Vipac Engineers and Scientists Limited
279 Normanby Rd, Port Melbourne, VIC 3207, Australia
Private Bag 16, Port Melbourne, VIC 3207, Australia
t. +61 3 9647 9700 | e. melbourne@vipac.com.au
w. www.vipac.com.au | A.B.N. 33 005 453 627 | A.C.N. 005 453 627

BEG Projects Pty Ltd

139-149 Boundary Road, North Melbourne

Pedestrian Level Winds - Wind Tunnel Test

30N-22-0300-TRP-56111-0

19 May 2023

Job Title:	139-149 Boundary Road, North Melbourne
Report Title:	Pedestrian Level Winds - Wind Tunnel Test
Document Reference:	30N-22-0300-TRP-56111-0

Prepared For:	**Prepared By:**
BEG Projects Pty Ltd Level 2,201 Fitzroy St St Kilda, Victoria, 3182, Australia **Contact:** Tarquin Leaver **Tel:** 0438 514 555	Vipac Engineers and Scientists Limited 279 Normanby Rd, Port Melbourne, VIC 3207, Australia **Tel:** +61 3 9647 9700

Author:	Zhuyun Xu 19 May 2023		Principal Engineer
Reviewer:	Eric Yuen 19 May 2023		Wind Group Leader
Issued By:	Eric Yuen 18 May 2023	[signature]	Wind Group Leader

Revision History:

Rev. #	*Comments / Details of change(s) made*	*Date*	*Revised by:*
Rev. 00	Original issue	15 Jun 22	

Executive Summary

BEG Projects Pty Ltd commissioned Vipac Engineers and Scientists Pty Ltd to carry out a wind tunnel test to determine the likely pedestrian level wind conditions for the proposed development at **139-149 Boundary Road, North Melbourne.**

The model was constructed based on drawings supplied by **CHT Architects** in **May 2023**. The proposed development and surrounding buildings covering a circular area of approximately 500 m radius were modelled at a 1:400 scale. The approaching mean and turbulent flows of Terrain Category 2.5 for 40-110 azimuth degrees and Terrain Category 3 for all other wind direction Atmospheric Boundary Layer were modelled based on Australian Standard AS 1170.2-2021.

The findings of the study are summarised as follows:

The proposed design of the development:

- fulfils the recommended criterion for **Safety** at all test locations;
- fulfils the recommended criterion for **Walking** at all footpath locations;
- fulfils the recommended criterion for **Standing** at all building entrances; and
- fulfils the recommended criteria for **Standing** at Level 11 rooftop terraces**.**

The proposed development would not cause significant adversely impact to the adjacent areas.

As a general statement, common to all new developments, educating occupants about wind conditions at high-level terraces/balconies during high-wind events and tying down loose furniture are highly recommended.

Table of Contents

1 Introduction

Vipac Engineers & Scientists Ltd was commissioned by **BEG Projects Pty Ltd** to carry out a wind tunnel test of the likely wind conditions for the proposed development at **139-149 Boundary Road, North Melbourne.**

The proposed development is a 15 storey office tower with a building height of approximately 57 m from street level. The site is bounded by Buckhurst St to the north, Ann Street to the west, Rosherville Place to the east and existing developments to the south. A satellite image of the proposed development site, east elevation of the building, and the ground floor plan with approximate dimensions overlaid are shown in Figure 1, Figure 2 and Figure 3 respectively.

The proposed development is located in southwest area to the Melbourne CBD and is immediately surrounded by high rise developments, high density suburban areas and parklands further out. Port Phillip Bay is also to the south west of the site. Considering the surroundings and terrain, within a 4 km radius, the site of the proposed development is assumed to be within Terrain Category 2.5 for 40-110 azimuth degrees and Terrain Category 3 for all other wind directions (Figure 4).

This report details the pedestrian level wind assessment results of the tests carried out on a 1:400 scale model of the proposed development in Vipac's Boundary Layer Wind Tunnel in Melbourne, during May 2023. The results show the wind effects in ground level public areas adjacent to the development as proposed.

The pedestrian wind environment study of the development was conducted using Omni-directional pressure sensor techniques to predict wind velocities. The study investigated safety and comfort in ground level pedestrian access-ways adjacent to the project.

The model was constructed to drawings supplied by **CHT Architects** in **May 2023**. Figure 5 and Figure 6 show the 1:400 scaled models in the wind tunnel. A complete list of the drawings used to construct the model is provided in Appendix A of this report.

Figure 1: Aerial view of the proposed development site.

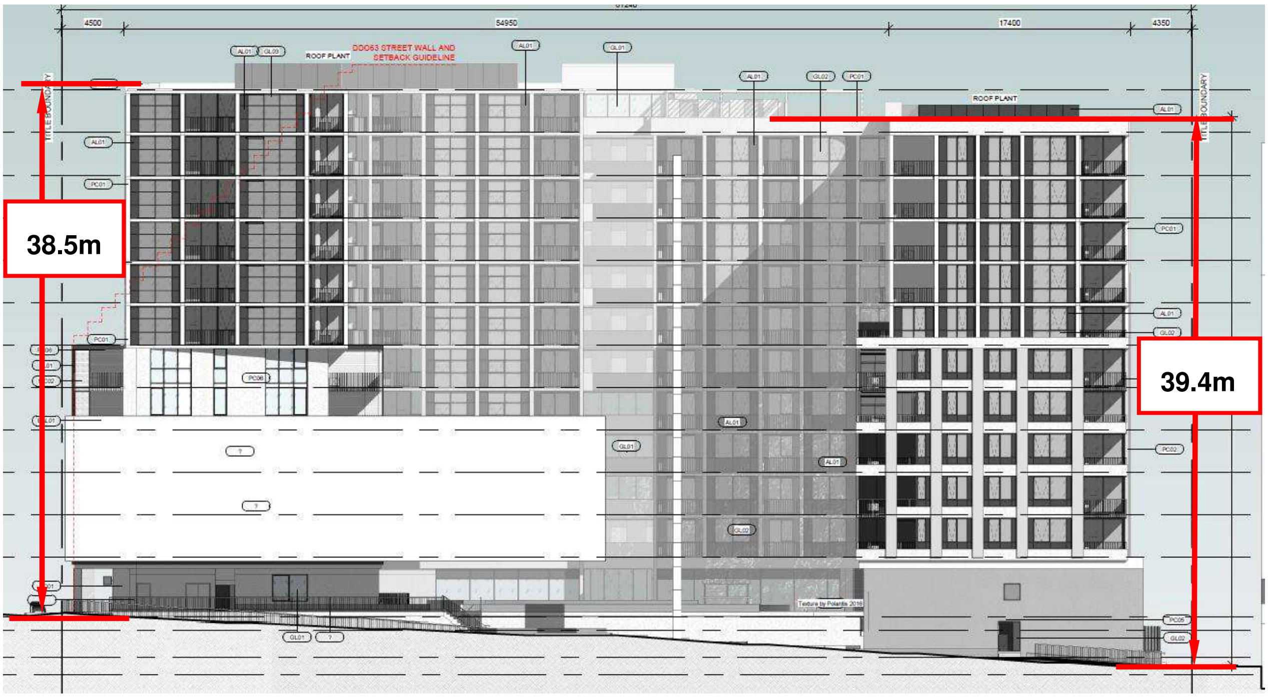


Figure 2: North Elevation of the proposed development.

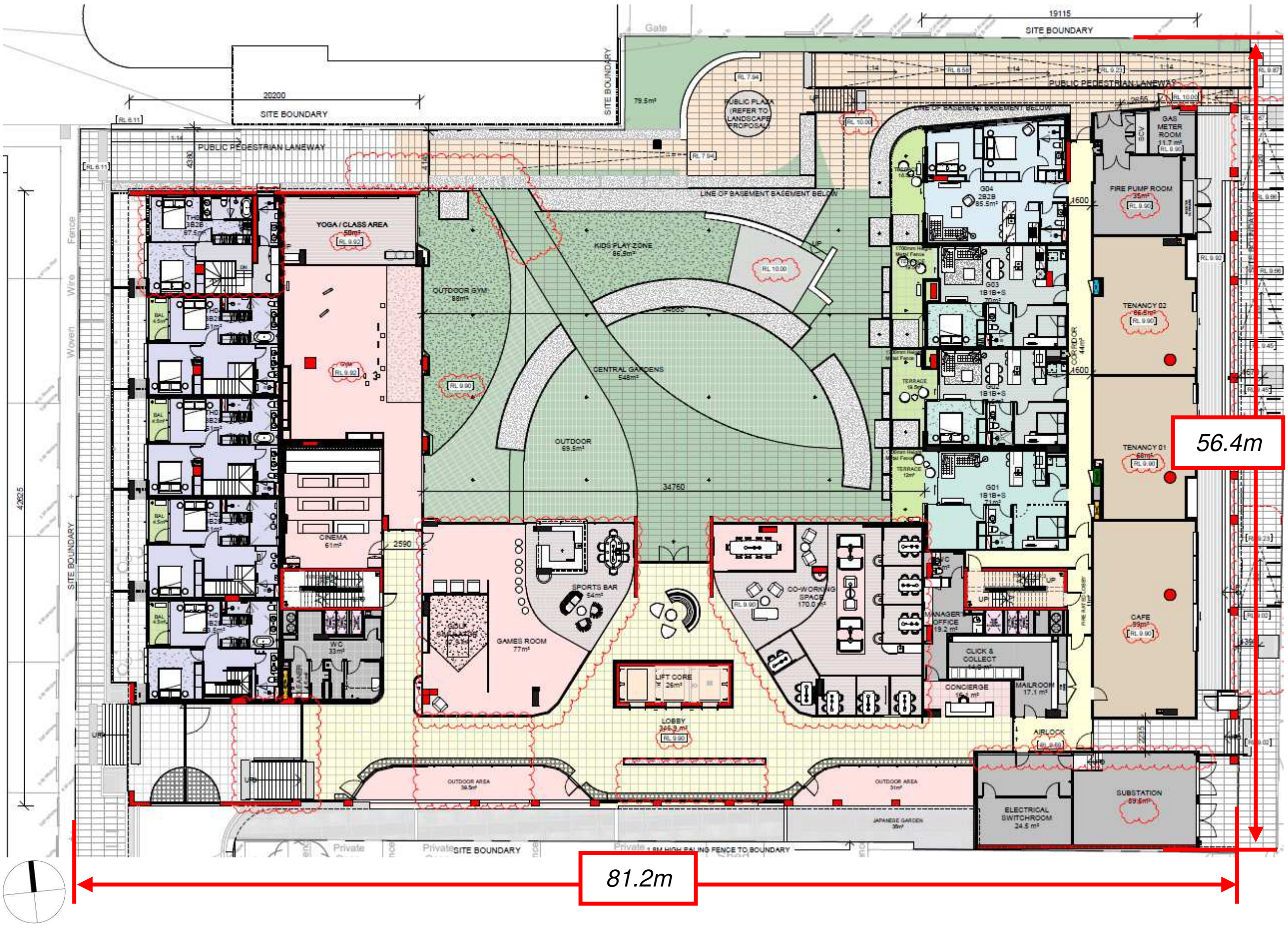


Figure 3: Ground level plan with the overall dimensions overlaid.

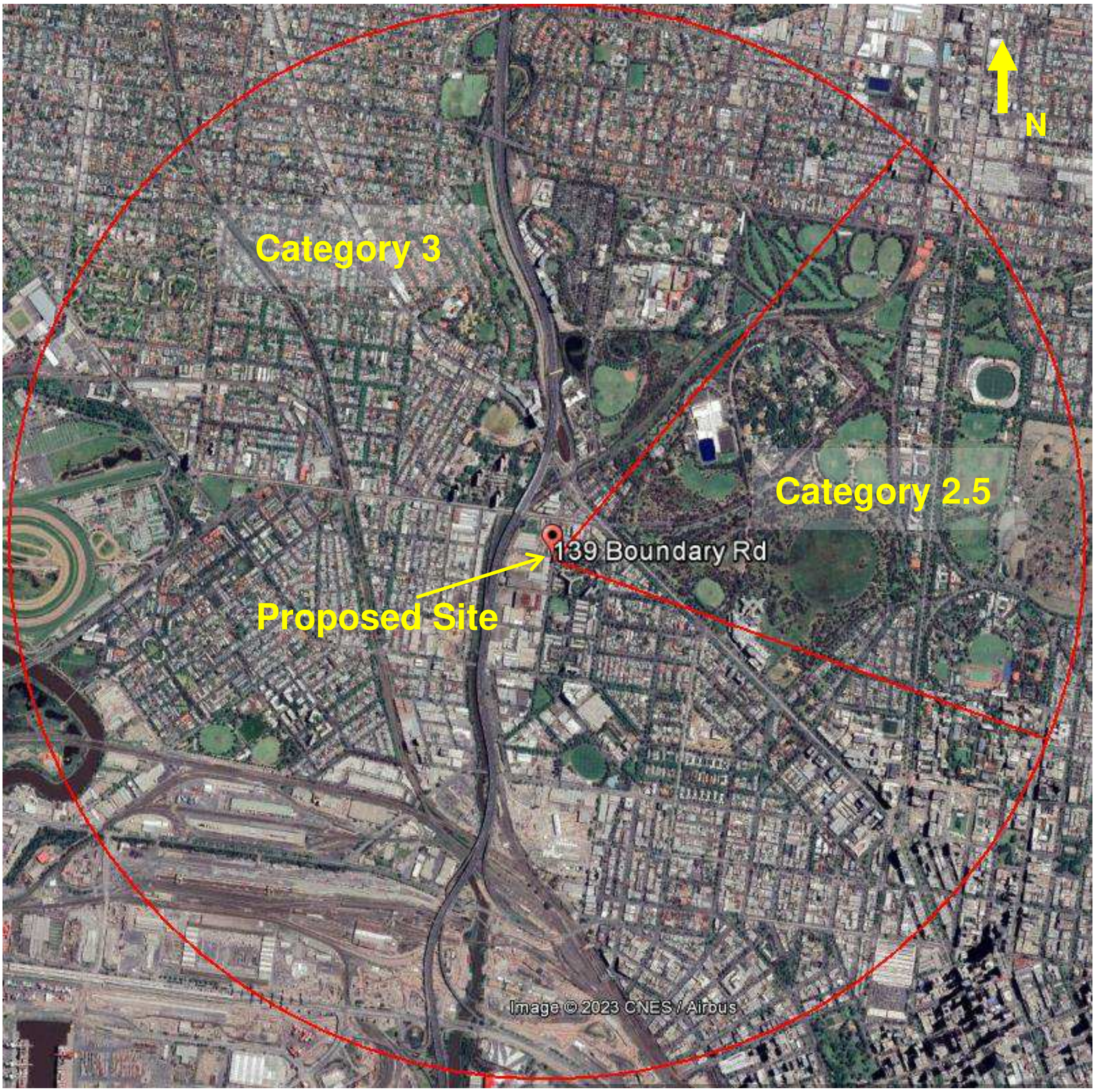


Figure 4: Assumed terrain roughness for wind speed estimation.

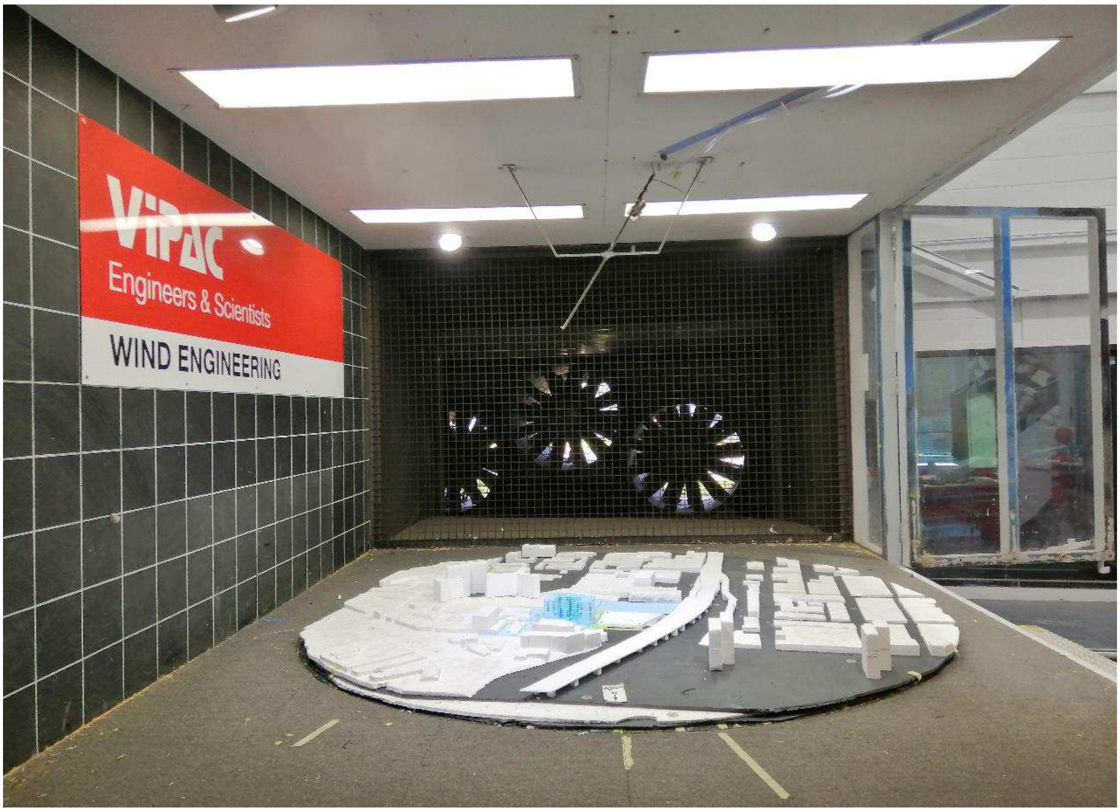


Figure 5: Overall view from north of the 1:400 scale model of the proposed development in the wind tunnel (Configuration 1)

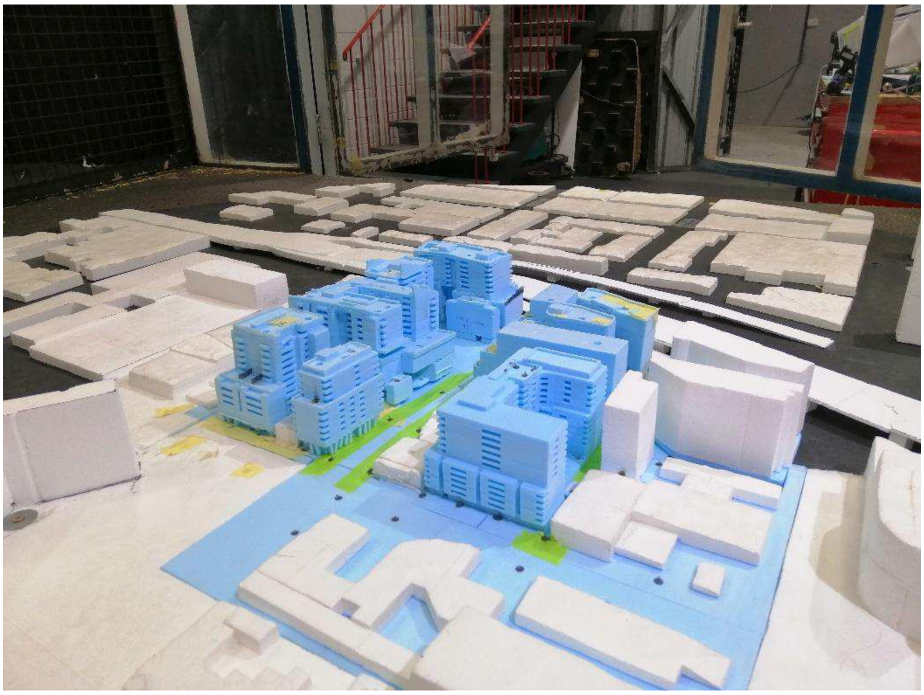


Figure 6:Close up view from the west of the 1:400 scaled model in the wind tunnel (Configuration 2).

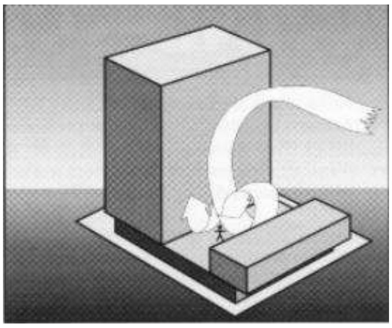
1.1 Environmental Wind Effects

Atmospheric Boundary Layer

As wind flows over the earth it encounters various roughness elements and terrain such as water, forests, houses and buildings. To varying degrees, these elements reduce the mean wind speed at low elevations and increase air turbulence. The wind above these obstructions travels with un-attenuated velocity, driven by atmospheric pressure gradients. The resultant increase in wind speed with height above ground is known as a wind velocity profile. When this wind profile encounters a tall building, some of the fast moving wind at upper elevations is diverted down to ground level resulting in local adverse wind effects.

The terminology used to describe the wind flow patterns around the proposed Development is based on the aerodynamic mechanism, direction and nature of the wind flow.

Downwash – refers to a flow of air down the exposed face of a tower. A tall tower can deflect a fast moving wind at higher elevations downwards.

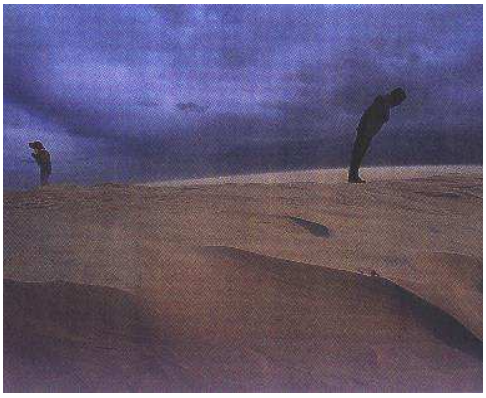


Corner accelerations – when wind flows around the corner of a building it tends to accelerate in a similar manner to airflow over the top of an aeroplane wing.

Flow separation – when wind flowing along a surface suddenly detaches from that surface and the resultant energy dissipation produces increased turbulence in the flow. Flow separation at a building corner or at a solid screen can result in gusty conditions.

Flow channelling – the well-known "street canyon" effect occurs when a large volume of air is funnelled through a constricted pathway. To maintain flow continuity the wind must speed up as it passes through the constriction. Examples of this might occur between two towers, in a narrowing street or under a bridge.

Direct exposure – a location with little upstream shielding for a wind direction of interest. The location will be exposed to the unabated mean wind and gust velocity. Piers and open water frontage may have such exposure.



2 Regional Wind Climate

The mean and gust wind speeds have been recorded in the Melbourne area for over 30 years. This data has been analysed and the directional probability distribution of wind speeds has been determined. The directional distribution of hourly mean wind speed at the gradient height, with a probability of 0.1% of time and 20% of time exceeded are shown in Figure 7. The wind data at this free stream height is common to all Melbourne city sites and may be used as a reference to assess ground level wind conditions at the site.

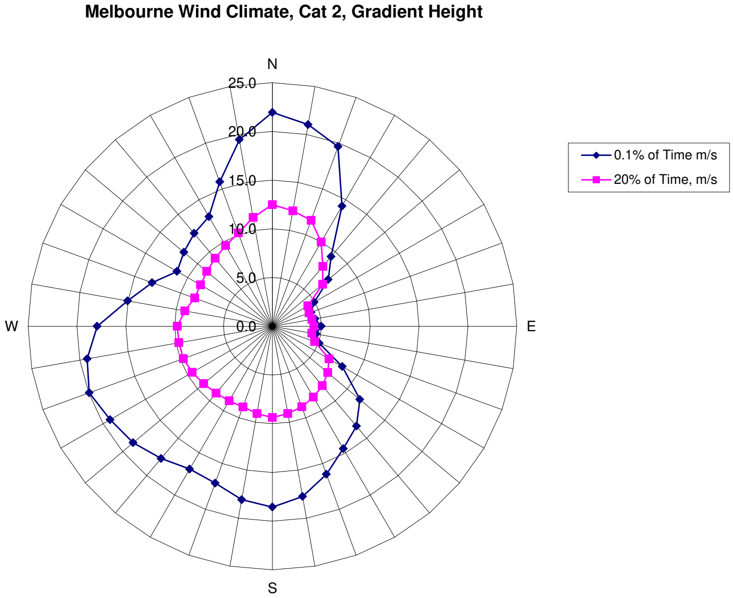


Figure 7: Directional Distribution of Mean Hourly Wind Velocities (m/s) for 0.1% and 20% exceeded at Gradient Height for Melbourne.

3 Assessment Criteria

The Better Apartment Guidelines Environment and Clause 58.04-4 criteria for wind impact were applied in the study. The document recommends the following wind comfort criteria (Table 1).

Table 1: Wind criteria from Clause 58.04-4

Unsafe	Comfortable
Annual maximum 3 second gust wind speed exceeding **20m/sec** with a probability of exceedance of 0.1% considering at least 16 wind directions.	Hourly mean wind speed or gust equivalent mean speed from all wind directions combined with probability of exceedance less than 20% of the time, equal to or less than: **3m/sec** for sitting areas (outdoor cafés) **4m/sec** for standing areas (window shopping, queuing) **5m/sec** for walking areas (steady steps for most pedestrians)

This criterion specifically calls for the safety criterion to be used to assess infrequent winds (e.g. peak event of ≤ 0.1% of the time); and the perceived pedestrian comfort to be assessed based on frequently occurring winds (e.g. winds that occurs 80% of the time).

The mean wind speed is hourly mean speed or gust equivalent mean (3 sec gust divided by 1.85), whichever is greater.

The Schedule specifies that safe and comfortable wind conditions must be achieved in publicly accessible areas within a distance equal to half the longest width of the building measured from all facades or half the overall height of the building, whichever is greater, as shown in Figure 8.

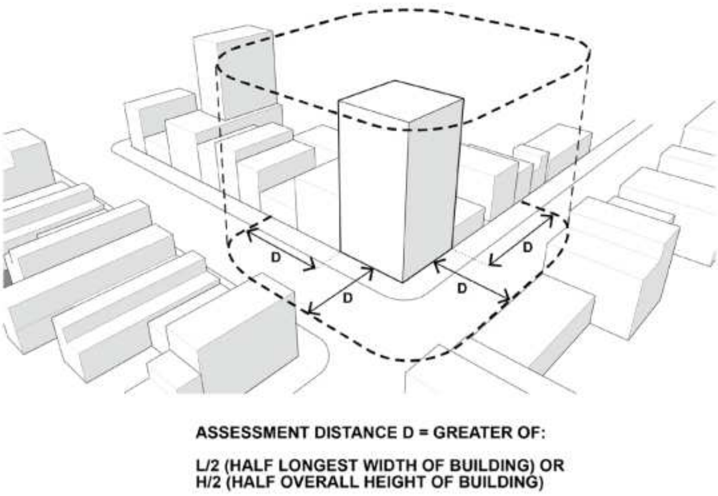


Figure 8: Assessment distance as detailed in Clause 58.04-4

3.1.1 Use of Adjacent Pedestrian Occupied Areas & Recommended Comfort Criteria

The following table lists the specific areas adjacent to the proposed development and the corresponding recommended criteria.

Table 2: Recommended application of criteria.

Area	**Specific location**	**Recommended Criteria**
Public Footpaths, Access ways	Around the proposed development along Boundary Road (Figure 9)	Walking
Building Entrances	Several locations throughout site (Figure 9)	Standing
Outdoor Communal Areas	On Upper Ground and Level 11 (Figure 10)	Standing
Balcony/Terraces	Up the height of the building	Walking (See discussion below)

3.1.2 Terrace / balcony Recommended Criterion Discussion

Vipac recommends as a minimum that rooftop terrace areas meet the criterion for walking since:

- these areas are not public spaces;
- the use of these areas is optional;
- many similar developments in Melbourne and other Australian capital cities experience wind conditions on balconies and elevated deck areas in the vicinity of the criterion for walking.

However, it should be noted that meeting the walking criterion on elevated recreation areas will be no guarantee that occupants will find wind conditions in these areas acceptable at all times.

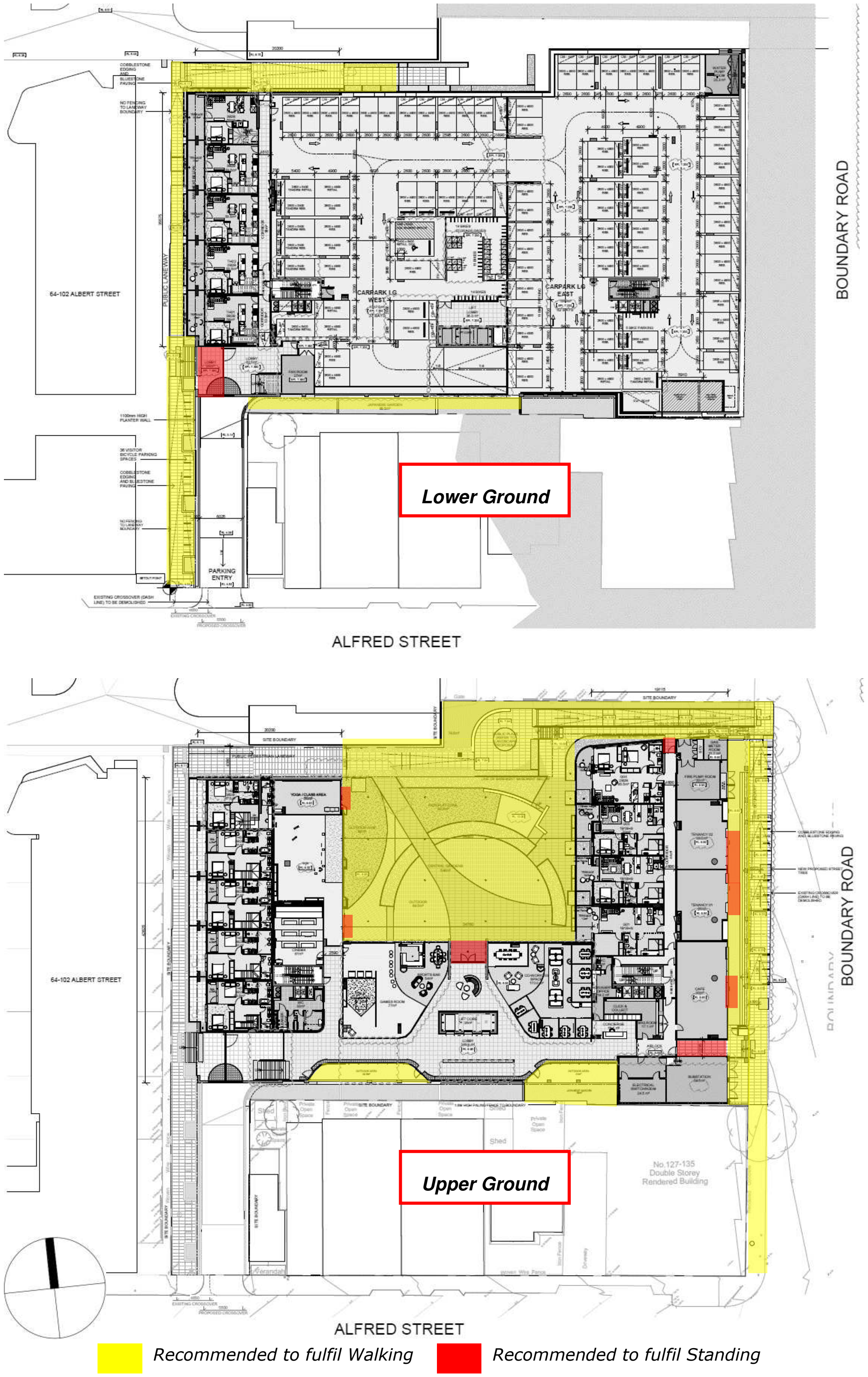
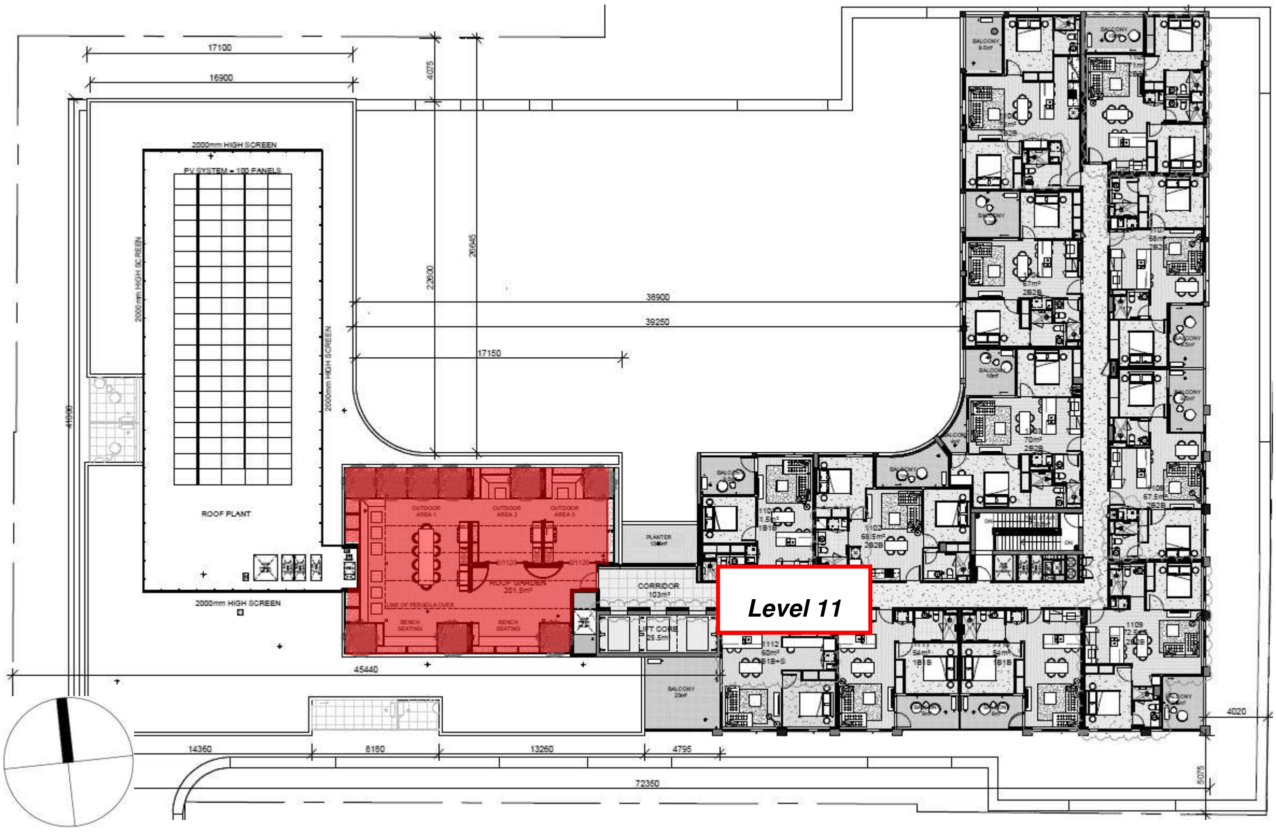


Figure 9: Lower Ground (top) and Upper Ground (bottom) floor plan with recommended wind criteria overlaid.



Recommended to fulfil Standing

Figure 10: Level 11 plan with recommended wind criteria overlaid.

4 Wind Tunnel Simulation

4.1 Similarity Requirements

The validity of wind tunnel testing relies on the similarity between model and full-scale parameters. This requires undistorted length scaling (ie. geometric similarity), similarity of flow parameters (i.e. kinematic similarity) and finally similarity of pressures and forces.

Complete similarity is usually impossible to obtain because of the competing requirements of the various non-dimensional parameters, (e.g. Reynolds Number, Rossby Number and Richardson Number). Some requirements (i.e. Reynolds Number equality) can be waived for sharp edged structures immersed in a neutrally stable atmospheric boundary layer and geometric and kinematic similarity suffice. These are the requirements specified in Section C1.4, AS/NZS 1170.2 Supplement 1: 2011 [4] and are employed in this study.

4.2 Approach Wind Simulation

The wind effects tests were carried out in the 3m wide × 2m tall × 16m long Boundary Layer Wind Tunnel at Vipac Engineers and Scientists Ltd in Melbourne. The Boundary Layer Wind Tunnel is designed to simulate the flow incident on a proposed development by modelling the upstream terrain characteristic roughness. To this end, an estimate of the upstream terrain properties for the Development has been made and reproduced in the wind tunnel.

The approaching mean and turbulent flows of the Terrain Categories 3 and 2.5 Atmospheric Boundary Layers based on different exposures were modelled based on Australia Standard AS 1170.2-2021. The wind tunnel calibration velocity and turbulence intensity profiles for Terrain Categories 3 and 2.5 are shown in Figure 11 and Figure 12. These represent the wind velocity and turbulence intensity profiles approaching the model of the development. Closer to the ground the wind moves more slowly but with increased turbulence. The simulated approach is indicative of full-scale planetary boundary layer velocity and turbulence intensity profiles.

Velocity correction factors are used to adjust the measured wind speed to ensure that the ratio of mean roof-height to reference height wind speed in the wind tunnel matches expected full-scale values.

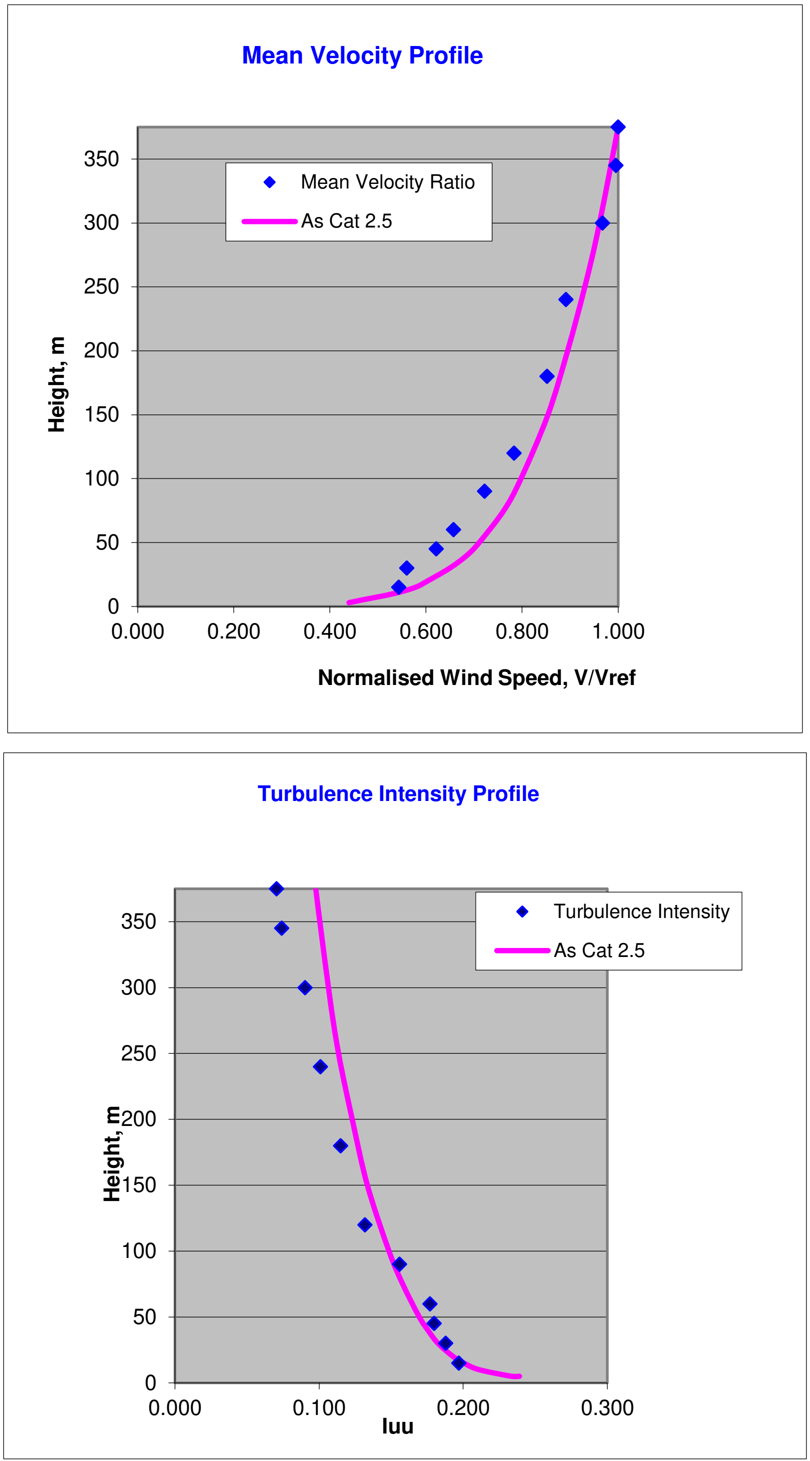
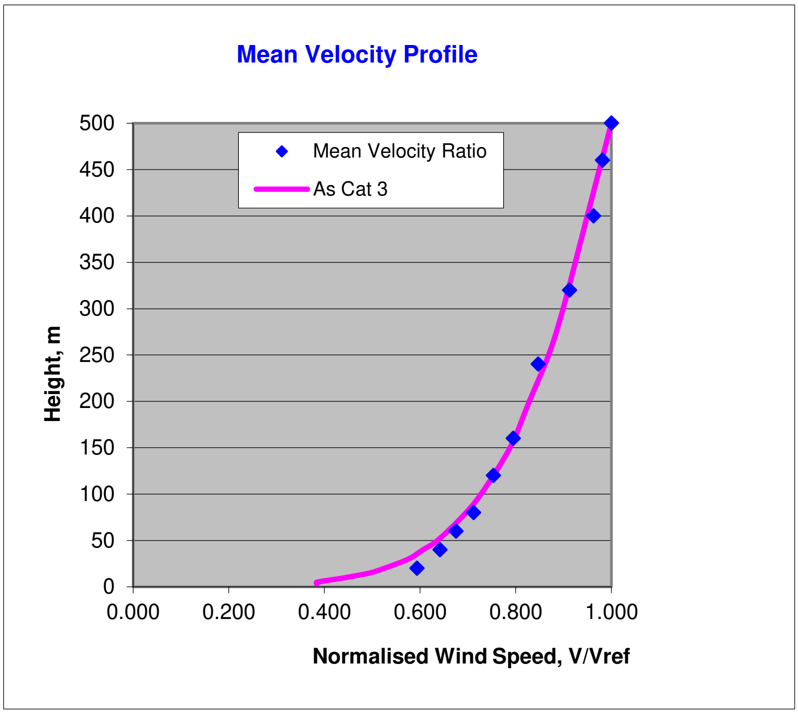


Figure 11: Mean Velocity and Turbulence Intensity Profiles for Terrain Category 2.5 (1:400 scale).



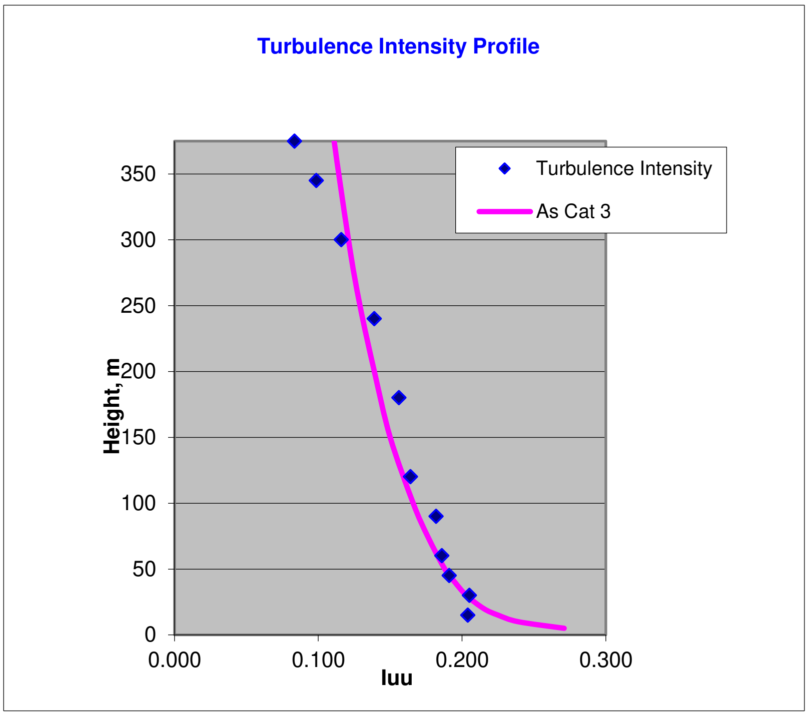


Figure 12: Mean Velocity and Turbulence Intensity Profiles for Terrain Category 3 (1:400 scale).

5 Test Procedure

The pedestrian wind environment in the adjacent footpath areas along Boundary Road, various Lanes around the project site, centre garden and some selected terrace areas at Level 11 were assessed using Omni-directional pressure sensor measurements [4].

Velocity measurements were made using Irwin sensors (Omni-directional pressure sensors) installed at different locations at the adjacent ground level footpath areas and podium level of the proposed development. The test was conducted without any landscaping. The distribution of Irwin sensors has allowed the determination of the variation in velocity sufficient to capture the changes in velocity distribution that can typically occur over such areas. The resolution of measurement locations is in accordance with that prescribed in the Wind Tunnel Testing Quality Assurance Manual of the Australasian Wind Engineering Society.

PVC tubes with 1.3 mm internal diameter linked the Irwin sensors to pressure transducer device using a tuned arrangement to prevent harmonic fluctuations.

Velocity measurements were obtained at 10° wind azimuth increments starting from 0° (north) for a full 360° circle. The sampling time is determined based on the similarity criteria and corresponds to a total time of one hour in full scale. Statistical analysis was carried out on the signals for the mean and standard deviation. All velocity coefficients derived from the wind tunnel were converted to velocities by integrating the data with the regional wind climate and corresponding to design wind speeds with a probability 0.1% of time for safety criterion assessment and 20% of time for comfort criteria assessment.

A total of **35** sensors were used in order to provide a quantitative measure of the ground level wind speeds at various locations around the footpaths and garden. The sensor locations are shown in Figure 13 and Figure 14.

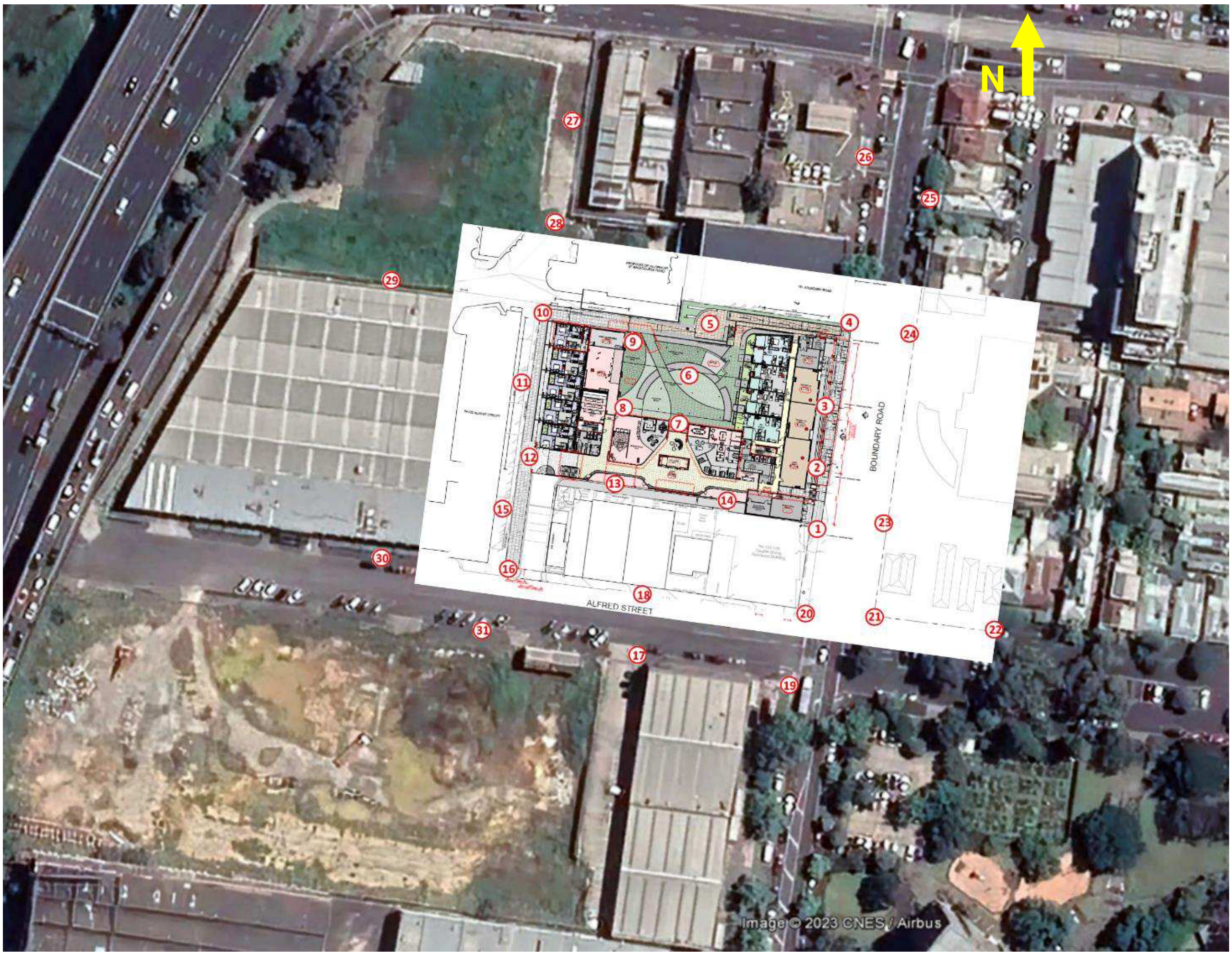


Figure 13: Sensor numbers and locations on the ground level.

Figure 14: Sensor numbers and locations on Level 11 roof.

6 Results and Discussion

The pedestrian wind environment in the footpath area, building entrance areas and communal terrace area were assessed using omnidirectional pressure sensor tests.

Three configurations were conducted, namely:

- **Configuration 1:** test with the proposed development with current surroundings (Figure 5 and Figure 15);
- **Configuration 2:** test with the proposed development and all proposed and likely future developments that will be built up within about 5 years (Figure 6 and Figure 16); and
- **Existing Conditions:** As a reference, the existing conditions are also tested for the ground level test locations (Figure 17).

The tests were conducted without any landscaping at the ground level. All testing was conducted for the proposed design without any street trees.

The proposed development with Configuration 1 was tested as a benchmark and if problematic areas were identified, then the required control strategies were implemented and afterwards Configuration 2 was tested.

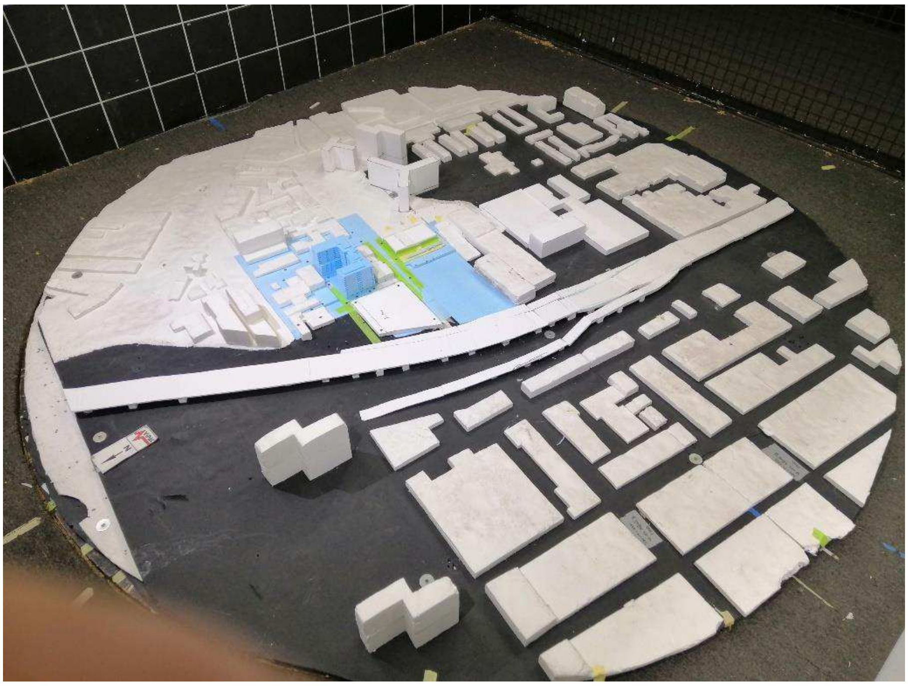


Figure 15: Overall view of the proposed development model in the wind tunnel (Configuration 1).

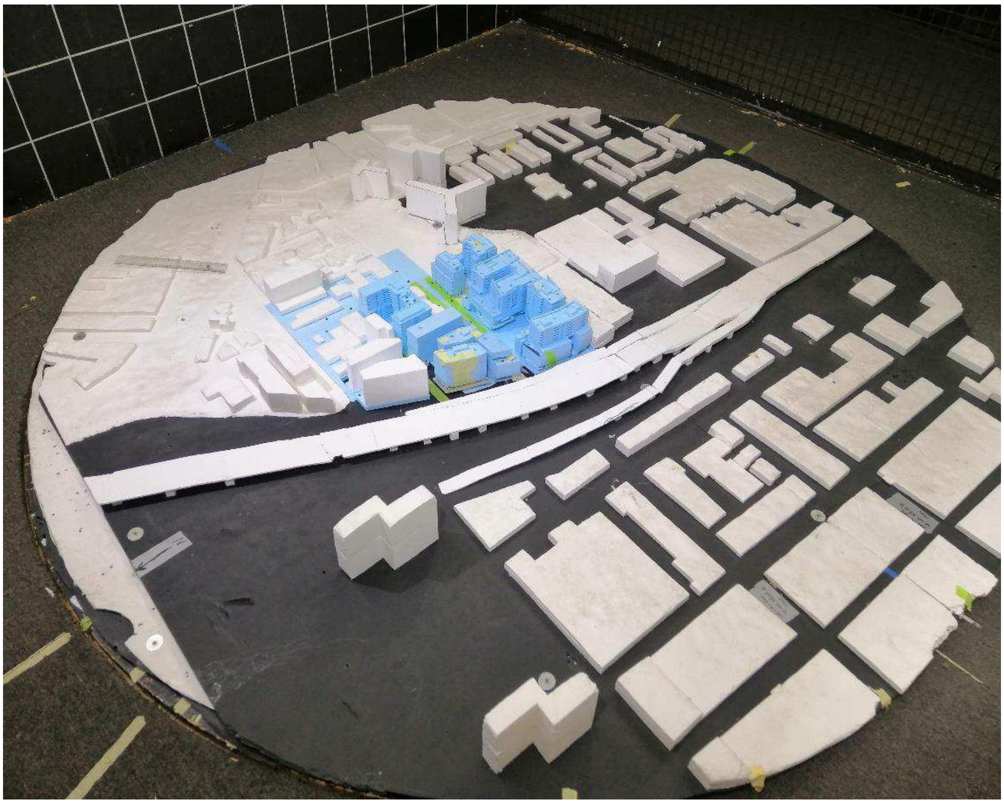


Figure 16: Overall view of the proposed development model in the wind tunnel (Configuration 2).

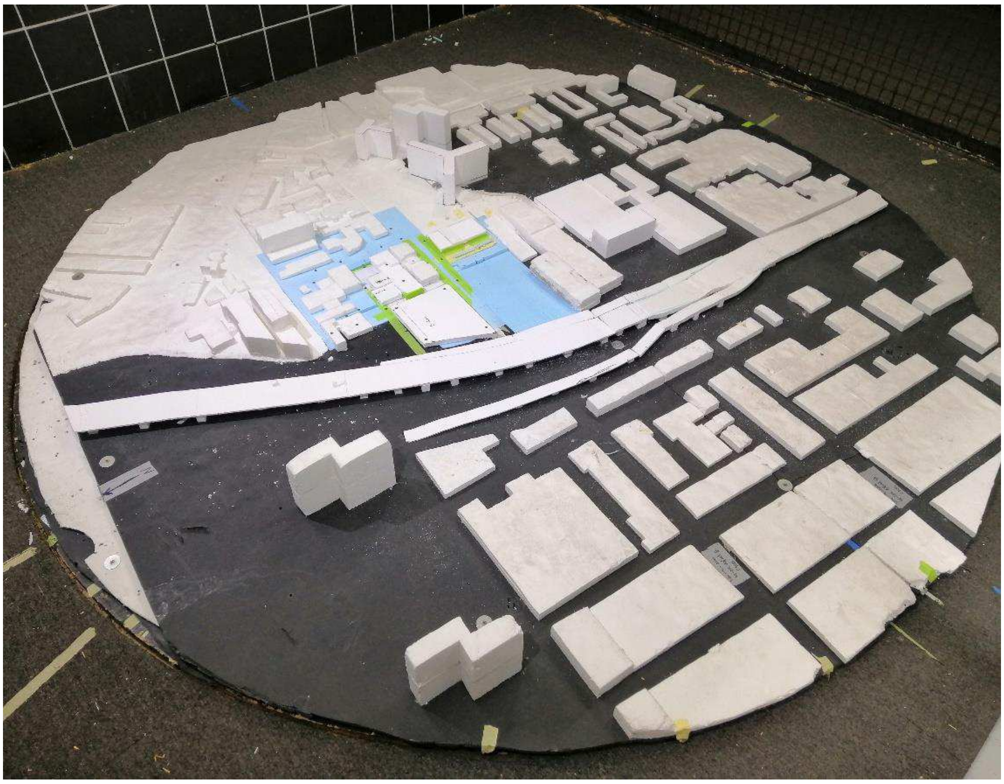


Figure 17: Overall view of the proposed development model in the wind tunnel (Existing conditions).

The results are presented as polar plots for the gust wind speeds appended in Appendix C of this report. Figure 18 shows an example of these plots. In the figure, the red circle represents the velocities for the safety criterion and the three sets of data points represent the different test configurations and their predicted gust wind speeds for the 36 directions for Location 1.

The plot shows that with the proposed design, Location 1 was within the recommended safety criterion in both Configurations as well as the existing conditions. The shape of the graphs tells us that wind conditions are most adverse from the south. The predicted hourly mean speeds (maximum of statistic mean and GEM) shown in Figure 19 are all within the recommended walking comfort criterion for the two configurations. Therefore, no wind control measures are necessary for this location.

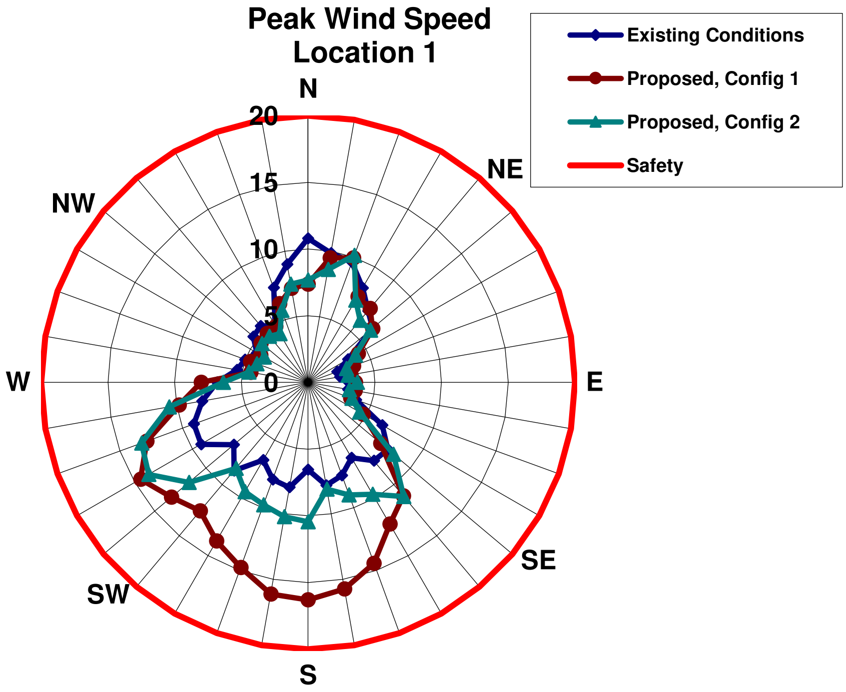


Figure 18: Polar plot showing the wind speed compared with safety criteria (Location 1).

Figure 19 shows the comparison between the comfort criteria and predicted hourly mean wind speeds (maximum of statistic mean and GEM). In these figures, the colour lines represent the threshold velocities for the different criteria and the data series (bars) represent the predicted values of the mean velocities. For the all wind direction combination, there are no particular methods specified in the BADS guidelines, the up-crossing prediction method described in Appendix D was used in the study.

Comfort Criteria

Mean wind speed (exceeded ≤20% probability)

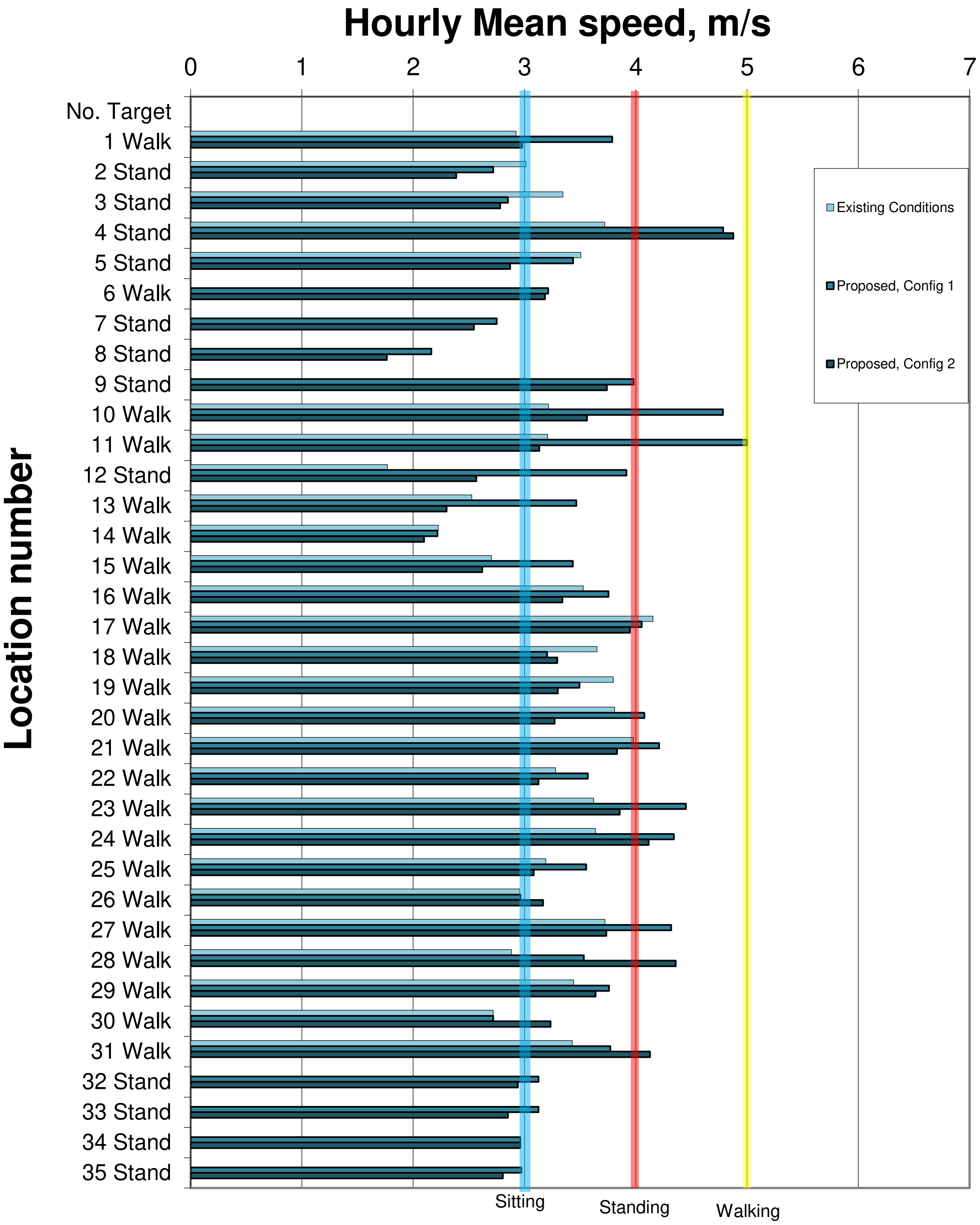


Figure 19: Bar plot showing the wind speed compared with comfort criteria (Locations 1- 35).

Based on the tests conducted, the following points were observed.

6.1 Safety Criterion Test

All test locations were measured gust windspeeds within the recommended safety criterion for the two Configurations. The high gusts were observed in the building corners (Locations 4 and 10) and the west laneway (Location 11).

6.2 Comfort Criteria

6.2.1 Footpath and Accessways

All locations measured windspeeds within the recommended walking/standing comfort criterion for both Configurations. No wind control measures are recommended.

6.2.2 Main Building Entrances

The lobby entry (Location 12) and other entrances (Locations 2, 3, 7-9) were measured wind speeds within the recommended standing criterion.

It is noted that the Central Garden at the upper ground level (Location 6) fulfilled standing criterion (better than the recommended walking).

6.2.3 Level 11 Terraces

With the proposed design features on the terraces at Level 11, the selected locations were measured wind speeds well below the standing comfort criterion for Configuration 1 and fulfil sitting for Configuration 2. The test results were better than the recommended.

6.2.4 Surrounding areas

All surrounding locations are measured wind speeds within the recommended walking criterion for both Configurations.

7 Conclusion

Vipac has carried out an assessment of the pedestrian level winds for the proposed development at **139-149 Boundary Road, North Melbourne** based on a scaled wind tunnel test.

The findings of the study are summarised as follows:

The proposed design of the development:

- fulfils the recommended criterion for **Safety** at all test locations;
- fulfils the recommended criterion for **Walking** at all footpath locations;
- fulfils the recommended criterion for **Standing** at all building entrances; and
- fulfils the recommended criteria for **Standing** at Level 11 rooftop terraces**.**

The proposed development would not cause significant adversely impact to the adjacent areas.

As a general statement, common to all new developments, educating occupants about wind conditions at high-level terraces/balconies during high-wind events and tying down loose furniture are highly recommended.

This Report has been Prepared

For

BEG Projects Pty Ltd

By

VIPAC ENGINEERS & SCIENTISTS LTD.

Appendix A References

1. Australian/New Zealand Standard 1170.2:2021, Wind actions
2. Melbourne, W. H., "Criteria for Environmental Wind Conditions", Jour. Industrial Aerodynamics, Vol. 3, 241-249, 1978
3. Simiu E, Scanlan R, "*Wind Effects on Structures*". Wiley-Interscience
4. Aynsley R., Melbourne W., Vickery B., *Architectural Aerodynamics* Applied Science Publishers

Appendix B Drawing List

Received May 2023:

NO. SHEET NAME REV.

TP0.00 COVER SHEET F

TP0.01 DEVELOPMENT SUMMARY 01 G

TP0.02 DEVELOPMENT SUMMARY 02 F

TP1.01 SITE PLAN E

TP2.00 BASEMENT 02 F

TP2.01 BASEMENT 01 F

TP2.03 LOWER GROUND FLOOR PLAN F

TP2.04 UPPER GROUND FLOOR PLAN F

TP2.05 LEVEL 01 F

TP2.06 LEVEL 02 F

TP2.07 LEVEL 03 F

TP2.08 LEVEL 04 F

TP2.09 LEVEL 05 F

TP2.10 LEVEL 06 F

TP2.11 LEVEL 07 F

TP2.12 LEVEL 08 F

TP2.13 LEVEL 09 F

TP2.14 LEVEL 10 F

TP2.15 LEVEL 11 F

TP2.16 ROOF F

TP2.17 LEVEL 01 Copy 1 E

TP2.17A BOUNDARY ROAD FACADE - DETAIL PLAN - A F

TP2.17B BOUNDARY ROAD FACADE - DETAIL PLAN - B F

TP2.18A BOUNDARY ROAD FACADE - DETAIL ELEVATION - A E

TP2.18B BOUNDARY ROAD FACADE - DETAIL ELEVATION - B E

TP3.00 ELEVATIONS F

TP3.01 ELEVATIONS F

TP3.02 ELEVATIONS F

TP3.03 ELEVATIONS F

TP3.05 ELEVATIONS F

TP3.06 ELEVATIONS F

TP4.01 SECTION A-A F

TP4.02 SECTION B-B F

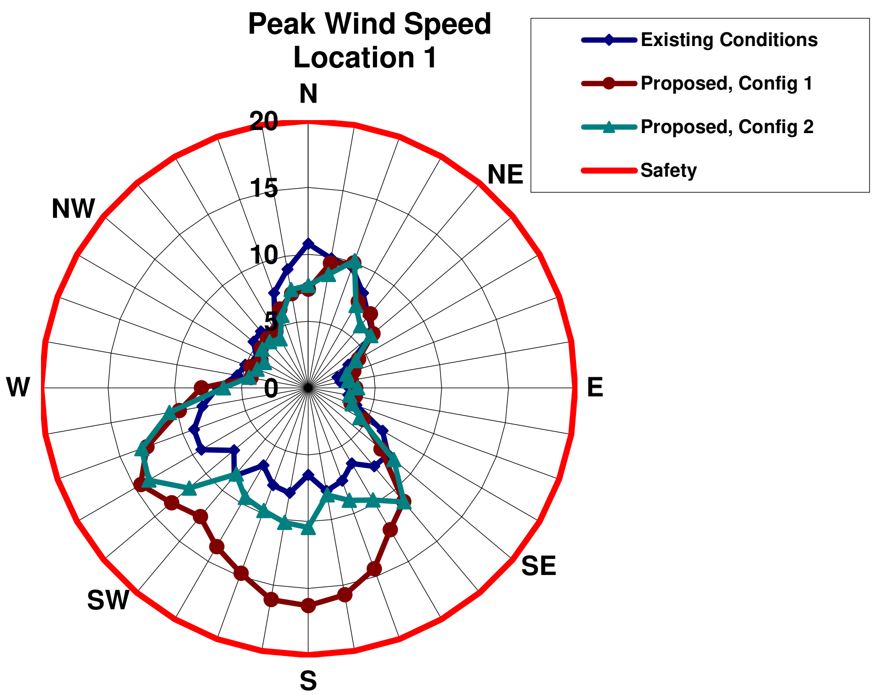
TP4.03 SECTION C-C F

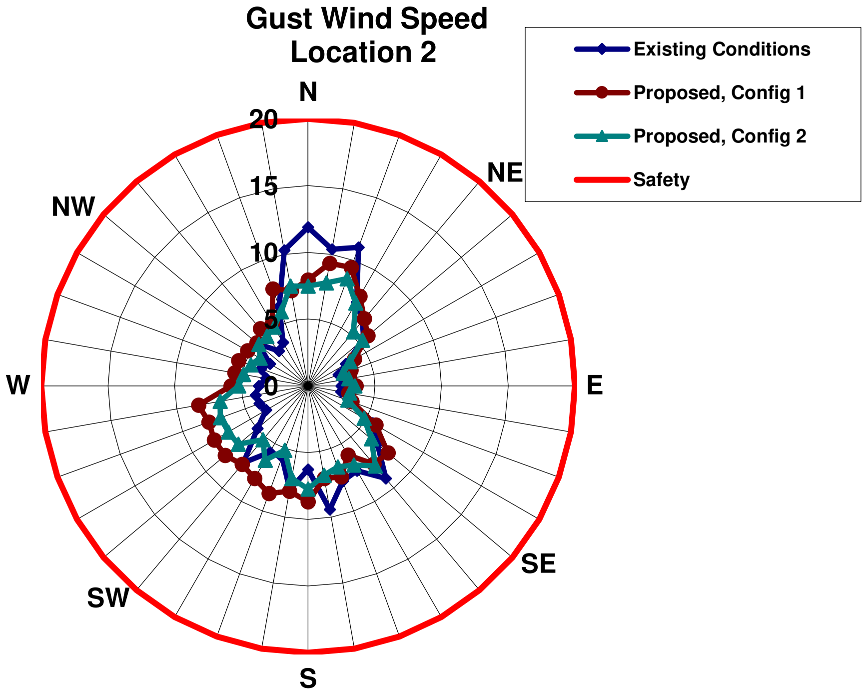
TP4.04 SECTION D-D F

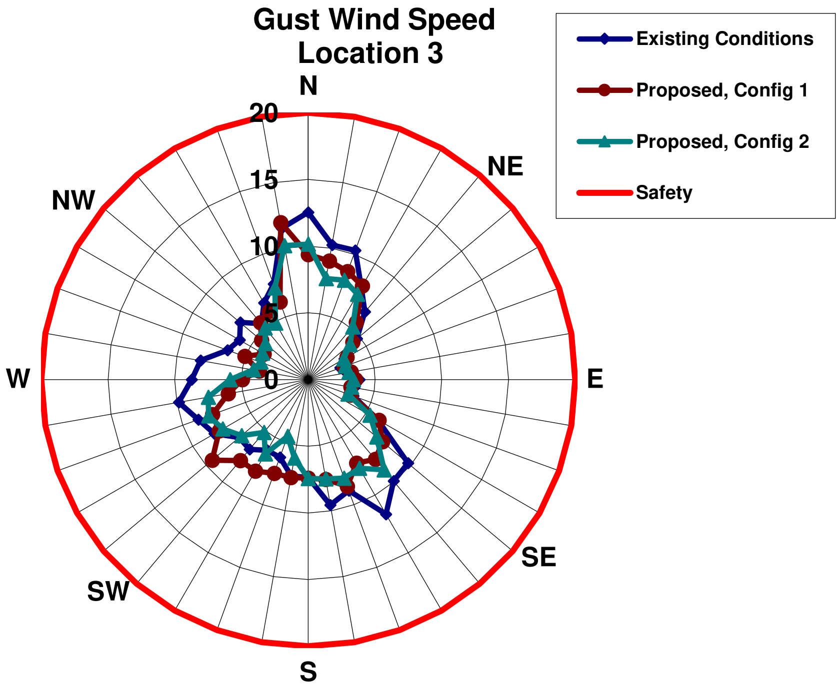
TP4.05 SECTION E-E F

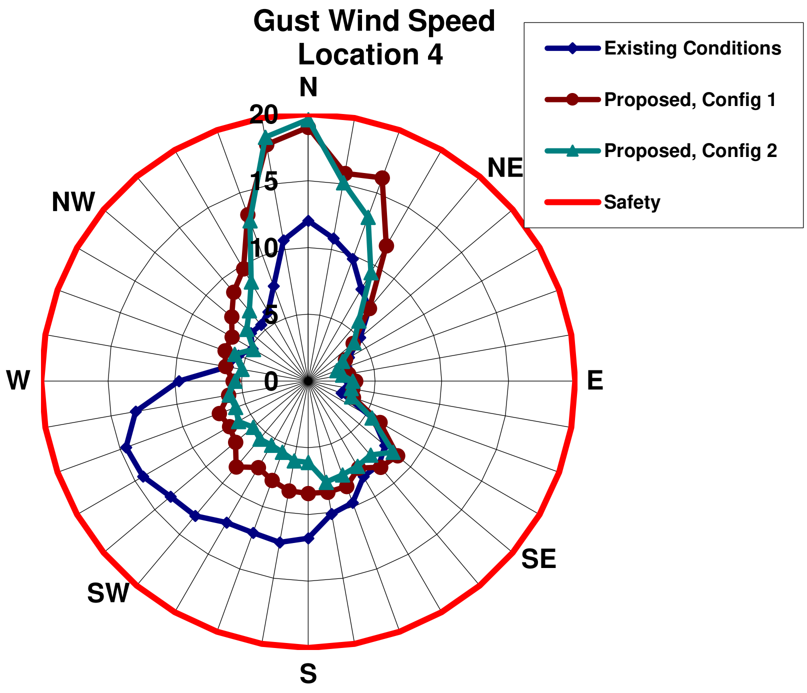
TP4.06 SECTION F-F F

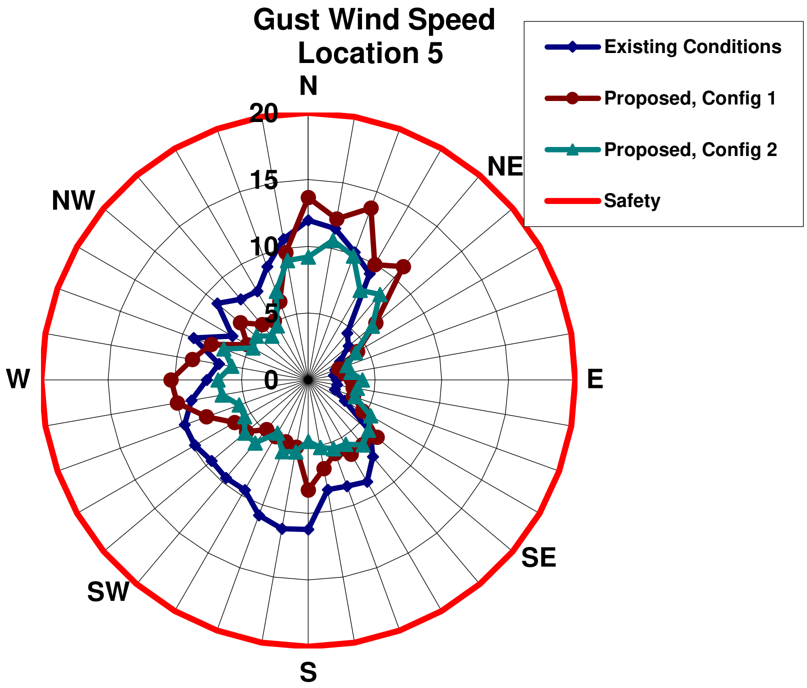
Appendix C Omni Polar Plots - Gust Wind Speed (Safety Criterion)

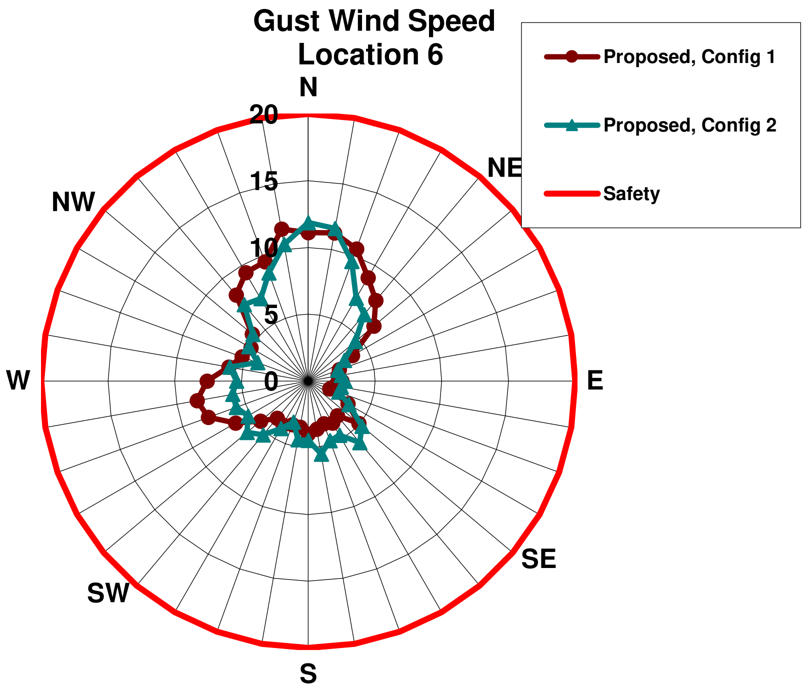


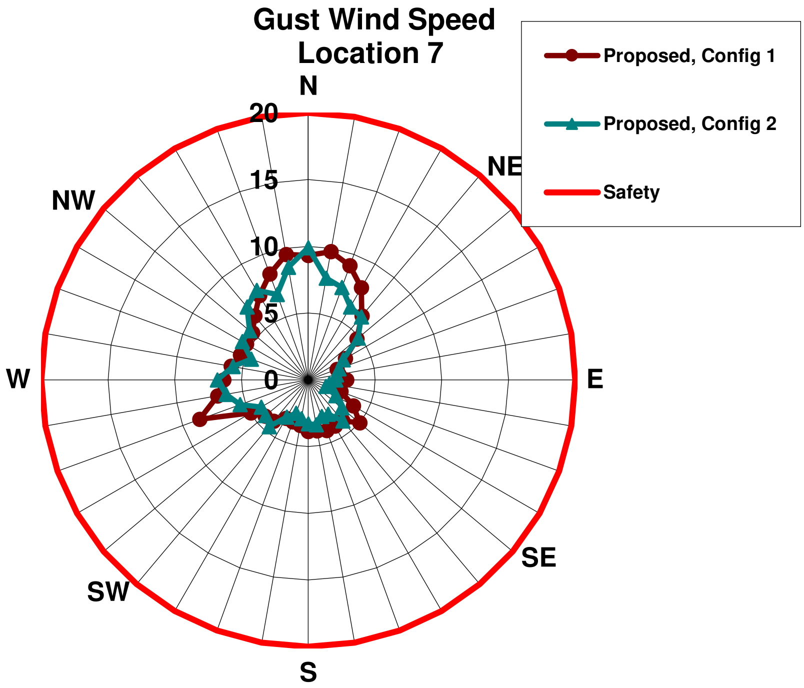


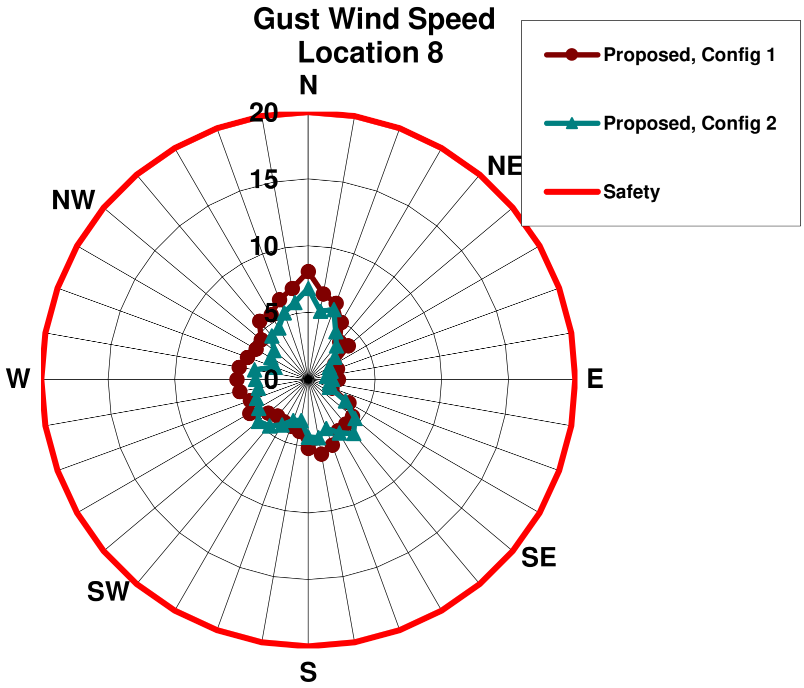

Gust Wind Speed
Location 3
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

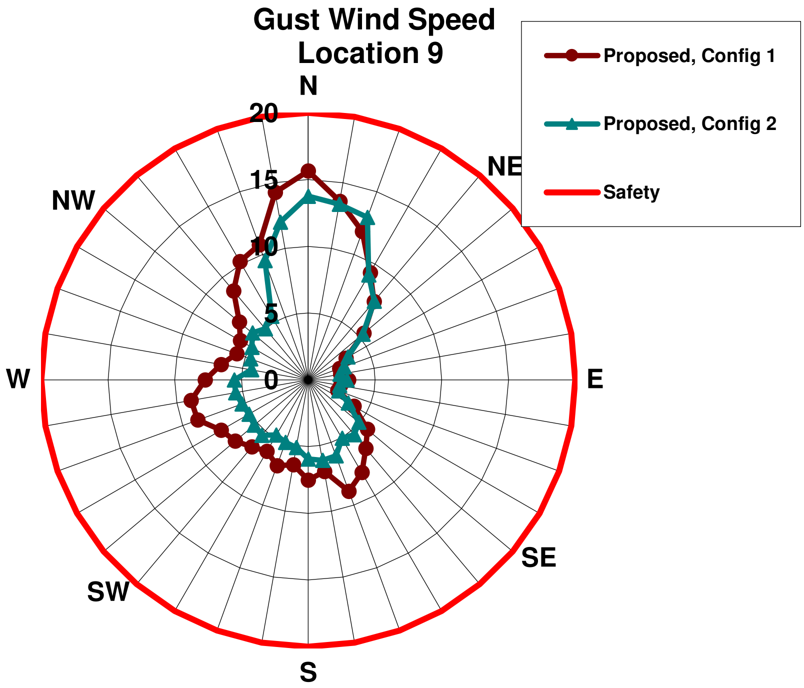

Gust Wind Speed
Location 4
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

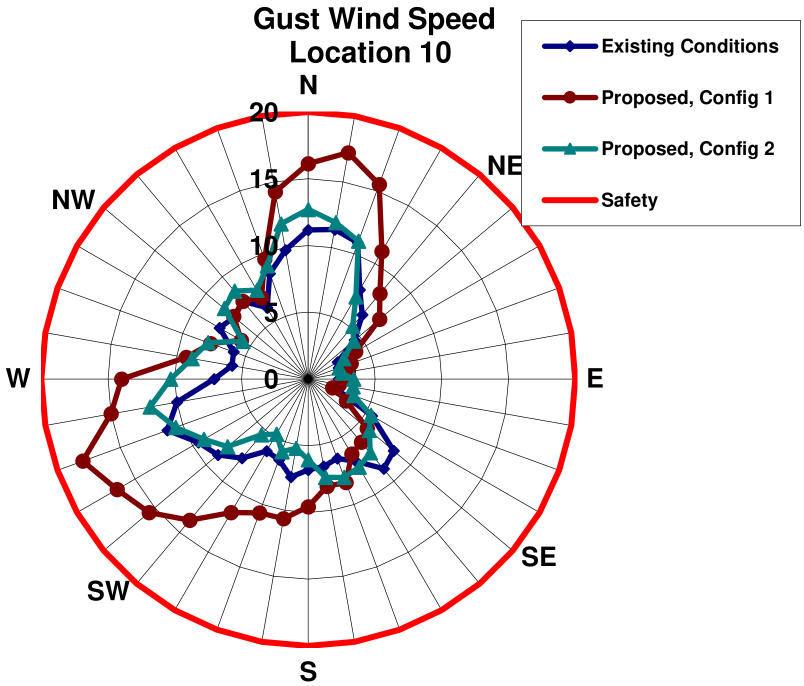

Gust Wind Speed
Location 5
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

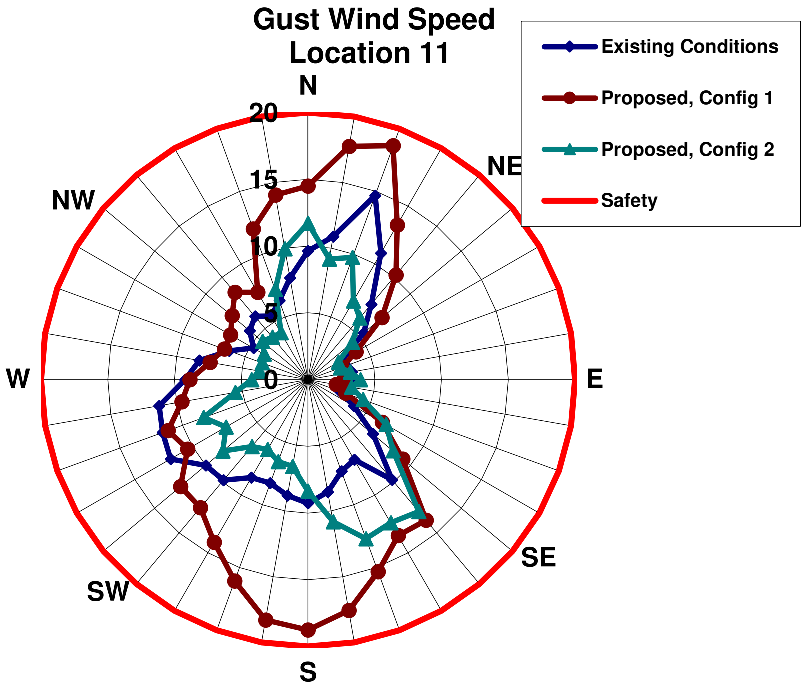

Gust Wind Speed
Location 6
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
Proposed, Config 1
Proposed, Config 2
Safety

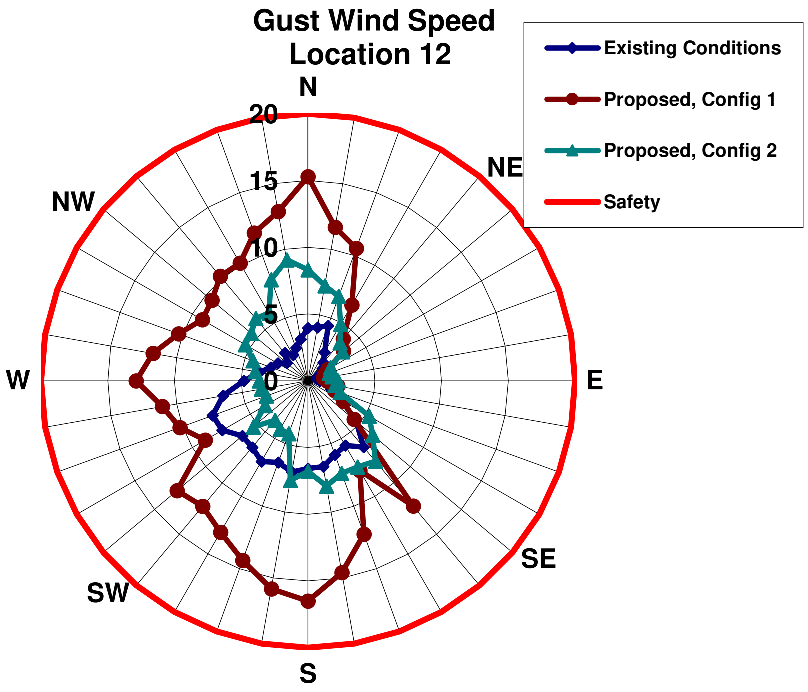

Gust Wind Speed
Location 7
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
Proposed, Config 1
Proposed, Config 2
Safety

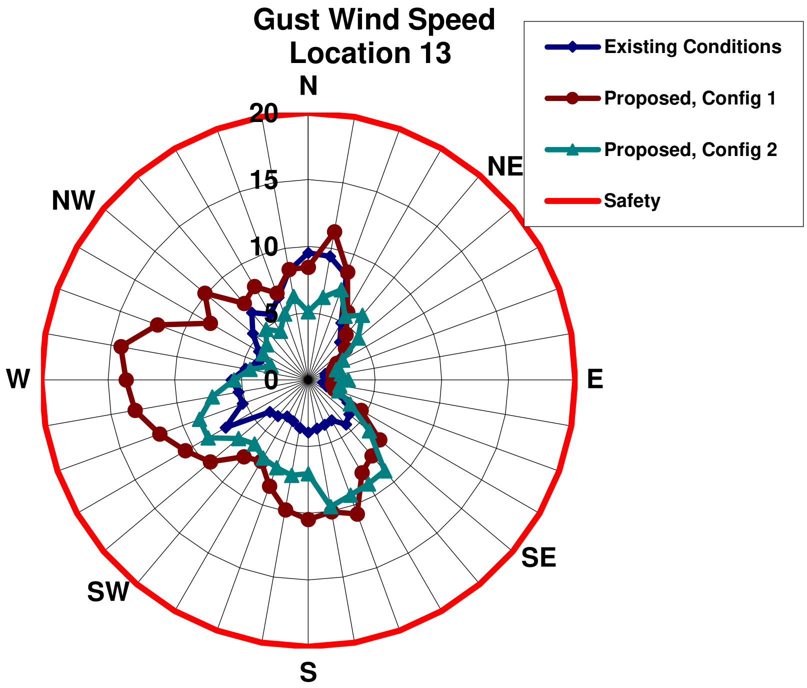

Gust Wind Speed
Location 8
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
Proposed, Config 1
Proposed, Config 2
Safety

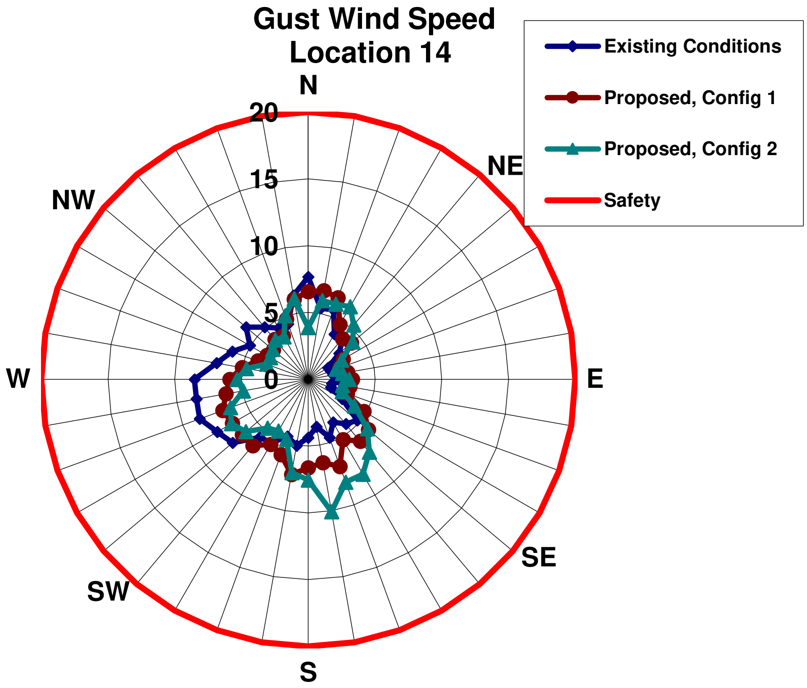

Gust Wind Speed
Location 9
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
Proposed, Config 1
Proposed, Config 2
Safety

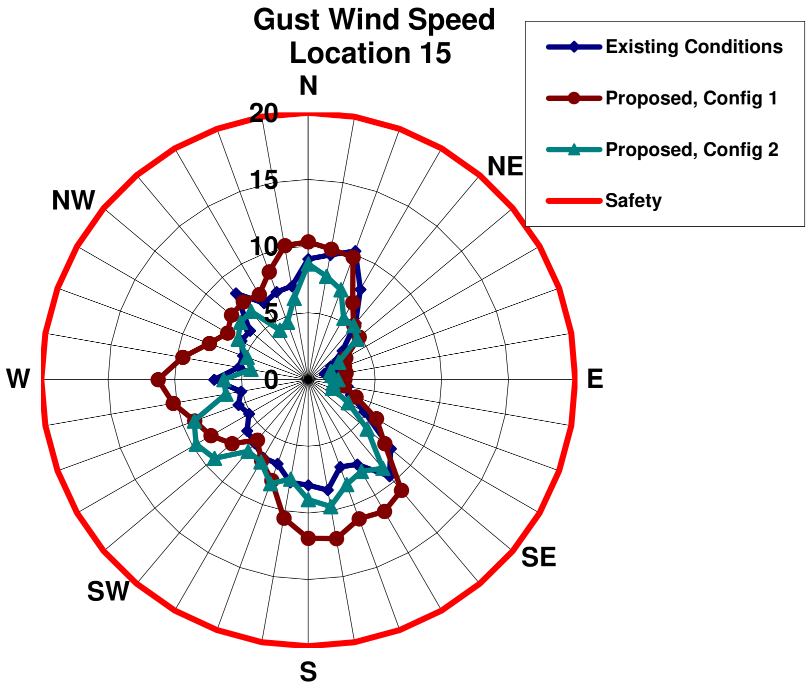

Gust Wind Speed
Location 10
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

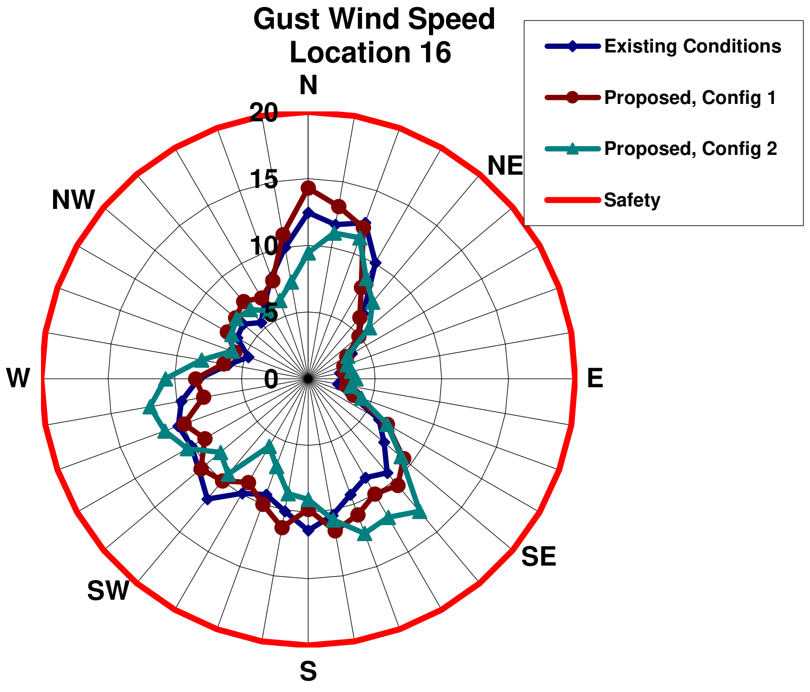

Gust Wind Speed
Location 11
N
NE
E
SE
S
SW
W
NW
0
5
10
15
20
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

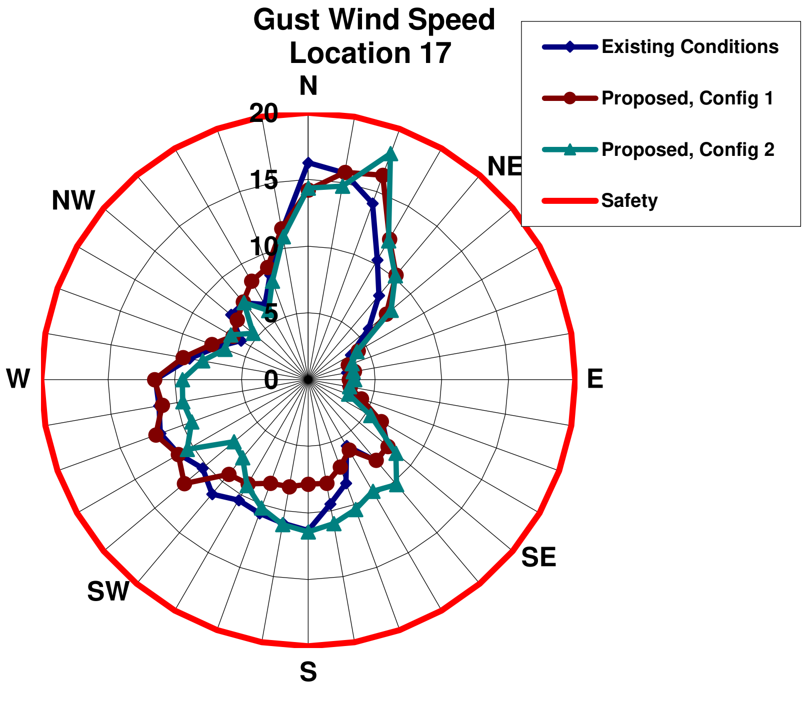

Gust Wind Speed
Location 12
N
NE
E
SE
S
SW
W
NW
0
5
10
15
20
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

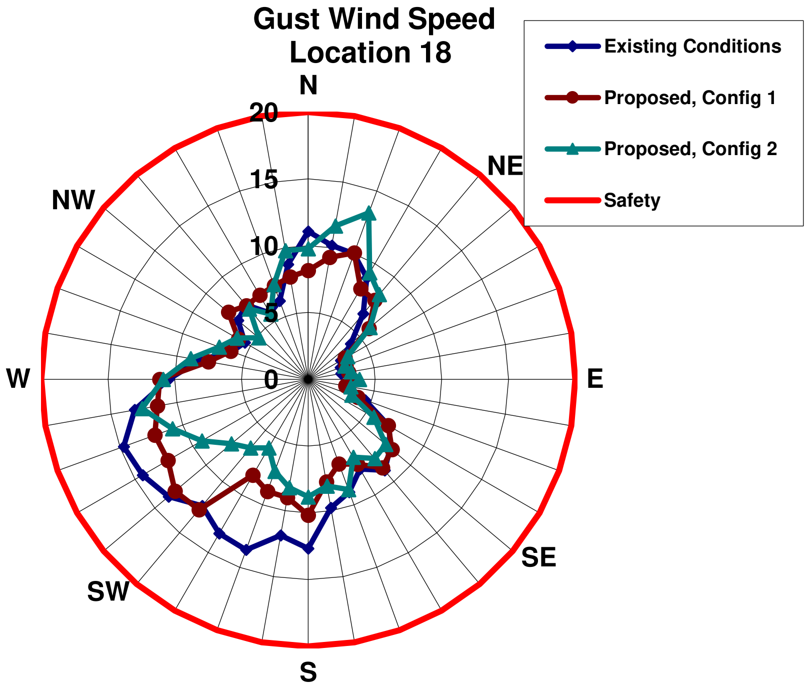

Gust Wind Speed
Location 13
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

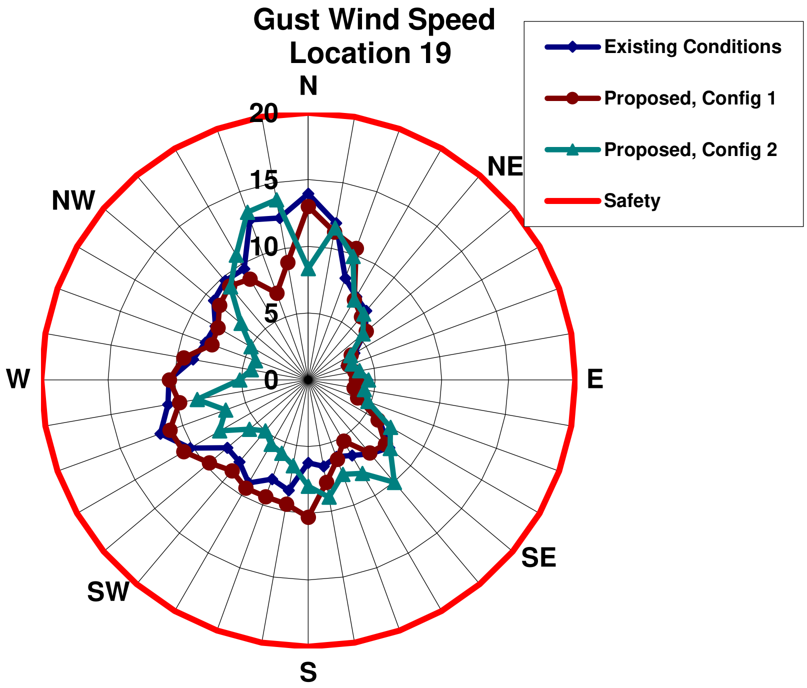

Gust Wind Speed
Location 14
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

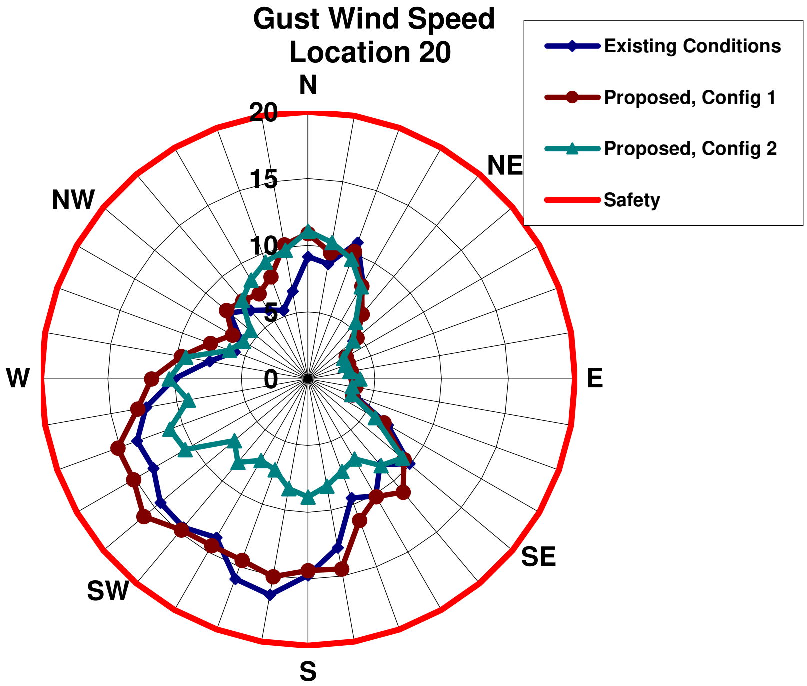

Gust Wind Speed
Location 15
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0

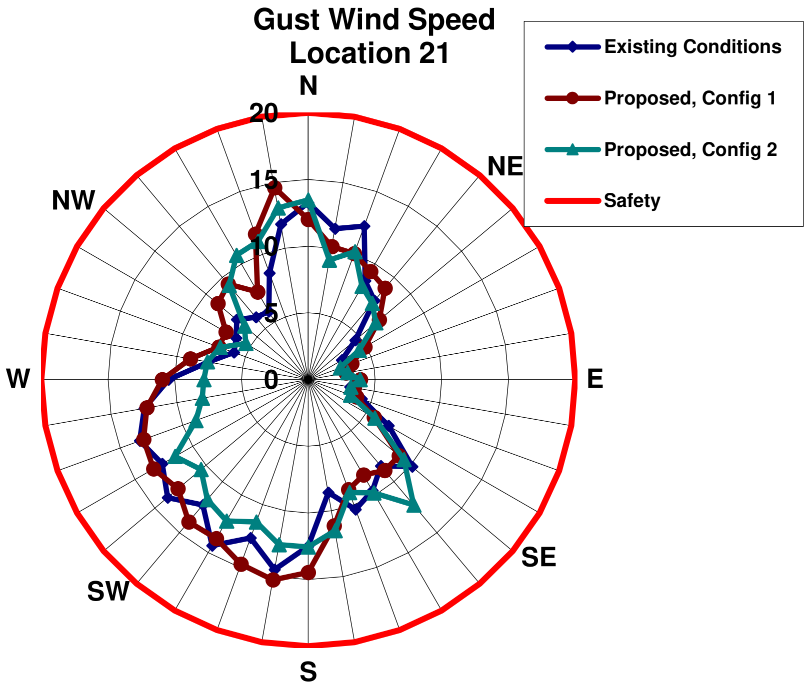

Gust Wind Speed
Location 16
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0

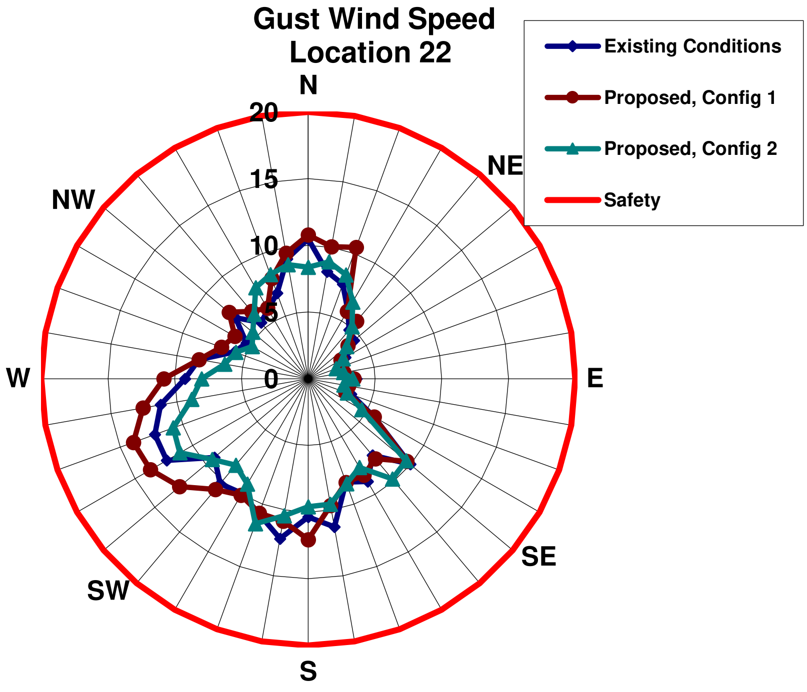

Gust Wind Speed
Location 17
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

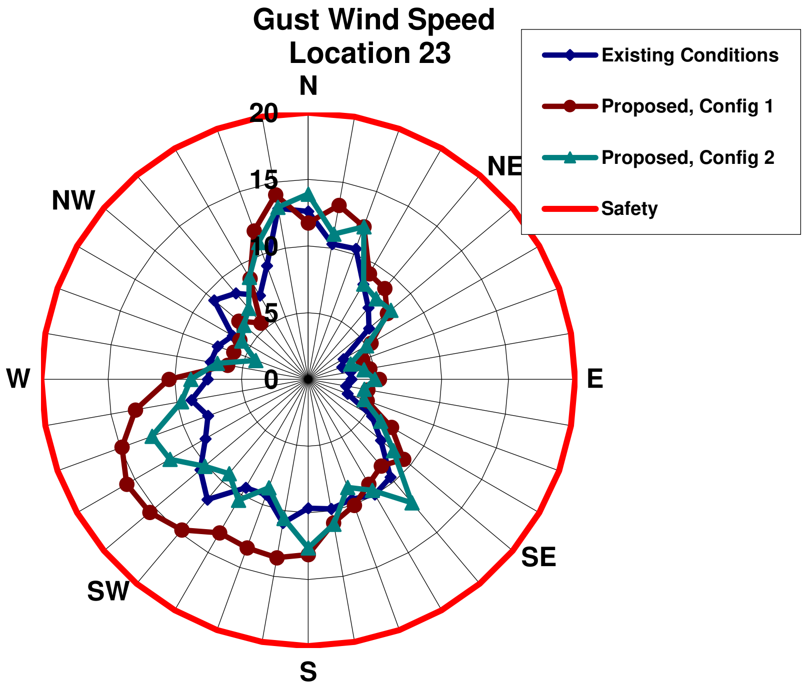

Gust Wind Speed
Location 18
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

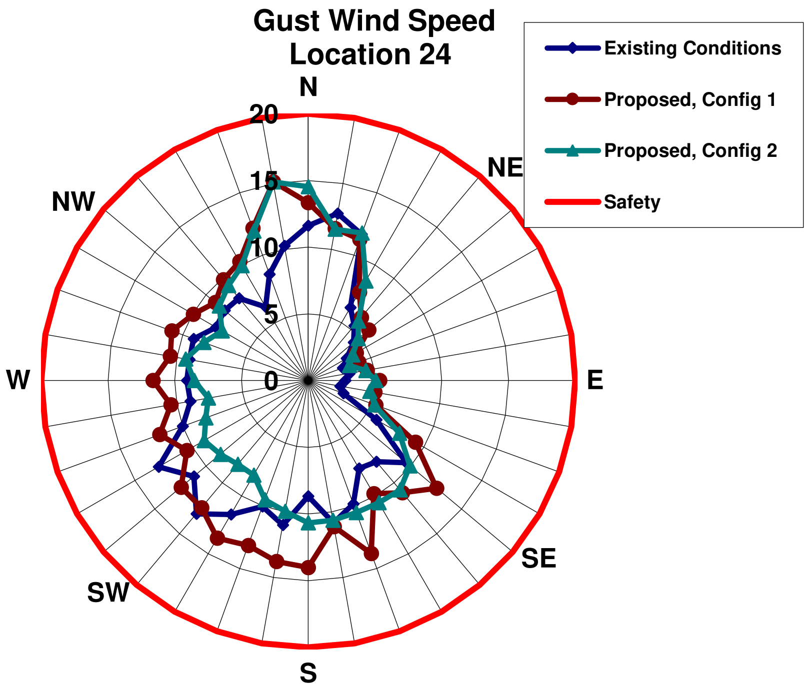

Gust Wind Speed
Location 19
N
NE
E
SE
S
SW
W
NW
0
5
10
15
20
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

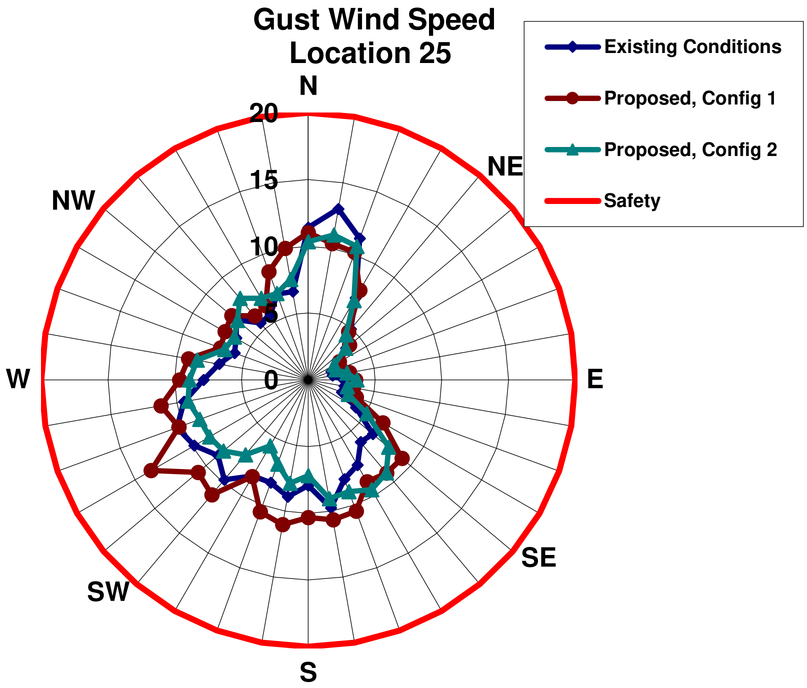

Gust Wind Speed
Location 20
N
NE
E
SE
S
SW
W
NW
0
5
10
15
20
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

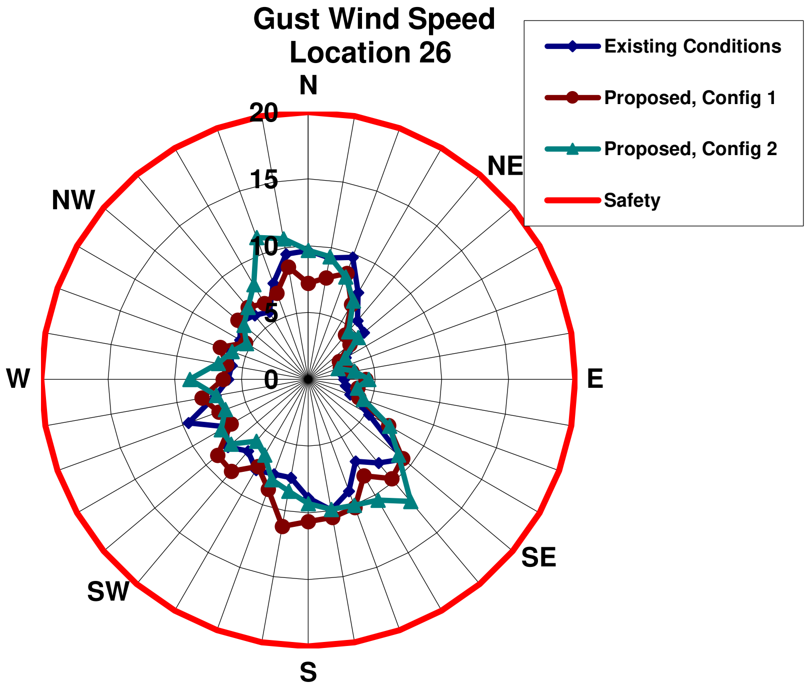

Gust Wind Speed
Location 21
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0

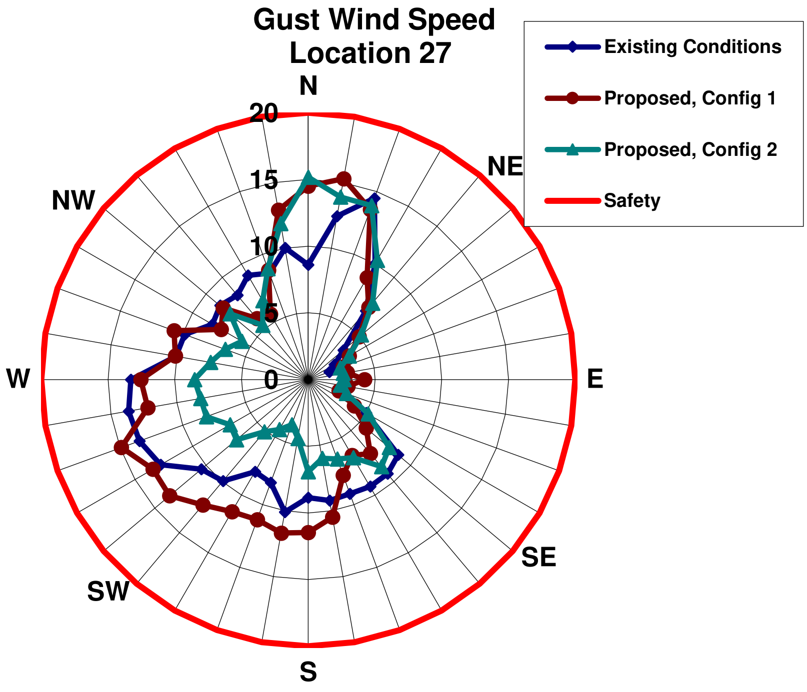

Gust Wind Speed
Location 22
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0

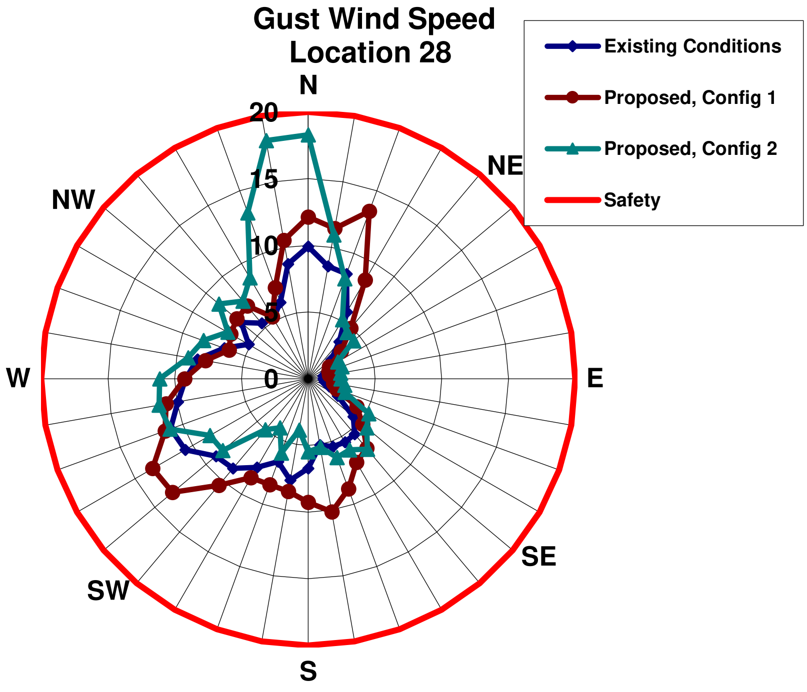

Gust Wind Speed
Location 23
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

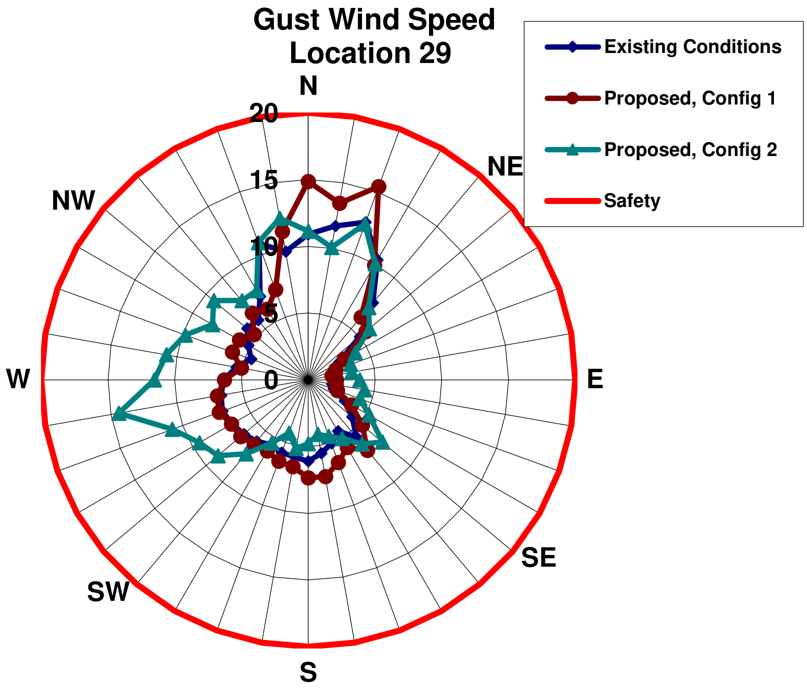

Gust Wind Speed
Location 24
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

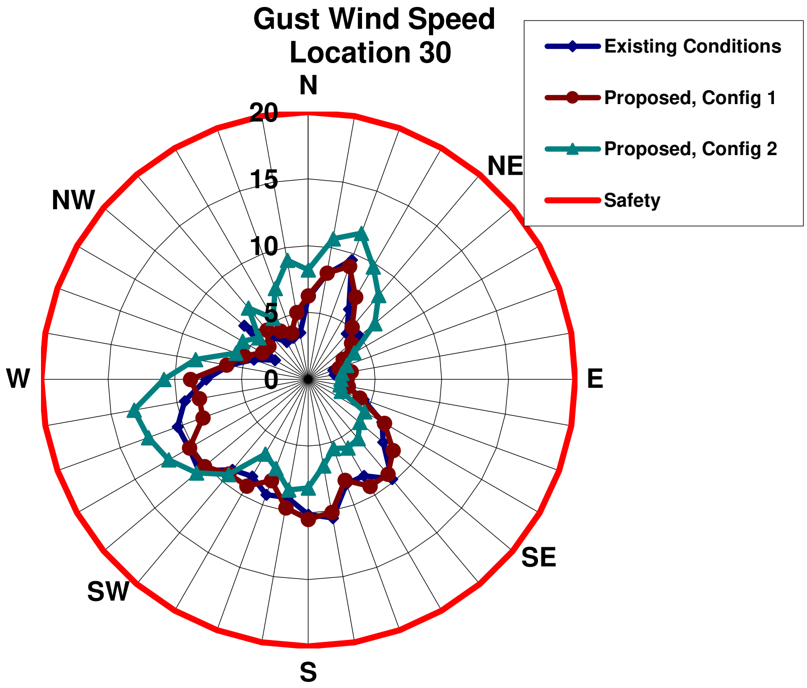

Gust Wind Speed
Location 25
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

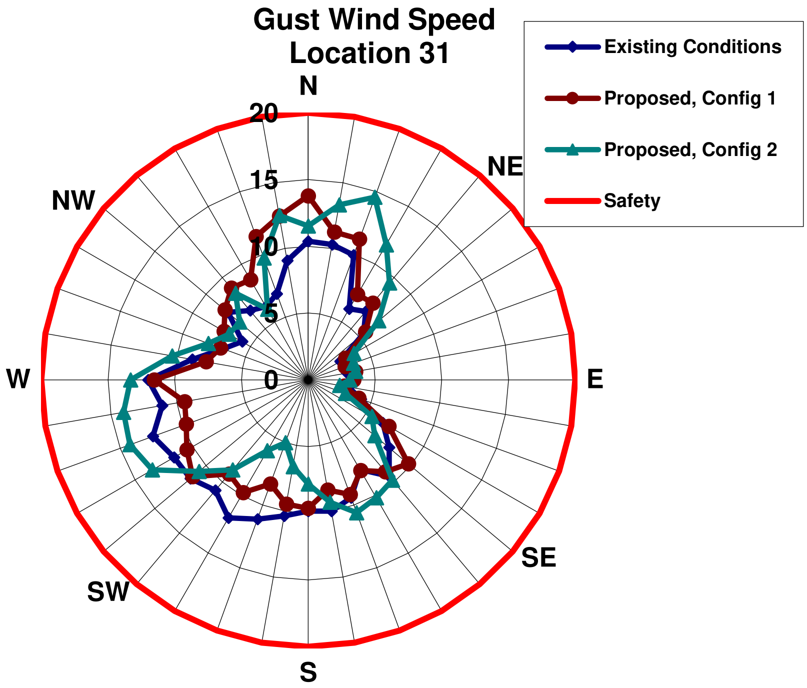

Gust Wind Speed
Location 26
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

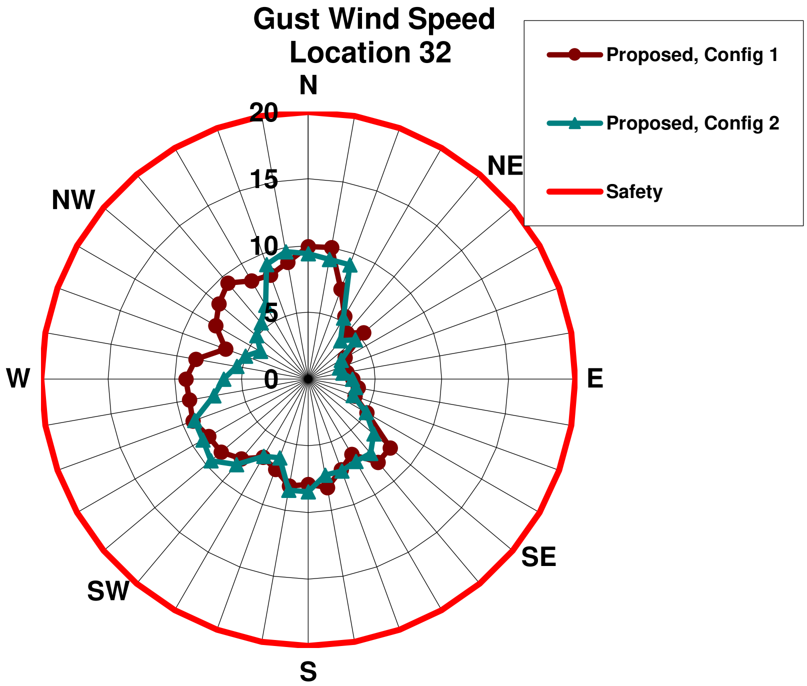

Gust Wind Speed
Location 27
N
NE
E
SE
S
SW
W
NW
0
5
10
15
20
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

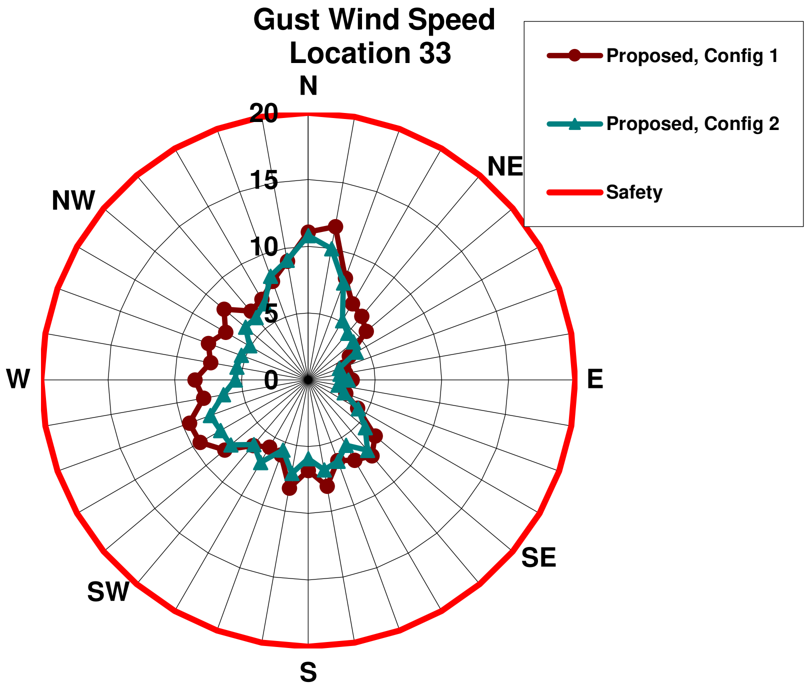

Gust Wind Speed
Location 28
N
NE
E
SE
S
SW
W
NW
0
5
10
15
20
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety

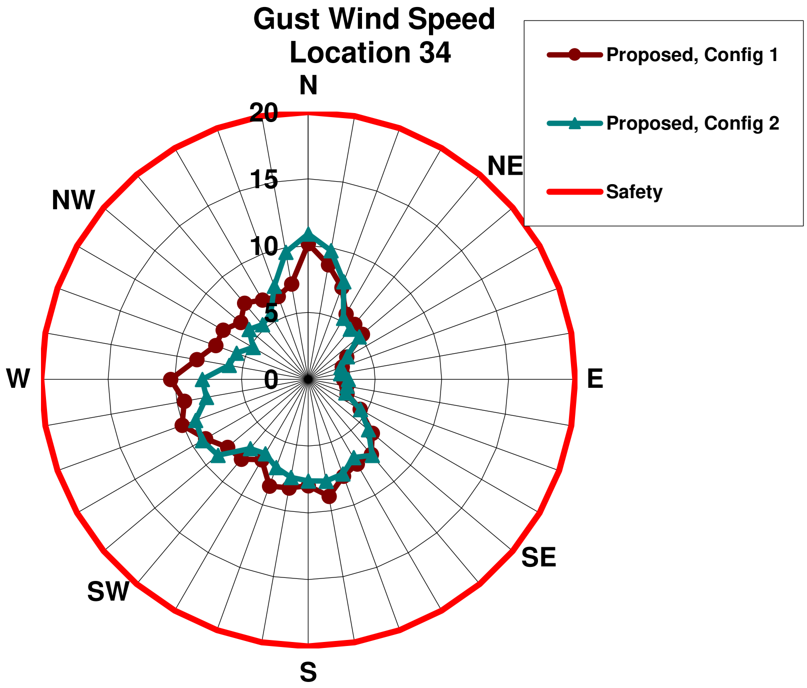

Gust Wind Speed
Location 29
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety
N
NE
E
SE
S
SW
W
NW
0
5
10
15
20

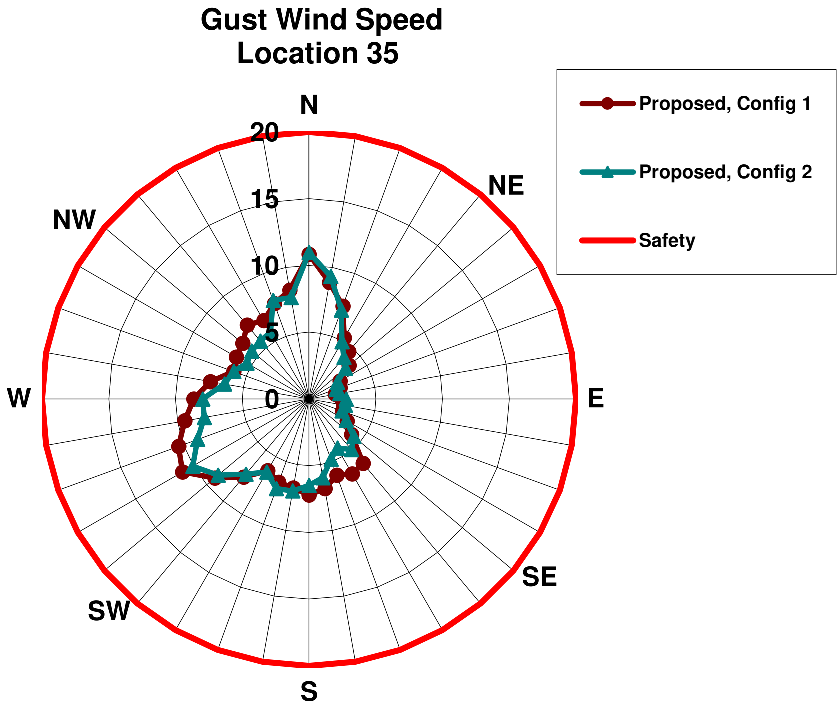

Gust Wind Speed
Location 30
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety
N
NE
E
SE
S
SW
W
NW
0
5
10
15
20


Gust Wind Speed
Location 31
N
NE
E
SE
S
SW
W
NW
0
5
10
15
20
Existing Conditions
Proposed, Config 1
Proposed, Config 2
Safety


Gust Wind Speed
Location 32
N
NE
E
SE
S
SW
W
NW
0
5
10
15
20
Proposed, Config 1
Proposed, Config 2
Safety


Gust Wind Speed
Location 33
N
NE
E
SE
S
SW
W
NW
0
5
10
15
20
Proposed, Config 1
Proposed, Config 2
Safety


Gust Wind Speed
Location 34
N
NE
E
SE
S
SW
W
NW
0
5
10
15
20
Proposed, Config 1
Proposed, Config 2
Safety


Gust Wind Speed
Location 35
N
NE
E
SE
S
SW
W
NW
0
5
10
15
20
Proposed, Config 1
Proposed, Config 2
Safety

Appendix D Up-crossing Prediction

The up-crossing method was used at Boundary Layer Wind Tunnel Laboratory, University of Western Ontario decades ago and adapted at VIPAC recently. The methodology is based on the following theory.

The expected number of excursions beyond a level x per unit time, or the rate of crossing with positive slope, according to Rice's theory (D.2), is given by:

$$N_x(x) = \int_0^{\infty} \dot{x}\, p(x, \dot{x})\, dx \quad (1)$$

where $\dot{X}$ is the rate of change of x and $p(x, \dot{x})$ is the joint probability density function of x and $\dot{X}$. For a stationary random process, x and $\dot{X}$ are statistically independent, thus

$$p(x, \dot{x}) = p(x)\, p(\dot{x}) \quad (2)$$

For a Gaussian process,

$$\int_0^{\infty} \dot{x}\, p(\dot{x})\, d\,\dot{x} = \frac{\sigma_{\dot{x}}}{\sqrt{2\pi}} \quad (3)$$

where $\sigma_{\dot{x}}$ is the standard deviation of $\dot{x}(t)$. Thus, the crossing rate now becomes

$$N_x(x) = \frac{\sigma_{\dot{x}}}{\sqrt{2\pi}}\, p(x) \quad (4)$$

The statistical frequency or the cycling rate of process $x(t)$ is defined as

$$\nu = \frac{1}{2\pi}\, \frac{\sigma_{\dot{x}}}{\sigma_x} \quad (5)$$

Substituting this in equation (4) yields

$$N_x(x) = \sqrt{2\pi}\; \nu\, \sigma_x\, p(x) \quad (6)$$

Extending Rice's theory, Davenport (D.3) has shown that for a two-dimensional variable, $x = x(V, \alpha)$, the crossing rate of a particular boundary $x = x_1$ becomes:

$$N_x(x) = \sqrt{2\pi}\; \nu\, \sigma \int_0^{2\pi} \sqrt{1 + \left(\frac{d\,V_1}{V_1\, d\alpha}\right)^2}\; p_V(V_1, \alpha)\, d\alpha \quad (7)$$

where $x_1 = x(V_1, \alpha)$ and $p_V(V, \alpha)$ is the joint probability density function of V and α.

Approximating the probability distribution of the wind speed V and the direction α by a generalized Weibull distribution,

$$p_V(>V, \alpha) = A(\alpha)\, e^{\left| V / C(\alpha) \right|^{K(\alpha)}} \quad (8)$$

the probability density function of V and α becomes

$$p_V(V, \alpha) = A(\alpha)\, \frac{K(\alpha)}{C(\alpha)} \left(\frac{V}{C(\alpha)}\right)^{|K(\alpha) - 1|} e^{-\left| V / C(\alpha) \right|^{K(\alpha)}}\, d\alpha \quad (9)$$

Hence the crossing rate of a particular boundary $x_1 = x_1(V_1, \alpha)$ from Equation (7) becomes:

$$N_x(x_1) = \sqrt{2\pi}\; \nu\, \alpha \int_0^{2\pi} \left\{ 1 + \frac{d\,V_1}{V_1\, d\alpha} \right\}^{\frac{1}{2}} A(\alpha)\, \frac{K(\alpha)}{C(\alpha)} \left(\frac{V}{C(\alpha)}\right)^{|K(\alpha) - 1|} e^{-\left| V / C(\alpha) \right|^{K(\alpha)}}\, d\alpha \quad (10)$$

The cycling rate, ν, and the standard deviation, σ, in Equation (10) are taken as those of the wind speed, V, regardless of direction; namely they are based on the marginal statistical properties of V and $\dot{V}$. With ν expressed in terms of occurrences per annum, $N_x(x_1)$ gives the yearly crossing rate.

The return period, or the average interval of time between events during which the response equals or exceeds the response boundary $x = x_1$, is the inverse of the crossing rate of that boundary. Consequently, from Equation (10) the return period for the response level $x = x_1$ in years is taken as

$$R_x(x_1) = \frac{1}{N_x(x_1)} \qquad (11)$$

The risk of exceeding the response level associated with the return period $R_x(x_1)$ in a time period L is:

$$r(x_1) = 1 - \left(1 - \frac{1}{R_x(x_1)}\right)^L \qquad (12)$$

From the above equation, the risk of exceeding x_1 within a time interval of $L = R_x(x_1)$ is approximately 63 percent.

Appendix E References for Appendix D

[D.1] Irwin, P, Garber, J and Ho, E., "Integration of Wind Tunnel Data with Full Scale Wind Climate", 10th Americas Conference on Wind Engineering, Baton Rouge, Louisiana, U.S.A., May 2005.

[D.2] Rice, S.O., "Mathematical Analysis of Random Noise", Bell Tech. Journal Vol. 18 and 19, 1945.

[D.3] Davenport, A.G., "The Prediction of Risk Under Wind Loading", 2nd International Conf. on Structural Safety and Reliability (ICOSSAR), Sept. 1977, Munich Germany.