Attachment A11

Wind Impact Assessment

CERMAK
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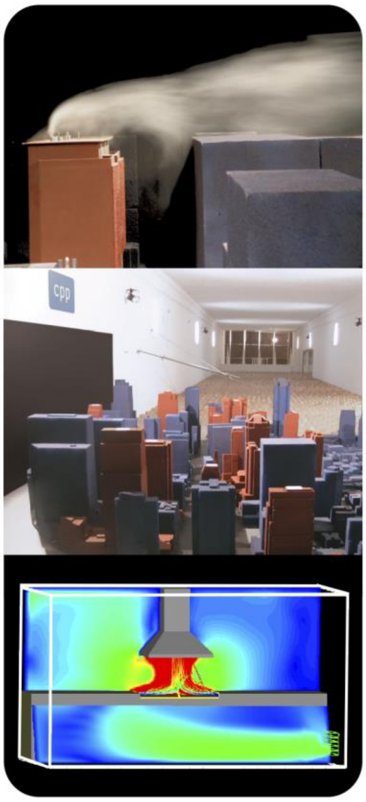
WIND ENGINEERING AND AIR QUALITY CONSULTANTS

Final Report



Pedestrian Wind Tunnel Tests for:

55 Pitt Street

Sydney, NSW

Prepared for:

Mirvac

200 George Street

Sydney, NSW 2000

Australia

March 2020

CPP Project: 7706

Prepared by:

Adam van Duijneveldt, Project Engineer

Joe Paetzold, Engineering Manager

CPP

Unit 2, 500 Princes Highway

St. Peters, NSW 2044, Australia

info-syd@cppwind.com

www.cppwind.com

EXECUTIVE SUMMARY

A wind tunnel study of the proposed development site at Sydney, NSW was conducted to assess the pedestrian wind environment in and around the development site. Two tower envelopes were investigated in this study, along with the existing site. The existing configuration has been included in the wind tunnel testing to demonstrate the wind conditions that exist in the absence of any tower massing on the subject site. A model of each envelope 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. For each configuration tested the surrounds modelled were kept constant.

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 9 locations for 16 wind directions each. These points were tested around the development site, focusing on access routes, doorways, and pedestrian thoroughfares. 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.

The wind environment around the development was found to be generally similar for the configurations tested. Measurement locations along Pitt Street were typically found to be suitable for pedestrian or business walking style activities from a comfort perspective, with all locations but one passing the once per annum 0.5-second gust safety criterion. The safety exceedance was seen across all three configurations tested. Comparing the results across all three configurations, it is considered that wind conditions along Pitt Street are predominantly caused by the general massing along the northern fringe of the Sydney CBD rather than the specific tower envelope present on the subject site. Locations along Dalley and Underwood Streets passed the safety criterion for all test cases, and were generally classified as suitable for pedestrian standing type activities. If required mitigation measures for localised areas can be developed and tested during further detailed environmental wind tunnel testing during the detailed design phase.

DOCUMENT VERIFICATION

Date	Revision	Prepared by	Checked by	Approved by
19/02/20	Initial release	AVD	JP	JP
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LIST OF SYMBOLS

D	Characteristic dimension (building height, width, etc.), m
n	Mean velocity profile power law exponent
T_u	Turbulence intensity, U_{rms}/U
U	Local mean velocity, m/s
U_{ref}	Reference mean velocity at reference height z_{ref}, m/s
U_{pk}	Peak wind speed in pedestrian studies, m/s
U_{rms}	Root-mean-square of fluctuating velocity, m/s
z	Height above surface, m
ν	Kinematic viscosity of approach flow, m^2/s
$\sigma(\ )$	Standard deviation of $(\ ), = (\ )'_{\mathrm{rms}}$
ρ	Density of approach flow, kg/m^3
$(\ )_{\mathrm{max}}$	Maximum value during data record
$(\ )_{\mathrm{min}}$	Minimum value during data record
$(\ )_{\mathrm{mean}}$	Mean value during data record
$(\ )_{\mathrm{rms}}$	Root mean square about the mean

1 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). While analytical methods such as computational fluid dynamics (CFD) have some utility in the field of pedestrian wind comfort, they are not yet capable of reliably and accurately predicting gust wind speeds for assessment of wind conditions from a safety perspective.

Table 1: Parameters and configurations for data acquisition.

General Information	
Model scale	1:400
Surrounding model radius (full-scale)	570 m
Reference height (full-scale)	200 m AGL
Approach Terrain Category	Suburban approach (Terrain Category 3)
Testing Configurations	
Configuration A (test points labelled X.1)	Existing site, with existing and approved surrounding buildings, as shown in Figure 4. Pedestrian winds measured at 9 locations for 16 wind directions at 22.5° increments from 0° (north).
Configuration B (test points labelled X.2)	Central Sydney Planning Strategy (CSPS) base case tower envelope (RL305 m), with existing and approved surrounding buildings, as shown in Figure 5 to Figure 7. Pedestrian winds measured at 9 locations for 16 wind directions at 22.5° increments from 0° (north).
Configuration C (test points labelled X.3)	Proposed tower envelope (RL234.7 m) with existing and approved surrounding buildings, as shown in Figure 8 to Figure 10. Pedestrian winds measured at 9 locations for 16 wind directions at 22.5° increments from 0° (north).

2 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 1. 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 2 and are explained more fully in Section 4.1.1.

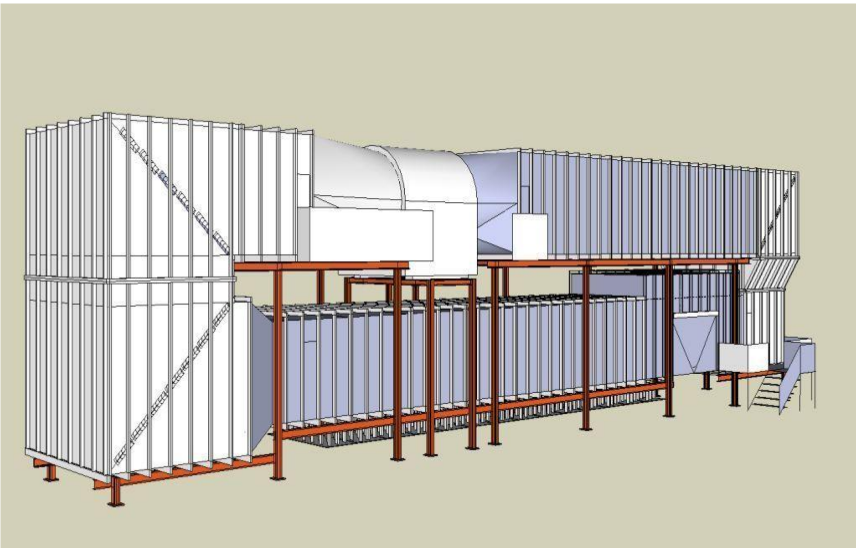

Figure 1: Schematic of the closed-circuit wind tunnel.

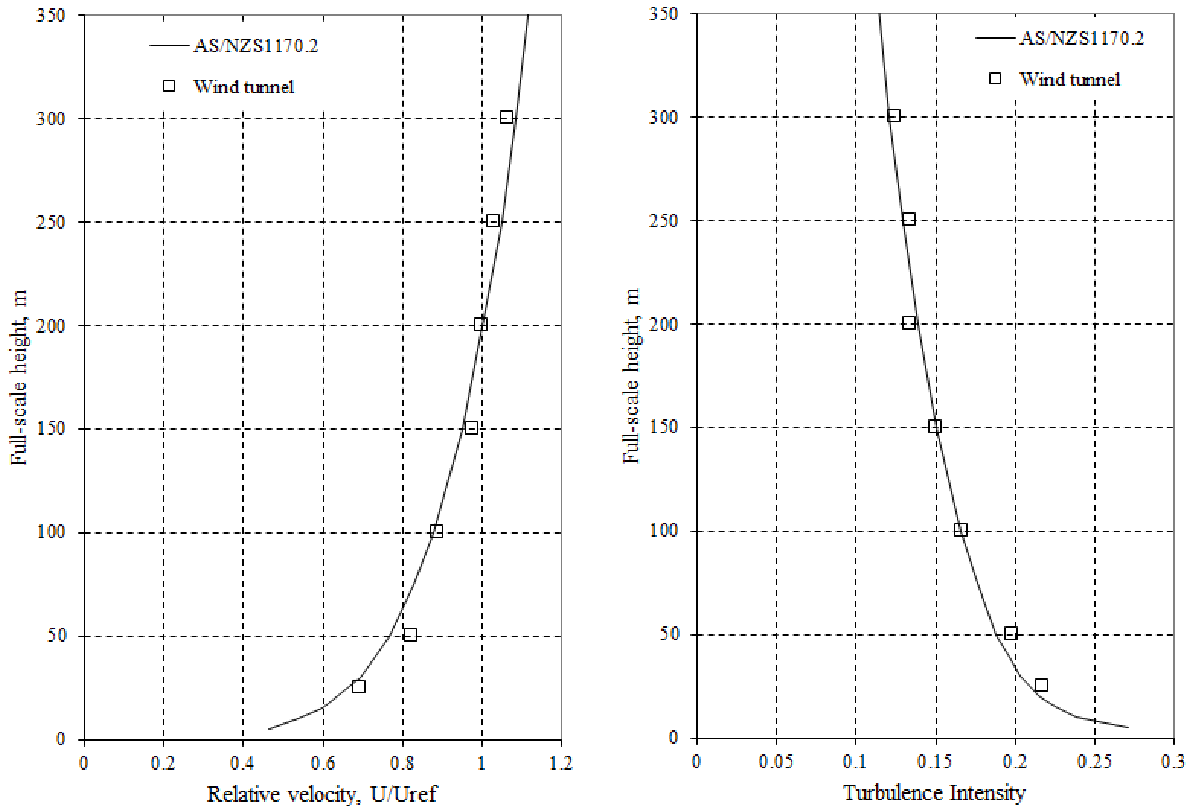

Figure 2: Mean velocity and turbulence profiles (Terrain Category 3) approaching the model.

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 3, 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 5. 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 3: Project location and turntable layout – Configuration B.

Figure 4: Configuration A existing site model in the wind tunnel viewed from above.

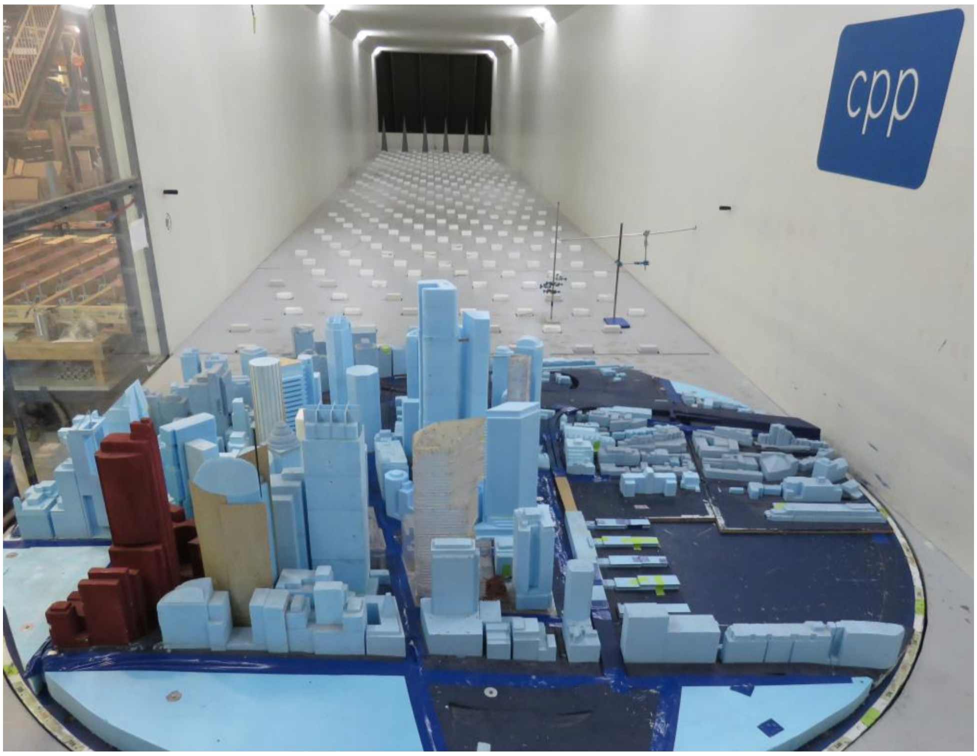

Figure 5: Configuration B tower envelope in the wind tunnel viewed from the east.

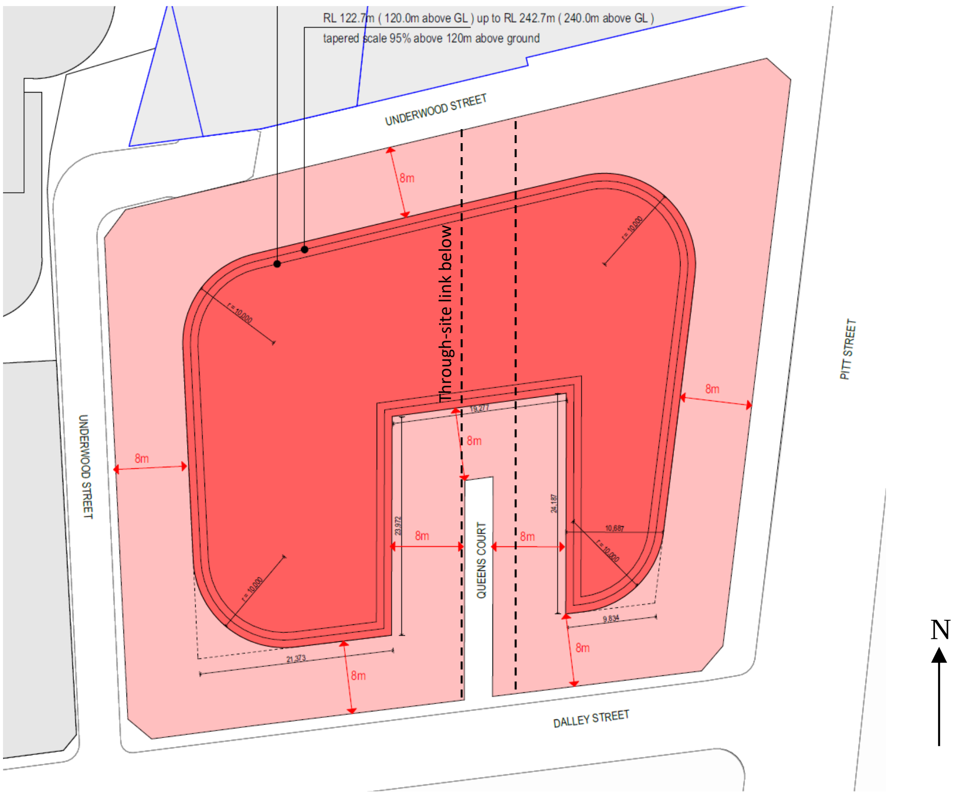

Figure 6: Plan view of CSPS base case envelope.

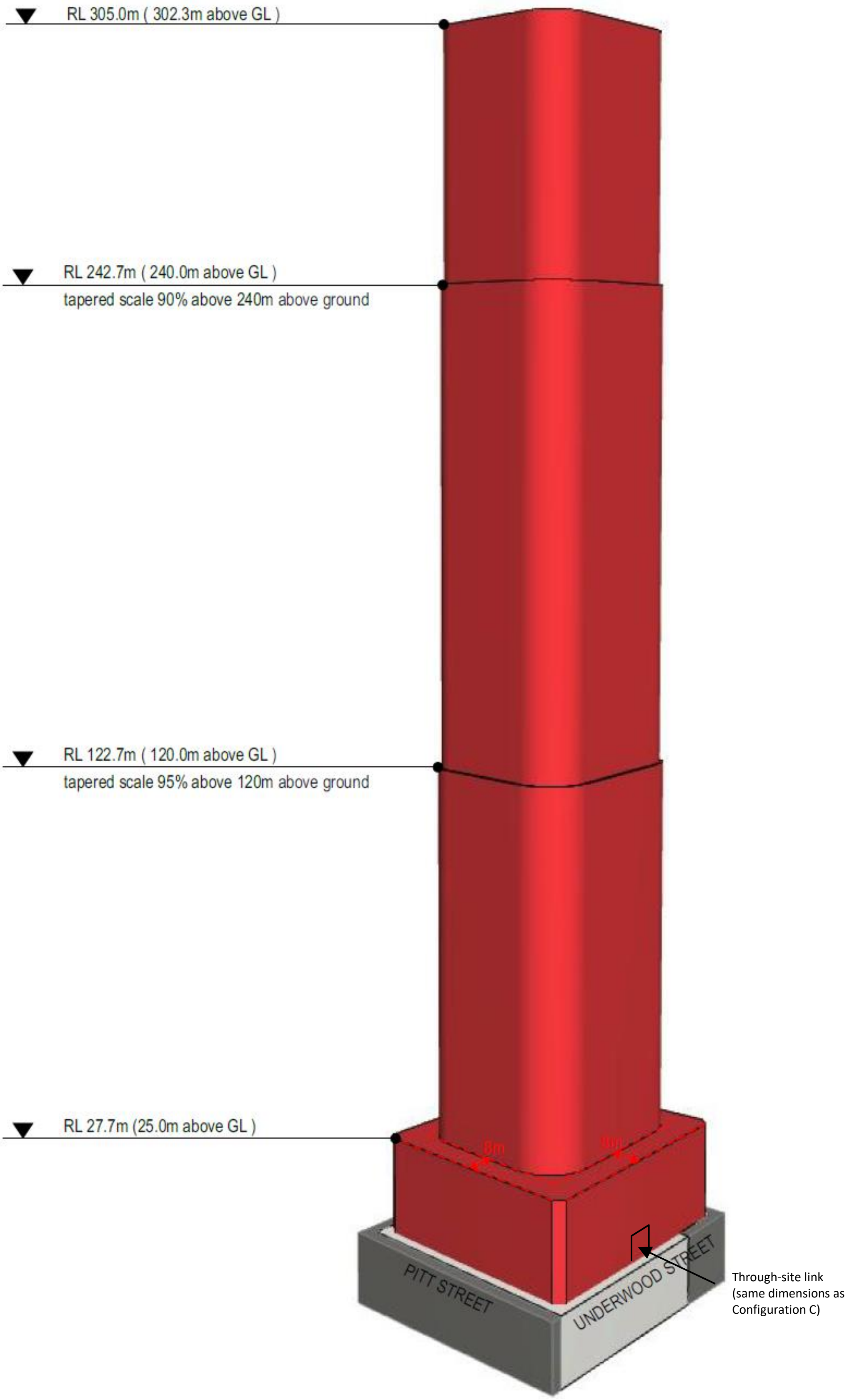

Figure 7: Perspective view of Configuration B envelope, viewed from the north-east

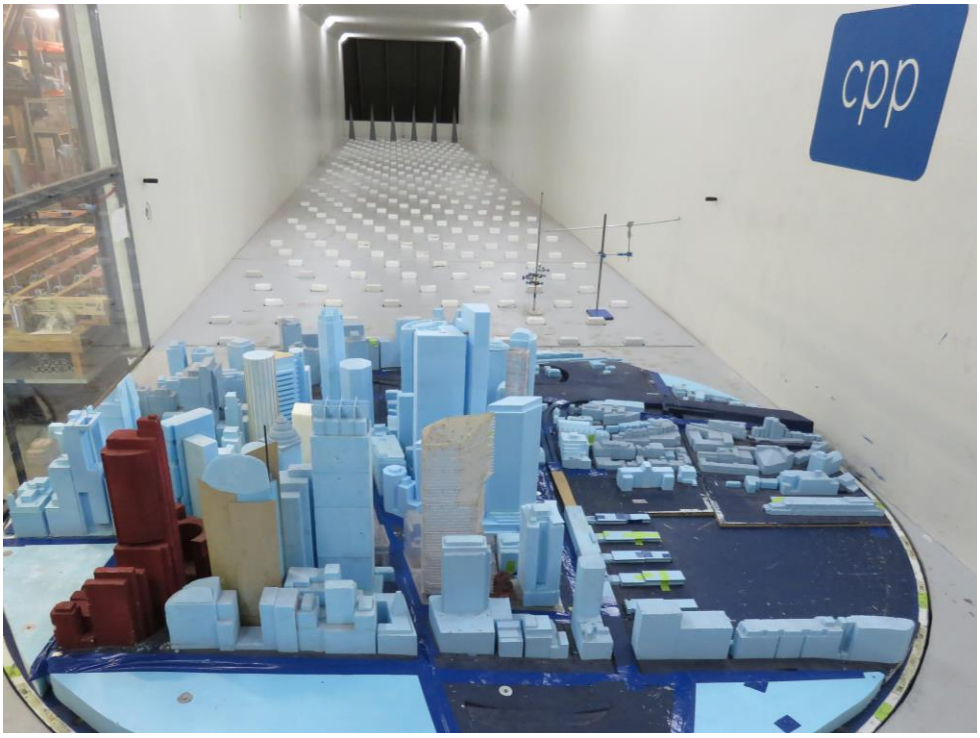

Figure 8: Configuration C tower envelope in the wind tunnel viewed from the east.

Figure 9: Plan view of Configuration C envelope.

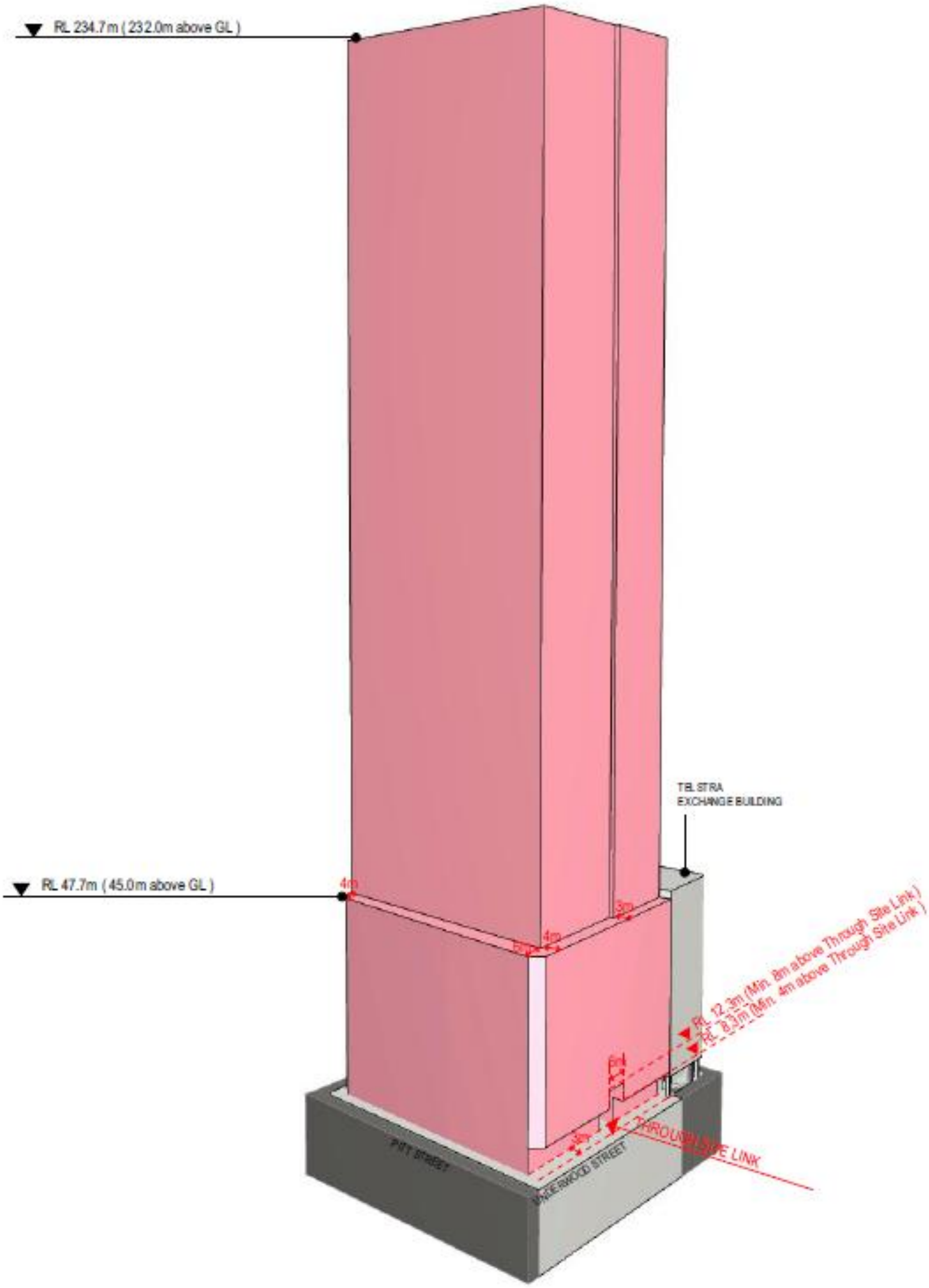

Figure 10: Perspective view of Configuration C envelope, viewed from the north-east.

3 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.

The draft City of Sydney DCP (2016) is based on the criteria of Lawson, with the modification that the analysis be conducted over daylight hours (6am – 10pm) only. 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 consideration of the local wind environment is recommended when evaluating the Lawson ratings. The wind speed used in the analysis 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. The distress criterion prescribed by the draft City of Sydney DCP is reminiscent of the criterion of Melbourne (1978), but uses a 0.5-second gust wind speed occurring during one hour of the year for daylight hours only, limited to a maximum of 24 m/s. It is not specified whether this annual gust is based on an integrated probability of all wind directions, or is considered on a direction-by-direction basis. It is assumed that the analysis is based on the latter approach.

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)	🔵
4 - 6 m/s	Pedestrian Standing (or sitting for a short time or exposure)	🟢
6 - 8 m/s	Pedestrian Walking	🟡
8 - 10 m/s	Business Walking (objective walking from A to B or for cycling)	🟠
> 10 m/s	Uncomfortable[1]	🔴

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

4 DATA ACQUISITION AND RESULTS

4.1 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).

4.1.1 Velocity Profiles

Mean velocity and turbulence intensity profiles for the boundary layer flow approaching the model are shown in Figure 2. 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.

4.1.2 Pedestrian Winds

The development site is located on the block bounded by Pitt, Dalley and Underwood Streets, and is surrounded by medium to high-rise buildings of the Sydney CBD. Most notably the development site is adjacent to the, currently under construction, Circular Quay Tower which provides significant shielding to the subject site from prevailing winds from the north-east.

For this report, wind speed measurements were recorded at 9 locations, as described in Table 1, to evaluate pedestrian wind comfort and safety in and around the project site shown in Figure 13. 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 at least one hour in prototype. All velocity data were digitally filtered to obtain the two to three second running mean wind speed, for comfort assessment, and 0.5-second running mean wind speed, for safety assessment, at each point; these gust durations are 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 3. 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 during daylight hours (6am – 10pm), Figure 11.

From these data, directional criterion lines for the Lawson rating wind speeds have been calculated and included on the polar plots in Appendix 3; 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 11 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 3. 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.

A colour coded summary assessment of pedestrian wind comfort with respect to the Lawson criteria is presented in Figure 13 for each test location. The implications of the results are discussed in Section 5.

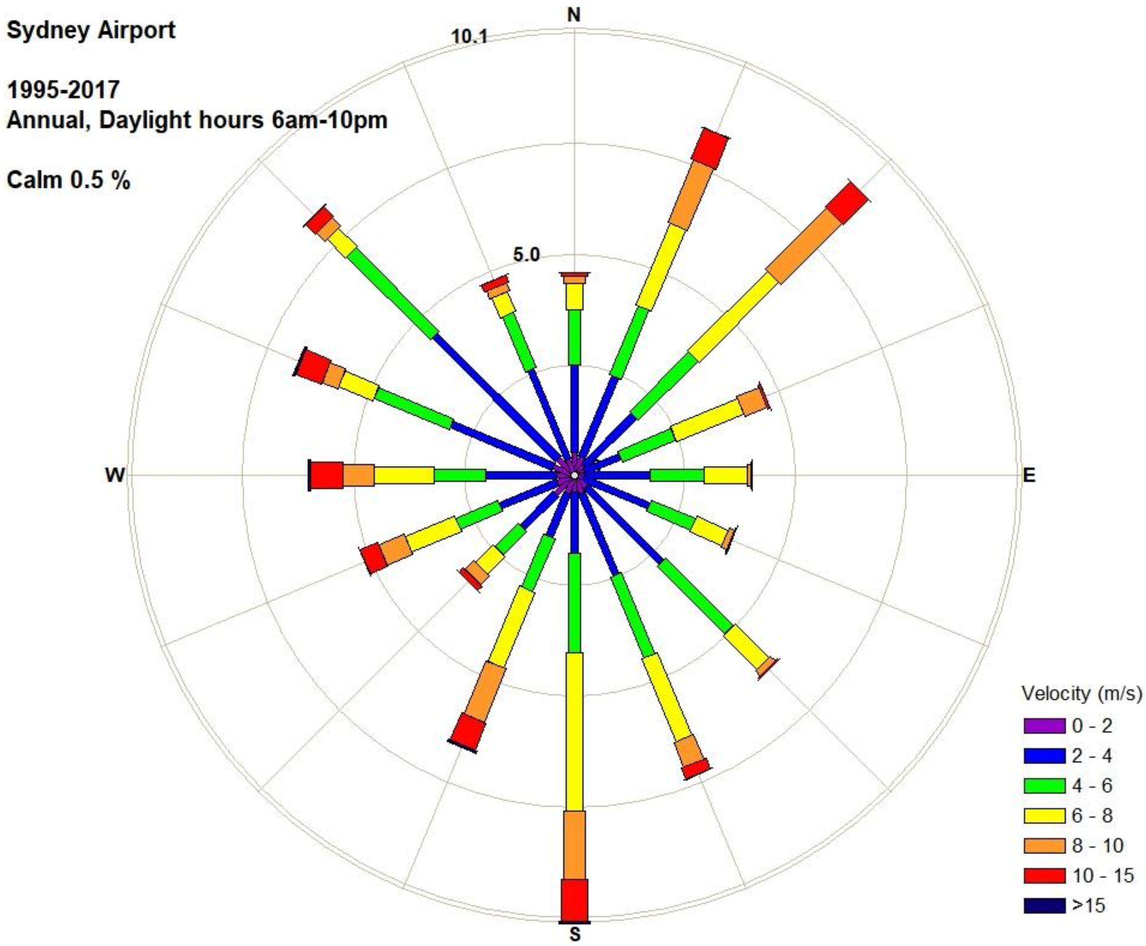

Figure 11: Wind rose for Sydney Airport.

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.

5 DISCUSSION

The wind climatology chart of Figure 11 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 tower envelope 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 3. 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 wind tunnel results for wind comfort at the investigated locations for each of the configurations described in Table 1, including the Lawson comfort ratings during daylight hours, are provided in Table 4. While the test locations used in the present study are similar to those in previous wind tunnel testing (CPP, 2018; CPP, 2019a; CPP, 2019b), a different numbering scheme has been used in the present results. It is worth noting that the results herein are not directly comparable with those in the reports for the previous studies due to slight differences in the measurement locations investigated. For evaluation of the wind safety criterion, the 0.5-second once per annum gust during daylight hours was calculated for each of the investigated locations, and the results are provided in Table 5; a comparison between Configurations B and C can be found in Table 6.

The primary conclusions of the pedestrian study can be understood by reviewing the colour coded image in Figure 13, which depicts the locations selected for investigation along with the Lawson comfort criterion ratings. The central colour indicates the comfort rating for the location, 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. Additional quantitative information for comfort and safety may be found for each configuration in Appendix 2.

Note that testing was performed without awnings, 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%. However, landscaping cannot be relied on to provide sufficient shielding from winds that potentially pose a safety risk due to their vulnerabilities. Inclusion of awnings along the Pitt Street frontage would be expected to provide some local protection to pedestrians, though would not significantly reduce the contribution of tower downwash to channelling flow along Pitt Street. Although conditions for some measurement locations 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 3.

Wind conditions along Pitt Street in this region of the Sydney CBD tend to be dominated by channelling flow for winds from the north and south quadrants. Conversely, wind conditions along Dalley and Underwood Streets tend to be calmer due to the misaligned nature of the east-west street pattern around this block. The wind conditions at locations around the project site, determined from the wind tunnel study, are presented in Figure 13.

Pitt Street

Wind conditions along Pitt Street are similar between the configurations tested, with wind conditions for Locations 1 – 6 varying between pedestrian standing and business walking from a Lawson comfort perspective. These results indicate that wind conditions at these locations are dictated more by the surrounding built environment than the tower envelope for the project site. Reference to the polar plots in Appendix 3 indicate that winds from the north quadrant tend to dominate the wind conditions for these locations. As these winds reach the northern fringe of the Sydney CBD they are brought to ground in the form of downwash by large exposed towers upstream of the project site, with the resulting flow being channelled along Pitt Street in the north-south direction. As a result of this flow mechanism, awnings along the Pitt Street frontage are considered unlikely to significantly improve wind conditions on Pitt Street, though may provide some local protection, particularly for wind-driven rain.

For Location 2, situated on Pitt Street adjacent to Underwood Street, wind conditions are affected by downwash of winds from the north-west. These winds approaching from the north-west are brought to ground by the towers upstream of the project site, which give rise to channelling flow along Pitt Street, this effect is consistent across all configurations. Reference to the polar plots in Appendix 3 indicate that in addition to wind impacts from the north-west Configuration A also experiences downwash at Location 2 for winds from the south quadrant, a mechanism that is not present in Configurations B and C. Due to the absence of tower massing on the subject site in Configuration A winds from the south stagnate on the southern façade of Circular Quay Tower, generating downwash which accelerates around the south-east corner and to a lesser extent the south-west corner of the tower creating slightly windier conditions for this configuration.

Conversely, for Location 5 the absence of tower massing has a positive effect for Configuration A, with wind conditions being dominated by winds from the north-east. Configurations B and C also experience strong wind effects for winds from the north-east, but from reference to the polar plots in Appendix 3 also exhibit contributions from winds from the south-east and south-west respectively which shift the Lawson comfort rating from pedestrian walking in Configuration A to business walking in Configurations B and C. In Configuration C winds from the south-west are captured by internal corner of the L-shaped floorplate of the proposed tower envelope, generating downwash along Queens Court. This downwash flow discharges along Dalley Street to the east, before accelerating around the south-east corner of the podium and being channelled along Pitt Street. To ameliorate wind conditions at Location 5 installation of a canopy at podium roof height over Queens Court would assist in deflecting downwash of winds from the south-west away from ground level, thus improving wind conditions along Queens Court and Dalley Street in general.

The once per annum 0.5-second gust wind speeds are below the 24 m/s criterion for all locations along Pitt Street in all configurations, with the exception of Location 6 which exceeds the distress criterion in all configurations. It is noted that the once per annum gust wind speed does not increase between the proposed envelope and existing site.

Potential Mitigation Measures – Pitt Street

Given that wind conditions along Pitt Street tend to be dominated by channelling flow of downwash brought to ground by buildings upstream of the subject site, it would not be expected that awnings on podium of the proposed tower would be effective at significantly reducing wind speeds along Pitt Street in proximity to the subject site. While not included in the tower envelope testing presented herein, awnings are planned along the Pitt Street frontage, Figure 12. These awnings would be expected to provide some limited local protection to pedestrians, particularly for wind-driven rain.

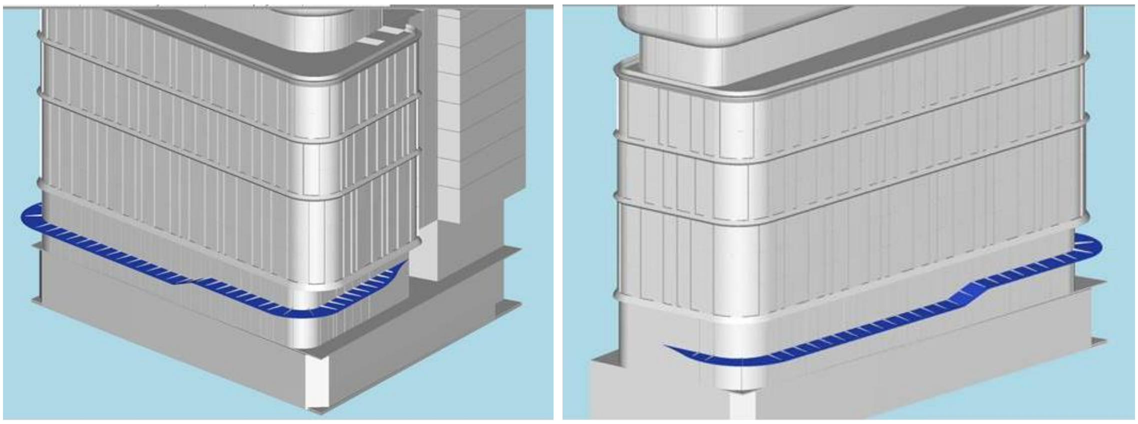

Figure 12: Proposed awnings along Pitt Street for Configuration B tower envelope viewed from the north-east (L) and south-east (R).

Dalley Street

As a result of the misaligned street pattern in this section of the Sydney CBD, wind conditions on Dalley and Underwood Streets are generally much calmer than for Pitt Street. Wind conditions at Location 7 on Dalley Street are similar between Configurations A and C and are classified as suitable for pedestrian standing, while Configuration B was rated as suitable for pedestrian walking type activities. Both Configurations B and C experience slightly windier conditions than Configuration A, due to an increase in flow along Dalley Street brought about by downwash from the east façade of the tower for winds from the north-east. All configurations pass the distress criterion for Location 7.

Underwood Street

Wind conditions along Underwood Street are generally classified as suitable for pedestrian standing type activities for each of the configurations tested, with the exception of Location 8 in Configuration B which is just below the threshold for the pedestrian sitting classification. The flow mechanism creating slightly windier conditions in Configuration A at Location 2 also causes Location 8 to experience slightly higher wind speeds for Configuration A, as the absence of a tower on the project site causes winds from the south to downwash from the southern façade of Circular Quay Tower before discharging around the south-west corner of the tower, adjacent to 200 George Street. The 0.5-second gust wind speed was below the 24 m/s criterion for all configurations.

Inspection of the polar plots in Appendix 3 indicates that Location 9 is subject to pressure-driven flow through the site link for winds from the south-west. This flow mechanism occurs for both Configuration B and C, though is more pronounced for Configuration C due to the shape of the floorplan. All configurations pass the distress criterion for Location 9.

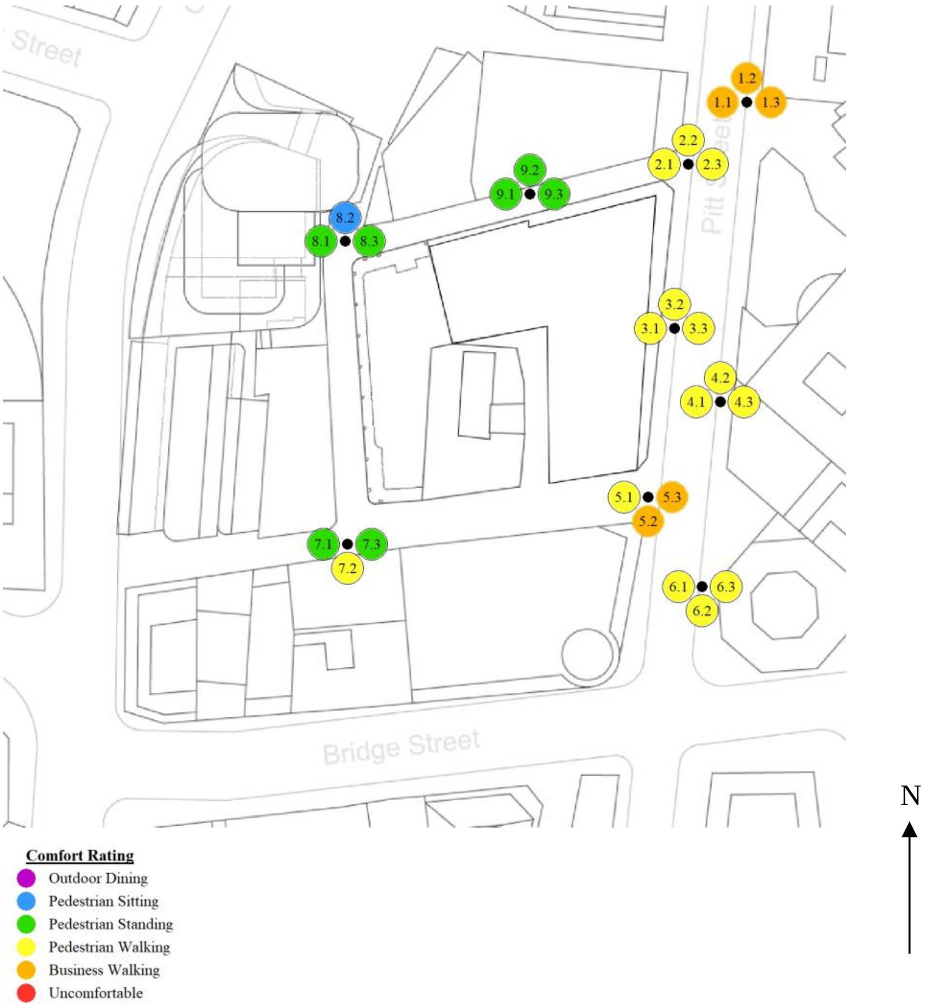

Figure 13: Pedestrian wind speed measurement locations with comfort/distress ratings – Ground plane. Existing site labelled X.1, CSPS Base Case labelled X.2, proposed tower envelope labelled X.3.

Table 4: Summary of wind tunnel results for pedestrian comfort.

Test Location	Config A - Existing	Config B - CSPS Base Case (RL305m)	Config C - Mirvac Setback 6 - 4m (RL234.7m)
1	BW	BW	BW
2	PW	PW	PW
3	PW	PW	PW
4	PW	PW	PW
5	PW	BW	BW
6	PW	PW	PW
7	PSt	PW	PSt
8	PSt	PS	PSt
9	PSt	PSt	PSt

LEGEND	
Comfort Criteria	Wind Speed range (m/s)
Outdoor Dining (OD)	0 - 2
Pedestrian Sitting (PS)	2 - 4
Pedestrian Standing (PSt)	4 - 6
Pedestrian Walking (PW)	6 - 8
Business Walking (BW)	8 - 10
Uncomfortable (U)	> 10

Table 5: Summary of wind tunnel results for pedestrian safety.

	Config A - Existing site	Config B - CSPS Base Case (RL305m)	Config C - Pitt St Setback 6 - 4m (RL234.7m)
Test location	Criterion	Criterion	Criterion
1	Pass	Pass	Pass
2	Pass	Pass	Pass
3	Pass	Pass	Pass
4	Pass	Pass	Pass
5	Pass	Pass	Pass
6	Exceed	Exceed	Exceed
7	Pass	Pass	Pass
8	Pass	Pass	Pass
9	Pass	Pass	Pass

Table 6: Summary of equivalent or improved wind comfort levels relative to CSPS base case tower envelope

Test Location	Config C - Mirvac Setback 6 - 4m (RL234.7m)	
	Equivalent	Improved
1	✓	
2	✓	
3	✓	
4	✓	
5	✓	
6	✓	
7		✓
8	✓	
9	Refer section 5 discussion	

Table 7: Summary of equivalent or improved wind safety levels relative to CSPS base case tower envelope

Test Location	Config C - Mirvac Setback 6 - 4m (RL234.7m)	
	Equivalent	Improved
1	✓	
2	✓	
3	✓	
4	✓	
5	✓	
6	✓	
7	✓	
8		✓
9		✓

6 CONCLUSION

A wind tunnel study of three tower configurations for the proposed development site at 55 Pitt Street, Sydney, NSW was conducted to assess the pedestrian wind environment around the development site. Our summary assessment of the proposed tower envelope, Configuration C, is as follows:

The wind conditions around the proposed development site were found to be generally similar across the configurations considered. Comparison of the proposed tower envelope to the CSPS base case tower envelope, Configuration B, indicated that wind comfort and safety levels around the development site were generally equivalent. Differences in wind speeds at most measurement locations between the two configurations were typically small, such that there would be little perceivable difference in wind conditions.

Locations along Pitt Street were typically classified as suitable for pedestrian walking or business walking type activities across all three configurations. Most locations along Pitt Street were found to pass the once per annum 0.5-second gust wind speed distress criterion for all configurations. The one exceedance of the distress criterion, Location 6, was found to not experience an increase in the gust wind speed between the existing site, Configuration A, and the proposed tower envelope. It is considered that wind conditions along Pitt Street are predominantly caused by the general massing along the northern fringe of the Sydney CBD rather than the specific tower envelope present on the subject site.

Locations on Dalley and Underwood Streets were much calmer with the wind conditions typically being classified as suitable for pedestrian standing type activities, and all configurations passing the once per annum gust distress criterion.

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

Appendix 1: Additional photographs of the CPP wind tunnel model

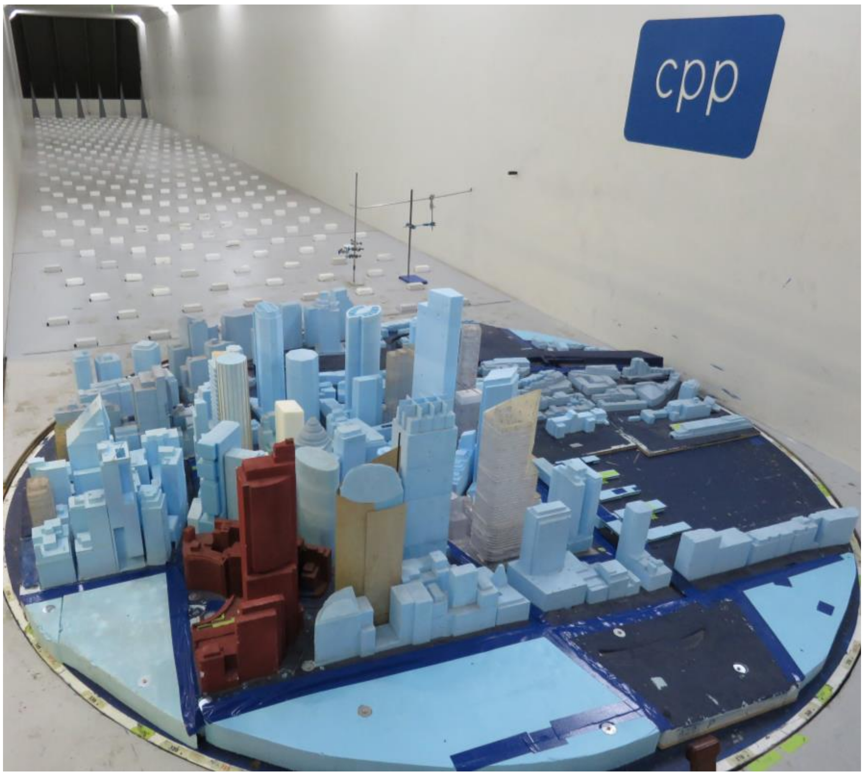


Figure 14: Configuration A model in the wind tunnel viewed from the south-east

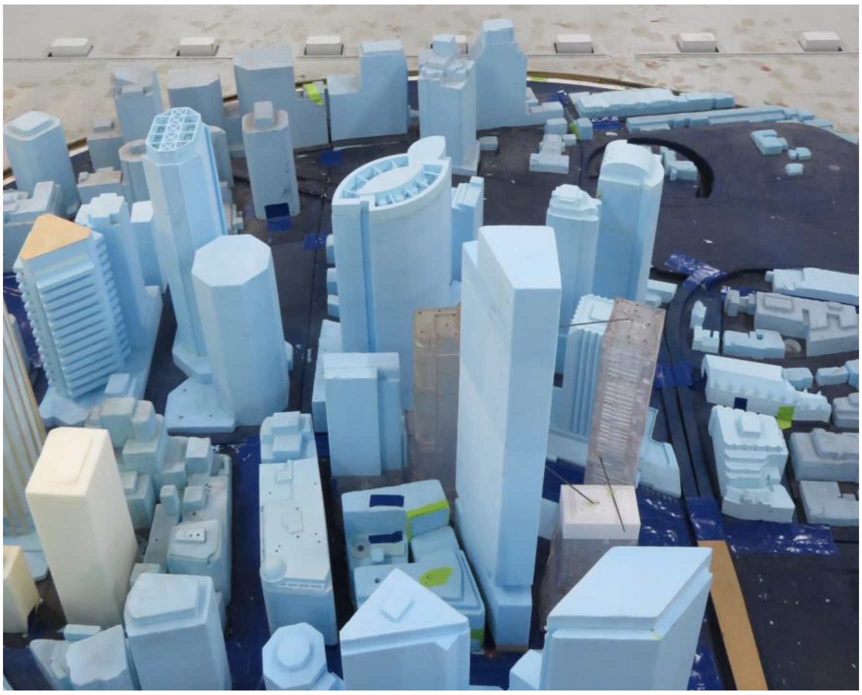


Figure 15: Close-up of Configuration A model in the wind tunnel viewed from the east

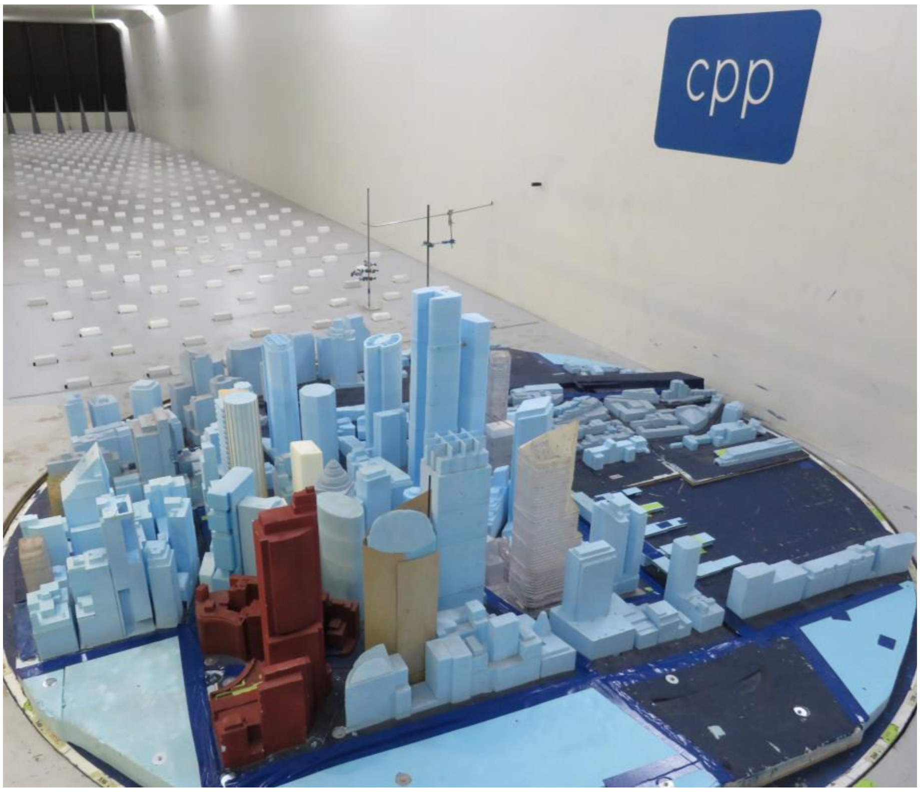


Figure 16: Configuration B model in the wind tunnel viewed from the south-east

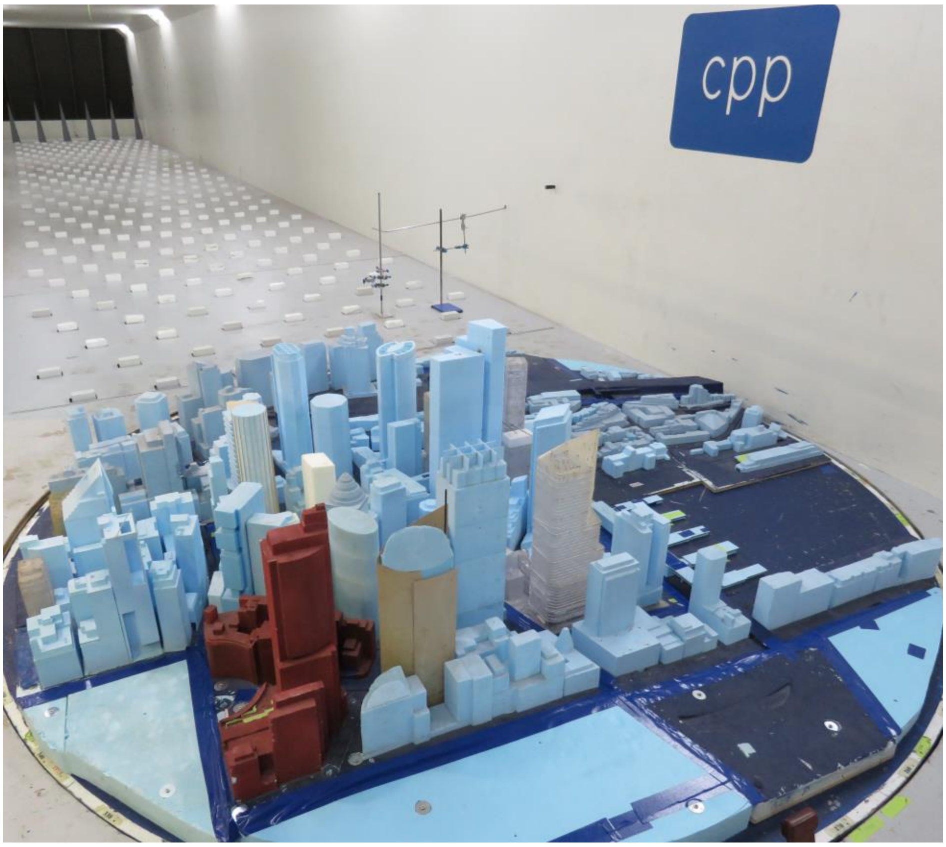


Figure 17: Configuration C model in the wind tunnel viewed from the south-east.

Appendix 2: Detailed wind tunnel results

Comfort

Quantitative wind comfort results for each of the tested configuration are presented in Table 8. Results between each of these configurations are similar for most locations, indicating that wind conditions are generally governed by the surrounding built environment rather than the specific tower form on the subject site.

Table 8: Summary of pedestrian wind comfort results for each configuration.

Test Location	Config A - Existing	Config B - CSPS Base Case (RL305m)	Config C - Mirvac Setback 6 - 4m (RL234.7m)
1	8.9	8.5	8.3
2	7.4	6.6	7.0
3	8.0	7.6	7.7
4	7.7	7.6	7.3
5	7.6	8.4	8.2
6	7.7	7.8	7.6
7	5.0	6.2	5.7
8	4.6	4.0	4.1
9	4.2	4.5	4.9

LEGEND

Comfort Criteria	Wind Speed range (m/s)
Outdoor Dining	0 - 2
Pedestrian Sitting	2 - 4
Pedestrian Standing	4 - 6
Pedestrian Walking	6 - 8
Business Walking	8 - 10
Uncomfortable	> 10

Safety

The purpose of the wind tunnel testing presented herein was to provide a comparative study between the three configurations of interest:

A. Existing site

B. CSPS base case tower envelope

C. Proposed tower envelope

Previous wind tunnel reports (CPP, 2018; CPP, 2019a; CPP, 2019b) were based on testing conducted at various stages throughout the design process. The criteria used in the assessment of safety has changed from the initial wind tunnel testing. The original wind tunnel testing conducted for the 55 Pitt

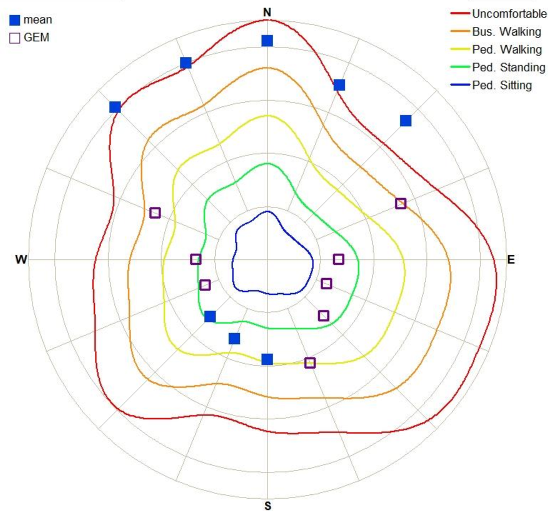
Street site utilised the Lawson criteria for both comfort and safety. These criteria use a 3-second wind speed as the basis for the analysis of gust wind speeds, while the draft City of Sydney DCP (2016) relies on a 0.5-second gust wind speed for the assessment of safety. CPP applies signal conditioning during data acquisitions to yield an output time history of appropriate gust duration for comparison to the relevant criteria. To remain consistent with previous wind tunnel studies, and allow some level of comparison between tests, sampling parameters of later tests where kept consistent with initial tests, and the change to a 0.5-second gust criterion for safety required analytical corrections to determine the equivalent 0.5-second gust from 3-second wind speed data. The present study thus represented an opportunity to develop a complete data set for all configurations of interest with signal conditioning optimised to yield the 0.5-second gust wind speed directly without the need for analytical corrections. Comparison of the 0.5-second gust wind speeds presented in Table 9 indicate that the correction previously applied were conservative for some test locations. The updated analysis represented by the results in Table 9 is considered more accurate, and in general similar results are observed across the three configurations of interest.

Table 9: Summary of wind tunnel results for pedestrian safety for tested configurations.

	Config A - Existing site			Config B - CSPS Base Case (RL305m)			Config C - Pitt St Setback 6 - 4m (RL234.7m)		
Test location	**Wind direction (°)**	**Once per annum gust (m/s)**	**Criterion**	**Wind direction (°)**	**Once per annum gust (m/s)**	**Criterion**	**Wind direction (°)**	**Once per annum gust (m/s)**	**Criterion**
1	315	22.8	Pass	315	22.9	Pass	315	22.8	Pass
2	315	21.5	Pass	315	20.2	Pass	315	20.5	Pass
3	45	22.4	Pass	45	22.0	Pass	45	22.2	Pass
4	315	19.8	Pass	315	20.6	Pass	45	22.1	Pass
5	45	22.6	Pass	157.5	21.7	Pass	45	23.4	Pass
6	45	25.0	Exceed	45	24.6	Exceed	45	25.0	Exceed
7	247.5	16.0	Pass	180	17.4	Pass	45	17.4	Pass
8	180	14.8	Pass	315	14.3	Pass	315	13.3	Pass
9	315	13.7	Pass	315	14.3	Pass	315	12.6	Pass

Appendix 3: Directional wind results

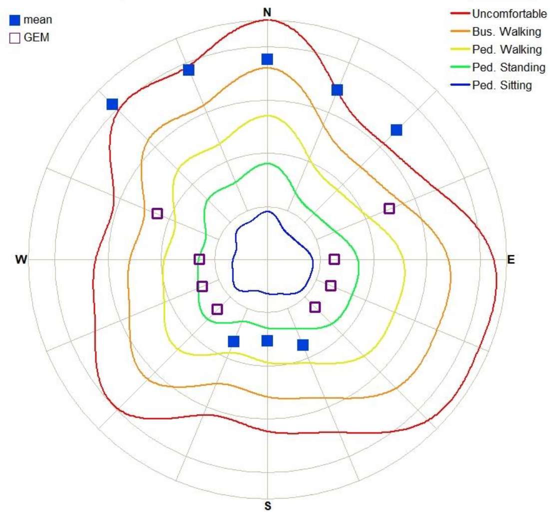
LOCATION 1.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	65.71	72.18	74.11
4	32.58	30.44	35.25
6	15.06	13.13	16.81
8	7.65	4.52	7.92
10	2.97	1.10	3.01

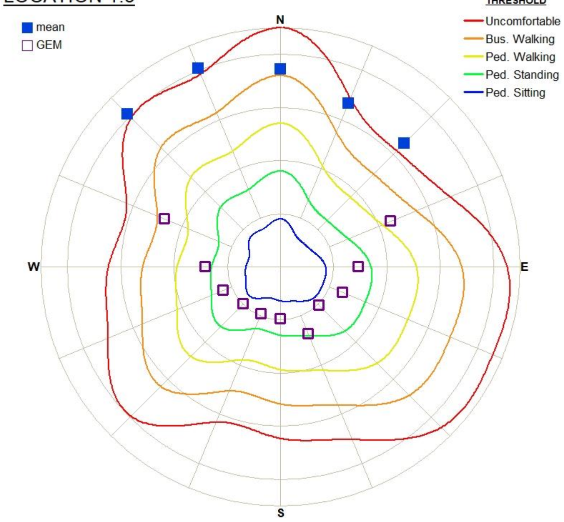
LOCATION 1.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	64.29	68.22	71.17
4	28.43	25.53	31.34
6	13.73	11.25	14.90
8	6.56	3.73	6.67
10	2.28	0.83	2.31

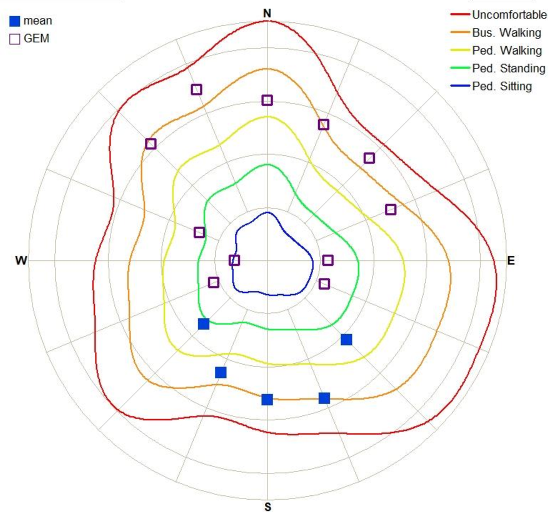
LOCATION 1.3



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	49.04	60.10	61.67
4	23.59	23.71	27.36
6	13.00	11.01	13.67
8	5.83	4.22	5.95
10	1.88	1.08	1.92

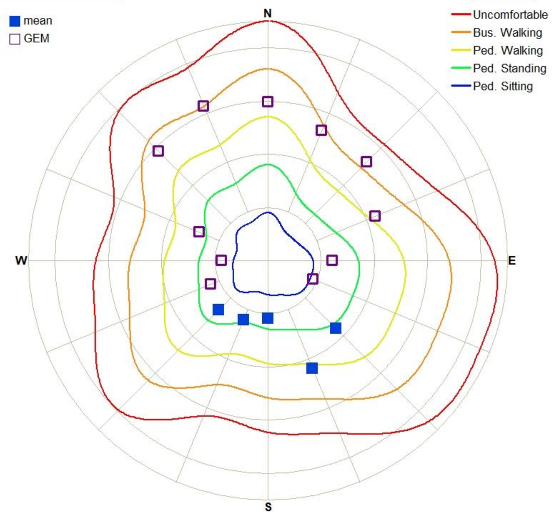
LOCATION 2.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	58.63	68.19	69.82
4	28.52	32.06	36.11
6	8.11	11.27	13.85
8	1.49	2.65	3.39
10	0.19	0.56	0.69

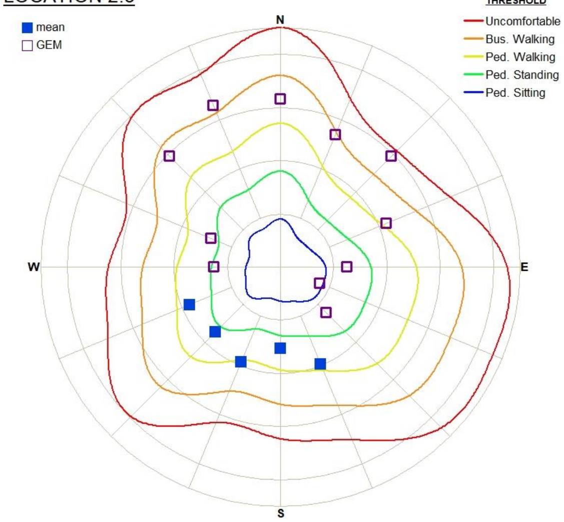
LOCATION 2.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	49.68	60.13	61.05
4	13.60	21.47	22.29
6	2.04	7.60	7.78
8	0.18	1.75	1.77
10	0.01	0.32	0.32

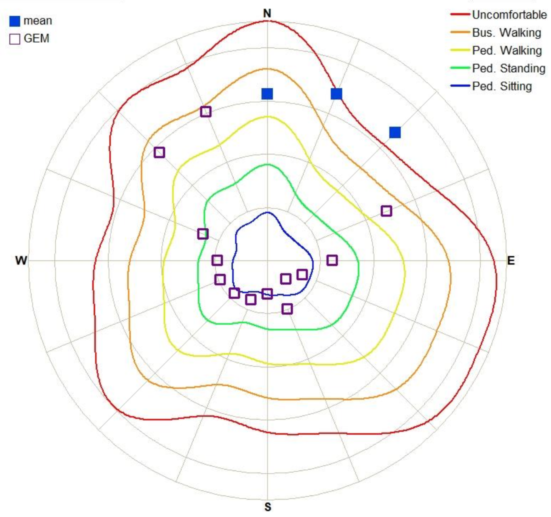
LOCATION 2.3



% of time in excess of wind speed V

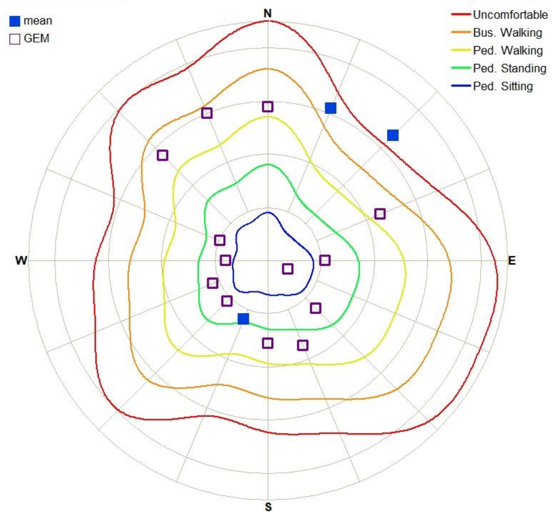
V (m/s)	MEAN	GEM	COMBINED
2	56.49	64.78	66.99
4	20.62	24.02	26.87
6	5.84	9.02	9.50
8	1.03	2.69	2.74
10	0.16	0.57	0.57

LOCATION 3.1



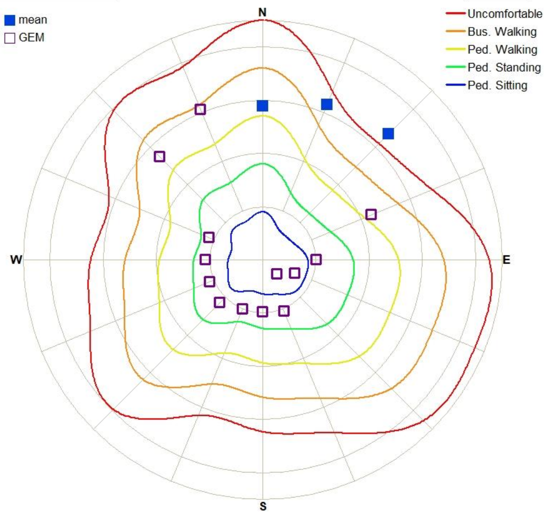
% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	36.47	44.98	45.49
4	19.65	19.72	21.01
6	11.04	9.70	11.75
8	4.99	3.03	5.20
10	1.41	0.58	1.46

LOCATION 3.2



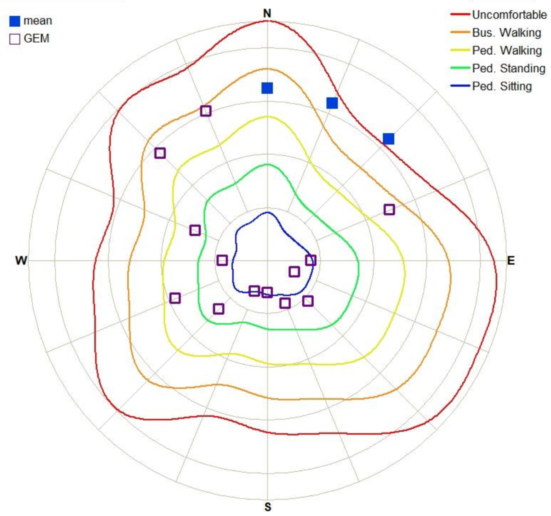
% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	50.76	58.11	58.67
4	20.06	21.12	22.14
6	9.95	8.61	10.58
8	4.02	2.46	4.29
10	1.00	0.49	1.07

LOCATION 3.3



% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	40.38	49.12	49.57
4	17.39	18.75	19.75
6	9.57	8.63	10.48
8	4.12	2.67	4.43
10	1.05	0.51	1.14

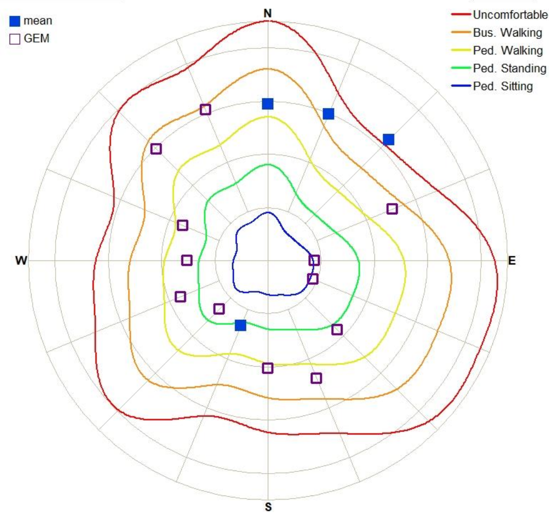
LOCATION 4.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	39.05	45.38	46.10
4	19.23	20.54	21.98
6	10.01	9.15	11.38
8	4.10	2.47	4.37
10	0.99	0.48	1.05

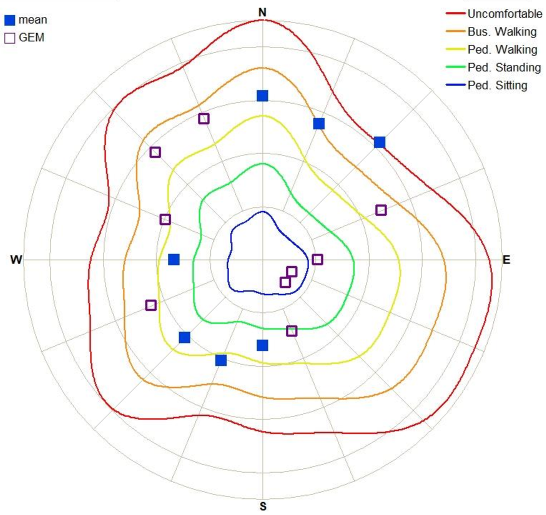
LOCATION 4.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	66.08	69.23	69.98
4	26.35	29.28	30.26
6	10.52	10.67	12.34
8	3.71	2.65	4.06
10	0.84	0.52	0.92

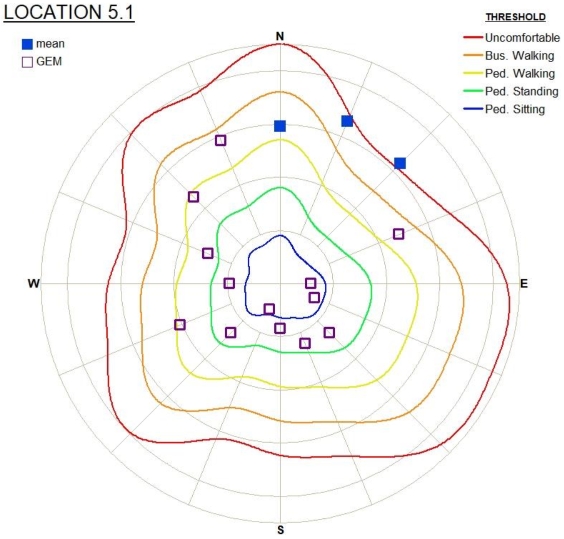
LOCATION 4.3



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	62.70	65.22	66.25
4	25.69	26.90	28.51
6	9.67	10.27	11.12
8	2.97	2.76	3.33
10	0.58	0.53	0.68

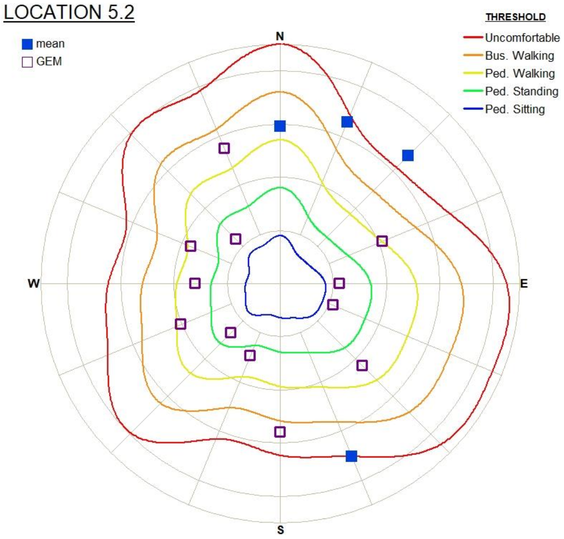
LOCATION 5.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	34.27	49.07	49.74
4	16.40	20.16	21.38
6	9.10	8.91	10.89
8	3.82	2.54	4.11
10	0.93	0.48	0.99

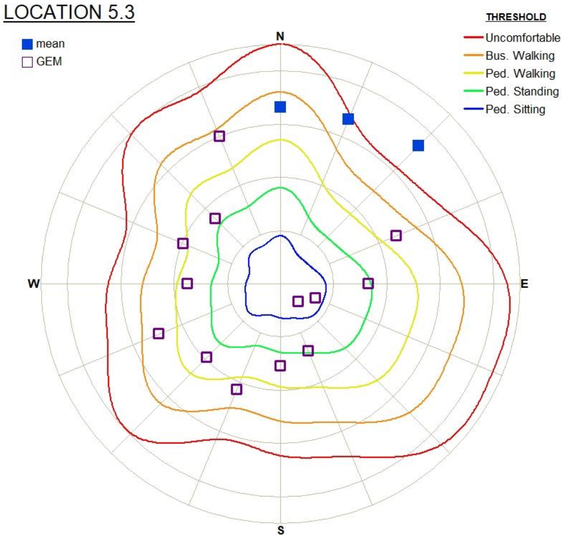
LOCATION 5.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	60.36	67.94	68.99
4	29.79	32.86	35.09
6	15.34	12.80	16.49
8	6.28	3.41	6.51
10	1.73	0.69	1.78

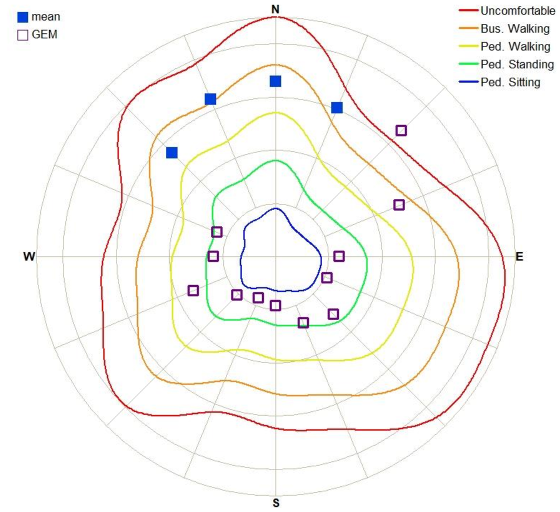
LOCATION 5.3



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	55.93	64.44	65.26
4	23.89	27.65	29.47
6	11.43	10.86	13.30
8	5.54	3.34	5.87
10	1.89	0.66	1.93

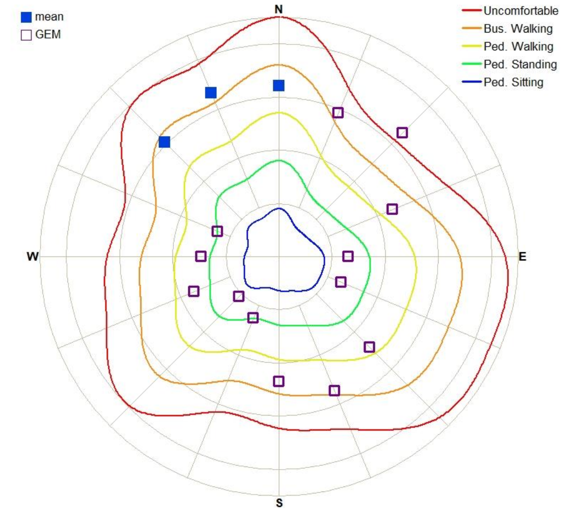
LOCATION 6.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	40.34	56.33	56.58
4	19.21	21.46	21.72
6	10.10	11.03	11.22
8	4.22	4.32	4.42
10	1.05	1.10	1.12

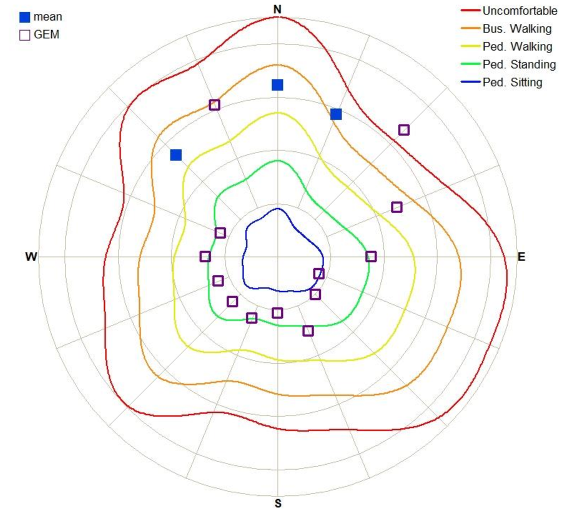
LOCATION 6.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	59.76	72.08	72.82
4	26.87	32.94	33.94
6	10.98	13.23	13.62
8	4.10	4.54	4.73
10	1.02	1.06	1.15

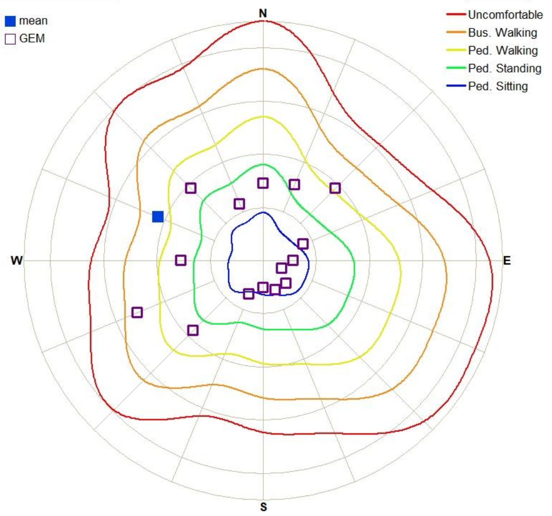
LOCATION 6.3



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	40.35	58.13	58.67
4	17.02	21.06	21.59
6	8.94	10.08	10.54
8	3.24	3.87	4.11
10	0.65	1.00	1.05

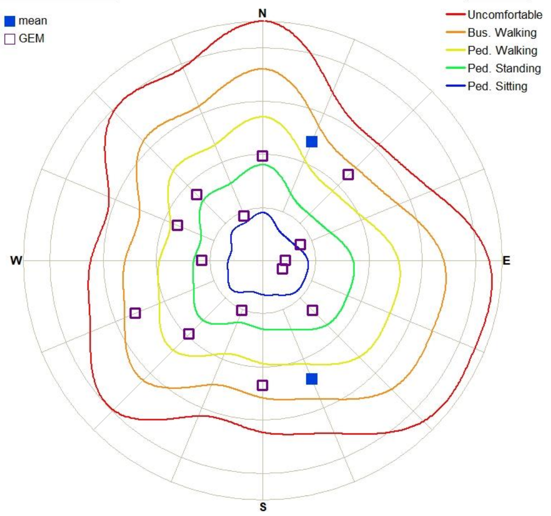
LOCATION 7.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	26.66	33.88	34.28
4	6.87	10.70	11.03
6	1.39	1.93	2.18
8	0.25	0.25	0.35
10	0.02	0.02	0.03

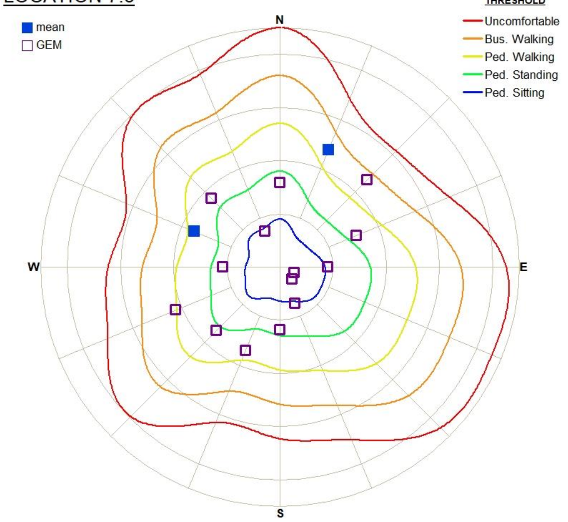
LOCATION 7.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	43.64	53.91	54.17
4	21.72	23.04	23.55
6	5.91	5.96	6.38
8	0.87	0.87	0.97
10	0.07	0.08	0.09

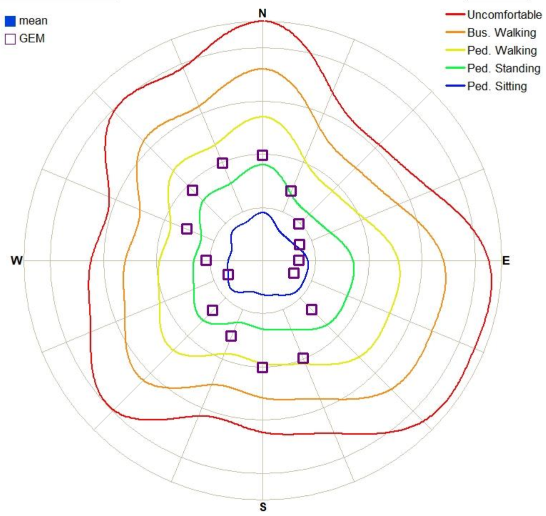
LOCATION 7.3



% of time in excess of wind speed V

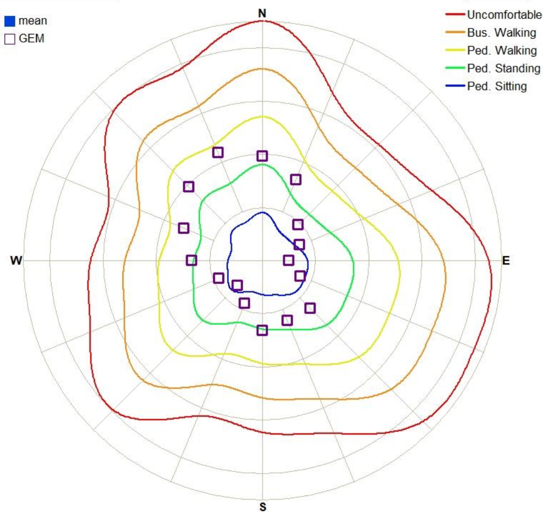
V (m/s)	MEAN	GEM	COMBINED
2	36.49	46.22	46.54
4	11.76	15.21	15.69
6	3.39	3.53	3.98
8	0.42	0.40	0.47
10	0.02	0.02	0.03

LOCATION 8.1



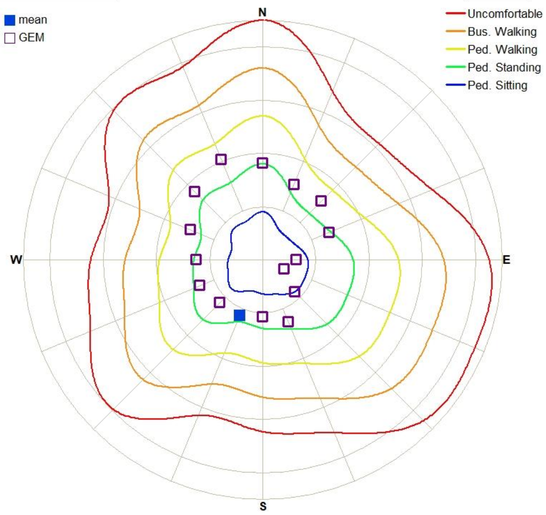
% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	32.26	46.00	46.00
4	7.05	9.67	9.67
6	0.89	1.34	1.34
8	0.07	0.11	0.11
10	0.00	0.01	0.01

LOCATION 8.2



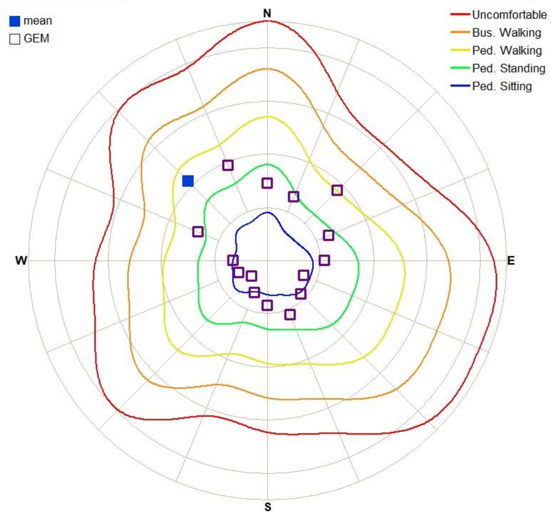
% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	22.46	40.48	40.48
4	1.76	5.11	5.11
6	0.19	0.58	0.58
8	0.02	0.06	0.06
10	0.00	0.01	0.01

LOCATION 8.3



% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	35.88	43.60	43.84
4	3.97	6.00	6.03
6	0.21	0.42	0.42
8	0.01	0.03	0.03
10	0.00	0.00	0.00

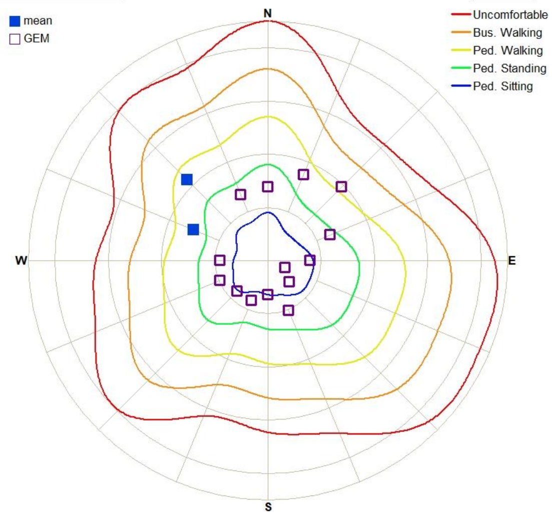
LOCATION 9.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	19.50	32.95	33.22
4	3.61	6.17	6.26
6	0.42	0.81	0.87
8	0.06	0.07	0.08
10	0.01	0.01	0.01

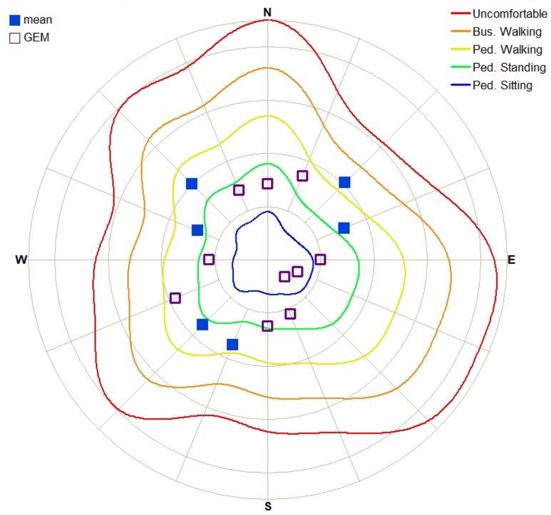
LOCATION 9.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	20.79	33.08	33.27
4	2.81	8.00	8.07
6	0.42	1.13	1.17
8	0.07	0.10	0.11
10	0.01	0.01	0.01

LOCATION 9.3



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	42.91	47.14	48.48
4	11.55	10.51	12.18
6	1.59	0.89	1.65
8	0.15	0.05	0.15
10	0.01	0.00	0.01