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CONCEPT PLAN - MODIFICATION APPLICATION
WIND ENVIRONMENT STUDY

Victoria Cross Over Station Development

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Prepared For – Lendlease Building Pty Limited | ABN 97 000 098 162

CONCEPT PLAN - MODIFICATION APPLICATION WIND ENVIRONMENT STUDY

Victoria Cross Over Station Development

Client:

Lendlease Building Pty Limited

Level 14, Tower Three, International Towers Sydney, Exchange Place, 300 Barangaroo Avenue, Barangaroo NSW 2000

ABN: 97 000 098 162

Prepared by:

Arcadis Australia Pacific Pty Ltd and Mott MacDonald Australia Pty Limited (ARCMAC Joint Venture)

Level 16, 580 George Street Sydney NSW 2000

ABN: 794 7393 1704

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Technical Checker	*Building Sciences Engineer*	*Tom Moyle*	*29 / 05 / 2019*
Reviewed By	*Technical Director*	*Neil Mackenzie*	*31 / 05 / 2019*
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Changes made to this document since its last revision, which affect its scope or sense, are marked in the right margin by a vertical bar (|).

Date	Rev	Amendment Description	By
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Contents

1. Introduction

This report has been prepared to accompany a section 4.55(2) modification application to the State Significant Development (SSD) Concept Approval (reference SSD 17_8874) granted for a commercial mixed-use Over Station Development (OSD) above the new Sydney Metro Victoria Cross Station. This report has been prepared having regard to the Secretary's Environmental Assessment Requirements dated 30 November 2017.

The Minister for Planning granted development consent to the Concept SSD Development Application (DA) on 18 December 2018. Concept Approval was granted for:

- A maximum building envelope, including street-wall and setbacks for the OSD
- A maximum building height of RL 230 or 168 metres, providing:
  - Approximately 40 commercial storeys and 2 additional storeys for rooftop plant for the high-rise portion of the building envelope
  - Approximately 13 storeys for the lower eastern portion of the building envelope at RL 118 or 55 metres
  - A maximum gross floor area (GFA) of 60,000sqm, excluding station floorspace
  - Basement car parking for a maximum 150 parking spaces.

Following Sydney Metro's appointment of Lendlease (Victoria Cross) Pty Limited as the preferred development partner to deliver the Victoria Cross OSD, and ongoing design development, minor modifications to the approved building envelope are now required.

The section 4.55(2) modification application proposes the following changes to the approved building envelope:

- Reduction in the massing and overall dimensions of the building cantilever above the Miller Street special area setback;
- Relocation of building massing from the low-rise levels the tower, north of the through-site link, to the high-rise levels of the tower; and Reduction of the Berry Street setback from 5 metres to 4.5 metres, extending the building envelope marginally to the north. and
- Increasing the approved maximum GFA for the over station development from 60,000sqm to 61,500sqm.

It is noted that the Concept SSD DA instrument of approval does not consent to any physical works commencing on site until a Detailed SSD DA is granted for the site. A Detailed SSD DA seeking consent for the detailed construction of the proposed development is lodged under a different cover concurrently with this Concept SSD DA modification application.

1.1 The Site

The site is generally described as 155-167 Miller Street, 181 Miller Street, 187-189 Miller Street, and part of 65 Berry Street, North Sydney (the site). The site occupies various addresses/allotments and is legally described as follows:

- 155-167 Miller Street (SP 35644) (which incorporates lots 40 and 41 of Strata Plan 81092 and lots 37, 38 and 39 of Strata Plan 79612)
- 181 Miller Street (Lot 15/DP 69345, Lot 1 & 2/DP 123056, Lot 10/DP 70667)
- 187 Miller Street (Lot A/DP 160018)
- 189 Miller Street (Lot 1/DP 633088)
- Formerly part 65 Berry Street (Lot 1/DP 1230458)

1.2 Sydney Metro Description

Sydney Metro is Australia's biggest public transport project. Services started in May 2019 in the city's North West with a train every four minutes in the peak. Metro rail will be extended into the CBD and beyond to Bankstown in 2024. There will be new metro railway stations underground at Crows Nest, Victoria Cross, Barangaroo, Martin Place, Pitt Street, Waterloo and new metro platforms under Central.

In 2024, Sydney will have 31 metro railway stations and a 66km standalone metro railway system – the biggest urban rail project in Australian history. There will be ultimate capacity for a metro train every two minutes in each direction under the Sydney city centre. The Sydney Metro Project is illustrated in the Figure below.

On 9 January 2017, the Minister for Planning approved the Sydney Metro City & Southwest - Chatswood to Sydenham project as a Critical State Significant Infrastructure project (reference SSI 15_7400) (CSSI Approval). The terms of the CSSI Approval includes all works required to construct the Sydney Metro Victoria Cross station, including the demolition of existing buildings and structures on both sites. The CSSI Approval also includes construction of below and above ground works within the metro station structure for appropriate integration with the OSD.

With regards to CSSI related works, any changes to the "metro box envelope" and public domain will be pursued in satisfaction of the CSSI conditions of approval and do not form part of the scope of the Concept SSD DA for the OSD.

Figure 1 – Site Aerial

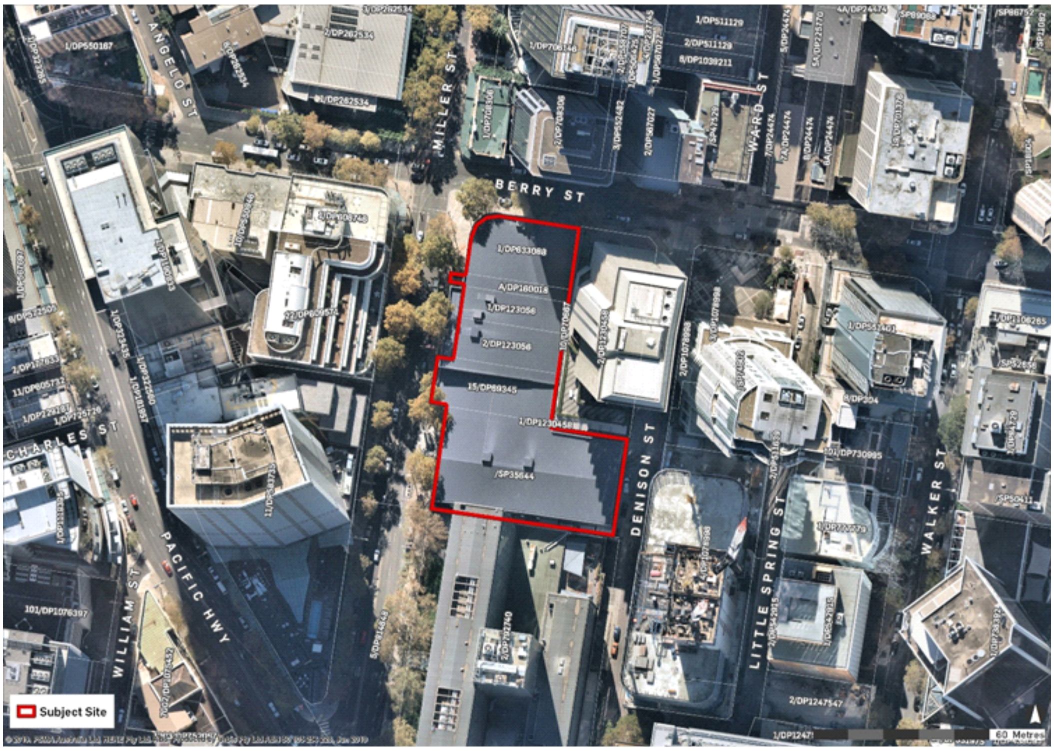
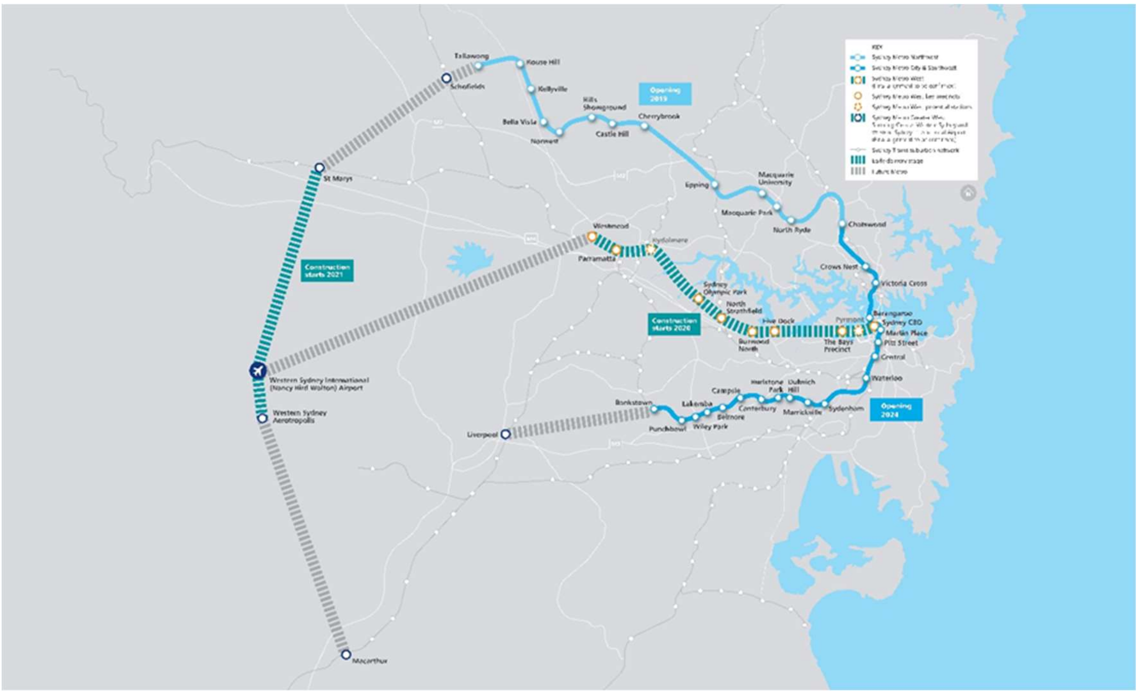


Figure 2 Sydney Metro Alignment Map



Source: Sydney Metro

2. Proposed Modification to the Building Envelope & Reference Design

Sydney Metro's Reference Design and the Proposed Design are shown in the figures below for comparison.

Sydney Metro's Reference Design for Victoria Crosss OSD (as depicted in the Concept Plan Approval) as detailed in Figure 3 and Figure 4 below, incorporates a canopy over the length of the through site link laneway which is 12m wide. The tower facade has an 18m set back to MLC and steps back on the south façade as height increases.

Figure 3 Sydney Metro's Reference Design

Figure 4 Sydney Metro's Reference Design showing canopy over the laneway

The Proposed Design (as detailed in Figure 5) includes an upper continuous awning below level 3 which extends 2m from the facade along Miller Street and wraps around the OSD entry on Berry Street and Metro Entry on the south. In addition, separate canopies are provided extending 3m from the facade for the station entrances as shown in Figure 6. The laneway width is reduced to 7.5m in the Proposed Design and the building envelope has a wider setback of 28m to MLC. The Proposed Design also includes a 6 Storey podium office building on the north of the laneway. The tower massing steps out to the west as height increases (as shown in Figure 5), with a roof terrace at Level 29 (and on the southern laneway building).

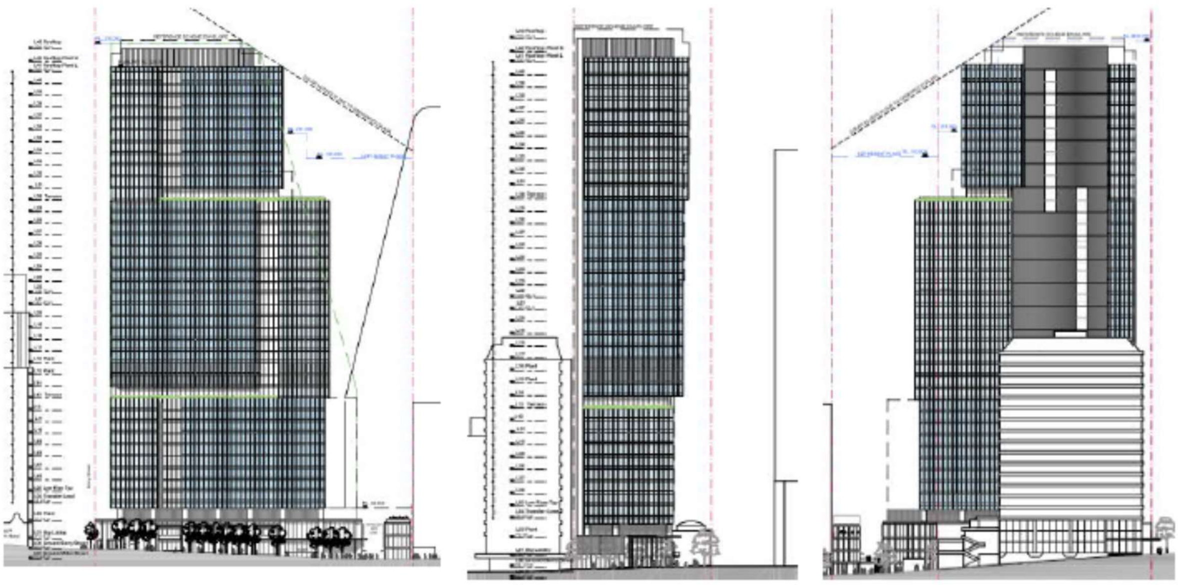


Figure 5 Proposed Design - elevations

Figure 6 Proposed Design

The site is well shielded by existing medium scale buildings in all directions with occasional tall buildings in the near vicinity as shown in Figure 7, in addition the proposed OSD and site will be further shielded by the 100 Mount Street and 1 Denison Street developments that are currently under construction.

Figure 7 Site Shielding context

3. Wind Effects

Typical wind flow patterns around a single wide high-rise building are indicated below in Figure 8 .

As the wind flow approaches the building, it gradually diverges. Part of the flow is deviated over the building (1) and part of it flows around the building (2). At the windward facade, a stagnation point with maximum pressure is situated at approximately 70% of the building height. From this point, the flow is deviated to the lower pressure zones of the facade: upwards (3), side-wards (4) and downwards (5).

The considerable amount of air flowing downwards produces a vortex at ground level (6) called standing vortex, frontal vortex or horseshoe vortex. The main flow direction of the standing vortex near ground level is opposite to the direction of the approach flow. Where both flows meet, a stagnation point with low wind speed values is created at the ground in front of the building (7). The standing vortex stretches out sideways and sweeps around the building corners where flow separation occurs and corner streams with high wind speed values are created (8). The corner streams subsequently merge into the general flow around the corners (9).

At the leeward side of the building, an under-pressure zone is created. As a result, backflow or recirculation flow occurs (10,13). A stagnation zone is marked downstream of the building at ground level where the flow directions are opposite and low wind speeds exist (11; end of the recirculation zone). Beyond the stagnation zone, the flow resumes its normal direction but wind speeds stay low for a considerable distance behind the building (i.e. the far wake) (12).

The backflow is also responsible for the creation of slow rotating vortices behind the building (13). Between these vortices and the corner streams (9), a zone with a high velocity gradient exists (the shear layer) that comprises small, fast rotating vortices (16). The shear layers originate at the building corners where flow separation occurs.

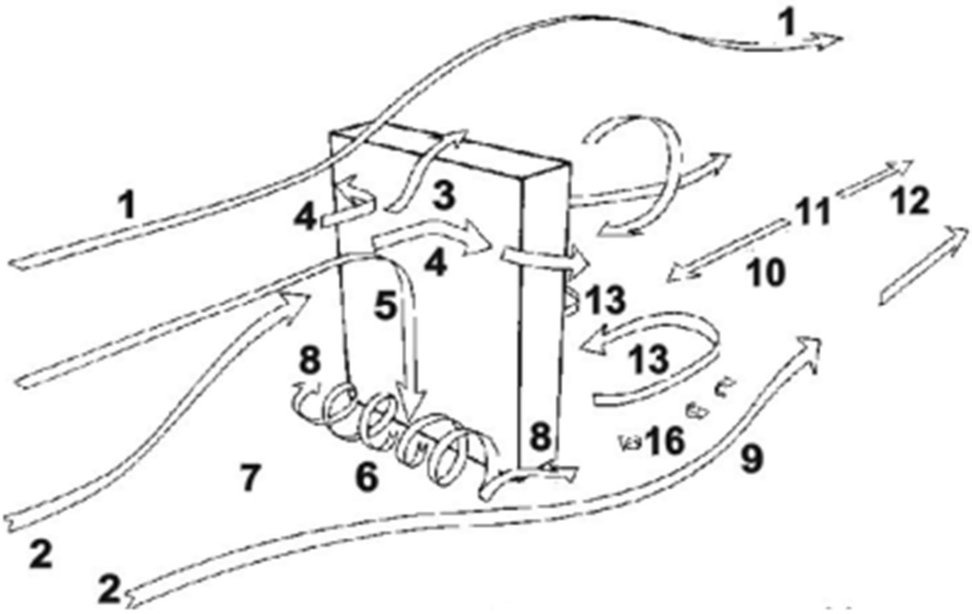


Figure 8 Wind Effects around a Building

4. Wind Climate

Wind is one of the most highly variable meteorological elements, both in speed and direction. It is influenced by a wide range of factors, from large scale pressure patterns, to the time of day and the nature of the surrounding terrain. Because the wind is highly variable it is often studied by means of frequency analyses (often in the form of wind roses) of data obtained from the Bureau of Meteorology (BOM) for a particular site (data from the closest weather station is used).

The wind data used for the assessment was acquired from the Bureau of Meteorology for the automatic weather station at Fort Denison1, which is located within Sydney Harbour, just under 3km to the south east of the new Victoria Cross Station as shown in Figure 9 .

Winds are predominantly from the West, with wind speeds at 10m AGL approaching 10m/s for 5% (95th percentile), with extreme wind speeds approaching 20m/s (annual return period)

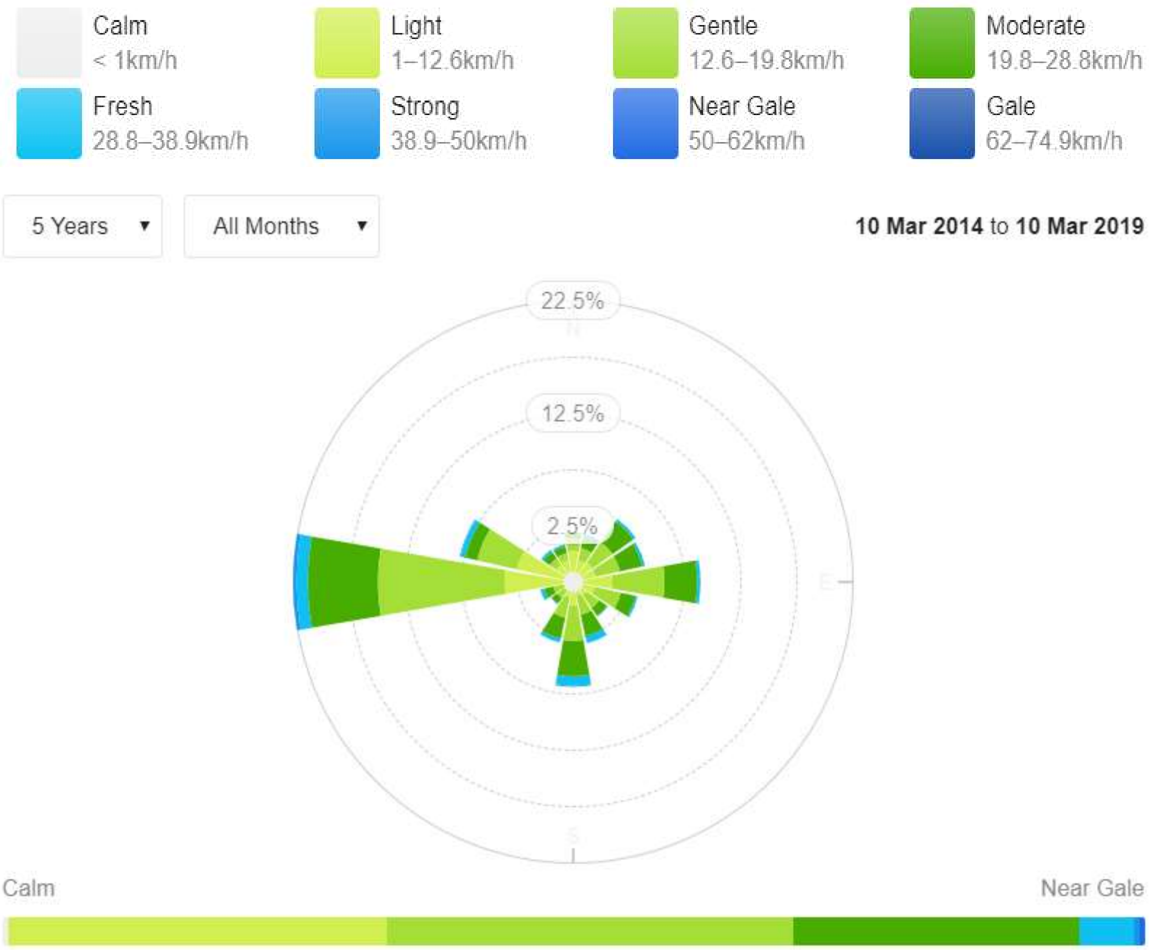


Figure 9 Wind Data

5. Wind and Site Simulation

Simulation of the atmospheric boundary layer requires the basic characteristics of the natural wind to be modelled. The natural wind at a site possesses the characteristics of the approach flow, determined using AS 1170.2 (2011) with the effect of nearby structures and terrain resulting in the near-field flow.

A suitable model of the atmospheric boundary layer is incorporated in the Australian Wind Actions Standard, AS 1170.2. This model uses a logarithmic law to describe the mean wind speed profile with the roughness length being the main parameter. The terrain categories and associated roughness lengths used to simulate approach flows are defined in Table 1 below;

Table 1 AS1170 Terrain Category Definitions

Terrain Category	Definition [Roughness Length]
2	Grassland with few, well-scattered obstructions having heights generally from 1.5m to 10m. [0.02 m]
3	Terrain with numerous closely spaced obstructions 3m to 5m high such as areas of suburban housing. [0.2 m]
4	Terrain with numerous large, high (10m to 30m high) and closely spaced obstructions such as large city centres. [2 m]

The turbulent boundary layer is established over a development length. AS 1170.2 defines the development length for a structure of about 150 m height as 6000 m, with a “lag distance” of 3000m over which the terrain shall be ignored. As a result, the terrain was deemed to be category 3.

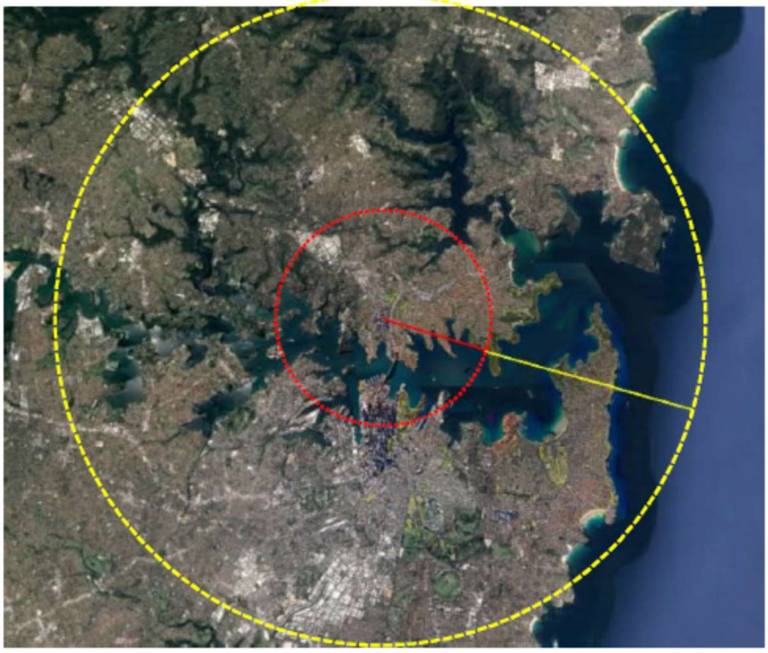


Figure 10 Definition of Terrain Category

6. Assessment Criteria

This report assesses pedestrian safety and comfort at the site against the criteria outlined in this section. These criteria have been developed using the Lawson Criteria and analysis of areas of concern around the site.

6.1 Comfort

The Lawson comfort criteria (Lawson and Penwarden, 1975 amended with input from Isyumov and Davenport, 1975) is often used for wind comfort assessments in outdoor areas as defined in Table 2. The commonly used Beaufort scale is also provided for comparison in Table 3. The Lawson criteria definitions are used to assess wind force only and do not allow for variations in ambient temperature, solar radiation, and other environmental variables.

The comfort criteria (Lawson, 1978) are based on the exceedance of the threshold wind speeds occurring less than 5% of the time (approximately once per month during daylight hours). The value of 5% has been established as giving a reasonable allowance for extreme and relatively infrequent winds that are tolerable within each category. For example, if the mean hourly wind speed at a particular location is less than 4 m/s for 95% of the time then that location is classified as C4. On the Beaufort scale, 4 m/s is described as a gentle breeze. At the other extreme, if the wind speed exceeds 8 m/s more than 5 % of the time but exceeds 10 m/s less than 5% of the time, then category C1 applies and the location would be considered windy though not necessarily unsafe. A wind speed in excess of 10 m/s more than 5% of the time would incur a category of C1+. Note that mean hourly wind speed is in terms of gust equivalent mean (GEM)

Table 2 Pedestrian Wind Comfort Criteria

Comfort rating	Description	Mean hourly wind speed	Appropriate Area Usage	Description of Wind Effects
C1+	Uncomfortable for all users	>10 m/s	Uncomfortable for all uses	Umbrellas difficult to use; Hair blown straight
C1	Fast or business walking	10 m/s	Areas where people are not expected to linger	Force of wind felt on body
C2	Leisurely walking	8 m/s	General walking or sightseeing	Dust and papers raised Hair disarranged
C3	Short period sitting/standing	6 m/s	Bus stops, building entrances	Light leaves and twigs in motion; Lightweight flags extend
C4	Long period sitting/standing	4 m/s	Reading a newspaper, eating and drinking	Light wind felt on face Leaves rustle

Table 3 Beaufort Scale

Beaufort number	Description	Mean hourly wind speed
0	Calm	0.3
1	Light air	0.3–1.5
2	Light breeze	1.6–3.3
3	Gentle breeze	3.4–5.4
4	Moderate breeze	5.5–7.9
5	Fresh breeze	8.0–10.7
6	Strong breeze	10.8–13.8
7	Near gale	13.9–17.1
8	Gale	17.2–20.7
9	Strong gale	20.8–24.4
10	Storm	24.5–28.4
11	Violent storm	28.5–32.6
12	Hurricane	32.7 and over

6.2 Safety

The pedestrian wind safety criteria is based on an exceedance once per annum during daylight hours. A mean hourly wind speed (as GEM) which is greater than 15 m/s but less than 20 m/s which occurs once a year is classified as unsuitable for general public which includes elderly, cyclists and children. Able bodied users are those determined to experience distress when the wind speed exceeds 20 m/s once per year. Such safety criteria indicate the potential for danger during normal pedestrian activity, for example, a pedestrian crossing on a busy road, where the consequences of being blown over would be very serious. Other examples include access ways to hospitals and schools where the local pedestrian population is unlikely to cope safely with extreme winds. Referring again to the Beaufort scale, S2 would be classified as gale force, S1 as strong gale force. Note that mean hourly wind speed is in terms of gust equivalent mean (GEM).

Table 4 Pedestrian Wind Safety Criteria

Safety rating	Description	Mean hourly wind speed
S1	Unsuitable for able bodied	20 m/s
S2	Unsuitable for general public	15 m/s

6.3 Project Specific Criteria

The areas shown in Figure 11 below have been considered relevant to the project site with the required comfort conditions nominated in Table 5. The wind comfort criteria selected for the project site have been proposed based on, similar projects of this nature, local area mapping and requirements, and the various conditions related to the different site uses, with the wind effects at the station entrances at Southern Metro entry and Denison Street concourse complying with the Lawson Comfort Criteria for Business walking criteria (C1), as required by Sydney Metro.

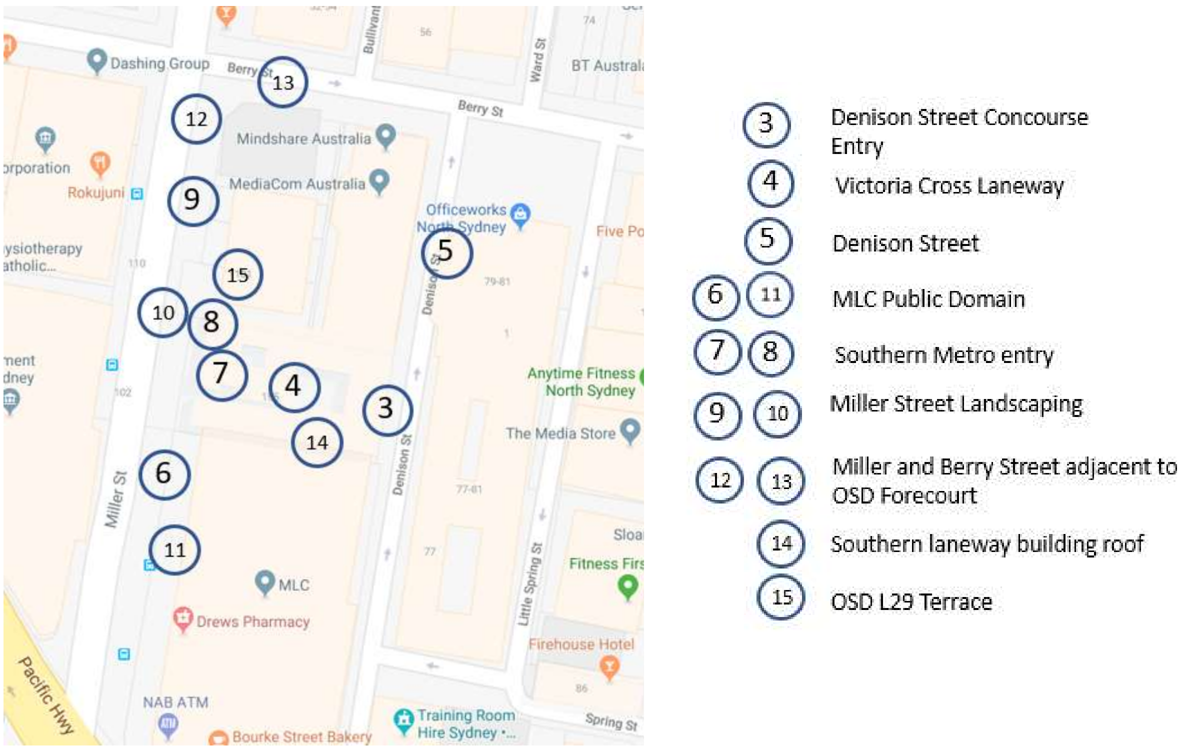


Figure 11 Assessment locations

Table 5 Assessment Criteria

Location	Description	Criteria	Definition
3	Victoria Cross Denison Street Concourse Entry	C1 (<10m/s)	General walking or sightseeing
4	Victoria Cross: Laneway	C2 (<8m/s)	General walking or sightseeing
5	Denison Street	C1 (<10m/s)	Short period sitting/standing
6 & 11	MLC public domain	C4 (<4 m/s)	Long periods sitting/standing
7 & 8	Southern Metro entry	C1 (<10m/s)	Short period sitting/standing
9 & 10	Miller Street	C3 (<6 m/s)	Long periods sitting/standing
12 & 13	Miller & Berry Street adjacent to OSD forecourt	C1 (<10m/s)	Fast or business walking
14	Southern laneway building roof	C4 (<4 m/s)	Long periods sitting/standing
15	OSD L29 Terrace	C3 (<6 m/s)	Long periods sitting/standing

Note: Lawson Comfort Criteria are based on exceedance of the threshold wind speed occurring 5% of the time.

7. Computational Model

The analysis presented uses Computational Fluid Dynamics (CFD) methods. Computational fluid dynamics predicts fluid flows by mathematically modelling the Reynolds Averaged Navier-Stokes equations, fundamental equations which describe fluid motion. CFD simplifies estimates of turbulence, modelling average flow conditions well and random flow conditions with less accuracy. The turbulence closure scheme used for the modelling in this report was the standard k-ε model. The commercial package SimScale (user interface to OpenFOAM) was used. Wind tunnel testing had not been as yet undertaken for pedestrian winds, though is planned to be completed and results reviewed during the further design stages.

A computational model of the proposed development with the surrounding built environment is shown below in Figure 12.

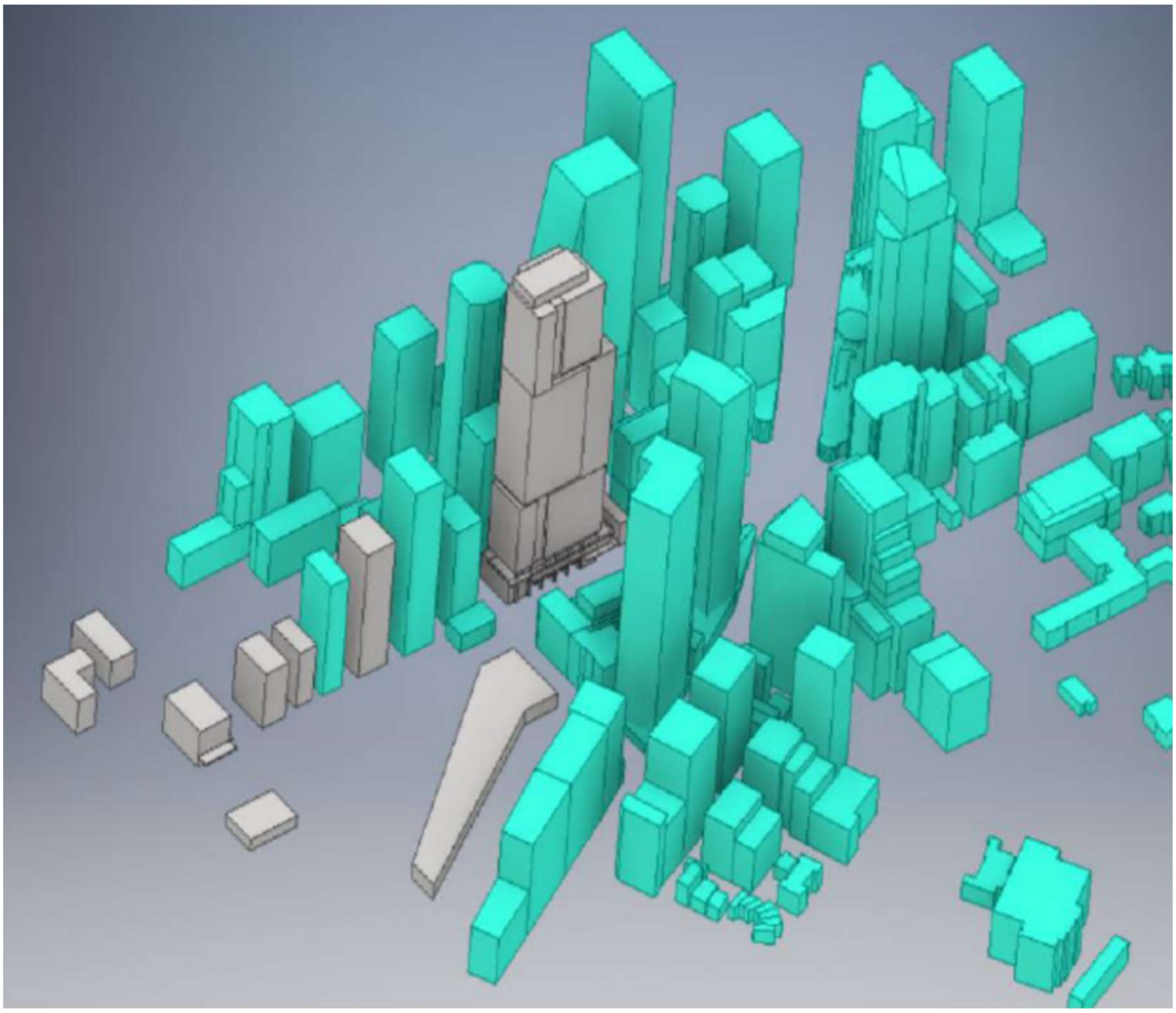


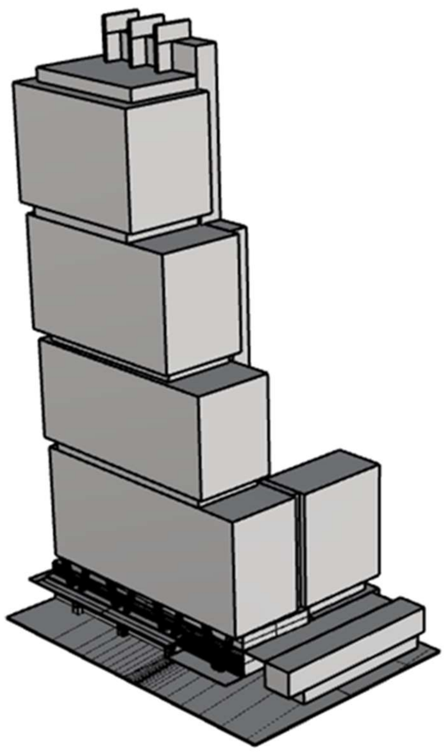
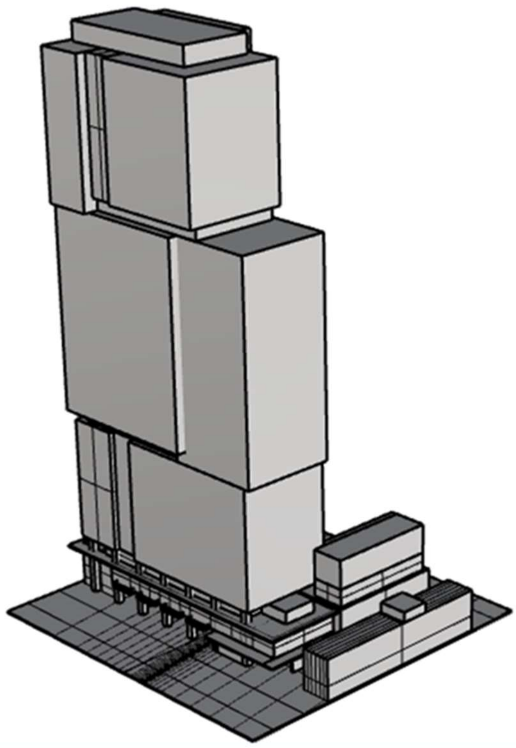
Figure 12 Computational Model

Simulation of the Atmospheric Boundary Layer (ABL) requires the basic characteristics of the natural wind to be modelled. A suitable model of the atmospheric boundary layer is incorporated in the Australian Wind Actions Standard, AS 1170.2 (Standards Australia, 1989 and 2011) based on the work of Melbourne (1981) and Deaves and Harris (1978). This model uses a logarithmic law to describe the mean wind speed profile as a function of the aerodynamic roughness length which, in turn, is related to the surrounding terrain category (TC).

The Deaves and Harris ABL model was implemented in SimScale (OpenFOAM), closely following all recommendations of Richards and Hoxey (1993) including upper boundary shear stress. The upper boundary turbulent gradients are also defined following the equations outlined in Sumner and Masson (2012). These equations were implemented for the k-epsilon class of turbulence models and the realizable k-epsilon model (Shih et. al. 1994) was used for the wind simulation.

Detailed models of each built form are shown below in **Table 6**

Table 6 Built Form Options

Sydney Metro's Reference Design	Proposed Design
	

8. Results

Visual results of the CFD modelling and wind effect assessments are shown (viewed from above) in Table 8 below for the ground plane and in Table 9 for the roof terraces. Table 7 below details the associated comfort rating assessment results (based on the Lawson comfort levels) relating to the assessment areas detailed in Figure 11 for the site. These are estimated only and not based on wind tunnel testing or a statistical analysis.

Table 7 Results: Estimated wind speeds exceeded no more than 5% of the time (95th percentile wind speeds)

Location	Description	Sydney Metro's Reference Design	Proposed Design	No-Build	Criteria
3	Victoria Cross Denison Street Concourse Entry	6	6	~10	C1 (<10m/s)
4	Victoria Cross: Laneway	<6	<6	~10	C2 (<8m/s)
5	Denison Street	<10	<10	~10	C1 (<10m/s)
6 & 11	MLC public domain	<4	<4	<6	C4 (<4 m/s)
7 & 8	Southern Metro entry	<4	<4	<10	C1 (<10m/s)
9 & 10	Miller Street	<6	<6	<10	C3 (<6 m/s)
12 & 13	Miller & Berry Street adjacent to OSD forecourt	<10	<10	<10	C1 (<10m/s)
14	Southern laneway building roof	<4	<4	n/a	C4 (<4 m/s)
15	OSD L29 Terrace	<6	<6	n/a	C3 (<6 m/s)

Table 8 Results : Ground Plane

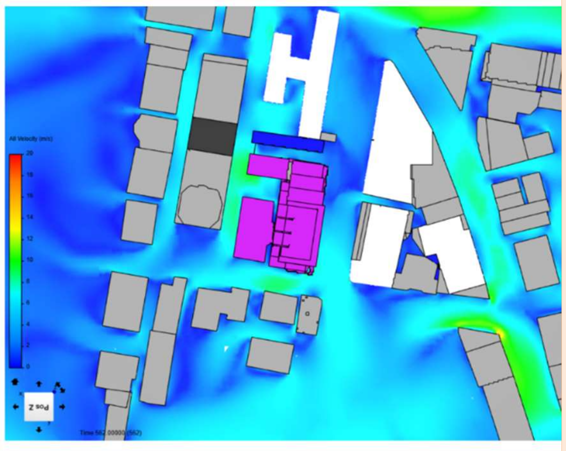
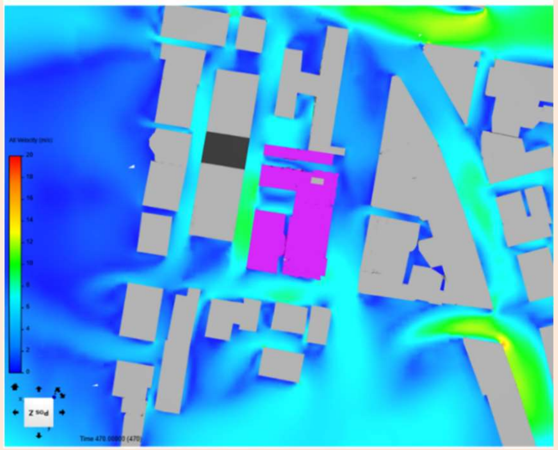
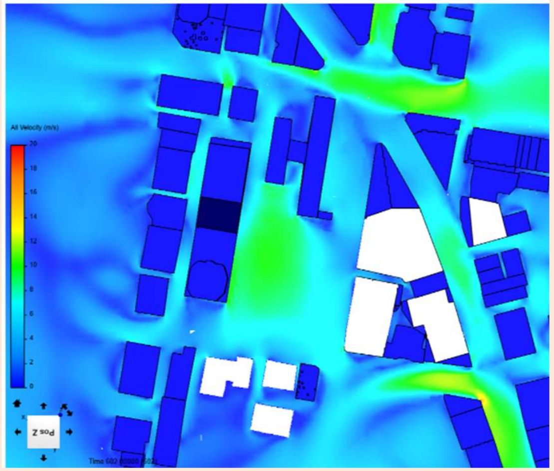
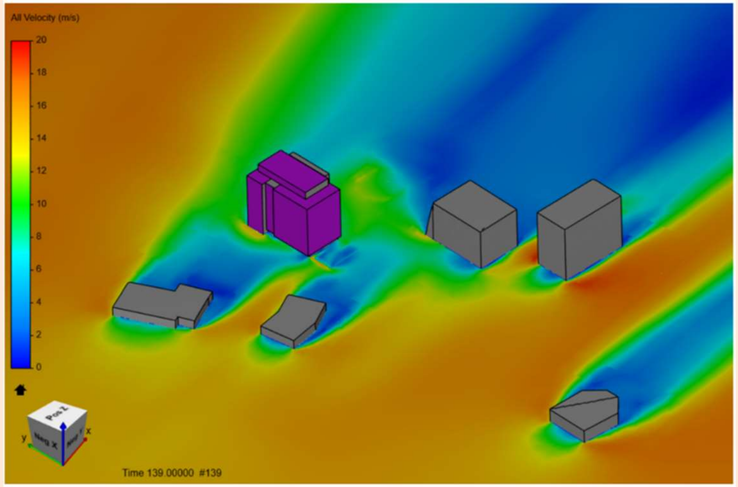
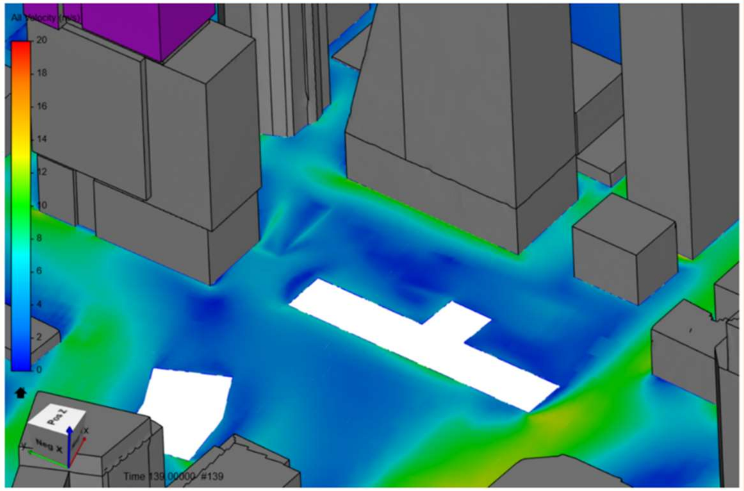
Sydney Metro's Reference Design	Proposed Design	No-Build
		

Table 9 Results : Roof Terraces

Level 29 Roof Terrace	Southern Laneway Building Roof
	

9. Assessment & Recommendations

Based on the completed CFD modelling and review of the results, to compare the ground level wind effects between the Sydney Metro's Reference Design (which has a canopy over the laneway and building envelope that has an 18m setback to the MLC building) and the Proposed Design (including a building envelope setback of 28m to the MLC building) , a summary of the key points of the wind effect's on each scheme are as follows (refer to Table 8 and Table 9 above):

No-Build:

- Many areas exceed the assessment criteria due to strong downwash from existing towers on Denison Street.
- Condition along the south of the site (proposed/existing laneway) poor without the development due to downwash from towers not shielded by the proposed development along Denison Street.
- Strong down-wash from the towers opposite the development on Miller Street.
- Denison Street is most affected with downwash from the existing towers not shielded by the proposed development.
- Berry Street is least affected without the development due to the absence of blockage of the new development.

Sydney Metro's Reference Design:

- Wind speeds on Miller Street comply with the criteria.
- Low wind speeds along the laneway due to the canopy with criteria compliance.
- Reduced wind speeds on Denison Street compared with no-build due to staggered set-back at higher levels and blockage of wind impacting towers along Denison Street.
- Slightly higher wind speeds on Berry Street for the Sydney Metro's Reference Design compared with the Proposed Design but compliance achieved with criteria.

Proposed Design:

- Comfort conditions on Miller Street (similar to Sydney Metro's Reference Design) comply with criteria.
- Conditions along the laneway similar to Sydney Metro's Reference Design with criteria compliance.
- Conditions on Denison Street slightly worse than the Sydney Metro's Reference Design but with criteria compliance achieved.
- Conditions on Berry Street similar to Sydney Metro's Reference Design, with criteria compliance.
- Conditions on roof terraces (Southern laneway building and Level 29 OSD) comply with comfort criteria.

In summary, the Proposed Design complies with the assessment criteria, avoiding the need for a canopy over the laneway due to the form of the proposed tower. The proposed canopies at the station entrances provide good mitigation of wind effects. The proposed landscaping form along Miller Street provides good mitigation of wind effects. The proposed high level "eye-brow" awning running along the north, west and south facades provides good mitigation of wind effects. Criteria compliance is achieved for the Proposed Design without the need for additional treatment.

10. Summary & Conclusion

Victoria Cross Station is to be a key station on the future Sydney Metro network, providing access to the growing North Sydney Central Business District (CBD). The proposal combines the Metro station with a significant commercial office tower, contributing to the North Sydney skyline. The OSD would assist in strengthening the role of North Sydney as a key component of Sydney's global economic arc and would contribute to the diversity, amenity and commercial sustainability of the CBD.

Wind effects for Sydney Metro's Reference Design were considered as part of the EIS by AECOM (2018) for Sydney Metro, with a canopy included in the Sydney Metro's Reference Design to above the laneway immediately to the south of the tower to control wind effects and an 18m setback of the building envelope to the MLC building. The EIS assessed wind effects qualitatively without using any approved method (computational or physical modelling) to assess wind effects quantitatively.

The Proposed Design proposed by Lendlease seeks to remove the awning, and instead set-back the tower by 28m to mitigate wind effects. A detailed computational wind impact assessment has been carried out to assess ground level wind conditions affecting public areas around the development.

It has been shown that wind effects for both the Sydney Metro's Reference Design and the Proposed Design are similar and improved over the "no-build" option. The amendments as part of the Proposed Design (set-backs and awnings) have enabled wind effects to be controlled without the need for an awning above the laneway to the south. The "no-build" option results in non-compliance with the proposed assessment criteria.

The assessment outlined herein was computational based, with wind tunnel testing using a physical scale model to be used to accurately assess wind effects by properly accounting for turbulence, assessing multiple directions (and associated statistics), and including effects of landscaping.