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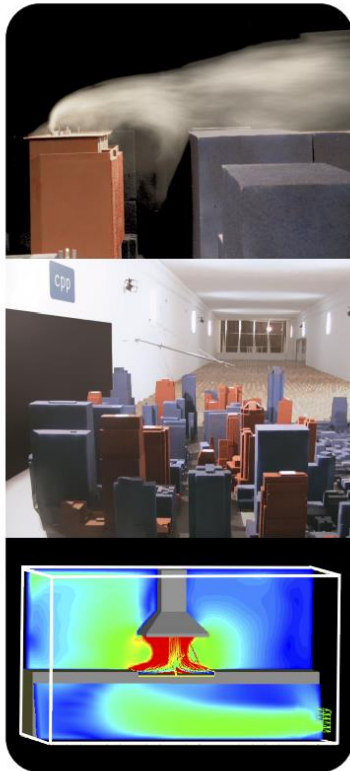
WIND ENGINEERING AND AIR QUALITY CONSULTANTS

Final Report

Wind Tunnel Test for:

MARTIN PLACE OVER STATION

Sydney, Australia



Prepared for:

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EXECUTIVE SUMMARY

A wind tunnel study of the proposed Martin Place Over Station development, to be located in Sydney, was conducted to assess pedestrian wind comfort at ground and upper terrace levels. A massing model of the envelope of the project was fabricated to a 1:400 length 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 southern tower was tested without a setback on the Martin Place façade and with a 25 m setback at RL 76.95 m. This report presents a subset of the results from the wind tunnel testing of the overall precinct presented in Cermak Peterka Petersen (2017) in support of the State Significant Development Application.

The wind tunnel testing was performed in the natural boundary layer wind tunnel of Cermak Peterka Petersen Pty. Ltd., St Peters. Measurements of wind speeds likely to be experienced by pedestrians were made with a hot-film anemometer. 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 Terrain Category 3 as defined in Standards Australia (2011).

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 25 locations for 16 wind directions each. These points were tested around the development in the proposed configuration, focusing on access routes, doorways, 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. Selective locations were tested in the existing configuration for comparison.

The wind environment around the development was found to be generally suitable for pedestrian standing and walking activities from a comfort perspective with reference to the Lawson criteria, with individual remote or elevated locations rated as suitable for business walking only. Most locations passed the Lawson distress criteria except for two locations exposed to winds from the south-east over the exposed Hyde Park, however, the conditions in these locations are slightly improved with the inclusion of the proposed development. The wind conditions on the ground plane were mainly found to

be similar to the existing conditions. Locations directly north of the proposed buildings, on Hunter Street and Martin Place, are more affected by increased downwash from the bluff northern façades of the proposed buildings, but still satisfy the comfort and safety criteria.

DOCUMENT VERIFICATION

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28/02/2017	Final Report	JP	GSW	GSW
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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_{stdev}/U
U	Local mean velocity (m/s)
U_{ref}	Reference velocity at reference height z_{ref} (m/s)
U_{pk}	Peak wind speed in pedestrian studies (m/s)
U_{stdev}	Standard deviation of fluctuating velocity (m/s)
z	Height above surface (m)
ν	Kinematic viscosity of approach flow (m ² /s)
$\sigma()$	Standard deviation of $()$, $=()_{rms}$
ρ	Density of approach flow (kg/m ³)
$()_{max}$	Maximum value during data record
$()_{min}$	Minimum value during data record
$()_{mean}$	Mean value during data record
$()_{stdev}$	Standard deviation

1. CLIENT PROVIDED PROJECT BACKGROUND

1.1 Introduction

This report supports a State Significant Development (SSD) Development Application (DA) submitted to the Minister for Planning pursuant to Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act).

Macquarie Corporate Holdings Pty Limited (Macquarie) is seeking to create a World Class Transport and Employment Precinct at Martin Place, Sydney.

The application seeks Stage 1 approval for the establishment of building envelopes, maximum Gross Floor Areas and design parameters for two predominantly commercial office Over Station Development (OSD) towers, located above the site of the future Martin Place Metro Station (part of the NSW Government's Sydney Metro project).

In particular, this report presents the results of wind tunnel testing of the pedestrian level wind environment around the proposed development.

1.2 Background

The New South Wales (NSW) Government is implementing Sydney's Rail Future (Transport for NSW, 2012), 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.

Sydney Metro is a new standalone rail network identified in Sydney's Rail Future. The Sydney Metro network consists of Sydney Metro Northwest (Stage 1) and Sydney Metro City & Southwest (Stage 2).

Stage 2 of the Metro entails the construction and operation of a new Metro rail line from Chatswood, under Sydney Harbour through Sydney's CBD to Sydenham and eventually onto to Bankstown through the conversion of the existing line to Metro standards. The project also involves the delivery of seven (7) new Metro stations, including Martin Place.

This step-change piece of public transport infrastructure once complete will have the capacity for 30 trains an hour (one every two minutes) through the CBD in each direction catering for an extra 100,000 customers per hour across the Sydney CBD rail lines.

On 9 January 2017 the Minister for Planning approved the Stage 2 (Chatswood to Sydenham) Metro application lodged by Transport for NSW (TfNSW) as a Critical State Significant Infrastructure (CSSI) project (reference SSI 15_7400).

TfNSW is also making provision for future Over Station Development (OSD) on the land it has acquired for the Stage 2 Sydney Metro project, including land acquired for the purposes of delivering Martin Place Station. The OSD development is subject to separate applications to be lodged under the relevant provisions of the EP&A Act.

An Unsolicited Proposal submission has been lodged by Macquarie to the NSW Government for the delivery of a single fully integrated station/OSD solution for the new Sydney Metro Martin Place Station.

1.3 Site Description

The Sydney Metro Martin Place Station Precinct (the Precinct) project relates to the following properties (refer to Figure 1):

- 50 Martin Place, 9 – 19 Elizabeth Street, 8 – 12 Castlereagh Street, 5 Elizabeth Street, 7 Elizabeth Street, and 55 Hunter Street (North Site);
- 39 – 49 Martin Place (South Site); and
- Martin Place (that part bound by Elizabeth Street and Castlereagh Street).

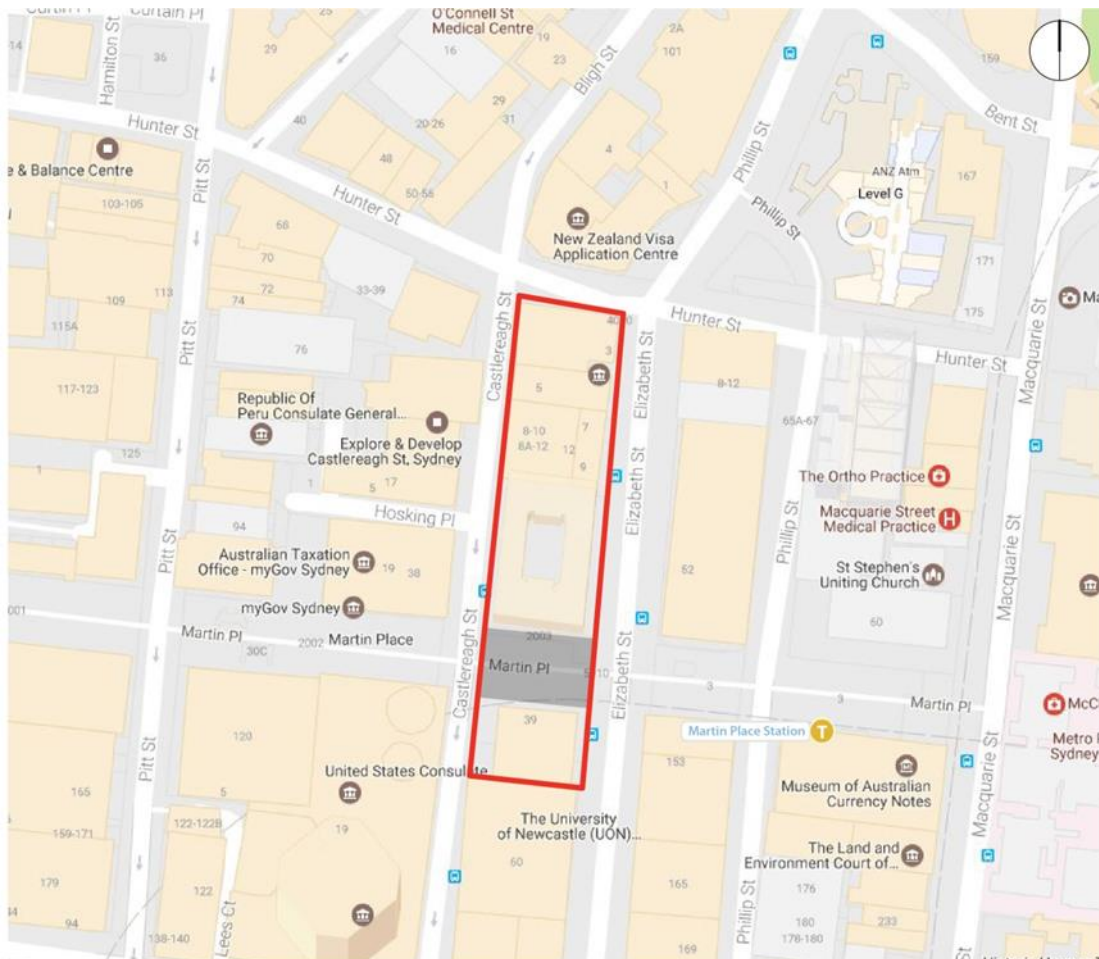
The land the subject of this application relates only to the North and South Site (refer to Figure 2). Each site will accommodate one OSD tower above the future Sydney Metro Martin Place Station (representing the northern and southern entries/gateways to the Sydney Metro station). The land acquired for the Sydney Metro Martin Place Station is the same as for the Macquarie proposal, except that the Macquarie proposal includes the two properties north of Martin Place owned by Macquarie, namely 50 Martin Place and 9-19 Elizabeth Street.

Both the North and South Sites are regular in shape and have area of approximately 6,022 m² and 1,897 m² respectively, totalling 7,919 m².

Located close to the centre of the Sydney CBD, the Precinct comprises of the entire City block bounded by Hunter Street, Elizabeth Street, Martin Place and Castlereagh Street; that portion of Martin Place located between Elizabeth Street and Castlereagh Street and the northern most property in the block bounded by Martin Place, Elizabeth Street, Castlereagh Street, and King Street. Together it constitutes an above ground site area of approximately 9,400 m², with a dimension from north to south

of approximately 210 metres and from east to west of approximately 45 metres. It incorporates a significant portion of one of Sydney’s most revered public spaces – Martin Place.

Martin Place is recognised as one of Central Sydney’s great public, civic and commemorative spaces, as well as being a historically valued commercial and finance location of Sydney’s CBD. Martin Place and a large number of buildings on, or in close proximity to, Martin Place are identified as heritage items, either as items of National, State or Local significance. Number 50 Martin Place, which forms part of the Macquarie North Site, is one of these major heritage items.



- The Precinct
- Land not subject to this application

Figure 1: Aerial photo of the site (Google Maps and JBA, 2017)



Figure 2: Location map of the site (Nearmap and JBA, 2017)

There has been a number of redevelopment and refurbishment proposals in recent years along Martin Place to improve existing assets and recapture their premium commercial status (e.g. 5 Martin Place, 50 Martin Place, 20 Martin Place, upgrades of the MLC Centre, and 60 Martin Place). The City of Sydney Council has also identified a need to reinvigorate Martin Place and upgrade the public spaces.

The surrounding locality is characterised by a variety of built forms and architectural styles, with many of the buildings, including those of relatively recent years, not complying with the current planning controls with respect to building heights, setbacks and street wall heights.

In terms of land use the area is characterised by a predominance of office uses, with some ground floor retailing, cafés, or restaurants and hotels (most notably the Westin and the Wentworth) to support its primary business centre function.

1.4 Overview of Proposed Development

The proposal by Macquarie is unique and innovative in aligning the aspirations for public transport, civic amenity and the long-term sustainability of Sydney as a financial centre. This will be achieved through a development designed to maximise the opportunities for an improved Metro Station, integration of the existing and new public transport infrastructure, integration of that infrastructure with modern commercial office towers and world class retailing, along with rejuvenating and complimenting

some of Sydney's most revered public spaces, and substantially improving station access and connectivity.

More specifically the development will comprise a concept proposal (under section 83B of the EP&A Act) for the OSD for the North and South Sites. It will be designed as a fully integrated Station and OSD project that, subject to approval, will be built and delivered as one integrated project for opening at the same time as the Sydney Metro is commissioned.

The concept proposal establishes the vision and planning and development framework which will be the basis for the consent authority to assess future detailed development proposals (Stage 2 DAs).

The North Site

The Concept Proposal for the North Site is for a new 40+ storey, predominately commercial office building. The proposal seeks to integrate with the existing 50 Martin Place building, supporting large commercial floor plates. No connections to 50 Martin Place are proposed for the basement levels of that building, including the level of the significant heritage Safe Deposit Vault.

The South Site

The Concept Proposal for the South Site is for a new 28+ storey predominately commercial office building.

The detailed design of the OSD is still in its preliminary stages. Critically it requires an integrated design approach to be adopted between the commercial OSD components classified as SSD, and the Station components, which are classified as CSSI and have already been approved. This is to ensure:

- all the operational needs of the Metro Station are accommodated in accordance with TfNSW requirements and the structural and other requirements of the OSD are accommodated within the Station building beneath, in what is essentially one building; and
- a cohesive public domain and built form outcome is achieved for Sydney.

In this regard, OSD uses and structural elements are located within the below ground and lower podium levels, as conceptually approved under the CSSI consent for the Martin Place Station.

The Staged DA will seek consent for, amongst other things, land uses, gross floor area, building envelopes, and vehicle access arrangements.

A more detailed and comprehensive description of the proposal is contained in the Environmental Impact Statement (EIS) prepared by JBA.

1.5 Planning Approvals Strategy

The *State Environmental Planning Policy (State and Regional Development) 2011 (SEPP SRD)* identifies development which is declared to be State Significant. Under Schedule 1 and Clause 19(2) of SEPP SRD, development within a railway corridor or associated with railway infrastructure that has a capital investment value of more than \$30 million and involves commercial premises is declared to be State Significant Development (SSD) for the purposes of the EP&A Act.

The proposed development (involving commercial development that is both located within a rail corridor and associated with rail infrastructure) is therefore SSD.

Pursuant to Section 83B of the EP&A Act a Staged DA may be made setting out concept proposals for the development of a site (including setting out detailed proposals for the first stage of development), and for which detailed proposals for separate parts of the site are to be the subject of subsequent DAs. This SSD DA is a staged development application made under Section 83B of the EP&A Act.

A detailed development application(s) (Stage 2 DAs) will accordingly follow, seeking approval for the detailed design and construction of all or specific aspects of the proposal in accordance with the approved staged development application.

Submitted separately to this SSD DA are applications to modify the CSSI approval together with a Planning Proposal relating to the North Site (FSR only) and South Site (height and FSR).

For clarity, Figure 3 below is a diagrammatic representation of the suite of applications proposed by Macquarie, to show the relationship of the SSD DA (the subject of this report) to the Planning Proposal and the Martin Place Metro CSSI.

The Department of Planning and Environment have provided Secretary's Environmental Assessment Requirements (SEARs) to the applicant for the preparation of an Environmental Impact Statement for the proposed development. This report has been prepared having regard to the SEARs as relevant.

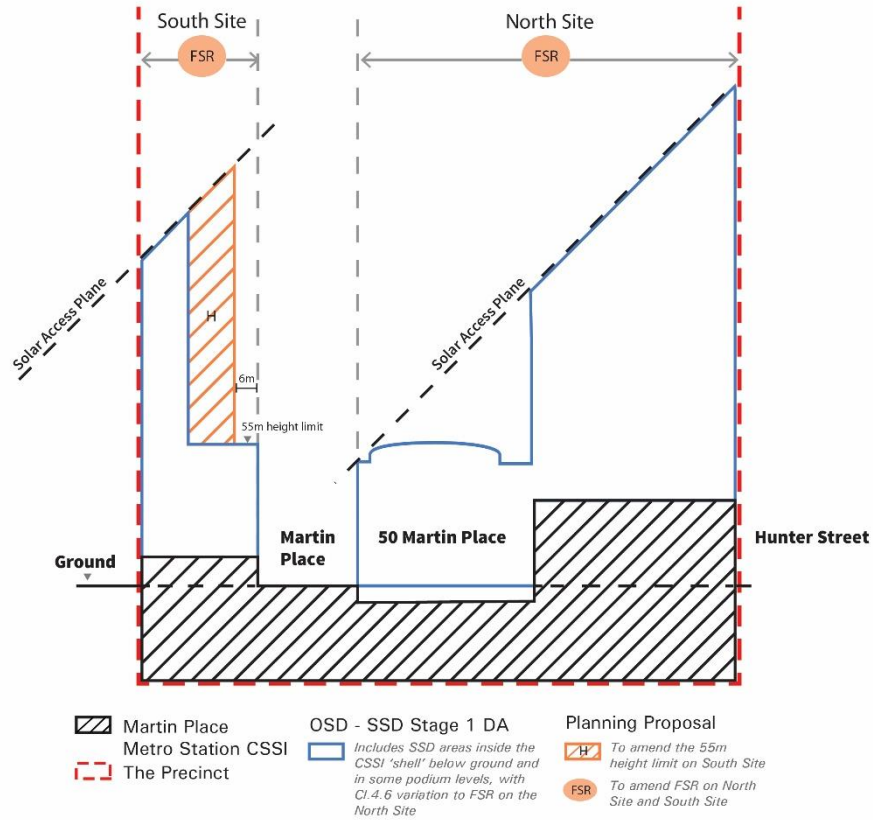


Figure 3: Relationship of planning applications (JBA, 2017)

2. INTRODUCTION

Pedestrian acceptability of footpaths, entrances, plazas, and terraces is often an important design parameter of interest to the development approvals body, 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.

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.

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 a discussion of 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).

Table 1: Configurations for data acquisition

<i>General Information</i>	
Model length scale	1:400
Surrounding model radius (full-scale)	570 m
Reference height (full-scale)	200 m above ground level
Approach Terrain Category	Suburban approach, terrain category 3
<i>Test Configuration Specifications</i>	
Configuration A: Proposed (Locations denoted XX)	Proposed Martin Place Over Station development with surrounding buildings and landscape, as shown in Figure 6 and Figure 7. Building envelope without setback. Pedestrian winds measured at 25 locations for 16 wind directions at 22.5° increments from 0° (north)
Configuration B: Existing (Locations denoted XX.1)	Existing development with surrounding buildings and landscape, as shown in Figure 8 and Figure 9. Pedestrian winds measured at 11 locations.
Configuration D: Proposed with 25 m setback (Locations denoted XX.3)	As the proposed configuration with an additional setback of 25 m on the northern façade of the southern tower at RL 76.95 m. Pedestrian winds measured at 12 locations.

3. THE WIND TUNNEL TEST

Modelling of the aerodynamic flow around structures 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 Australasian Wind Engineering Society Quality Assurance Manual (2001) suggests a minimum Reynolds number of 50,000, based on representative 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 4. 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 a 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 5 and are explained more fully in Section 5.1.1.

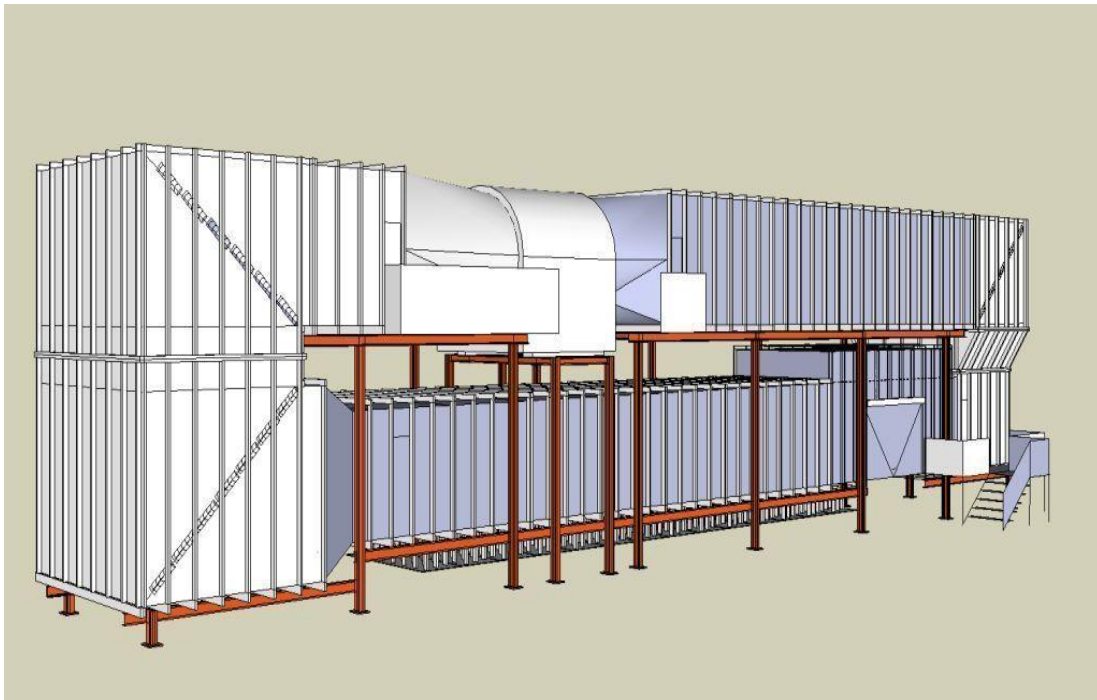


Figure 4: Schematic of the closed circuit wind tunnel

A massing model of the proposed development and surrounds to a radius of 570 m was constructed at a length scale of 1:400, which was consistent with the modelled atmospheric flow, and permitted a reasonable test model size with an adequate portion of the adjoining environment to be included in a proximity model that was within wind tunnel blockage limitations. The model was mounted on the turntable located near the downstream end of the wind tunnel test section, Figure 7. The turntable permitted rotation of the modelled area for examination of velocities from any approach wind direction. Additional photos of the testing are included in Appendix 1.

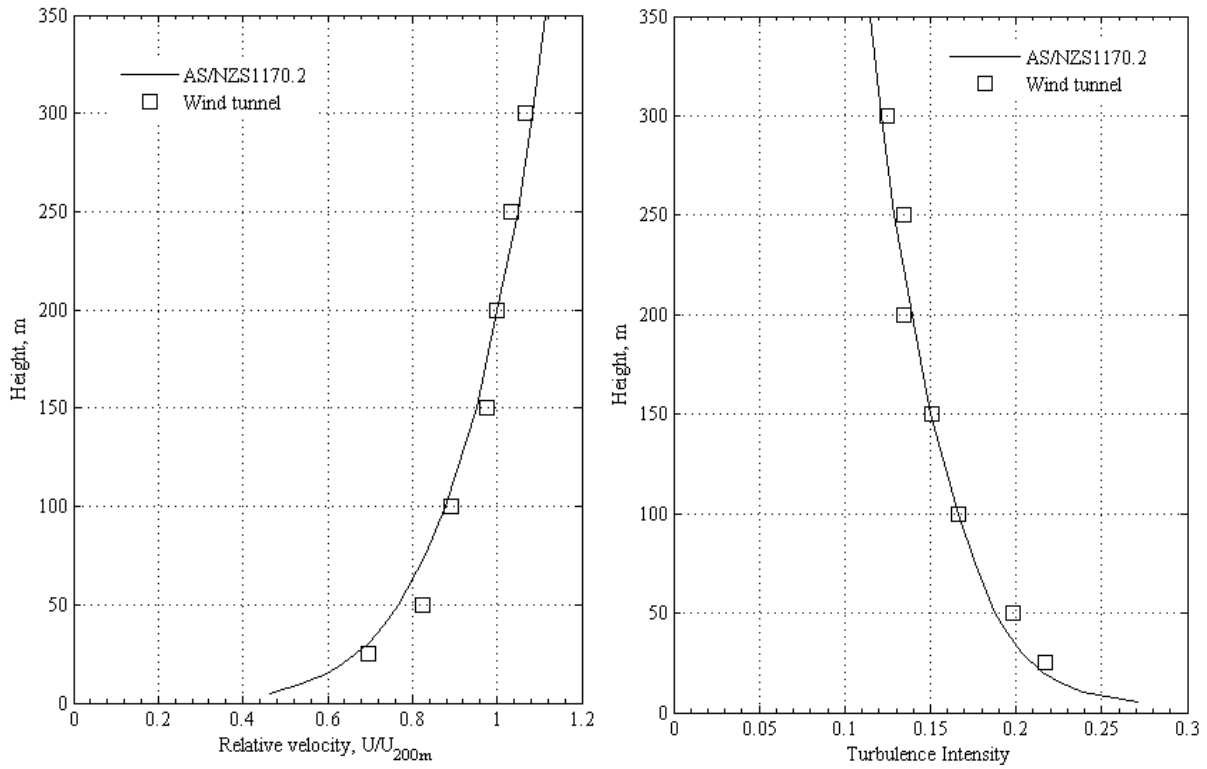


Figure 5: Mean velocity and turbulence profiles approaching the model, terrain category 3

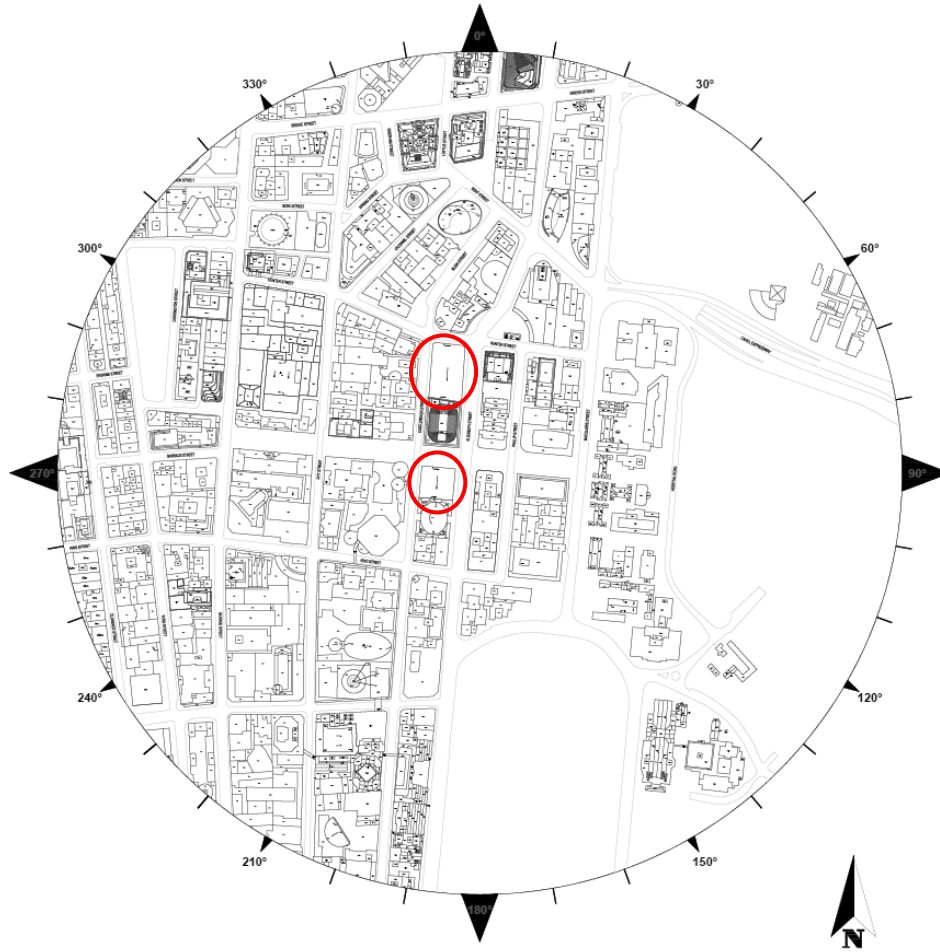


Figure 6: Turntable layout with proposed buildings



Figure 7: Photograph of the Martin Place Over Station development model in the CPP wind tunnel viewed from the south

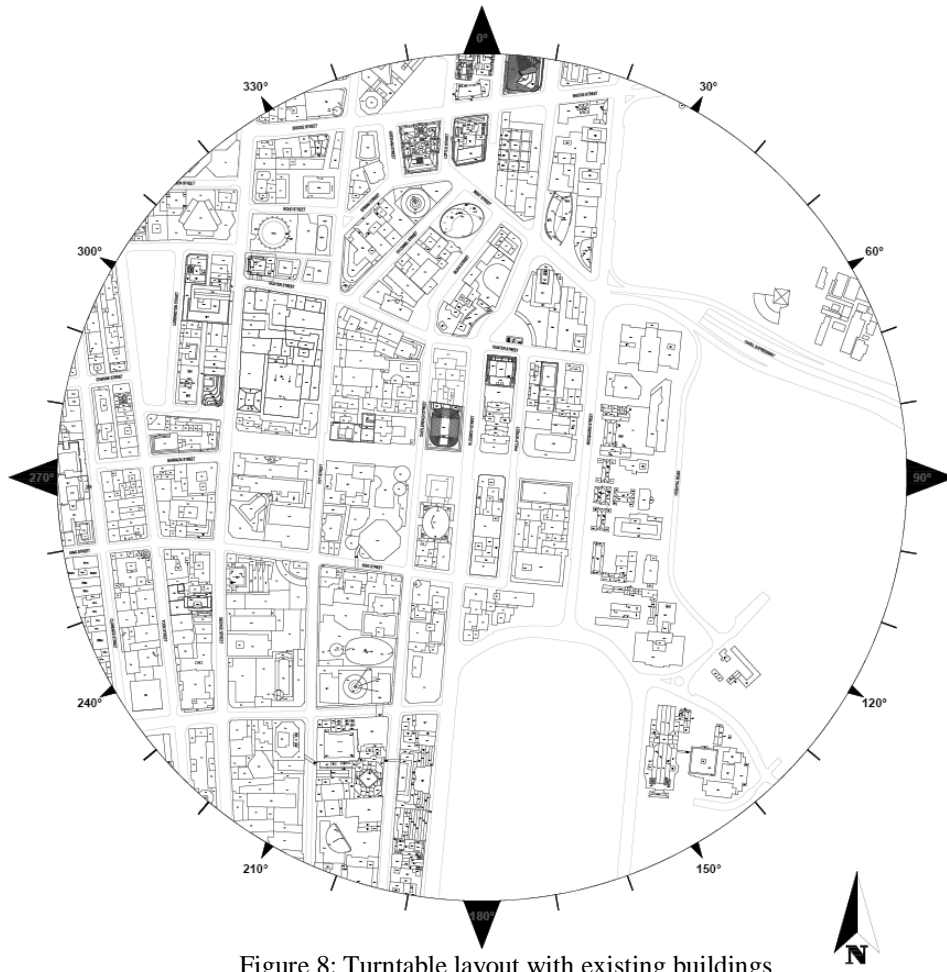


Figure 8: Turntable layout with existing buildings

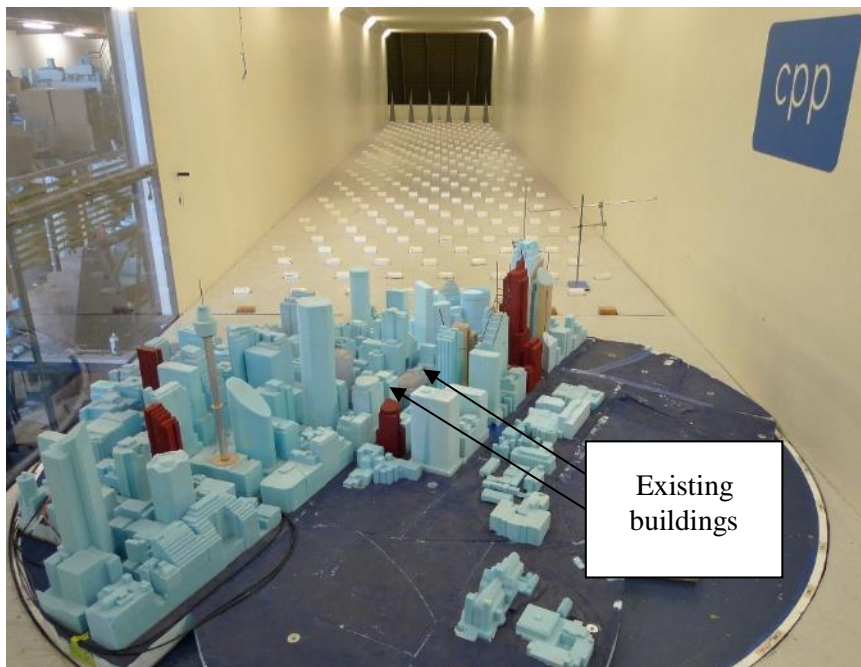


Figure 9: Photograph of the existing configuration model in the CPP wind tunnel viewed from south-east

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. A location can further 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.

Table 2: The Lawson comfort 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
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
<20 m/s	not to be exceeded more than two times per year (or one time per season) where only able 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.	

Lawson’s criteria have categories for discomfort, based on wind speeds exceeded five percent 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 speed¹. 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 the once per annum gust, which was the basis of the City of Sydney (2011) DCP, however provides additional information regarding the serviceability wind climate. The current City of Sydney (2012) DCP specifies wind effects not to exceed 16 m/s, and 10 m/s for ‘active frontages’. In the vicinity of the Martin Place Over Station development Martin Place, Hunter Street, and parts of Castlereagh Street are classified as active frontages, while Elizabeth Street is not. There are few locations in Sydney

¹ The rating of “uncomfortable” in Table 2 is the word of the acceptance criteria author and may not apply directly to any particular project. High wind areas are certainly not uncomfortable all the time, just on windier days. The word uncomfortable, in our understanding, refers to acceptability of the site by pedestrians for typical pedestrian use; i.e., on the windiest days, pedestrians will not find the areas “acceptable” for walking and will tend to avoid such areas if possible. The distress rating fail indicates some unspecified potential for causing injury to a less stable individual who might be blown over. The likelihood of such events is not well described in the literature and is likely to be strongly affected by individual differences, presence of water, blowing dust or particulates, and other variables in addition to the wind speed.

that would meet the DCP criteria without shielding to improve the wind conditions. From discussions with Council the criterion wind speed 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 once per annum gust wind speed criterion is based on the work of Melbourne (1978), and the 16 m/s level is classified as acceptable for pedestrian walking along a main accessway, and 10 m/s level is classified as generally acceptable for use for pedestrian sitting. This criterion gives the once per annum (actually 0.1% of the time) gust wind speed, and uses this as an estimator of the general wind conditions at a site, which may be more relevant. To combat this limitation, this study is based upon the criteria of Lawson (1990), which are described above. Assessment using the Lawson criteria provides a similar comfort classification as using the once per annum gust criteria, which is the basis of the City of Sydney (2012) DCP; however, it also provides significantly more information regarding the serviceability wind climate.

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 5.1.2. 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 5. Turbulence intensities are related to the local mean wind speed. These profiles have the form as derived from Standards Australia (2011) and are appropriate for the approach conditions.

5.1.2 Pedestrian Winds

The proposed development is situated in the Sydney CBD between Castlereagh and Elizabeth Streets with the proposed towers being located north and south of the existing 50 Martin Place building, Figure 11. The site is surrounded by high-rise buildings of the Sydney CBD. The site is in the centre of the CBD and consequently receives some shielding from all wind directions.

Wind speed measurements were recorded at 25 locations to evaluate pedestrian comfort in and around the project site, Figure 11 to Figure 15 in various configurations. Of the 25 locations, 11 were tested in the existing configuration for comparative purposes, Figure 12. Wind speed 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 pedestrian comfort at the building corners where relatively severe conditions frequently are found, near building entrances, on adjacent pavements with heavy pedestrian traffic, and in areas potentially intended as upper level outdoor terraces. In addition, selected locations were tested with an additional setback of 25 m on the northern façade of the southern tower, Figure 13 and Figure 15.

The hot-film signal was sampled for a period corresponding to one hour in prototype. All wind speed 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 the gust duration on which the wind criteria are based.

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

$$\frac{U_{\text{pk}}}{U_{\text{ref}}} = \frac{U + 3 \cdot \sigma_U}{U_{\text{ref}}}$$

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, the wind tunnel data were combined with wind frequency and direction information measured by the Bureau of Meteorology (BoM) at a standard height of 10 m at Sydney Airport from 1995 to 2015, Figure 10.

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 summarized in Figure 10 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 comfort and safety with respect to the Lawson criteria is presented in Figure 11 to Figure 15 for each test location. The implications of the results are discussed in Section 6.

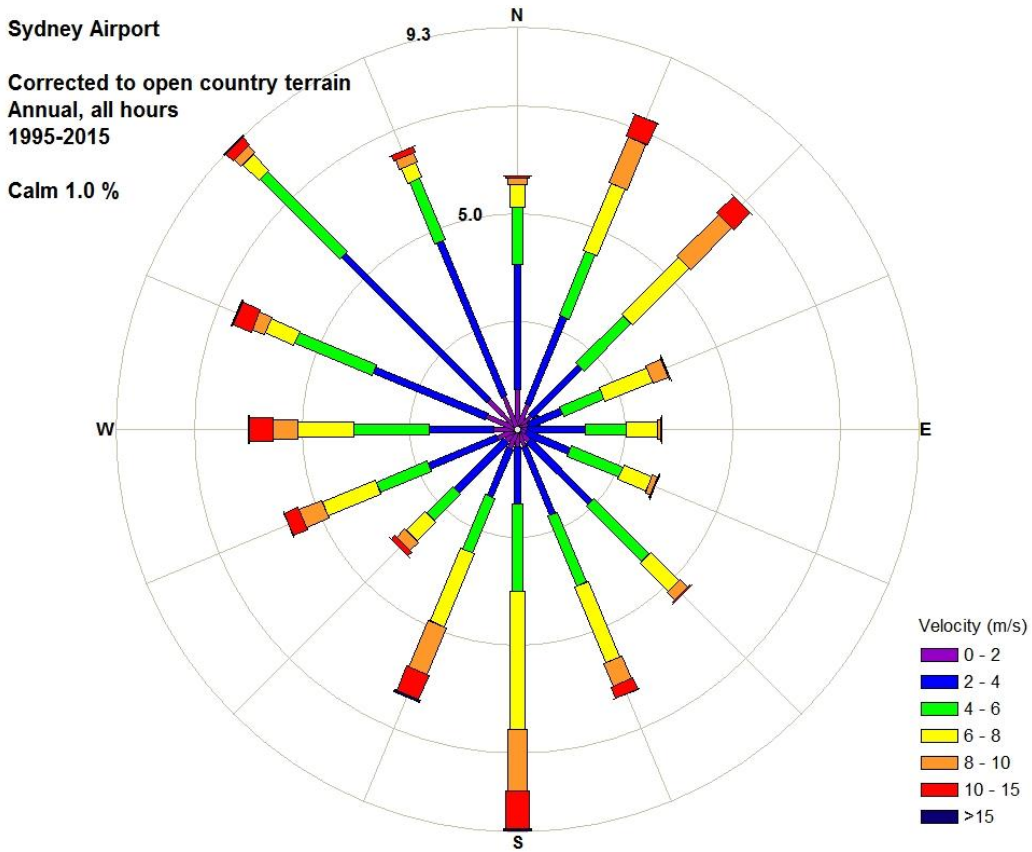


Figure 10: Wind rose of direction and speed for Sydney Airport

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.

6. DISCUSSION

The wind climatology chart of Figure 10 indicates that the most frequent strong winds are from the south, and to a lesser extent, the west and north-east. The development is located in a central area of the city leading to some shielding effects from all wind directions. The topography and surrounding building layout relative to the prevailing strong wind directions influence the local wind flow in and around the development. Individual locations around the development are more susceptible to winds from different directions, depending on the relative location of the point tested to the geometry of the surrounding buildings. 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.

A high-level summary of the target criteria based on the intended use of the space for the pedestrian level measurement locations and the wind tunnel results including the Lawson comfort and safety ratings is provided in Table 4. It is evident that all ground plane locations meet the intended use of the space from a comfort perspective and pass the safety criterion, with the exception of location 23 remote from the site, which is an existing condition and is not affected by the proposed development.

More detailed conclusions of the pedestrian study can be understood by reviewing the colour coded images in Figure 11 to Figure 15, which present the locations selected for investigation of pedestrian wind comfort in and around the site along with the Lawson criteria rating for both comfort and distress. The central colour indicates the comfort rating for the location, and the colour of the outer ring indicates whether the location passes the distress criterion.

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

Table 4: Summary of target criteria and wind tunnel results

Description / Location			Target Comfort rating, 5% exceedance wind speed (m/s)	Wind Tunnel Results					Notes	
				Proposed Configuration			Existing Configuration			
				Comfort rating, 5% exceedance wind speed (m/s)	Meets target Y(es)/N(o)	Safety rating, 0.022% exceedance wind speed (m/s)	Comfort rating, 5% exceedance wind speed (m/s)	Meets target Y(es)/N(o)		Safety rating, 0.022% exceedance wind speed (m/s)
Ground Plane		1	>6 to 8	4.2	Y	8.2	3.7	Y	7.2	
		2	>6 to 8	6.2	Y	13.1	n/a		n/a	
		3	>6 to 8	6.6	Y	13.6	5.8	Y	11.8	
		4	>6 to 8	6.4	Y	12.2	4.8	Y	9.2	
		5	>6 to 8	4.0	Y	9.2	n/a		n/a	
		6	>6 to 8	4.6	Y	9.0	n/a		n/a	
		7	>6 to 8	4.3	Y	8.4	n/a		n/a	
		8	>6 to 8	4.2	Y	8.3	n/a		n/a	
		9	>6 to 8	4.0	Y	8.1	n/a		n/a	
		10	>6 to 8	5.0	Y	9.6	4.5	Y	9.3	
		11	>6 to 8	5.3	Y	10.7	n/a		n/a	
		12	>6 to 8	6.1	Y	13.8	4.8	Y	10.6	
		13	>6 to 8	6.6	Y	12.1	4.7	Y	8.7	
		14	>6 to 8	6.5	Y	12.1	6.4	Y	11.6	
		15	>6 to 8	5.8	Y	10.3	5.0	Y	8.6	
		16	>6 to 8	5.8	Y	10.6	n/a		n/a	
		17	>6 to 8	3.6	Y	7.7	n/a		n/a	
		18	>6 to 8	4.7	Y	10.0	n/a		n/a	
		19	>6 to 8	5.2	Y	9.8	n/a		n/a	
		20	>6 to 8	6.8	Y	13.8	7.5	Y	15.6	
		21	>6 to 8	4.5	Y	8.2	4.6	Y	8.3	
		22	>6 to 8	5.1	Y	9.8	n/a		n/a	
		23	>6 to 8	7.6	Y	17.2	8.0	N	17.4	
North Tower	Rooftop	24	>4 to 6	8.8	N	17.4	n/a		n/a	depending on architectural details and intended use, local amelioration measures would be required
		25	>4 to 6	7.9	N	18.3	n/a		n/a	
South Tower	Podium	28.3	>4 to 6	6.9	N	14.5	n/a		n/a	depending on architectural details and intended use, local amelioration measures would be required
		29.3	>4 to 6	5.9	Y	12.1	n/a		n/a	

LEGEND	
Comfort Criteria	Safety Criteria
Outdoor Dining	Passes safety criteria
Pedestrian Sitting	Able bodied
Pedestrian Standing	Fails safety criteria
Pedestrian Walking	
Business Walking	
Uncomfortable	

6.1.1 – Proposed development with existing surroundings

In the surrounding area of the proposed development, the wind conditions at pedestrian level are generally classified as suitable for pedestrian standing and walking with some specific locations meeting the sitting criterion, Table 4 and Figure 11.

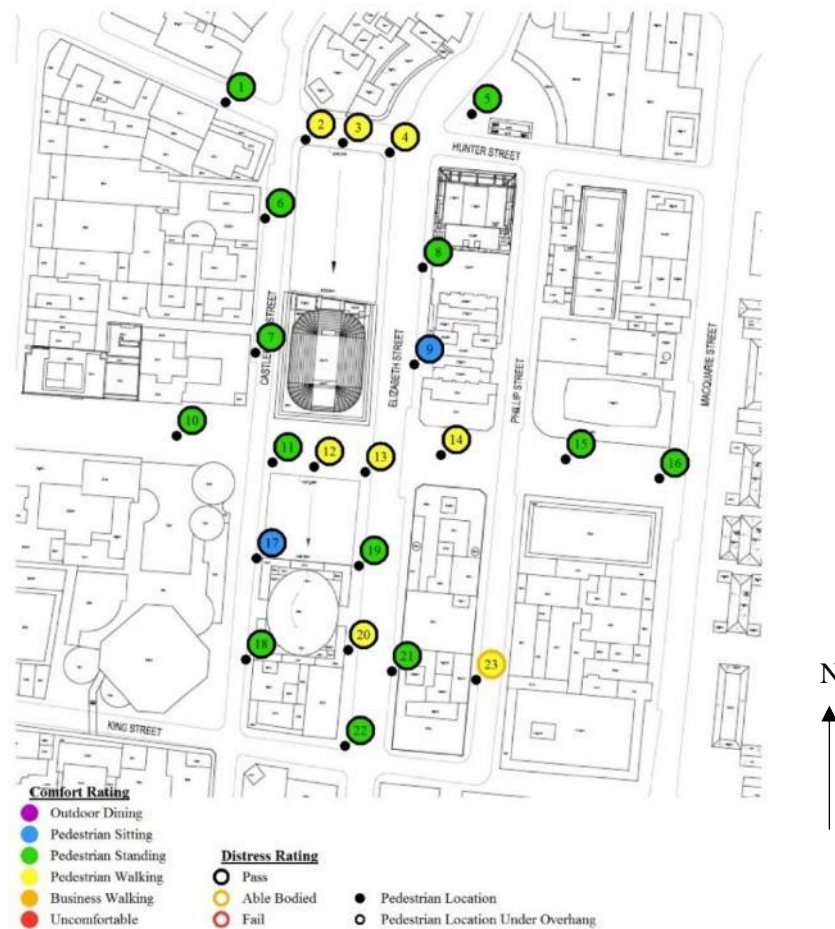


Figure 11: Pedestrian wind speed measurement locations with comfort/distress ratings – Configuration A

Winds conditions close to the northern façade of the northern tower, Locations 2 to 4 along Hunter Street, are rated as suitable for pedestrian walking from a comfort perspective. These locations are subject to winds from the north-west and north-east quadrants respectively, caused by channelled flow along Hunter Street augmented by downwash from the north façade of the proposed north tower.

Similarly, the complete massing of south tower causes similar windy conditions at ground level immediately to the north of the proposed development, with Locations 12 and 13 on Martin Place being classified as suitable for pedestrian walking. These areas become windier through the addition of the proposed development, as discussed in section 6.1.2. The test locations further away from the proposed site on Martin Place and Hunter Street, Locations 1, 5, 10, and 14-16, are all rated as suitable for pedestrian standing except for Location 14, which rated as suitable for pedestrian walking.

Along Castlereagh and Elizabeth Streets, Locations 6-9, and 17-22 are generally suitable for pedestrian standing with the exception of Location 20, which is rated as suitable for pedestrian walking, and Locations 9 and 17, which are at the upper level of the pedestrian sitting classification. Location 20 experiences windy conditions for winds from the south-east quadrant coming over the exposed Hyde Park area and channelling up Elizabeth Street. All locations pass the distress criterion.

Location 23, remote from the site at the southern end of Philip Street is classified as suitable for pedestrian walking from a comfort perspective and fails the Lawson distress criterion being classified as suitable for able bodied pedestrians. This location is more exposed to strong winds from the south-east quadrant than Location 20, as it is closer to the exposed area of Hyde Park. The strong wind conditions at Locations 20 and 23 are not caused by the proposed development as discussed in section 6.1.2.

6.1.2 – Existing development with existing surroundings

The wind conditions at ground level in the existing configuration, Figure 12, are generally similar to those with the proposed development. Immediately north of the two towers, Locations 3.1-4.1 on Hunter Street, and 12.1-13.1 on Martin Place, wind conditions are stronger with the proposed development than in the existing configuration. The existing buildings on the site are significantly shorter than the proposed towers and therefore the downwash is weaker than from the proposed buildings.

Wind conditions along Martin Place to the east and west of the proposed development, Locations 10.1, 14.1-15.1, are almost unchanged compared with the proposed development.

Wind conditions to the south of the site on Elizabeth and Philip Street, Locations 20.1 and 23.1, achieve a worse rating in the existing configuration than they do with the proposed development. In Location 20, the proposed development slightly improves the existing wind conditions for winds from the south-east quadrant. Despite the change in classification category, the difference in the wind conditions at Location 23 is relatively minor.

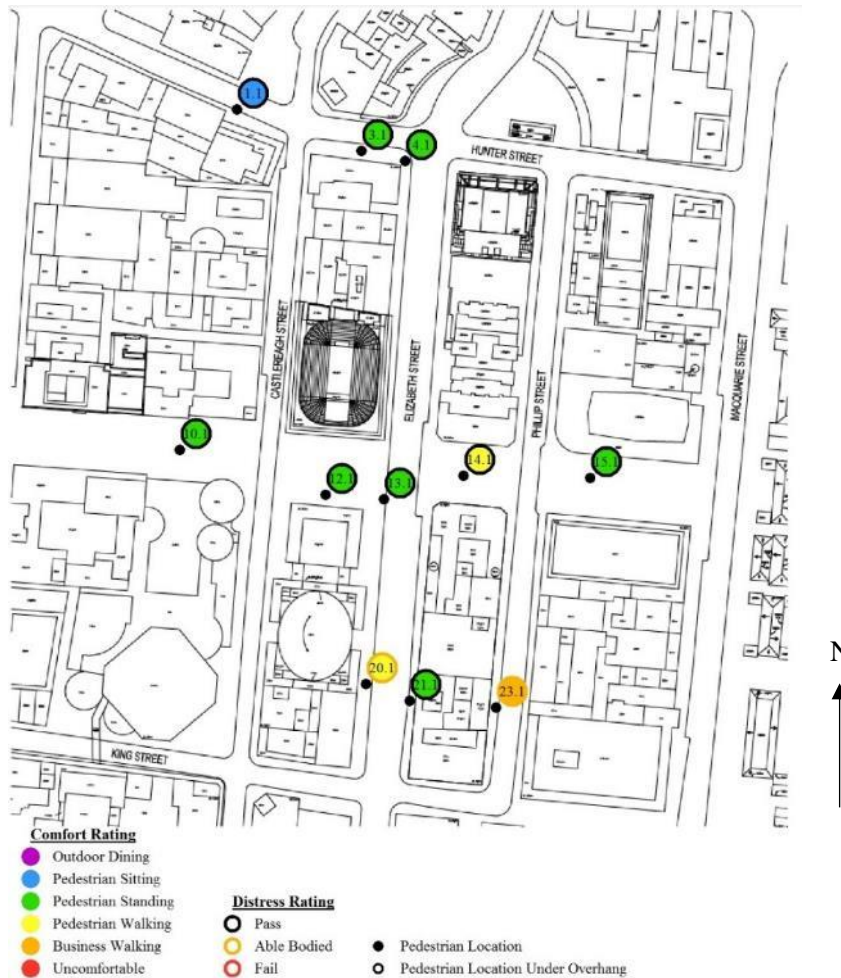


Figure 12: Pedestrian wind speed measurement locations with comfort/distress ratings – Configuration B

6.1.3 – Proposed development with existing surroundings and setback to south tower

Additional testing was conducted with a compliant tower setback of 25 m at RL 76.95 m on the northern side of the south tower, Figure 17 in Appendix 1. The addition of the tower setback slightly reduces the wind speeds adjacent to the north façade of the south tower on Martin Place, Figure 13. Most other test locations in the surrounding area along Elizabeth and Castlereagh Streets and Martin Place showed a minimal difference in the wind conditions for these configurations. Wind conditions at the more remote locations from south tower would not be expected to change with the setback. The setback causes higher wind speeds in location 20.3, which are similar to the existing configuration. Location 20.3 fails the Lawson distress criterion with an able bodied rating the same as the existing conditions.

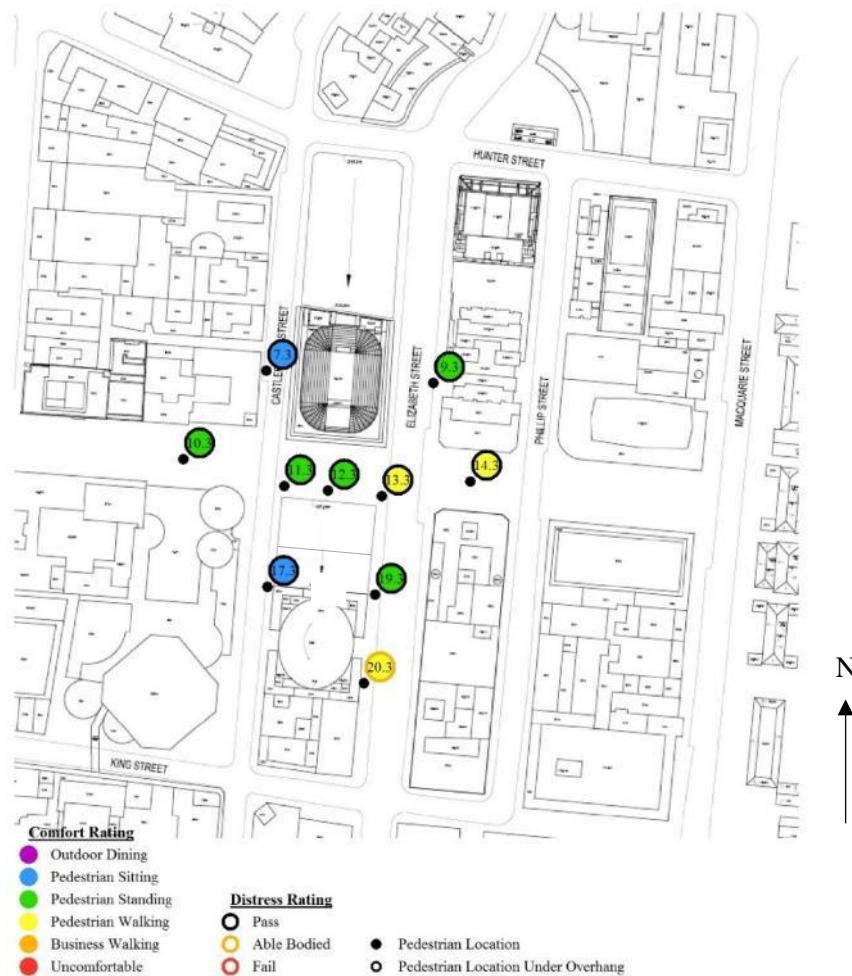


Figure 13: Pedestrian wind speed measurement locations with comfort/distress ratings – Configuration D
25 m setback

6.2 Serviceability considerations

6.2.1 – Upper level outdoor terraces

Wind conditions on upper level areas on the two towers are potentially to be used as outdoor terraces are presented in Figure 14 and Figure 15. Wind conditions on the exposed inclined roof of the northern tower are windy, particularly for winds from the south-west and south-east quadrants with winds accelerating around the roof corners. Wind conditions on the north tower, are classified as suitable for pedestrian walking and business walking and both fail the distress criterion with an able-bodied rating, Figure 14. This massing model of the tower does not consider any architectural details of the roof space, e.g. recessed terraces, parapets, screening, or awnings, which will significantly affect the wind conditions at any outdoor terraces. Depending on these features as well as the exact location and the intended use of any outdoor space at roof level, additional amelioration measures would be required and addressed during detailed design.

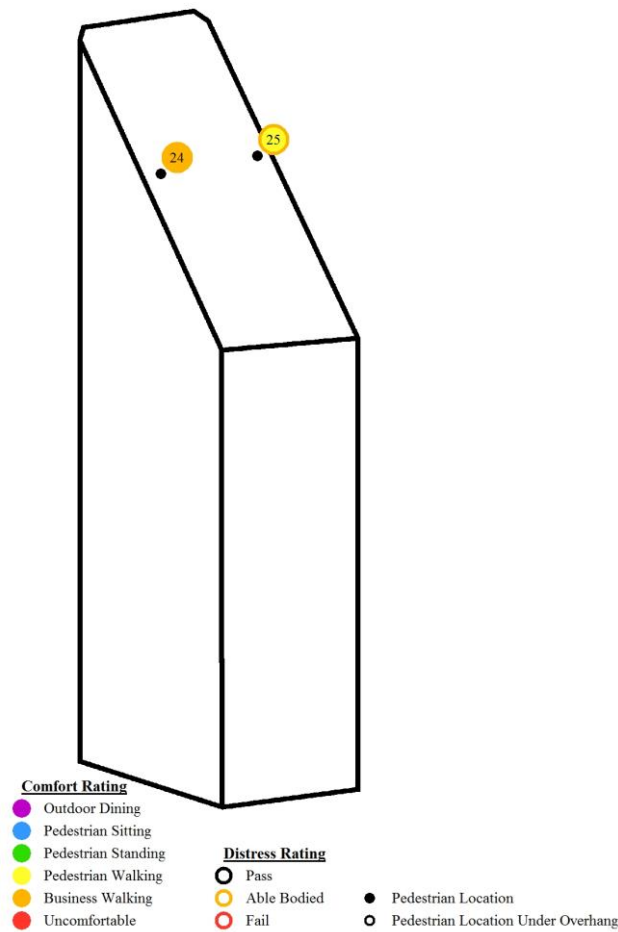


Figure 14: Upper level wind speed measurement locations with comfort/distress ratings – north tower

The south tower is anticipated to have a podium setback on the northern side with the potential of using the podium roof as an outdoor terrace. Wind conditions at test locations on the podium in Configuration D are rated as suitable for pedestrian walking and standing, Figure 15. The wind conditions on the terrace show winds accelerating around the tower for winds from the south-east and north-west quadrants. As with the potential outdoor terraces of the north tower, architectural details and the desired intended use of the outdoor space will significantly influence the level of amelioration required. Wind conditions on a 3-sided open terrace would not be expected to meet the outdoor sitting criteria. To achieve wind conditions for such a use of the space significant amelioration would be required to be developed during detailed design, but would be expected to require full-height screening to the east and west, or a central structure with a perimeter terrace to achieve some calm areas depending on the incident wind direction.

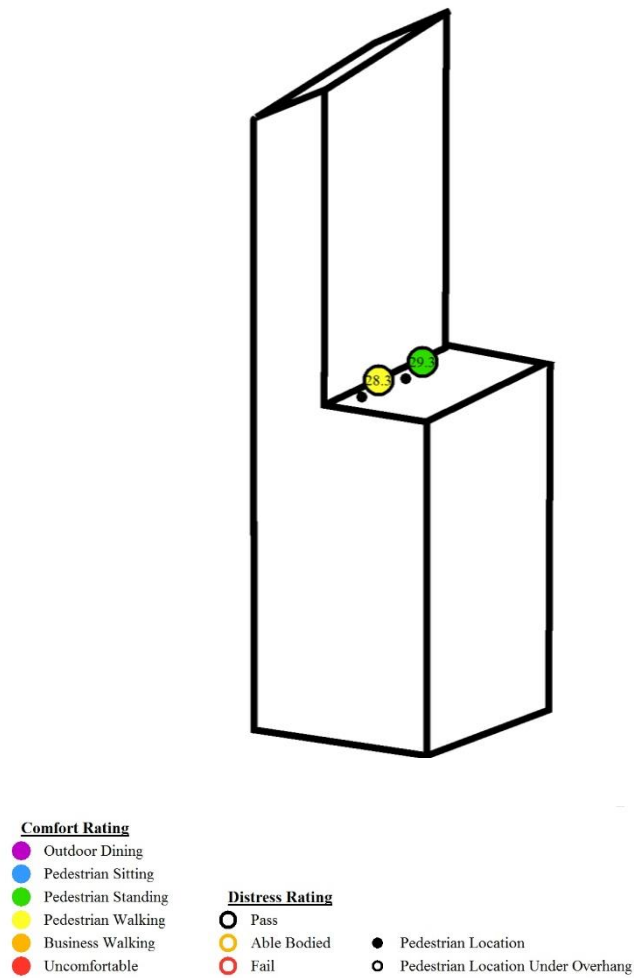


Figure 15: Upper level wind speed measurement locations with comfort/distress ratings – south tower Configuration D 25 m setback

7. CONCLUSIONS

A wind tunnel investigation of the pedestrian level wind environment in and around the proposed Martin Place Over Station development has been conducted. At street level, the existing wind environment near the development site is generally suitable for pedestrian standing and walking. Some areas on Elizabeth and Philip Street to the south of the site are windy and currently exceed the distress criterion, due to being exposed to unimpeded winds flowing over Hyde Park from the south-east quadrant.

The addition of the proposed development changes the wind flow patterns in the area, causing some areas to be windier and improving others from existing conditions. The general wind amenity at street level around the development site will remain similar to existing conditions and considered suitable for an area in this section of the city.

Any upper level outdoor terraces are expected to be windy and would require amelioration through screening to achieve a comfort rating as suitable for pedestrian sitting. This would be addressed during detailed design.

8. REFERENCES

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Appendix 1: Additional Photographs of the Wind Tunnel Model

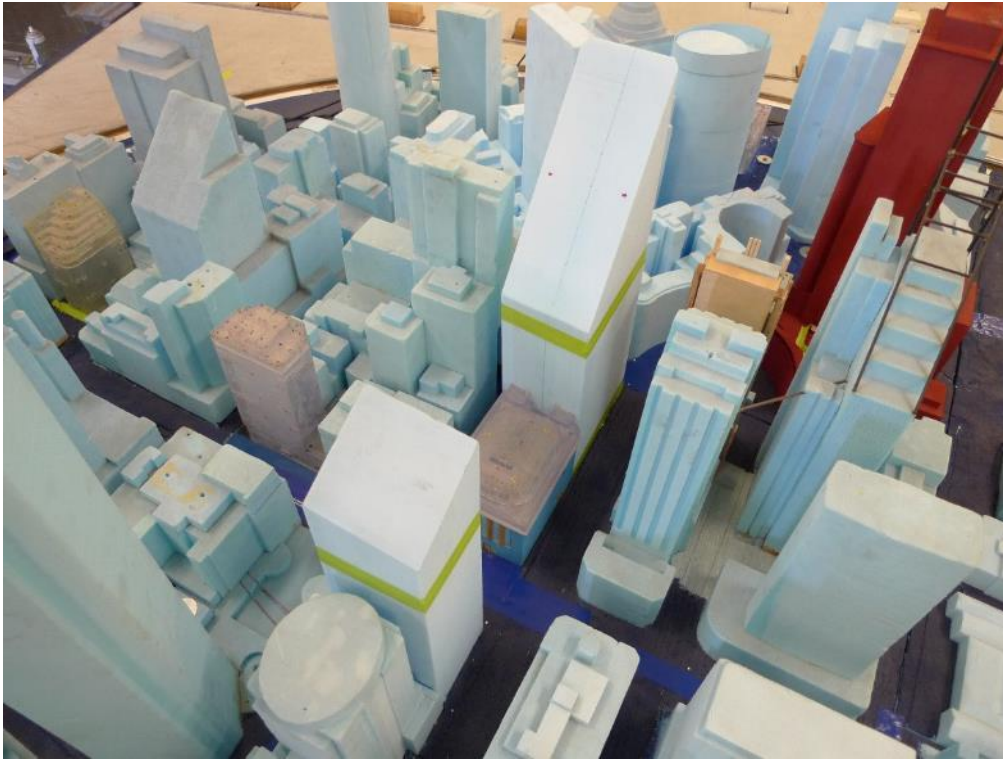


Figure 16: Massing model of the proposed development viewed from the south-east

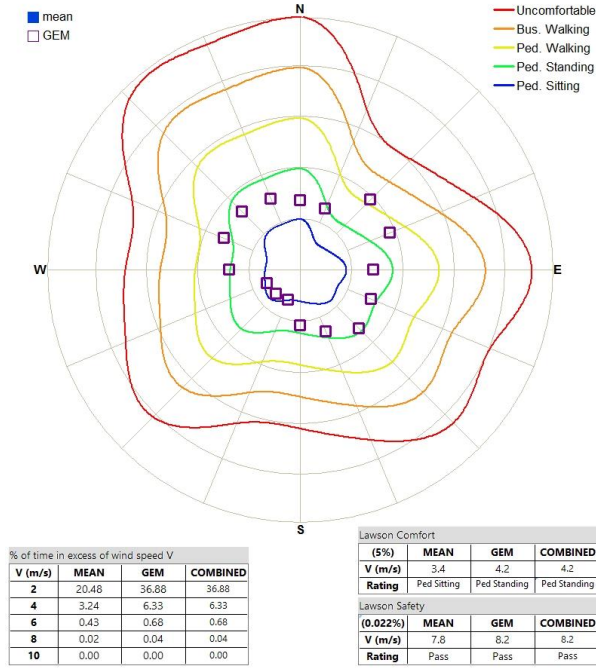


Figure 17: Wind tunnel model of the south tower with a setback of 25 m on the north façade, viewed from the west – Configuration D

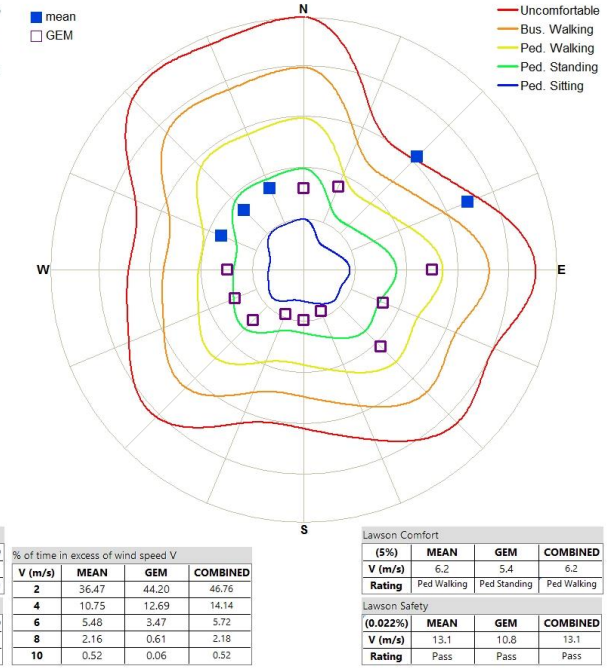
Appendix 2: Directional Wind Results

8.1 Configuration A – Proposed

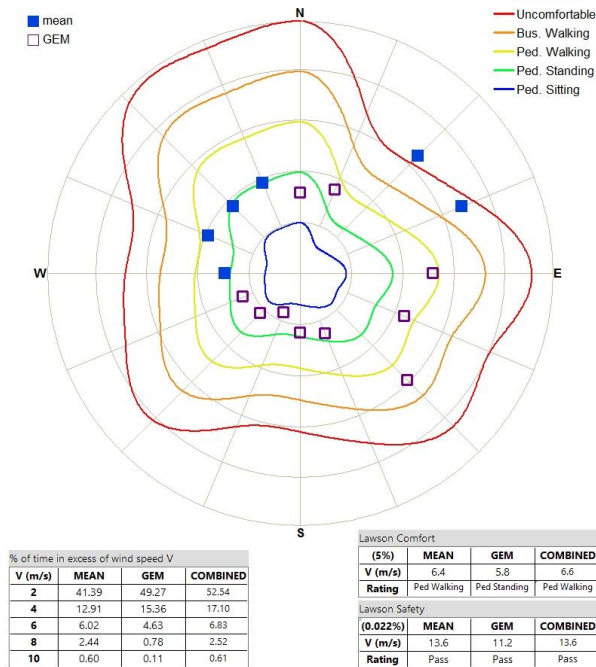
LOCATION 1



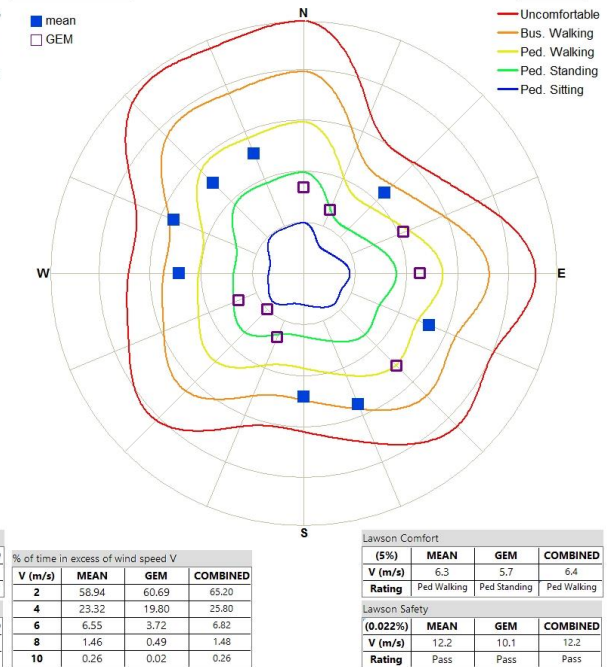
LOCATION 2



LOCATION 3

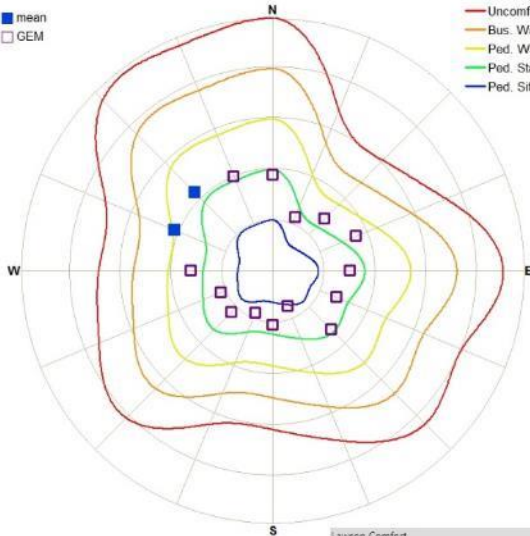


LOCATION 4



LOCATION 5

■ mean
□ GEM

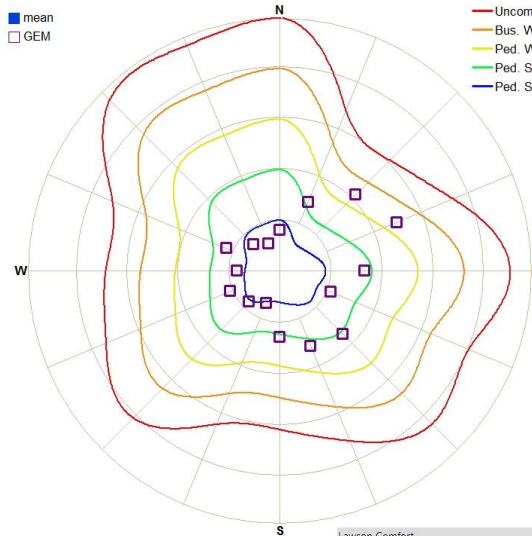


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	29.71	41.97	42.15
4	2.87	5.19	3.26
6	0.57	0.64	0.68
8	0.11	0.09	0.11
10	0.01	0.01	0.01

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	3.4	4.0	4.0
Rating	Ped Sitting	Ped Sitting	Ped Standing
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.2	9.0	9.2
Rating	Pass	Pass	Pass

LOCATION 6

■ mean
□ GEM

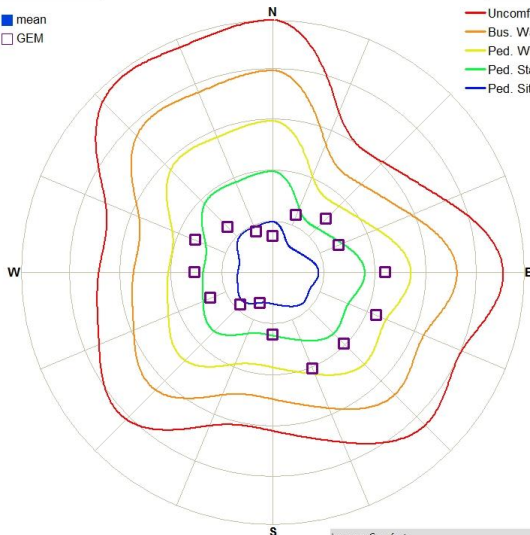


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	23.91	33.95	33.95
4	4.96	7.88	7.88
6	0.49	1.39	1.39
8	0.01	0.12	0.12
10	0.00	0.00	0.00

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	3.9	4.6	4.6
Rating	Ped Sitting	Ped Standing	Ped Standing
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	7.7	9.0	9.0
Rating	Pass	Pass	Pass

LOCATION 7

■ mean
□ GEM

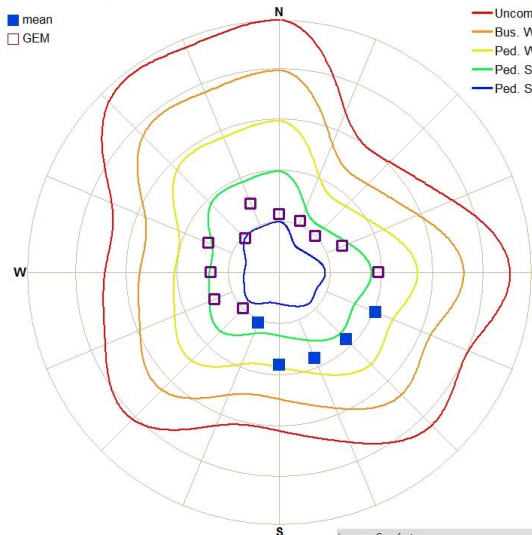


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	21.36	41.32	41.32
4	0.86	7.49	7.49
6	0.02	0.60	0.60
8	0.00	0.04	0.04
10	0.00	0.00	0.00

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	3.0	4.3	4.3
Rating	Ped Sitting	Ped Standing	Ped Standing
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	5.9	8.4	8.4
Rating	Pass	Pass	Pass

LOCATION 8

■ mean
□ GEM

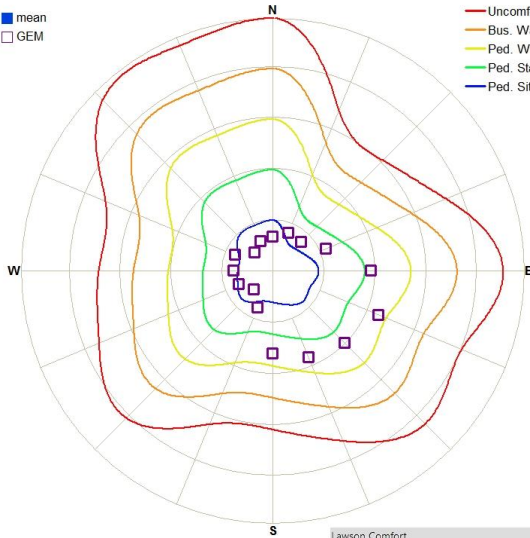


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	30.53	40.34	42.04
4	5.27	4.56	6.58
6	0.59	0.24	0.65
8	0.04	0.01	0.04
10	0.00	0.00	0.00

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.0	3.9	4.2
Rating	Ped Standing	Ped Sitting	Ped Standing
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	8.3	7.3	8.3
Rating	Pass	Pass	Pass

LOCATION 9

■ mean
□ GEM



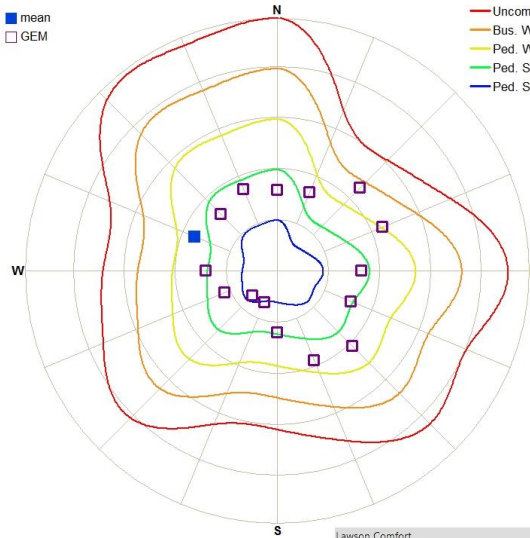
THRESHOLD
 — Uncomfortable
 — Bus. Walking
 — Ped. Walking
 — Ped. Standing
 — Ped. Sitting

% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	19.53	27.95	27.95
4	3.11	5.11	5.11
6	0.19	0.44	0.44
8	0.01	0.03	0.03
10	0.00	0.00	0.00

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	3.6	4.0	4.0
Rating	Ped Sitting	Ped Sitting	Ped Sitting
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	7.3	8.1	8.1
Rating	Pass	Pass	Pass

LOCATION 10

■ mean
□ GEM



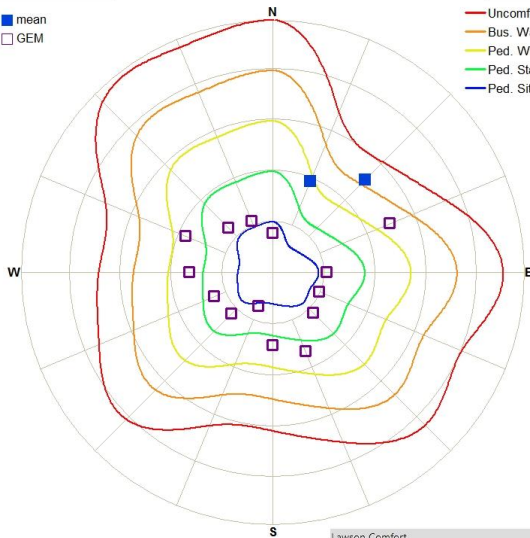
THRESHOLD
 — Uncomfortable
 — Bus. Walking
 — Ped. Walking
 — Ped. Standing
 — Ped. Sitting

% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	35.14	45.53	45.71
4	7.20	11.40	11.45
6	1.17	1.93	1.95
8	0.13	0.26	0.26
10	0.00	0.01	0.01

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.4	5.0	5.0
Rating	Ped Standing	Ped Standing	Ped Standing
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.0	9.6	9.6
Rating	Pass	Pass	Pass

LOCATION 11

■ mean
□ GEM



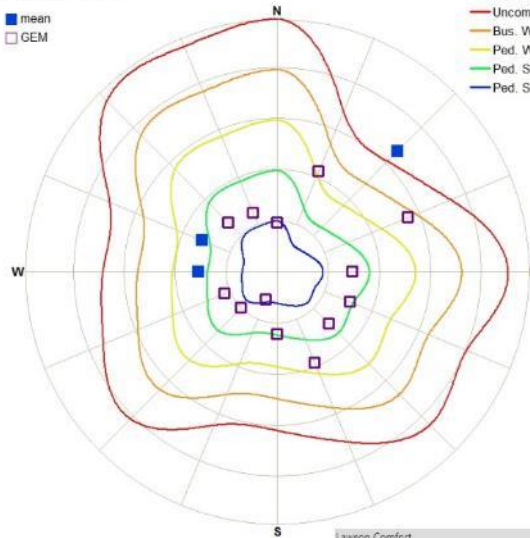
THRESHOLD
 — Uncomfortable
 — Bus. Walking
 — Ped. Walking
 — Ped. Standing
 — Ped. Sitting

% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	26.95	39.87	40.51
4	8.08	10.96	11.92
6	2.35	2.38	3.18
8	0.48	0.31	0.52
10	0.05	0.02	0.06

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.8	5.1	5.3
Rating	Ped Standing	Ped Standing	Ped Standing
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	10.6	9.8	10.7
Rating	Pass	Pass	Pass

LOCATION 12

■ mean
□ GEM



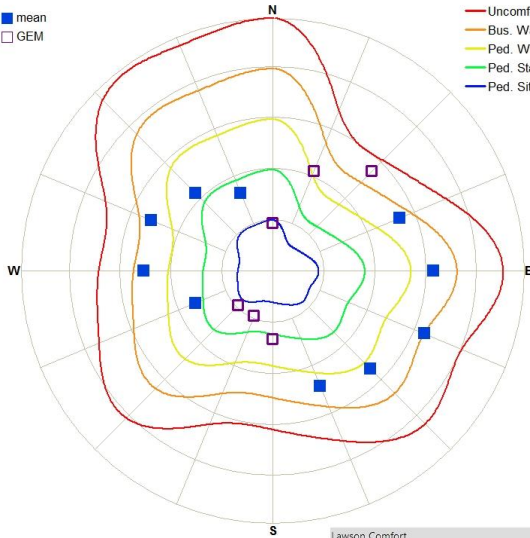
THRESHOLD
 — Uncomfortable
 — Bus. Walking
 — Ped. Walking
 — Ped. Standing
 — Ped. Sitting

% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	32.51	42.42	43.10
4	9.84	13.31	13.87
6	4.25	4.75	5.52
8	1.90	1.19	2.63
10	0.55	0.29	0.56

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	5.4	5.8	6.1
Rating	Ped Standing	Ped Standing	Ped Walking
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	13.8	12.2	13.8
Rating	Pass	Pass	Pass

LOCATION 13

■ mean
□ GEM



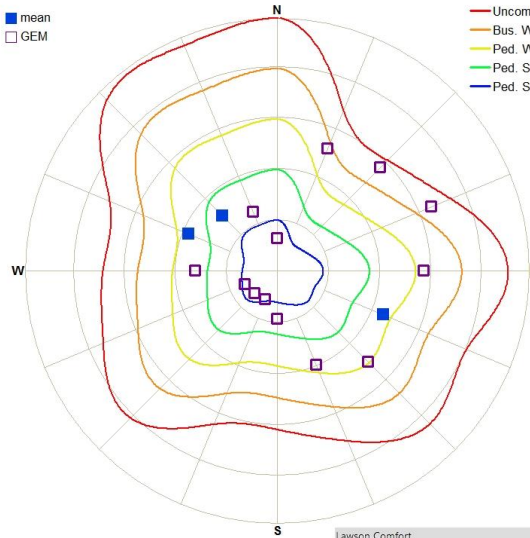
THRESHOLD
 — Uncomfortable
 — Bus. Walking
 — Ped. Walking
 — Ped. Standing
 — Ped. Sitting

% of time in excess of wind speed V				
V (m/s)	MEAN	GEM	COMBINED	
2	55.63	54.96	59.89	
4	22.01	18.86	24.57	
6	6.79	4.71	8.14	
8	1.28	0.91	1.65	
10	0.21	0.16	0.33	

Lawson Comfort				
(5%)	MEAN	GEM	COMBINED	
V (m/s)	6.3	5.9	6.6	
Rating	Ped Walking	Ped Standing	Ped Walking	
Lawson Safety				
(0.022%)	MEAN	GEM	COMBINED	
V (m/s)	11.6	11.5	12.1	
Rating	Pass	Pass	Pass	

LOCATION 14

■ mean
□ GEM



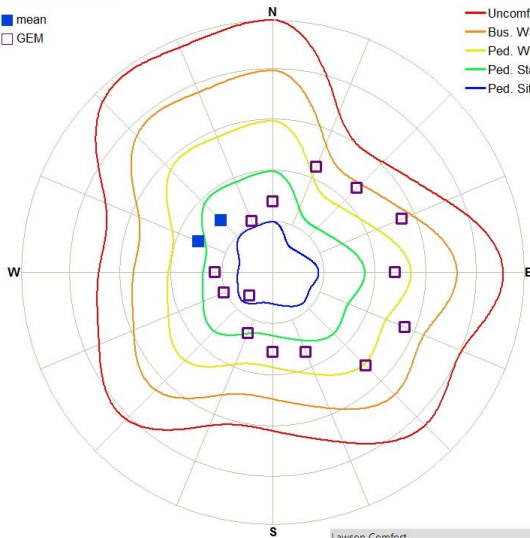
THRESHOLD
 — Uncomfortable
 — Bus. Walking
 — Ped. Walking
 — Ped. Standing
 — Ped. Sitting

% of time in excess of wind speed V				
V (m/s)	MEAN	GEM	COMBINED	
2	36.42	44.49	44.73	
4	14.00	18.74	18.83	
6	4.87	7.03	7.07	
8	0.86	1.67	1.68	
10	0.08	0.29	0.29	

Lawson Comfort				
(5%)	MEAN	GEM	COMBINED	
V (m/s)	5.9	6.5	6.5	
Rating	Ped Standing	Ped Walking	Ped Walking	
Lawson Safety				
(0.022%)	MEAN	GEM	COMBINED	
V (m/s)	10.9	12.1	12.1	
Rating	Pass	Pass	Pass	

LOCATION 15

■ mean
□ GEM



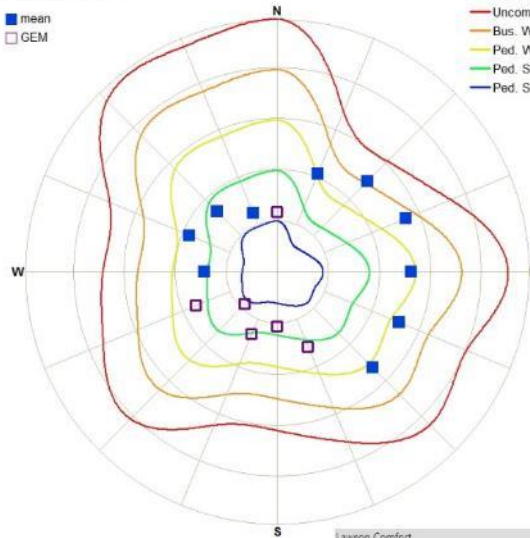
THRESHOLD
 — Uncomfortable
 — Bus. Walking
 — Ped. Walking
 — Ped. Standing
 — Ped. Sitting

% of time in excess of wind speed V				
V (m/s)	MEAN	GEM	COMBINED	
2	38.04	49.61	50.23	
4	7.00	17.32	17.46	
6	0.41	4.14	4.18	
8	0.01	0.53	0.53	
10	0.00	0.03	0.03	

Lawson Comfort				
(5%)	MEAN	GEM	COMBINED	
V (m/s)	4.3	5.7	5.8	
Rating	Ped Standing	Ped Standing	Ped Standing	
Lawson Safety				
(0.022%)	MEAN	GEM	COMBINED	
V (m/s)	7.7	10.3	10.3	
Rating	Pass	Pass	Pass	

LOCATION 16

■ mean
□ GEM



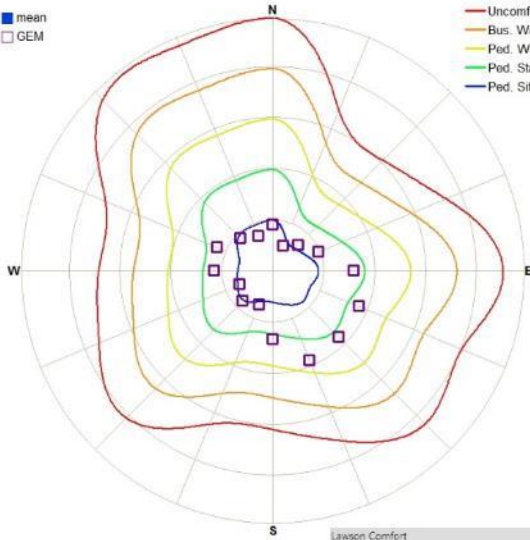
THRESHOLD
 — Uncomfortable
 — Bus. Walking
 — Ped. Walking
 — Ped. Standing
 — Ped. Sitting

% of time in excess of wind speed V				
V (m/s)	MEAN	GEM	COMBINED	
2	42.88	49.76	52.50	
4	15.98	14.69	17.11	
6	4.29	2.56	4.34	
8	0.64	0.30	0.64	
10	0.06	0.01	0.06	

Lawson Comfort				
(5%)	MEAN	GEM	COMBINED	
V (m/s)	5.8	5.3	5.8	
Rating	Ped Standing	Ped Standing	Ped Standing	
Lawson Safety				
(0.022%)	MEAN	GEM	COMBINED	
V (m/s)	10.6	9.6	10.6	
Rating	Pass	Pass	Pass	

LOCATION 17

■ mean
□ GEM



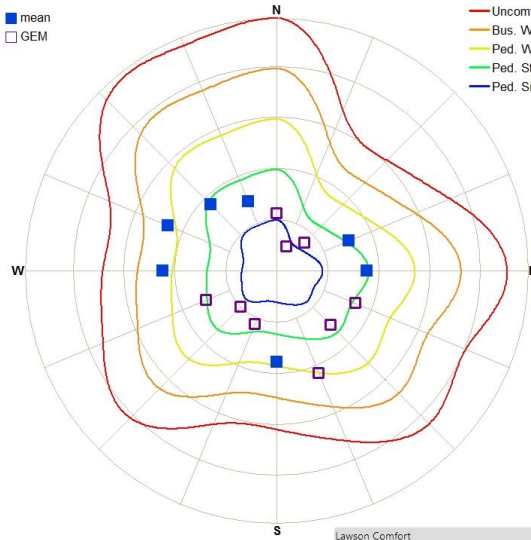
THRESHOLD
 — Uncomfortable
 — Bus. Walking
 — Ped. Walking
 — Ped. Standing
 — Ped. Sitting

% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	17.65	26.01	26.01
4	1.57	3.31	3.31
6	0.06	0.22	0.22
8	0.00	0.01	0.01
10	0.00	0.00	0.00

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	3.2	3.6	3.6
Rating	Ped Sitting	Ped Sitting	Ped Sitting
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	6.9	7.7	7.7
Rating	Pass	Pass	Pass

LOCATION 18

■ mean
□ GEM



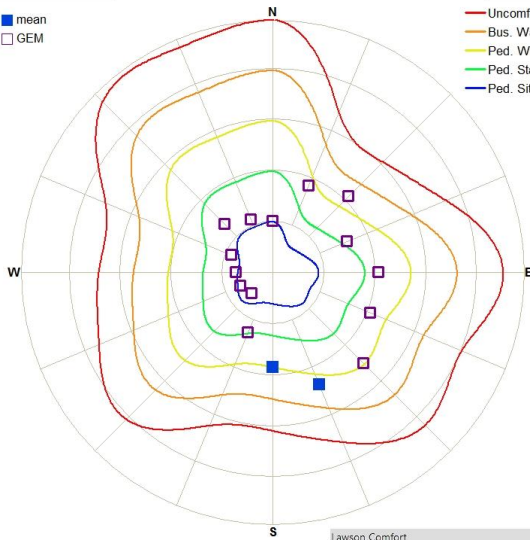
THRESHOLD
 — Uncomfortable
 — Bus. Walking
 — Ped. Walking
 — Ped. Standing
 — Ped. Sitting

% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	37.94	41.00	43.76
4	8.49	7.32	9.62
6	1.61	1.02	1.81
8	0.25	0.11	0.28
10	0.02	0.00	0.02

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.5	4.4	4.7
Rating	Ped Standing	Ped Standing	Ped Standing
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.9	9.1	10.0
Rating	Pass	Pass	Pass

LOCATION 19

■ mean
□ GEM



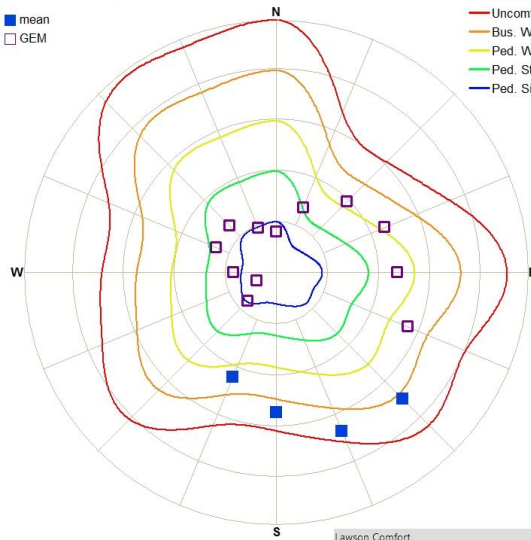
THRESHOLD
 — Uncomfortable
 — Bus. Walking
 — Ped. Walking
 — Ped. Standing
 — Ped. Sitting

% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	39.21	43.91	44.12
4	11.19	14.31	14.94
6	1.40	2.15	2.38
8	0.14	0.21	0.25
10	0.02	0.01	0.02

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.8	5.2	5.2
Rating	Ped Standing	Ped Standing	Ped Standing
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.7	9.7	9.8
Rating	Pass	Pass	Pass

LOCATION 20

■ mean
□ GEM



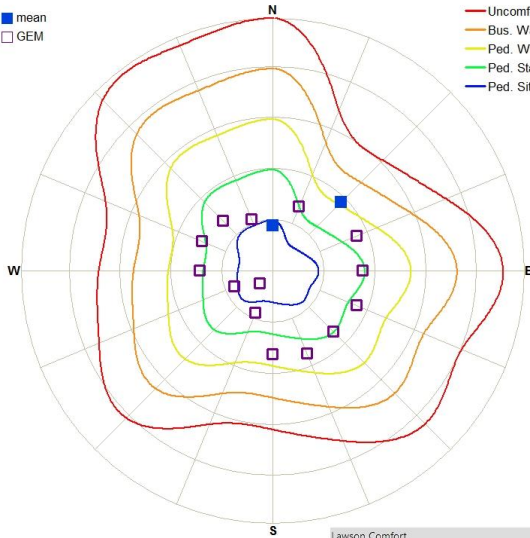
THRESHOLD
 — Uncomfortable
 — Bus. Walking
 — Ped. Walking
 — Ped. Standing
 — Ped. Sitting

% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	43.39	47.37	48.02
4	22.19	23.47	25.60
6	7.94	5.88	8.56
8	2.09	1.05	2.16
10	0.46	0.15	0.47

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	6.7	6.2	6.8
Rating	Ped Walking	Ped Walking	Ped Walking
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	13.8	12.0	13.8
Rating	Pass	Pass	Pass

LOCATION 21

■ mean
□ GEM

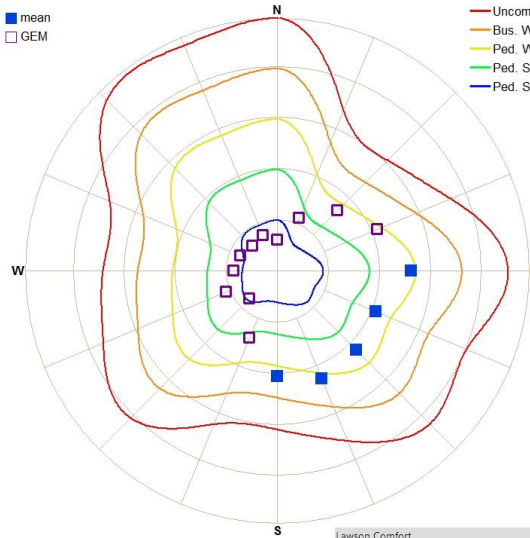


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	26.69	40.61	40.71
4	3.74	8.31	8.54
6	0.46	0.72	0.79
8	0.02	0.02	0.03
10	0.00	0.00	0.00

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	3.6	4.4	4.5
Rating	Ped Sitting	Ped Standing	Ped Standing
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	7.9	8.0	8.2
Rating	Pass	Pass	Pass

LOCATION 22

■ mean
□ GEM

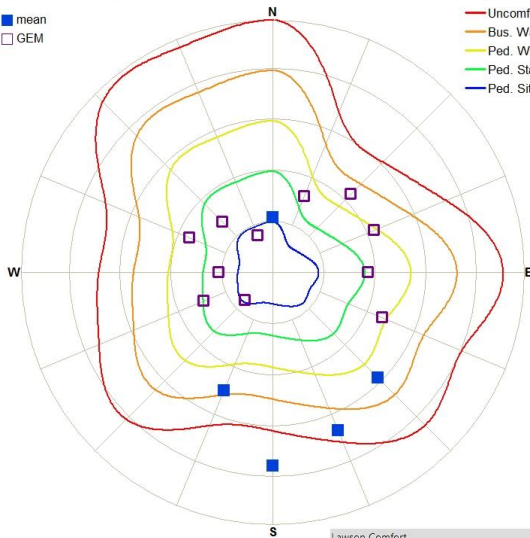


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	37.75	41.42	42.46
4	12.64	11.63	13.83
6	1.74	1.18	1.87
8	0.18	0.09	0.19
10	0.02	0.00	0.02

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.9	4.8	5.1
Rating	Ped Standing	Ped Standing	Ped Standing
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.8	8.9	9.8
Rating	Pass	Pass	Pass

LOCATION 23

■ mean
□ GEM

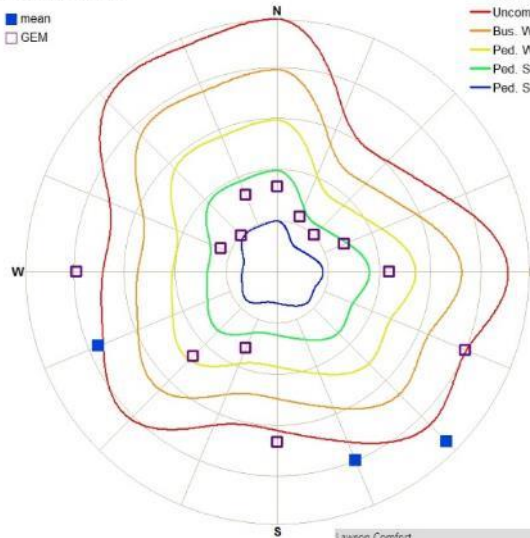


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	46.81	53.41	54.11
4	25.12	25.15	27.14
6	11.37	7.93	11.88
8	4.18	2.02	4.26
10	1.64	0.49	1.64

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	7.5	6.6	7.6
Rating	Ped Walking	Ped Walking	Ped Walking
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	17.2	13.7	17.2
Rating	Able Body	Pass	Able Body

LOCATION 24

■ mean
□ GEM



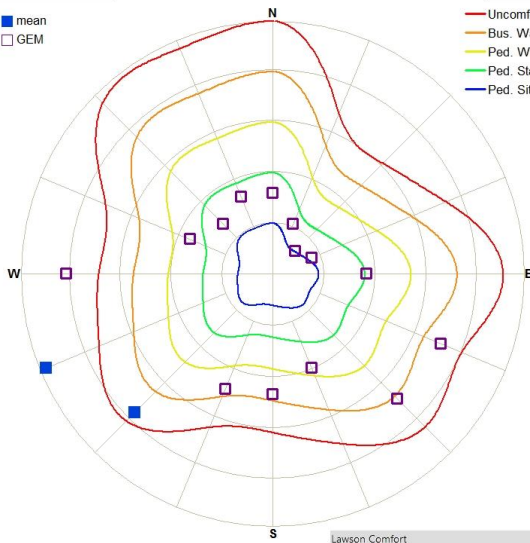
% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	44.50	58.30	58.46
4	25.77	30.23	30.97
6	14.40	16.71	17.73
8	6.22	6.92	7.97
10	2.04	2.46	2.97

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	8.3	8.5	8.8
Rating	Bus Walking	Bus Walking	Bus Walking
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	16.8	16.8	17.4
Rating	Able Body	Able Body	Able Body

LOCATION 25

■ mean
□ GEM

THRESHOLD
 — Uncomfortable
 — Bus. Walking
 — Ped. Walking
 — Ped. Standing
 — Ped. Sitting



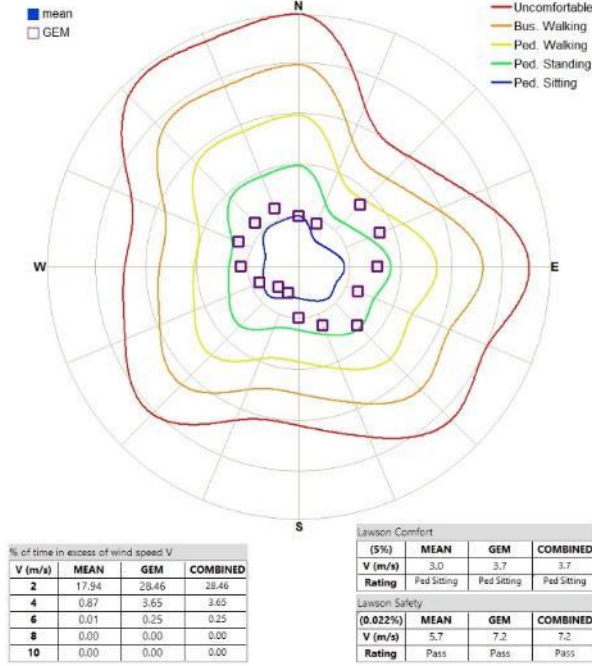
% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	47.62	55.02	55.14
4	23.63	27.84	28.29
6	9.69	12.05	12.62
8	3.86	4.35	5.08
10	1.57	1.50	2.03

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	7.3	7.7	7.9
Rating	Ped Walking	Ped Walking	Ped Walking

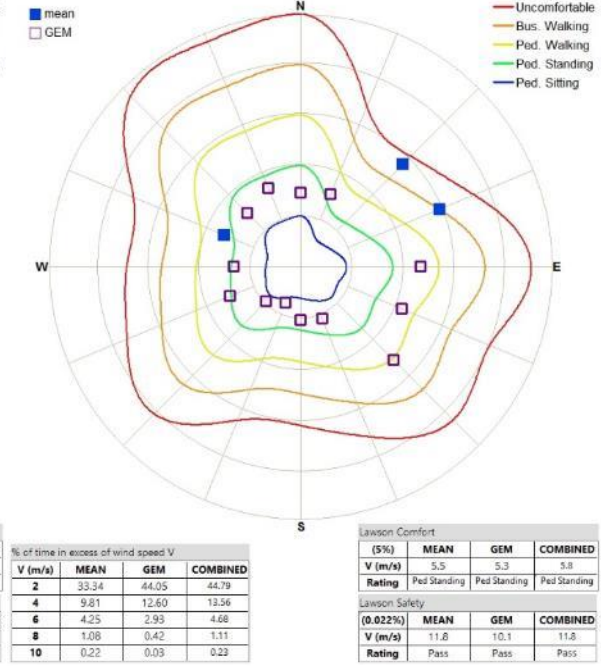
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	18.0	17.0	18.3
Rating	Able Body	Able Body	Able Body

8.2 Configuration B – Existing

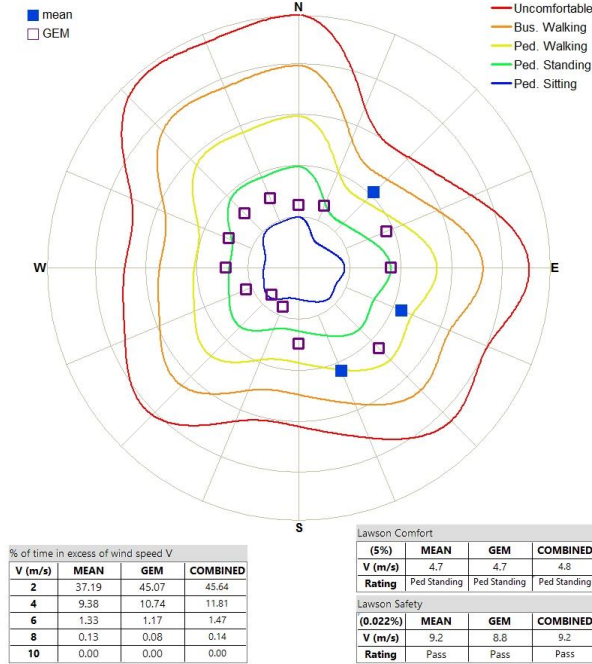
LOCATION 1.1



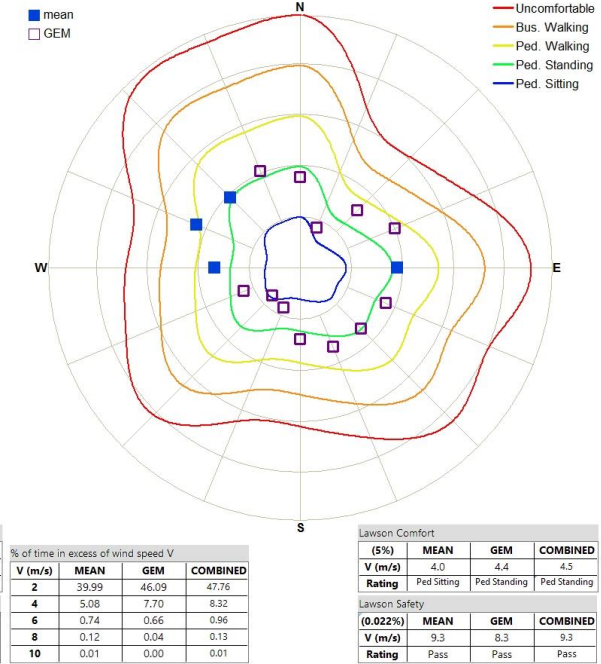
LOCATION 3.1



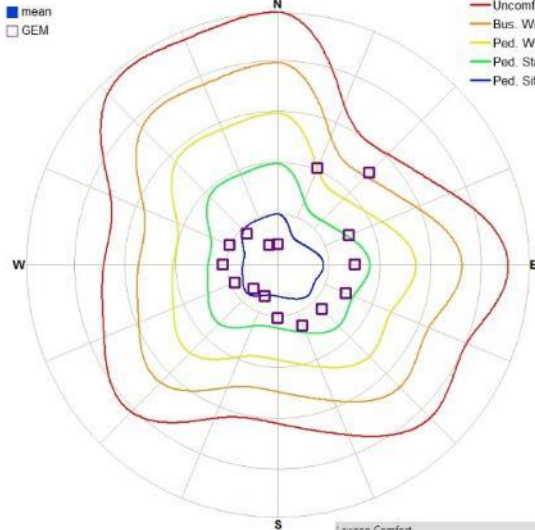
LOCATION 4.1



LOCATION 10.1



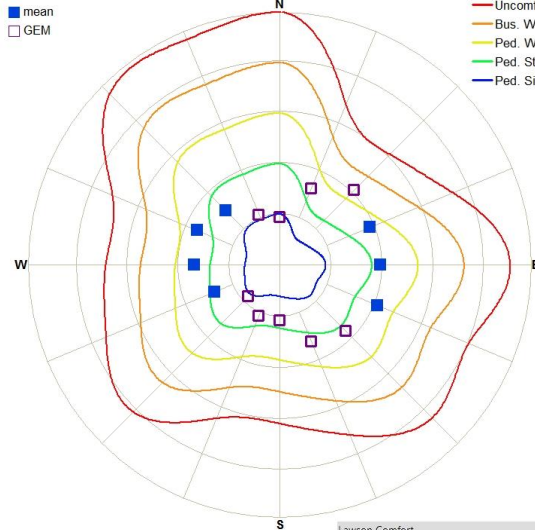
LOCATION 12.1



% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	16.17	31.19	31.19
4	6.29	7.64	7.64
6	2.09	2.46	2.46
8	0.42	0.48	0.48
10	0.04	0.05	0.05

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.5	4.8	4.8
Rating	Ped Standing	Ped Standing	Ped Standing
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	10.4	10.6	10.6
Rating	Pass	Pass	Pass

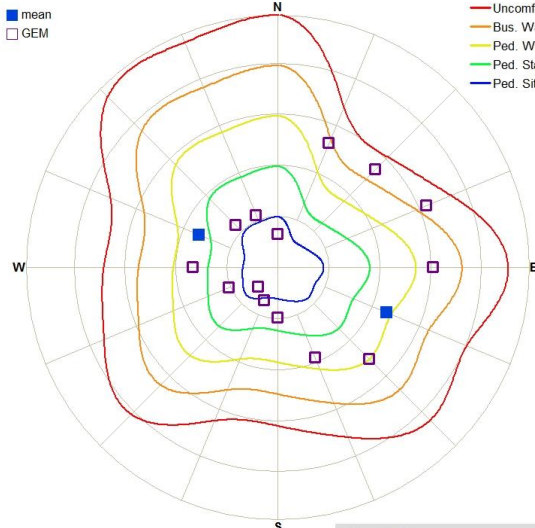
LOCATION 13.1



% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	37.76	44.30	45.71
4	8.01	9.13	9.95
6	0.84	1.05	1.18
8	0.03	0.07	0.08
10	0.00	0.00	0.00

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.4	4.6	4.7
Rating	Ped Standing	Ped Standing	Ped Standing
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	8.2	8.6	8.7
Rating	Pass	Pass	Pass

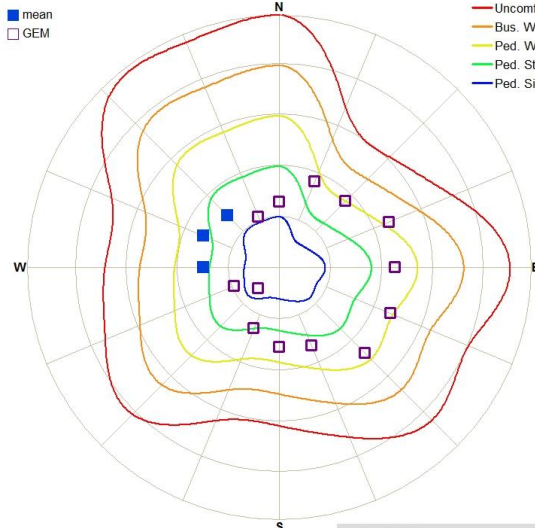
LOCATION 14.1



% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	36.20	44.57	45.00
4	14.09	18.09	18.27
6	4.31	6.75	6.82
8	0.68	1.37	1.38
10	0.06	0.20	0.20

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	5.7	6.4	6.4
Rating	Ped Standing	Ped Walking	Ped Walking
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	10.6	11.6	11.6
Rating	Pass	Pass	Pass

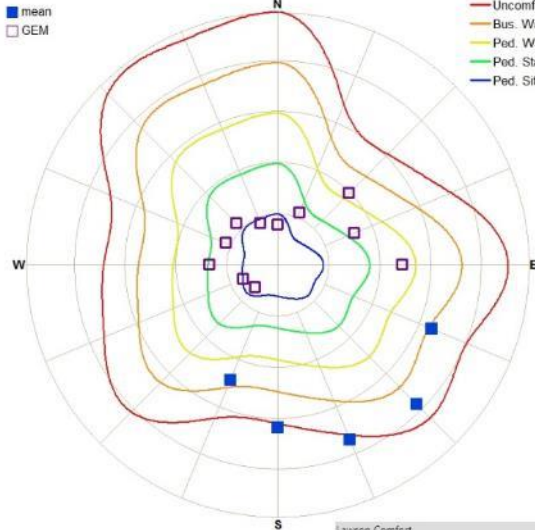
LOCATION 15.1



% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	38.58	47.62	48.80
4	5.32	13.24	13.63
6	0.24	1.38	1.47
8	0.01	0.06	0.06
10	0.00	0.00	0.00

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.0	4.9	5.0
Rating	Ped Standing	Ped Standing	Ped Standing
Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	7.2	8.5	8.6
Rating	Pass	Pass	Pass

LOCATION 20.1

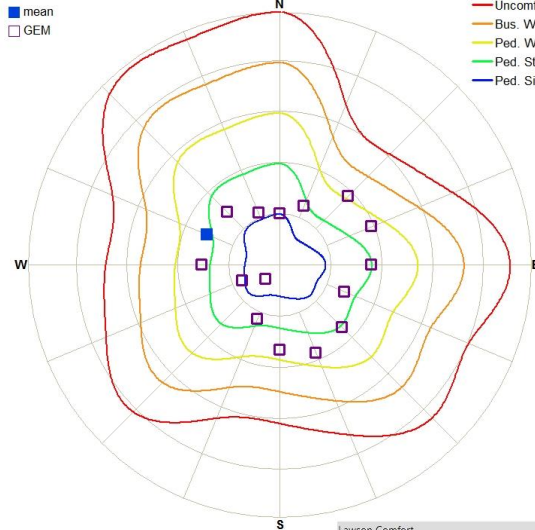


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	43.96	47.77	48.71
4	25.02	23.14	26.67
6	11.67	6.99	11.93
8	3.95	1.53	3.86
10	1.14	0.27	1.14

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	7.5	6.4	7.5
Rating	Ped Walking	Ped Walking	Ped Walking

Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	15.6	12.8	15.6
Rating	Able Body	Pass	Able Body

LOCATION 21.1

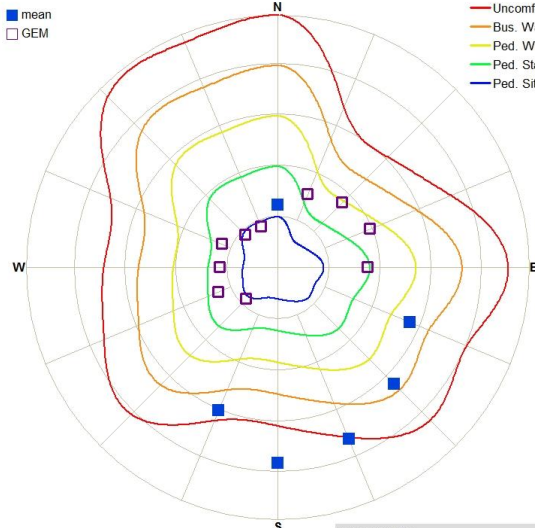


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	29.55	42.72	42.80
4	3.79	9.51	9.52
6	0.30	0.93	0.94
8	0.00	0.04	0.04
10	0.00	0.00	0.00

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	3.7	4.6	4.6
Rating	Ped Sitting	Ped Standing	Ped Standing

Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	7.2	8.3	8.3
Rating	Pass	Pass	Pass

LOCATION 23.1



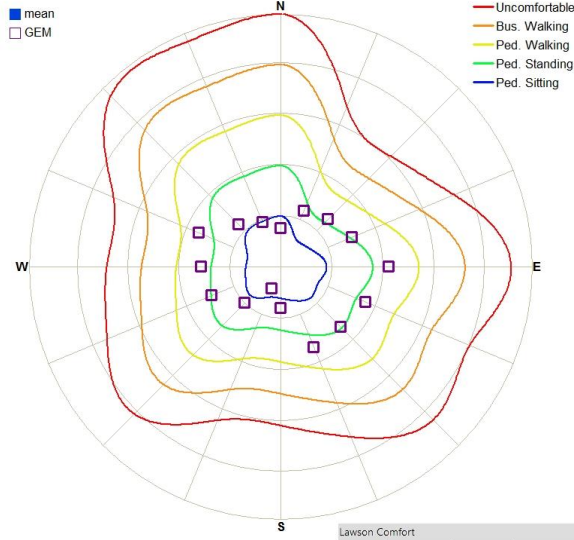
% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	44.66	50.42	51.18
4	25.19	24.52	26.65
6	13.22	9.34	13.38
8	5.35	2.67	5.35
10	2.02	0.74	2.02

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	8.0	7.0	8.0
Rating	Bus Walking	Ped Walking	Bus Walking

Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	17.4	14.3	17.4
Rating	Able Body	Pass	Able Body

8.3 Configuration D – 25 m setback

LOCATION 7.3

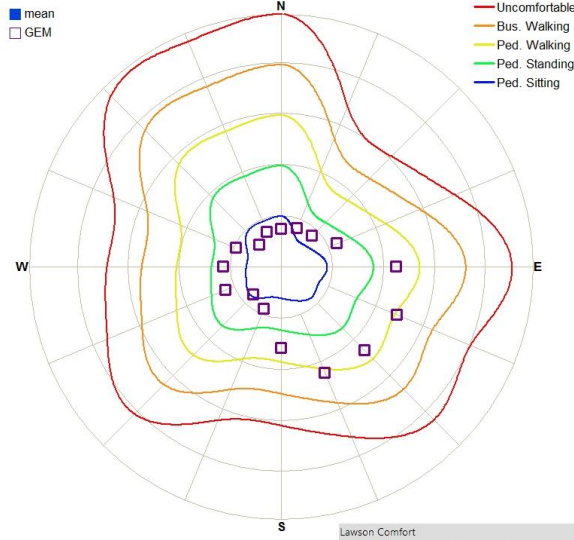


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	24.23	35.51	35.51
4	1.45	4.46	4.46
6	0.04	0.30	0.30
8	0.00	0.01	0.01
10	0.00	0.00	0.00

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	3.2	3.9	3.9
Rating	Ped Sitting	Ped Sitting	Ped Sitting

Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	6.3	7.6	7.6
Rating	Pass	Pass	Pass

LOCATION 9.3

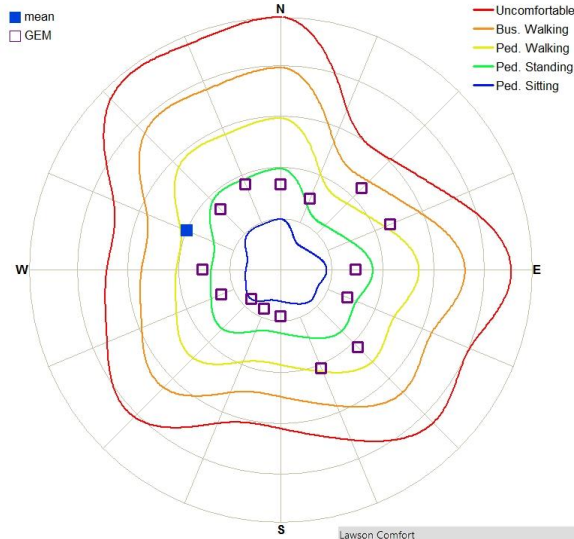


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	23.67	34.76	34.76
4	5.97	7.91	7.91
6	0.58	0.91	0.91
8	0.05	0.10	0.10
10	0.00	0.01	0.01

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.1	4.5	4.5
Rating	Ped Standing	Ped Standing	Ped Standing

Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	8.8	9.3	9.3
Rating	Pass	Pass	Pass

LOCATION 10.3

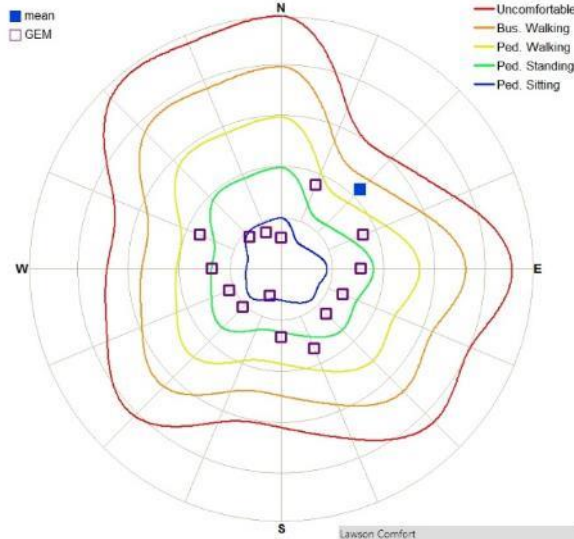


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	33.33	45.42	45.82
4	7.27	11.76	11.94
6	1.00	2.12	2.22
8	0.09	0.26	0.28
10	0.00	0.01	0.01

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.4	5.0	5.1
Rating	Ped Standing	Ped Standing	Ped Standing

Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	8.8	9.6	9.6
Rating	Pass	Pass	Pass

LOCATION 11.3



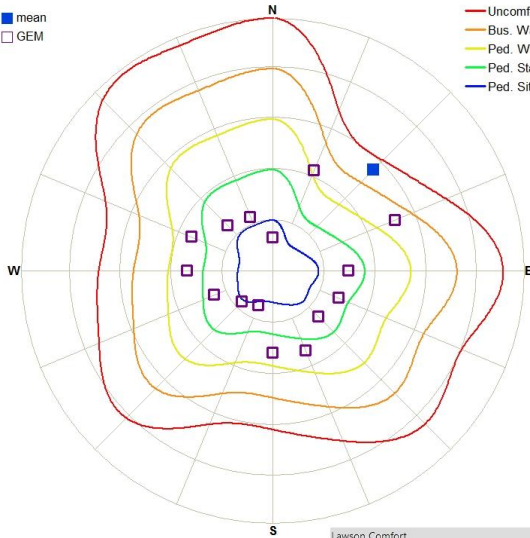
% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	21.94	38.01	38.05
4	5.57	8.53	8.60
6	1.12	1.27	1.34
8	0.15	0.14	0.16
10	0.00	0.00	0.00

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.1	4.6	4.6
Rating	Ped Standing	Ped Standing	Ped Standing

Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.1	9.0	9.2
Rating	Pass	Pass	Pass

LOCATION 12.3

■ mean
□ GEM



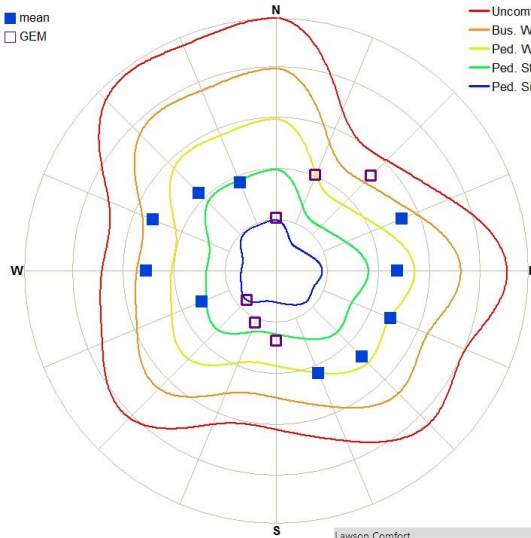
THRESHOLD
 — Uncomfortable
 — Bus. Walking
 — Ped. Walking
 — Ped. Standing
 — Ped. Sitting

% of time in excess of wind speed V				
V (m/s)	MEAN	GEM	COMBINED	
2	33.51	43.44	43.62	
4	8.97	13.34	13.69	
6	3.15	3.65	4.31	
8	0.80	0.54	0.86	
10	0.17	0.06	0.18	

Lawson Comfort				
(5%)	MEAN	GEM	COMBINED	
V (m/s)	5.0	5.5	5.7	
Rating	Ped Standing	Ped Standing	Ped Standing	
Lawson Safety				
(0.022%)	MEAN	GEM	COMBINED	
V (m/s)	11.6	10.6	11.6	
Rating	Pass	Pass	Pass	

LOCATION 13.3

■ mean
□ GEM



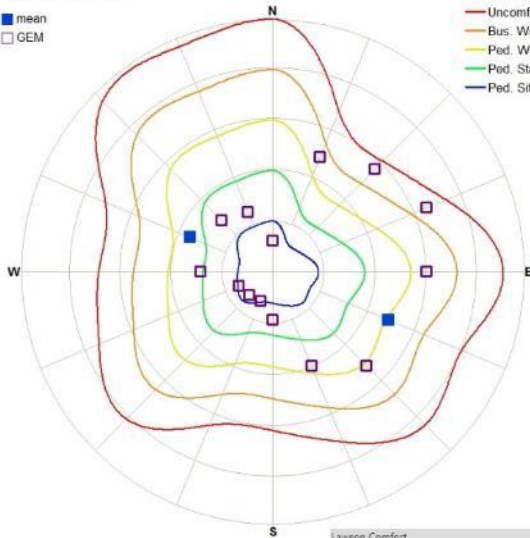
THRESHOLD
 — Uncomfortable
 — Bus. Walking
 — Ped. Walking
 — Ped. Standing
 — Ped. Sitting

% of time in excess of wind speed V				
V (m/s)	MEAN	GEM	COMBINED	
2	56.66	54.94	60.02	
4	18.89	16.47	21.58	
6	4.63	4.06	5.83	
8	0.90	0.69	1.16	
10	0.13	0.09	0.20	

Lawson Comfort				
(5%)	MEAN	GEM	COMBINED	
V (m/s)	5.9	5.7	6.2	
Rating	Ped Standing	Ped Standing	Ped Walking	
Lawson Safety				
(0.022%)	MEAN	GEM	COMBINED	
V (m/s)	11.2	10.9	11.5	
Rating	Pass	Pass	Pass	

LOCATION 14.3

■ mean
□ GEM



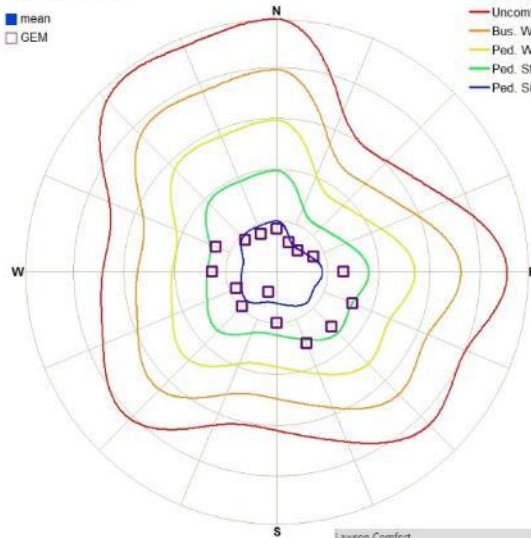
THRESHOLD
 — Uncomfortable
 — Bus. Walking
 — Ped. Walking
 — Ped. Standing
 — Ped. Sitting

% of time in excess of wind speed V				
V (m/s)	MEAN	GEM	COMBINED	
2	35.64	43.52	43.71	
4	14.11	18.51	18.70	
6	4.80	6.84	6.91	
8	0.81	1.57	1.58	
10	0.09	0.28	0.28	

Lawson Comfort				
(5%)	MEAN	GEM	COMBINED	
V (m/s)	5.9	6.4	6.4	
Rating	Ped Standing	Ped Walking	Ped Walking	
Lawson Safety				
(0.022%)	MEAN	GEM	COMBINED	
V (m/s)	11.0	12.0	12.0	
Rating	Pass	Pass	Pass	

LOCATION 17.3

■ mean
□ GEM



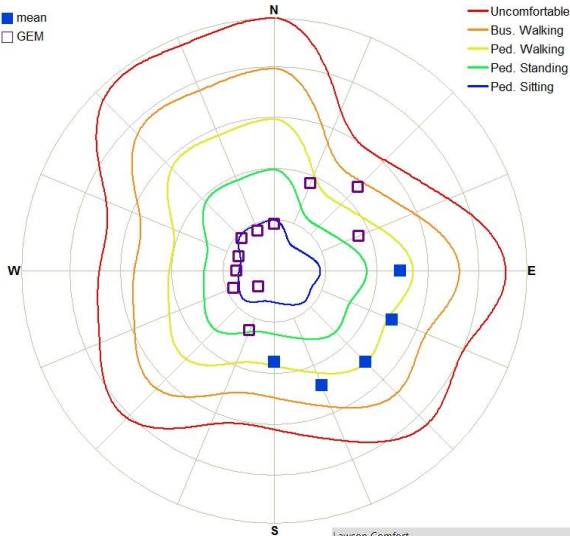
THRESHOLD
 — Uncomfortable
 — Bus. Walking
 — Ped. Walking
 — Ped. Standing
 — Ped. Sitting

% of time in excess of wind speed V				
V (m/s)	MEAN	GEM	COMBINED	
2	10.43	20.13	20.13	
4	0.26	1.22	1.22	
6	0.00	0.04	0.04	
8	0.00	0.00	0.00	
10	0.00	0.00	0.00	

Lawson Comfort				
(5%)	MEAN	GEM	COMBINED	
V (m/s)	2.5	3.1	3.1	
Rating	Ped Sitting	Ped Sitting	Ped Sitting	
Lawson Safety				
(0.022%)	MEAN	GEM	COMBINED	
V (m/s)	5.2	6.3	6.3	
Rating	Pass	Pass	Pass	

LOCATION 19.3

■ mean
□ GEM



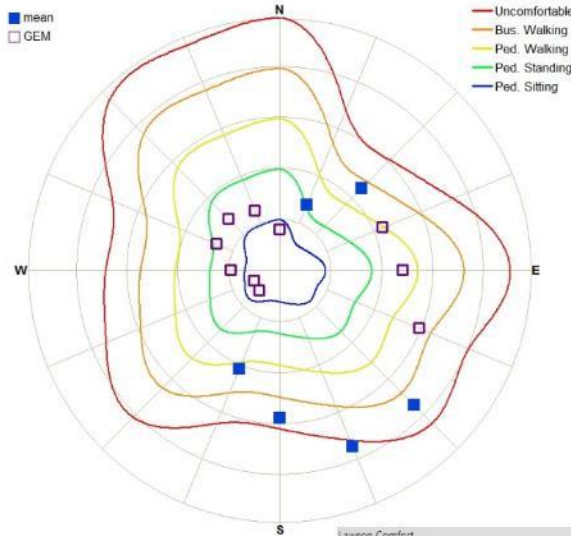
% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	40.71	43.70	44.06
4	14.34	15.60	16.69
6	2.01	2.78	3.09
8	0.21	0.39	0.46
10	0.02	0.03	0.03

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	5.1	5.3	5.4
Rating	Ped Standing	Ped Standing	Ped Standing

Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.9	10.1	10.2
Rating	Pass	Pass	Pass

LOCATION 20.3

■ mean
□ GEM



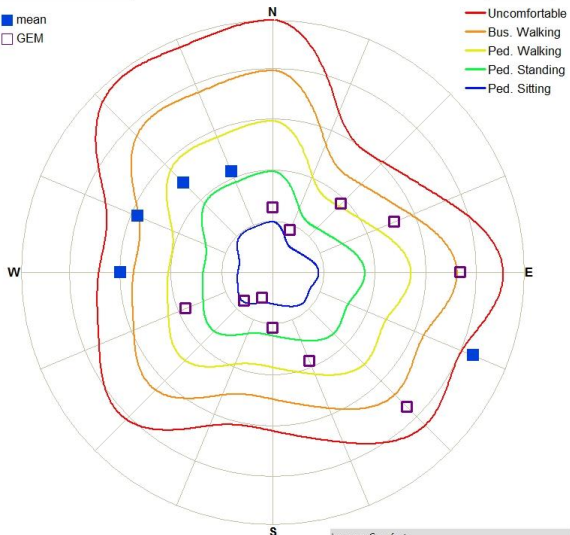
% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	45.85	49.08	49.68
4	24.72	25.01	27.28
6	10.27	7.61	10.58
8	3.28	1.60	3.21
10	0.78	0.28	0.79

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	7.2	6.5	7.3
Rating	Ped Walking	Ped Walking	Ped Walking

Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	15.1	12.9	15.1
Rating	Able Body	Pass	Able Body

LOCATION 28.3

■ mean
□ GEM



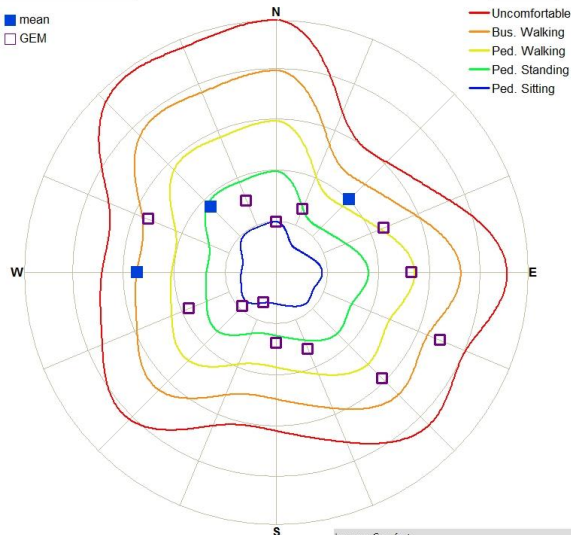
% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	46.86	52.40	54.72
4	17.73	21.02	22.45
6	6.14	7.47	8.49
8	2.06	1.96	2.67
10	0.54	0.39	0.63

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	6.3	6.6	6.9
Rating	Ped Walking	Ped Walking	Ped Walking

Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	14.3	13.5	14.5
Rating	Pass	Pass	Pass

LOCATION 29.3

■ mean
□ GEM



% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	43.65	52.44	53.16
4	12.24	16.62	19.01
6	3.10	4.56	4.76
8	0.69	0.97	1.04
10	0.14	0.23	0.25

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	5.3	5.8	5.9
Rating	Ped Standing	Ped Standing	Ped Standing

Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	11.4	12.1	12.1
Rating	Pass	Pass	Pass