# Appendix Y

## Pedestrian wind assessment

Sydney Metro West

# Parramatta Over and Adjacent Station Development Pedestrian Wind Assessment

Appendix Y

September 2022

NSW GOVERNMENT

sydney METRO

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# Glossary

| Term | Definition |
| --- | --- |
| AS | Australian Standard |
| AWES | Australasian Wind Engineering Society |
| CAD | Computer-aided design |
| CBD | Central business district |
| Concept and Stage 1 CSSI Approval | SSI-10038 (approved 11 March 2021), including all major civil construction works between Westmead and The Bays, including station excavation and tunnelling, associated with the Sydney Metro West line |
| Concept SSDA | A concept development application as defined in section 4.22 of the EP&A Act. It is a development application that sets out the concept for the development of a site, and for which detailed proposals for the site or for separate parts of the site are to be the subject of a subsequent development application or applications |
| Council | City of Parramatta |
| DCP | Development control plan |
| DPE | Department of Planning and Environment |
| EIS | Environmental impact statement |
| EP&A Act | *Environmental Planning and Assessment Act 1979* |
| NZS | New Zealand Standard |
| OSD | Over station development |
| QAM | Quality Assurance Manual |
| SEARs | Secretary's Environmental Assessment Requirements |
| SEPP | State Environmental Planning Policy |
| SSDA | State Significant Development Application |
| SSI | State Significant Infrastructure |
| Stage 2 CSSI Application | (SSI- 19238057) – All major civil construction works between The Bays and Sydney CBD (under assessment, lodged) |
| Stage 3 CSSI Application | (SSI- 22765520) – Tunnel fit-out, construction of stations, ancillary facilities and station precincts between Westmead and the Sydney CBD, and operation and maintenance of the Sydney Metro West line (under assessment, lodged). |
| Sydney Metro West | Construction and operation of a metro rail line and associated stations between Westmead and the Sydney CBD as described in section 1.1 |

# Executive summary

This Pedestrian Wind Assessment report supports a Concept State Significant Development Application (Concept SSDA) submitted to the Department of Planning, Industry and Environment pursuant to Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act). The Concept SSDA is made under section 4.22 of the EP&A Act.

Sydney Metro is seeking to secure concept approval for an over station development (OSD) and adjacent station development (ASD) on the Parramatta metro station site (referred to as the 'proposed development'). The proposed development will comprise three new commercial office buildings (Buildings A, C, D), and one new residential building (Building B).

The Concept SSDA seeks consent for a building envelope and mixed-use purposes, maximum building height, a maximum gross floor area (GFA), pedestrian and vehicular access, circulation arrangements and associated car parking, and the strategies and design parameters for the future detailed design of the proposed development.

This Pedestrian Wind Assessment report assesses the proposal for any wind impacts that may affect the environmental amenity of the area. It will assess the wind speeds for the existing site and the proposed development, through wind tunnel and computational fluid dynamics (CFD) assessments, to determine the change in the local wind environment and the wind speeds across the site, and surrounds, based on the proposed development. These wind speeds are then assessed against the local and industry accepted wind criteria to determine the suitability of different areas of the site and to identify if any mitigation is required to ensure environmental amenity due to the proposed development.

Wind comfort was assessed using Computational Fluid Dynamics (CFD) and wind tunnel testing methods. The methods used were compliant with relevant Australian standards and industry best-practice guidelines. CFD simulations were conducted initially to inform the wind tunnel testing setup of the key areas to be analysed and provide a point of reference for the wind tunnel results.

The wind tunnel results form the basis for the assessment, which has been made against the industry-standard Lawson comfort criteria and criteria outlined in the City of Parramatta Development Control Plan (DCP) 2011.

The results demonstrate that wind conditions satisfying the City of Parramatta DCP criteria and Lawson comfort criteria are achieved throughout the majority of the proposed development. The two areas where the required criteria are not achieved are the east-west pedestrian link and footpath/frontages along the eastern side of buildings A and D. In both of these areas' conditions suitable for retail streets or sitting for longer periods of time will require design refinements. However, the wind conditions are categorised as more suitable for major pedestrian streets, parks, or areas where people are expected to sit or stand for shorter periods.

Design refinements, at the Detailed SSDA stage, will therefore be required to reduce wind speeds in these areas. These may include the introduction of fixed canopies or retractable awnings over these walkways, provision of a dense tree canopy near the eastern side of Buildings A and D, the use of podium balustrades, and/or the use of banners as roughing element.

# 1 Introduction

## 1.1 Sydney metro west

Sydney Metro West will double rail capacity between Greater Parramatta and the Sydney Central Business District (CBD), transforming Sydney for generations to come. The once in a century infrastructure investment will have a target travel time of about 20 minutes between Parramatta and the Sydney CBD, link new communities to rail services and support employment growth and housing supply.

Stations have been confirmed at Westmead, Parramatta, Sydney Olympic Park, North Strathfield, Burwood North, Five Dock, The Bays, Pyrmont and Hunter Street (Sydney CBD).

Sydney Metro West station locations are shown in Figure 1-1

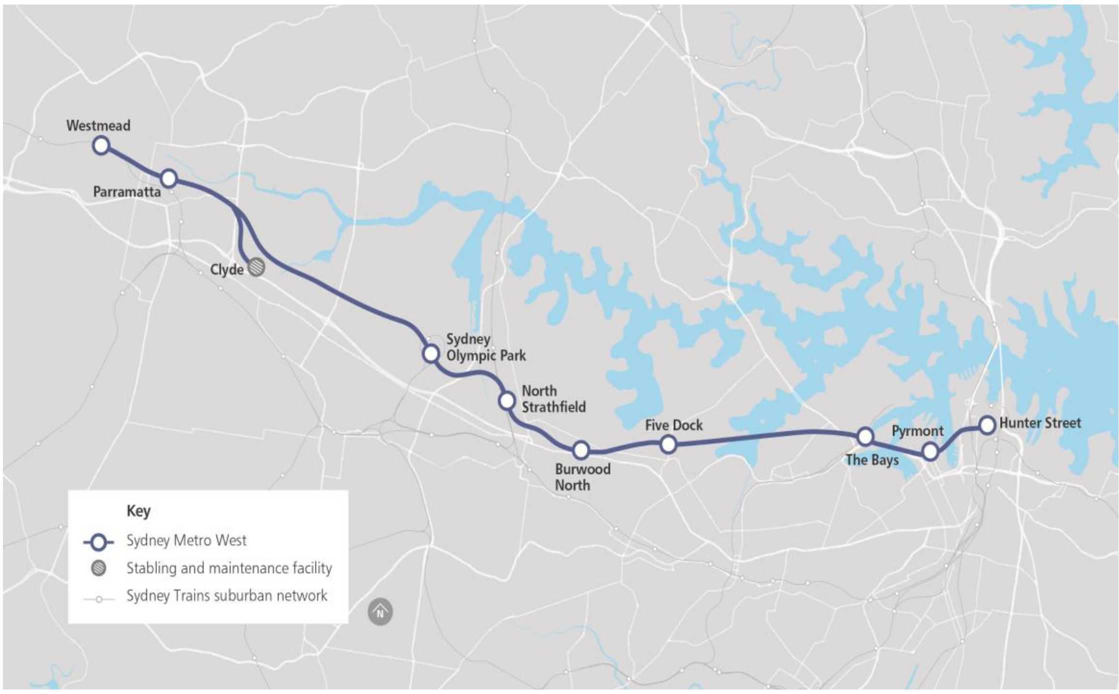


**Figure 1-1 Sydney Metro West**

## 1.2 Background and planning context

Sydney Metro is seeking to deliver Parramatta metro station under a two-part planning approval process. The station fit-out infrastructure is to be delivered under a Critical State Significant Infrastructure (CSSI) application subject to provisions under Division 5.2 of the *Environmental Planning and Assessment Act 1979* (EP&A Act), whereas the over and adjacent station developments are to be delivered under a State Significant Development (SSD) subject to the provisions of Part 4 of the EP&A Act.

### 1.2.1 Critical State Significant Infrastructure

The State Significant Infrastructure (SSI) planning approval process for the Sydney Metro West metro line, including delivery of station infrastructure, has been broken down into a number of planning application stages, comprising the following:

- Concept and Stage 1 CSSI Approval (SSI-10038) – All major civil construction works between Westmead and The Bays including station excavation, tunnelling and demolition of existing buildings (approved 11 March 2021)
- Stage 2 CSSI Application (SSI- 19238057) – All major civil construction works between The Bays and Sydney CBD (under assessment, lodged)
- Stage 3 CSSI Application (SSI- 22765520) – Tunnel fit-out, construction of stations, ancillary facilities and station precincts between Westmead and the Sydney CBD, and operation and maintenance of the Sydney Metro West line (under assessment, lodged).

### 1.2.2 State Significant Development Application

The SSD will be undertaken as a staged development with the subject Concept State Significant Development Application (Concept SSDA) being consistent with the meaning under section 4.22 of the EP&A Act and seeking conceptual approval for a building envelope, land uses, maximum building heights, a maximum gross floor area, pedestrian and vehicle access, vertical circulation arrangements and associated car parking. A subsequent Detailed SSD/s is to be prepared by a future development partner which will seek consent for detailed design and construction of the development.

## 1.3 Purpose and scope

This Pedestrian Wind Assessment report supports a Concept SSDA submitted to the Department of Planning and Environment (DPE) pursuant to Part 4 of the EP&A Act. The Concept SSDA is made under section 4.22 of the EP&A Act.

This report has been prepared to specifically respond to the Secretary's Environmental Assessment Requirements (SEARs) issued for the Concept SSDA on 22 February 2022 which states that the environmental impact statement is to address the following requirements shown in Table 1-1.

**Table 1-1 SEARs and where this is addressed in this SSD report**

| Key issue | SEARs requirement | Where addressed in report |
|---|---|---|
| 4. Environmental Amenity | Assess amenity impacts on the surrounding locality, including lighting impacts, reflectivity, solar access, visual privacy, visual amenity, 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. | Throughout this report. |

# 2 The site and proposal

## 2.1 Site location and description

The subject application is in the Parramatta CBD, in the City of Parramatta Local Government Area (LGA). It is within the city block bounded by George Street, Church Street, Smith Street, and Macquarie Street.

The site presents a 164m long frontage to Macquarie Street, 125m frontage to George Street, 48m frontage to Church Street, and 15.5m frontage to Smith Street (in the form of Macquarie Lane). The site location is shown in Figure 2-1 and Table 2-1.

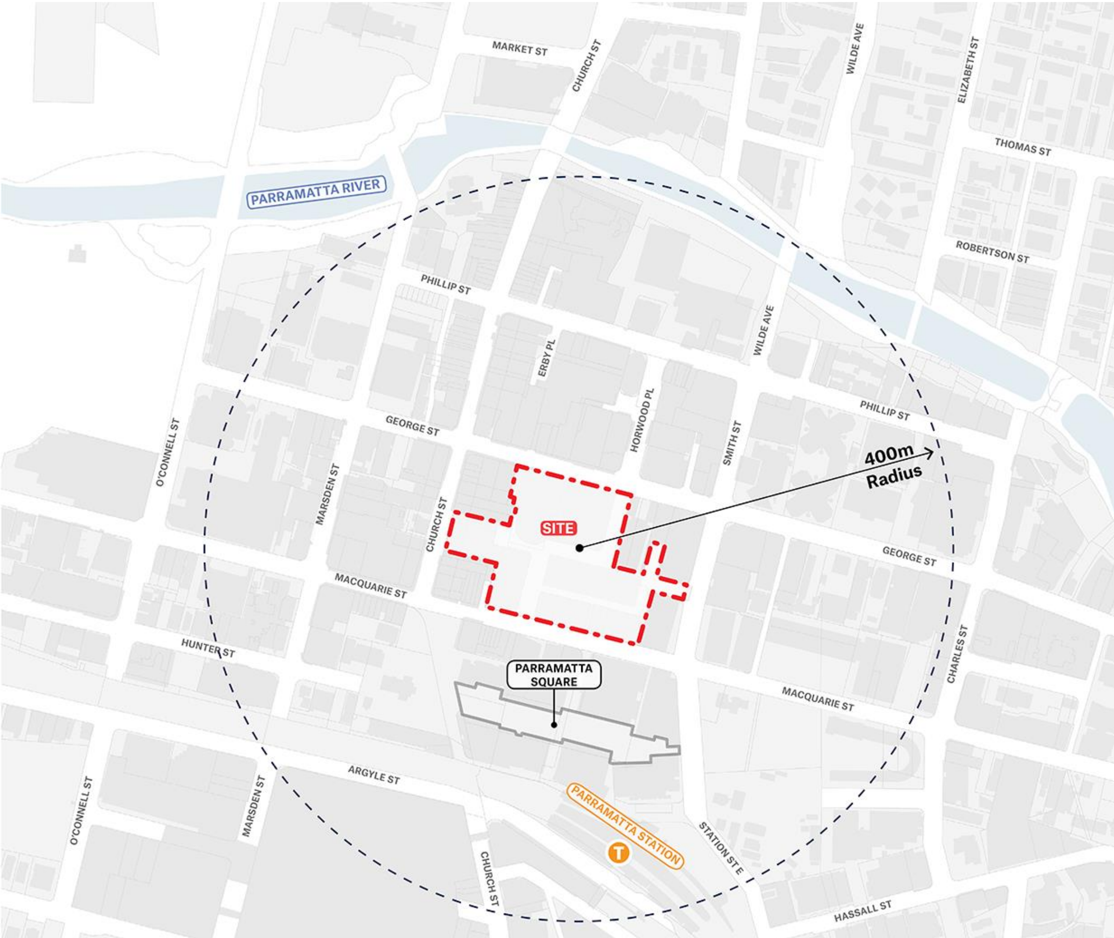


**Figure 2-1 Parramatta metro station location precinct**

As described inTable 2-1, the site comprises fourteen different allotments of varying sizes. It is irregular in shape, with a total area of approximately 24,899m$^2$.

**Table 2-1 Site legal description**

| Street address | Legal description |
|---|---|
| 41-59 George Street | Lot 10 in DP858392 |
| 45A George Street | Lot 2 in DP701456 |
| 61B George Street | Lot 1 in DP607181 |
| 71 George Street | Lot 100 in DP607789 |
| 220 Church Street | Lot 1 in DP1041242 |
| 222 Church Street | Lot 1 in DP702291 |
| 232 Church Street | Lot 1 in DP651992 |
| 236 Church Street | Lot 1 in DP128437 |
| 238 Church Street | Lot 2 in DP591454 |
| 48 Macquarie Street | Lot B in DP394050 |
| 58-60 Macquarie Street | Lot 1 in DP399104 |
| 62-64 Macquarie Street | Lot AY in DP400258 |
| 68 Macquarie Street | Lot 1 in DP711982 |
| 70 Macquarie Street | Lot E DP 402952 |
| 72 Macquarie Street | Lot 3 in DP218510 |
| 74 Macquarie Street | Lot H in DP405846 |

## 2.2 Overview of this proposal

The Concept SSDA will seek consent for four building envelopes, as detailed in Table 2-2 and Figure 2-2.

**Table 2-2 Proposed development overview**

| Item | Description |
|---|---|
| Building use | **Building A:** Commercial and retail<br>**Building B:** Residential and retail<br>**Building C:** Commercial<br>**Building D:** Commercial and retail |
| Building Height (Number of storeys) | **Building A:** 38 storeys<br>**Building B:** 33 storeys<br>**Building C:** 26 storeys<br>**Building D:** 25 storeys |
| Gross Floor Area ($m^2$) | **Building A:** 78,700<br>**Building B:** 20,000<br>**Building C:** 35,950<br>**Building D:** 55,350<br>**TOTAL: 190,000** |
| Car parking spaces | 455 |

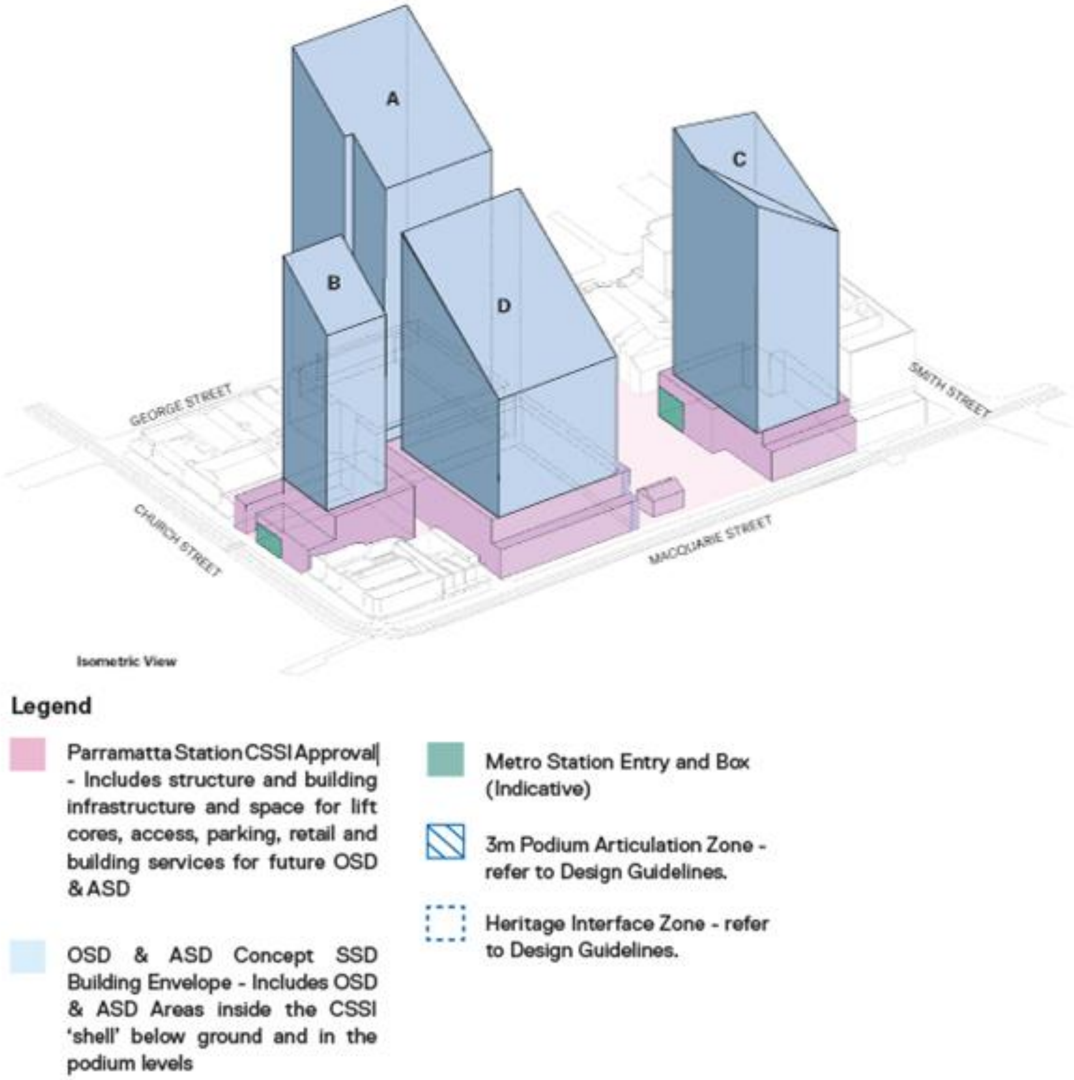


**Figure 2-2 Proposed Concept SSDA development and CSSI scope**

# 3 Scope of assessment

As outlined in section 1.3, the purpose of this report is to address the SEARs pertaining to potential wind impacts.

This assessment considers the potential wind impacts from, and on, the proposed development. This wind assessment has been prepared generally and in accordance with the Australasian Wind Engineering Society Quality Assurance Manual (AWES QAM). This involved:

- establishing prevailing topography and meteorological conditions around the proposed site using observation data from a representative monitoring station operated by the Bureau of Meteorology (BoM)
- establishing wind conditions at the proposed site, for the proposed built form, using computational fluid dynamics (CFD)
- determining Irwin sensor locations for wind speed measurements in the wind tunnel for the proposed built form based on key areas noted in the CFD
- establishing wind conditions at the proposed site, for the existing built form, using wind tunnel results
- establishing wind conditions at the proposed site, for the proposed built form, wind tunnel results
- undertaking a statistical analysis of the results to determine overall exceedance wind speeds based on the observation meteorological conditions
- assessing the exceedance wind speeds against established Lawson pedestrian comfort wind criteria (an industry accepted criteria) and the City of Parramatta DCP criteria to determine if the future site wind conditions are suitable for the expected activity at the proposed development
- identifying any mitigation measures required to address or manage potential wind speed impacts.

# 4 Methodology

## 4.1 Assessment criteria

Specific wind criteria are used to determine the acceptability of the measured wind environment to determine if it will be suitable for the intended use. This section outlines how the measured wind speeds were obtained, the criteria considered for the development, and the assessment locations.

### 4.1.1 City of Parramatta Council criteria

The City of Parramatta DCP provides some limits for appropriate wind speeds in different areas, stating:

*"To ensure public safety and comfort the following maximum wind criteria are to be met by new buildings:*

- 10 m/s in retail streets
- 13 m/s along major pedestrian streets, parks and public places
- 16 m/s in all other streets."

However, the DCP criteria does not mention the duration of the wind event or probability of occurrence. Therefore, we have included assessment against the Lawson Criteria (with reference back to this criteria) which is an industry-standard pedestrian comfort criteria (section 4.1.2).

### 4.1.2 Lawson criteria

As the City of Parramatta DCP criteria requires assumptions to be made about the wind event duration and occurrence probability, assessment has been made against the Lawson (2001) criteria. The Lawson criteria for comfort, shown in Table 4-1, can be considered an industry-standard pedestrian comfort criteria.

Comfort wind speeds are defined as the exceedance of threshold wind speeds occurring less than 5% of the time (i.e., 95$^{th}$ percentile wind speeds). The value of 5% has been established as giving a reasonable allowance for extreme and relatively infrequent winds that are tolerable within each category. Note that the Lawson Criteria are defined in terms of equivalent mean wind speeds (see section 4.3.2), which account for the impact of turbulent/gusty conditions on comfort.

**Table 4-1 Lawson comfort criteria**

| Comfort rating | Description | Wind speed | Appropriate usage | Description of wind effects |
|---|---|---|---|---|
| C1+ - Uncomfortable | Uncomfortable for all users | > 10 m/s | Uncomfortable for all users | Umbrellas difficult to use. Hair blown straight |
| C1 – Fast walking | Fast or business walking | 8 – 10 m/s | Areas where people are not expected to linger | Force of wind felt on body |
| C2 - Strolling | Leisurely walking | 6 – 8 m/s | General walking or sightseeing | Dust and papers raised. Hair disarranged |
| C3 - Standing | Short period sitting/standing | 4 – 6 m/s | Bus stops, building entrances | Light leaves and twigs in motion. Lightweight flags extend |
| C4 - Sitting | Long period sitting/standing | 0 – 4 m/s | Reading a newspaper, eating a drinking | Light wind felt on face. Leaves rustle |

Based on the Lawson criteria, and DCP descriptions of wind speeds for usage of different areas, regions around the proposed development have been assigned comfort ratings based on the below assumptions about their intended use (Figure 4-1):

- thoroughfares with retail frontages may have outdoor café/restaurant seating and therefore should achieve a sitting criterion (C4)
- building entrances, open park areas and main thoroughfares are areas where people may congregate and be expected to stand or sit for short periods of time and therefore should achieve a standing criterion (C3)
- thoroughfares that run alongside streets, and the streets themselves, may have people walking leisurely around them, or crossing the street, should achieve a strolling criterion (C2).


**Figure 4-1 Lawson criteria for the proposed development showing the different regions and the criteria that they should meet**

## 4.2 Wind climate

Wind is a highly variable meteorological element, both in speed and direction. The selection of data and statistical representation of the wind climate can therefore have a large bearing on the outcome of a wind comfort assessment.

### 4.2.1 Meteorological data

Historical weather data was used for the analysis and obtained from the Bureau of Meteorology weather station at Bankstown Airport, which is situated 12 km due south of the site. Airport weather stations are generally the most reliable source of wind data as they are typically free from nearby obstructions and have uninterrupted, quality-controlled data for suitable time periods. While there are closer weather stations (notably the Sydney Olympic Park (Archery Centre)), the use of Bankstown Airport data ensures that there are no shielding effects which will impact the results of the pedestrian wind assessment.

From 2000 to 2019, 10-minute wind observations were converted to hourly means using methods outlined in Grange (2014). Scaling to correct for the difference in terrain roughness surrounding the site (i.e., due to buildings, trees, and other obstructions) was made and detailed in Appendix A.

Details of the statistical methods used and coefficients describing the wind probability distributions can also be found in Appendix A.

The scaled data is presented in the wind rose plot below, Figure 4-2. Here, the length and colour of the spoke sections represent the frequency and amplitude of recorded wind events, respectively.

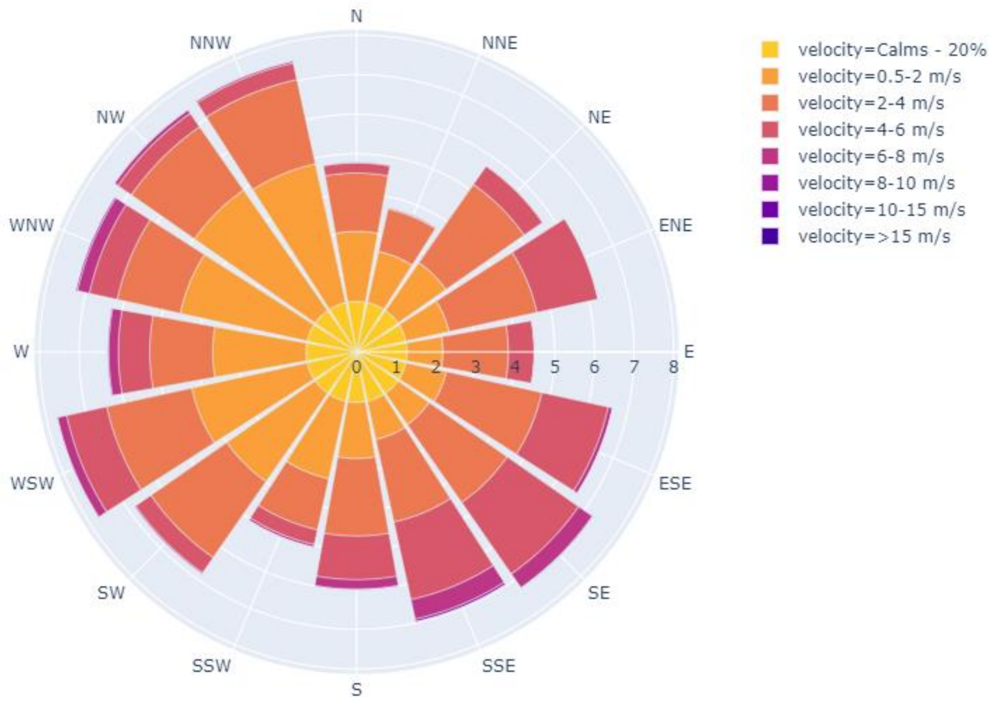


**Figure 4-2 Wind rose plot of Bankstown Airport BOM Data, 2000-2019**

## 4.3 The computational fluid dynamics model

CFD modelling was undertaken to provide an initial estimation and understanding of the wind environment throughout and surrounding the proposed development, and to inform the wind tunnel study of the key areas to be considered. A detailed explanation of the computational fluid dynamics methodology is provided in Appendix B.

### 4.3.1 Model geometry

Surrounding physical features which influence the near field flow, such as significant buildings, structures or topography, are essential to accurate wind modelling. The site and surrounding buildings within 375 m were modelled to sufficient accuracy, following the Australasian Wind Engineering Society Quality Assurance Manual (2019). Images of the simplified model are provided below in Figure 4-3 to Figure 4-5.

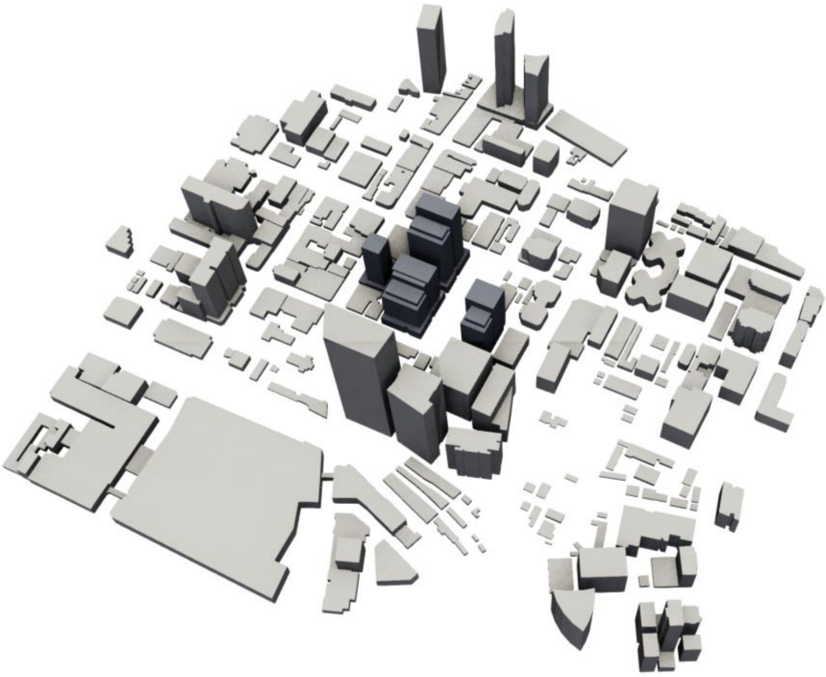

**Figure 4-3 CFD model geometry showing detail and extent of surrounding environment**

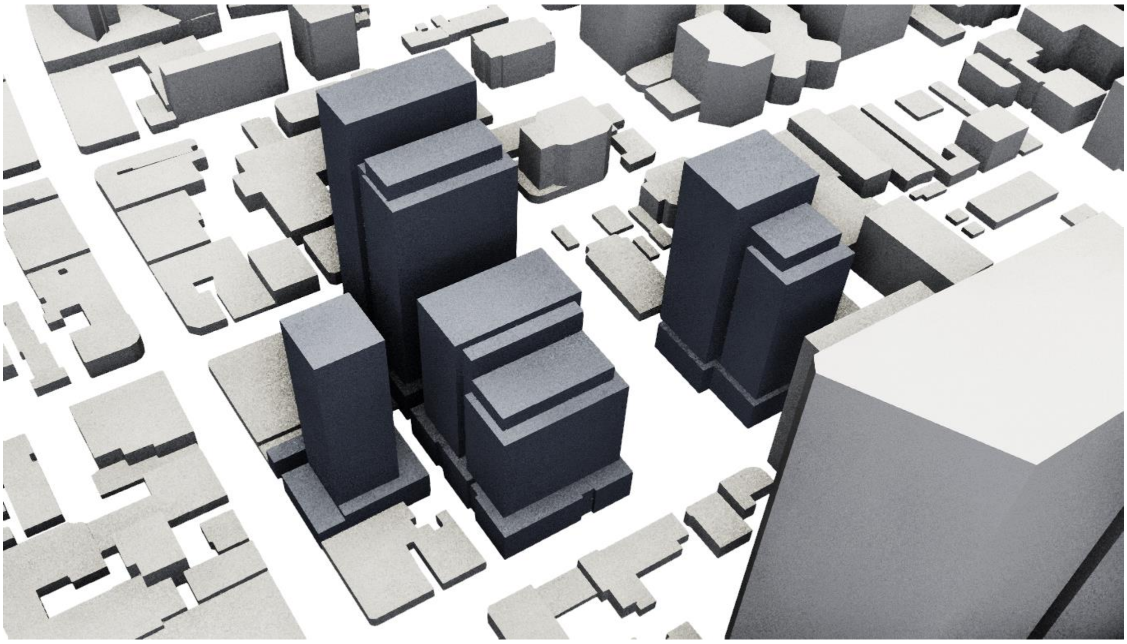

**Figure 4-4 CFD model geometry showing site model detail**

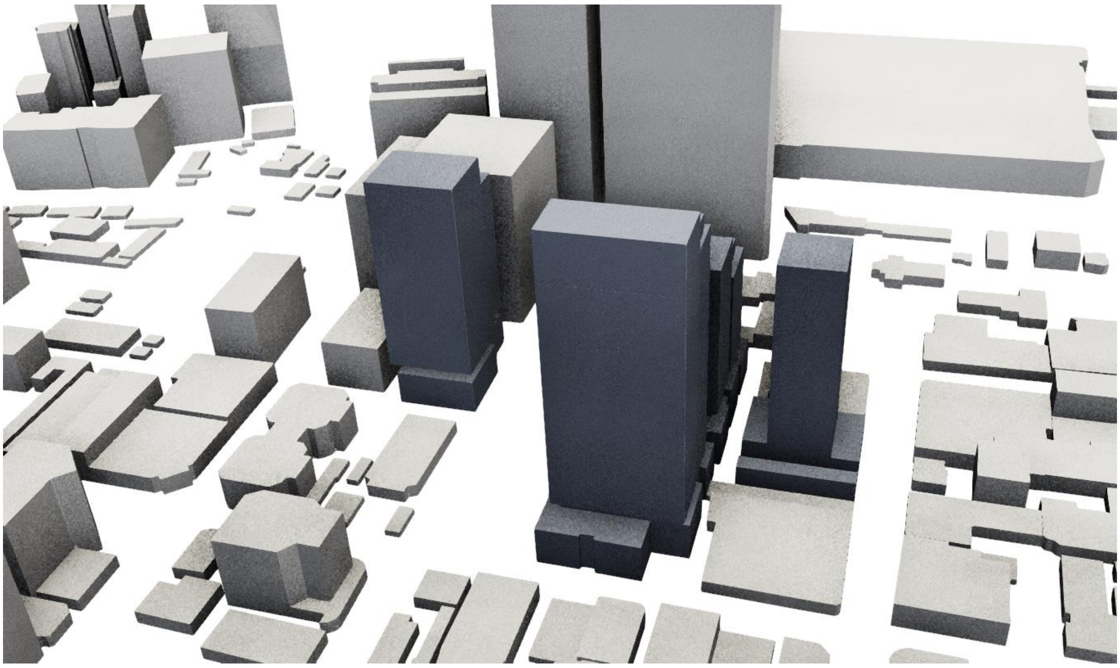

**Figure 4-5 CFD model geometry showing site model detail**

### 4.3.2 Statistical analysis

Comfort and safety conditions were assessed using the following method:

- CFD was used to determine the mean wind speed ($\overline{U}$) and turbulent kinetic energy ($k$) at pedestrian height for 16 wind directions relative to a reference wind speed of 10 m/s.
- Gust equivalent mean wind speeds, $U_{GEM}$, were calculated using:
- $U_{GEM} = \max\left(\overline{\mathrm{U}}, \frac{\overline{U}+3.5\sqrt{k}}{1.85}\right)$

Where 3.5 is the peak factor corresponding to a 0.2-second gust relative to an hourly mean. The gust factor of 1.85 has been used based on the research published by Lawson (2001).

Comfort wind speeds were calculated using a Weibull analysis (see Appendix A) of hourly mean wind speed observations, resulting in wind speeds with a 5% probability of exceedance from all directions.

## 4.4 The wind tunnel model

Wind tunnel experiments were undertaken to determine the site-specific wind speeds for the existing buildings and proposed built form. Due to the nature of wind tunnel experiments, there are several factors that need to be considered (e.g., the wind tunnel configuration, approach flow, built environment, assessment locations, etc.).

### 4.4.1 Wind tunnel

Testing was conducted in the three-quarter open-jet test section of the Monash University 1.4 MW Wind Tunnel. The wind tunnel is a closed-circuit wind tunnel that is powered by four DC electric motors that drive two fans, each five metres in diameter. Testing was conducted with the jet in a lowered position at a height of 2.6 m and a width of 4.0 m, providing a jet area of ~10.5 m$^2$. The collector was in the forward position, known as the “ABCD” configuration.

### 4.4.2 Establishment of the approach flow

The minimum requirements for an acceptable simulation of a neutrally stable atmospheric boundary layer are the modelling of:

- the variation of mean wind speed with height
- the variation of longitudinal component of turbulence with height
- the integral scale of turbulence
- a zero longitudinal pressure gradient.

The mean wind speed and turbulence intensity in the approach flow were modelled to within 10% of their target values. The integral length scale was within a factor of 3 of the value determined from the chosen geometric scaling ratio (1:300 in this case) (refer to Appendix C for the relevant scaling laws). Appendix C shows confirmation that the wind tunnel (using a trip board, turbulence elements and development length) adequately models the variation of mean wind speed with height and the variation of longitudinal component of turbulence with height for each terrain category.

### 4.4.3 Modelling of the near-field flow

Physical features such as significant buildings, structures, or topography, influence the near field flow and must be included as part of the local wind flow simulation. In general, all major structures and topographical features within a radius of 300 m to 600 m of the building site should be modelled to the correct scale, to an accuracy of 10% or better in accordance with AWES-QAM-1-2019.

A survey of the site shown in Figure 4-6 was carried out to acquire information on the footprint, form, and height of all buildings within a 375 m radius of the site. Figure 4-7 to Figure 4-9 show the wind tunnel model and surroundings. The site and surroundings were modelled consistent to the CAD geometry used in the CFD study (refer to section 4.3.1).

**Figure 4-6 Existing buildings in the Parramatta region with an overlay of the proposed site (red boundary) and the development footprints (green areas)**

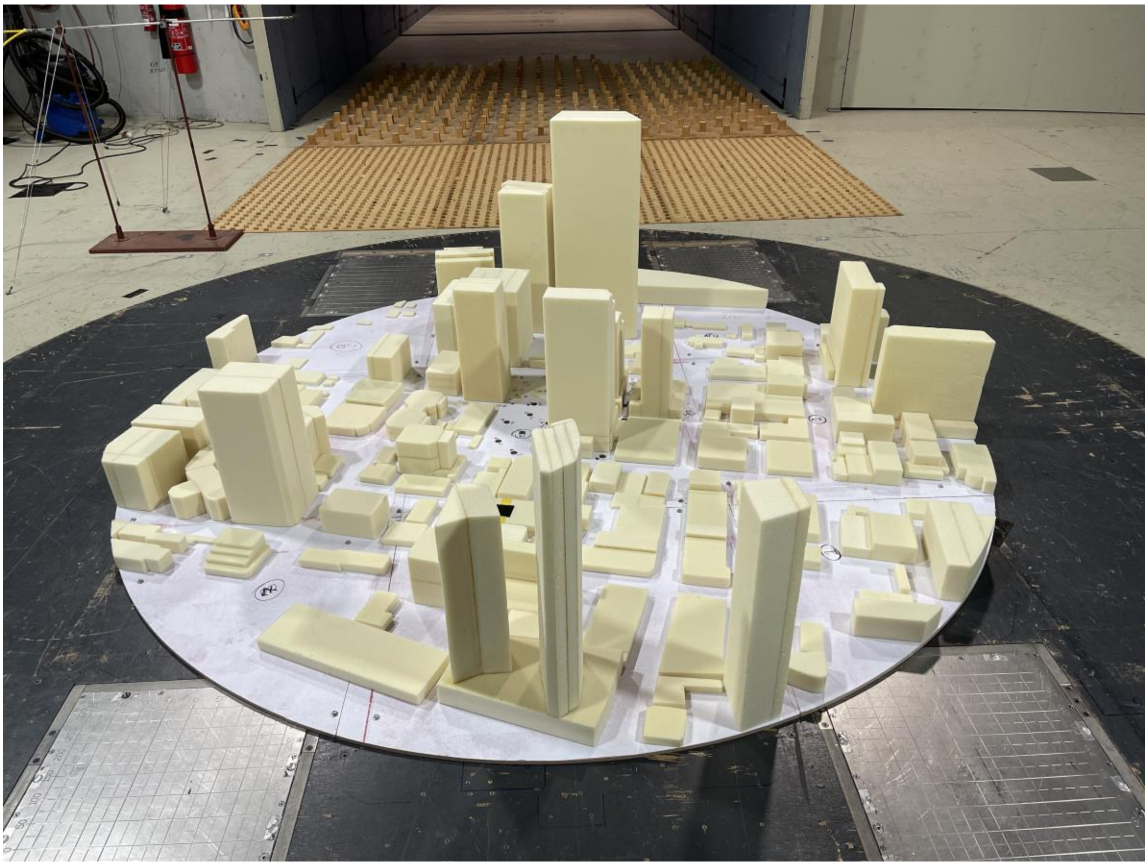

**Figure 4-7 Wind tunnel model showing the approach region and overall modelled site with the proposed development**

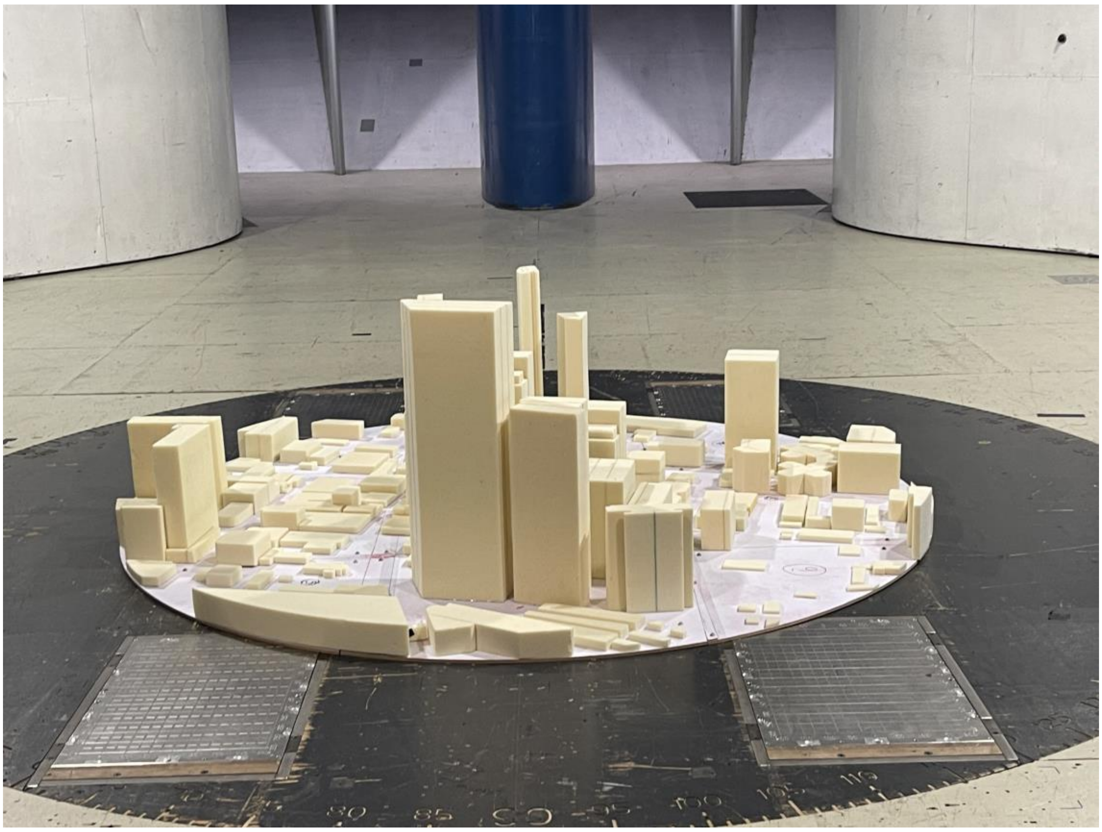

**Figure 4-8 Wind tunnel model showing the overall modelled site**

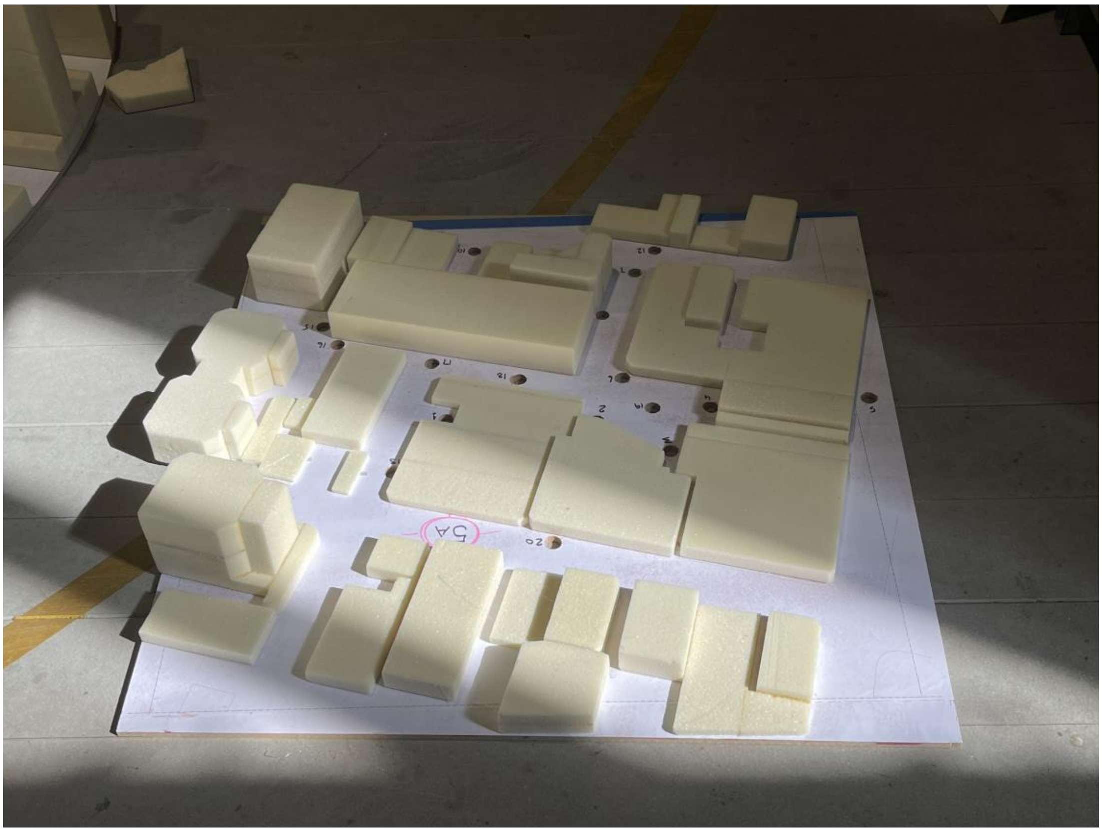

**Figure 4-9 Centre section showing the wind tunnel model for the existing buildings on the site of the proposed development**

### 4.4.4 Test methodology

Measurements from the sensor array were taken for the full 360$^{O}$ azimuth range at 10$^{O}$ intervals, as required by AWES QAM. In addition to the local total and static pressures measured at each Irwin sensor, reference measurements of static and total pressure (measured using a pitot-static tube) were taken at the upstream edge of the turntable at a height of 1 m (300 m full-scale). This reference height is required to avoid interference with the flow over the model.

These measurements of ground-level wind speeds at the various locations are combined with the probability distribution of reference wind speed and direction to provide predictions of full-scale ground-level wind speeds. The following method was used for the analysis:

- time series of ground-level wind speeds were calculated from the Irwin sensor data using the calibration equation (refer to Appendix C)
- the maximum hourly 3-second gusts were calculated for each of these time series
- the gust wind speeds were converted to velocity ratios by dividing by the wind tunnel reference velocity (from the pitot-static tube) (refer to Appendix C for the sensor calibration and conversion from a pressure difference to a velocity)
- velocity ratios were then scaled to the 10 m reference height of the Bureau of Meteorology anemometer using AS/NZS 1170.2 gust profiles

- Comfort and safety wind speeds, representing the relative contributions of wind from all directions, were calculated using the statistical methods outlined in Appendix A. For each location, the probability of exceeding a certain wind speed was calculated using an iterative method, with the wind speed varied until the comfort exceedance probability was reached. This method was then repeated using the extreme value distribution and safety exceedance probability.
- gust wind speeds were converted to gust equivalent mean (GEM) wind speeds by dividing by a scaling factor of 1.85 (Lawson, 2001), to be used for comparison against the comfort criteria.

## 4.5 Assessment locations

The wind tunnel test is split in to two stages:

- baseline investigations – assessing the existing buildings (pre-demolition) on the site to determine the existing wind climate
- proposed development – assessing the proposed development to determine the future wind climate.

### 4.5.1 Baseline investigations

For this study, a total of 20 ground level assessment locations within and around the site of the proposed development have been selected for analysis in the wind tunnel. The locations of the various assessment locations are presented in Figure 4-10 in the form of a marked-up plan drawing.

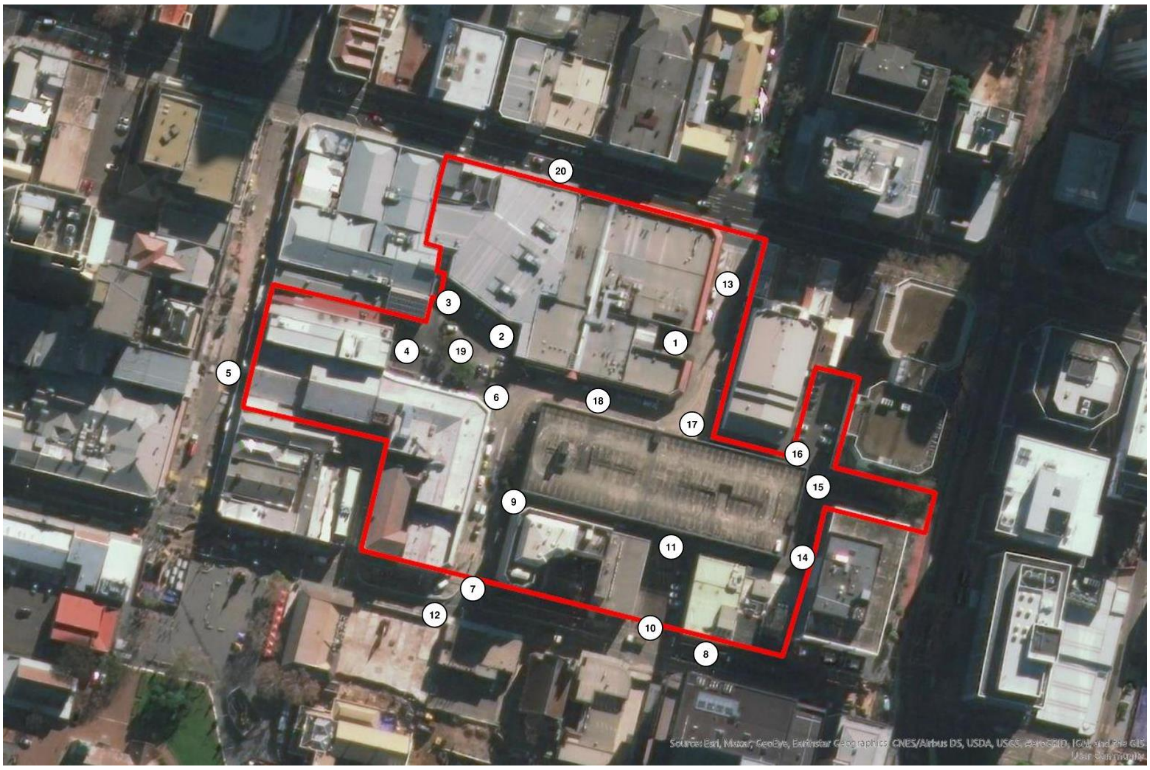


**Figure 4-10 Irwin probe assessment locations for the existing built environment (red outline shows the extent of the proposed development)**

### 4.5.2 Proposed development

For this study, a total of 40 ground level assessment locations within and around the proposed development have been selected for analysis in the wind tunnel. These points have been selected based on the CFD model to ensure coverage of all key areas. The locations of the various assessment locations are presented in Figure 4-11 in the form of a marked-up plan drawing where the metro station entrances are shown in green, retail spaces are shown in orange and commercial spaces are shown in blue.

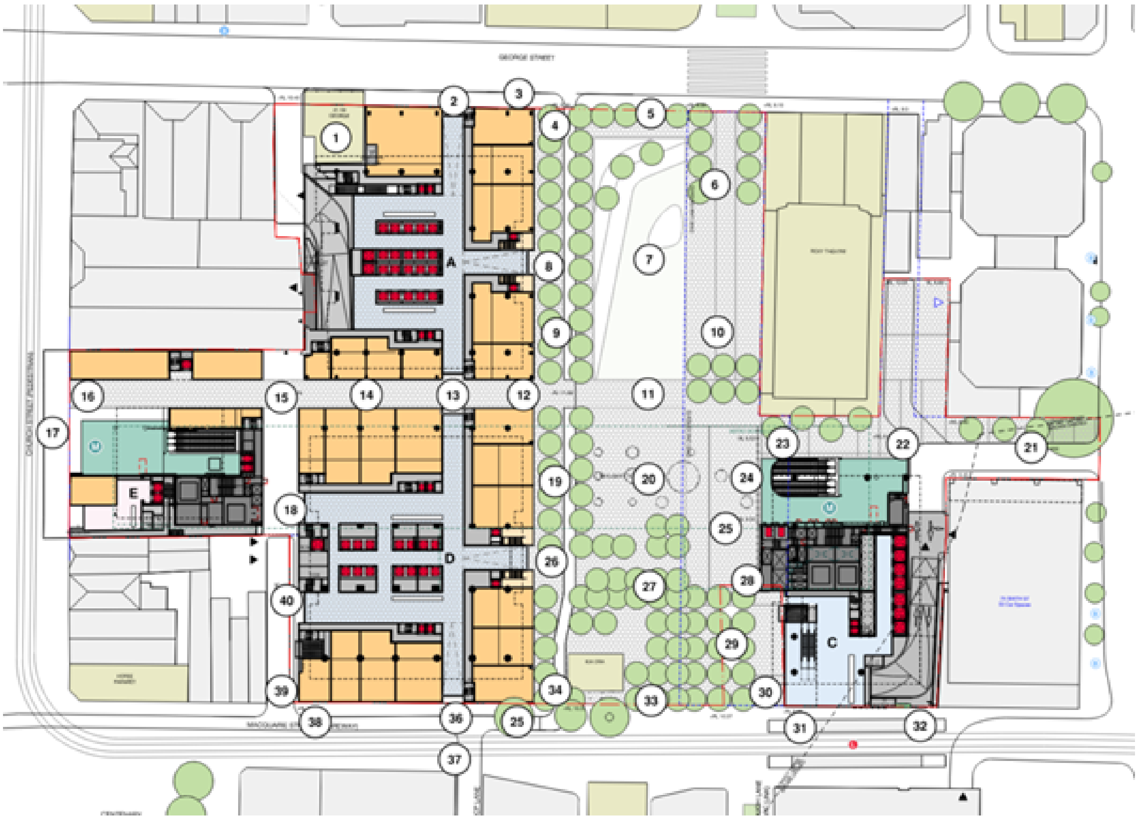


**Figure 4-11 Irwin probe assessment locations for the proposed development (layout is taken from the space planning report**

# 5 Assessment

Results from the initial CFD simulations and wind tunnel testing (for both baseline investigations and proposed development) are presented in this section.

## 5.1 Computational fluid dynamics

Results from the initial CFD modelling are shown below in Figure 5-1, illustrating the combined effect and relative contributions of wind from all directions. All areas see reasonably comfortable wind conditions; suitable for standing and waiting at bus stops or building entrances (teal) or longer periods of sitting such as outdoor dining or concerts (blue).

The results highlight that the main areas of interest are the east-west-aligned pedestrian link, eastern side of Buildings B and D, and around Building C to the south-east of the site. The wind tunnel sensors were positioned to ensure adequate coverage of these key areas, with results shown in the following section.

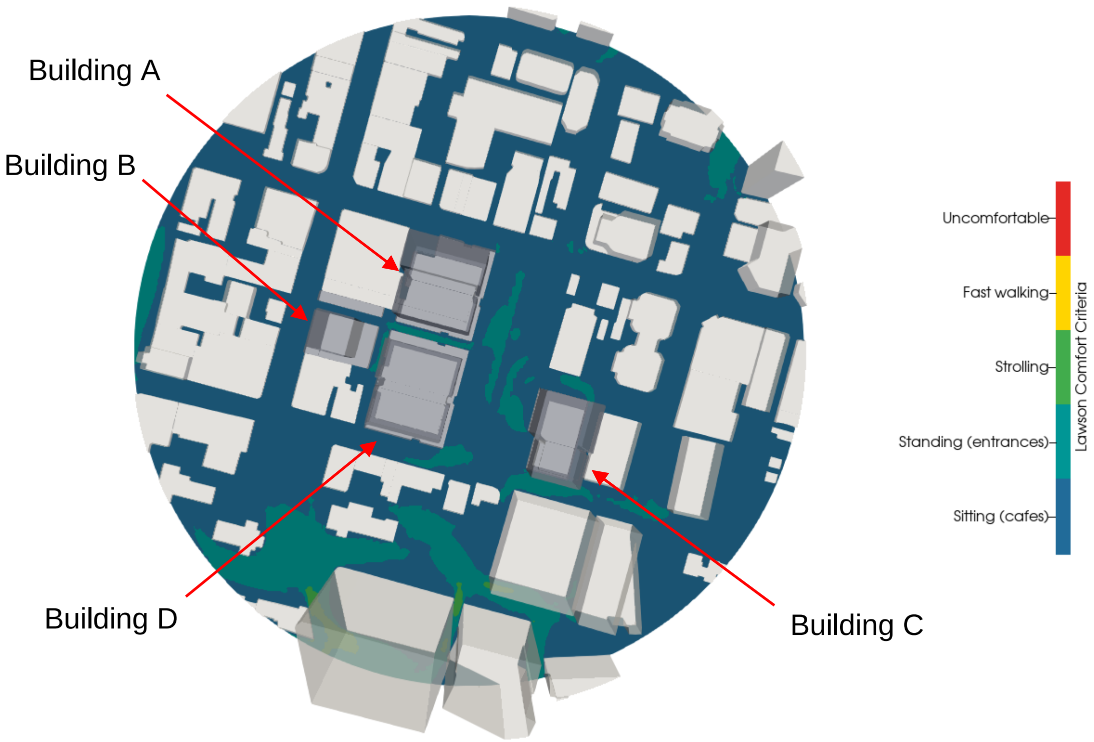


**Figure 5-1 Results from initial CFD modelling**

## 5.2 Wind tunnel

The wind tunnel results show wind speeds at 1.5 m above the ground plane at the discrete sensor locations outlined in section 4.5. The wind tunnel test was undertaken to assess the baseline case (pre-demolition) and with the proposed development.

### 5.2.1 Baseline investigations

This assessment included 20 Irwin probes, located around the proposed development, and their results are shown against the Lawson comfort criteria in Figure 5-2. Results are also tabulated in Table 5-1 to show the wind speeds and the achieved criteria. Conditions are shown to be generally suitable for standing for short periods or sitting for long periods.

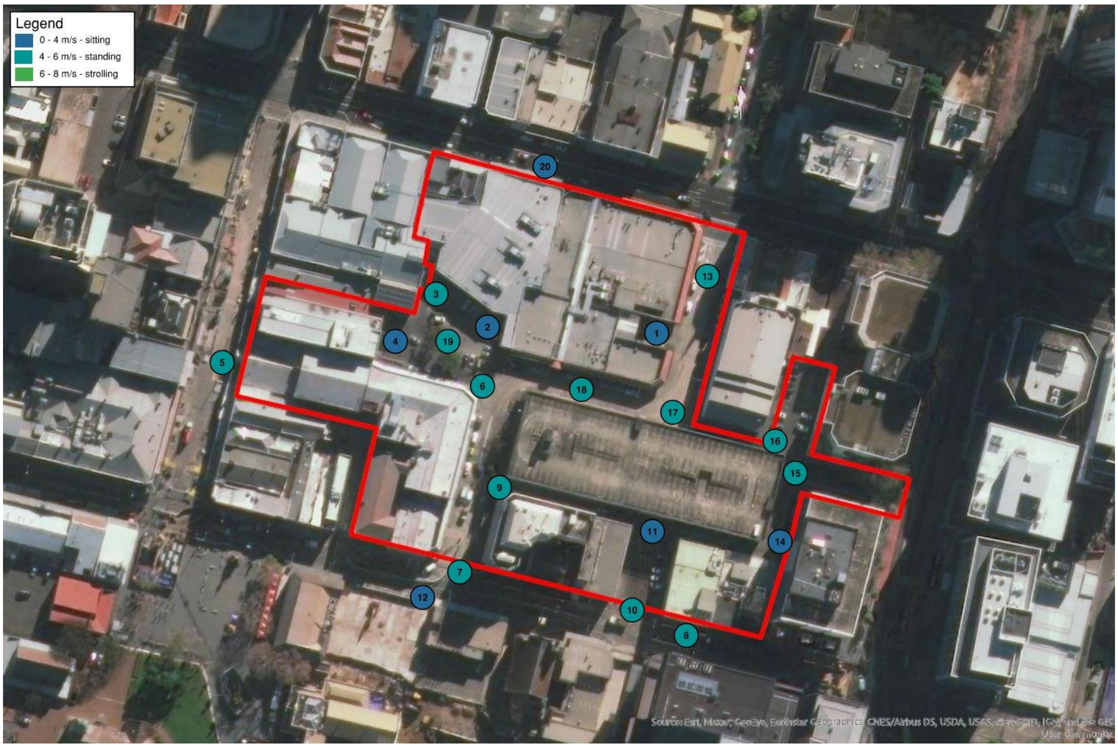


**Figure 5-2 Irwin sensor Lawson comfort results for existing buildings occupying the site of the proposed development**

**Table 5-1 Irwin sensor wind speed results for existing buildings occupying the site of the proposed development**

| Location | Lawson wind speed [m/s] | Lawson criteria |
|---|---|---|
| 1 | 3.7 | Sitting |
| 2 | 3.6 | Sitting |
| 3 | 4.5 | Standing |
| 4 | 3.9 | Sitting |
| 5 | 4.5 | Standing |
| 6 | 4.1 | Standing |
| 7 | 4.4 | Standing |
| 8 | 5.2 | Standing |
| 9 | 4.8 | Standing |
| 10 | 4.5 | Standing |
| 11 | 3.1 | Sitting |
| 12 | 3.8 | Sitting |
| 13 | 4.1 | Standing |
| 14 | 3.6 | Sitting |
| 15 | 4.8 | Standing |
| 16 | 4.9 | Standing |
| 17 | 4.1 | Standing |
| 18 | 4.4 | Standing |
| 19 | 4.1 | Standing |
| 20 | 3.7 | Sitting |

### 5.2.2 Proposed development

This assessment included 40 Irwin probes, located around the proposed development, and their results are shown against the Lawson criteria in Figure 5-3. Results are also tabulated in Table 5-2 to show the comparison between the target criteria and the achieved criteria, along with a pass/fail grade to determine if the wind speed is suitable for the intended use.

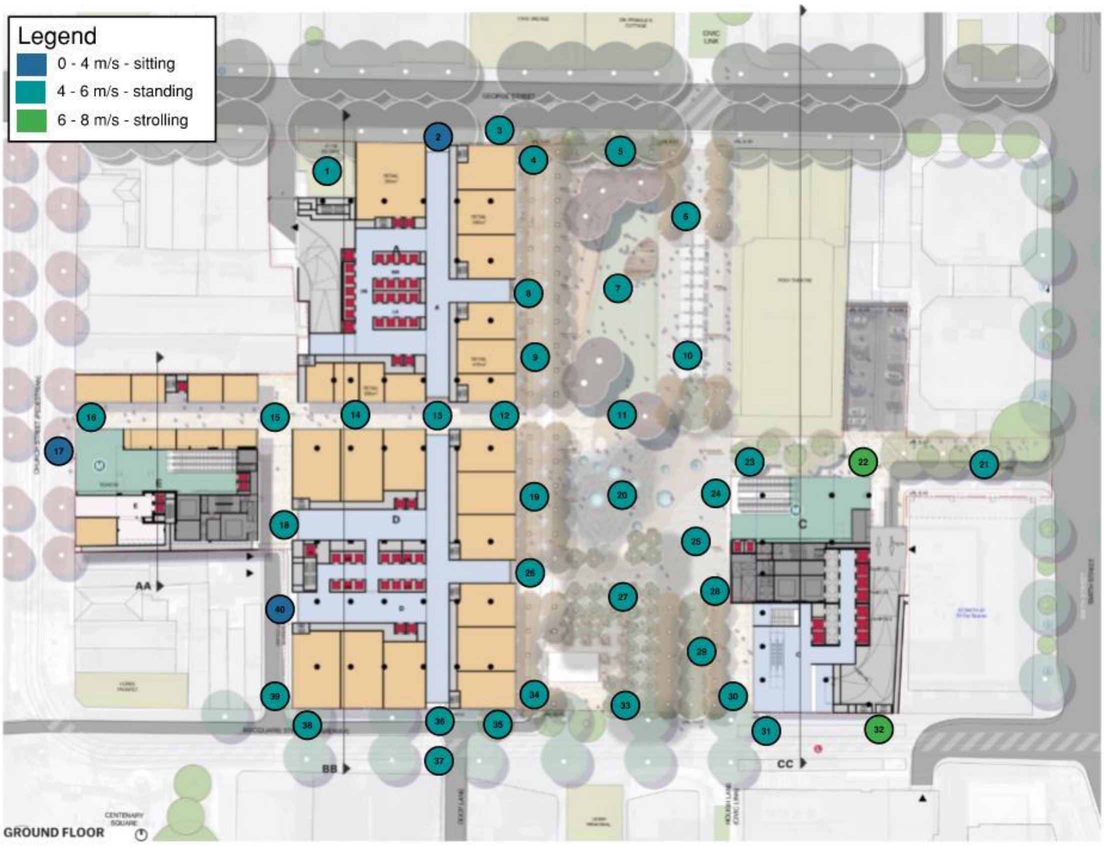


**Figure 5-3 Irwin sensor Lawson comfort results for proposed development**

**Table 5-2 Irwin sensor wind speed results for the proposed development**

| Location | Target | Wind speed [m/s] | Criteria | Achieves target |
|---|---|---|---|---|
| 1 | Standing | 5.3 | Standing | Pass |
| 2 | Standing | 3.5 | Sitting | Pass |
| 3 | Standing | 5.6 | Standing | Pass |
| 4 | Sitting | 4.9 | Standing | Fail |
| 5 | Standing | 5.4 | Standing | Pass |
| 6 | Standing | 4.9 | Standing | Pass |
| 7 | Standing | 4.8 | Standing | Pass |
| 8 | Sitting | 4.5 | Standing | Fail |
| 9 | Sitting | 5.2 | Standing | Fail |
| 10 | Standing | 5.1 | Standing | Pass |
| 11 | Standing | 5.2 | Standing | Pass |
| 12 | Sitting | 5.1 | Standing | Fail |
| 13 | Sitting | 4.5 | Standing | Fail |
| 14 | Sitting | 4.7 | Standing | Fail |
| 15 | Sitting | 4.3 | Standing | Fail |
| 16 | Sitting | 4.4 | Standing | Fail |
| 17 | Standing | 3.7 | Sitting | Pass |
| 18 | Standing | 4.3 | Standing | Pass |

| Location | Target | Wind speed [m/s] | Criteria | Achieves target |
|---|---|---|---|---|
| 19 | Sitting | 4.7 | Standing | Fail |
| 20 | Standing | 4.8 | Standing | Pass |
| 21 | Strolling | 4.9 | Standing | Pass |
| 22 | Standing | 6.1 | Strolling | Pass |
| 23 | Standing | 5.2 | Standing | Pass |
| 24 | Standing | 5.2 | Standing | Pass |
| 25 | Standing | 4.8 | Standing | Pass |
| 26 | Strolling | 4.2 | Standing | Pass |
| 27 | Standing | 5.4 | Standing | Pass |
| 28 | Standing | 5.0 | Standing | Pass |
| 29 | Standing | 4.8 | Standing | Pass |
| 30 | Standing | 4.9 | Standing | Pass |
| 31 | Strolling | 4.8 | Standing | Pass |
| 32 | Strolling | 6.1 | Strolling | Pass |
| 33 | Standing | 4.8 | Standing | Pass |
| 34 | Sitting | 4.3 | Standing | Fail |
| 35 | Standing | 4.6 | Standing | Pass |
| 36 | Standing | 4.5 | Standing | Pass |
| 37 | Strolling | 4.4 | Standing | Pass |
| 38 | Standing | 4.5 | Standing | Pass |
| 39 | Standing | 4.3 | Standing | Pass |
| 40 | Standing | 3.8 | Sitting | Pass |

## 5.3 Discussion

The results of the assessment indicate that wind speeds are generally compliant with the intended usage of each area of the proposed development, when assessed against the Lawson Criteria aligning with the required DCP criteria. However, there are some areas that will require further mitigation to ensure that the wind conditions are suitable for their intended use.

Both CFD and wind tunnel results indicate that conditions are suitable for standing for short-periods or sitting for long-periods throughout the majority of the site. A comparison of the two methods shows that wind tunnel results are generally higher than the CFD results. This is expected as large eddy structures produced by vortex shedding are captured in the wind tunnel whereas the CFD method used produces a time-averaged approximation of these phenomena. However, the CFD results do demonstrate that the key areas throughout, and surrounding, the development have been captured by the wind tunnel model.

The different areas of the proposed development are discussed in more detail below:

- **Open area between buildings A, D and C:** Wind conditions are suitable for comfortably sitting or standing for short periods, which corresponds with reasonable conditions for major pedestrian streets, parks, and public places. Conditions can therefore be considered to satisfy the DCP criteria.
- **East-west pedestrian link:** Wind conditions are higher than those recommended for outdoor dining, which corresponds to the DCP criteria for retail streets and is understood to match the intended use for this area. Design refinements will be required to provide mitigation against these unfavourable conditions (refer to section 5.4 for mitigation strategies).
- **North-south pedestrian link:** Wind conditions are considered appropriate for short periods of sitting or standing, i.e. suitable for 'major pedestrian streets'.
- **Retail frontages (facing East from buildings A and D):** Wind conditions are higher than the those required for retail streets or frontages and will require some mitigation measures (refer to section 5.4 for mitigation strategies).
- **Other non-retail frontages:** Wind conditions along the George Street and Macquarie Street pedestrian footpaths are comfortable for short periods of sitting or standing or suitable for 'major pedestrian streets'.
- **Macquarie Lane:** Conditions are acceptable and can be considered comfortable for walking.

Refinements at a further design stage will be required to satisfy the Parramatta DCP required wind conditions throughout the east-west pedestrian link and retail frontages along the eastern side of buildings A and D.

## 5.4 Mitigation measures

Based on the wind tunnel results there are two areas that will require mitigation to meet the required wind criteria for the intended use and ensure compliance with the DCP criteria. These areas are in the east-west pedestrian link and at the retail frontages facing east from buildings A and D where a standing criterion is met instead of the intended sitting criterion. Potential mitigation strategies include the introduction of:

- fixed or retractable canopies or awnings to protect patrons
- roughing elements (e.g., banners, etc.) as a means of diffusing the energy contained in the wind
- architectural screening in critical positions. Such as:
  - balustrading along the top of the podiums alongside the east-west pedestrian link to funnel along the side of the buildings and away from the pedestrian link.
  - landscape screening in critical positions. Such as an evergreen tree canopy can provide a wind break to the exposed facades. These trees will need to be mature and evergreen (i.e., have leaves all year round) to be an effective mitigation strategy.

# 6 Conclusion

A CFD assessment and wind tunnel study was conducted to provide assessment of wind speeds throughout the proposed development and recommendations of any necessary mitigation measures.

Wind speeds across the entire proposed site and surrounding streets, up to a radius of 375 m, were simulated using CFD to provide an initial understanding of the wind environment and to inform the Irwin sensor locations of for the wind tunnel study to ensure key areas are considered.

Wind speeds have been assessed against the industry-standard Lawson comfort criteria and criteria outlined in the 2011 City of Parramatta Council DCP. The development, surrounding terrain, local built environment and approach flow were modelled at the necessary accuracy to satisfy the AWES-QAM-1-2019. Atmospheric wind was simulated according to AS/NZS 1170.2:2011 profiles and the local wind environment modelled via statistical analysis of Bureau of Meteorology historical weather data.

The results of the assessment indicate that wind speeds are generally compliant with the intended usage of each area of the proposed development, when assessed against the Lawson Criteria. However, there are some areas that will require further mitigation to ensure that the wind conditions are suitable for their intended use. These areas of concern are in the east-west pedestrian link and along the retail frontages that face east from buildings A and D. These areas may be intended to have outdoor dining for cafés/restaurants and do not meet the DCP requirements for ‘retail streets’ or the Lawson sitting criteria.

Potential mitigation strategies include introducing canopies or retractable awnings, architectural or landscape screening in critical positions, or roughening elements to assist in diffusing the amount of energy contained in the wind. Future Detailed SSDAs will include updated wind modelling and mitigation measures for the final building design.

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# Appendix A Statistical analysis of meteorological data

## A.1 Scaling methods

Modelling of local wind effects requires accurate representation of the surrounding terrain and built environment. The influence of terrain and built environment over the development length is incorporated into AS/NZS 1170.2:2021 as different terrain categories. Based on the terrain category, a suitable model of the atmospheric boundary layer (change in velocity and turbulence intensity with height) is given, which accounts for nearby structures and terrain (roughness). This model uses a logarithmic law to describe the mean wind speed profile in terms of roughness length.

Wind data from Bankstown was corrected to open terrain (category 2) using methods outlined in Holmes, 2021. To scale to the terrain roughness surrounding the site (category 3), scaling was applied using mean wind speed terrain/height multipliers from AS/NZS 1170.2:1989; i.e., multiplying by 0.44/0.6 = 0.733.

## A.2 Weibull analysis

To accurately account for the relative contributions of wind events from different directions, comfort exceedance probabilities were defined using a Weibull distribution. The probability of the wind speed at a certain location, $U_i$, exceeding a speed, $V$, for any given direction, $\theta$, is given by:

$$p(U_i > V, \theta) = A(\theta)e^{\left[-\left(\frac{V}{C(\theta)}\right)^{k(\theta)}\right]}$$

Here $k(\theta)$ and $C(\theta)$ are Weibull coefficients for the azimuth sector, $\theta$, and $A(\theta)$ is the marginal probability of the wind direction being within the azimuth sector. Therefore, the sum of all the marginal probabilities will be equal to one and the following will hold true:

$$\sum_{all\ sectors} A(\theta) = 1$$

Consequently, the exceedance probability is given by:

$$p(U_i > V) = \sum_{all\ sectors} A(\theta)e^{\left[-\left(\frac{V}{C(\theta)}\right)^{k(\theta)}\right]}$$

The coefficients obtained from the Bankstown Airport BoM data are shown below in Table A-1.

**Table A-1 Weibull coefficients for all 16 assessment directions**

| Direction | A | C | k |
|---|---|---|---|
| N | 0.04 | 2.64 | 1.95 |
| NNE | 0.02 | 2.32 | 2.47 |
| NE | 0.04 | 3.07 | 2.45 |
| ENE | 0.05 | 3.97 | 2.72 |
| E | 0.03 | 3.54 | 2.48 |
| ESE | 0.05 | 4.42 | 2.61 |
| SE | 0.06 | 4.93 | 2.51 |
| SSE | 0.06 | 4.91 | 2.29 |
| S | 0.05 | 3.88 | 1.96 |
| SSW | 0.04 | 2.74 | 1.76 |
| SW | 0.06 | 2.69 | 1.98 |
| WSW | 0.06 | 3.11 | 1.72 |
| W | 0.05 | 3.19 | 1.63 |
| WNW | 0.06 | 2.94 | 1.56 |
| NW | 0.06 | 2.5 | 1.77 |
| NNW | 0.06 | 2.47 | 1.85 |

# Appendix B Computational fluid dynamics model – detailed methodology

## B.1 Numerical methods

The analysis uses a Computational Fluid Dynamics (CFD) model which predicts fluid flows by mathematically modelling the Reynolds Averaged Navier-Stokes equations; fundamental equations which describe fluid motion. CFD simplifies estimates of turbulence, models average flow conditions well and random flow conditions with less accuracy. The turbulence closure scheme used for the modelling in this report was the realisable k-ε model. This model has been extensively validated for urban flows and has been shown to have superior performance for highly separated flows when compared with the standard k-ε model. OpenFOAM software was used; its reliability well-validated by academic researchers and independent organisations.

## B.2 Computational domain and meshing

A cylindrical computational domain was used for the analysis. The domain size was selected to allow 5*h* upstream, laterally and above the extents of significant geometry, where *h* is the height of the tallest building, following COST recommendations (Franke et al. 2004). An outflow length of 7h was used and mesh refinements were made down to a minimum 0.5 m edge length.

## B.3 Approach flow and boundary conditions

Accurate CFD simulations require appropriate modelling of conditions at the model boundaries. Of particular importance are the inlet velocity and turbulence conditions, which were modelled using the AS/NZS 1170.2:1989 boundary layer profiles for Terrain Category 3. The ground plane roughness was modelled to ensure the boundary layer profile remained constant (neutrally stable) throughout the approach and far-field.

Additional boundary definitions were:

- the top boundary having a shear stress and vertical gradient in epsilon following the recommendations of Richards and Hoxey
- outflow boundary with zero gradient in pressure
- side boundaries based on a mixed inlet/outlet condition
- bottom (ground) boundary as a no-slip wall with wall roughness function applied
- building surfaces as no-slip walls.

Wall functions were used to model the viscous sublayer flows near no-slip walls to accurately model wall friction effects. Changes in wind speed with direction were accounted for in post-processing calculations using Weibull distribution parameters (refer Appendix A.2).

# Appendix C Wind tunnel calibration

## C.1 Scaling laws

The fundamental concept is that the model of the structure and that the wind should be at approximately the same scale.

- geometric Scale: The geometric scale was at 1:300, and affects the ratio of roughness length and integral scales of longitudinal turbulence:

$$L = \frac{(z_o)m}{(z_o)p} = \frac{(L_u)m}{(L_u)p} = 1{:}\,300$$

- Velocity Scale: The wind tunnel reference mean velocity was chosen as about 10 m/s to maximise the sensitivity of the measurement instrumentation. The velocity sale for the simulation was (with a design mean speed of about 30 m/s):

$$V = \frac{\left(V_{ref}\right)m}{\left(V_{ref}\right)p} = \frac{1}{3}$$

In addition, the following scales are necessary to determine wind tunnel instrumentation sampling and frequency response characteristics:

- time Scale: $T = \frac{L}{V} = \frac{t_m}{t_p} = 1{:}\,100$
- frequency Scale: $F = \frac{1}{T} = \frac{f_m}{f_p} = 100{:}\,1$

A sampling rate of 1000 Hz was used for the following reasons (consistent with the Australasian Wind Engineering Society Quality Assurance Manual):

- The rate corresponds to about 10 Hz in full-scale, which will allow pressure fluctuations with frequencies up to about 3.33 Hz (full-scale) to be determined without distortion or attenuation.

A sampling duration of 36 seconds was used as it ensures measured maximum and minimum wind speeds provide representative estimates of peaks encountered during a full-scale interval of about one hour, and a statistically stable estimate of the mean and RMS wind speeds.

## C.2 Wind tunnel calibration

The wind tunnel approach flow was calibrated to match the AS 1170.2:2011 terrain category 3 approach flow, within a margin of 10% as per the Australasian Wind Engineering Society Quality Assurance Manual. The approach flow was normalised against a height of 143.5 m (top of the tallest tower). The normalised approach flow and turbulence intensity are shown in Figure C-1 and Figure C-2, respectively. However, the wind tunnel results are referenced to a pitot-static tube at 300 m (full-scale) and therefore a dynamic pressure correlation ratio of 0.798 was taken to account for the difference in the normalised height of the approach flow and reference height.

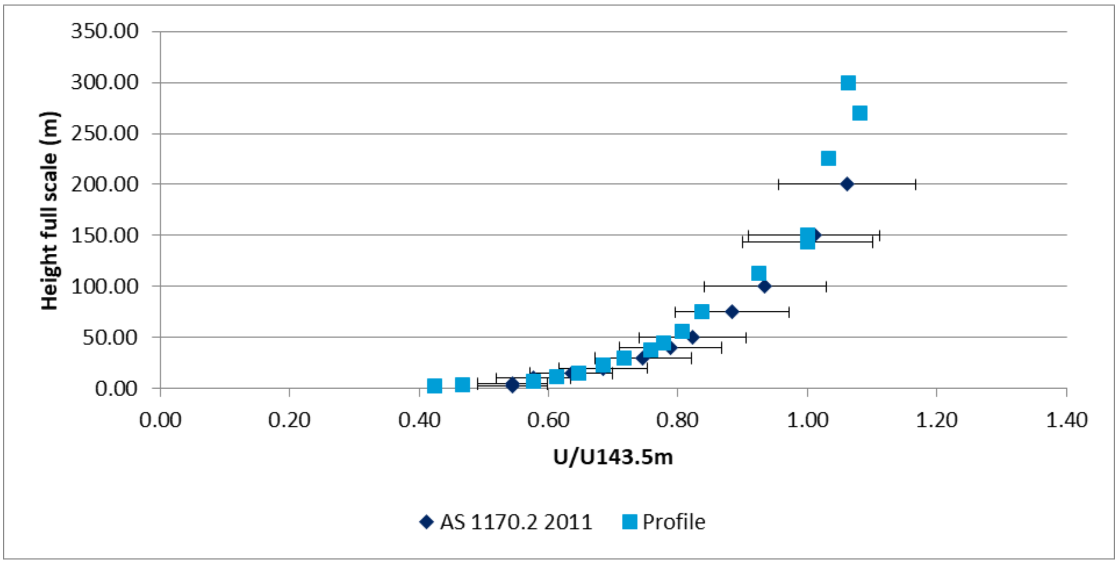


**Figure C-1 Mean velocity profile comparison with AS1170.2:2011**

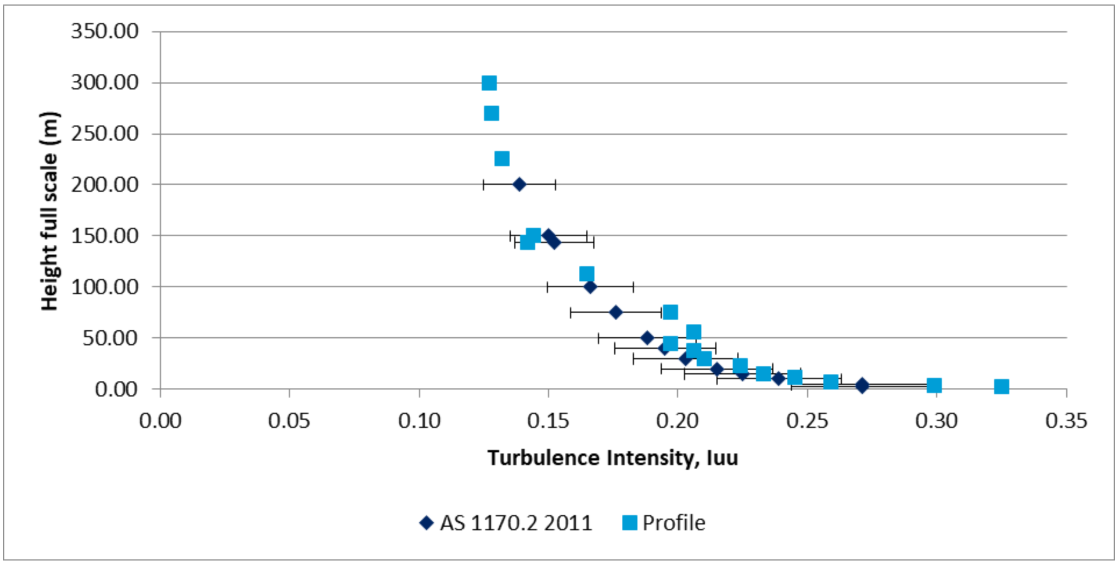


**Figure C-2 turbulence intensity profile comparison with AS1170.2:2011**

## C.3 Sensor calibration

Irwin sensors were used at various locations to determine the ground level wind speeds. These sensors were calibrated prior to their use in accordance with Irwin's 1980 paper, "A Simple Omnidirectional Sensor for Wind Tunnel Studies of Pedestrian Level Winds". The below equation describes the relationship between the measured pressure difference between the two parts of the sensor and the Reynolds number ($Re$) at the desired height (1.5 m). The velocity can then be calculated from the Reynolds number.

$$Re_{height} = A + B * \left(\frac{\Delta p h^2}{\rho v^2}\right)^C$$

where:

- $\boldsymbol{A}$ is a constant, taken as 85
- $\boldsymbol{B}$ is a constant, taken as 1.74
- $\boldsymbol{C}$ is a constant, taken as 0.5
- $\boldsymbol{\Delta p}$ is the difference in static pressures at the two measurement locations on each sensor
- $\boldsymbol{h}$ is the height of the probe, 1.8 mm
- $\boldsymbol{\rho}$ is the density of air, taken as 1.2 kg/m$^3$
- $\boldsymbol{v}$ is the kinematic viscosity, taken as 1.57x10$^{-5}$ m$^2$/s

The constants of the curve were found by fitting a power curve to the mean of the individual probe curves which were within 2% (in terms of static pressure) of each other. Probes that were outside this range but within 5% of the mean were kept and probes with responses outside 5% were not used.