

Perpetual Corporate Trust Yield Plus Infrastructure Property Fund No.2 Trust 2B Ownership Trust No.5

675 Victoria Street, Abbotsford

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Pedestrian Level Winds - Wind Tunnel Test



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Executive Summary

Perpetual Corporate Trust Yield Plus Infrastructure Property Fund No.2 Trust 2B Ownership Trust No.5 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 **675 Victoria Street, Abbotsford**.

The model was constructed based on drawings supplied by **SJB Architects** in **October 2024**. 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 the Terrain Category 2.5 (340 to 360 & 0 to 20 azimuth degrees), Terrain and Terrain Category 3 (all other wind directions) 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 **with recommendations**;
- fulfils the recommended criterion for **Walking** at all footpath locations;
- fulfils the recommended criterion for **Standing** at all building entrances **with recommendations**; and
- fulfils the recommended criteria for **Walking** at all open terraces and communal terraces **with the recommendations**.

The proposed development would not cause a significant adverse impact on 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.

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1 Introduction

Vipac Engineers & Scientists Ltd was commissioned by **Perpetual Corporate Trust Yield Plus Infrastructure Property Fund No.2 Trust 2B Ownership Trust No.5** to carry out a wind tunnel test of the likely wind conditions for the proposed development at **675 Victoria Street, Abbotsford**.

The proposed development is a 12-storey residential building with a roof height of 41.7m from Victoria Street and 45.9m from Yarra Riverbank. The site is bounded by Victoria Street to the south, Yarra Riverbank to the North, and existing developments to the west and east. 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 on southern bank of the Yarra River. The site is surrounded within an approximately 3 km radius predominately by low to mid-rise developments with the high-rise development of the Melbourne CBD to the far west. Considering the surroundings and terrain, the site of the proposed development is assumed to be within Terrain Category 2.5 for the azimuth degrees of 340° to 360° and Terrain Category 3 for all other 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 October 2024. 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 **SJB Architects** in **October 2024**. 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 B of this report.

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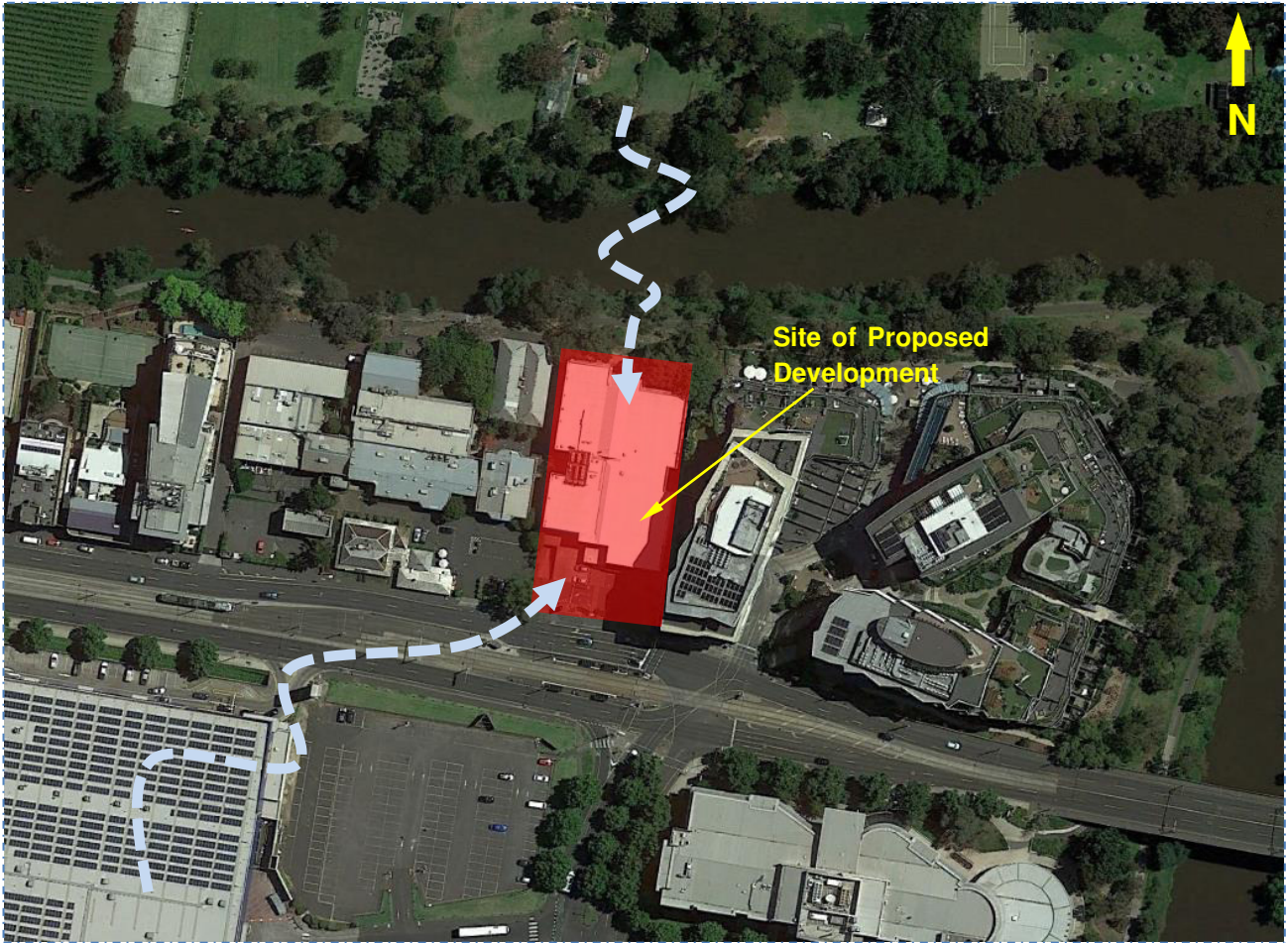


Figure 1: Aerial view of the proposed development site.



Figure 2: East Elevation of the proposed development.

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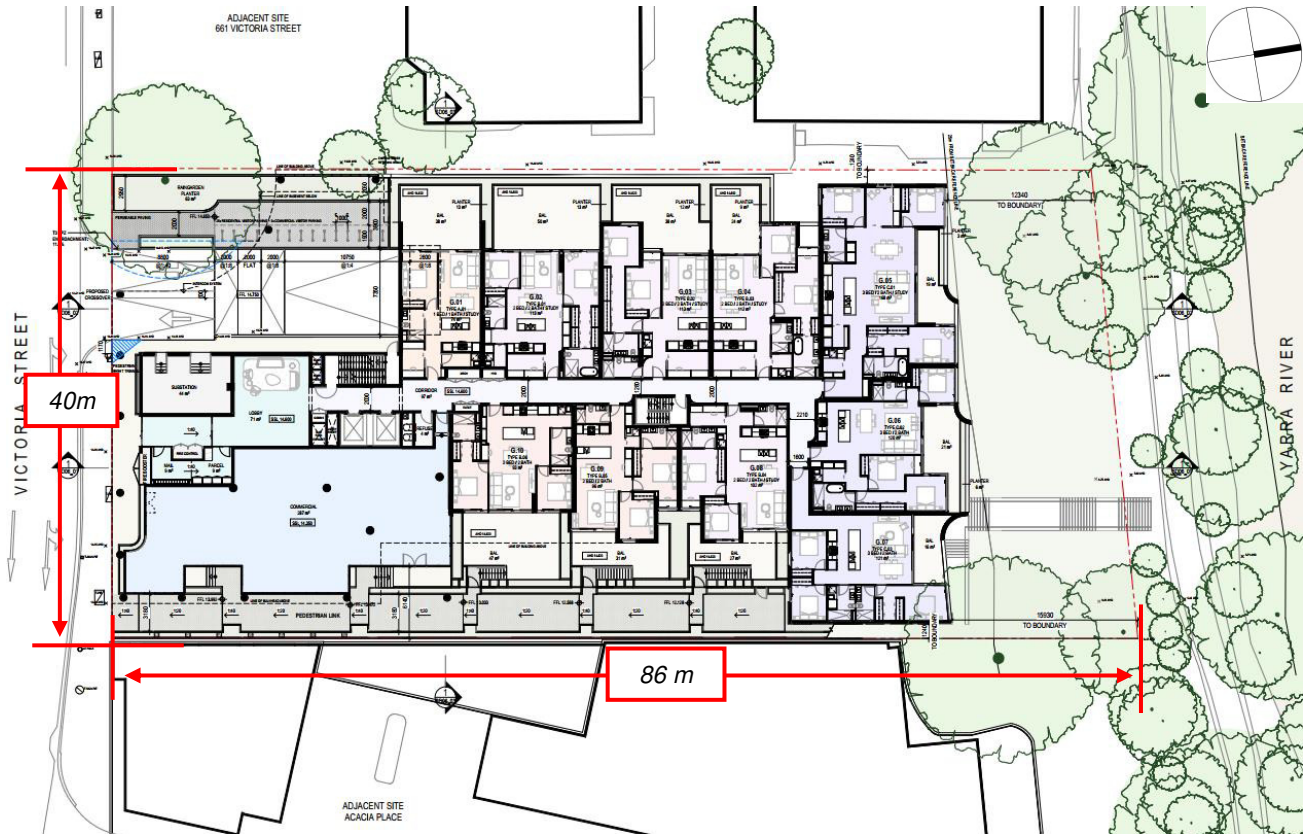


Figure 3: Ground level plan with the overall dimensions overlaid.

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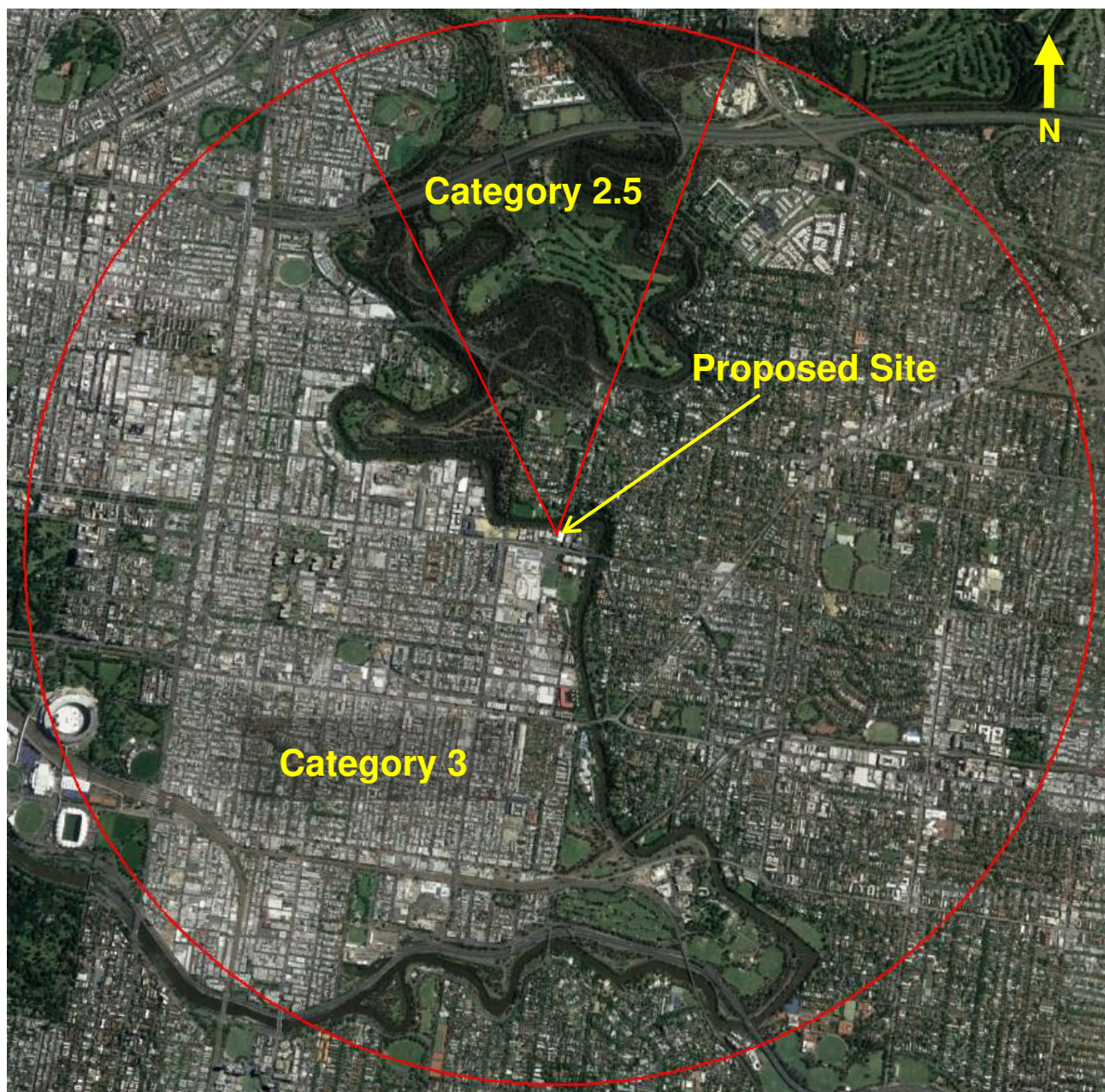


Figure 4: Assumed terrain roughness for wind speed estimation.

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Figure 5: Overall view from northwest of the 1:400 scale model of the proposed development in the wind tunnel.

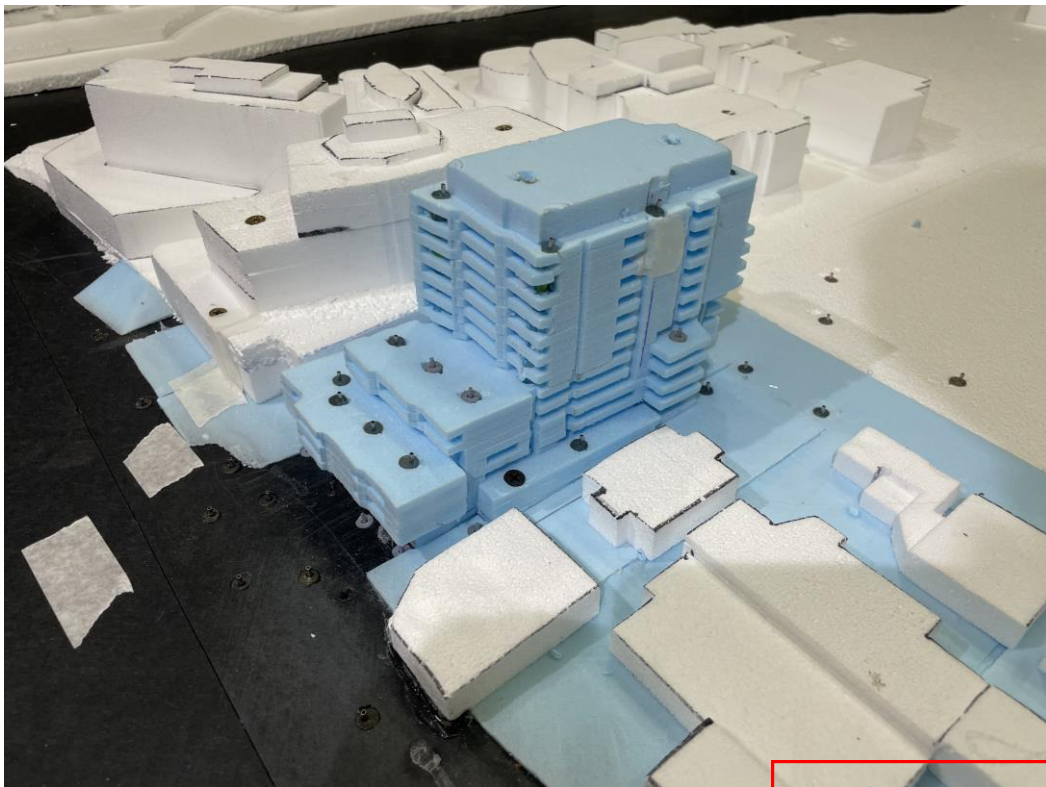


Figure 6: Close up view from the northwest of the 1:400 scaled model in the wind tunnel.

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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.

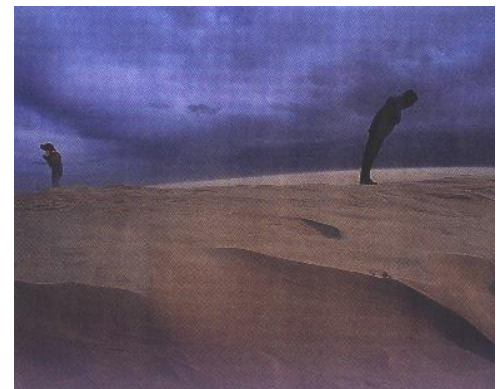
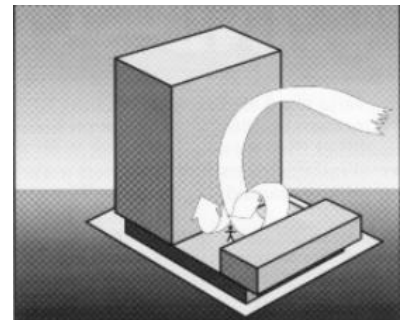
Downwash – refers to a flow of air down the exposed face of a tower. A tall tower can deflect a fast moving wind at higher elevations downwards.

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.



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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.

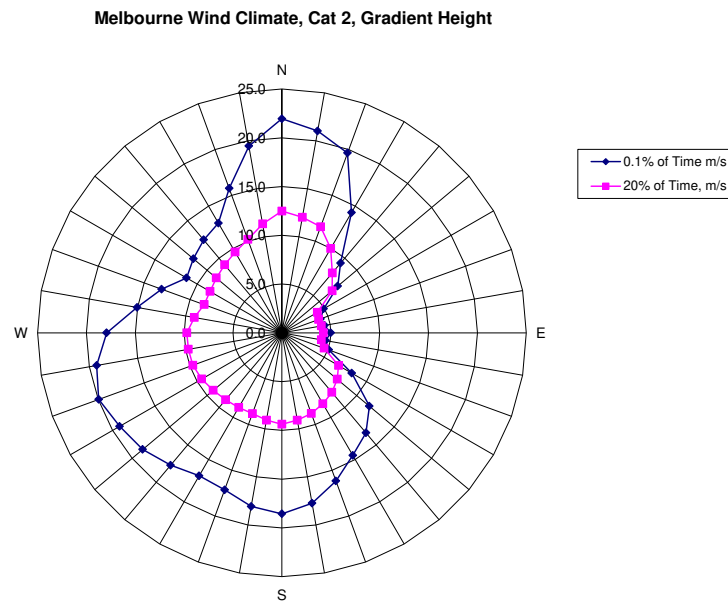


Figure 7: Directional Distribution of Mean Hourly Wind Velocities (m/s) for 0.1% and 20% exceeded at Gradient Height for Melbourne.

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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.

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 $\leq 0.1\%$ 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.

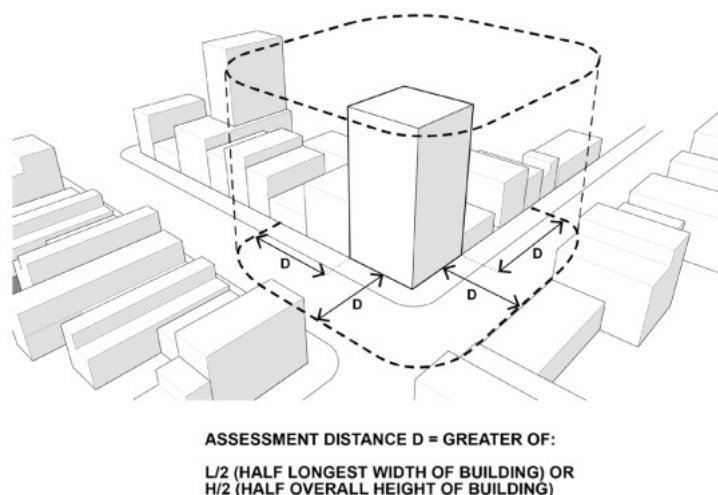


Figure 8: Assessment distance as detailed in Clause 58.04-4

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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 3 – Recommended application of criteria.

Area	Specific location	Recommended Criteria
Public Footpaths, Accessways	Along Victoria Street, Pedestrian link to east and the Yarra Riverbank (Figure 9)	Walking
Building Entrances	Main building entrance throughout site (Figure 9)	Standing
Outdoor Amenity Areas	North of site on the ground level (Figure 9)	Walking
Balcony/Terraces	Up the height of the building (Figure 10 and Figure 11)	Walking

3.1.2 Terrace / balcony Recommended Criterion Discussion

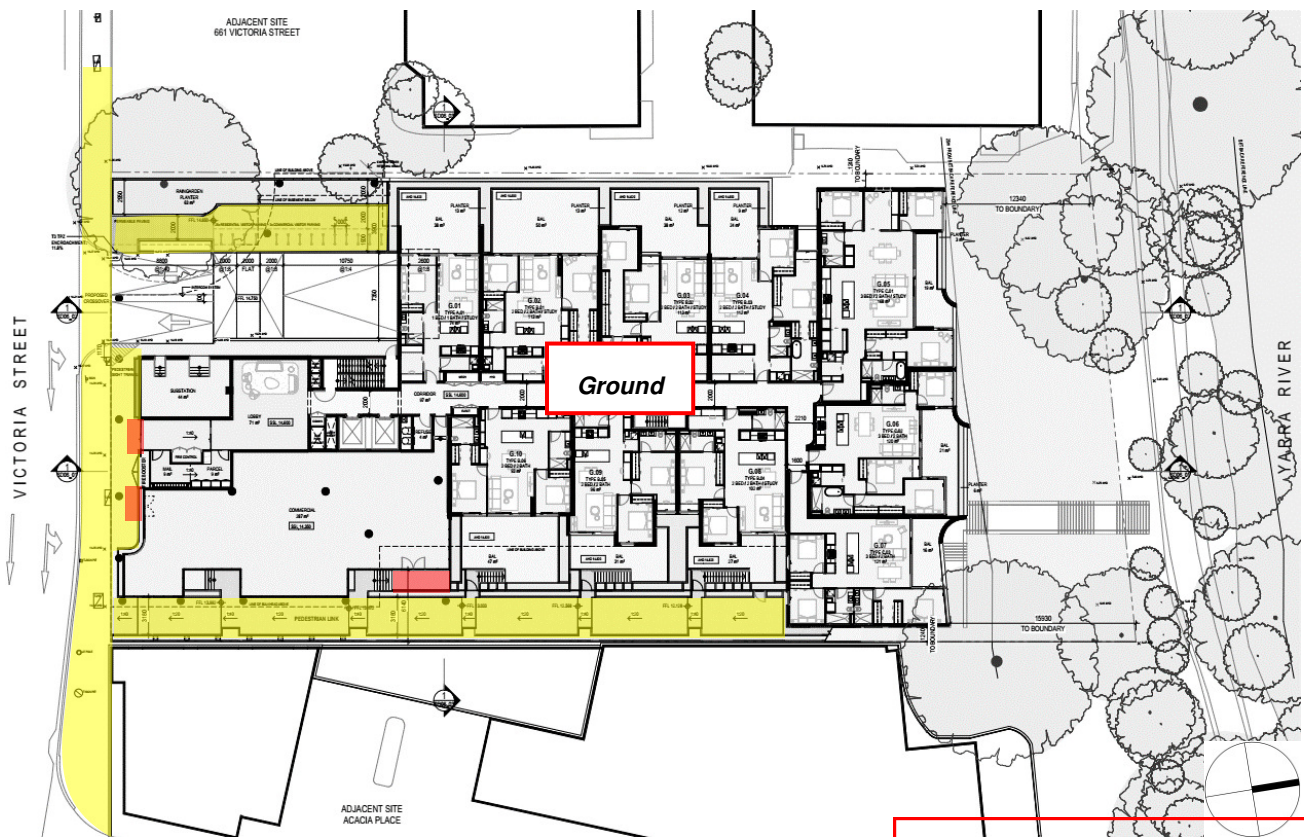
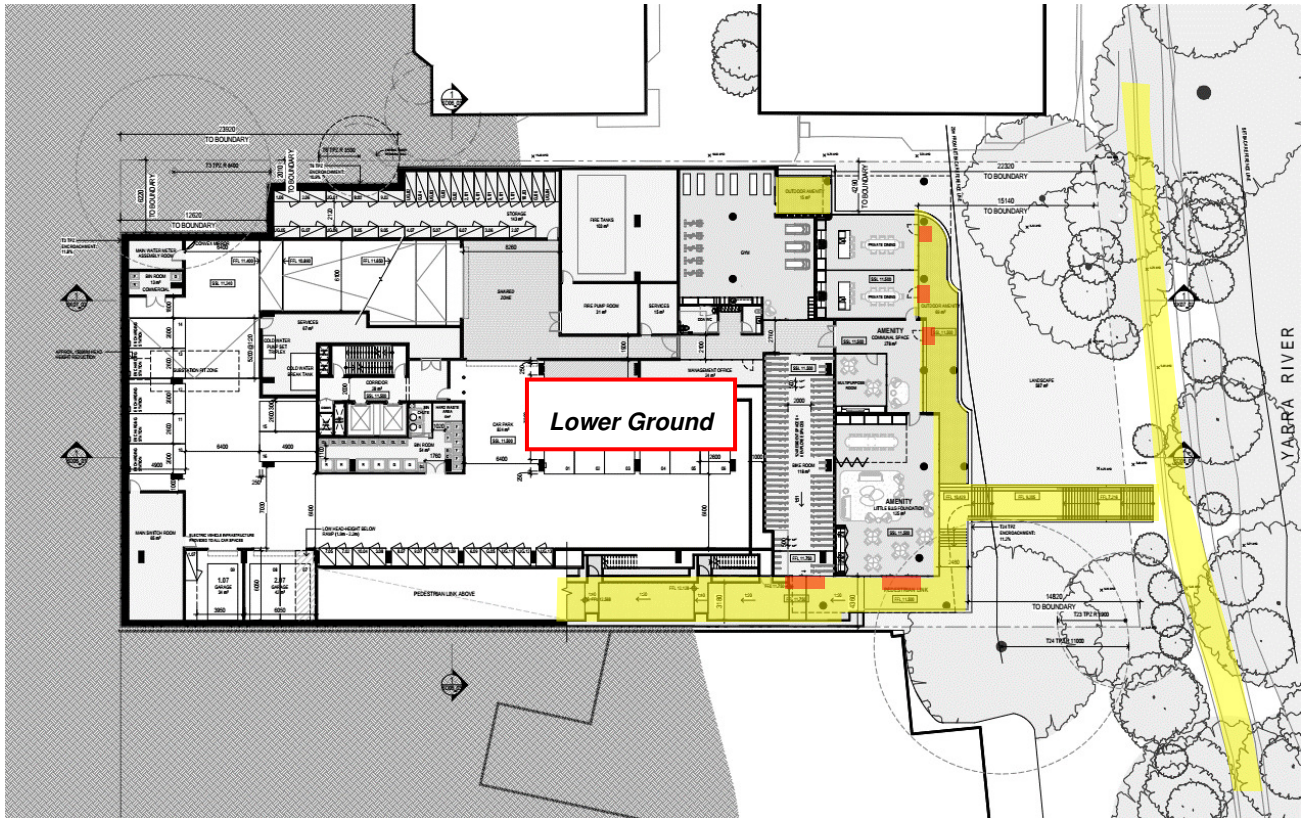
Vipac recommends as a minimum that rooftop terrace areas meet the criterion for walking since:

- 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.

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Recommended to fulfil Walking

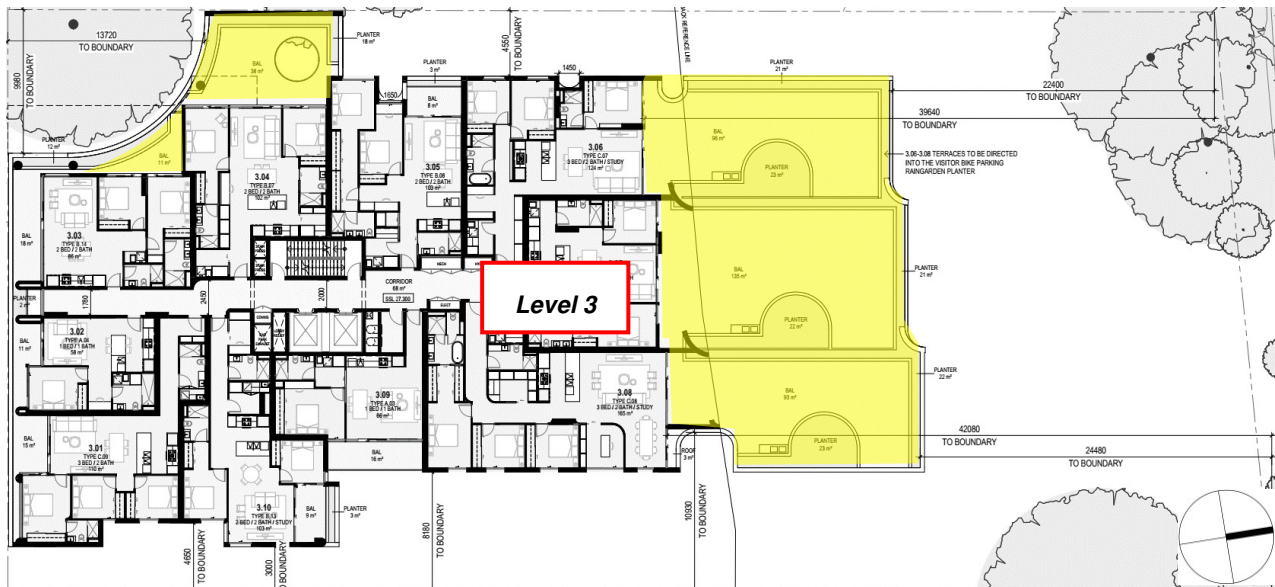
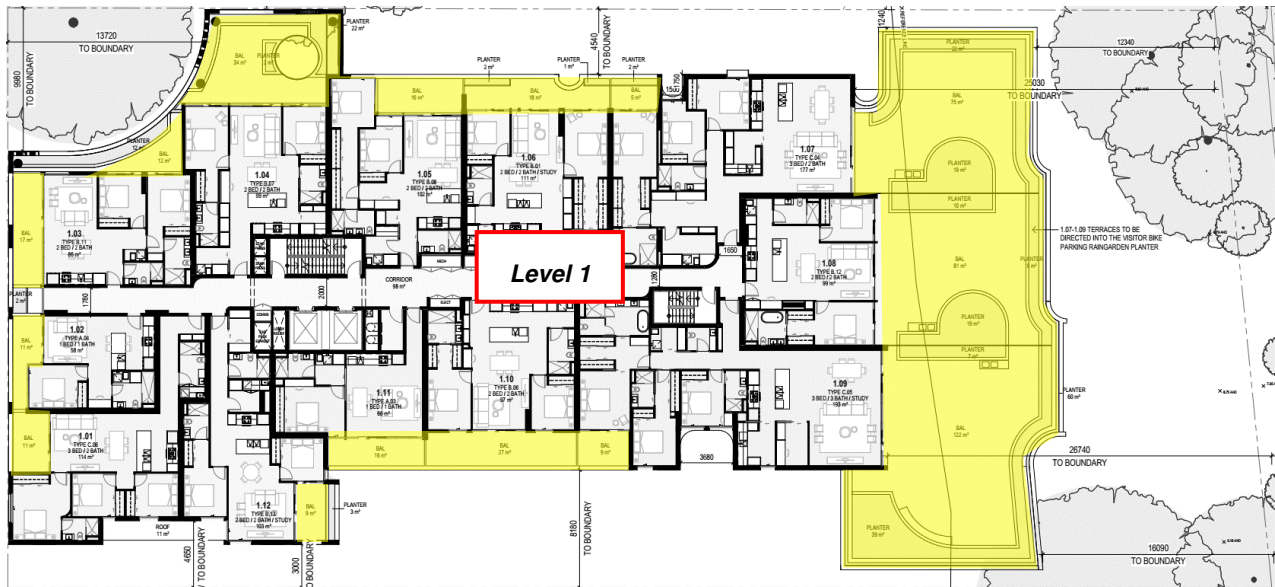


Recommended to fulfil Standing

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

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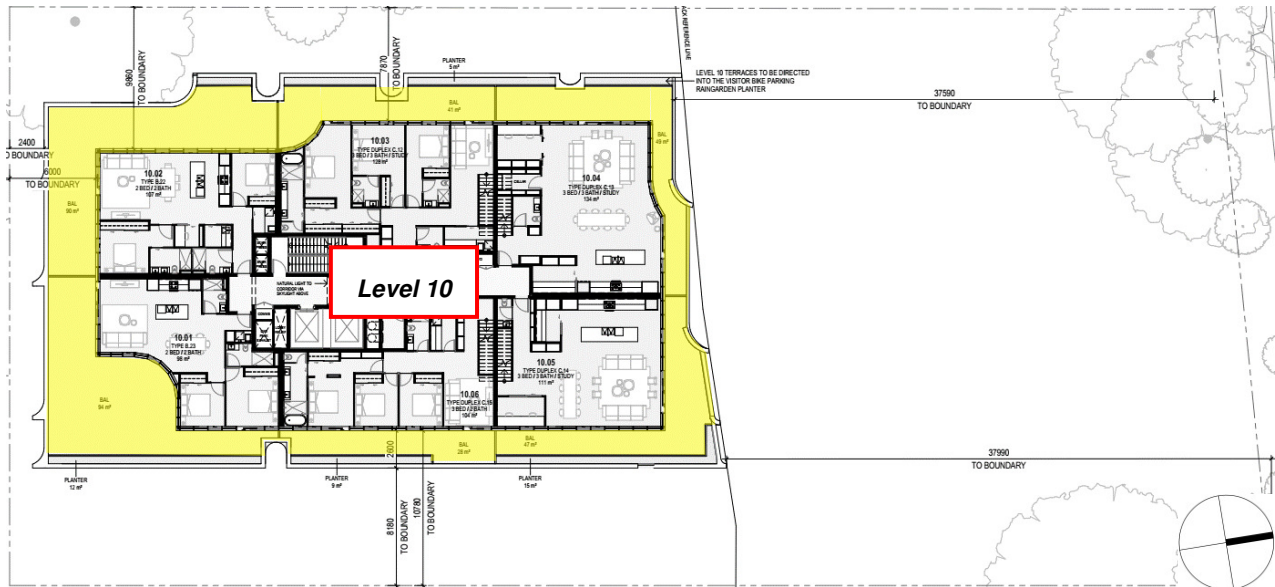


Recommended to fulfil Walking

Figure 10: Level 1 (top) and Level 3 (bottom) plans with recommended wind criteria overlaid.

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 Recommended to fulfil Walking

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

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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 2.5 and 3 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 2.5 and 3 are shown in Figure 12 and Figure 13 respectively. 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.

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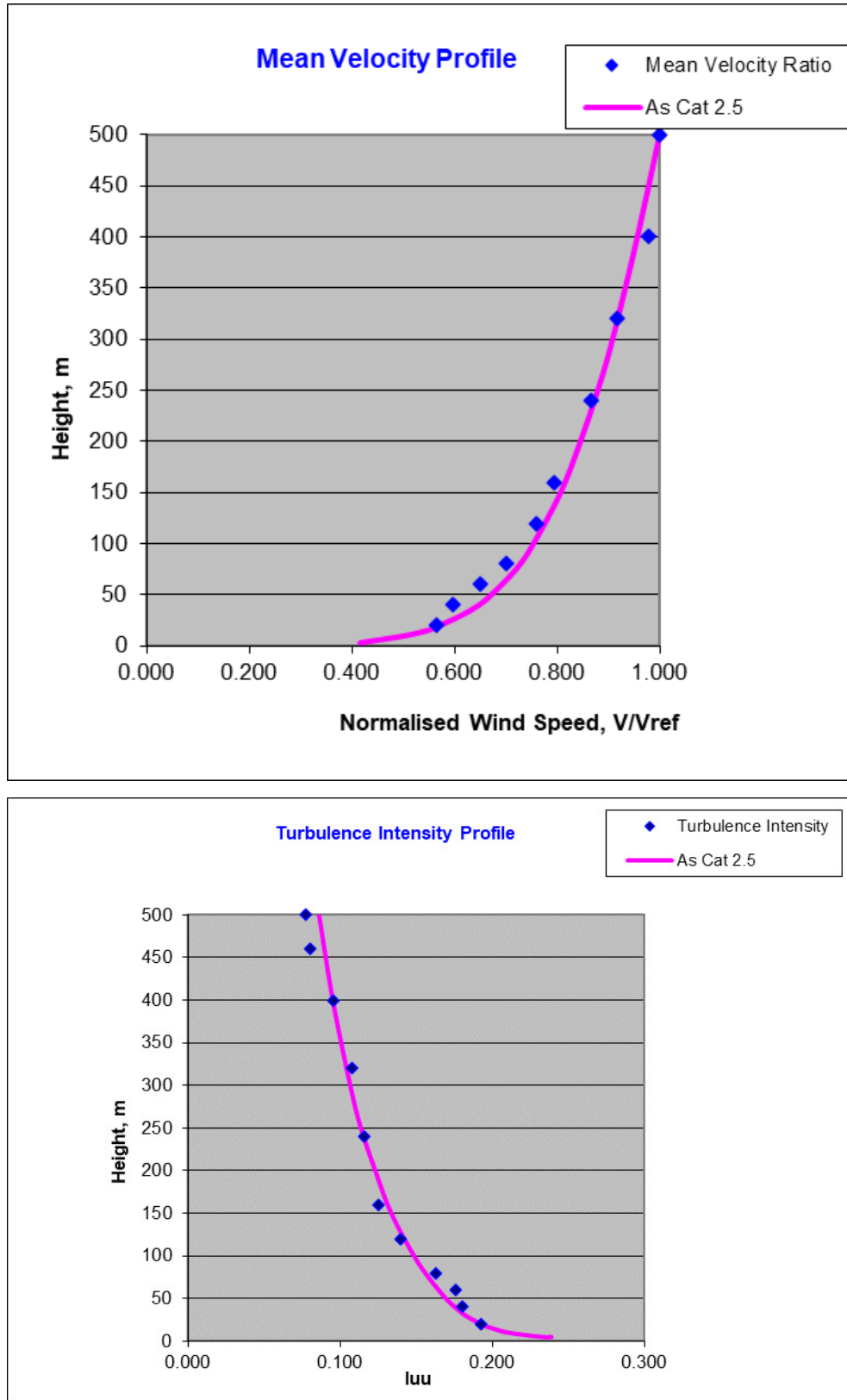


Figure 12: Mean Velocity and Turbulence Intensity Profiles for Terrain Category 2.5 (1:400 scale).

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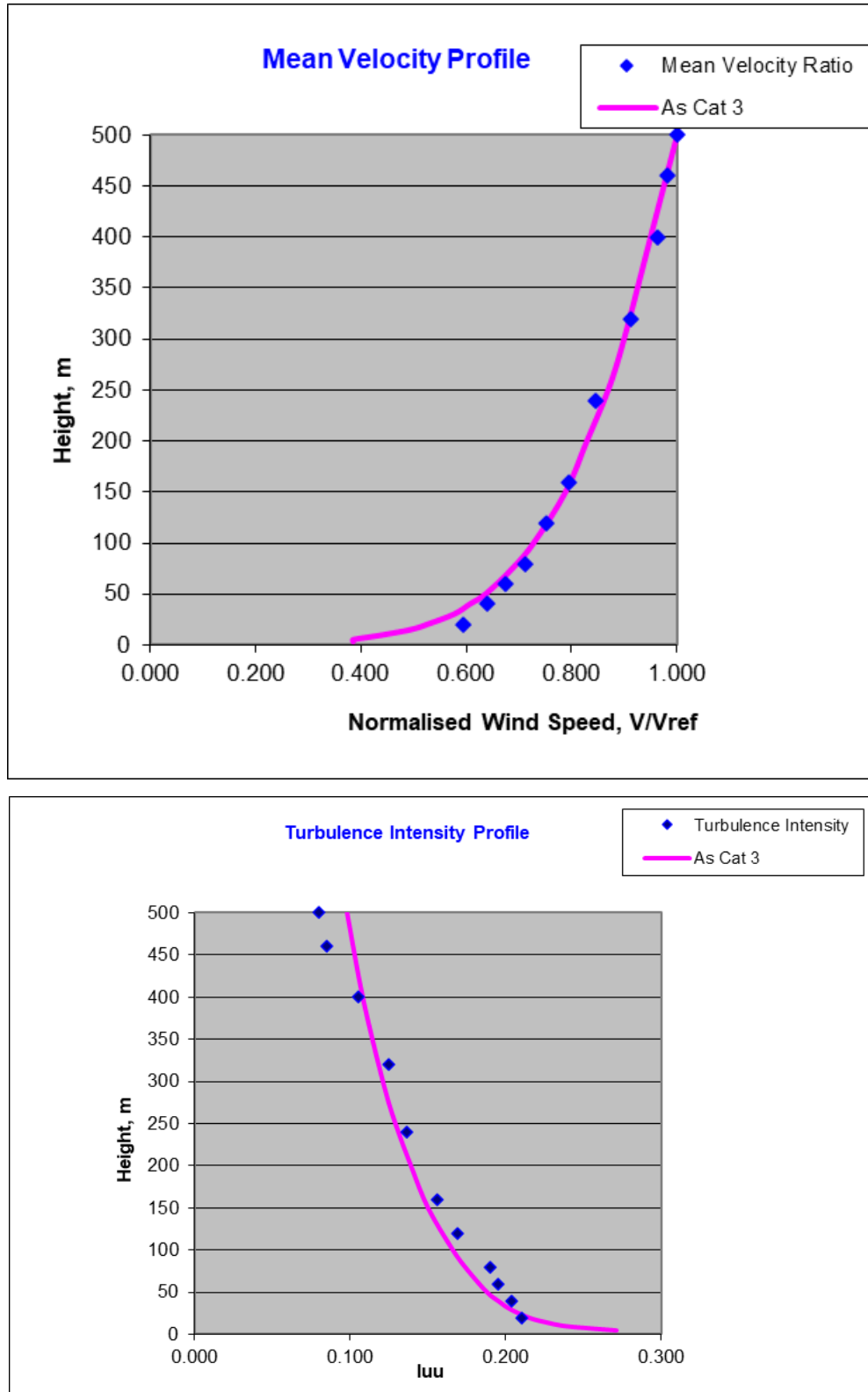


Figure 13: Mean Velocity and Turbulence Intensity Profiles for Terrain Category 3 (1:400 scale).

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5 Test Procedure

The pedestrian wind environment in the adjacent footpath areas along Victoria Street, Yarra Trail, eastern pedestrian link and some selected private terrace areas 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 terraces at different levels 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 **47** 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 14 to Figure 17.

Ground Level

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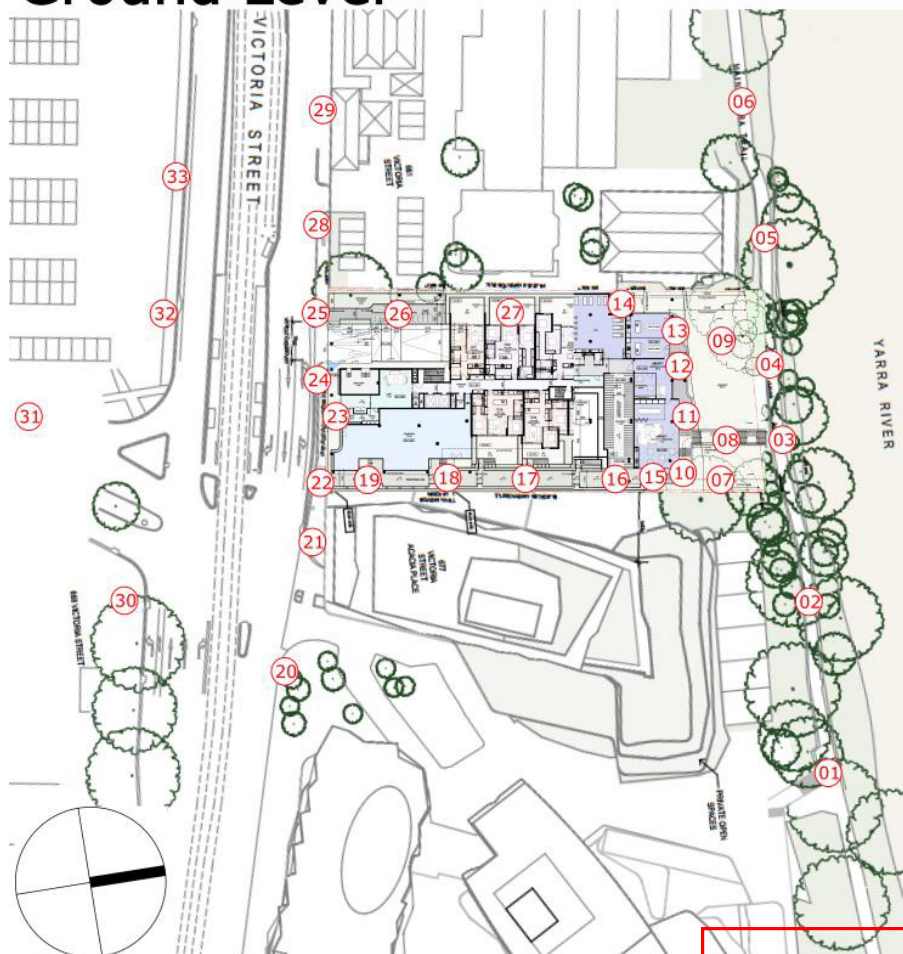


Figure 14: Sensor numbers and locations on the ground level

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Level 1

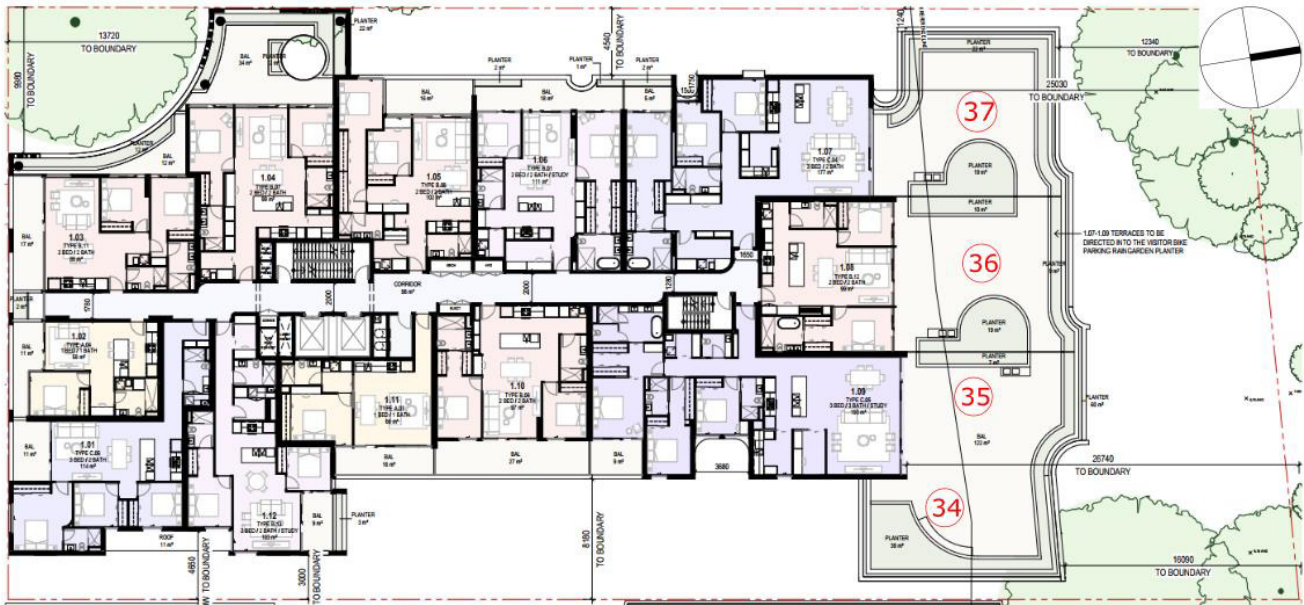


Figure 15: Sensor numbers and locations on Level 1.

Level 3

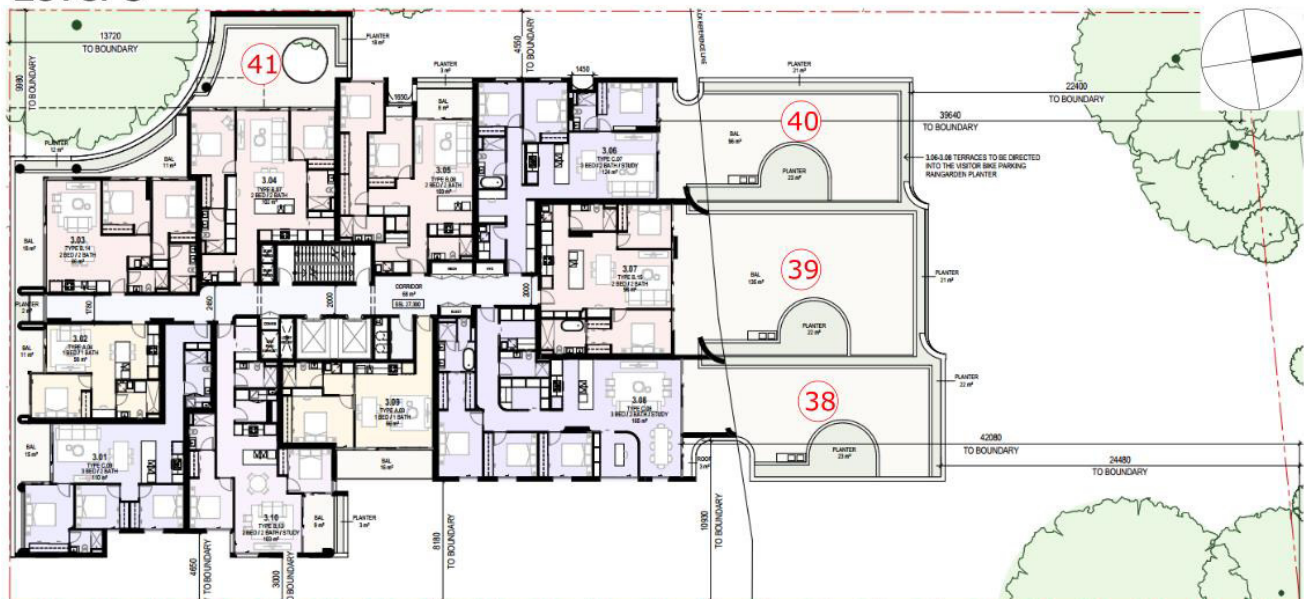


Figure 16: Sensor numbers and locations on Level 3.

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Level 10

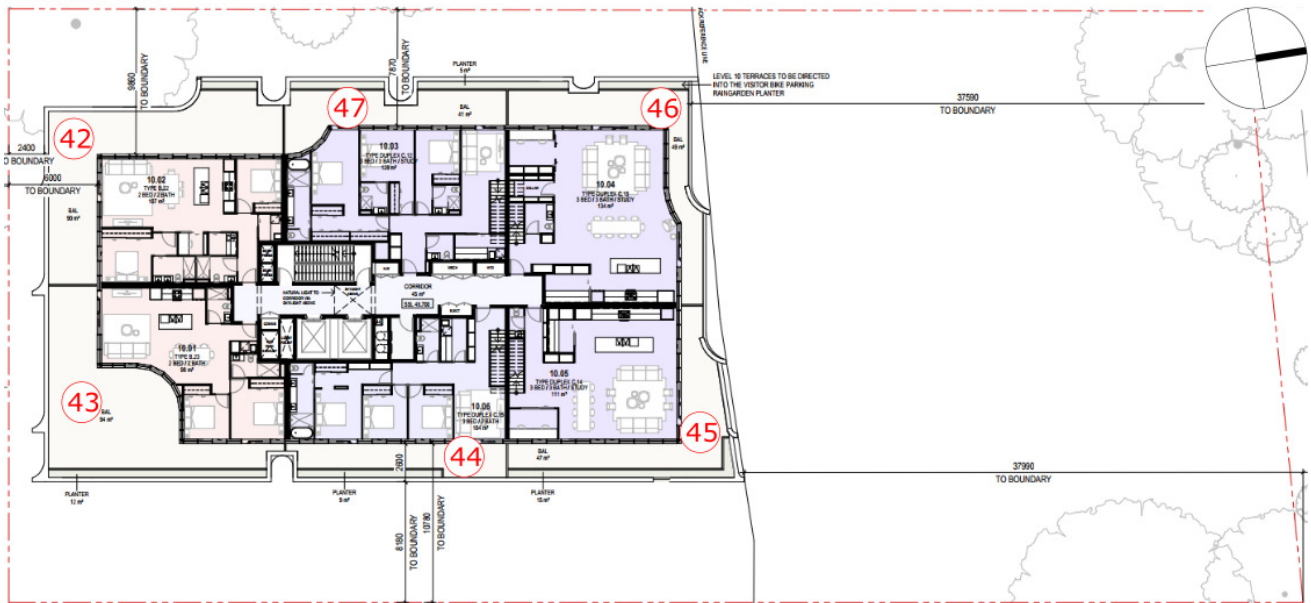


Figure 17: Sensor numbers and locations on Level 10.

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6 Results and Discussion

The pedestrian wind environment in the footpath, main entrances and outdoor communal terraces were assessed using omnidirectional pressure sensor tests.

Two configurations were conducted, namely:

- 1) **Existing:** a reference configuration of low-rise building conditions with Lower Ground to Level 2 only (Figure 18).
- 2) **Proposed:** test with the proposed development and existing surrounding developments (Figure 19).

The tests were conducted without any landscaping at the ground level.

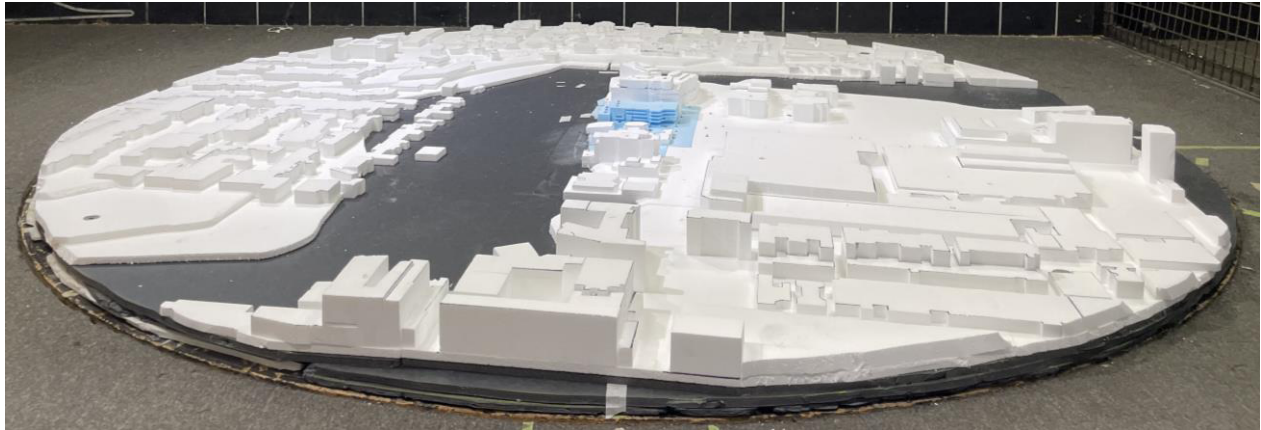


Figure 18: Overall view of the proposed development model from the east in the wind tunnel (Existing).

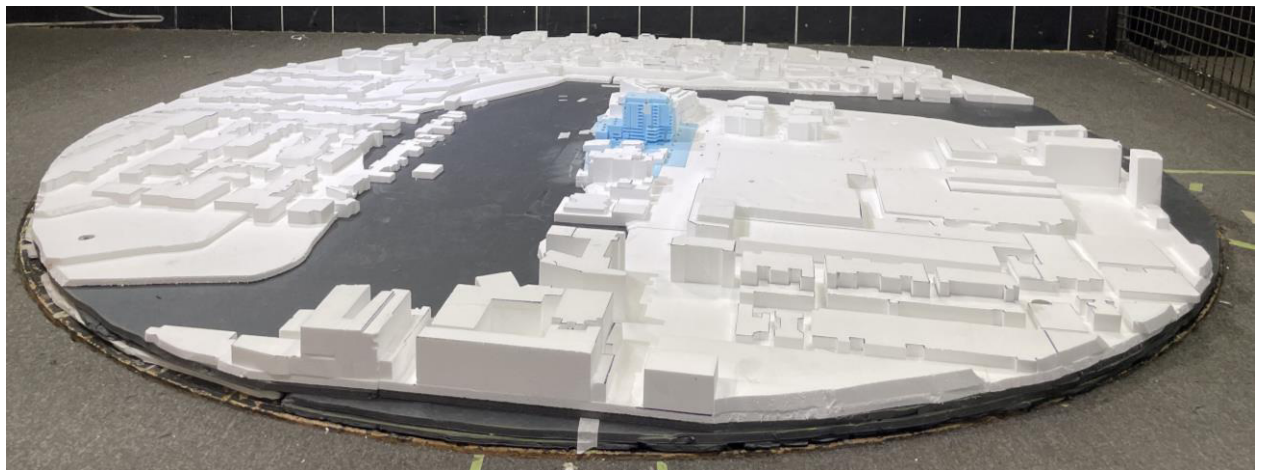


Figure 19: Overall view of the proposed development model from the east in the wind tunnel (Proposed).

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The test results are presented as polar plots for the gust wind speeds appended in Appendix C of this report. Figure 20 shows an example of these plots. In the figure, the red circle represents the velocities for the safety criterion and the set of data points represent the different test configurations and the predicted gust wind speeds for the 36 directions for Location 23.

The plot shows that with the proposed design, Location 23 was within the recommended safety criterion for the Proposed configuration. This location also measured windspeeds within the recommended standing comfort criterion (Figure 21).

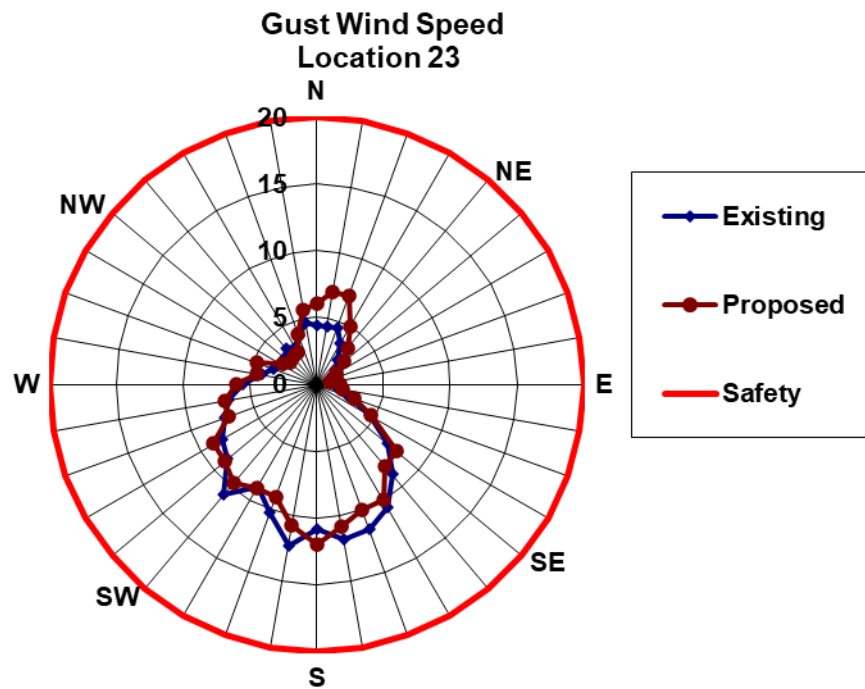


Figure 20: Polar plot showing the wind speed compared with safety criteria (Location 23).

Figure 21 and Figure 23 show 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 guidelines, the up-crossing prediction method described in Appendix D was used in the study.

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Comfort Criteria

Mean wind speed (20% probability)

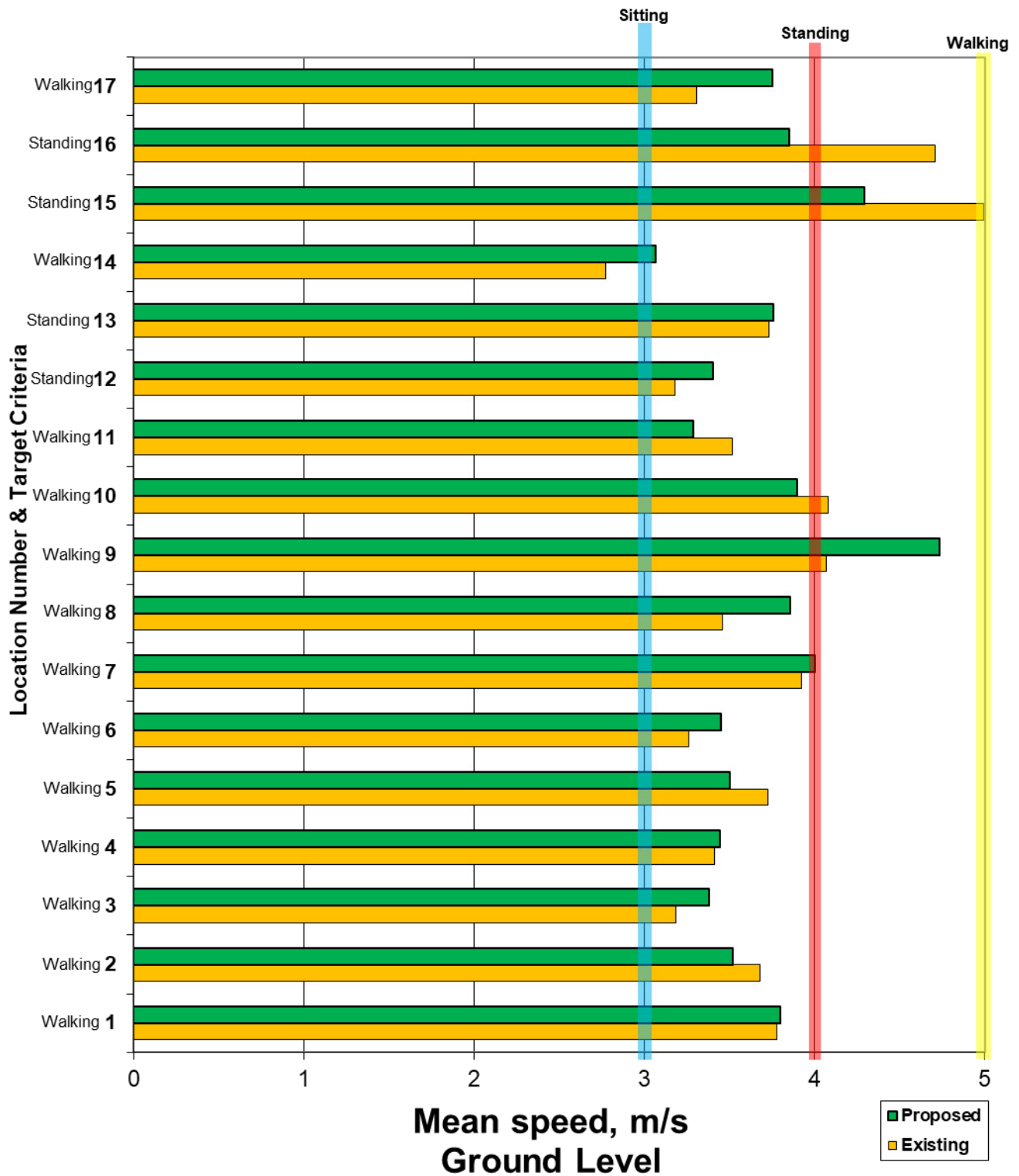


Figure 21: Bar plot showing the wind speed compared with comfort criteria (Locations 1 - 17)

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Comfort Criteria

Mean wind speed (20% probability)

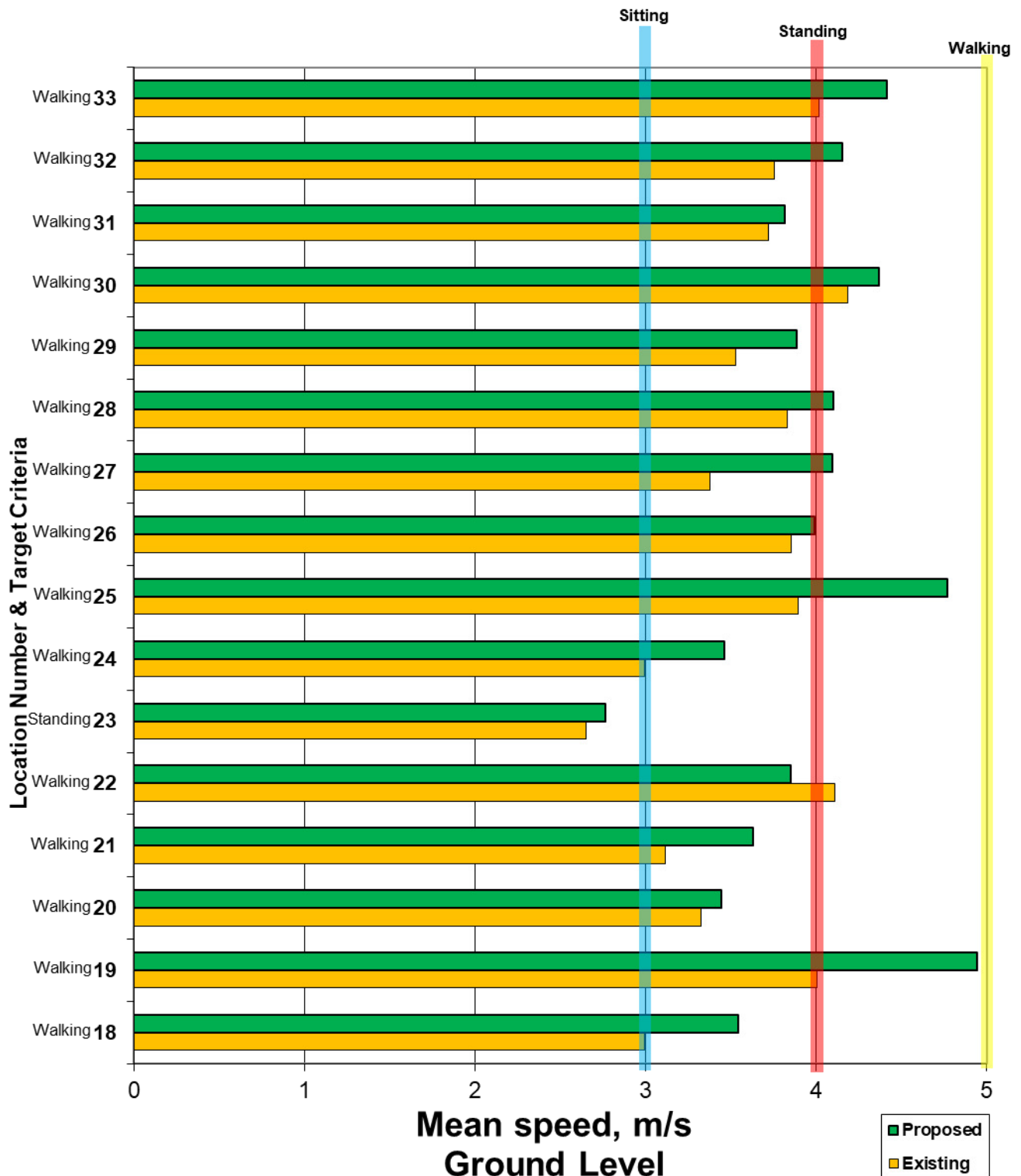


Figure 22: Bar plot showing the wind speed compared with comfort criteria (Locations 18 - 33)

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Comfort Criteria

Mean wind speed (20% probability)

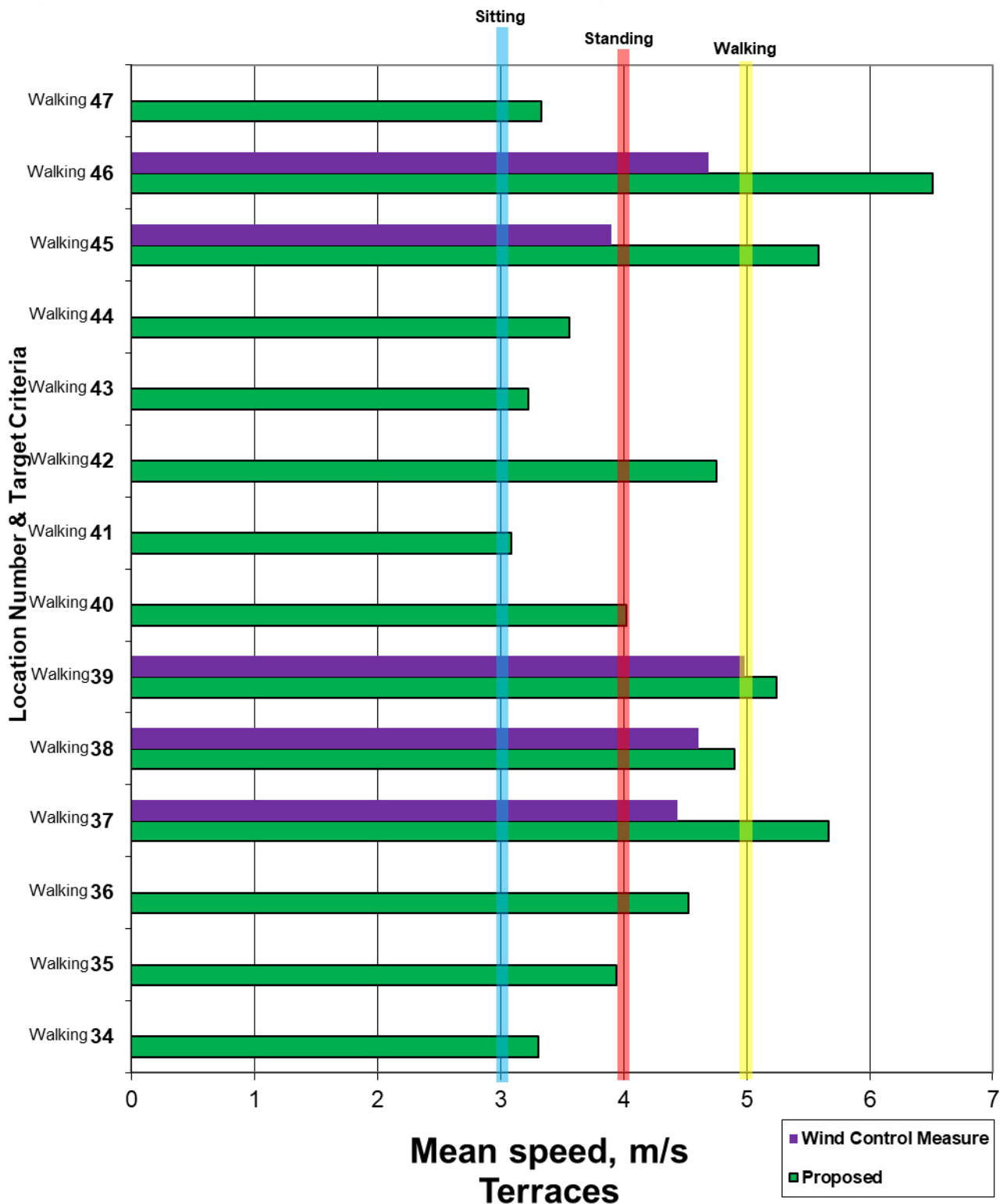


Figure 23: Bar plot showing the wind speed compared with comfort criteria (Locations 34 - 47)

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

6.1 Safety Criterion Test

All ground level locations within the immediate vicinity of the proposed development measured gust windspeeds within the recommended safety criterion for the Proposed configuration.

Locations 39 (level 3) and 45 (level 10) exceeded the safety criterion. Recommendations for wind amelioration have been provided for these locations and are discussed further in Section 6.2.4.3 and 6.2.4.4 respectively.

6.2 Comfort Criteria

6.2.1 Pedestrian Footpath and Accessways

Locations 1-14 & 15-33

All locations within the immediate vicinity of the proposed development measured mean windspeeds within the recommended walking comfort criterion for the Proposed configuration. As such, no recommendations for wind amelioration have been provided.

6.2.2 Building Entrances

Locations 12, 13, 15, 16 & 23

Most locations measured mean windspeeds within the recommended standing comfort criterion for the Proposed configuration.

Location 15 exceeded this criterion, however, was within the walking comfort criterion. As such, this entrance is recommended to be setback by 1m (Figure 24).

6.2.3 Outdoor Amenity Areas

Locations 11-14

All locations measured mean windspeeds well within the recommended walking comfort criterion for the Proposed configuration. As such, no recommendations for wind amelioration have been provided.

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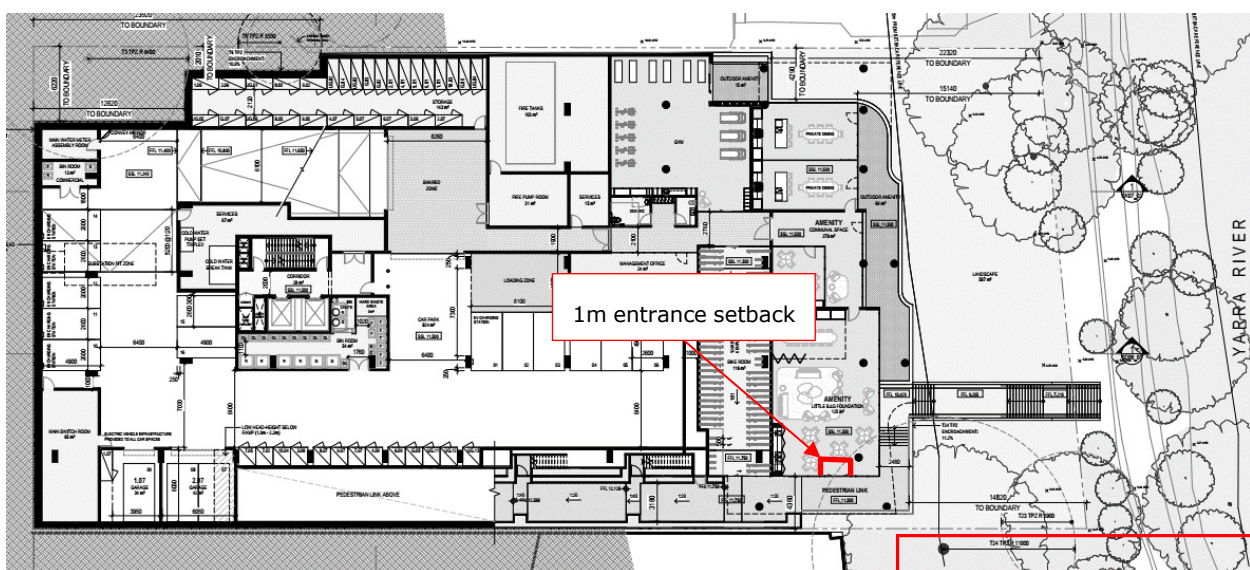


Figure 24: Recommendations for wind amelioration overlaid on the Lower Ground floor plan.

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6.2.4 Terraces

6.2.4.1 Ground Floor

Location 27

This location measured mean windspeeds within the recommended walking comfort criterion for the Proposed configuration. As such, no recommendations for wind amelioration have been provided.

6.2.4.2 Level 1

Locations 34-37

Tests were performed with 1.1m high solid balustrades and privacy screens, as proposed

Most locations measured mean windspeeds within the recommended walking comfort criterion for the Proposed configuration.

Location 37 exceeded this criterion. As such, a 2m deep porous canopy (40% porosity) is recommended along the balcony line above (Figure 25).

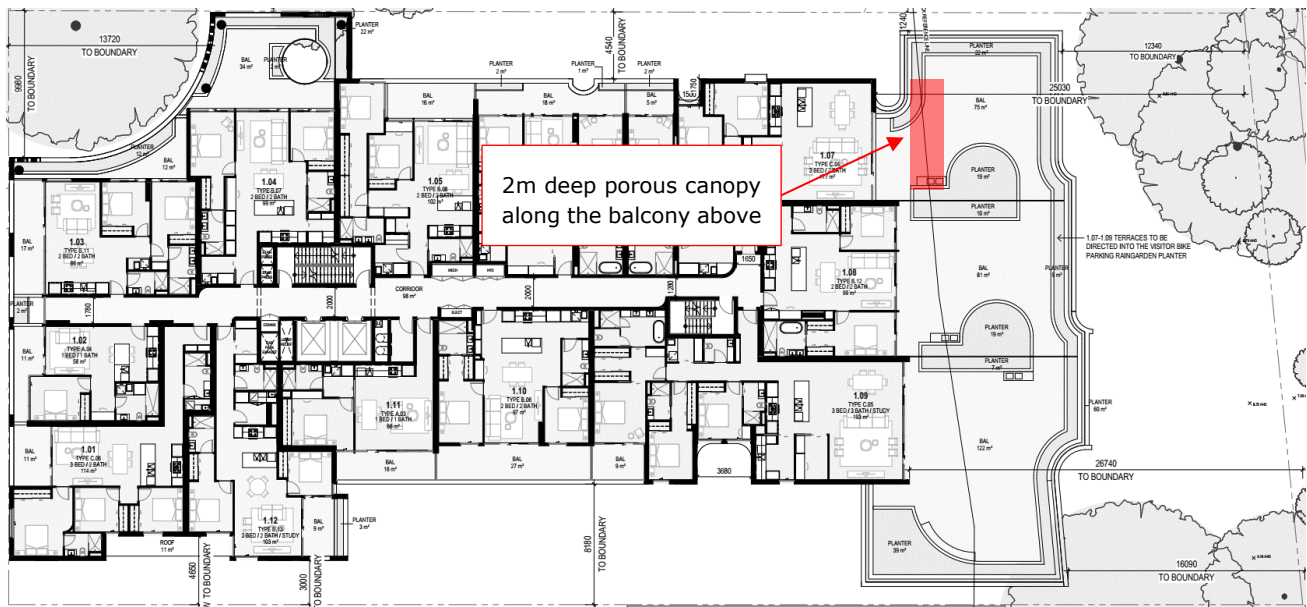


Figure 25: Recommendations for wind amelioration overlaid on the Level 1 floor plan.

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6.2.4.3 Level 3

Locations 38-41

Tests were performed with 1.1m high solid balustrades and privacy screens, as proposed

Location 40 measured mean windspeeds within the recommended walking comfort criterion for the Proposed configuration. As such, no recommendations for wind amelioration have been provided.

Locations 38 and 39 measured windspeeds exceeding this comfort criterion. As such, a 3m deep porous canopy (40% porosity) is recommended along the balcony line above (Figure 26).

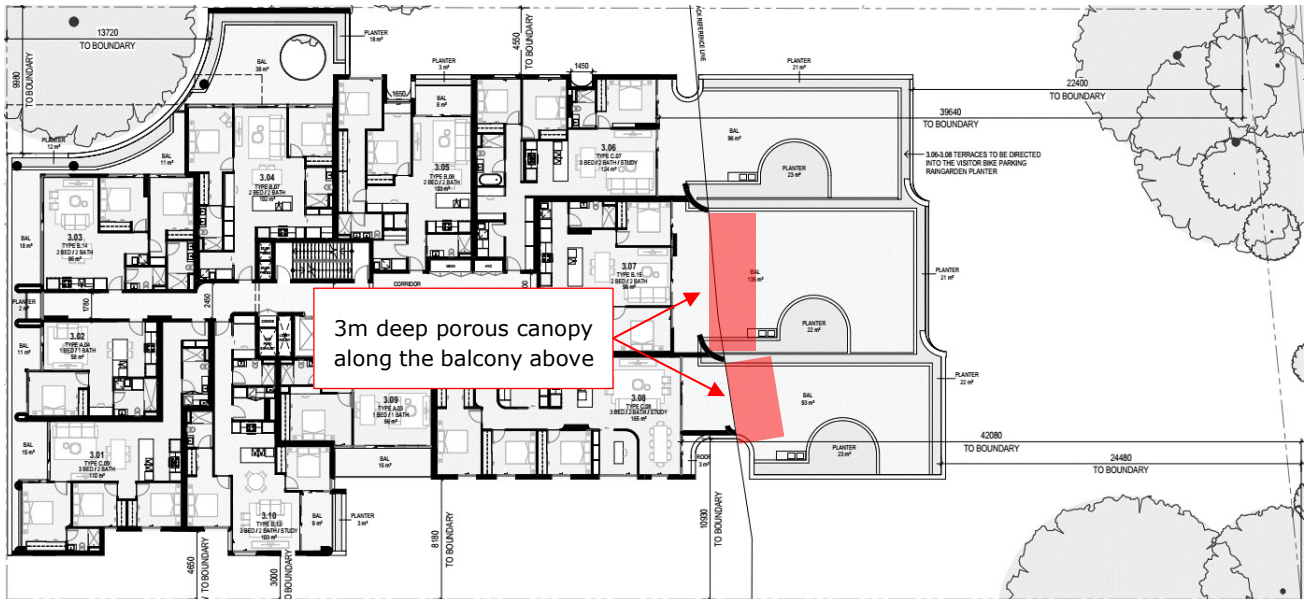


Figure 26: Recommendations for wind amelioration overlaid on the Level 3 floor plan.

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6.2.4.4 Level 10

Locations 42-47

Tests were performed with 1.1m high solid balustrades and privacy screens, as proposed

Most locations measured mean windspeeds within the recommended walking comfort criterion for the Proposed configuration.

Locations 45 and 46 measured windspeeds exceeding this comfort criterion. As such, the balustrades along the perimeter of the northern balconies are recommended to be raised to 1.8m high (Figure 27).

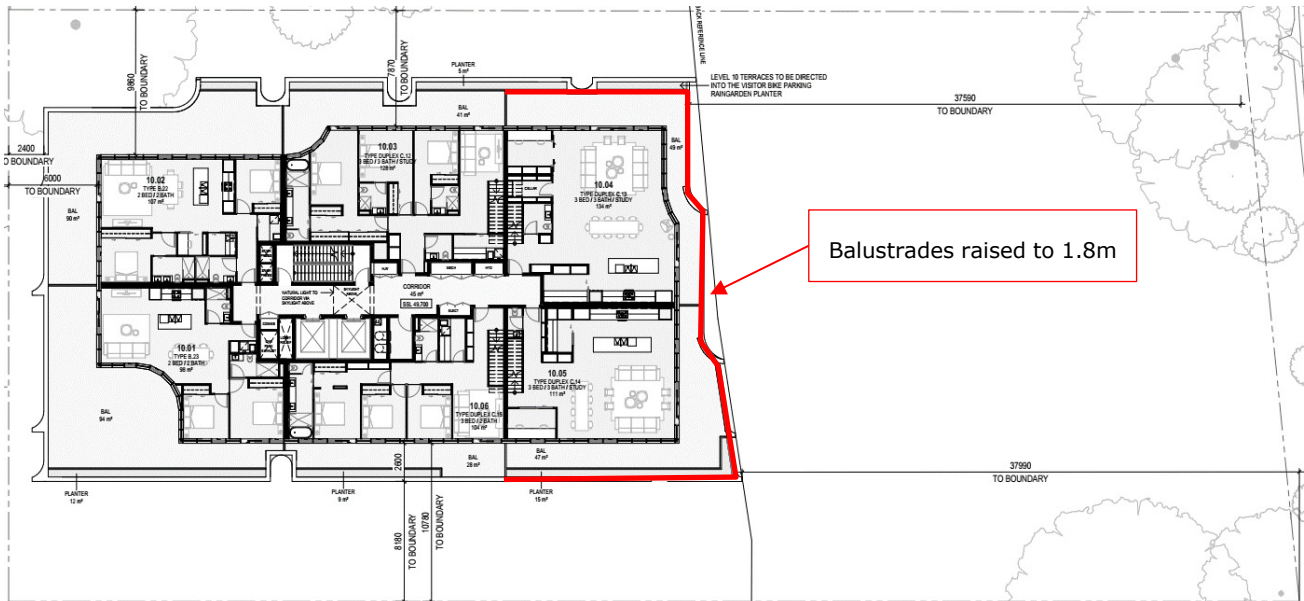


Figure 27: Recommendations for wind amelioration overlaid on the Level 10 floor plan.

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7 Conclusion

Vipac has carried out an assessment of the pedestrian level winds for the proposed development at **675 Victoria Street, Abbotsford** 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 **with recommendations**;
- fulfils the recommended criterion for **Walking** at all footpath locations;
- fulfils the recommended criterion for **Standing** at all building entrances **with recommendations**; and
- fulfils the recommended criteria for **Walking** at all open terraces and communal terraces **with the recommendations**.

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.

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Appendix A References

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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

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Appendix B Drawing List

Drawings Received: October 2024

SD02-01 Revision 1 Basement 2 Floor
SD02-02 Revision 1 Basement 1 Floor
SD02-03 Revision 1 Lower Ground Floor
SD02-04 Revision 1 Ground Floor Plan
SD02-05 Revision 1 Upper Ground Floor
SD02-06 Revision 1 Level 1 Floor Plan
SD02-07 Revision 1 Level 2 Floor Plan
SD02-08 Revision 1 Level 3 Floor Plan
SD02-09 Revision 1 Level 4-6 Floor Plan
SD02-12 Revision 1 Level 7 Floor Plan
SD02-13 Revision 1 Level 8 Floor Plan
SD02-14 Revision 1 Level 9 Floor Plan
SD02-15 Revision 1 Level 10 Floor Plan
SD02-16 Revision 1 Level 11 Floor Plan
SD02-17 Revision 1 Roof Plan

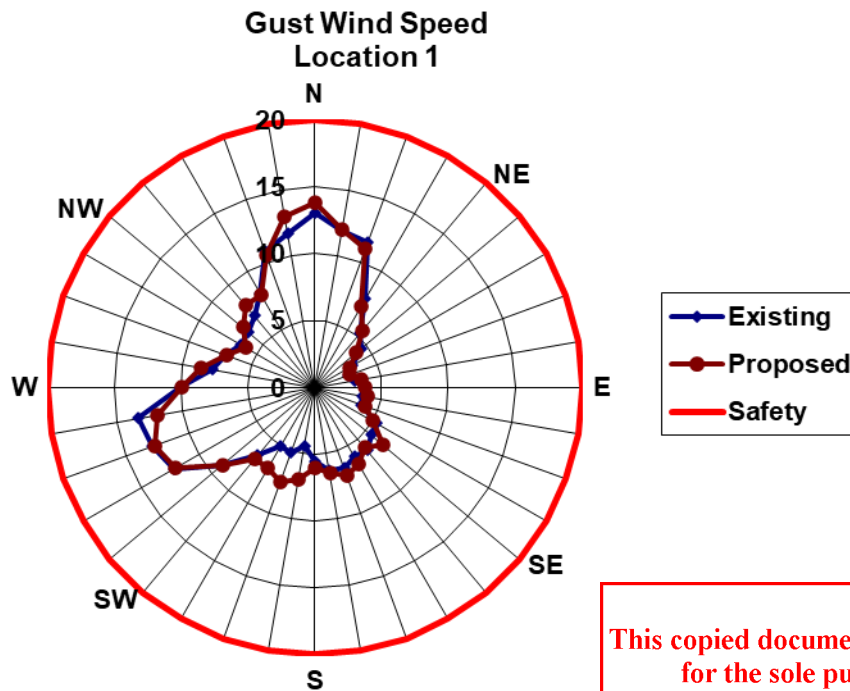
SD05-01 Revision 1 North Elevation
SD05-02 Revision 1 East Elevation
SD05-03 Revision 1 South Elevation
SD05-04 Revision 1 West Elevation

SD06-01 Revision 1 Sections
SD06-02 Revision 1 Sections
SD06-03 Revision 1 Sections

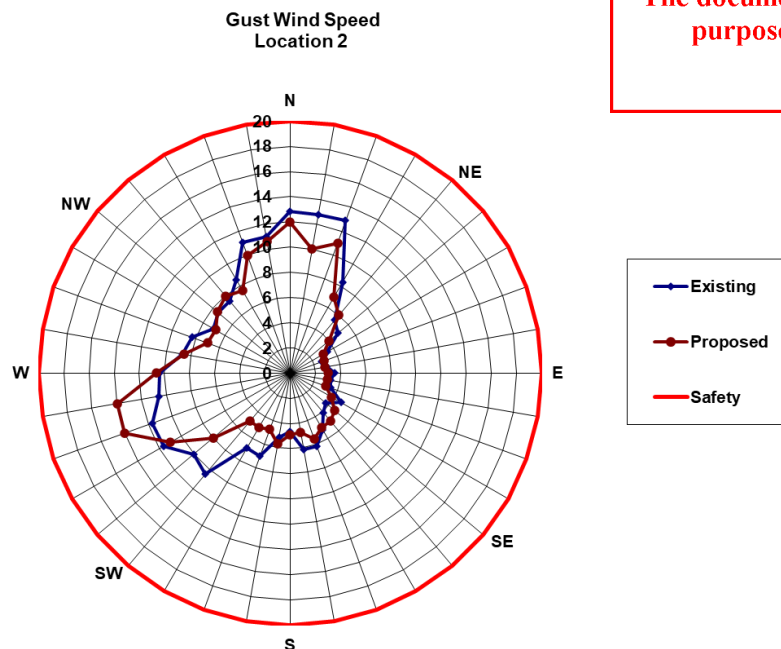
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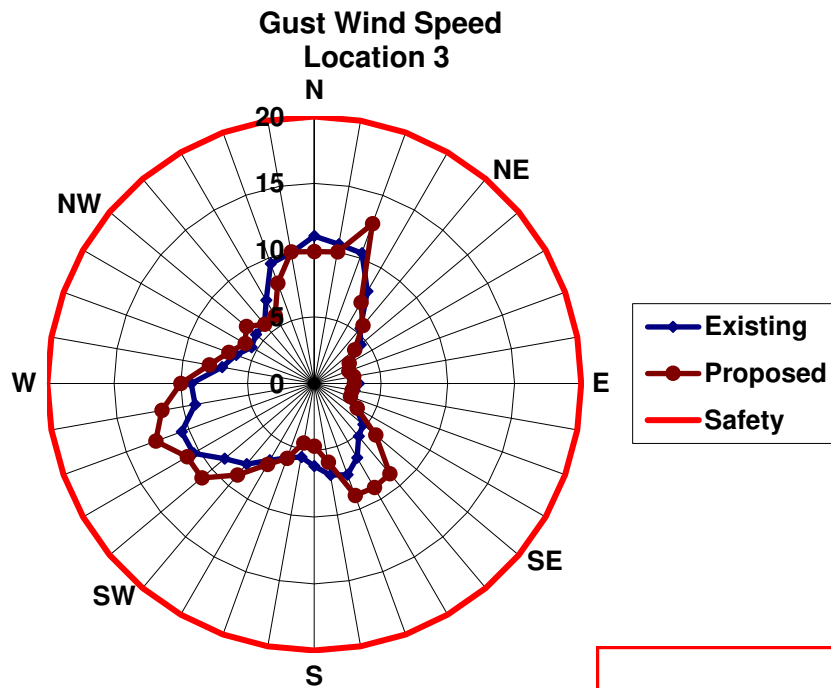
Appendix C Omni Polar Plots – Gust Wind Speeds (Safety Criterion)



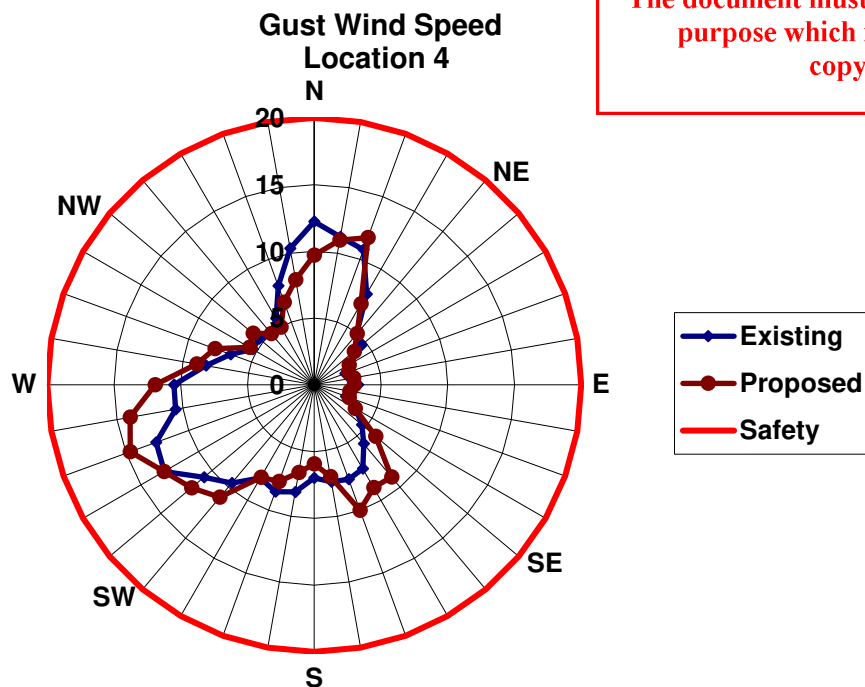
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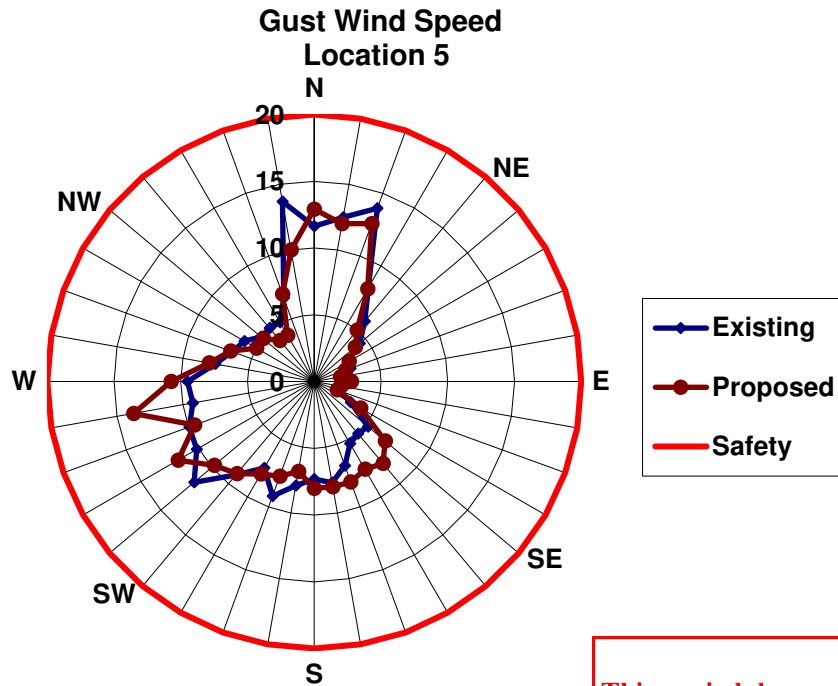
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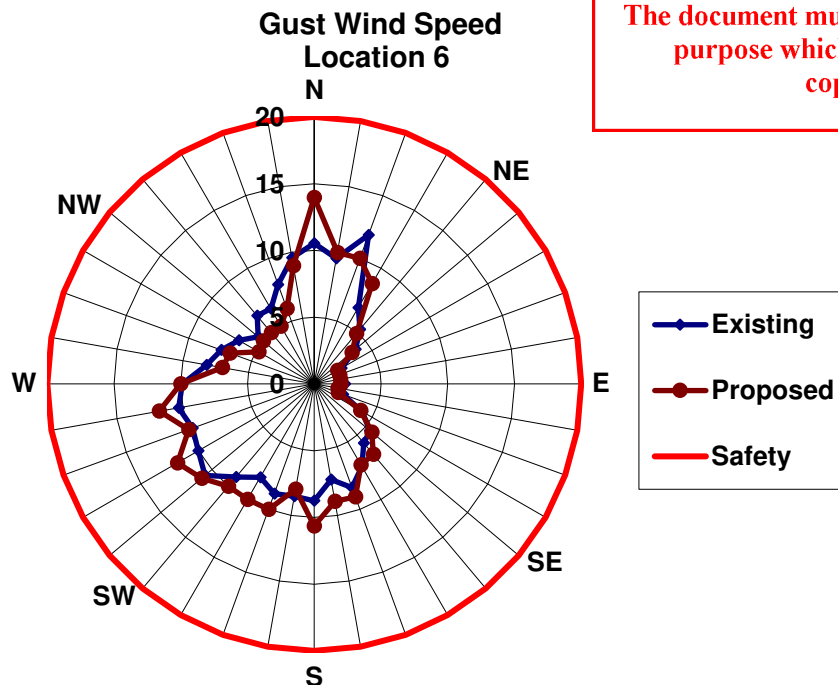
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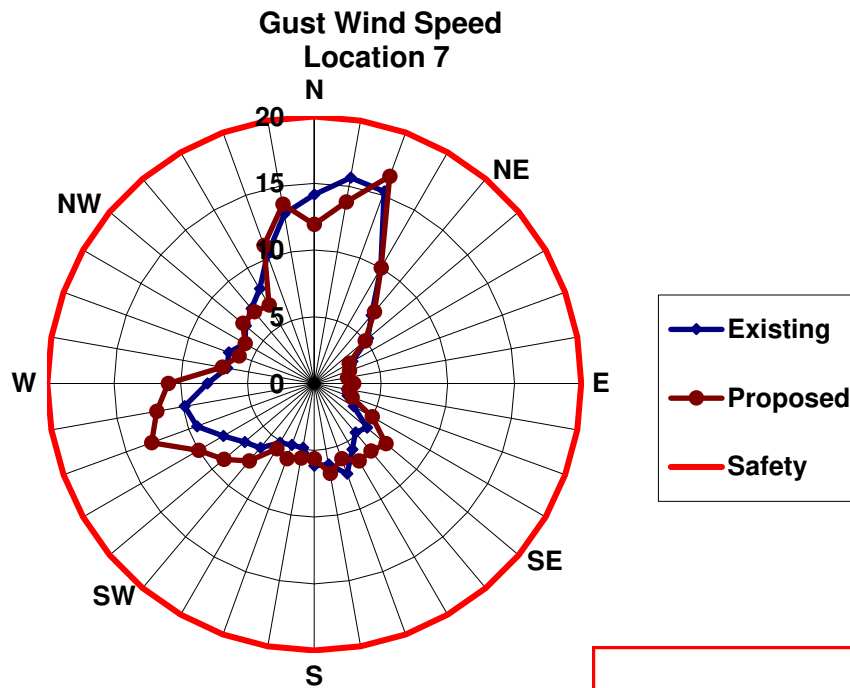
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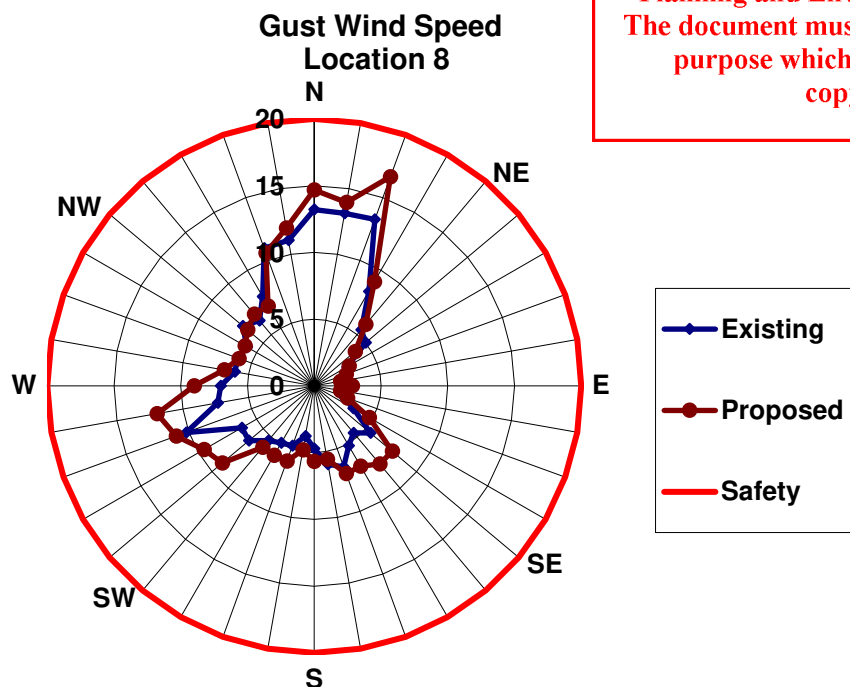
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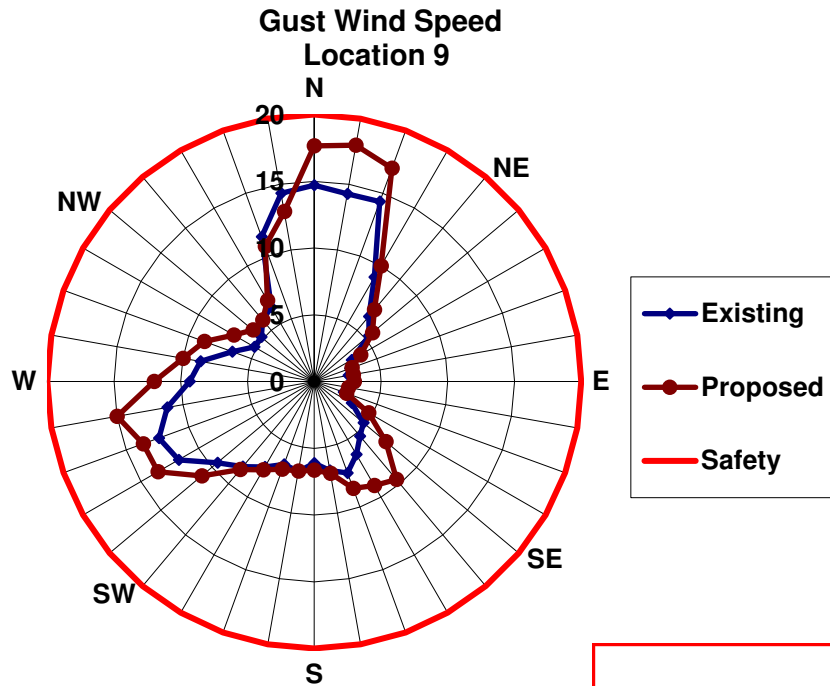
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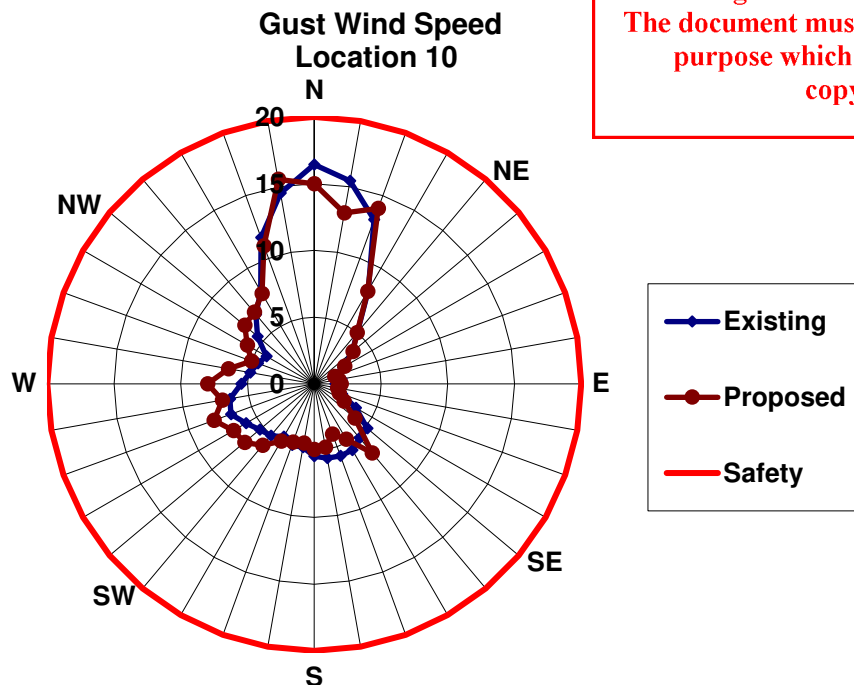
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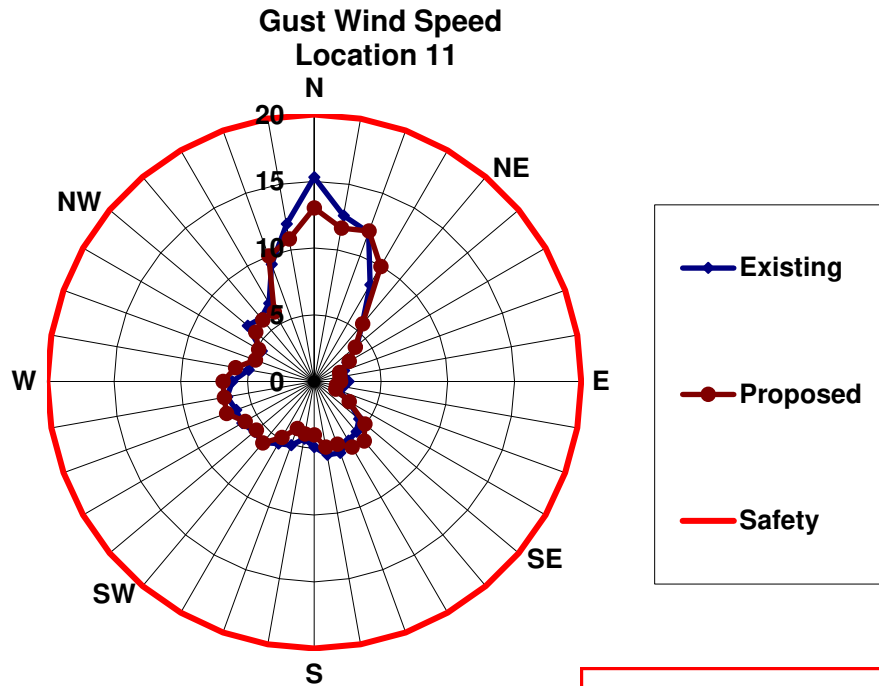
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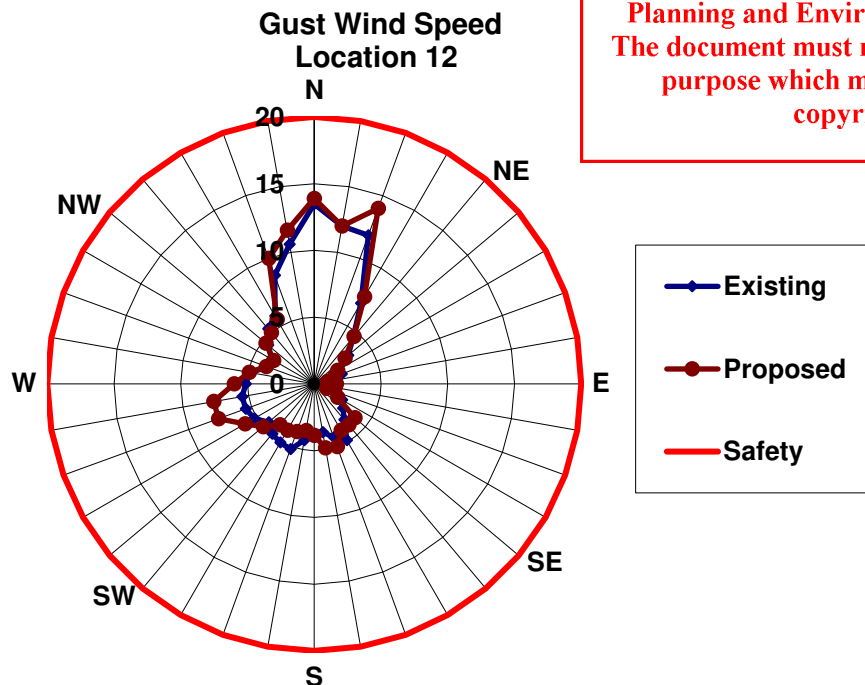
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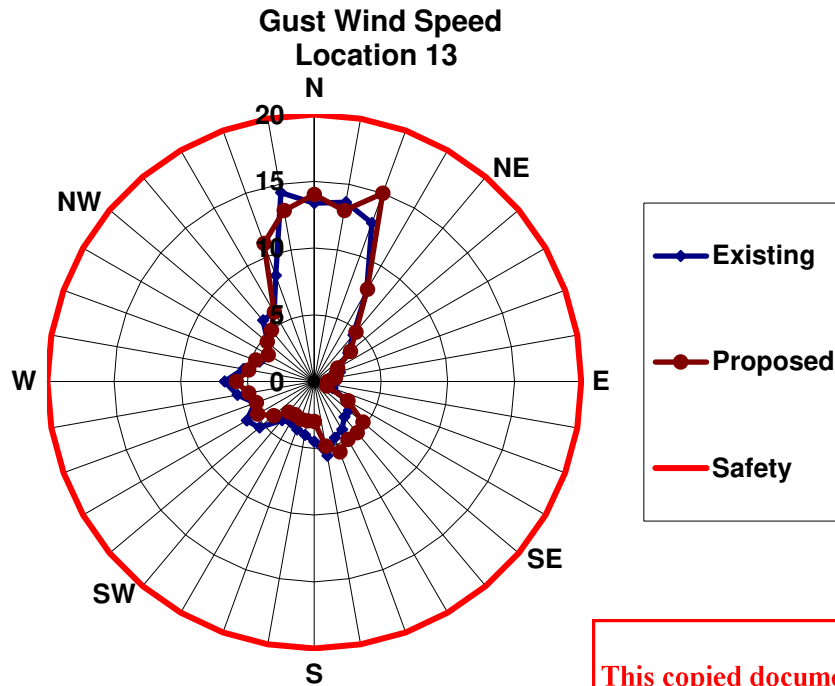
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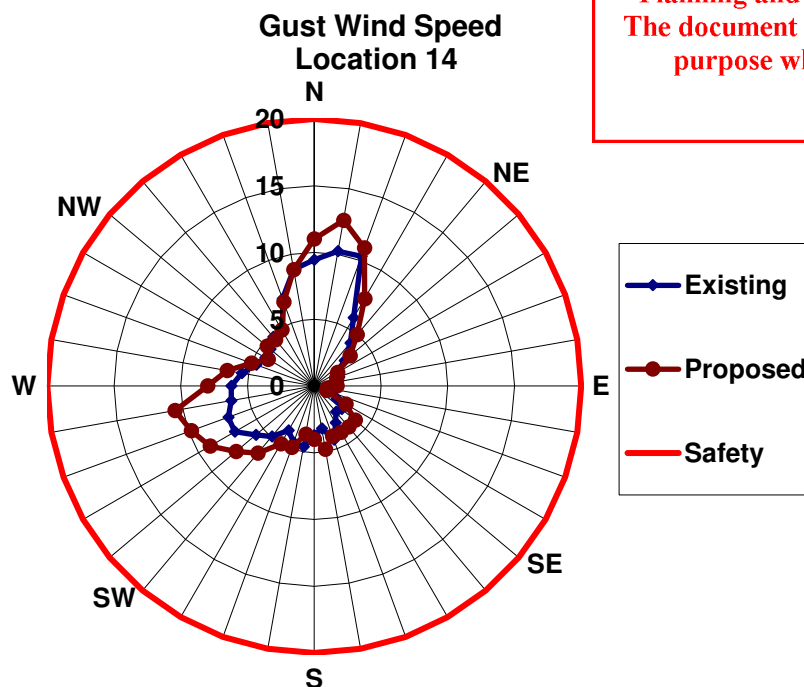
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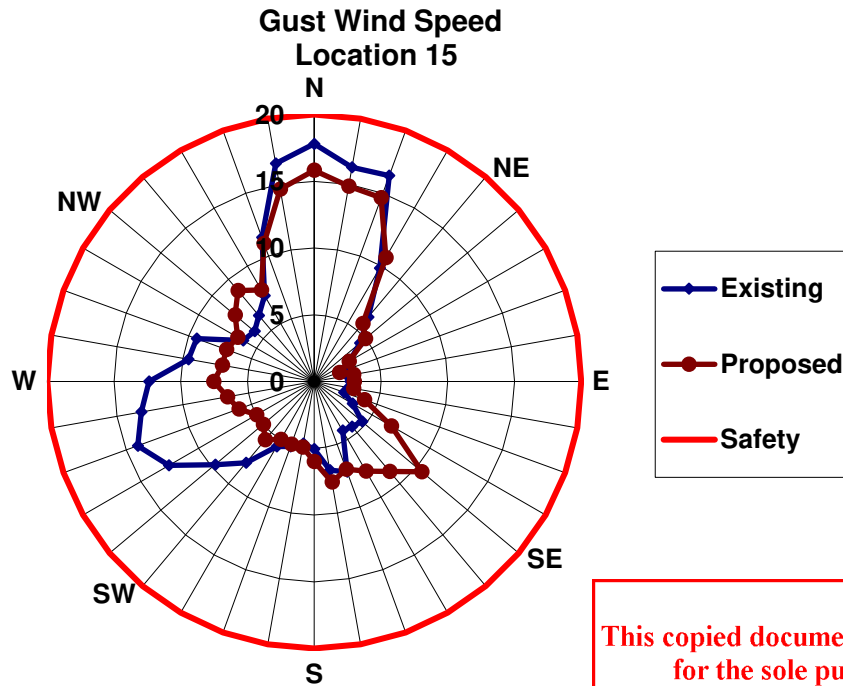
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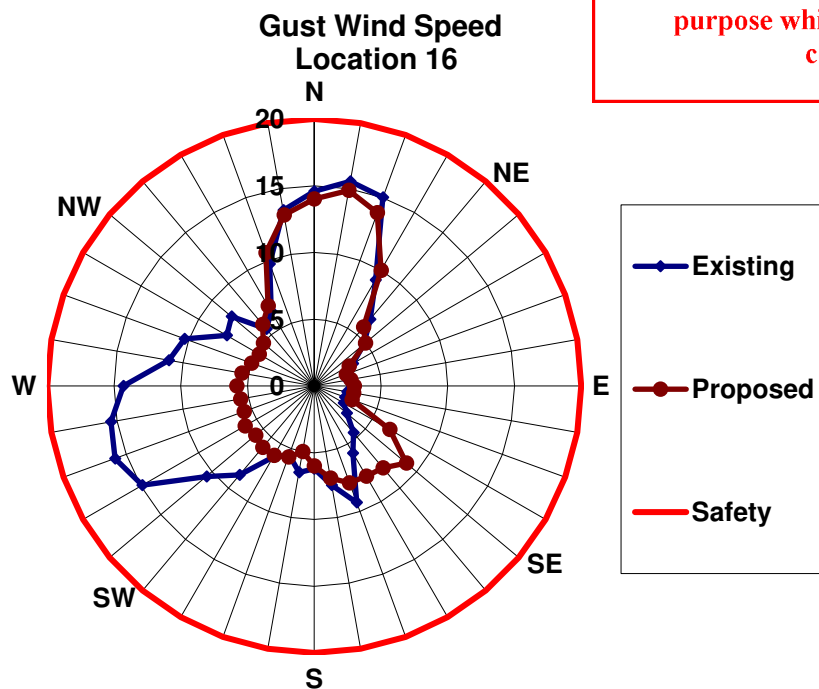
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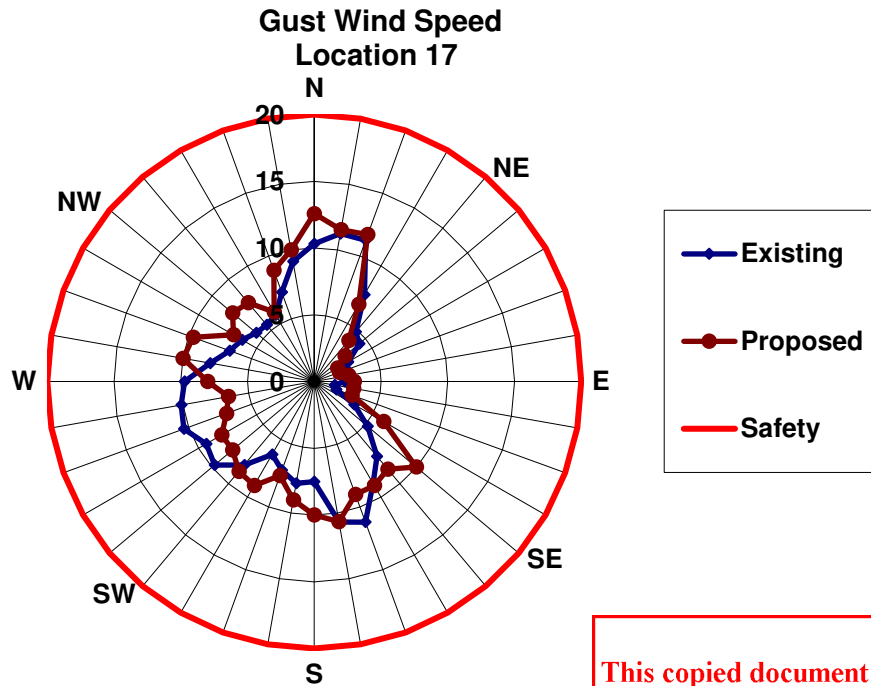
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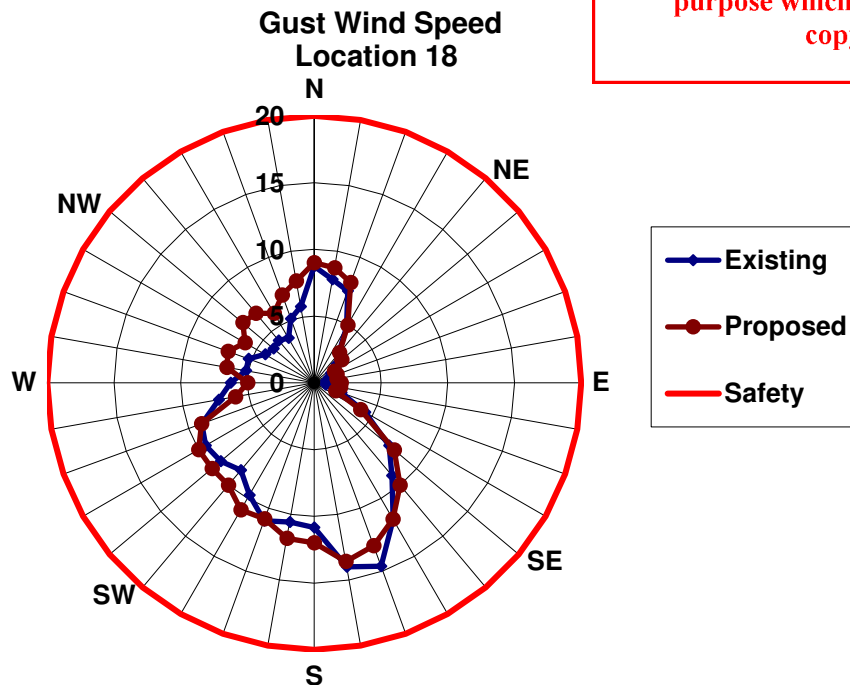
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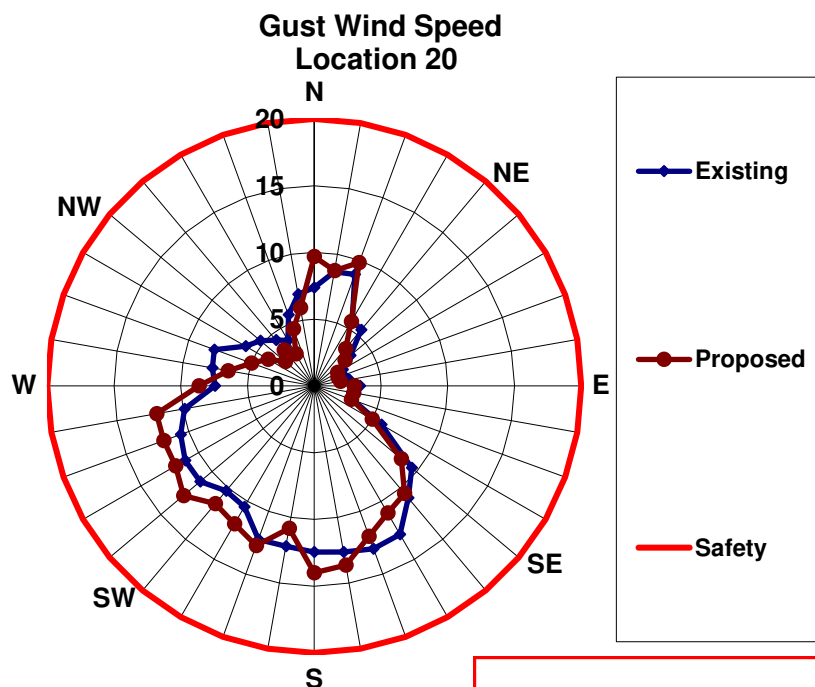
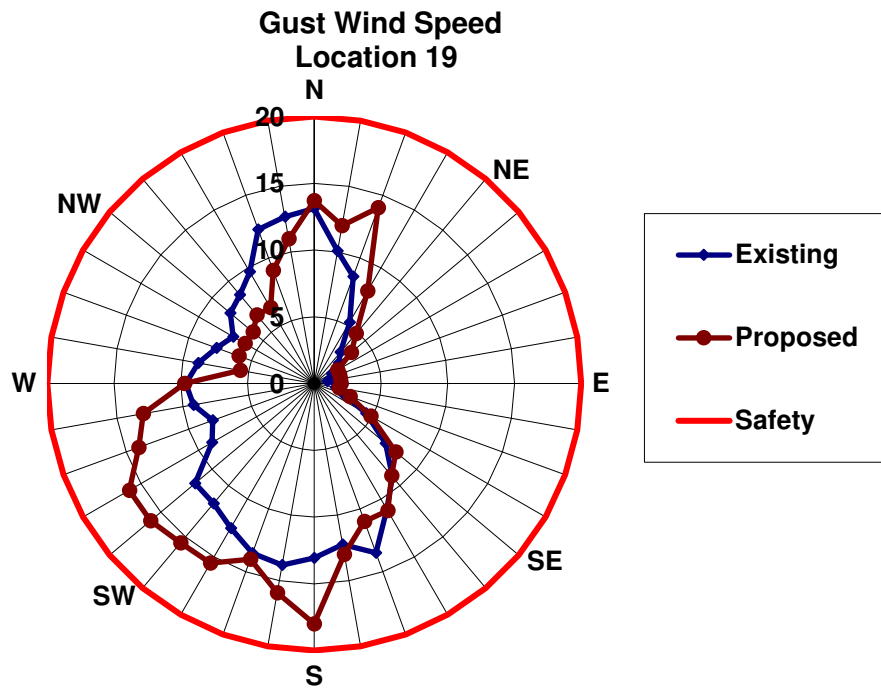
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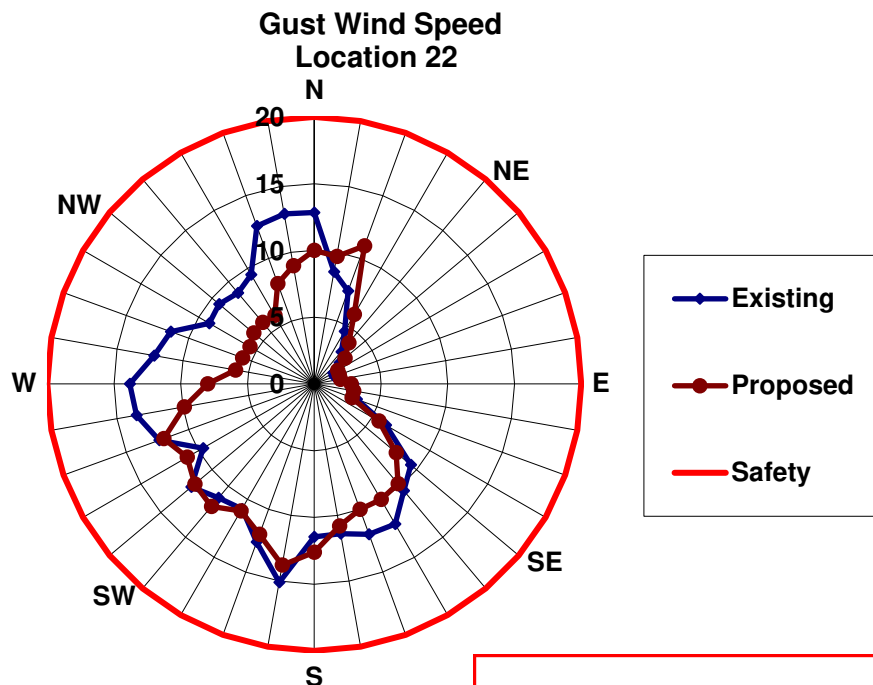
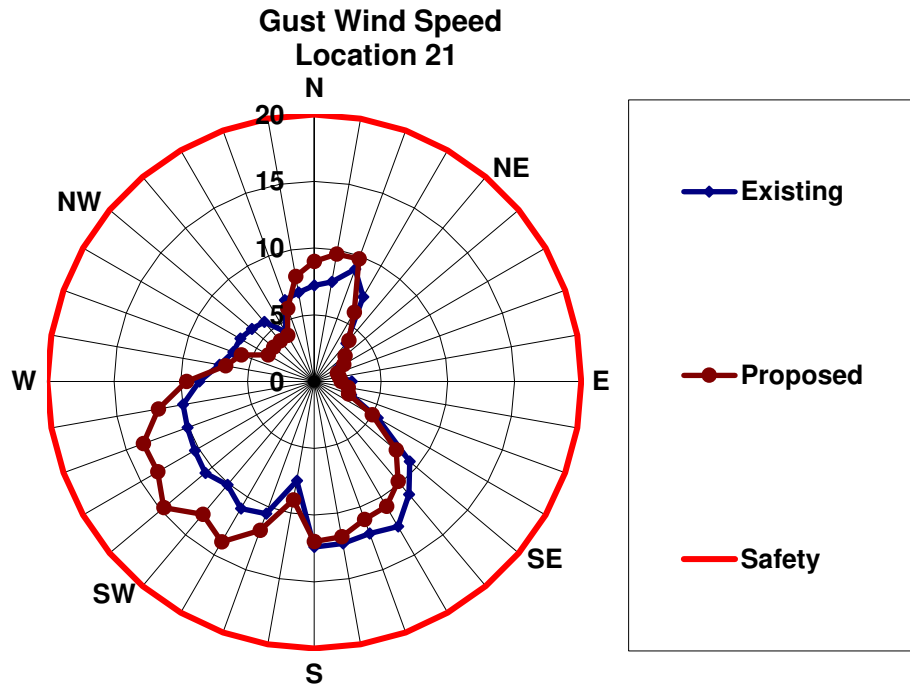


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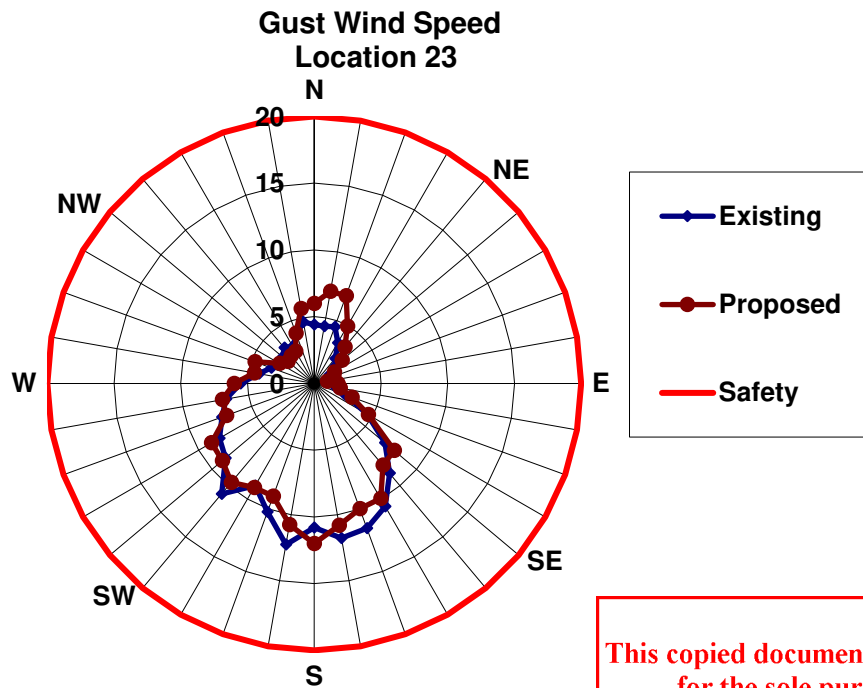
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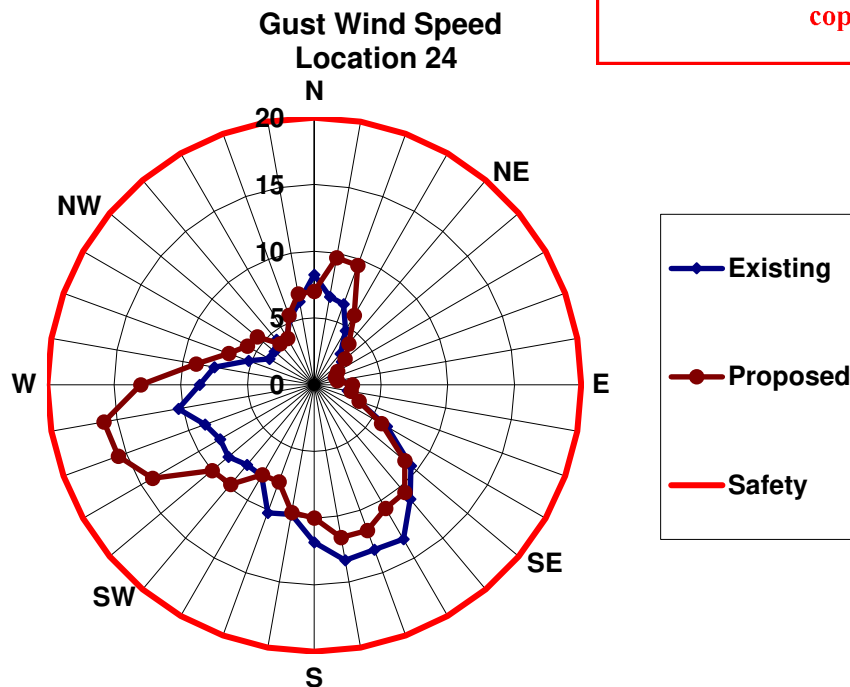


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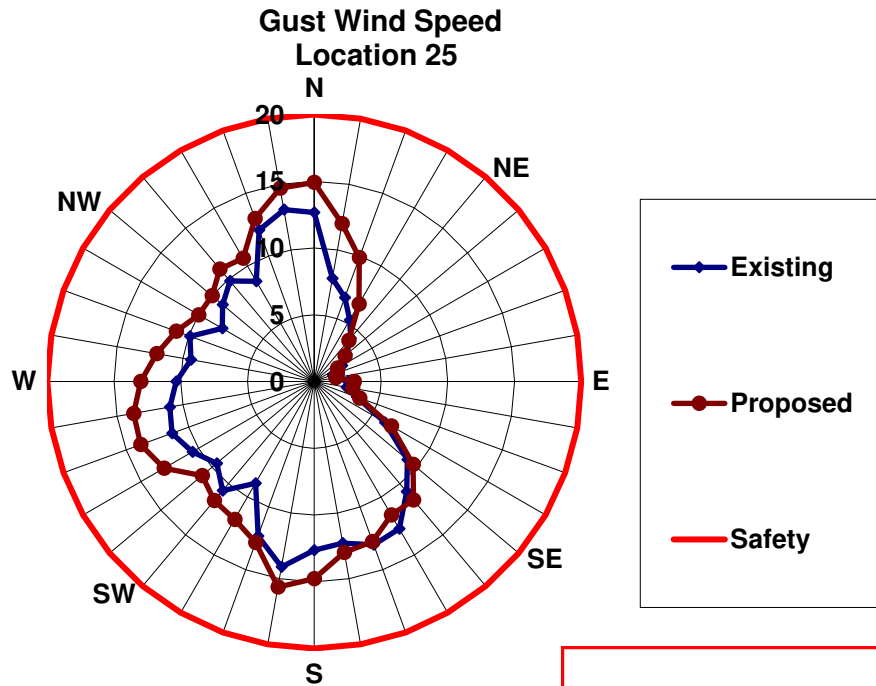
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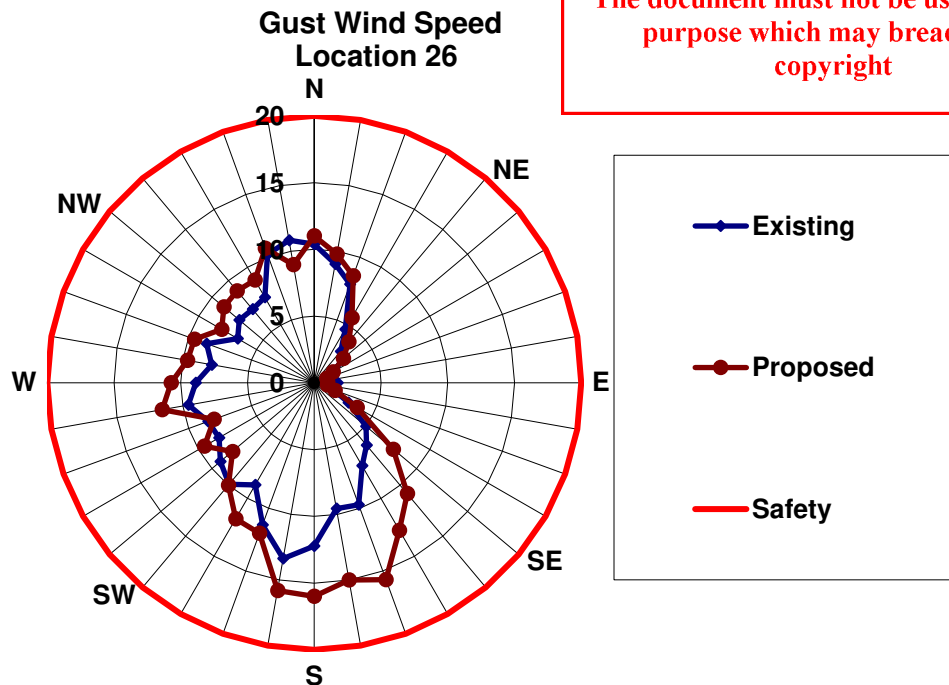
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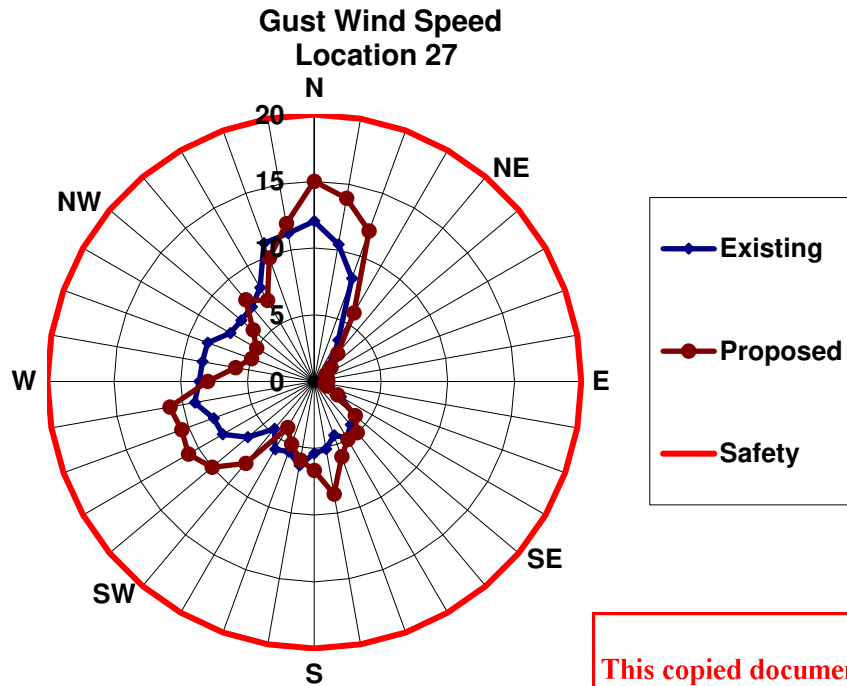
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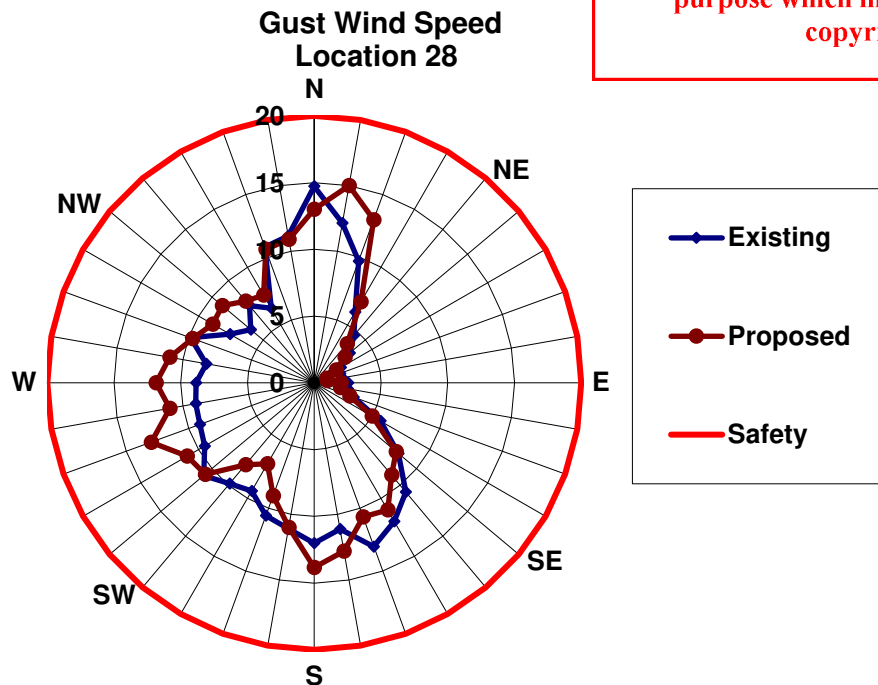
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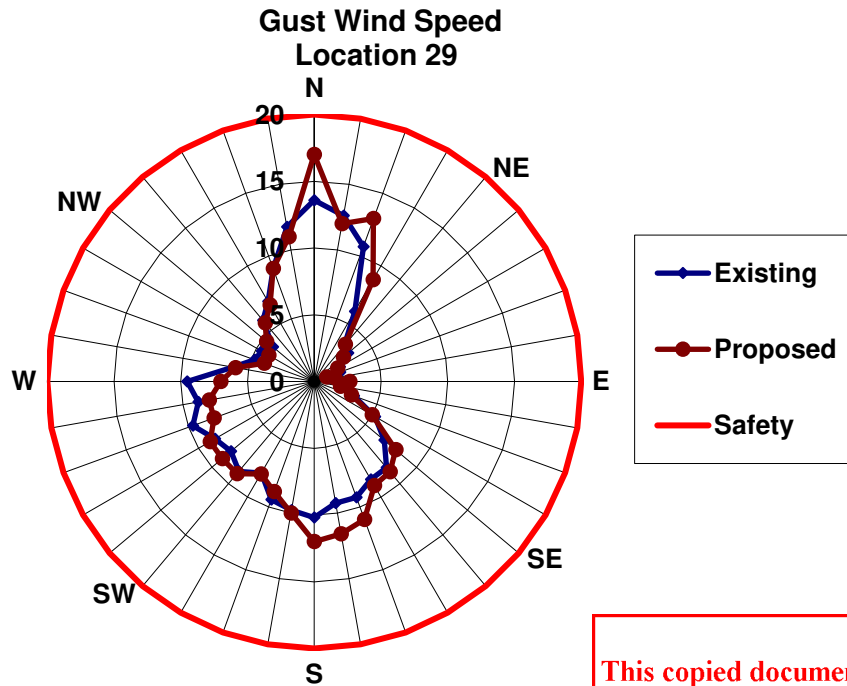
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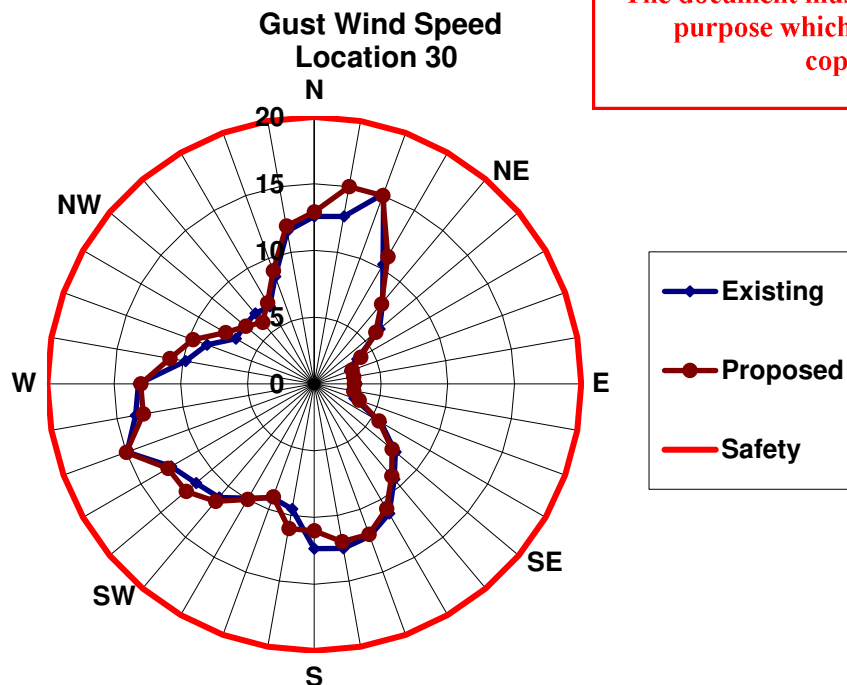
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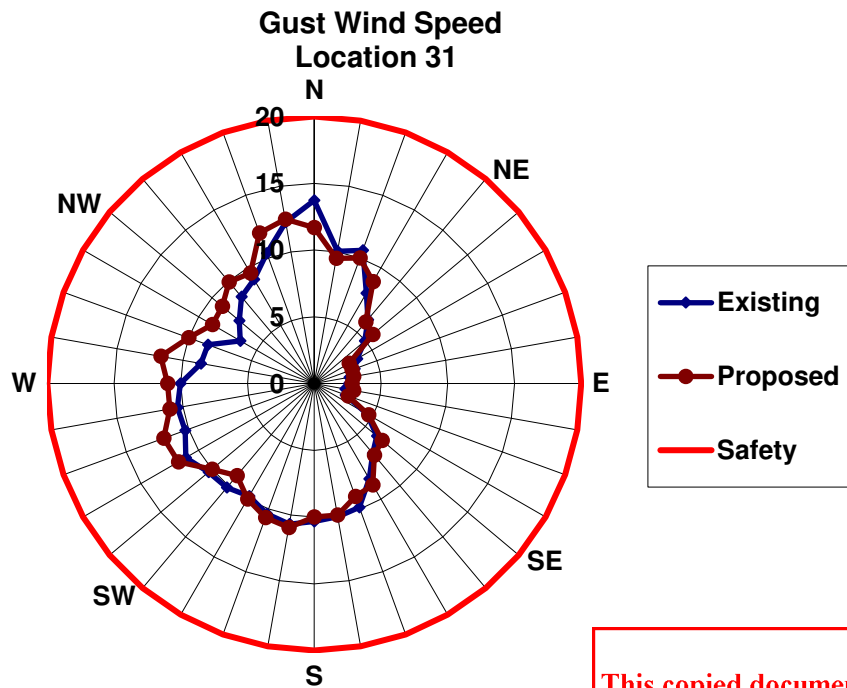
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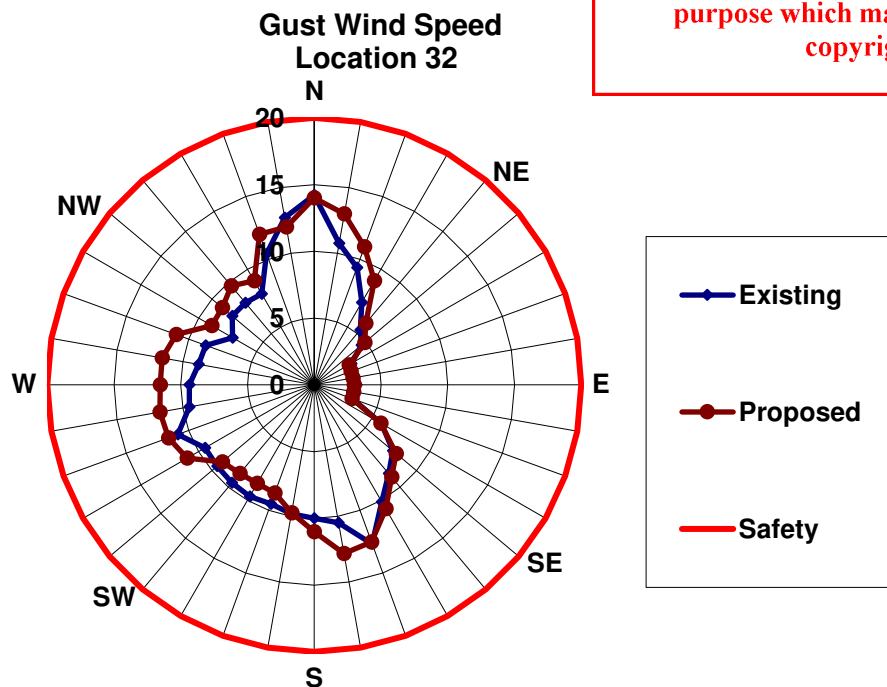
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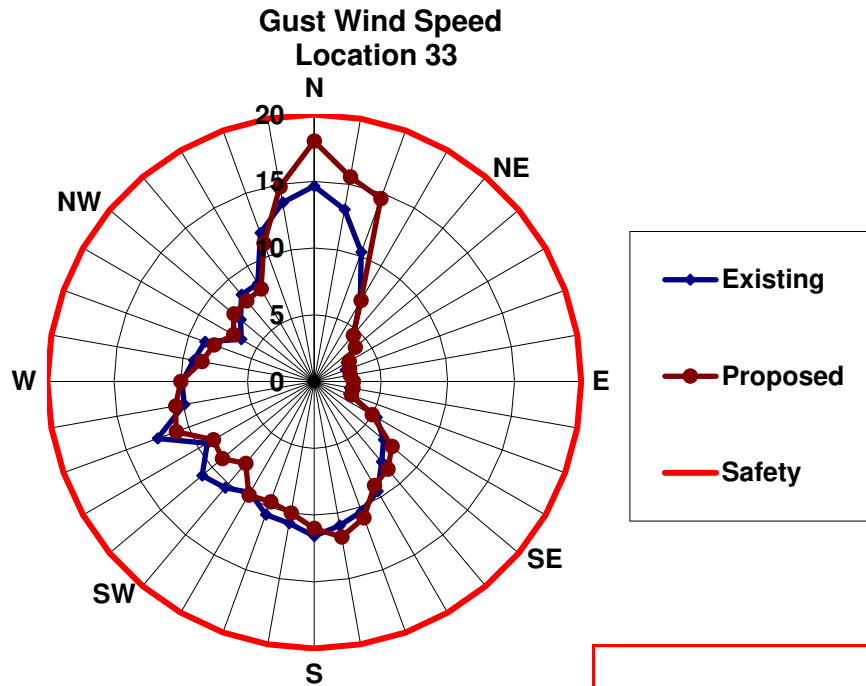
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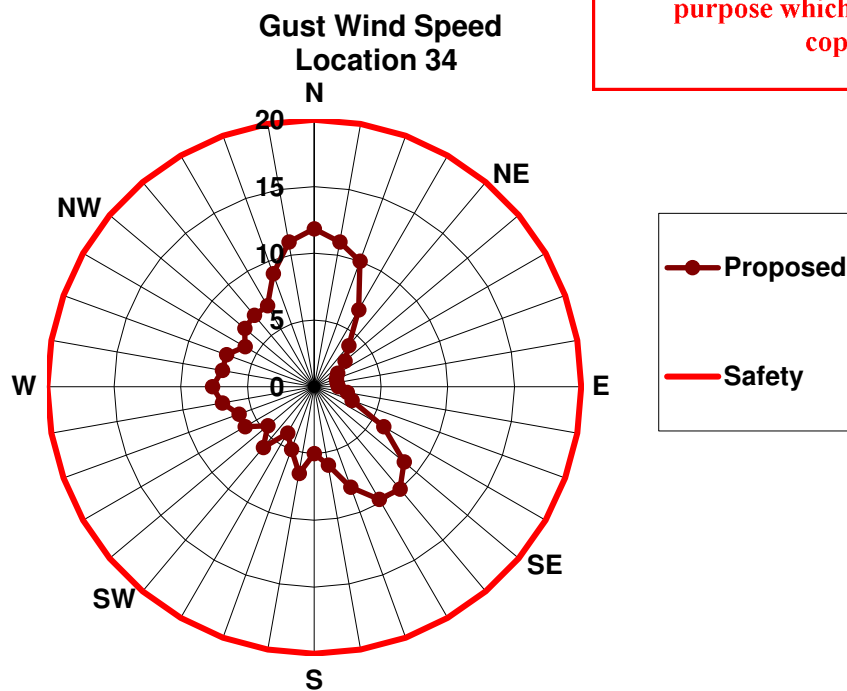
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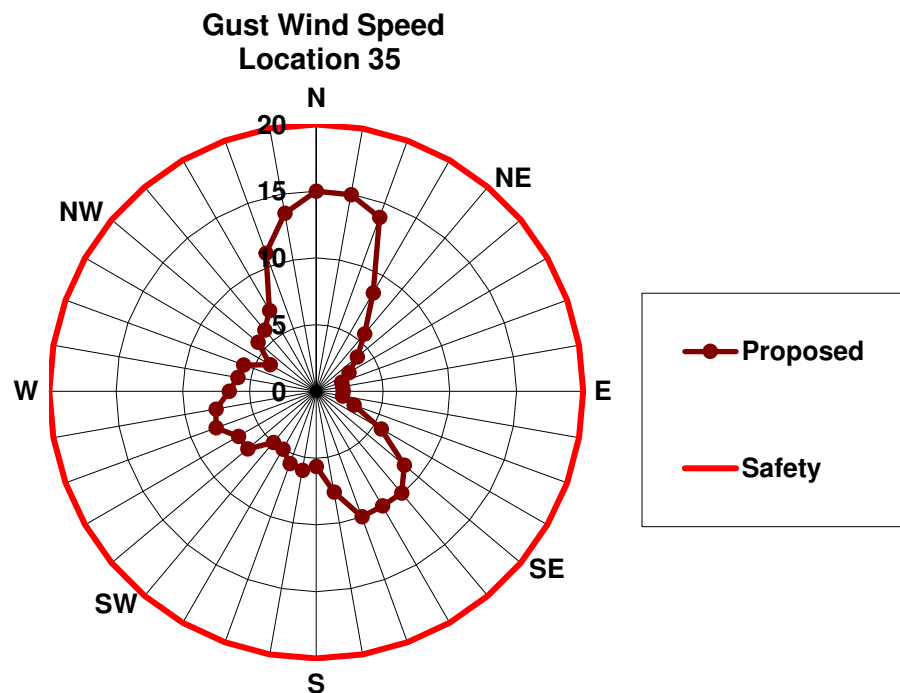
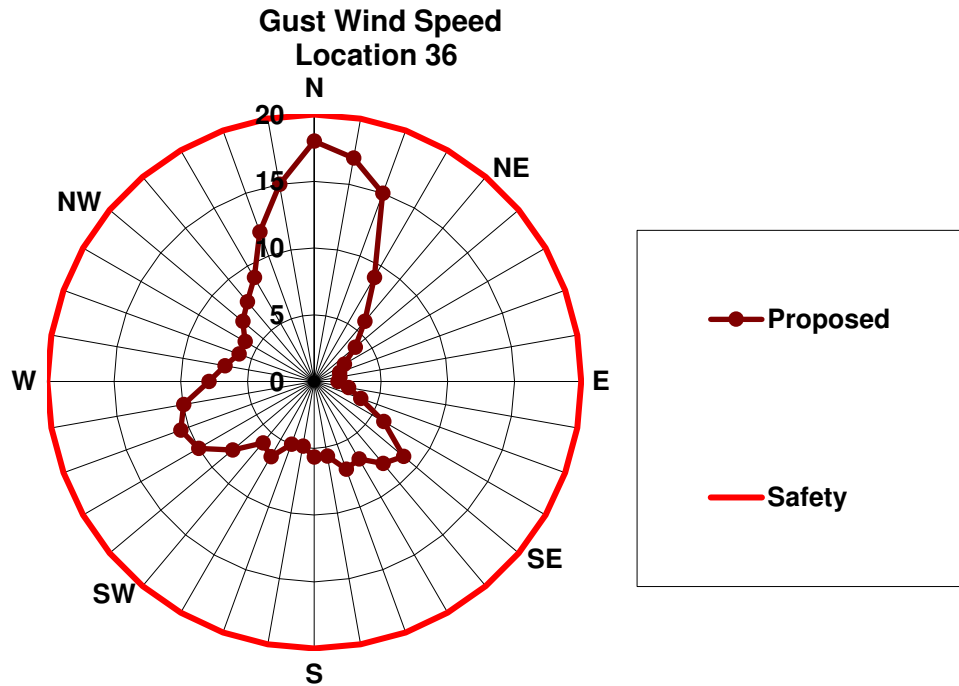
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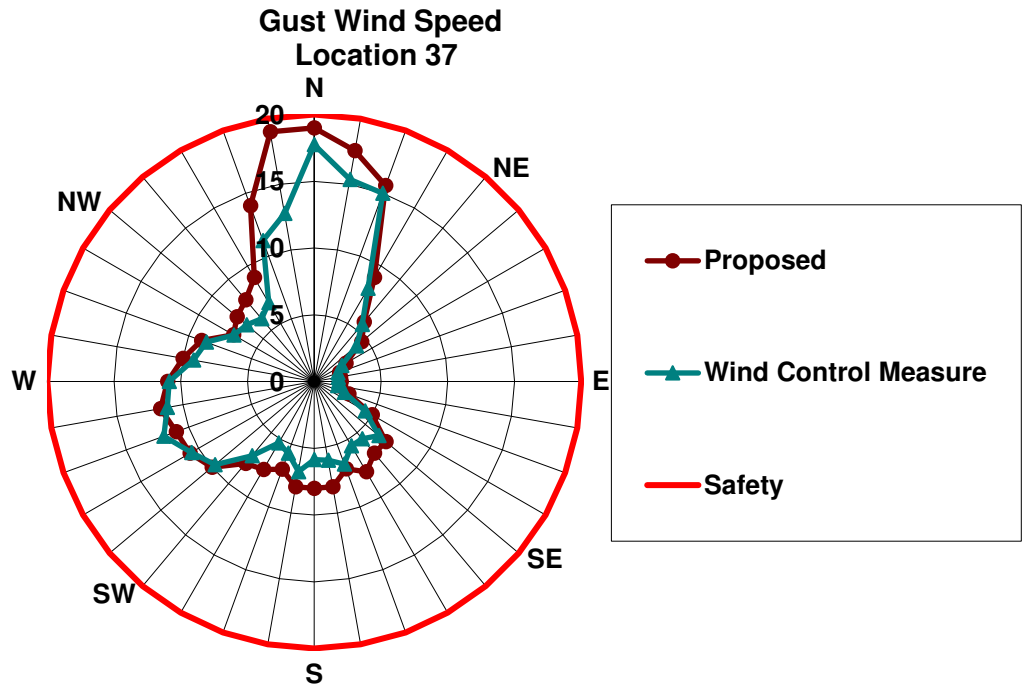


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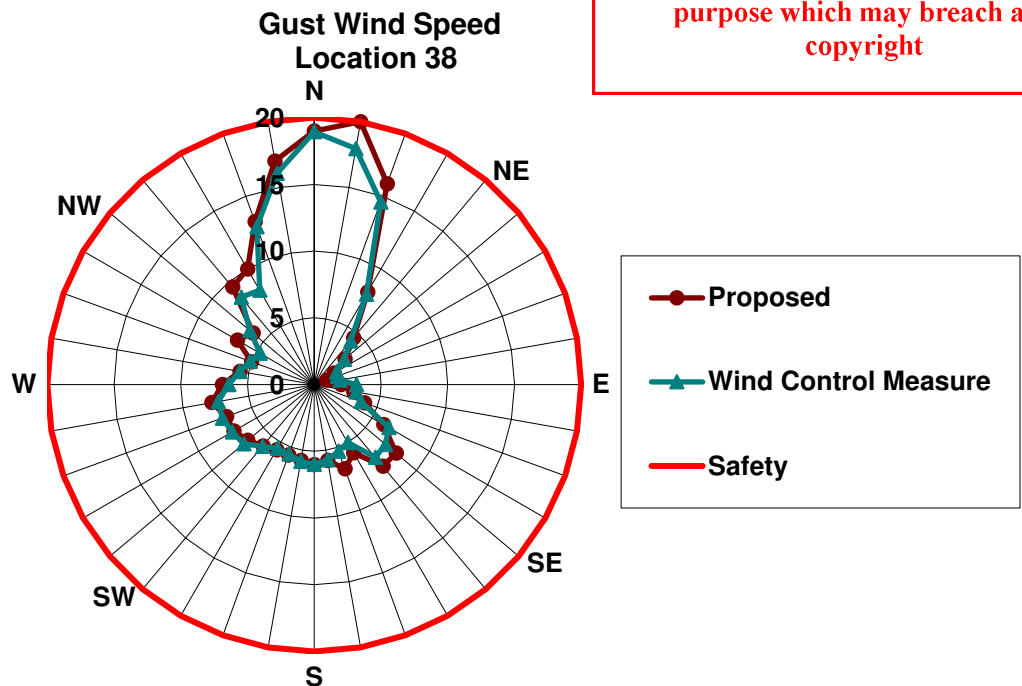


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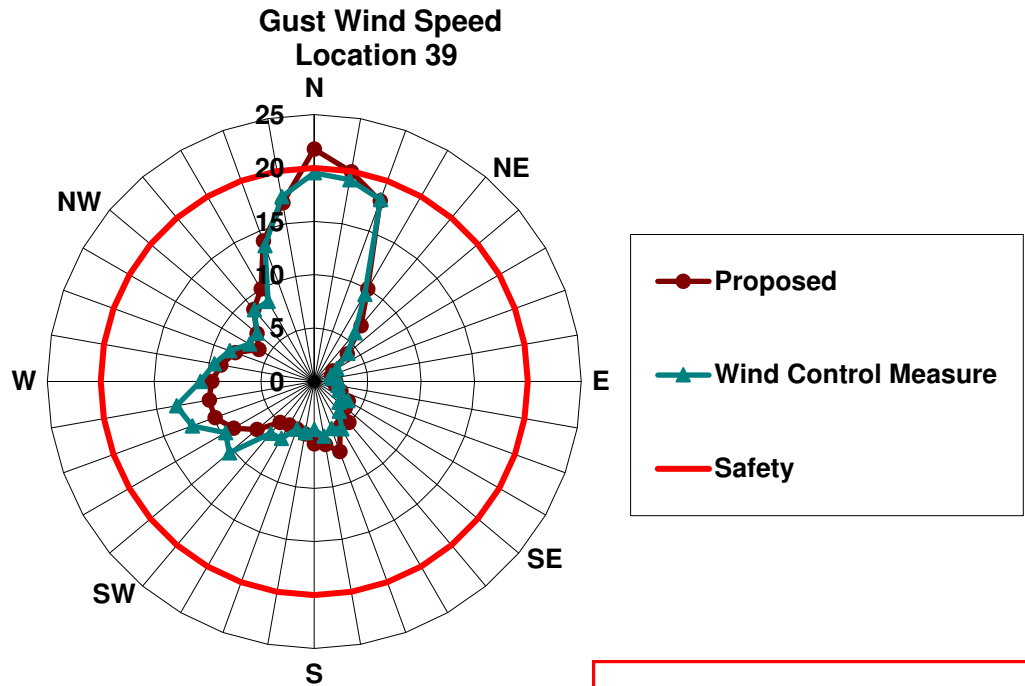
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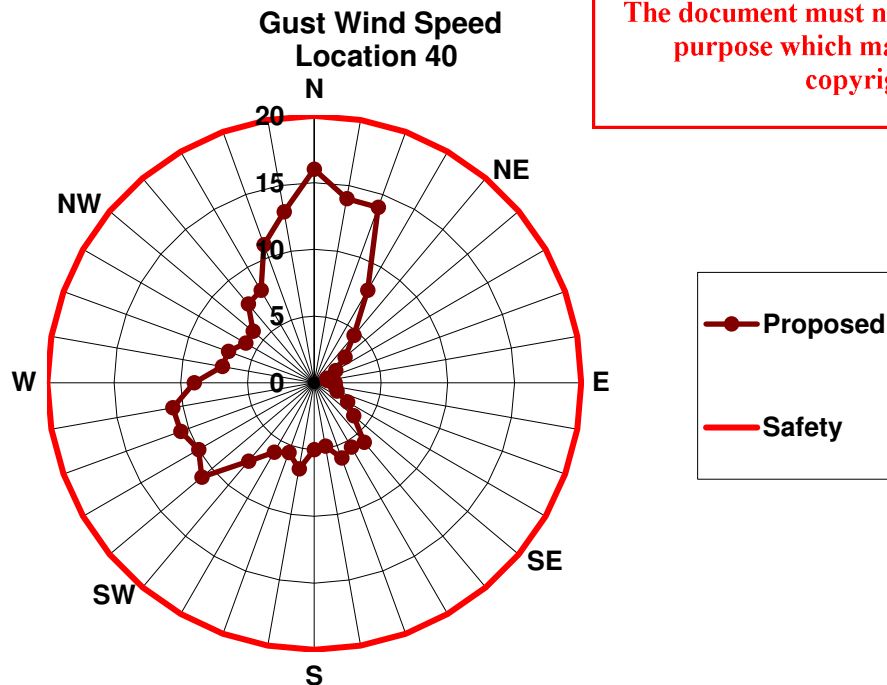
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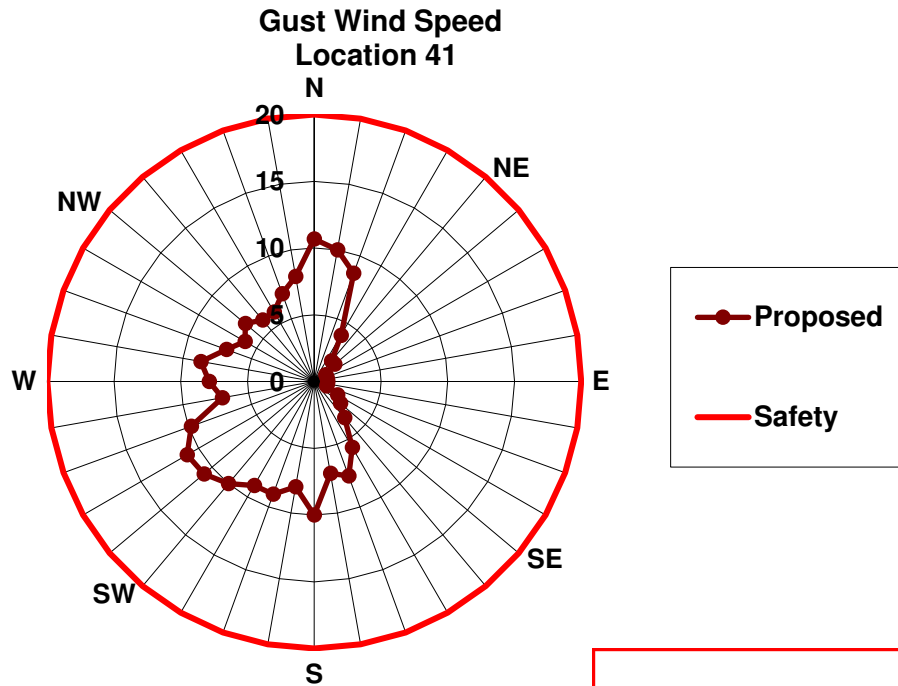
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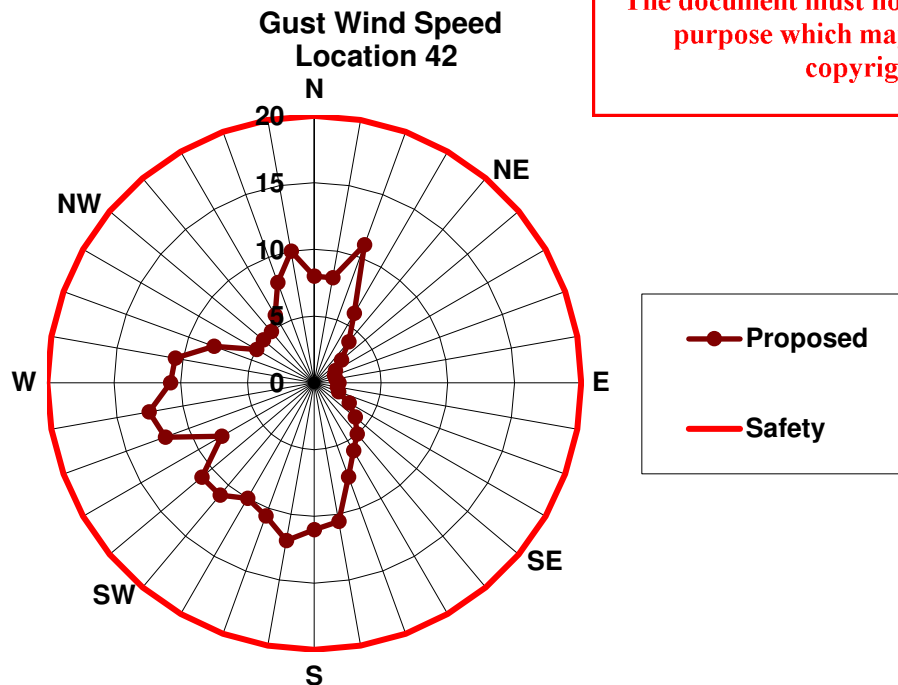
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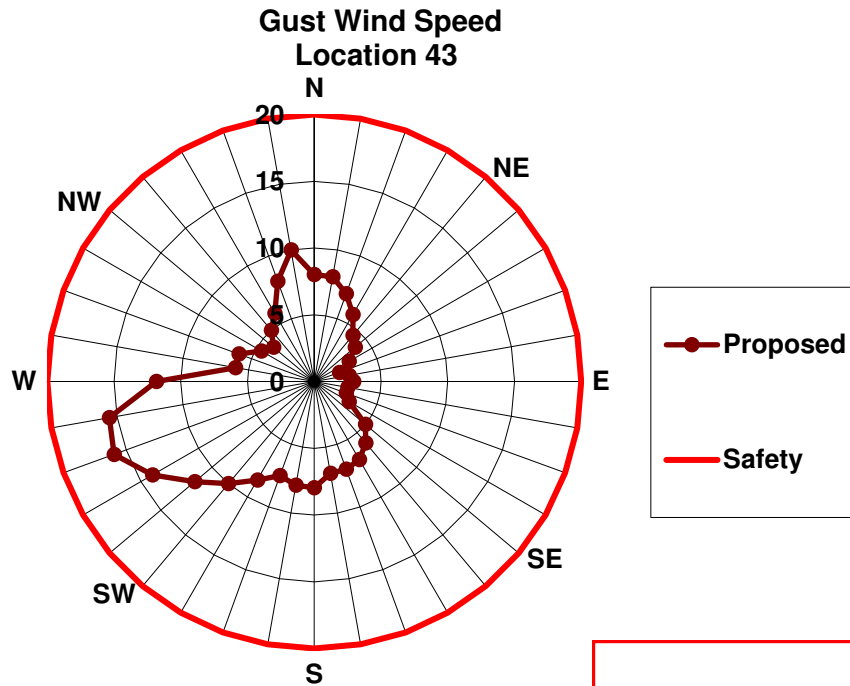
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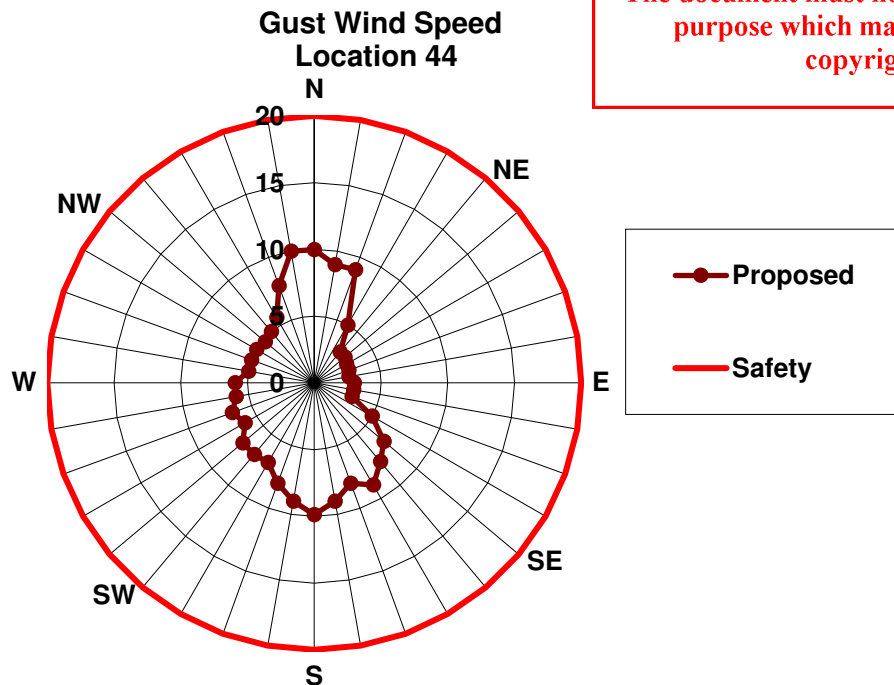
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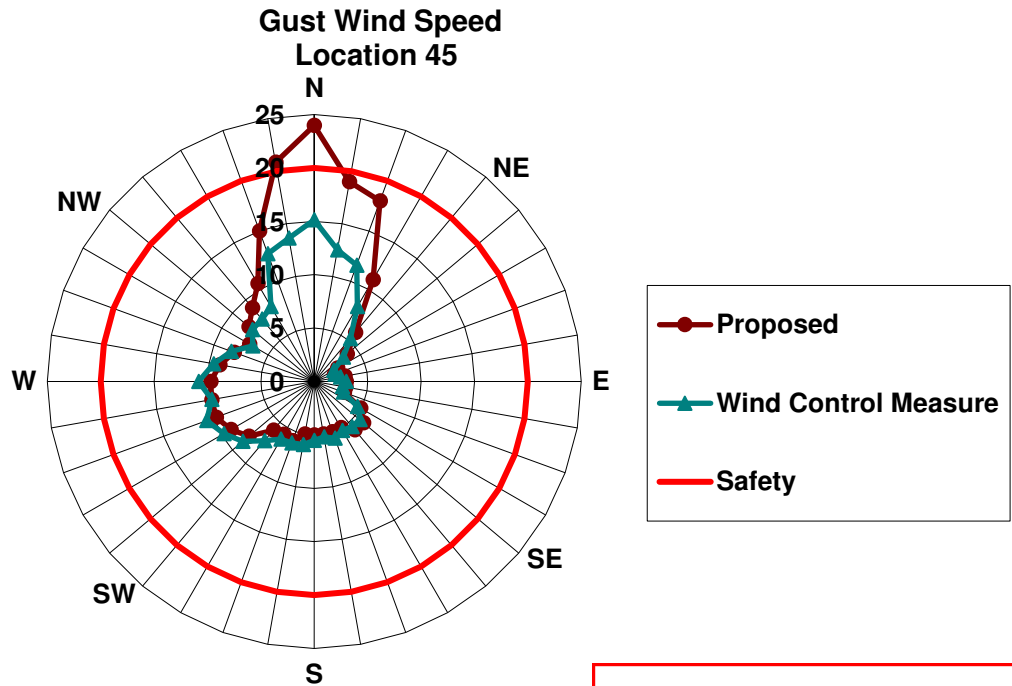
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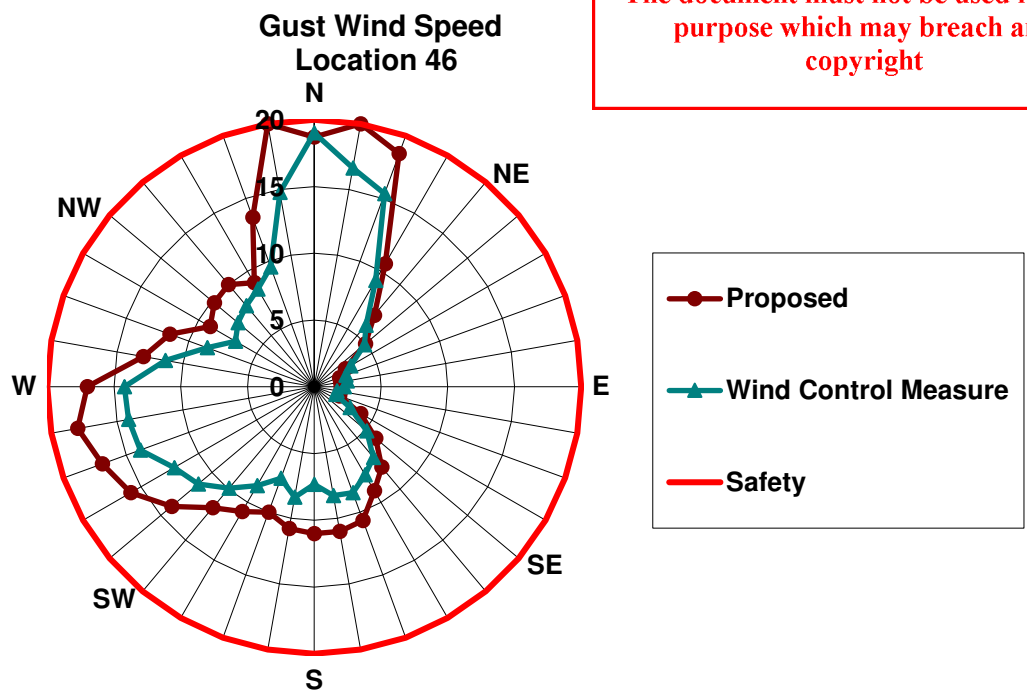
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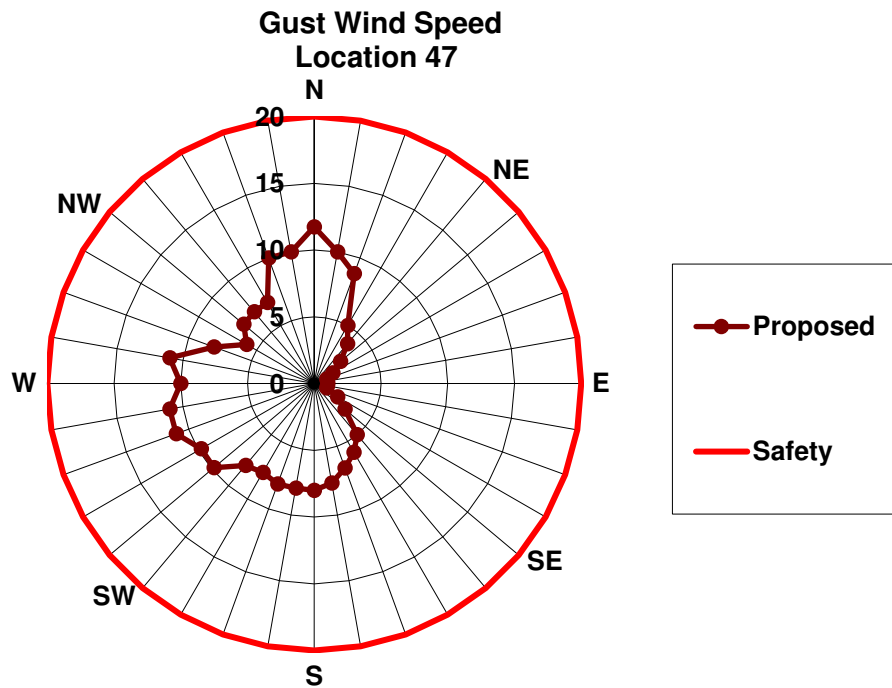
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Appendix D Up-crossing Prediction

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:

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

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:

$$N_x(x) = \sqrt{2\pi} \nu \sigma \int_0^{2\pi} \sqrt{1 + \left(\frac{dV_1}{V_1 d\alpha} \right)^2} p_V(V_1, \alpha) d\alpha \quad (7)$$

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,

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

the probability density function of V and α becomes

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

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

$$N_x(x_1) = \sqrt{2\pi} \nu \sigma \int_0^{2\pi} \left\{ 1 + \frac{dV_1}{V_1 d\alpha} \right\}^{\frac{1}{2}} A(\alpha) \frac{K(\alpha)}{C(\alpha)} \left(\frac{V}{C(\alpha)} \right)^{K(\alpha)-1} e^{-|V/C(\alpha)|^{K(\alpha)}} d\alpha \quad (10)$$

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.

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

$$R_x(x_I) = \frac{1}{N_x(x_I)} \quad (11)$$

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

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

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

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