PEDESTRIAN WIND TUNNEL TESTS

APPENDIX N

Sydney Metro City & Southwest

Pitt Street North Over Station Development:

Pedestrian Wind Tunnel Tests

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Executive Summary

A wind tunnel study of the proposed Pitt Street North Over-Station Development, to be located in Sydney, NSW was conducted to assess the pedestrian wind environment in and around the development site. A model of the proposed planning envelope for the project was fabricated to a 1:400 scale and centred on a turntable in the wind tunnel. Replicas of surrounding buildings within a 570 m radius were constructed and placed on the turntable.

The wind tunnel testing was performed in the natural boundary layer wind tunnel of Cermak Peterka Petersen Pty. Ltd., St. Peters. Approach boundary layers, representative of the environment surrounding the proposed development, were established in the test section of the wind tunnel. The approach wind flow had appropriate turbulence characteristics corresponding to a Suburban Approach as defined in Standards Australia (2011).

Measurements of winds likely to be experienced by pedestrians were made with a hot-film anemometer at 19 locations for 16 wind directions each. These points were tested around the development in the proposed configuration, focusing on pedestrian thoroughfares, entry areas, and outdoor seating areas. The measurements were combined with site specific wind statistics to produce results of wind speed versus the percentage of time that wind speed is exceeded for each location. A number of locations were tested in the existing configuration for purposes of comparison.

The wind environment around the development was found to be generally suitable for Pedestrian Standing and Pedestrian Walking activities under the criteria of Lawson. Conditions at locations to the immediate south-east and south of the subject site were generally degraded by the inclusion of the proposed planning envelope building, relative to existing conditions. Elsewhere conditions remained largely similar or improved relative to existing. A small number of locations exceeded the Able-Bodied Lawson distress threshold.

1. Purpose of this report

1.1 Background

This report supports a concept State Significant Development application (concept SSD Application) submitted to the Department of Planning and Environment (DPE) pursuant to Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act). The concept SSD Application is made under section 4.22 of the EP&A Act.

Sydney Metro is seeking to secure concept approval for a mixed use tower above the northern portal of Pitt Street Station, otherwise known as the over station development (OSD). The concept SSD Application seeks consent for a building envelope and its use for residential accommodation, visitor accommodation and commercial premises, maximum gross floor area (GFA), pedestrian and vehicular access, circulation arrangements and associated car parking as well as the strategies and design parameters for the future detailed design of development.

Sydney Metro proposes to construct the OSD as part of an integrated station development package, which would result in the combined delivery of the station, OSD and public domain improvements. The station and public domain elements form part of a separate planning approval for Critical State Significant Infrastructure (CSSI) approved by the Minister for Planning on 9 January 2017.

As the development is within a rail corridor, is associated with railway infrastructure and is for the purposes of residential or commercial premises with a Capital Investment Value of more than $30 million, the project is State Significant Development (SSD) pursuant to Schedule 1, clause 19(2)(a) of the *State Environmental Planning Policy (State and Regional Development) 2011* (SRD SEPP). The full extent of the proposed development is also State Significant Development by virtue of clause 8(2) of the SRD SEPP.

This report has been prepared to respond to the Secretary's Environmental Assessment Requirements (SEARs) issued for the concept SSD Application for Pitt Street North on 30th November 2017 which state that the Environmental Impact Statement (EIS) is to address the following requirement:

> *Plans & Documents: wind tunnel study*

1.2 Overview of the Sydney Metro in its context

The New South Wales (NSW) Government is implementing *Sydney's Rail Future*, a plan to transform and modernise Sydney's rail network so that it can grow with the city's population and meet the needs of customers in the future (Transport for NSW, 2012). Sydney Metro is a new standalone rail network identified in *Sydney's Rail Future*.

Sydney Metro is Australia's biggest public transport project, consisting of Sydney Metro Northwest, which is scheduled for completion in 2019 and Sydney Metro City & Southwest, which is scheduled for completion in 2024.

Sydney Metro West is expected to be operational in the late 2020s. (Refer to **Figure 1**).

Figure 1: Sydney Metro alignment map

Sydney Metro City & Southwest includes the construction and operation of a new metro rail line from Chatswood, under Sydney Harbour through Sydney's CBD to Sydenham and on to Bankstown through the conversion of the existing line to metro standards.

The project also involves the delivery of seven new metro stations, including at Pitt Street. Once completed, Sydney Metro will have the ultimate capacity for 30 trains an hour (one every two minutes) through the CBD in each direction - a level of service never seen before in Sydney.

On 9 January 2017, the Minister for Planning approved the Sydney Metro City & Southwest - Chatswood to Sydenham application as a Critical State Significant Infrastructure project (reference SSI 15_7400), hereafter referred to as the CSSI Approval.

The CSSI Approval includes all physical work required to construct the CSSI, including the demolition of existing buildings and structures on each site. Importantly, the CSSI Approval also includes provision for the construction of below and above-ground structures and other components of the future ISD (including building infrastructure and space for future lift cores, plant rooms, access, parking and building services, as relevant to each site). The rationale for this delivery approach, as identified within the CSSI Application, is to enable the ISD to be more efficiently built and appropriately integrated into the metro station structure.

The EIS for the Chatswood to Sydenham component of the Sydney Metro City & Southwest project identified that the OSD would be subject to a separate assessment process.

Since the CSSI Approval was issued, Sydney Metro has lodged four modification applications to amend the CSSI Approval as outlined below:

- Modification 1- Victoria Cross and Artarmon Substation which involves relocation of the Victoria Cross northern services building from 194-196A Miller Street to 50 McLaren Street together with inclusion of a new station entrance at this location referred to as Victoria Cross North. 52 McLaren Street would also be used to support construction of these works. The modification also involves the relocation of the substation at Artarmon from Butchers Lane to 98 – 104 Reserve Road. This modification application was approved on 18 October 2017.
- Modification 2- Central Walk which involves additional works at Central Railway Station including construction of a new eastern concourse, a new eastern entry, and upgrades to suburban platforms. This modification application was approved on 21 December 2017.
- Modification 3 - Martin Place Station which involves changes to the Sydney Metro Martin Place Station to align with the Unsolicited Proposal by Macquarie Group Limited (Macquarie) for the development of the station precinct. The proposed modification involves a larger reconfigured station layout, provision of a new unpaid concourse link and retention of the existing MLC pedestrian link and works to connect into the Sydney Metro Martin Place Station. It is noted that if the Macquarie proposal does not proceed, the modification (if approved) would be surrendered. This modification application was approved on 22 March 2018.
- Modification 4 - Sydenham Station and Sydney Metro Trains Facility South which incorporated Sydenham Station and precinct works, the Sydney Metro Trains Facility South, works to Sydney Water’s Sydenham Pit and Drainage Pumping Station and ancillary infrastructure and track and signalling works into the approved project. This modification application was approved on 13 December 2017.

Given the modifications, the CSSI Approval is now approved to operate to Sydenham Station and also includes the upgrade of Sydenham Station.

The remainder of the City & Southwest project (Sydenham to Bankstown) proposes the conversion of the existing heavy rail line and the upgrade of the existing railway stations along this alignment to metro standards. This portion of the project, referred to as the Sydenham to Bankstown Upgrade, is the subject of a separate CSSI Application (No. SSI 17_8256) for which an Environmental Impact Statement was exhibited between September and November 2017 and a Response to Submissions and Preferred Infrastructure Report was submitted to the NSW Department of Planning & Environment (DPE) in June 2018 for further exhibition and assessment.

1.3 Planning relationship between Pitt Street Station and the OSD

While the northern portal of Pitt Street Station and the OSD will form an Integrated Station Development, the planning pathways defined under the *Environmental Planning and Assessment Act 1979* require separate approval for each component of the development. In this regard, the approved station works (CSSI Approval) are subject to the provisions of Part 5.1 of the EP&A Act (now referred to as Division 5.2) and the OSD component is subject to the provisions of Part 4 of the EP&A Act.

For clarity, the approved station works under the CSSI Approval included the construction of below and above ground structures necessary for delivering the station and also enabling construction of the integrated OSD. This included but is not limited to:

- demolition of existing development
- excavation
- station structure including concourse and platforms
- lobbies
- retail spaces within the station building
- public domain improvements
- station portal link (between the northern and southern portals of Pitt Street Station)
- access arrangements including vertical transport such as escalators and lifts
- structural and service elements and the relevant space provisioning necessary for constructing OSD, such as columns and beams, space for lift cores, plant rooms, access, parking, retail and building services.

The vertical extent of the approved station works above ground level is defined by the 'transfer slab' level (which for Pitt Street North is defined by RL 48.00), above which would sit the OSD. This delineation is illustrated in **Figure 2** below.

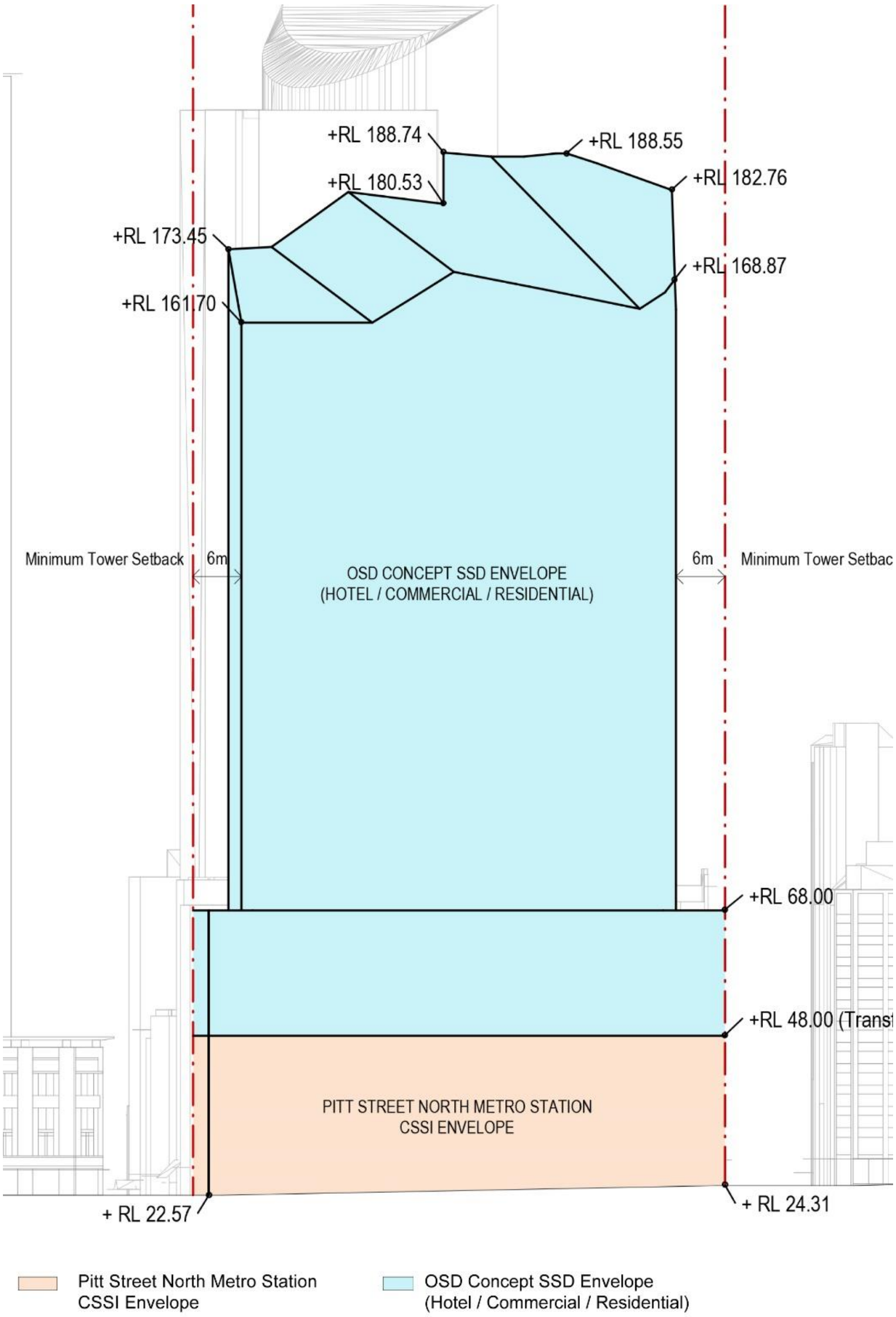


Figure 2: Delineation between station and OSD

The CSSI Approval also establishes the general concept for the ground plane of Pitt Street Station including access strategies for commuters, pedestrians and workers. In this regard, pedestrian access to the station would be from Park Street and the OSD lobbies would be accessed from Pitt Street, Park Street and Castlereagh Street.

Since the issue of the CSSI Approval, Sydney Metro has undertaken sufficient design work to determine the space planning and general layout for the station and identification of those spaces within the station area that would be available for the OSD. In addition, design work has been undertaken to determine the technical requirements for the structural integration of the OSD with the station. This level of design work has informed the concept proposal for the OSD. It is noted that ongoing design development of the works to be delivered under the CSSI Approval would continue with a view to developing an Interchange Access Plan (IAP) and Station Design Precinct Plan (SDPP) for Pitt Street Station to satisfy Conditions E92 and E101 of the CSSI Approval.

The public domain improvement works around the site would be delivered as part of the CSSI Approval.

1.4 The Site

The Pitt Street North OSD site is located at the southern portion of the Sydney CBD block bounded by Pitt Street, Park Street and Castlereagh Street, above the northern portal of the future Pitt Street Station (refer to **Figure 3** below).

Figure 3: Pitt Street Station location plan

The site is located in the City of Sydney Local Government Area. The site (refer to **Figure 4** below) is irregular in shape, has a total area of approximately 3,150 square metres and has street frontages of approximately 28 metres to Pitt Street, 81 metres to Park Street and 48 metres to Castlereagh Street.

The site address is 175-183 Castlereagh Street, Sydney and comprises the following properties:

- Lot 3 in DP 74952
- Lot 1 in DP 229365
- Lot 2 in DP 900055
- Lot 1 in DP 596474
- Lot 17 in DP 1095869
- Lot 2 in DP 509677

- Lot 1 in DP 982663
- Lot 2 in DP 982663
- Lot 3 in DP 61187
- Lot 1 in DP 74367

Figure 4: Aerial photo of Pitt Street North

1.5 Overview of the proposed development

The concept SSD Application seeks concept approval in accordance with section 4.22 of the EP&A Act for the OSD above the approved Pitt Street Station (northern portal). This application establishes the planning framework and strategies to inform the detailed design of the future OSD and specifically seeks planning approval for:

- a building envelope as illustrated at Figure 5
- a maximum building height of approximately Relative Level (RL) 189 which equates to approximately 43 storeys including a podium height of RL68 (approximately 45m), which equates to approximately 12 storeys above ground
- a maximum GFA of 49,120 square metres for the OSD component, which equates to a Floor Space Ratio (FSR) of 15.59:1, resulting in a total maximum GFA at the site

(including station floorspace) of 50,309 square metres and a total maximum FSR of 15.97:1, including flexibility to enable a change in the composition of land uses within the maximum FSR sought

- conceptual use of the building envelope for a range of uses including commercial office space, visitor accommodation and residential accommodation
- use of the conceptual OSD space provisioning within the footprint of the CSSI Approval (both above and below ground), including the OSD lobby areas, podium car parking, storage facilities, services and back-of-house facilities
- car parking for approximately 50 spaces located across five levels of the podium
- loading and vehicular access arrangements from Pitt Street
- pedestrian access from Pitt Street, Park Street and Castlereagh Street
- strategies for utilities and service provision
- strategies for the management of stormwater and drainage
- a strategy for the achievement of ecologically sustainable development
- indicative signage zones
- a strategy for public art
- a design excellence framework
- the future subdivision of parts of the OSD footprint (if required)

As this concept SSD Application is a staged development pursuant to section 4.22 of the EP&A Act, future approval would be sought for detailed design and construction of the OSD. A concept indicative design, showing a potential building form outcome at the site, has been provided as part of this concept SSD Application at Appendix E.

Pitt Street Station is to be a key station on the future Sydney Metro network, providing access to the Sydney Central Business District (CBD). The proposal combines the metro station with a significant mixed use tower, contributing to the Sydney skyline. The OSD would assist in strengthening the role of Central Sydney as the key centre of business in Australia and would contribute to the diversity, amenity and sustainability of the CBD.

It is noted that Pitt Street Station southern portal OSD has been subject to a separate application, and does not form part of this concept SSD Application.

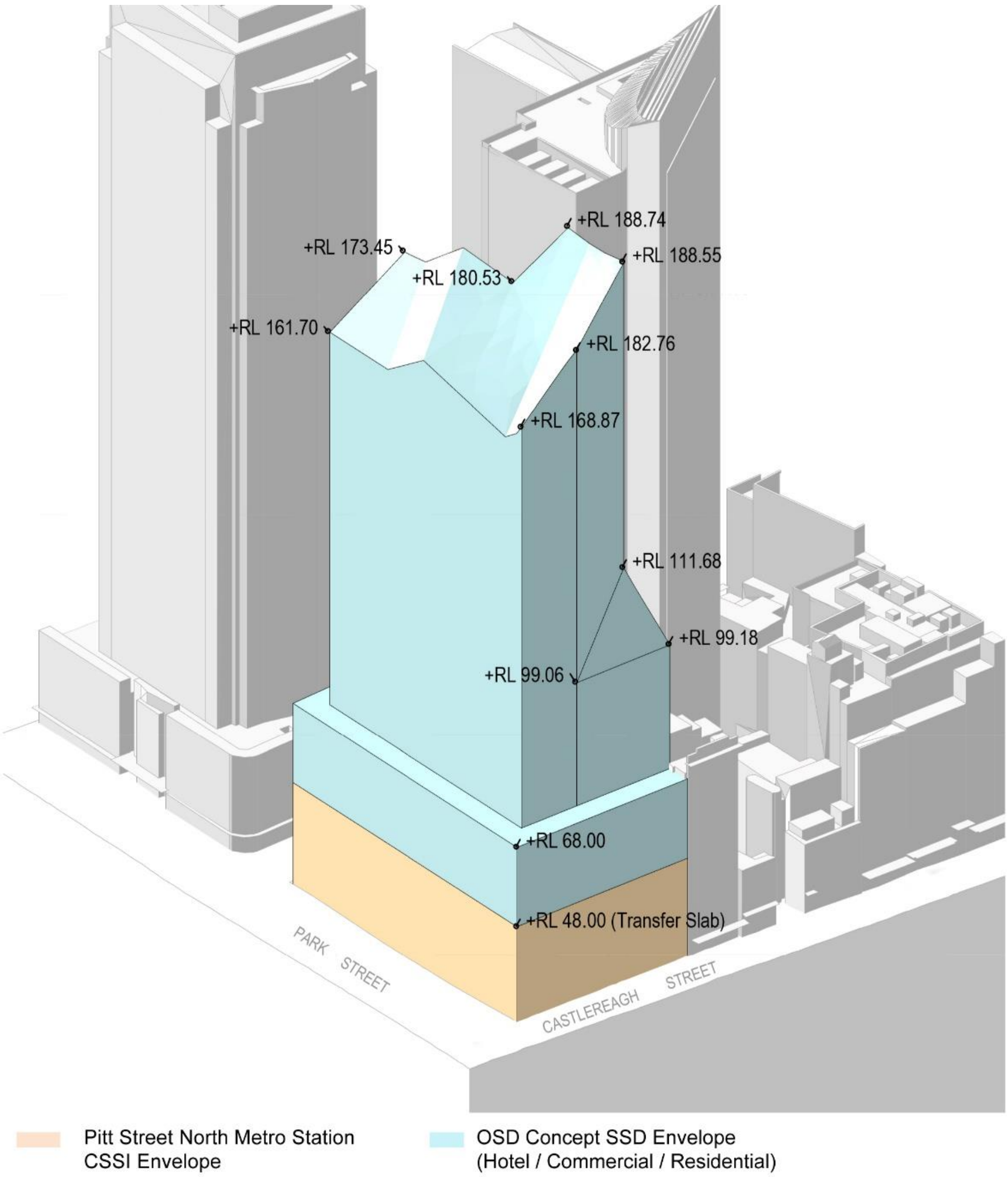


Figure 5: Pitt Street North OSD building, including OSD components (orange) and station box (grey)

Figure 6: Pitt Street North OSD indicative design, as seen from eastern, southern and western elevations

1.6 Staging and framework for managing environmental impacts

Sydney Metro proposes to procure the delivery of the Pitt Street North integrated station development in one single package, which would entail the following works:

- station structure
- station fit-out, including mechanical and electrical
- OSD structure
- OSD fit-out, including mechanical and electrical.

Separate delivery packages are also proposed by Sydney Metro to deliver the excavation of the station boxes/shafts ahead of the ISD delivery package, and line-wide systems (e.g. track, power, ventilation) and operational readiness works prior to the Sydney Metro City & Southwest metro system being able to operate.

Three possible staging scenarios have been identified for delivery of the Integrated Station Development:

1. Scenario 1 – the station and OSD are constructed concurrently by constructing the transfer slab first and then building in both directions. Both the station and OSD would be completed in 2024.
2. Scenario 2 – the station is constructed first and ready for operation in 2024. OSD construction may still be incomplete or soon ready to commence after station construction is completed. This means that some or all OSD construction is likely to still be underway upon opening of the station in 2024.
3. Scenario 3 – the station is constructed first and ready for operation in 2024. The OSD is built at a later stage, with timing yet to be determined. This creates two distinct construction periods for the station and OSD.

Scenario 1 represents Sydney Metro's preferred option as it would provide for completion of the full integrated station development and therefore the optimum public benefit at the site at the earliest date possible (i.e. on or near 2024 when the station is operational). However, given the delivery of the OSD could be influenced by property market forces, Scenarios 2 or 3 could also occur, where there is a lag between completion of the station component of the ISD (station open and operational), and a subsequent development.

The final staging for the delivery of the OSD would be resolved as part of the detailed SSD application(s).

For the purposes of providing a high level assessment of the potential environmental impacts associated with construction, the following have been considered:

- Impacts directly associated with the OSD, the subject of this SSD application
- Cumulative impacts of the construction of the OSD at the same time as the station works (subject of the CSSI Approval).

Given the integration of the delivery of the Sydney Metro City & Southwest metro station with an OSD development, Sydney Metro proposes the framework detailed in

Figure 7 to manage the design and environmental impacts, consistent with the framework adopted for the CSSI Approval, which includes:

- project design – measures which are inherent in the design of the project to avoid and minimise impacts
- mitigation measures – additional to the project design which are identified through the environmental impact assessment
- construction environmental management framework – details the management processes and documentation for the project

- construction noise and vibration strategy – identifies measures to manage construction noise and vibration
- design guidelines – provides an assurance of end-state quality
- environmental performance outcomes – establishes intended outcomes which would be achieved by the project

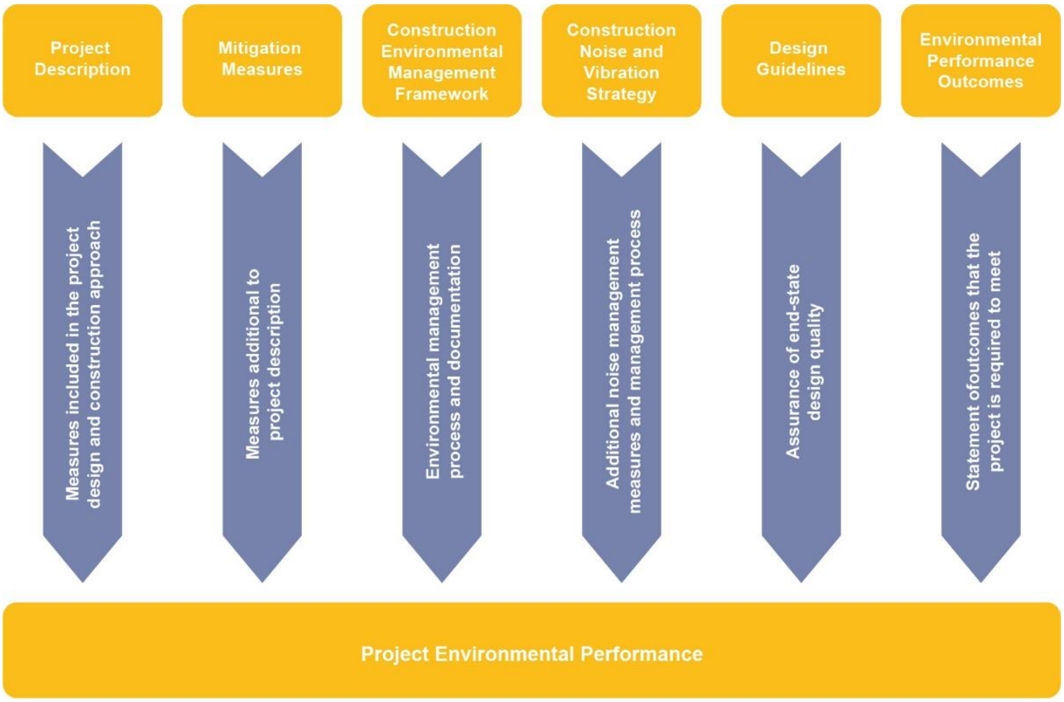


Figure 7: Project approach to environmental mitigation and management

Sydney Metro proposes to implement a similar environmental management framework where the integrated delivery of the CSSI station works and the OSD occur concurrently. This would ensure a consistent approach to management of design interface and construction-related issues.

Sydney Metro proposes this environmental management framework would apply to the OSD until completion of the station and public domain components of the integrated station development delivery contract (i.e. those works under the CSSI Approval). Should the OSD be constructed beyond the practical completion and opening of the section, standard practices for managing construction related environmental impacts would apply in accordance with the relevant guidelines and Conditions of Approval for the detailed SSD application(s).

2. Introduction

Pedestrian acceptability of footpaths, entrances, plazas and terraces is an important design parameter of interest to the building owner and architect. Assessment of the acceptability of the pedestrian level wind environment is desirable during the project design phase so that modifications can be made, if necessary, to create wind conditions suitable for the intended use of the space.

Techniques have been developed which permit boundary layer wind tunnel modelling of buildings to determine wind velocities in pedestrian areas. This report includes wind tunnel test procedures, test results, and discussion of acquired test results. Table 1 summarises the model configurations, test methods, and data acquisition parameters used. All the data collection was performed in accordance with Australasian Wind Engineering Society (2001), and American Society of Civil Engineers (1999, 2010). Analytical methods such as computational fluid dynamics (CFD) are not capable, except in very simple geometries, to estimate wind pressures, frame loads, or windiness in pedestrian areas.

Table 1: Parameters and configurations for data acquisition.

General Information	
Model scale	1:400
Surrounding model radius (full-scale)	570m
Reference height (full-scale)	200 m Above ground leve
Approach Terrain Category	Suburban (Terrain Category 3)
Testing Configurations	
Configuration A – Existing. Test locations numbered *XX*	Existing site with existing and approved surrounding buildings, as shown in Figure 10 and Figure 11 Pedestrian winds measured at 14 locations for 16 wind directions at 22.5° increments from 0° (north).
Configuration B – Proposed envelope. Test locations numbered *XX.1*	Proposed development planning envelope, with existing and approved surrounds, as shown in Figure 12 and Figure 13 Pedestrian winds measured at 19 locations for 16 wind directions at 22.5° increments from 0° (north).

3. The Wind Tunnel Test

Modelling of the aerodynamic flow around a structure requires special consideration of flow conditions to obtain similitude between the model and the prototype. A detailed discussion of the similarity requirements and their wind tunnel implementation can be found in Cermak (1971, 1975, 1976). In general, the requirements are that the model and prototype be geometrically similar, that the approach mean velocity and turbulence characteristics at the model building site have a vertical profile shape similar to the full-scale flow, and that the Reynolds number for the model and prototype be equal. Due to modelling constraints, the Reynolds number cannot be made equal and the Australasian Wind Engineering Society Quality Assurance Manual (2001) suggests a minimum Reynolds number of 50,000, based on minimum model width and wind velocity at the top of the model; in this study the modelled Reynolds number was over 50,000.

The wind tunnel test was performed in the boundary layer wind tunnel shown in Figure 8. The wind tunnel test section is 3.0 m wide, by 2.4 m high with a porous slatted roof for passive blockage correction. This wind tunnel has a 21 m long test section, the floor of which is covered with roughness elements, preceded by vorticity generating fence and spires. The spires, barrier, and roughness elements were designed to provide a modelled atmospheric boundary layer approximately 1.2 m thick with a mean velocity and turbulence intensity profile similar to that expected to occur in the region approaching the modelled area. The approach wind characteristics used for the model test are shown in Figure 9 and are explained more fully in Section 4.1.1.

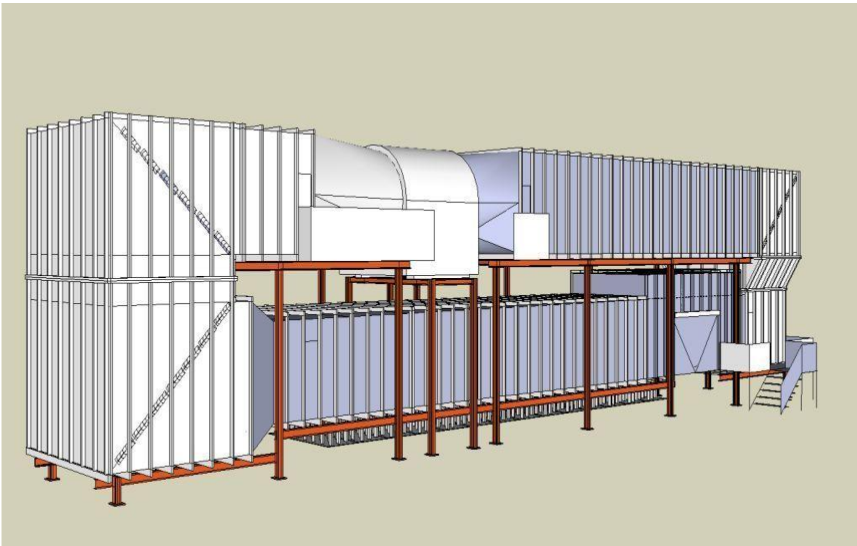


Figure 8: Schematic of the closed-circuit wind tunnel.

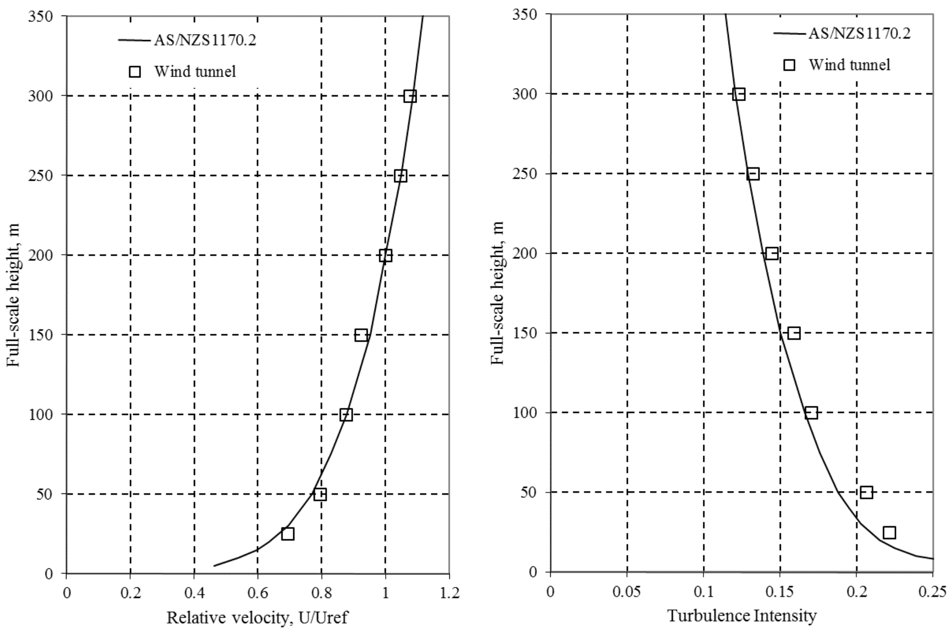


Figure 9: Mean velocity and turbulence profiles (Terrain Category 3) approaching the model.

A model of the proposed development and surrounds to a radius of 570 m was constructed at a scale of 1:400, which was consistent with the modelled atmospheric flow, permitted a reasonable test model size with an adequate portion of the adjoining environment to be included in a proximity model, Figure 10, and was within wind tunnel blockage limitations. Significant variations in the building surface were formed into the model. The models were mounted on the turntable located near the downstream end of the wind tunnel test section, Figure 11 and Figure 13. The turntable permitted rotation of the modelled area for examination of velocities from any approach wind direction. Additional photos of the test models are included in **Appendix 1.**

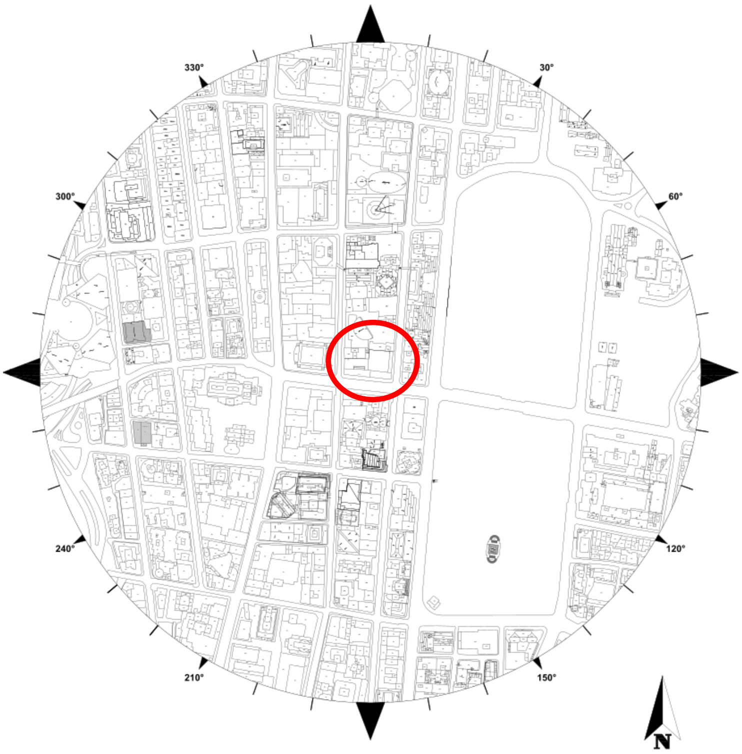


Figure 10: Project location and turntable layout – Configuration A (Existing)

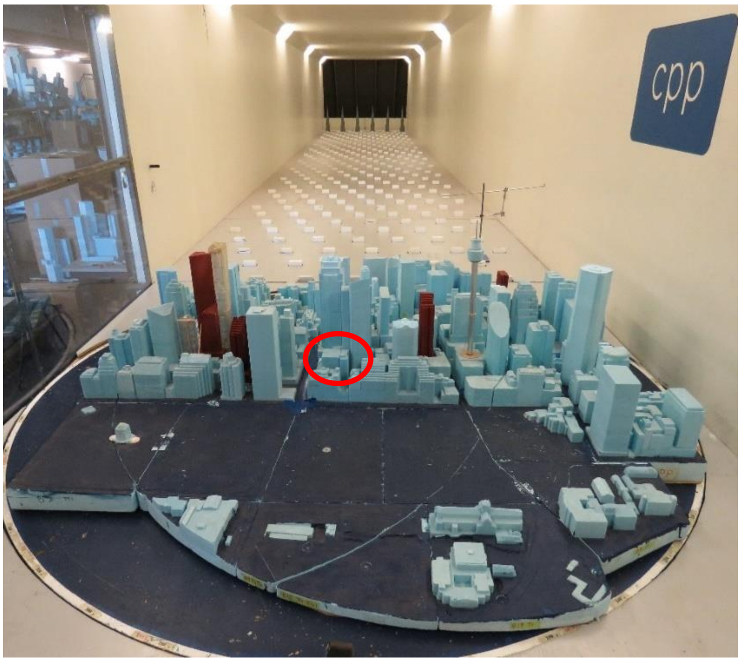


Figure 11: Existing proximity model in the wind tunnel viewed from the east.

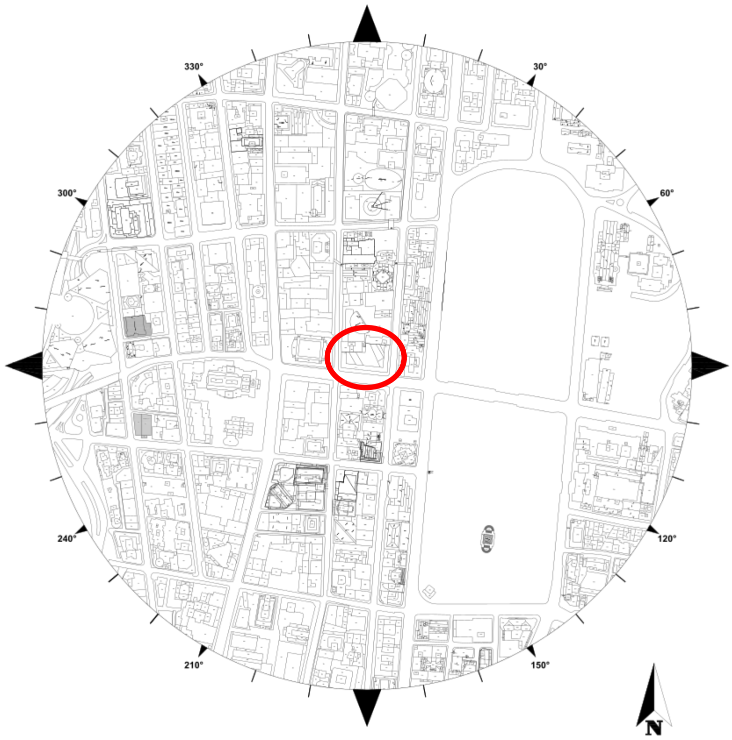


Figure 12: Project location and turntable layout – Configuration B (Planning Envelope)

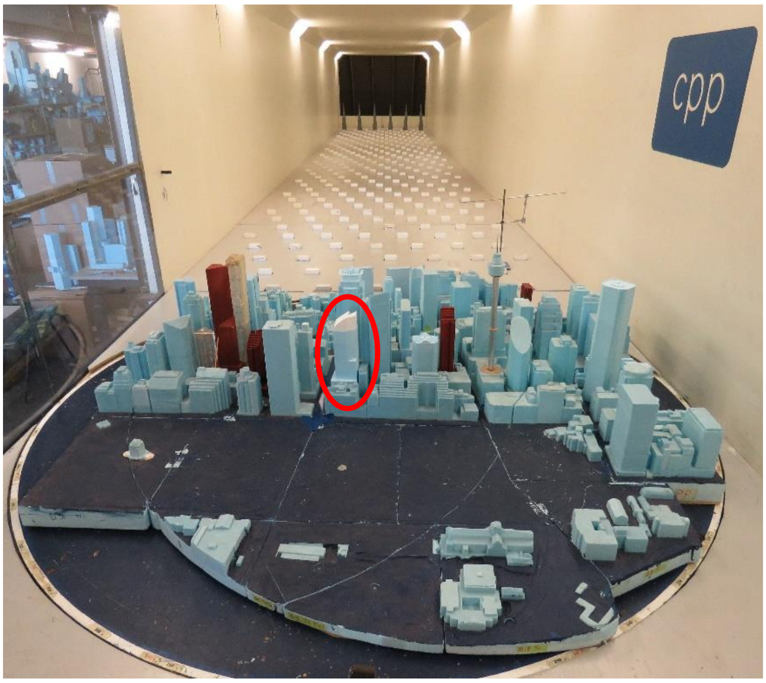


Figure 13: Proposed Pitt Street North OSD planning envelope model in the wind tunnel viewed from the east.

4. Environmental Wind Criteria

Over the years, a number of researchers have added to the knowledge of wind effects on pedestrians by suggesting criteria for comfort and safety. Because pedestrians will tolerate higher wind speeds for a smaller period of time than for lower wind speeds, these criteria provide a means of evaluating the overall acceptability of a pedestrian location. Also, a location can be evaluated for its intended use, such as for an outdoor café or a footpath. One of the most widely accepted set of criteria was developed by Lawson (1990), which is described in Table 2.

Lawson's criteria have categories for comfort, based on wind speeds exceeded 5% of the time, allowing planners to judge the usability of locations for various intended purposes ranging from "Business Walking" to "Pedestrian sitting". The level and severity of these comfort categories can vary based on individual preference, so calibration to the local wind environment is recommended when evaluating the Lawson ratings. The criteria also include a distress rating, for safety assessment, which is based on occasional (once or twice per year) wind speeds . In both cases, the wind speed used is the larger of a mean or gust equivalent-mean (GEM) wind speed. The GEM is defined as the peak gust wind speed divided by 1.85; this is intended to account for locations where the gustiness is the dominant characteristic of the wind.

Assessment using the Lawson criteria provides a similar classification as using once per annum gust criteria, but also provides significantly more information regarding the serviceability wind climate. The current City of Sydney (2012) DCP specifies wind effects not to exceed 10 m/s along Park, Castlereagh, and Pitt Streets, as the area is classified as an 'active frontage'. From discussions with Council, this is a once per annum gust wind speed similar to the 2004 DCP, but is meant to be interpreted as a comfort level criterion to promote outdoor café style activities and is not a distress requirement. The wind speed criteria in the DCP are based on the work of Melbourne (1978), and use an infrequent gust event to characterise conditions at a site which often produces conservative results. The 5% of the time event is considered a more appropriate comfort threshold for a public precinct.

Table 2: Summary of Lawson criteria

Comfort (maximum of mean or gust equivalent mean (GEM+.) wind speed exceeded 5% of the time)		
< 4 m/s	Pedestrian Sitting (considered to be of long duration)	● (blue)
4 - 6 m/s	Pedestrian Standing (or sitting for a short time or exposure)	● (green)
6 - 8 m/s	Pedestrian Walking	● (yellow)
8 - 10 m/s	Business Walking (objective walking from A to B or for cycling)	● (orange)
> 10 m/s	Uncomfortable	● (red)
Distress (maximum of mean or GEM wind speed exceeded 0.022% of the time)		
<15 m/s	not to be exceeded more than two times per year (or one time per season) for general access area	○ (black)
<20 m/s	not to be exceeded more than two times per year (or one time per season) where only able-	○ (yellow)

Comfort (maximum of mean or gust equivalent mean (GEM†˙) wind speed exceeded 5% of the time)	
	bodied people would be expected; frail or cyclists would not be expected

Note: †˙ The gust equivalent mean (GEM) is the peak 3 s gust wind speed divided by 1.85.

5. Data Acquisition and Results

5.1. Velocities

Velocity profile measurements were taken to verify that appropriate boundary layer flow approaching the site was established and to determine the likely pedestrian level wind climate around the test site. Pedestrian wind measurements and analysis are described in Section 4.1.2. All velocity measurements were made with hot-film anemometers, which were calibrated against a Pitot-static tube in the wind tunnel. The calibration data were described by a King's Law relationship (King, 1914).

5.1.1. Velocity Profiles

Mean velocity and turbulence intensity profiles for the boundary layer flow approaching the model are shown in Figure 9. Turbulence intensities are related to the local mean wind speed. These profiles have the form as defined in Standards Australia (2011) and are appropriate for the approach conditions.

5.1.2. Pedestrian Winds

The site is located in the Sydney CBD, surrounded in most directions by medium to high-rise structures. To the east and north-east is the open region of Hyde Park, which will allow the development of stronger winds from these directions. Ground conditions in such densely built up areas are particularly affected by the interaction of larger buildings with prevailing strong winds.

For this report, wind speed measurements were recorded at 24 locations, as described in Table 1, to evaluate pedestrian wind comfort and safety in and around the project site shown in Figure 15 to Figure 17. Velocity measurements were made at the model scale equivalent of 1.5 to 2.1 m above the surface for 16 wind directions at 22.5° intervals. Locations were chosen to determine the degree of pedestrian wind comfort and safety at building corners where relatively severe conditions are frequently found, near building entrances and passageways, and at upper level outdoor locations.

The hot-film signal was sampled for a period corresponding to one hour in prototype. All velocity data were digitally filtered to obtain the two to three second running mean wind speed at each point; this is the minimum size of a gust affecting a pedestrian and is the basis for the various acceptability criteria. These local wind speeds, U, were normalised by the tunnel reference velocity, U_{ref} . Mean and turbulence statistics were calculated and used to calculate the normalised effective peak gust using:

$$\frac{U_{pk}}{U_{ref}} = \frac{U + 3U_{rms}}{U_{ref}}$$

The mean and gust equivalent mean velocities relative to the free stream wind tunnel reference velocity at a full-scale elevation of 200 m are plotted in polar form in Appendix 2. The graphs show velocity magnitude and the approach wind direction for which that velocity was measured. The polar plots aid in visualisation of the effects of the nearby structures or topography, the relative significance of various wind azimuths, and whether the mean or gust wind speed is of greater importance.

To enable a quantitative assessment of the wind environment in the region, the wind tunnel data were combined with wind frequency and direction information measured by the Bureau of Meteorology at a standard height of 10 m at Sydney Airport from 1995 to 2017, Figure 14.

From these data, directional criterion lines for the Lawson rating wind speeds have been calculated and included on the polar plots in Appendix 2; this gives additional information regarding directional sensitivity at each location.

The criteria of Lawson consider the integration of the velocity measurements with local wind climate statistical data summarised in Figure 14 to rate each location. From the cumulative wind speed distributions for each location, the percentage of time each of the Lawson comfort rating wind speeds are exceeded are presented in tabular form under the polar plots in Appendix 2. In addition to the rating wind speeds, the percentage of time that 2 m/s is exceeded is also reported. This has been provided as it has been found that the limiting wind speed for long-term stationary activities such as fine outdoor dining should be about 2 to 2.5 m/s rather than 4 m/s.

Interpretation of these wind levels can be aided by the description of the effects of wind of various magnitudes on people. The earliest quantitative description of wind effects was established by Sir Francis Beaufort in 1806, for use at sea; the Beaufort scale is reproduced in Table 3 including qualitative descriptions of wind effects.

The tables in Appendix 2 additionally provide the wind speed exceeded 5% and 0.022% of the time for direct comparison with the Lawson comfort and distress criteria, and the associated Lawson ratings for both mean and GEM wind speeds. A colour coded summary assessment of pedestrian wind comfort and safety with respect to the Lawson criteria is presented in Figures 15-17 for each test location. The implications of the results are discussed in Section 5.

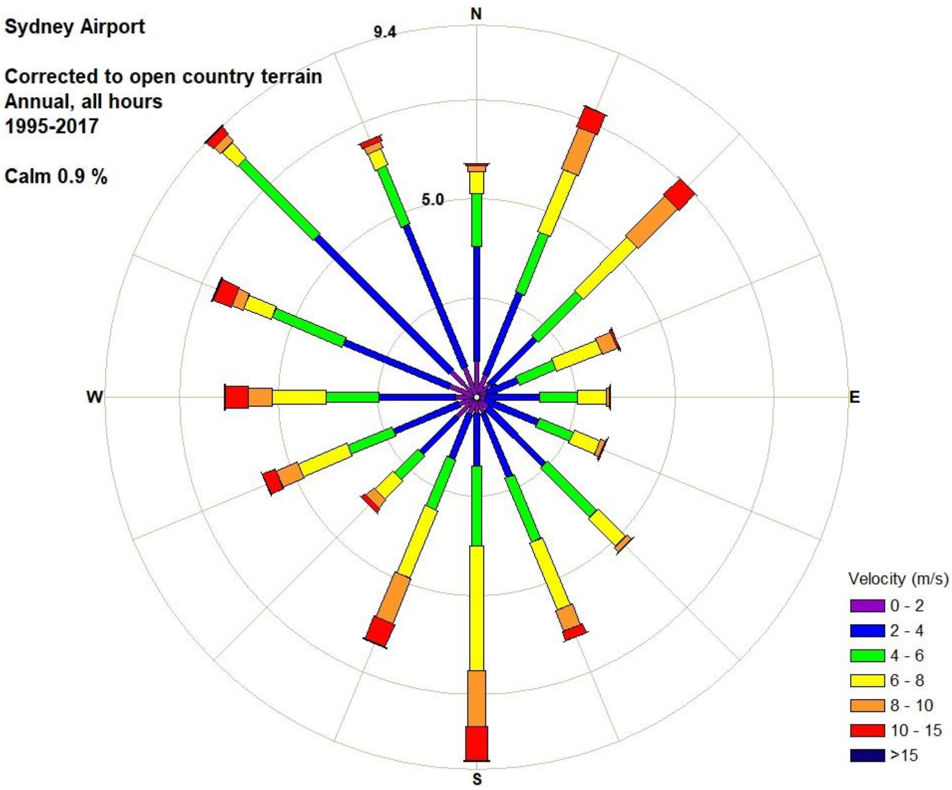


Figure 14: Wind rose of speed and direction measured at Sydney Airport

Table 3: Summary of wind effects on people, Penwarden (1973)

Description	Beaufort Number	Speed (m/s)	Effects
Calm, light air	0, 1	0–2	Calm, no noticeable wind.
Light breeze	2	2–3	Wind felt on face.
Gentle breeze	3	3–5	Wind extends light flag. Hair is disturbed. Clothing flaps
Moderate breeze	4	5–8	Raises dust, dry soil, and loose paper. Hair disarranged.
Fresh breeze	5	8–11	Force of wind felt on body. Drifting snow becomes airborne. Limit of agreeable wind on land.
Strong breeze	6	11–14	Umbrellas used with difficulty. Hair blown straight. Difficult to walk steadily. Wind noise on ears unpleasant. Windborne snow above head height (blizzard).
Near gale	7	14–17	Inconvenience felt when walking.
Gale	8	17–21	Generally impedes progress. Great difficulty with balance in gusts.
Strong gale	9	21–24	People blown over by gusts.

6. Discussion

The wind climatology chart of Figure 14 indicates that the most frequent strong winds are from the north-east, south and west quadrants. The locations tested around the development site are susceptible to winds from these directions, depending on the relative position of the location tested to the geometry of the proposed development and surrounds. The influence of wind direction on the suitability of a location for an intended purpose can be ascertained from the polar plots in Appendix 2. The polar plots show the severity, distribution, and frequency of steady winds and gusts from 16 directions at 22.5° intervals.

A summary of the expected wind rating targets based on the intended use of the space at the investigated locations and the wind tunnel results, including the Lawson comfort and safety ratings, is provided in Table 4.

The primary conclusions of the pedestrian study can be understood by reviewing the colour coded images of Figure 15 (showing existing conditions) and Figures 16 and 17 (showing proposed envelope conditions), which depict the locations selected for investigation along with the Lawson comfort and distress criteria ratings. The central colour indicates the comfort rating for the location, and the colour of the outer ring indicates whether the location passes or exceeds the distress criterion, Table 2. Interpretation of these wind levels can be aided by the description of the effects of wind of various magnitudes on people found in Table 3.

Note that testing was performed without existing and proposed trees, and other plantings to provide a worst-case assessment;. Heavy landscape planting typically reduces the wind speeds by less than 10%. Mitigation measures are likely to be required for orange locations and may be necessary for other locations depending on the intended use of the space. Although conditions may be classified as acceptable, there may be certain wind directions that cause regular strong events, and these can be determined by an inspection of the polar plots in Appendix 2.

Table 4: Summary of expected wind rating targets versus wind tunnel results.

Description / Location		Target	Wind Tunnel Results			
		Comfort rating, 5% exceedance wind speed (m/s)	Comfort rating, 5% exceedance wind speed (m/s)	Meets target Y/N	Safety rating, 0.022% exceedance wind speed (m/s)	Notes
Existing	1	>6 to 8	4.6	Y	8.6	Distress criterion exceeded at several locations close to larger towers.
	2	>6 to 8	5.8	Y	10.7	
	3	>6 to 8	5.4	Y	10.3	
	4	>6 to 8	4.9	Y	9.9	
	5	>6 to 8	8.1	N	15.6	
	6	>6 to 8	5.0	Y	10.8	
	7	>6 to 8	6.7	Y	13.3	
	8	>6 to 8	6.1	Y	12.3	
	9	>6 to 8	7.8	Y	14.9	
	10	>6 to 8	7.1	Y	12.7	
	11	>6 to 8	7.5	Y	15.7	
	12	>6 to 8	5.3	Y	10.1	
	13	>6 to 8	8.7	N	17.2	
	14	>6 to 8	8.2	N	15.7	
Proposed	1.1	>6 to 8	5.1	Y	10.2	Points 8.1 and 9.1 suitable for Business Walking, exceed distress criterion
	2.1	>6 to 8	5.9	Y	11.4	
	3.1	>6 to 8	6.0	Y	11.4	
	4.1	>6 to 8	6.6	Y	13.1	
	5.1	>6 to 8	6.9	Y	12.5	
	6.1	>6 to 8	6.7	Y	13.1	
	7.1	>6 to 8	7.3	Y	14.3	
	8.1	>6 to 8	8.6	N	15.8	
	9.1	>6 to 8	8.4	N	16.0	
	15.1	>6 to 8	6.1	Y	11.7	
	16.1	>6 to 8	6.7	Y	13.7	
	17.1	>6 to 8	5.8	Y	11.1	
	18.1	>6 to 8	3.8	Y	7.8	
	19.1	>6 to 8	6.5	Y	13.1	
	20.1	>6 to 8	5.2	Y	10.6	
	21.1	>6 to 8	7.9	Y	16.2	
Podium	22.1	>6 to 8	7.3	Y	14.3	
	23.1	>6 to 8	8.6	N	17.9	
	24.1	>6 to 8	4.5	Y	9.0	

LEGEND

Comfort Criteria					
OD	Outdoor Dining	PSt	Pedestrian Standing	BW	Business Walking
PSi	Pedestrian Sitting	PW	Pedestrian Walking	U	Uncomfortable
Distress/Safety Criteria					
Pass	Passes safety criteria	AB	Able bodied	Fail	Fails safety criteria

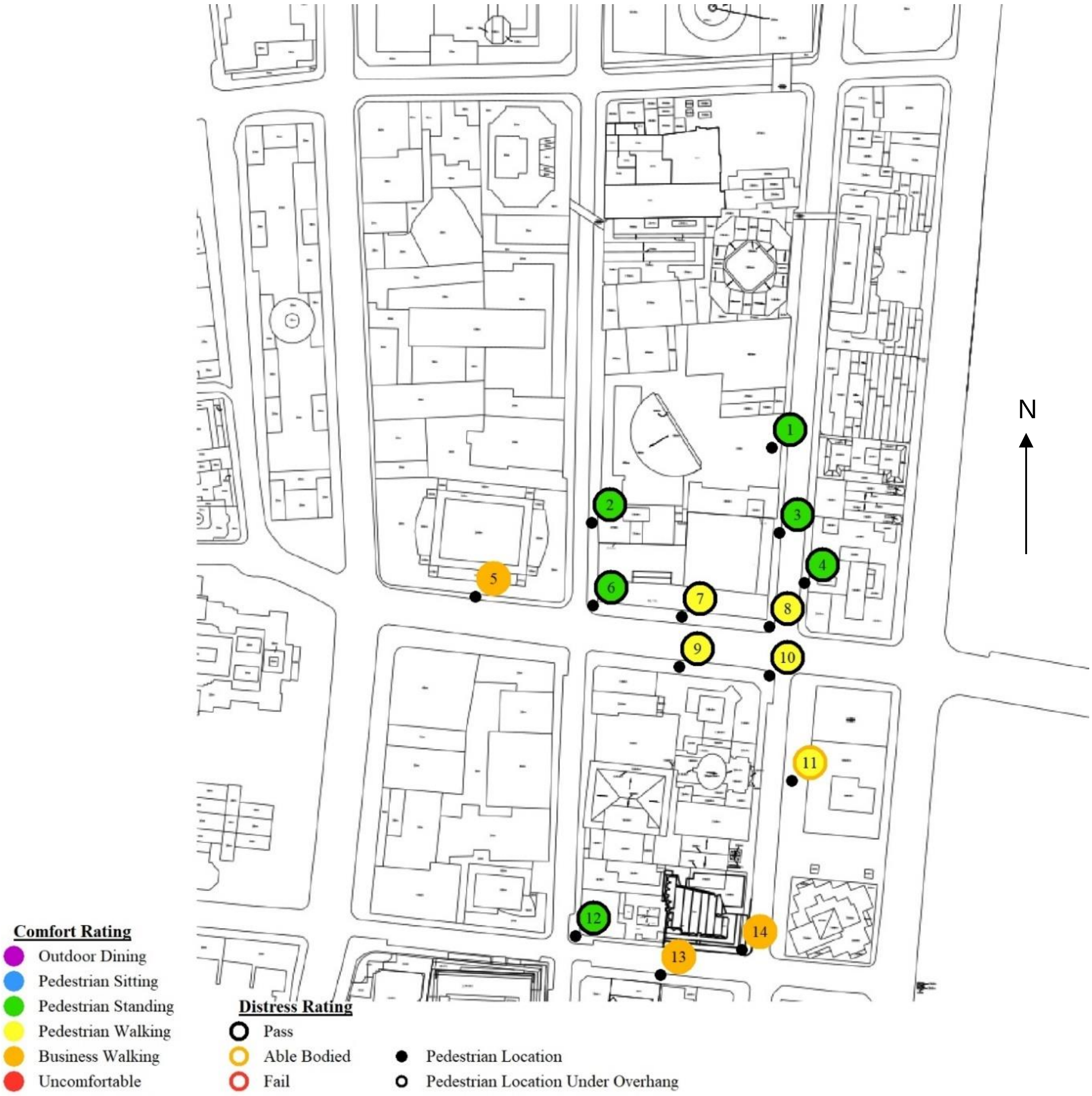


Figure 15: Pedestrian wind speed measurement locations with comfort/distress ratings – Configuration A (Existing).

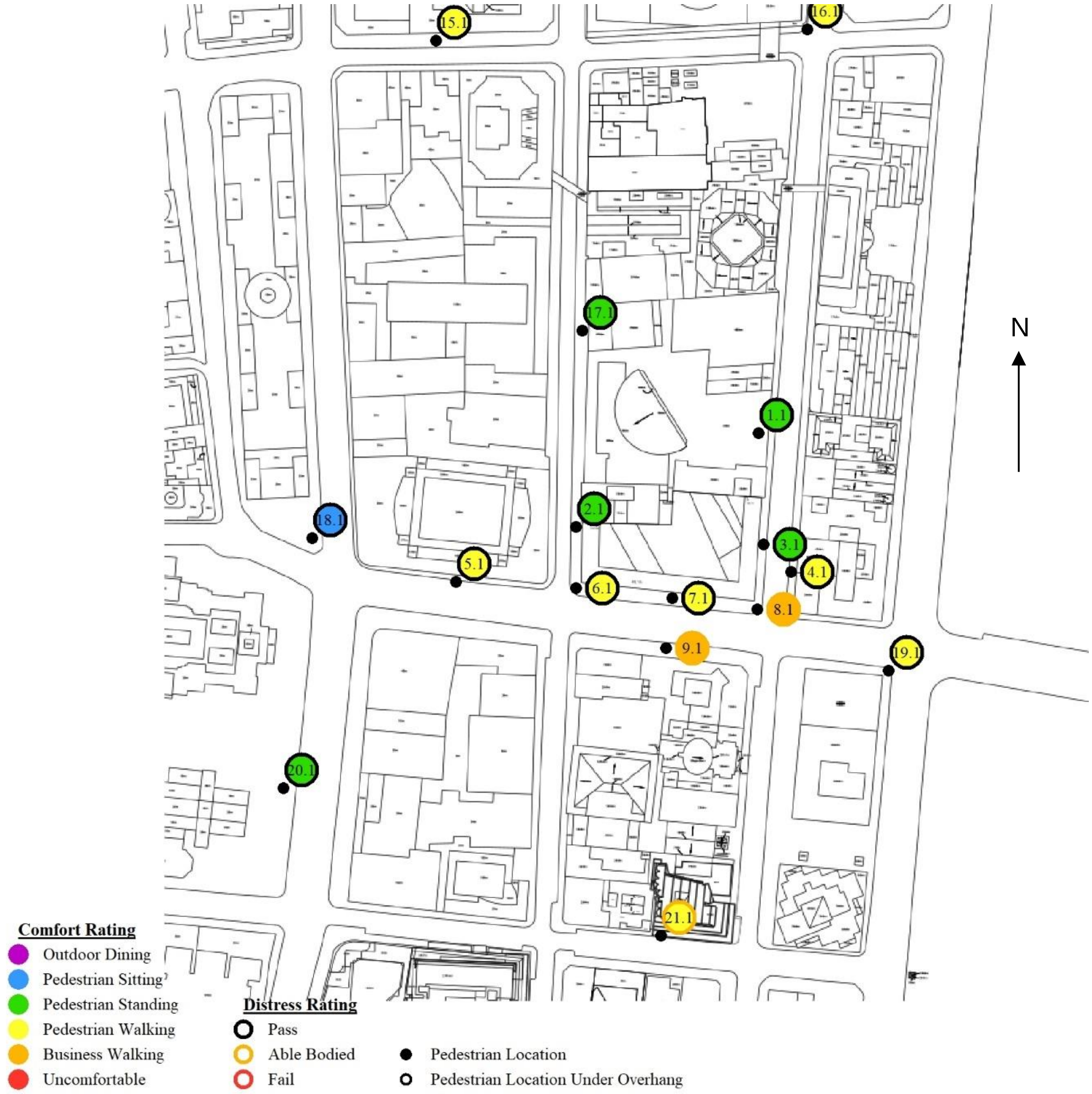


Figure 16: Pedestrian wind speed measurement locations with comfort/distress ratings – Configuration B (Proposed envelope).

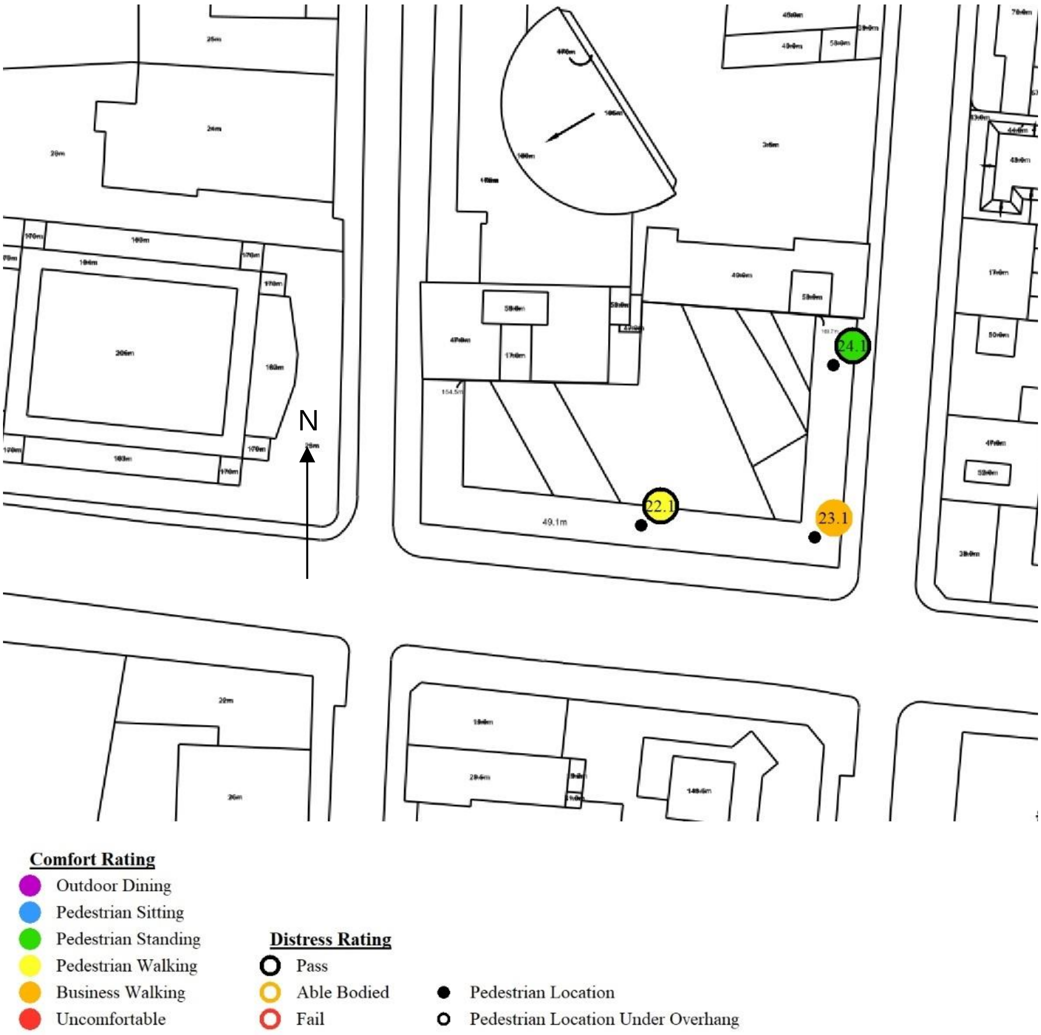


Figure 17: Pedestrian wind speed measurement locations with comfort/distress ratings – Configuration B (Proposed envelope) – Podium roof locations

In the existing massing configuration, conditions around the site are generally classified in the Pedestrian Standing and Pedestrian Walking categories. To the immediate south of the subject site on Park Street, locations 7-10 meet the Walking criterion. This area is most strongly affected by wind from the east and west quadrants, which are channelled along Park Street. Locations 1-4 and location 6 are more protected from these flows and are calmer as a result.

In the existing configuration, several locations in the surrounding area were found to experience stronger wind conditions, with locations 5, 11, 13 and 14 falling into the Able-Bodied category of the Lawson distress criteria. It is noted that these windier results are mostly found close to taller buildings and on the east-west running streets. In particular, location 5 is affected by downwash from the Citibank tower at 2 Park Street during winds from the north-east and east.

With the inclusion of the planning envelope model, a general increase in wind speeds on the Park Street site boundary is noted, with locations 6, 8, and 9 changing comfort category. Location 4 also moves from standing to walking classification. Locations 1-3 are mostly unaffected by the inclusion of the new building envelope. Interestingly, conditions at location 5 improve significantly relative to the existing configuration. This is likely a result of a modification to the flow pattern between the neighbouring ANZ and Citibank towers during winds from the north-east caused by the addition of the new building. The resulting shielding reduces the intensity of downwash reaching the ground plane at this location.

The distress rating of locations 8 and 9 are degraded by the addition of the new building envelope, falling into the Able-Bodied band. The critical directions are evident in the relevant polar plots in Appendix 2. Location 8.1 is affected by downwash flow caused by winds from the north-east, as well as an increase in channelled flow accelerating around the site corner during winds from the east and west. The increase in speeds at location 9.1 is mainly due to the effect of wind from the north-east, which is directed toward this area by the new building. In the context of the surrounding massing and street grid pattern, locations 13 and 14 are comparable to 8.1 and 9.1, and experience similar conditions in the existing configuration.

It would be suggested to mitigate the strong wind conditions occurring around the south-east corner of the site by incorporating a street-level awning or colonnade extending around this corner and along Castlereagh Street. A similar approach would be suggested along the Park Street boundary of the site. Increasing the setback distance of the building from the podium edge would also be expected to improve wind conditions on the ground plane. The detail of these treatments is outside the scope of the current work and would be subject to further studies.

On the podium roof, wind conditions range from Pedestrian Standing to Business Walking (locations 22.1, 23.1, and 24.1), Figure 17. Location 23.1 on the south-east corner is particularly windy, falling into the Able Bodied distress classification. Significant mitigation measures such as horizontal awnings and vertical screening elements would be required for areas on the podium roof intended for medium or long-term stationary activity.

7. References

American Society of Civil Engineers (1999), Wind Tunnel Model Studies of Buildings and Structures (ASCE Manual of Practice Number 67).

American Society of Civil Engineers (2010), Minimum Design Loads for Buildings and Other Structures (ASCE 7–10).

Australasian Wind Engineering Society (2001), Wind Engineering Studies of Buildings (AWES-QAM-1-2001).

Cermak, J.E. (1971), "Laboratory Simulation of the Atmospheric Boundary Layer," AIAA Jl., Vol. 9, September.

Cermak, J.E. (1975), "Applications of Fluid Mechanics to Wind Engineering," A Freeman Scholar Lecture, ASME Journal of Fluids Engineering, Vol. 97, No. 1, March.

Cermak, J.E. (1976), "Aerodynamics of Buildings," Annual Review of Fluid Mechanics, Vol. 8, pp. 75 – 106.

King, C.V. (1914), "On the Convection of Heat from Small Cylinders in a Stream of Fluid," Philosophical Transactions of the Royal Society, London, Vol. A214, p. 373.

Lawson, T.V. (1990), "The Determination of the Wind Environment of a Building Complex before Construction" Department of Aerospace Engineering, University of Bristol, Report Number TVL 9025.

Penwarden, A.D. (1973), "Acceptable wind speeds in towns", Building Science, Vol.8, pp. 259-267.

Standards Australia (2011), Australian/New Zealand Standard, Structural Design Actions, Part 2: Wind Actions (AS/NZS1170 Pt.2).

Appendix 1 – Additional Photographs of the wind tunnel model

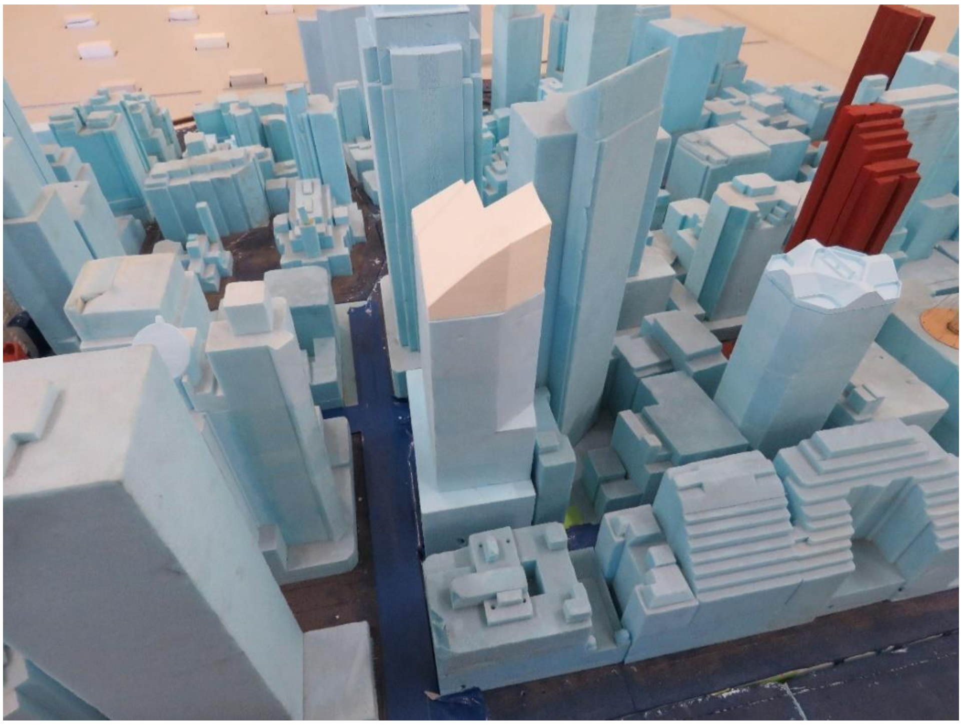


Figure 18: Proposed Pitt Street North OSD model in the wind tunnel viewed from the east.

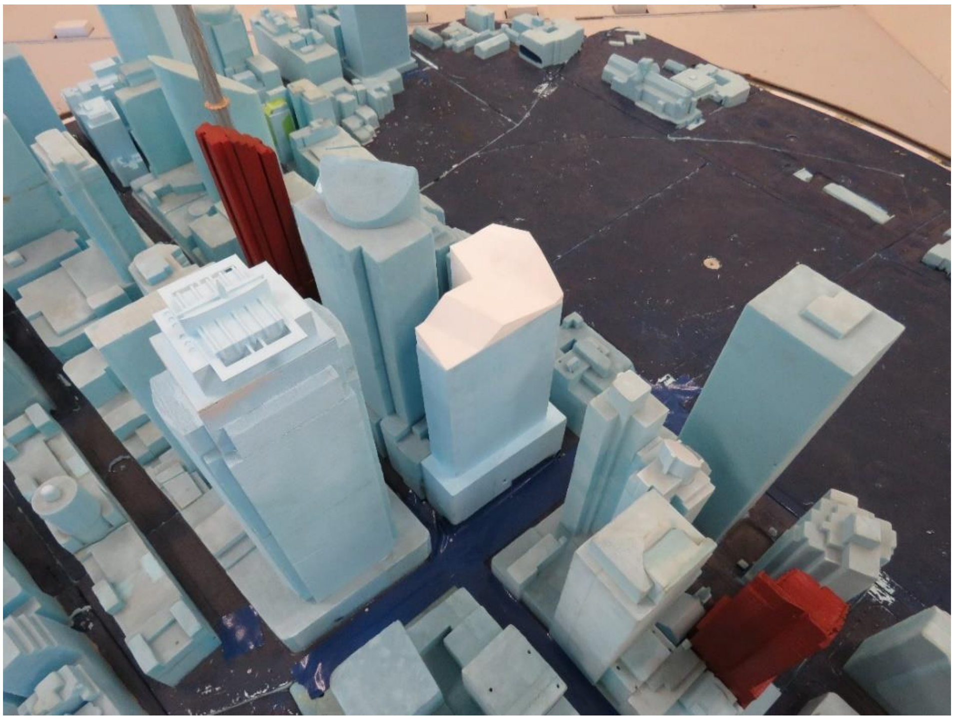
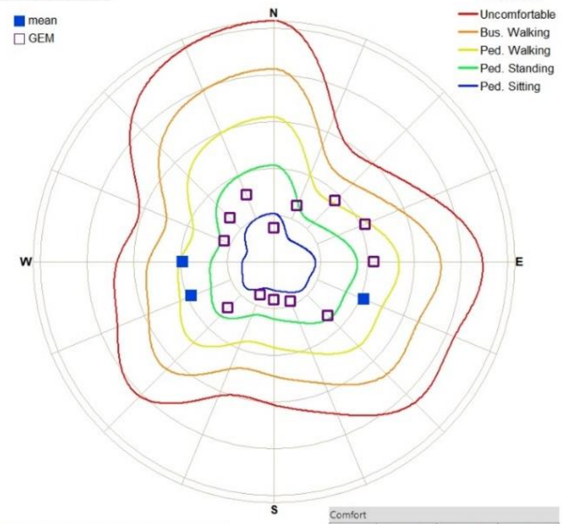


Figure 19: Proposed Pitt Street North OSD model in the wind tunnel viewed from the south-west

Appendix 2 – Directional wind results

Existing

LOCATION 1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	25.51	38.25	38.60
4	4.68	9.12	9.58
6	0.47	1.02	1.12
8	0.03	0.07	0.08
10	0.00	0.00	0.00

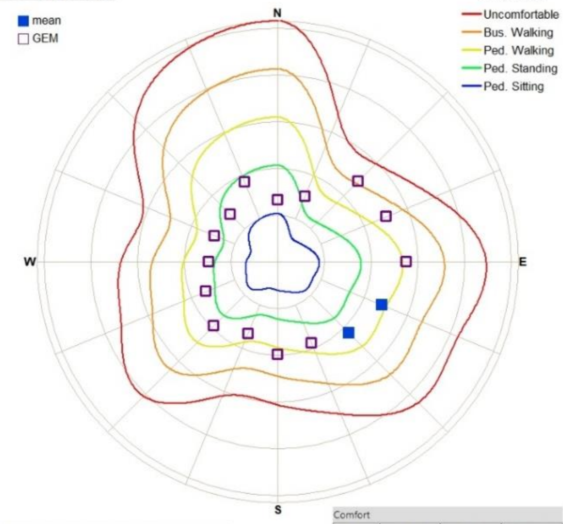
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	3.9	4.6	4.6
Rating	Ped Sitting	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	8.2	8.5	8.6
Rating	Pass	Pass	Pass

LOCATION 2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	42.50	57.27	57.95
4	13.44	19.66	20.50
6	3.01	4.42	4.54
8	0.48	0.62	0.64
10	0.05	0.07	0.08

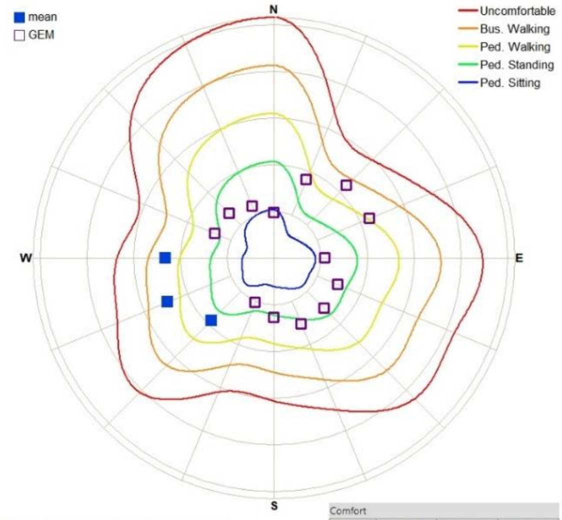
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	5.3	5.8	5.8
Rating	Ped Standing	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	10.5	10.7	10.7
Rating	Pass	Pass	Pass

LOCATION 3



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	31.40	47.62	48.34
4	5.64	13.51	14.59
6	1.19	2.76	3.16
8	0.20	0.33	0.44
10	0.02	0.02	0.04

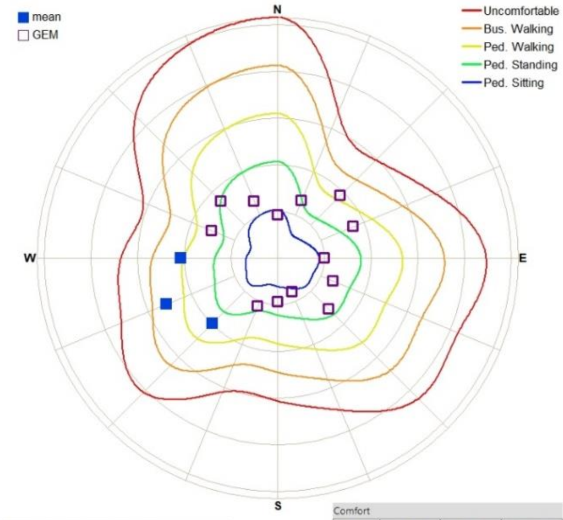
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	4.1	5.3	5.4
Rating	Ped Standing	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.9	10.0	10.3
Rating	Pass	Pass	Pass

LOCATION 4



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	22.84	41.55	42.22
4	5.16	9.51	10.47
6	1.05	1.48	1.84
8	0.17	0.13	0.23
10	0.02	0.01	0.02

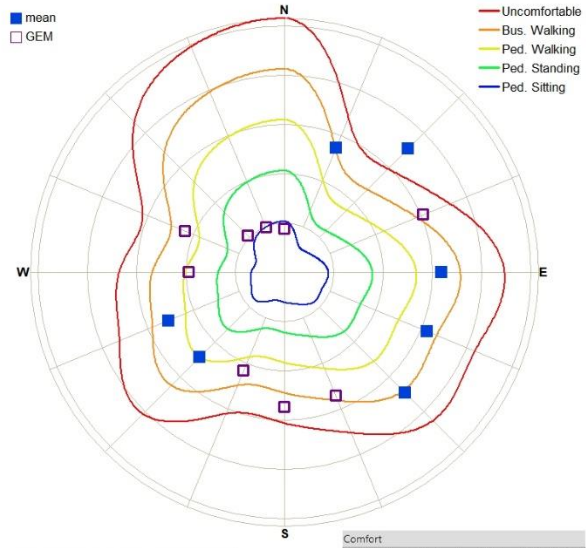
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	4.0	4.7	4.9
Rating	Ped Sitting	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.8	9.1	9.9
Rating	Pass	Pass	Pass

LOCATION 5



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	62.17	63.81	64.86
4	35.44	36.44	38.25
6	14.69	14.59	16.80
8	4.98	4.84	5.67
10	1.48	1.42	1.67

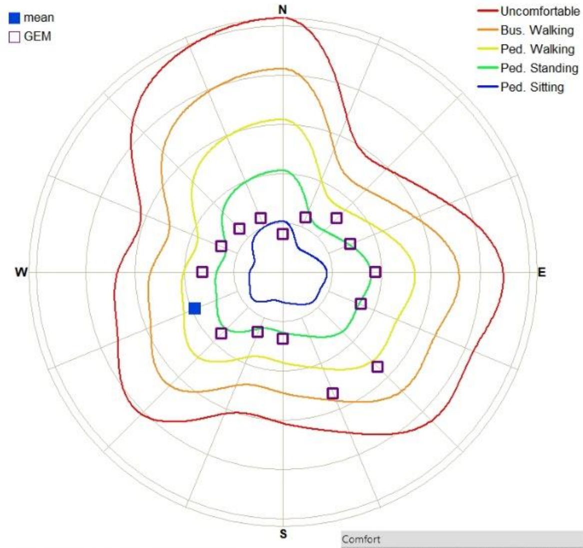
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	7.9	7.9	8.1
Rating	Ped Walking	Ped Walking	Bus Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	15.6	15.2	15.6
Rating	Able Body	Able Body	Able Body

LOCATION 6



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	35.39	49.58	49.67
4	6.47	12.23	12.37
6	0.81	1.99	2.02
8	0.11	0.28	0.28
10	0.02	0.05	0.05

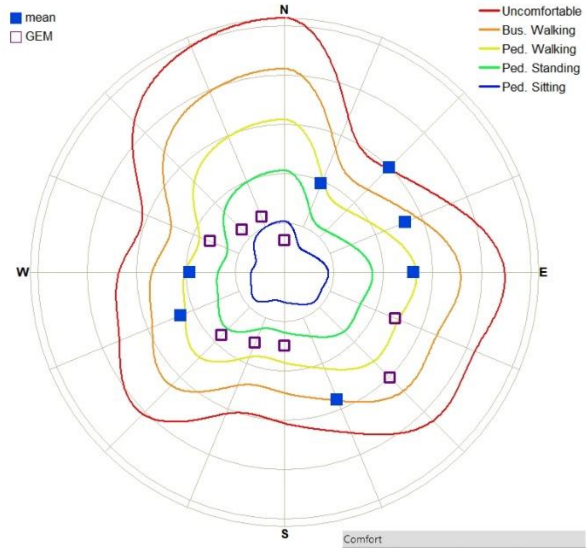
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	4.2	5.0	5.0
Rating	Ped Standing	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.7	10.8	10.8
Rating	Pass	Pass	Pass

LOCATION 7



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	50.18	58.12	58.99
4	21.88	23.85	25.64
6	7.37	6.54	8.23
8	2.14	1.24	2.24
10	0.50	0.24	0.52

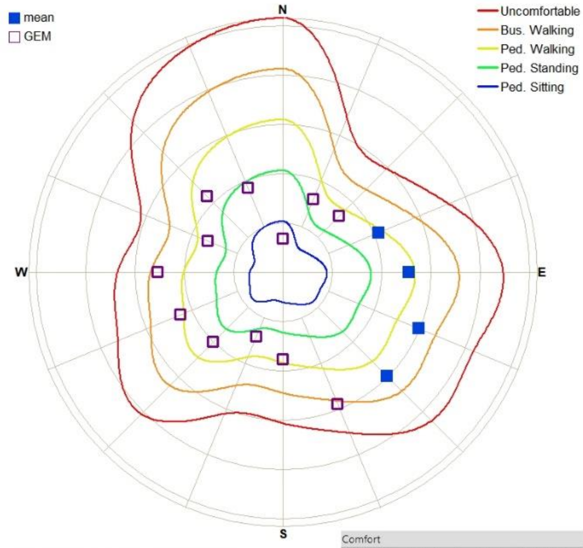
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	6.5	6.3	6.7
Rating	Ped Walking	Ped Walking	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	13.3	12.0	13.3
Rating	Pass	Pass	Pass

LOCATION 8



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	53.01	63.12	63.39
4	16.17	23.38	24.08
6	3.58	4.92	5.52
8	0.55	0.85	0.94
10	0.09	0.15	0.16

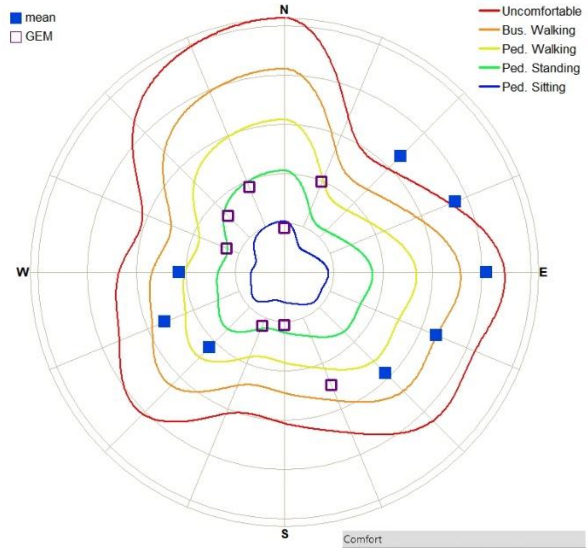
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	5.6	5.9	6.1
Rating	Ped Standing	Ped Standing	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	11.5	12.2	12.3
Rating	Pass	Pass	Pass

LOCATION 9



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	49.19	58.14	59.82
4	25.16	23.44	27.17
6	11.10	7.85	11.69
8	4.50	1.70	4.62
10	1.31	0.30	1.33

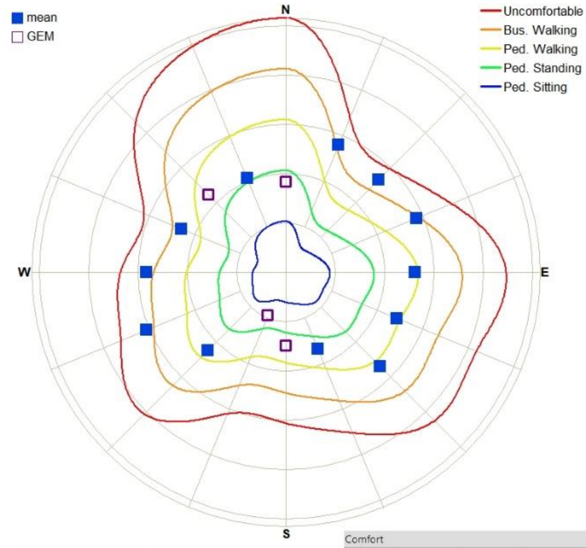
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	7.7	6.6	7.8
Rating	Ped Walking	Ped Walking	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	14.9	12.3	14.9
Rating	Pass	Pass	Pass

LOCATION 10



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	64.11	65.87	67.83
4	27.73	25.02	28.06
6	10.49	7.56	10.53
8	2.72	1.48	2.73
10	0.50	0.22	0.50

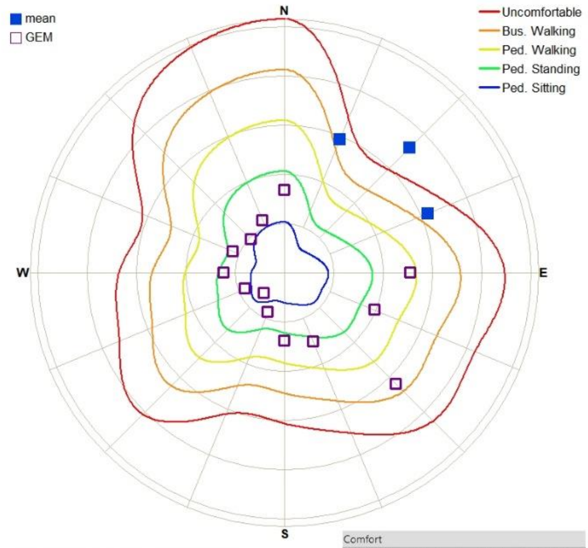
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	7.1	6.6	7.1
Rating	Ped Walking	Ped Walking	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	12.7	11.7	12.7
Rating	Pass	Pass	Pass

LOCATION 11



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	39.82	46.64	47.48
4	15.64	17.61	19.05
6	8.37	7.00	9.48
8	3.97	1.90	4.12
10	1.42	0.38	1.45

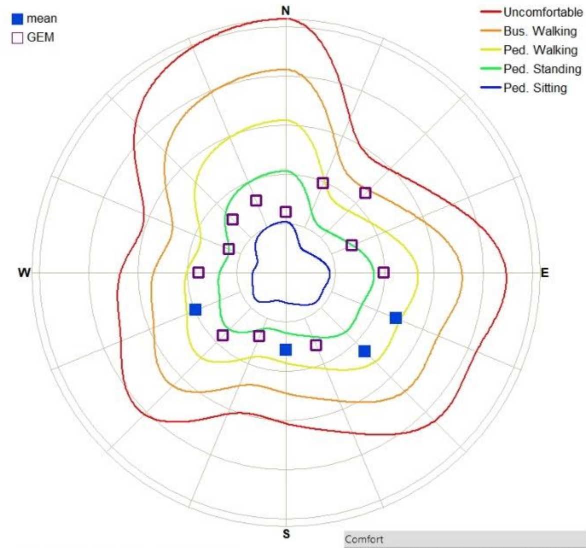
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	7.3	6.6	7.5
Rating	Ped Walking	Ped Walking	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	15.7	12.9	15.7
Rating	Able Body	Pass	Able Body

LOCATION 12



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	50.03	54.57	55.55
4	13.56	14.52	15.85
6	1.88	2.62	2.85
8	0.18	0.31	0.33
10	0.01	0.03	0.03

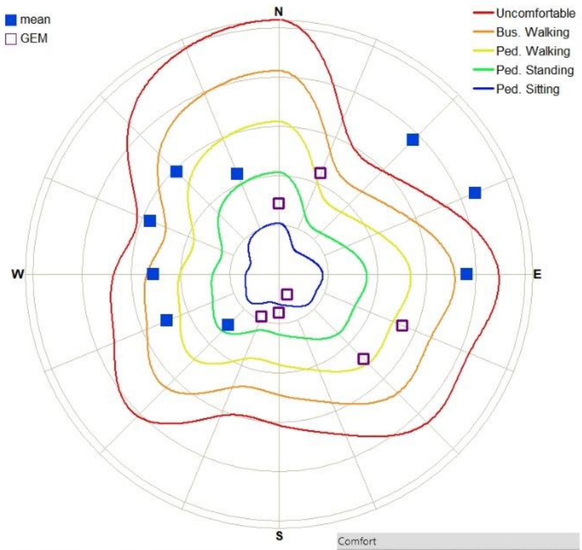
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	5.1	5.2	5.3
Rating	Ped Standing	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.2	10.1	10.1
Rating	Pass	Pass	Pass

LOCATION 13



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	53.38	53.96	59.18
4	25.41	21.91	27.72
6	12.07	9.11	12.82
8	6.52	3.18	6.60
10	2.99	0.79	2.99

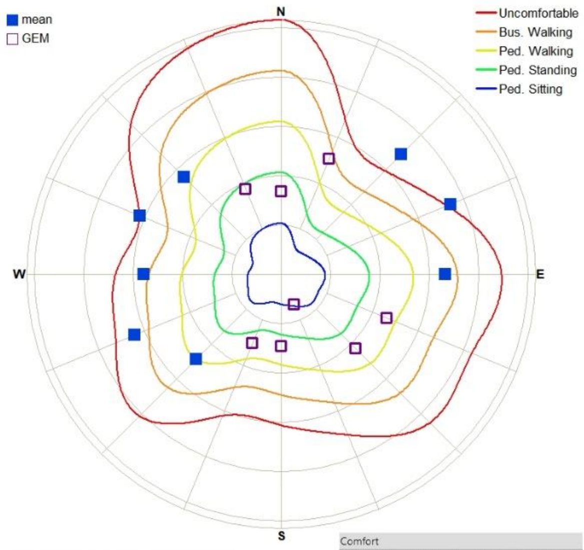
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	8.7	7.1	8.7
Rating	Bus Walking	Ped Walking	Bus Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	17.2	14.0	17.2
Rating	Able Body	Pass	Able Body

LOCATION 14



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	63.54	63.49	68.27
4	27.53	25.43	30.64
6	13.31	9.84	13.71
8	5.72	3.03	5.78
10	1.93	0.65	1.94

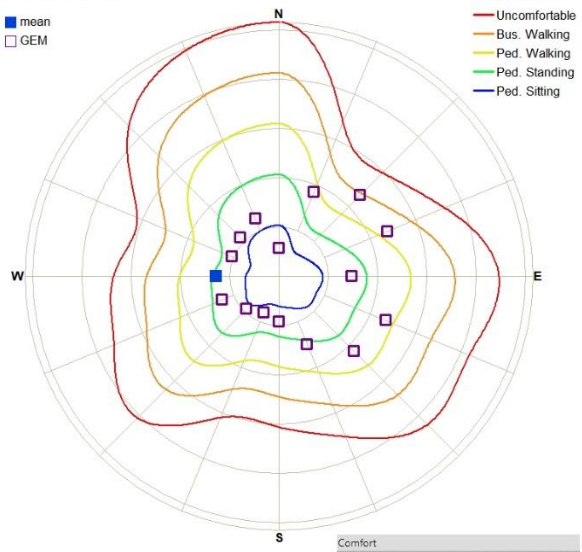
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	8.2	7.2	8.2
Rating	Bus Walking	Ped Walking	Bus Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	15.7	13.5	15.7
Rating	Able Body	Pass	Able Body

LOCATION 1.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	26.56	39.98	40.12
4	3.91	11.38	11.43
6	0.25	2.65	2.65
8	0.00	0.34	0.34
10	0.00	0.04	0.04

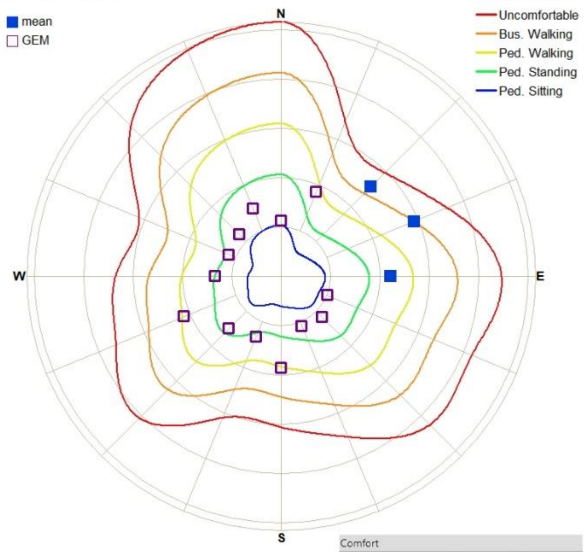
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	3.8	5.1	5.1
Rating	Ped Sitting	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	7.2	10.2	10.2
Rating	Pass	Pass	Pass

LOCATION 2.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	32.31	46.42	47.08
4	11.11	14.67	15.91
6	3.97	2.88	4.80
8	0.84	0.30	0.90
10	0.15	0.02	0.15

Comfort

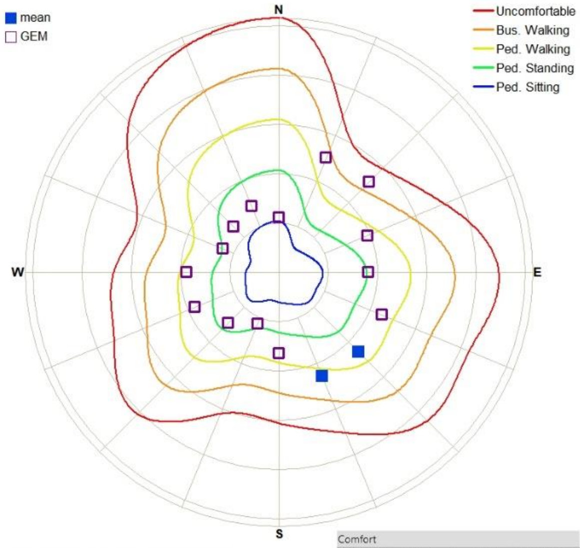
(5%)	MEAN	GEM	COMBINED
V (m/s)	5.5	5.3	5.9
Rating	Ped Standing	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	11.4	9.8	11.4
Rating	Pass	Pass	Pass

Proposed planning envelope

LOCATION 3.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	44.97	54.87	55.27
4	11.98	18.96	19.56
6	1.26	5.07	5.21
8	0.10	1.00	1.03
10	0.01	0.17	0.18

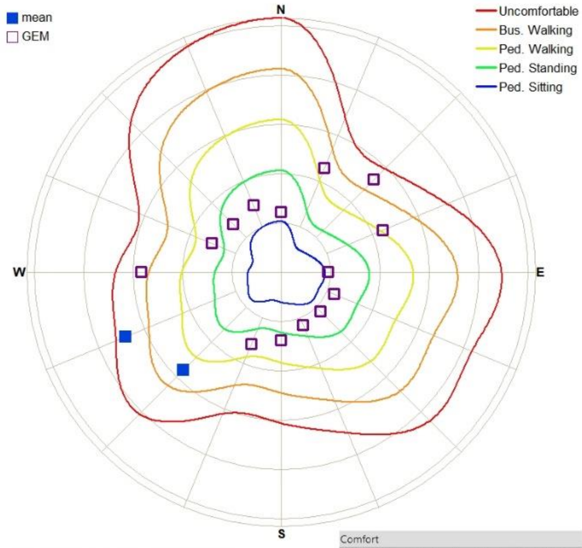
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	4.9	5.9	6.0
Rating	Ped Standing	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.4	11.4	11.4
Rating	Pass	Pass	Pass

LOCATION 4.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	35.33	50.92	51.83
4	13.65	19.64	20.79
6	4.51	6.32	7.61
8	1.23	1.57	2.03
10	0.29	0.31	0.47

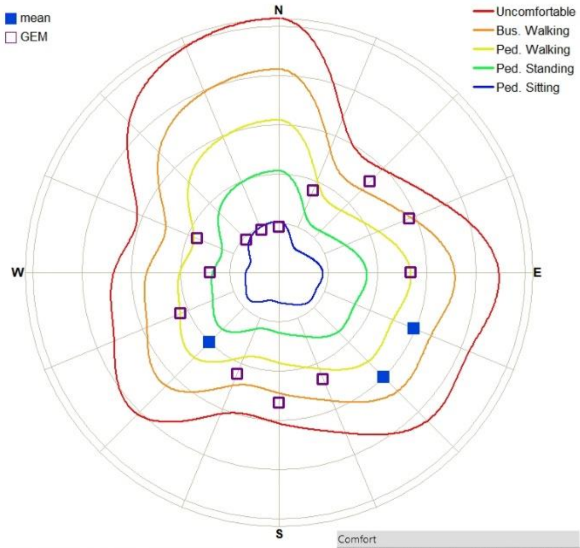
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	5.8	6.3	6.6
Rating	Ped Standing	Ped Walking	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	13.1	12.3	13.1
Rating	Pass	Pass	Pass

LOCATION 5.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	52.30	59.12	59.54
4	24.91	29.79	30.64
6	6.84	9.47	10.14
8	1.24	2.04	2.14
10	0.17	0.36	0.37

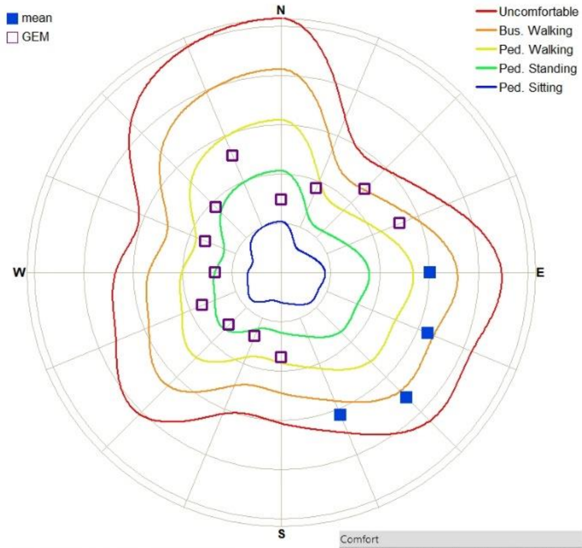
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	6.3	6.8	6.9
Rating	Ped Walking	Ped Walking	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	11.8	12.4	12.5
Rating	Pass	Pass	Pass

LOCATION 6.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	52.63	63.88	64.28
4	18.87	24.41	25.65
6	6.17	7.11	8.87
8	1.30	1.17	1.76
10	0.26	0.19	0.32

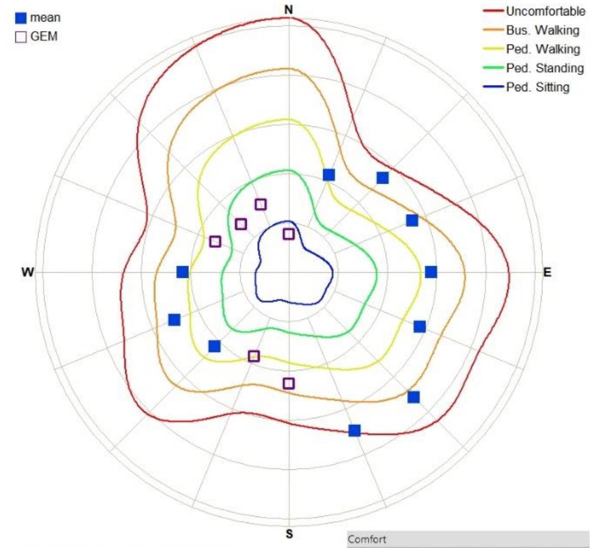
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	6.2	6.4	6.7
Rating	Ped Walking	Ped Walking	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	13.1	12.1	13.1
Rating	Pass	Pass	Pass

LOCATION 7.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	59.96	62.07	63.50
4	29.36	31.98	34.37
6	10.83	10.39	12.40
8	2.72	2.08	3.02
10	0.61	0.39	0.64

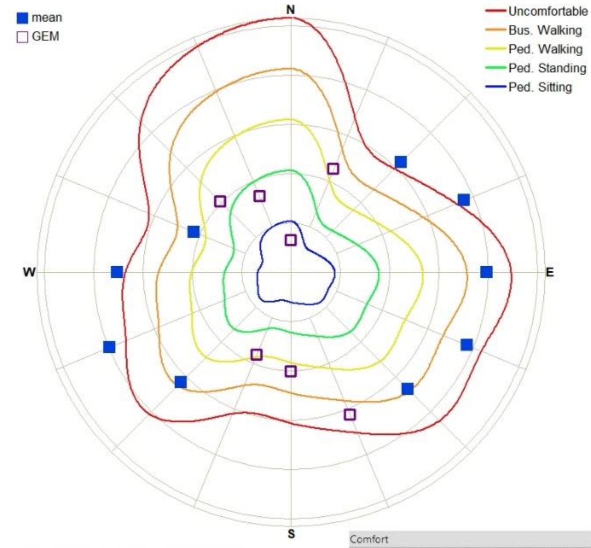
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	7.2	6.9	7.3
Rating	Ped Walking	Ped Walking	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	14.2	13.1	14.3
Rating	Pass	Pass	Pass

LOCATION 8.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	67.87	68.85	71.72
4	35.90	35.02	40.63
6	18.73	12.55	20.33
8	7.21	2.61	7.47
10	2.17	0.48	2.21

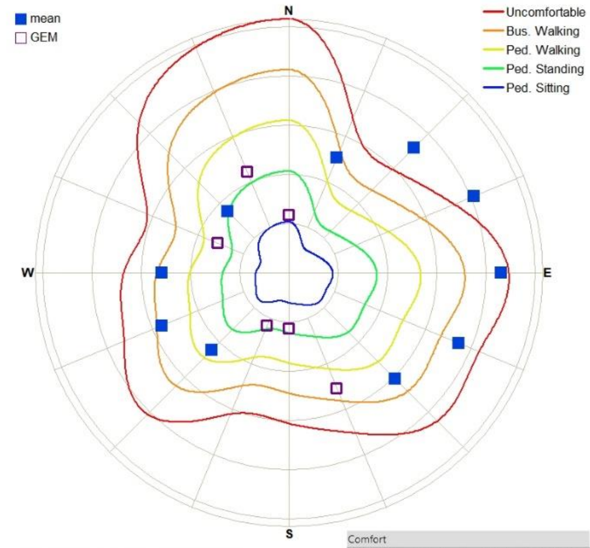
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	8.6	7.2	8.6
Rating	Bus Walking	Ped Walking	Bus Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	15.8	13.3	15.8
Rating	Able Body	Pass	Able Body

LOCATION 9.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	56.72	62.29	65.39
4	30.42	25.60	31.62
6	14.49	9.06	14.90
8	6.30	1.94	6.42
10	2.14	0.34	2.16

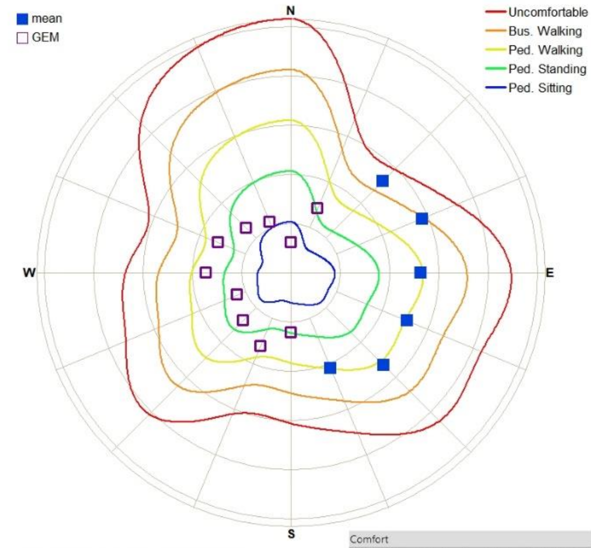
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	8.4	6.7	8.4
Rating	Bus Walking	Ped Walking	Bus Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	16.0	12.4	16.0
Rating	Able Body	Pass	Able Body

LOCATION 15.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	41.84	50.17	52.59
4	16.00	13.54	18.56
6	5.13	1.80	5.42
8	1.09	0.16	1.11
10	0.20	0.00	0.20

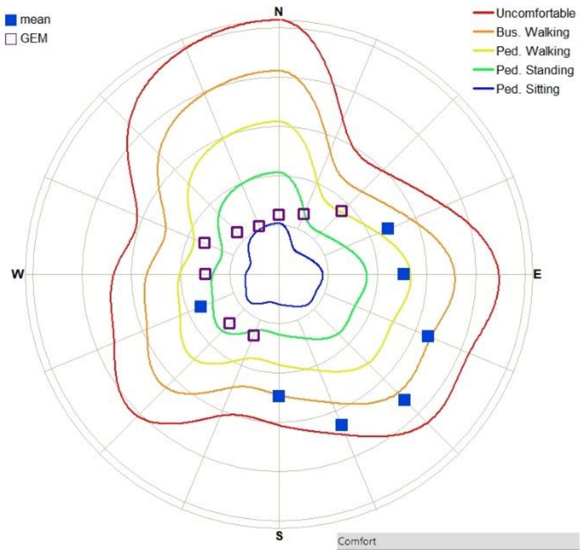
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	6.0	5.0	6.1
Rating	Ped Standing	Ped Standing	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	11.7	9.1	11.7
Rating	Pass	Pass	Pass

LOCATION 16.1

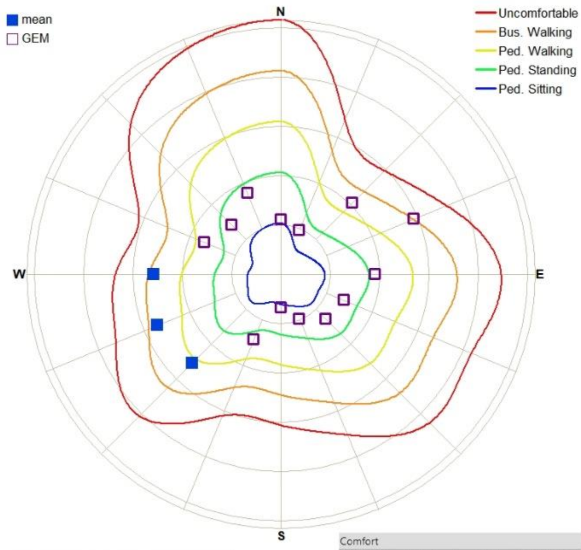


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	47.93	54.93	56.03
4	22.58	21.61	24.68
6	7.79	4.86	8.19
8	1.88	0.80	1.91
10	0.39	0.11	0.39

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	6.6	5.9	6.7
Rating	Ped Walking	Ped Standing	Ped Walking

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	13.7	11.8	13.7
Rating	Pass	Pass	Pass

LOCATION 17.1

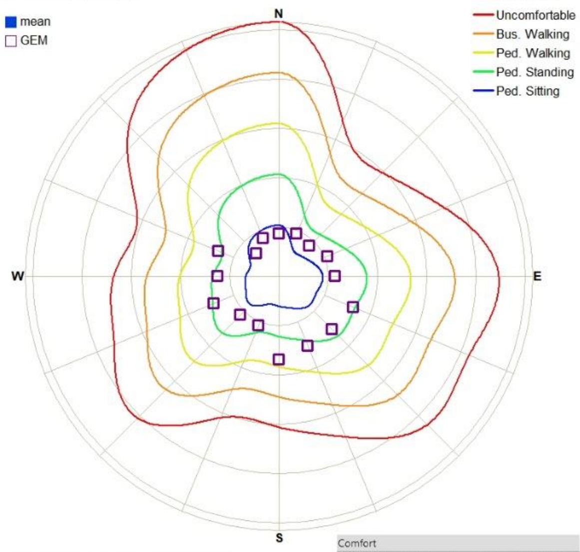


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	31.46	42.82	44.15
4	11.79	13.05	15.07
6	2.95	3.45	4.50
8	0.53	0.45	0.83
10	0.08	0.03	0.09

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	5.3	5.4	5.8
Rating	Ped Standing	Ped Standing	Ped Standing

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	11.2	10.3	11.4
Rating	Pass	Pass	Pass

LOCATION 18.1

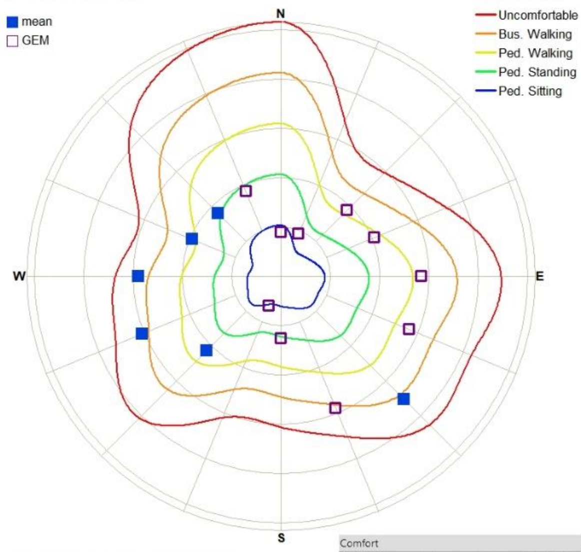


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	16.52	35.03	35.03
4	0.79	4.04	4.04
6	0.02	0.33	0.33
8	0.00	0.02	0.02
10	0.00	0.00	0.00

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	2.9	3.8	3.8
Rating	Ped Sitting	Ped Sitting	Ped Sitting

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	5.9	7.8	7.8
Rating	Pass	Pass	Pass

LOCATION 19.1

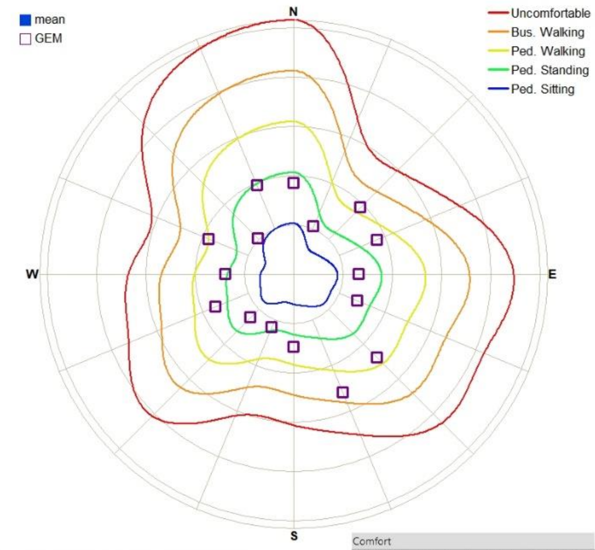


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	46.23	55.74	57.07
4	18.04	22.16	24.45
6	5.60	5.74	7.65
8	1.52	1.04	1.91
10	0.27	0.16	0.35

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	6.1	6.1	6.5
Rating	Ped Walking	Ped Walking	Ped Walking

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	12.8	12.3	13.1
Rating	Pass	Pass	Pass

LOCATION 20.1

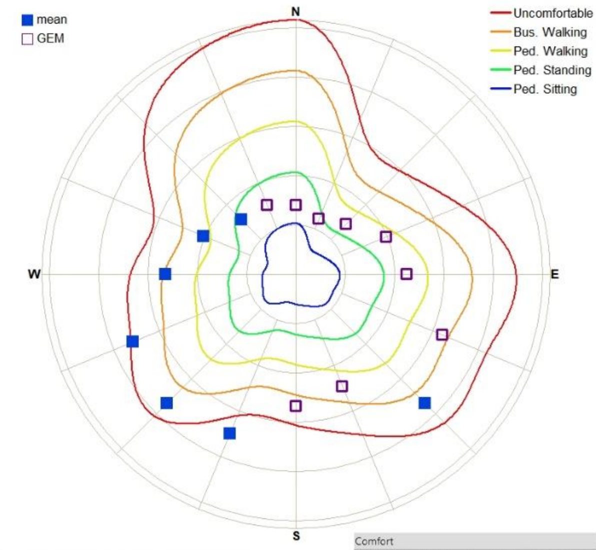


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	29.51	51.63	51.63
4	7.86	13.42	13.42
6	1.18	2.29	2.29
8	0.19	0.35	0.35
10	0.03	0.04	0.04

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.5	5.2	5.2
Rating	Ped Standing	Ped Standing	Ped Standing

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	10.3	10.6	10.6
Rating	Pass	Pass	Pass

LOCATION 21.1

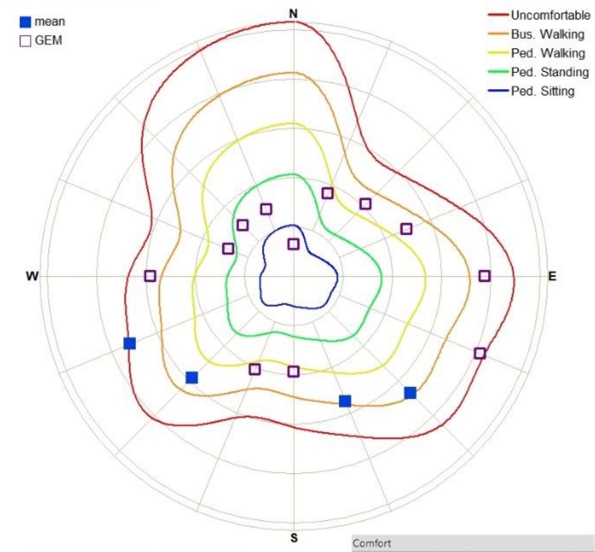


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	57.94	62.39	65.21
4	26.61	29.23	33.28
6	11.60	9.76	14.24
8	4.23	2.50	5.05
10	1.22	0.51	1.39

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	7.6	6.9	7.9
Rating	Ped Walking	Ped Walking	Ped Walking

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	16.1	13.7	16.2
Rating	Able Body	Pass	Able Body

LOCATION 22.1

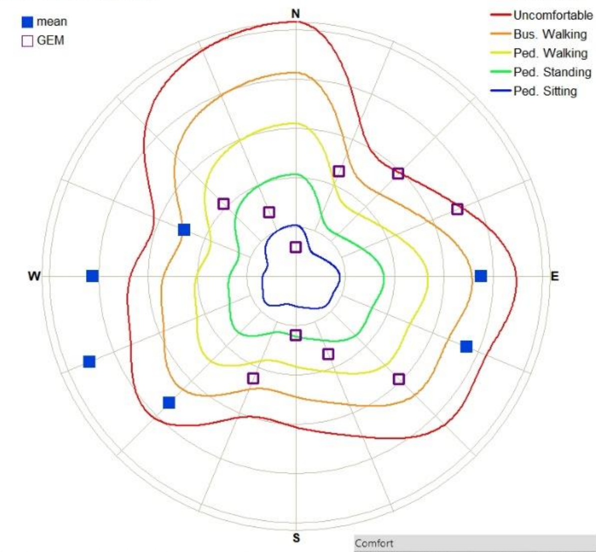


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	54.07	63.43	64.06
4	23.19	33.31	34.43
6	7.67	10.78	12.35
8	2.02	2.53	3.13
10	0.51	0.49	0.72

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	6.6	7.0	7.3
Rating	Ped Walking	Ped Walking	Ped Walking

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	13.8	13.8	14.3
Rating	Pass	Pass	Pass

LOCATION 23.1

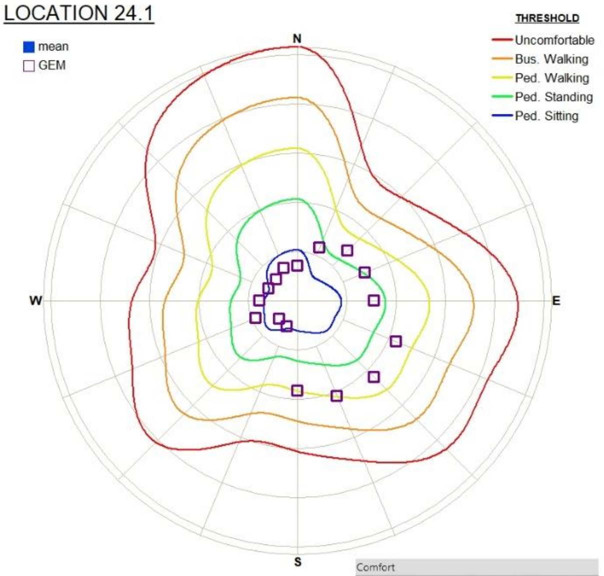


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	55.67	67.55	68.81
4	27.91	33.04	35.88
6	13.14	15.14	18.73
8	5.02	4.78	7.37
10	1.96	1.19	2.48

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	7.9	7.8	8.6
Rating	Ped Walking	Ped Walking	Bus Walking

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	17.9	14.5	17.9
Rating	Able Body	Pass	Able Body

LOCATION 24.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	22.05	34.78	34.78
4	1.95	8.64	8.64
6	0.08	0.95	0.95
8	0.00	0.08	0.08
10	0.00	0.00	0.00

Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	3.3	4.5	4.5
Rating	Ped Sitting	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	6.9	9.0	9.0
Rating	Pass	Pass	Pass