PROPOSED MIXED-USE REDEVELOPMENT

4-6 Bligh Street, Sydney CBD
Environmental Wind Impact Assessment

Prepared for:

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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 Holdmark (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
610.31041-R01-v2.0	21 December 2022	Dr Peter Georgiou	Dr Neihad Al-Khalidy	Dr Neihad Al-Khalidy
610.31041-R01-v1.0	1 November 2022	Dr Peter Georgiou	Dr Neihad Al-Khalidy	Dr Neihad Al-Khalidy

EXECUTIVE SUMMARY

SLR Consulting Australia Pty Ltd (SLR) has been engaged by Holdmark to assess the ground level wind environment around a proposed mixed-use hotel and commercial redevelopment (herein the "Project") located at 4-6 Bligh Street, Sydney.

This assessment has been performed via 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 assessment was supplemented by detailed 3D CFD (Computational Fluid Dynamics) Simulation Modelling which was validated against the results of the wind tunnel testing and then used to examine localised windflow impacts at elevated locations (eg Level 1 Terrace, Level 12 Terrace) as well as semi-enclosed spaces.

Response to SEARs - SSD 48674209

This report has been prepared to accompany a State Significant Development Application (SSDA) for the Project, specifically to address the Secretary's Environmental Assessment Requirements (SEARs) issued for the Project (SSD-48674209) with respect to **wind effects**.

Issue and Assessment Requirements	Documentation
5. Environmental Amenity • *Address how good internal and external environmental amenity is achieved, including access to natural daylight and ventilation, pedestrian movement throughout the site, access to landscape and outdoor spaces.* • *Assess amenity impacts on the surrounding locality, including li8ghting impacts, solar access, visual privacy, view loss and view sharing, overshadowing and **wind impacts.** A high level of environmental amenity for any surrounding residential or other sensitive land uses must be demonstrated.*	Pedestrian Wind Environment Study (this report)

Site Context

The site for the purposes of this SSDA is a single allotment identified as 4-6 Bligh Street, Sydney and known as Lot 1 in Deposited Plan 1244245. The application seeks consent for the construction of a 59-storey mixed-use hotel and commercial development. The purpose of the project is to revitalise the site and deliver new commercial floorspace and public realm improvements consistent with the City's vision to strengthen the role of Central Sydney as an international tourism and commercial destination.

The development site is located within the northern part of Sydney's Central CBD precinct surrounded by numerous high-rise buildings, including No.1 O'Connell Street, No.1 Bligh Street, Governor Phillip and Governor Macquarie Towers, Aurora Place, Chifley Tower, etc. Circular Quay and Sydney Cove are located just over 500 m north of the site. To the east are the parkland areas of the Royal Botanic Gardens and The Domain. To the south are the main central spine of the Sydney CBD precinct (south to southwest) and Hyde Park (south-southeast). To the west are more Sydney CBD buildings, Barangaroo and Darling Harbour.

EXECUTIVE SUMMARY

Background to this Report

This Project was subject to a detailed environmental wind study undertaken in 2019 (in response to the then-relevant SEARs requirements – refer SSD 9527). That study involved both scale model Wind Tunnel Testing and 3D Advanced CFD (Computational Fluid Dynamics) Simulation.

The 2019 study – herein referred to as the **2019 SLR Wind Study** – was documented in:

- SLR Report 610.18713-R01, *"Proposed Mixed-Use Development, 4-6 Bligh Street, Sydney CBD, Environmental Wind Study"*, September 2019.

The 2019 SLR Wind Study is attached to this report – refer **ATTACHMENT A**.

The following is noted:

- The current design of the Project is essentially IDENTICAL in overall bulk envelope to the previous design. On this basis, all other factors being constant, the wind impact of the Project would be essentially identical.
- Since the time of the 2019 SLR Wind Study, several new developments have been (or are being) delivered in near proximity to the Project, the nearest being the AMP site redevelopment at 50 Bridge Street, Sydney CBD. However, this site is effectively shielded from the Project by the Governor Phillip and Governor Macquarie towers. Accordingly, with respect to the surrounds, and again with all other factors being constant, the wind impact of the Project would be identical.
- Finally, in relation to the governing criteria relevant to the Project, the 2019 SLR Wind Study assessed the previous design against BOTH the well-known Melbourne and Lawson Safety and Comfort wind acceptability criteria – refer also Sydney DCP2012 (December 2012), Section 3.2.6 *Wind Effects*. Since that time, these criteria have remained unchanged.

On the basis of the above considerations, it has been concluded that the 2019 SLR Wind Study comprehensively covers all necessary aspects of the UPDATED (SSD-48674209) SEARs requirements for the (current) Project.

This report therefore summaries the key elements of the 2019 SLR Wind Study and confirms its recommendations for the most recent (October 2022) design iteration of the Project.

Project Site Wind Speed Characteristics

A site-specific wind climate model was developed in 2019, based on Sydney (KS) Airport 10 m height Bureau of Meteorology wind data, adjusted to take into account the local airport terrain exposure and then amended for the Project taking into account the approach wind characteristics for the Sydney CBD site. The latter vary significantly from a mixture of over-water and relatively open terrain to the east-northeast (over the Royal Botanic Gardens) to a very "dense urban" terrain to the south to southwest. In between these two approach directions are intermediate terrain types, eg a combination of open terrain (The Domain) and dense suburban terrain to the southeast and a combination of CBD buildings, over-water (Sydney Harbour) and suburban to the northwest.

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2019 SLR Wind Study - Acceptability Criteria

As noted above, the 2019 SRL Wind Study assessed the previous redevelopment proposal using both the Melbourne and Lawson criteria. In general, reasonable correlation was found in terms of the impact of the proposal when assessed against the two nominated acceptability criteria, with the Melbourne criteria being overall slightly more restrictive in terms of the acceptability or otherwise of specific locations.

However, the recommendations emanating from the 2019 SLR Wind Study were found to be identical when assessing the development's impact in terms of the two nominated wind criteria.

2019 SLR Wind Study - Wind Tunnel Test Methodology

To account for the range of upstream terrain categories at the site, an innovative approach was used in the 2019 SLR Wind Study to predict local wind conditions surrounding the site in the 2019 SLR Wind Study:

- TWO built environment scenarios were examined:
  - The "Baseline" built environment; and
  - The "Future" built environment – "Baseline" + proposed development.
- For EACH of the above Built Environment scenarios, TWO tests were carried out for the "limiting" terrain category conditions affecting the site:
  - An open terrain category equivalent to AS1170.2 Terrain Category 2.5; and
  - A dense urban terrain equivalent to AS1170.2 Terrain Category 3.6.

In order to produce a single set of local wind speed responses versus wind direction, the following procedure was then employed:

- Separate responses were determined for each "extreme" Terrain Test, "TC2.5" and "TC3.6"
- A "terrain transition factor" (TTF) was developed to linearly interpolate between the two extreme terrains tested for intermediate terrains.

2019 SLR Wind Study – Results

The reader is referred to **Figure 8** for the test locations discussed below.

Ground Level Locations - Compliance with Melbourne (1978) Criteria

- There were NO locations which exceeded the 23 m/s Melbourne safety criterion in either the "Baseline" scenario or "Future" scenario.
- In the "Baseline" scenario, 7 of the 30 tested locations (Nos. 10, 11. 19, 22, 26, 27 and 28) experienced predicted annual peak gusts which exceeded the 16 m/s walking criterion.
- In the "Future" scenario, 5 of those locations (Nos. 11. 19, 22, 27 and 28) continued to remain above the 16 m/s criterion; however, they all experienced a DECREASE compared to the "Baseline" scenario.
- There were NO locations BELOW the 16 m/s criterion in the "Baseline" scenario which experienced an increase to then be OVER the 16 m/s criterion in the "Future" scenario.

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In terms of relative change between “Baseline” and “Future” scenarios:

- 25 of the 30 tested locations experienced a DECREASE, albeit modest, in predicted annual peak gust;
- 4 locations experienced NO CHANGE in predicted annual peak gust; and
- 1 location (position 9) experienced a modest 0.5 m/s INCREASE in annual peak gust (from 11 m/s to 11.5 m/s).

Ground Level Locations - Compliance with Lawson (1990) Criteria

- In the “Baseline” scenario, 5 of the 30 tested locations (Nos. 18, 19, 21, 23 and 28) experienced Lawson Comfort levels of “C2”, 21 locations were at Lawson “C3” and 4 locations were at Lawson “C4”.
- In the “Future” scenario, 4 of the 30 tested locations (Nos. 18, 19, 22 and 28) experienced Lawson Comfort levels of “C2”, 20 locations were at Lawson “C3” and 6 locations were at Lawson “C4”
- There were NO locations which experienced Lawson Comfort levels in the “C1” category – ie only suitable for “purpose/business” walking.
- ALL locations were within the Lawson “S2” level, suitable from a safety point of view for all-weather use.

In terms of relative change between “Baseline” and “Future” scenarios:

- 5 of the 30 tested locations experienced a DECREASE (by one grade) in Lawson Comfort Level.
- 23 locations experienced NO CHANGE in Lawson Comfort Level.
- 2 locations (Nos. 13,22) experienced a one-grade INCREASE in Lawson Comfort Level (“C4” to “C3” and “C3” to “C2” respectively). Note that for these locations, the annual peak gust did not change between the “Baseline” and “Future” scenarios (13 m/s and 16 m/s respectively).

Comment on Locations Exceeding the 16 m/s Walking Comfort Criterion

As noted above, there were 7 locations (Nos. 10, 11. 19, 22, 26, 27 and 28) which exceeded the Melbourne 16 m/s criterion in the “Baseline” scenario (noting none of these exceeded the 23 m/s safety criterion).

- NONE of these locations is in front of the Project redevelopment site on Bligh Street.
- They are located at either (a) the northern end of Bligh Street, where they are impacted primarily by northwest winds which accelerate around the northeast façade of the No.1 Bligh Street tower, or (b) on Phillip Street and Hunter Street, where they are influenced by southeast winds with no interaction with the proposed redevelopment.

2019 SLR Wind Study – Overall Conclusions

- NO locations surrounding the site exceeding the Melbourne 16 m/s criterion experienced an INCREASE in peak annual wind speed with the addition of the proposed redevelopment.
- Indeed, with the addition of the proposed development, peak annual gust wind speeds at these same locations either REMAINED THE SAME or DECREASED.

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2019 SLR Wind Study – Wind Mitigation for the Surrounds

On the basis of the above, the 2019 SLR Wind Study concluded that …

- No wind mitigation was warranted to address potential wind impacts related to the "Future" scenario.

2019 SLR Wind Study – Wind Mitigation in the Immediate Proximity of the Site

In relation to the Melbourne (1978) criteria, ground level locations immediately in front of the site (same side footpath and opposite footpath) were all found to be either AT or BELOW the 13 m/s strolling comfort criterion. In terms of Lawson Comfort Level, these locations were either at the "C4" (sitting) or "C3" (standing) level.

It was concluded that this reflected:

- The major 8 m set-back at Level 12 of the tower's Bligh Street façade, and
- The full width Level 1 canopy protecting the Bligh Street footpath below.

In light of all of the above, "internal" development recommendations in relation to wind comfort were restricted to the already planned landscaping along Bligh Street: two existing trees either side of the site perimeter footpath to be retained, two existing trees to be replaced and one new tree in front of the site.

- It was noted that this landscaping was NOT included in the wind tunnel testing, and would be expected to further reduce wind speeds compared to those predicted in the wind tunnel testing.

2019 SLR Wind Study – Elevated Terrace Locations - CFD Modelling

The proposed redevelopment has elevated locations of interest, namely the Level 1 Outdoor Terrace and Level 12 Pool Deck Outdoor Area overlooking Bligh Street. Because of the relative narrowness of these elevated terraces (at a scale of 1:400), these areas were examined via CFD Numerical Modelling using ANSYS FLUENT software.

2019 SLR Wind Study – CFD Modelling Recommendations

Level 1 Outdoor Terrace

The following conclusions were reached based on the results of CFD simulations:

- For wind directions ranging from northeast clockwise around to the southwest, shielding from nearby buildings and the proposed development itself result in very low wind speeds being experienced on the Level 1 Outdoor Terrace.
- Winds from the northwest able to penetrate past upstream buildings and impact directly on the Bligh Street façade of the proposed development generate moderate downwash flow down this façade. However, due to the deflection action of the Level 12 Bligh Street façade set-back of the tower, this downwash does not seem to impact with any significance on the Level 1 Outdoor Terrace.

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In terms of wind mitigation for this terrace:

- A "formal" requirement for wind mitigation is not indicated, especially as this terrace would not be used for outdoor dining.
- Some form of horizontal protection for this terrace may be under consideration for NON-WIND reasons, eg rain prevention. In this case, and in terms of their wind mitigation context, these would only need to be "temporary", moveable, etc - ie retractable canopies, umbrellas, etc.

Level 12 Outdoor Pool Terrace

It is noted that the usage of this space is qualitatively different from the Level 1 Terrace, in particular, this space should be suited for more long-term stationary activities compared to the Level 1 Terrace, and hence the wind criteria triggering mitigation should be more stringent.

- For wind directions ranging from northeast clockwise around to the southwest, shielding from nearby buildings and the proposed development itself result in moderate wind speeds being experienced on the Level 12 Outdoor Pool Terrace.
- However, winds from the northwest able to penetrate past upstream buildings and impact directly on the Bligh Street façade of the proposed development generate significant downwash flow on the tower façade above which then impacts on the Pool terrace area. Although this causes adverse wind conditions on the Pool Terrace, this does assist in mitigating winds at lower levels, at both street level and the Level 1 Outdoor Terrace.

In terms of wind mitigation for this terrace:

- The northwest wind condition of concern is overwhelmingly a WINTER condition. Consideration of wind mitigation options for this area should therefore take into account the intended usage, and in particular if the Pool Terrace is likely to be used all-year-round.
- If this <u>is</u> the case, wind mitigation should be considered given the potential impact of downwash winds. The wind mitigation would need to be "horizontal" in nature – awnings, pergolas, canopies, etc. Operable awnings, retractable canopies, etc, are also a viable option if accompanied by a Management Plan which ensures that the protection is in place once terrace winds exceed a given comfort criterion.

EXECUTIVE SUMMARY

UPDATED SUMMARY FOR THE OCTOBER 2022 PROJECT DESIGN

The following has already been noted:

- The current design of the Project is essentially IDENTICAL in overall bulk envelope to the previous (2019) design. On this basis, all other factors being constant, the wind impact of the Project would be essentially identical to that predicted in the 2019 SLR Wind Study.
- Since the time of the 2019 SLR Wind Study, several new developments have been (or are being) delivered in near proximity to the Project, the nearest being the AMP site redevelopment at 50 Bridge Street, Sydney CBD. However, this site is effectively shielded from the Project by the Governor Phillip and Governor Macquarie towers. Accordingly, with respect to the surrounds, and again with all other factors being constant, the wind impact of the Project would be identical to that predicted in the 2019 SLR Wind Study.
- Finally, there has been no change to the Safety and Comfort wind acceptability criteria applied to suchj projects.

Based on the above, the 2019 SLR Wind Study comprehensively covers all necessary aspects of the UPDATED (SSD-48674209) SEARs requirements for the (current) Project, including all associated wind mitigation treatments, summarised below.

Wind Mitigation

Taking into account BOTH the Melbourne and Lawson criteria:

- No wind mitigation is warranted to address potential wind impacts of the proposed redevelopment in relation to the “surrounds”, away from the site.
- Thanks to the 8 m set-back at Level 12 of the tower’s Bligh Street façade and the full width Level 1 canopy protecting the Bligh Street footpath below, immediate site footpath recommendations in relation to wind comfort comprise the already planned landscaping along Bligh Street: two existing trees either side of the site perimeter footpath to be retained, three existing trees to be replaced in front of the site.
- In relation to the redevelopment’s Level 1 Terrace, wind mitigation is not required, especially as this terrace would not be used for outdoor dining. Some form of horizontal protection for this terrace may be under consideration for “non-wind” reasons, eg rain prevention. In this case, and in terms of their wind mitigation context, these would only need to be “temporary”, moveable, etc - ie retractable canopies, umbrellas, etc.
- In relation to the redevelopment’s Level 12 Pool Terrace, the northwest wind condition of concern is overwhelmingly a WINTER condition. Consideration of wind mitigation options for this area should therefore take into account the intended usage, and in particular if the Pool Terrace is likely to be used all-year-round. If this is the case, wind mitigation should be considered given the potential impact of downwash winds. The wind mitigation would need to be “horizontal” in nature – awnings, pergolas, canopies, etc. Operable awnings, retractable canopies, etc, are also a viable option if accompanied by a Management Plan which ensures that the protection is in place once terrace winds exceed a given comfort criterion.

It is noted that recommended Level 1 and Level 12 Podium awnings have now been incorporated in the most recent design of the Project.

EXECUTIVE SUMMARY

Finally, a review (**Section 7**) has been undertaken of several future high-rise developments in the vicinity of the Project site, in particular the proposed second commercial tower at 2 Chifley Square and a new tower at 19-25 Hunter Street.

The presence of these future high-rise towers in the vicinity of the Project site is expected to provide some beneficial shielding of easterly and westerly winds. It is noted that recommendations regarding Podium wind conditions (related to stronger northwest winds) would remain unchanged with the addition of these future buildings.

Based on all of the above, the overall effect of the proposed development on the local wind microclimate, with the wind mitigation treatments recommended (and already implemented in the design), is predicted to be "not significant" (refer Lawson terminology, **Section 3.2**).

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ATTACHEMENT

Attachement A 2019 SRL Wind Study

1 INTRODUCTION

SLR Consulting Australia Pty Ltd (SLR) has been engaged by Holdmark to assess the ground level wind environment around a proposed mixed-use hotel and commercial redevelopment (herein the "Project") located at 4-6 Bligh Street, Sydney.

This assessment has been performed via 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 assessment was supplemented by detailed 3D CFD (Computational Fluid Dynamics) Simulation Modelling which was validated against the results of the wind tunnel testing and then used to examine localised windflow impacts at elevated locations (eg Level 1 Terrace, Level 12 Terrace) as well as semi-enclosed spaces.

Response to SEARs - SSD 48674209

This report has been prepared to accompany a State Significant Development Application (SSDA) for the Project, specifically to address the Secretary's Environmental Assessment Requirements (SEARs) issued for the Project (SSD-48674209) with respect to **wind effects**.

Issue and Assessment Requirements	Documentation
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1.1 Site Context

The site for the purposes of this SSDA is a single allotment identified as 4-6 Bligh Street, Sydney and known as Lot 1 in Deposited Plan 1244245 - refer **Figure 1**.

The application seeks consent for the construction of a 59-storey mixed-use hotel and commercial development. The purpose of the project is to revitalise the site and deliver new commercial floorspace and public realm improvements consistent with the City's vision to strengthen the role of Central Sydney as an international tourism and commercial destination.

The development site is located within the northern part of Sydney's Central CBD precinct surrounded by numerous high-rise buildings, including No.1 O'Connell Street, No.1 Bligh Street, Governor Phillip and Governor Macquarie Towers, Aurora Place, Chifley Tower, etc. Circular Quay and Sydney Cove are located just over 500 m north of the site. To the east are the parkland areas of the Royal Botanic Gardens and The Domain. To the south are the main central spine of the Sydney CBD precinct (south to southwest) and Hyde Park (south-southeast). To the west are more Sydney CBD buildings, Barangaroo and Darling Harbour.

Figure 1 Site Context

The proposed mixed-use redevelopment will involve the construction of a 59-storey hotel and commercial office tower. The tower will have a maximum building height of RL225.88 (205m) and a total gross floor area (GFA) provision of 26,796 sqm, and will include the following elements:

- Five basement levels accommodating a substation, rainwater tank, hotel back of house, plant and services. A Porte Cochere and four service bays will be provided on basement level 1, in addition to 137 bicycle spaces and end of trip facilities on basement level 2, as well as 28 car parking spaces.
- Replacement planting of three trees on Bligh Street in front of the site.
- A 12-storey podium accommodating hotel concierge and arrival at ground level, conference facilities, eight levels of commercial floor space and co-working facilities, and hotel amenities including a pool and gymnasium at level 12.
- 42 tower levels of hotel facilities including 417 hotel keys comprising standard rooms, suites and a penthouse.
- Two tower levels accommodating restaurant, bar, back of house and a landscaped terrace at level 57.
- Plant, servicing and BMU at level 59 and rooftop.

1.2 Background to this Report

This Project was subject to a detailed environmental wind study undertaken in 2019 (in response to the then-relevant SEARs requirements – refer SSD 9527). That study involved both scale model Wind Tunnel Testing and 3D Advanced CFD (Computational Fluid Dynamics) Simulation.

The 2019 study – herein referred to as the **2019 SLR Wind Study** – was documented in:

- SLR Report 610.18713-R01, *"Proposed Mixed-Use Development, 4-6 Bligh Street, Sydney CBD, Environmental Wind Study"*, September 2019.

The 2019 SLR Wind Study is attached to this report.

The following is noted:

- The current design of the Project is essentially IDENTICAL in overall bulk envelope to the previous design. On this basis, all other factors being constant, the wind impact of the Project would be essentially identical.
- Since the time of the 2019 SLR Wind Study, several new developments have been (or are being) delivered in near proximity to the Project, the nearest being the AMP site redevelopment at 50 Bridge Street, Sydney CBD. However, this site is effectively shielded from the Project by the Governor Phillip and Governor Macquarie towers. Accordingly, with respect to the surrounds, and again with all other factors being constant, the wind impact of the Project would be identical.
- Finally, in relation to the governing criteria relevant to the Project, the 2019 SLR Wind Study assessed the previous design against BOTH the well-known Melbourne and Lawson Safety and Comfort wind acceptability criteria – refer also Sydney DCP2012 (December 2012), Section 3.2.6 *Wind Effects*. Since that time, these criteria have remained unchanged.

On the basis of the above considerations, the following has been concluded:

The 2019 SLR Wind Study comprehensively covers all necessary aspects of the UPDATED (SSD-48674209) SEARs requirements for the (current) Project.

This report therefore summaries the key elements of the 2019 SLR Wind Study and confirms its recommendations for the most recent (October 2022) design iteration of the Project.

The reader is referred to the attached 2019 SLR Wind Study for all details covering the testing, modelling, analysis and recommendations summarised in the sections which follow.

2 PROJECT SITE WIND SPEED CHARACTERISTICS

For details covering the following summary information, refer **2019 SLR Wind Study – Section 2**.

2.1 "Local" Site-Specific Wind Climate Model

The SLR 2019 Wind Study developed a local, site-specific wind climate probability model as follows:

- Data was obtained from the Sydney (KS) Airport 10 m height Bureau of Meteorology weather station and then adjusted for its own local airport exposure, eg taking into account the open water exposure upstream of the BoM anemometer station to the south-southeast (Botany Bay), suburban exposure to the west to northwest, open runway exposure to the north-northeast followed by suburban exposure further afield, etc.
- The resulting Terrain Category 2 equivalent wind climate model can be considered to be a "regional" model applicable to the Sydney CBD Project Site, given the comparable distances from the coast of the project site and the airport location.
- The above "regional" (TC2) wind model was then adjusted to the Project site, by taking into the local terrain, topography and built environment, all of which influence the "local" wind environment.
- For the Project site, the approach wind characteristics vary significantly from a mixture of over-water and relatively open terrain to the east-northeast (over the Royal Botanic Gardens) to a very "dense urban" terrain to the south to southwest. In between these two approach directions are intermediate terrain types, eg a combination of open terrain (The Domain) and dense suburban terrain to the southeast and a combination of CBD buildings, over-water (Sydney Harbour) and suburban to the northwest. These variations are illustrated in **Figure 2**.

2.2 Project Reference Height Design Wind Speeds

The measurements made in the environmental wind tunnel study make use of a reference height design wind speed, $\bar{V}_{ref}$, very close to the top height of the building:

- $\bar{V}_{ref}$ – mean wind speed at the reference height of 200 m

$\bar{V}_{ref}$ takes into account the local exposure factors, denoted $C_{exp,H}$, determined for the site. The variation of $C_{exp,H}$ is shown in **Figure 3**, including a polar plot form superimposed on an aerial view of the site and surrounds. The variation of $C_{exp,H}$ reflects the varying upstream terrain types evident in **Figure 2**.

Combining the adjusted Sydney (KS) Airport 10 m height ("regional" TC2) wind data with the local project site exposure adjustment factors gives the reference height, annual return period, mean wind speeds for the Project Site shown in **Figure 4**.

Figure 2 Upstream Terrain Views for the Development Site

View looking towards the Northeast

View looking towards the South

View looking towards the Northwest to North

Figure 3 Reference Height Terrain Category (Exposure) Factor, $C_{exp,H}$

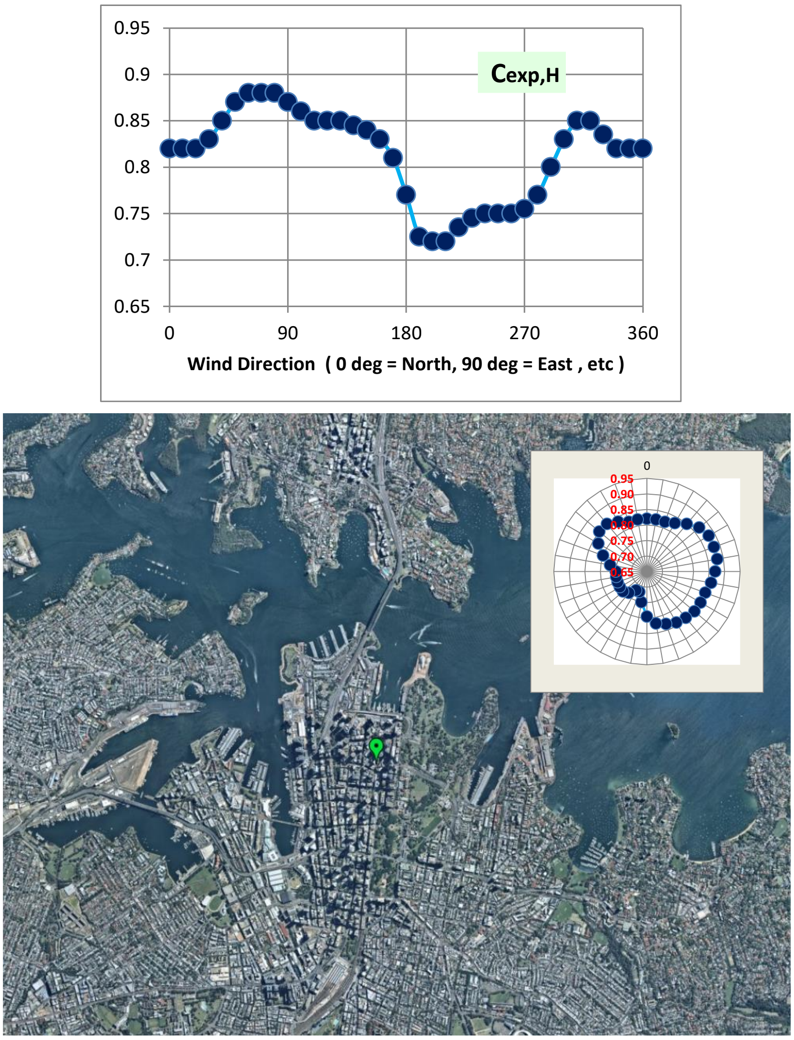
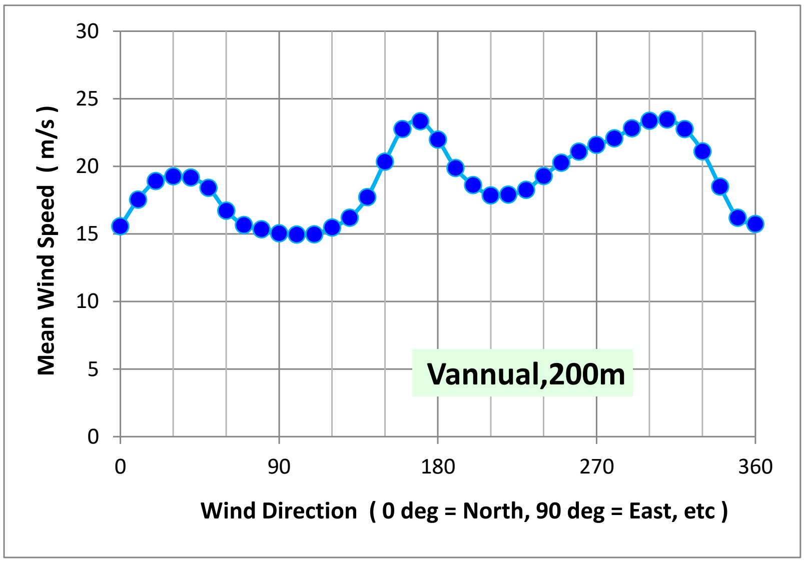


Figure 4 Reference Height Design Mean Wind Speed – Annual Return Period



3 WIND ACCEPTABILITY CRITERIA

For details covering the following summary information, refer **2019 SLR Wind Study – Section 3**.

The 2019 SLR Wind Study adopted two wind acceptability criteria for the Project.

3.1 The "Melbourne" Wind Criteria

The first of the acceptability criteria used in the 2019 SLR Wind Study 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

3.2 The "Lawson" Wind Criteria

The second set of criteria employed in the 2019 SLR Wind Study 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 Error! Reference source not found..

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 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 so-called "GEM" wind speed which is exceeded 5% of the time, on an annual return period basis – refer **Table 2**.
- **"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 3**.

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 2 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.

Table 3 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	Non-Sensitive Usage / All-Weather Use
S1	7	20 m/sec	Sensitive Usage / Fair-Weather Use
SX	> 7	> 20 m/sec	Exceeds Safety Criteria

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

S1 may be suitable for less frequently trafficked areas or areas which can be closed off in high wind conditions
S1 typically suited to able-bodied persons - not generally suited to frail people, cyclists, etc.

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

3.3 Proposed Wind Criteria for the Project

It was noted in the 2019 SLR Wind Study that the proposed redevelopment involves a high profile and relatively tall building in the Sydney CBD 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 throughout Sydney.

Accordingly, the 2019 SLR Wind Study assessed the Project using **BOTH** the Melbourne and Lawson criteria.

Good correlation was found in terms of the impact of the proposal when assessed against the two nominated acceptability criteria, with the Melbourne criteria being overall slightly more restrictive in terms of acceptability than the Lawson criteria for the relevant Comfort levels.

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.

4 WIND TUNNEL TEST METHODOLOGY

For details covering the following summary information, refer **2019 SLR Wind Study – Section 4**.

4.1 Simulation of the Project Site Upstream Wind Conditions

The 2019 SLR Wind Study was 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.

For practical reasons, it was not feasible to carry out the testing for ALL of the terrain category types evident in **Figure 2**. For the present wind study, the testing strategy used to capture the variation in upstream profile conditions is summarised in **Table 4**.

- Two pairs of tests were carried out for each of the built environment configurations examined:
  - The “Existing” built environment; and
  - The “Future” built environment – “Existing” + proposed development.
- For each of the above Built Environment scenarios, two tests were carried out for the “limiting” terrain category conditions affecting the site:
  - An open terrain category equivalent to AS1170.2 Terrain Category 2.5; and
  - A dense urban terrain equivalent to AS1170.2 Terrain Category 3.6.

Table 4 Wind Tunnel Test Configurations

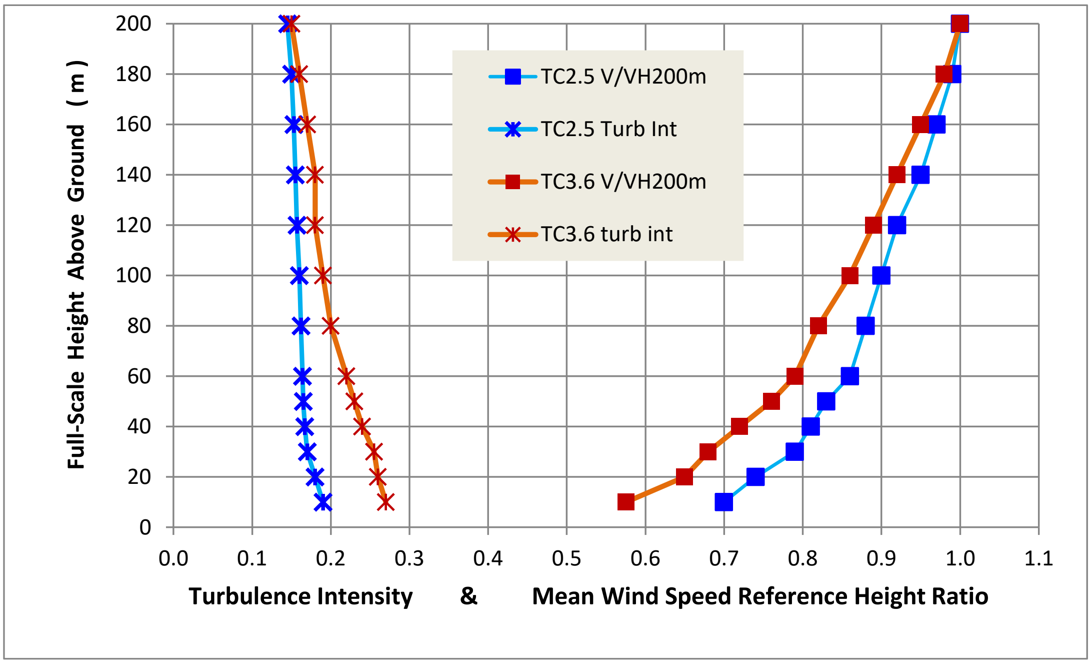
Built Environment Scenario	Test ID	Terrain Category	Terrain Description
“Existing”	T-EX-2.5	AS1170.2 TC2.5	Open terrain, few upstream obstacles
	T-EX-3.6	AS1170.2 TC3.6	Dense urban
“Future”	T-FU-2.5	AS1170.2 TC2.5	Open terrain, few upstream obstacles
	T-FU-3.6	AS1170.2 TC3.6	Dense urban

The “TC2.5” and “TC3.6” tests therefore covered the “extremes” of the range between the more “open” and more “dense” terrain categories relevant to the Project site, allowing interpolation for intermediate terrain exposure.

4.2 Wind Tunnel TC2.5 and TC3.6 Profiles

The two "open" (TC2.5) and "urban" (TC3.6) upstream profile conditions simulated in the 2019 SLR Wind Study are shown in **Figure 5**. The TC2.5 profiles of mean wind speed and turbulence intensity are shown in blue, the corresponding TC3.6 profiles in ochre. The mean wind speed profiles are shown as a ratio of the mean wind speed at different height to the mean wind speed at a full-scale equivalent height of 200 m (very close to the top height of the proposed development).

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



4.3 Combining Responses for Transition Terrain Categories

As shown in **Figure 2**, the upstream terrain category varies considerably with wind direction at the Project site. The testing strategy used to capture this variation involved carrying out tests was follows:

- "TC2.5" - "most open" terrain category: open terrain equivalent to AS1170.2 Terrain Category 2.5
- "TC3.6" - "most urban" terrain category: urban terrain equivalent to AS1170.2 Terrain Category 3.6

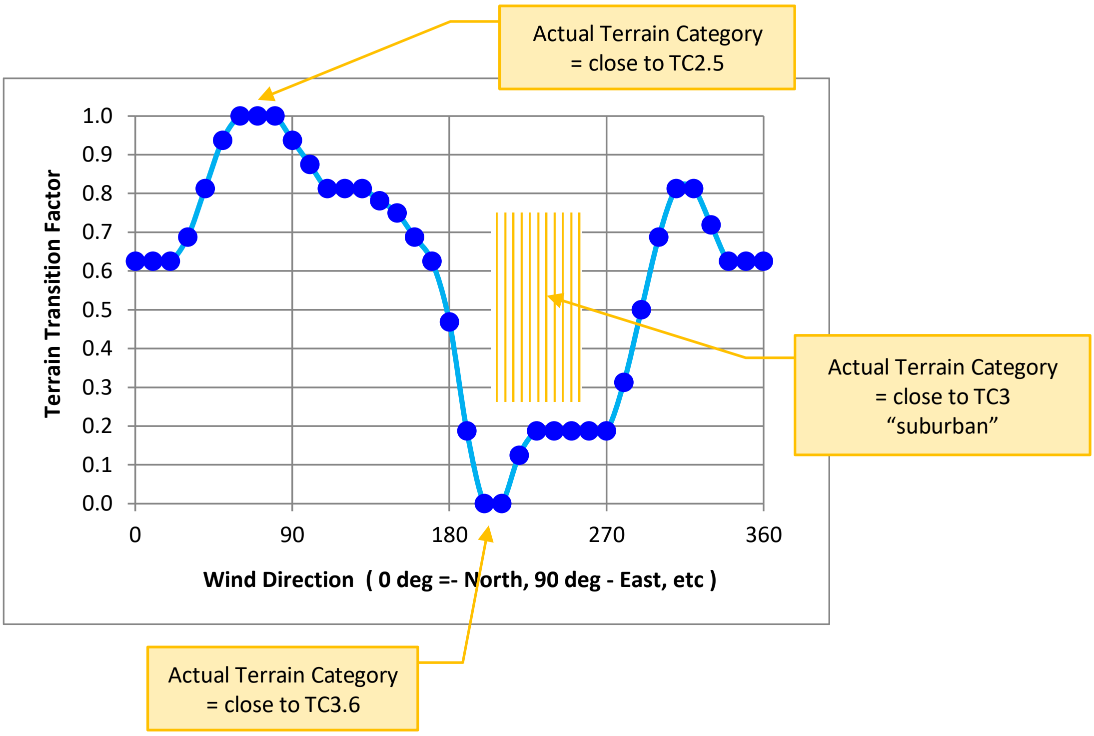
In order to produce a single set of local wind speed responses versus wind direction, the following procedure was then employed:

- Responses were determined for each Terrain Test, "TC2.5" and "TC3.6"
- A "terrain transition factor" (TTF) was developed based on the exposure factor variation, linearly extrapolated to range from 0 to 1.

The TTF factor is shown in **Figure 6**.

- A TTF of 1 corresponds to an angle where the actual terrain category is the same as "TC2.5", in this instance from the east-northeast with winds approaching the site over Sydney Harbour
- A TTF of 0 corresponds to an angle where the actual terrain category is the same as "TC3.6", in this instance from the south-southwest with winds approaching the site over the Sydney CBD
- Intermediate terrain categories are calculated as TTF x "TC2.5" + (1-TTF) x "TC3.6"

Figure 6 Terrain Transition Factor



4.4 Wind Tunnel 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 1 km around the site were included in the purpose-built 1:400 scale "proximity model" used for the test as shown in **Figure 7**.

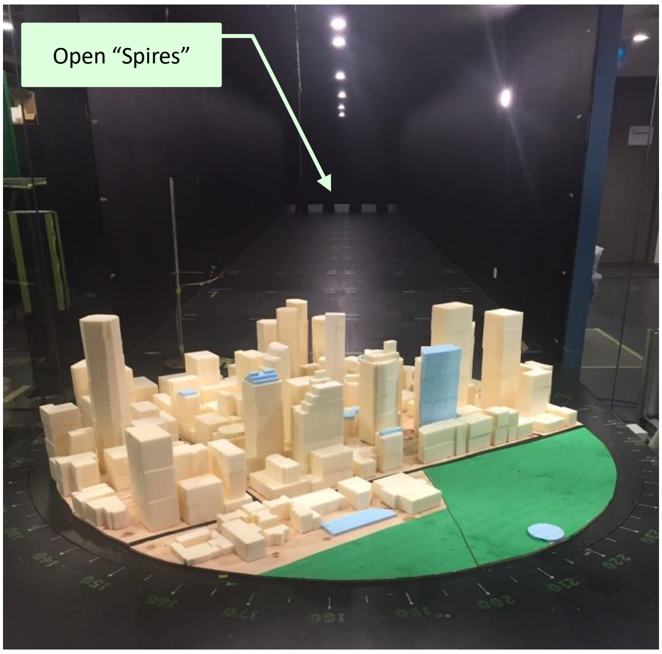
The proximity model simulates two built environment "scenarios":

- **"Baseline"** scenario: simulating the existing built environment; and
- **"Future"** scenario: "Baseline" + future proposed development.

Figure 7 Proposed Development and Proximity Models Used in the Wind Tunnel Testing

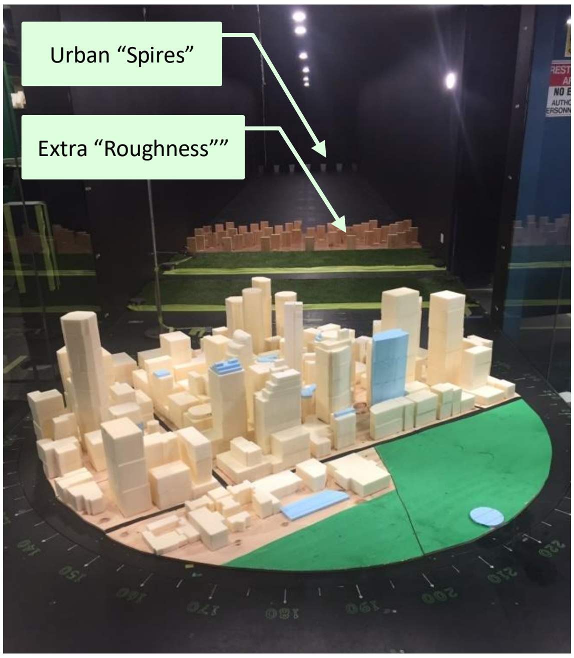
"BASELINE"

Test Profile "TC2.5"
Looking Northwest



"FUTURE"

Test "TC3.6"
Looking Northwest



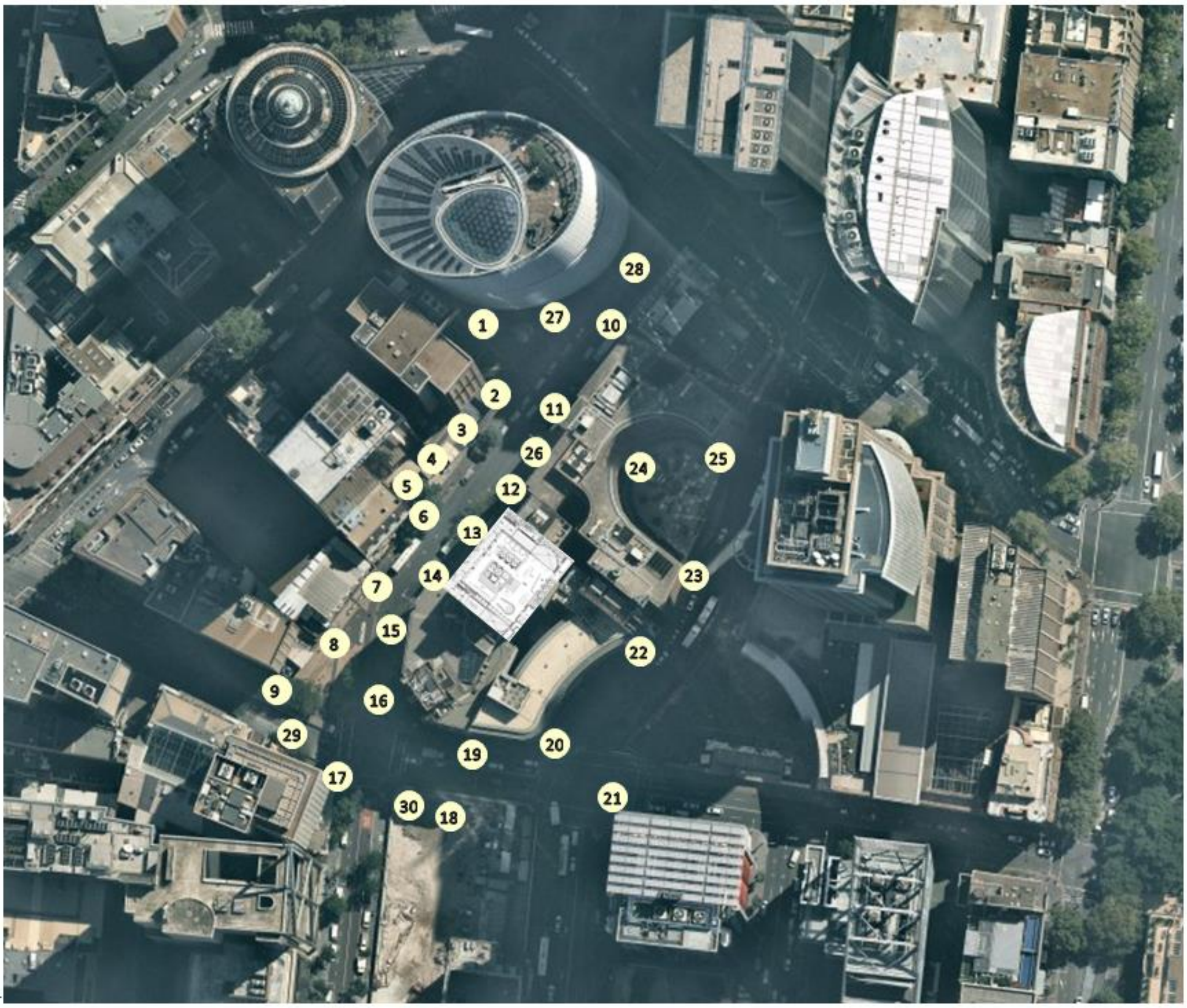
4.5 Sensor Locations – Ground Level

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 surrounding the development, eg near primary building entrances and along footpaths.

- All locations 1-30 were ground level sensors placed at public access and footpath locations surrounding the site
- All locations were tested in BOTH the "Baseline" and "Future" scenarios.

Figure 8 Wind Tunnel Test Sensor Locations



4.6 Sensor Locations – Upper Level Terraces

The redevelopment has elevated locations of interest, namely the Level 1 Outdoor Terrace and Level 12 Pool Deck Outdoor Area. These are relatively narrow width areas, where measurements with Irwin Sensors are challenging at the wind tunnel test scale of 1:400. These areas were therefore examined via the parallel CFD Modelling undertaken for the study – refer **Section 8**.

4.7 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 representative gust wind speeds at:

Sensor:	Location 7
Location:	Bligh Street footpath, opposite the site's southwest corner

The polar diagrams show the output of the wind tunnel test results for:

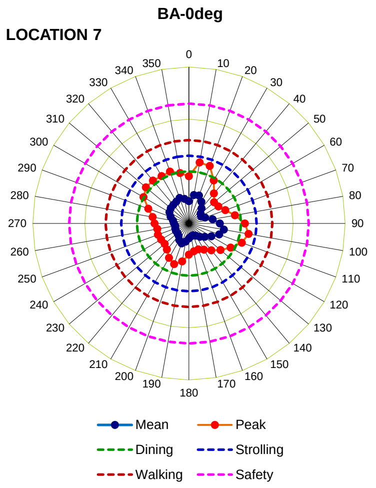
Mean wind speed:	"navy blue" data points
Gust wind speed:	"red" data points.

The polar diagrams also include three circumferential lines representing criteria for:

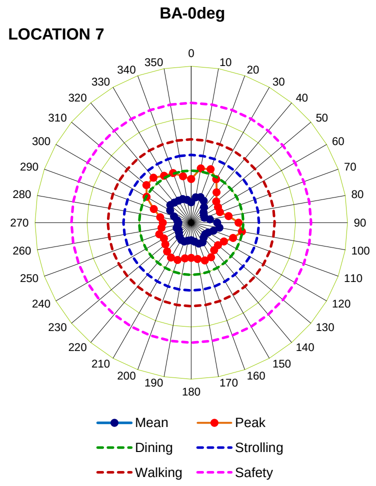
Public Safety:	23 m/sec (purple)
Walking Comfort:	16 m/sec (ochre)
Strolling Comfort:	13 m/sec (blue)
Dining Comfort:	10 m/sec (green)

Figure 9 Sample Polar Plot – Location 7: "Baseline" and "Future" Scenarios

"Baseline" Scenario



"Future" Scenario



"Baseline" scenario …

- Winds at Location 7 are the strongest at 100°, where they are close to the Melbourne 13 m/sec walking comfort criterion, mainly due to winds accelerating along Bligh Street.

"Future" scenario …

- With the addition of the proposed development, winds between 100° to 110° decrease slightly and winds between 150° to 170° increase slightly.

5 TEST RESULTS

For details covering the following summary information, refer **2019 SLR Wind Study – Sections 5-8**.

5.1 Detailed Wind Tunnel Test Polar Plots

SLR 2019 Wind Study **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.

The results had a modest degree of conservativeness given that landscaping (eg street trees) was not incorporated in the "Baseline" and "Future" proximity models.

Detailed discussion relevant to wind conditions at individual locations can be found in the 2019 SLR Wind Study.

5.2 Overall Wind Impact

Table 5 gives the peak annual gust wind speeds and the 5% and 0.2% annual exceedance GEM wind speed Lawson class 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 respectively.

Ground Level Locations - Compliance with Melbourne (1978) Criteria

- There were NO locations which exceeded the 23 m/s Melbourne safety criterion in either the "Baseline" scenario or "Future" scenario.
- In the "Baseline" scenario, 7 of the 30 tested locations (Nos. 10, 11. 19, 22, 26, 27 and 28) experienced predicted annual peak gusts which exceeded the 16 m/s walking criterion.
- In the "Future" scenario, 5 of those locations (Nos. 11. 19, 22, 27 and 28) continued to remain above the 16 m/s criterion; however, they all experienced a DECREASE compared to the "Baseline" scenario.
- There were NO locations BELOW the 16 m/s criterion in the "Baseline" scenario which experienced an increase to then be OVER the 16 m/s criterion in the "Future" scenario.

Ground Level Locations - Compliance with Lawson (1990) Criteria

- ALL locations were within the Lawson "S2" level, suitable from a safety point of view for all-weather use.
- There were NO locations which experienced Lawson Comfort levels in the "C1" category – ie only suitalbe for "purpose/business" walking.
- In the "Baseline" scenario, 5 of the 30 tested locations (Nos. 18, 19, 21, 23 and 28) experienced Lawson Comfort levels of "C2", 21 locations were at Lawson "C3" and 4 locations were at Lawson "C4".
- In the "Future" scenario, 4 of the 30 tested locations (Nos. 18, 19, 22 and 28) experienced Lawson Comfort levels of "C2", 20 locations were at Lawson "C3" and 6 locations were at Lawson "C4"

Table 5 Predicted Peak Gust and GEM 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"	"Future"	"Baseline"	"Future"
1	13.5	13.0	C3	C3	S2	S2
2	15.5	14.5	C3	C3	S2	S2
3	13.0	11.5	C3	C4	S2	S2
4	10.0	8.0	C4	C4	S2	S2
5	7.5	6.5	C4	C4	S2	S2
6	14.0	13.0	C3	C3	S2	S2
7	12.0	11.5	C3	C3	S2	S2
8	11.5	10.5	C3	C3	S2	S2
9	11.0	11.5	C3	C3	S2	S2
10	16.5	15.5	C3	C3	S2	S2
11	18.0	17.0	C3	C3	S2	S2
12	10.0	9.5	C4	C4	S2	S2
13	13.0	13.0	C4	C3	S2	S2
14	13.5	12.0	C3	C4	S2	S2
15	13.5	12.5	C3	C3	S2	S2
16	10.0	9.5	C3	C4	S2	S2
17	13.0	13.0	C3	C3	S2	S2
18	14.5	14.0	C2	C2	S2	S2
19	16.5	16.5	C2	C2	S2	S1
20	12.0	11.5	C3	C3	S2	S2
21	14.5	13.5	C2	C3	S2	S2
22	16.0	16.0	C3	C2	S2	S2
23	13.5	13.0	C2	C3	S2	S2
24	12.0	11.5	C3	C3	S2	S2
25	13.5	13.0	C3	C3	S2	S2
26	16.5	16.0	C3	C3	S2	S2
27	18.0	16.5	C3	C3	S2	S2
28	19.5	19.0	C2	C2	S2	S2
29	14.0	13.0	C3	C3	S2	S2
30	13.0	12.5	C3	C3	S2	S2

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

Relative Change in Wind Conditions: "Baseline" and "Future" Scenarios

In terms of the Melbourne criteria results:

- 25 of the 30 tested locations experienced a DECREASE, albeit modest, in predicted annual peak gust;
- 4 locations experienced NO CHANGE in predicted annual peak gust; and
- 1 location (position 9) experienced a modest 0.5 m/s INCREASE in annual peak gust (from 11 m/s to 11.5 m/s).

In terms of the Lawson criteria results:

- 5 of the 30 tested locations experienced a DECREASE (by one grade) in Lawson Comfort Level.
- 23 locations experienced NO CHANGE in Lawson Comfort Level.
- 2 locations (Nos. 13,22) experienced a one-grade INCREASE in Lawson Comfort Level ("C4" to "C3" and "C3" to "C2" respectively). Note that for these locations, the annual peak gust did not change between the "Baseline" and "Future" scenarios (13 m/s and 16 m/s respectively).

Comment on Locations Exceeding the 16 m/s Walking Comfort Criterion

As noted above, there were 7 locations (Nos. 10, 11. 19, 22, 26, 27 and 28) which exceeded the Melbourne 16 m/s criterion in the "Baseline" scenario (noting none of these exceeded the 23 m/s safety criterion).

- NONE of these locations is in front of the Project redevelopment site on Bligh Street.
- They are located at either (a) the northern end of Bligh Street, where they are impacted primarily by northwest winds which accelerate around the northeast façade of the No.1 Bligh Street tower, or (b) on Phillip Street and Hunter Street, where they are influenced by southeast winds with no interaction with the proposed redevelopment.

2019 SLR Wind Study – Overall Conclusions

- NO locations surrounding the site exceeding the Melbourne 16 m/s criterion experienced an INCREASE in peak annual wind speed with the addition of the proposed redevelopment.
- Indeed, with the addition of the proposed development, peak annual gust wind speeds at these same locations either REMAINED THE SAME or DECREASED.

5.3 2019 SLR Wind Study – Wind Mitigation for the Surrounds

On the basis of the above, the 2019 SLR Wind Study concluded that …

- No wind mitigation was warranted to address potential wind impacts related to the "Future" scenario.

5.4 2019 SLR Wind Study – Wind Mitigation in the Immediate Proximity of the Site

In relation to the Melbourne (1978) criteria, ground level locations immediately in front of the site (same side footpath and opposite footpath) were all found to be either AT or BELOW the 13 m/s strolling comfort criterion. In terms of Lawson Comfort Level, these locations were either at the "C4" (sitting) or "C3" (standing) level.

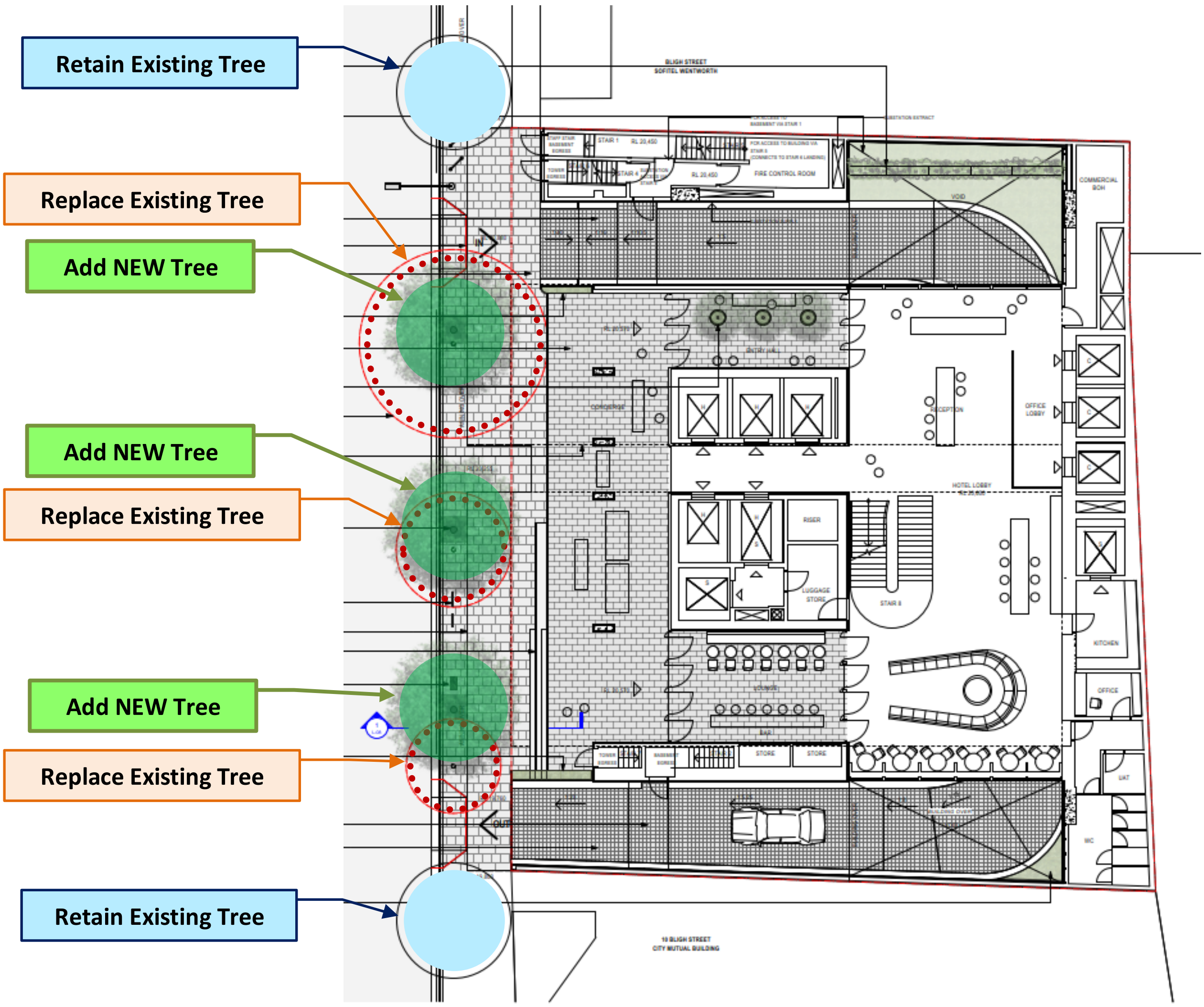
It was concluded that this reflected:

- The major 8 m set-back at Level 12 of the tower's Bligh Street façade, and
- The full width Level 1 canopy protecting the Bligh Street footpath below.

In light of all of the above, "internal" development recommendations in relation to wind comfort were restricted to the already planned landscaping along Bligh Street: two existing trees either side of the site perimeter footpath to be retained, three existing trees to be replaced in front of the site – refer **Figure 10**.

- It was noted that this landscaping was NOT included in the wind tunnel testing and would be expected to further reduce wind speeds compared to those predicted in the wind tunnel testing.

Figure 10 Already Planned Landscaping for Bligh Street Frontage



6 UPPER LEVEL TERRACE WIND CONDITIONS

For details covering the following summary information, refer **2019 SLR Wind Study – Section 9**.

The proposed redevelopment has elevated locations of interest, namely the Level 1 Outdoor Terrace and Level 12 Pool Deck Outdoor Area overlooking Bligh Street.

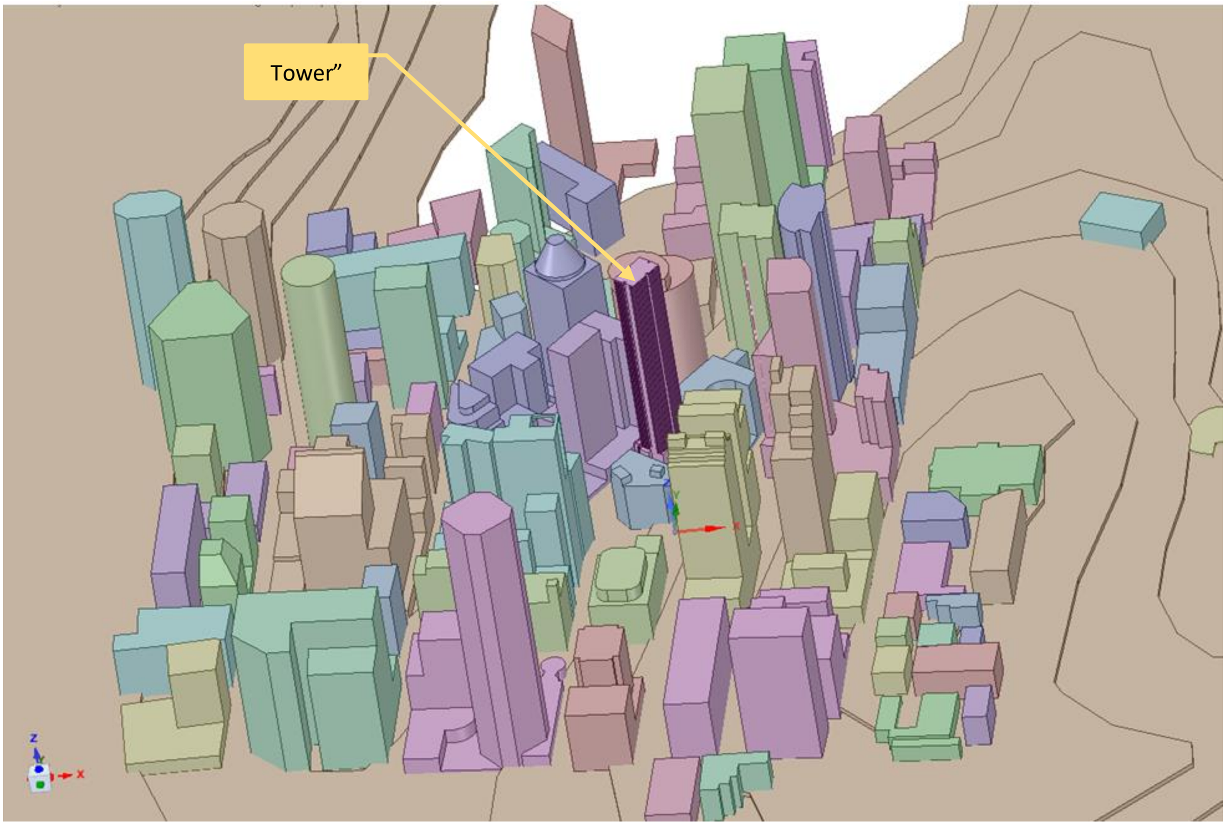
To assess these areas in detail, the 2019 SLR Wind Study employed Advanced 3D CFD (Computational Fluid Dynamics) Numerical Modelling using ANSYS FLUENT software.

6.1 CFD Modelling Methodology

Model Geometry

A 3D model of the development area and surrounding buildings was created from Sydney CBD AutoCAD files that have been developed over many years by SLR. The geometry for CFD Modelling is shown in **Figure 11**.

Figure 11 3D Geometry used for the CFD Modelling Simulations



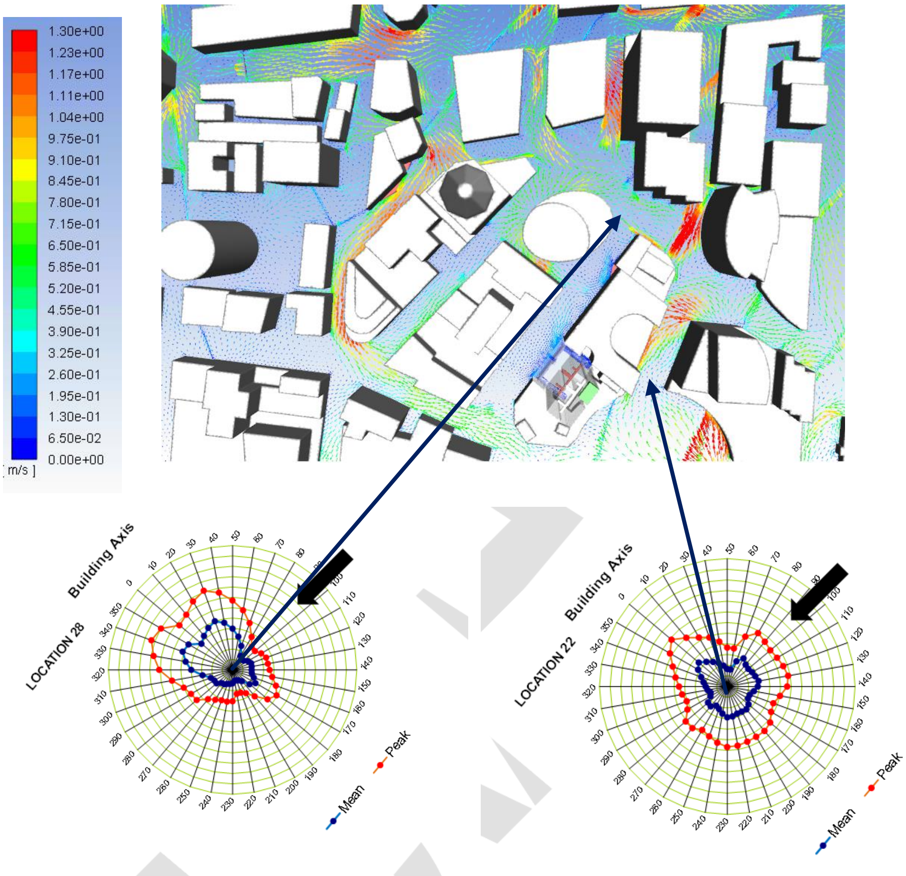
6.2 CFD Validation

Prior to examining the output of the CFD Modelling for the elevated areas of interest, the CFD output at ground level was compared to the results of the Wind Tunnel Testing for the purpose of validation. Focus was placed on two test angles in particular:

- Wind Direction = 45° (NE) = Building Axis BA-95° refer example in **Figure 12**
- Wind Direction = 337.5° (NNW) = Building Axis BA-27.5°

The CFD and wind tunnel testing results were found to correlate well at the areas of interest.

Figure 12 CFD Simulation Mean Wind Speeds: 45°, V_{local}/V_{10m} Ratios



6.3 Level 1 Terrace Results

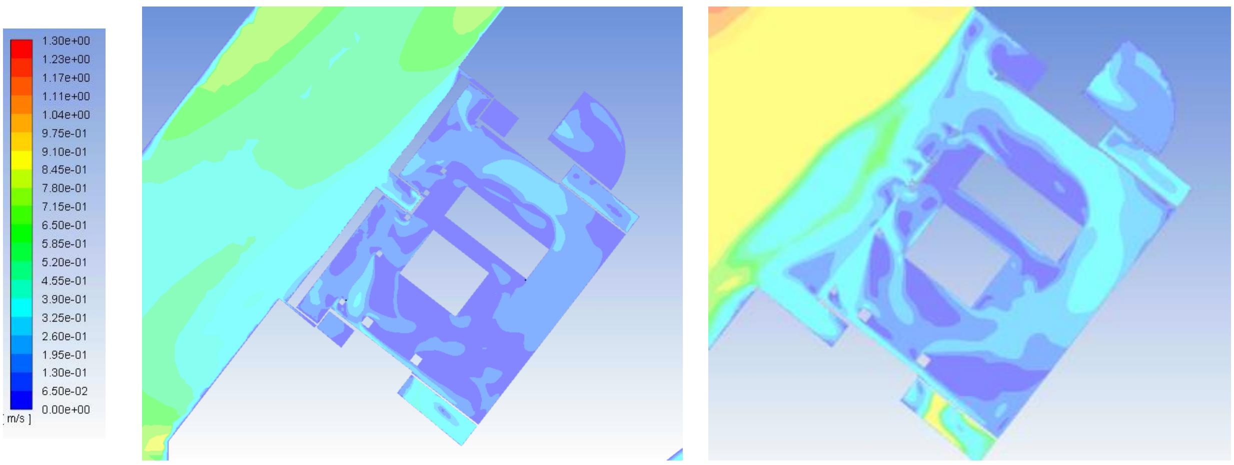
Figure 13 provides a sample result showing the mean wind speed ratios on the Level 1 Outdoor Terrace for a potential "high-downwash" oncoming wind angle of 337.5°:

- For these north-northwest (NNW) winds, mean wind speed ratios (V_{local}/V_{10m}) on the terrace range from 0.2 to 0.3.
- This compares to a ratio of close to 0.9 further out from the facade (above the centreline of Bligh Street) and a ratio of 0.5 on the footpath directly below.
- The vertical cross-section windflow diagrams indicate that the impact of downwash on the Level 1 Outdoor Terrace is modest, largely due to the "set-back" impact of the Level 12 step in the building's Bligh Street façade.

Figure 13 Level 1 Outdoor Terrace Mean Wind Speed Ratios: 337.5°, V_{local}/V_{10m}

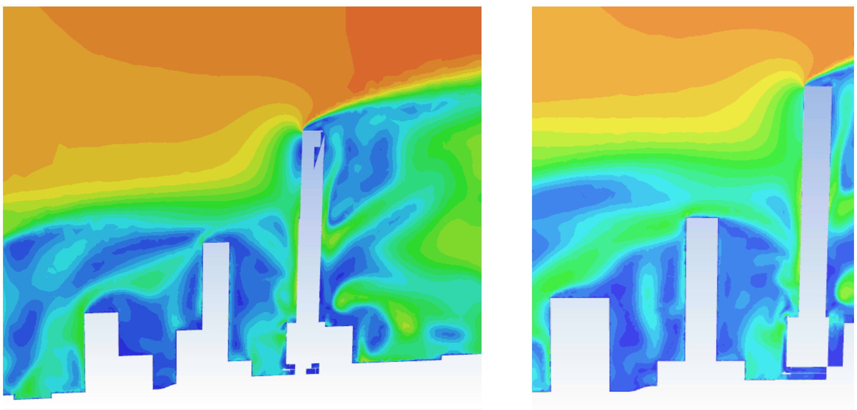
Horizontal Plane Wind Contours

0.5m above Level 1 RL **1.5m above Level 1 RL**



Vertical Cross-Section Flow Diagram (parallel to tower short dimension)

Through mid-façade "Gap" **Close to NE facade**



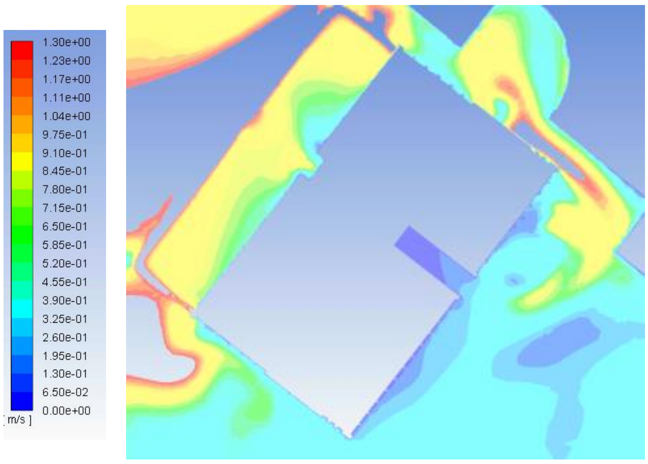
6.4 Level 12 Outdoor Pool Terrace Results

Figure 14 provides a sample result showing the mean wind speed ratios on the Level 12 Outdoor Pool Terrace for a potential "high-downwash" oncoming wind angle of 337.5°:

- For these north-northwest (NNW) winds, mean wind speed ratios (V_{local}/V_{10m}) on the terrace range from 0.8 to 0.9.
- This compares to a ratio of 0.5 on the footpath directly below.
- The vertical cross-section windflow diagrams indicate that the impact of downwash on the Level 12 Outdoor Terrace is significant, confirming that the Level 12 "set-back" fronting Bligh Street does deflect considerable windflow away from the roadway below

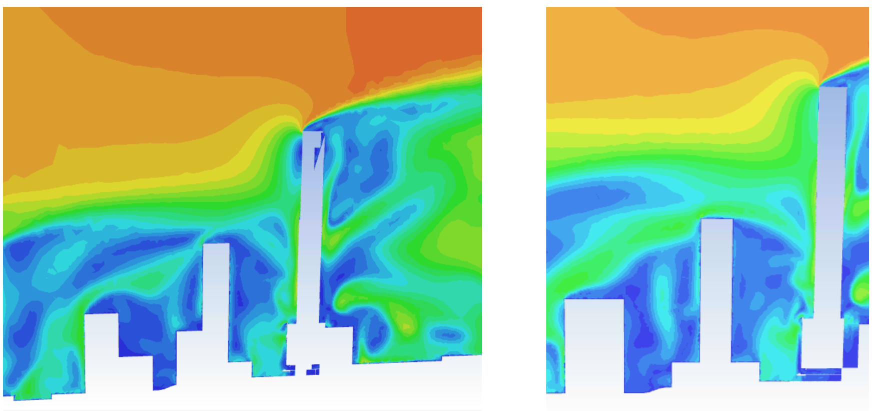
Figure 14 Level 12 Terrace Mean Wind Speed Ratios: 337.5°, V_{local}/V_{10m}

337.5° / 1m above Level 12 RL



Vertical Cross-Section Flow Diagram (parallel to tower short dimension)

Through mid-façade "Gap" | **Close to NE facade**



6.5 Recommended Wind Mitigation

Level 1 Outdoor Terrace

The following conclusions were reached based on the results of CFD simulations:

- For wind directions ranging from northeast clockwise around to the southwest, shielding from nearby buildings and the proposed development itself result in very low wind speeds being experienced on the Level 1 Outdoor Terrace.
- Winds from the northwest able to penetrate past upstream buildings and impact directly on the Bligh Street façade of the proposed development generate moderate downwash flow down this façade. However, due to the deflection action of the Level 12 Bligh Street façade set-back of the tower, this downwash does not seem to impact with any significance on the Level 1 Outdoor Terrace.

In terms of wind mitigation for this terrace:

- A "formal" requirement for wind mitigation is not indicated, especially as this terrace would not be used for outdoor dining. Some form of horizontal protection for this terrace may be under consideration for "non-wind" reasons, eg rain prevention. In this case, and in terms of their wind mitigation context, these would only need to be "temporary", moveable, etc - ie retractable canopies, umbrellas, etc.

Level 12 Outdoor Pool Terrace

It is noted that the usage of this space is qualitatively different from the Level 1 Terrace, in particular, this space should be suited for more long-term stationary activities compared to the Level 1 Terrace, and hence the wind criteria triggering mitigation should be more stringent.

- For wind directions ranging from northeast clockwise around to the southwest, shielding from nearby buildings and the proposed development itself result in moderate wind speeds being experienced on the Level 12 Outdoor Pool Terrace.
- However, winds from the northwest able to penetrate past upstream buildings and impact directly on the Bligh Street façade of the proposed development generate significant downwash flow on the tower façade above which then impacts on the Pool terrace area. Although this causes adverse wind conditions on the Pool Terrace, this does assist in mitigating winds at lower levels, at both street level and the Level 1 Outdoor Terrace.

In terms of wind mitigation for this terrace:

- The northwest wind condition of concern is overwhelmingly a WINTER condition. Consideration of wind mitigation options for this area should therefore take into account the intended usage, and in particular if the Pool Terrace is likely to be used all-year-round.
- If this is the case, wind mitigation should be considered given the potential impact of downwash winds. The wind mitigation would need to be "horizontal" in nature – awnings, pergolas, canopies, etc. Operable awnings, retractable canopies, etc, are also a viable option if accompanied by a Management Plan which ensures that the protection is in place once terrace winds exceed a given comfort criterion.

It is noted that recommended Level 1 and Level 12 Podium awnings have now been incorporated in the most recent design of the Project.

7 RESIDUAL EFFECTS AND CUMULATIVE IMPACT

There are a number of other high-density buildings proposed in proximity to the site including:

- 2 Chifley Square,
- 19-25 Hunter Street,
- Sydney Metro OSD East site,
- Sydney Metro OSD West site,
- Martin Place OSD North site.

The Sydney Metro and Martin Place site are sufficiently far away from the Project site such that they might perhaps provide some modest sheltering of winds from the relevant directions, ie southwest quadrants.

The remaining two sites – 2 Chifley Square and 19-25 Hunter Street – are relatively close to the Project site and hence warrant closer consideration in terms of cumulative impact.

2 Chifley Square – refer Figure 15

This development comprises a second commercial office tower on the site up to a maximum height of approximately RL 213 m. It would be located south of the existing Chifley Square Tower and east-southeast of the Bligh Street Project site.

- The impact of the new 2 Chifley Square tower would be to provide additional sheltering at the Project for easterly winds.
- These winds (refer **Section 2**) are not a “strong” prevailing wind direction for the Project site.
- Accordingly, while the new 2 Chifley Square tower might benefit the Bligh Street Project site by moderating easterly winds, the overall impact will be minor, especially noting the wind directions of interest in relation to Podium winds (ie northwest winds).

19-25 Hunter Street – refer Figure 16

This development comprises a tower 52 storeys in height, located west of the Bligh Street Project site.

- The impact of this future tower would be to provide additional sheltering at the Project for westerly winds.
- These winds (refer **Section 2**) are a “strong” prevailing wind direction for the Project site.
- If the future Hunter Street tower had been located closer to the Project site, say less than 100 m, there may have been potentially complex environmental wind interactions between the two buildings. However, given the actual distance involved, the impact will be overwhelmingly beneficial (for westerly winds).
- It is also noted that, despite the potential beneficial impact of the Hunter Street tower, the impact in relation to northwest winds will be minimal, and hence the mitigation recommendations made in relation to Podium winds remain the same.

Figure 15 Site Context – 2 Chifley Square "New Tower"

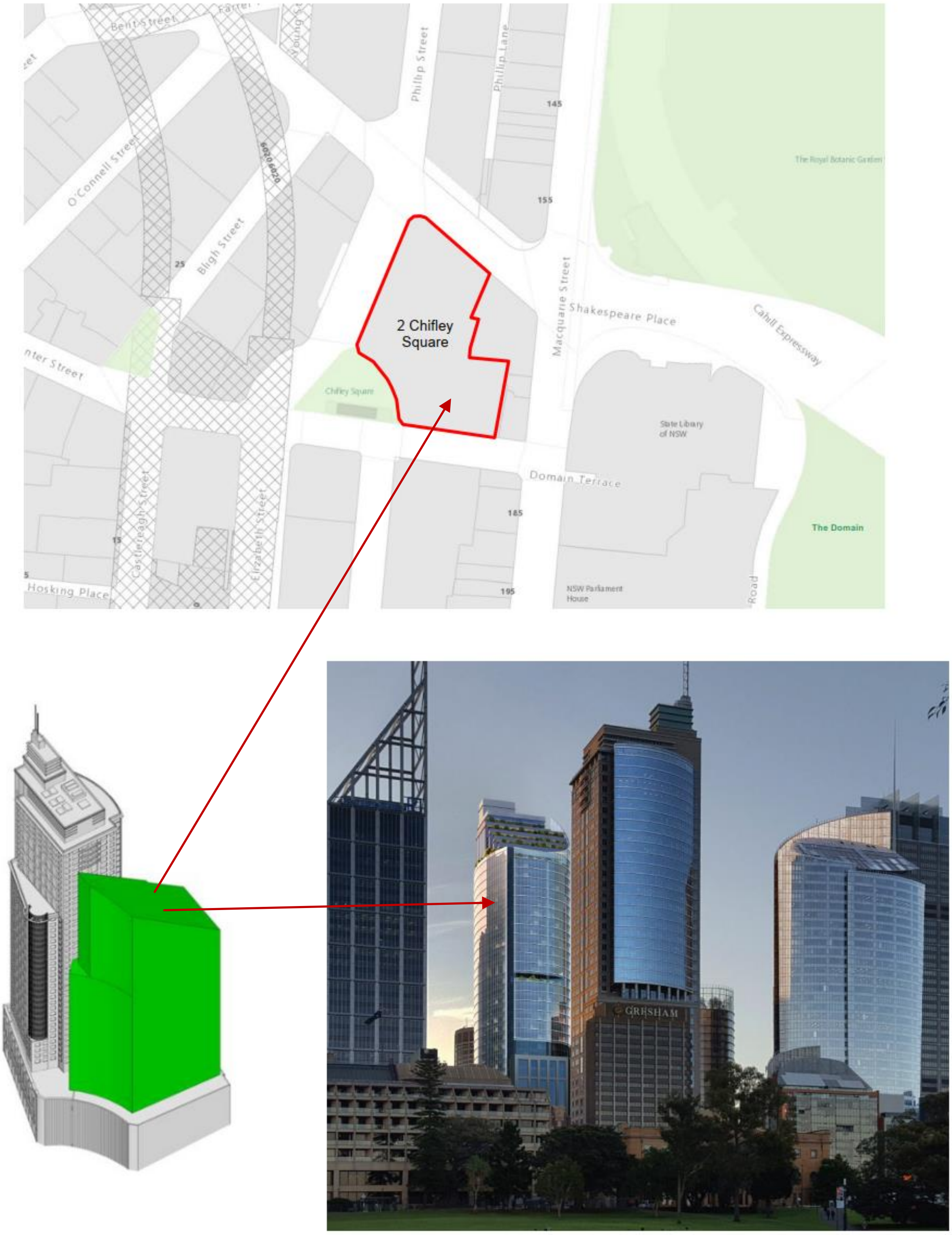
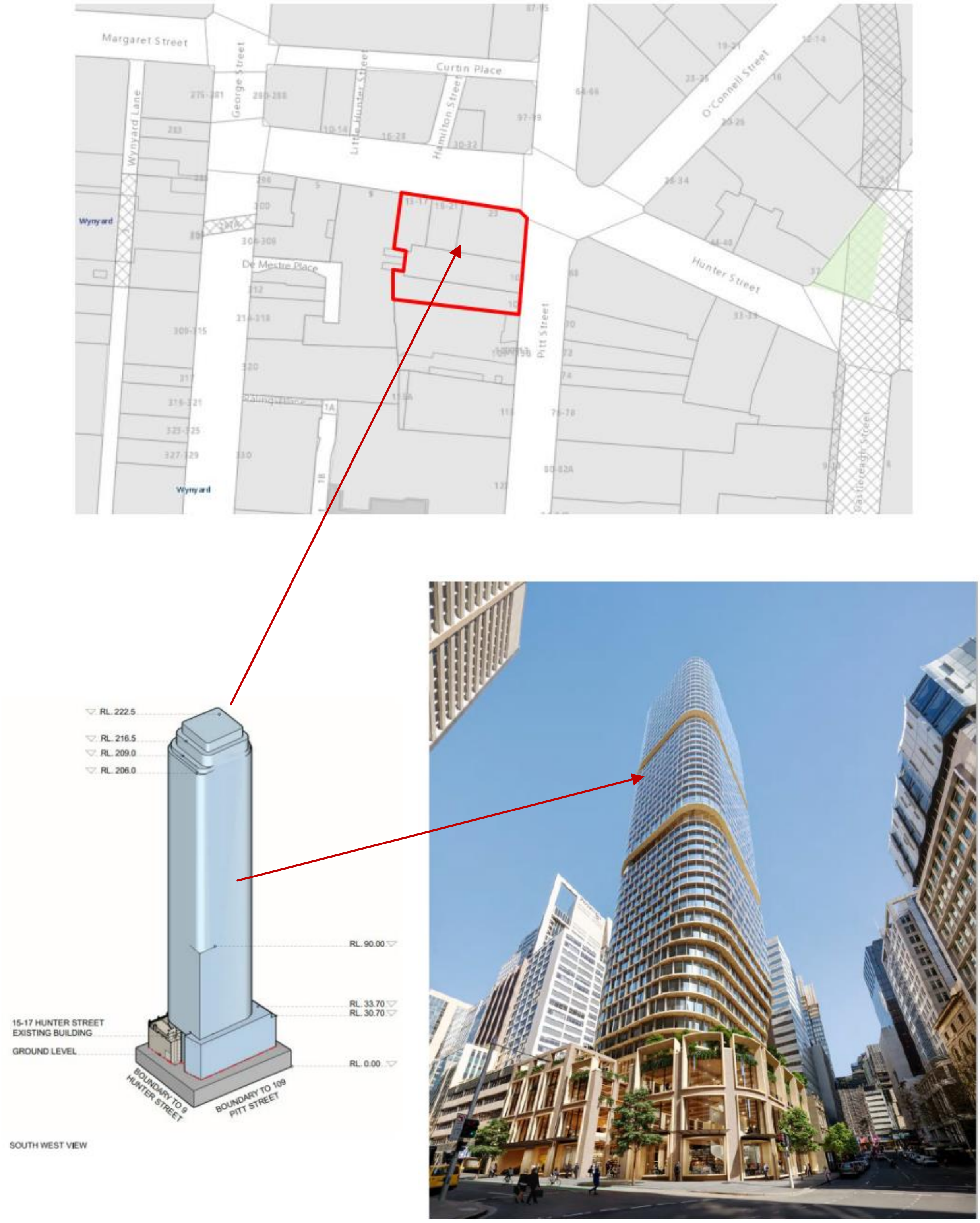


Figure 16 Site Context – 19-25 Hunter Street



Overall Conclusion

With the incorporation of proposed windbreak mitigation treatments, all amenity locations within the proposed development including upper ground and all terrace level locations are expected to achieve the target Lawson Comfort Criteria and Melbourne Safety Criterion established for the project.

The presence of future high-rise towers in the vicinity of the Project site is expected to provide some beneficial shielding of easterly and westerly winds. It is noted that recommendations regarding Podium wind conditions (related to stronger northwest winds) would remain unchanged with the addition of these future buildings.

Based on all of the above, the overall effect of the proposed development on the local wind microclimate, with the wind mitigation treatments recommended (and already implemented in the design), is predicted to be "not significant" (refer Lawson terminology, **Section 3.2**).

8 FEEDBACK

At SLR, we are committed to delivering professional quality service to our clients. We are constantly looking for ways to improve the quality of our deliverables and our service to our clients. Client feedback is a valuable tool in helping us prioritise services and resources according to our client needs.

To achieve this, your feedback on the team's performance, deliverables and service are valuable and SLR welcome all feedback via https://www.slrconsulting.com/en/feedback. We recognise the value of your time and we will make a $10 donation to our 2022 Charity Partner – Lifeline, for every completed form.

Attachment A:

2019 SLR Wind Study

SLR Report 610.18713-R01
“Proposed Mixed-Use Development, 4-6 Bligh Street, Sydney CBD, Environmental Wind Study”
September 2019

PROPOSED MIXED-USE DEVELOPMENT

4-6 Bligh Street, Sydney CBD
Environmental Wind Study

Prepared for:

Coffey
Level 3, 101 Sussex Street
SYDNEY NSW 2000

SLR

SLR Ref: 610.18713-R01
Version No: -v1.0
September 2019

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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 Coffey (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.

This report is for the exclusive use of the Client. 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.

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
610.18713-R01-v1.0	13 September 2019	Dr Peter Georgiou	Dr Neihad Al-Khalidy	Dr Neihad Al-Khalidy

EXECUTIVE SUMMARY

SLR Consulting Australia Pty Ltd (SLR) has been engaged by Coffey to assess the ground level wind environment around a proposed mixed-use building (herein the “Project”) located at 4-6 Bligh Street, Sydney, which will include hotel, commercial and ancillary retail uses.

This assessment has been performed via 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 assessment was supplemented by detailed 3D CFD (Computational Fluid Dynamics) Simulation Modelling which was validated against the results of the wind tunnel testing and then used to examine localised windflow impacts at elevated locations (eg Level 1 Terrace, Level 12 Terrace) as well as semi-enclosed spaces.

Response to SEARs - SSD 9527

The Project is classified as a State Significant Development (SSD 9527) on the basis that it falls within the requirements of Clause 13 of Schedule 1 of State Environmental Planning Policy (State and Regional Development) 2011 (SRD SEPP), being a “development that has a capital investment value of more than $100 million for the purpose of other tourist related facilities”.

This report has been prepared to accompany the SSD Development Application (DA) for the project. The Minister for Planning, or their delegate, is the consent authority for the SSD DA and the DA is being lodged with the NSW Department of Planning, Industry and Environment (NSW DPIE) for assessment.

This report addresses relevant requirements contained in the SSD 9527 SEARs (Secretary’s Environmental Assessment Requirements) dated 3 September 2018, with respect to wind effects, specifically, the following SEARs requirement:

Section	Sub-Section
Key Issues	7. Amenity The EIS shall: • provide wind analysis (including wind tunnel modelling) outlining the impacts, in particular any impacts to existing and proposed public domain areas and open space. The wind impact assessment must identify the existing wind characteristics of the site and its locality, significant locations for wind sensitivity and mitigating measures. • demonstrate the impacts of the proposal on the amenity of surrounding development and public domain, including measures to minimise potential overshadowing, noise, reflectivity, visual privacy, wind, daylight and view impacts.

EXECUTIVE SUMMARY

Site Context

The development site is located within the northern part of Sydney's Central CBD precinct surrounded by numerous high-rise buildings, including No.1 O'Connell Street, No.1 Bligh Street, Governor Phillip and Governor Macquarie Towers, Aurora Place, Chifley Tower, etc. Circular Quay and Sydney Cove are located just over 500 m north of the site. To the east are the parkland areas of the Royal Botanic Gardens and The Domain. To the south are the main central spine of the Sydney CBD precinct (south to southwest) and Hyde Park (south-southeast). To the west are more Sydney CBD buildings, Barangaroo and Darling Harbour.

Project Site Wind Speed Characteristics

A Project-specific wind climate model was developed for the study, based on Sydney (KS) Airport 10 m height Bureau of Meteorology wind data, which was adjusted to take into account the local airport terrain exposure and then amended for the Project site taking into account the approach wind characteristics for the Sydney CBD site. The latter vary significantly from a mixture of over-water and relatively open terrain to the east-northeast (over the Royal Botanic Gardens) to a very "dense urban" terrain to the south to southwest. In between these two approach directions are intermediate terrain types, eg a combination of open terrain (The Domain) and dense suburban terrain to the southeast and a combination of CBD buildings, over-water (Sydney Harbour) and suburban to the northwest.

Combining the Sydney (KS) Airport 10 m height (Terrain Category 2) wind data with the local project site exposure adjustment factors gives the reference height, annual return period, mean wind speeds for the Project Site – this is shown in Figure 6.

Wind Acceptability Criteria

The proposed development involves a significant building within the Sydney CBD 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 buildings in Sydney LGA precincts.

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.

Wind Tunnel Testing Methodology

For practical reasons, it was not feasible to carry out the testing for all the terrain category types relevant to approaching winds at the site (refer Figures 4 and 5). To account for this wide range of upstream terrain categories, an innovative approach was used to predict local wind conditions surrounding the site:

EXECUTIVE SUMMARY

- Two built environment scenarios were examined:
  - The "Baseline" built environment – existing buildings included as of August 2019; and
  - The "Future" built environment – "Baseline" + proposed development.
- For each of the above Built Environment scenarios, two tests were carried out for the "limiting" terrain category conditions affecting the site:
  - An open terrain category equivalent to AS1170.2 Terrain Category 2.5; and
  - A dense urban terrain equivalent to AS1170.2 Terrain Category 3.6.

In order to produce a single set of local wind speed responses versus wind direction, the following procedure was then employed:

- Responses were determined for each Terrain Test, "TC2.5" and "TC3.6"
  - A "terrain transition factor" (TTF) was developed based on the exposure factor variation shown in Figure 5, linearly extrapolated to range from 0 to 1 – this is shown in Figure 8.
  - A TTF of 1 corresponds to an angle where the actual terrain category is the same as "TC2.5", in this instance from the east-northeast with winds approaching the site over Sydney Harbour
  - A TTF of 0 corresponds to an angle where the actual terrain category is the same as "TC3.6", in this instance from the south-southwest with winds approaching the site over the Sydney CBD
  - Intermediate terrain category results were then calculated as TTF x "TC2.5" + (1-TTF) x "TC3.6"

Ground Level Results from the Wind Tunnel Testing - Compliance with Melbourne (1978) Criteria

- In the "Baseline" scenario, 7 of the 30 tested locations (Nos. 10, 11. 19, 22, 26, 27 and 28) experience predicted annual peak gusts which exceed the 16 m/s walking criterion.
- In the "Future" scenario, 5 of these locations (Nos. 11. 19, 22, 27 and 28) continue to remain above the 16 m/s criterion; however, they all experience a decrease compared to the "Baseline" scenario.
- There are NO locations BELOW the 16 m/s criterion in the "Baseline" scenario which experience an increase to then be OVER the 16 m/s criterion in the "Future" scenario.
- There are NO locations which exceed the 23 m/s safety criterion in either the "Baseline" scenario or "Future" scenario.

In terms of relative change between "Baseline" and "Future" scenarios:

- 25 of the 30 tested locations experience a DECREASE, albeit modest, in predicted annual peak gust
- 4 locations experience NO CHANGE in predicted annual peak gust
- 1 location (position 9) experiences a modest 0.5 m/s INCREASE in annual peak gust (from 11 m/s to 11.5 m/s)

EXECUTIVE SUMMARY

Ground Level Results from the Wind Tunnel Testing - Compliance with Lawson (1990) Criteria

- In the "Baseline" scenario, 5 of the 30 tested locations (Nos. 18, 19, 21, 23 and 28) experience Lawson Comfort levels of "C2", 21 locations are at Lawson "C3" and 4 locations are at Lawson "C4"
- In the "Future" scenario, 4 of the 30 tested locations (Nos. 18, 19, 22 and 28) experience Lawson Comfort levels of "C2", 20 locations are at Lawson "C3" and 6 locations are at Lawson "C4"
- There are no locations which experience Lawson Comfort levels in the "C1" category – ie only suitalbe for "purpose/business" walking
- All locations are within the Lawson "S2" level, suitable from a safety point of view for all-weather use.

In terms of relative change between "Baseline" and "Future" scenarios:

- 5 of the 30 tested locations experience a DECREASE (by one grade) in Lawson Comfort Level
- 23 locations experience NO CHANGE in Lawson Comfort Level
- 2 locations (Nos. 13,22) experience a one-grade INCREASE in Lawson Comfort Level ("C4" to "C3" and "C3" to "C2" respectively). Note that for these locations, the annual peak gust does not change between the "Baseline" and "Future" scenarios (13 m/s and 16 m/s respectively).

Locations Exceeding the Melbourne 16 m/s Walking Comfort Criterion

As noted above, there are 7 locations (Nos. 10, 11. 19, 22, 26, 27 and 28) which exceed the Melbourne 16 m/s criterion in the "Baseline" scenario (noting that none of these exceeds the 23 m/s safety criterion).

- None of these locations is in front of the project development site on Bligh Street.
- They are located at either the northern end of Bligh Street, where they are impacted primarily by northwest winds which accelerate around the northeast façade of the No.1 Bligh Street tower, or on Phillip Street and Huinter Street, where they are influenced by southeast winds with no interaction with the proposed development.

In summary …

- No locations surrounding the site which currently exceed the Melbourne 16 m/s criterion experience an INCREASE in peak annual wind speed with the addition of the proposed development.
- Indeed, with the addition of the proposed development, peak annual gust wind speeds at these same locations either REMAIN THE SAME or DECREASE.

Accordingly …

- No wind mitigation is warranted to address potential wind impacts related to the "Future" scenario.

Ground Level Wind Conditions at the Site

In relation to the Melbourne (1978) criteria, ground level locations immediately in front of the site (same side footpath and opposite footpath) all satisfy the 16 m/s walking comfort criterion. In fact, they are at or below the 13 m/s strolling comfort criterion. In terms of Lawson Comfort Level, these locations are either at the "C4" (sitting) or "C3" (standing) level.

EXECUTIVE SUMMARY

This almost certainly reflects two proposed development design features:

- The major 8 m set-back at Level 12 of the tower's Bligh Street façade, and
- The full perimeter Level 1 canopy protecting the Bligh Street footpath below

In light of all of the above, further recommendations in relation to wind comfort would be restricted to:

- The already planned landscaping – refer Figure 19 - along Bligh Street: two existing trees either side of the site perimeter footpath to be retained, two existing trees to be replaced and one new tree in front of the site.
- This landscaping was NOT included in the wind tunnel testing, and would be expected to further reduce wind speeds compared to those predicted in the current study.

Elevated Terrace Location Wind Conditions - Results from CFD Modelling

The proposed development has elevated locations of interest, namely the Level 1 Outdoor Terrace and Level 12 Pool Deck Outdoor Area overlooking Bligh Street. Both of these elevated terraces are relatively narrow, where measurements with Irwin Sensors are challenging at the wind tunnel test scale of 1:400.

These areas were therefore examined via CFD Numerical Modelling using ANSYS FLUENT software.

A 3D model of the development area and surrounding buildings was created from Sydney CBD AutoCAD files that have been developed over many years by SLR. The geometry for CFD Modelling is shown in Figure 20.

CFD Model

For the current study, the following discretization and numerical schems were utilised:

- Polyhedral elements with a total of 30,147,018 nodes were employed to cover the computational domain. Polyhedral cells are especially beneficial for handling recirculating flows and are able to provide more accurate results than even hexahedra mesh.
- A Realizable k-epsilon (rke) turbulence model was used for all analysed cases. The rke model is capable of providing more accurate results for flow involving separation and pressure gradients.
- A Second Order numerical scheme for momentum and pressure discretisation was used to obtain more accurate results.
- An iterative procedure was used to estimate the air velocity in terms of three directions, pressure profile and turbulence parameters.

EXECUTIVE SUMMARY

CFD Modelling Mitigation Recommendations

Level 1 Outdoor Terrace

The following conclusions have been reached based on results of CFD simulations:

- For wind directions ranging from northeast clockwise around to the southwest, shielding from nearby buildings and the proposed development itself result in very low wind speeds being experienced on the Level 1 Outdoor Terrace.
- Winds from the northwest able to penetrate past upstream buildings and impact directly on the Bligh Street façade of the proposed development generate moderate downwash flow down this façade. However, due to the deflection action of the Level 12 Bligh Street façade set-back of the tower, this downwash does not seem to impact with any significance on the Level 1 Outdoor Terrace.

In terms of wind mitigation for this terrace:

- A "formal" requirement for wind mitigation is therefore not indicated, especially as this terrace would not be used for outdoor dining.
- Some form of horizontal protection for this terrace may be under consideration for non-wind reasons, eg rain prevention. In this case, and in terms of their wind mitigation context, these would only need to be "temporary", moveable, etc - ie retractable canopies, umbrellas, etc.

Level 12 Outdoor Pool Terrace

It is noted that the usage of this space is qualitatively different from the Level 1 Terrace, in particular, this space should be suited for more long-term stationary activities compared to the Level 1 Terrace, and hence the wind criteria triggering mitigation should be more stringent.

- For wind directions ranging from northeast clockwise around to the southwest, shielding from nearby buildings and the proposed development itself result in moderate wind speeds being experienced on the Level 12 Outdoor Pool Terrace.
- However, winds from the northwest able to penetrate past upstream buildings and impact directly on the Bligh Street façade of the proposed development generate significant downwash flow on the tower façade above which then impacts on the Pool terrace area. Although this causes adverse wind conditions on the Pool Terrace, this does assist in mitigating winds at lower levels, at both street level and the Level 1 Outdoor Terrace.

In terms of wind mitigation for this terrace:

- The northwest wind condition of concern is a winter condition. Consideration of wind mitigation options for this area should therefore take into account the intended usage, and in particular if the Pool Terrace is likely to be used all-year-round. If this is the case, wind mitigation is indicated given the potential impact of downwash winds.
- The wind mitigation will need to be "horizontal" in nature – awnings, pergolas, canopies, etc. Operable awnings, retractable canopies, etc, are a viable option if accompanied by a Management Plan which ensures that the protection is in place once terrace winds exceed a given comfort criteria.

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APPENDICES

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1 INTRODUCTION

SLR Consulting Australia Pty Ltd (SLR) has been engaged by Coffey to assess the ground level wind environment around a proposed mixed-use building (herein the "Project") located at 4-6 Bligh Street, Sydney, which will include hotel, commercial and ancillary retail uses.

This assessment has been performed via 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.

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Response to SEARs - SSD 9527

The project is classified as a State Significant Development (SSD) on the basis that it falls within the requirements of Clause 13 of Schedule 1 of State Environmental Planning Policy (State and Regional Development) 2011 (SRD SEPP), being "development that has a capital investment value of more than $100 million for the purpose of other tourist related facilities". The project SSD reference is SSD 9527.

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Key Report Parameters

In undertaking the environmental study for the proposed development, the following is noted:

- **Wind Climate** — a Project-specific wind climate model was used, based on terrain corrected wind data obtained from Sydney (Kingsford Smith) Airport
- **Environment** — the testing modelled the surrounding built environment as of August 2019
- **Wind Speeds** — Wind Tunnel testing was used to predict ground level wind speeds at ground level pedestrian locations surrounding the site
  CFD Simulation Modelling was used to predict wind speeds at elevated outdoor locations on the proposed development (Level 1 and Level 12)
- **Criteria** — The wind tunnel test results were compared to two Wind Comfort and Safety Criteria: the Melbourne (1978) Criteria and Lawson (1990) Criteria
- **Return Period** — Wind speeds were calculated for various annual return period recurrence intervals, relevant to the nominated wind acceptability criteria

1.1 Structure of the Report

The remainder of this report is structured as follows:

Section 2 ...	describes the proposed development
Section 3 ...	describes the characteristics of Sydney regional wind climate as well as the local Project Site wind climate statistics used in the present assessment
Section 4 ...	presents the wind comfort and safety criteria used in the study
Section 5 ...	details the wind tunnel testing methodology used to predict ground level wind speeds and their statistical occurrence
Section 6 ...	presents the wind tunnel results for ground level locations and how they vary with wind direction
Section 7 ...	presents the overall results and their compliance with the adopted wind comfort and safety criteria
Section 8 ...	presents recommended wind mitigation options for the proposed development
Section 9 ...	presents the CFD Modelling methodology and mitigation recommendations for the upper level, outdoor areas of interest within the proposed development

2 DESCRIPTION OF THE PROPOSED DEVELOPMENT

2.1 Development Site Location

The development site – refer Figure 1 - is located within the northern part of Sydney's Central CBD precinct surrounded by numerous high-rise buildings, including No.1 O'Connell Street, No.1 Bligh Street, Governor Phillip and Governor Macquarie Towers, Aurora Place, Chifley Tower, etc. Circular Quay and Sydney Cove are located just over 500 m north of the site. To the east are the parkland areas of the Royal Botanic Gardens and The Domain. To the south are the main central spine of the Sydney CBD precinct (south to southwest) and Hyde Park (south-southeast). To the west are more Sydney CBD buildings, Barangaroo and Darling Harbour.

Figure 1 Development Site Location

2.2 Proposed Development Description

The proposed mixed-use development will comprise:

- A 59-storey tower with three basement levels;
- Ground level (RL20.78) for Office and Hotel lift lobbies, Hotel Concierge, Café and Bar;
- Mezzanine (Level 1) for functions, including an outdoor terrace overlooking Bligh Street;
- Levels 2-10 for the Office component of the tower
- Levels 11 and 13 for plant and mechanical equipment;
- Level 12 for clubhouse amenities, including a pool and outdoor terrace overlooking Bligh Street;
- Levels 14-55 for the Hotel component, including the two “penthouse floors” (Levels 54-55);
- Upper levels (Levels 56-58) for Restaurant, Bar and Plant Room respectively, including an outdoor landscape area on the southeast facing balcony; and
- Roof Level (RL225.88), giving a total building height above ground of 205 m.

Figure 2 Architectural Views of the Proposed Hyatt Hotel

Bligh Street View (looking north)

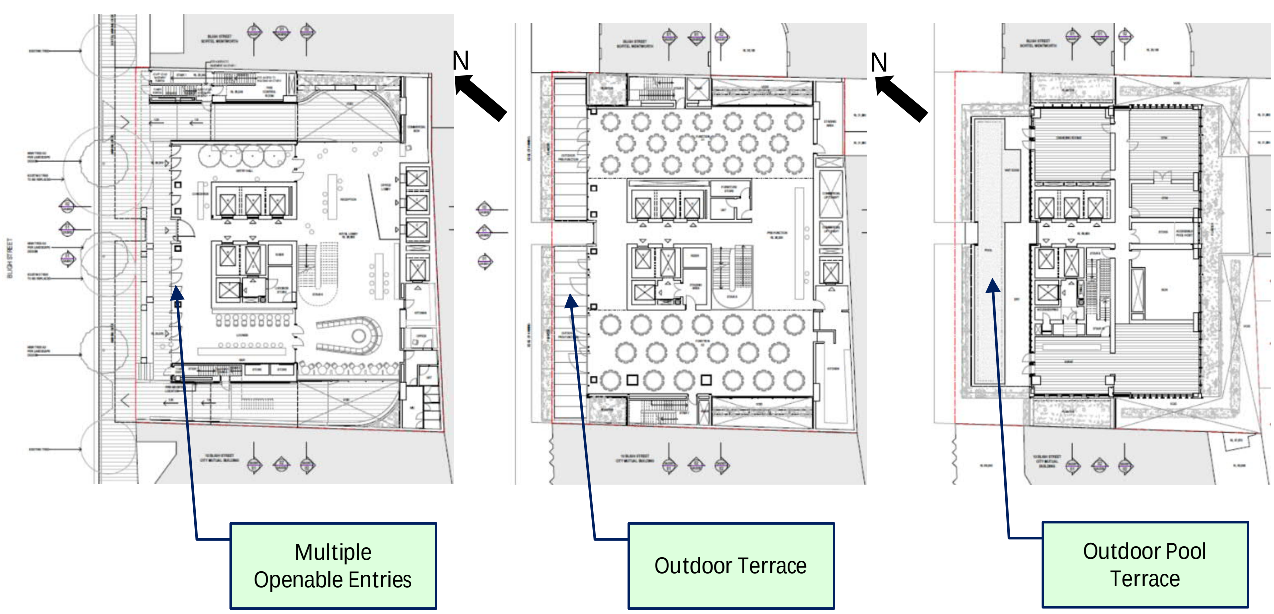
Perspective View from South

Elevations

Northeast | Southeast | Southwest | Northwest

Typical Floor Plans

Ground Floor | Mezzanine (Level 1) | Level 12



3 PROJECT SITE WIND SPEED CHARACTERISTICS

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.

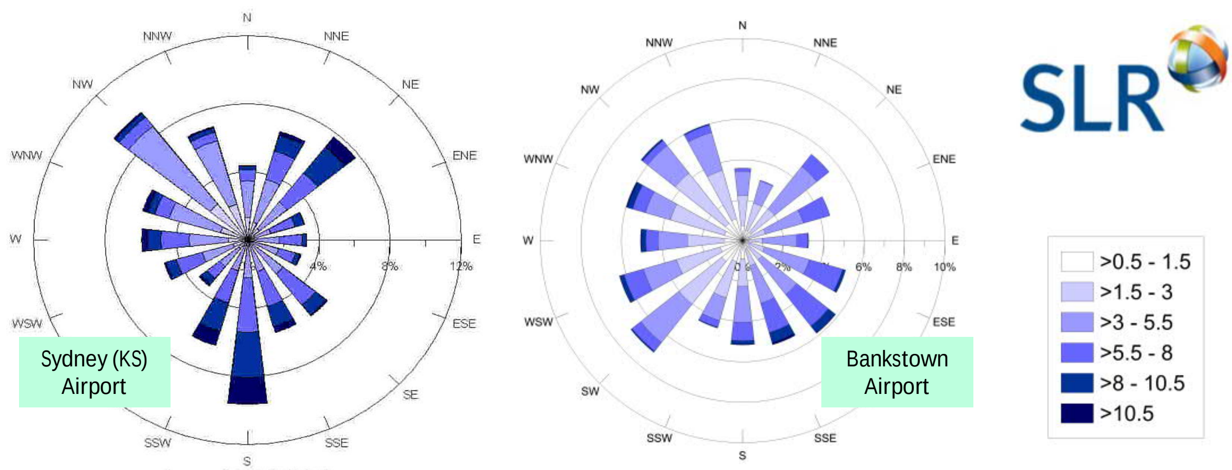
3.1 Sydney Region Winds and Seasonal Variations

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.

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. 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 weather events such as "Southerly Busters" and "East Coast Lows" typically have a noticeably 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)



For the CBD project site, local upper level winds associated with the weather systems experienced at the site would have characteristics similar to Sydney (KS) Airport, given the similar distance inland and proximity to Sydney Harbour onshore winds – please refer:

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

3.2 Sydney (KS) Airport Derived "Regional" Wind Climate Model

The first step in developing the local Project Site wind climate model was to adjust the Sydney (KS) Airport 10 m height BoM data for its own local airport exposure, eg taking into account the open water exposure upstream of the BoM anemometer station to the south-southeast (Botany Bay), suburban exposure to the west to northwest, open runway exposure to the north-northeast followed by suburban exposure further afield, etc.

The resulting Terrain Category 2 equivalent wind climate model can be considered to be a "regional" model applicable to the Sydney CBD Project Site, given the comparable distances from the coast of the project site and the airport location (particular with respect to any alternative BoM stations that have both a long-term wind record and suitable surrounding, generally unobstructed terrain).

3.3 The "Local"' Wind Environment

Close to the ground at any particular site, the "regional" model described in Section 3.2 will be affected by the local terrain, topography and built environment, all of which influence the "local" wind environment.

For the Project Site, the approach wind characteristics vary significantly from a mixture of over-water and relatively open terrain to the east-northeast (over the Royal Botanic Gardens) to a very "dense urban" terrain to the south to southwest. In between these two approach directions are intermediate terrain types, eg a combination of open terrain (The Domain) and dense suburban terrain to the southeast and a combination of CBD buildings, over-water (Sydney Harbour) and suburban to the northwest.

The above variations are illustrated in Figure 4.

3.4 Project Reference Height Design Wind Speeds

The measurements made in the environmental wind tunnel study make use of a reference height design wind speed, $\bar{V}_{ref}$, which happens to be very close to the top height of the building:

- $\bar{V}_{ref}$ – mean wind speed at the reference height of 200 m

$\bar{V}_{ref}$ can be determined using the "regional" wind climate model (Section 3.2) wind speeds combined with adjustment factors (found in AS1170.2-2011) based on the Terrain Category for wind directions ranging from 0° to 360°. These local exposure factors, denoted $C_{exp,H}$, are the ratio of mean wind speed at the reference height, H=200m, to the "regional" 10 m height (Terrain Category 2) wind speed.

The variation of $C_{exp,H}$ is shown in Figure 5, including a polar plot form superimposed on an aerial view of the site and surrounds. The variation of $C_{exp,H}$ reflects the varying upstream terrain types evident in Figure 4.

Combining the Sydney (KS) Airport 10 m height (Terrain Category 2) wind data with the local project site exposure adjustment factors gives the reference height, annual return period, mean wind speeds for the Project Site – this is shown in Figure 6.

Figure 4 Upstream Terrain Views for the Development Site

View looking towards the Northeast

View looking towards the South

View looking towards the Northwest to North

Figure 5 Reference Height Terrain Category (Exposure) Factor, $C_{exp,H}$

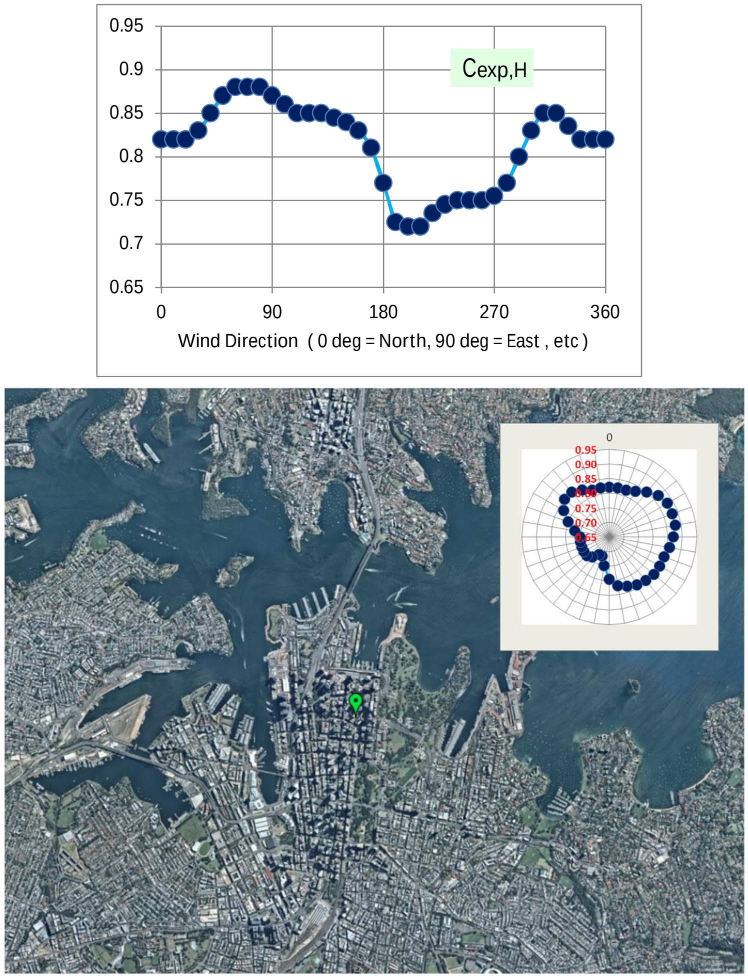
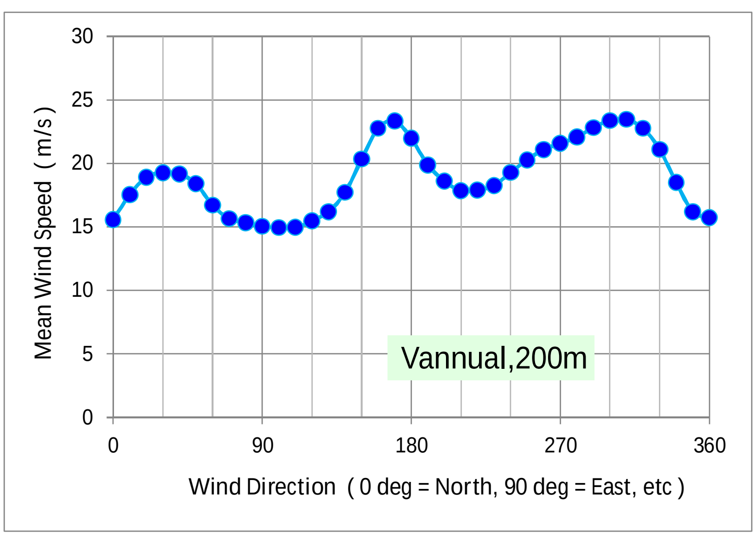


Figure 6 Reference Height Design Mean Wind Speed – Annual Return Period



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 deem 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 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 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).

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 Beaufort Scale 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 for UK high-rise building developments, eg the Canary Wharf precinct. They have been increasingly used internationally as well, including Australia.

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 the 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 so-called "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 Error! Reference source not found..

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.

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	Non-Sensitive Usage / All-Weather Use
S1	7	20 m/sec	Sensitive Usage / Fair-Weather Use
SX	> 7	> 20 m/sec	Exceeds Safety Criteria

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

S1 may be suitable for less frequently trafficked areas or areas which can be closed off in high wind conditions
S1 typically suited to able-bodied persons - not generally suited to frail people, cyclists, etc.

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

As in the case of the Melbourne comfort-related 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).

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.

Application of the Lawson Acceptability Criteria

In many urban locations, either because of exposure to open upstream conditions or because of street "canyon" effects, etc, the Lawson 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 should be applied to the Comfort Criteria in particular, 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 involves a high profile and relatively tall building in the Sydney CBD 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 throughout Sydney.

Accordingly, SLR has assessed the Project using BOTH the Melbourne and Lawson criteria.

As will be seen in the results that follow, good 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 slightly more restrictive in terms of acceptability than the Lawson criteria for the relevant Comfort levels.

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, ie for environmental wind speeds, it is possible to waive strict adherence to the full range of similarity parameters, eg buoyancy effects important to pollutant dispersion studies do not need to be reproduced.

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 upstream trip fence and a 15-metre fetch of appropriate roughness elements.

For practical reasons, it was not feasible to carry out the testing for all of the terrain category types evident in Figure 5. For the present wind study, the testing strategy used to capture the variation in upstream profile conditions is summarised in Table 1.

- Two pairs of tests were carried out for each of the built environment configurations examined:
  - The “Existing” built environment – buildings included as of August 2019; and
  - The “Future” built environment – “Existing” + proposed development.
- For each of the above Built Environment scenarios, two tests were carried out for the “limiting” terrain category conditions affecting the site:
  - An open terrain category equivalent to AS1170.2 Terrain Category 2.5; and
  - A dense urban terrain equivalent to AS1170.2 Terrain Category 3.6.

Table 5 Structural Test Configurations

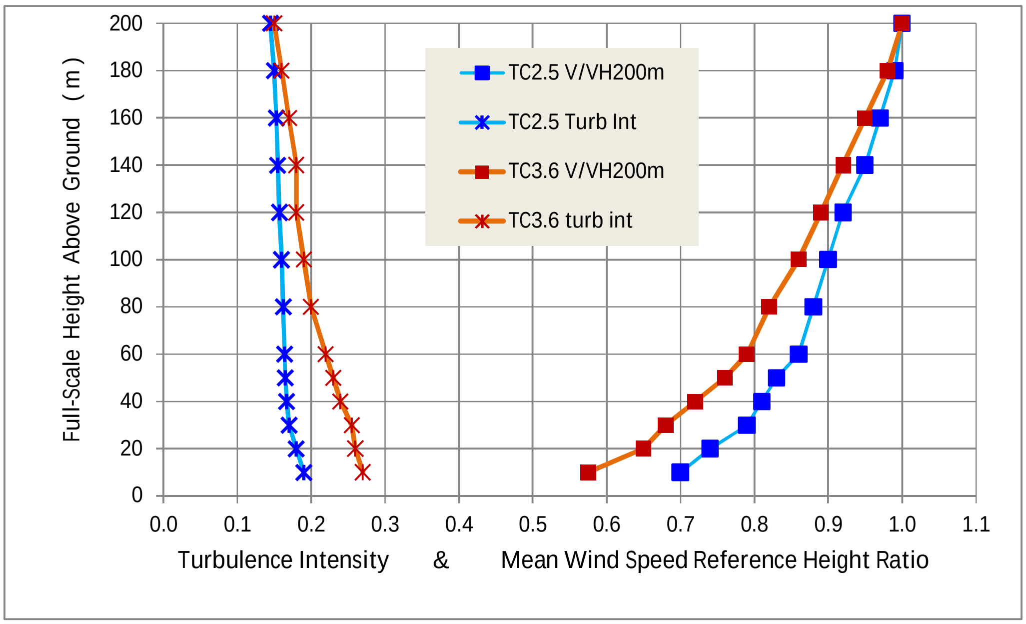
Built Environment Scenario	Test ID	Terrain Category	Terrain Description
“Existing”	T-EX-2.5	AS1170.2 TC2.5	Open terrain, few upstream obstacles
	T-EX-3.6	AS1170.2 TC3.6	Dense urban
“Future”	T-FU-2.5	AS1170.2 TC2.5	Open terrain, few upstream obstacles
	T-FU-3.6	AS1170.2 TC3.6	Dense urban

The “TC2.5” and “TC3.6” tests therefore covered the range of the more “open” and more “dense” terrain categories relevant to the project site, allowing interpolation for intermediate terrain exposure.

5.2 Wind Tunnel TC2.5 and TC3.6 Profiles

The two "open" (TC2.5) and "urban" (TC3.6) upstream profile conditions simulated in the present study are shown in Figure 7. The TC2.5 profiles of mean wind speed and turbulence intensity are shown in blue, the corresponding TC3.6 profiles in ochre. The mean wind speed profiles are shown as a ratio of the mean wind speed at different height to the mean wind speed at a full-scale equivalent height of 200 m (very close to the top height of the proposed development).

Figure 7 Wind Tunnel Test Profiles for Mean Wind and Turbulence Intensity



5.3 Combining Responses for Transition Terrain Categories

As shown in Figure 5, the upstream terrain category varies considerably with wind direction at the Project site. The testing strategy used to capture this variation involved carrying out tests as follows:

- "TC2.5" - "most open" terrain category: open terrain equivalent to AS1170.2 Terrain Category 2.5
- "TC3.6" - "most urban" terrain category: urban terrain equivalent to AS1170.2 Terrain Category 3.6

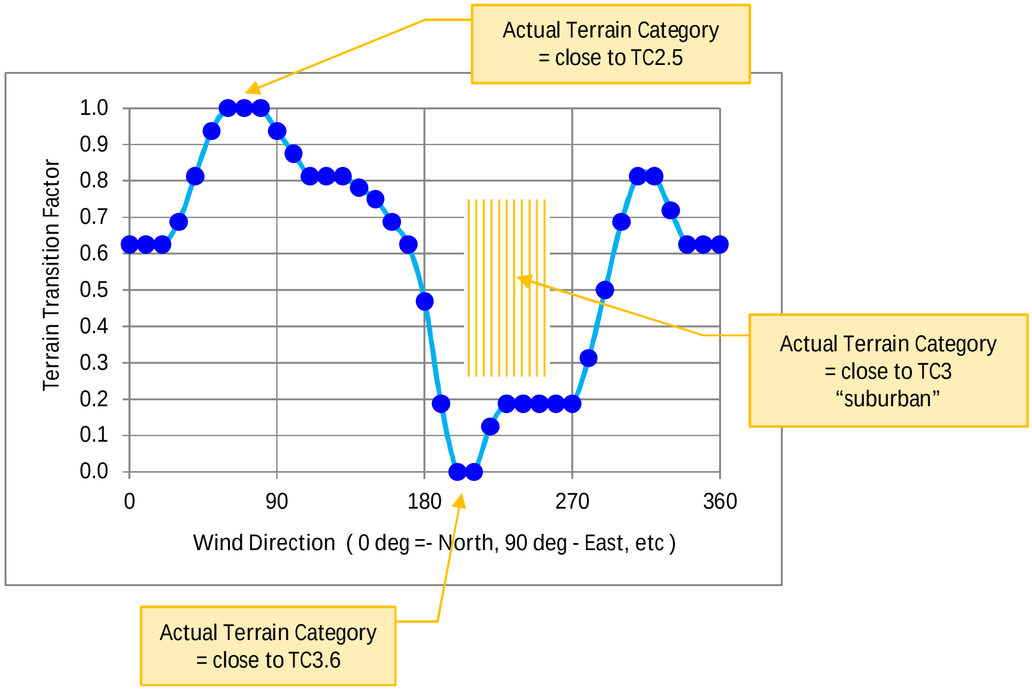
In order to produce a single set of local wind speed responses versus wind direction, the following procedure was then employed:

- Responses were determined for each Terrain Test, "TC2.5" and "TC3.6"
- A "terrain transition factor" (TTF) was developed based on the exposure factor variation shown in Figure 5, linearly extrapolated to range from 0 to 1.

The TTF factor is shown in Figure 8.

- A TTF of 1 corresponds to an angle where the actual terrain category is the same as "TC2.5", in this instance from the east-northeast with winds approaching the site over Sydney Harbour
- A TTF of 0 corresponds to an angle where the actual terrain category is the same as "TC3.6", in this instance from the south-southwest with winds approaching the site over the Sydney CBD
- Intermediate terrain categories are calculated as TTF x "TC2.5" + (1-TTF) x "TC3.6"

Figure 8 Terrain Transition Factor



5.4 Wind Tunnel Proximity Model

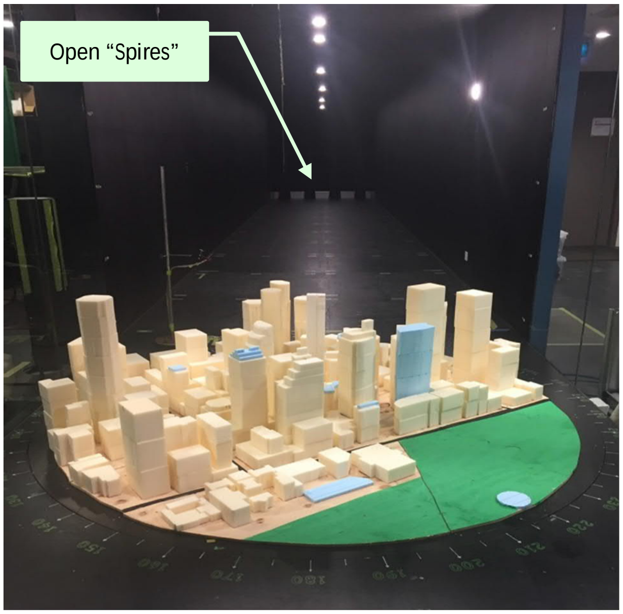
To take into account the influence of the immediate surrounding physical environment, all neighbouring buildings and local topography within a diameter of almost 1 km around the site were included in the purpose-built 1:400 scale "proximity model" used for the test as shown in Figure 9. The proximity model simulates two built environment "scenarios":

- "Baseline" scenario: simulating the existing built environment (August 2019); and
- "Future" scenario: "Baseline" + future proposed development.

Figure 9 Proposed Development and Proximity Models Used in the Wind Tunnel Testing

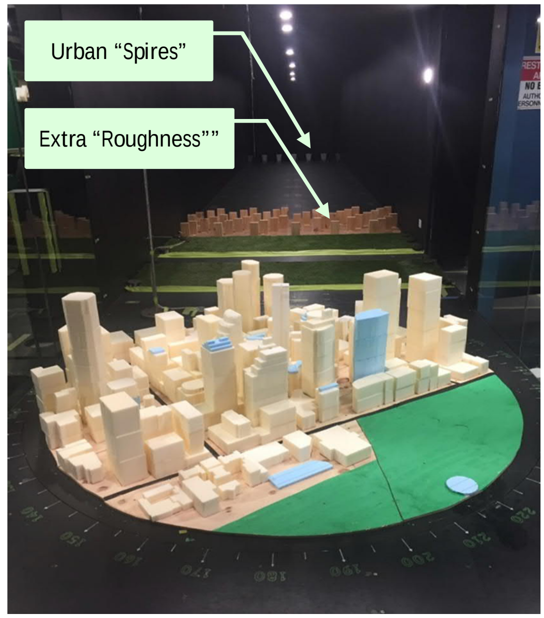
"BASELINE"

Test Profile "TC2.5"
Looking Northwest



"FUTURE"

Test "TC3.6"
Looking Northwest



5.5 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 project site wind climate model to yield ground level wind speeds as a function of annual return period and directional mean reference wind speed – refer Figure 6. The ground level wind speeds thus incorporate both

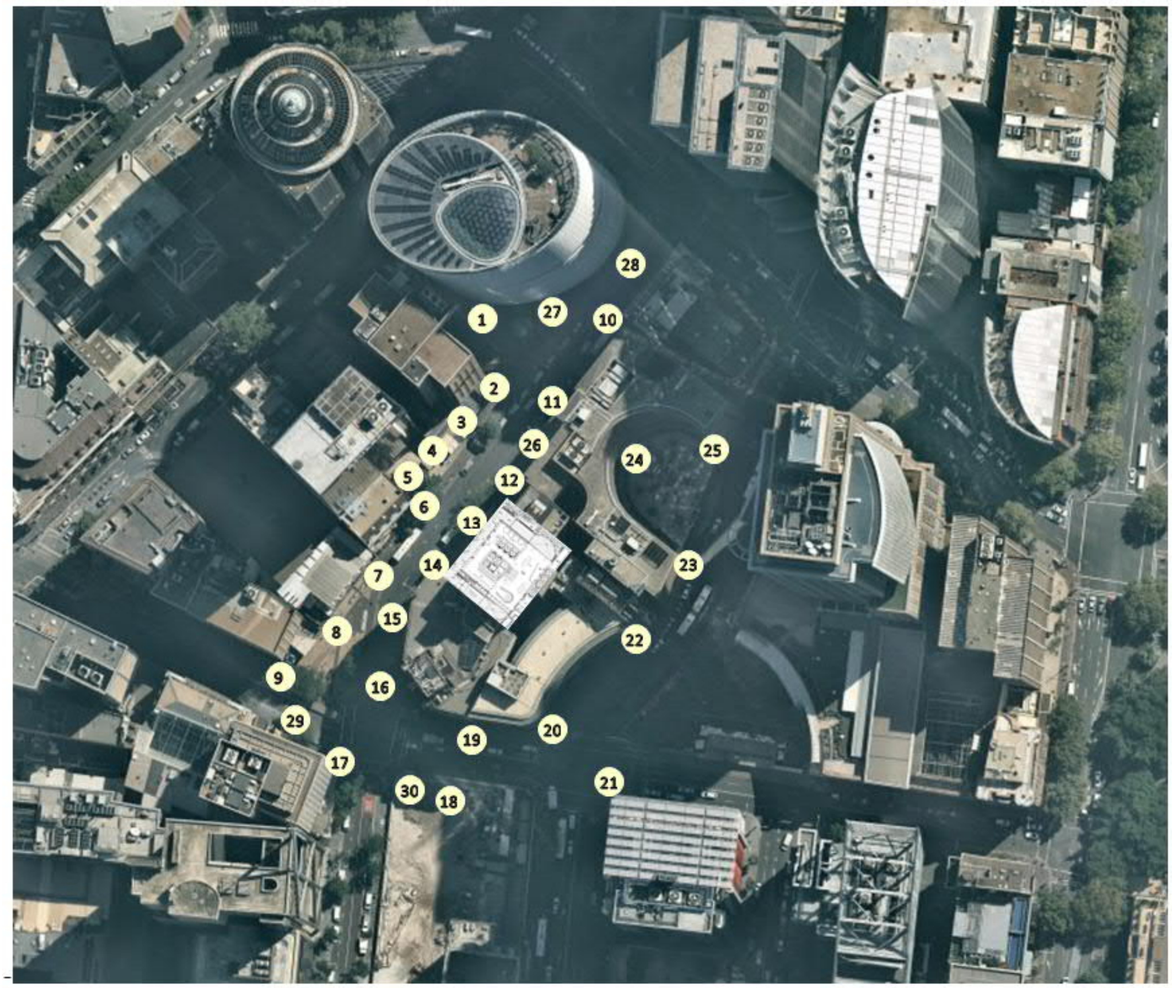
- the building and terrain/topographical aspects of the location; and
- the directional probability of wind speed at the project site.

5.6 Sensor Locations – Ground Level

In the wind tunnel testing, Irwin wind sensors were positioned at the locations shown in Figure 10. These locations were chosen as potentially susceptible to adverse wind conditions, eg near building corners, or represent locations of interest surrounding the development, eg near primary building entrances and along footpaths.

- All locations 1-30 are ground level sensors placed at public access and footpath locations surrounding the site for BOTH the "Baseline" scenario and "Future" scenario;

Figure 10 Wind Tunnel Test Sensor Locations



5.7 Sensor Locations – Upper Level

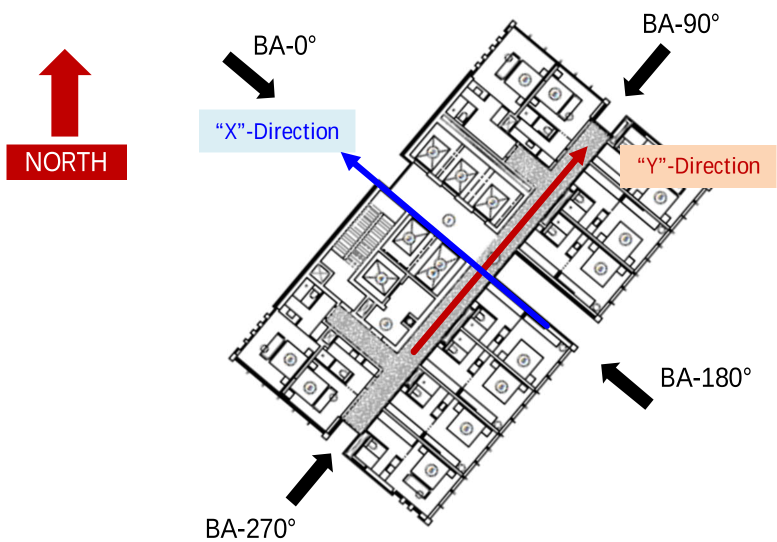
The development has elevated locations of interest, namely the Level 1 Outdoor Terrace and Level 12 Pool Deck Outdoor Area. These are relatively narrow width areas, where measurements with Irwin Sensors are challenging at the wind tunnel test scale of 1:400. These areas were therefore examined via the parallel CFD Modelling undertaken for the study – refer Section 8.

5.8 Wind Tunnel Test Axis Notation

Of particular interest in this study are the primary orthogonal approach angles of the proposed development, shown in Figure 11.

- The “Building X-Axis” aligns roughly northwest-southeast;
  - The wind direction corresponding to positive “X” is 310°;
  - This wind direction corresponds to wind impacting the proposed development perpendicular to the Bligh Street façade .
- The “Building Y-Axis” aligns roughly northeast-southwest
  - The wind direction corresponding to positive “Y” is 40°;
  - This wind direction corresponds to wind passing by the site in the direction of Bligh Street, towards the southwest.

Figure 11 Building Axis Notation Used in the Wind Tunnel Testing



For convenience sake, the results derived from the wind tunnel testing were documented using the Figure 11 “Building Axis” notation:

- BA-0° (Building Axis 0°) corresponds to a compass direction of ... 310°
- BA-90° (Building Axis 90°) corresponds to a compass direction of ... 40°
- BA-180° (Building Axis 90°) corresponds to a compass direction of ... 130°
- BA-270° (Building Axis 90°) corresponds to a compass direction of ... 220°

5.9 Sample Test Result

An example of the test results and interpretation of these results is shown in Figure 12, illustrating the peak annual mean and representative gust wind speeds at:

Sensor:	Location 7
Location:	Bligh Street footpath, opposite site southwest corner

The polar diagrams (using "Building Axis" notation) show the output of the wind tunnel test results for:

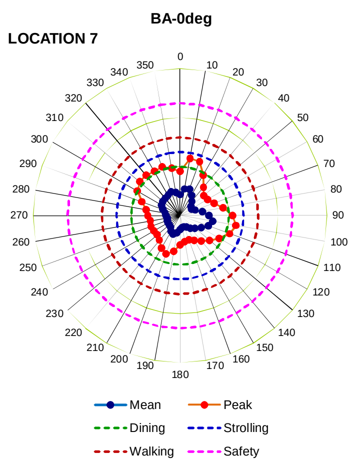
Mean wind speed:	"navy blue" data points
Gust wind speed:	"red" data points.

The polar diagrams also include three circumferential lines representing criteria for:

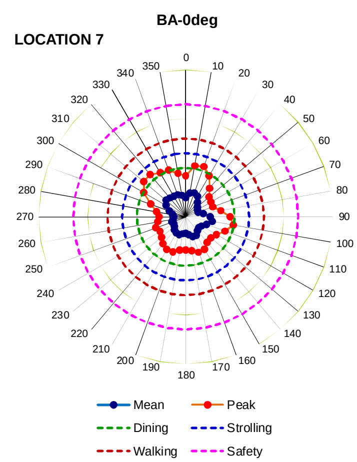
Public Safety:	23 m/sec (purple)
Walking Comfort:	16 m/sec (ochre)
Strolling Comfort:	13 m/sec (blue)
Dining Comfort:	10 m/sec (green)

Figure 12 Sample Polar Plot – Location 7: "Baseline" and "Future" Scenarios

"Baseline" Scenario



"Future" Scenario



"Baseline" scenario ...

- Winds at Location 7 are the strongest from BA-100°, where they are close to the Melbourne 13 m/sec walking comfort criterion, mainly due to winds accelerating along Bligh Street.

"Future" scenario ...

- With the addition of the proposed development, winds at BA-100° to BA-110° decrease slightly and winds at BA-150° to BA-170° increase slightly.

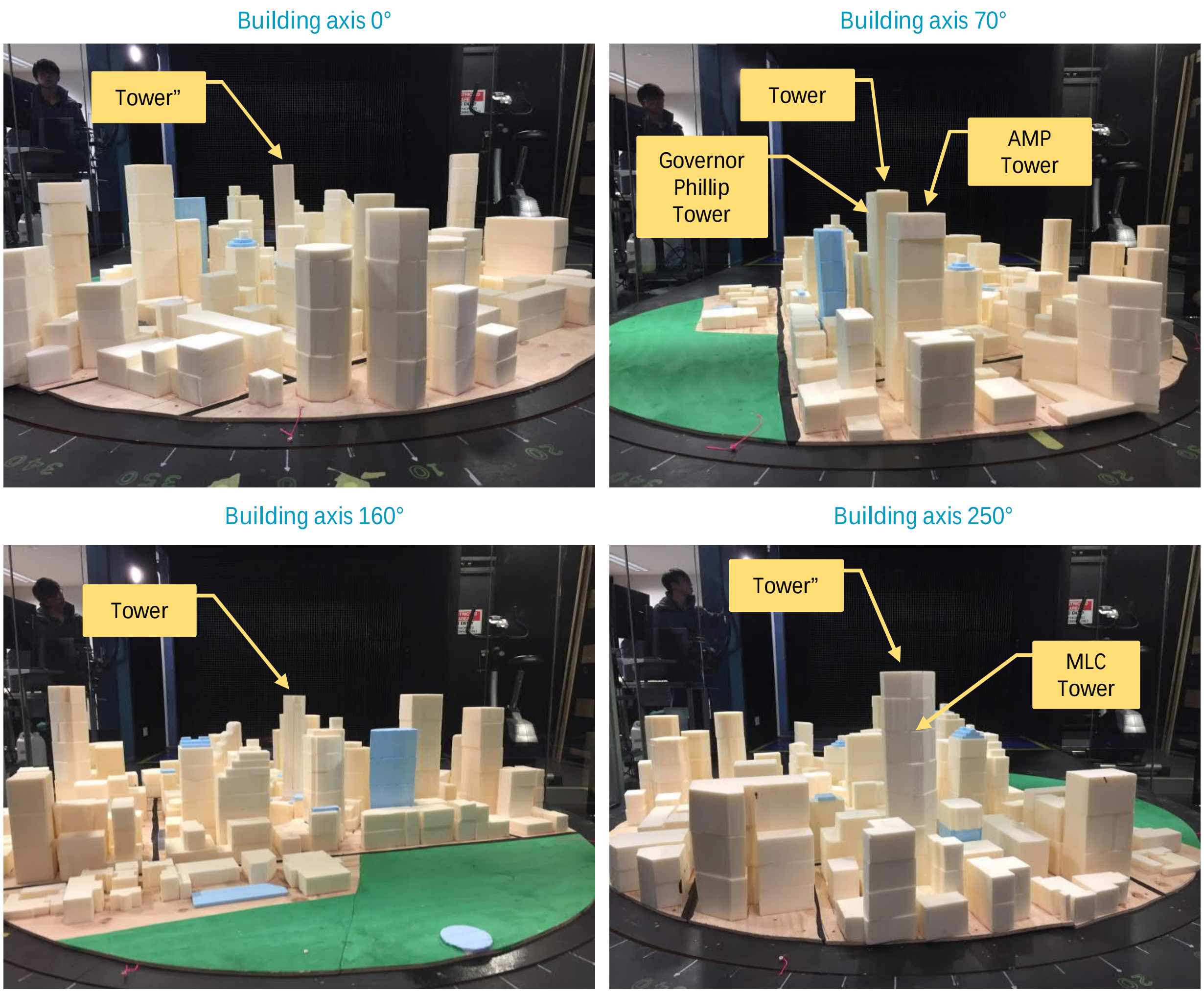
5.10 Influence of Surrounding Buildings on Local Wind Conditions

Through the present study and accompanying structural load studies, it became apparent that the dominant factor influencing local wind responses for both the “Baseline” and “Future” scenarios was the surrounding built environment. The significant sheltering created by surrounding buildings has a greater influence on resulting local wind conditions than both the upstream terrain category conditions and the presence of the proposed development itself.

Figure 13 shows several aspects of the project site, illustrating the significant impact of the surrounding buildings on the wind response associated with the proposed development.

- In some cases (eg BA-70°, BA-260°), upstream buildings completely shield the proposed development from oncoming winds.
- At BA-0°, only the top half of the proposed development is “visible” to oncoming winds. At BA-160°, most of the proposed development is “visible” to oncoming winds.

Figure 13 Representative Project Site Views (Wind Tunnel Test Photos)



The full set of Building Axis views of the wind tunnel model is included in Appendix B.

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.

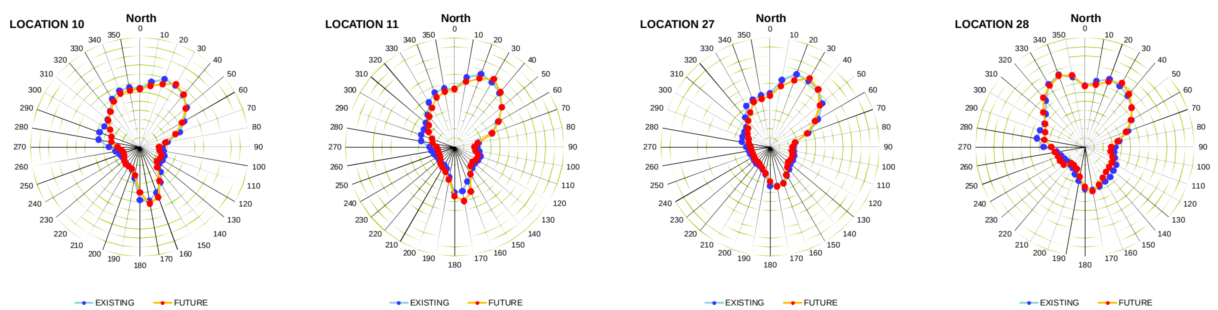
It should be noted that no landscaping (eg street trees) was incorporated in the “Baseline” and “Future” proximity models.

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: Bligh Street North (representative locations shown in Fig.14)

- Locations along Bligh Street north of the site experience their highest wind speeds from around BA-20° to BA-30°. These are winds which accelerate around the eastern façade of No.1 Bligh Street.
- These winds are essentially unaffected by the additional of the proposed development.
- Winds aligned with Bligh Street itself (ie northeast winds, BA-90°) are modest, due to the overwhelming shielding afforded to Bligh Street from the “wall” of buildings upstream in this direction: Governor Phillip, Governor Macquarie, Aurora Tower, etc.
- With the addition of the proposed development, these winds remain essentially unchanged.
- There is only a very modest increase in winds from BA-170° to BA-180° (ie winds approaching the site from the southeast) with the addition of the proposed development. This is one of the few directions where oncoming winds can “see” a significant part of the proposed development.
- There appears to be minimal impact by the proposed development on winds approaching the site from the site along Bligh Street.

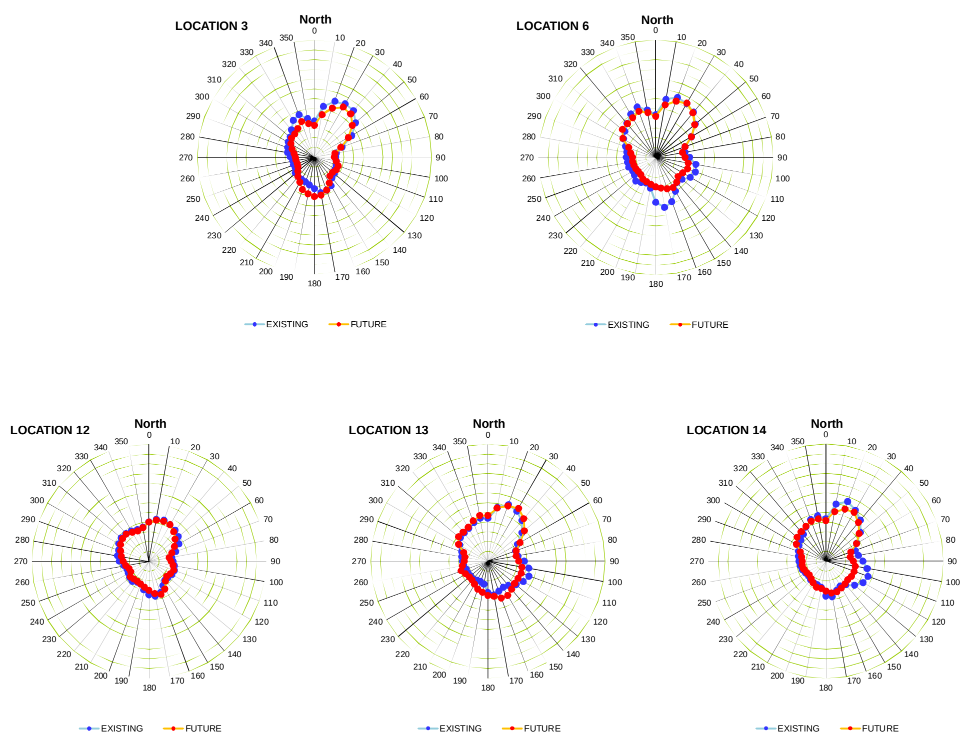
Figure 14 Bligh Street North Representative Peak Annual Gust Ratios V/Vref: “Baseline” versus “Future”



6.2 Sensor Locations: Bligh Street at Site (representative locations shown in Fig.15)

- Locations along Bligh Street in front of the proposed development and on the opposite footpath experience generally milder wind conditions in both the “Baseline” and “Future” scenarios.
- The highest wind speeds at these locations for the “Baseline” occur for BA-20° to BA-30°, BA-110° and BA-170°. These are either winds from the northwest or winds from the relatively open exposure of the southeast.
- The northwest winds are essentially unaffected by the additional of the proposed development. At some locations, sheltering by the proposed development reduces local wind speeds, eg on the opposite footpath to the site for southeast winds.
- Again, winds aligned with Bligh Street itself (ie northeast winds, BA-90°) are modest, due to the overwhelming shielding afforded to Bligh Street from the “wall” of buildings upstream in this direction: Governor Phillip, Governor Macquarie, Aurora Tower, etc.
- With the addition of the proposed development, these winds remain essentially unchanged.
- Overall, there is minimal change in winds for footpath locations at or opposite the site with the addition of the proposed development.

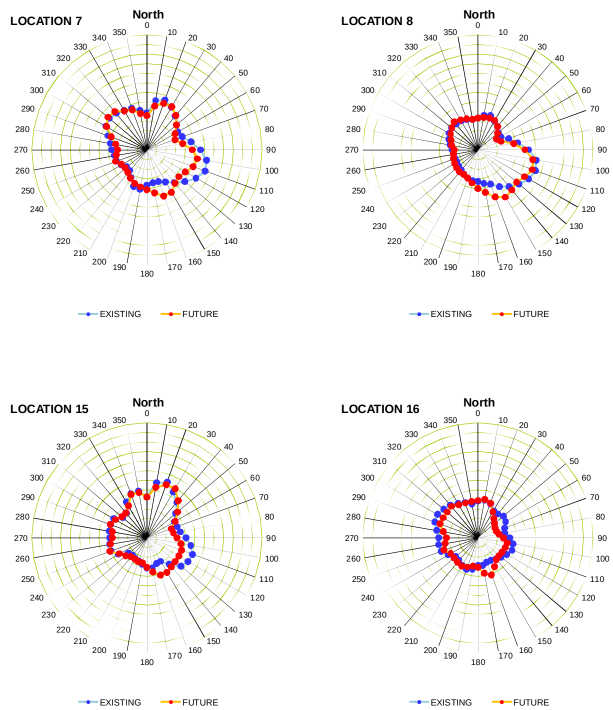
Figure 15 Bligh Street at Site Representative Peak Annual Gust Ratios V/Vref: “Baseline” versus “Future”



6.3 Sensor Locations: Bligh Street South (representative locations shown in Fig.16)

- Locations along Bligh Street south of the site experience generally mild wind conditions in both the “Baseline” and “Future” scenarios.
- The highest wind speeds at these locations for the “Baseline” occur for BA-20° to BA-30° and BA-110°. These are either winds from the northwest or winds from the east-northeast.
- The northwest winds are essentially unaffected by the additional of the proposed development.
- At some of these locations, the proposed development produces both modest increases and decreases in local wind speed, eg at Location 15, “Future” winds reduce slightly for BA-110° and increase slightly for BA-160°.
- Winds aligned with Bligh Street (ie northeast winds, BA-90° and southwest winds, BA-270°) experience no change with the addition of the proposed development at these locations.
- Again, and largely due to the influence of the many high-rise buildings surrounding the site, there is minimal change in winds for Bligh Street footpath locations south of the site with the addition of the proposed development.

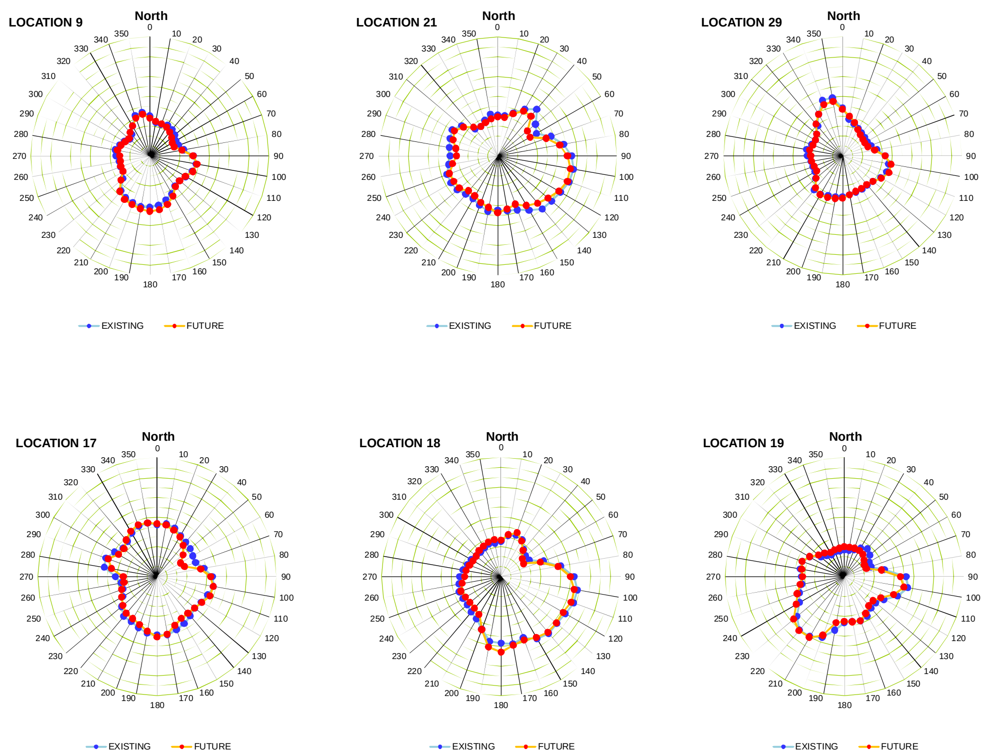
Figure 16 Bligh Street South Representative Peak Annual Gust Ratios V/Vref: “Baseline” versus “Future”



6.4 Sensor Locations: Hunter Street (representative locations shown in Fig.17)

- Overall, there is virtually no change in winds along Hunter Street, south of the site, with the addition of the proposed development.
- The highest wind speeds at these locations for both the "Baseline" and "Future" scenarios occur for winds approaching from the northwest along Hunter Street and east along Hunter Street.
- These winds are essentially unaffected by the additional of the proposed development.

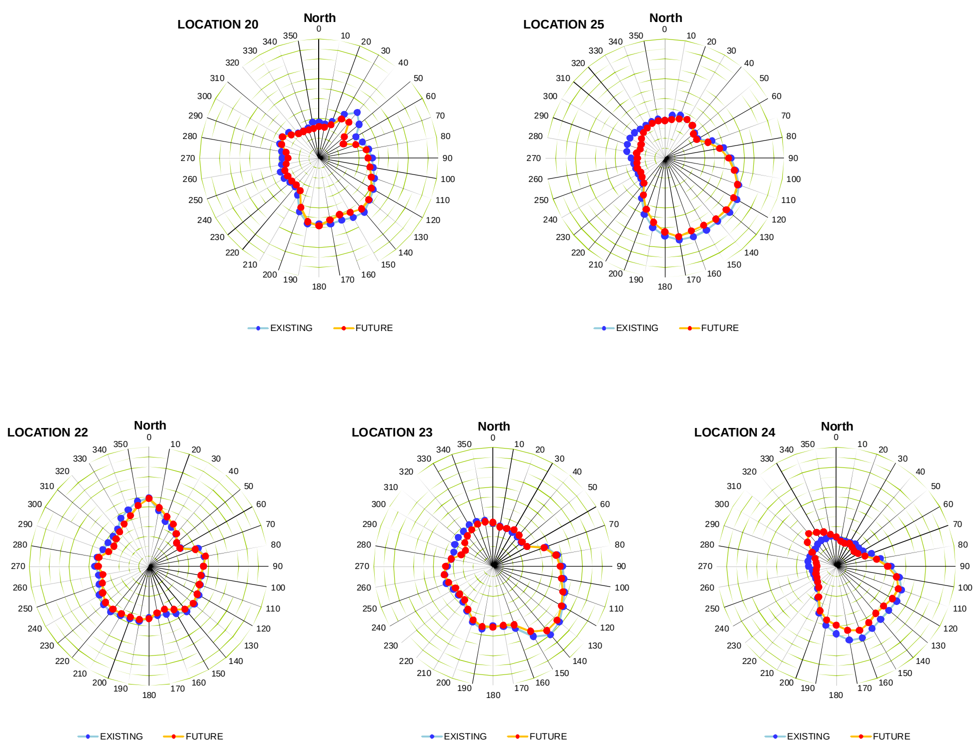
Figure 17 Hunter Street Representative Peak Annual Gust Ratios V/Vref: "Baseline" versus "Future"



6.5 Sensor Locations: Phillip Street (representative locations shown in Fig.18)

- As in the case of Hunter Street, there is virtually no change in winds along Phillip Street, east of the site, with the addition of the proposed development.
- The highest wind speeds at these locations for both the "Baseline" and "Future" scenarios occur for winds approaching from the southeast (~BA-120° to BA-160°). For these directions, winds can aporach the area from over The Domain through gaps between the high-rise buildings that run along the west side of Macquarie Street.
- These winds are essentially unaffected by the additional of the proposed development – if anything, the proposed development causes a very small decrease in local winds along Phillip Street for southeast winds.

Figure 18 Phillip Street Representative Peak Annual Gust Ratios V/Vref: "Baseline" versus "Future"



7 OVERALL WIND IMPACT

Table 6 gives the peak annual gust wind speeds and the 5% and 0.2% annual exceedance GEM wind speed Lawson class 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 respectively.

Table 6 Predicted Peak Gust and GEM 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"	"Future"	"Baseline"	"Future"
1	13.5	13.0	C3	C3	S2	S2
2	15.5	14.5	C3	C3	S2	S2
3	13.0	11.5	C3	C4	S2	S2
4	10.0	8.0	C4	C4	S2	S2
5	7.5	6.5	C4	C4	S2	S2
6	14.0	13.0	C3	C3	S2	S2
7	12.0	11.5	C3	C3	S2	S2
8	11.5	10.5	C3	C3	S2	S2
9	11.0	11.5	C3	C3	S2	S2
10	16.5	15.5	C3	C3	S2	S2
11	18.0	17.0	C3	C3	S2	S2
12	10.0	9.5	C4	C4	S2	S2
13	13.0	13.0	C4	C3	S2	S2
14	13.5	12.0	C3	C4	S2	S2
15	13.5	12.5	C3	C3	S2	S2
16	10.0	9.5	C3	C4	S2	S2
17	13.0	13.0	C3	C3	S2	S2
18	14.5	14.0	C2	C2	S2	S2
19	16.5	16.5	C2	C2	S2	S1
20	12.0	11.5	C3	C3	S2	S2
21	14.5	13.5	C2	C3	S2	S2
22	16.0	16.0	C3	C2	S2	S2
23	13.5	13.0	C2	C3	S2	S2
24	12.0	11.5	C3	C3	S2	S2
25	13.5	13.0	C3	C3	S2	S2
26	16.5	16.0	C3	C3	S2	S2
27	18.0	16.5	C3	C3	S2	S2
28	19.5	19.0	C2	C2	S2	S2
29	14.0	13.0	C3	C3	S2	S2
30	13.0	12.5	C3	C3	S2	S2

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

7.1 Wind Impact Relative to Intended Usage

Wind category objective: Melbourne 16 m/s Walking Comfort criterion in general
Melbourne 13 m/s Standing-Window Shopping criterion, selected areas
or
Lawson C2 (Strolling) criterion
Lawson C2 (Standing, Window Shopping) criterion, selected areas

Compliance with Melbourne (1978) Criteria

In terms of compliance with the Melbourne (1978) criteria:

- In the "Baseline" scenario, 7 of the 30 tested locations (Nos. 10, 11. 19, 22, 26, 27 and 28) experience predicted annual peak gusts which exceed the 16 m/s walking criterion
- In the "Future" scenario, 5 of these locations (Nos. 11. 19, 22, 27 and 28) continue to remain above the 16 m/s criterion; however, they all experience a decrease compared to the "Baseline" scenario
- There are NO locations BELOW the 16 m/s criterion in the "Baseline" scenario which experience an increase to then be OVER the 16 m/s criterion in the "Future" scenario.
- There are NO locations which exceed the 23 m/s safety criterion in either the "Baseline" scenario or "Future" scenario.

In terms of relative change between "Baseline" and "Future" scenarios:

- 25 of the 30 tested locations experience a DECREASE, albeit modest, in predicted annual peak gust
- 4 locations experience NO CHANGE in predicted annual peak gust
- 1 location (position 9) experiences a modest 0.5 m/s INCREASE in annual peak gust (from 11 m/s to 11.5 m/s)

Compliance with Lawson (1990) Criteria

In terms of compliance with the Lawson (1990) criteria:

- In the "Baseline" scenario, 5 of the 30 tested locations (Nos. 18, 19, 21, 23 and 28) experience Lawson Comfort levels of "C2", 21 locations are at Lawson "C3" and 4 locations are at Lawson "C4"
- In the "Future" scenario, 4 of the 30 tested locations (Nos. 18, 19, 22 and 28) experience Lawson Comfort levels of "C2", 20 locations are at Lawson "C3" and 6 locations are at Lawson "C4"
- There are no locations which experience Lawson Comfort levels in the "C1" category – ie only suitalbe for "purpose/business" walking
- All locations are within the Lawson "S2" level, suitable from a safety point of view for all-weather use.

In terms of relative change between "Baseline" and "Future" scenarios:

- 5 of the 30 tested locations experience a DECREASE (by one grade) in Lawson Comfort Level
- 23 locations experience NO CHANGE in Lawson Comfort Level
- 2 locations (Nos. 13,22) experience a one-grade INCREASE in Lawson Comfort Level ("C4" to "C3" and "C3" to "C2" respectively). Note that for these locations, the annual peak gust does not change between the "Baseline" and "Future" scenarios (13 m/s and 16 m/s respectively).

Locations Exceeding the Melbourne 16 m/s Walking Comfort Criterion

As noted above, there are 7 locations (Nos. 10, 11. 19, 22, 26, 27 and 28) which exceed the Melbourne 16 m/s criterion in the "Baseline" scenario (noting that none of these exceeds the 23 m/s safety criterion).

- None of these locations are in front of the project development site on Bligh Street
- They are located at either the northern end of Bligh Street, where they are impacted primarily by northwest winds which accelerate around the northeast façade of the No.1 Bligh Street tower, or on Phillip Street and Huinter Street, where they are influenced by southeast winds with no interaction with the proposed development.

In summary …

- No locations which currently exceed the Melbourne 16 m/s criterion experience an INCREASE in peak annual wind speed with the addition of the proposed development.
- Indeed, with the addition of the proposed development, peak annual gust wind speeds at these same locations either REMAIN THE SAME or DECREASE.

Comparing the Melbourne and Lawson Criteria

Previous studies have suggested that the Melbourne (1978) criteria often deliver predictions of comfort level wind speeds which indicate a more significant impact as compared to the equivalent Lawson (1990) criteria. Put another way, a location with a mean wind speed 5% exceedance level in the range 8 m/s to 10 m/s (ie satisfying the Lawson Comfort criterion for "purpose-walking", would likely have a corresponding annual peak gust speed in excees of 16 m/s, ie exceeding the Melbourne walking comfort criterion.

The present study follows this trend at most locations.

- The locations which have predicted peak annual gust winds just above 16 m/s (in either the "Bsaeline" or "Future" scenarios) have corresponding Lawson Comfort Levels ranging from "C3" to "C2" – below (ie "better") than the "purpose-walking" "C1" level.

8 GROUND LEVEL MITIGATION TREATMENT RECOMMENDATIONS

Sections 6 and7 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).

Ground Level Wind Conditions Surrounding the Site

In relation to the Melbourne (1978) criteria, ground level locations exceeding the criteria in the "Baseline" scenario include:

- Locations 10, 11, 26, 27 and 28 - at the northern end of Bligh Street, and
- Locations 19 and 22 – along Hunter Street and Phillip Street respectively.

In relation to the Melbourne (1978) criteria, ground level locations exceeding the criteria in the "Future" scenario include:

- Locations 11, 27 and 28 - at the northern end of Bligh Street, and
- Locations 19 and 22 – along Hunter Street and Phillip Street respectively.

In all cases above, the wind conditions resulting in these exceedances are not adversely impacted by the addition of the proposed development. Indeed, at two of the locations, Nos 10 and 26, peak annual gust winds drop below the 16 m/s criterion in the "Future" scenario.

Accordingly ...

- No wind mitigation is warranted to address concerns related to the "Future" scenario.

Ground Level Wind Conditions at the Site

In relation to the Melbourne (1978) criteria, ground level locations immediately in front of the site (same side footpath and opposite footpath) all satisfy the 16 m/s walking comfort criterion. IN fact, they are at or below the 13 m/s strolling comfort criterion. In terms of Lawson Comfort Level, these locations are either at the "C4" (sitting) or "C3" (standing) level.

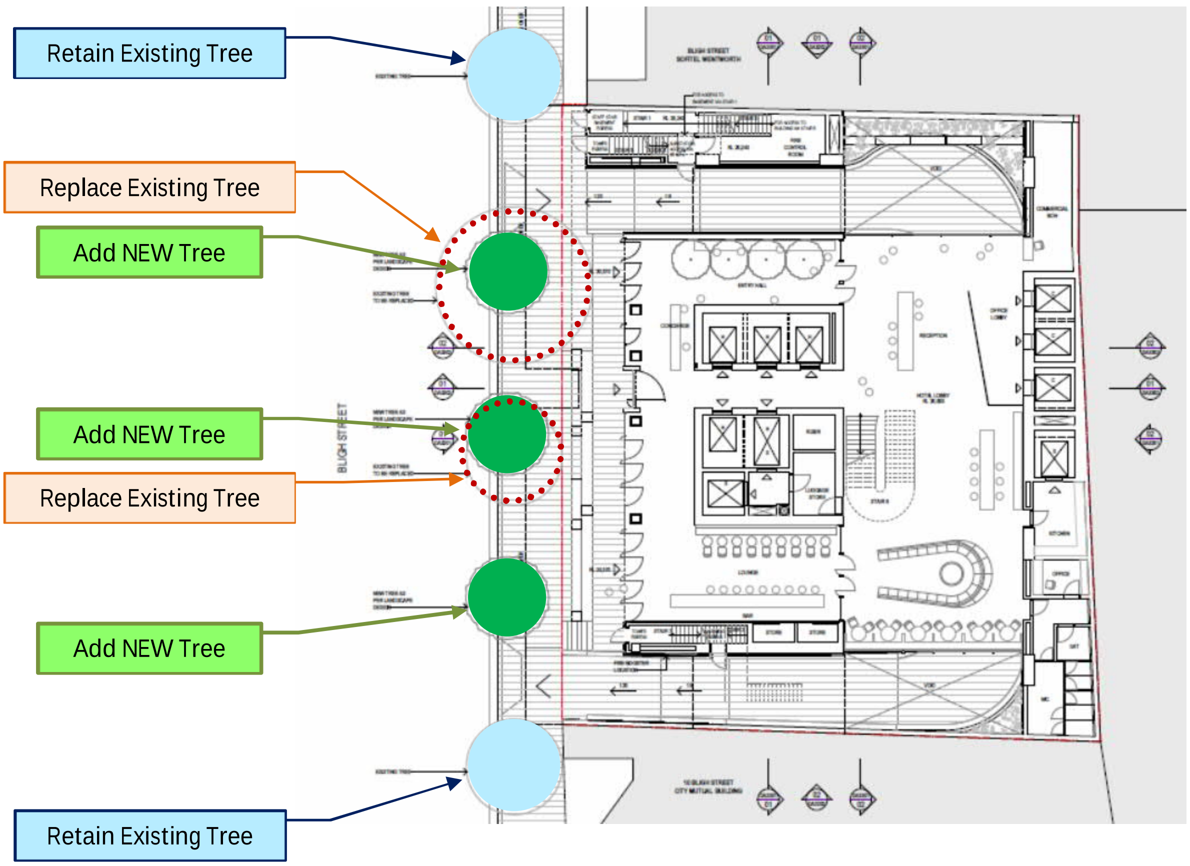
This almost certainly reflects two proposed development design features:

- The major 8 m set-back at Level 12 of the tower's Bligh Street façade, and
- The full perimeter Level 1 canopy protecting the Bligh Street footpath below

In light of the above, further recommendations in relation to wind comfort would be restricted to:

- The already planned landscaping – refer Figure 19 - along Bligh Street: two existing trees either side of the site perimeter footpath to be retained, two existing trees to be replaced and one new tree in front of the site.
- This landscaping was NOT included in the wind tunnel testing, and would be expected to further reduce wind speeds compared to those predicted in the current study.

Figure 19 Already Planned Landscaping for Bligh Street Frontage



9 UPPER LEVEL WIND CONDITIONS

As noted in Section 5, the proposed development has elevated locations of interest, namely the Level 1 Outdoor Terrace and Level 12 Pool Deck Outdoor Area overlooking Bligh Street.

Both of these elevated terraces are relatively narrow, where measurements with Irwin Sensors are challenging at the wind tunnel test scale of 1:400.

These areas were therefore examined via CFD Numerical Modelling using ANSYS FLUENT software.

9.1 CFD Modelling Methodology

SLR modelled the geometry of the proposed development and the surrounds using the Creo Parametric software package. This was then imported to ANSYS to prepare the model for solving. The modelling scenarios were run using the specialised state-of-the-art CFD software ANSYS-FLUENT V18.1 for computation.

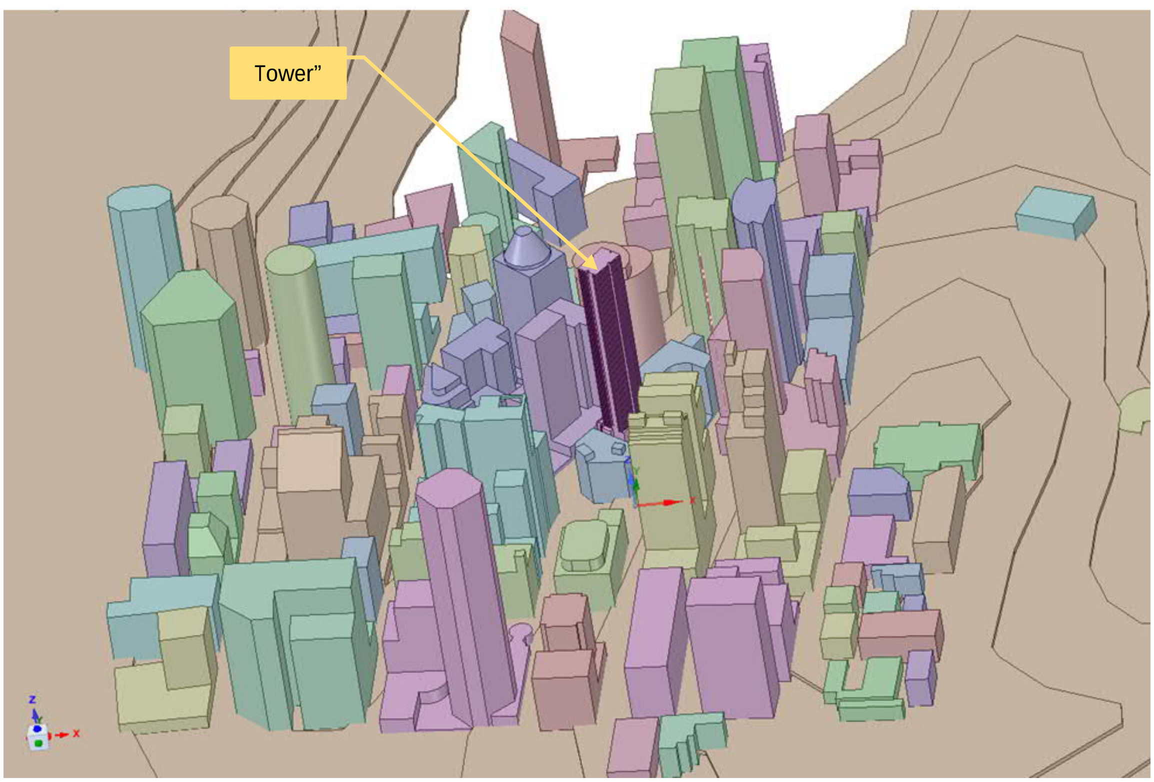
Model Geometry

A 3D model of the development area and surrounding buildings was created from Sydney CBD AutoCAD files that have been developed over many years by SLR. The geometry for CFD Modelling is shown in Figure 20.

In the present study, only the “Future” (with proposed development) was modelled.

The calculation domain for the modelling covers an area of 2.5 km by 2.5 km centred on the Project site.

Figure 20 3D Geometry used for the CFD Modelling Simulations



Upstream Reference Wind Profiles

All CFD simulations were runs with an upstream, 200 m height mean wind speed of 25 m/s.

The mean wind and turbulence profiles varied according to wind direction as per the variations shown in Figure 5.

FLUENT allows modelling output to be expressed in either absolute magnitude terms or as ratios of the upstream reference wind speed. Both were used for presentation purposes in the present study.

Discretisation

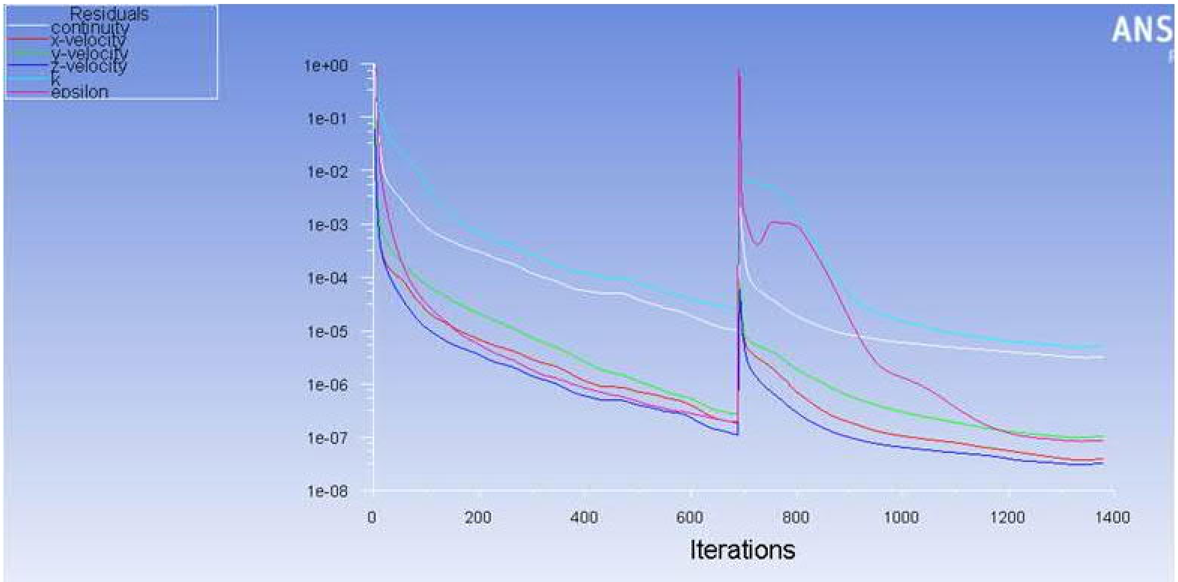
The quality of the CFD model mesh is a critical aspect of the overall numerical simulation - it has a significant impact on the accuracy of the results and solver run time.

A mesh sensitivity assessment was therefore carried out for the "Future" scenarios examined.

- Polyhedral elements with a total 30,147,018 nodes were employed to cover the computational domain. Polyhedral cells are especially beneficial for handling recirculating flows and are able to provide more accurate results than even hexahedra mesh. For a hexahedral cell, there are three optimal flow directions which lead to the maximum accuracy, while for a polyhedron with 12 faces there are six optimal directions which, together with the larger number of neighbours, lead to a more accurate solution with a lower cell count.
- A Realizable k-epsilon (rke) turbulence model was used for all analysed cases. The rke model is capable of providing more accurater results for flow involving separation and pressure gradients.
- A Second Order numerical scheme for momentum and pressure discretisation was used to obtain more accurate results.
- An iterative procedure was used to estimate the air velocity in terms of three directions, pressure profile and turbulence parameters.

Figure 21 shows that the normalised residuals of continuity for all cases were reduced by between five and six orders of magnitude while the normalised residuals of x-, y-, and z-velocity, k and epsilon were reduced between five and eight orders of magnitude demonstrating a valid solution.

Figure 21 Scaled Residual History for a Wind Direction Test Angle of 310°



9.2 CFD Validation

Prior to examining the output of the CFD Modelling for the elevated areas of interest, the CFD output at ground level was compared to the results of the Wind Tunnel Testing for the purpose of validation.

Two test angles reviewed are:

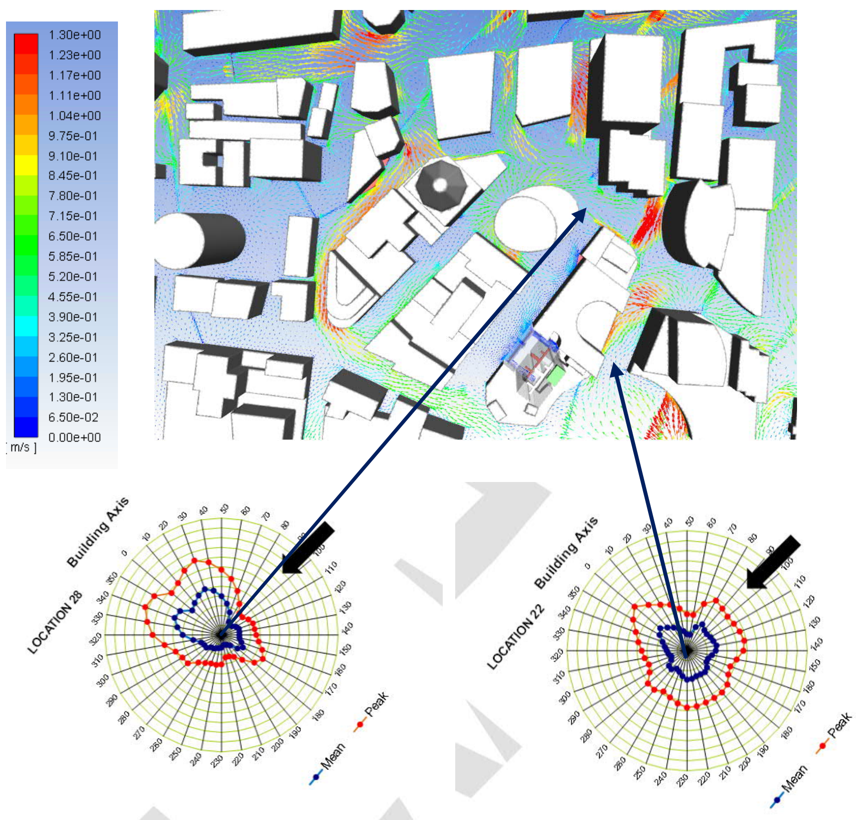
- Wind Direction = 45° (NE) = Building Axis BA-95°
- Wind Direction = 337.5° (NNW) = Building Axis BA-27.5°

Wind Angle = 45°

Figure 22 shows wind conditions close to ground level (as a ratio of the upstream 10 m height reference mean wind speed) for winds approaching the site from the northeast (NE). In the immediate blocks surrounding the Project site, the following can be observed:

- The immediate surrounding buildings provide reasonable shielding to the site for NE winds
- Near the No.1 Bligh Street tower, the mean wind speed ratio of V_{local}/V_{10m} indicated by the CFD output is close to 0.35, corresponding to a ratio of ~0.18 for V_{local}/V_{200m}
- The wind tunnel testing gave ratios of V_{local}/V_{200m} at Sensor Location No.28 of 0.2.
- Along Phillip Street, just south of the Wentworth Hotel, the mean wind speed ratio of V_{local}/V_{10m} indicated by the CFD output is also close to 0.65, corresponding to a ratio of ~0.32 for V_{local}/V_{200m}
- The wind tunnel testing gave ratios of V_{local}/V_{200m} at Sensor Location No.22 of 0.3.
- The CFD model gave Vlocal/V10m of 0.36 at Sensor Location No.13 along Bligh Street in front of the proposed development corresponding to a ratio of ~0.18 for Vlocal/V200m. The wind tunnel testing gave ratios of V_{local}/V_{200m} at Sensor Location No.13 of 0.26. In both the CFD and the wind tunnel testing, the results for sensors 12, 13 and 14 along the Bligh Street are similar.
- The CFD and wind tunnel testing results correlate well at the areas of interest.

Figure 22 CFD Simulation Mean Wind Speeds: 45°, V_{local}/V_{10m} Ratios



Wind Angle = 337.5°

Figure 23 shows wind conditions close to ground level (as a ratio of the upstream 10 m height reference mean wind speed) for winds approaching the site from the north-northwest (NNW). In the immediate blocks surrounding the Project site, the following can be observed:

- The highest winds occur along Bent Street and Bligh Street north of the site, as NNW winds accelerate in front of the northern façade of the No.1 Bligh Street tower.
- Close to the No.1 Bligh Street tower, the mean wind speed ratio of V_{local}/V_{10m} indicated by the CFD output is close to 1, corresponding to a ratio of ~0.5 for V_{local}/V_{200m}.
- The wind tunnel testing gave ratios of V_{local}/V_{200m} at Sensor Location No.28 of 0.46, which shows good agreement with the CFD output.
- The CFD model gave Vlocal/V10m of 0.34 at Sensor Location No.13 along Bligh Street in front of the proposed development (refer Figure 24) corresponding to a ratio of ~0.17 for Vlocal/V200m.
- The wind tunnel testing gave ratios of V_{local}/V_{200m} at Sensor Location No.13 of 0.2. In both the CFD and the wind tunnel testing, the results for sensors 12,13 1nd 14 along the Bligh Street are similar.
- Again, the CFD and wind tunnel testing results correlate well at the areas of interest.

Figure 23 CFD Simulation Mean Wind Speeds337.5°, V_{local}/V_{10m} Ratios

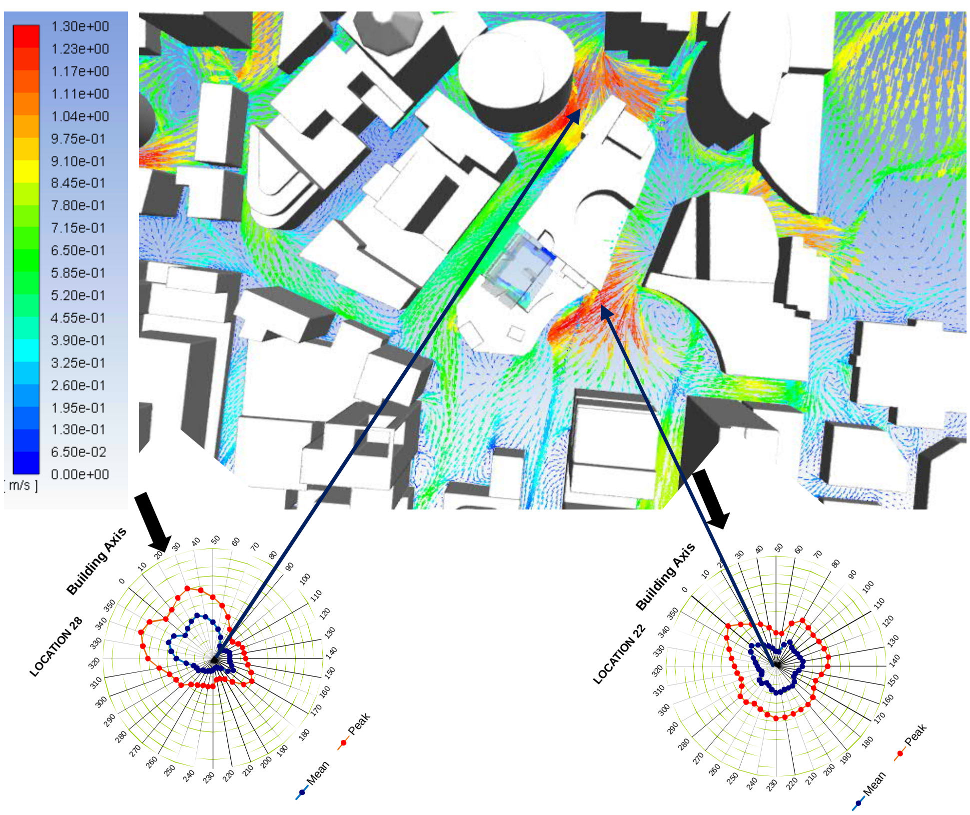
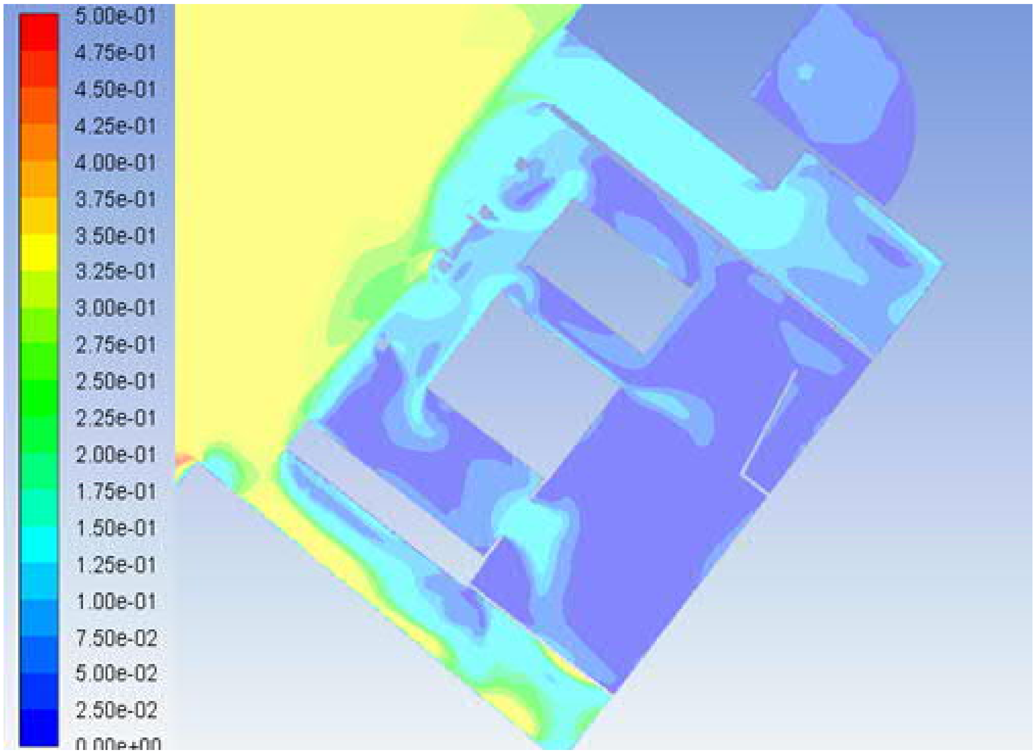


Fig.23 (cont'd)

CFD Simulation Mean Wind Speeds337.5°, V_{local}/V_{10m} Ratios
Results at 1.5 m above ground along Bligh Street



9.3 Wind Speeds on the Level 1 Outdoor Terrace

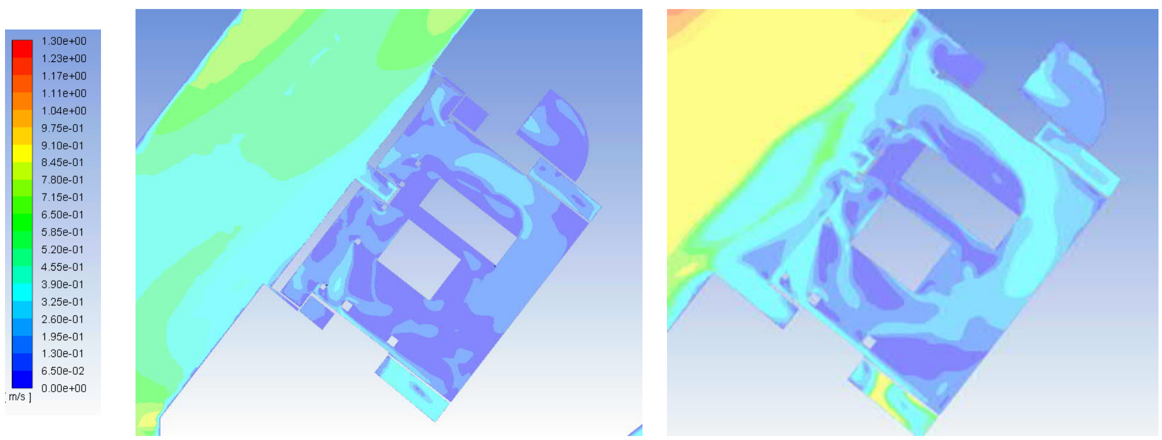
Figure 24 shows mean wind speed ratios on the Level 1 Outdoor Terrace for a potential "high-downwash" oncoming wind angle of 337.5°:

- For these north-northwest (NNW) winds, mean wind speed ratios (V_{local}/V_{10m}) on the terrace range from 0.2 to 0.3
- This compares to a ratio of close to 0.9 further out from the facade (above the centreline of Bligh Street) and a ratio of 0.5 on the footpath directly below.
- The vertical cross-section windflow diagrams indicate that the impact of downwash on the Level 1 Outdoor Terrace is modest, largely due to the "set-back" impact of the Level 12 step in the building's Bligh Street façade.

Figure 24 Level 1 Outdoor Terrace Mean Wind Speed Ratios: 337.5°, V_{local}/V_{10m}

Horizontal Plane Wind Contours

0.5m above Level 1 RL | 1.5m above Level 1 RL



Vertical Cross-Section Flow Diagram (parallel to tower short dimension)

Through mid-façade "Gap" | Close to NE facade

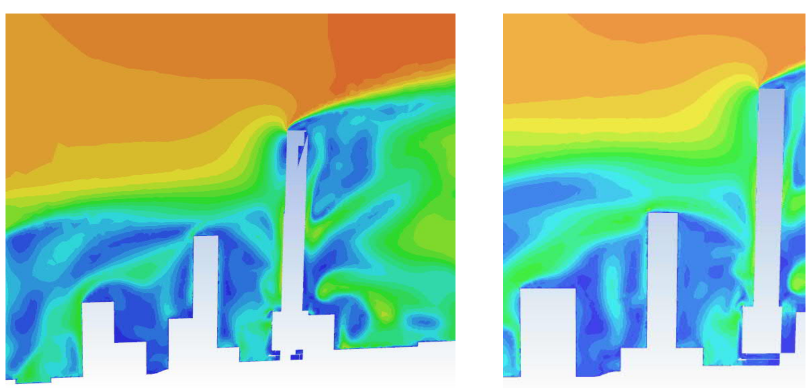
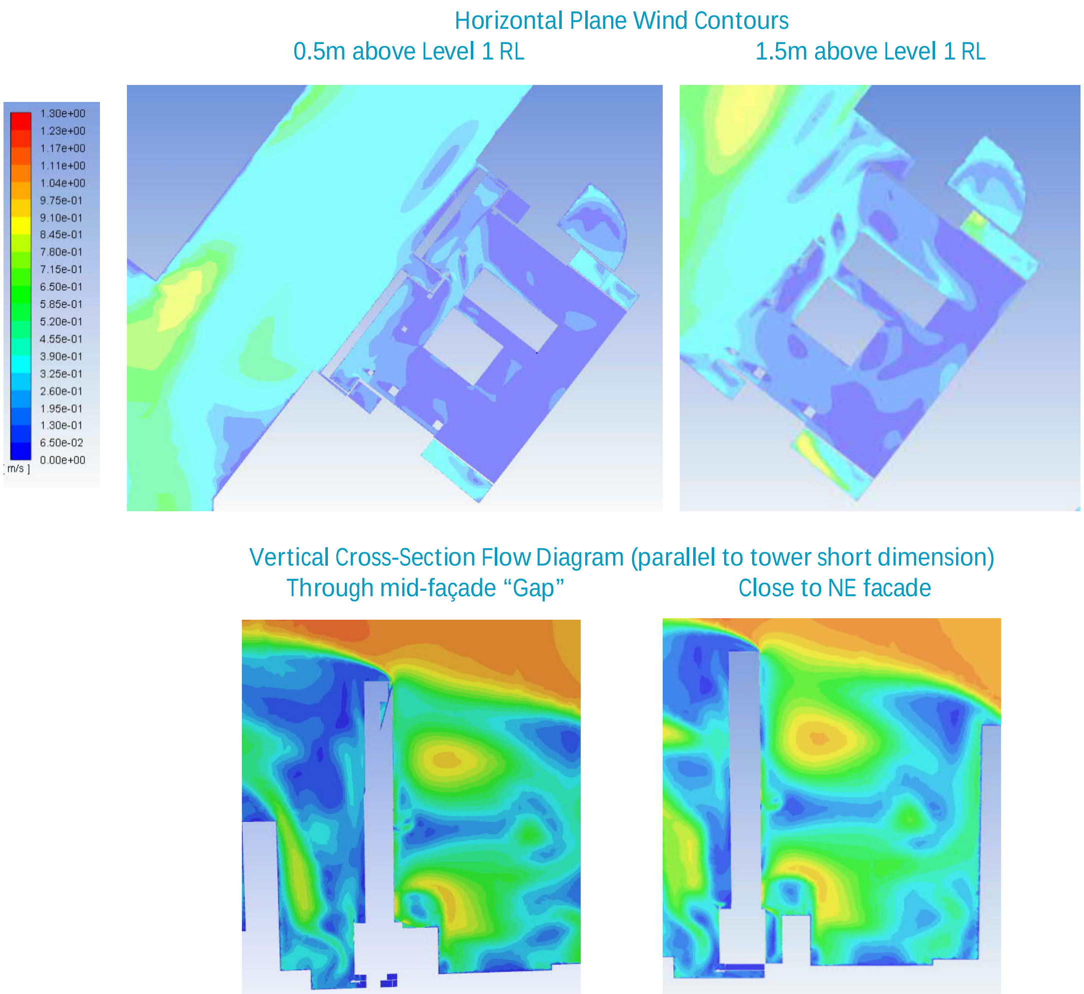


Figure 25 shows the same mean wind speed ratios on the Level 1 Outdoor Terrace for an oncoming wind angle of 112.5°:

- For these east-southeast (ESE) winds, mean wind speed ratios (V_{local}/V_{10m}) on the terrace range from 0.2 to 0.33.
- This compares to a ratio in the range 0.6 to 0.9 further out from the facade (above the centreline of Bligh Street) and a ratio of 0.5 on the footpath directly below.
- The vertical cross-section windflow diagrams indicate that the impact of downwash on the Level 1 Outdoor Terrace is very modest, largely due to the sheltering of the area by the proposed development itself.

Figure 25 Level 1 Outdoor Terrace Mean Wind Speed Ratios: 112.5°, V_{local}/V_{10m}



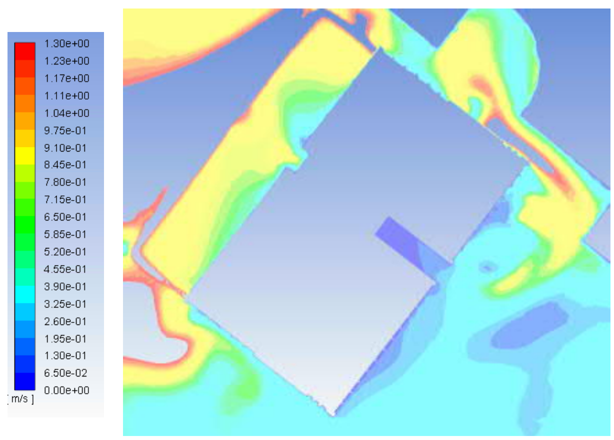
9.4 Wind Speeds on the Level 12 Outdoor Pool Terrace

Figure 26 shows same mean wind speed ratios as Figure 24, but this time on the Level 12 Outdoor Pool Terrace, again for a potential "high-downwash" oncoming wind angle of 337.5°:

- For these north-northwest (NNW) winds, mean wind speed ratios (V_{local}/V_{10m}) on the terrace range from 0.8 to 0.9.
- This compares to a ratio of 0.5 on the footpath directly below.
- The vertical cross-section windflow diagrams indicate that the impact of downwash on the Level 12 Outdoor Terrace is significant, confirming that the Level 12 "set-back" fronting Bligh Street does deflect considerable windflow away from the roadway below

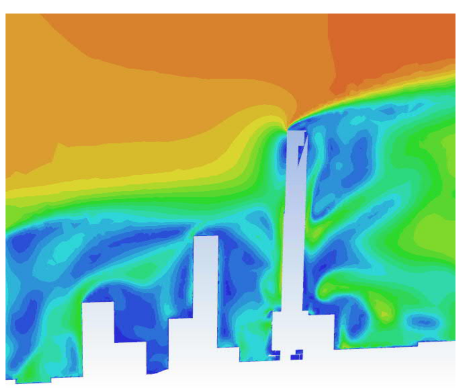
Figure 26 Level 1 Outdoor Terrace Mean Wind Speed Ratios: 337.5°, V_{local}/V_{10m}

337.5° / 1m above Level 12 RL

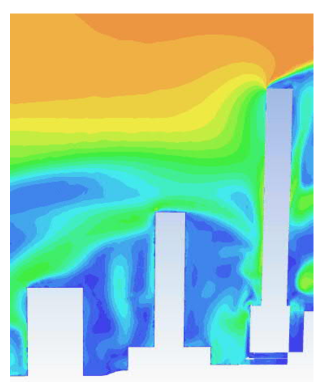


Vertical Cross-Section Flow Diagram (parallel to tower short dimension)

Through mid-façade "Gap"



Close to NE facade



9.5 Recommended Wind Mitigation

Level 1 Outdoor Terrace

The following conclusions have been achived based on results of CFD simulations:

- For wind directions ranging from northeast clockwise around to the southwest, shielding from nearby buildings and the proposed development itself result in very low wind speeds being experienced on the Level 1 Outdoor Terrace.
- Winds from the northwest able to penetrate past upstream buildings and impact directly on the Bligh Street façade of the proposed development generate moderate downwash flow down this façade. However, due to the deflection action of the Level 12 Bligh Street façade set-back of the tower, this downwash does not seem to impact with any significance on the Level 1 Outdoor Terrace.

In terms of wind mitigation for this terrace:

- A “formal” requirement for wind mitigation is not indicated (ie one mandated by the criteria applying to typical public-access pedestrian locations). This is especially the case given that this terrace would not be used for outdoor dining.
- Some form of horizontal protection for this terrace may be under consideration for non-wind reasons, eg rain prevention. In this case, and in terms of their wind mitigation context, these would only need to be “temporary”, moveable, etc - ie retractable canopies, umbrellas, etc.
- Finally, it si noted that the northwest wind condition of interest is a winter condition. The above wind mitigation options (retractable canopies, etc) should only be considered if usage of this terrace is aimed for all-year-round use.

Level 12 Outdoor Pool Terrace

It is noted that the usage of this space is qualitatively different from the Level 1 Terrace, in particular, this space should be suited for more long-term stationary activities compared to the Level 1 Terrace, and hence the wind criteria triggering mitigation should be more stringent.

- The following conclusions have been achived based on results of CFD simulationsFor wind directions ranging from northeast clockwise around to the southwest, shielding from nearby buildings and the proposed development itself result in moderate wind speeds being experienced on the Level 12 Outdoor Pool Terrace.
- However, winds from the northwest able to penetrate past upstream buildings and impact directly on the Bligh Street façade of the proposed development generate significant downwash flow on the tower façade above which then impacts on the Pool terrace area. Although this causes adverse wind conditions on the Pool Terrace, this does assist in mitigating winds at lower levels, at both street level and the Level 1 Outdoor Terrace.

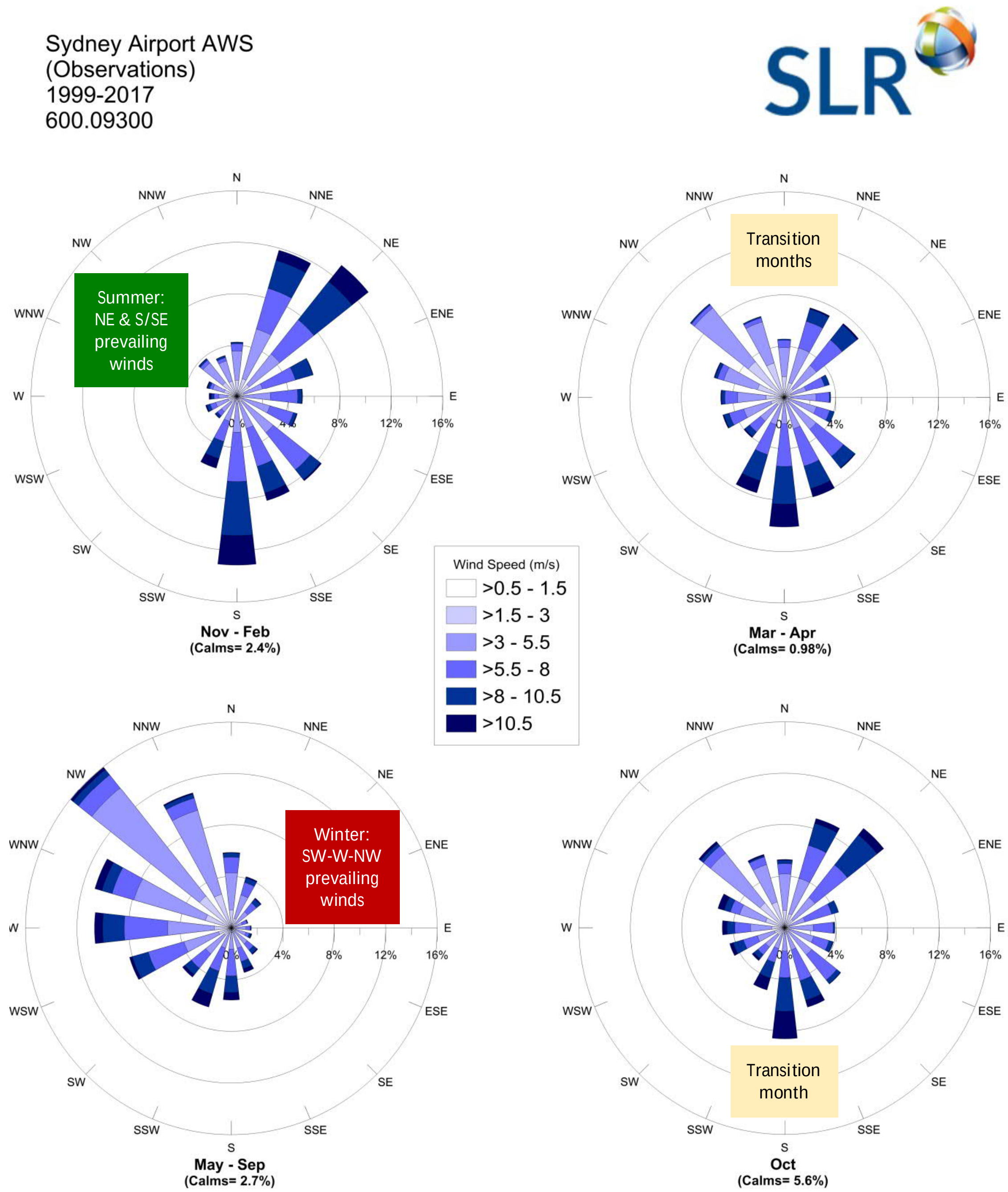
In terms of wind mitigation for this terrace:

- The northwest wind condition of concern is a winter condition. Consideration of wind mitigation options for this area should therefore take into account the intended usage, and in particular if the Pool Terrace is likely to be used all-year-round.
- If it intended to use the Pool Terrace all-year-round, wind mitigation is indicated given the potential impact of downwash winds.

- The wind mitigation will need to be “horizontal” in nature – awnings, pergolas, canopies, etc.
- Operable awnings, retractable canopies, etc, are a viable option if accompanied by a Management Plan which ensures that the protection is in place once terrace winds exceed a given comfort criteria.

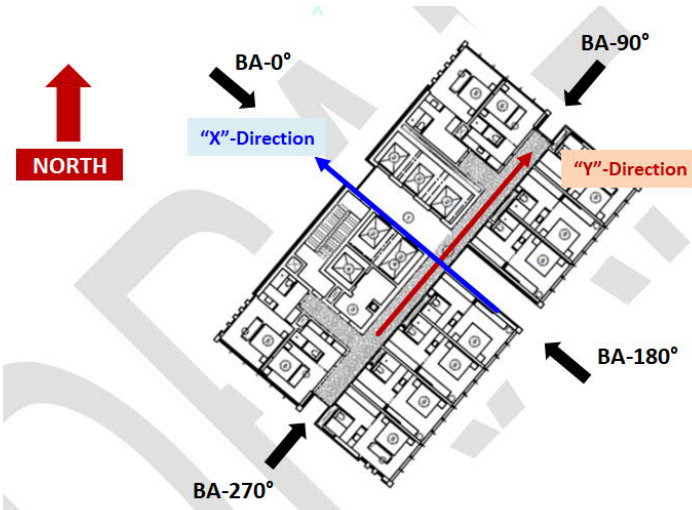
APPENDIX A

Seasonal Wind Roses for Bureau of Meteorology Met Station at Sydney (Kingsford Smith) Airport (BoM 66037)



APPENDIX B

Views of the Proposed Development for Oncoming Wind Directions: 0° to 360° using the Building Axis degree Notation (refer Figure 11)



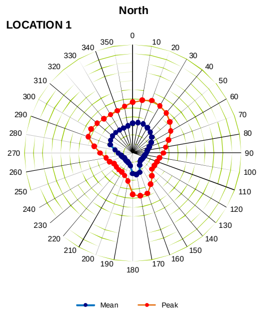
APPENDIX C

Wind Tunnel Test Data (Polar Plots) – BASELINE Scenario

The polar diagram plots show the local (ground level) mean and peak gust wind speed as a ratio of the reference height mean wind speed (at a full-scale height of 200 m).

The polar diagram circumferential lines represent gradations in 0.1 intervals, ie 10% ratios.

LOCATION 1



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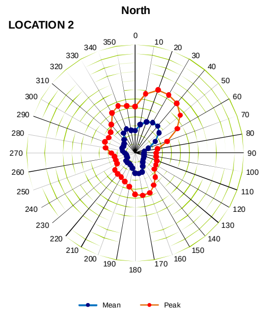

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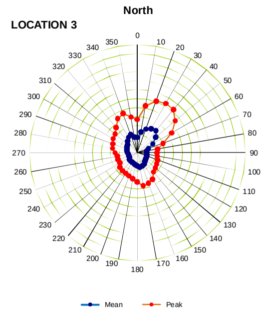

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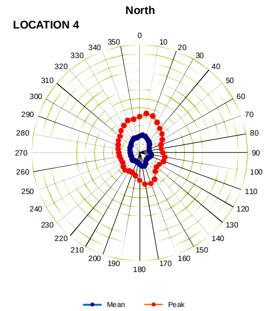

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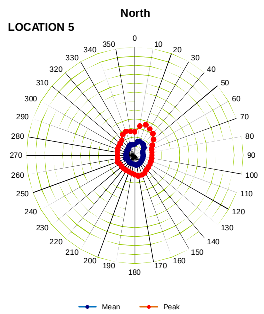

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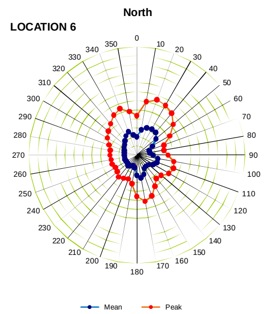

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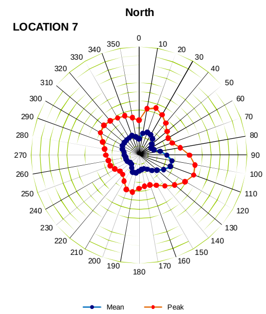

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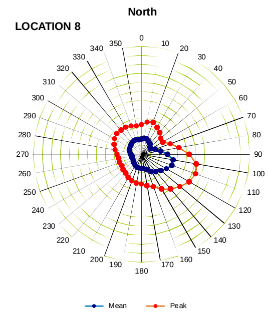

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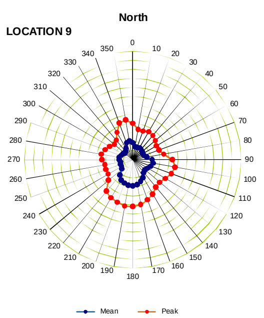

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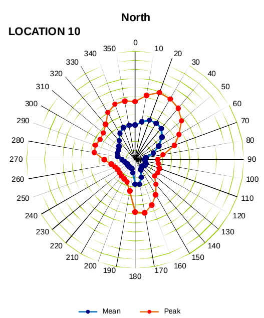

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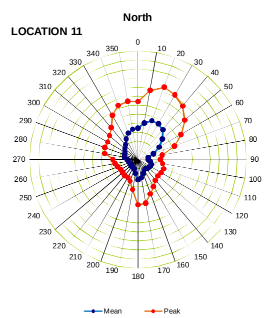

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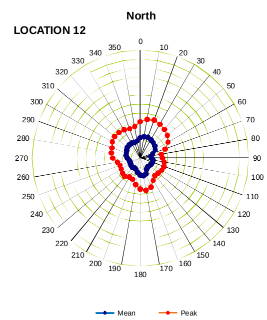

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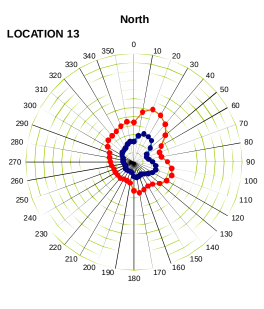

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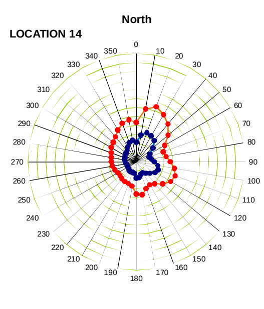

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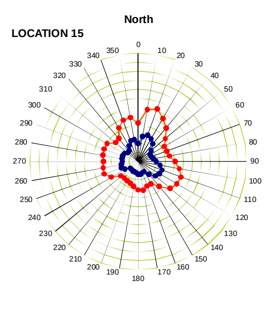

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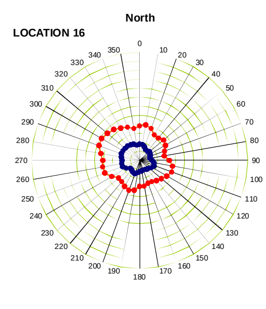

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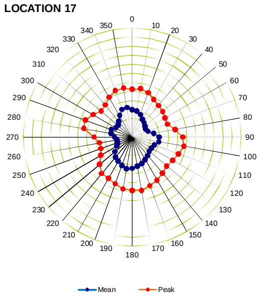

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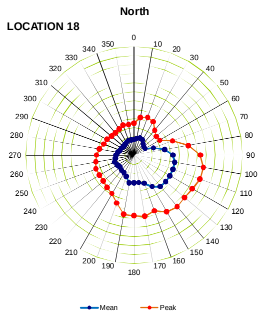

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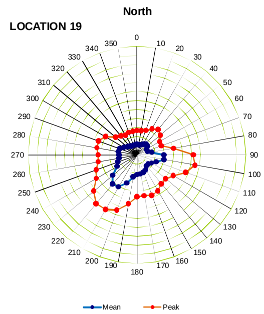

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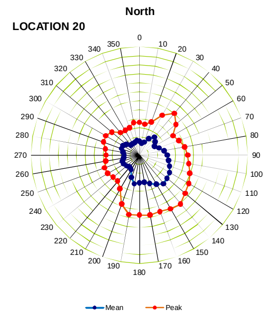

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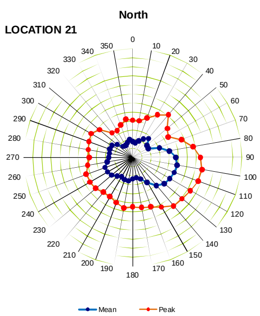

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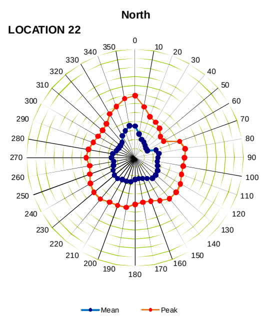

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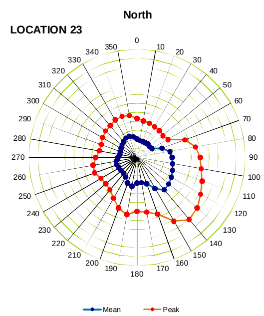

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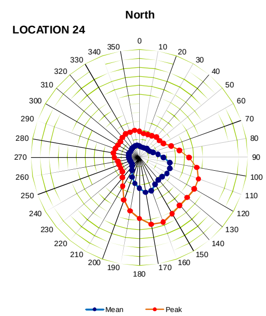

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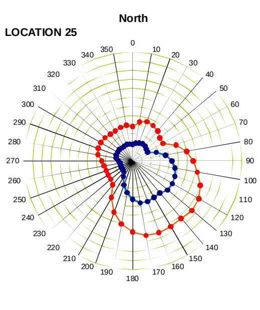

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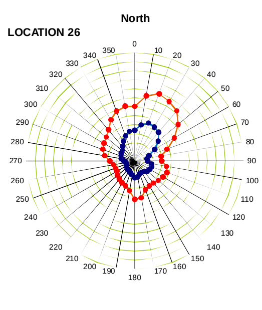

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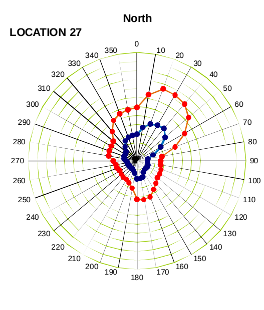

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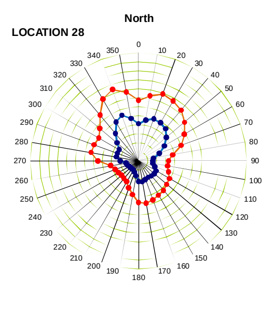

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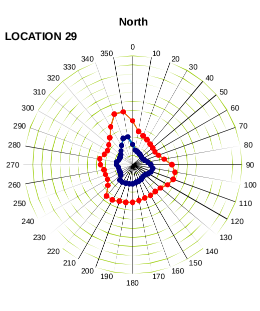

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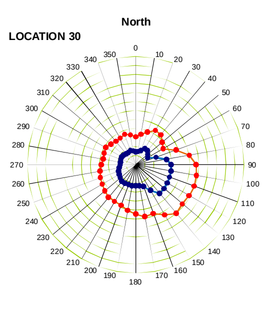
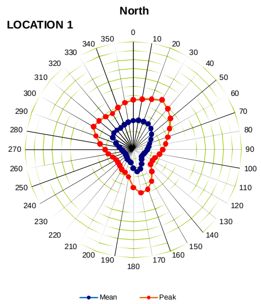


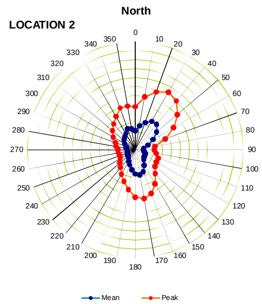
APPENDIX D

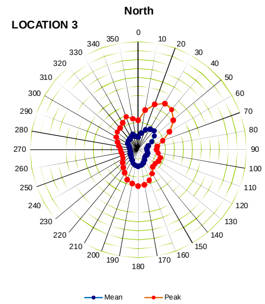
Wind Tunnel Test Data (Polar Plots) – FUTURE Scenario

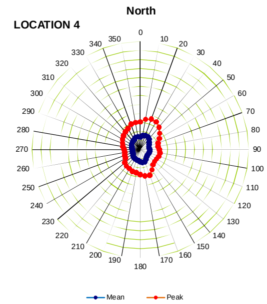
The polar diagram plots show the local (ground level) mean and peak gust wind speed as a ratio of the reference height mean wind speed (at a full-scale height of 200 m).

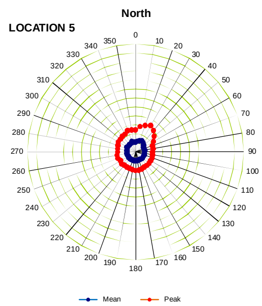
The polar diagram circumferential lines represent gradations in 0.1 intervals, ie 10% ratios.

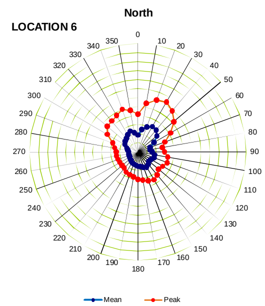

LOCATION 1
North
Mean
Peak

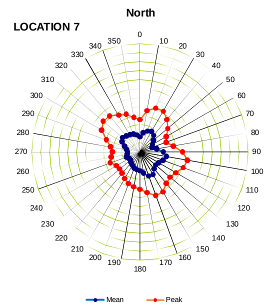

LOCATION 2
North
Mean
Peak

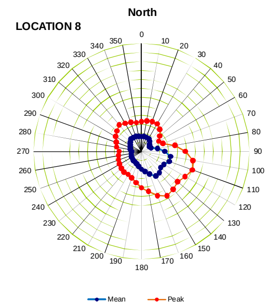

LOCATION 3
North
Mean
Peak

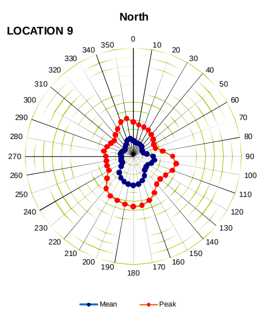

LOCATION 4
North
Mean
Peak

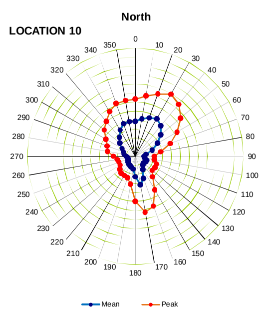

LOCATION 5
North
Mean
Peak

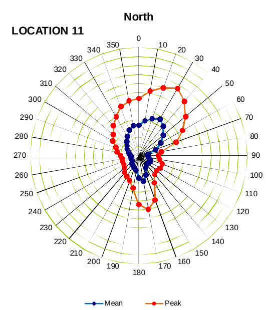

LOCATION 6
North
Mean
Peak

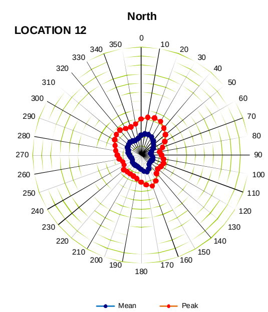

LOCATION 7
North
Mean
Peak


LOCATION 8
North
Mean
Peak


LOCATION 9
North
Mean
Peak


LOCATION 10
North
Mean
Peak


LOCATION 11
North
Mean
Peak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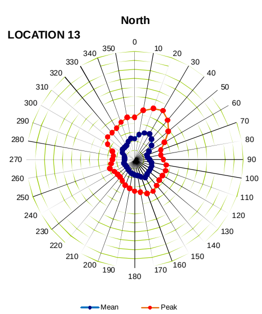
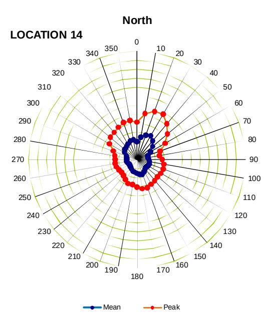
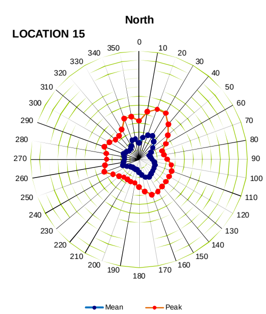
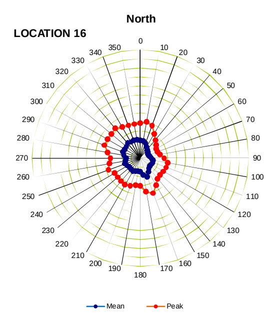
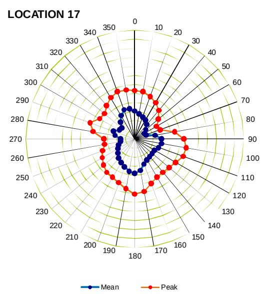
Mean
Peak


LOCATION 13
North
Mean
Peak


LOCATION 14
North
Mean
Peak


LOCATION 15
North
Mean
Peak


LOCATION 16
North
Mean
Peak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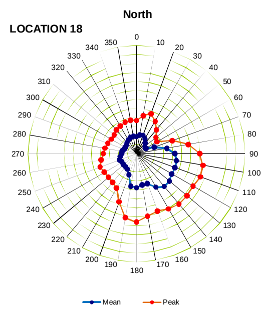
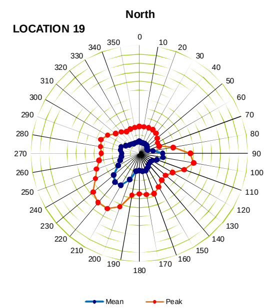
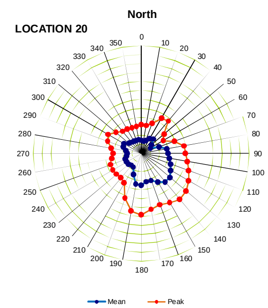
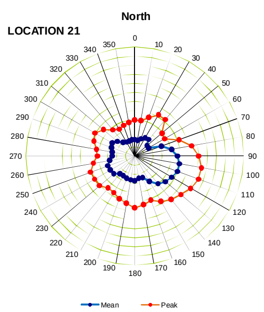
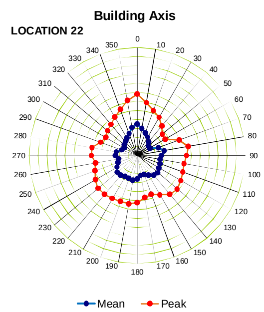
Mean
Peak

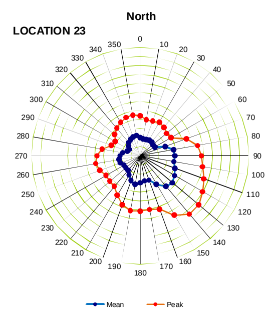

North
LOCATION 18
Mean
Peak

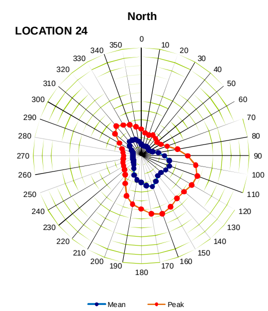

North
LOCATION 19
Mean
Peak

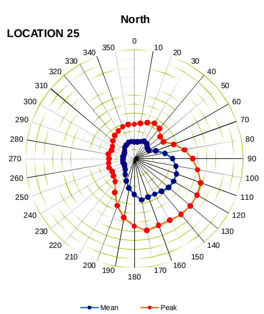

North
LOCATION 20
Mean
Peak

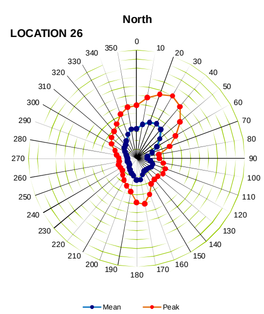

North
LOCATION 21
Mean
Peak


Building Axis
LOCATION 22
Mean
Peak


North
LOCATION 23
Mean
Peak


North
LOCATION 24
Mean
Peak


North
LOCATION 25
Mean
Peak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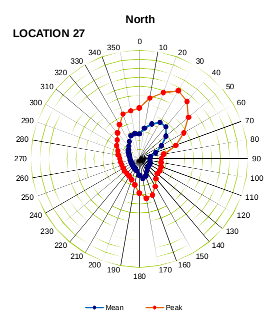
North
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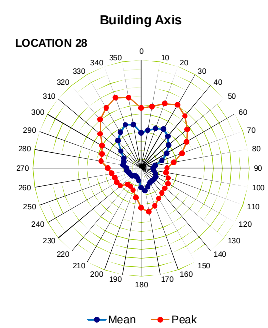
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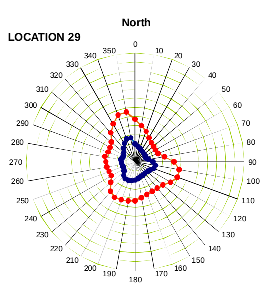
LOCATION 28
Mean
Peak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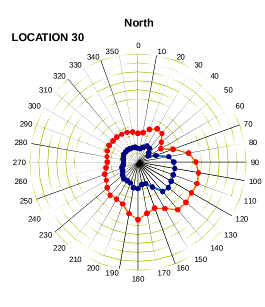
Mean
Peak


North
LOCATION 30
Mean
Peak

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