Attachment A10

Pedestrian Wind Impact Assessment

Sydney Metro West:

Planning Proposal for Hunter Street Over Station Development Pedestrian Wind Assessment

Document Number: SMWSTEDS-SMD-SCB-SN100-EN-RPT-044007

Revision	Date	Suitability Code	Teambinder Document Number	Tb Revision
E	25/03/2022	S4	SMWSTEDS-SMD-SCB-SN100-EN-RPT-044007	E

Approval Record

Function	Position	Name	Date
Author	Sciences Engineer	Benjamin Bleckly	04/04/2022
Technical Checker	Technical Director – Built Environment	Seifu Bekele	04/04/2022
Technical Reviewer	Technical Director	Neil Mackenzie	04/04/2022
Coordinator	Technical Director – Environmental	Lucy Baker	04/04/2022
Approver	SM EDS Lead	Adrian Garnero	04/04/2022

Amendment Record

Date	Revision	Amendment Description	Author
03/12/2021	A	Initial issue	Benjamin Bleckly
17/12/2021	B	Second issue	Benjamin Bleckly
12/01/2022	C	Updated with base case comparison	Benjamin Bleckly
20/01/2022	D	Final issue	Benjamin Bleckly
29/03/2022	E	Final for submission	Benjamin Bleckly

Contents

Glossary

Term	Definition
2D	Two-dimensional
3D	Three-dimensional
AS	Australian Standard
ASD	Adjacent site development
AWES	Australasian Wind Engineering Society
BIM	Building information model
BOM	Bureau of Meteorology
CAD	Computer-aided design
CBD	Central business district
CSSI	Critical state significant infrastructure
DCP	Development control plan
DPE	Department of Planning and Environment
EIS	Environmental impact statement
EP&A Act	Environmental Planning and Assessment Act 1979
ISD	Integrated station development
NZS	New Zealand Standard
OSD	Over station development
QAM	Quality Assurance Manual
RL	Relative level
SEARs	Secretary's Environmental Assessment Requirements
SSD	State significant development

Executive summary

This pedestrian wind study report has been prepared to support the Planning Proposal Request for the Hunter Street over station developments. This report details the assessment of potential wind impacts on pedestrians throughout the proposed mixed-use developments above the Hunter Street station entrances.

Wind comfort and safety was assessed using a physical wind tunnel model and was tested at Monash University. The methods used were compliant with relevant Australian Standards, the Australasian Wind Engineering Society Quality Insurance Manual and industry best-practice guidelines. Atmospheric wind was simulated according to AS/NZS 1170.2:2021 profiles and the local wind environment modelled via statistical analysis of Bureau of Meteorology historical weather data.

The wind tunnel results were assessed against the Sydney Development Control Plan to ensure compliance with local requirements. A comparison of the base case to the proposed development was undertaken which showed that on average, the proposed development performed better than the base case. The average wind speed across the site and surrounds for the base case was 3.5 m/s whereas the proposed development had an average wind speed of 3.4 m/s. The results of the assessment also indicate that wind speeds are compliant with the intended usage of each area around the proposed development. There are some areas where the wind speed is increased, when compared to the baseline investigations and base case, due to the proposed development, but wind speeds are still acceptable for the intended use. In addition, all measured locations are below the 24 m/s wind speed safety criteria and can be deemed safe for all users.

1 Introduction

The Sydney Metro West Hunter Street Station Over Station Development (OSD) planning proposal seeks to amend the *Sydney Local Environmental Plan (2012)*. This pedestrian wind assessment report forms part of the planning proposal submitted for the Sydney Metro Hunter Street Station OSD.

1.1 Objectives and intended outcomes

1.1.1 Planning proposal

The Planning Proposal Request has been prepared to address the following objectives for future development on the Eastern and Western sites:

- Be a catalyst for positive change by regenerating and invigorating the city with new development that engages with the precinct, raises the urban quality and enhances the overall experience of the city.
- Facilitate future development that promotes design excellence and is consistent with the objectives of the Central Sydney Planning Framework.
- Deliver high quality employment generating floorspace that aligns with the objectives for development within the tower cluster areas identified within the Central Sydney Planning Framework.
- Contribute towards the establishment of an integrated transport hub within the Sydney CBD which strengthens Sydney's rail network improving connectivity.
- Delivers employment density alongside the delivery of significant new public transport infrastructure servicing the site and surrounding precinct.

The intended outcomes of the requested amendments include:

- To amend the maximum building height and maximum floor space ratio (FSR) permitted for both the east and west sites under the Sydney Local Environmental Plan 2012 (Sydney LEP 2012) and allow an alternative approach to design excellence to deliver integrated station development that optimises the development potential of both sites
- To facilitate new development that demonstrates an appropriate distribution of built form and floor space as part of the delivery of the integrated station development

1.1.2 Purpose of report

The pedestrian wind assessment considers the potential wind impacts from, and on, the planning proposal envelope. This wind assessment has been prepared 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 existing built form, using wind tunnel results

- Establishing wind conditions at the proposed site, for the base case (based on the DCP requirements) built form (3D model provided by FJMT), using wind tunnel results
- Establishing wind conditions at the proposed site, for the proposed built form (planning proposal 3D model provided by FJMT), using 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 the Sydney Development Control Plan criteria to determine if the future site wind conditions are suitable for the expected activity around the development
- Identifying any mitigation measures required to address or manage potential wind speed impacts

1.2 Planning process

1.2.1 State Significant Infrastructure

Sydney Metro West was declared as State Significant Infrastructure (SSI) and Critical State Significant Infrastructure (CSSI) under sections 5.12(4) and 5.13 of the *Environmental Planning and Assessment Act 1979* (EP&A Act) respectively on 23 September 2020.

Sydney Metro West is being assessed as a staged infrastructure application under Section 5.20 of the *Environment Planning & Assessment Act 1979*. The approved Concept and major civil construction work for Sydney Metro West between Westmead and The Bays (Stage 1 of the planning approval process application number SSI-10038) were approved on 11 March 2021.

Stage 2 of the planning approval process (application number SSI-19238057) includes all major civil construction work, including station excavation and tunnelling, between The Bays and Sydney CBD (an Environmental Impact Statement for this application was exhibited between 3 November and 15 December 2021).

Stage 3 of the planning approval process (application number SSI-22765520), being the application for the tunnel fit-out, construction of stations, ancillary facilities and station precincts, and operation and maintenance of the Sydney Metro West line. This application seeks approval for the construction of the Hunter Street Station, including above and below ground structures, public domain works, and spatial provisioning and works to facilitate the construction and operation of an OSD above the two station entries which are described further in this report.

1.2.2 Over Station Development

The OSD components of the Hunter Street integrated station development are not declared as SSI or CSSI under *State Environmental Planning Policy (State and Regional Development) 2011* (SRD SEPP). As such, separate development consent is required to be granted for the construction and operation of development above the Hunter Street Station.

The primary land use of the OSD sites is anticipated to be ‘commercial premises’ which has a capital investment value of more than $30 million, and which are located within a rail corridor and/or are associated with railway infrastructure. Consequently, the future

OSD will be classified as State Significant Development. The Sydney LEP 2012 is a relevant environmental planning instrument for the future development, though the Sydney Development Control Plan 2012 (Sydney DCP 2012) will not apply to the OSD sites.

To inform the planning controls relevant for the Hunter Street OSD sites, amendments are proposed to the Sydney LEP 2012 to provide additional Maximum Height of Building and floor space ratio (FSR) controls. Further, as the Sydney DCP 2012 does not apply to the land, the Proponent will prepare a design and amenity guideline to support the planning proposal to inform the future built form on the site including details such as street frontage heights, setbacks, massing and tapering, development adjacent to heritage items, building exteriors, and managing wind impact.

The inter-relationship of the scope of Sydney Metro EIS 3 (part of Critical State Significant Infrastructure CSSI) and this planning proposal is illustrated in Figure 1-1.

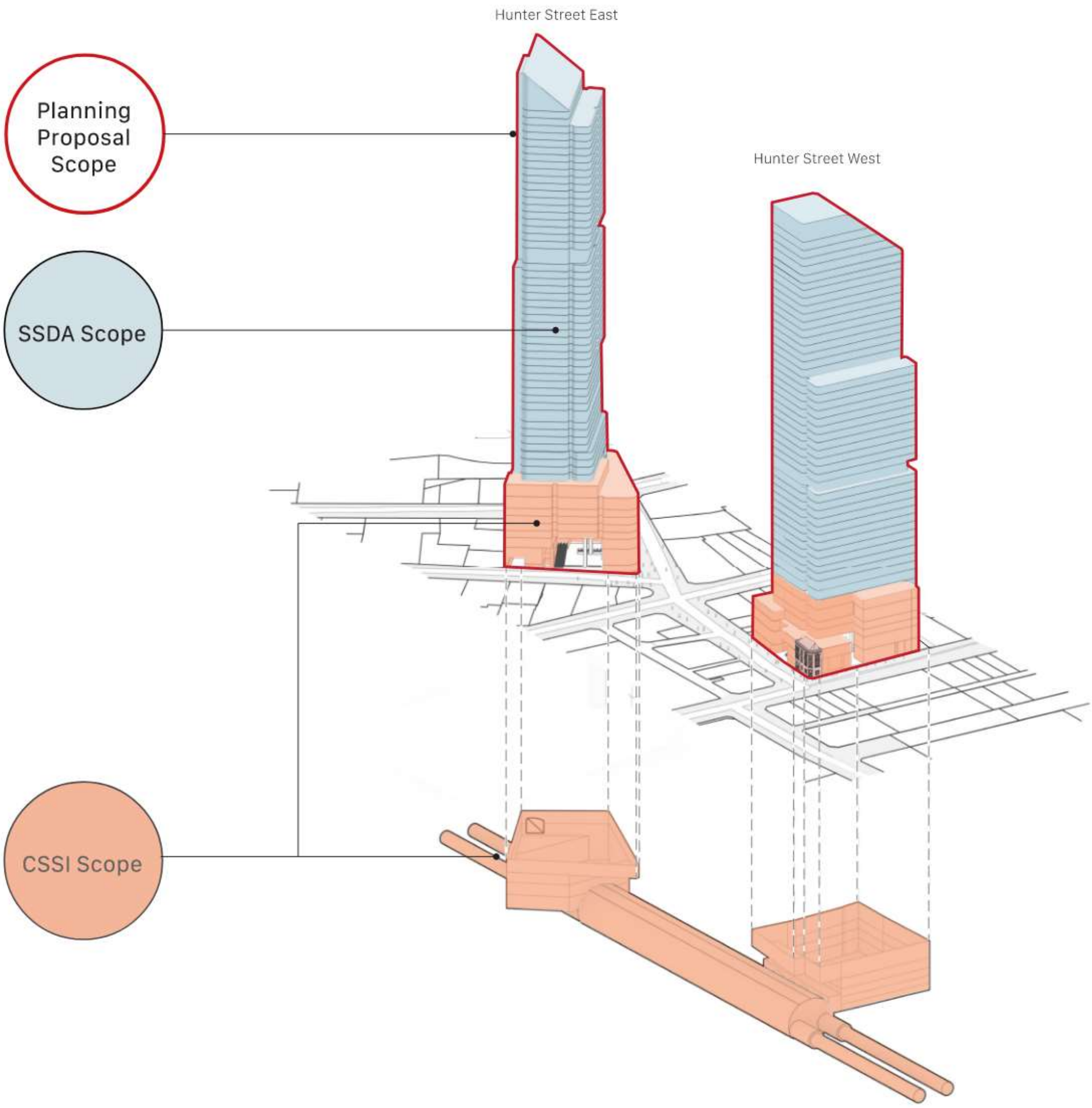

Figure 1-1: Hunter Street Station and Proposed OSD

1.2.3 Planning proposal

The planning proposal seeks to amend the *Sydney Local Environmental Plan 2012* to enable development on the site(s) as follows:

- Establish a maximum Height of Buildings control and maximum FSR control on the identified land, being the Hunter Street Station East and West sites.
- Enable the development of a commercial office building on the Hunter Street Station East and West sites
- Integration with the Hunter Street Station, the subject of a separate application process
- Adaptive reuse of the existing Former Skinners Family Hotel within the overall development on the West site
- Include site-specific controls which ensure the provision of employment and other non-residential land uses only on both the Hunter Street Station East and West sites.
- Include site-specific control allowing the provision of up to a maximum of 70 car parking spaces maximum total across both the Hunter Street Station East and West sites.
- Include a site-specific design guideline within the site-specific controls to guide future development sought under a State Significant Development Application process.
- Establish an alternative design excellence process for the Hunter Street Station East and West sites that responds to the integration of the development with the Sydney Metro West project and specifically the Hunter Street Station.

A summary of the key development outcomes resulting from the Planning Proposal is set out in Table 1-1 below.

Table 1-1: Proposed concept built form outcomes

Built form component	Proposed development outcome
East Site	**Based on a site area of 3,666 sqm**
Height	Building height of 257.7m (RL 269.10)
FSR	22.82:1
GFA	Up to 84,287 sqm of GFA
Land Use(s)	Non-residential land uses only
West Site	**Based on a site area of 3,735 sqm**
Height	Building height of 213.0m (RL 220.00), including a setback interface from the heritage-listed Skinner Family Hotel
FSR	18.71:1
GFA	Up to 69,912 sqm of GFA
Land Use(s)	Non-residential land uses only

Built form component	Proposed development outcome
Cl 7.6 – Carparking for Office and Business premises	• Up to 70 car parking spaces, maximum total across both the Eastern and Western sites

1.3 Site context

1.3.1 The Site

The Hunter Street (Sydney CBD) integrated station development is located in the northern part of the Sydney CBD, within the commercial core precinct of Central Sydney, within the Sydney Local Government Area.

The east site is located on the corner of O'Connell Street, Hunter Street and Bligh Street adjacent to the existing CBD and South East Light Rail that extends from Circular Quay to Moore Park, Kensington and Kingsford. The east site is adjacent to the new Martin Place Station which forms part of the Sydney Metro City and Southwest, Australia's biggest public transport project connecting Chatswood to Sydenham and extending to Bankstown.

The west site is located on the corner of George and Hunter Street, including De Mestre Place and land predominantly occupied by the existing Hunter Connection retail plaza.

Refer to Figure 1-3 below which illustrates the location of the Hunter Street Station (Sydney CBD) within its regional context.

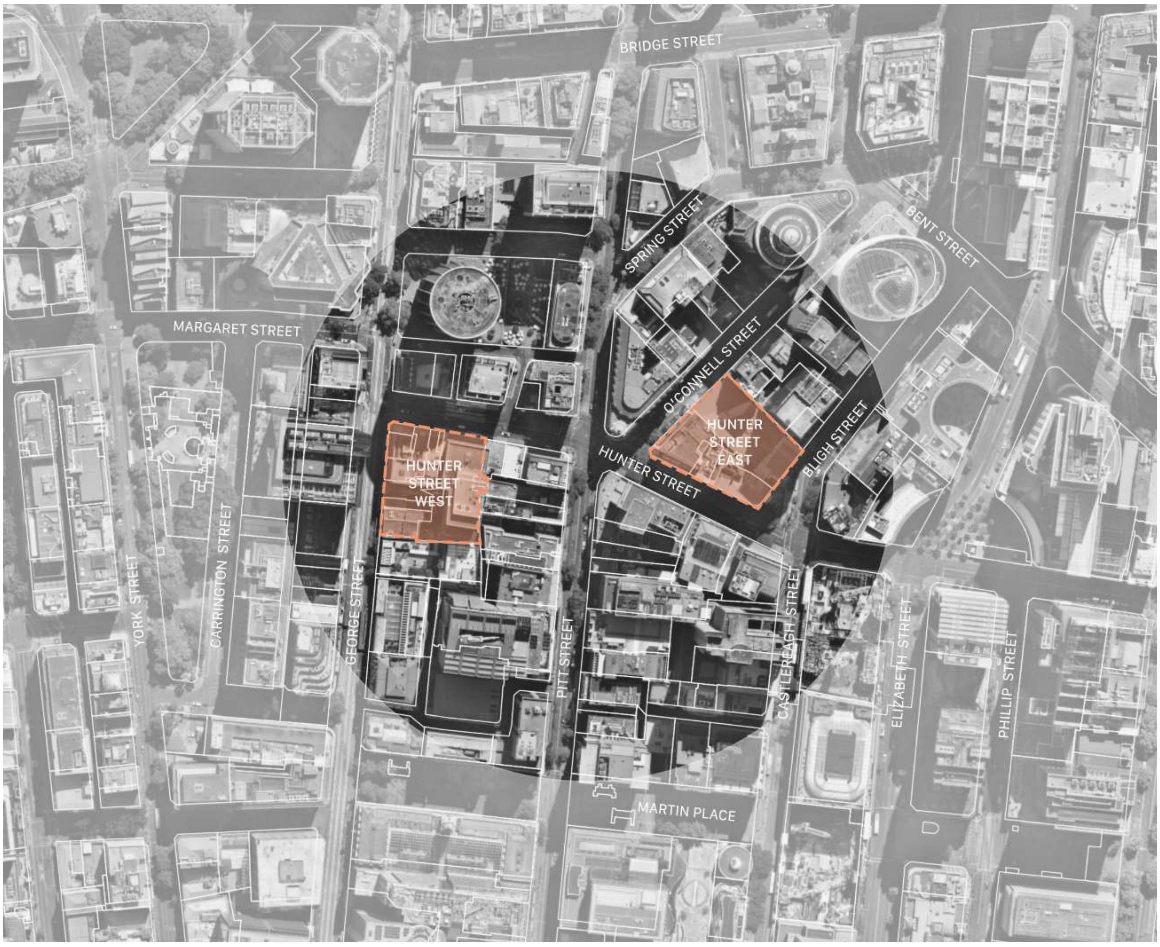

Figure 1-2: Location of the proposed Hunter Street Station OSD sites

1.3.2 Local context

The Sydney CBD is a highly developed commercial core with a ride range of commercial, retail, health, government and community-based uses, as well as high density residential developments.

A number of key commercial buildings are located in or around the Sydney CBD, including educational facilities, historic buildings and structures, law courts, public gathering spaces and places of worship. Significant areas of open space, such as the Botanical Gardens, the Domain and Hyde Park are also located within or near the Sydney CBD area, as well as the World Heritage Sydney Opera House and iconic Sydney Harbour Bridge.

Land uses surrounding the Hunter Street Station (Sydney CBD) sites include:

- North of the sites is a major commercial area comprising high density commercial towers along George Street, Pitt Street, and Bridge Street, including the MetCentre and Australia Square buildings. The area also comprises tourism and entertainment related uses including hotels, shops, restaurants, cafes, nightclubs and bars, with the area around Circular Quay and the Rocks a major tourism precinct and providing significant support for the night time economy.
- East of the sites are major commercial towers along Hunter Street, including Chifley Tower, 8 Chifley Square, Aurora Place and Deutsche Bank Place. Beyond Hunter Street, the State Library of NSW and the NSW Parliament

House front onto Macquarie Street, and beyond that lies the public open space of The Domain.

- South of the sites, the land use remains predominantly multi-storey commercial offices but also includes cafes, bars and nightclubs, including the Ivy complex. Martin Place is a significant east–west pedestrian thoroughfare which contains many culturally significant buildings and structures including the Cenotaph memorial and the General Post Office building, as well as Martin Place Station. Beyond Martin Place the Sydney CBD continues towards Town Hall, Haymarket and the Central Station precinct.
- West of the sites, the land use remains predominantly high-density commercial offices, anchored by Wynyard Station. George Street contains the Sydney Light Rail (L2 Randwick Line and L3 Kingsford Line) and is a major north–south axis through the CBD, and along with Pitt Street connects Circular Quay, Wynyard, Town Hall and Central. East of Wynyard, the CBD continues towards the major commercial and entertainment areas around King Street Wharf and Barangaroo, which also contain significant high density residential apartment buildings.

1.3.3 Site description

The Hunter Street (Sydney CBD) integrated station development relates to the following properties:

- 28 O'Connell Street, 48 Hunter Street, and 37 Bligh Street, Sydney (East Site); and
- 296 George Street, 300 George Street, 312 George Street, 314-318 George Street, 5010 De Mestre Place (Over Pass), 5 Hunter Street, 7-13 Hunter Street, 9 Hunter Street and De Mestre Place, Sydney (West Site).

Table 1-1 and Table 1-2 below set out the address, legal description and area of the parcels of land that comprise the Hunter Street Station (Sydney CBD) land that is the subject of this Planning Proposal.

Table 1-2: Legal description of Hunter Street Station (Sydney CBD) East Site

Address	Lot and DP
28 O'Connell Street, Sydney	Lot 1, DP217112
28 O'Connell Street, Sydney	Lot 1, DP536538
28 O'Connell Street, Sydney	Lot 1, DP1107981
48 Hunter Street, Sydney	Lot 1, DP59871
48 Hunter Street, Sydney	Lot 2, DP217112
33 Bligh Street, Sydney	Lot 1, DP626651
37 Bligh Street, Sydney	CP and Lots 1-14, 21-31, 33-36, and 40, SP58859
37 Bligh Street, Sydney	CP and Lots 41-49, SP61852

Address	Lot and DP
37 Bligh Street, Sydney	CP and Lots 50-57, SP61922
37 Bligh Street, Sydney	CP and Lots 58-65, SP61923
37 Bligh Street, Sydney	CP and Lots 66 and 67, SP63146
37 Bligh Street, Sydney	CP and Lots 67-70, SP63147
37 Bligh Street, Sydney	CP and Lot 72, SP74004
37 Bligh Street, Sydney	CP and Lots 75-82, SP87437
37 Bligh Street, Sydney	CP and Lots 73-74, SP87628
	Total Area: 3,666 m^2

Table 1-3: Legal description of Hunter Street Station (Sydney CBD) West Site

Address	Lot and DP
296 George Street, Sydney	Lot 1, DP438188
300 George Street, Sydney	CP and Lots 1-43, SP596
312 George Street, Sydney	Lot 1, DP211120
314-318 George Street, Sydney	Lot 13, DP622968
5010 De Mestre Place, Sydney (Over Pass)	Lot 1, DP1003818
9 Hunter Street, Sydney	Lot 2, DP850895
5 Hunter Street, Sydney (Leda House & Hunter Arcade)	CP and Lots 1-63, SP71068
5 Hunter Street, Sydney (Leda House & Hunter Arcade)	CP and Lots 1-14, SP65054
7-13 Hunter Street, Sydney (Hunter Connection)	CP and Lots 1-53, SP50276
7-13 Hunter Street, Sydney (Hunter Connection)	Lots 57 and 58, SP61007
7-13 Hunter Street, Sydney (Hunter Connection)	Lots 54, 55 and 56, SP60441

Address	Lot and DP
7-13 Hunter Street, Sydney (Hunter Connection)	Lots 59, 60 and 61, SP62889
7-13 Hunter Street, Sydney (Hunter Connection)	Lots 62, 63, 64 and 65, SP69300
7-13 Hunter Street, Sydney (Hunter Connection)	Lots 66 and 67, SP77409
7-13 Hunter Street, Sydney (Hunter Connection)	Lot 2, SP50276
De Mestre Place, Sydney	N/A
	Total Area: 3,743 m^2

1.3.4 Existing development

The east site is currently partially occupied for the Sydney Metro City & Southwest construction site. The remainder of the site is currently occupied by commercial office buildings and a range of ground floor business premises including retail, restaurants and cafes.

The west site is occupied by commercial office buildings, restaurants, shops, as well as a range of business premises and employment and medical/health services premises. De Mestre Place provides access to the Hunter Connection from George Street, providing access to the loading dock for delivery trucks and service vehicles.

The west site includes the State heritage-listed ‘former Skinners Family Hotel including interiors’ at 296 George Street which will be retained as part of the development of the Hunter Street (Sydney CBD) integrated station development.

2 Methodology

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 and the criteria considered for the development.

2.1 City of Sydney Criteria

2.1.1 Managing wind impacts

The City of Sydney Development Control Plan (DCP) 2012 covers wind effects for the public realm (Section 5.1.9). The criteria are reproduced below:

Value Statement

The wind environment is a major determinant of amenity. Tall buildings can create or exacerbate windy conditions in built up areas and can have a significant effect on the wind environment at street level.

Buildings must be designed to mitigate unsafe and uncomfortable wind effects on Public Places and should create comfortable and pleasant conditions.

Generally the provision of a reasonable sized podium will mitigate the greatest adverse wind effects from tall buildings. Provision of a podium is particularly important at the exposed edges of Central Sydney where buildings are not shielded by their neighbours and on short east-west running streets where wind speeds are highest.

Objectives

- (a) To ensure streets and Public Places have wind conditions that are safe and comfortable for walking and to encourage conditions that are comfortable for sitting.
- (b) To ensure new developments mitigate adverse wind effects.
- (c) To ensure air quality does not exceed environmental/health standards
- (d) To provide wind climate data that can be applied consistently for assessing new developments.

Provisions

- (1) A quantitative wind effects report is to be submitted with a development application for development:
    - (a) Over 55m in height as measured from the lowest ground level to the highest structure; or
    - (b) With a frontage to an east-west street; or
    - (c) On a site within the B8 zone and within 50m of the zone boundary; or
    - (d) As required by the City of Sydney.
- (2) Development subject to a quantitative wind effects report must not:
    - (a) Cause a wind speed that exceeds the Wind Safety Standard, the Wind Comfort Standard for Walking and the Wind Comfort Standard of Sitting in Parks except where the existing wind speeds exceed the standard; and
    - (b) Worsen, by increasing spatial extent and or frequency and/or speed, an existing wind speed that exceeds the Wind Safety Standard, the Wind

Comfort Standard for Walking and the Wind Comfort Standard for Sitting in Parks.

(3) Development subject to a quantitative wind effects report must take all reasonable steps to create a comfortable wind environment is consistent with the Wind Comfort Standards for Sitting and Standing related to the use of the public place. For example, the Standing criteria should be achieved at bus stops or other places where people wait and the Sitting criteria should be achieved where outdoor dining is located.

(4) For the purposes of complying with Section 5.1.9 (2) and (3):

Wind Safety Standard is an annual maximum peak 0.5 second gust wind speed in one hour measured between 6am and 10pm Eastern Standard Time of 24 metres per second.

Wind Comfort Standard for Walking is an hourly mean wind speed, or gust equivalent mean wind speed, whichever is greater for each wind direction, for no more than 292 hours per annum measured between 6 am and 10 pm Eastern Standard Time (i.e. 5% of those hours) of 8 metres per second.

Wind Comfort Standard for Sitting in Parks is an hourly mean wind speed, or gust equivalent mean wind speed, whichever is greater for each wind direction, for no more than 292 hours per annum measured between 6 am and 10 pm Eastern Standard Time of 4 metres per second and applies to Public Places protected by Sun Access Planes and/or No Additional Overshadowing Controls.

Wind Comfort Standards for Sitting and Standing is hourly mean wind speed, or gust equivalent mean wind speed, whichever is greater for each wind direction, for no more than 292 hours per annum measured between 6 am and 10 pm Eastern Standard time of; 4 meters per second for sitting; and 6 meters per second for standing.

Note: Section 5.1.9 prevails over Section 3.2.6 in Central Sydney

Note: 292 hours is 5% of all hours between 6 am and 10 pm each day (16 hours per day) over a year (365 days).

Note: It is assumed that the Eastern Standard Time referred to in the Draft DCP is Australian Eastern Standard Time (+10 hours from the Coordinated Universal Time).

2.1.2 Equivalence method

As outlined by the City of Sydney, the pedestrian wind assessment must follow Procedure B (Schedule 12.2) to show an equivalent or improved wind comfort and wind safety environment. The relevant sections of Schedule 12.2 are reproduced below:

(4) Model Testing

The wind and daylight testing of the base case model and alternative building envelopes are to include measurements in public places for a distance of at least 50m and no more than 100m from the site boundary. The tests must exclude any elements within a Public Place (e.g. trees and awnings) and must satisfy the following requirements for wind and daylight (or sky view factor):

(a) Wind: wind speeds are defined by Section 5.1.9 Managing Wind Impacts, Sydney DCP 2012 for comfort and safety

Wind speeds must be measured within the existing city form and be distributed evenly across the surrounding public places and include testing locations in areas where wind speeds are likely to change as determined by a wind report.

(5) Equivalence reporting

All data that is relied on for equivalence testing must form part of the report including individual data points as tables and model geometries for the base case and alternative building envelopes. These must be described with sufficient dimensions to allow for the equivalent model to be created by a third party for checking.

(a) For wind: the 5% exceedance comfort wind speed values in metres per second must be averaged and compared. The comfort categories are not relevant in demonstrating equivalence.

Note that the proposed alternative building envelopes must both demonstrate equivalence and also not cause wind speeds that exceed comfort or safety standards or cause worsening of existing exceedances

Note: if the equivalence testing shows new or worsened exceedances of the comfort or safety standards, additional wind tunnel testing will be required to show how these exceedances can be mitigated. This testing may include modelling of awnings consistent with DCP requirements.

2.2 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.

2.2.1 Meteorological data

Historical weather data was used for the analysis and obtained from the Bureau of Meteorology (BOM) weather station at Sydney Airport, which is situated 8.5 km southwest 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.

From 2001 to 2020, 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 (a Weibull analysis for comfort and an extreme value analysis for safety) can also be found in Appendix A.

The scaled data is presented in the wind rose plot below, Figure 2-1. Here, the length and colour of the spoke sections represent the frequency and amplitude of recorded wind events, respectively.

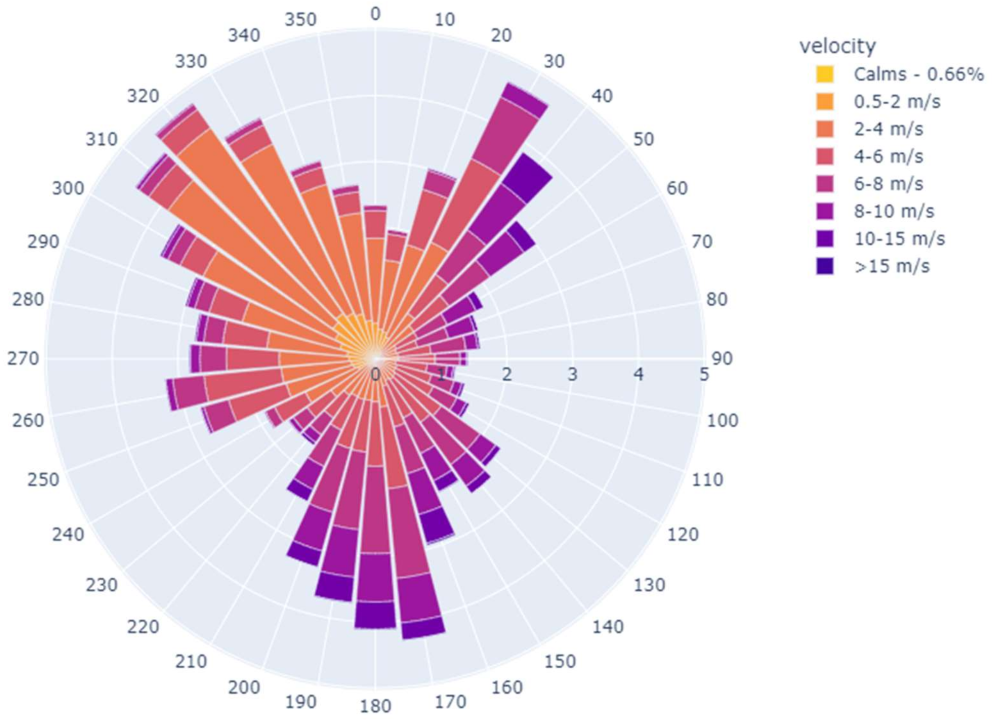

Figure 2-1 Wind rose plot of Sydney Airport BOM Data, 2001-2020

2.3 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.).

2.3.1 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.

2.3.2 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 (1:400 in this case) (refer to Appendix B for the relevant scaling laws). 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 is provided in Appendix B.

2.3.3 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 2-2 was carried out to acquire information on the footprint, form, and height of all buildings within a 470 m radius centre point between the two sites (minimum of 350 m distance between each site and the closest edge of the model). Figure 2-3 to Figure 2-6 show the wind tunnel model and surroundings.

Figure 2-2 Existing buildings in the Sydney CBD region with an overlay of the proposed sites (image sourced from document number SMWSTEDS-SMD-SN100-AT-RPT-044003)

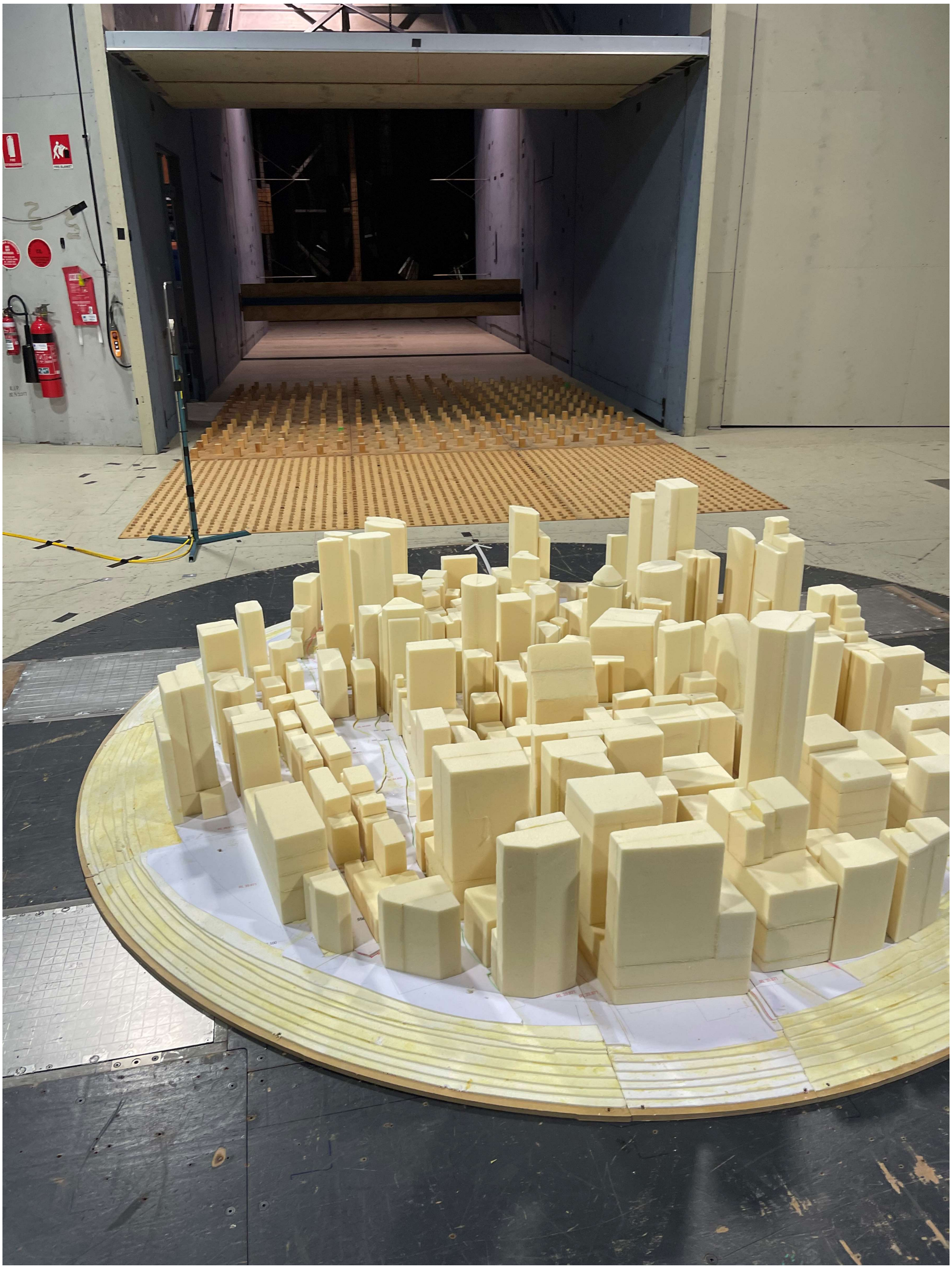

Figure 2-3 Wind tunnel model showing the approach region and overall modelled site for the baseline investigations

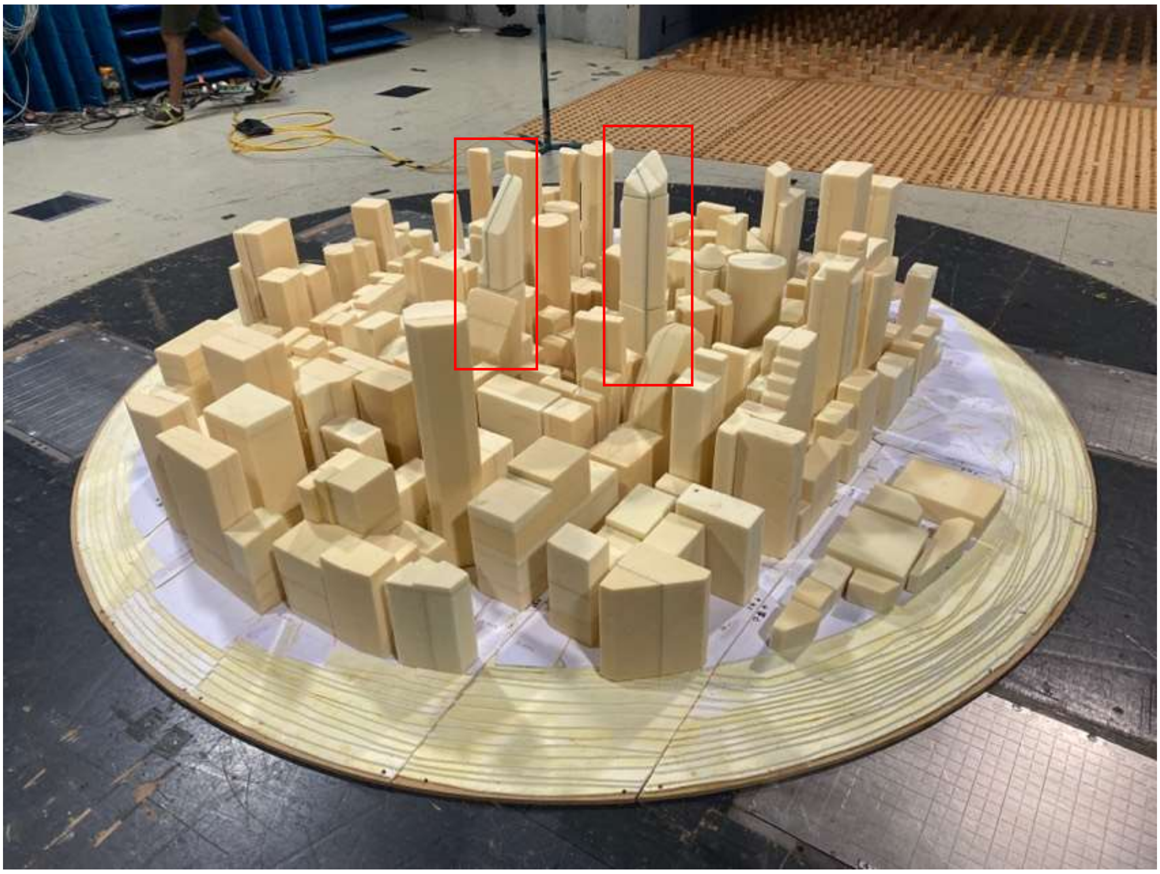

Figure 2-4 Wind tunnel model showing the overall modelled site for the base case envelopes (outlined by the red boxes) from an aerial perspective (viewed from the Southeast)

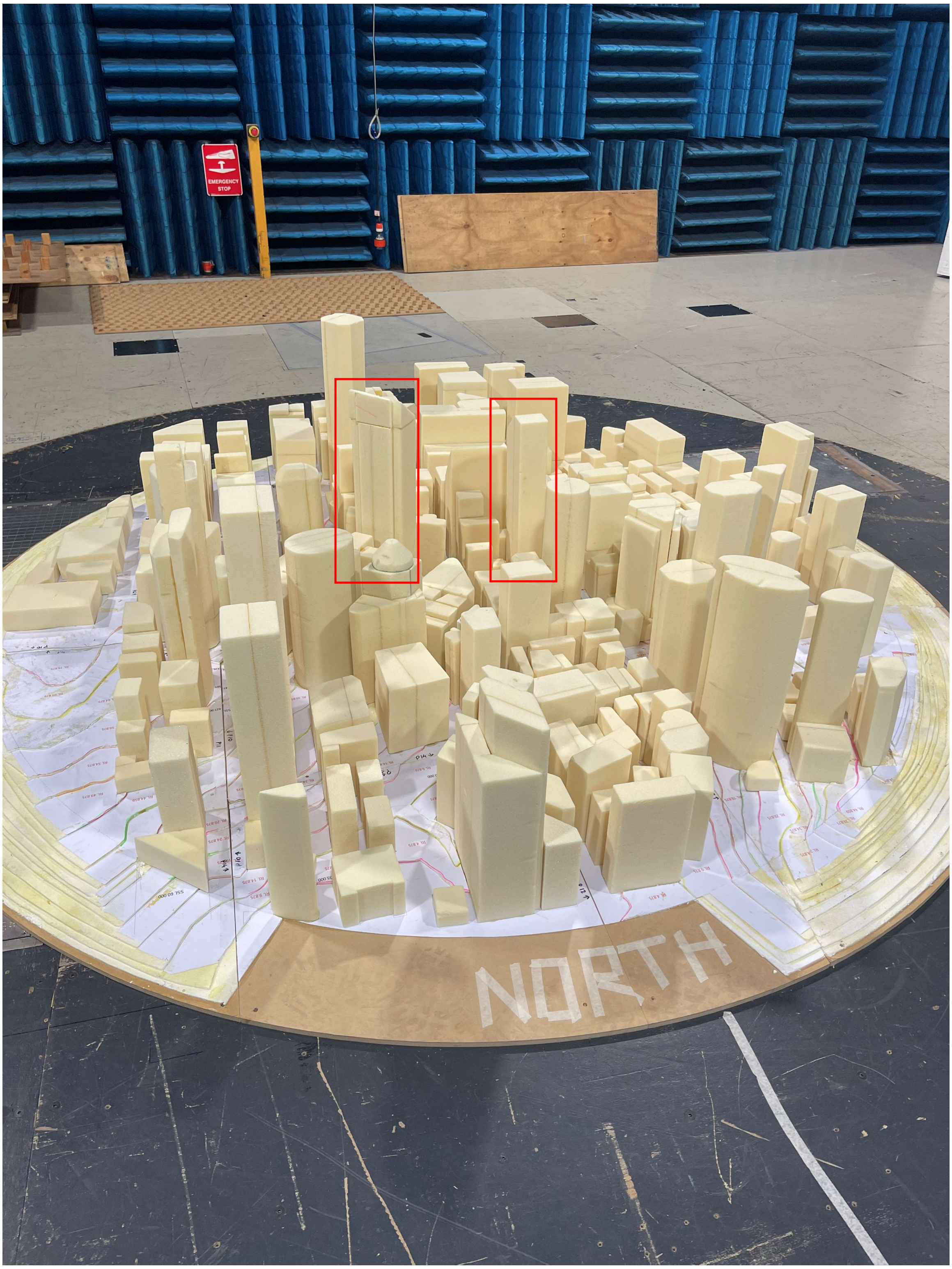

Figure 2-5 Wind tunnel model showing the overall modelled site for the proposed developments (outlined by the red boxes) from an aerial perspective (viewed from the North)

Figure 2-6 Wind tunnel model showing the overall modelled site

2.4 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 1.5 m (600 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:

1. Time series of ground-level wind speeds were calculated from the Irwin sensor data using the calibration equation (refer to Appendix B).
2. The maximum hourly 3-second gusts were calculated for each of these time series.
3. 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 B for the sensor calibration and conversion from a pressure difference to a velocity).
4. Velocity ratios were then scaled to the 10 m reference height of the Bureau of Meteorology anemometer using AS/NZS 1170.2 gust profiles.
5. 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.
6. 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.

2.5 Assessment locations

The wind tunnel test is split in to three stages:

- Baseline Investigations – assessing the existing buildings (pre-demolition) on the site to determine the existing wind climate
- Base Case – assessing the proposed building form based on the DCP requirements to determine the future wind climate
- Proposed Development – assessing the proposed development to determine the future wind climate

2.5.1 Baseline investigations

For this study, a total of 40 ground level assessment locations within and around the proposed development site have been selected for analysis in the wind tunnel. The locations of the various assessment locations are presented in Figure 2-7 in the form of a marked-up plan drawing.

Figure 2-7 Irwin probe assessment locations for the existing built environment (red outline shows the extent of the proposed development sites). Layout of the development sites and existing buildings is provided in the Space Planning report (document number: SMWSTEDS-SMD-SCB-SN100-AT-RPT-044003-B)

2.5.2 Base case

For this study, a total of 37 ground level assessment locations within and around the proposed development site have been selected for analysis in the wind tunnel. The sensor locations in the surrounding streets are identical to the baseline investigations and the three missing sensors relate to those that fall within the proposed site due to the change in the building footprints and ground level. The numbering of the sensor locations has been kept consistent with the numbering in the baseline investigations for ease of comparison. The locations of the various assessment locations are presented in Figure 2-8 in the form of a marked-up plan drawing.

Figure 2-8 Irwin probe assessment locations for the base case (layout was provided by FJMT) which shows the layout of the two developments and the surrounding environment

The proposed developments are modelled as shown in Figure 2-9 (East site) and Figure 2-10 (West site) and include no mitigative measures (e.g. no awnings, landscaping, etc.).

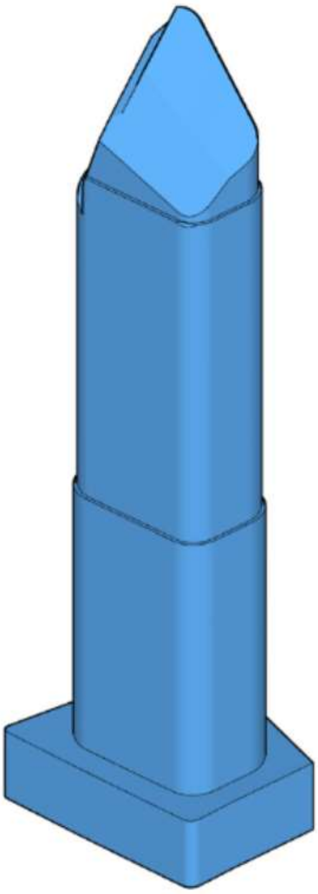

Figure 2-9 3D view of the Hunter Street Station Base Case East site provided by FJMT

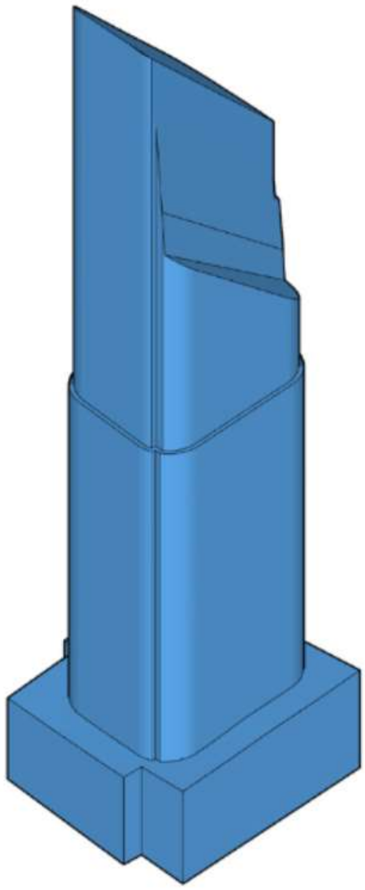

Figure 2-10 3D view of the Hunter Street Station Base Case West site provided by FJMT

2.5.3 Proposed development

For this study, a total of 40 ground level assessment locations within and around the proposed development site have been selected for analysis in the wind tunnel. The sensor locations in the surrounding streets are identical to the baseline investigations but those that fall within the proposed site are different due to the change in the building footprints at ground level. The locations of the various assessment locations are presented in Figure 2-11 in the form of a marked-up plan drawing.

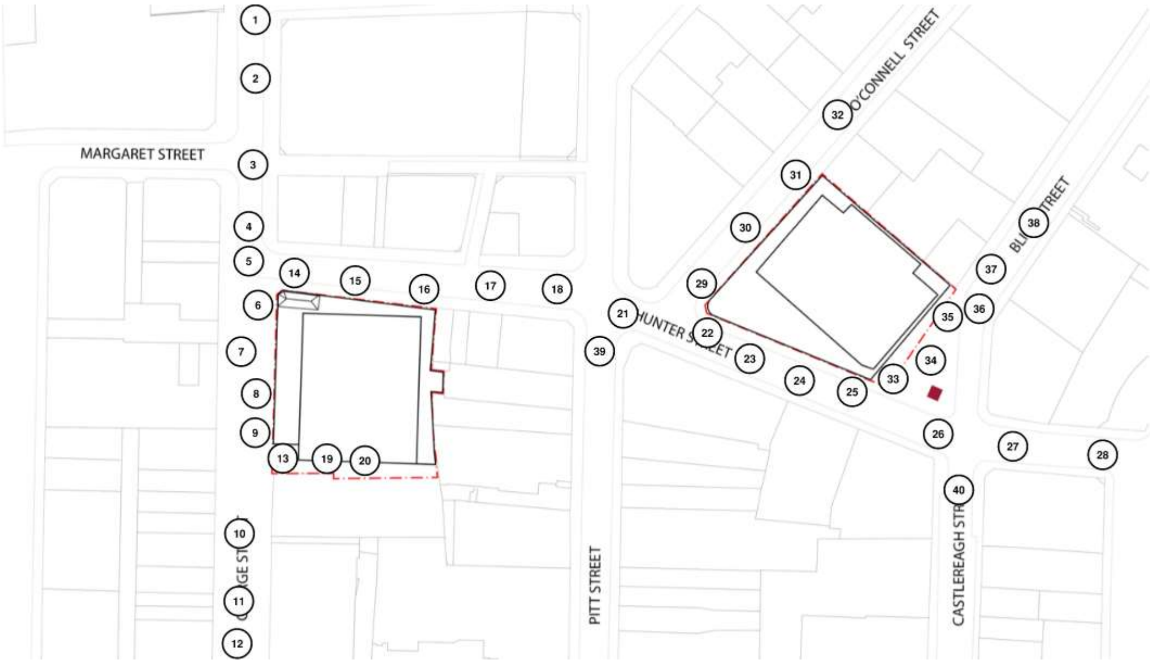

Figure 2-11 Irwin probe assessment locations for the proposed development (layout was provided by FJMT) which shows the layout of the two developments and the surrounding environment

The proposed developments are modelled as shown in Figure 2-12 (East site) and Figure 2-13 (West site) and include no mitigative measures (e.g. no awnings, landscaping, etc.).

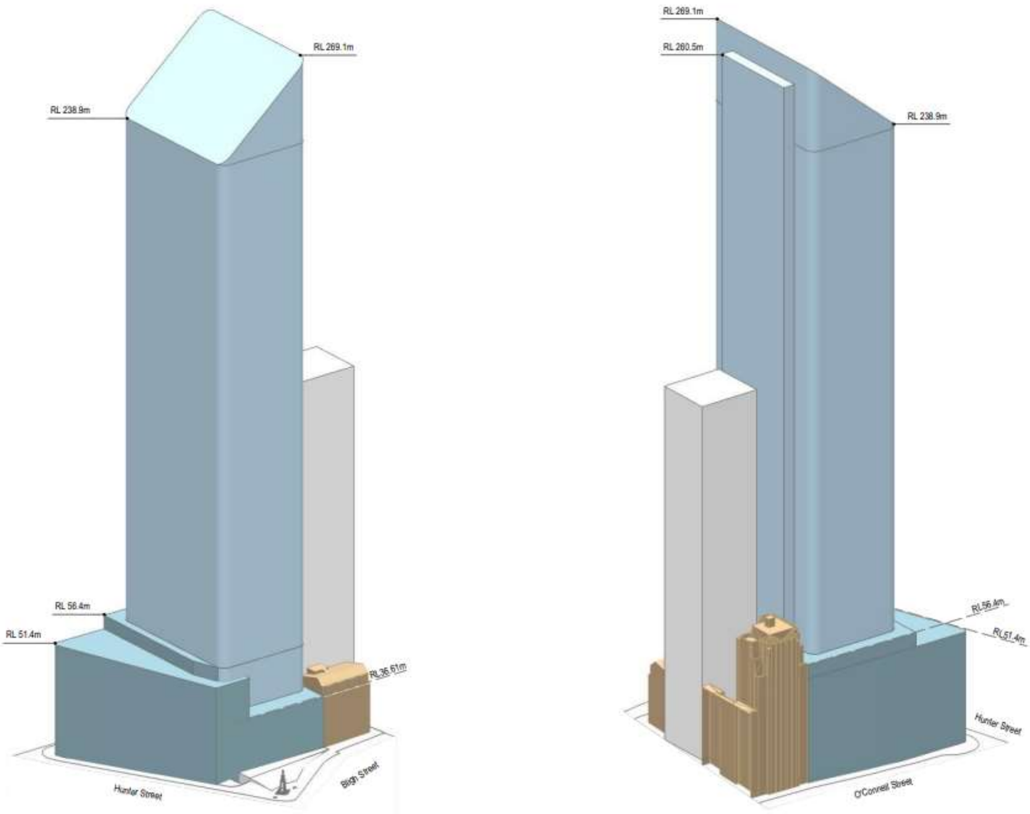

Figure 2-12 3D view of the proposed planning envelope Hunter Street East site provided by FJMT

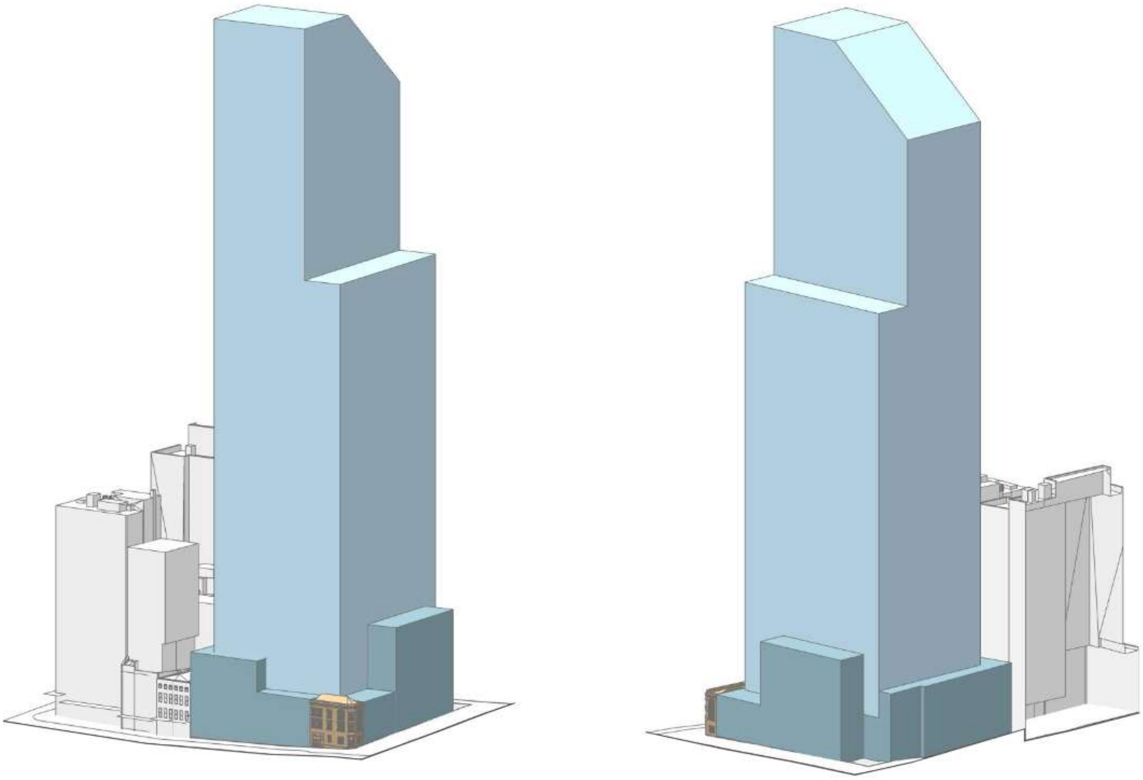

Figure 2-13 3D view of the proposed planning envelope Hunter Street West site provided by FJMT

3 Assessment

The wind tunnel results show wind speeds at 1.5 m above the ground plane at the discrete sensor locations outlined in Section 2.5. The wind tunnel test was undertaken to assess the baseline case (pre-demolition), base case (DCP requirements) and with the proposed development.

3.1 Baseline investigations

This assessment included 40 Irwin probes, located around the development site, and their results are shown against the Sydney DCP wind criteria in Figure 3-1 (comfort results) and Figure 3-2 (safety results). Results are also tabulated in Table 3-1 to show the wind speeds and the achieved criteria. Conditions are shown to be generally suitable for sitting in parks and can considered safe at all locations, with no adverse conditions that need to be ameliorated (provision three of the Sydney DCP). Note: sensors 10, 23 and 33 are excluded from the below analysis due to issues caused by the data acquisition system.

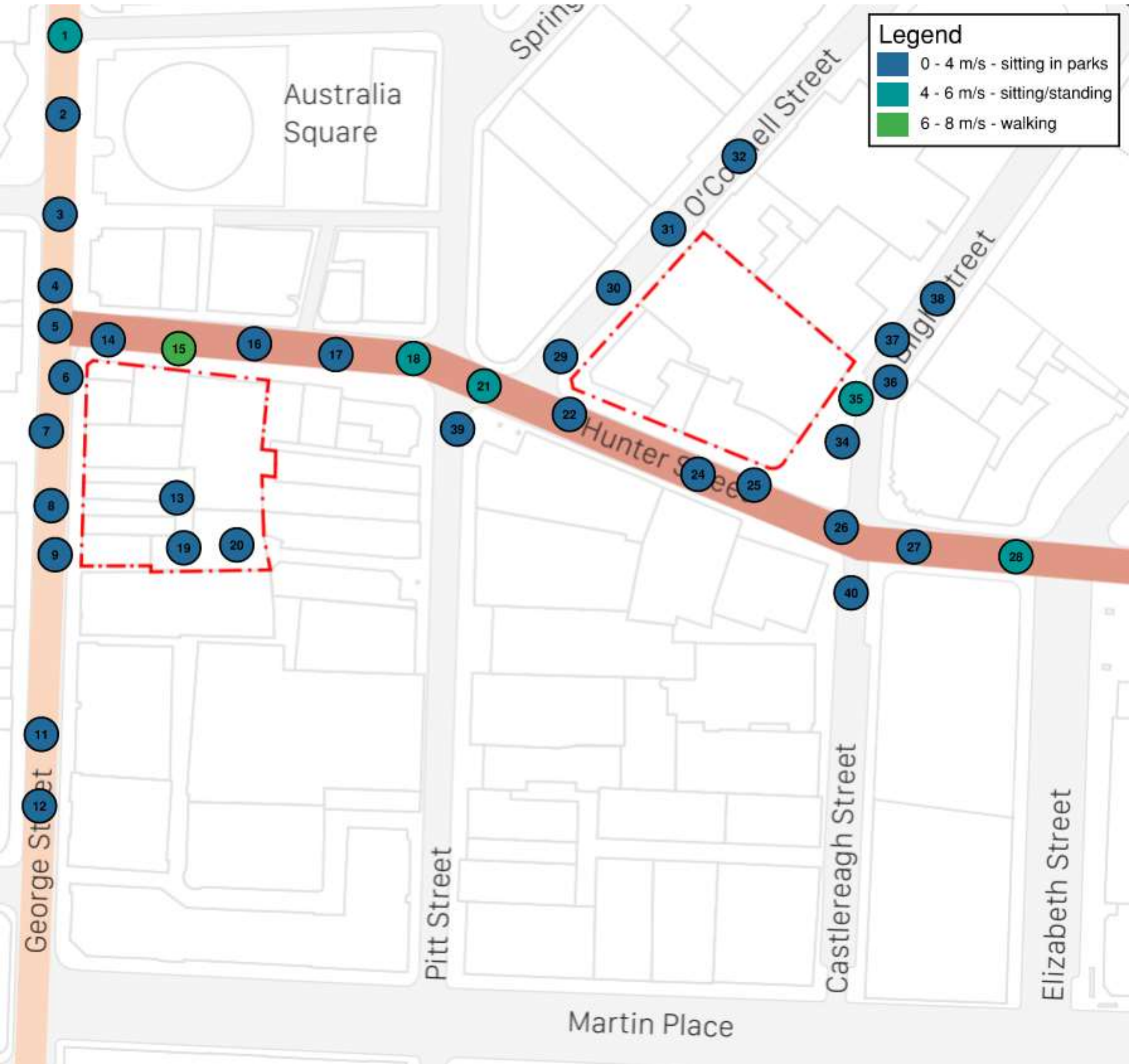

Figure 3-1 Irwin sensor comfort results for existing buildings occupying the development site

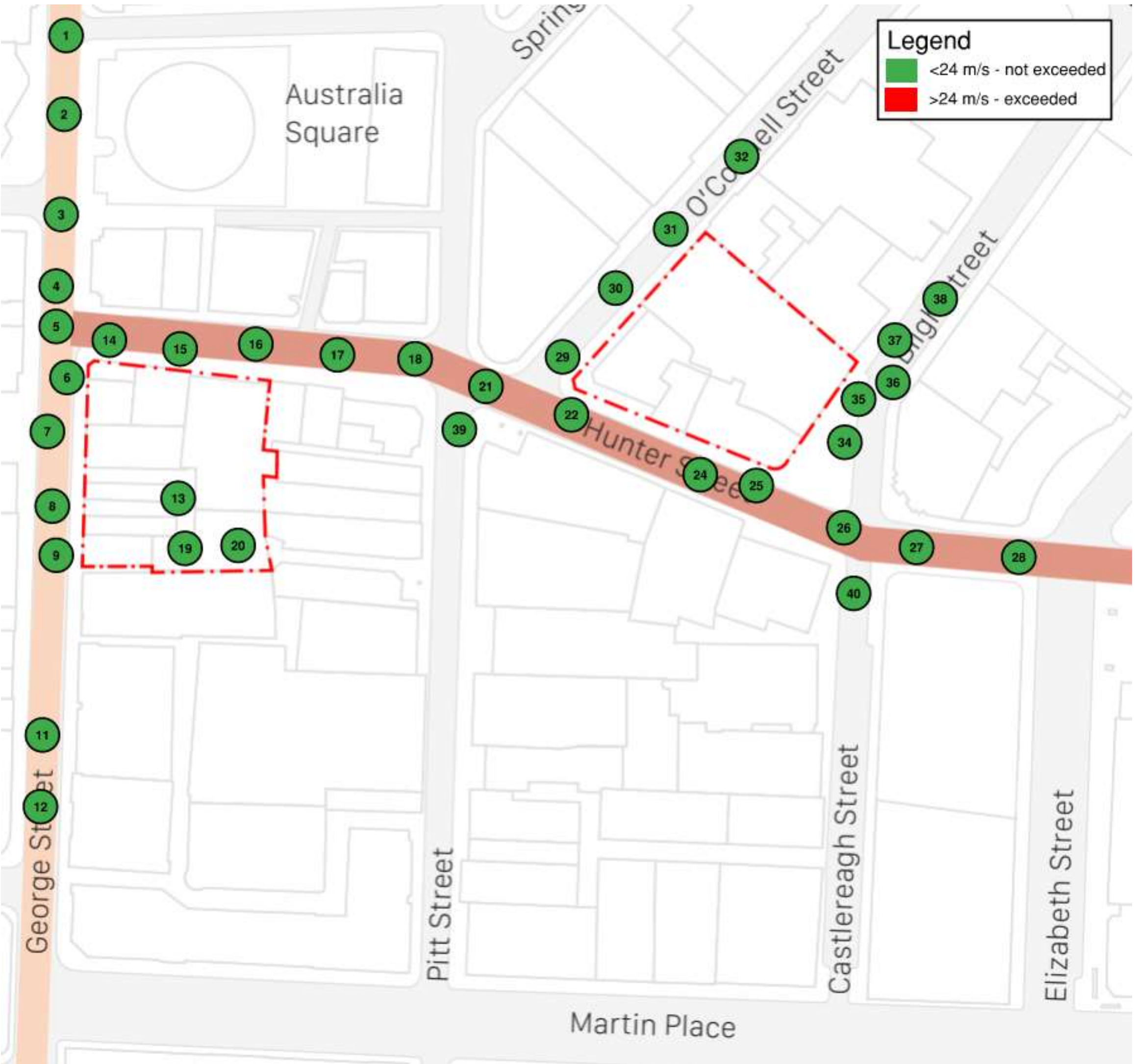

Figure 3-2 Irwin sensor safety results for existing buildings occupying the development site

Table 3-1 Irwin sensor wind speed results for existing buildings occupying the development site

Location	Comfort Wind Speed [m/s]	Comfort Criteria	Safety Wind Speed [m/s]	Safety Criteria
1	4.9	Standing	14.6	Not exceeded
2	3.6	Sitting	10.5	Not exceeded
3	3.2	Sitting	9.6	Not exceeded
4	3.1	Sitting	8.8	Not exceeded
5	3.1	Sitting	9.1	Not exceeded
6	2.9	Sitting	8.4	Not exceeded
7	3.6	Sitting	11.2	Not exceeded
8	3.2	Sitting	8.7	Not exceeded
9	2.4	Sitting	6.3	Not exceeded
10	N/A	N/A	N/A	N/A
11	3.2	Sitting	9.1	Not exceeded
12	2.3	Sitting	6.8	Not exceeded
13	2.7	Sitting	7.8	Not exceeded
14	2.6	Sitting	7.7	Not exceeded
15	6.3	Walking	16.5	Not exceeded
16	2.9	Sitting	8.2	Not exceeded
17	2.4	Sitting	6.6	Not exceeded
18	4.2	Standing	11.4	Not exceeded
19	2.6	Sitting	8.0	Not exceeded
20	3.7	Sitting	10.9	Not exceeded
21	4.6	Standing	12.5	Not exceeded

589

Location	Comfort Wind Speed [m/s]	Comfort Criteria	Safety Wind Speed [m/s]	Safety Criteria
22	2.8	Sitting	8.5	Not exceeded
23	N/A	N/A	N/A	N/A
24	2.6	Sitting	7.9	Not exceeded
25	3.0	Sitting	9.6	Not exceeded
26	3.0	Sitting	8.5	Not exceeded
27	3.6	Sitting	10.3	Not exceeded
28	4.2	Sitting	12.0	Not exceeded
29	3.1	Sitting	9.7	Not exceeded
30	2.1	Sitting	6.2	Not exceeded
31	2.8	Sitting	7.7	Not exceeded
32	2.5	Sitting	7.2	Not exceeded
33	N/A	N/A	N/A	N/A
34	3.7	Sitting	10.7	Not exceeded
35	4.4	Standing	12.3	Not exceeded
36	3.6	Sitting	10.4	Not exceeded
37	3.6	Sitting	10.2	Not exceeded
38	3.9	Sitting	11.7	Not exceeded
39	3.2	Sitting	9.1	Not exceeded
40	3.4	Sitting	10.0	Not exceeded

3.2 Base case

This assessment included 37 Irwin probes, located around the development site, and their results are shown against the Sydney DCP wind criteria in Figure 3-3 (comfort results) and Figure 3-4 (safety results). Results are also tabulated in Table 3-2 to show the comparison between the target criteria and the achieved criteria. The results show that the wind results for all locations are suitable for the intended activities and safe. Note: sensor 13, 19 and 20 were not included due to their location within the West site boundary and the base case geometry.

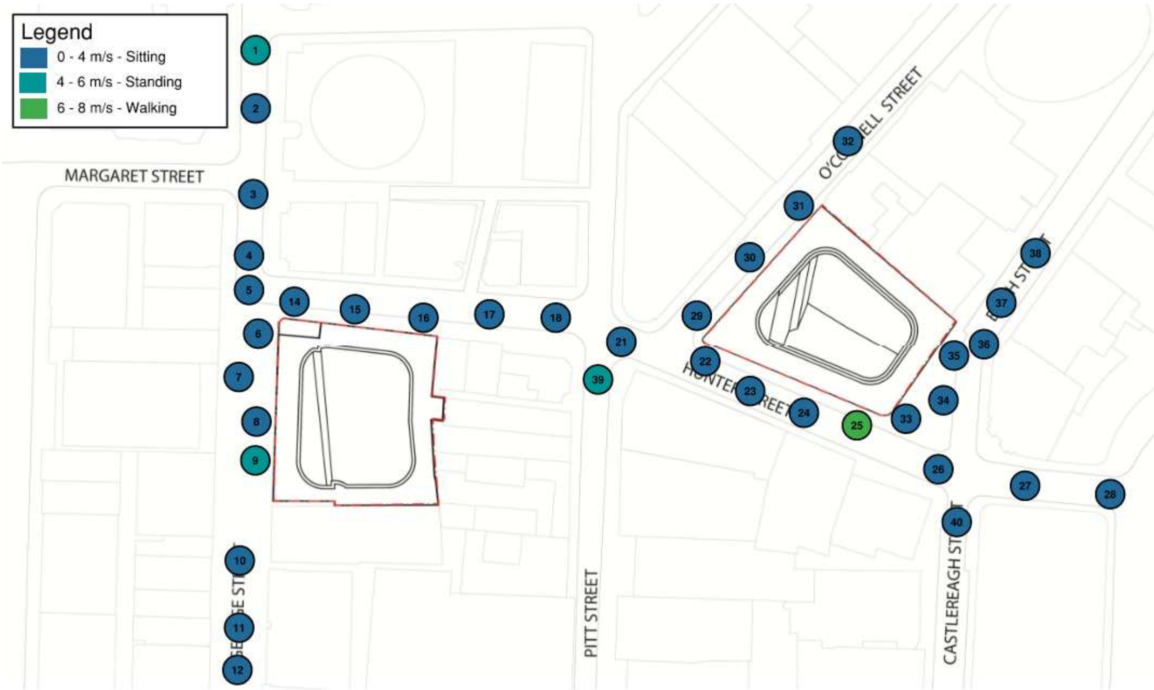

Figure 3-3 Irwin sensor comfort results for the base case (DCP requirements)

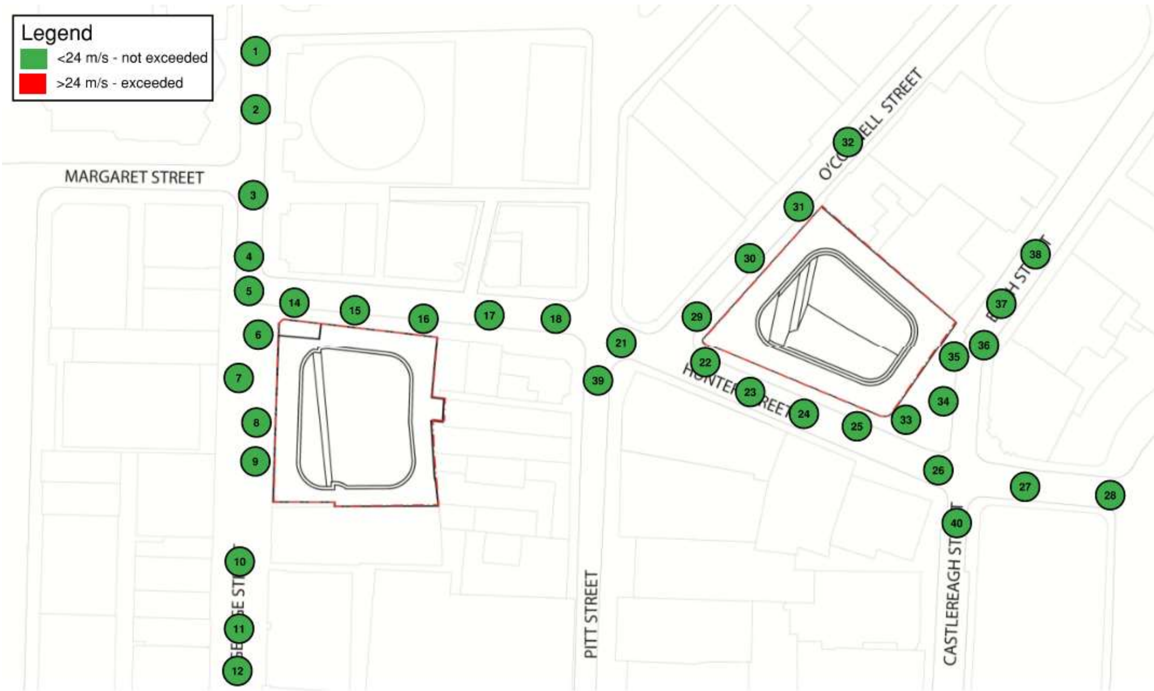

Figure 3-4 Irwin sensor safety results for the base case (DCP requirements)

Table 3-2 Irwin sensor wind speed results for the base case (DCP requirements)

Location	Comfort Target	Comfort Wind Speed [m/s]	Comfort Criteria	Safety Wind Speed [m/s]	Safety Criteria
1	Walking	4.5	Standing	13.4	Not exceeded
2	Walking	4.0	Sitting	11.0	Not exceeded
3	Walking	3.3	Sitting	9.1	Not exceeded
4	Walking	3.2	Sitting	9.1	Not exceeded
5	Walking	2.8	Sitting	7.7	Not exceeded
6	Standing	3.1	Sitting	8.4	Not exceeded
7	Standing	2.8	Sitting	7.8	Not exceeded
8	Standing	2.9	Sitting	8.4	Not exceeded
9	Standing	4.4	Standing	12.1	Not exceeded
10	Walking	2.5	Sitting	7.7	Not exceeded
11	Walking	3.1	Sitting	9.4	Not exceeded
12	Walking	4.0	Sitting	12.3	Not exceeded
13	N/A	N/A	N/A	N/A	N/A
14	Standing	4.0	Sitting	10.8	Not exceeded
15	Standing	3.2	Sitting	10.3	Not exceeded
16	Standing	3.3	Sitting	10.5	Not exceeded
17	Walking	3.2	Sitting	9.8	Not exceeded
18	Walking	3.5	Sitting	10.1	Not exceeded
19	N/A	N/A	N/A	N/A	N/A
20	N/A	N/A	N/A	N/A	N/A
21	Walking	2.7	Sitting	7.8	Not exceeded

Location	Comfort Target	Comfort Wind Speed [m/s]	Comfort Criteria	Safety Wind Speed [m/s]	Safety Criteria
22	Standing	3.1	Sitting	8.9	Not exceeded
23	Standing	3.2	Sitting	9.3	Not exceeded
24	Standing	3.2	Sitting	9.2	Not exceeded
25	Standing	6.2	Walking	16.5	Not exceeded
26	Walking	3.6	Sitting	10.8	Not exceeded
27	Walking	3.3	Sitting	9.8	Not exceeded
28	Walking	3.9	Sitting	11.5	Not exceeded
29	Standing	3.9	Sitting	11.4	Not exceeded
30	Standing	3.8	Sitting	11.0	Not exceeded
31	Standing	2.1	Sitting	6.0	Not exceeded
32	Walking	2.7	Sitting	7.6	Not exceeded
33	Sitting	3.7	Sitting	10.3	Not exceeded
34	Sitting	3.0	Sitting	8.3	Not exceeded
35	Sitting	2.9	Sitting	8.4	Not exceeded
36	Walking	2.8	Sitting	7.8	Not exceeded
37	Walking	4.0	Sitting	11.7	Not exceeded
38	Walking	3.4	Sitting	10.9	Not exceeded
39	Walking	4.4	Standing	13.1	Not exceeded
40	Walking	4.1	Standing	11.7	Not exceeded

3.3 Proposed development

This assessment included 40 Irwin probes, located around the development site, and their results are shown against the Sydney DCP wind criteria in Figure 3-5 (comfort results) and Figure 3-6 (safety results). Results are also tabulated in Table 3-3 to show the comparison between the target criteria and the achieved criteria. The results show that the wind results for all locations are suitable for the intended activities and safe. Note: sensors 7, 20 and 30 are excluded from the below analysis due to issues caused by the data acquisition system.

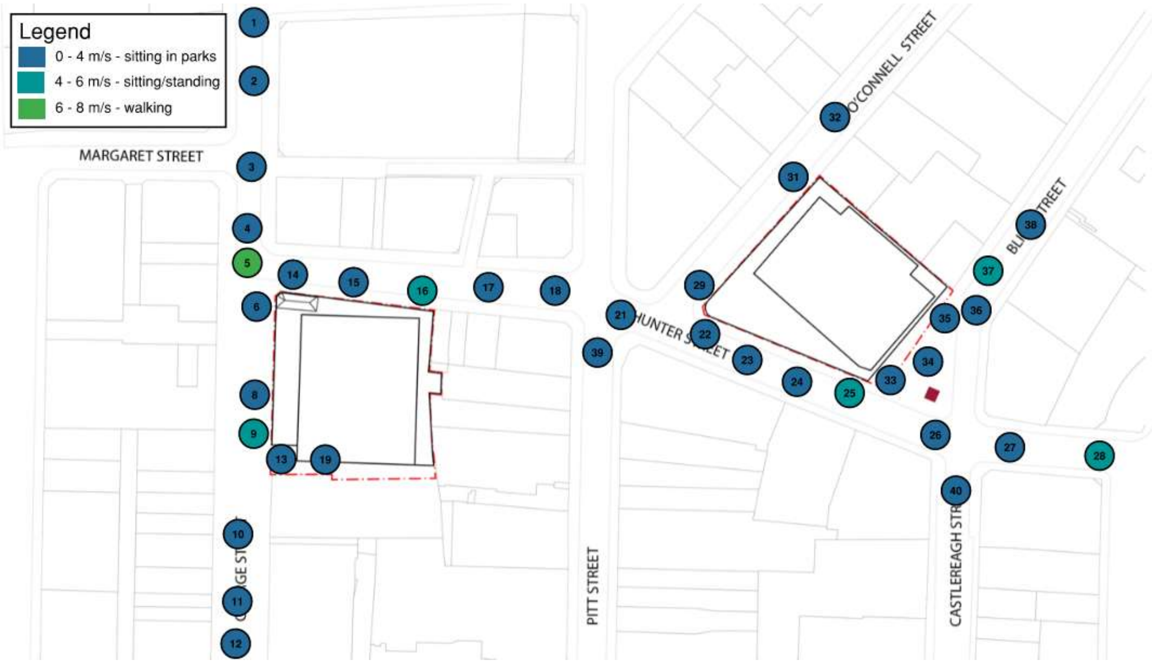

Figure 3-5 Irwin sensor comfort results for proposed development

Figure 3-6 Irwin sensor safety results for proposed development

Table 3-3 Irwin sensor wind speed results for the proposed development

Location	Comfort Target	Comfort Wind Speed [m/s]	Comfort Criteria	Safety Wind Speed [m/s]	Safety Criteria
1	Walking	3.5	Sitting	10.0	Not exceeded
2	Walking	2.6	Sitting	7.7	Not exceeded
3	Walking	2.8	Sitting	8.0	Not exceeded
4	Walking	2.9	Sitting	8.4	Not exceeded
5	Walking	6.0	Standing	15.7	Not exceeded
6	Standing	3.1	Sitting	8.9	Not exceeded
7	N/A	N/A	N/A	N/A	N/A
8	Standing	3.0	Sitting	9.0	Not exceeded
9	Standing	4.5	Standing	12.6	Not exceeded
10	Walking	3.4	Sitting	9.1	Not exceeded
11	Walking	3.3	Sitting	9.5	Not exceeded
12	Walking	2.1	Sitting	6.3	Not exceeded
13	Standing	2.8	Sitting	8.4	Not exceeded
14	Standing	3.3	Sitting	9.4	Not exceeded
15	Standing	3.3	Sitting	10.2	Not exceeded
16	Standing	4.2	Standing	13.1	Not exceeded
17	Walking	3.7	Sitting	11.2	Not exceeded
18	Walking	3.6	Sitting	10.0	Not exceeded
19	Standing	2.5	Sitting	7.1	Not exceeded
20	N/A	N/A	N/A	N/A	N/A
21	Walking	2.8	Sitting	7.7	Not exceeded
22	Standing	3.0	Sitting	8.9	Not exceeded

Location	Comfort Target	Comfort Wind Speed [m/s]	Comfort Criteria	Safety Wind Speed [m/s]	Safety Criteria
23	Standing	2.6	Sitting	7.2	Not exceeded
24	Standing	3.4	Sitting	9.3	Not exceeded
25	Standing	4.3	Standing	11.7	Not exceeded
26	Walking	3.5	Sitting	9.7	Not exceeded
27	Walking	3.3	Sitting	9.0	Not exceeded
28	Walking	5.0	Standing	13.6	Not exceeded
29	Standing	2.8	Sitting	8.3	Not exceeded
30	N/A	N/A	N/A	N/A	N/A
31	Standing	3.0	Sitting	8.4	Not exceeded
32	Walking	2.5	Sitting	7.3	Not exceeded
33	Sitting	3.8	Sitting	10.8	Not exceeded
34	Sitting	3.2	Sitting	9.3	Not exceeded
35	Sitting	3.1	Sitting	9.0	Not exceeded
36	Walking	2.8	Sitting	7.9	Not exceeded
37	Walking	5.3	Standing	14.8	Not exceeded
38	Walking	3.6	Sitting	11.7	Not exceeded
39	Walking	3.6	Sitting	10.6	Not exceeded
40	Walking	3.4	Sitting	9.7	Not exceeded

3.4 Discussion

Provision 3 of the Sydney DCP requires “new developments are to incorporate design features that will ameliorate existing adverse wind conditions so that the criteria … are achieved”. Figure 3-7 shows a comparison of the wind speeds at locations where results were recorded for identical positions of the Irwin sensors in the baseline investigations, base case, and proposed development wind tunnel tests. As can be seen, there is some difference in the wind speeds due to the proposed development, but all locations still achieve the desired criteria (as outlined in the Sydney DCP).

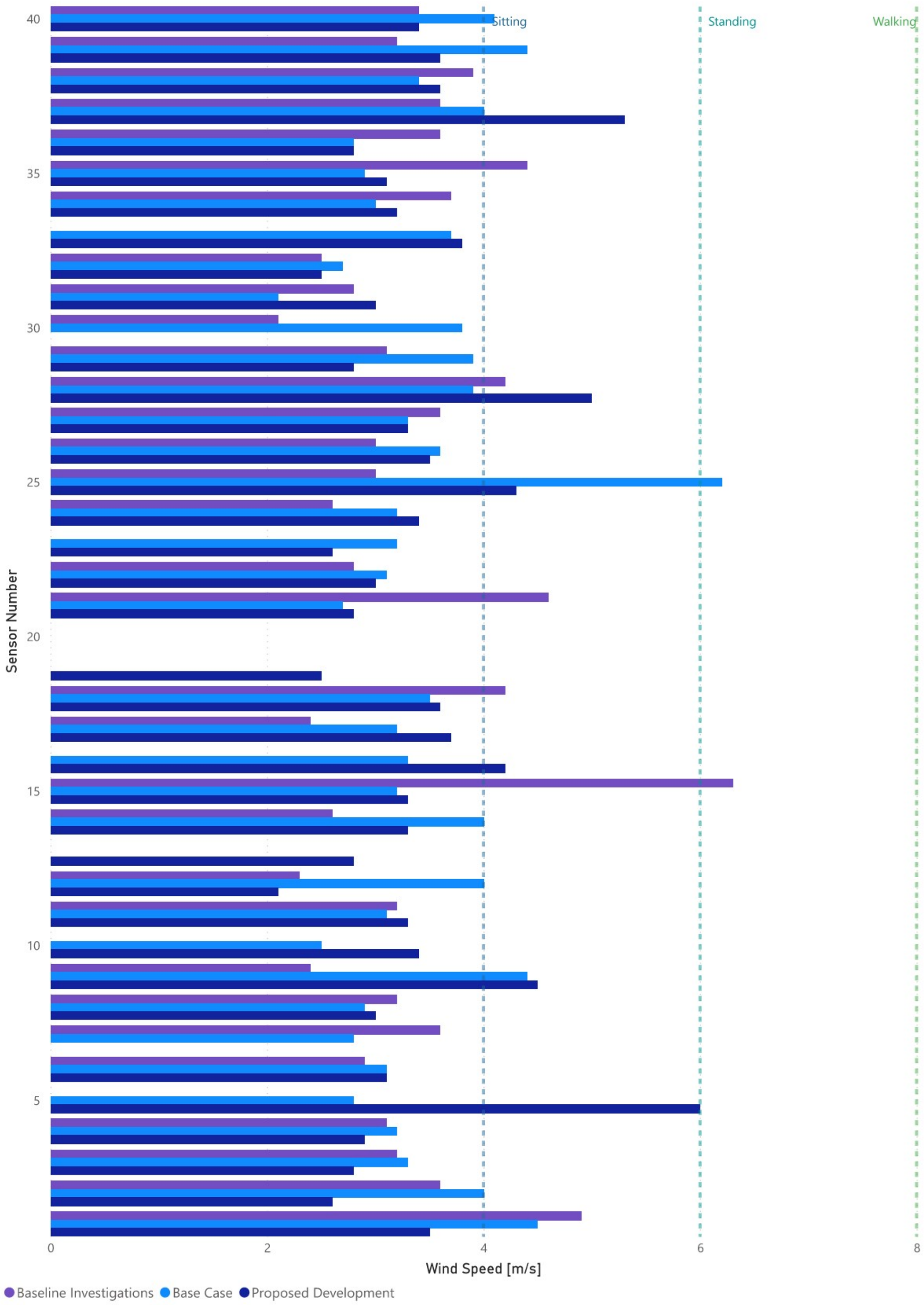

Figure 3-7 Comparison of Irwin sensor comfort results as per Provision 3 of the Sydney DCP

Similarly, Figure 3-8 shows a comparison of the safety results for locations where Irwin sensors were placed in identical locations between the baseline investigations, base case, and proposed development wind tunnel tests. There are some locations where the wind speed increases, but they are still below the safety limit that is prescribed in the Sydney DCP.

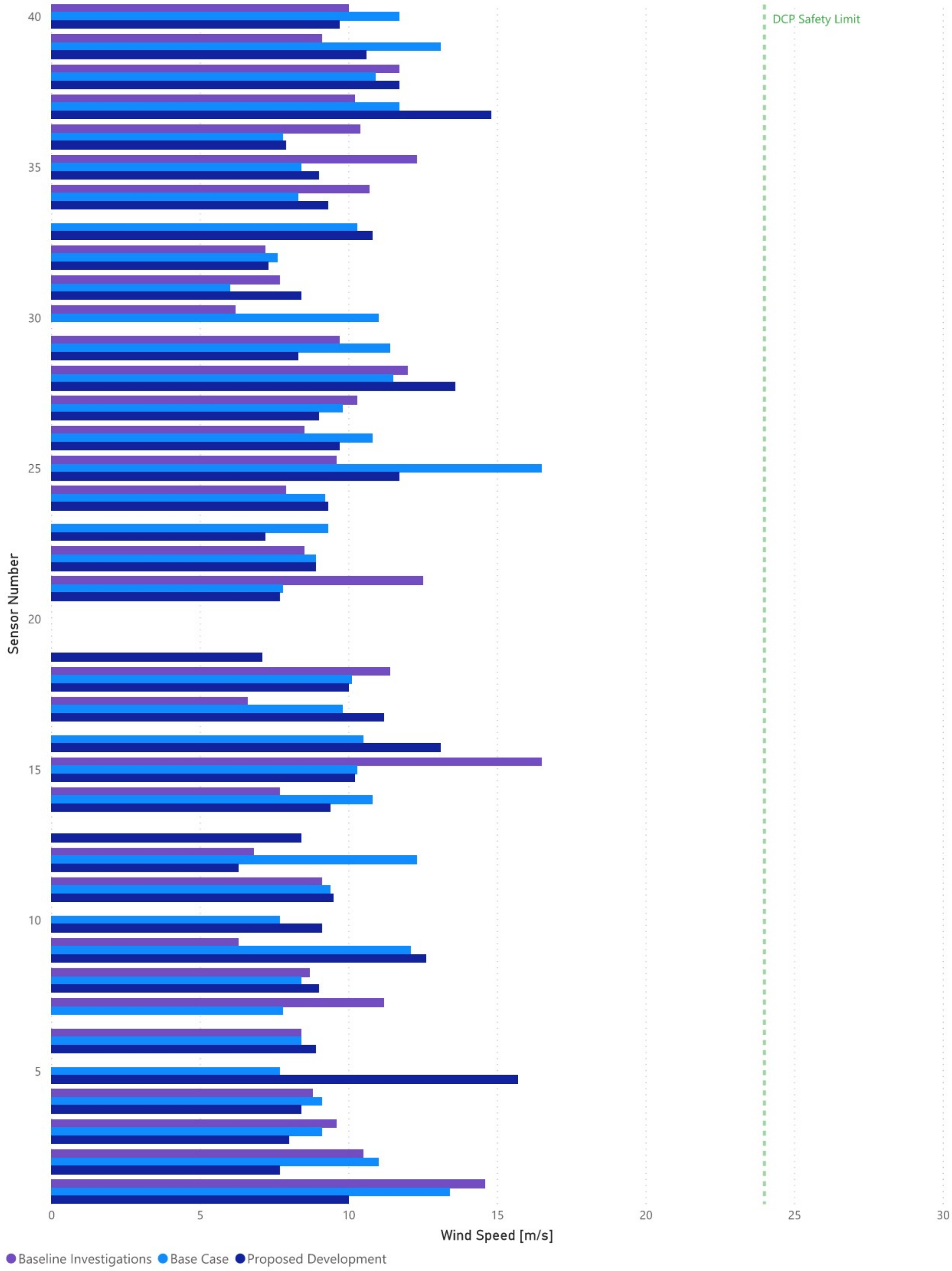

Figure 3-8 Comparison of Irwin sensor safety results as per Provision 3 of the Sydney DCP

This planning proposal must show that the proposed development performs better, in terms of wind conditions, than the base case for all identical locations. Table 3-4 shows the comparison between the base case and proposed development comfort wind speeds, with the difference in the two wind speeds shown. It also includes a pass/fail specification to determine if the average wind speed for the proposed development is better (pass) or worse (fail) than the base case.

Table 3-4 Comparison of the base case and proposed development comfort and safety wind speeds

Location	Base Case	Proposed Development	Difference [m/s]
1	4.5	3.5	-1.0
2	4.0	2.6	-1.4
3	3.3	2.8	-0.5
4	3.2	2.9	-0.3
5	2.8	6.0	+3.2
6	3.1	3.1	0.0
7	2.8	N/A	N/A
8	2.9	3.0	+0.1
9	4.4	4.5	+0.1
10	2.5	3.4	+0.9
11	3.1	3.3	+0.2
12	4.0	2.1	-1.9
13	N/A	2.8	N/A
14	4.0	3.3	-0.7
15	3.2	3.3	+0.1
16	3.3	4.2	+0.9
17	3.2	3.7	+0.5
18	3.5	3.6	+0.1
19	N/A	2.5	N/A
20	N/A	N/A	N/A
21	2.7	2.8	+0.1
22	3.1	3.0	-0.1
23	3.2	2.6	-0.6
24	3.2	3.4	+0.2
25	6.2	4.3	-1.9
26	3.6	3.5	-0.1
27	3.3	3.3	0.0
28	3.9	5.0	+1.1
29	3.9	2.8	-1.1
30	3.8	N/A	N/A
31	2.1	3.0	+0.9
32	2.7	2.5	-0.2

Location	Base Case	Proposed Development	Difference [m/s]
33	3.7	3.8	+0.1
34	3.0	3.2	+0.2
35	2.9	3.1	+0.2
36	2.8	2.8	0.0
37	4.0	5.3	+1.3
38	3.4	3.6	+0.2
39	4.4	3.6	-0.8
40	4.1	3.4	-0.7
Average	3.5	3.4	-0.1 (Pass)

3.5 Mitigation strategies

Based on the wind tunnel results all locations achieve the required Sydney DCP criteria and can be deemed safe when compared to the safety criteria set out in the Sydney DCP. However, there are some locations where the wind speeds around the proposed development are higher than the baseline investigations and/or base case and therefore mitigation strategies may be required at a future design stage (assessed through an state significant development application). Potential mitigation strategies include the introduction of:

- Fixed or retractable canopies or awnings to protect patrons.
- 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.
- Roughing elements (e.g., banners, etc.) as a means of diffusing the energy contained in the wind

4 Conclusion

A wind tunnel study was conducted to provide assessment of wind conditions at the Hunter development sites and nearby surrounding environment based on the Planning Proposal Request. Wind speeds around the development have been assessed against the Sydney Development Control Plan wind criteria (section 5.1.9 of the draft December 2020 version) to ensure compliance with local requirements. 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.

A comparison of the base case to the proposed planning envelope subject of the Planning Proposal Request was undertaken which showed that on average, the proposed planning envelope performed better than the base case. The average wind speed across the site and surrounds for the base case was 3.5 m/s whereas the proposed development had an average wind speed of 3.4 m/s. The results of the assessment also indicate that wind speeds are compliant with the intended usage of each area around the proposed development. There are some areas where the wind speed is increased, when compared to the baseline investigations and base case, due to the proposed development, but wind speeds are still acceptable for the intended use. In addition, all measured locations are below the 24 m/s wind speed safety criteria and can be deemed safe for all users.

5 References

AS/NZS 1170.2:2021, "Structural Design Actions", Part 2: Wind Actions.

AS/NZS 1170.2:1989, "Minimum design loads on structures" (known as the SAA Loading Code), Part 2: Wind Loads.

Australasian Wind Engineering Society, (2019), AWES-QAM-1-2019, "Quality Assurance Manual: Wind Engineering Studies of Buildings".

Bureau of Meteorology, (2001 – 2020), Sydney Airport Wind Data.

City of Sydney, (2012), "Sydney Development Control Plan 2012", pp. 3.2-11 - 3.2-12.

Davenport, A (1972), "An Approach to Human comfort criteria for Environmental Wind Conditions", Proceeding of the colloquium on Building Climatology, Stockholm, Sweden.

Deaves, D and Harris, R (1978), "A mathematical model of the structure of strong winds", CIRIA, London, UK.

Grange, S, (2014), "Technical note: Averaging wind speeds and directions", 10.13140/RG.2.1.3349.2006.

Holmes, J, (2021), "The Wind Climate of The Melbourne Metropolitan Area - wind speed and directional probabilities at four stations", 10.13140/RG.2.2.16175.66725.

Lawson, T, (2001), "Building Aerodynamics", Imperial College Press, U.K. pp. 117-137.

Lawson, T, (1975), "The determination of the wind environment of a building complex before construction", Bristol University, Department of Aeronautical Engineering.

Lawson, T, (1973), "The wind environment of buildings: a logical approach to the establishment of criteria", Bristol University, Department of Aeronautical Engineering.

Melbourne, W.H., (1978), "Criteria for Environmental Wind Conditions", Journal of Wind Engineering and Industrial Aerodynamics, Vol. 3, pp. 241-249.

Melbourne, W.H., (1978), "Wind Environment Studies in Australia", Journal of Wind Engineering and Industrial Aerodynamics, Vol. 3, pp. 201-214.

Standards Australia and Standards New Zealand, (2021), AS/NZS 1170.2:2021, "Structural design actions, Part 2: Wind actions".

Standards Australia and Standards New Zealand, (1989), AS/NZS 1170.2:1989, "Minimum design loads on structures, Part 2: Wind Loads".

Yuan, C, Norford, L, Ng, E, (2017), "A semi-empirical model for the effect of trees on the urban wind environment", Landscape and Urban Planning 168, 84-93.

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, θ, 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, θ, 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 Weibull coefficients obtained from the Sydney Airport BoM data, for the Sydney DCP assessment hours, are shown below in Table A-1.

Table A-1 Weibull coefficients for all 36 assessment directions

Direction	A	C	k
0	0.019	3.90	2.41
10	0.015	3.55	2.44
20	0.024	4.55	2.36
30	0.049	6.14	2.80
40	0.046	9.29	3.10
50	0.036	8.66	3.12
60	0.022	8.81	3.51
70	0.020	8.47	3.45
80	0.019	7.03	3.31
90	0.016	6.48	3.23
100	0.014	6.46	2.74
110	0.016	6.29	2.94
120	0.018	6.95	2.85
130	0.028	7.49	3.17
140	0.028	7.70	3.12
150	0.024	7.95	2.84
160	0.032	8.90	2.69
170	0.049	7.96	2.96
180	0.048	8.44	2.92
190	0.039	8.66	2.93
200	0.034	8.31	2.85
210	0.023	8.04	2.44
220	0.014	6.37	2.18
230	0.013	5.51	2.33
240	0.015	4.76	2.39
250	0.024	5.49	2.51
260	0.030	5.81	2.58
270	0.027	5.81	2.29
280	0.025	5.30	2.10
290	0.029	4.98	1.96
300	0.036	4.54	1.95
310	0.045	4.07	2.16
320	0.044	3.80	2.37
330	0.032	3.94	2.30
340	0.022	4.14	2.16
350	0.019	4.51	2.25

A.3 Extreme value analysis

For analyses involving high return periods, infrequent wind events of high wind speed are considered. Such wind events have been described using a Type 1 Extreme Value Distribution (or Gumbel Distribution) with Gringorten's modification, which models infrequent events more accurately than the Weibull distribution. The probability of the wind speed at a given location, U_i, exceeding a speed, V, for any given direction, θ, is given by:

$$p(U_i > V, \theta) = 1 - e^{-e^{\left[\frac{V-u(\theta)}{a(\theta)}\right]}}$$

Where u(θ) and $a(\theta)$ are the calculated coefficients for each azimuth sector. The return period for exceedance velocity, V, for each sector is the inverse of the exceedance probability, i.e.:

$$R_\theta = \frac{1}{p(U_i > V, \theta)}$$

The overall exceedance probability for all wind directions is given by:

$$1 - \frac{1}{R} = \prod_\theta \left(1 - \frac{1}{R_\theta}\right)$$

$$1 - \frac{1}{R} = \prod_\theta e^{-e^{\left[\frac{V-u(\theta)}{a(\theta)}\right]}}$$

Therefore, the return period for winds from all directions is:

$$R = \frac{1}{1 - \prod_\theta e^{-e^{\left[\frac{V-u(\theta)}{a(\theta)}\right]}}}$$

The Extreme Value coefficients obtained from the Sydney Airport BoM data, for all hours, are shown below in Table A-2.

Table A-2 Extreme Value coefficients for all 36 assessment directions

Direction	A	u	a
0	0.023	7.12	0.75
10	0.019	6.68	0.79
20	0.029	8.03	0.91
30	0.045	9.78	0.64
40	0.037	12.97	0.83
50	0.029	12.14	1.02
60	0.017	11.30	0.96
70	0.016	10.78	1.30
80	0.015	10.66	1.67
90	0.013	9.86	1.33
100	0.011	10.25	1.89
110	0.013	10.19	1.07

Direction	A	u	a
120	0.015	11.01	1.62
130	0.022	11.52	1.87
140	0.024	12.50	1.61
150	0.021	12.43	1.91
160	0.028	14.50	1.89
170	0.041	12.64	1.19
180	0.039	14.22	1.25
190	0.036	14.08	0.96
200	0.032	12.63	1.52
210	0.023	12.69	1.42
220	0.015	10.96	1.47
230	0.016	9.79	1.17
240	0.018	8.53	0.58
250	0.027	9.46	0.97
260	0.031	9.71	0.96
270	0.027	10.22	1.08
280	0.027	10.46	0.84
290	0.029	10.21	0.71
300	0.035	10.04	0.77
310	0.043	9.46	1.18
320	0.046	8.73	1.63
330	0.039	8.56	0.99
340	0.030	8.03	0.93
350	0.026	7.68	0.99

Appendix B – Wind tunnel calibration

B.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 1:400, and affects the ratio of roughness length and integral scales of longitudinal turbulence:

$$L = \frac{(z_o)m}{(z_o)p} = \frac{(L_u)m}{(L_u)p} = 1:400$$

- 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 26 m/s):

$$V = \frac{(V_{ref})m}{(V_{ref})p} = 0.38$$

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

- Time Scale: $T = \frac{L}{V} = \frac{t_m}{t_p} = 1:150$
- Frequency Scale: $F = \frac{1}{T} = \frac{f_m}{f_p} = 150:1$

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 6.67 Hz in full-scale, which will allow pressure fluctuations with frequencies up to about 2.53 Hz (full-scale) to be determined without distortion or attenuation.

A sampling duration of 40 seconds was used as it ensures measured maximum and minimum wind speeds provide representative estimates of peaks encountered during a full-scale interval of just above 1.6 hrs, and a statistically stable estimate of the mean and RMS wind speeds.

B.2 Wind tunnel calibration

The wind tunnel approach flow was calibrated to match the AS 1170.2:2011 terrain category 1 and 3 approach flows, within a margin of 10% as per the Australasian Wind Engineering Society Quality Assurance Manual. The approach flow was normalised against a height of 235.2 m. The normalised approach flow and turbulence intensity are shown in Figure B-1 to Figure B-4, respectively. The terrain category 3 turbulence intensity is just below the 10% limit set out by the Australasian Wind Engineering Society Quality Assurance Manual for heights at or above 235.2 m. This is still suitable for the wind tunnel test as this is above the height of the development and away from the region of interest, ground plane wind speeds.

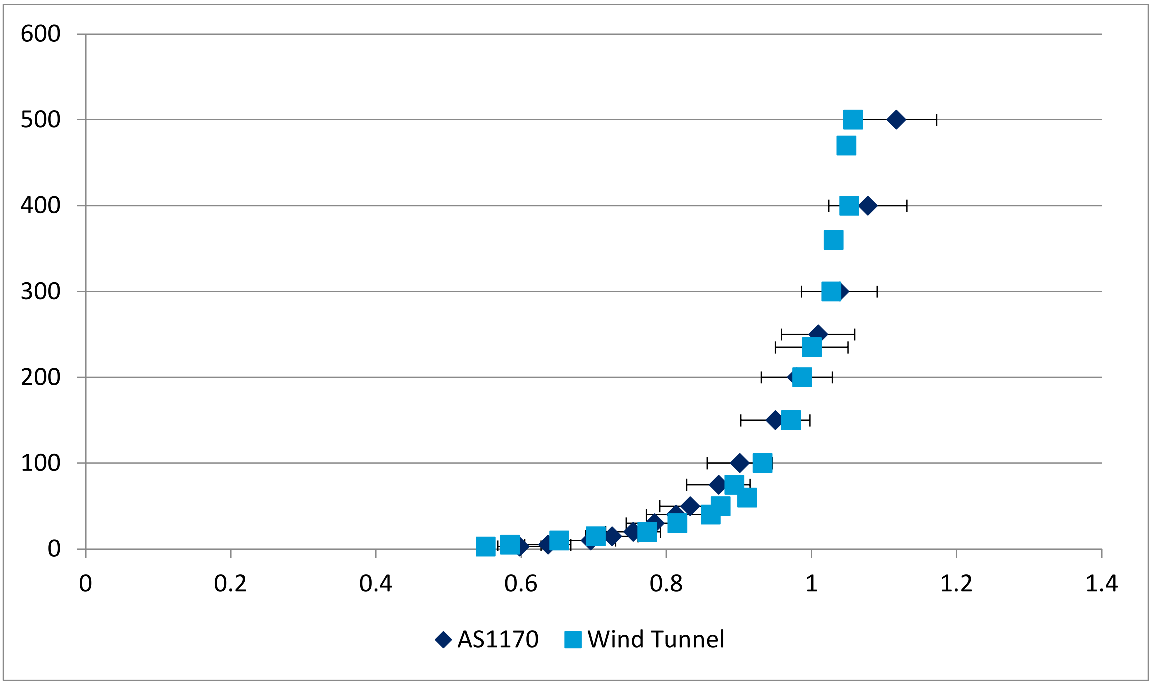

Figure B-1 Mean velocity profile for terrain category 1 comparison with AS1170.2:2011

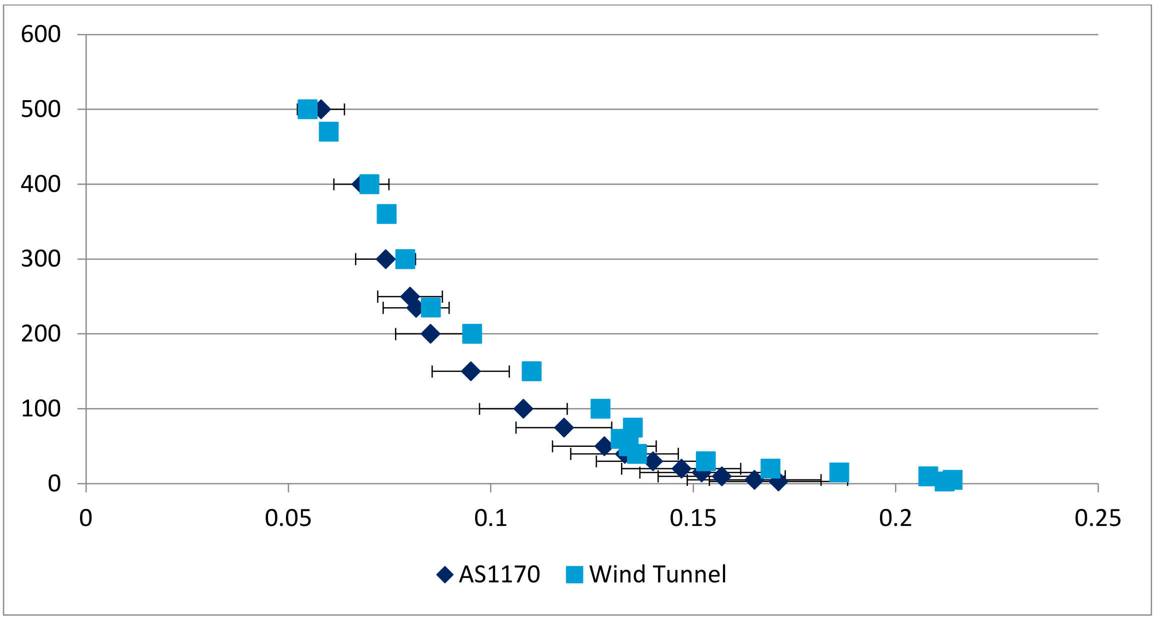

Figure B-2 Turbulence intensity profile for terrain category 1 comparison with AS1170.2:2011

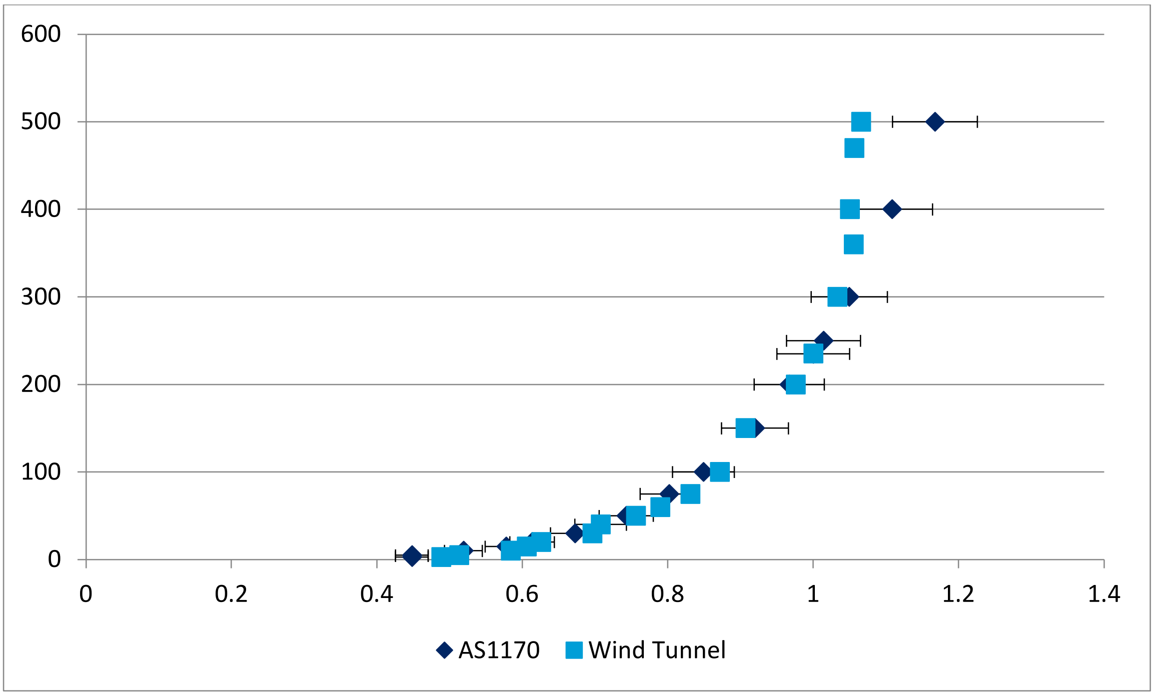

Figure B-3 Mean velocity profile for terrain category 3 comparison with AS1170.2:2011

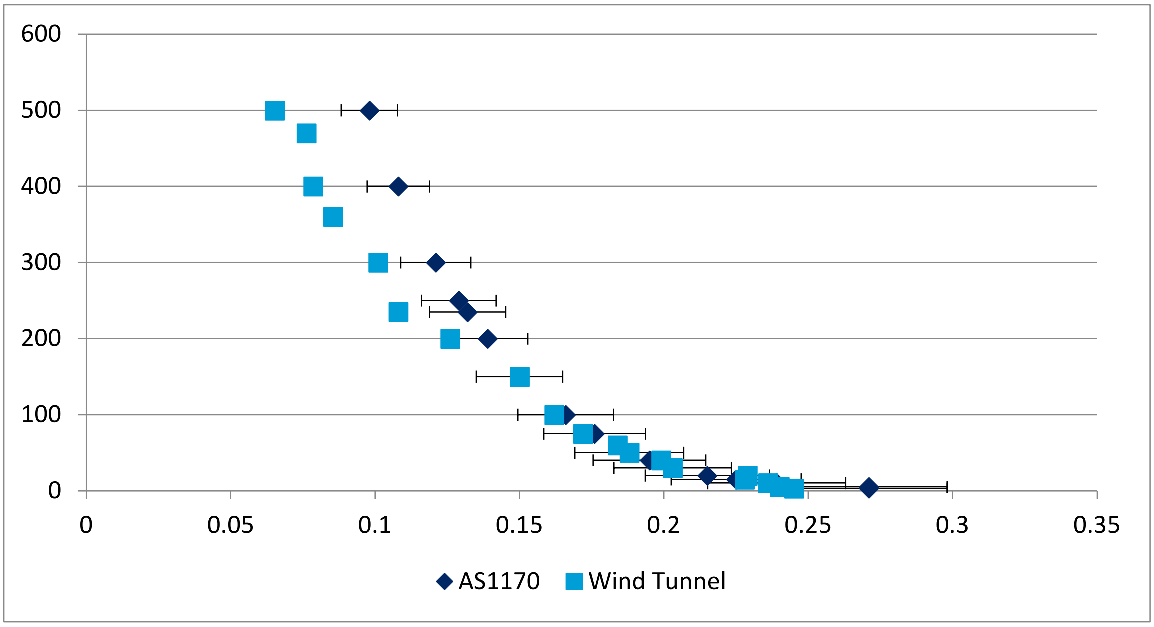

Figure B-4 Turbulence intensity profile for terrain category 3 comparison with AS1170.2:2011

B.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.

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

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
- $\boldsymbol{\nu}$ is the kinematic viscosity, taken as 1.57×10^{-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.