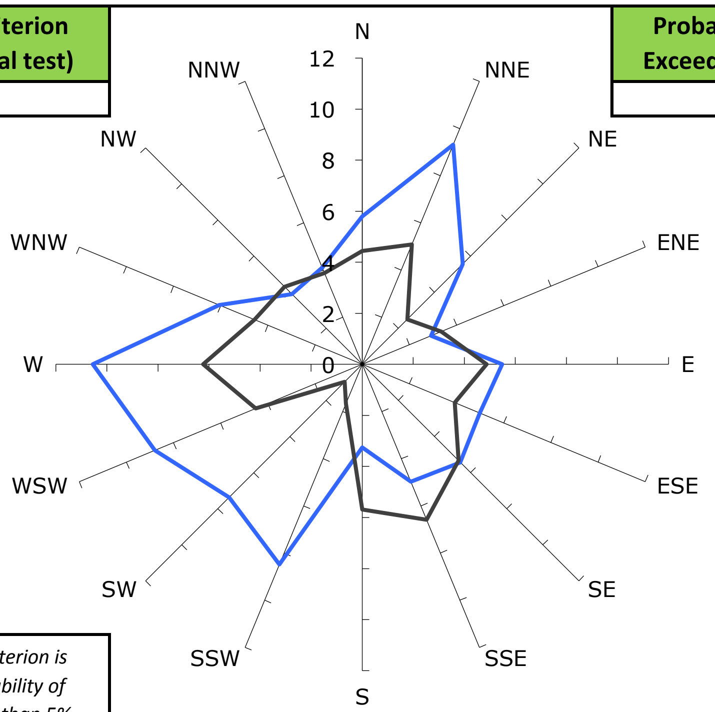
Desired Criterion
23m/s

Measured Wind Speeds at Point 06

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
11%

Probability of Criterion Exceedence (final retest)
N/A



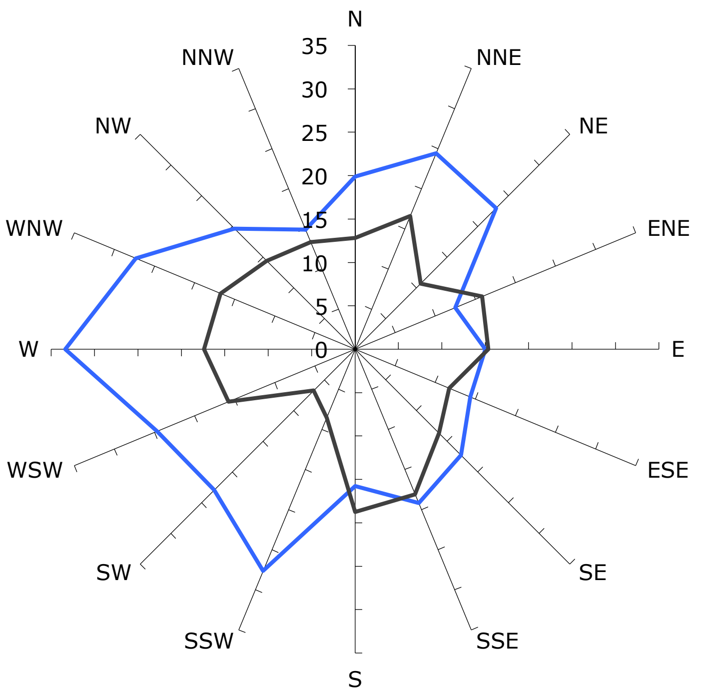
NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Existing site conditions.

Annual Maximum Gust (m/s)

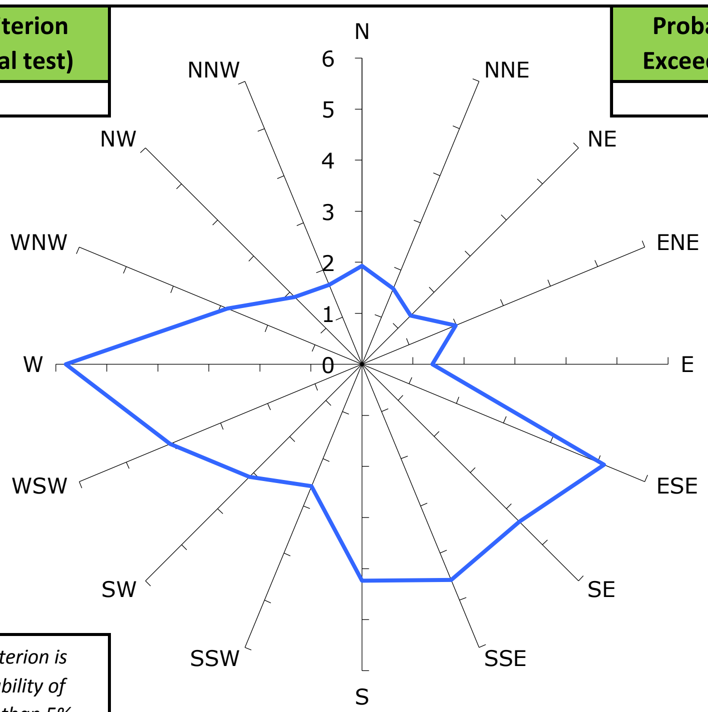


Desired Criterion
23m/s

Measured Wind Speeds at Point 07

Probability of Criterion Exceedence (initial test)	Probability of Criterion Exceedence (final retest)
1%	N/A

Weekly Maximum GEM (m/s)

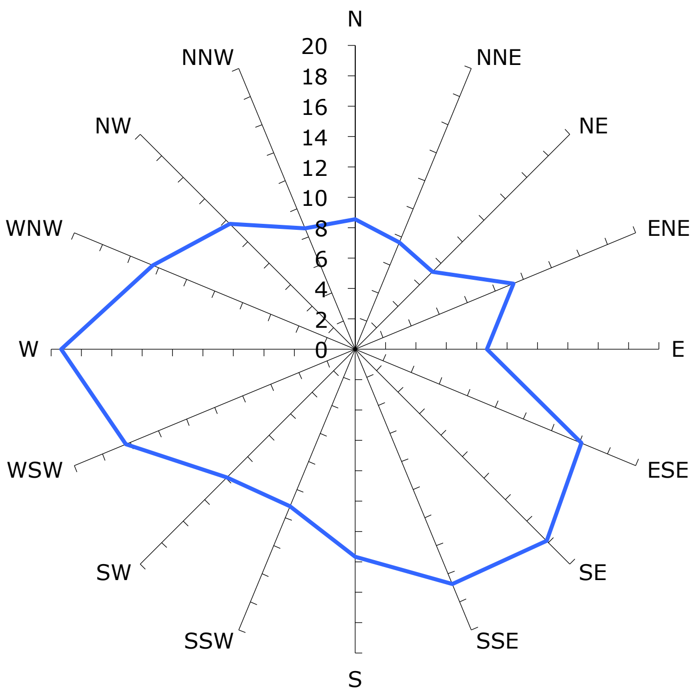


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



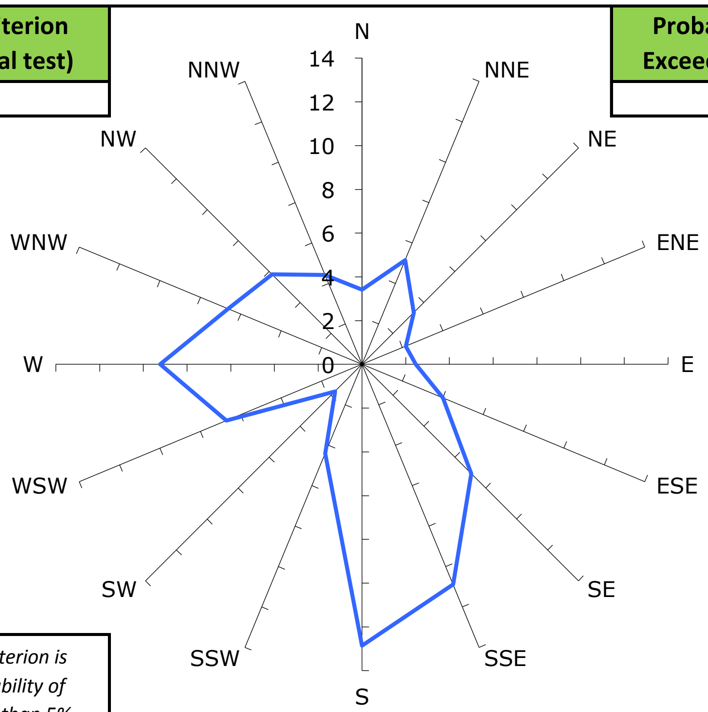
Desired Criterion
23m/s

Measured Wind Speeds at Point 08

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
14%

Probability of Criterion Exceedence (final retest)
N/A

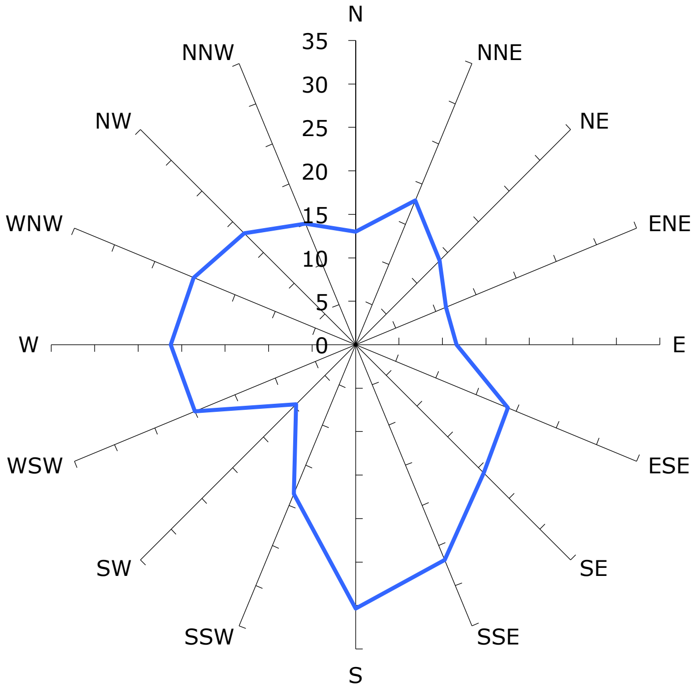


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



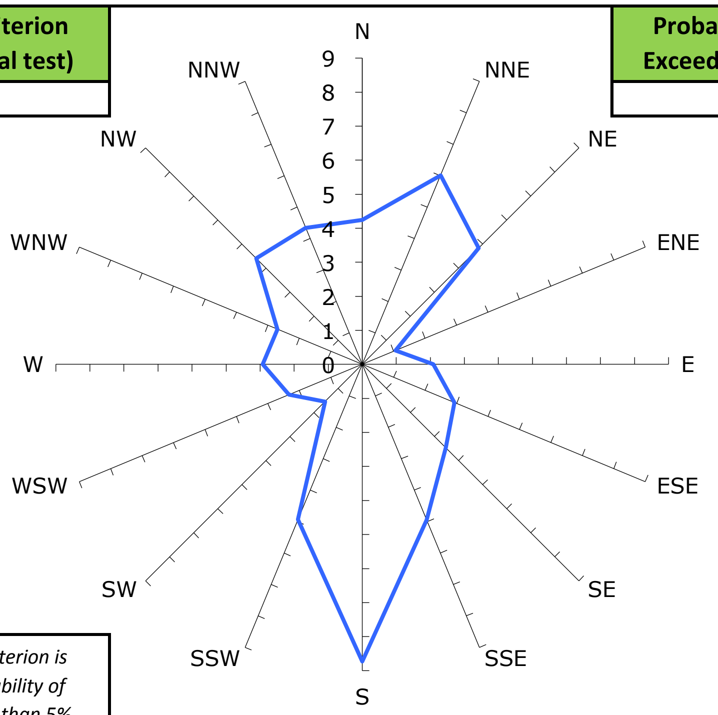
Desired Criterion
23m/s

Measured Wind Speeds at Point 09

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
3%

Probability of Criterion Exceedence (final retest)
N/A

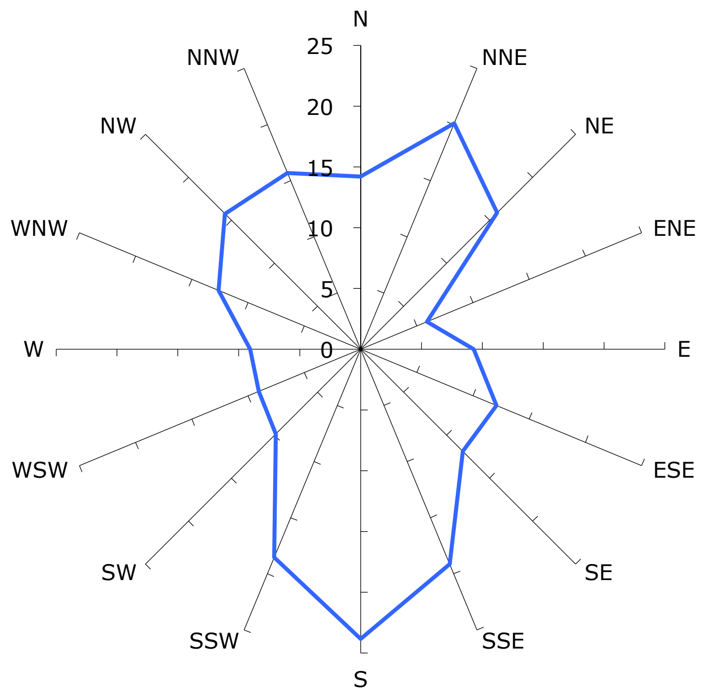


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)

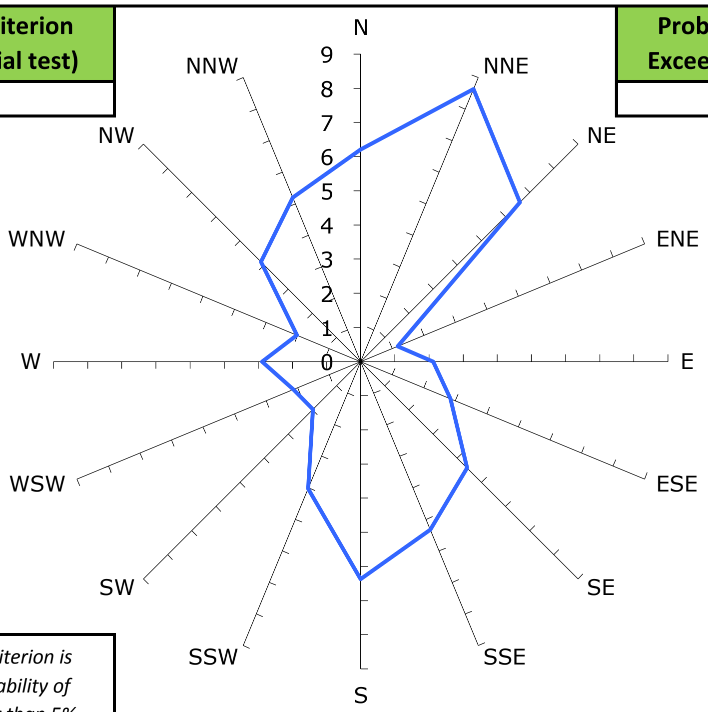


Desired Criterion
23m/s

Measured Wind Speeds at Point 10

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)	Probability of Criterion Exceedence (final retest)
4%	N/A

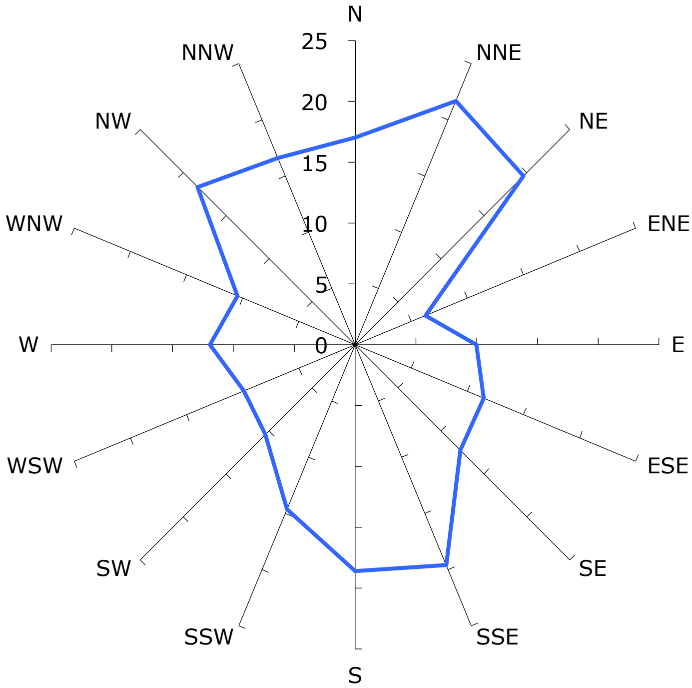


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)

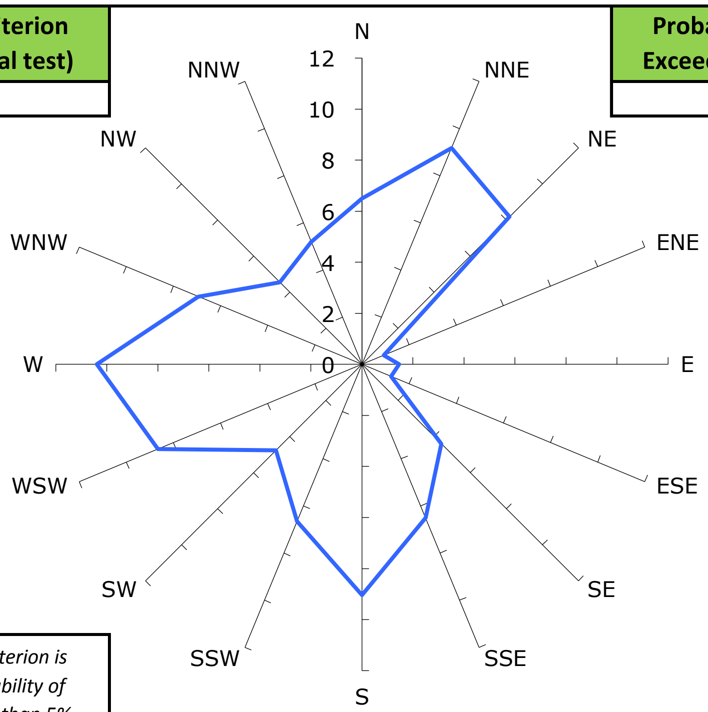


Desired Criterion
23m/s

Measured Wind Speeds at Point 11

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)	Probability of Criterion Exceedence (final retest)
15%	N/A

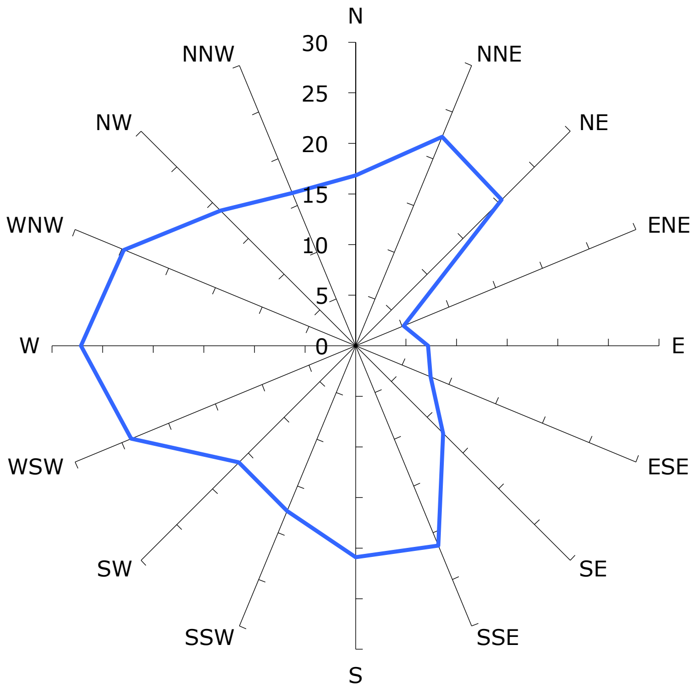


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



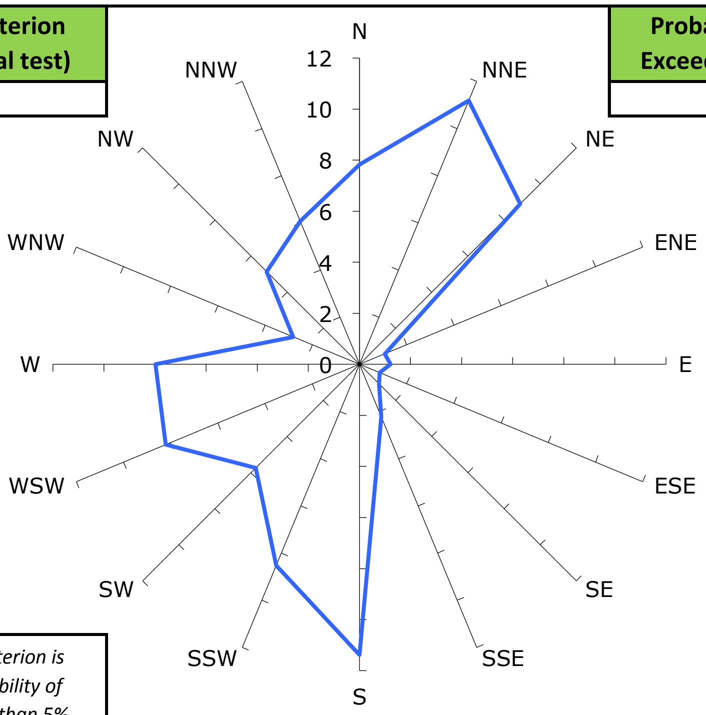
Desired Criterion
23m/s

Measured Wind Speeds at Point 12

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
17%

Probability of Criterion Exceedence (final retest)
N/A

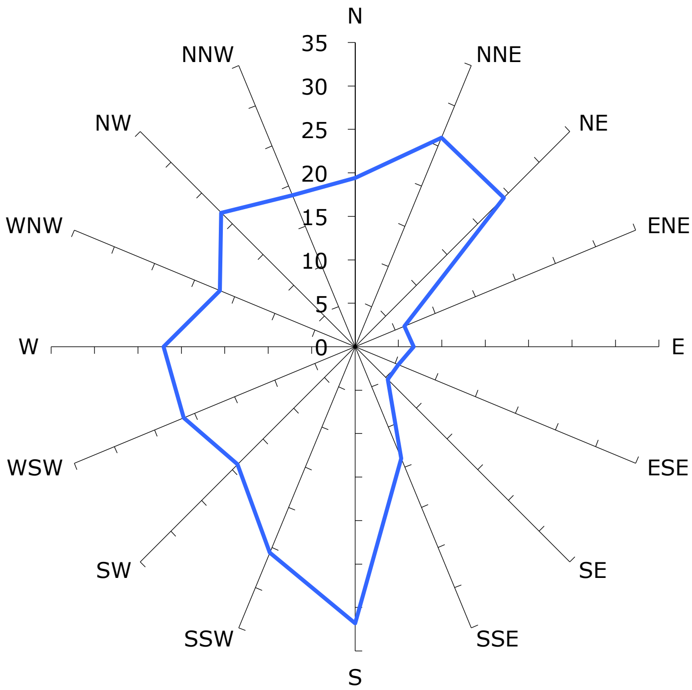


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



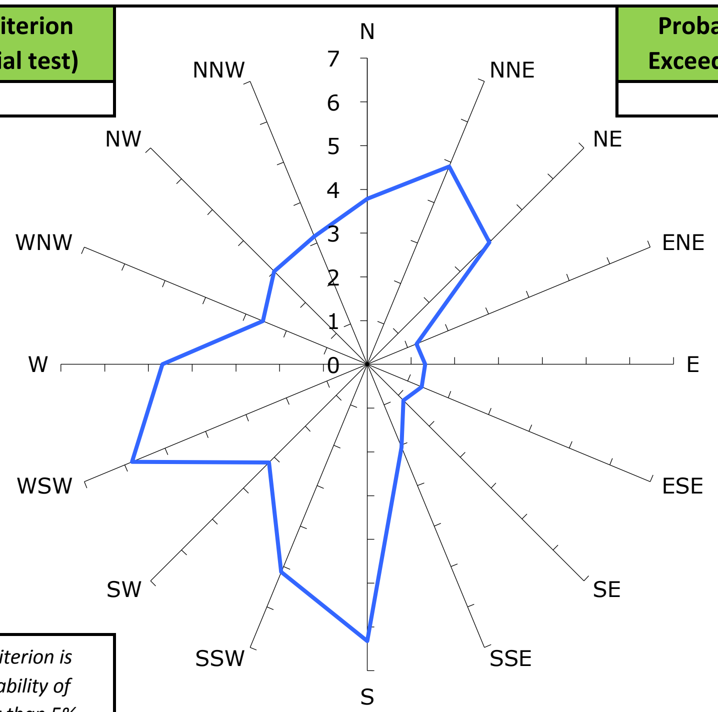
Desired Criterion
23m/s

Measured Wind Speeds at Point 13

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
1%

Probability of Criterion Exceedence (final retest)
N/A

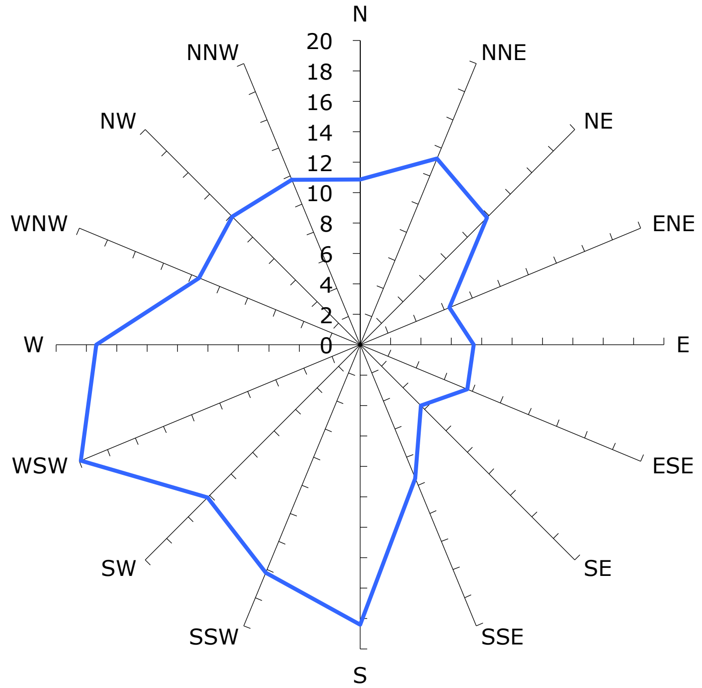


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



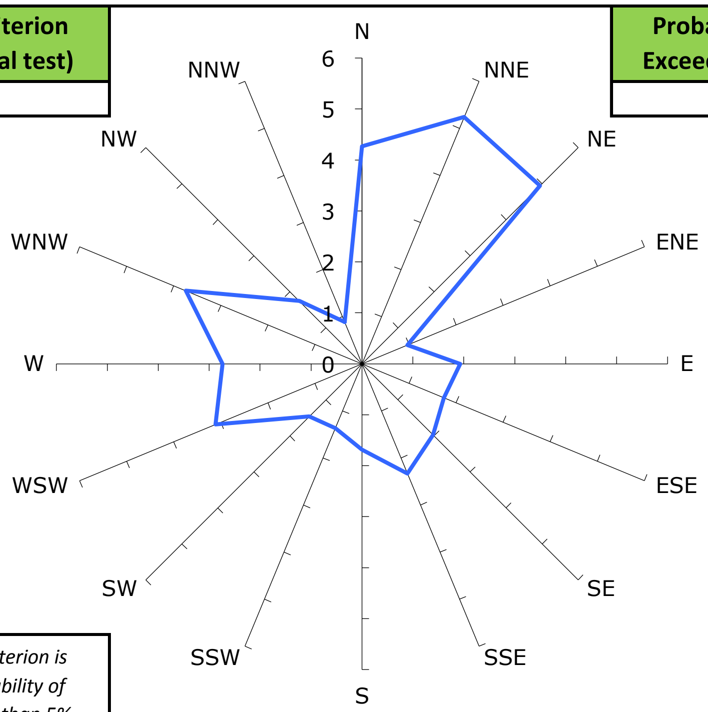
Desired Criterion
23m/s

Measured Wind Speeds at Point 14

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

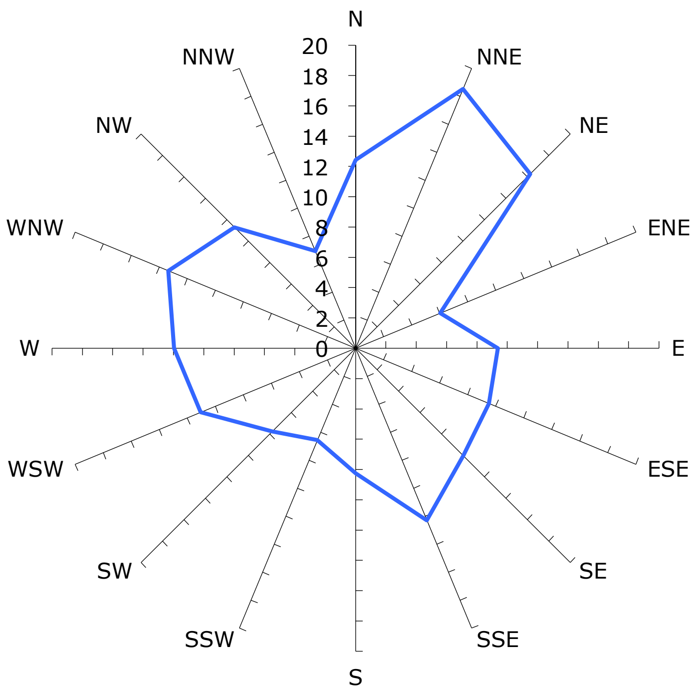


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



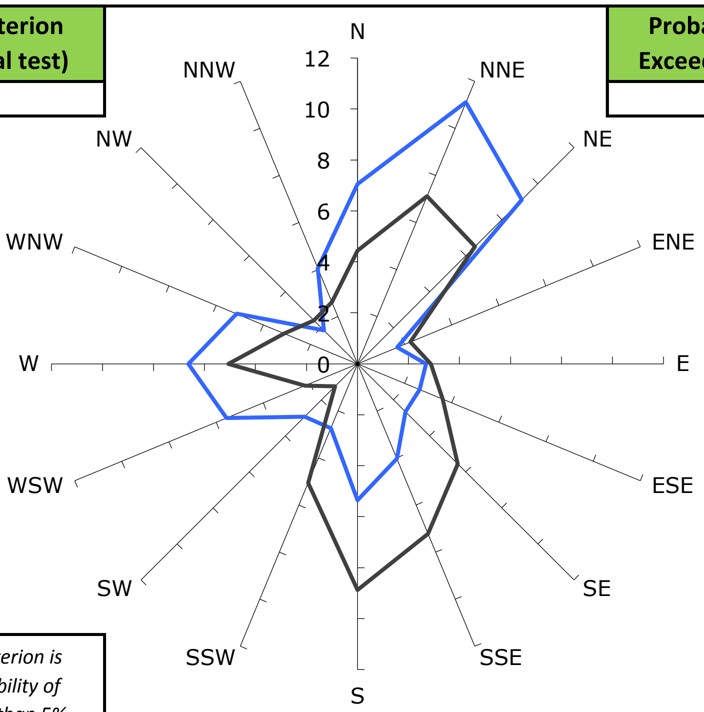
Desired Criterion
23m/s

Measured Wind Speeds at Point 15

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
7%

Probability of Criterion Exceedence (final retest)
N/A



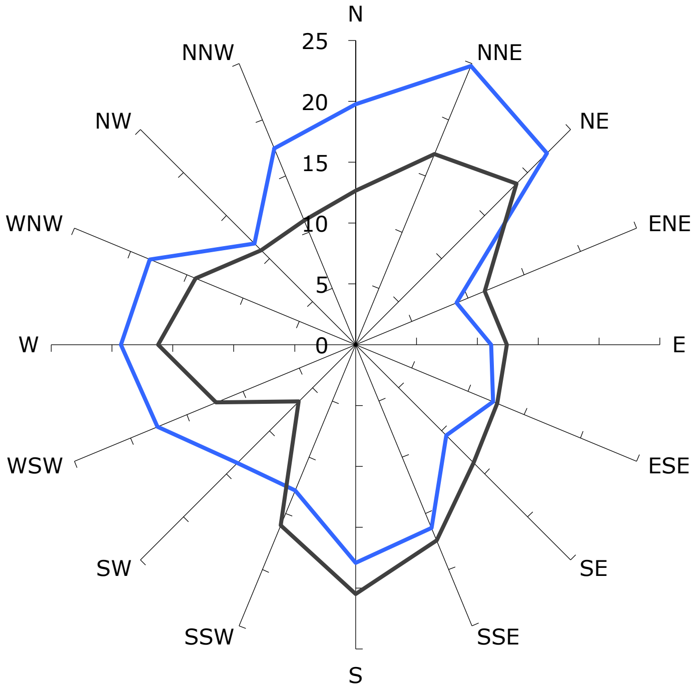
NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Existing site conditions.

Annual Maximum Gust (m/s)

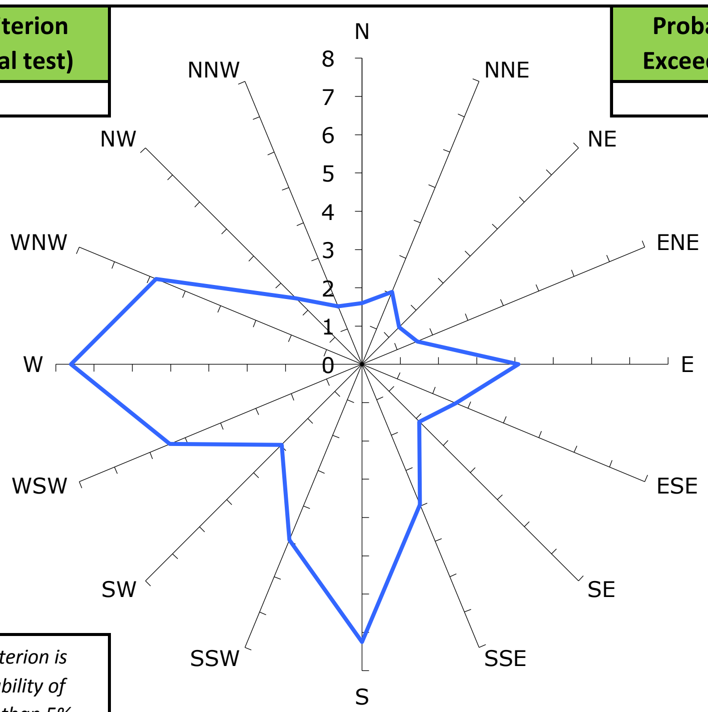


Desired Criterion
23m/s

Measured Wind Speeds at Point 16

Probability of Criterion Exceedence (initial test)	Probability of Criterion Exceedence (final retest)
2%	N/A

Weekly Maximum GEM (m/s)

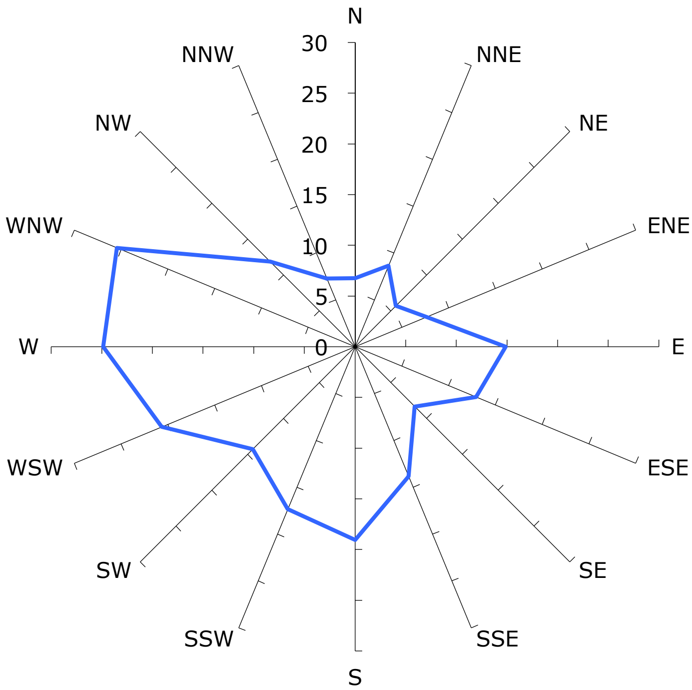


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



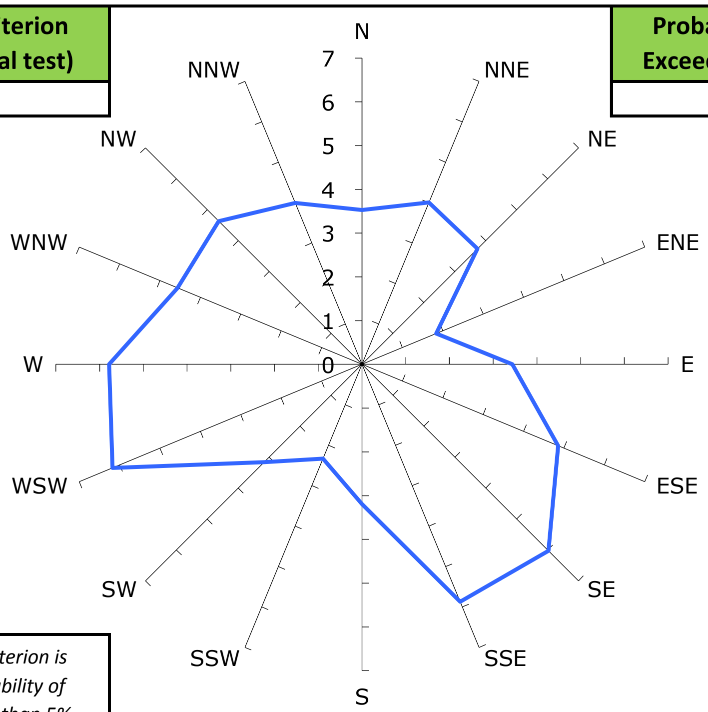
Desired Criterion
23m/s

Measured Wind Speeds at Point 17

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
2%

Probability of Criterion Exceedence (final retest)
N/A

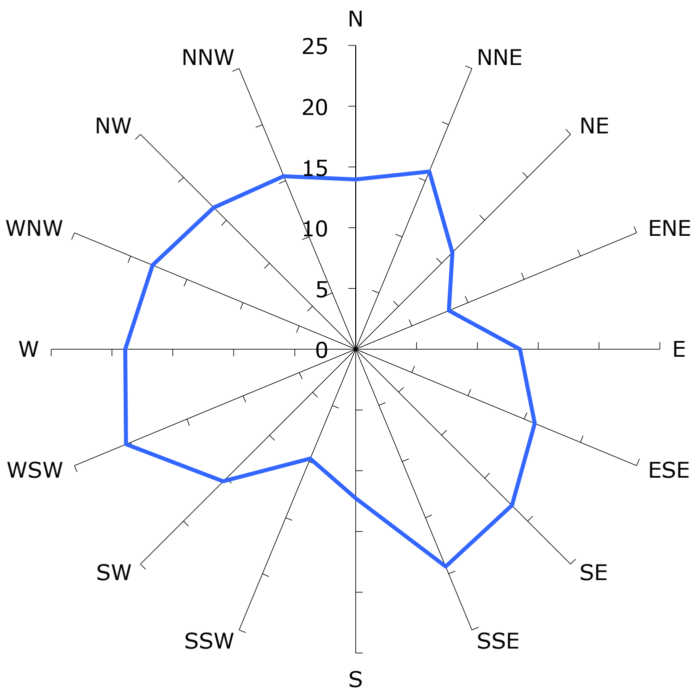


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



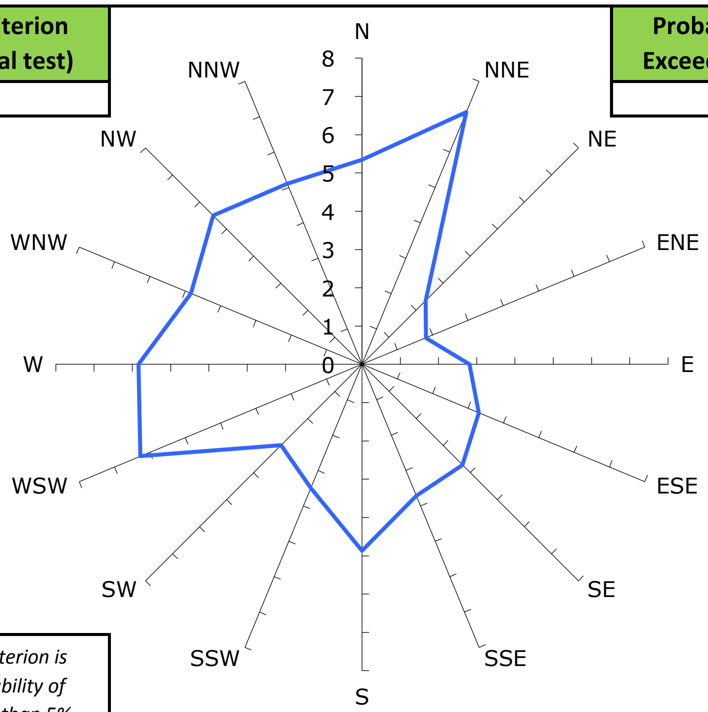
Desired Criterion
23m/s

Measured Wind Speeds at Point 18

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
2%

Probability of Criterion Exceedence (final retest)
N/A

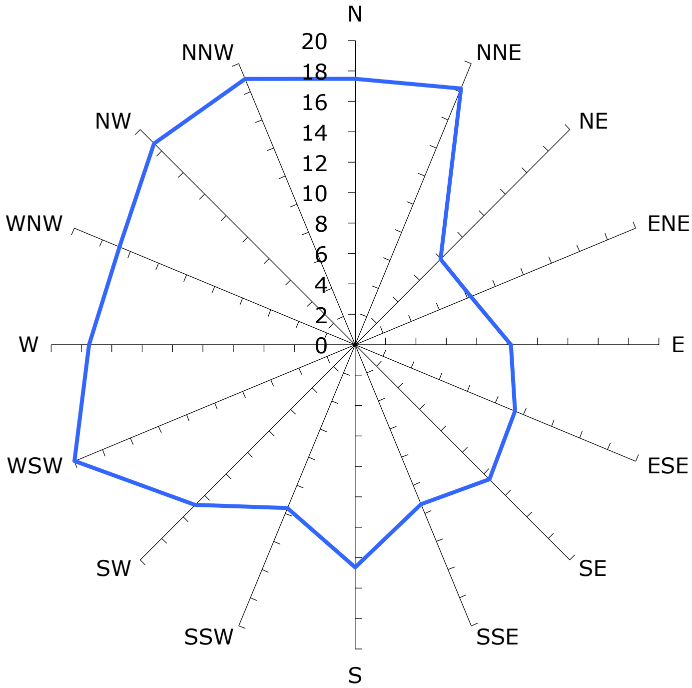


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



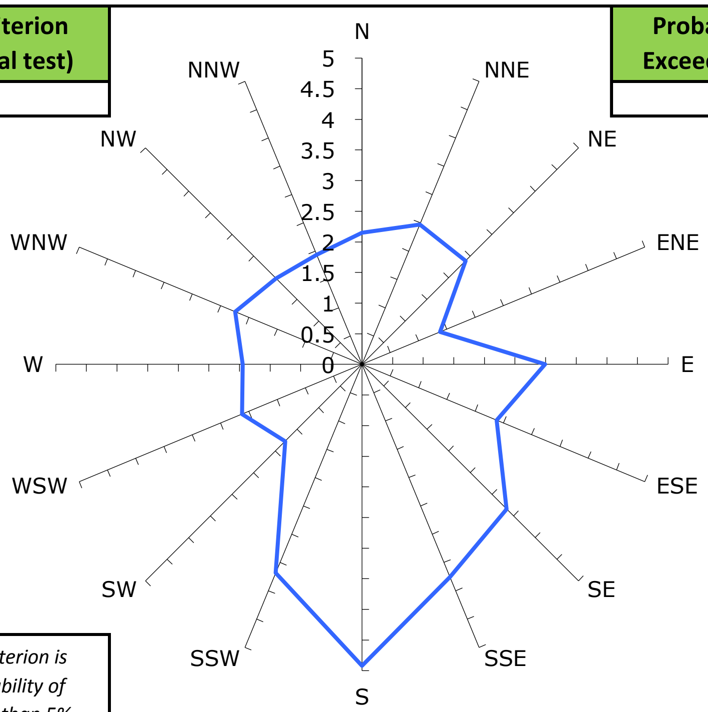
Desired Criterion
23m/s

Measured Wind Speeds at Point 19

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

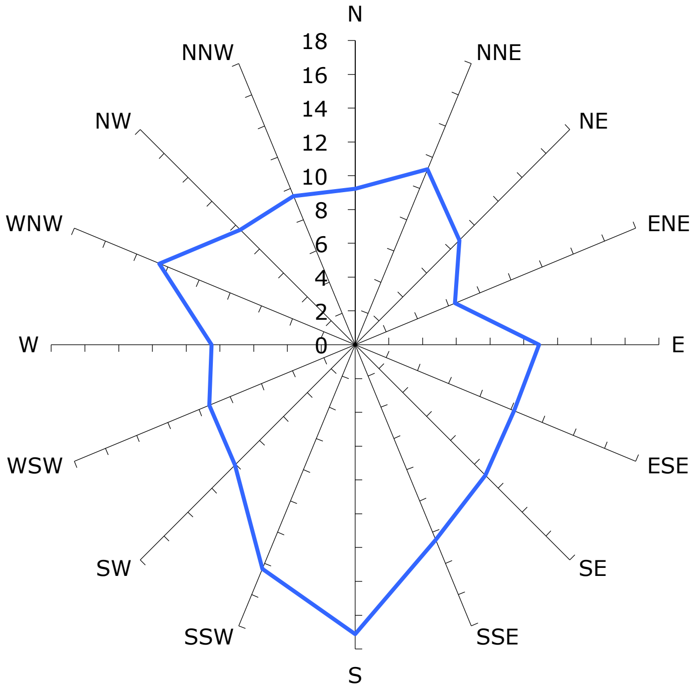


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)

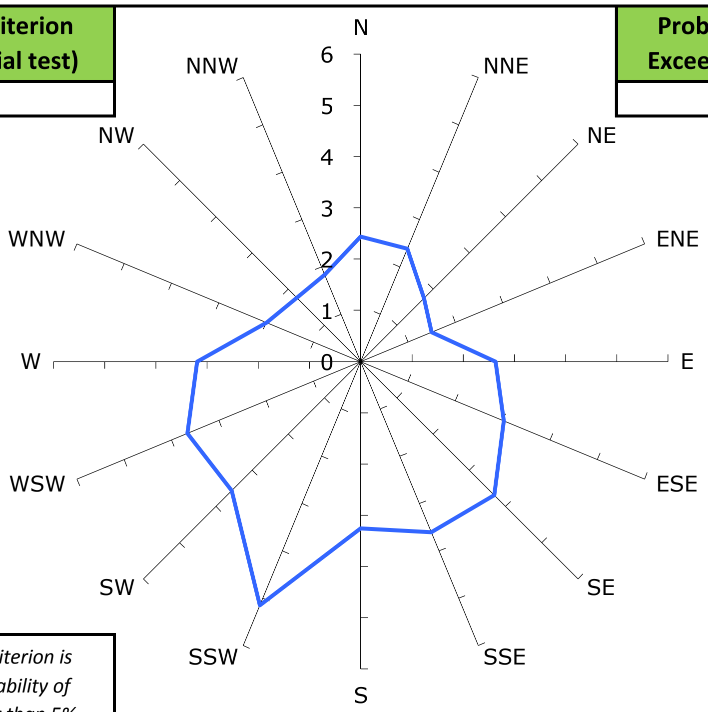


Desired Criterion
23m/s

Measured Wind Speeds at Point 20

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)	**Probability of Criterion Exceedence (final retest)**
0%	N/A

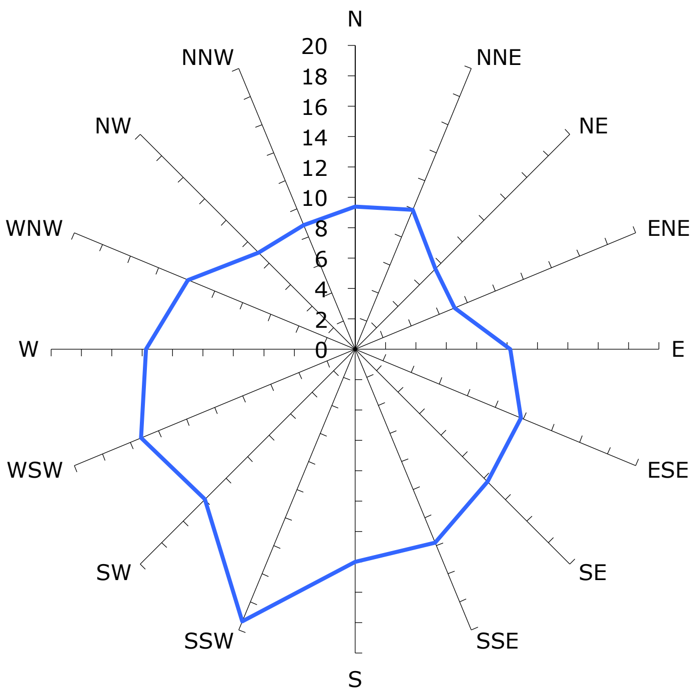


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



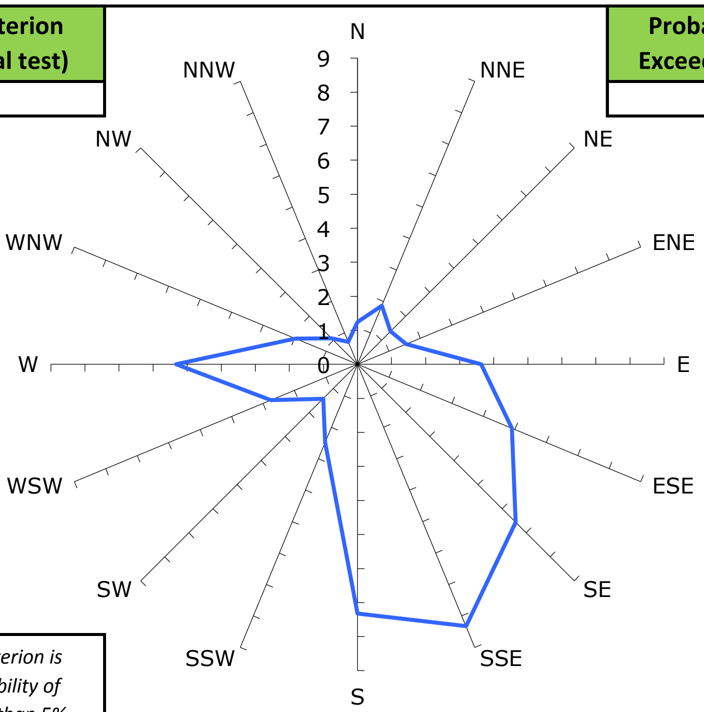
Desired Criterion
23m/s

Measured Wind Speeds at Point 21

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
4%

Probability of Criterion Exceedence (final retest)
N/A

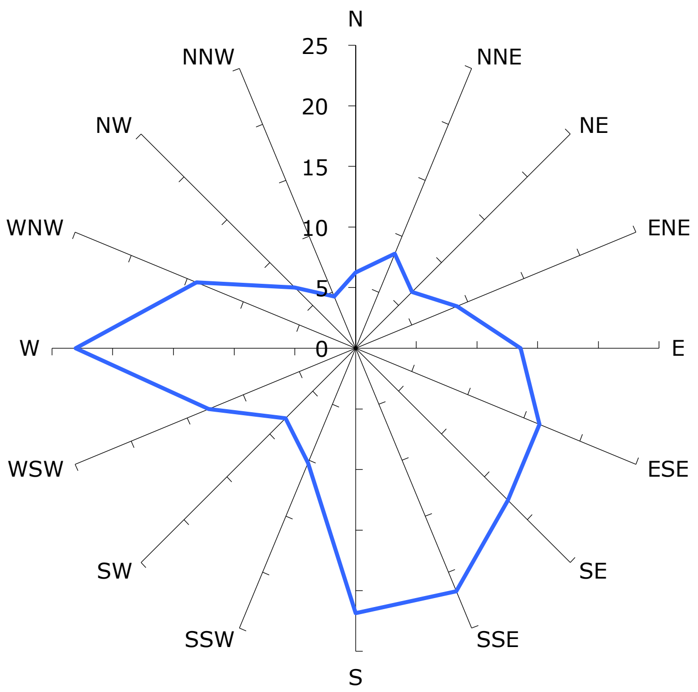


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)

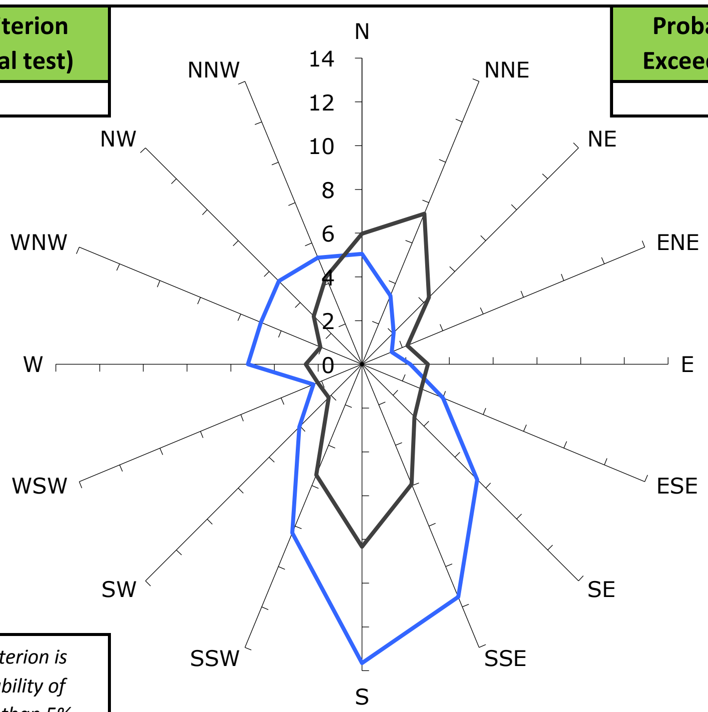


Desired Criterion
23m/s

Measured Wind Speeds at Point 22

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
14%



Probability of Criterion Exceedence (final retest)
N/A

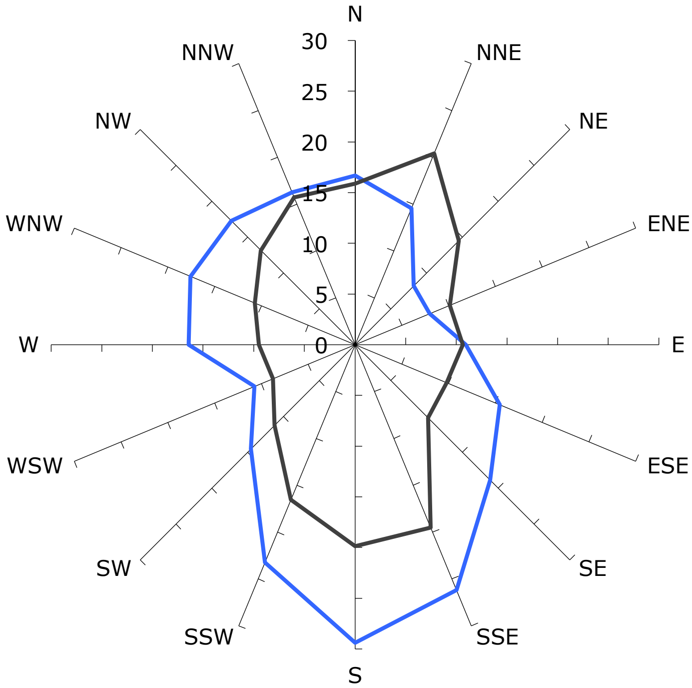
NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Existing site conditions.

Annual Maximum Gust (m/s)

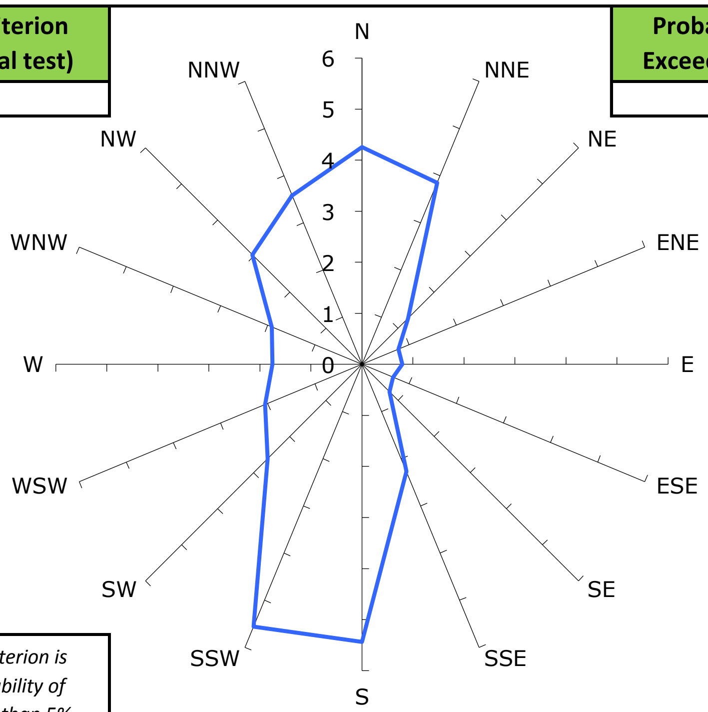


Desired Criterion
23m/s

Measured Wind Speeds at Point 23

Probability of Criterion Exceedence (initial test)	Probability of Criterion Exceedence (final retest)
0%	N/A

Weekly Maximum GEM (m/s)

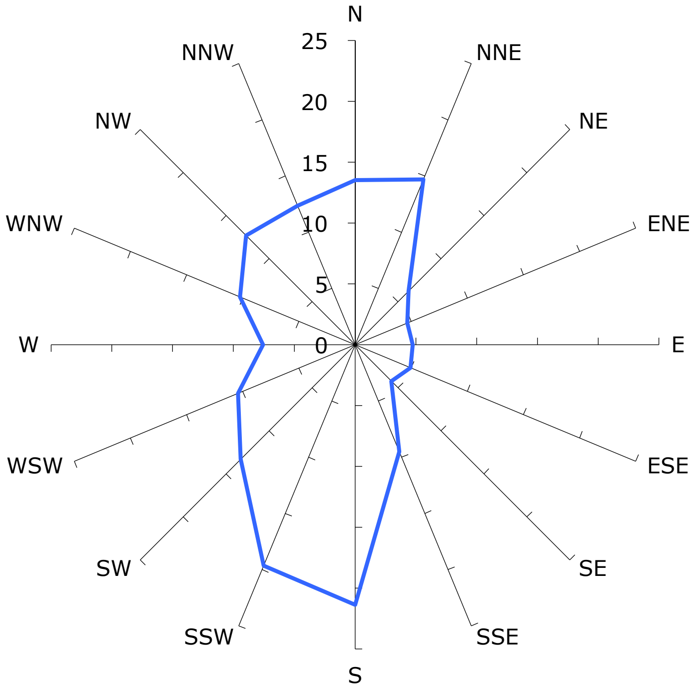


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



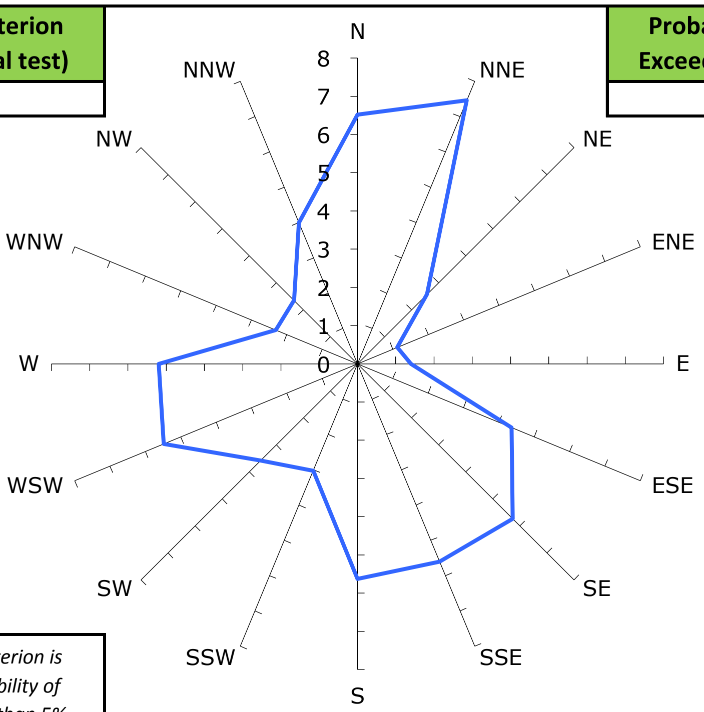
Desired Criterion
23m/s

Measured Wind Speeds at Point 24

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
3%

Probability of Criterion Exceedence (final retest)
N/A

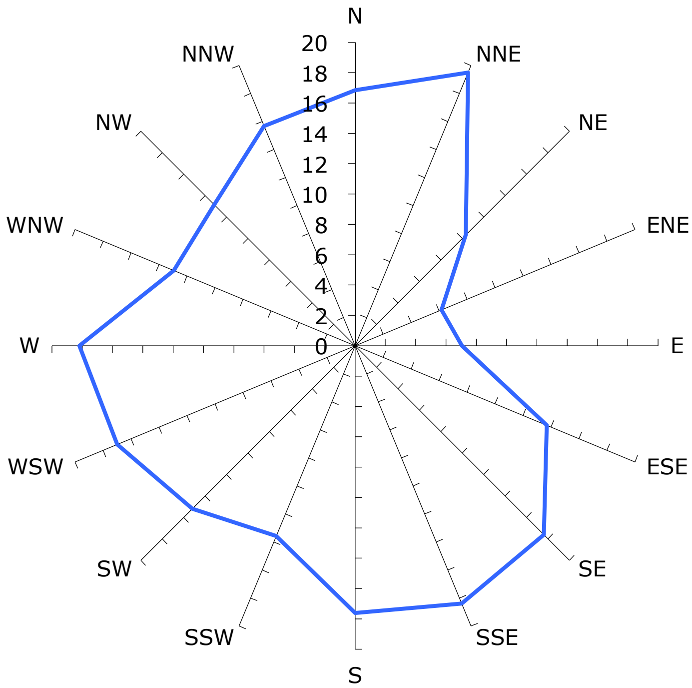


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
7.5m/s

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



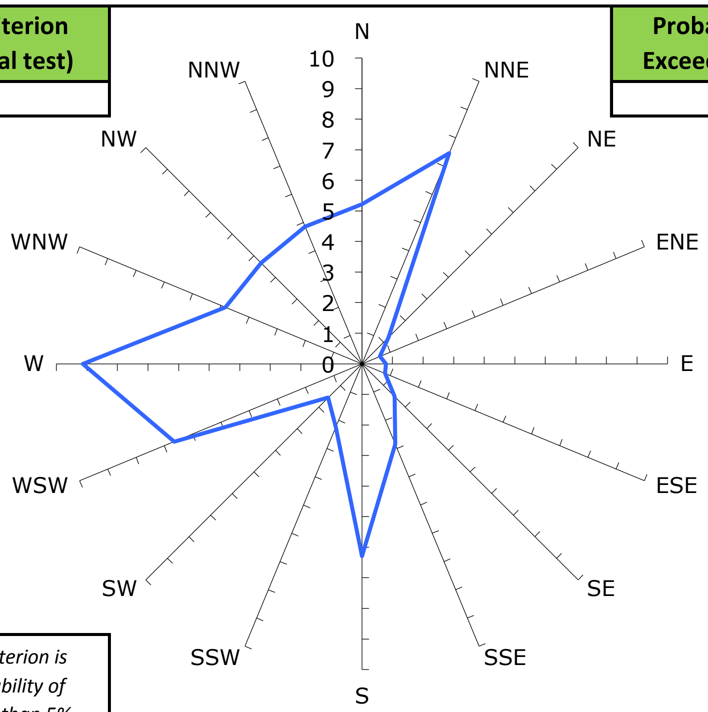
Desired Criterion
23m/s

Measured Wind Speeds at Point 25

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
N/A

Probability of Criterion Exceedence (final retest)
N/A

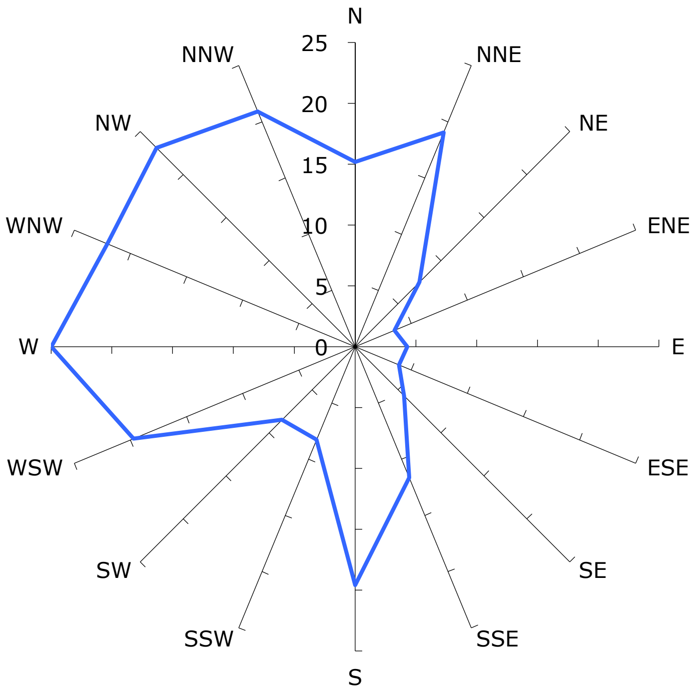


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
N/A

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



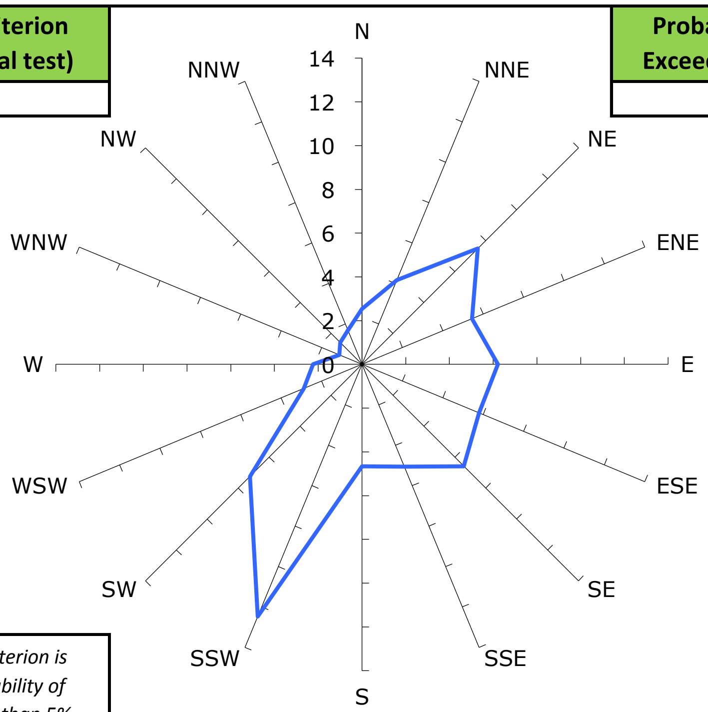
Desired Criterion
23m/s

Measured Wind Speeds at Point 26

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
N/A

Probability of Criterion Exceedence (final retest)
N/A

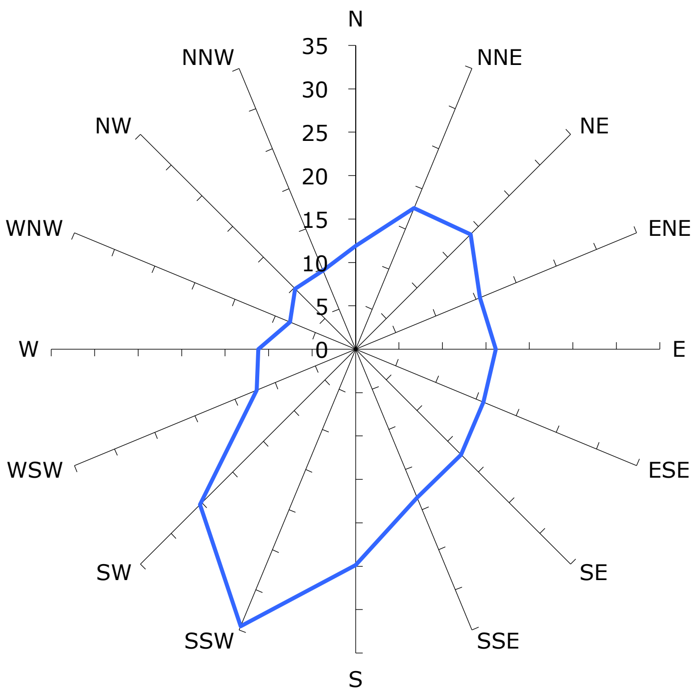


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
N/A

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



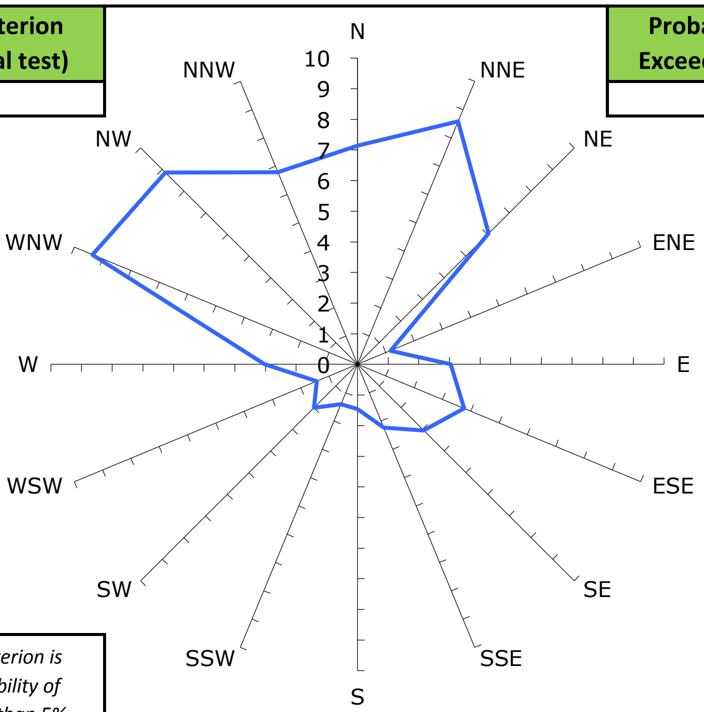
Desired Criterion
23m/s

Measured Wind Speeds at Point 27

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
N/A

Probability of Criterion Exceedence (final retest)
N/A

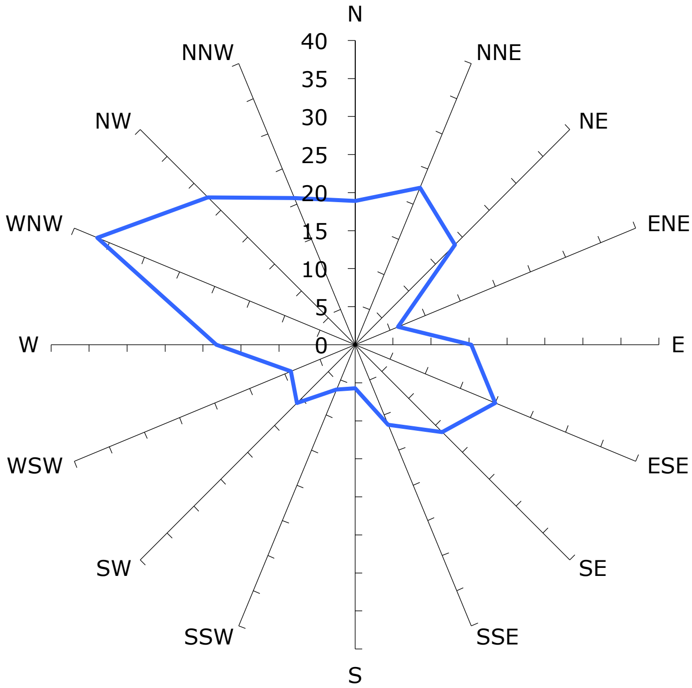


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
N/A

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)

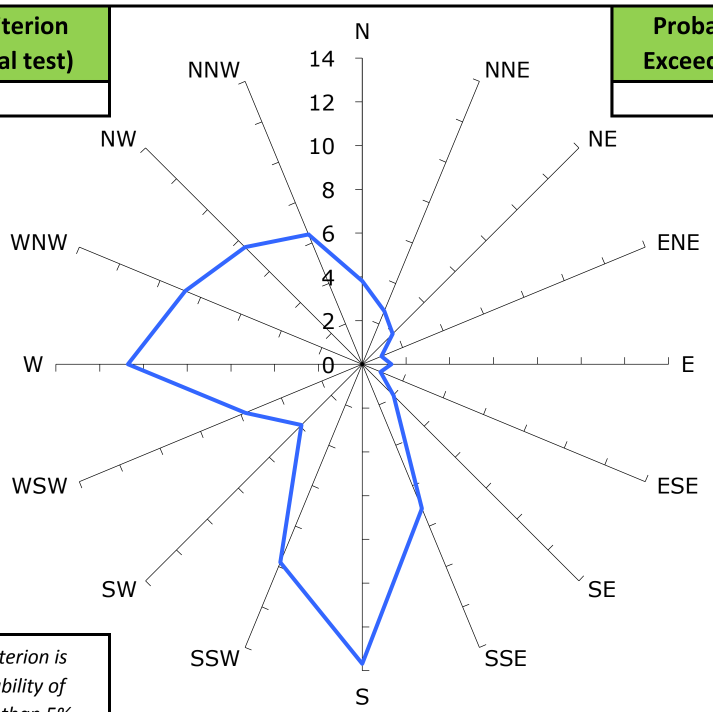


Desired Criterion
23m/s

Measured Wind Speeds at Point 28

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
N/A



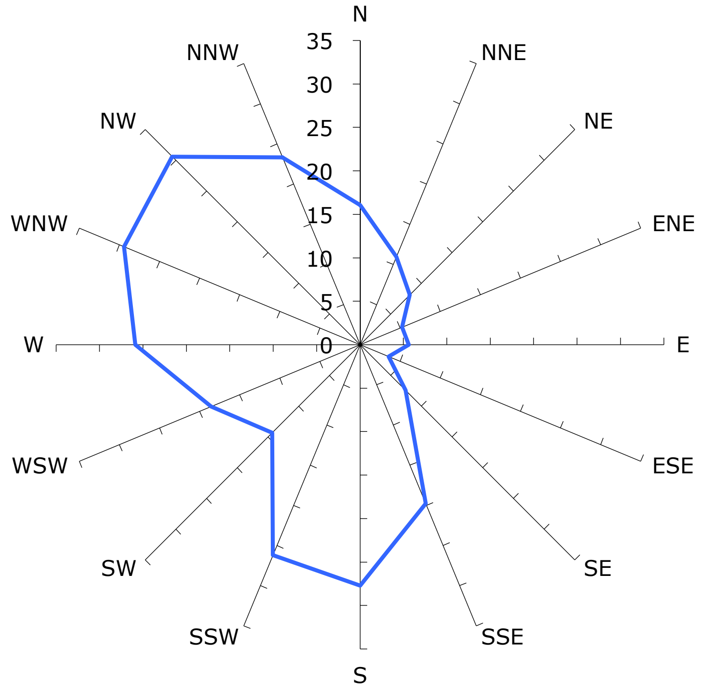
Probability of Criterion Exceedence (final retest)
N/A

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

Desired Criterion
N/A

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



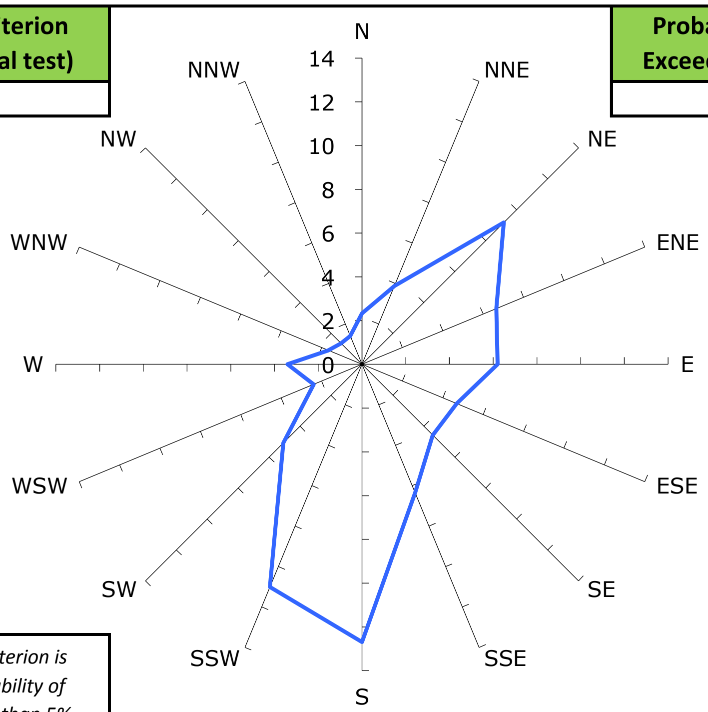
Desired Criterion
23m/s

Measured Wind Speeds at Point 29

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
N/A

Probability of Criterion Exceedence (final retest)
N/A

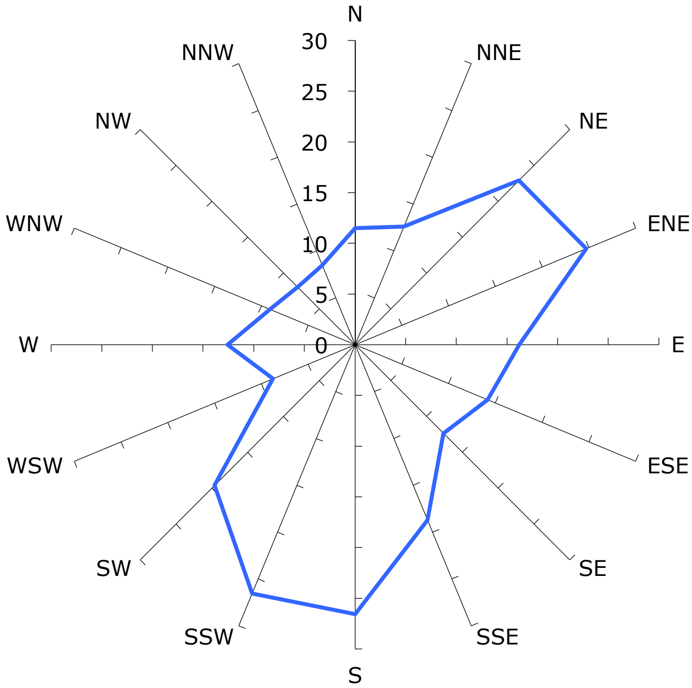


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
N/A

With development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



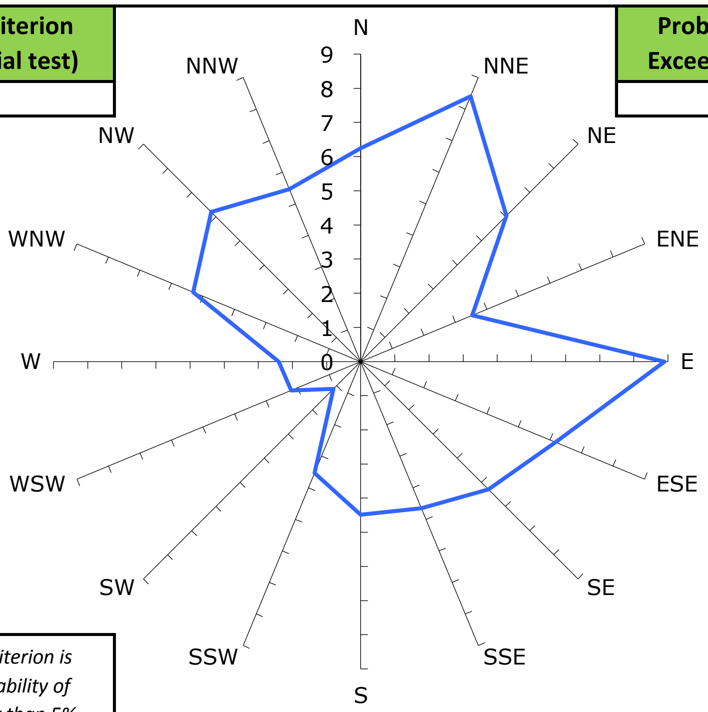
Desired Criterion
23m/s

Measured Wind Speeds at Point 30

Weekly Maximum GEM (m/s)

Probability of Criterion Exceedence (initial test)
N/A

Probability of Criterion Exceedence (final retest)
N/A

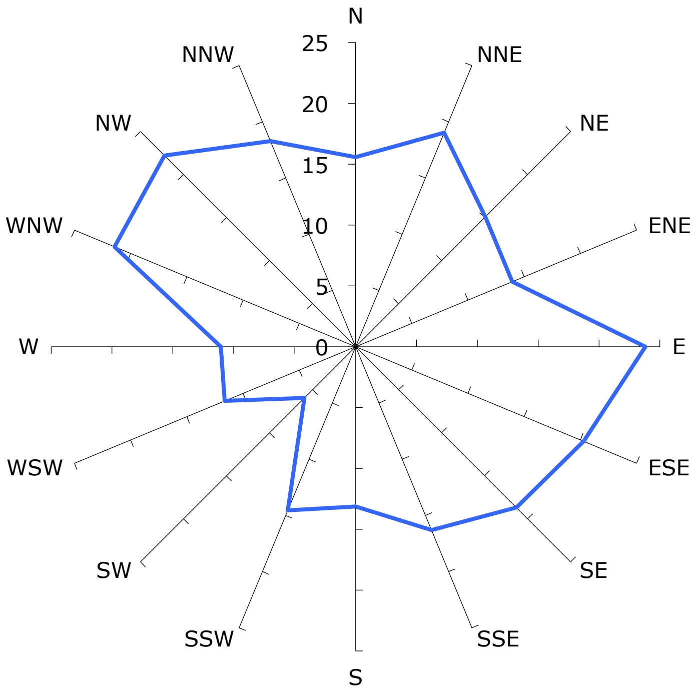


NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Desired Criterion
N/A

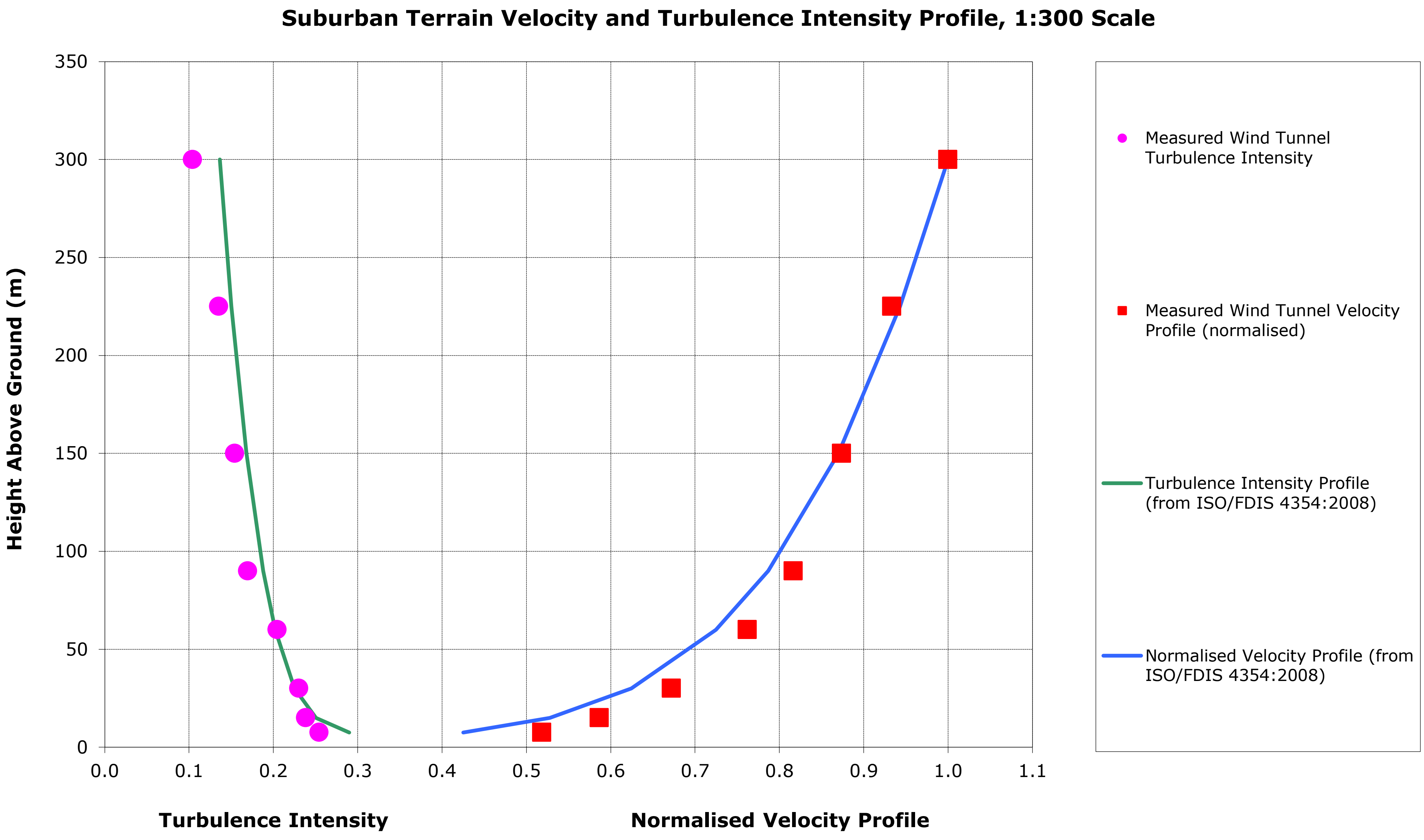
With development as proposed. No vegetation or other treatments.

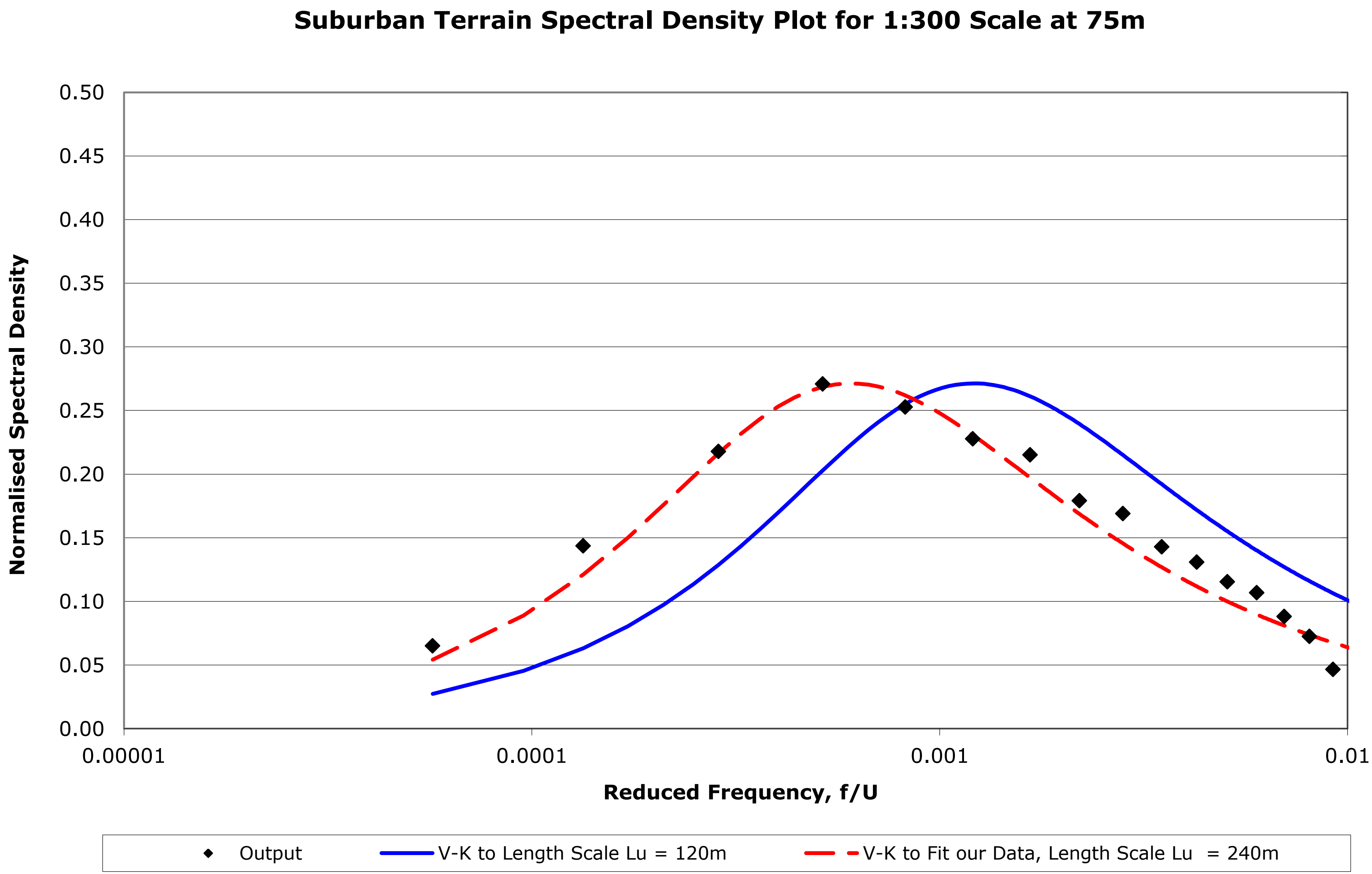
Annual Maximum Gust (m/s)



Desired Criterion
23m/s

APPENDIX B - VELOCITY AND TURBULENCE INTENSITY PROFILES


Suburban Terrain Velocity and Turbulence Intensity Profile, 1:300 Scale
Height Above Ground (m)
350
300
250
200
150
100
50
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
Turbulence Intensity
Normalised Velocity Profile
Measured Wind Tunnel Turbulence Intensity
Measured Wind Tunnel Velocity Profile (normalised)
Turbulence Intensity Profile (from ISO/FDIS 4354:2008)
Normalised Velocity Profile (from ISO/FDIS 4354:2008)


Suburban Terrain Spectral Density Plot for 1:300 Scale at 75m
Normalised Spectral Density
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.00001
0.0001
0.001
0.01
Reduced Frequency, f/U
Output
V-K to Length Scale Lu = 120m
V-K to Fit our Data, Length Scale Lu = 240m