167 NORTHUMBERLAND STREET, LIVERPOOL

Environmental Wind Tunnel Study

Prepared for:

Karimbla Construction Services (NSW) Pty Ltd
Level 11, 528 Kent Street
SYDNEY NSW 2000

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BASIS OF REPORT

This report has been prepared by SLR Consulting Australia Pty Ltd (SLR) with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with Karimbla Construction Services (NSW) Pty Ltd (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

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DOCUMENT CONTROL

Reference	Date	Prepared	Checked	Authorised
610.19152-R01-v3.1	13 May 2021	Nikhil Pardeshi	Dr Peter Georgiou	Dr Neihad Al-Khalidy
610.19152-R01-v3.0	4 March 2021	Nikhil Pardeshi	Dr Peter Georgiou	Dr Neihad Al-Khalidy
610.19152-R01-v2.0	23 December 2020	Andy Huynh	Dr Peter Georgiou	Dr Neihad Al-Khalidy
610.19152-R01-v1.1	26 February 2020	Andy Huynh	Dr Peter Georgiou	Dr Neihad Al-Khalidy
610.19152-R01-v1.0	28 January 2020	Andy Huynh	Dr Peter Georgiou	Dr Neihad Al-Khalidy

SLR Consulting Australia Pty Ltd (SLR) has been engaged by Karimbla Construction Services (NSW) Pty Ltd to assess the local wind environment within and around their proposed development at 167 Northumberland Street, Liverpool, via an Environmental Wind Tunnel Study.

This assessment has been performed using a Discrete Sensor Environmental Wind Tunnel Study whereby wind tunnel measurements were made to investigate wind conditions throughout the proposed development (simulated via a 1:400 scale model) at areas to be used by visitors and occupants of the development itself.

The mixed-use development will comprise of a four-storey podium with commercial use tenancies at Level 00, 01 and 02, and a childcare facility at Level 03. Above the podium is a 28-storey residential component.

Liverpool Wind Climate

Using long-term wind records obtained from nearby Bureau of Meteorology stations at Bankstown Airport and Sydney Kingsford Smith Airport, SLR has determined that Liverpool has local winds characteristics closer to Bankstown Airport than Sydney (KS) Airport, given Liverpool's distance being even further inland than Bankstown Airport. Accordingly, key prevailing wind directions of interest are the northeast, southeast and south for summer and mainly west quadrant winds for winter.

Built Environment Scenarios Assessed

The study has involved the testing of two "scenarios": the "Baseline" scenario reflecting the existing built environment (as of March 2018) and the "Future" scenario, with the addition of the proposed development.

Wind Acceptability Criteria

The proposed development would include the highest building in the Liverpool area and as such, it is expected that there will be considerable interest in its potential wind impact on surrounding areas. SLR is aware that both the well-known Melbourne and Lawson criteria (and indeed a hybrid of both) have been used in recent Wind Impact Assessments of high-rise building precincts such as Parramatta.

Accordingly, SLR has assessed the proposal using both the Melbourne and Lawson criteria. In general, reasonable correlation has been found in terms of the impact of the proposal when assessed against the two nominated acceptability criteria, with the Melbourne criteria being generally more restrictive in terms of the acceptability or otherwise of specific locations.

However, the recommendations emanating from this study were found to be essentially identical when assessing the development's impact in terms of the two nominated wind criteria.

"Baseline" (Existing) Wind Environment

Pedestrian footpaths around the site are exposed to prevailing wind directions from the northeast, northwest and southern quadrants.

"Future" Wind Environment

In terms of the *future* wind environment with the proposed development, the following features of the development are noted as being of most significance:

- Ground level locations to the east of the site; and
- Locations throughout the upper levels of the Podium: Level 3 Child Care Outdoor area and Level 4 podium roof areas.

Site perimeter pedestrian areas – Northumberland Street

It is recognised that these areas are beyond the site perimeter of the development and hence beyond the automatic control of the project.

- It is also recognised that the potential increase in local winds along Northumberland Street suggested through the wind tunnel testing did not include the ameliorating impact of the vegetation and trees which are part of the current surrounding environment – refer **Figure 16**.

The following is therefore recommended for the Detailed Design phase of the proposal:

- The Proponent carries out a site survey to confirm the integrity of current trees in the area
- Further detailed modelling is carried out (via CFD simulation) to confirm the efficacy of the current landscaping and identify areas where enhanced wind sheltering could be considered. The preference here is for CFD modelling rather than additional wind tunnel testing, given the difficulties in reproducing accurate tree aerodynamics at 1:400 or similar scale.

Podium Level 3 – Outdoor childcare area

- It is recognised that additional wind mitigation treatments will be required for the outdoor childcare areas. Potential horizontal wind mitigation (options involving, canopies, awnings, pergolas, shadecloth, etc) is recommended to be included, predominantly within the area towards the southern end of the western childcare outdoor area, around the vicinity of sensor location 26 (Refer to **Figure 17-A**).
- Since the eastern childcare outdoor area almost satisfies the target criteria, inclusion of the abovementioned horizontal wind mitigations can be optional within this area. These horizontal wind mitigations may not be included over this area to get more solar access as well as to receive some cool breezes to cool down the area during the hot summer months. This will also assist in maximising the usage of the area.
- **Figure 17-B** shows the most recent Design Proposal for these outdoor areas, involving shadecloth canopies protecting the southern and northern end of the west outdoor area, as well as the northern end of the east outdoor area.

Level 4 – Podium Roof

The following is recommended if this area is accessible for public use:

- 2 m vertical screens along the western and northern perimeter of the podium roof, refer **Figure 18**.
- An awning extending from the Level 5 slab of the tower along the northern façade, refer **Figure 18**.
- Alternatively, if this region is only accessible by staff/maintenance crews/etc, a safety measure should be implemented prior to accessing the area, such as a safety signage, wearing of safety harnesses, etc, under extreme wind conditions.

Upper Level Balconies

The upper residential component of the proposed development has balconies around all facades – refer **Figure 19**.

It is almost certain, given the absence of nearby similar height buildings, that some of these balconies, especially those at upper levels and near building corners and exposed to stronger southerly, northeasterly and west quadrant winds, will experience adverse wind conditions requiring wind treatment beyond standard height (ie code-compliant) balustrades.

Such treatments might include increased balustrade height or partial screening via moveable louvres, to take advantage of the beneficial of cooler, milder winds during summer, while providing the capacity to limit the impact of colder and potentially much stronger winds during winter.

Figure 19-B shows the most recent design proposal for the balcony areas of interest, with full height glazing for corner balconies of interest.

- Further detailed modelling should be carried out (via CFD simulation) to confirm zones of the building, by height and by plan view location (eg building corners), where the above wind mitigation is required. The preference here is for CFD modelling rather than additional wind tunnel testing, given the difficulties in reproducing accurate balcony wind profiles at 1:400 or similar scale.

DOCUMENT REFERENCES

TABLES

FIGURES

APPENDICES

1 INTRODUCTION

SLR Consulting Australia Pty Ltd (SLR) has been engaged by Karimbla Construction Services (NSW) Pty Ltd to assess the local wind environment within and around their proposed development at 167 Northumberland Street, Liverpool, via an Environmental Wind Tunnel Study.

The assessment has been performed using a Discrete Sensor Environmental Wind Tunnel Study whereby wind tunnel measurements were made to investigate wind conditions throughout the proposed development (simulated via a 1:400 scale model) at areas to be used by visitors and occupants of the development itself.

1.1 Location of the Development Site

The development site is bounded by Northumberland Street to the east and Laurantus Serviceway to the south, north and west. Furthermore, to the south of the site is Moore Street, Elizabeth Drive to the north and Bathurst Street to the west. – refer **Figure 1**.

Figure 1 Site Location

Image: Nearmap 2020

1.1 Description of the Proposed Development

The proposed mixed-use development will comprise:

- Three levels of basement car parking;
- Ground level with retail, commercial and carpark space allocations;
- A 4-storey Podium with, commercial tenancies and a outdoor childcare areas;
- 28-storey tower with serviced apartments (163 units) above the podium.

Figure 2 Architectural Views of the Proposed Development

1.2 Surrounds

In terms of surrounding buildings:

- To the north is Liverpool Westfield Shopping Centre,
- To the east is Bigge Park, Liverpool Hospital and Liverpool Train Station.

- To the south and west is a mixture of low to medium-rise commercial and residential dwellings.
- The terrain is generally flat in the surrounding built environment, with no particularly significant topographical variations influencing local wind speeds.

Figure 3 Surrounding Built Environment

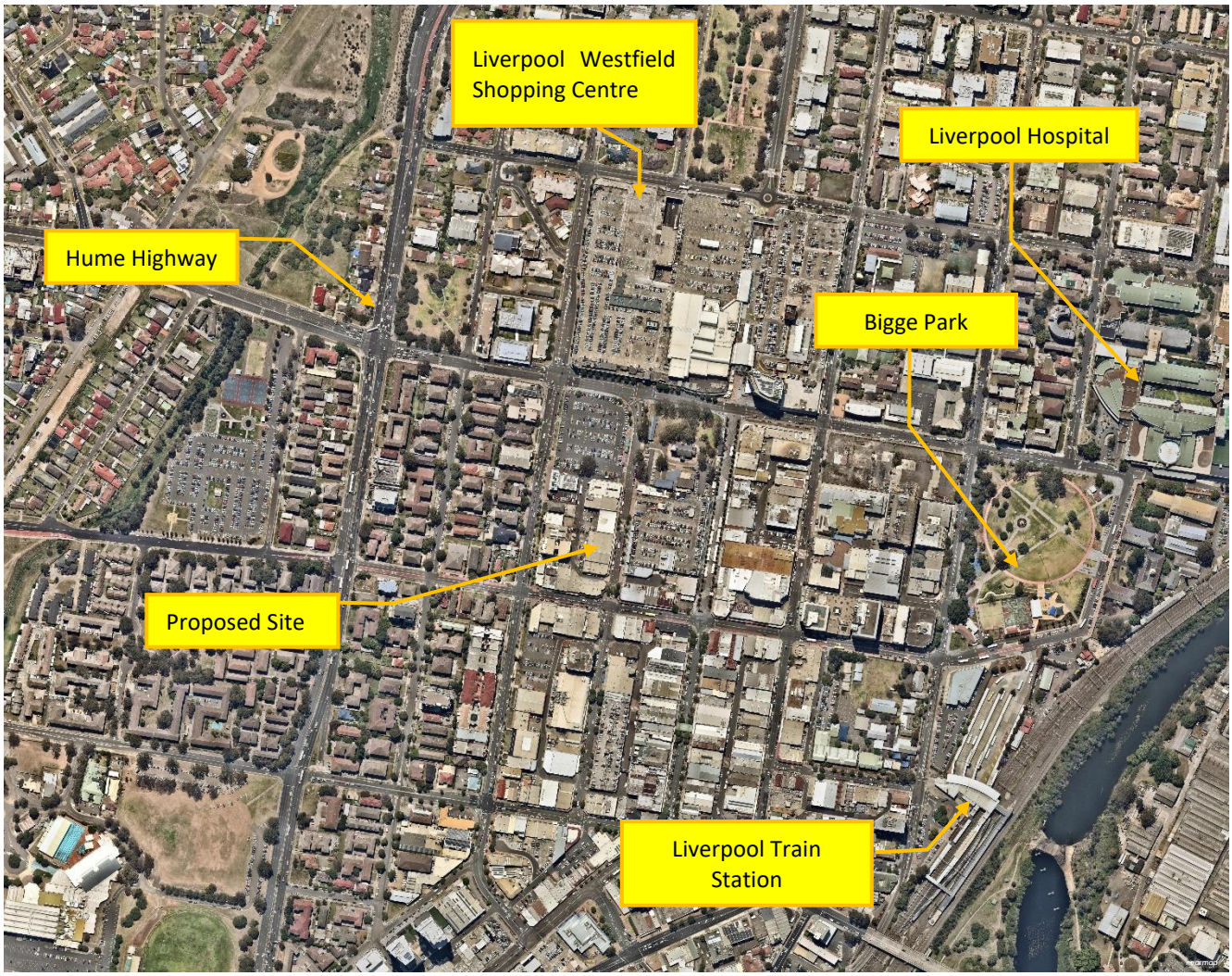


Image: Nearmap 2020

2 SYDNEY'S WIND CLIMATE

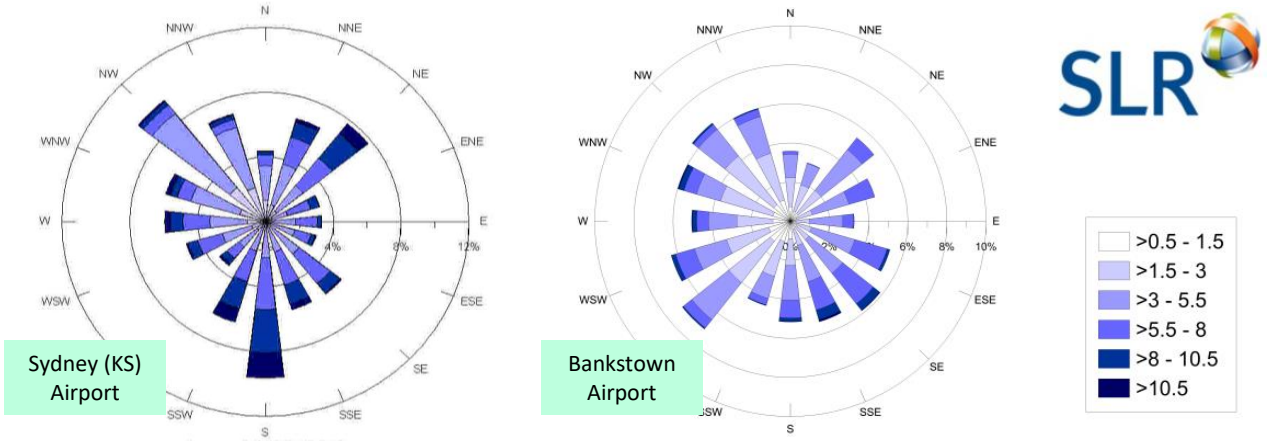
The data of interest in this study are the mean hourly wind speeds and largest gusts experienced throughout the year (especially higher, less frequent winds), how these winds vary with azimuth, and the seasonal break-up of winds into the primary Sydney Region wind seasons.

2.1 Annual and Seasonal Variations

Key characteristics of Sydney's Regional Wind Climate are illustrated in two representative wind roses shown in **Figure 4**, taken from Bureau of Meteorology (BoM) data recorded during the period 1999-2017 at Sydney (Kingsford Smith) Airport and Bankstown Airport. A review of the associated seasonal wind roses (refer **Appendix A**) shows that Sydney is affected by two primary wind seasons with relatively short (1-2 month) transition periods in between:

- Summer winds occur mainly from the northeast, southeast and south. While northeast winds are the more common prevailing wind direction (occurring typically as offshore land-sea breezes), southeast and southerly winds generally provide the strongest gusts during summer. Both northeast winds (as sea breezes) and stronger southerly winds associated with "Southerly Busters" and "East Coast Lows" typically have a significantly greater impact along the coastline. Inland, these systems lose strength and have altered wind direction characteristics.
- Winter/Early Spring winds occur mainly from west quadrants and to a lesser extent from the south. West quadrant winds provide the strongest winds during winter and in fact for the whole year, particularly at locations away from the coast.

Figure 4 Annual Wind Roses for Sydney (KS) Airport and Bankstown Airport (BoM Data)



2.2 Wind Exposure at the Site – the "Local"' Wind Environment

Close to the ground, the "regional" wind patterns described above are affected by the local terrain, topography and built environment, all of which influence the "local" wind environment.

- The development site currently receives a reasonable shielding from the medium to high-rise developments surrounding the site to the north, west and south.
- The site is more exposed to winds from the northwest and southeast.

3 DESIGN WIND SPEEDS

3.1 Methodology

SLR has carried out a detailed study of Sydney Basin wind speeds using continuous records of wind speed and direction measured at the Bureau of Meteorology's (BoM) Sydney weather stations.

In particular, SLR has determined statistical wind information for locations not situated in close proximity (ie within say approximately a kilometre) of BoM weather stations. Particular emphasis was given to weather stations with a "clean" surrounding exposure, ie stations such as Sydney (Kingsford Smith) Airport and Bankstown Airport, which are relatively free of immediately surrounding obstacles such as buildings, vegetation, trees, etc, which would otherwise distort the winds seen by the weather station anemometer.

For Liverpool, SLR has determined that local upper level winds reflective of the weather systems experienced at the site have characteristics somewhat closer to Bankstown Airport than Sydney (KS) Airport, given the site's distance inland from the coast.

Accordingly, the adopted Liverpool wind model has slightly lower strength characteristics from the northeast and south compared to Sydney (Kingsford Smith) Airport and correspondingly higher strengths from the southeast and southwest/northwest compared to Sydney (KS) Airport.

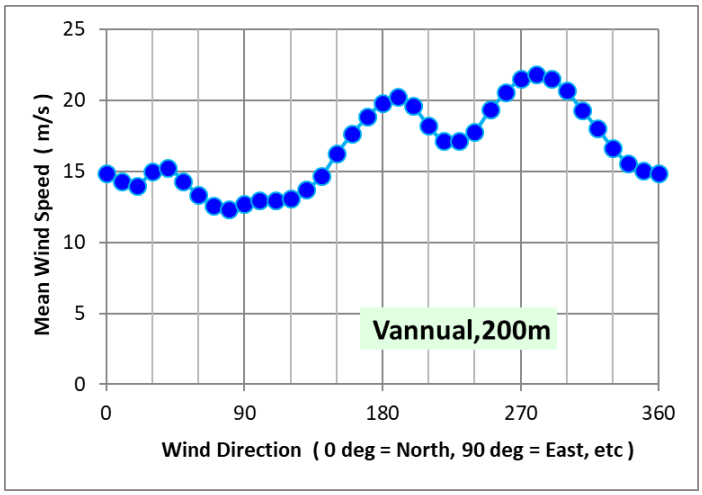
The above analysis is described in detail in …

- SLR Technical Note: *"9300-TN-CW&E-v2.0 Sydney Region Design Winds"*, March 2018.

3.2 Reference Height Annual Mean Wind Speeds

In the wind tunnel testing, the reference dynamic pressure used to record all wind speed data was measured at an equivalent (full-scale) height of 200 m above ground level (500 mm in the wind tunnel). Accordingly, conversion from wind tunnel speeds to full-scale speeds requires the determination of reference height design mean wind speeds for the site. These are shown in **Figure 5** and have been based on the adopted Liverpool wind model as described above. The winds shown have a once-per-year exceedance probability.

Figure 5 Reference Height (200 m) Annual Recurrence Mean Wind Speed at Homebush



4 WIND ACCEPTABILITY CRITERIA

The choice of suitable criteria for evaluating the acceptability of particular ground level conditions has been the subject of international research over several decades.

4.1 The "Melbourne" Wind Criteria

One of the acceptability criteria developed from this research, and currently referenced by many Australian Local Government Development Control Plans, are the so-called "Melbourne" criteria, summarised in **Table 1**.

Table 1 Melbourne-Derived Wind Acceptability Criteria

Type of Criteria	Gust Wind Speed Occurring Once Per Year	Activity Concerned
Safety	24 m/s	Knockdown in Isolated Areas
	23 m/s	Knockdown in Public Access Areas
Comfort	16 m/s	Comfortable Walking
	13 m/s	Standing, Waiting, Window Shopping
	10 m/s	Dining in Outdoor Restaurant

The primary objectives relating to the above wind impact criteria are as follows:

- The general objective is for annual 3-second gust wind speeds to remain at or below the 16 m/sec "walking comfort" criterion. Whilst this magnitude may appear somewhat arbitrary, its value represents a level of wind intensity above which the majority of the population would find unacceptable for comfortable walking on a regular basis at any particular location.
- In many urban locations, either because of exposure to open coastal conditions or because of street "channelling" effects, etc, the 16 m/sec criterion may already be currently exceeded. In such instances a new development should ideally not exacerbate existing adverse wind conditions and, wherever feasible and reasonable, ameliorate such conditions.
- The recommended limiting wind speeds for spaces designed for activities such as seating, outdoor dining, etc, are lower (ie more stringent) than for "walking comfort".

The **Table 1** criteria for Comfort should not be viewed as *"hard"* numbers as the limiting values were generally derived from subjective assessments of wind acceptability. Such assessments have been found to vary with the height, strength, age, etc, of the pedestrian concerned.

A further factor for consideration is the extent of windy conditions, and some relaxation of the above criteria may be acceptable for small areas under investigation which are infrequently used, provided the general site satisfies the relevant criteria.

Finally, it is noted that the limiting wind speed criteria in **Table 1** are based on the maximum wind gust occurring (on average) once per year. Winds occurring more frequently, eg monthly winds, weekly winds, etc, would be of lesser magnitude. So for example, a location with a maximum annual gust of 10 m/sec would experience winds throughout the year of a much lower and hence generally mild nature, conducive to stationary activities (seating, dining, etc).

Liverpool DCP Wind Criteria

Liverpool Council's DCP 2008 was accompanied by a supporting document:

- Liverpool DCP 2008. *Part 4 Development in Liverpool City Centre* – released April 2014

The DCP (2014) Part 4 document contained provisions for wind amenity in Section 5.4 (p55). Following a review of the DCP (in its entirety), an amended Part 4 was released in June 2017:

- Liverpool DCP 2008. *Part 4 Development in Liverpool City Centre* – amended February 2017

The amended DCP (2017) Part 4 document contained updated and simplified wind amenity provisions - refer Section 4.5.4 (p37)
(reproduced adjacent)

Controls

1. Design all new buildings to meet the following maximum wind criteria :
   a) 10m/second in retail streets;
   b) 13m/second along major pedestrian streets, parks and public places; and
   c) 16m/second in all other streets.
2. Submit a Wind Effects Report with the DA for all buildings greater than 35m in height.
3. Submit results of a Wind Tunnel Testing report for buildings over 48m in height.

The maximum wind and height-related Report criteria in both 2014 and 2017 Part 4 documents were identical.

4.2 The "Lawson" Wind Criteria

Another set of commonly used criteria employed in the evaluation of pedestrian level winds are the so-called "Lawson" criteria which couple the probability of exceeding winds at given statistical levels with wind speed magnitudes and associated impacts originally related to the Beaufort Wind Speed Land Scale - refer **Table 2**.

Table 2 Beaufort Wind Speed - LAND Scale

Beaufort Force	Hourly Average Wind Speed (m/s)	Description of Wind	Noticeable Wind Effect
0	< 0.45	Calm	Smoke rises vertically
1	0.45 to 1.55	Light air	Direction shown by smoke drift but not by wind vanes
2	1.55 to 3.35	Light breeze	Wind felt on face; leaves rustle; wind vanes begin to move
3	3.35 to 5.0	Gentle breeze	Leaves, small twigs in constant motion; Light flags extended
4	5.6 to 8.25	Moderate breeze	Raises dust and loose paper; small branches move
5	8.25 to 10.95	Fresh breeze	Small trees, in leaf, sway
6	10.95 to 14.10	Strong breeze	Large branches begin to move; telephone wires whistle Umbrellas used with difficulty
7	14.1 to 17.2	Moderate Gale	Whole trees in motion Inconvenience felt when walking against the wind.
8	17.2 to 20.8	Gale	Twigs break off trees; personal progress impeded
9	20.8 to 24.35	Strong/Severe Gale	Slight structural damage (chimney pots, slates removed)
10	24.35 to 28.4	Storm	Trees uprooted; considerable structural damage
11	28.4 to 32.4	Violent Storm	Widespread damage - unusual event (in the UK)
12	> 32.4	Hurricane	Devastation – only occurs in the tropics

The Lawson criteria make use of the same wind speed ranges to address issues of interest in terms of both pedestrian comfort and safety.

These criteria, or rather guidelines, have been adopted widely, including by UK authorities such as the London Docklands Development Commission (LDDC) and have been used for a number of decades on UK high-rise building developments, eg the Canary Wharf precinct, and increasingly internationally.

The Lawson criteria are aligned with a set of long-established pedestrian wind criteria developed originally at UWO's Alan G. Davenport Boundary Layer Wind Tunnel Facility and subsequently updated at the time of early UK London high-rise building studies noted above, as discussed in …

- Kapoor, V., Page, C., Stepfanowicz, P., Livery, F. and Isyumov, N., *"Pedestrian Level Wind Studies to Aid in the Planning of a Major Development"*, Structures Congress Abstracts, ASCE, 1990.

There are two distinct sets of wind criteria:

- **"Comfort"** criteria relate a range of typical pedestrian activities such as purpose-walking, strolling, sitting, etc, to the local "GEM" wind speed which is exceeded 5% of the time, on an annual return period basis – refer **Table 3**.
- **"Safety"** criteria cover instances when pedestrians might encounter difficulty in walking. They are defined by the incidence of "GEM" wind speeds occurring once or twice per year (probability exceedance level of 0.02%), ie during the most intense windstorm of the year – refer **Table 4**.

The "GEM" (Gust Equivalent Mean) wind speed used in the criteria is the maximum of the local mean wind speed or the local gust speed divided by 1.85.

Table 3 Lawson Wind Acceptability Criteria – COMFORT Guidelines

Comfort Level	Beaufort Equivalent	"GEM" Wind Speed 5% Annual Exceedance	Description (see also Notes)
C5	1	≤ 2.5 m/sec	Dining
C4	2	4 m/sec	Sitting
C3	3	6 m/sec	Standing
C2	4	8 m/sec	Leisure Walking (Strolling)
C1	5	10 m/sec	Business (Purpose) Walking
CX	> 5	> 10 m/sec	Exceeds Comfort Criteria

Notes:
C5 is suitable for seated dining

C4 is suitable for promenades, popular recreation areas with seating, reading newspapers, etc

C3 is suitable for locations where pedestrians will likely be waiting for relatively short periods, eg at building entrances, at pedestrian crossings, bus stops, etc

C2 is suitable for activities such as window-shopping

C1 is suitable for footpaths used for purposeful pedestrian traffic only (eg not where shops might induce slower activities like window-shopping)

CX suggest winds whose force can be felt by the body (branches on trees would be visibly swaying) and where walking will start to become inconvenient or challenging for certain classes of pedestrians, eg the frail, pedestrians holding parcels, parents holding children, etc.

As in the case of the Melbourne criteria, the Lawson Comfort criteria shown in **Table 3** should not be taken as "hard" numbers for the specific activity in the sense of being unsuitable all the time. The probabilistic way in which the criteria are defined indicates that the relevant activity may be unsuitable at a particular location for about 5% of the time (say around 18 days per year). For the rest of the time, the relevant activity may be suitable (given that winds will be lower than the prescribed acceptability level).

Table 4 Lawson Wind Acceptability Criteria – SAFETY Guidelines

Safety Level	Beaufort Equivalent	"GEM" Wind Speed 0.2% Annual Exceedance	Description (see also Notes)
S2	6	≤ 15 m/sec	All-Weather Usage
S1	7	20 m/sec	Fair Weather Usage
SX	> 7	> 20 m/sec	Exceeds Safety Criteria

Notes: S2 should be used for areas in constant usage, eg building entry points.

S1 may be suitable for less frequently trafficked areas, areas only to be used by able-bodied persons (not the general public) or areas which can be closed off in high wind conditions

SX suggest conditions where winds pose an actual hazard to pedestrians regardless of the activity

The safety criteria shown in **Table 4** reflect the potential for stronger winds to cause a loss of balance and even possible wind knock-down, especially for frail pedestrians. The criteria are accordingly significantly more stringent.

Additional Comments regarding the Application of the Lawson Criteria

In many urban locations, either because of exposure to open upstream conditions or because of street "canyon" effects, etc, the Comfort and Safety criteria relevant to a particular usage may already be currently exceeded. In such instances a new development should ideally not exacerbate existing adverse wind conditions and, wherever feasible and reasonable, ameliorate such conditions.

Some latitude may be applied to the Comfort Criteria for localised areas known to be used very infrequently, as the recommended limiting values were generally derived from subjective assessments of wind acceptability. Such assessments have been found to vary considerably with the height, strength, age, etc, of the pedestrian concerned.

4.3 Proposed Wind Criteria for the Proposal

The proposed development would include the highest building in the Liverpool area and as such, it is expected that there will be considerable interest in its potential wind impact on surrounding areas.

SLR notes that both the Melbourne and Lawson criteria (and indeed a hybrid of both) have been used in recent Wind Impact Assessments of high-rise buildings in precincts such as Parramatta.

Accordingly, SLR has assessed the proposal using both the Melbourne and Lawson criteria.

As will be seen in the results that follow, reasonable correlation has been found in terms of the impact of the proposal when assessed against the two nominated acceptability criteria, with the Melbourne criteria generally being more restrictive in terms of acceptability than the Lawson criteria.

However, it is noted that the recommendations emanating from this study were found to be essentially identical when assessing the development's impact in terms of the two nominated wind criteria.

5 WIND TUNNEL TEST METHODOLOGY

5.1 Simulation of Natural Wind

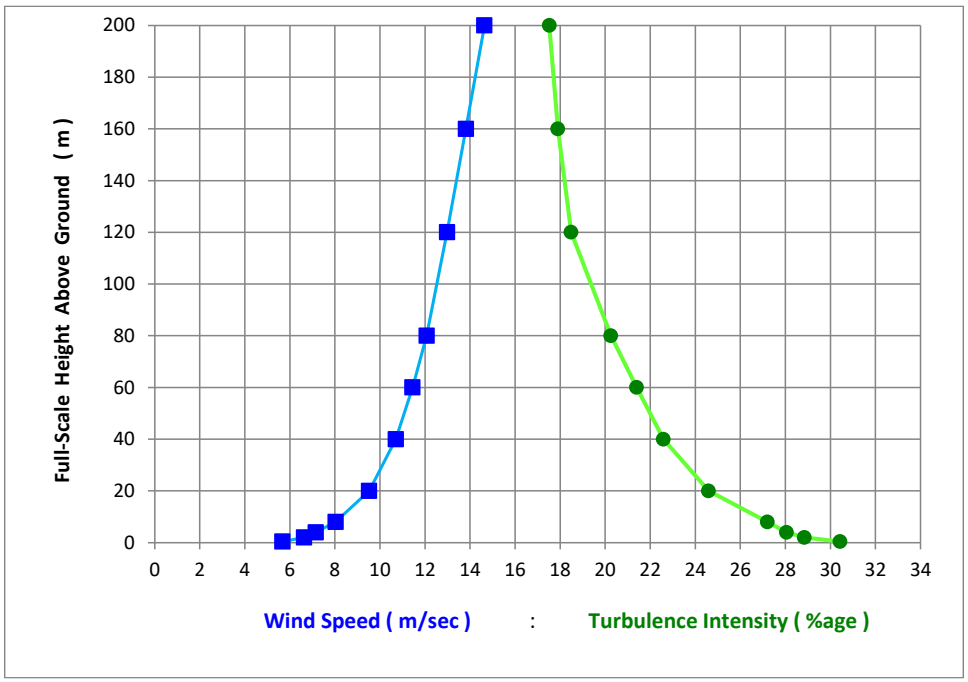
Similarity requirements between the wind tunnel model and prototype (ie full-scale) need to be fulfilled so that similitude in the flow conditions is satisfied. Usually all requirements cannot be satisfied and compromises need to be made. In this type of wind tunnel test it is possible to waive strict adherence to the full range of similarity parameters.

The wind tunnel test has been carried out using a geometric length scale of 1:400 for all dimensions (standard wind tunnel test scaling) and by scaling the boundary layer approach wind in the wind tunnel to the same scale as in the atmosphere.

The approach wind was modelled by matching terrain category conditions for all wind directions. In the wind tunnel, this is achieved by an almost 20-metre fetch of appropriate roughness elements.

The upstream profile conditions simulated in the present study is Terrain Category 3 associated with medium density suburban surroundings. The variation of mean wind speed (blue curve) and turbulence intensity (green curve) is shown in **Figure 6**.

Figure 6 Wind Tunnel Test Profiles for Mean Wind and Turbulence Intensity

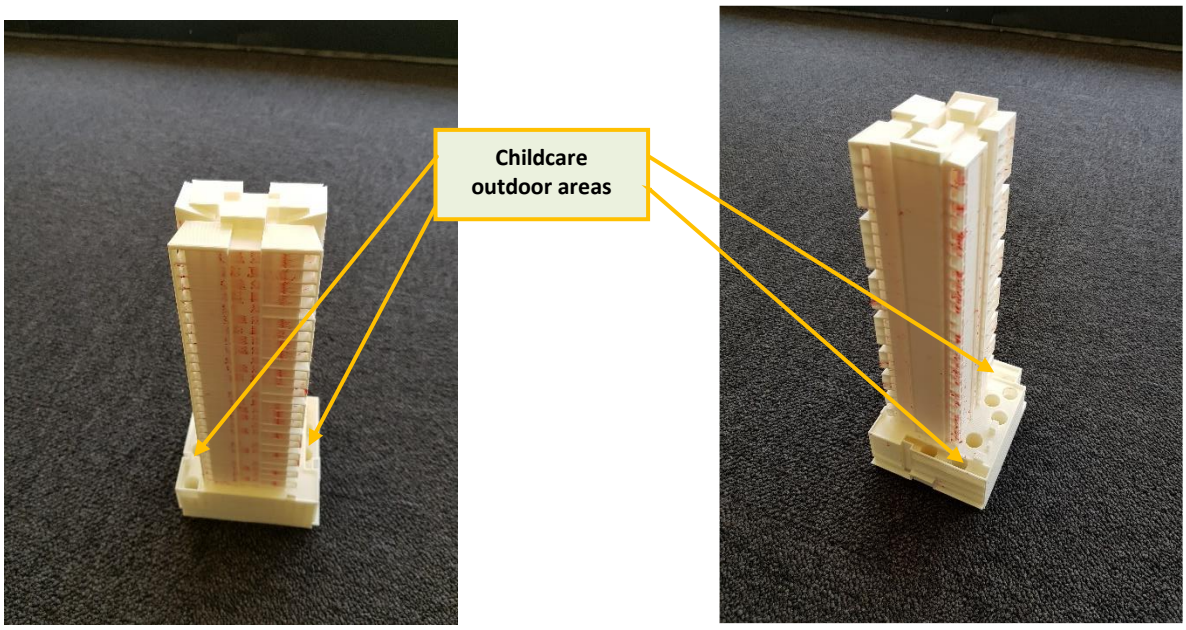


5.2 Proposed Development Model and Proximity Model

Development Model

A 1:400 scale model of the proposed development was built (using 3D printing) for the testing – refer **Figure 7**.

Figure 7 1:400 Scale Model of the Proposed Development



Proximity Model

To take into account the influence of the immediate surrounding physical environment, all neighbouring buildings and local topography within a diameter of almost 900 m around the site were included in the purpose-built 1:400 scale "proximity model" used for the test as shown in **Figure 7**.

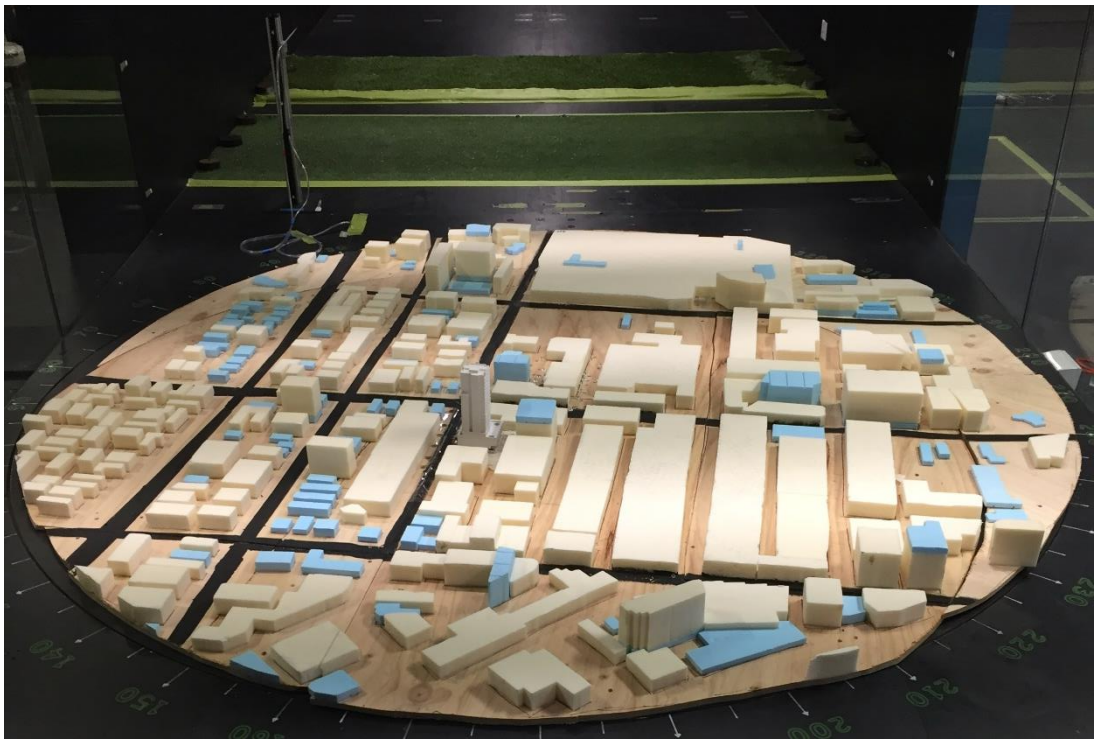
The proximity model simulates two built environment "scenarios":

- "Baseline" scenario: simulating the existing built environment (as of October 2019); and
- "Future" scenario: which includes the addition of the future proposed development.

Figure 8 Proximity Model in Wind Tunnel

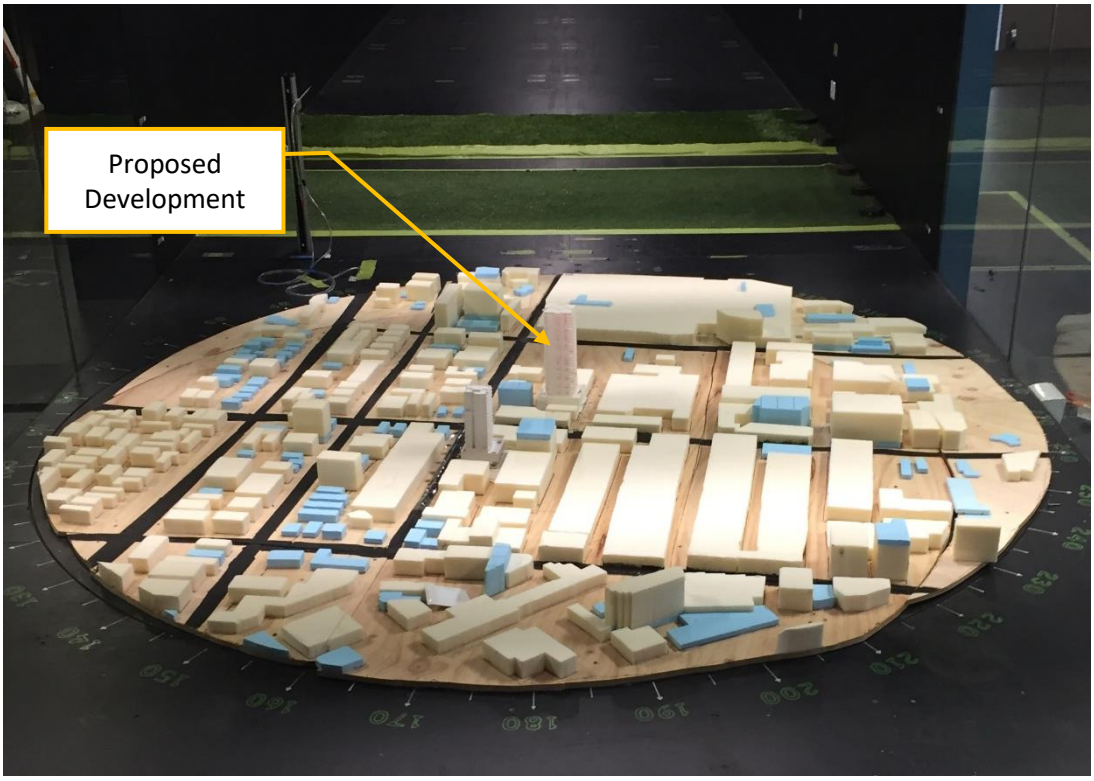
"Baseline" Scenario (Existing)

View from South



"Future" Scenario (with Proposal)

View from South



5.3 Data Processing

The wind speeds at the locations of interest are measured in the wind tunnel using Irwin sensors. The reader is referred to the publication referenced below for a full description of this technique and validation of Irwin sensor data using hot-wire anemometry.

- LTR-LA-242 *"A Simple Omni-Directional Sensor for Wind Tunnel Studies of Pedestrian Level Winds"* (Irwin, National Aeronautical Establishment, Ottawa, Canada, May 1980)

Wind speeds in the wind tunnel …

- were measured at a height corresponding to approximately chest height (1.5 m) in full scale;
- were measured at 10° intervals (north is at 0°, east at 90°, south at 180°, etc).

The 60-second sampling duration velocities are recorded as dimensionless ratios of the mean and gust ground level velocity to a mean reference wind speed at a height of 200 m above ground level. The data is then processed using the directional wind speed information derived from the Liverpool wind climate model to yield ground level wind speeds as a function of annual return period and directional mean reference wind speed – refer **Figure 4**.

The ground level wind speeds thus incorporate both the building and terrain/topographical aspects of the location as well as the directional probability of wind speed for the site.

The results have been computed on an annual exceedance basis, to compare to the adopted wind acceptability criteria, using Liverpool statistical wind data.

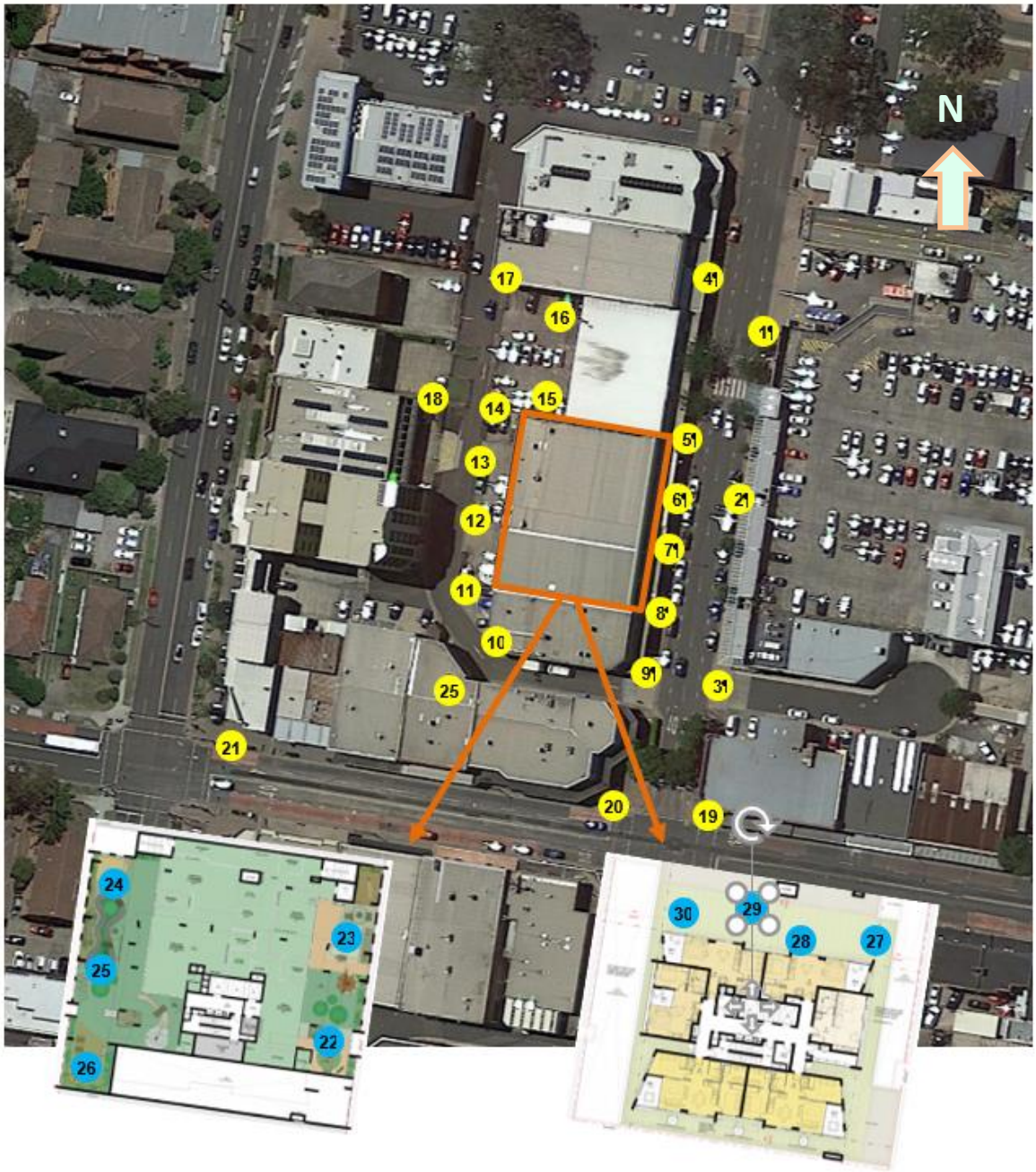
5.4 Test Method – Sensor Locations

In the wind tunnel testing, Irwin wind sensors were positioned at the locations shown in **Figure 8.**

These locations were chosen as potentially susceptible to adverse wind conditions, eg near building corners, or represent locations of interest throughout the development, eg near primary building entrances and along footpaths.

- Locations 1-21 are ground level sensors, shown in yellow; these positions were measured for both the "Baseline" and "Future" scenarios; and
- Locations 22-30 are upper level sensors, shown in white; as these positions are located on the Levels 3 and 4, the outdoor childcare and outdoor pedestrian accessible areas, they were only measured for the "Future" scenario.

Figure 9 Sensor Locations



5.5 Sample Test Result

An example of the test results and interpretation of these results is shown in **Figure 10**, illustrating the peak annual mean and representative gust wind speeds at:

Sensor: **Location 11**
Location: Laurantus Serviceway, close to the SW corner of the proposed development

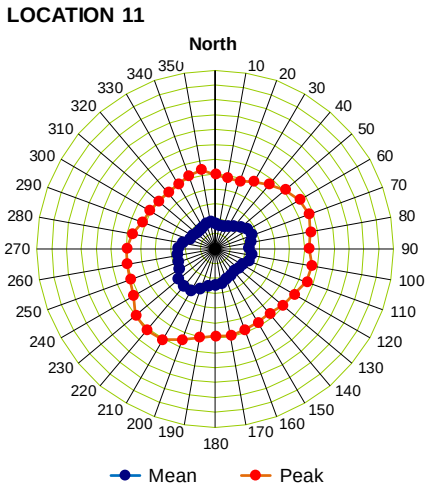
The polar diagram shows the output of the wind tunnel test results in terms of the ratio of local ground level wind speeds to the 200 m height reference mean wind speed:

Mean wind speed ratio: "navy blue" data points
Gust wind speed ratio: "red" data points.

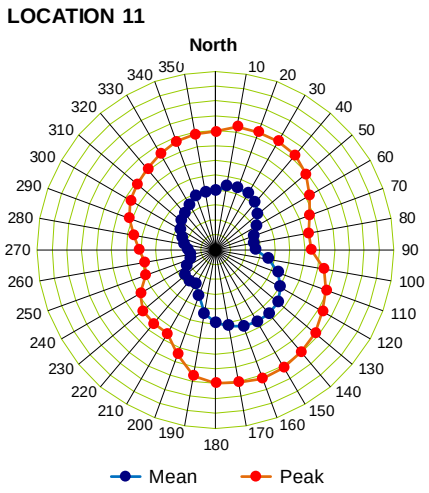
The polar diagram circumferential markings show ratios in "0.1" intervals.

Figure 10 Sample Polar Plot Test Result – Location 11 – 'Baseline' & 'Future' Scenarios

"Baseline" Scenario



"Future" Scenario



"Baseline" scenario …

- Existing winds at Location 11 are strongest from the southwest, then the northeast.

"Future" scenario …

- With the addition of the proposed development, winds at Location 11 increase from both the north and south as winds accelerate around the proposed development's northwest and southwest corners respectively.

6 TEST RESULTS

Appendices B & C shows the relevant wind tunnel test result polar plots respectively for all locations for the "Baseline" (existing built environment) and "Future" (with the proposal) scenarios.

It should be noted that no landscaping was incorporated in the "Baseline" and "Future" proximity models. This is done to provide a clear insight as to the approach angles resulting in potential adverse wind conditions and the magnitude of such adverse conditions. This information can then be used to develop effective additional windbreak mitigation options such as increased landscaping, additional canopies, awnings, etc.

6.1 Sensor Locations – Northumberland Street

- Winds at these locations will potentially experience a significant change in magnitude for west winds and southerly winds, mainly reflecting the influence of windflow around the proposed development's building form.
- Southerly and westerly prevailing winds are observed to accelerated around the south eastern corner of the development onto Northumberland Street.
- The proposed development will likely have a variable impact on these winds, more pronounced towards the eastern aspect of the development site.

6.2 Sensor Locations – Laurantus Serviceway

- Winds are experiencing a downwash effect on the southern façade of the proposed development and recirculating onto the southern region of Laurantus Serviceway.
- Southerly prevailing winds are observed to accelerated around the south western corner of the development onto Laurantus Serviceway.
- Northerly winds are observed to increase in magnitude due to winds side streaming across the western façade of the proposed development.
- The proposed development will likely have a variable impact on these winds, more pronounced towards the eastern aspect of the development site.

6.3 Sensor Locations – Corner of Moore Street and Bathurst Street

- Winds are accelerating around the north-western and south-eastern corners of the tower section of the development onto this area.
- The proposed development will likely have a variable and modest impact on these winds.

Figure 11 Peak Annual Gusts V/Vref: "Baseline" versus "Future" Scenario – Locations 1 to 9, 19 and 20

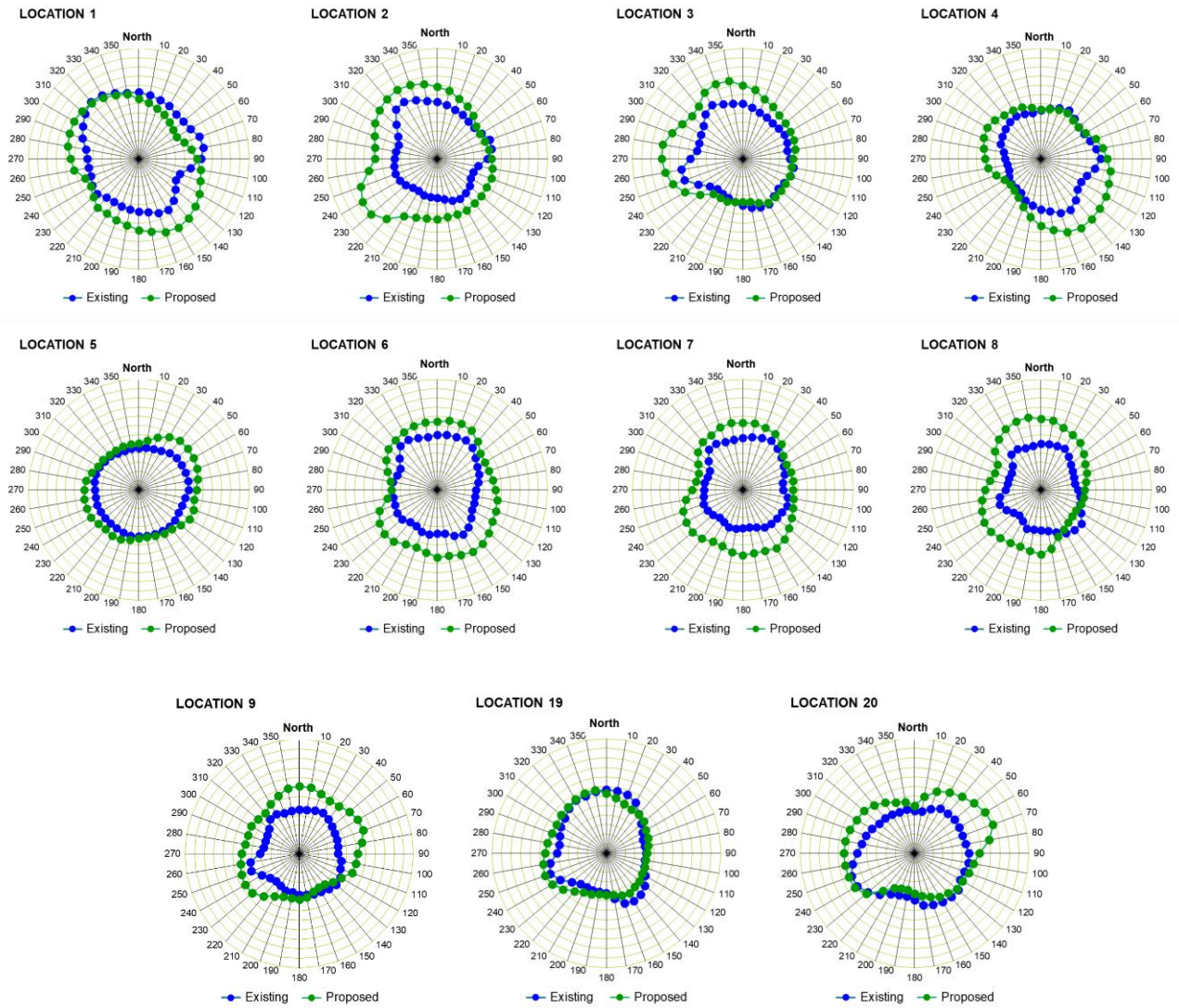


Figure 12 Peak Annual Gusts V/Vref: "Baseline" versus "Future" Scenario – Locations 10 to 18

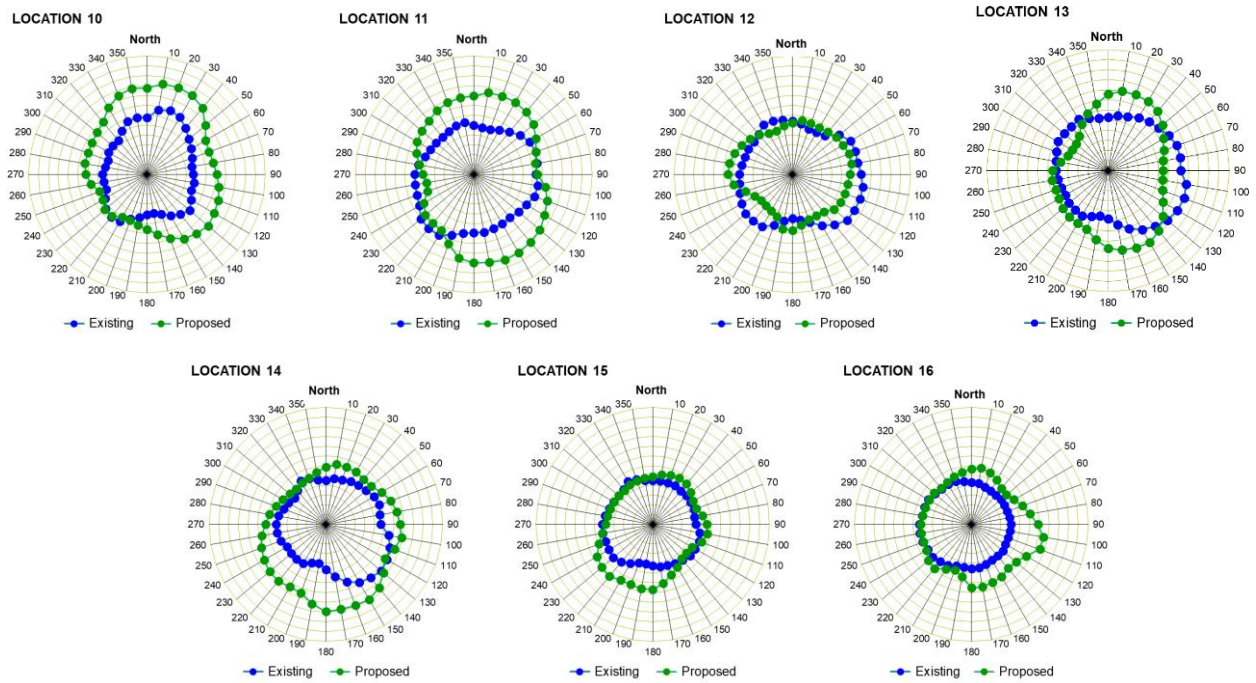
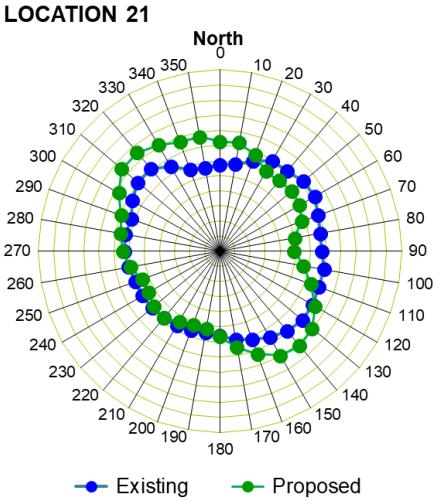


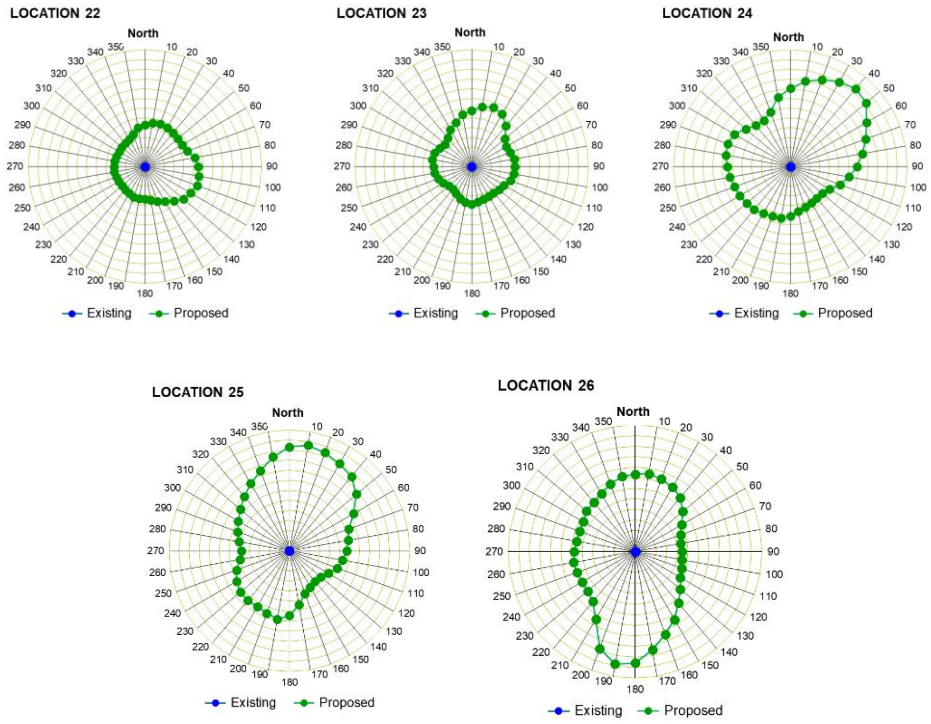
Figure 13 Peak Annual Gusts V/Vref: "Baseline" versus "Future" Scenario – Location 21



6.4 Sensor Locations – Outdoor Childcare Area

- Winds in these locations are observed to have a significant impact on pedestrian comfort, especially for the western aspect of the proposed development.
- The south western corner of the development experiences corner accelerations and downwashed winds due to building form and the prevailing southerly wind direction.
- Similarly, this is also evident for the westerly prevailing wind direction with winds being deflected from the western façade of the tower form onto the outdoor childcare areas.
- The proposed development will likely have a variable impact on these winds, more pronounced towards the western aspect of the development site.

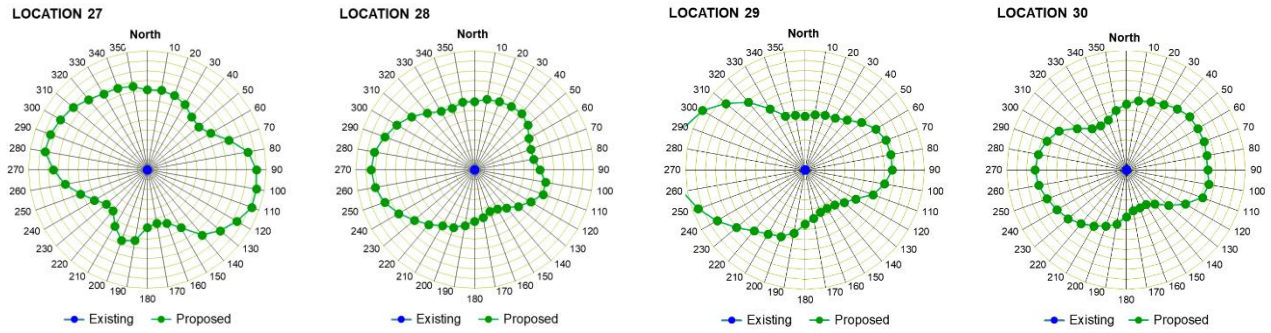
Figure 14 Peak Annual Gusts V/Vref: "Baseline" versus "Future" Scenario – Locations 22 to 26



6.5 Sensor Locations – Level 04 Podium (Child Care Roof)

- Winds in this region have a significant impact on the proposed development especially from the westerly wind direction.
- Due to the exposure of the podium roof, winds are observed to experience corner accelerations from the north western corner of the tower section of the proposed development from the westerly prevailing wind direction.
- The proposed development will likely have a variable impact on these winds, more pronounced towards the northern aspect of the development site.

Figure 15 Peak Annual Gusts V/Vref: "Baseline" versus "Future" Scenario – Locations 27 to 30



7 OVERALL WIND IMPACT

Table 2 gives the peak annual gust wind speeds and the 5% and 0.2% annual exceedance GEM wind speeds predicted to occur at the wind monitoring locations for the "Baseline" and "Future" built environment scenarios, relevant to assessment of the Melbourne and Lawson Criteria.

Table 5 Predicted Peak Annual Gust Wind Speeds at all Sensor Locations

Sensor No	Peak Annual Gust (m/s) [1]		Lawson 5% Comfort Class			Lawson 0.2% Safety Class		
	"Baseline"	"Future"	"Baseline"	Target	"Future"	"Baseline"	Target	"Future"
1	14.5	17.0	C2	C2	C2	S2	S2	S2
2	12.5	17.0	C3	C2	C2	S2	S2	S2
3	14.0	19.5	C3	C2	C2	S2	S2	S2
4	11.0	15.0	C3	C2	C2	S2	S2	S2
5	10.5	12.5	C3	C3	C3	S2	S2	S2
6	11.0	14.5	C3	C2	C2	S2	S2	S2
7	10.5	14.0	C3	C3	C2	S2	S2	S2
8	9.5	14.0	C3	C2	C2	S2	S2	S2
9	10.5	13.0	C3	C2	C3	S2	S2	S2
10	10.0	14.0	C3	C2	C2	S2	S2	S2
11	13.0	17.5	C3	C2	C2	S2	S2	S2
12	11.5	14.0	C3	C2	C3	S2	S2	S2
13	12.0	15.5	C2	C2	C2	S2	S2	S2
14	11.0	17.5	C3	C2	C2	S2	S2	S2
15	11.0	13.5	C3	C2	C3	S2	S2	S2
16	11.5	13.0	C3	C2	C3	S2	S2	S2
17	11.5	13.5	C3	C2	C2	S2	S2	S2
18	8.5	12.5	C3	C2	C3	S2	S2	S2
19	12.0	14.0	C3	C2	C3	S2	S2	S2
20	13.5	16.0	C3	C2	C2	S2	S2	S2
21	14.0	16.5	C2	C2	C2	S2	S2	S2
22		7.5		C4	C4		S2	S2
23		9.5		C4	C3		S2	S2
24		16.0		C4	C2		S2	S2
25		15.5		C4	C2		S2	S2
26		22.0		C4	C2		S2	S1
27		23.0		C3 [4]	C1		S2	S1
28		22.5		C3 [4]	C2		S2	S1
29		29.0		C3 [4]	C1		S2	SX
30		19.5		C3 [4]	C2		S2	S1

Note 1: Peak Gust Values rounded off to the nearest 0.5 m/s (the experimental error in results is ±0.5 m/s)

Note 2: Locations 22-30 are Podium locations and only exist in the "Future" scenario.

Note 3: Target only applicable if Level 4 Podium is public access area

7.1 Wind Impact Relative to Intended Usage

Pedestrian Footpath Areas along Northumberland Street

Wind category objective: 16 m/s Walking Comfort criterion (pedestrian walking areas)
13 m/s Standing-Waiting-Window Shopping criterion
Combination of Lawson C2 (Strolling) and C3 (Standing) criteria.

Locations to the east of the site will be affected by the proposed development, with most locations experiencing increases in local wind speed.

- In terms of the Melbourne Criteria, majority of locations currently experience annual gusts which are below the 13 m/s standing, waiting, window shopping criterion and in one case above the comfort criterion. In regards to the "Future" scenario, several locations may experience peak annual gusts above the 16 m/s walking comfort criterion and in several cases above the 13 m/s standing, waiting, window shopping criterion.
- In terms of the Lawson Criteria, these locations vary between Lawson Comfort classes C2 (Strolling) and C3 (Standing) for both "Baseline" and "Future" scenarios

Observation:

- In the above instance, wind conditions when compared against the Melbourne criteria suggest a more significant impact than compared against the Lawson criteria, ie for these locations, the Melbourne criteria are more restrictive than the Lawson criteria.
- Wind conditions predicted in the wind tunnel testing did not have the advantage of the significant and widespread vegetation and tall trees in the pedestrian areas of interest – refer **Figure 16**. These would have a noticeable sheltering effect on local wind speeds.

Figure 16 Vegetation and Trees along Northumberland Street

Pedestrian Footpath Areas along Laurantus Serviceway

Wind category objective: 16 m/s Walking Comfort criterion (pedestrian walking areas)
Lawson C2 (Strolling) criterion.

Locations to the west and south of the site may have the potential to experience increases in local wind speed.

- In terms of the Melbourne Criteria, these locations currently experience peak annual gusts which lie within the 16 m/s walking comfort criterion.
  - For the "Future" scenario, these winds may potentially exceed the 16 m/s walking comfort criterion, but remain below the 23 m/s safety criterion.
- In terms of the Lawson Criteria, most of these locations fall currently within the Lawson Comfort class C3 (Standing).
  - For the "Future" scenario, several locations may potentially increase to the Lawson Comfort class C2 (Strolling).

Observations:

- While wind conditions for Locations 11 and 14 on Laurantus Servivceway are just over the Melbourne, 16 m/s Walking Comfort level, they lie between the Lawson C2 and C3 Comfort Classes, suggesting their acceptability in relation to Strolling comfort.
- Moreover, Laurantus Serviceway is not a properly designated pedetrain access area: there are no footpaths for pedestrians along the serviceway.

Pedestrian Footpath Areas along the Corner of Moore Street and Bathurst Street

Wind category objective: 16 m/s Walking Comfort criterion (pedestrian walking areas)

Locations to the southwest of the site experience wind speed from the northeast and southwest wind directions.

- In terms of the Melbourne Criteria, these locations currently experience peak annual gusts which lie within the 16 m/s walking comfort criterion.
  - For the "Future" scenario, these winds may potentially just exceed the 16 m/s walking comfort criterion, but remain below the 23 m/s safety criterion.
- In terms of the Lawson Criteria, Location 21 falls currently within the Lawson Comfort class C2 (Strolling), this is the same for the "Future" scenario.

Level 3 Outdoor Childcare Areas (East and West Podium Areas)

Wind category objective: Melbourne 13 m/s Standing-Waiting-Window Shopping criterion
ideally selected areas 10 m/s Dining criterion; or
Lawson C4 (Sitting) criterion, ideally selected areas C5 (Dining) criterion

These locations only exist in the "Future" scenario. Unsurprisingly, the 4-storey Podium has the potential to generate elevated wind conditions as windflow accelerates around the base of the tower, is directed downwards as downwash and channels into the open areas.

- In terms of the Melbourne Criteria, almost all locations may potentially exceed the 16 m/s walking comfort criterion, but remain below the 23 m/s safety criterion.
- In terms of the Lawson Criteria, several locations are at the Lawson Comfort class C2 (Strolling) or Safety class S2.
  - Location 22 is in the Lawson Comfort class C4 and Safety class S2.
  - Location 23 is in the Lawson Comfort class C3 and Safety class S2.
  - Location 26 is borderline Lawson Safety class S2/S1

Observations:

- Comparison against both the Melbourne and Lawson criteria indicate winds in excess of the target objectives in many Level 3 Podium areas.
- It is important to note however that wind conditions on the new Podium were tested in the wind tunnel without the benefit of any of the landscaping, canopies, shadecloth, etc, planned for these areas.

Level 4 Podium (Child Care Roof)

Wind category objective: 16 m/s Walking Comfort criterion (pedestrian walking areas)
(on the basis of the currently unspecified usage of the area)

These locations only exist in the "Future" scenario. Unsurprisingly, the 4-storey Podium has the potential to generate elevated wind conditions as windflow accelerates aorund the base of the tower, is directed downwards as downwash and channels into the open areas.

- In terms of the Melbourne Criteria …
  - Almost all locations may potentially exceed the 16 m/s walking comfort criterion; Location 27 is just at the 23 m/s safety criterion; Location 29 exceeds the 23 m/s safety criterion.
- In terms of the Lawson Criteria …
  - Location 27 is Lawson Comfort class C1 and Safety class S1; Locations 28 and 30 are at the Lawson Comfort class C2 (Purpose Walking) or Safety class S1; Location 29 is in the Lawson Comfort class C1 and Safety class SX.

Observations:

- Comparison against both the Melbourne and Lawson criteria indicate winds in excess of the target objectives in many Podium area and indeed potentially unsafe winds at locations, 29.
- It is important to note however that wind conditions on the new Podium were tested in the wind tunnel without the benefit of any of the landscaping, canopies, etc, planned for these areas.

8 MITIGATION AND TREATMENT RECOMMENDATIONS

Sections 6 and 7 provided guidance as to the areas where the adopted wind acceptability criteria had the potential to be exceeded and an indication as to the likely local optimum wind treatment strategy, eg whether the wind condition of interest is likely to arise from accelerating winds which require vertical windbreaks (such as landscaping) or downwash winds which require horizontal windbreaks (such as awnings, canopies).

Wind Conditions of Concern

The wind conditions of potential concern in relation to the proposed development are:

- Ground level locations to the east of the site, particularly at the building entry points; and
- Locations throughout the upper levels of the Podium: Level 3 Child Care Outdoor area and Level 4 Podium.

8.1 Wind Mitigation Recommendations

Site perimeter pedestrian areas – Northumberland Street

It is recognised that these areas are beyond the site perimeter of the development and hence beyond the automatic control of the project.

- It is also recognised that the potential increase in local winds along Northumberland Street suggested through the wind tunnel testing did not include the ameliorating impact of the vegetation and trees which are part of the current surrounding environment – refer **Figure 16**.

The following is therefore recommended for the Detailed Design phase of the proposal:

- The Proponent carries out a site survey to confirm the integrity of current trees in the area; and
- Further detailed modelling is carried out (via CFD simulation) to confirm the efficacy of the current landscaping and identify areas where enhanced wind sheltering could be considered. The preference here is for CFD modelling rather than additional wind tunnel testing, given the difficulties in reproducing accurate tree aerodynamics at 1:400 or similar scale.

Podium Level 3 – Potential Concept Mitigation Options for Outdoor Childcare Area

Potential concept wind mitigation options for the Podium Level 3 are:

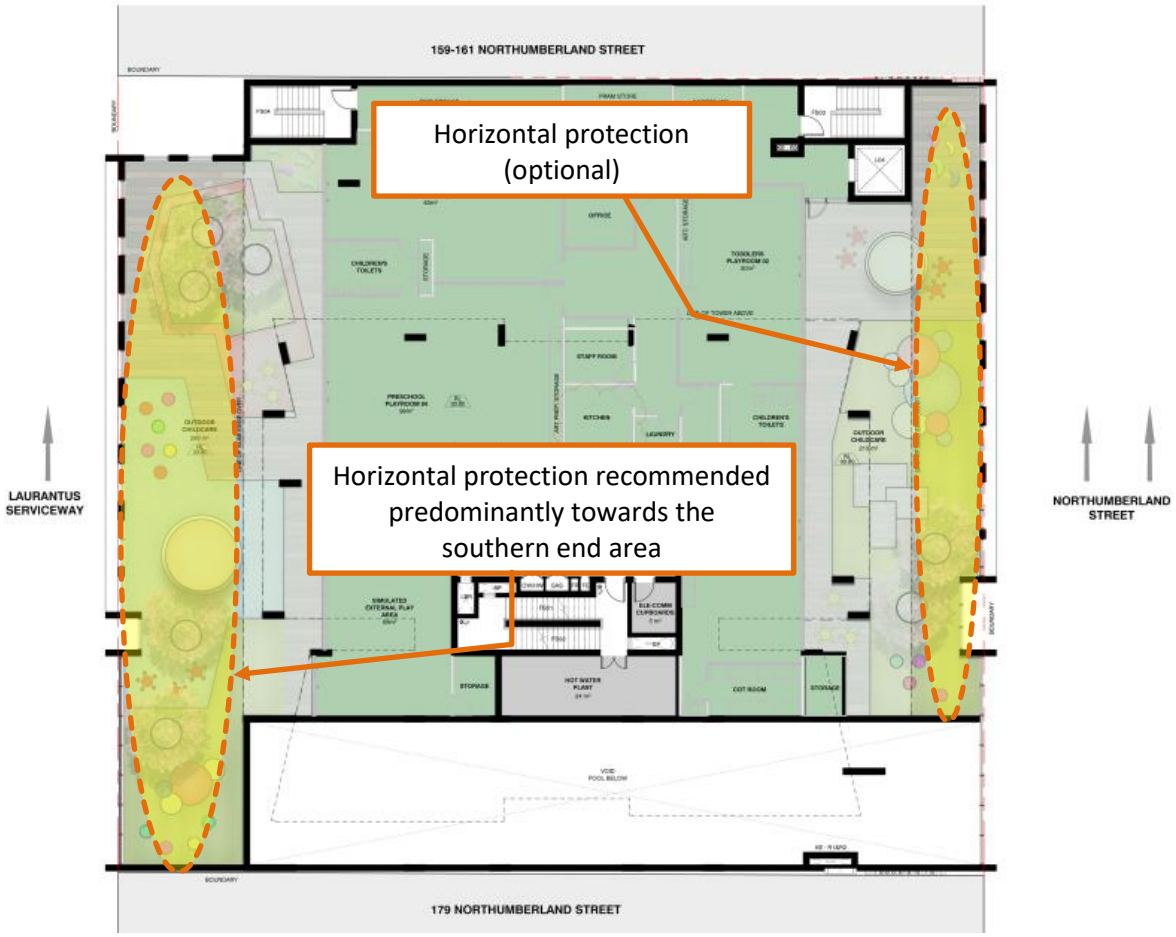
- Potential horizontal wind mitigation (options involving, canopies, awnings, pergolas, shadecloth, etc) is recommended to be included, predominantly within the area towards the southern end of the western childcare outdoor area, around the vicinity of sensor location 26 (Refer to Figure 17-A); and
- Since the eastern childcare outdoor area almost satisfies the target criteria, inclusion of the abovementioned horizontal wind mitigations can be optional within this area. These horizontal wind mitigations may not be included over this area to get more solar access as well as to receive some cool breezes to cool down the area during the hot summer months. This will also assist in maximising the usage of the area.

Podium Level 3 – Latest (PTW) Design Proposal for Outdoor Childcare Area

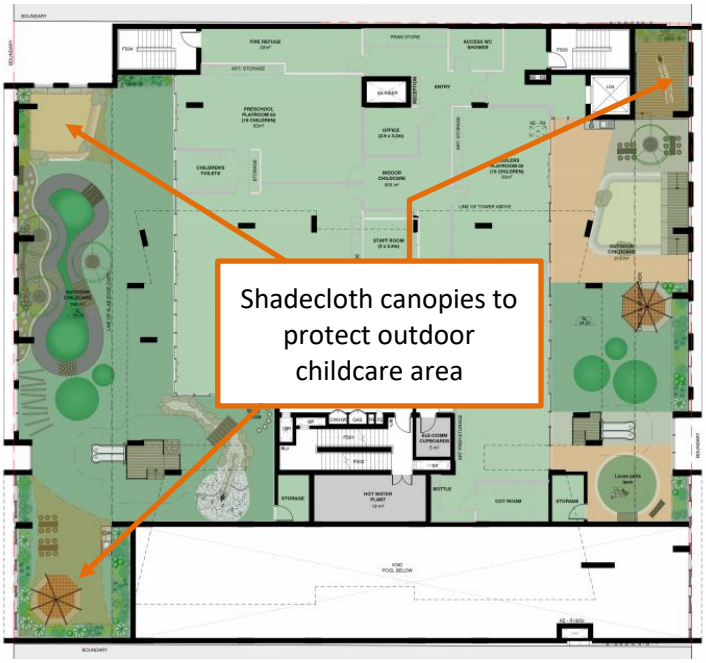
Figure 17-B shows the most recent Design Proposal for these outdoor areas, involving shadecloth canopies protecting the southern and northern end of the west outdoor area, as well as the northern end of the east outdoor area.

Figure 17 Level 3 Outdoor Childcare areas

A. Concept Mitigation Proposal



B. Latest Design Proposal for Level 3 Wind Mitigation



Level 4 – Podium roof

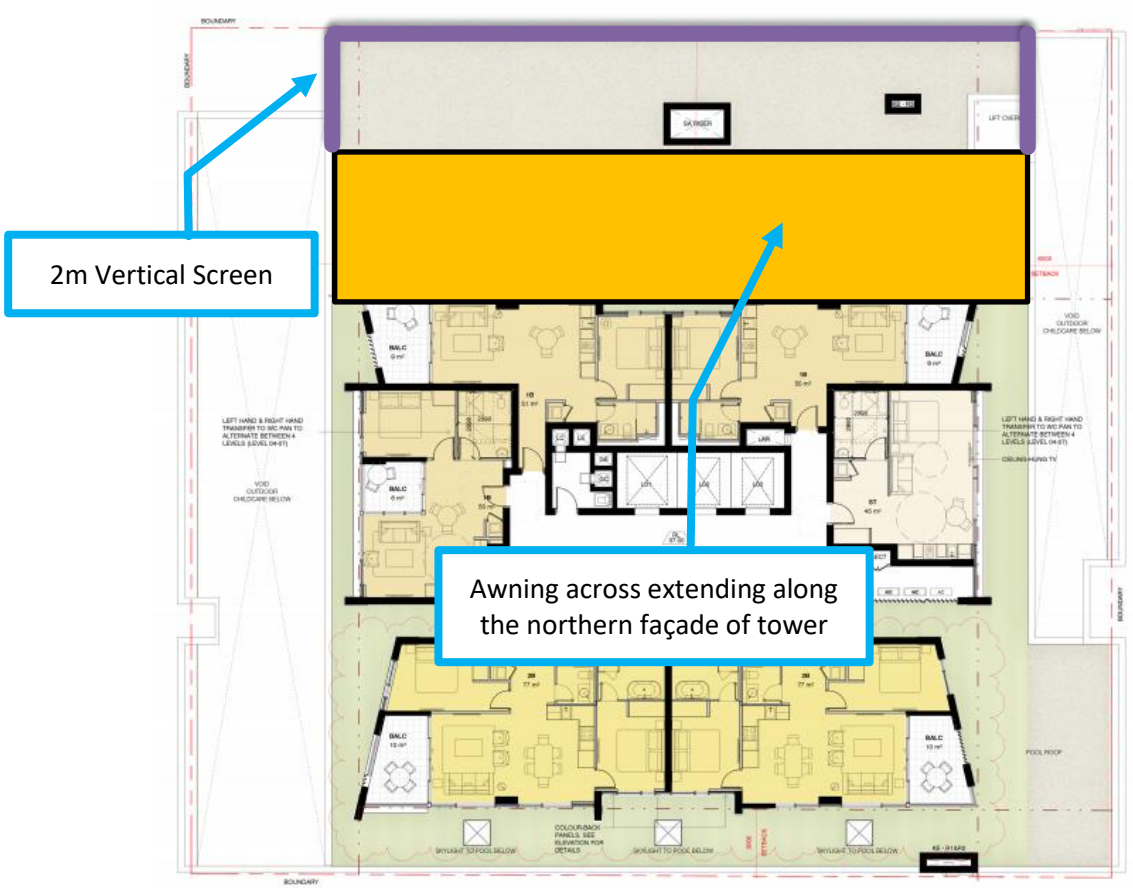
IF the Level 4 Podium Roof is to be accessible by residents of the development, the following is recommended:

- 2m vertical screens along the western and northern perimeter of the podium roof, combined with an awning extending from the Level 5 slab of the tower along the northern façade, refer **Figure 18**.

IF the Level 4 Podium Roof is access only by staff/maintenance crews/etc:

- a safety measure should be implemented prior to accessing the area, such as safety signage warning of potentially high wind conditions, the need to wear safety harnesses, etc.

Figure 18 Level 4 podium roof



8.2 Areas Not Assessed Via Wind Tunnel Testing

The upper residential component of the proposed development has balconies around all facades – refer **Figure 19**.

It is almost certain, given the absence of nearby similar height buildings, that some of these balconies, especially those at upper levels and near building corners and exposed to stronger southerly, northeasterly and west quadrant winds, will experience adverse wind conditions requiring wind treatment beyond standard height (ie code-compliant) balustrades.

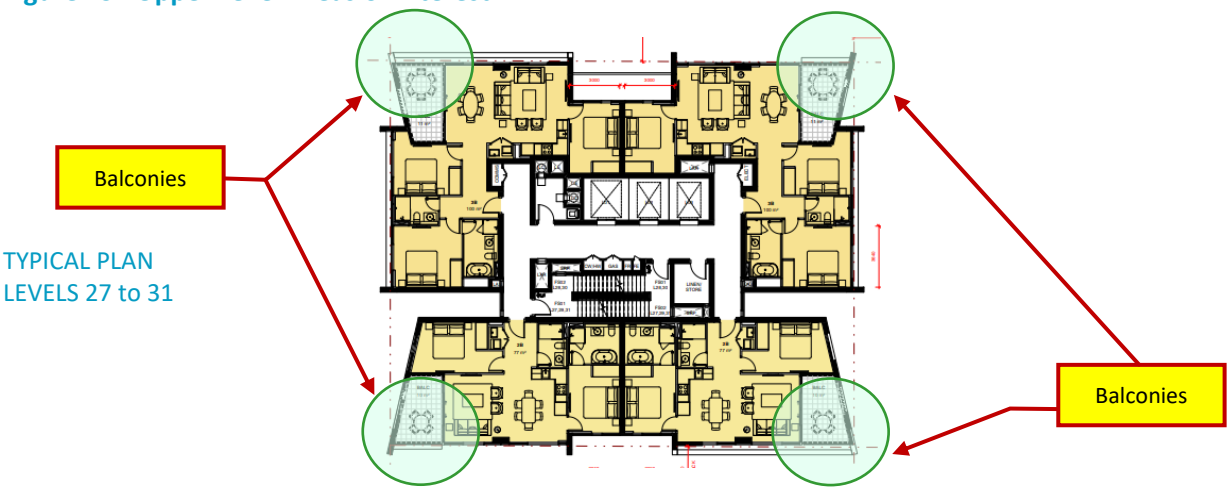
Such treatments might include increased balustrade height or partial screening via moveable louvres, to take advantage of the beneficial of cooler, milder winds during summer, while providing the capacity to limit the impact of colder and potentially much stronger winds during winter.

Upper Level Balcony Treatments

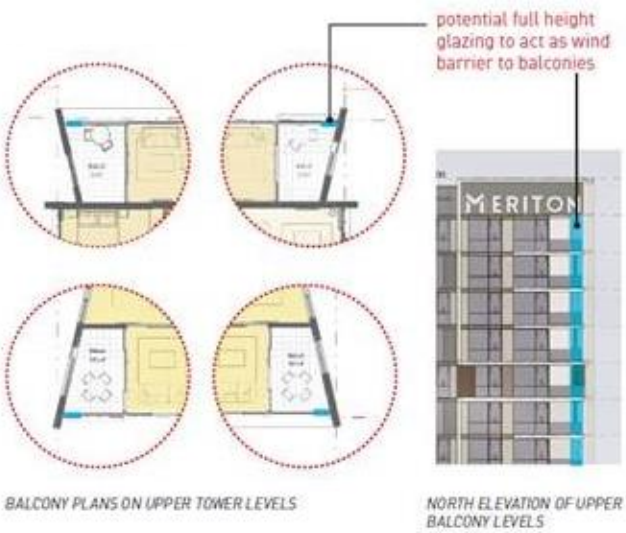
Figure 19-B shows the most recent design proposal for the balcony areas of interest, with full height glazing for corner balconies of interest.

- Further detailed modelling should be carried out (via CFD simulation) to confirm zones of the building, by height and by plan view location (eg building corners), where the above wind mitigation is required. The preference here is for CFD modelling rather than additional wind tunnel testing, given the difficulties in reproducing accurate balcony wind profiles at 1:400 or similar scale.

Figure 19 Upper Level Areas of Interest



Latest Design Proposal for Corner Balconies



9 Conclusion

SLR Consulting Australia Pty Ltd (SLR) has been engaged by Karimbla Construction Services (NSW) Pty Ltd to assess the local wind environment within and around their proposed development at 167 Northumberland Street, Liverpool, via an Environmental Wind Tunnel Study.

This assessment has been performed using a Discrete Sensor Environmental Wind Tunnel Study whereby wind tunnel measurements were made to investigate wind conditions throughout the proposed development (simulated via a 1:400 scale model) at areas to be used by visitors and occupants of the development itself.

The mixed-use development will comprise of a four-storey podium with commercial use tenancies at Level 00, 01 and 02, and a childcare at Level 03. Furthermore, the proposed development has a 28-storey residential component consisting of serviced apartments at Levels 04 to 31.

Liverpool Wind Climate

Using long-term wind records obtained from nearby Bureau of Meteorology stations at Bankstown Airport and Sydney Kingsford Smith Airport, SLR has determined that Liverpool has local winds characteristics closer to Bankstown Airport than Sydney (KS) Airport, given Liverpool's distance being even further inland than Bankstown Airport. Accordingly, key prevailing wind directions of interest are the northeast, southeast and south for summer and mainly west quadrant winds for winter.

Built Environment Scenarios Assessed

The study has involved the testing of two "scenarios": the "Baseline" scenario reflecting the existing built environment (as of March 2018) and the "Future" scenario, with the addition of the proposed development.

Wind Acceptability Criteria

The proposed development would include the highest building in the Liverpool area and as such, it is expected that there will be considerable interest in its potential wind impact on surrounding areas. SLR is aware that both the well-known Melbourne and Lawson criteria (and indeed a hybrid of both) have been used in recent Wind Impact Assessments of high-rise building precincts such as Parramatta.

Accordingly, SLR has assessed the proposal using both the Melbourne and Lawson criteria. In general, reasonable correlation has been found in terms of the impact of the proposal when assessed against the two nominated acceptability criteria, with the Melbourne criteria being generally more restrictive in terms of the acceptability or otherwise of specific locations.

However, the recommendations emanating from this study were found to be essentially identical when assessing the development's impact in terms of the two nominated wind criteria.

"Baseline" (Existing) Wind Environment

The pedestrian footpaths around the site are exposed to prevailing wind directions from the northeast, northwest and southern quadrants.

"Future" Wind Environment

In terms of the *future* wind environment with the proposed development, the following features of the development are noted as being of most significance:

- Ground level locations to the east of the site; and
- Locations throughout the upper levels of the Podium: Level 3 Child Care Outdoor area and Level 4 podium roof areas.

Site perimeter pedestrian areas – Northumberland Street

It is recognised that these areas are beyond the site perimeter of the development and hence beyond the automatic control of the project.

- It is also recognised that the potential increase in local winds along Northumberland Street suggested through the wind tunnel testing did not include the ameliorating impact of the vegetation and trees which are part of the current surrounding environment – refer **Figure 16**.

The following is therefore recommended for the Detailed Design phase of the proposal:

- The Proponent carries out a site survey to confirm the integrity of current trees in the area
- Further detailed modelling is carried out (via CFD simulation) to confirm the efficacy of the current landscaping and identify areas where enhanced wind sheltering could be considered. The preference here is for CFD modelling rather than additional wind tunnel testing, given the difficulties in reproducing accurate tree aerodynamics at 1:400 or similar scale.

Podium Level 3 – Outdoor childcare area

- It is recognised that additional wind mitigation treatments will be required for the outdoor childcare areas. Potential horizontal wind mitigation (options involving, canopies, awnings, pergolas, shadecloth, etc) is recommended to be included, predominantly within the area towards the southern end of the western childcare outdoor area, around the vicinity of sensor location 26 (Refer to **Figure 17-A**).
- Since the eastern childcare outdoor area almost satisfies the target criteria, inclusion of the abovementioned horizontal wind mitigations can be optional within this area. These horizontal wind mitigations may not be included over this area to get more solar access as well as to receive some cool breezes to cool down the area during the hot summer months. This will also assist in maximising the usage of the area.
- **Figure 17-B** shows the most recent Design Proposal for these outdoor areas, involving shadecloth canopies protecting the southern and northern end of the west outdoor area, as well as the northern end of the east outdoor area.

Level 4 – Podium Roof

The following is recommended if this area is accessible for public use:

- 2 m vertical screens along the western and northern perimeter of the podium roof, refer **Figure 18**.
- An awning extending from the Level 5 slab of the tower along the northern façade, refer **Figure 18**.
- Alternatively, if this region is only accessible by staff/maintenance crews/etc, a safety measure should be implemented prior to accessing the area, such as a safety signage, wearing of safety harnesses, etc, under extreme wind conditions.

Upper Level Balconies

The upper residential component of the proposed development has balconies around all facades – refer **Figure 19**.

It is almost certain, given the absence of nearby similar height buildings, that some of these balconies, especially those at upper levels and near building corners and exposed to stronger southerly, northeasterly and west quadrant winds, will experience adverse wind conditions requiring wind treatment beyond standard height (ie code-compliant) balustrades.

Such treatments might include increased balustrade height or partial screening via moveable louvres, to take advantage of the beneficial of cooler, milder winds during summer, while providing the capacity to limit the impact of colder and potentially much stronger winds during winter.

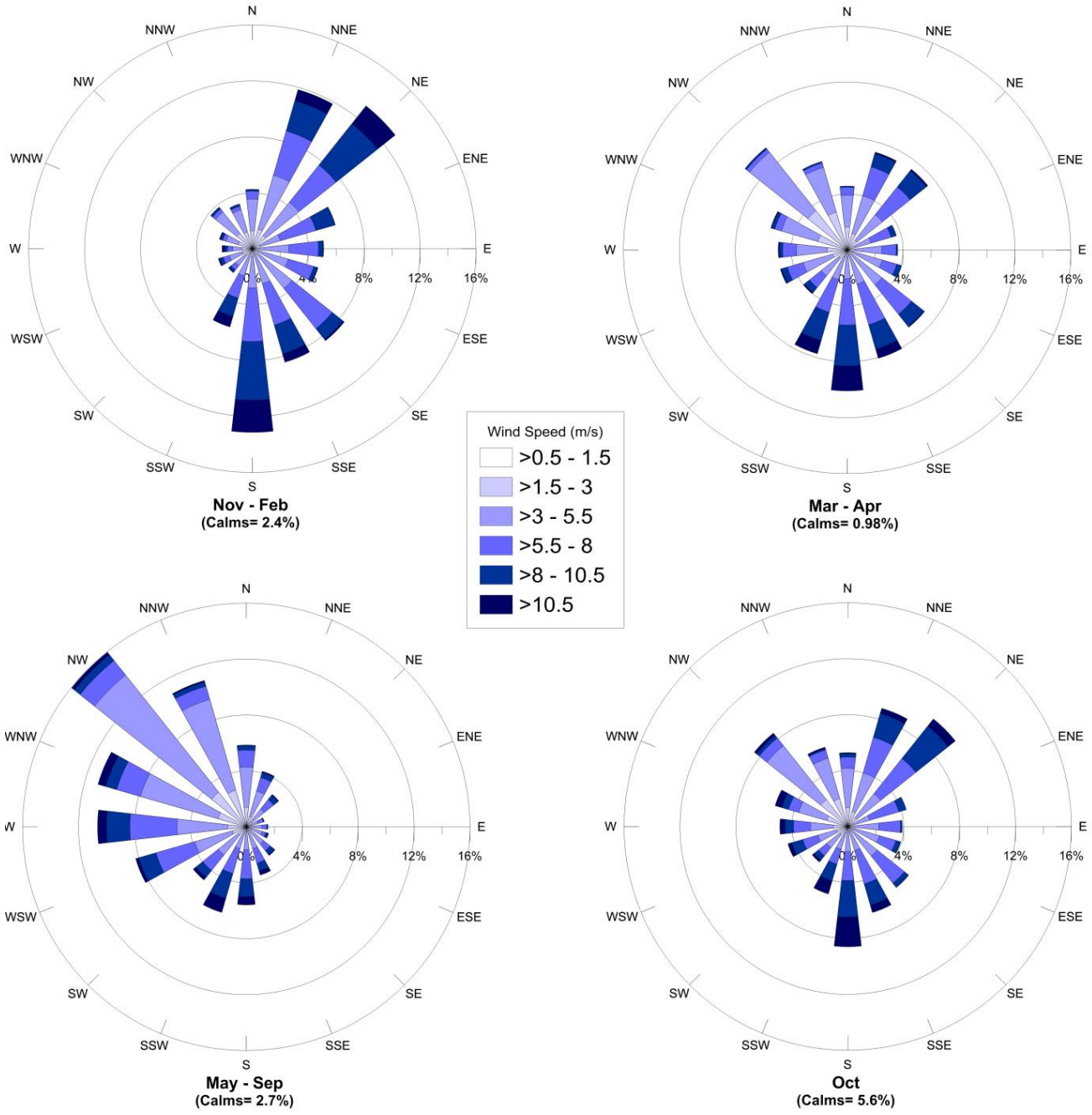
Figure 19-B shows the most recent design proposal for the balcony areas of interest, with full height glazing for corner balconies of interest.

- Further detailed modelling should be carried out (via CFD simulation) to confirm zones of the building, by height and by plan view location (eg building corners), where the above wind mitigation is required. The preference here is for CFD modelling rather than additional wind tunnel testing, given the difficulties in reproducing accurate balcony wind profiles at 1:400 or similar scale.

APPENDIX A

Seasonal Wind Roses for Bureau of Meteorology Met Stations at Sydney (Kingsford Smith) Airport and Bankstown Airport

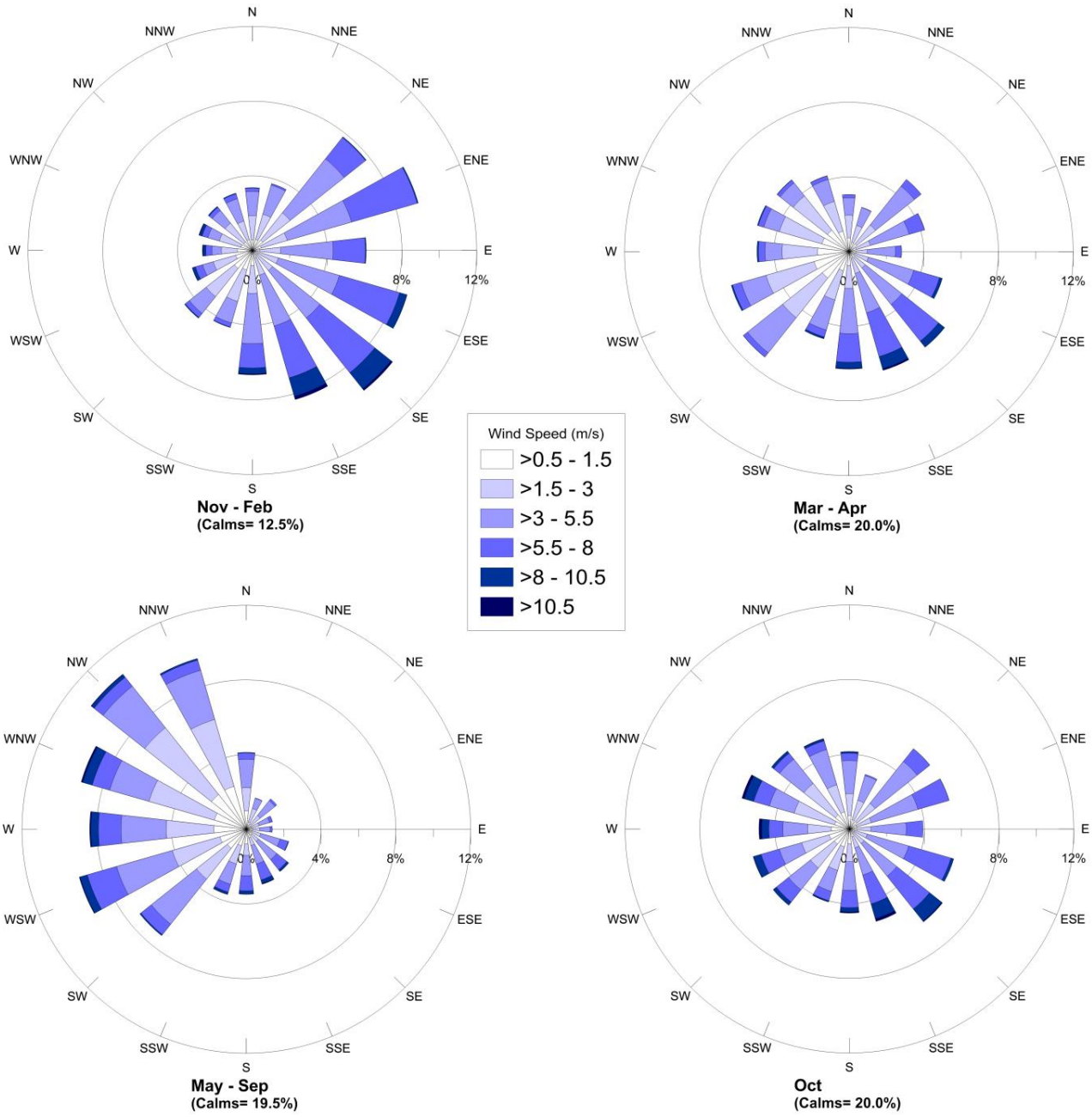
Sydney Airport AWS
(Observations)
1999-2017
600.09300



APPENDIX A

Seasonal Wind Roses for Bureau of Meteorology Met Stations at Sydney (Kingsford Smith) Airport and Bankstown Airport

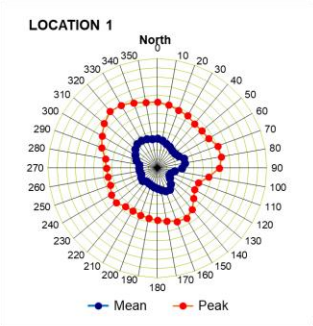
Bankstown Airport AWS
(Observations)
1999-2017
600.09300

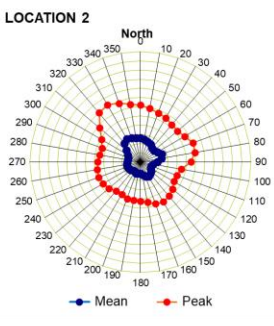


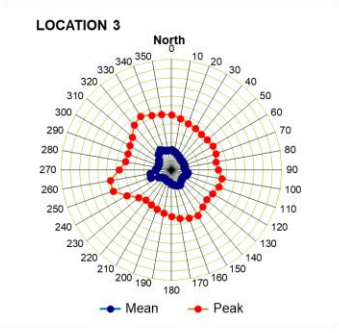
APPENDIX B

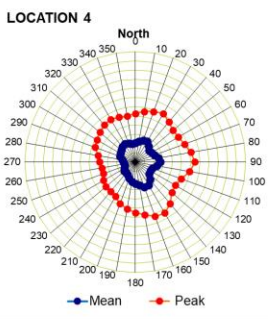
Wind Tunnel Test Results: BASELINE Scenario

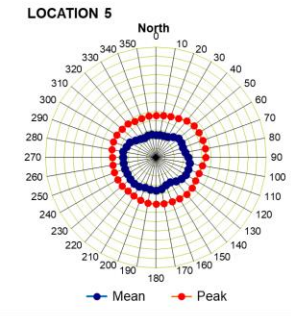
Polar Plots: Ratio of Ground Level Wind Speed to Reference Wind Speed

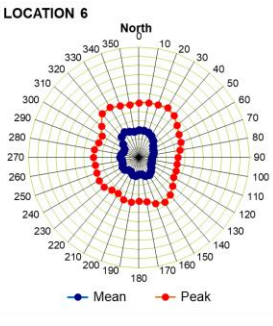


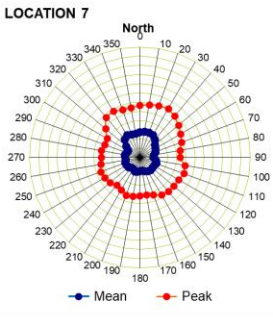


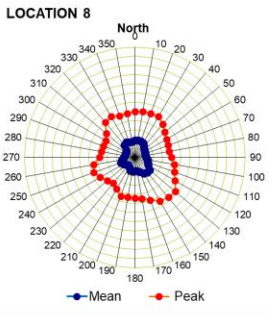


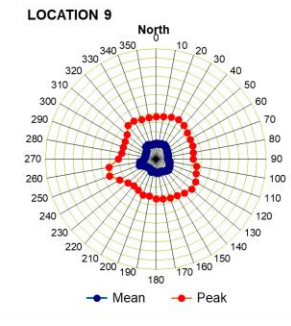


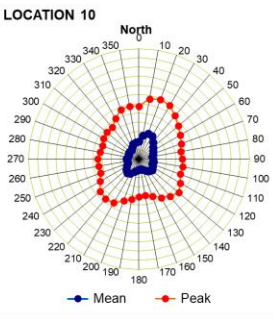


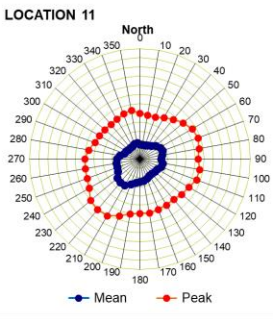


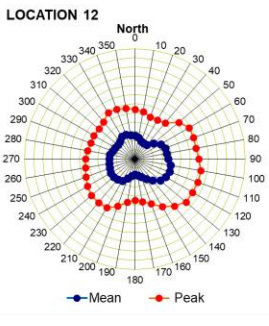


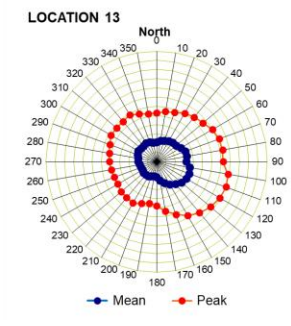


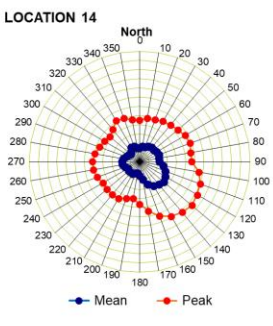


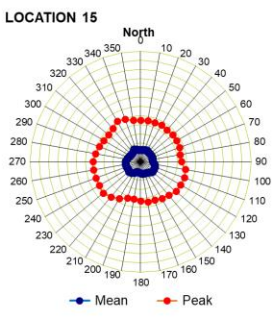


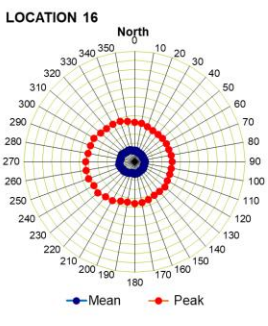


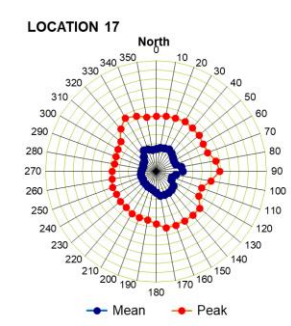


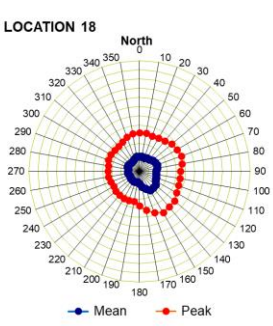


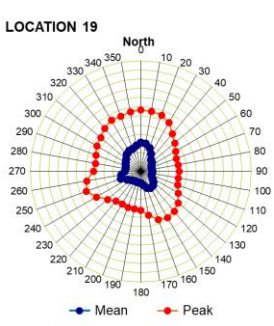


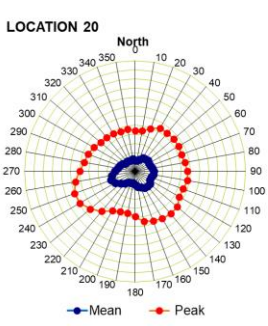








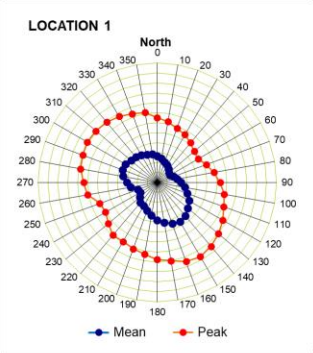


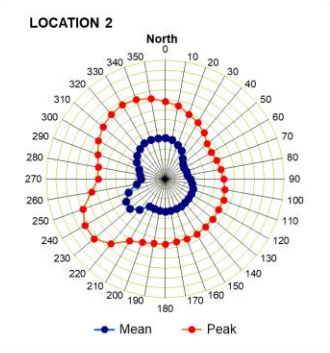


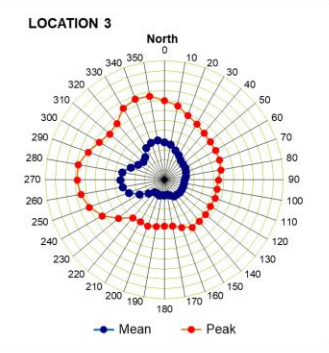
APPENDIX C

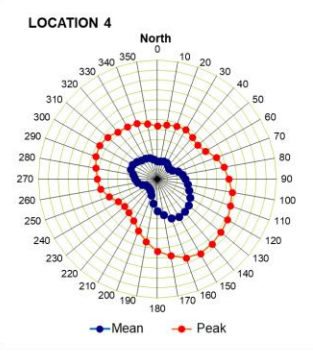
Wind Tunnel Test Results: FUTURE Scenario

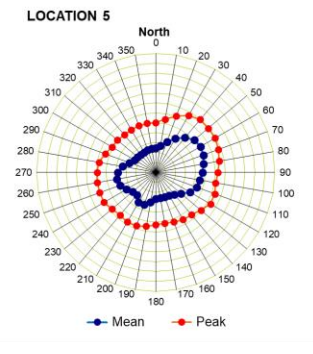
Polar Plots: Ratio of Ground Level Wind Speed to Reference Wind Speed

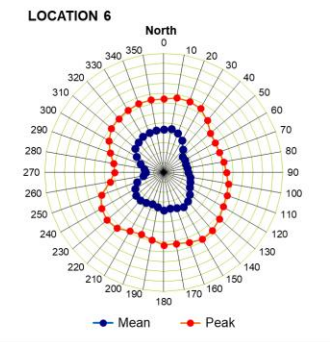


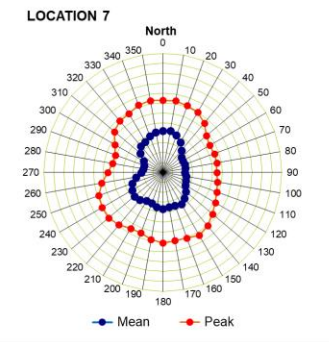


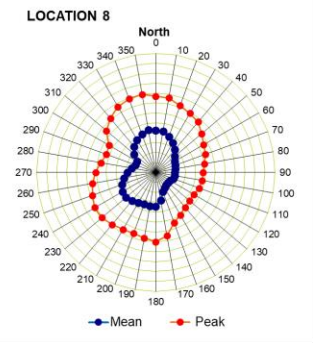


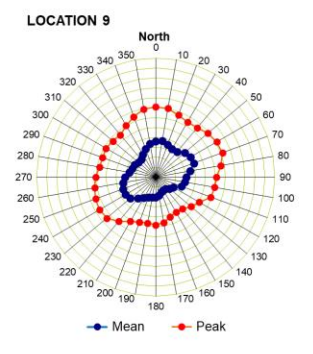


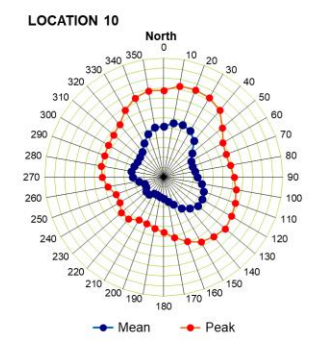


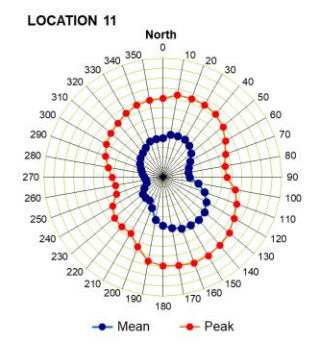


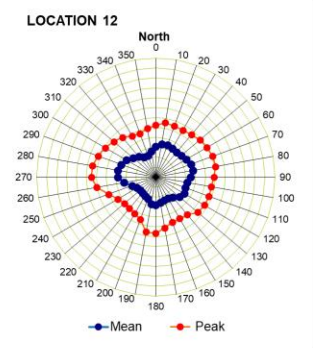


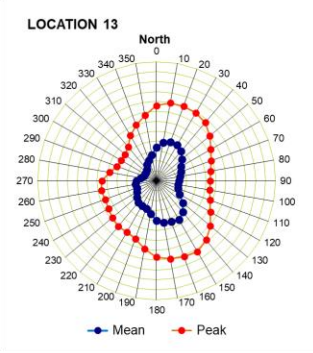


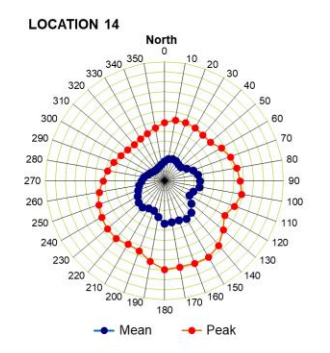


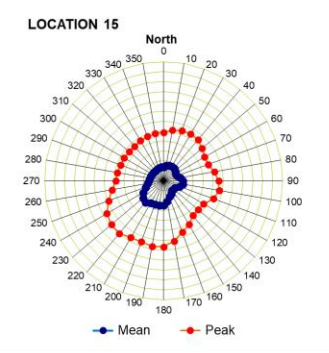


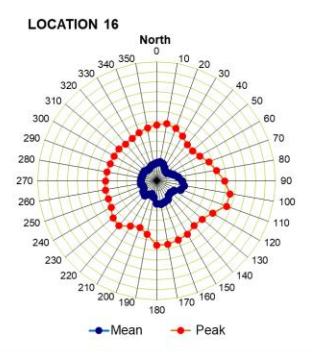


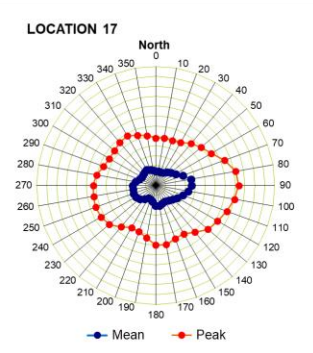


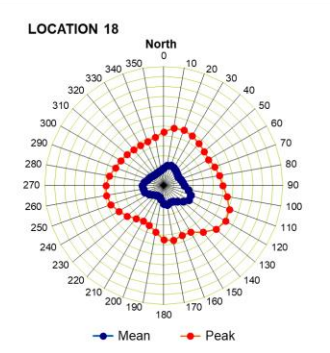


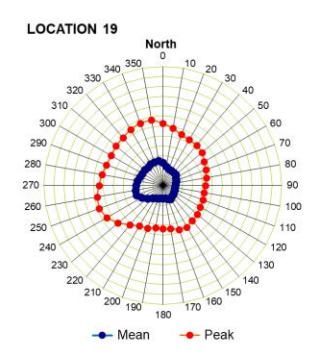


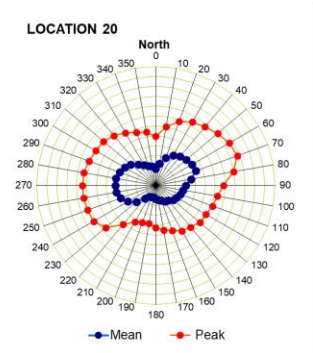








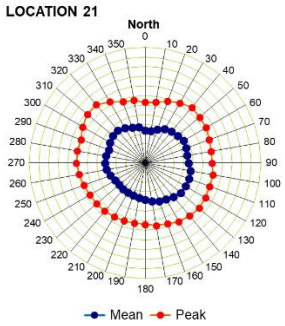




APPENDIX C

Wind Tunnel Test Results: FUTURE Scenario

Polar Plots: Ratio of Ground Level Wind Speed to Reference Wind Speed

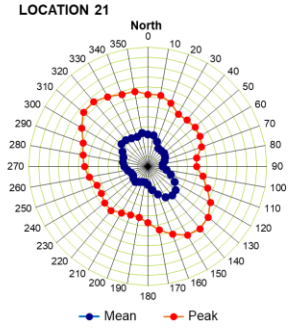


APPENDIX C

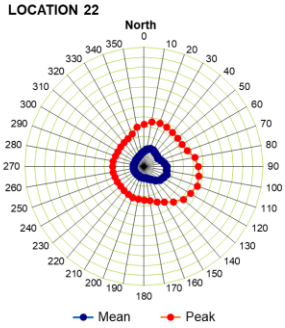
Wind Tunnel Test Results: FUTURE Scenario

Polar Plots: Ratio of Ground Level Wind Speed to Reference Wind Speed

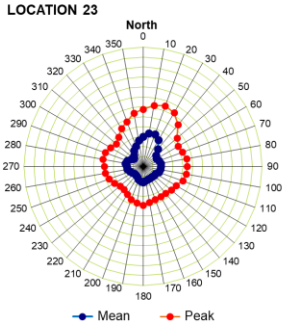
LOCATION 21



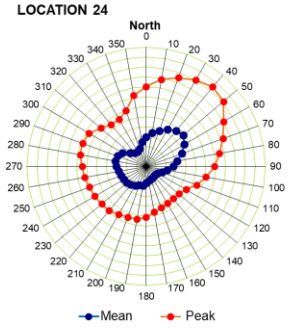
LOCATION 22



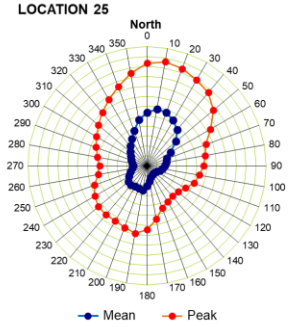
LOCATION 23



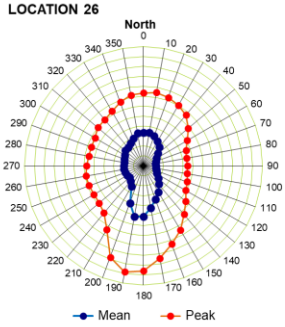
LOCATION 24



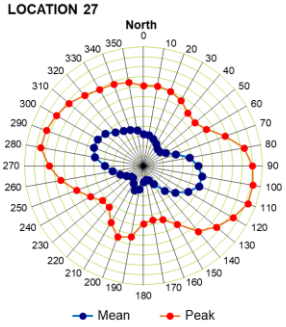
LOCATION 25



LOCATION 26



LOCATION 27



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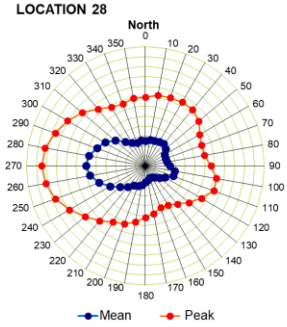

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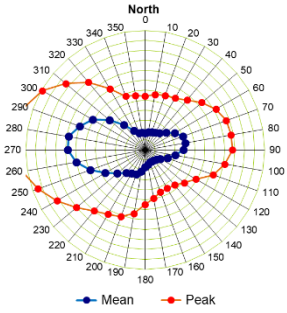
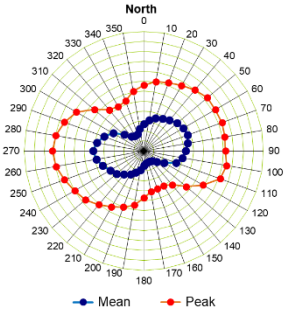


LOCATION 30



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