MEMORIAL AVENUE, LIVERPOOL

Environmental Wind Tunnel Test

Prepared for:

Il Capitano Investments Pty Ltd
c/o Allen Jack + Cottier
79 Myrtle Street
CHIPPENDALE NSW 2008

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BASIS OF REPORT

This report has been prepared by SLR Consulting Australia Pty Ltd with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with Il Capitano Investments 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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SLR disclaims any responsibility to the Client and others in respect of any matters outside the agreed scope of the work.

DOCUMENT CONTROL

Reference	Date	Prepared	Checked	Authorised
610.18183-R02-v1.0	8 March 2019	Dr Peter Georgiou	Dr Neihad Al-Khalidy	Dr Neihad Al-Khalidy

EXECUTIVE SUMMARY

SLR Consulting Pty Ltd (SLR) has been commissioned by Allen, Jack + Cottier, on behalf of Il Capitano Investments Pty Ltd, to assess the ground level wind environment around a proposed mixed-use development at Memorial Avenue, Liverpool.

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

The proposed development is bounded by Memorial Avenue to the north, Castlereagh Street to the west and Bathurst Street to the east as far as the Norfolk Street intersection.

The proposed development comprises 3 levels of basement car parking, a podium which covers the entire site at ground level and then extends three additional levels only beneath each of the two main high-rise components of the development, a 23 storey excluding ground floor residential component within the western part of the site and an 17 storey excluding ground floor residential component within the eastern part of the site.

The buildings surrounding site are generally low-rise, comprising mainly residential buildings to the northwest and commercial and retail buildings within the Liverpool business district to the north clockwise around to the southwest. Further afield are several planned and approved similar height buildings to the south and east.

Liverpool Wind Climate

The study has developed a site-specific statistical wind climate model based on long-term wind records obtained from nearby Bureau of Meteorology stations at Sydney Kingsford Smith Airport and Bankstown Airport. For Liverpool, SLR has determined that local winds have characteristics closer to Bankstown Airport than Sydney (KS) Airport, given Liverpool's distance being even further inland than Bankstown Airport. Key prevailing wind directions of interest are the northeast, southeast and south for summer and mainly west quadrant winds for winter.

Wind Acceptability Criteria

The study has adopted the so-called "Melbourne" criteria for the present assessment, currently referenced by many Australian Local Government Development Control Plans in relation to wind impact.

Built Environment Scenarios Assessed

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

"Baseline" (Existing) Wind Environment

With the existing built environment, pedestrian areas in surrounding thoroughfares were found to lie within the adopted 16 m/s walking comfort criterion. The testing showed some modest channelling of northerly and southerly winds along Castlereagh Street and Bathurst Street and westerly winds along Memorial Avenue.

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"Future" Wind Environment – Surrounding Pedestrian Footpath Areas

Ground level locations surrounding the site (to the west, north and east) have the potential to experience increases in wind speed for key prevailing wind directions (northeast, southeast, south and west).

- A number of these locations have the potential to exceed the 16 m/s walking comfort criterion, but remain below the 23 m/s safety criterion.

Observation:

- Wind conditions predicted in the wind tunnel testing did not have the advantage of the mature and extensive vegetation and trees along the footpath areas of interest – refer **Figure 16**. These would have an ameliorating (ie sheltering) effect, in some cases significant, on local wind speeds; and throughout the year, provided they comprise evergreen species.

"Future" Wind Environment – Podium Areas

The proposed development's Podium has the potential to generate elevated wind conditions as windflow accelerates around the development's high-rise components and is directed downwards as downwash and accelerated shear flow.

- In terms of the nominated wind acceprtability critieria, almost all Podium locations may potentially exceed the 13 m/standing-waiting-window shopping criterion. Locations 27 to 29 may also potentially exceed the 16 m/s walking comfort criterin.

Observation:

- Wind conditions on the new Podium were tested in the wind tunnel without the benefit of any of the landscaping, pergolas, etc, including the perimeter planting already proposed for the Podium.
- It is also important to appreciate that, while the Podium has the potential to attract elevated winds from building floors above (downwash, etc), these winds are thereby prevented from generating the same impact at ground level locations immediately below. The Podium therefore plays a potentially important role in ameliorating ground level wind conditions in surrounding pedestrian areas.

Already Planned Mitigation Treatments

The current round of wind tunnel testing did not include the following features, all of which would have had an ameliorating impact on local wind speeds:

- Vegetation and Trees along surrounding thoroughfares - refer **Figure 16**;
- Awnings surrounding the proposed development's façade – refer **Figure 17**; and
- Extensive landscaping and pergolas planned for the Level 1 Podium – refer **Figure 18**.

Additional Wind Mitigation Treatments – Ground Level Landscaping and Protective Awnings

We recommend retaining the already planned trees along the Castlereagh Street, Memorial Avenue and Bathurst Street footpaths and adding in two additional trees of evergreen variety as shown in Figure 19.

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Current plans for the proposed development show extensive awnings around the development's western, northern and eastern facades – refer **Figure 17**. These will assist in protecting relevant footpath areas.

The wind tunnel testing indicated elevated wind speeds along Memorial Avenue along the northern façade of the west tower. There is an outdoor dining area in this location which will be exposed to "undercroft" winds from the west – refer left diagram **Figure 20**.

Noting the intended usage of this area, if it is intended for outdoor dining to be made available on an all-year round basis, we recommend either (a) a full width canopy at Level 1 elevation extending out from the main building façade line of the west tower to the two external feature columns or (b) a vertical, retractable screen filling in the opening which allows the undercroft winds – refer right diagram **Figure 20**.

Additional Wind Mitigation Treatments – Podium Level 1

The test results indicated the potential for elevated winds in a number of areas throughout the Level 1 Podium. Because of physical constraints associated with the scale used in the testing, none of the planned wind mitigation elements (landscaping, shadecloth, pergolas, awnings, etc) were incorporated in the testing. On this basis, the following is recommended:

- All of the currently planned extensive landscaping and horizontal windbreaks (shadecloth, pergolas, awnings, etc) should be retained;
- Seating areas in particular should be provided with such horizontal windbreaks;
- A full perimeter 1.8 m high balustrade should be provided along any open perimeter areas of the Podium (northeast section and southern perimeter). The balustrade could be enabled through any combination of "barrier", eg solid parapet wall, combination parapet wall plus planting, glazing, etc.

Additional Wind Mitigation Treatments – East Tower Level 1 "Exercise Court"

This terrace will be exposed to winds from the northeast (generally mild and cooling during summer) and the northwest (stronger and occurring in winter). However, given its intended usage and the perimeter balustrade which has been supplied with a planter box for landscaping, no further treatment is indicated for this location.

Additional Wind Mitigation Treatments – West Tower Level 4 Extended Terrace

This area will be exposed to winds from the northeast (generally mild and cooling during summer), the northwest (stronger and occurring in winter) and southwest to southeast (all-year, including stronger winds). On this basis, the following is recommended:

- All of the currently planned landscaping and horizontal windbreaks (pergolas, etc) should be retained and seating areas in particular should be provided with such horizontal windbreaks;
- A full perimeter 1.8 m high balustrade should be provided along all perimeter areas. The balustrade could be enabled through any combination of "barrier", eg solid parapet wall, combination parapet wall plus planting, glazing, etc.

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Additional Wind Mitigation Treatments – East Tower Level 4 Corner Terraces

These terraces will be exposed to winds from at least several prevailing wind directions depending upon location, eg the southeast corner terrace will be exposed to northeast, southeast and southerly winds. They have all been provided with a perimeter balustrade and planting.

These areas do not appear to be accessible to the public; accordingly, no further treatment is indicated.

Additional Wind Mitigation Treatments – East Tower Level 8 Extended Terrace

This area will be exposed to elevated wind conditions for northwest winds (impacting the east tower's northwest facing façade) and south to southwest winds. Current pans appear to show this terrace not being accessible to the public. If this is not the case, the following is recommended:

- All of the currently planned landscaping and horizontal windbreaks (awnings, etc) should be retained and seating areas in particular should be provided with such horizontal windbreaks;
- A full perimeter 1.8 m high balustrade should be provided along all perimeter areas. The balustrade could be enabled through any combination of "barrier", eg solid parapet wall, combination parapet wall plus planting, glazing, etc.

Additional Wind Mitigation Treatments – Upper Level Balconies

The two high-rise components of the proposed development (east and west towers) have balconies around all facades, including at building corners.

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 which are exposed to stronger southerly and westerly 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.

Indeed, the proposed development's west tower has already been provided with movable balcony screens from Level 19 upwards. At this stage, upper levels of the proposed development's east tower have not been provided with such movable screens.

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

- Further detailed modelling is carried out (via CFD simulation) to confirm zones of the proposed development's high-rise components, by height and by plan view location (eg building corners), where wind mitigation is indicated (ie beyond the standard balustrade height). 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.
- The above recommendation does not apply to the west tower Levels 19-23, where movable balcony screens have already been designed.

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Additional Wind Mitigation Treatments – Roof Level Terraces

The above upper-level balcony recommendations would normally apply also to any public access areas located on the proposed development's two high-rise Roof Levels, where a combination of both vertical screening (eg solid balustrades, balustrades combined with planter boxes, etc) and horizontal screening might normally be required to ensure all-year-round amenity, especially areas exposed to southerly and westerly winds.

However, these areas are currently designated for solar panel arrays with no public access areas. Accordingly, no wind mitigation is recommended for these areas, although the high winds likely to occur in these locations suggest additional care will need to be taken in considering the structural wind loading of the solar panels.

Taking into account all of the above, it is believed that the proposed development will comply with the adopted wind acceptability criteria at all pedestrian and public access locations within and around the development.

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1 INTRODUCTION

SLR Consulting Pty Ltd (SLR) has been commissioned by Allen, Jack + Cottier, on behalf of Il Capitano Investments Pty Ltd, to assess the ground level wind environment around a proposed mixed-use development at Memorial Avenue, Liverpool.

This assessment has been performed using a Discrete Sensor Environmental Wind Tunnel Study whereby wind tunnel measurements were made to investigate wind conditions within and around 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 Proposed Development

The proposed development is bounded by Memorial Avenue to the north, Castlereagh Street to the west and Bathurst Street to the east as far as the Norfolk Street intersection - refer **Figure 1**.

Figure 1 Satellite Image of the Proposed Development Site

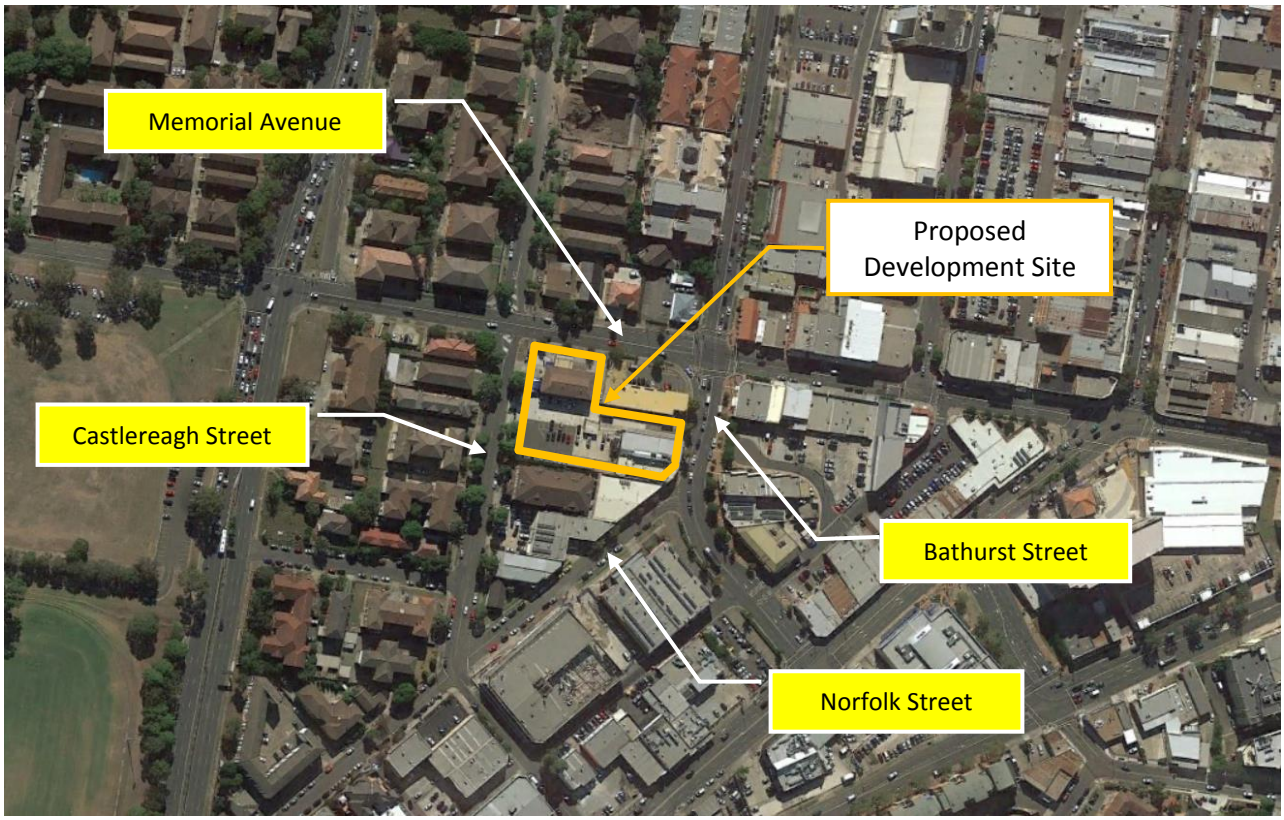


Image: Google, December 2018

1.2 Proposed Development Description

The proposal comprises (refer **Figure 2**):

- 3 levels of basement car parking;
- A 4-storey podium which covers the entire site at Ground Floor level and extends an additional three levels only beneath each of the two high-rise components of the development; and
- Two residential tower components above, with the western tower extending to Level 24 and the eastern tower extending to Level 18.

Figure 2 Architectural Plans of Floors of Interest

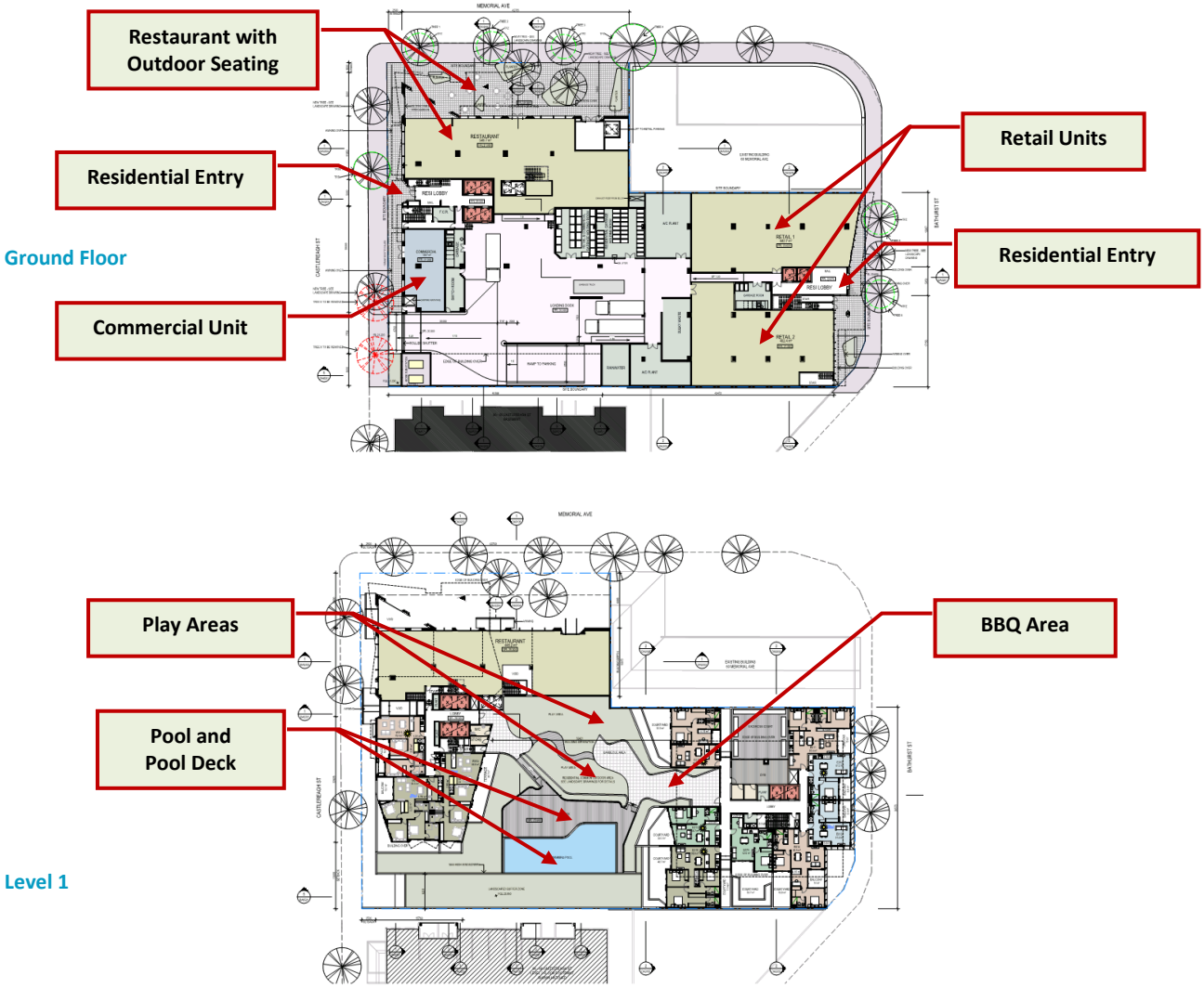
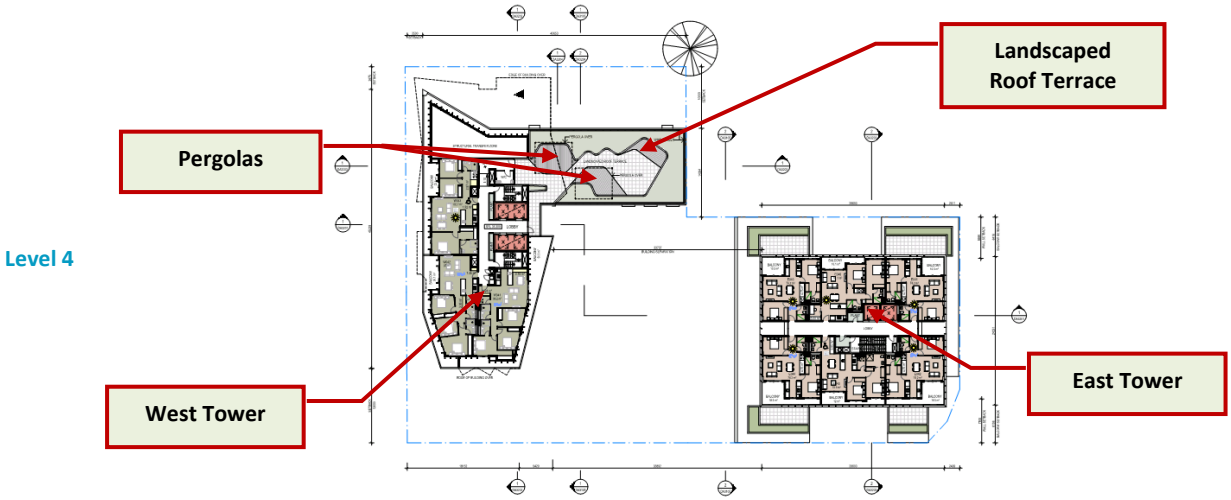


Fig.2 (cont'd)



Perspective View from North

1.3 The Surrounding Built Environment

In terms of surrounding buildings:

- To the southwest clockwise around to the north are low level residential areas;
- To the north clockwise around to the southwest are the commercial and retail areas of the Liverpool CBD area; these areas contain a number of newly approved buildings of a similar height to the proposed development; and
- Liverpool Station and rail line are located 650 m to the east of the site.

The terrain is undulating in the surrounding built environment, with no particularly significant topographical variations (ie hills, escarpments, etc) influencing local wind speeds.

These aspects are shown in a representative view in **Photo 1**.

Photo 1 Representative Project Surrounds (View from Northeast)

2 SYDNEY'S REGIONAL WIND CLIMATE

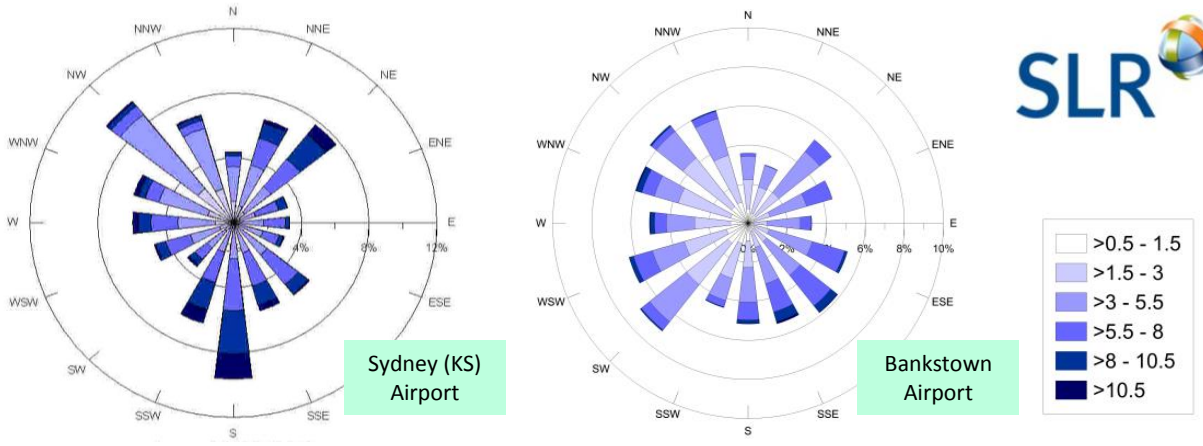
The data of interest in this study are the mean hourly wind speeds and largest gusts experienced throughout the year (especially higher, less frequent winds), how these winds vary with azimuth, and the seasonal break-up of winds into the primary Sydney Region wind seasons.

2.1 Seasonal Variations

Key characteristics of Sydney's Regional Wind Climate are illustrated in two representative wind roses shown in **Figure 3**, taken from Bureau of Meteorology (BoM) data recorded during the period 1999-2017 at Sydney (Kingsford Smith) Airport and Bankstown Airport. The associated seasonal wind roses (refer **Appendix A**) show that Sydney is affected by two primary wind seasons with 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. Northeast sea breeze winds 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 3 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.

- As noted in **Section 1.3**, the site is currently surrounded by generally low residential, commercial and retail buildings with several similar height buildings located within the Liverpool CBD area. The site will therefore receive moderate wind shielding depending upon oncoming wind direction at lower levels with upper levels exposed to higher winds from most wind directions.

3 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 recent decades.

3.1 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 following objectives relate to the above wind impact criteria:

- The general objective for pedestrian areas is for annual 3-second gust wind speeds to remain at or below the 16 m/s "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.
- In many urban locations, either because of exposure to open coastal conditions or because of street "channelling" effects, etc, the 16 m/s 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 criteria for spaces designed for activities such as seating, outdoor dining, etc, are lower (ie more stringent) than for "walking comfort".

The **Table 1** criteria 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 provided the general site satisfies the relevant criteria.

Finally, it is noted that the 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/s 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 July 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.

Relationship of Adopted Melbourne Criteria to Liverpool DCP Wind Criteria

In the late 1960s, observations made by Professor Bill Melbourne of wind effects on pedestrians led to papers - Melbourne (1971) and Melbourne and Joulbert (1971) – which formed the basis of criteria for pedestrian comfort and safety. These were published in 1978 and referred to therein as the Melbourne (1978) criteria.

The Melbourne criteria initially contained two wind "limits" based on the annual 3-second gust wind speed exceeded 0.1% of the time from any 22.5˚ wind direction sector: 23 m/s relevant to public safety (people knockdown) and 16 m/s for "walking comfort" (generally acceptable for walking in urban and suburban areas). The criteria were extended to cover two additional "comfort"-related activities: 13 m/s for short-term activities such as "strolling", "window shopping" and 10 m/s for long-term activities such as "outdoor dining".

Melbourne (1978) made comparisons of his criteria and those of Davenport (1972), Lawson (1973), Penwarden and Wise (1975), and Hunt, Poulton and Mumford (1976) and concluded that there was good agreement between the various criteria, especially in view of the degree of variation in response of people of different ages, heights, etc, to wind impacts. This agreement provided support for the adoption of the Melbourne criteria by Councils throughout Australia over the past four decades.

It can be seen that the Melbourne comfort criteria (10 m/s, 13 m/s and 16 m/s) were the basis for the three Liverpool DCP wind criteria. However, it is noted that the Melbourne criteria are accompanied by statistical requirements (ie requirements based on the annual frequency of exceedance per angular segment) which are absent in the Liverpool DCP criteria. It is also noted that the Melbourne criteria cover the case of public safety, also absent in the Liverpool criteria.

Accordingly, this study has adopted the statistically-based Melbourne criteria (as originally formulated).

The principles behind the two (essentially comparable) criteria however are the same: where a specific criterion (eg for walking, dining, etc) is already being currently exceeded (because of existing exposure, street canyon channelling, etc) a new development should ideally not exacerbate existing adverse wind conditions and, wherever feasible and reasonable, ameliorate such conditions.

4 DESIGN WIND SPEEDS

4.1 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. The objective of this study was to develop statistical wind information for locations not situated in close proximity (ie within say approximately a kilometre) of BoM weather stations.

Wind records given particular emphasis were from weather stations with a "clean" surrounding exposure, eg stations such as Sydney (Kingsford Smith) Airport and Bankstown Airport, ie locations 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 winds reflective of the weather systems experienced at the site have characteristics closer to Bankstown Airport than Sydney (KS) Airport, given Liverpool's distance being even further inland than Bankstown Airport.

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

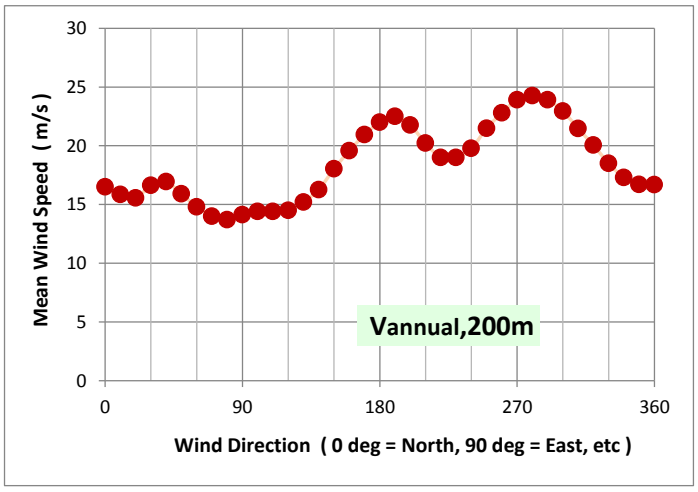
The above analysis is described in detail in …

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

4.2 Reference Height 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 4** and have been based on the adopted Liverpool wind model as described above. The winds shown in **Figure 4** have a once-per-year exceedance probability.

Figure 4 Reference Height (200 m) Annual Recurrence Mean Wind Speed at Liverpool



5 WIND TUNNEL TEST METHODOLOGY

5.1 Simulation of Natural Wind

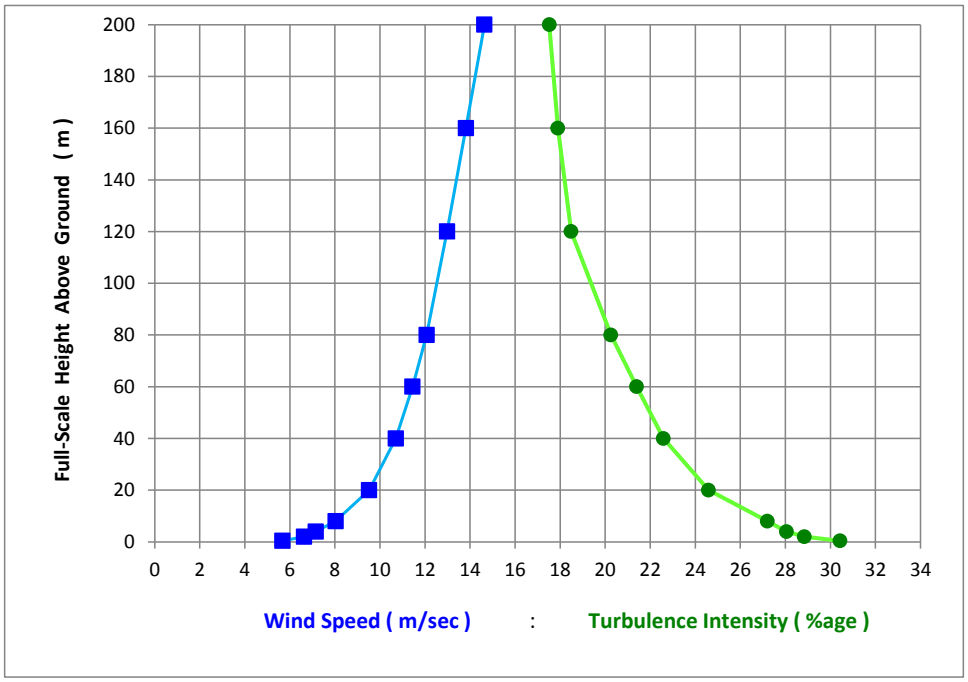
Similarity requirements between the wind tunnel model and prototype (ie full-scale) need to be fulfilled so that similitude in the flow conditions is satisfied. Usually all requirements cannot be satisfied and compromises need to be made. In this type of wind tunnel test it is possible to waive strict 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 5**.

Figure 5 Wind Tunnel Test Profiles for Mean Wind and Turbulence Intensity



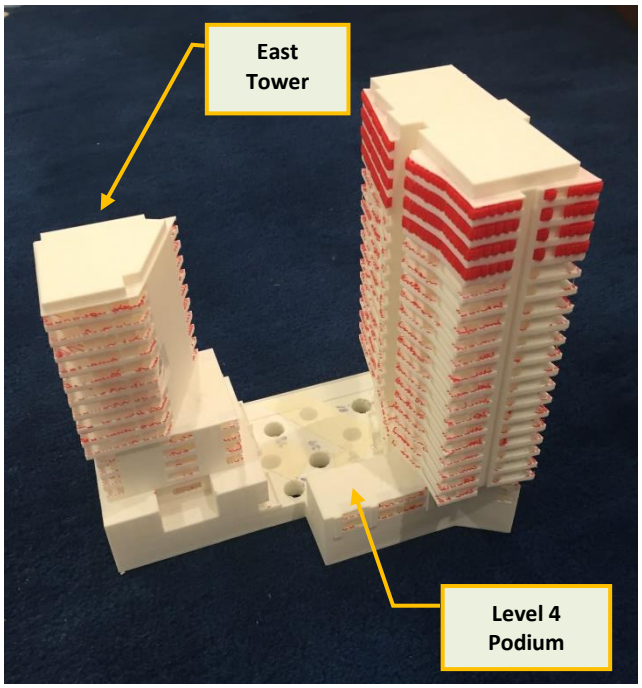
5.2 Development Model and Proximity Model

Development Model

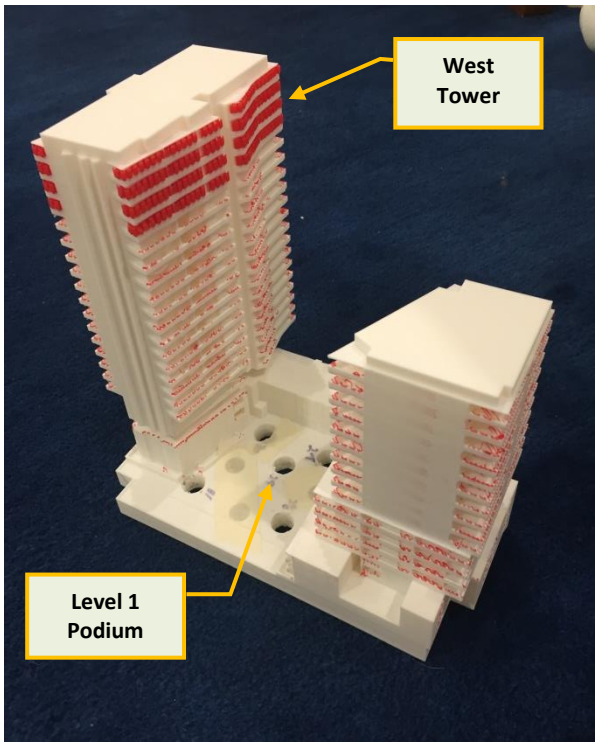
A 1:400 scale model of the proposed development was built (using 3D printing) for the testing – refer **Figure 6**.

Figure 6 1:400 Scale Model of the Proposed Development

View from North



View from Southeast



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**.

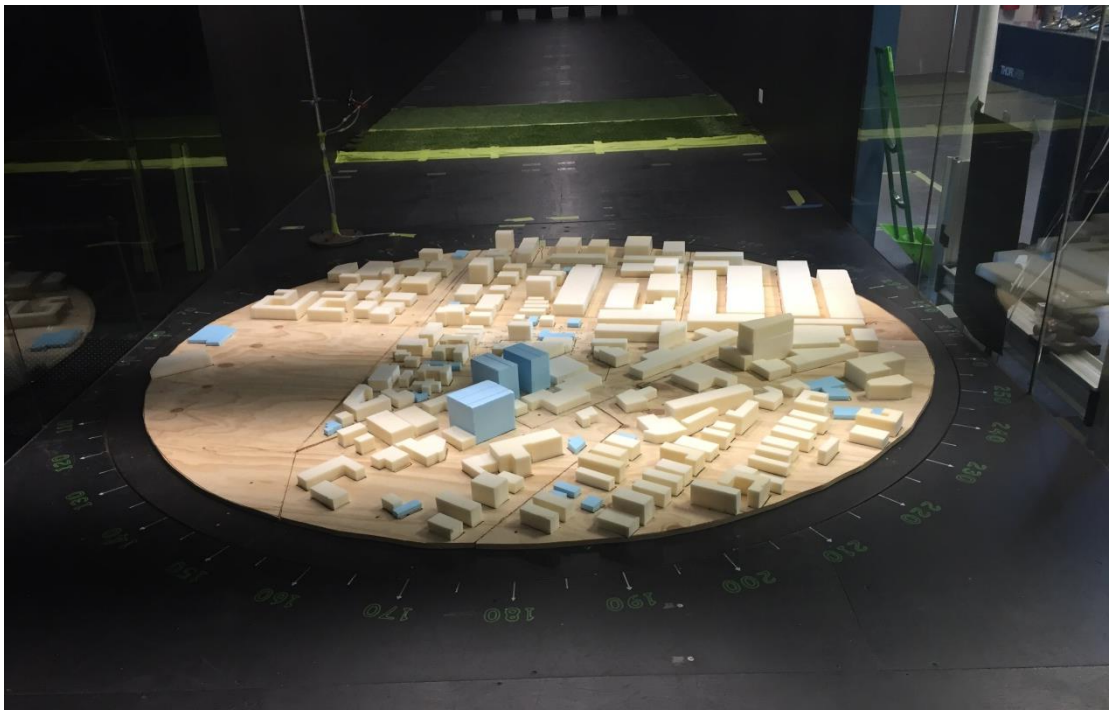
The proximity model simulates two built environment "scenarios":

- "Baseline" scenario: simulating the existing built environment (as of October 2018); and
- "Future" scenario: which includes the addition of the future proposed development.

Figure 7 Proximity Models Used in the Wind Tunnel Testing

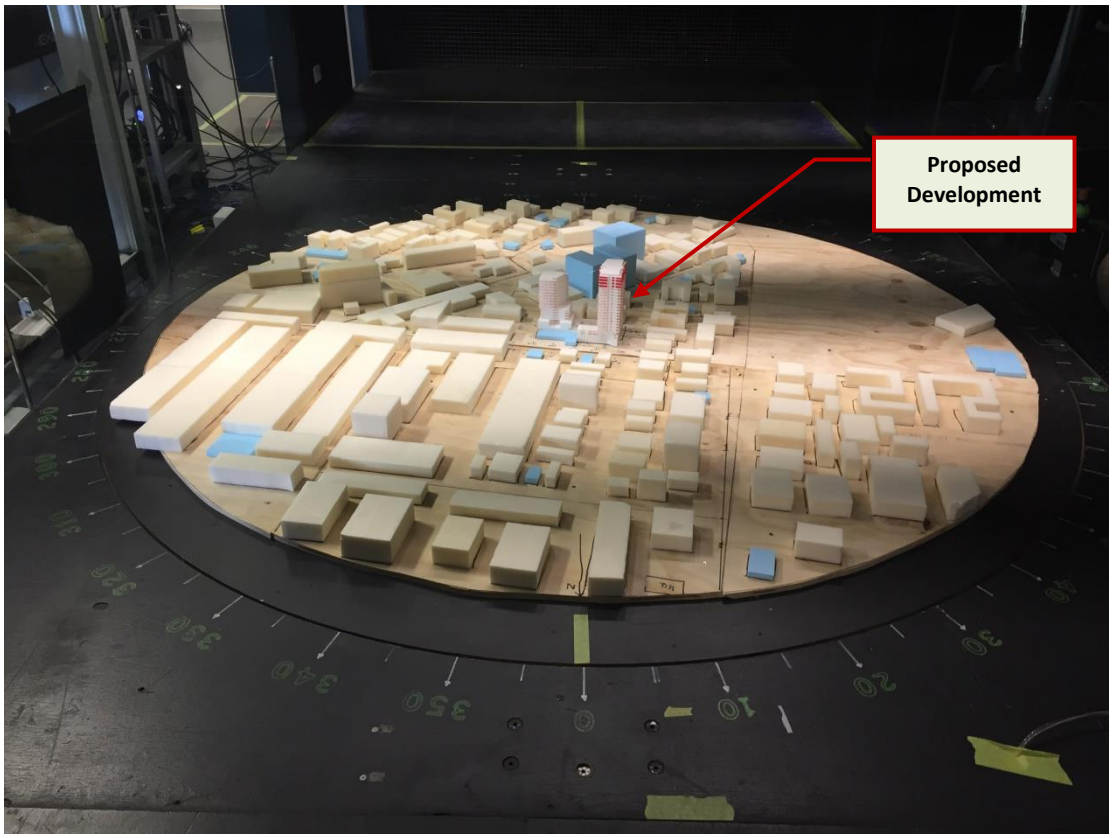
"Baseline" Scenario (Existing)

View from South



"Future" Scenario (with Proposal)

View from North



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 90-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.

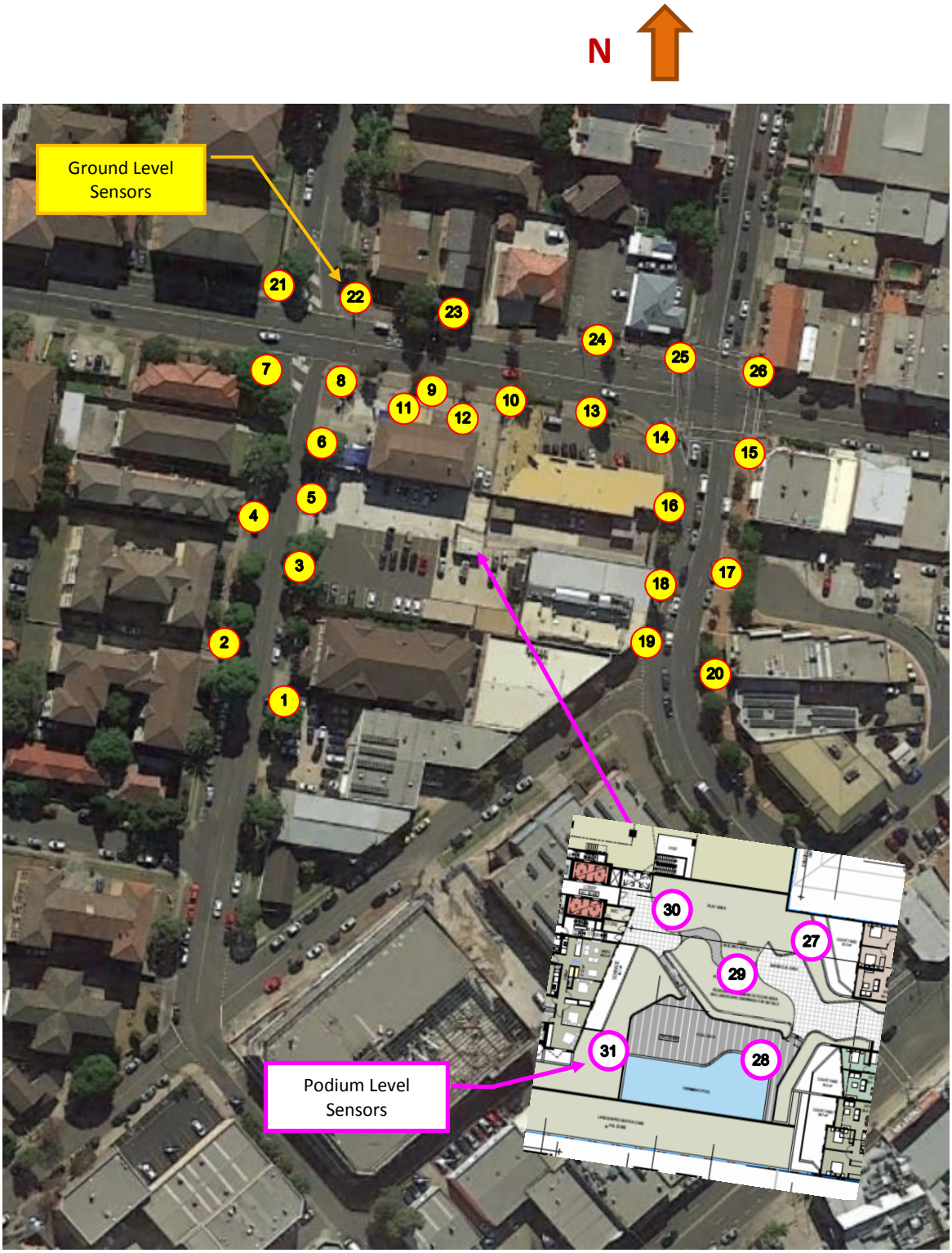
5.4 Test Method – Sensor Locations

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.

- The 26 Ground level sensors are shown in yellow; these positions were measured for both the "Baseline" and "Future" scenarios; and
- The 5 Podium level sensors are shown separately (purple circles); as these positions are located on the newly proposed development Podium, they were only measured for the "Future" scenario.

Figure 8 Wind Tunnel Test Sensor Locations



5.5 Sample Test Result

An example of the test results and interpretation of these results is shown in **Figure 9**, illustrating the peak annual mean and gust wind speeds at:

Sensor:	**Location 8**
Location:	Bathurst Street footpath at southwest corner of proposal site

The polar diagram shows the output of the wind tunnel test results in terms of:

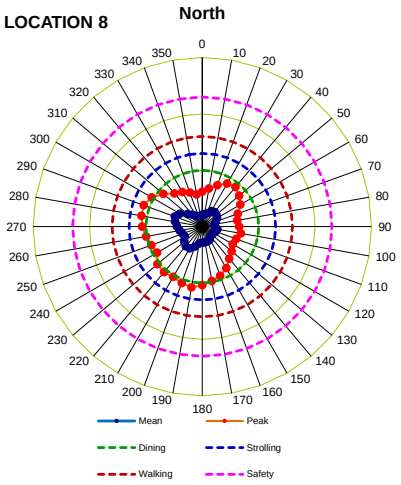
Mean wind speed:	"navy blue" data points
Gust wind speed:	"red" data points.

The polar diagram also includes three circumferential lines representing criteria for:

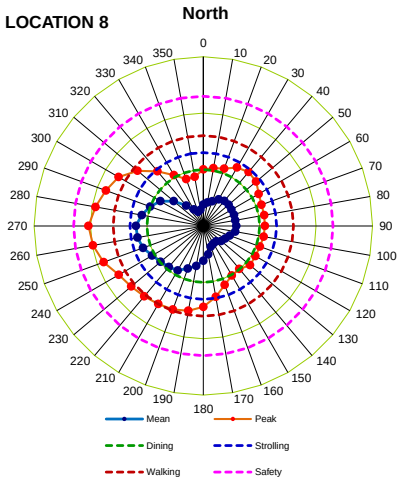
Public Safety:	23 m/s (purple)
Walking Comfort:	16 m/s (ochre)
Strolling Comfort:	13 m/s (blue)
Dining Comfort:	10 m/s (green)

Figure 9 Sample Polar Plot Test Result – Location 8 – "Baseline" & "Future" Scenarios

"Baseline" Scenario



"Future" Scenario



For the **"Baseline"** scenario …

- Winds at Location 8 are strongest from the south around to the west, and then northeast, where winds are both from these directions and can channel along relevant thoroughfares: Castlereagh Street for southerly winds, Memorial Avenue for westerly winds.

For the **"Future"** scenario …

- With the addition of the proposed development, winds at Location 8 increase from the west and northwest, exceeding the Melbourne 16 m/s walking comfort criterion for the westerly wind direction. These winds reflect the impact of accelerated windflow around the development's northwest corner.

6 TEST RESULTS

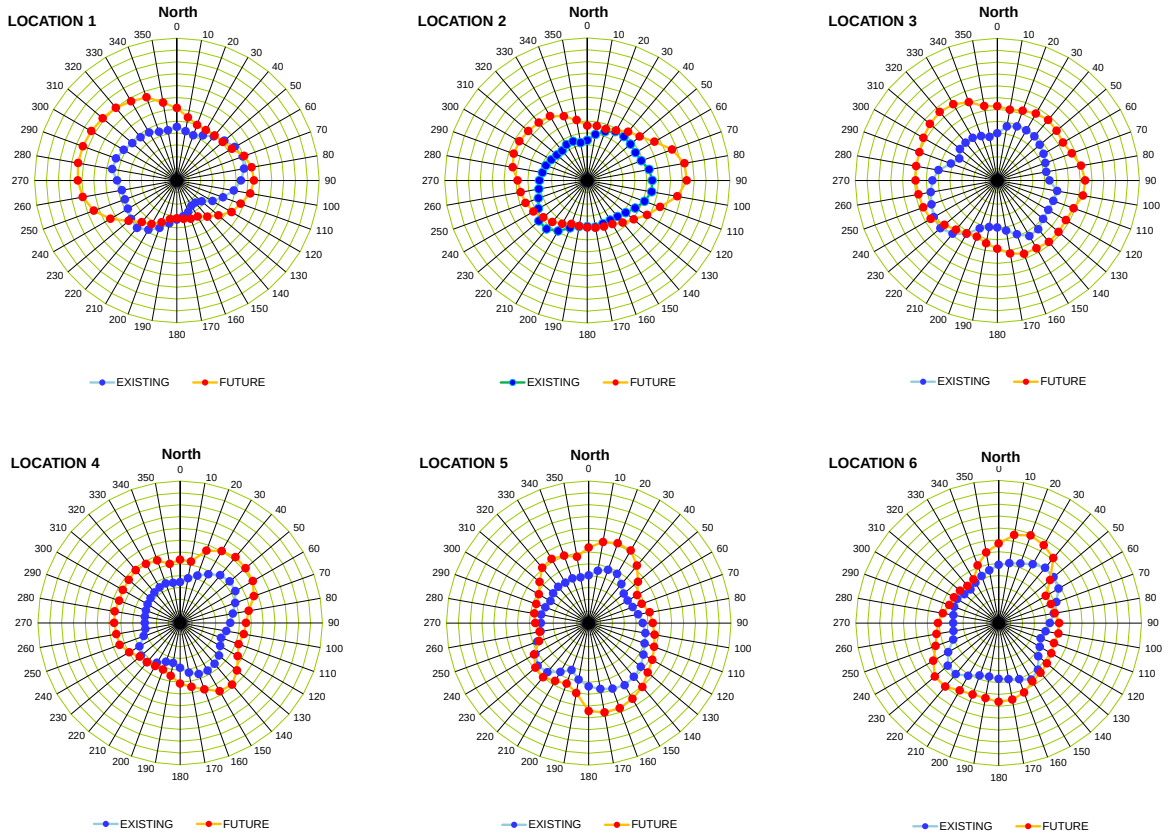
Appendices B & C shows the relevant wind tunnel test result polar plots respectively for all locations for the "Baseline" (existing built environment) and "Future" (with the proposal) scenarios.

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: Castlereagh Street - Fig.10

- Winds along Castlereagh Street close to the site are currently highest for directions where wind channelling can take place in a roughly north-south direction or where winds can pass unsheltered over open areas, eg at Location 1 which lies adjacent to a carpark lot.
- At the southern end of the site, winds increase for westerly winds which impact the proposed development's west tower western facade creating downwash below.
- Close to the intersection of Castlereagh Street and Memorial Avenue, wind conditions increase for northerly and southerly winds, again reflecting windflow moving past the proposed development's west tower western façade.

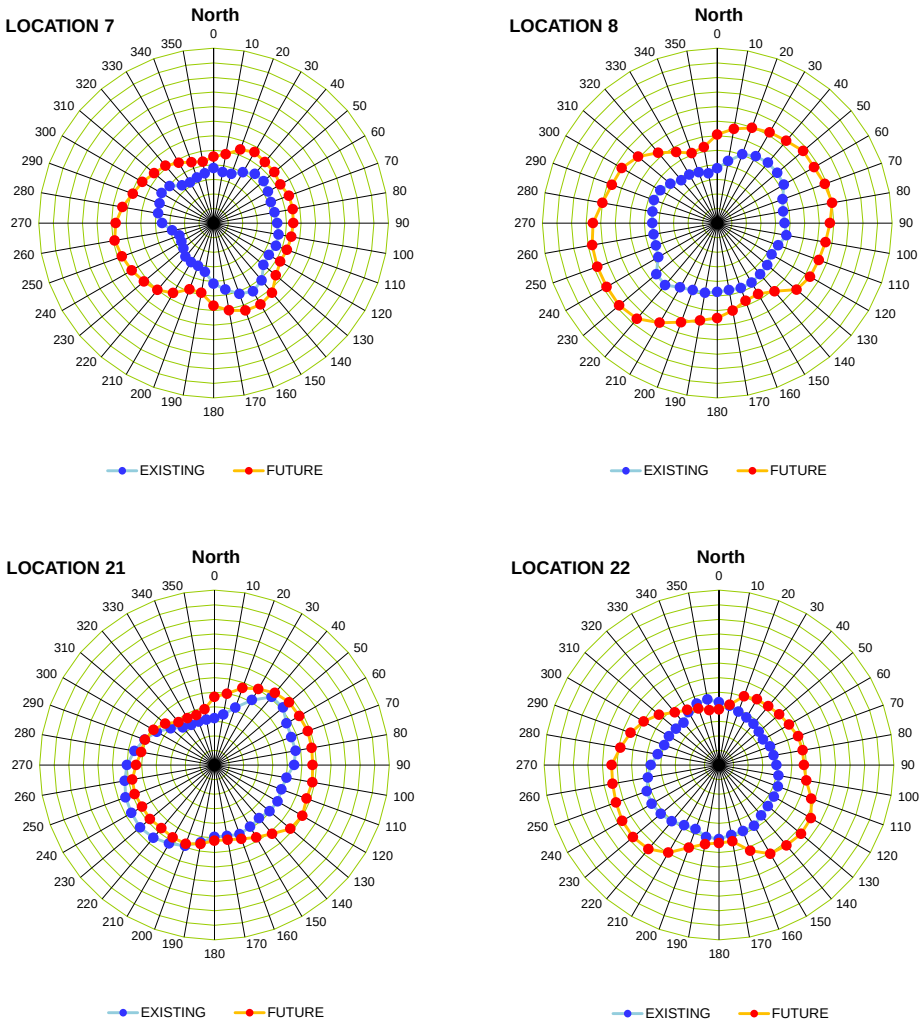
Figure 10 Peak Annual Gusts V/Vref: "Baseline" versus "Future" Scenario – Locations 1-6



6.2 Sensor Locations: Castlereagh Street and Memorial Avenue - Fig.11

- Winds at the intersection of Castlereagh Street and Memorial Avenue display an even spread for all the dominant Sydney region wind directions (northeast, southeast, south and west) and reflect the mainly low-rise nature of surrounding buildings.
- With the addition of the proposed development, winds are predicted to increase noticeably at the northwest corner of the site (Location 8) for both westerly winds and northeasterly winds as winds accelerate past the northwest corner of the site.
- Winds at the other three intersection locations (Locations 7,21,22) are less affected by the proposed development, eg winds at the opposite footpath corner to Location 8 (ie Location 21) are only slightly impacted by the proposed development.

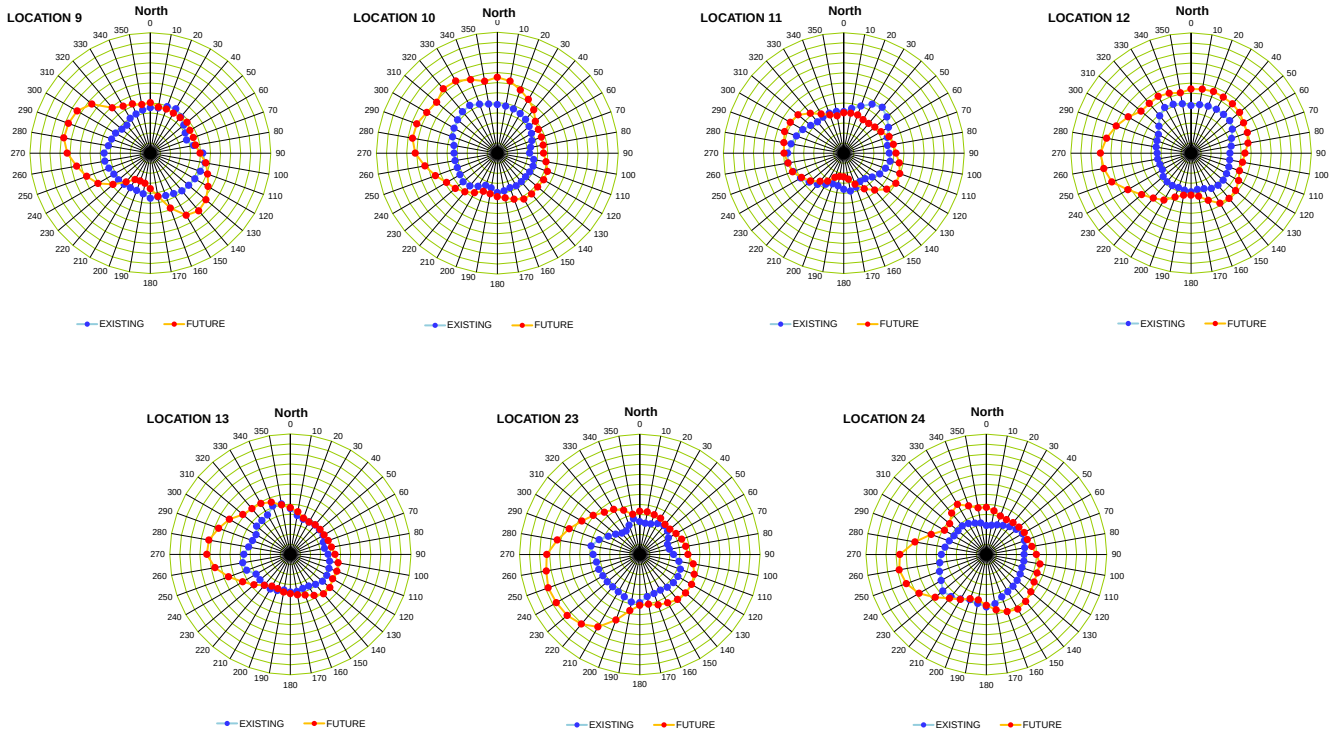
Figure 11 Peak Annual Gusts V/Vref: "Baseline" versus "Future" Scenario – Locations 7-8, 21-22



6.3 Sensor Locations: Memorial Avenue - Fig.12

- Winds along Memorial Avenue display an even spread for all the dominant Sydney region wind directions (northeast, southeast, south and west) with a slight east-west bias indicating moderate channelling along this thoroughfare.
- With the addition of the proposed development, winds are predicted to increase for westerly winds in particular, reflecting the downwash effect of westerly winds passing around the northern façade of the development's west tower.
- The set-back of the proposed development's east tower (the existing building at northeast corner of the block will remain) results in minimal impact along Memorial Avenue for winds from east quadrants (northeast and southeast).

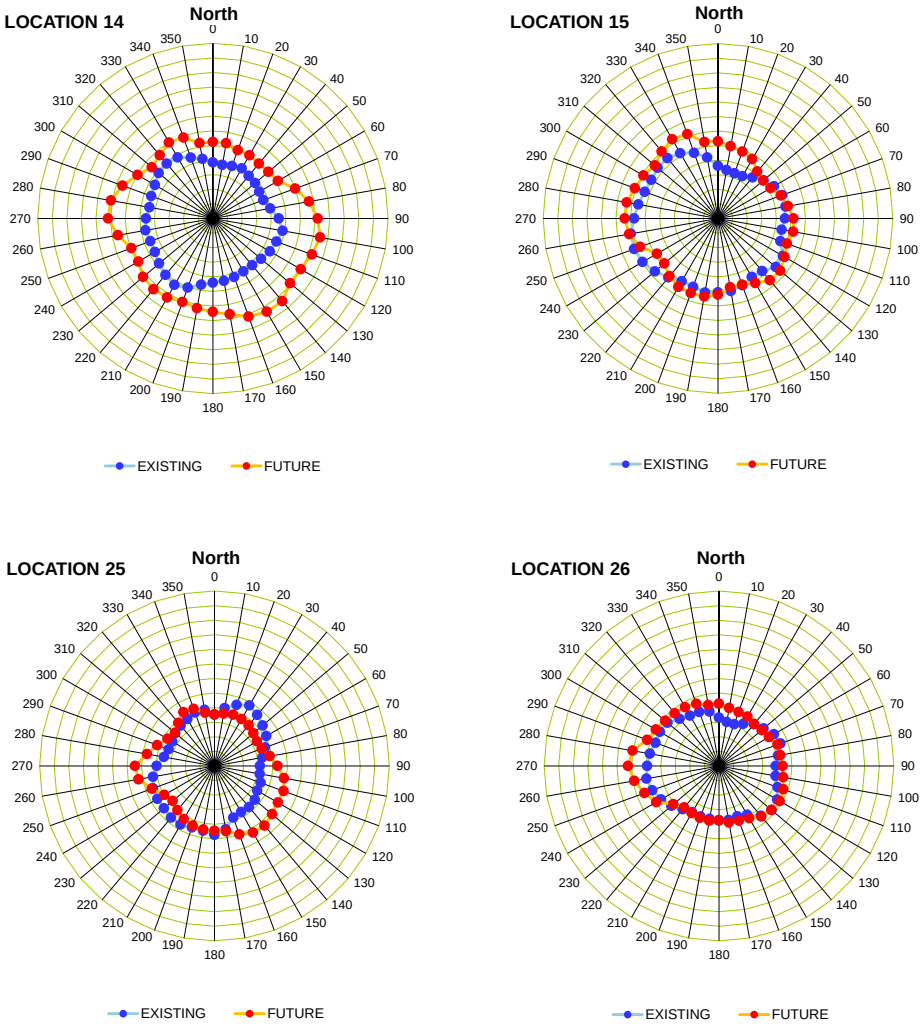
Figure 12 Peak Annual Gusts V/Vref: "Baseline" versus "Future" Scenario – Locations 9-13, 23-24



6.4 Sensor Locations: Memorial Avenue and Bathurst Street - Fig.13

- Winds at the intersection of Castlereagh Street and Memorial Avenue display an even spread for all the dominant Sydney region wind directions (northeast, southeast, south and west) and reflect the mainly low-rise nature of surrounding buildings.
- With the addition of the proposed development, winds are predicted to increase at the northeast corner of the block (Location 14) for southeasterly winds, reflecting moderate downwash flow off the proposed development's east tower.
- Winds at the other three intersection locations (Locations 15,25,26) are only minimally affected by the proposed development.

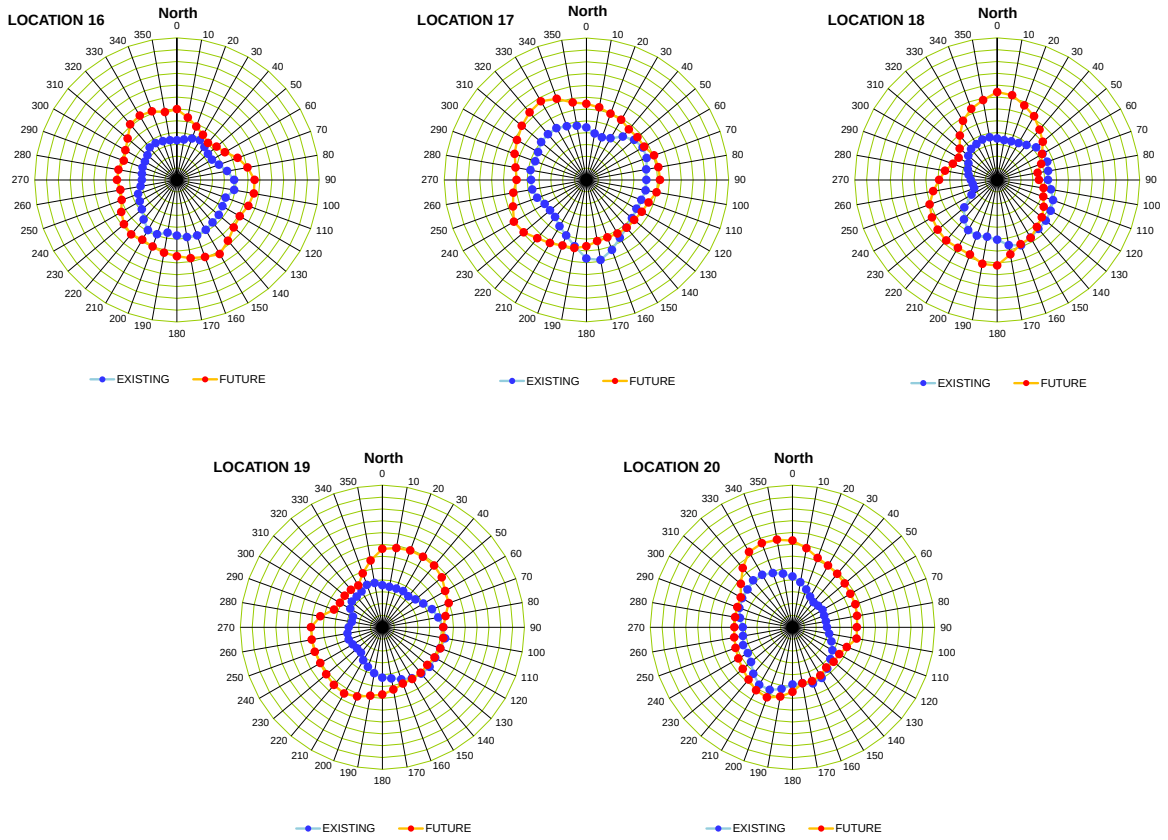
Figure 13 Peak Annual Gusts V/Vref: "Baseline" versus "Future" Scenario – Locations 14-15, 25-26



6.5 Sensor Locations: Bathurst Street - Fig.14

- Winds along Bathurst Street close to the site are currently highest for directions where wind channelling can take place in a roughly north-south direction or where winds can pass unsheltered over open areas, eg at Location 20 which is exposed to southwesterly winds approaching from Norfolk Street.
- With the addition of the proposed development, winds along Castlereagh Street are predicted to increase for both northerly and southerly wind directions, reflecting windflow moving past the proposed development's east tower eastern façade.
- Away from the site, eg Location 20, winds only experience an increase for northerly wind conditions. At Location 19, near the southeast corner of the site, winds also experience an increase for southwest wind conditions, reflecting windflow conditions along Norfolk Street.

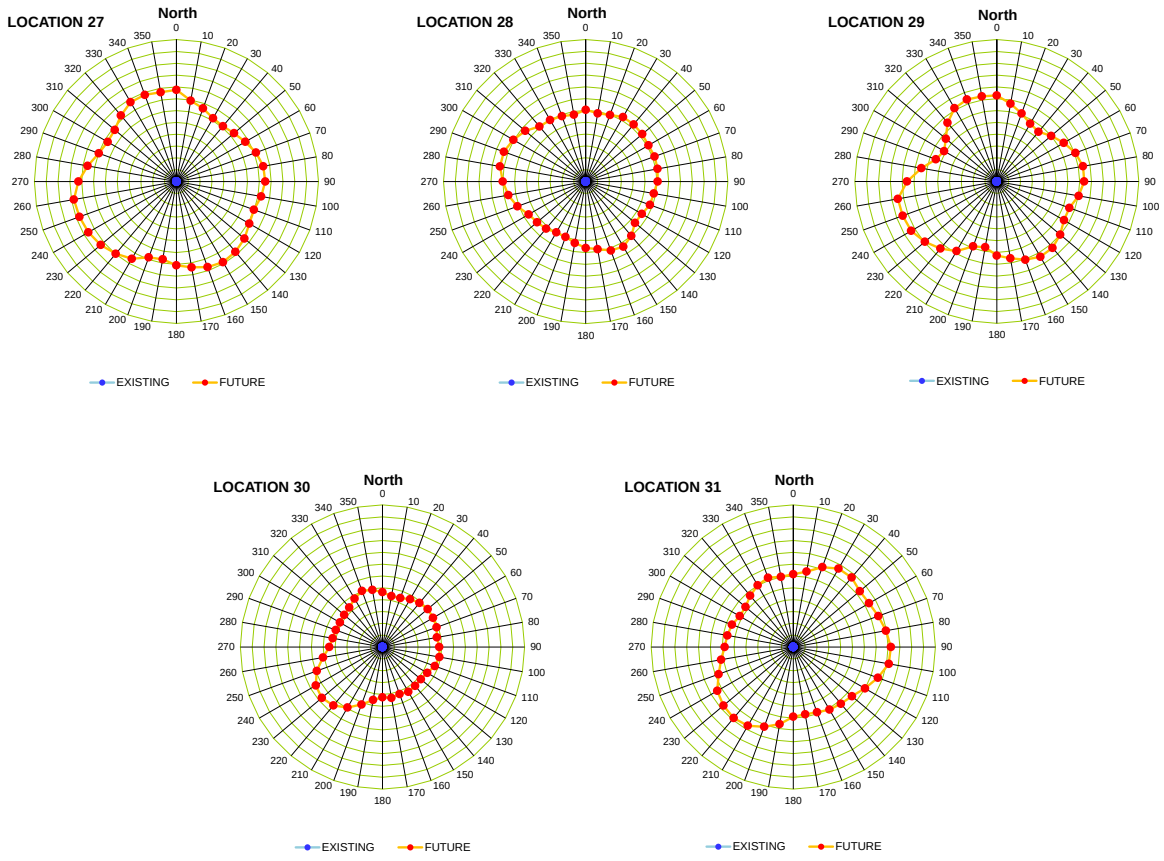
Figure 14 Peak Annual Gusts V/Vref: "Baseline" versus "Future" Scenario – Locations 14-20



6.6 Podium Sensor Locations - Fig.15

- These are “Future” scenario locations located on Level 1, with extended communal spaces featuring play areas, seating areas and a pool with pool deck.
- Winds at these locations receive minimal sheltering from surrounding buildings and are mostly impacted by windflow interactions with the two high-rise components of the proposed development itself.
- This includes westerly winds passing around the southern façade of the proposed development’s west tower, northwesterly winds passing around the northeast corner of the proposed development’s west tower and over the Level 4 podium, northeast winds passing around the northern façade of the proposed development’s east tower and southerly winds channelling between both of the proposed development’s high-rise components.

Figure 15 Peak Annual Gusts V/Vref: “Baseline” versus “Future” Scenario – Locations 27-31



7 OVERALL WIND IMPACT

Table 2 gives the peak annual gust wind speeds predicted to occur at the test sensor locations for the "Baseline" and "Future" built environment scenarios, relevant to assessment of the Melbourne Criteria.

Table 2 Predicted Peak Gust Wind Speeds at all Sensor Locations

Sensor No and Location Description (refer Error! Reference source not found.)		Peak Annual Gust (m/s)	
		"BASELINE"	"FUTURE"
1	Castlereagh Street – east footpath, south of site	13.5	20.5
2	Castlereagh Street – west footpath, south of site	10	15.5
3	Castlereagh Street – east footpath, southwest corner of site	13	17
4	Castlereagh Street – west footpath, opposite site	9	13.5
5	Castlereagh Street – east footpath, midway along west tower façade	12	16.5
6	Castlereagh Street – east footpath, midway along west tower façade	10.5	14.5
7	Intersection Castlereagh Street & Memorial Avenue – SW corner	10	16
8	Intersection Castlereagh Street & Memorial Avenue – SE corner	11	20.5
9	Memorial Avenue – south footpath, at site	11	21
10	Memorial Avenue – south footpath, at site	11.5	21
11	Memorial Avenue – within site	13.5	15
12	Memorial Avenue – within site	10	21.5
13	Memorial Avenue – south footpath, east of site	11	20
14	Intersection Memorial Avenue & Bathurst Street – SW corner	11	17
15	Intersection Memorial Avenue & Bathurst Street – SE corner	14	15.5
16	Bathurst Street – west footpath, northeast corner of site	10.5	14
17	Bathurst Street – east footpath, opposite site	14.5	15.5
18	Bathurst Street – west footpath, at site	11.5	16
19	Bathurst Street – west footpath, southeast corner of site	9.5	14.5
20	Bathurst Street – east footpath, south of site	12	13.5
21	Intersection Castlereagh Street & Memorial Avenue – NW corner	14.5	13
22	Intersection Castlereagh Street & Memorial Avenue – NE corner	11.5	17.5
23	Memorial Avenue – north footpath, opposite site	12	22
24	Memorial Avenue – north footpath, east of site	11.5	20.5
25	Intersection Memorial Avenue & Bathurst Street – NW corner	10.5	13
26	Intersection Memorial Avenue & Bathurst Street – NE corner	12	15
27	Level 1 Podium – NE quadrant	*Refer Note 2*	20
28	Level 1 Podium – SE quadrant		18
29	Level 1 Podium – central		19.5
30	Level 1 Podium – NW quadrant		13
31	Level 1 Podium – SW quadrant		15.5

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 27-310 are Podium locations and only exist in the "Future" scenario

7.1 Wind Impact Relative to Intended Usage

Pedestrian Footpath Areas Surroduning the Site

Wind category objective: 16 m/s Walking Comfort criterion

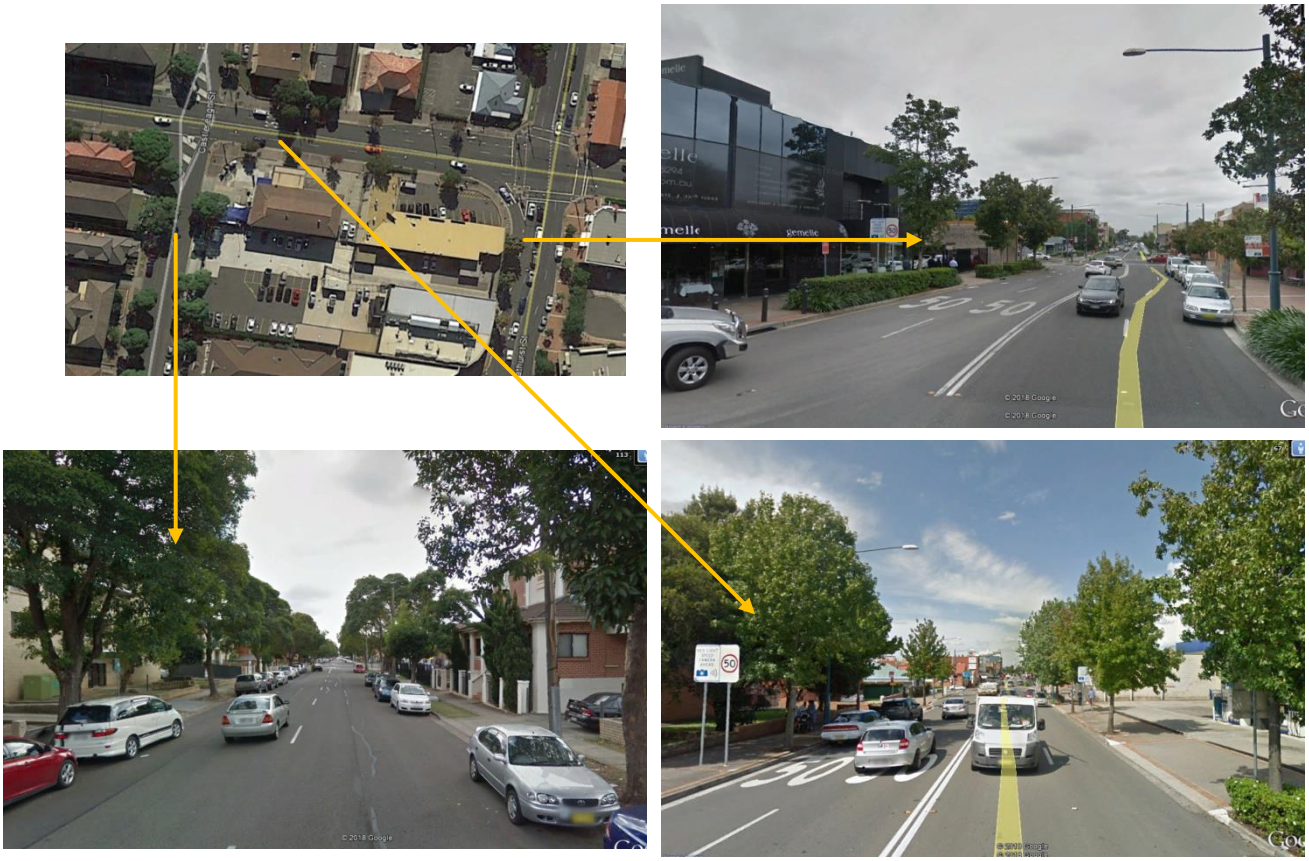
Ground level locations surrounding the site (to the west, north and east) have the potential to experience increases in wind speed for key prevailing wind directions (northeast, southeast, south and west).

- In terms of the Melbourne Criteria, these locations typically currently experience peak annual gusts which lie within the 16 m/s walking comfort criterion.
- In the "Future" scenario, a number of these locations have the potential to exceed the 16 m/s walking comfort criterion, but remain below the 23 m/s safety criterion.

Observation:

- Wind conditions predicted in the wind tunnel testing did not have the advantage of the mature and extensive vegetation and trees along the footpath areas of interest – refer **Figure 16**. These would have an ameliorating (ie sheltering) effect, in some cases significant, on local wind speeds; and throughout the year, provided they comprise evergreen species.

Figure 16 Vegetation and Trees along Surrounding Footpath Areas



Podium Areas

Wind category objective: 13 m/s Standing-Waiting-Window Shopping criterion
Ideally 10 m/s Outdoor Dining criterion for seating areas intended for dining

The proposed development's Podium has the potential to generate elevated wind conditions as windflow accelerates around the development's high-rise components and is directed downwards as downwash and accelerated shear flow.

- In terms of the nominated wind acceprtability critieria, almost all Podium locations may potentially exceed the 13 m/standing-waiting-window shopping criterion. Locations 27 to 29 may also potentially exceed the 16 m/s walking comfort criterin.

Observation:

- It is important to note that wind conditions on the new Podium were tested in the wind tunnel without the benefit of any of the landscaping, pergolas, etc, including the perimeter planting already proposed for the Podium.
- It is also important to appreciate that, while the Podium has the potential to attract elevated winds from building floors above (downwash, etc), these winds are thereby prevented from generating the same impact at ground level locations immediately below. The Podium therefore plays a potentially important role in ameliorating ground level wind conditions in surrounding pedestrian areas.

8 MITIGATION 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).

The wind conditions of potential concern in relation to the proposed development revealed by the wind tunnel study are:

- Selected footpath areas along Castlereagh Street, Memorial Avenue and Bathurst Street; and
- Locations throughout the Level 1 Podium.

8.1 Already Planned Wind Amelioration Treatments

It has been noted that the current round of wind tunnel testing did not include the following features, all of which would have had an ameliorating impact on local wind speeds:

- Vegetation and Trees along surrounding thoroughfares - refer **Figure 16**;
- Awnings surrounding the proposed development's façade – refer **Figure 17**; and
- Extensive landscaping and pergolas planned for the Level 1 Podium – refer **Figure 18**.

Figure 17 Already Planned Level 1 Canopies

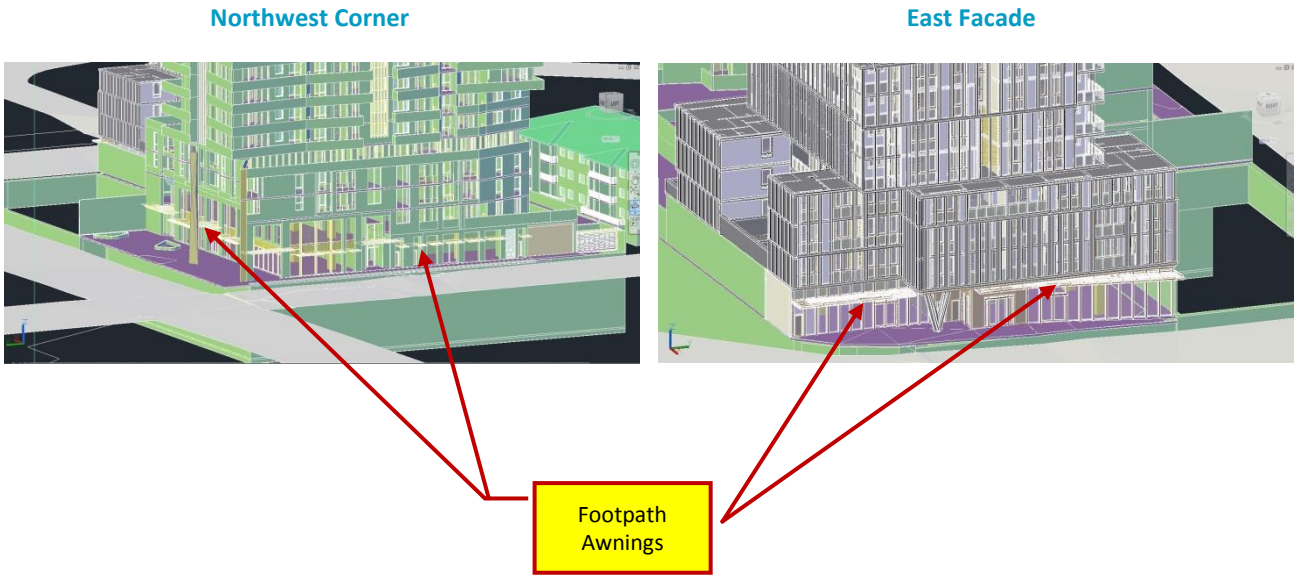


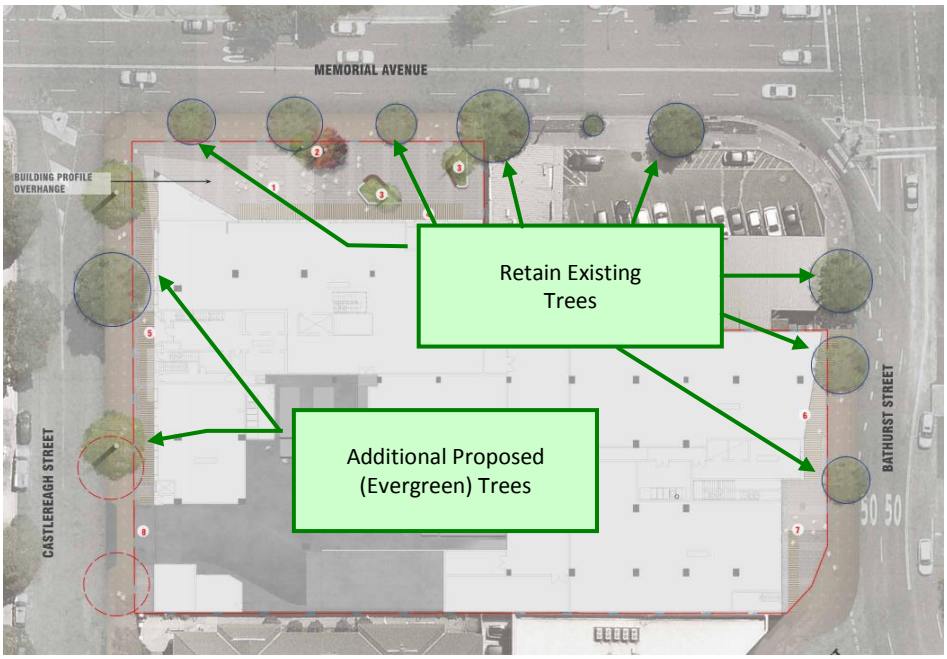
Figure 18 Already Planned Landscaping for Level 1 Podium (View from North)

Pedestrian Areas Surrounding the Site

Current plans for the proposed development retain the significant landscaping surrounding the site along Castlereagh Street, Memorial Avenue and Bathurst Street – refer **Figure 19**.

We recommend retaining the already planned trees along the Castlereagh Street, Memorial Avenue and Bathurst Street footpaths and adding in two additional trees of evergreen variety as shown in **Figure 19**.

Figure 19 Proposed Additional Ground Level Landscaping



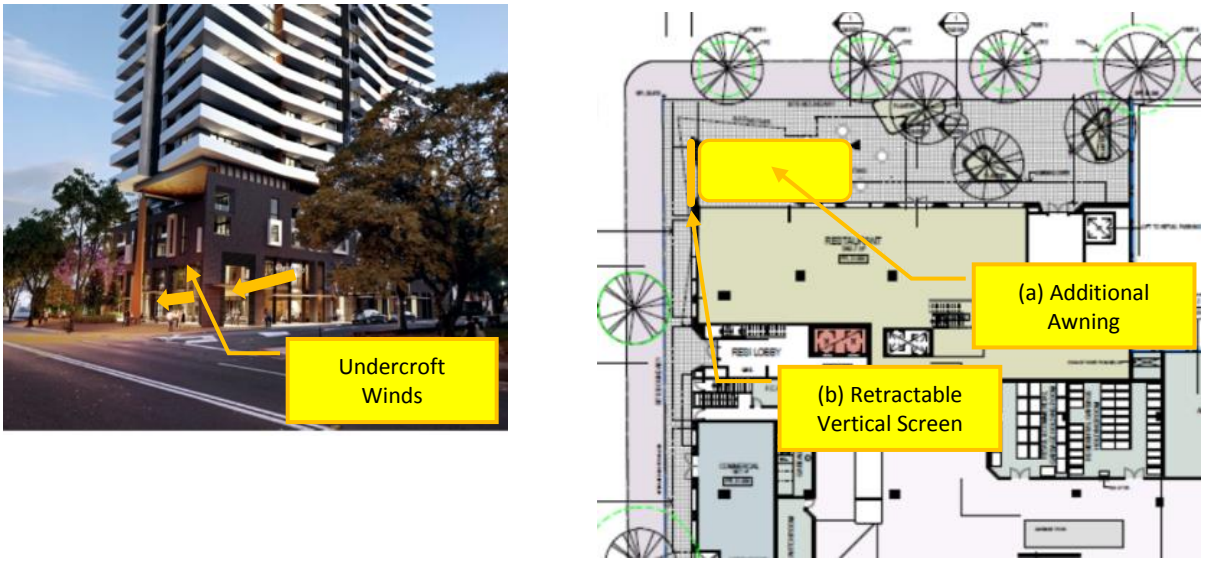
Ground Level Protective Awnings

Current plans for the proposed development show extensive awnings around the development's western, northern and eastern facades – refer **Figure 17**. These will assist in protecting relevant footpath areas.

The wind tunnel testing indicated elevated wind speeds along Memorial Avenue along the northern façade of the west tower. There is an outdoor dining area in this location which will be exposed to "undercroft" winds from the west – refer left diagram **Figure 20**.

Noting the intended usage of this area, if it is intended for outdoor dining to be made available on an all-year round basis, we recommend either (a) a full width canopy at Level 1 elevation extending out from the main building façade line of the west tower to the two external feature columns or (b) a vertical, retractable screen filling in the opening which allows the undercroft winds – refer right diagram **Figure 20**.

Figure 20 Proposed Additional Ground Level Awning



Podium – Level 1

The test results indicated the potential for elevated winds in a number of areas throughout the Level 1 Podium. Because of physical constraints associated with the scale used in the testing, none of the planned wind mitigation elements (landscaping, shadecloth, pergolas, awnings, etc) were incorporated in the testing. On this basis, the following is recommended:

- All of the currently planned extensive landscaping and horizontal windbreaks (shadecloth, pergolas, awnings, etc) should be retained;
- Seating areas in particular should be provided with such horizontal windbreaks;
- A full perimeter 1.8 m high balustrade should be provided along any open perimeter areas of the Podium (northeast section and southern perimeter). The balustrade could be enabled through any combination of "barrier", eg solid parapet wall, combination parapet wall plus planting, glazing, etc.

8.2 Areas Not Assessed Via Wind Tunnel Testing

Due to currently intended usages (or rather absence of public access usage) and the physical constraints associated with the scale used in the testing, a number of areas were not tested in the present DA-phase assessment, including:

- The "Exercise Court" located midway along the northern façade of the east tower at Level 1
- The landscaped Level 4 roof terrace located at the northeast corner of the west tower at Level 4;
- The Level 4 extended terraces at each corner of the east tower;
- The Level 8 extended terrace of the east tower;
- Balconies throughout the proposed development's high-rise components; and
- The development's Roof Levels (West Tower Level 24 and East Tower Level 18) which currently show no areas of public access on the development drawings, but have dedicated solar panel arrays.

East Tower Level 1 "Exercise Court"

This terrace will be exposed to winds from the northeast (generally mild and cooling during summer) and the northwest (stronger and occurring in winter). However, given its intended usage and the perimeter balustrade which has been supplied with a planter box for landscaping, no further treatment is indicated for this location.

West Tower Level 4 Extended Terrace

This area will be exposed to winds from the northeast (generally mild and cooling during summer), the northwest (stronger and occurring in winter) and southwest to southeast (all-year, including stronger winds). On this basis, the following is recommended:

- All of the currently planned landscaping and horizontal windbreaks (pergolas, etc) should be retained and seating areas in particular should be provided with such horizontal windbreaks;
- A full perimeter 1.8 m high balustrade should be provided along all perimeter areas. The balustrade could be enabled through any combination of "barrier", eg solid parapet wall, combination parapet wall plus planting, glazing, etc.

East Tower Level 4 Corner Terraces

These terraces will be exposed to winds from at least several prevailing wind directions depending upon location, eg the southeast corner terrace will be exposed to northeast, southeast and southerly winds. They have all been provided with a perimeter balustrade and planting.

These areas do not appear to be accessible to the public; accordingly, no further treatment is indicated.

East Tower Level 8 Extended Terrace

This area will be exposed to elevated wind conditions for northwest winds (impacting the east tower's northwest facing façade) and south to southwest winds. Current plans appear to show this terrace not being accessible to the public. If this is not the case, the following is recommended:

- All of the currently planned landscaping and horizontal windbreaks (awnings, etc) should be retained and seating areas in particular should be provided with such horizontal windbreaks;

- A full perimeter 1.8 m high balustrade should be provided along all perimeter areas. The balustrade could be enabled through any combination of "barrier", eg solid parapet wall, combination parapet wall plus planting, glazing, etc.

Upper Level Balconies

The two high-rise components of the proposed development (east and west towers) have balconies around all facades, including at building corners.

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 which are exposed to stronger southerly and westerly 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.

Indeed, the proposed development's west tower has already been provided with movable balcony screens from Level 19 upwards. At this stage, upper levels of the proposed development's west tower have not been provided with such movable screens.

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

- Further detailed modelling is carried out (via CFD simulation) to confirm zones of the proposed development's high-rise components, by height and by plan view location (eg building corners), where wind mitigation is indicated (ie beyond the standard balustrade height). 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.
- The above recommendation does not apply to the west tower Levels 19-23, where movable balcony screens have already been designed.

High-Rise Tower Roof Level Areas

The above upper-level balcony recommendations would normally apply also to any public access areas located on the proposed development's two high-rise Roof Levels, where a combination of both vertical screening (eg solid balustrades, balustrades combined with planter boxes, etc) and horizontal screening might normally be required to ensure all-year-round amenity, especially areas exposed to southerly and westerly winds.

However, these areas are currently designated for solar panel arrays with no public access areas. Accordingly, no wind mitigation is recommended for these areas, although the high winds likely to occur in these locations suggest additional care will need to be taken in considering the structural wind loading of the solar panels.

Taking into account all of the above, it is believed that the proposed development
will comply with the adopted wind acceptability criteria
at all pedestrian and public access locations within and around the development.

9 CLOSURE

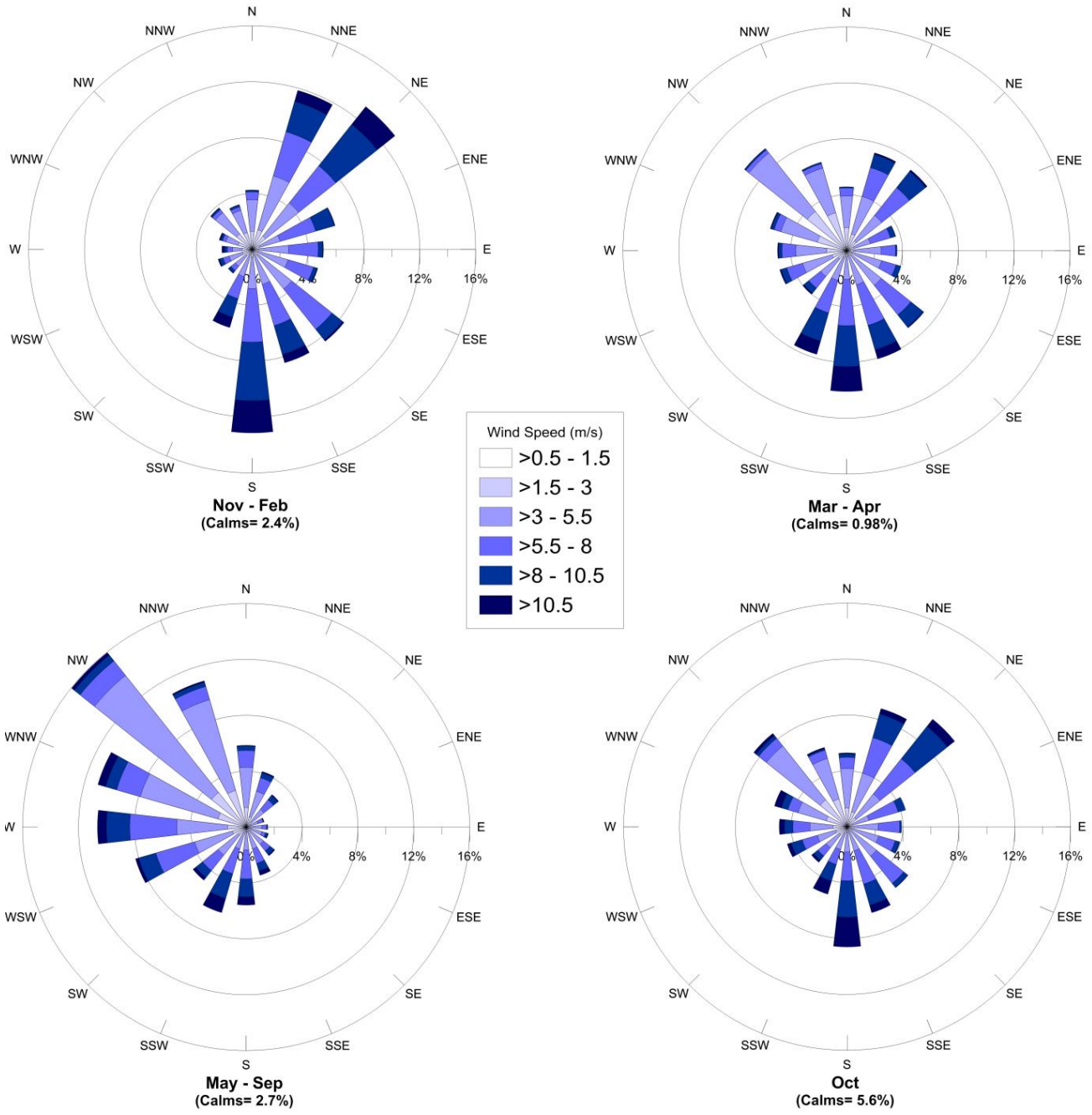
This report has been prepared by SLR Consulting Australia Pty Ltd with all reasonable skill, care and diligence, and taking account of the manpower and resources devoted to it by agreement with the client. Information reported herein is based on the interpretation of data collected and has been accepted in good faith as being accurate and valid.

This report is for the exclusive use of Il Capitano Investments Pty Ltd. No warranties or guarantees are expressed or should be inferred by any third parties. This report may not be relied upon by other parties without written consent from SLR Consulting.

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



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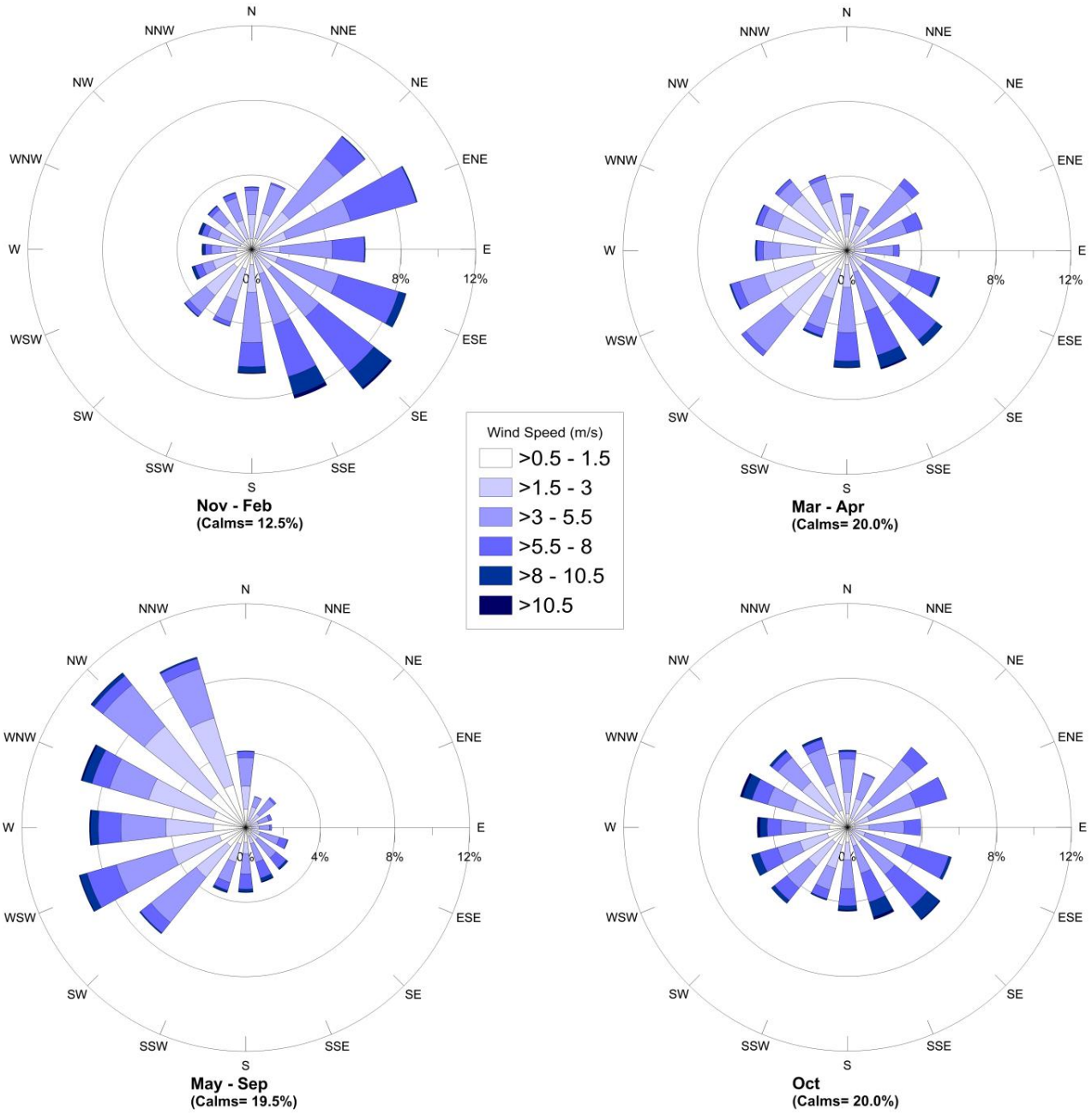
Seasonal Wind Roses for Bureau of Meteorology Met Stations at Sydney (Kingsford Smith) Airport and Bankstown Airport

Bankstown Airport AWS
(Observations)
1999-2017
600.09300

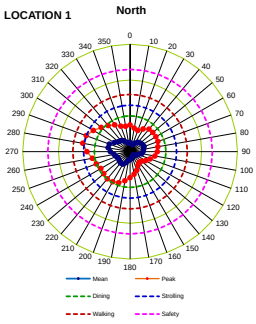


APPENDIX B

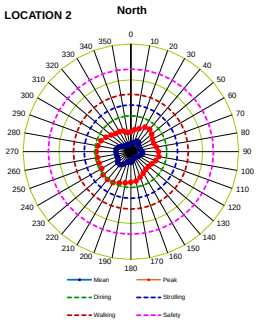
Wind Tunnel Test Results: BASELINE Scenario

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

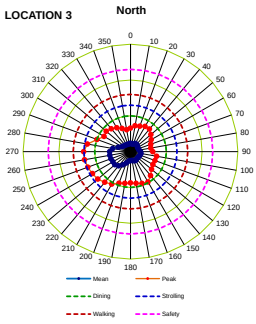
LOCATION 1



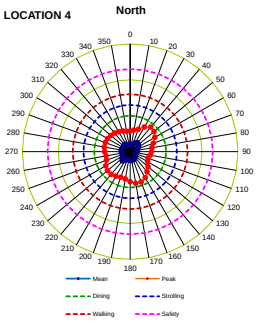
LOCATION 2



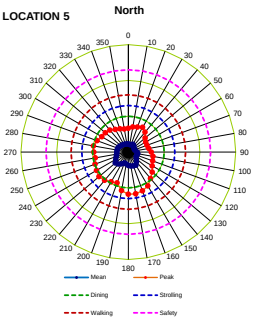
LOCATION 3



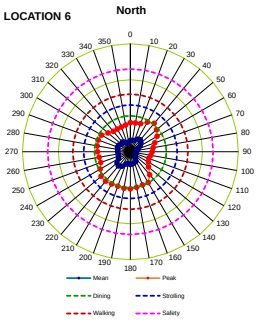
LOCATION 4



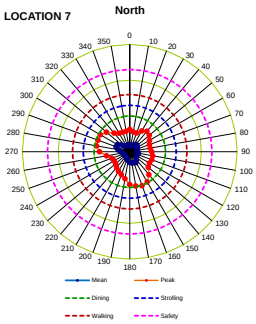
LOCATION 5



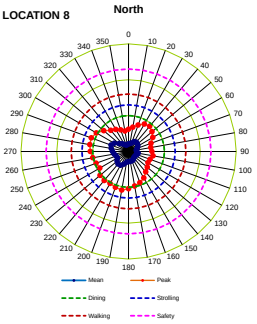
LOCATION 6



LOCATION 7



LOCATION 8



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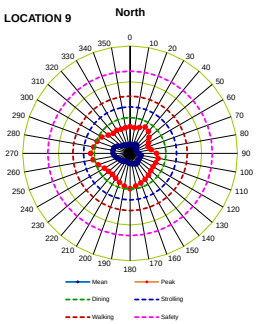

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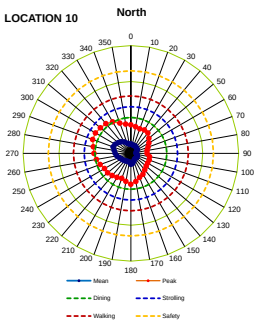

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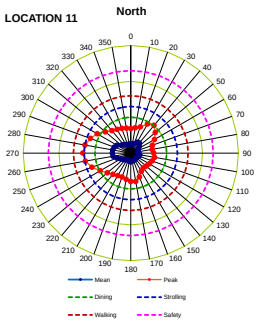

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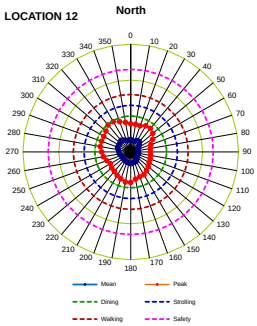

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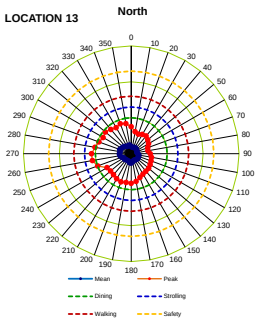

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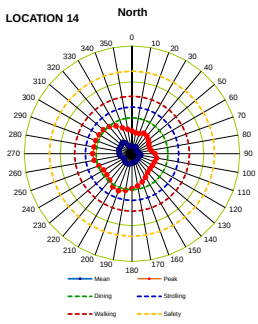

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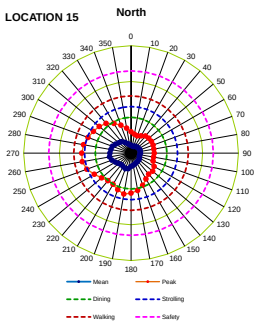

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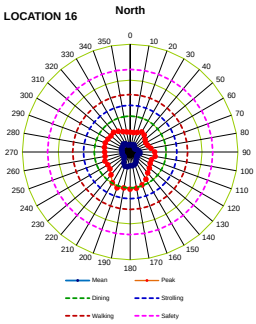
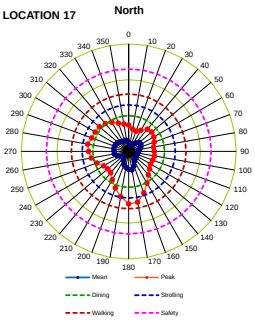


APPENDIX B

Wind Tunnel Test Results: BASELINE Scenario

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

LOCATION 17



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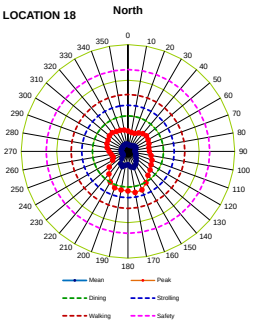

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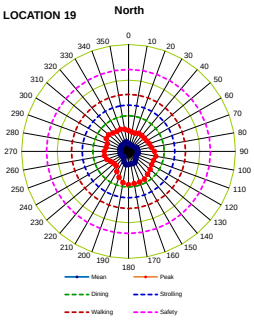

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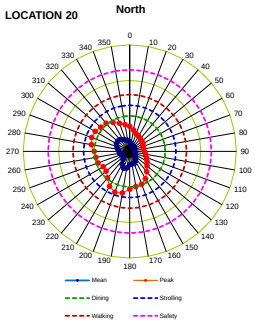

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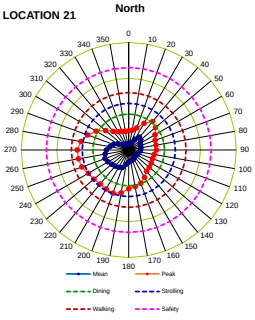

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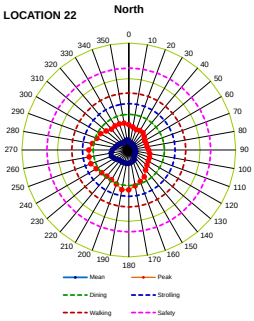

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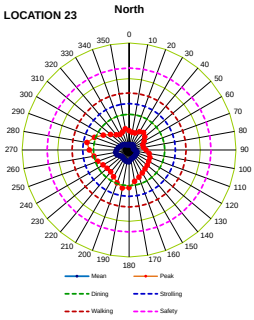

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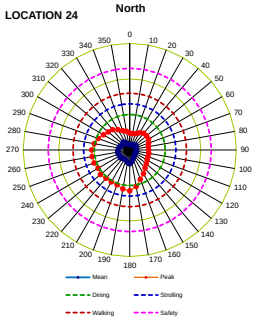

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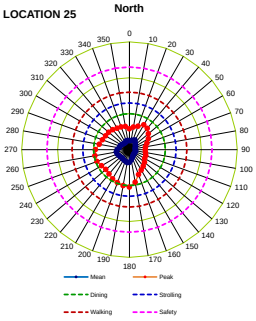

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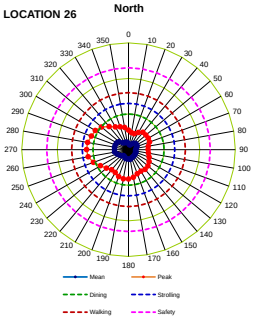

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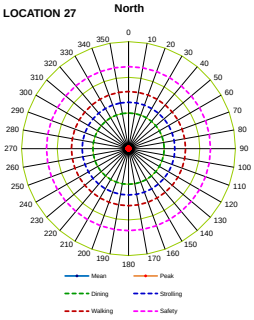

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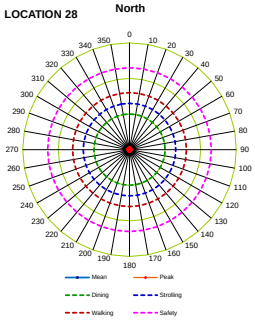

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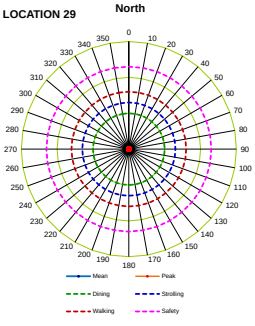

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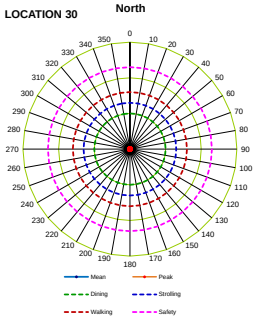

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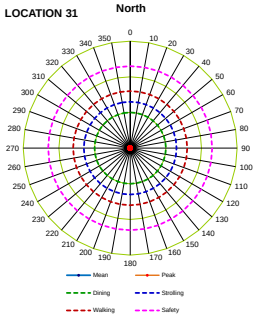

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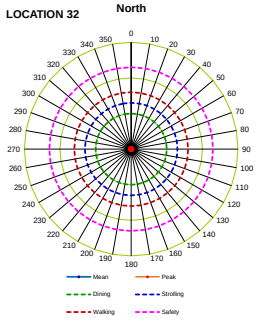
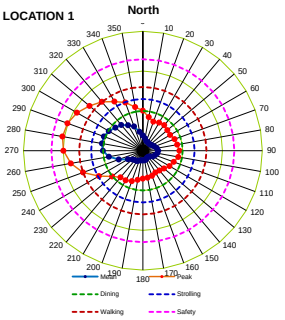


APPENDIX C

Wind Tunnel Test Results: FUTURE Scenario

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

LOCATION 1



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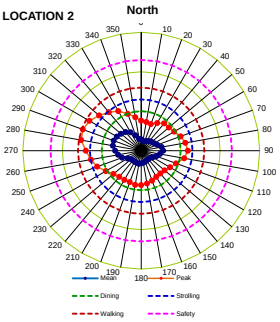

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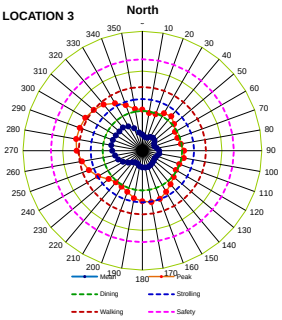

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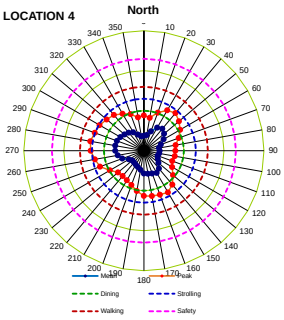

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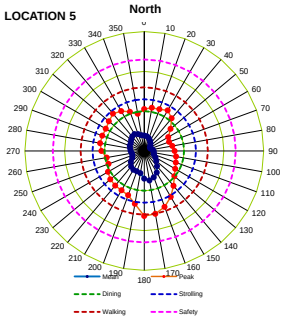

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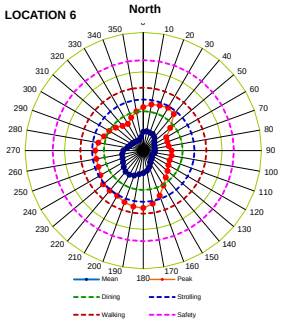

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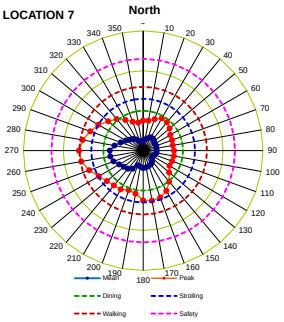

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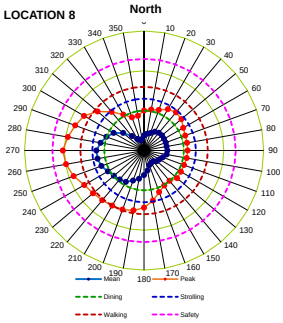

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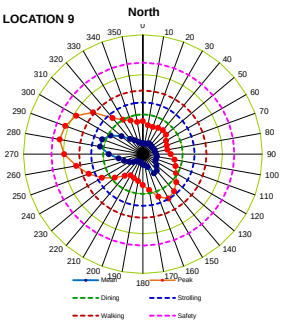

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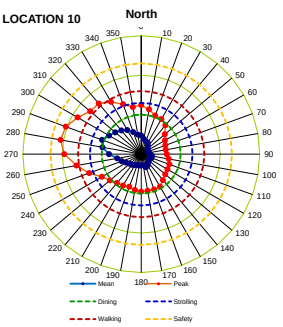

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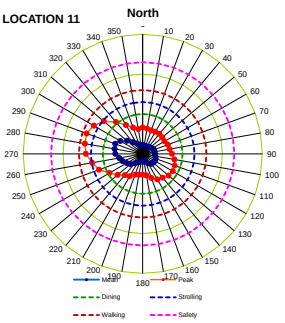

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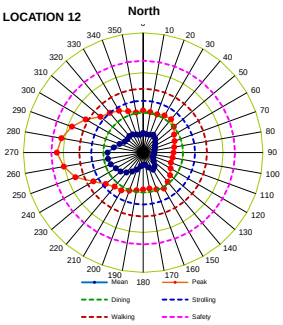

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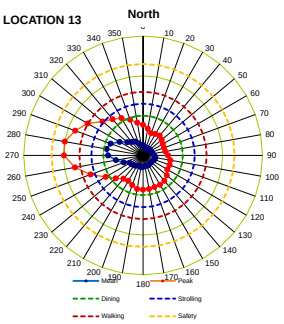

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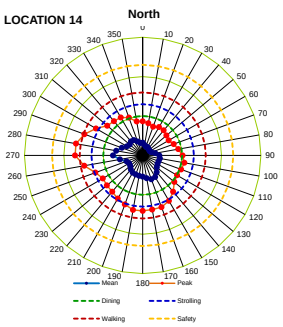

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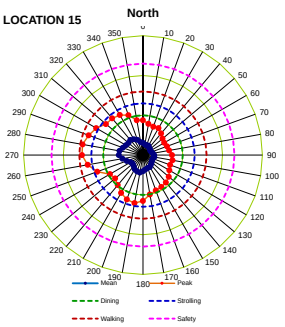

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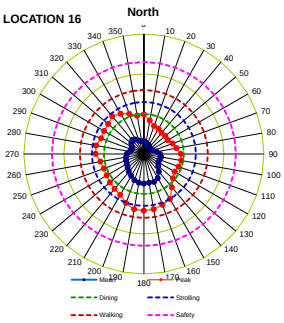
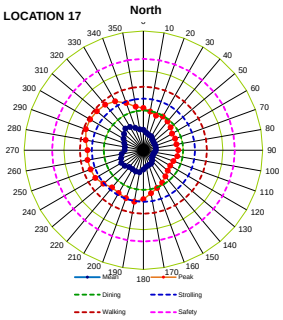


APPENDIX C

Wind Tunnel Test Results: FUTURE Scenario

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

LOCATION 17



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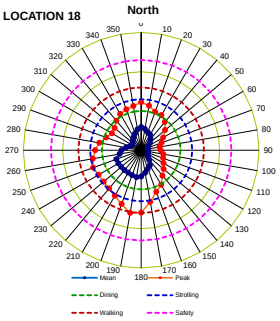

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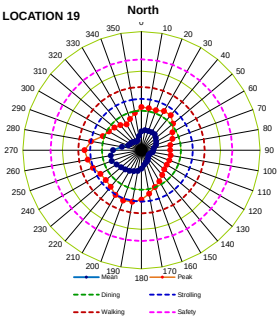

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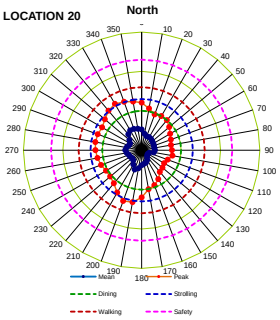

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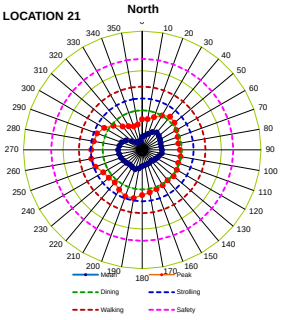

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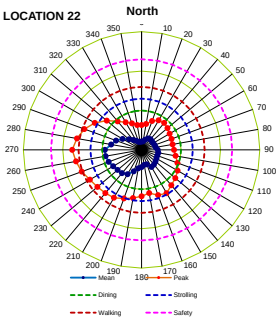

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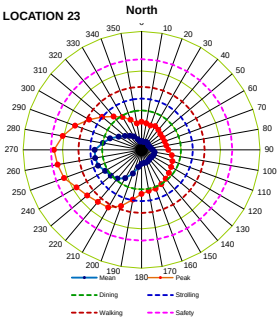

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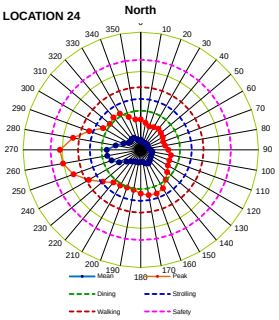

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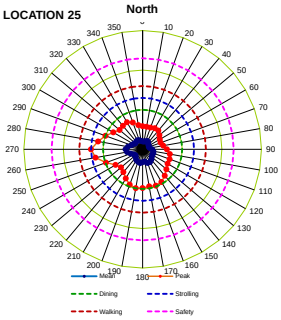

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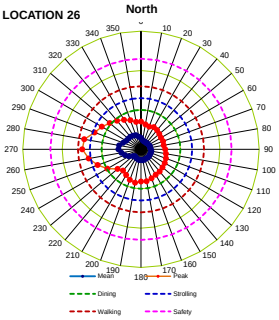

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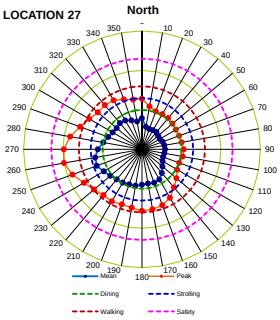

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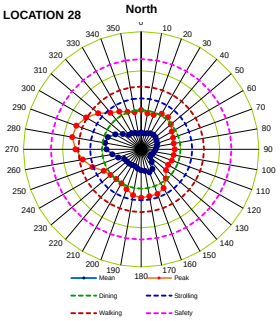

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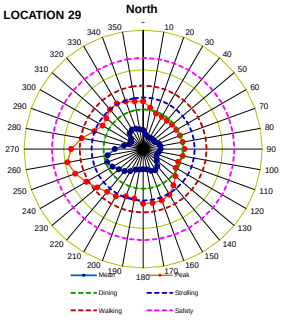

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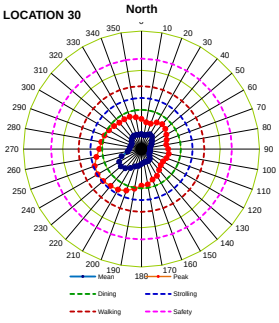

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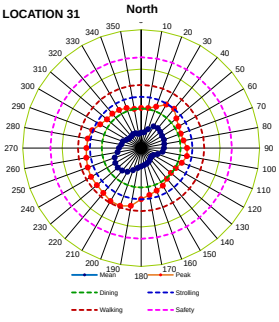

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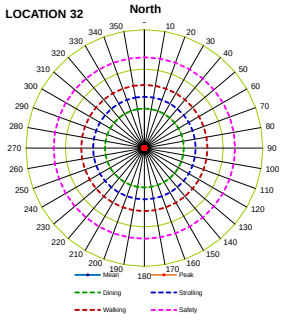

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