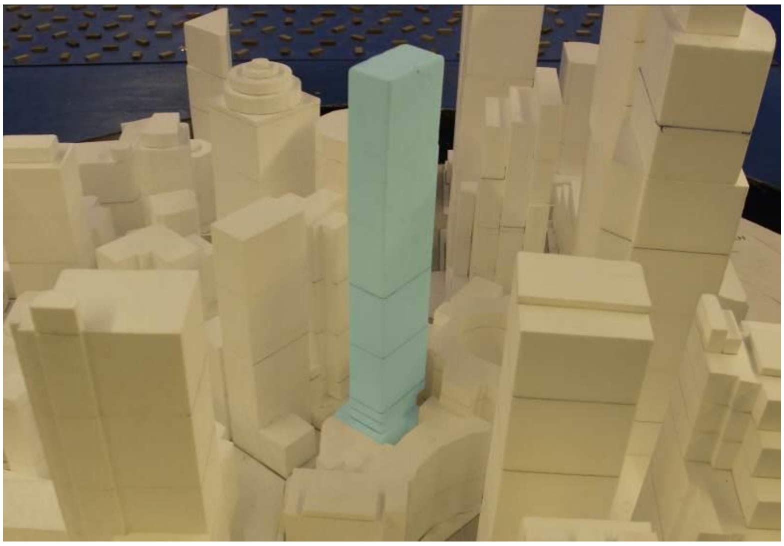

4-6 BLIGH STREET, SYDNEY

PEDESTRIAN WIND ENVIRONMENT STUDY

WD690-04F02(REV0)- WE REPORT

AUGUST 24, 2017

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DOCUMENT CONTROL

Date	Revision History	Issued Revision	Prepared By (initials)	Instructed By (initials)	Reviewed & Authorised by (initials)
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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 4-6 Bligh Street, Sydney. 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 outdoor locations within and around the development (including locations as specified in the Draft City of Sydney DCP - 2012) from 16 wind directions at 22.5 degree increments using a 1:300 scale detailed model. 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 375m.

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 study 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. It is noted that the Draft City of Sydney DCP – 2012 outlines the bases case development envelope for frontage heights and street setbacks. Therefore, to determine the impact of the proposed development design and the base case design on existing wind conditions the following three cases have been examined as part of this study:

- Existing Site Scenario: Includes the existing 4-6 Bligh Street building and existing adjacent buildings.
- Concept design scheme (Proposed Scenario): Includes the proposed development design with the existing adjacent buildings.
- Base case building massing (Compliant Scenario) – Subject development has a podium height of 25m, setbacks (front, rear and side) defined as per the specifications of the Draft City of Sydney DCP (2012) using a tower height of 245m.

The results of the study indicate with the inclusion of the proposed scenario that all ground level areas along Bligh Street satisfy the appropriate wind comfort and safety criteria as outlined in the Draft City of Sydney DCP – 2012. However, the results of the study indicated that a number of areas on the proposed podium roof experience exceedances of the appropriate comfort criteria. These exceedances occur for winds primarily from the West and South towards the building corners where these winds tend to be accelerated. It should be noted that there was no exceedances of the safety limit criteria at the podium roof area for the proposed development design scenario. To improve the wind conditions at the podium roof areas it is recommended that an awning be included along the Western aspect of the tower to wrap around both the northern and southern aspects of the tower. It is expected that further podium roof landscaping and screening would also improve wind conditions in these areas.

Further testing of the Compliant Scenario provided results that were similar to or worse than the proposed test scenario and Existing site conditions.

CONTENTS

1 WIND CLIMATE FOR THE SYDNEY REGION

Details of the wind climate of the Sydney region have been determined from a detailed statistical analysis of measured mean wind speed data from the meteorological observation station located at Kingsford Smith airport (Sydney Airport). The data has been collected from this station from 1995 to 2016 between 6am to 10pm, and corrected so that it represents winds over standard open terrain at a height of 10m above ground. The corrected data is summarised Table 1 for the weekly and annual return periods in the form of hourly means and the corresponding 3-second gust values. These directional wind speeds are also presented in Figure 1 (referenced as hourly mean wind speeds), as well as the directional frequency of occurrences for the region.

The data indicates that, for the weekly and annual return periods, the southerly winds are by far the most frequent winds for the Sydney region, and are also the strongest. 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 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 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: Directional Mean and Gust Wind Speeds for the Sydney Region (referenced to 10m height above ground in standard open terrain)

Wind Direction	Reference Wind Speeds (m/s)			
	Weekly Recurrence		Annual Recurrence	
	Hourly Mean	3-second Gust	Hourly Mean	3-second Gust
N	5.9	9.1	9.9	15.1
NNE	9.9	15.1	12.9	19.6
NE	9.7	14.7	12.3	18.8
ENE	7.5	11.5	10.0	15.3
E	6.3	9.6	9.3	14.2
ESE	6.2	9.5	9.1	13.8
SE	7.0	10.6	10.1	15.4
SSE	8.5	13.0	12.2	18.6
S	10.3	15.7	13.9	21.3
SSW	10.0	15.3	14.1	21.5
SW	6.9	10.5	11.9	18.1
WSW	9.3	14.2	13.6	20.7
W	9.8	15.0	14.4	22.0
WNW	8.8	13.4	14.3	21.9
NW	6.7	10.2	12.6	19.2
NNW	5.5	8.4	10.7	16.4

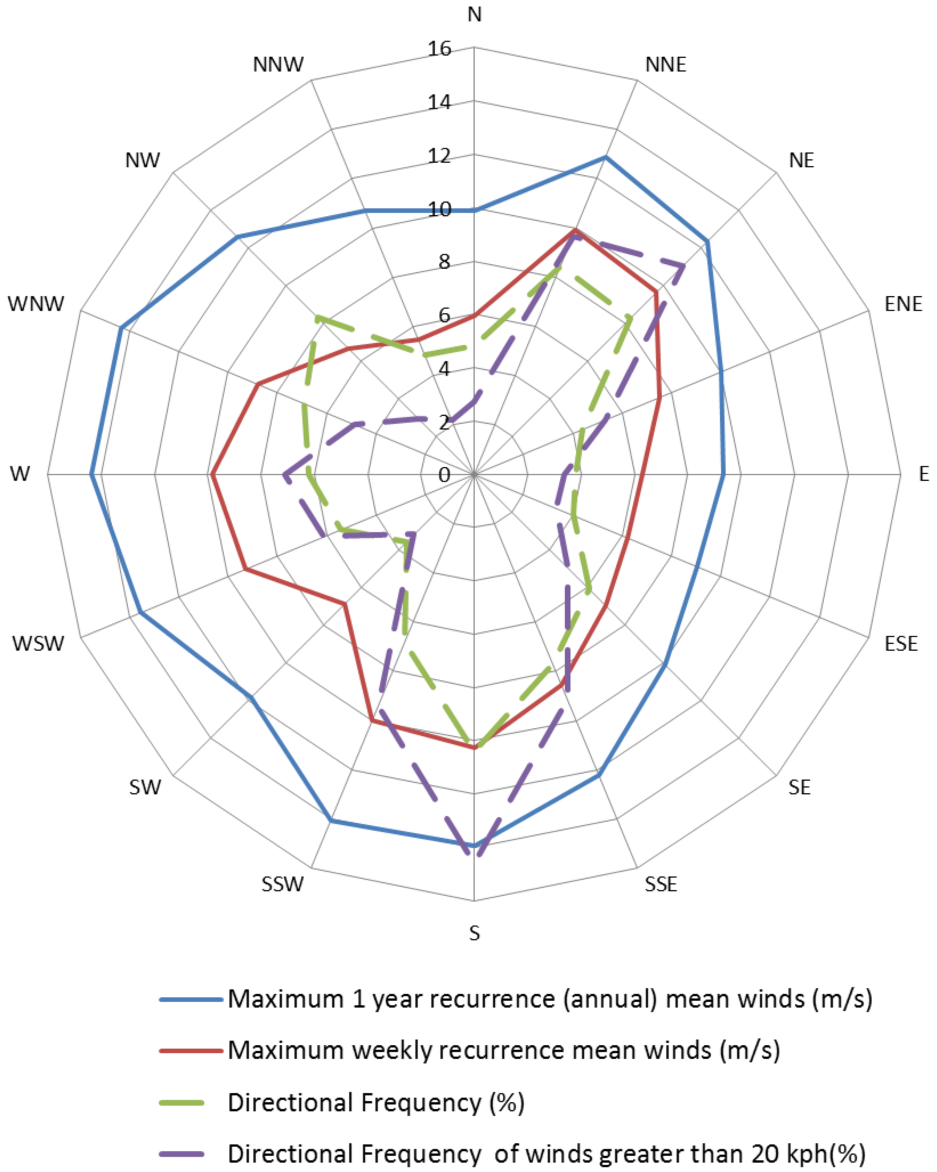

Figure 1: Directional Hourly Mean Wind Speeds, and Frequencies of Occurrence, for the Sydney Region (for the annual and weekly return periods, referenced to standard open terrain at a height of 10m above ground)

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 1:300 scale models. The study models incorporate all necessary architectural features on the development to ensure an accurate wind flow is achieved around the models. A proximity model has also been constructed and represents the surrounding buildings and significant topographical effects within a radius of 375m, centred on the development site. The following three cases have been examined as part of this study:

- Existing Site Scenario: Includes the existing 4-6 Bligh Street building and existing adjacent buildings, as indicated in Figures 2d to 2e.
- Concept design scheme (Proposed Scenario): Includes the proposed development design with the existing adjacent buildings, as indicated in Figures 2a to 2c.
- Base case building massing (Compliant Scenario) – Subject development has a podium height of 25m, setbacks (front, rear and side) defined as per the specifications of the Draft City of Sydney DCP (2012) using a tower height of 245m, as indicated in Figures 2f to 2g.

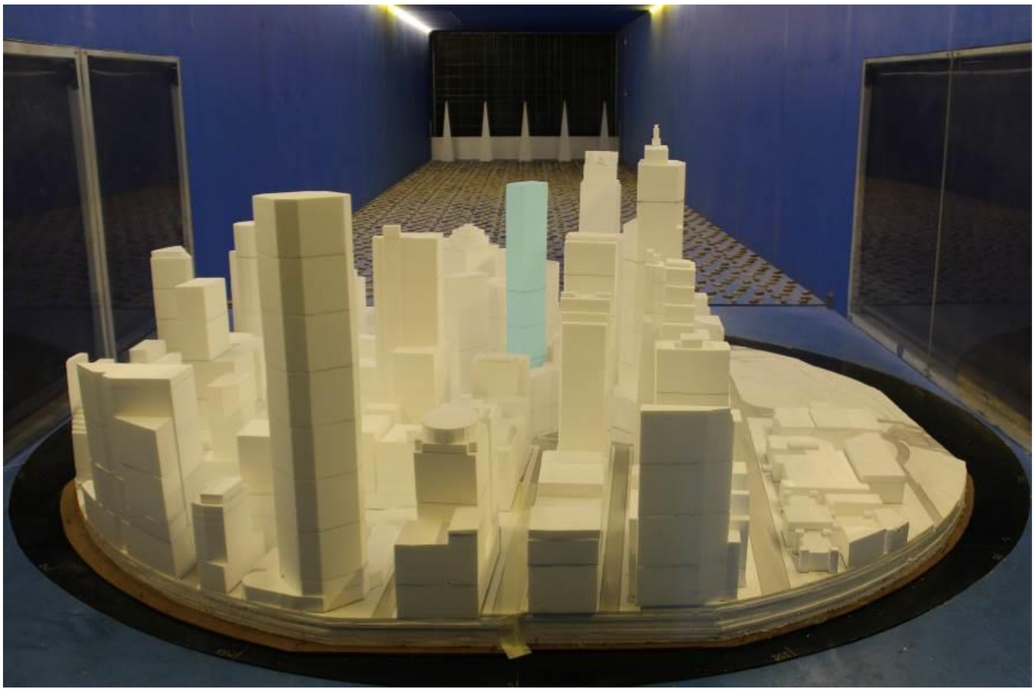

Figure 2a: Photograph of the Wind Tunnel Model – Proposed Scenario (view from the south)

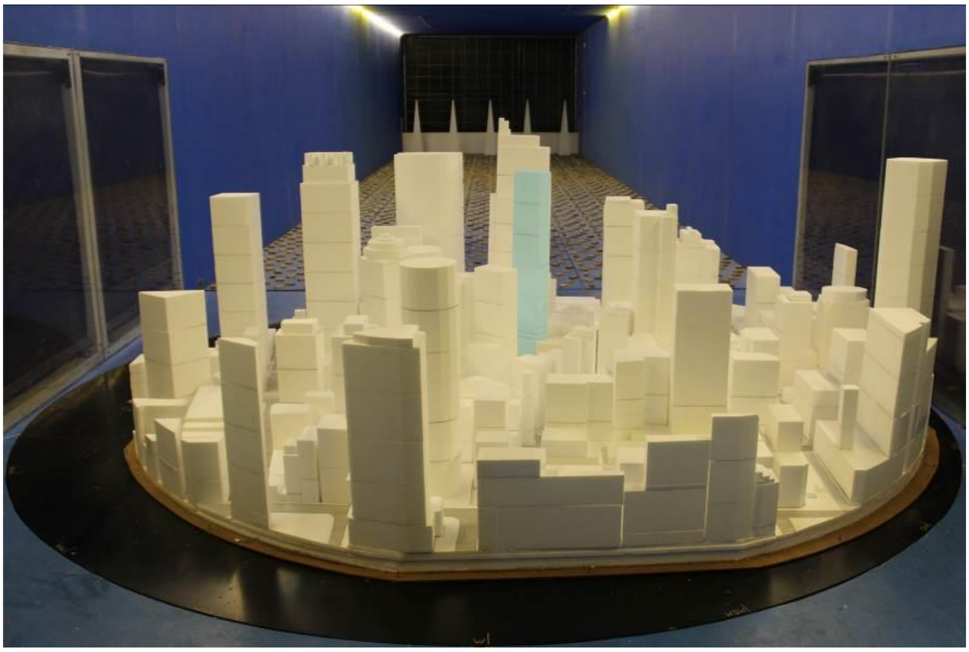

Figure 2b: Photograph of the Wind Tunnel Model– Proposed Scenario (view from the west)

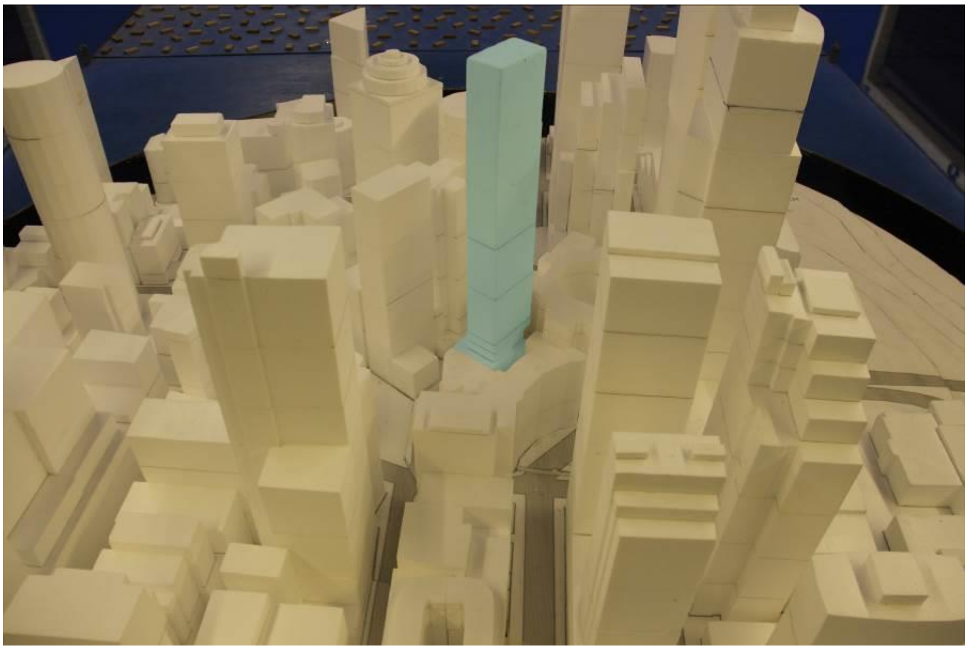

Figure 2c: Photograph of the Wind Tunnel Model – Proposed Scenario (view from the south)

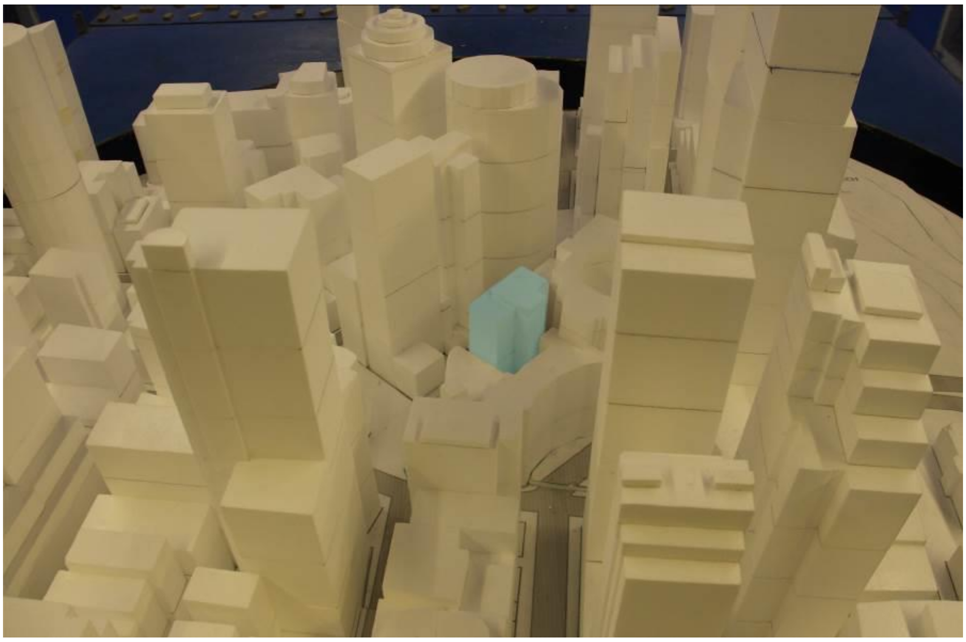

Figure 2d: Photograph of the Wind Tunnel Model – Existing Scenario (view from the south)

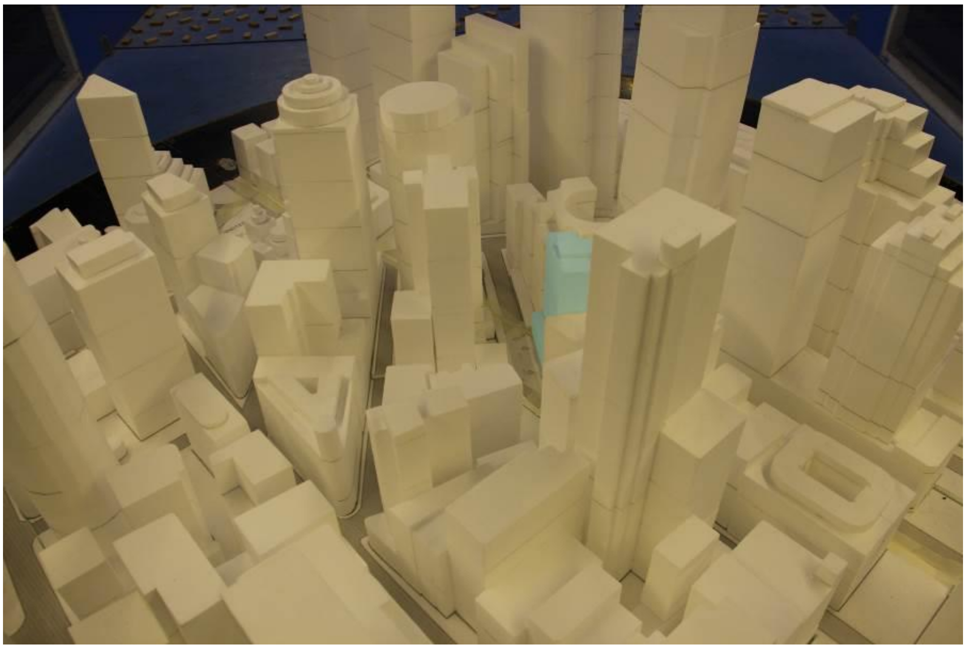

Figure 2e: Photograph of the Wind Tunnel Model – Existing Scenario (view from the south-west)

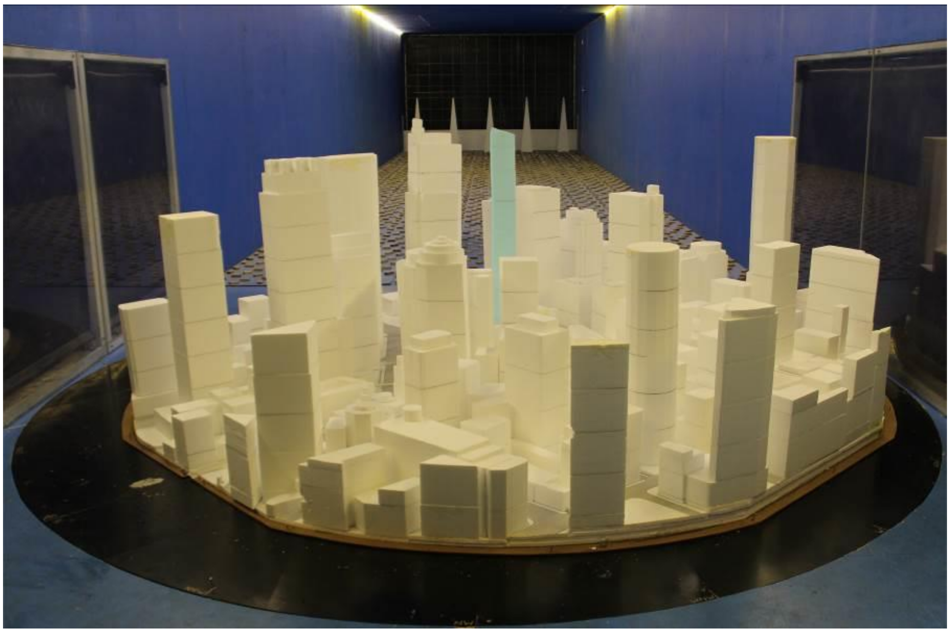

Figure 2f: Photograph of the Wind Tunnel Model – Compliant Scenario (view from the north-west)

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

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 oceans, inland and enclosed water bodies such as lakes, dams, rivers, etc.
- **Terrain Category 1.5:** Relatively flat terrain. Examples include flat deserts and 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 90m 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 I_v	Roughness Length (m) $z_{0,r}$
	$k_{tr,T=3600s}$ *(hourly)*	$k_{tr,T=600s}$ *(10-minute)*	$k_{tr,T=3s}$ *(3-second)*		
1.0	1.02	1.05	1.32	0.098	0.003
1.5	0.97	1.00	1.30	0.114	0.01
2.0	0.92	0.95	1.28	0.131	0.03
2.5	0.85	0.89	1.25	0.157	0.1
3.0	0.77	0.82	1.21	0.188	0.3
3.5	0.68	0.72	1.16	0.237	1
4.0	0.57	0.62	1.09	0.309	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 5.4km 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 extent of the proximity model. Plots of the wind tunnel boundary layer wind profiles are presented in Appendix B of this report.

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	0.76	0.80	1.21
30	0.81	0.85	1.23
60	0.92	0.96	1.28
90	0.90	0.94	1.27
120	0.78	0.82	1.21
150	0.82	0.85	1.23
180	0.74	0.79	1.20
210	0.68	0.72	1.16
240	0.78	0.82	1.21
270	0.82	0.86	1.23
300	0.91	0.94	1.27
330	0.86	0.90	1.26

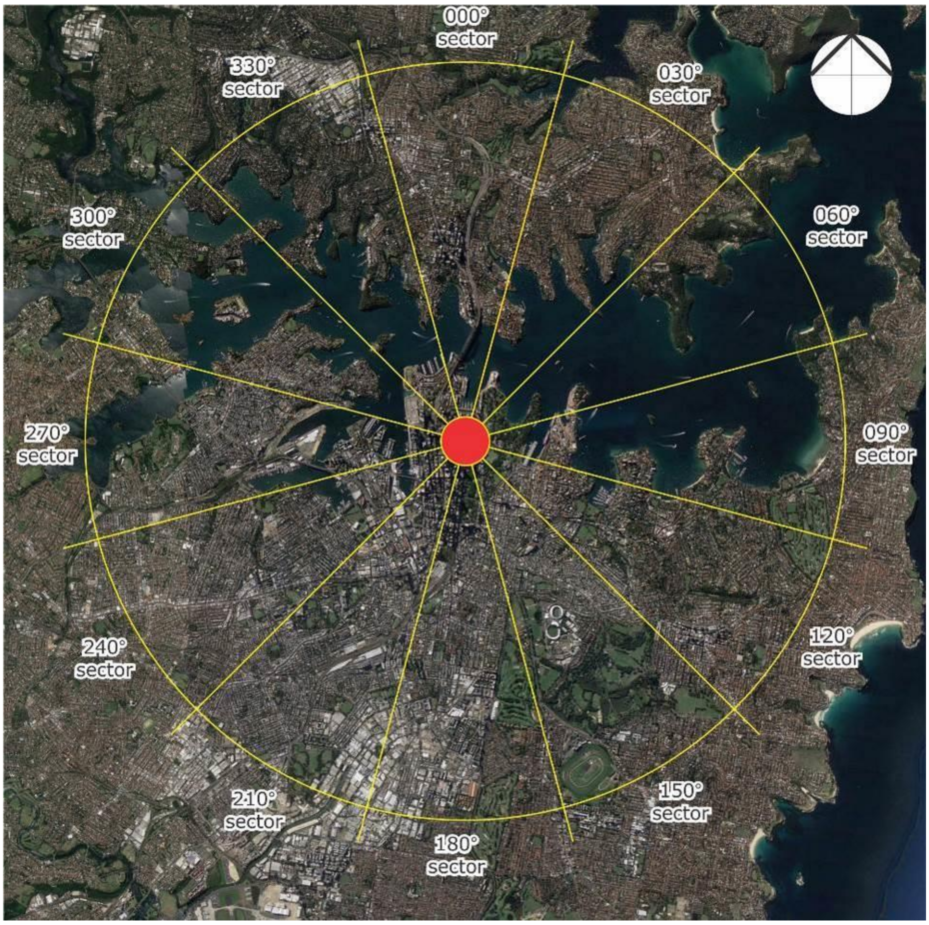

Figure 3: Aerial Image of the Surrounding Terrain (radius of 5.4km from the edge of the proximity model, which is coloured red)

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

Table 5: Criteria by A.G. 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 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 (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 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 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 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%.

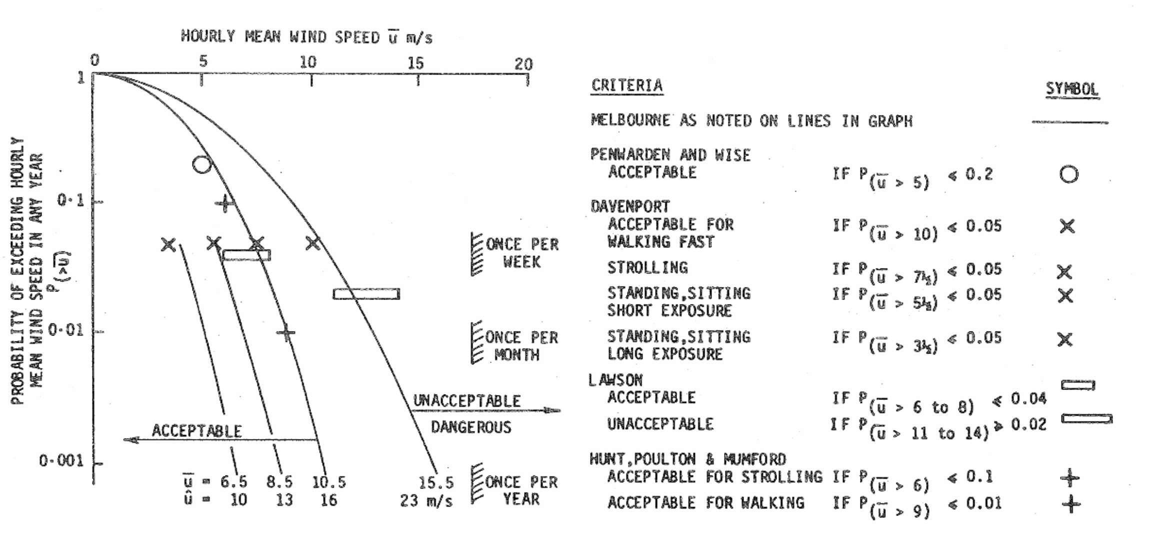

Figure 4: Comparison of Various Mean and Gust Wind Environment Criteria, assuming 15% turbulence and a Gust Factor of 1.5 (after W.H. Melbourne, 1978)

4.3 Wind Speed Criteria Used for This Study

For this study, the measured wind conditions for the various critical outdoor trafficable areas around the subject development are compared against the criteria presented in the Draft City of Sydney DCP (2012). For comfort, Draft City of Sydney DCP (2012) Central Sydney Planning Review Agreement requires that the hourly mean wind speed, or gust equivalent mean wind speed (GEM), whichever is greater for each wind direction, must not exceed 8m/s for comfortable walking and 6m/s for standing. Similarly, the safety limit criterion of annual maximum peak 0.5 second gust wind speed of 24m/s is also applied to all areas.

The existing conditions for the pedestrian footpaths around the site are also analyzed as part of this study to determine the impact of the subject development. If it is found that the existing conditions exceed the relevant criteria, then the target wind speed for that area with the inclusion of the proposed development is to at least match the existing site conditions with an upper limit bound of the safety limit criterion of 24m/s for the annual maximum peak gust wind speeds.

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

- **Draft City of Sydney DCP Requirement Wind Comfort Standards for Comfortable Walking, Standing and Safety:**
    - 8m/s gust equivalent mean wind speed for comfortable walking.
    - 6m/s gust equivalent mean wind speed for standing.
    - Safety Limit: 24.0m/s annual maximum gust wind speeds.
- **Existing Conditions:** Where relevant, if the existing site conditions exceed the City of Sydney DCP (2012) 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, and should be less than the 24m/s safety limit criterion.

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 Draft City of Sydney DCP (2012) criteria for the maximum GEM wind speeds (which are representative of approximately a weekly recurrence), and the other comparing to the Draft City of Sydney DCP (2012) 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 3.0 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.
- Long Exposure applies to outdoor dining areas in restaurants, 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, 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-1-2001), ASCE 7-10 (Chapter C31), and CTBUH (2013) guidelines.

The various models used for the study were 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 the 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 3-second 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 3s gust and 3.4 for a 0.5s gust

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 9.6m/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 14 seconds was used for each wind direction tested, which is equivalent to a minimum sample time of approximately 30 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 comprises of 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 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:

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

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:

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

$C_{V,study}$ 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 45deg sectors.

5.2.2 Weekly 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 Draft DCP criteria (2012), which is used in this study, is referenced to a probability of exceedance of 5.5% of a specified wind speed and is representative of approximately a weekly recurrence interval.

5.3 Layout of Study Points

In this study, 7 study point locations have been selected for the Existing Scenario, 13 study point locations for the Proposed Scenario, and 13 study point locations for the Compliant Scenario for analysis in the wind tunnel. This includes the following:

- 4 study points at Ground Level along the pedestrian footpath and 3 study points in the middle of the Bligh Street (as specified in the Draft City of Sydney DCP - 2012). The selected study points are common between all three tested cases.
- 6 study points on the Podium Level for the Proposed and Compliant Scenarios.

The locations of the various study points tested for this study are presented in Figures 5a to 5d 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.

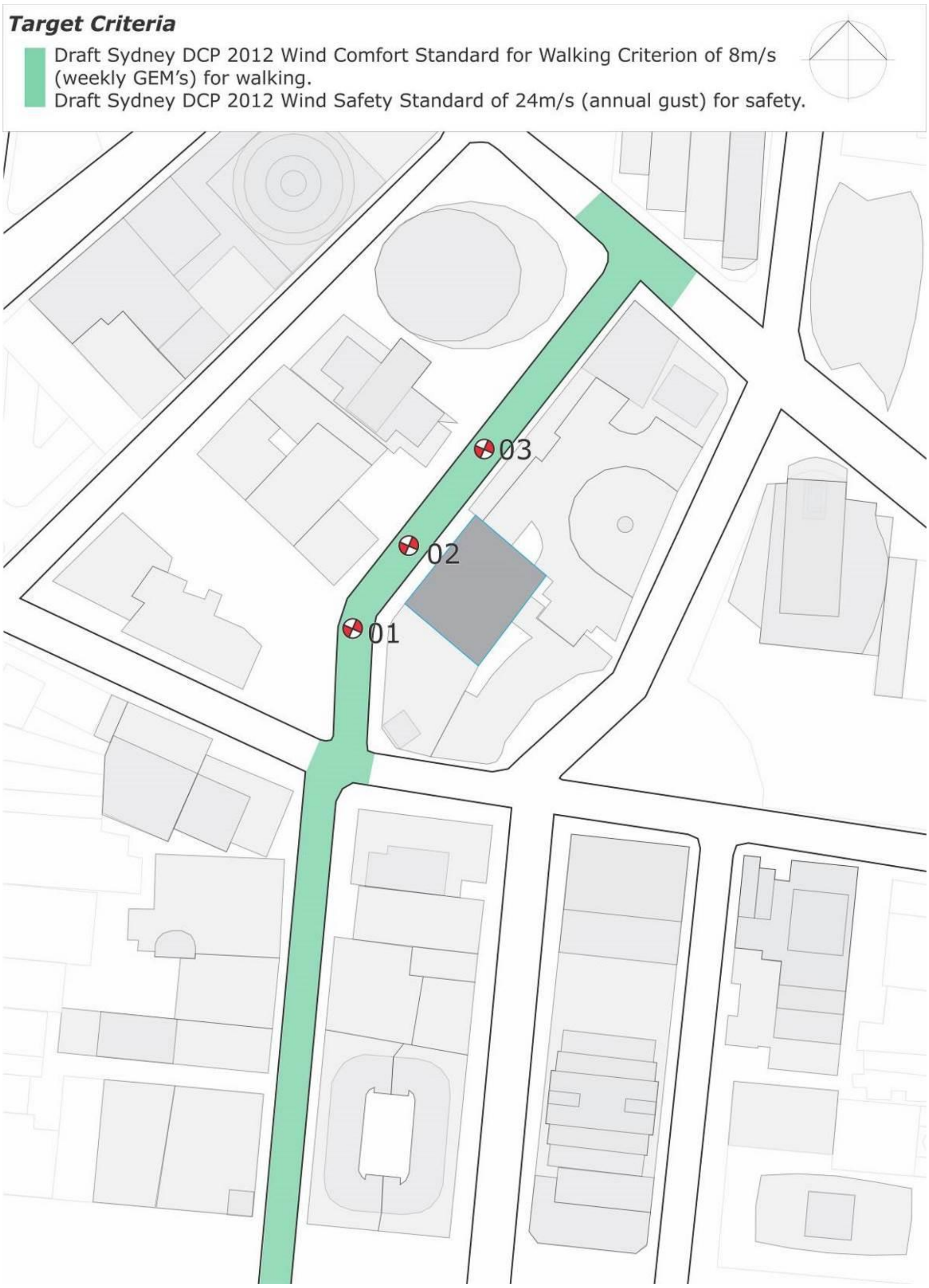

Figure 5a: Study Point Locations and Wind Speed Criteria – Surrounding Areas (Existing, Proposed and Compliant Scenarios)

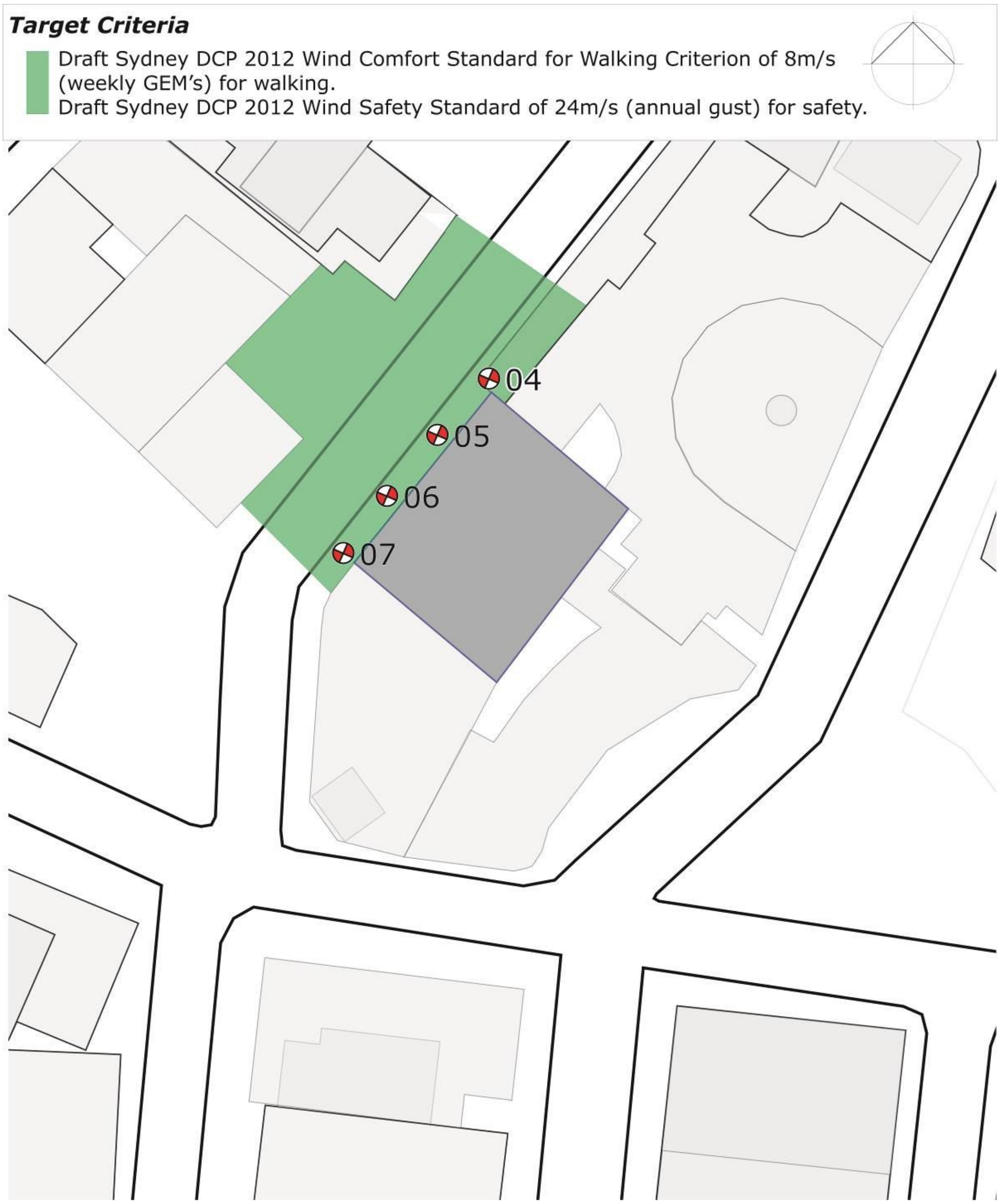

Figure 5b: Study Point Locations and Wind Speed Criteria – Ground Floor (Existing, Proposed and Compliant Scenarios)

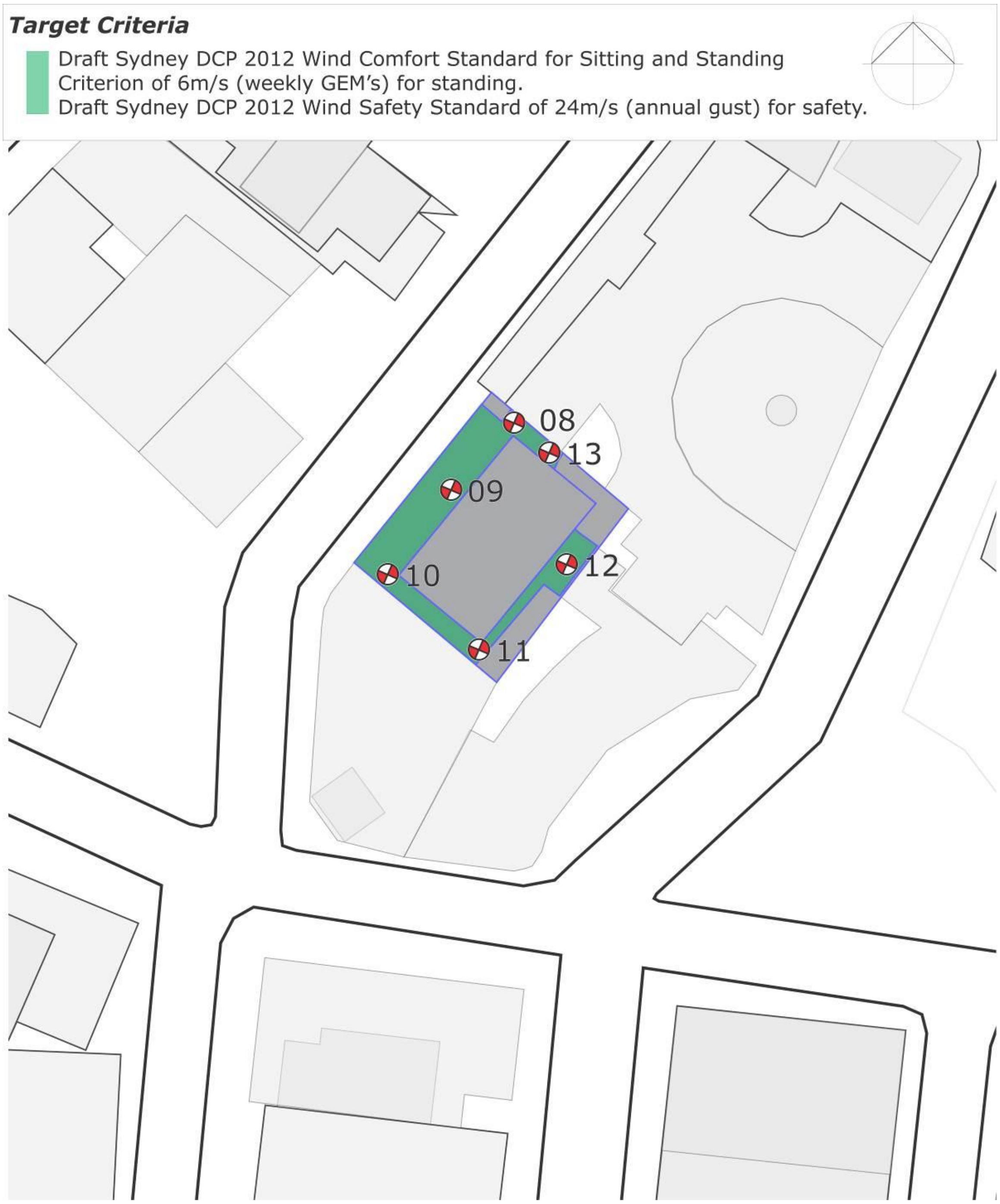

Figure 5c: Study Point Locations and Wind Speed Criteria – Podium (Proposed Scenario)

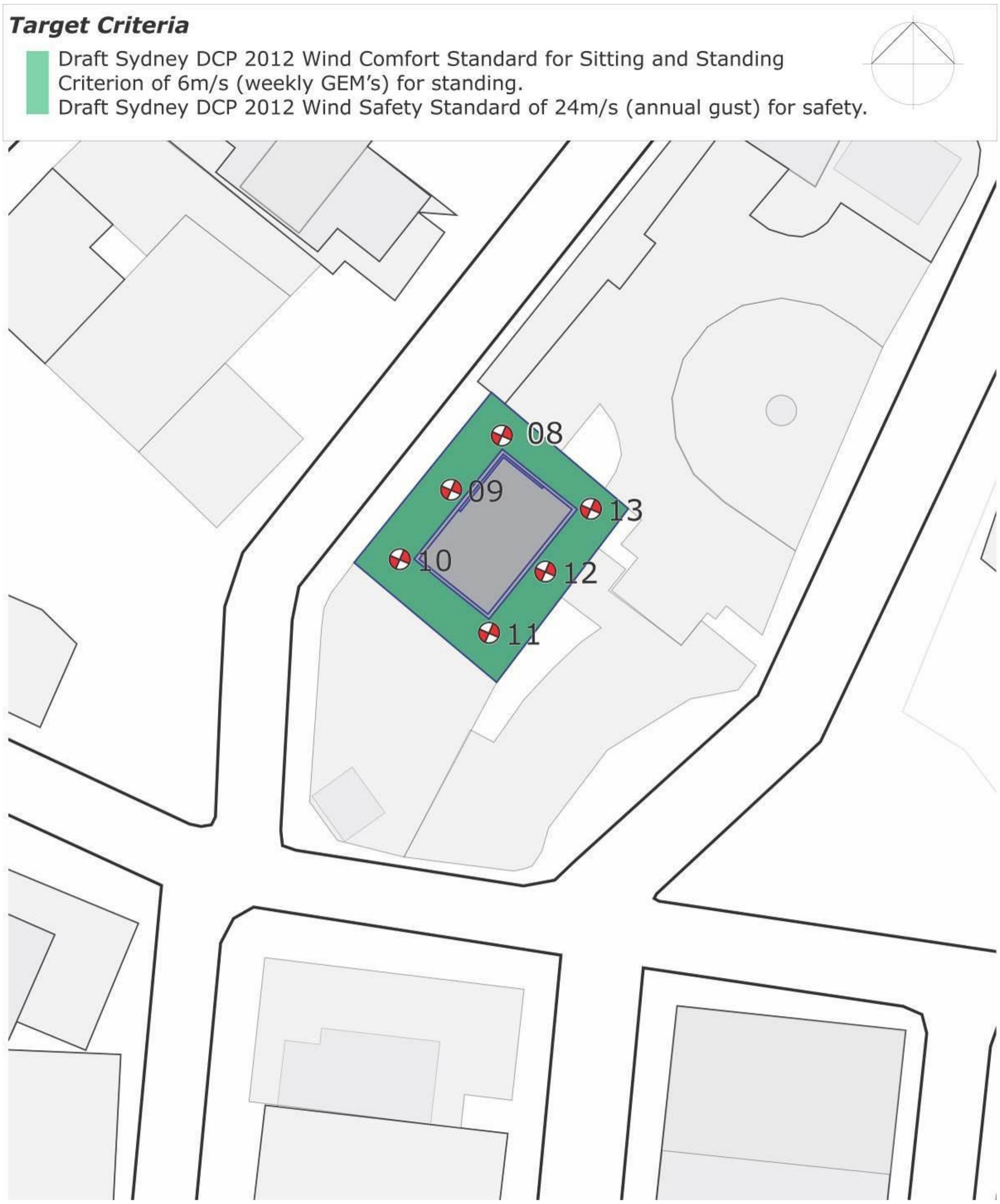

Figure 5d: Study Point Locations and Wind Speed Criteria – Podium (Compliant Scenario)

6 RESULTS AND DISCUSSION

The study models were 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.

The results for all study point locations are presented in the form of directional plots in Appendix A, and are summarised in Table 9 below and also in Figures 6a to 6h. 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 5d.

The results of the study indicate with the inclusion of the proposed scenario that all ground level areas along Bligh Street represented by Study Points 1, 2 and 3 satisfy the appropriate wind comfort and safety criteria as outlined in the Draft City of Sydney DCP – 2012. However, the results of the study indicated that a number of areas on the proposed podium roof experience exceedances of the appropriate comfort criteria. These exceedances occur for winds primarily from the West and South where these winds tend to be down washed from the building façade and accelerated around the tower corners. It should be noted that there was no exceedances of the safety limit criteria at the podium roof area for the proposed development design scenario. To improve the wind conditions at the podium roof areas it is recommended that an awning be included along the Western aspect of the tower to wrap around both the northern and southern aspects of the tower. It is expected that further podium roof landscaping and screening would also improve wind conditions in these areas.

Further testing of the Compliant Scenario provided results that were similar to or worse than the proposed test scenario and Existing site conditions.

Table 9: Wind Tunnel Results Summary

Study Point	Desired Criterion (m/s)		Equivalent to or Better than Existing Scenario	Equivalent to or Better than Compliant Scenario	Treatment Necessary to Pass?	Description of Suggested Treatment/ Notes
	Weekly GEM	Annual Peak				
Point 01	8.0	24.0	YES	YES	NO	-
Point 02	8.0	24.0	YES	YES	NO	-
Point 03	8.0	24.0	YES	YES	NO	-
Point 04	8.0	24.0	YES	YES	NO	-
Point 05	8.0	24.0	YES	YES	NO	-
Point 06	8.0	24.0	YES	YES	NO	-
Point 07	8.0	24.0	YES	YES	NO	-
Point 08	6.0	24.0	-	-	YES	Awning along the western aspect to wrap the N and S corners
Point 09	6.0	24.0	-	-	NO	-
Point 10	6.0	24.0	-	-	YES	Awning along the western aspect to wrap the N and S corners
Point 11	6.0	24.0	-	-	YES	Awning along the western aspect to wrap the N and S corners
Point 12	6.0	24.0	-	-	NO	-
Point 13	6.0	24.0	-	-	YES	Awning along the western aspect to wrap the N and S corners

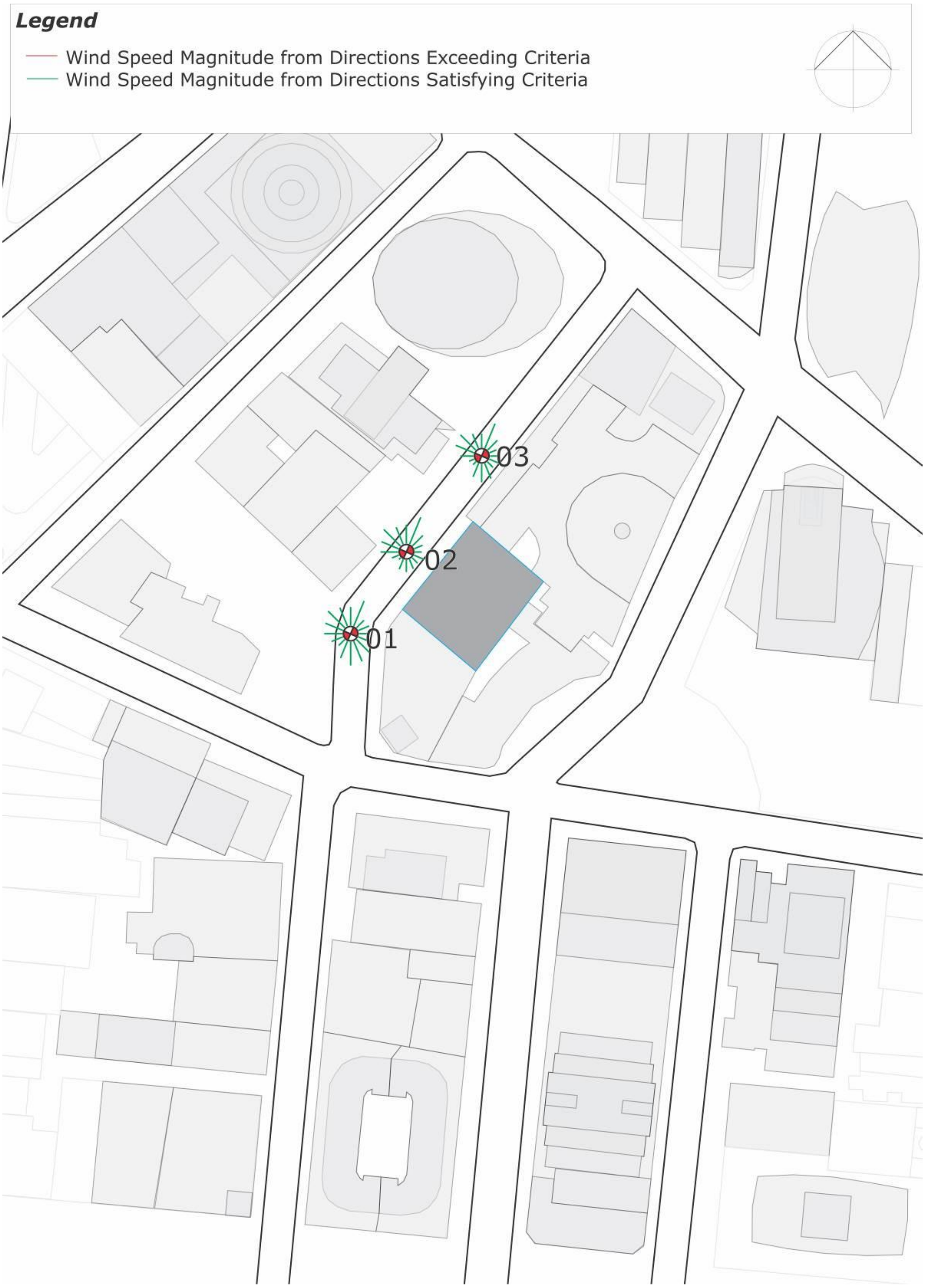

Figure 6a: Wind Directionality Plots for Proposed Scenario – Surrounding Areas

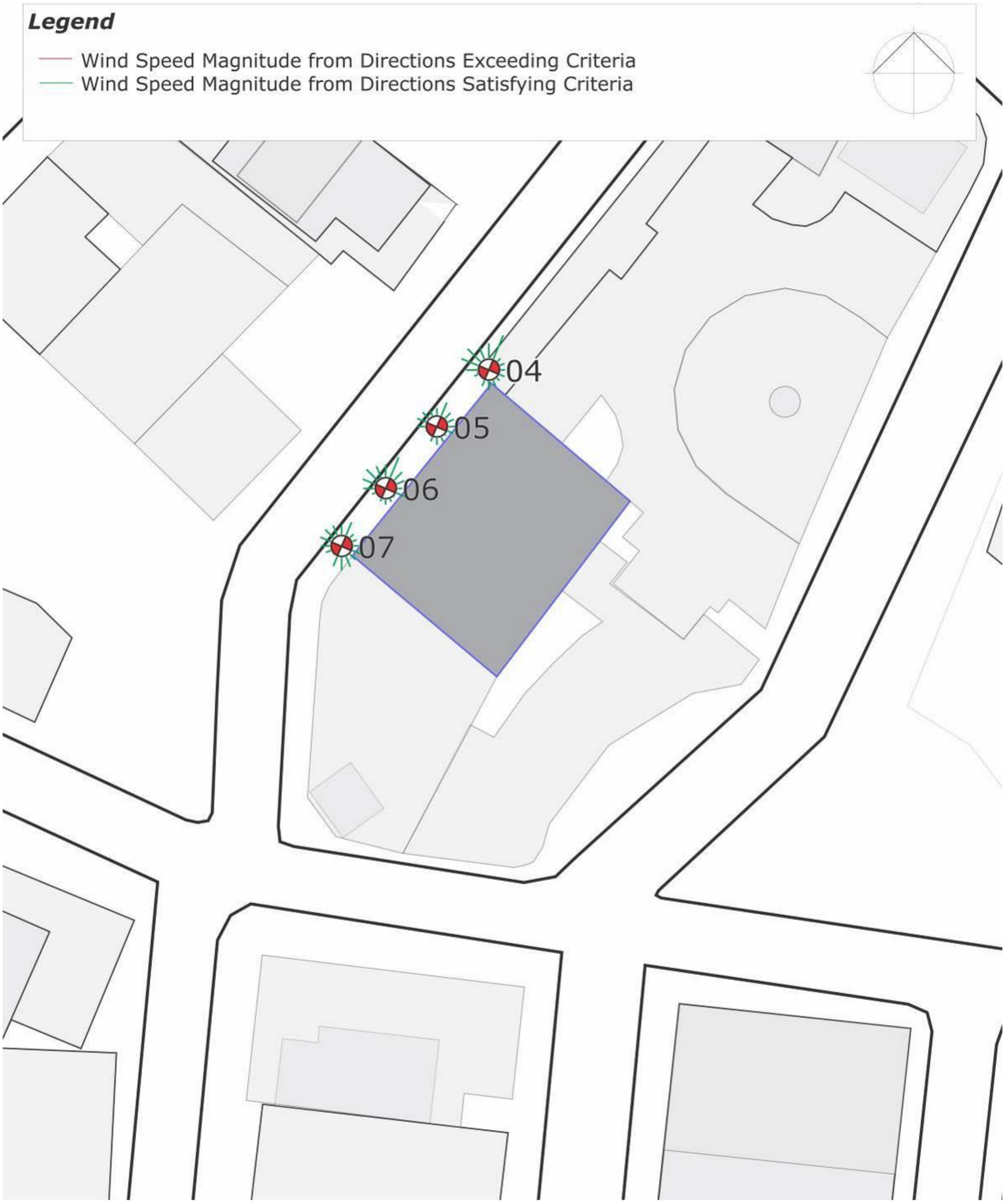

Figure 6b: Wind Directionality Plots for Proposed Scenario – Ground Floor

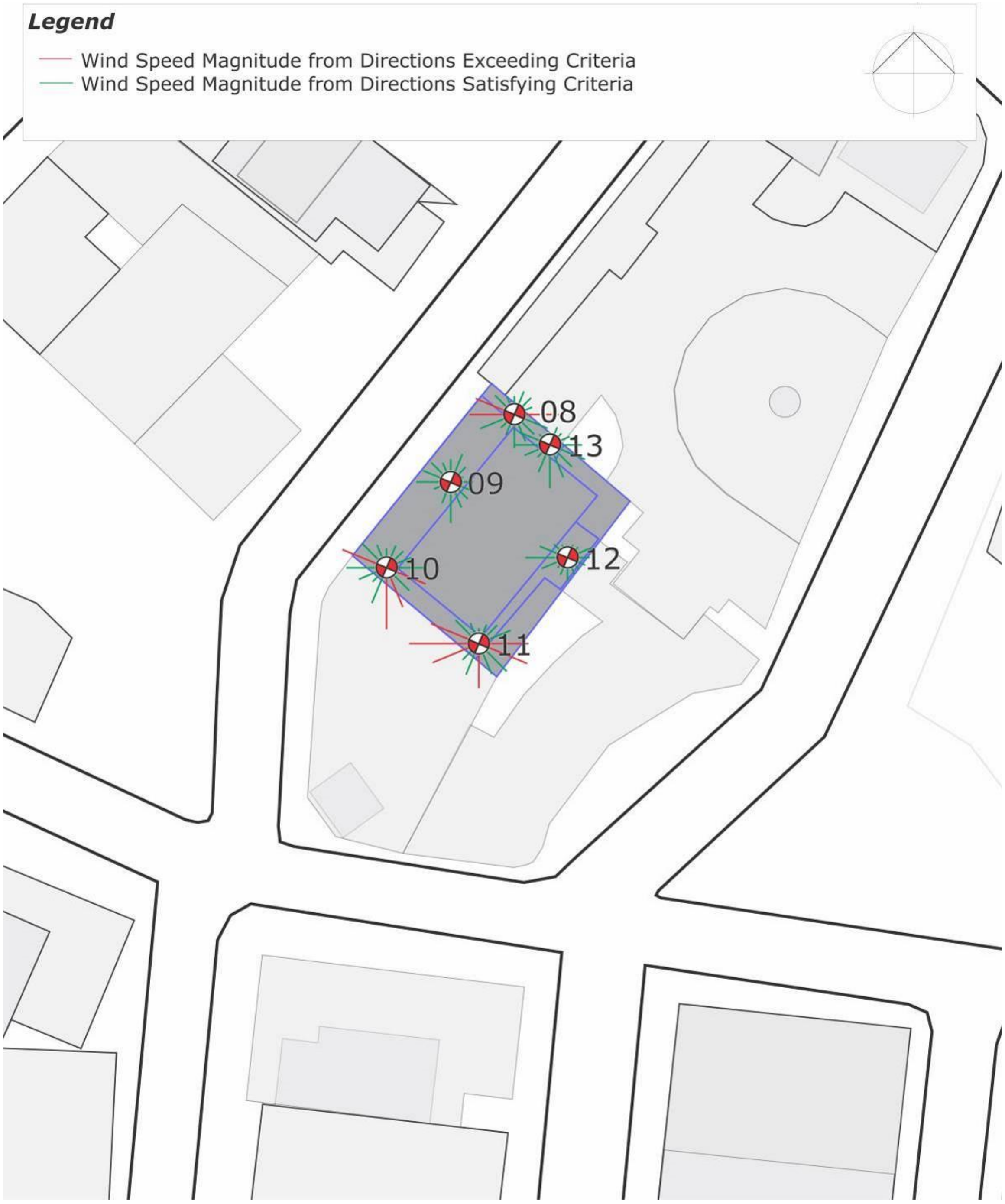

Figure 6c: Wind Directionality Plots for Proposed Scenario – Podium

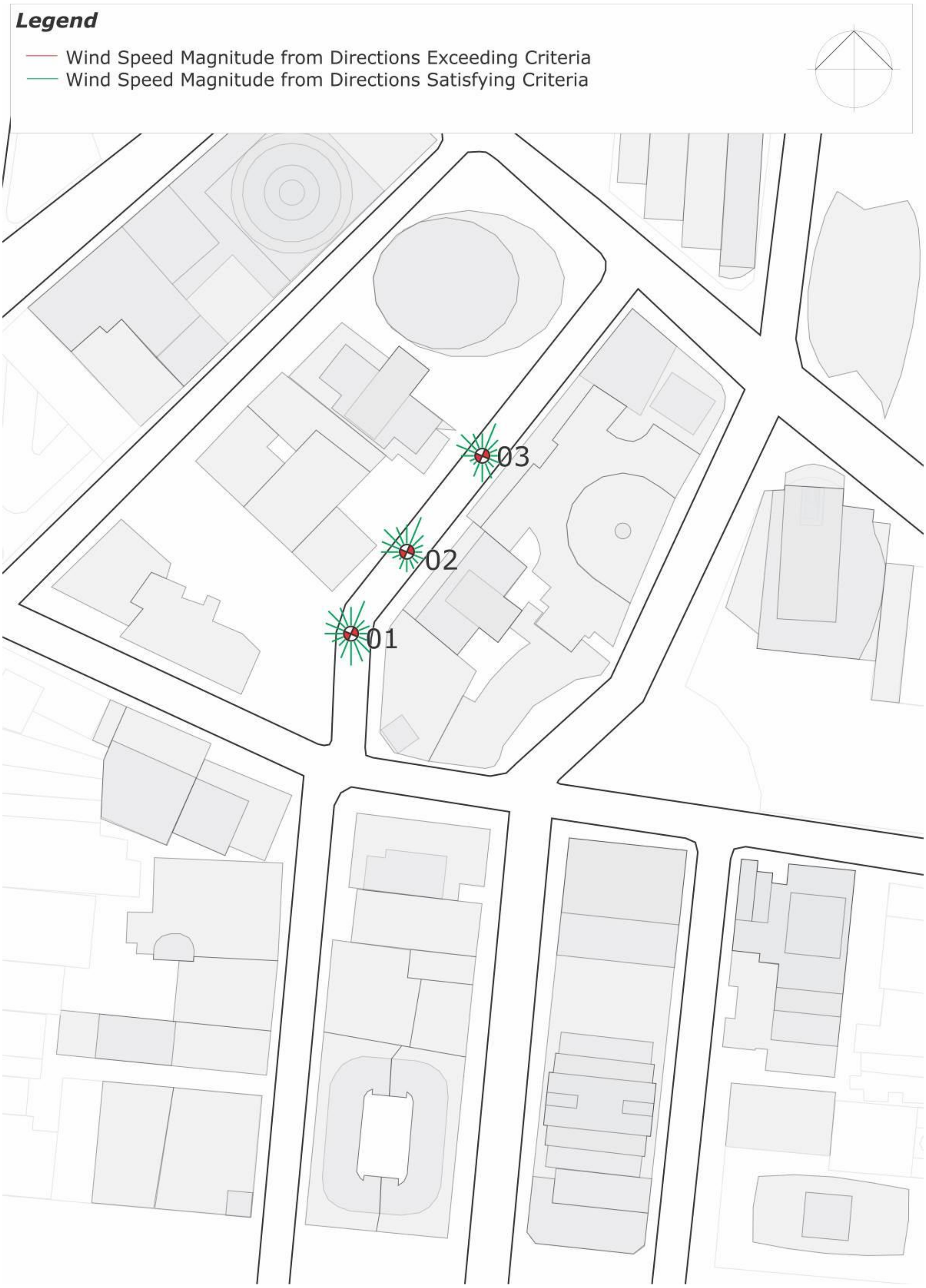

Figure 6d: Wind Directionality Plots for Existing Scenario – Surrounding Areas

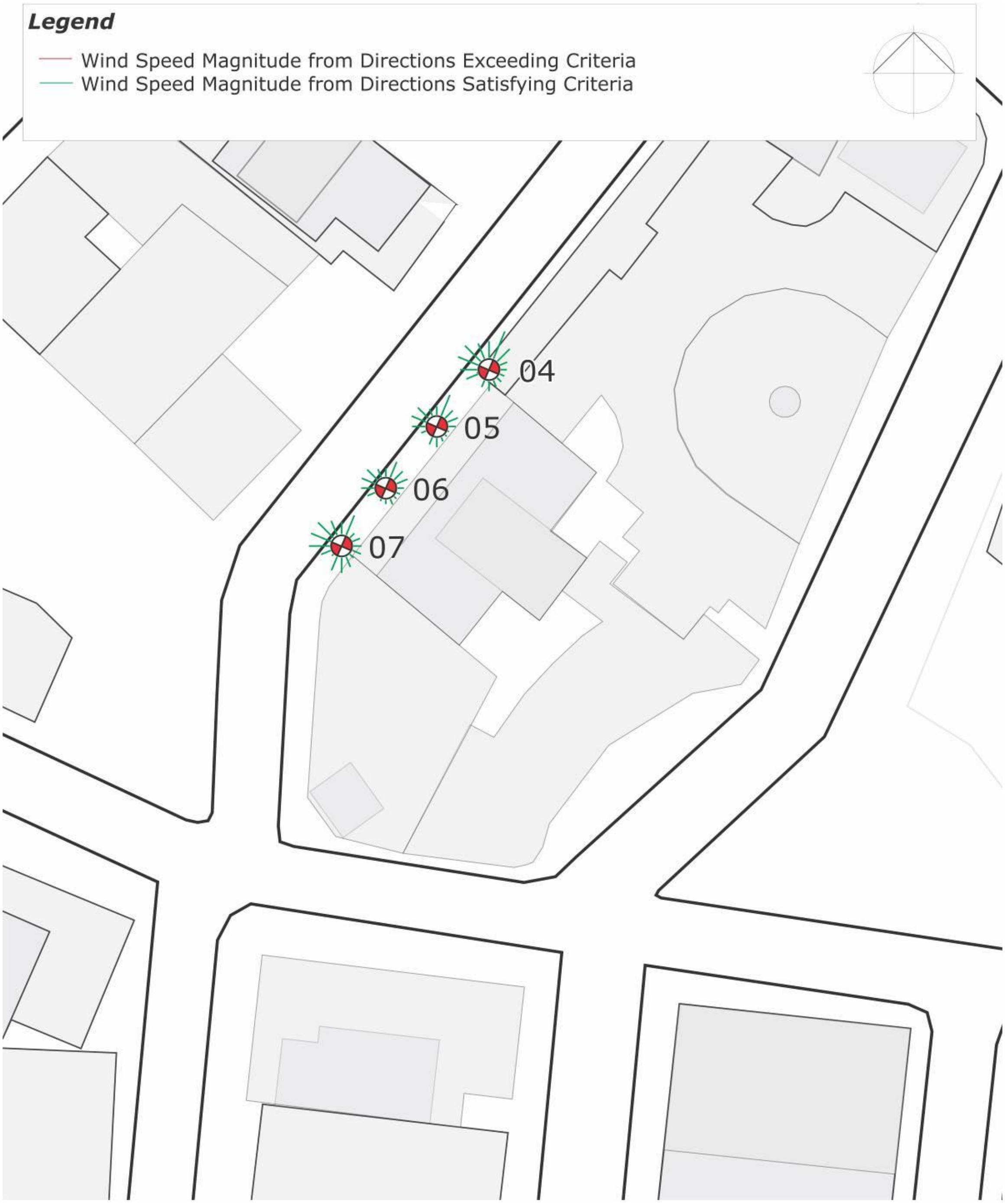

Figure 6e: Wind Directionality Plots for Existing Scenario – Ground Floor

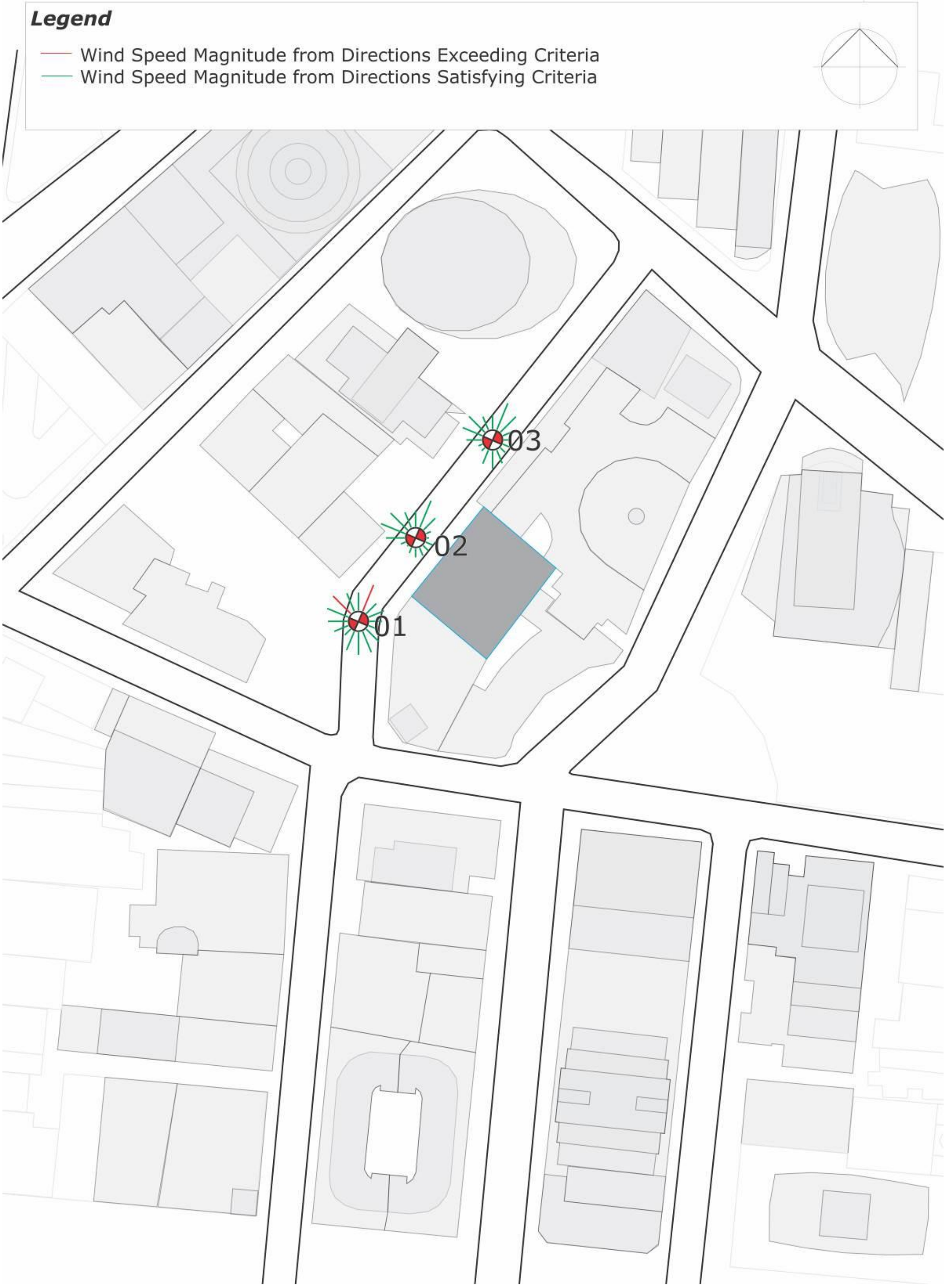

Figure 6f: Wind Directionality Plots for Compliant Scenario – Surrounding Areas

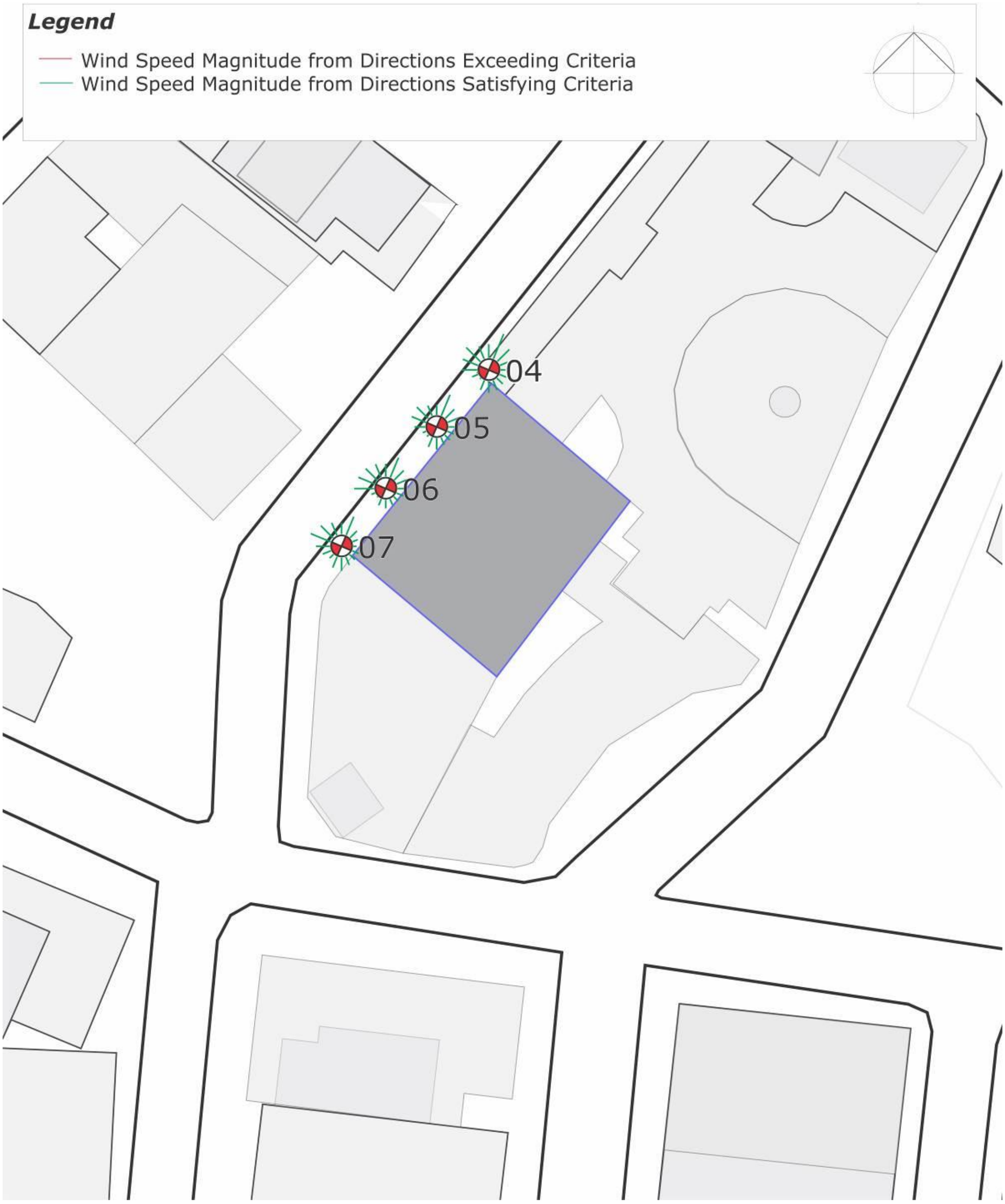

Figure 6g: Wind Directionality Plots for Compliant Scenario – Ground Floor

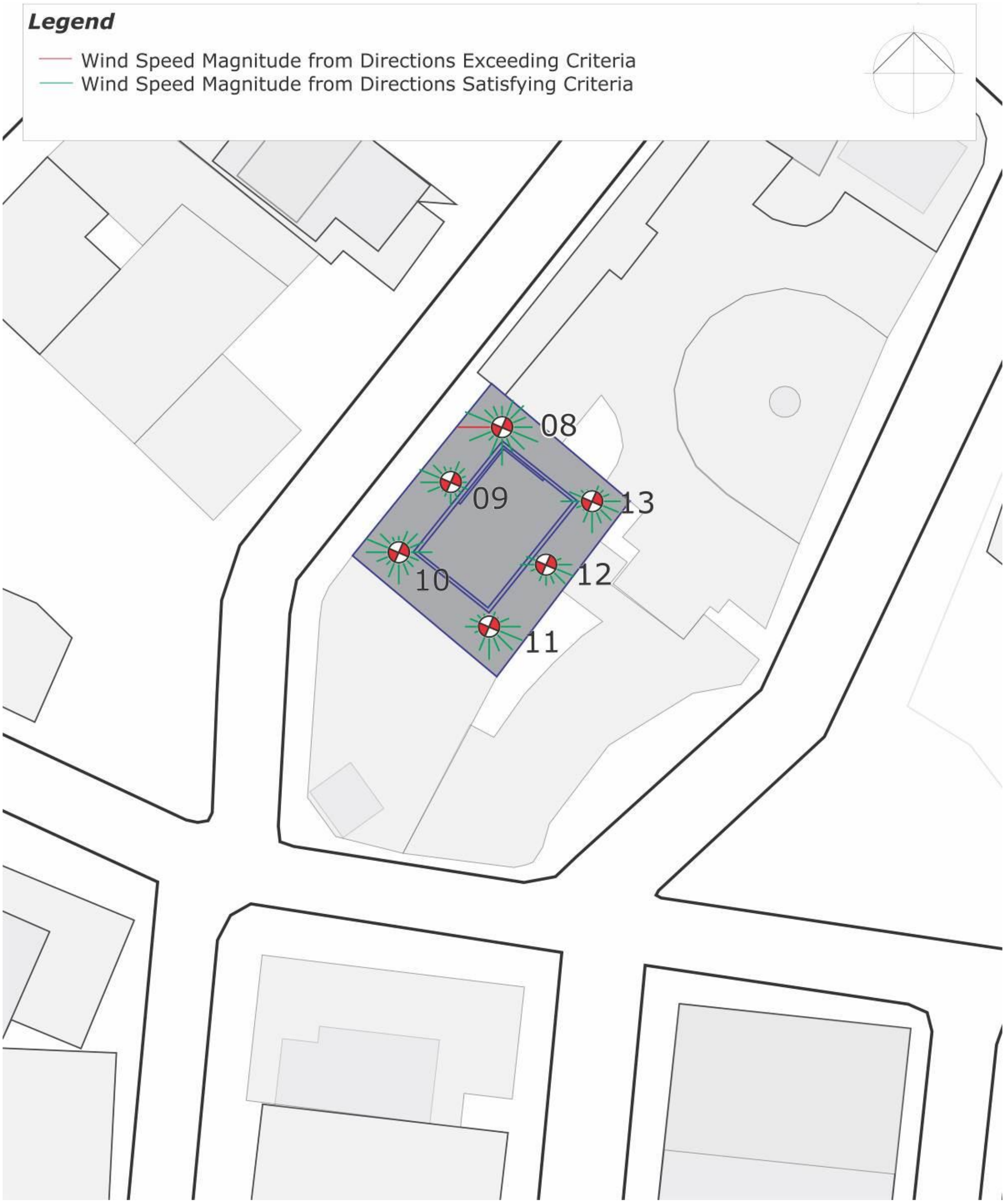

Figure 6h: Wind Directionality Plots for Compliant Scenario – Podium

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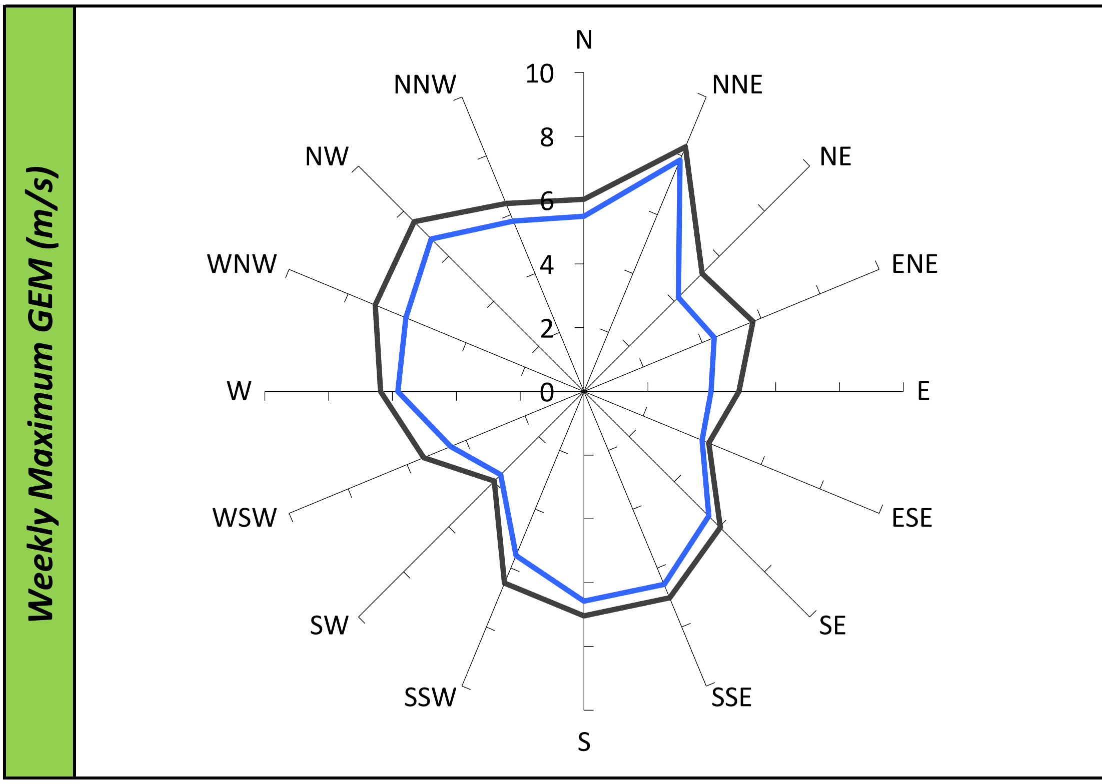
APPENDIX A - DIRECTIONAL PLOTS OF THE WIND TUNNEL RESULTS

Comparison of Proposed and Compliant Scenario (Ground Level)

Measured Wind Speeds at Point 01



Desired Criterion
8m/s

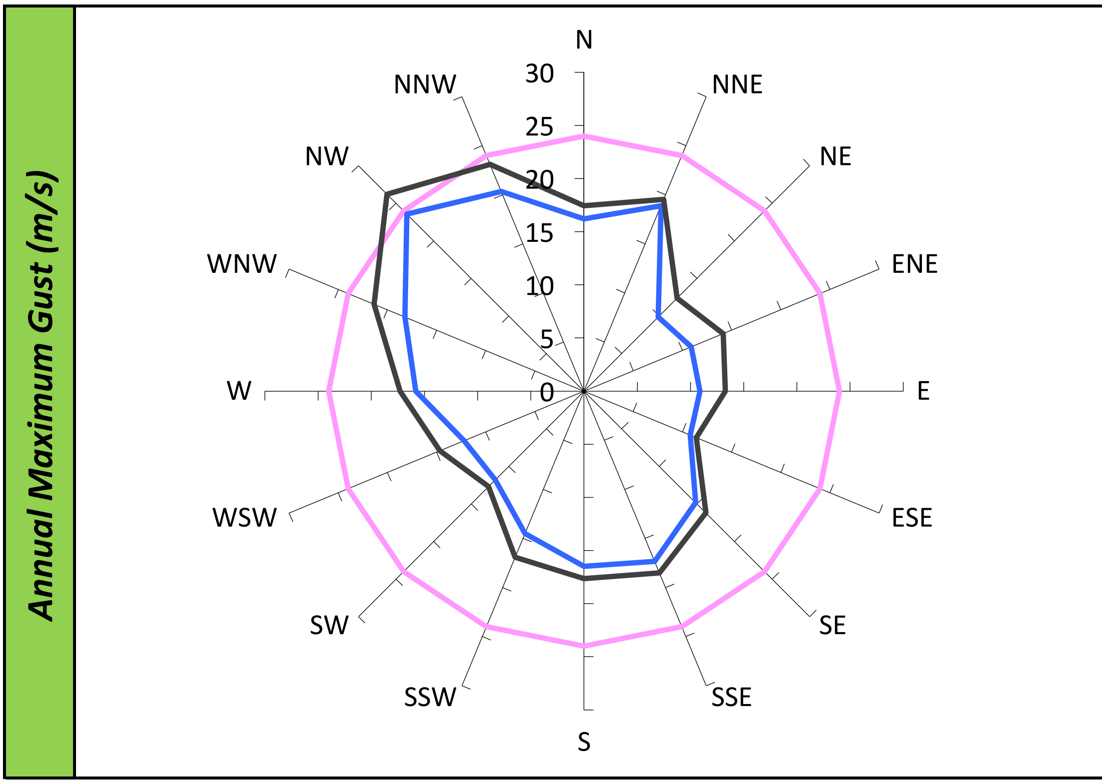
Prob. of Criterion Exceedence (existing site conditions)
6%

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%

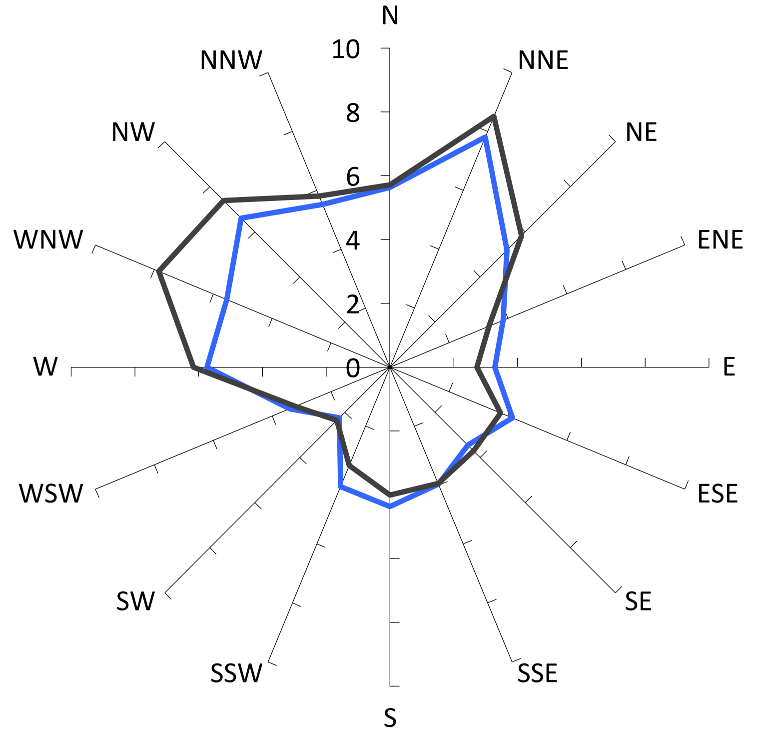
Criterion.
Development as Proposed - No vegetation or treatments
Base Case Building Massing - No vegetation or treatments



Desired Criterion
24m/s

Measured Wind Speeds at Point 02

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

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

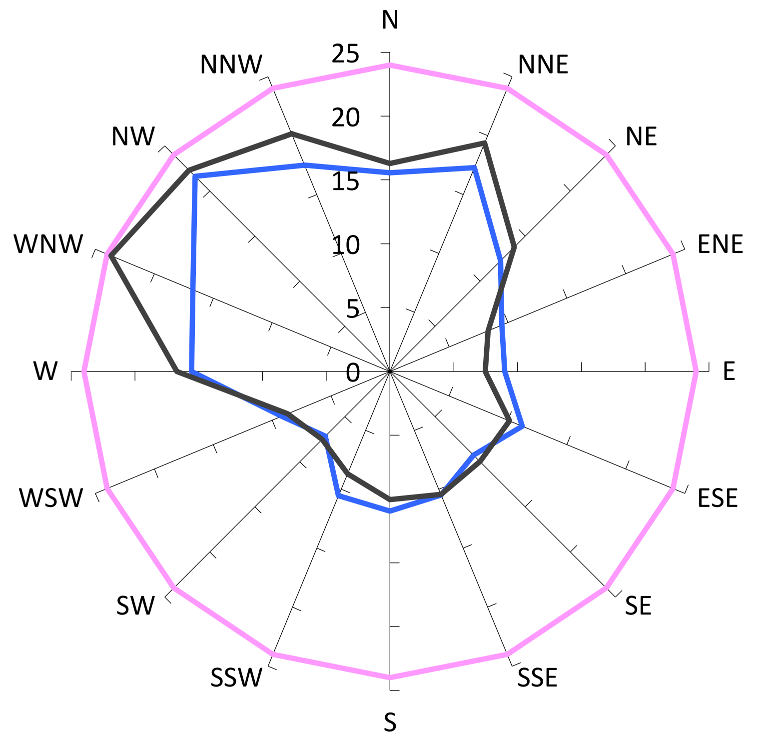
Probability of Criterion Exceedence (initial test)
3%

Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.
Development as Proposed - No vegetation or treatments
Base Case Building Massing - No vegetation or treatments

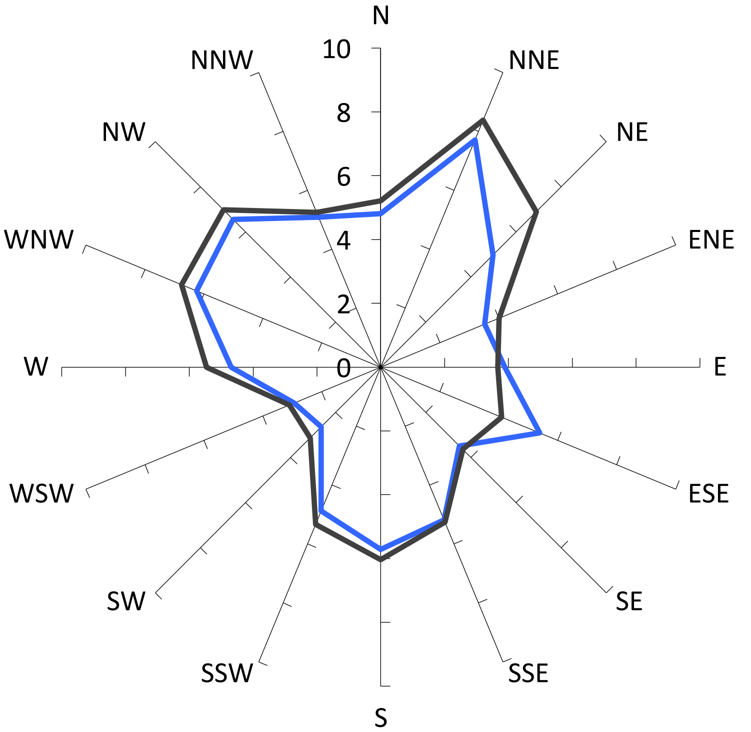
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 03

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
4%

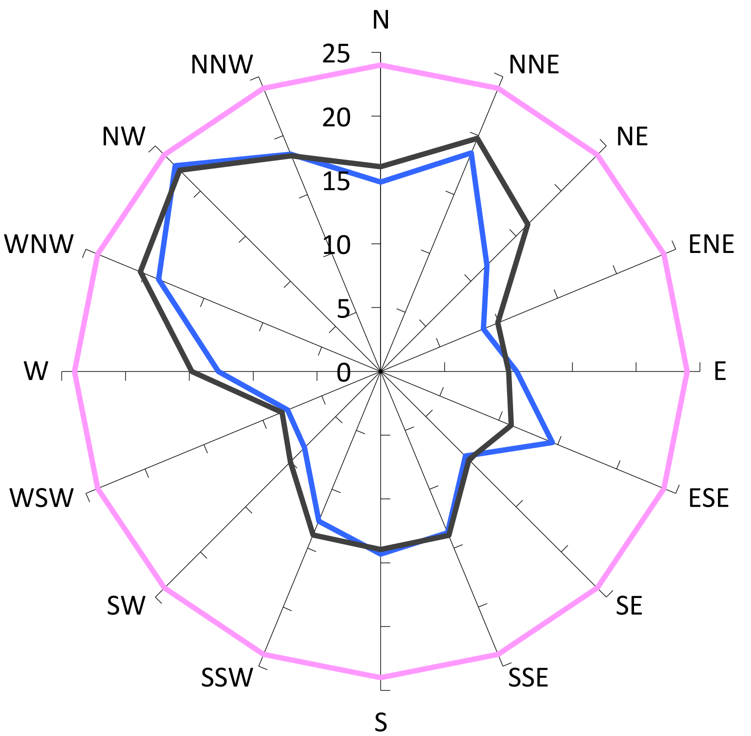
Probability of Criterion Exceedence (initial test)
2%

Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.
Development as Proposed - No vegetation or treatments
Base Case Building Massing - No vegetation or treatments

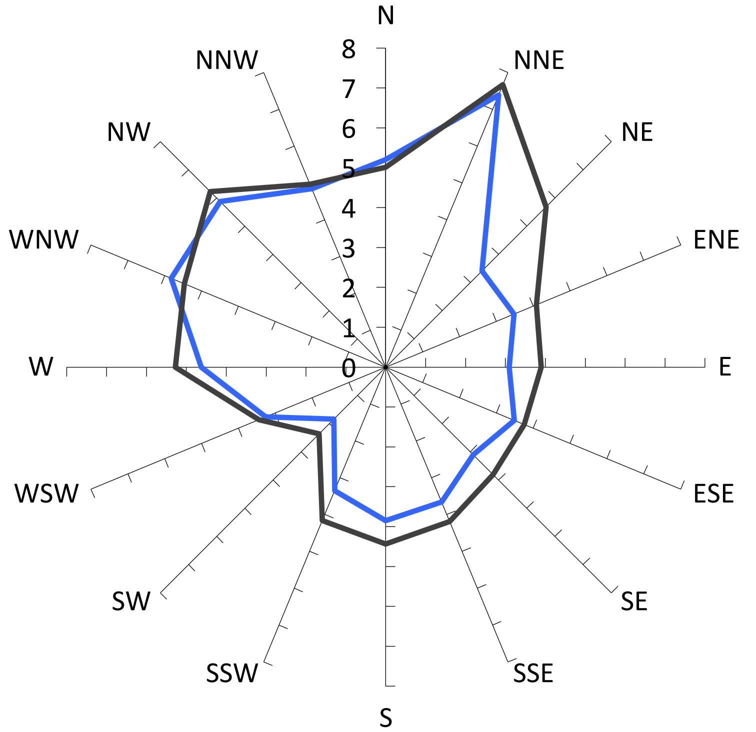
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 04

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

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

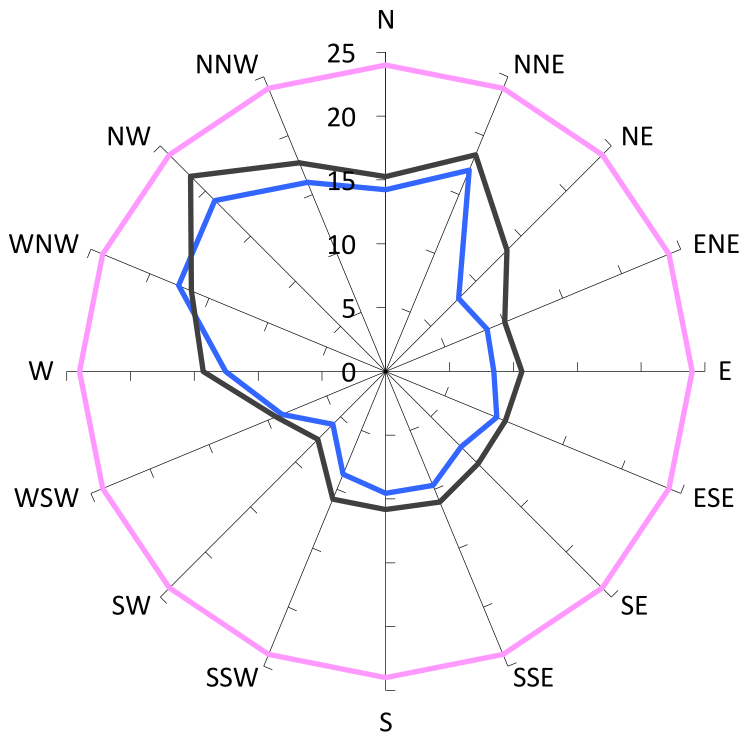
Probability of Criterion Exceedence (initial test)
2%

Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.
Development as Proposed - No vegetation or treatments
Base Case Building Massing - No vegetation or treatments

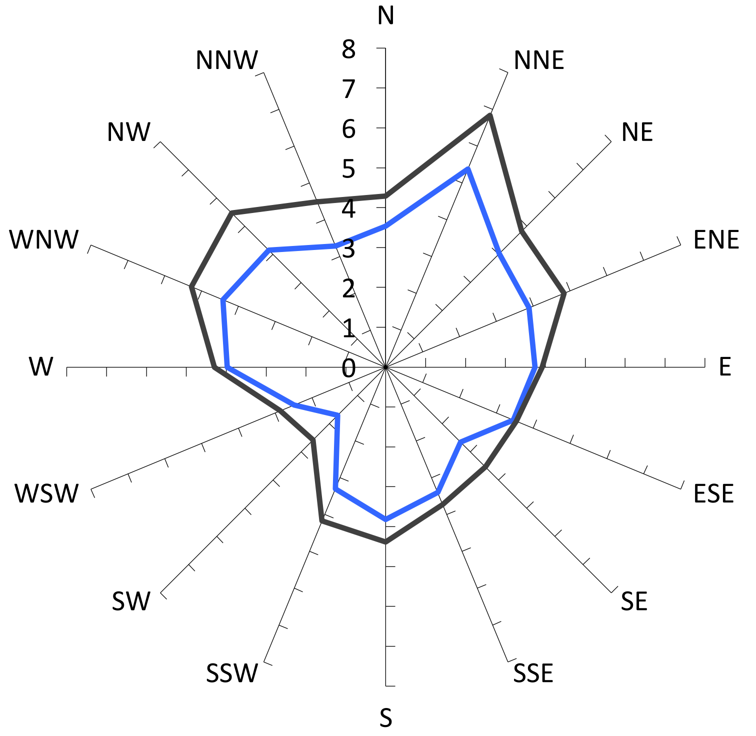
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 05

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

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

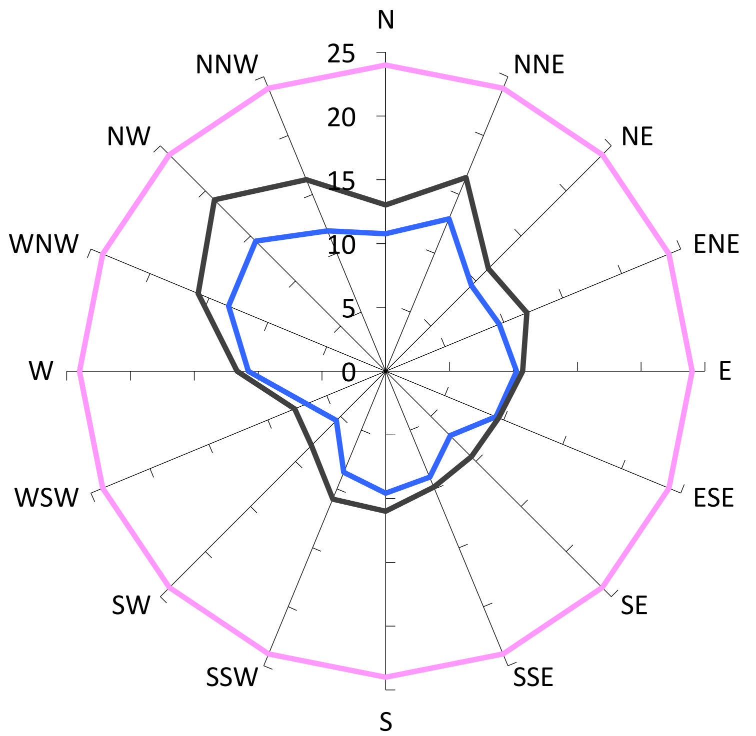
Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.
Development as Proposed - No vegetation or treatments
Base Case Building Massing - No vegetation or treatments

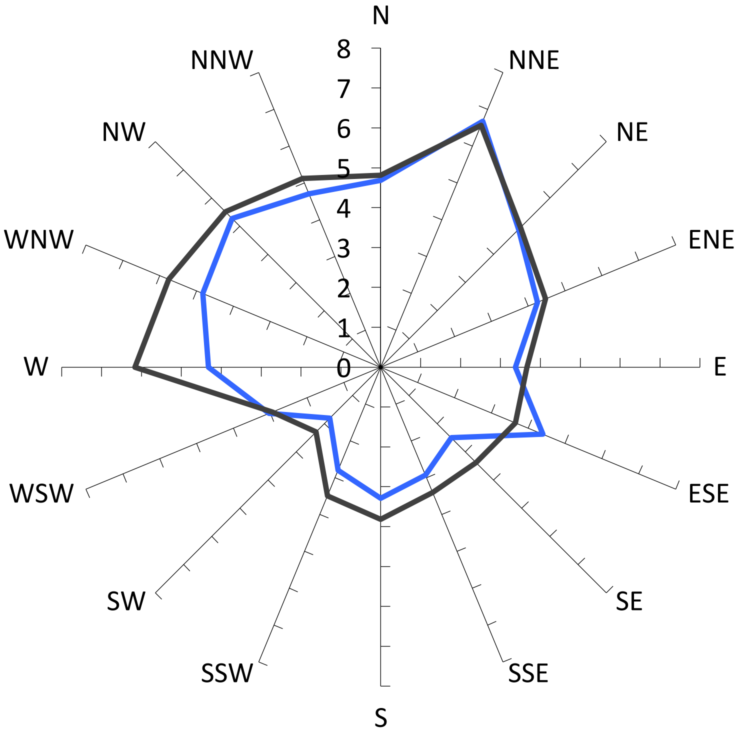
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 06

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

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

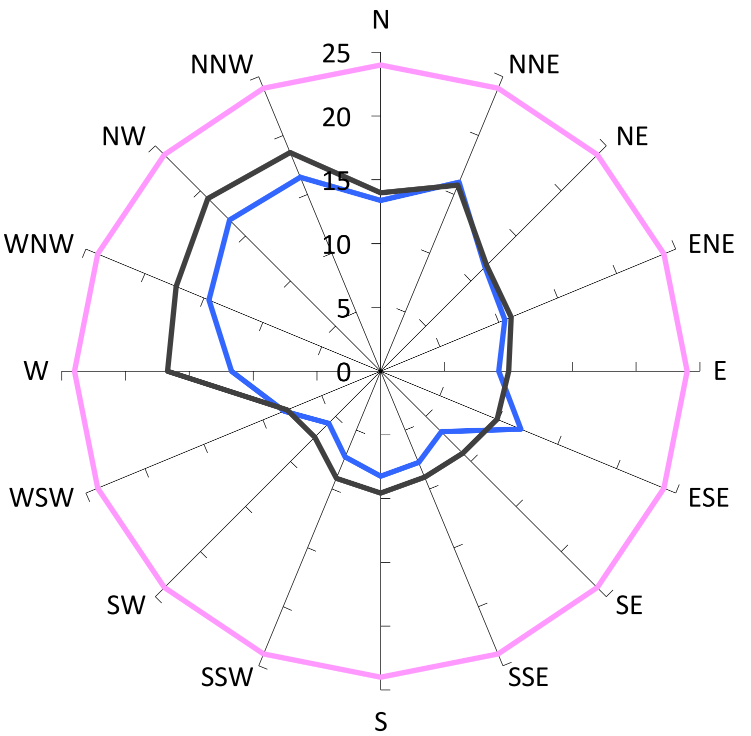
Probability of Criterion Exceedence (initial test)
1%

Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.
Development as Proposed - No vegetation or treatments
Base Case Building Massing - No vegetation or treatments

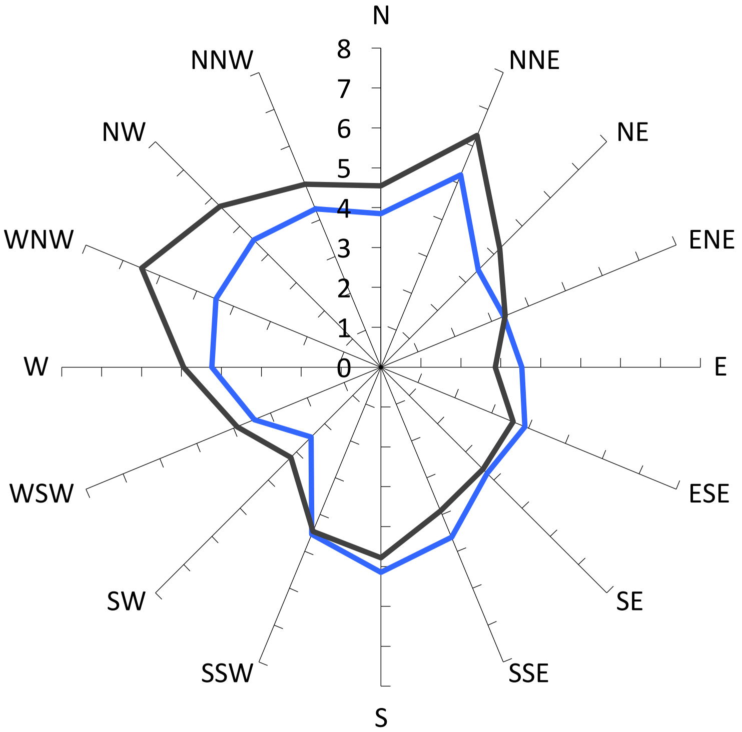
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 07

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

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

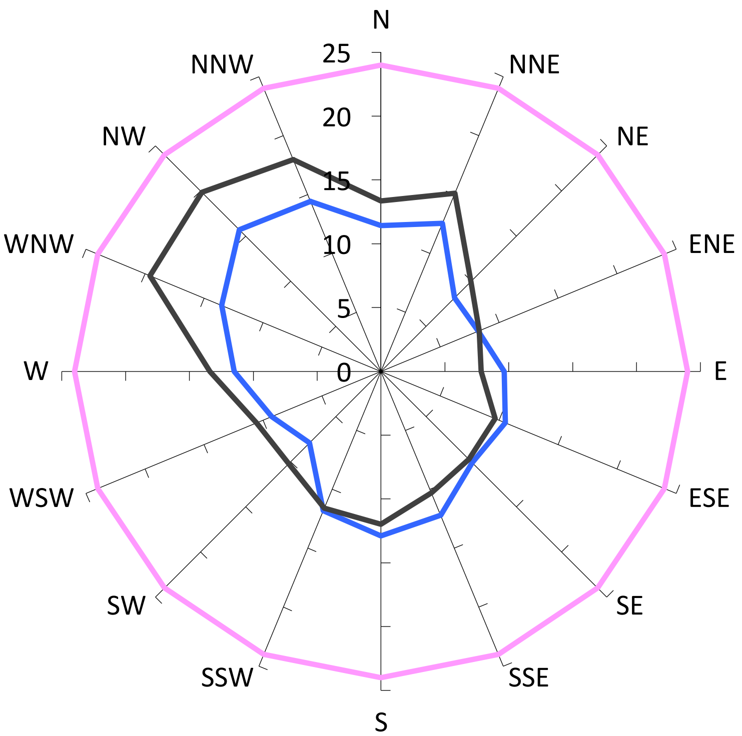
Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.
Development as Proposed - No vegetation or treatments
Base Case Building Massing - No vegetation or treatments

Annual Maximum Gust (m/s)

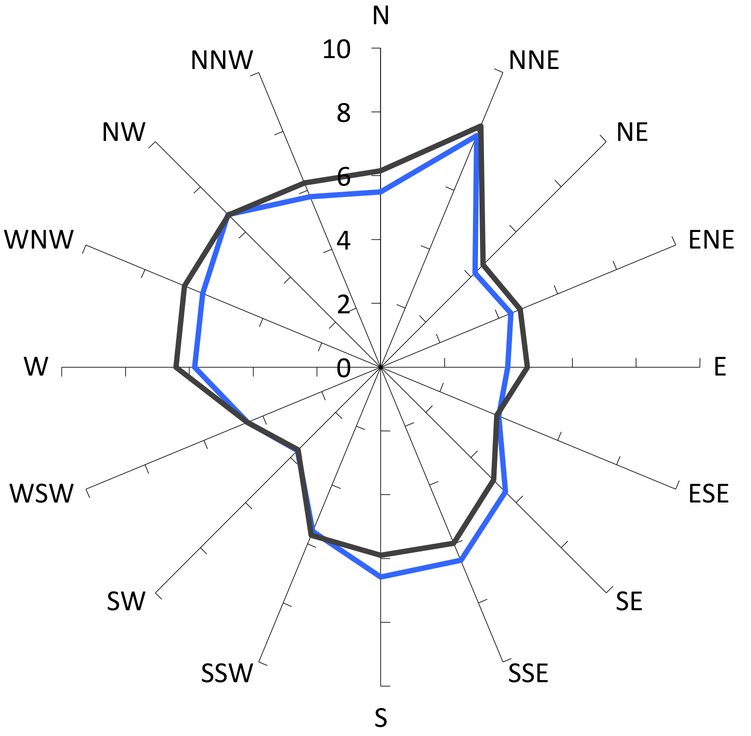


Desired Criterion
24m/s

Comparison of Proposed and Existing Scenario (Ground Level)

Measured Wind Speeds at Point 01

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
4%

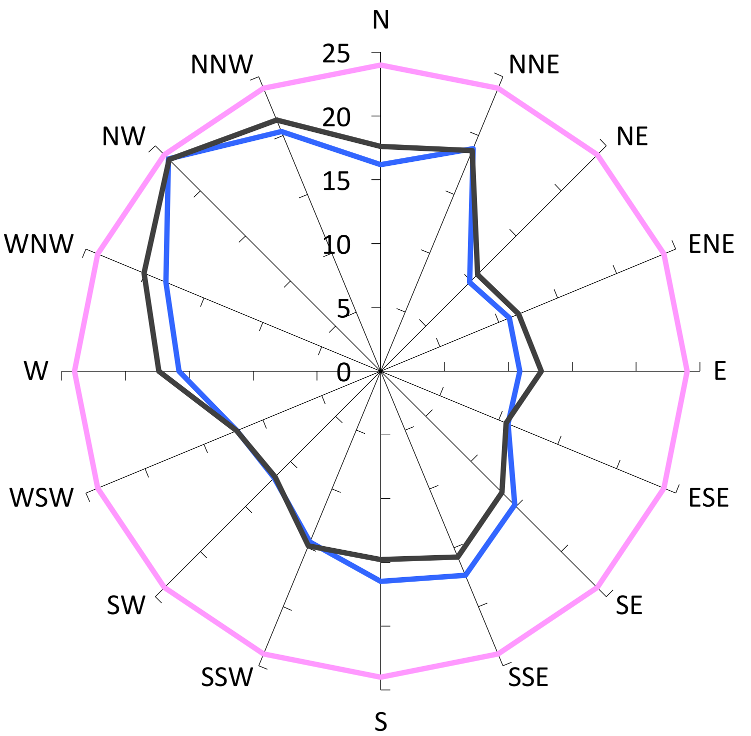
Probability of Criterion Exceedence (initial test)
4%

Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.
Development as Proposed - No vegetation or treatments
Existing Site Conditions - No vegetation or treatments

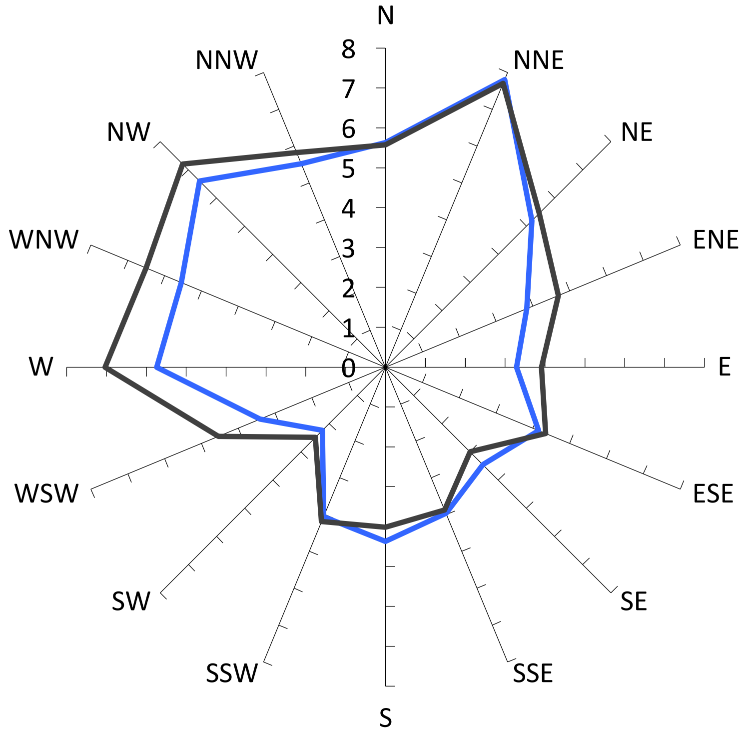
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 02

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
4%

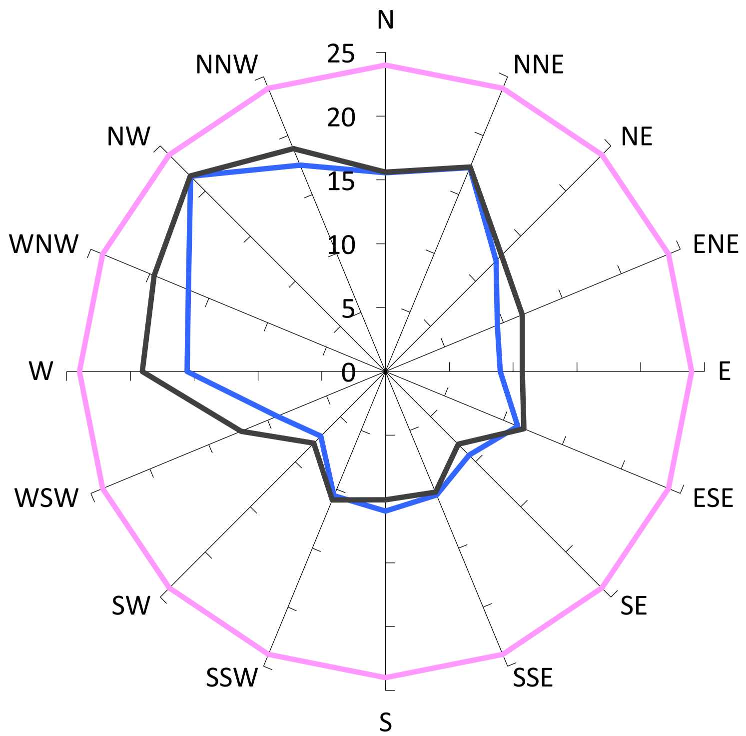
Probability of Criterion Exceedence (initial test)
3%

Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.
Development as Proposed - No vegetation or treatments
Existing Site Conditions - No vegetation or treatments

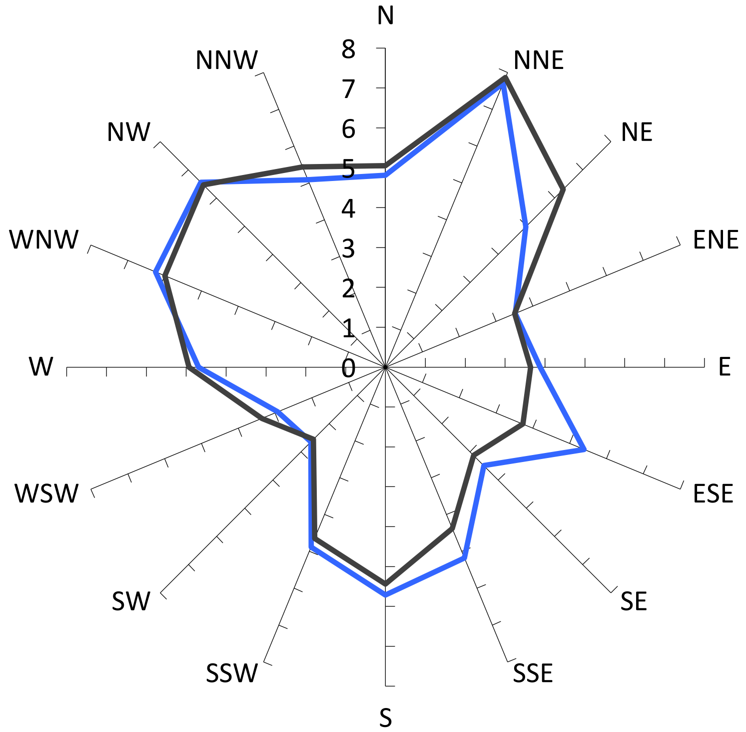
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 03

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
3%

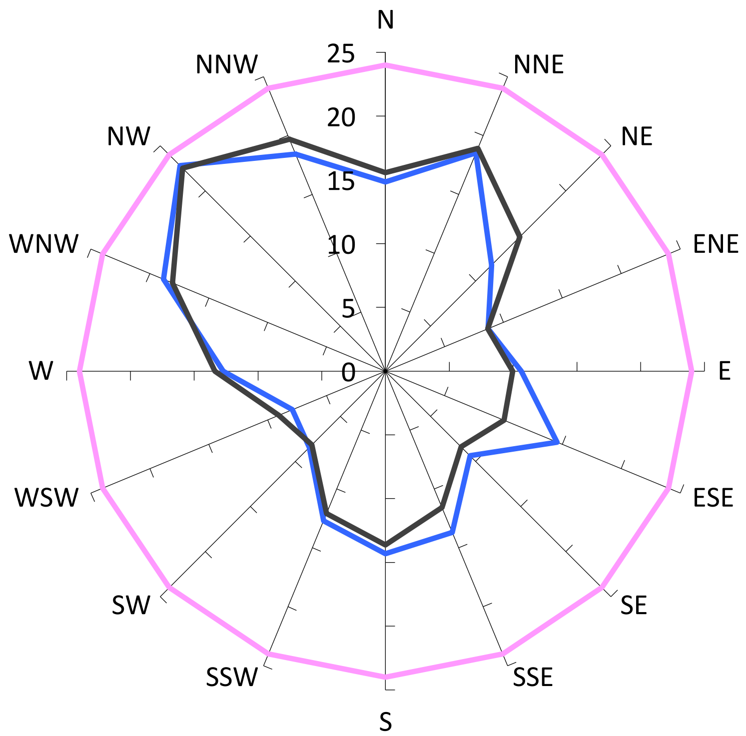
Probability of Criterion Exceedence (initial test)
2%

Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.
Development as Proposed - No vegetation or treatments
Existing Site Conditions - No vegetation or treatments

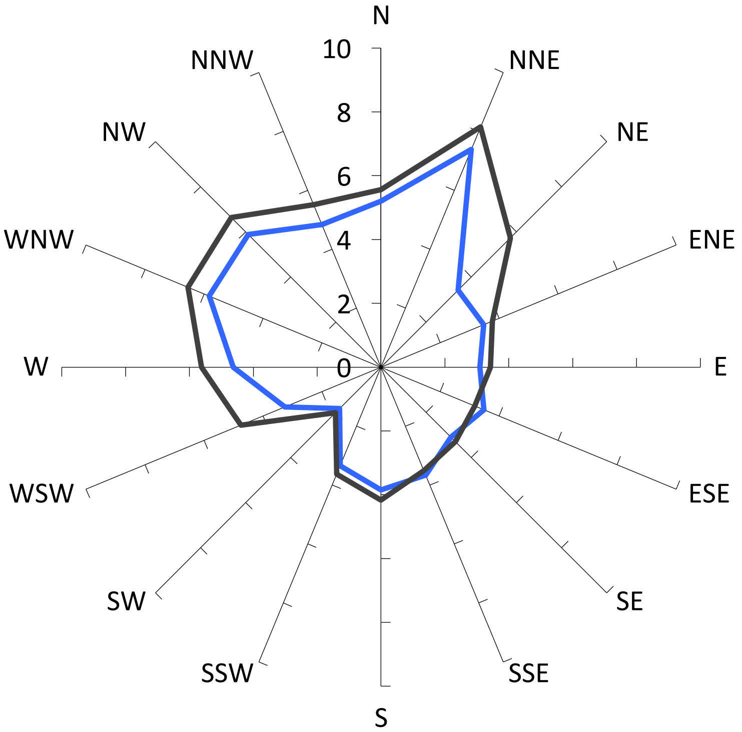
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 04

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
3%

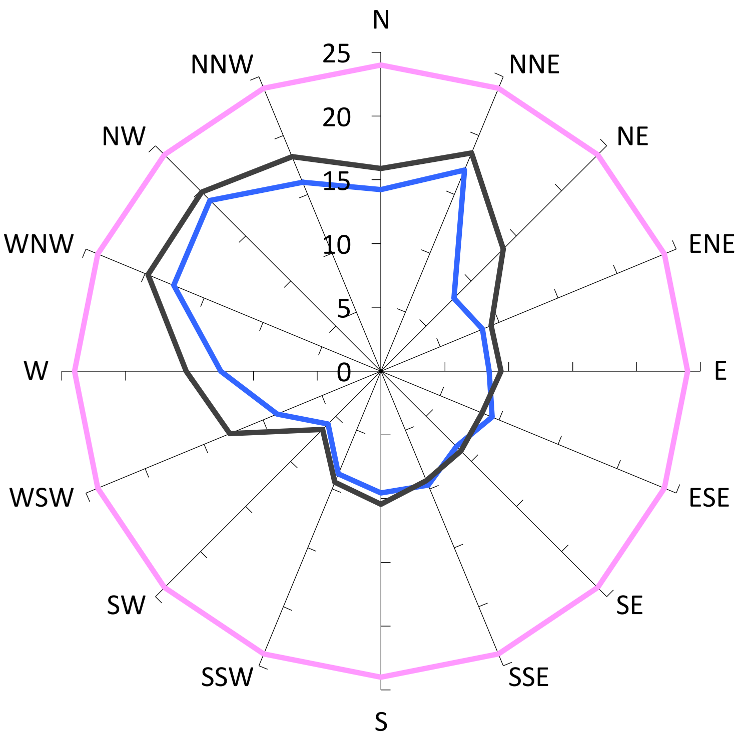
Probability of Criterion Exceedence (initial test)
2%

Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.
Development as Proposed - No vegetation or treatments
Existing Site Conditions - No vegetation or treatments

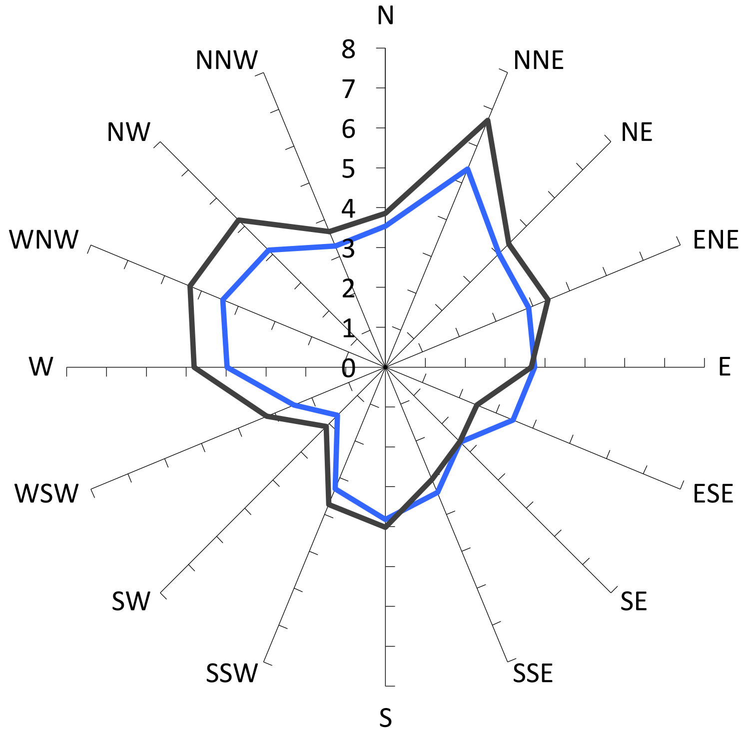
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 05

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

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

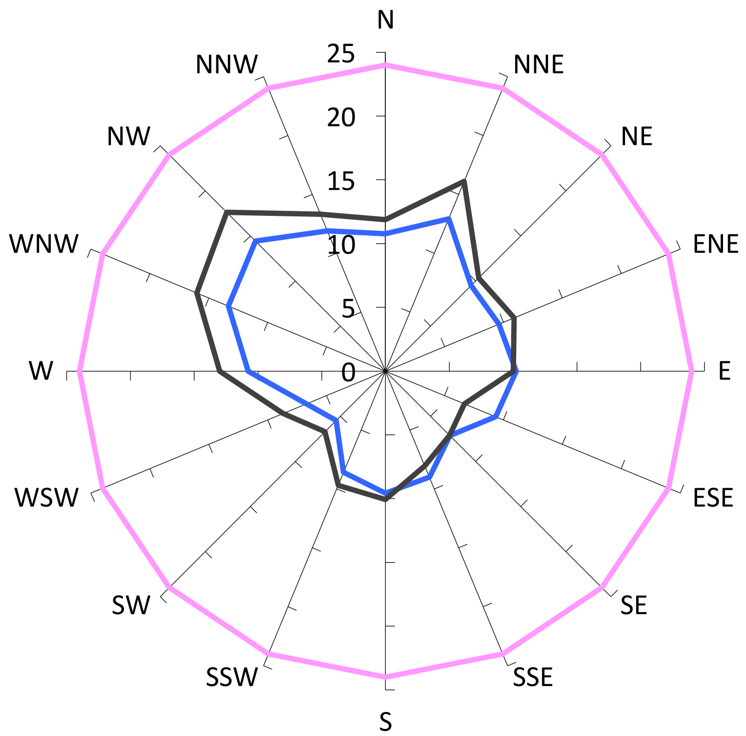
Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

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

- *Criterion.*
- *Development as Proposed - No vegetation or treatments*
- *Existing Site Conditions - No vegetation or treatments*

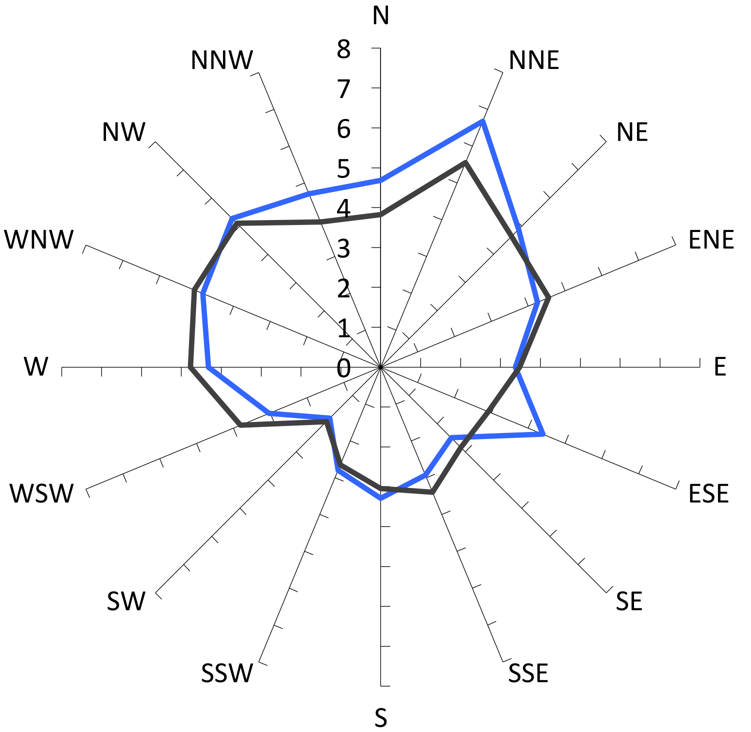
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 06

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

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

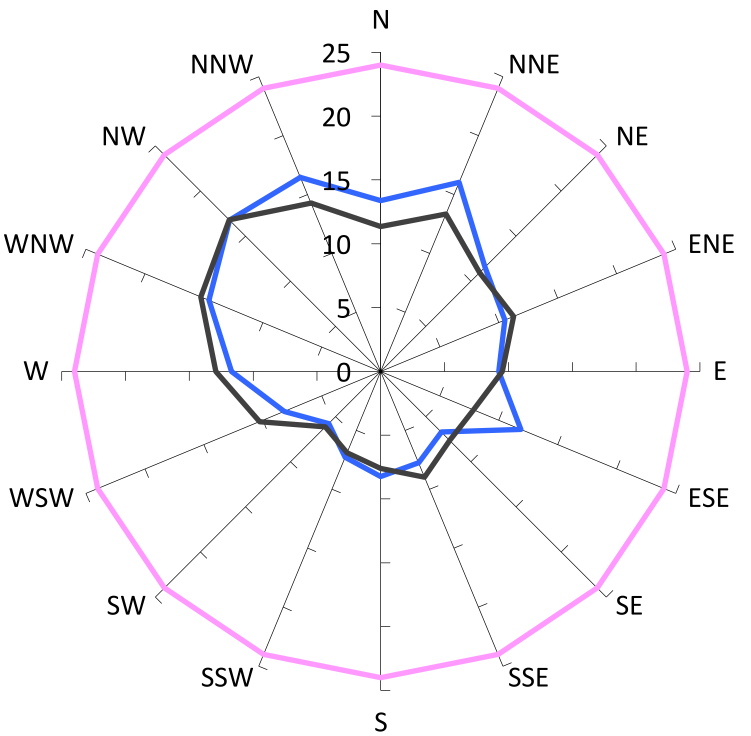
Probability of Criterion Exceedence (initial test)
1%

Probability of Criterion Exceedence (final retest)
N/A

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

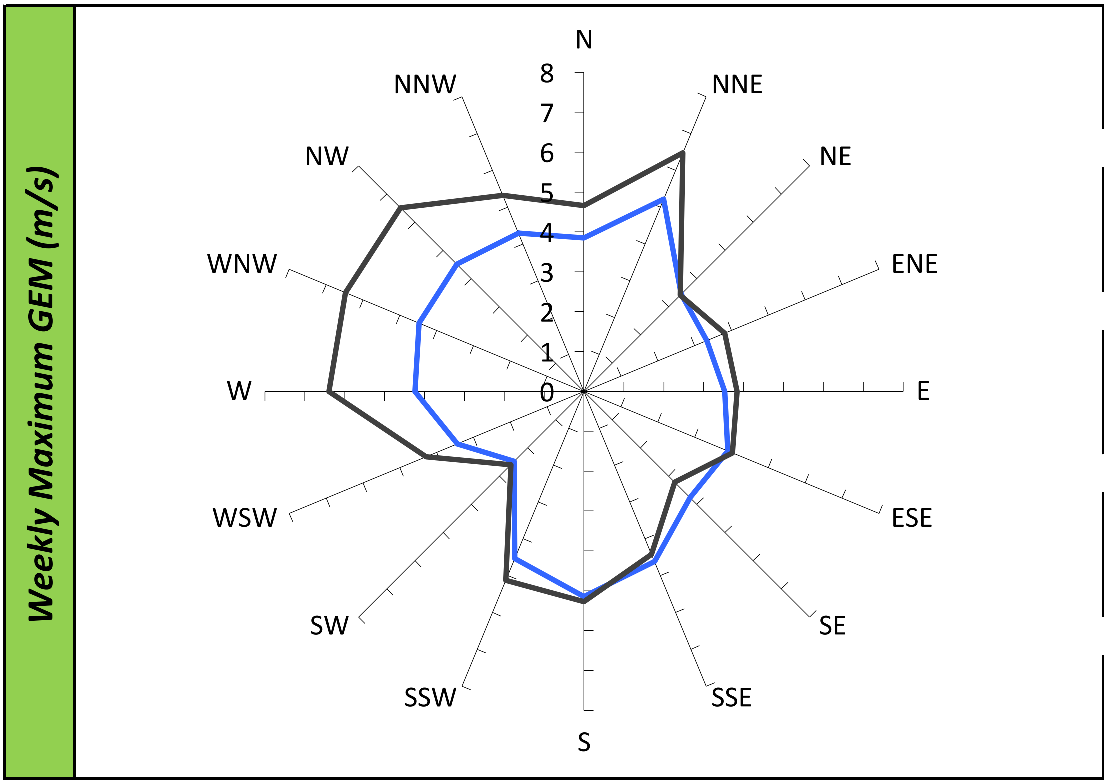
Criterion.
Development as Proposed - No vegetation or treatments
Existing Site Conditions - No vegetation or treatments

Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 07



Desired Criterion

8m/s

Prob. of Criterion Exceedence (existing site conditions)

2%

Probability of Criterion Exceedence (initial test)

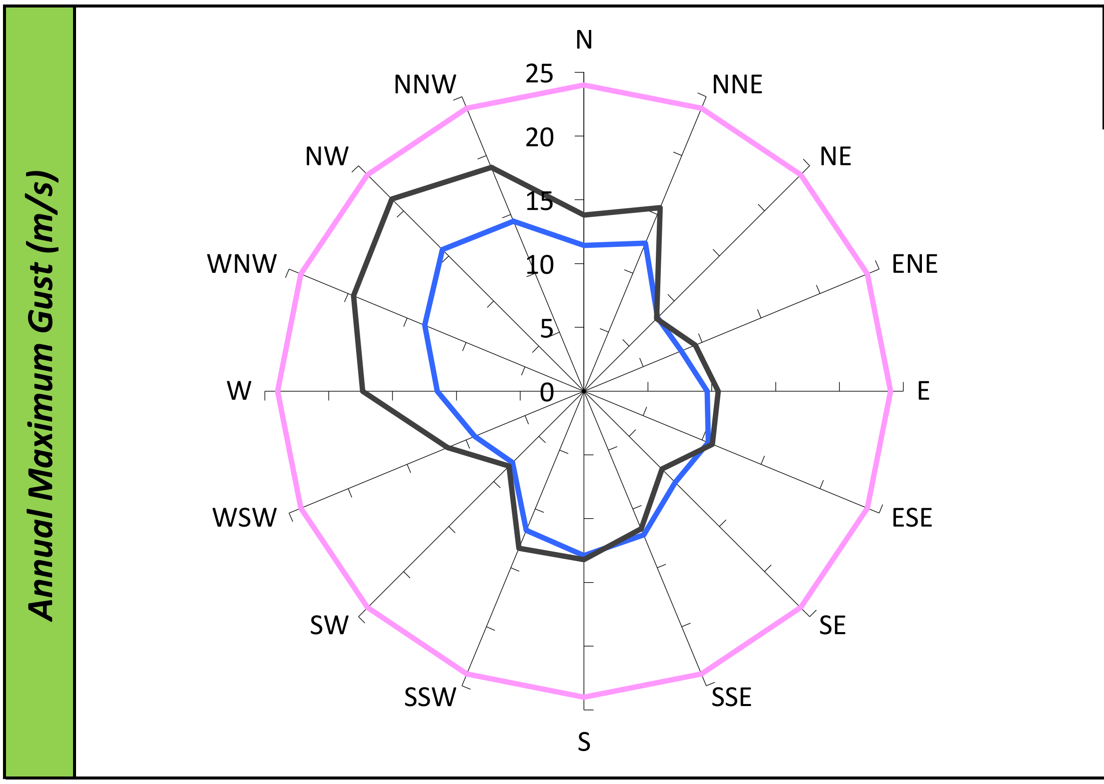
0%

Probability of Criterion Exceedence (final retest)

N/A

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

Criterion.
Development as Proposed - No vegetation or treatments
Existing Site Conditions - No vegetation or treatments



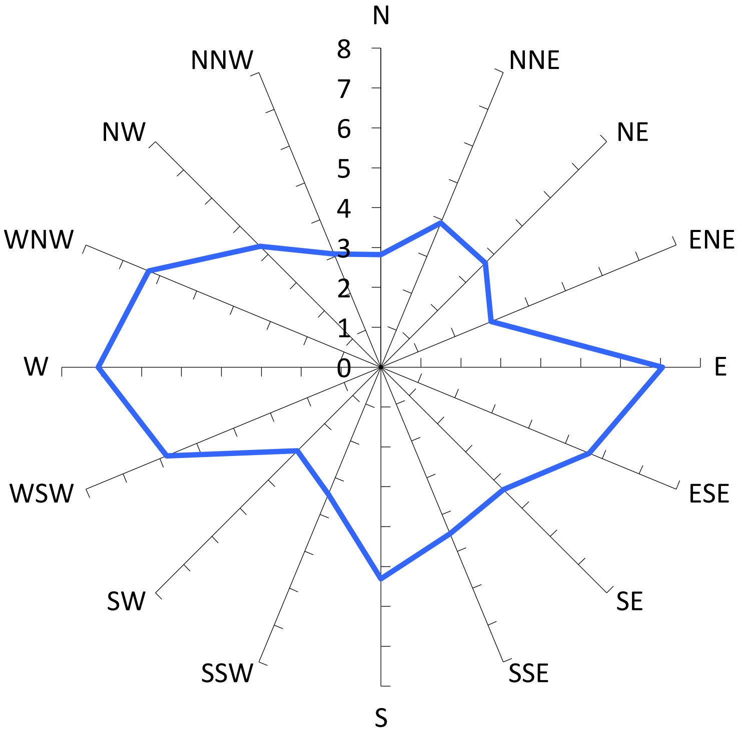
Desired Criterion

24m/s

Proposed Scenario (Podium)

Measured Wind Speeds at Point 08

Weekly Maximum GEM (m/s)



Desired Criterion
6m/s

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

Probability of Criterion Exceedence (initial test)
10%

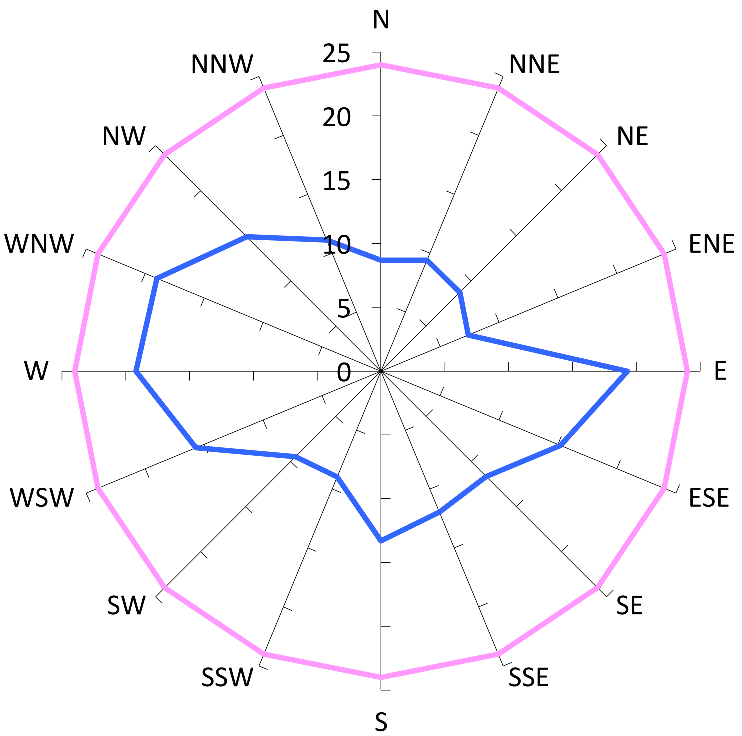
Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.

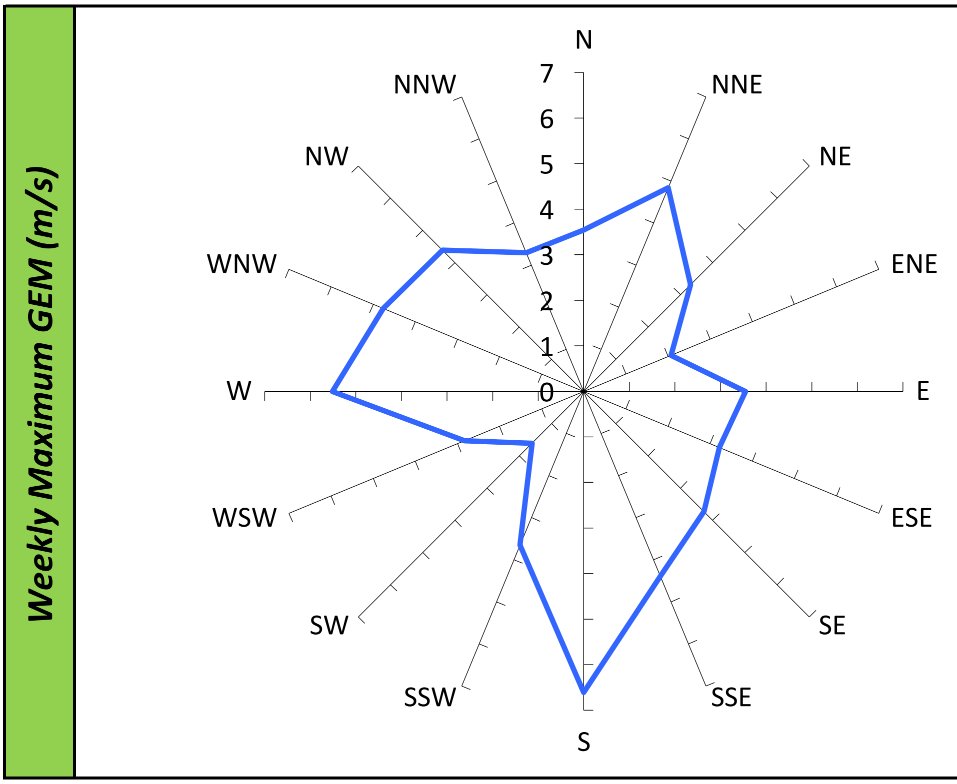
Development as Proposed - No vegetation or treatments

Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 09



Desired Criterion
6m/s

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

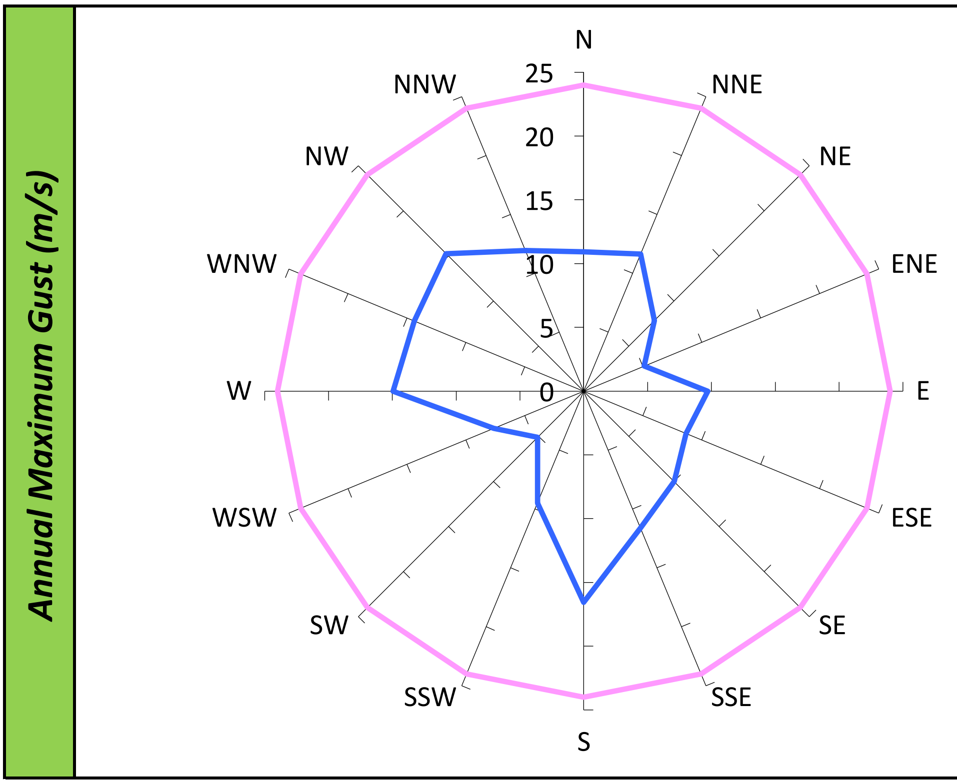
Probability of Criterion Exceedence (initial test)
4%

Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.

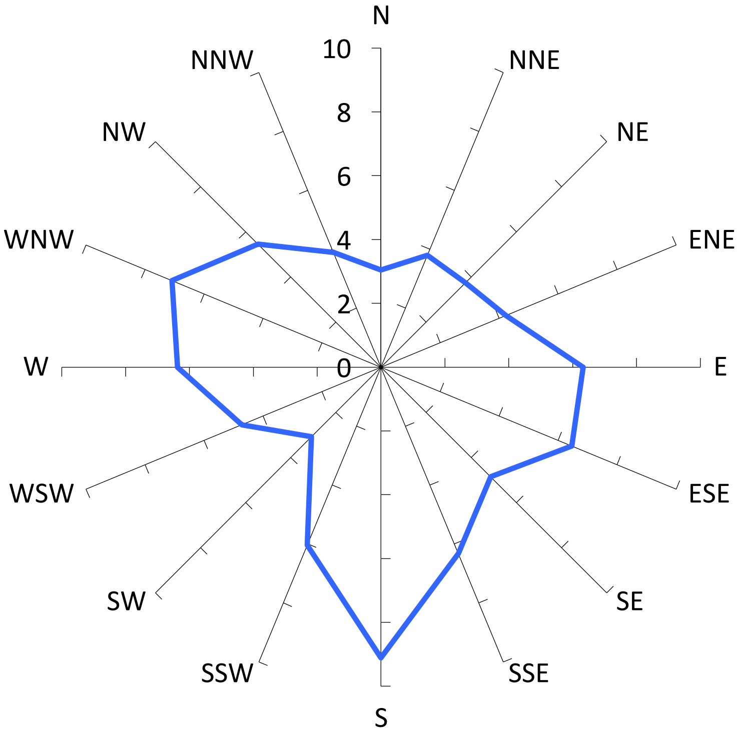
Development as Proposed - No vegetation or treatments



Desired Criterion
24m/s

Measured Wind Speeds at Point 10

Weekly Maximum GEM (m/s)



Desired Criterion
6m/s

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

Probability of Criterion Exceedence (initial test)
20%

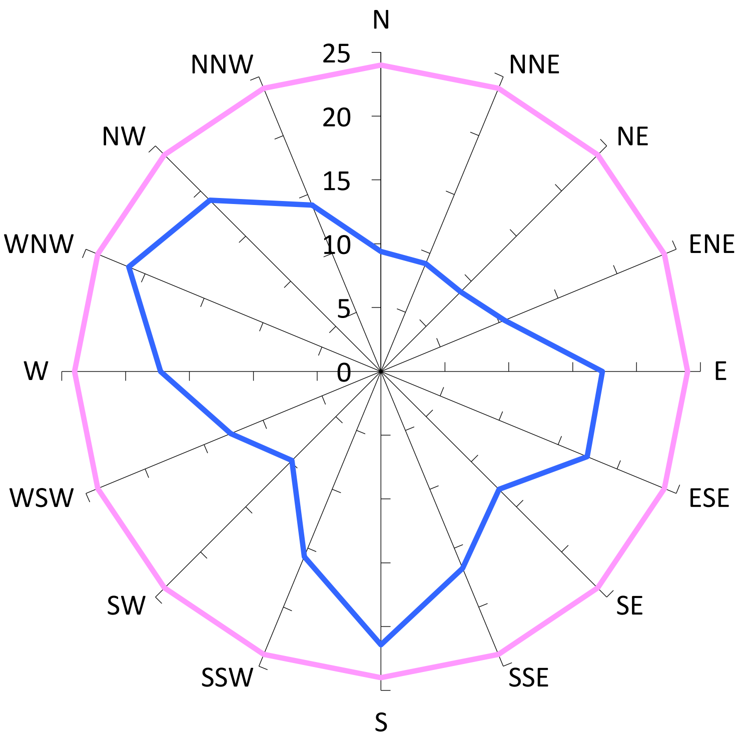
Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.

Development as Proposed - No vegetation or treatments

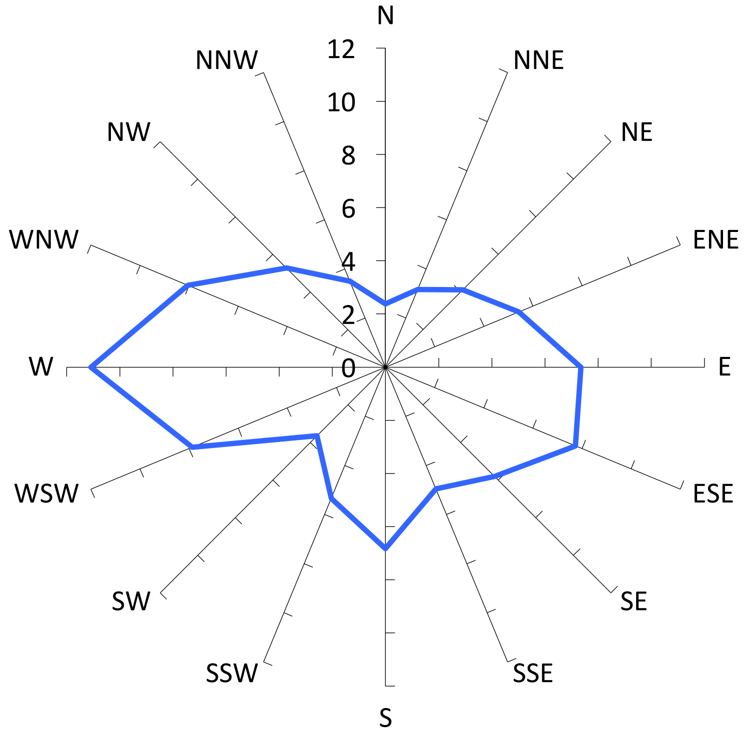
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 11

Weekly Maximum GEM (m/s)



Desired Criterion
6m/s

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

Probability of Criterion Exceedence (initial test)
22%

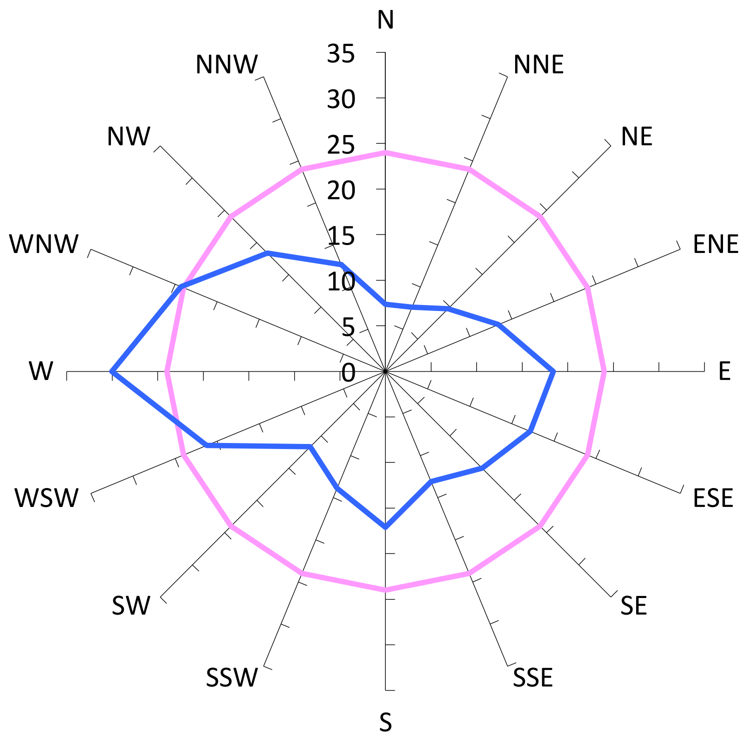
Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.

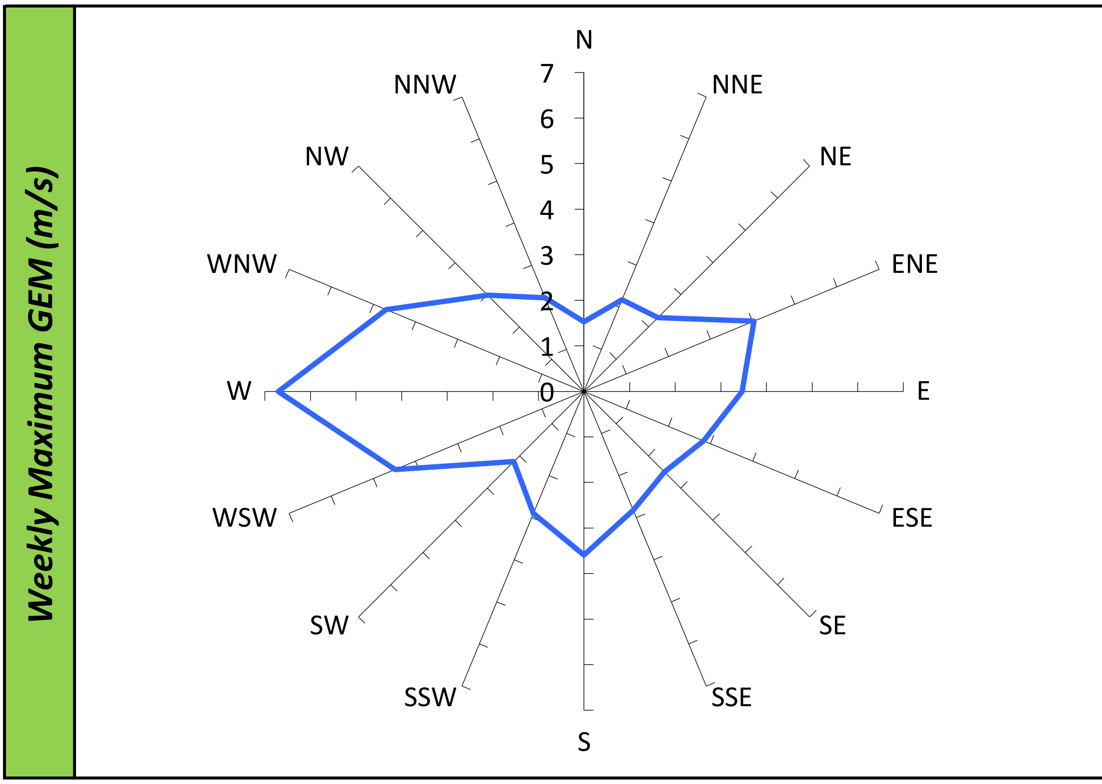
Development as Proposed - No vegetation or treatments

Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 12



Desired Criterion
6m/s

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

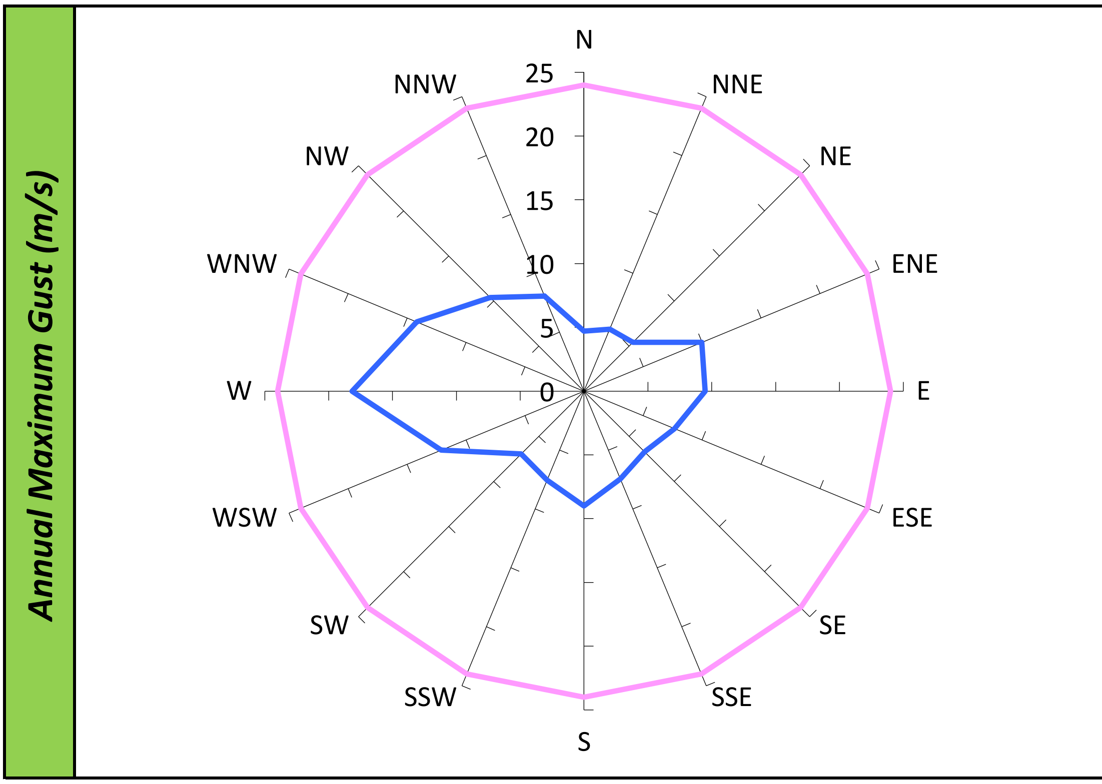
Probability of Criterion Exceedence (initial test)
3%

Probability of Criterion Exceedence (final retest)
N/A

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

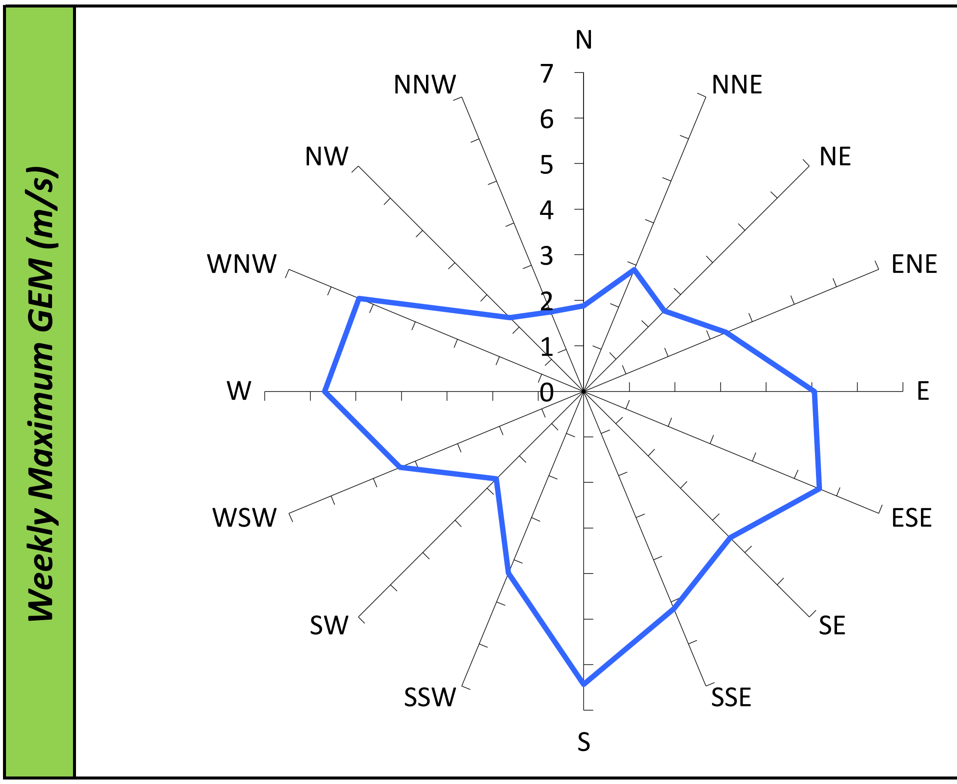
Criterion.

Development as Proposed - No vegetation or treatments



Desired Criterion
24m/s

Measured Wind Speeds at Point 13



Desired Criterion
6m/s

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

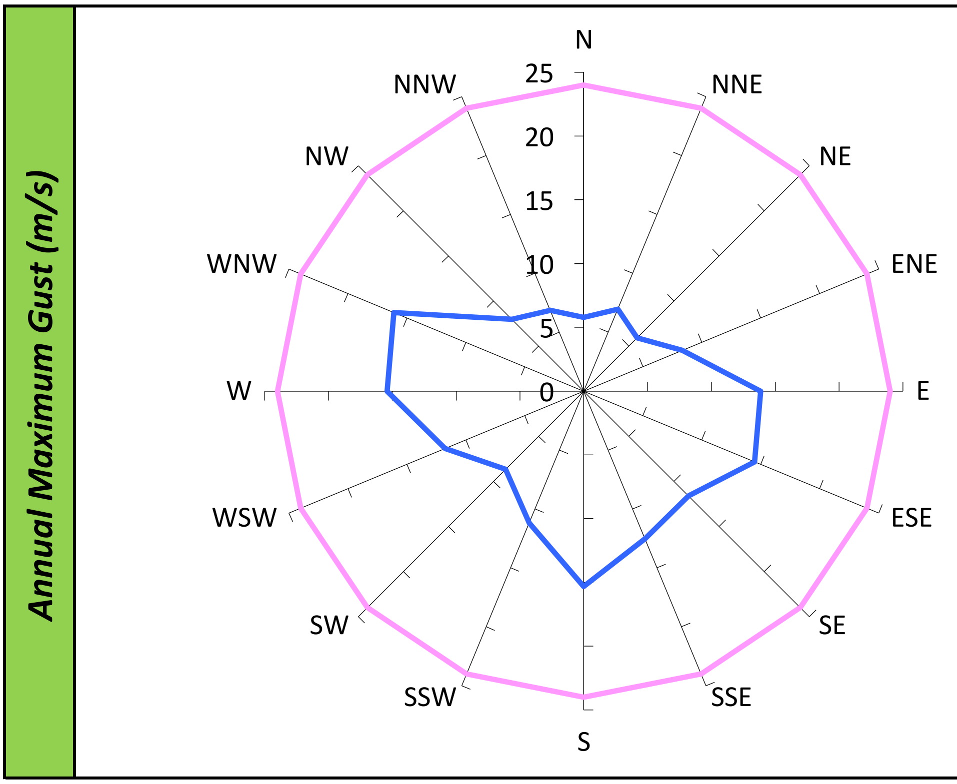
Probability of Criterion Exceedence (initial test)
6%

Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.

Development as Proposed - No vegetation or treatments

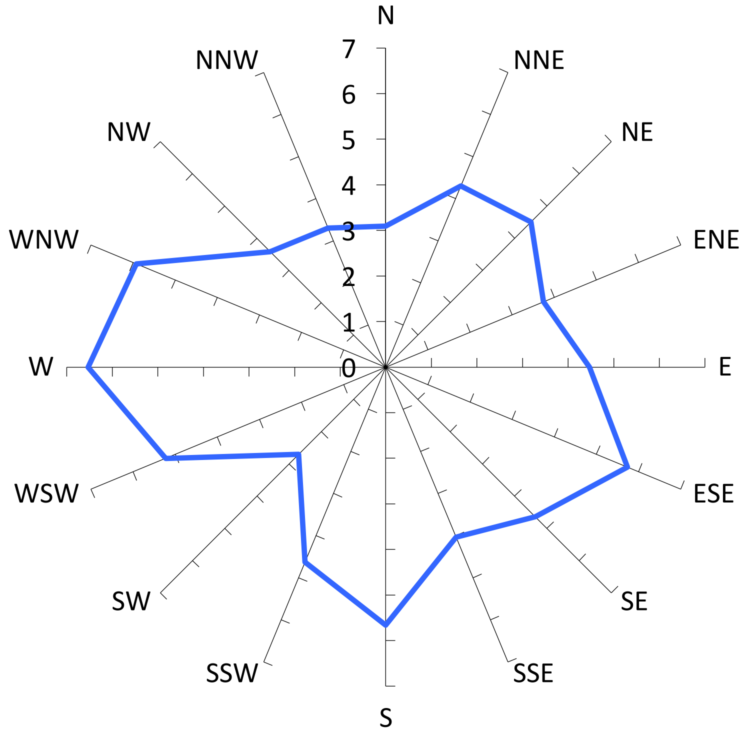


Desired Criterion
24m/s

Compliant Scenario (Podium)

Measured Wind Speeds at Point 08

Weekly Maximum GEM (m/s)



Desired Criterion
6m/s

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

Probability of Criterion Exceedence (initial test)
6%

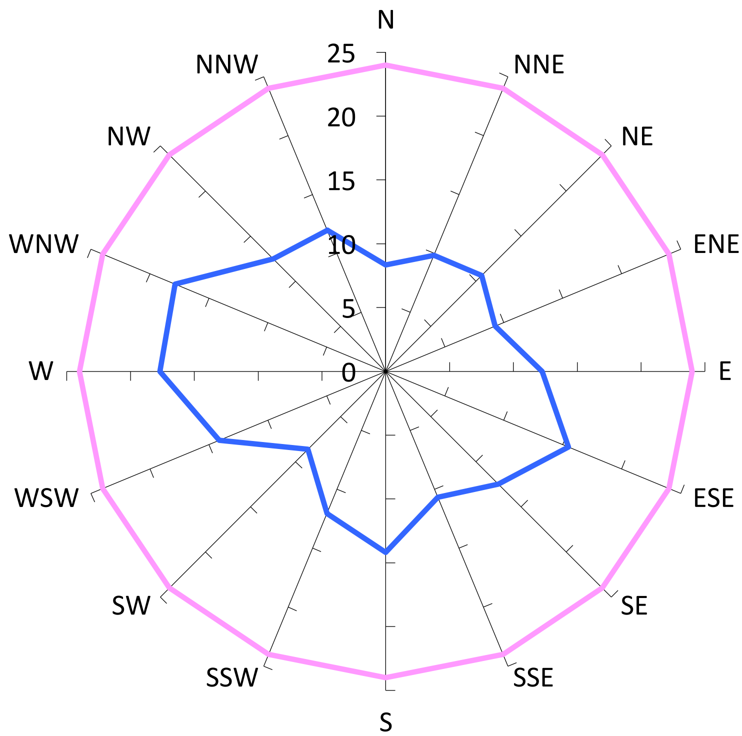
Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.

Base Case Building Massing - No vegetation or treatments

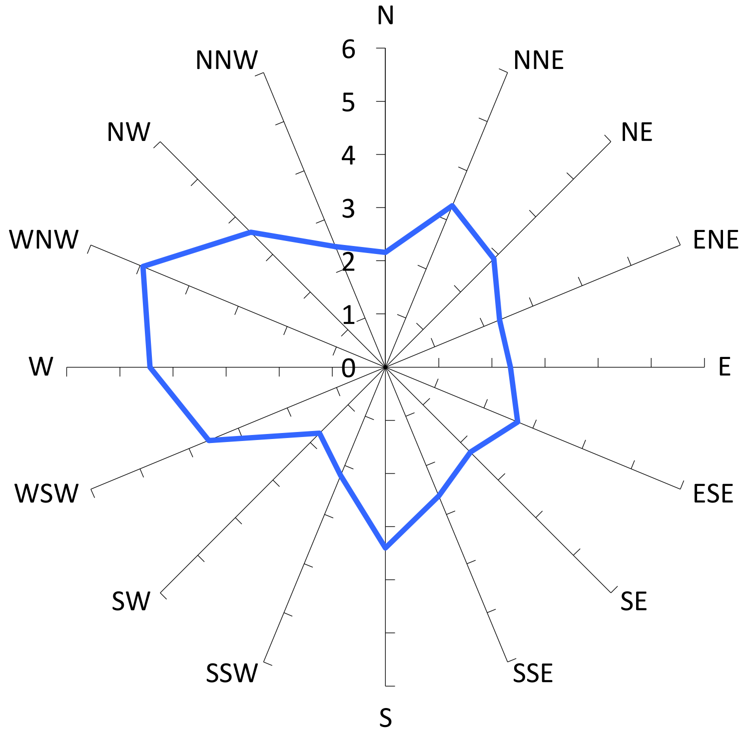
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 09

Weekly Maximum GEM (m/s)



Desired Criterion
6m/s

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

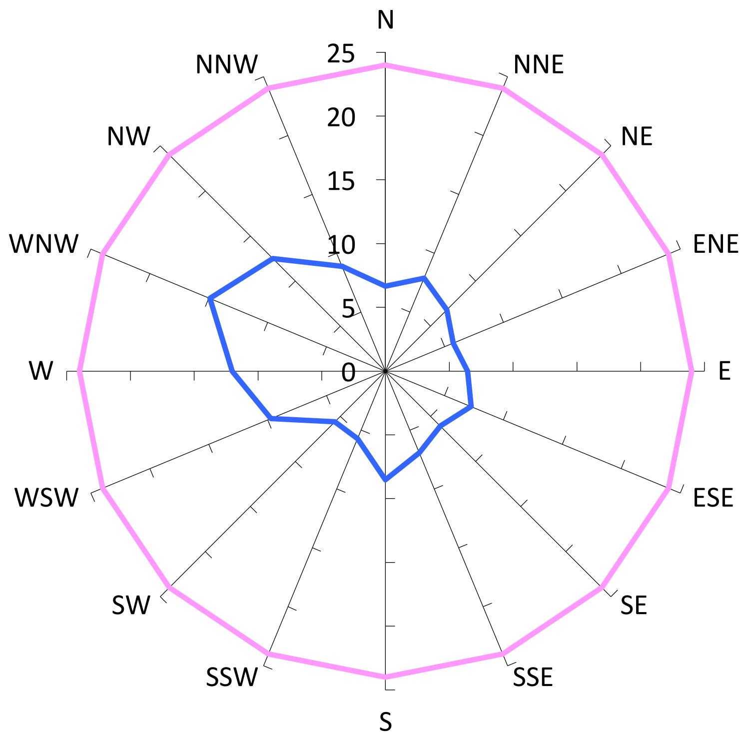
Probability of Criterion Exceedence (initial test)
1%

Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.
Base Case Building Massing - No vegetation or treatments

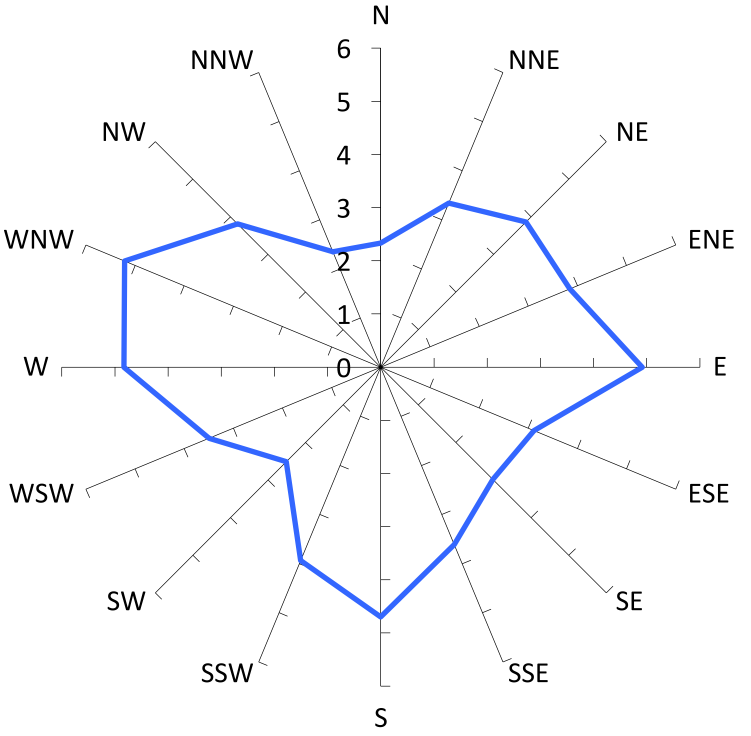
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 10

Weekly Maximum GEM (m/s)



Desired Criterion
6m/s

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

Probability of Criterion Exceedence (initial test)
2%

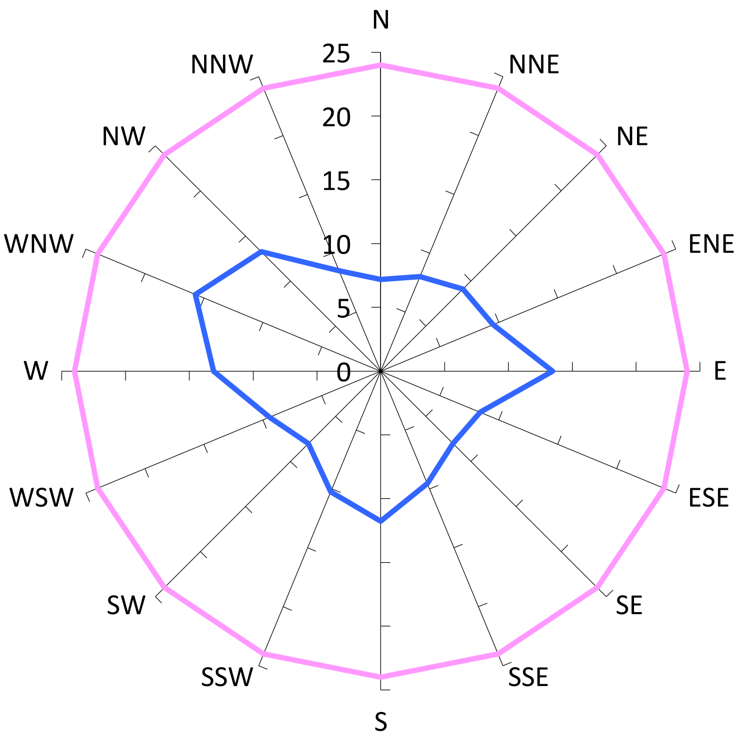
Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.

Base Case Building Massing - No vegetation or treatments

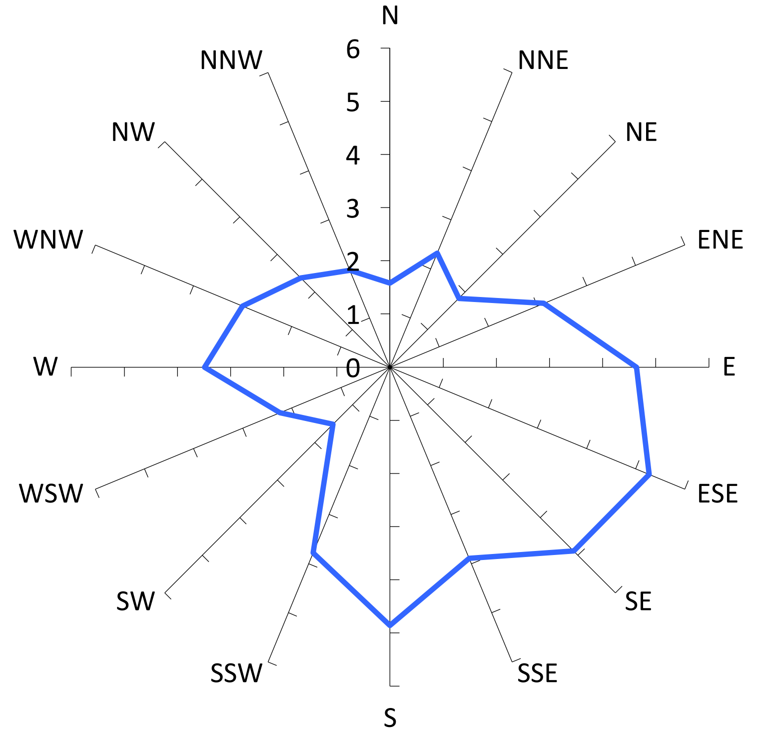
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 11

Weekly Maximum GEM (m/s)



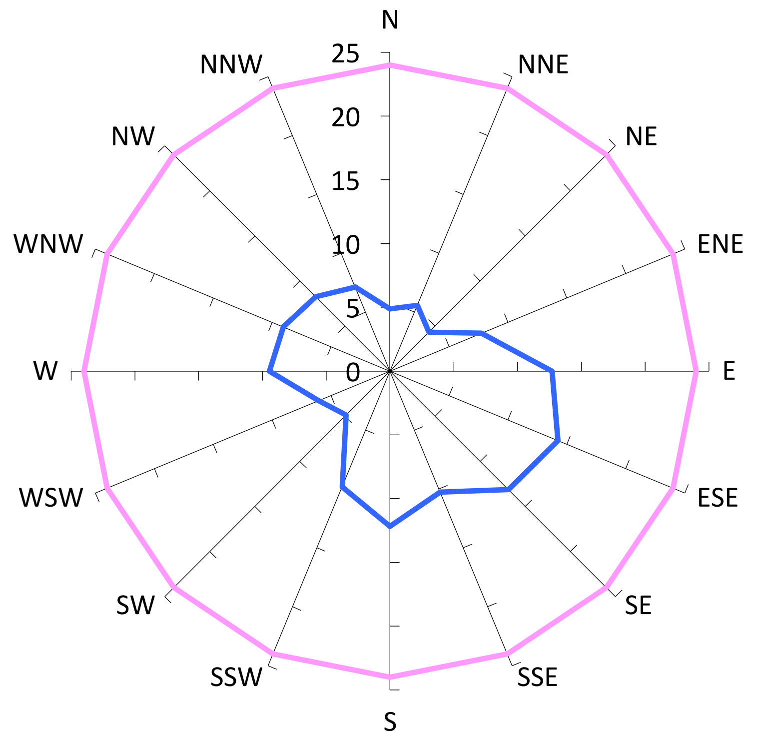
Desired Criterion
6m/s
Prob. of Criterion Exceedence (existing site conditions)
N/A
Probability of Criterion Exceedence (initial test)
2%
Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.

Base Case Building Massing - No vegetation or treatments

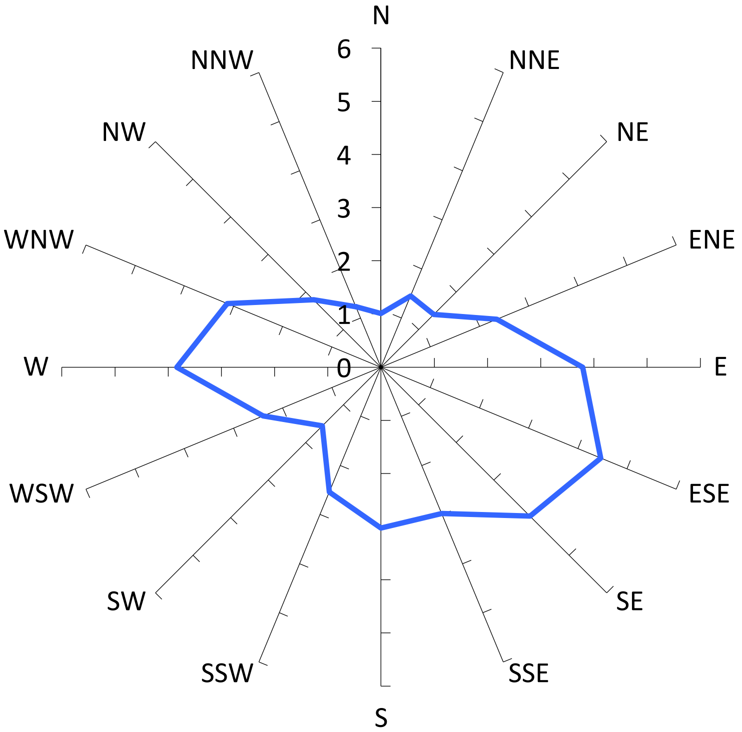
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 12

Weekly Maximum GEM (m/s)



Desired Criterion
6m/s

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

Probability of Criterion Exceedence (initial test)
0%

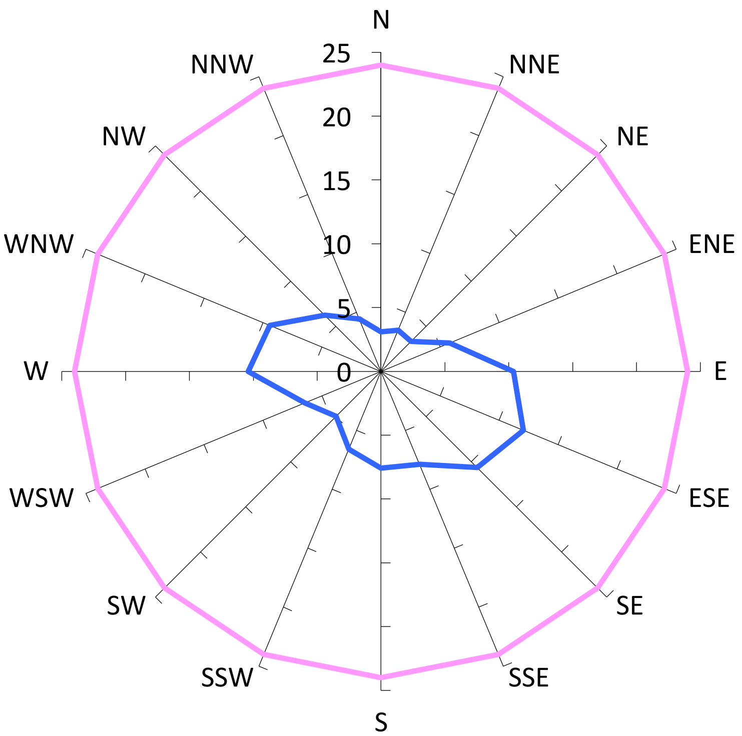
Probability of Criterion Exceedence (final retest)
N/A

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

Criterion.

Base Case Building Massing - No vegetation or treatments

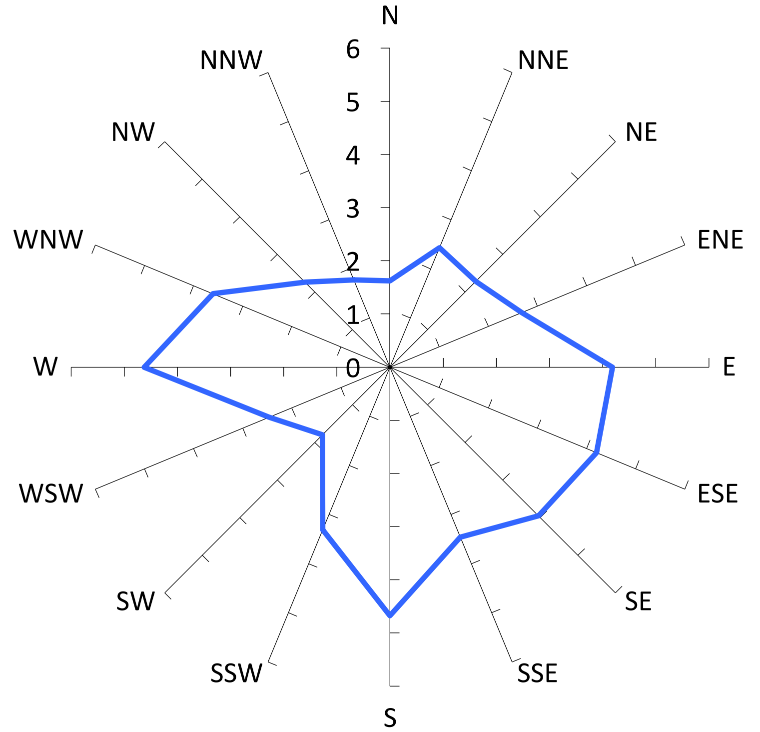
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at Point 13

Weekly Maximum GEM (m/s)



Desired Criterion
6m/s

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

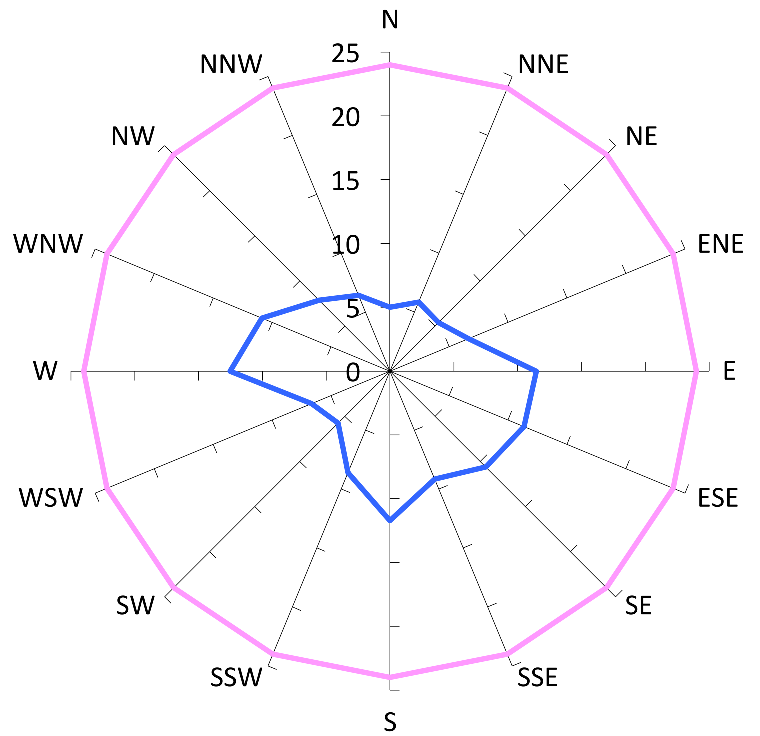
Probability of Criterion Exceedence (initial test)
1%

Probability of Criterion Exceedence (final retest)
N/A

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

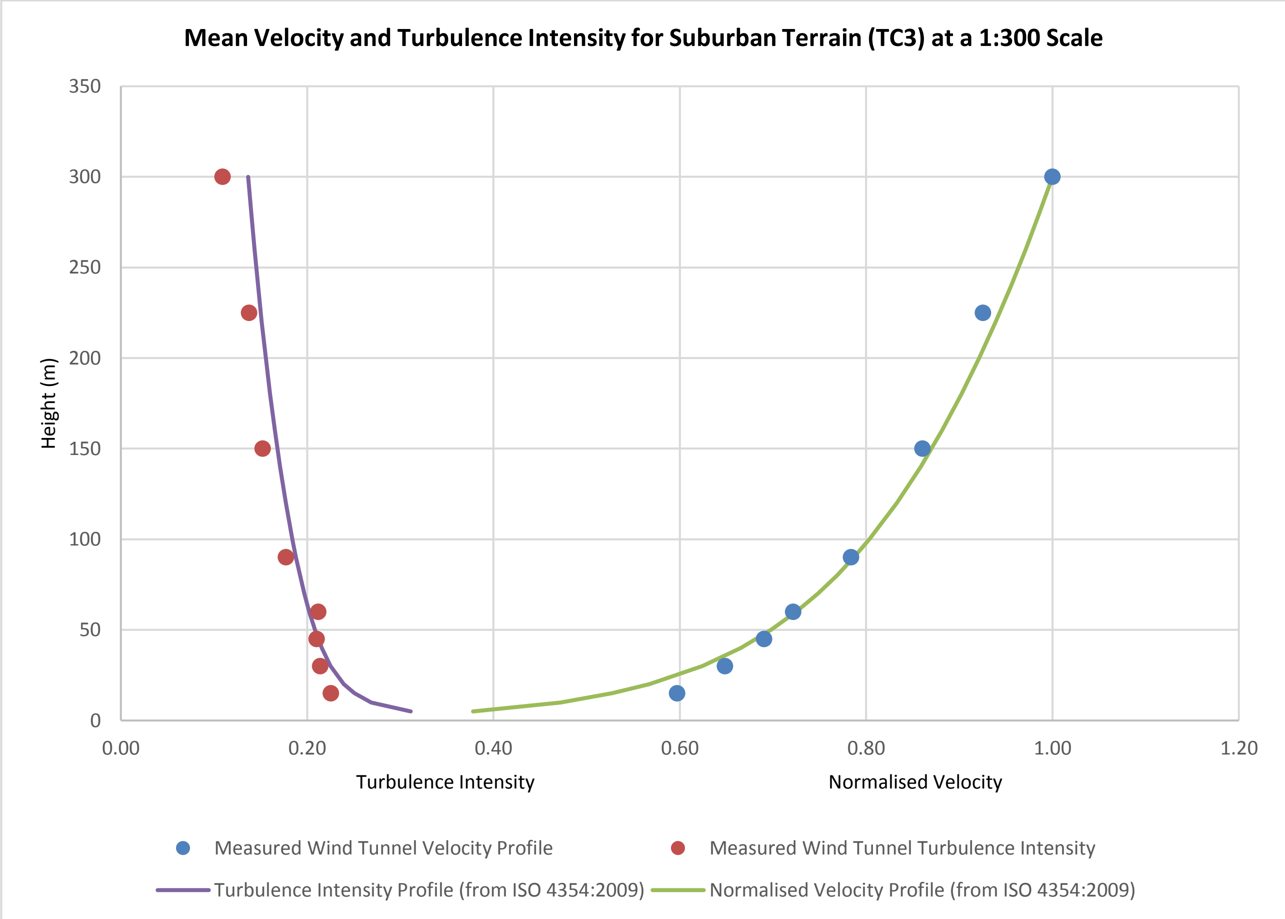
Criterion.
Base Case Building Massing - No vegetation or treatments

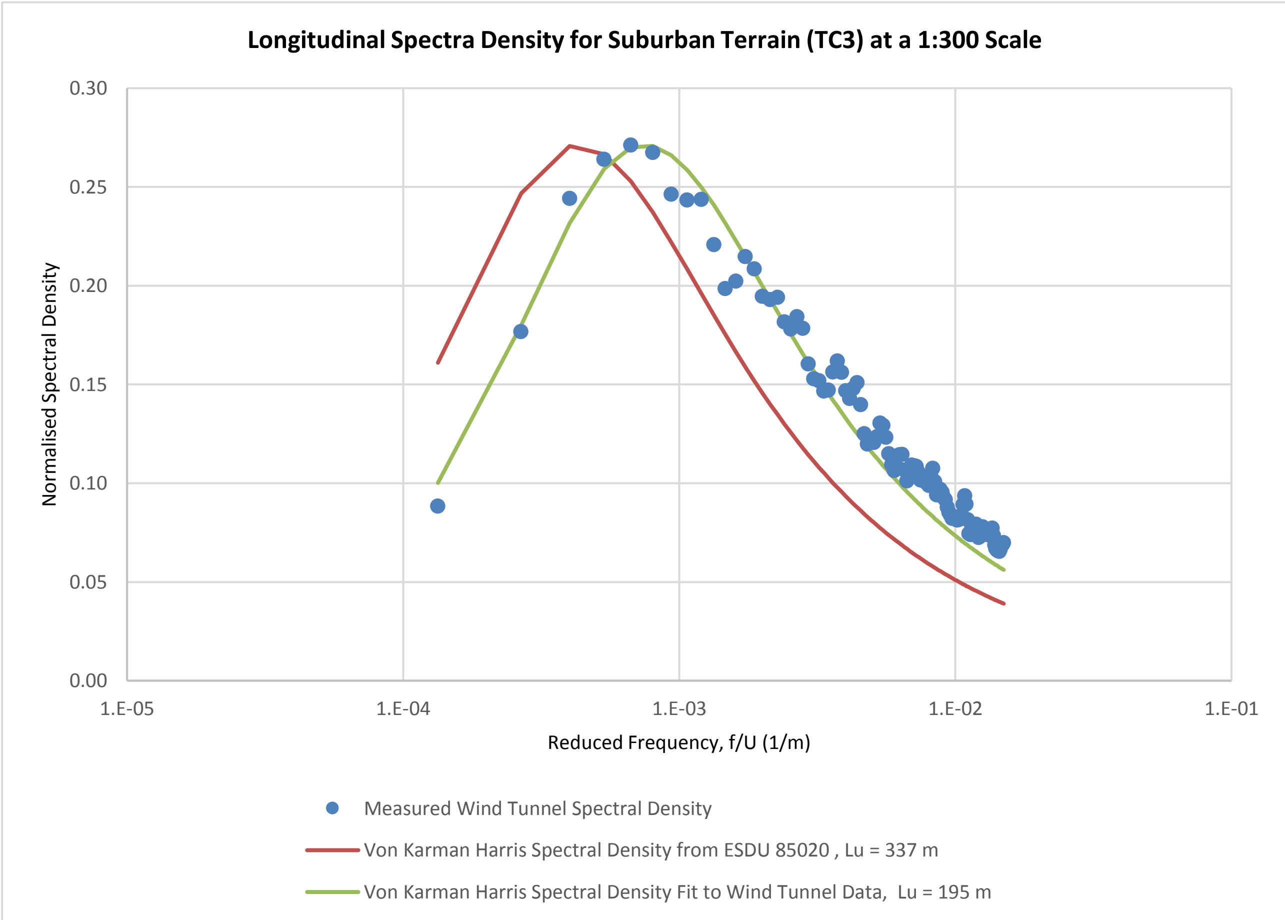
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

APPENDIX B - VELOCITY AND TURBULENCE INTENSITY PROFILES





Windtech Consultants

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