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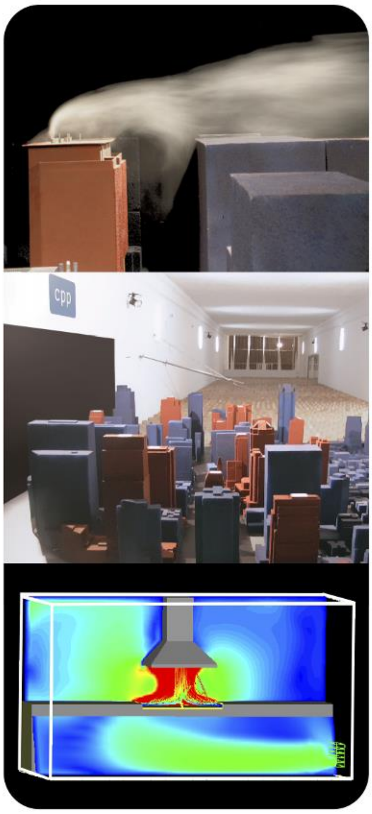
Final Report



Wind Tunnel Tests for:

DARLING SQUARE – SOUTH EAST PLOT REDUCED SCHEME

Sydney, Australia

CPP Project 8253
February 2016

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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).

The Application (referred to as SSDA 9) follows the approval of a staged SSD DA (SSDA 2) in December 2013. SSDA 2 sets out a Concept Proposal for a new mixed use residential neighbourhood at Haymarket referred to as “Darling Square”, previously known as “The Haymarket”. Darling Square forms part of the Sydney International Convention, Exhibition and Entertainment precinct (SICEEP) Project, which will deliver Australia’s global city with new world class convention, exhibition and entertainment facilities and support the NSW Government’s goal to “make NSW number one again”.

More specifically this subsequent DA seeks approval for mixed use development within the South East development plot of Darling Square and associated public domain works. The DA has been prepared and structured to be consistent with the Concept Proposal DA.

Overview of Proposed Development

The proposal relates to a detailed (‘Stage 2’) DA for a mixed use residential development in the South East Plot of Darling Square together with associated public domain works. The Darling Square Site is to be developed for a mix of residential and non-residential uses, including but not limited to residential buildings, commercial, retail, community and open space. The South East Plot is one of six development plots identified within the approved Concept Proposal.

Under the Concept Proposal, the South East Plot is planned to accommodate a mixed use podium and three residential buildings (SE1, SE2, and SE3) above and within the podium structure. More specifically, this SSD DA seeks approval for the following components of the development:

Demolition of existing site improvements, including the existing Sydney Entertainment Centre (SEC);

- Associated tree removal and planting;
- Construction and use of a predominantly 5 storey mixed use podium, including:

- retail floor space and residential lobbies on Ground Level;
- above ground parking;
- residential apartments; and
- communal facilities.

- Construction and use of three residential buildings above podium;
- Public domain improvements adjacent to the site;
- Provision of vehicle access to the development from Harbour Street;
- Landscaping works to the podium roof level; and
- Extension and augmentation of physical infrastructure / utilities as required.

Background

The NSW Government considers that a precinct-wide renewal and expansion of the existing convention, exhibition and entertainment centre facilities at Darling Harbour is required, and is committed to Sydney reclaiming its position on centre stage for hosting world-class events with the creation of SICEEP.

Following an extensive and rigorous Expressions of Interest and Request for Proposals process, a consortium comprising AEG Ogden, Lend Lease, Capella Capital and Spotless was announced by the NSW Government in December 2012 as the preferred proponent to transform Darling Harbour and create SICEEP.

Key features of the Preferred Master Plan include:

- Delivering world-class convention, exhibition and entertainment facilities, including:
    - Up to 40,000m2 exhibition space;
    - Over 8,000m2 of meeting rooms space, across 40 rooms;
    - Overall convention space capacity for more than 12,000 people;

- A ballroom capable of accommodating 2,000 people; and
- A premium, red-carpet entertainment facility with a capacity of 8,000 persons.

- Providing a hotel complex at the northern end of the precinct.
- A vibrant and authentic new neighbourhood at the southern end of the precinct, now called 'Darling Square', including apartments, student accommodation, shops, cafes and restaurants.
- Renewed and upgraded public domain that has been increased by a hectare, including an outdoor event space for up to 27,000 people at an expanded Tumbalong Park; and
- Improved pedestrian connections linking to the proposed Ultimo Pedestrian Network drawing people between Central, Chinatown and Cockle Bay Wharf as well as east-west between Ultimo/Pyrmont and the City.

On 21 March 2013 a critical step in realising the NSW Government's vision for the SICEEP Project was made, with the lodgement of the first two SSD DAs with the (now) Department of Planning and Environment. The key components of these proposals are outlined below.

Public Private Partnership SSD DA (SSD 12_5752)

The Public-Private Partnership (PPP) SSD DA (SSDA 1) includes the core facilities of the SICEEP Project, comprising the new, integrated and world-class convention, exhibition and entertainment facilities along with ancillary commercial premises and public domain upgrades. SSDA1 was approved on 22 August 2013.

Concept Proposal (SSD 13_5878)

The Concept Proposal SSD DA (SSDA 2) establishes the vision and planning and development framework which will be the basis for the consent authority to assess detailed development proposals within the Darling Square Site. SSDA2 was approved on 5 December 2013. The Stage 1 Concept Proposal approved the following key components and development parameters:

- Indicative staging of demolition and development of future development plots;

- Land uses across the site including residential and non-residential uses;
- Street and laneway layouts and pedestrian routes;
- Open spaces and through-site links;
- Six separate development plots, development plot sizes and separation, building envelopes, building separation, building depths, building alignments, and benchmarks for natural ventilation and solar access provisions;
- A maximum total gross floor area (non-residential and residential GFA);
- Above ground car parking including public car parking;
- Residential car parking rates;
- Design Guidelines to guide future development and the public domain; and
- A remediation strategy.

The Concept Proposal was modified on 26 November 2015 to increase the amount of non-residential GFA. This minor increase in GFA was allocated to the approved North-West Plot building to meet tenant requirements. In addition to the approval of SSDA2, the following approvals have been granted for various stages of Darling Square site:

- Darling Drive (part) development plot (SSDA3) for the construction and use of a residential building (student accommodation) and the provision of associated public domain works approved on 7 May 2014;
- North-West development plot (SSDA4) for the construction and use of a mixed use commercial development and public car park building and associated public domain works approved on 7 May 2014; and
- South-West development plot (SSDA5) – construction and use of a mixed use residential development and associated public domain works approved on 21 May 2014.

- North-East development plot (SSDA7) – construction and use of a mixed use residential development and associated public domain works approved on 16 April 2014.

Approval was also granted on 15 June 2014 for SSDA6 which includes the construction and use of the International Convention Centre (ICC) Hotel and provision of public domain works. Approval was also granted for SSDA8 on 16 October 2015 which comprised the ICC Hotel fitout, external lighting and subdivision.

This report has been prepared to support a detailed Stage 2 SSD DA for mixed use development and associated public domain works within Darling Square (SSDA 9), consistent with the Concept Proposal (SSDA 2).

Site Description

The SICEEP Site is located within Darling Harbour. Darling Harbour is a 60 hectare waterfront precinct on the south-western edge of the Sydney Central Business District that provides a mix of functions including recreational, tourist, entertainment and business.

With an area of approximately 20 hectares, the SICEEP Site is generally bound by the light rail Line to the west, Harbourside shopping centre and Cockle Bay to the north, Darling Quarter, the Chinese Garden and Harbour Street to the east, and Hay Street to the south (refer to Figure 1). The Darling Square Site is:

- located in the south of the SICEEP Site, within the northern portion of the suburb of Haymarket;

- bounded by the Powerhouse Museum to the west, the Pier Street overpass and Little Pier Street to the north, Harbour Street to the east, and Hay Street to the south; and

- irregular in shape and occupies an area of approximately 37,700m2.

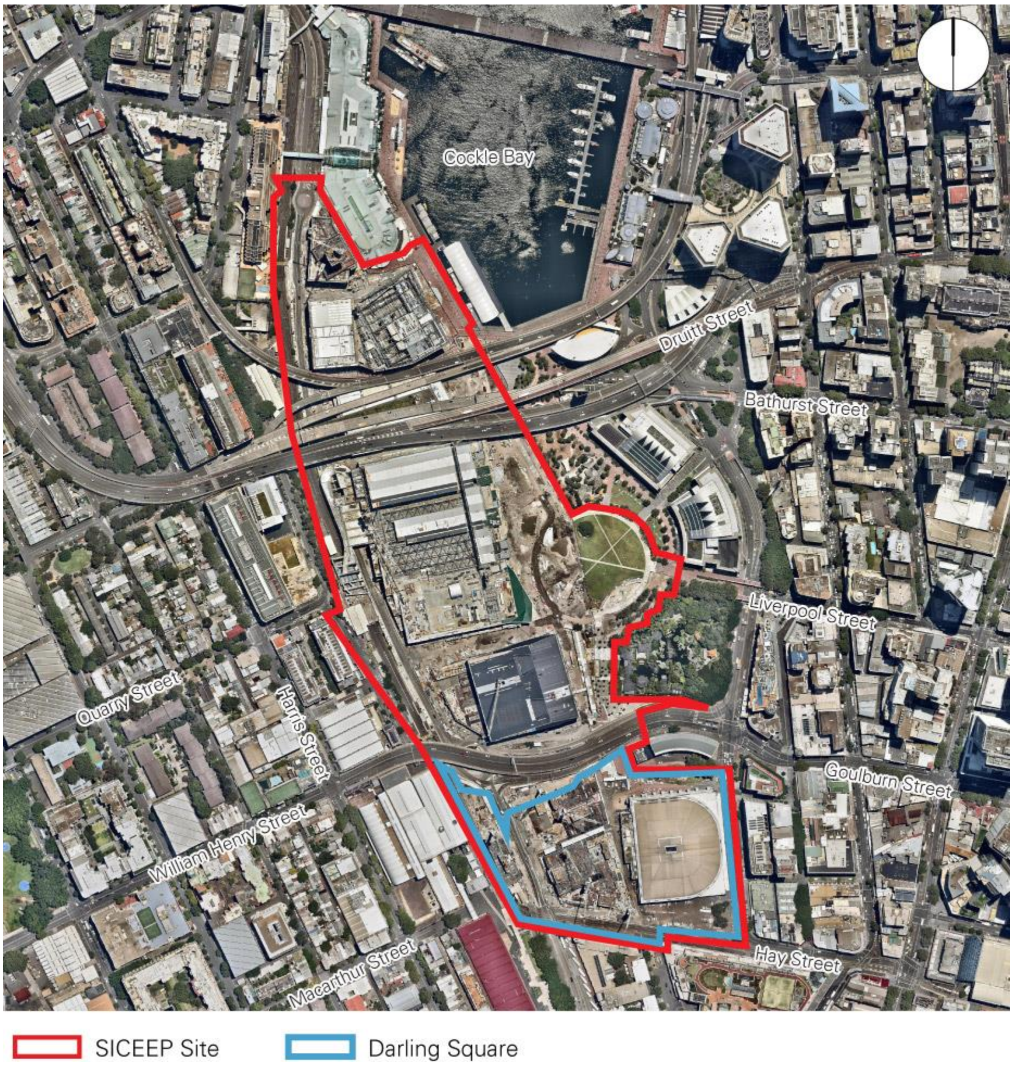

Figure 1 – Aerial Photograph of the SICEEP Site

The Concept Proposal DA provides for six (6) separate development plots across the Darling Square Site (refer to Figure 2):

1. North Plot;
2. North East Plot;
3. South East Plot;
4. South West Plot;
5. North West Plot; and
6. Western Plot (Darling Drive).

The Application Site area relates to the South East Plot and surrounds as detailed within the architectural and landscape plans submitted in support of the DA.

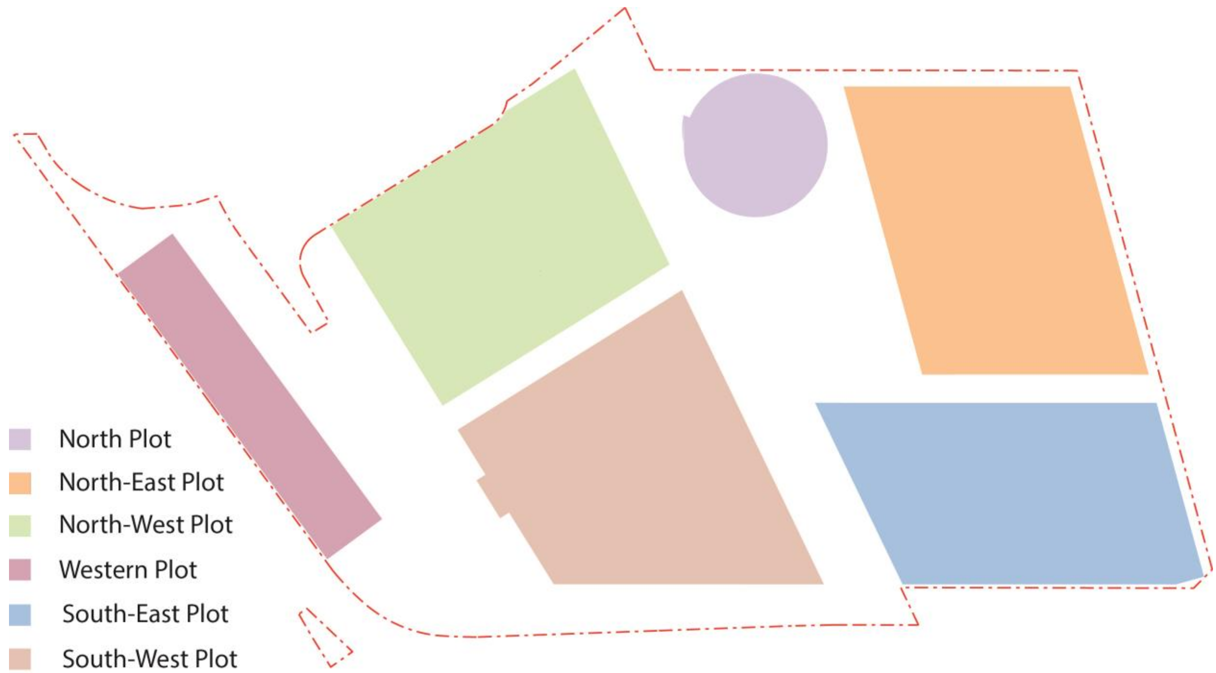

Figure 2 – Concept Proposal Development Plots

Planning Approvals Strategy

The SICEEP Project has resulted in the lodgement of numerous SSD DAs for the various components of the redevelopment project. Future applications will continue to be lodged in accordance with the Concept Proposal SSD DA for the remaining development plots of Darling Square Site.

EXECUTIVE SUMMARY

A wind tunnel study of the proposed Darling Square – South East Plot Reduced Scheme development to be located in Sydney, Australia, was conducted to assess pedestrian wind comfort. A model of the project was fabricated to a 1:400 scale and centred on a turntable in the wind tunnel. Replicas of surrounding buildings within a 570 m radius were constructed and placed on the turntable.

The wind tunnel testing was performed in the natural boundary layer wind tunnel of Cermak Peterka Petersen Pty. Ltd., St Peters. Approach boundary layers representative of the environment surrounding the proposed development were established in the test section of the wind tunnel. The approach wind flow had appropriate turbulence characteristics corresponding to Terrain Category 3, as defined in Standards Australia (2011).

Measurements of winds likely to be experienced by pedestrians were made with a hot-film anemometer at 24 locations for 16 wind directions each. These points were tested around the development in the proposed configuration, focusing especially on access routes, doorways and 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.

The wind environment around the development was found to be suitable for pedestrian sitting and standing, under the Lawson criteria, at various locations. All ground level areas passed the Lawson distress criterion. Some recommendations for localised amelioration have been provided.

DOCUMENT VERIFICATION

Date	Revision	Prepared by	Checked by	Approved by
01/02/2016	Final Report	MNC	MG	MG
15/02/2016	Client Standard Information	MNC	MG	MG

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

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 discussion. 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

General Information	
Model length scale	1:400
Surrounding model radius (full-scale)	570 m
Reference height (full-scale)	200 m AGL
Approach Terrain Category	Terrain Category 3
Testing Configuration(s)	
Configuration A	Proposed Darling Square – South East Plot Reduced Scheme development with surrounding buildings, as shown in Figure 5. Pedestrian winds measured at 24 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 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 3. 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 4, and are explained more fully in Section 4.1.1.

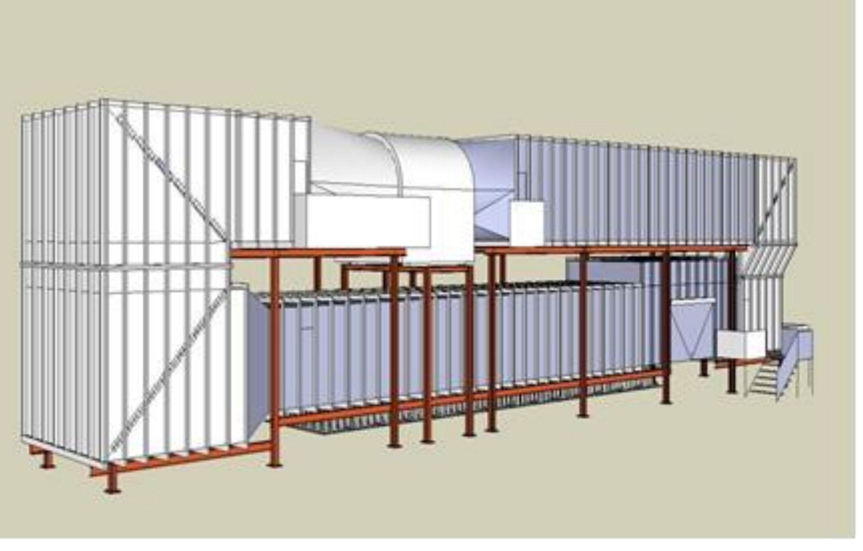

Figure 3: Schematic of the closed circuit wind tunnel

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 5, 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 6. 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.

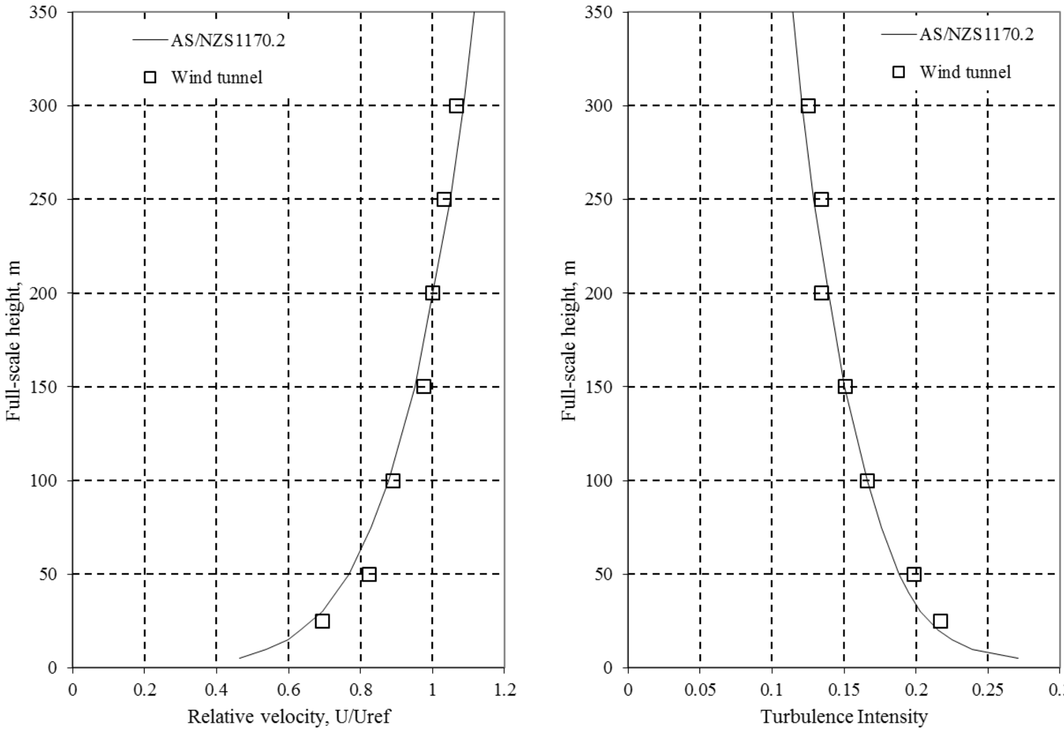

Figure 4: Mean velocity and turbulence profiles

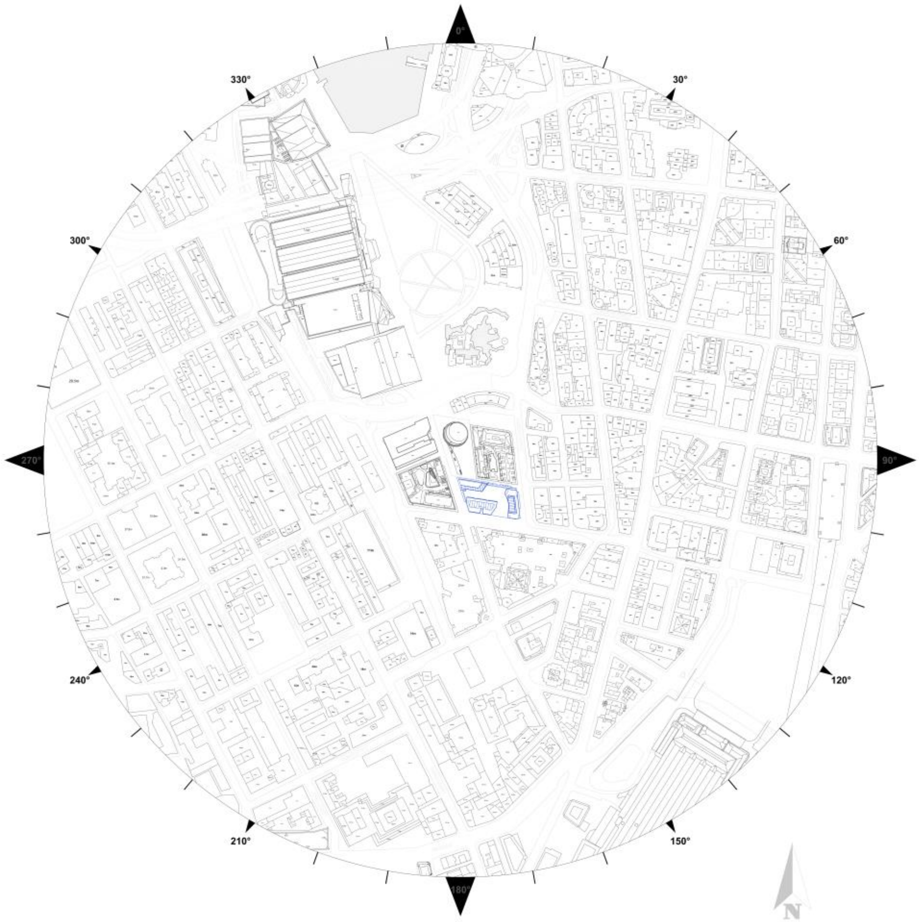

Figure 5: Project location and turntable layout

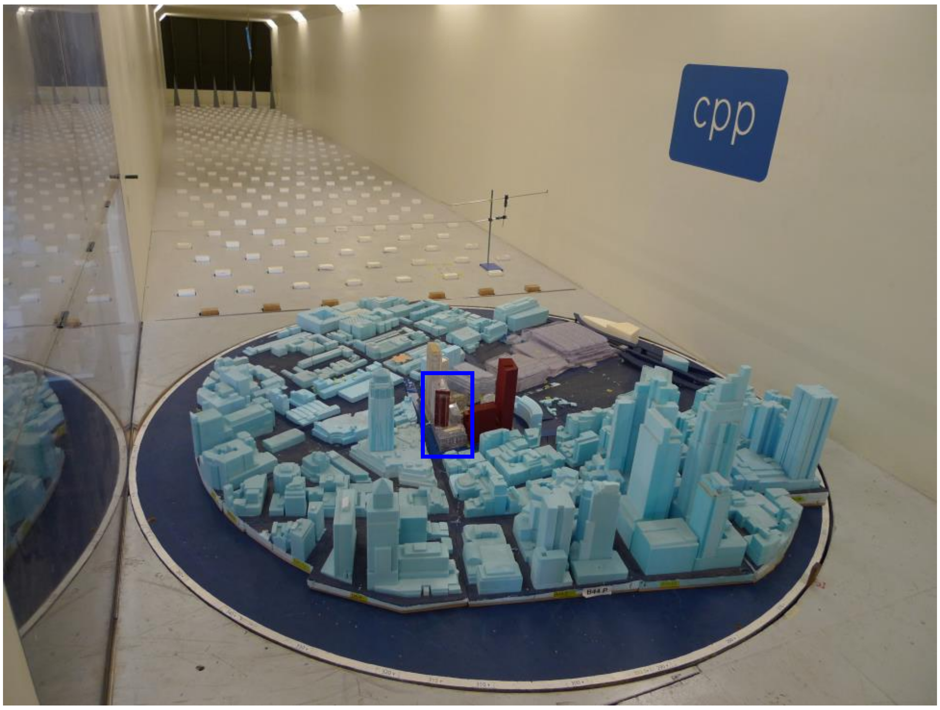

Figure 6: Proposed Darling Square – South East Plot Reduced Scheme model in the wind tunnel viewed from the south-east

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.

Lawson's criteria have categories for comfort, 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[1]. In both cases, the wind speed used the larger of a mean or gust equivalent-mean (GEM) wind speed. The GEM is defined as the peak gust wind speed divided by 1.85; this is intended to account for locations where the gustiness is the dominant characteristic of the wind. Assessment using the Lawson criteria provides a similar classification as using once per annum gust criteria, however provides significantly more information regarding the serviceability wind climate.

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
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

[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.

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 4. 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 proposed development is located in Sydney's Darling Harbour. The site is bounded by The Boulevard, Hay Street, Little Hay Street and Harbour Street. The development is surrounded by Sydney's CBD high rise buildings to the east quadrant and by medium rise buildings to the west quadrant. The site is thus exposed to winds from the north and south.

For this report wind speed measurements were recorded at 24 locations to evaluate pedestrian comfort in and around the project site, Figure 8 to Figure 10. All points tested were for the configurations described in Table 1. 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 comfort primarily for the outdoor leisure areas, as well as at building corners where relatively severe conditions are frequently found, near building entrances, and on adjacent pavements with pedestrian traffic.

The hot-film signal was sampled for a period corresponding to one hour in prototype. All velocity data was digitally filtered to obtain the two to three second running mean wind speed at each point; this is the minimum size of a gust affecting a pedestrian and is the basis for the various acceptability criteria.

These local wind speeds, U, were normalised by the tunnel reference velocity U_{ref}. Mean and turbulence statistics were calculated and used to calculate the normalised effective peak gust using:

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

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

To enable a quantitative assessment of the wind environment, the wind tunnel data was 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 2011, Figure 7.

From this 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 7 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 8 to Figure 10, for each test location. The implications of the results are discussed in Section 5.

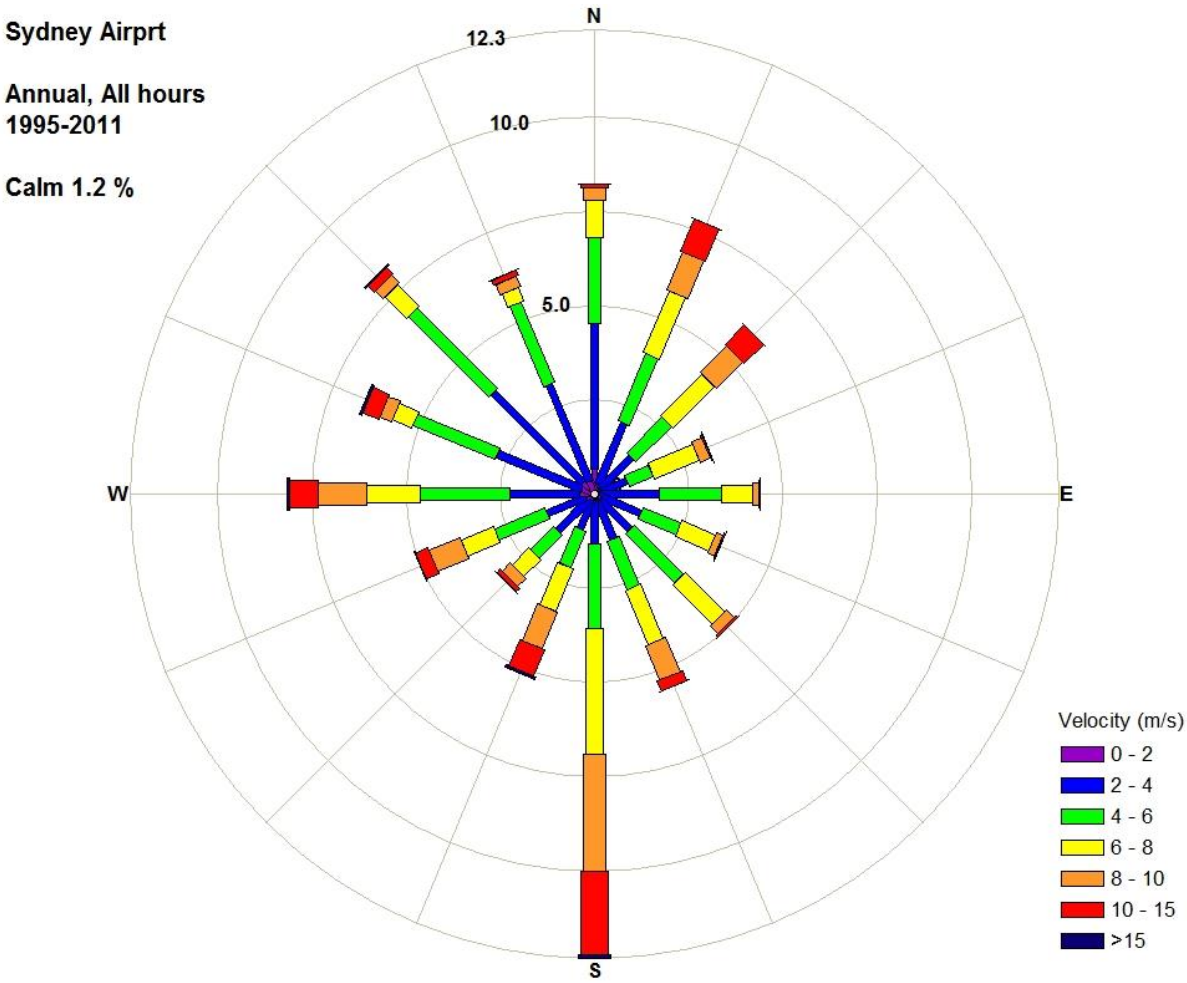

Figure 7: Wind rose of direction and speed for Sydney Airport

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.

5. DISCUSSION

The wind climatology chart of Figure 7 indicates that the most frequent strong winds are from the south quadrant. The locations tested around the development site are susceptible to winds from the different directions, depending on the relative location of the point tested to the geometry of the proposed development and surrounds. The influence of wind direction on the suitability of a location for an intended purpose can be ascertained from the graphs in Appendix 2.

The primary conclusions of the pedestrian study can be understood by reviewing the colour coded images of Figure 8 to Figure 10, which depict the locations selected for investigation of pedestrian wind comfort along with the Lawson criteria rating for both comfort and distress. Note that testing was performed without planned trees, or other plantings to provide a worst case assessment; heavy landscape planting typically reduces the wind speeds by less than 10%. 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. Mitigation measures are likely to be required for red 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.

It is evident from Figure 8, that the wind environment around the proposed development, at ground level on The Boulevard, Hay Street, Little Hay Street and Harbour Street, is generally satisfactory for pedestrian standing activities. Locations 1 to 3 situated on the corner of Hay Street and Harbour Street, rated as suitable for pedestrian standing activities, under the Lawson comfort criterion, and passed the distress criterion. Polar plots show these locations are primarily influenced by winds from the north and south quadrants channelling along Hay and Harbour Streets. Locations 4 and 5, on Harbour Street, rated as suitable for pedestrian sitting activities and passed the distress criterion, due in part to shielding by the podium and SE3 tower.

Locations 6 to 9, located along Little Hay Street, classified as suitable for pedestrian sitting activities, with the exception of Location 9 which classified as suitable for pedestrian standing activities. All locations passed the distress criterion. This section of Little Hay Street is expected to be used for stationary outdoor seating activities such as restaurant dining and bar/café style eating. Polar plots, in Appendix 2, show these locations are primarily affected by north-west and south-east winds channelling through the lane. Furthermore, the plots show the lane would be suitable for outdoor dining activities approximately 60% of the time.

Location 10, situated on Haymarket Square, classified as suitable for pedestrian sitting activities and passed the distress criterion; showing wind conditions around the square are relatively calm.

Locations along The Boulevard, Figure 8, classified as suitable for pedestrian walking and standing activities. Polar plots show Locations 11 and 12 are primarily influenced by channelling winds from the south-west and north-east quadrants; whilst Locations 13 and 14 are largely affected by downwash winds caused by winds from the north quadrant hitting the SE1 tower west façade.

Locations 15 and 16, along Hay Street, rated for pedestrian standing and pedestrian walking activities, respectively; passing the distress criterion. Polar plots show these locations are subject to winds from the south-west quadrant.

Podia decks are generally windy locations, as they deflect downwash winds away from street level. Figure 9, shows environmental wind conditions at podium level are generally satisfactory for pedestrian walking activities. Locations 18 to 22 present the windiest conditions, due to southerly and northerly winds accelerating between the SE1 and SE3 towers; generally rating for pedestrian walking and passing the distress criterion, with the exception of Locations 20 and 22 which classified for business walking and pedestrian walking, respectively, and rated for able bodied pedestrians under the distress criterion. Location 23 rated as suitable for pedestrian walking activities and passed the distress criterion. This location is mainly influenced by winds from the south-west quadrant channelling between the SE1 and SE2 towers.

The podium is intended for use as an outdoor space area for residents. Wind amenity such as landscaping will provide local shelter for patrons. Despite potentially misleadingly low velocities, Location 17 will present high positive pressures. It is understood that glazing, at this location, will be permanently sealed, which will help prevent strong internal lobby flows linking to the lift shaft.

Figure 10, shows wind conditions at the SE3 roof level are relatively calm, due to shielding from high perimeter walls, with Location 24 rating as suitable for pedestrian standing, under the Lawson criterion, and passing the distress criterion.

Figure 8: Pedestrian wind speed measurement locations with comfort/distress ratings – Ground Level

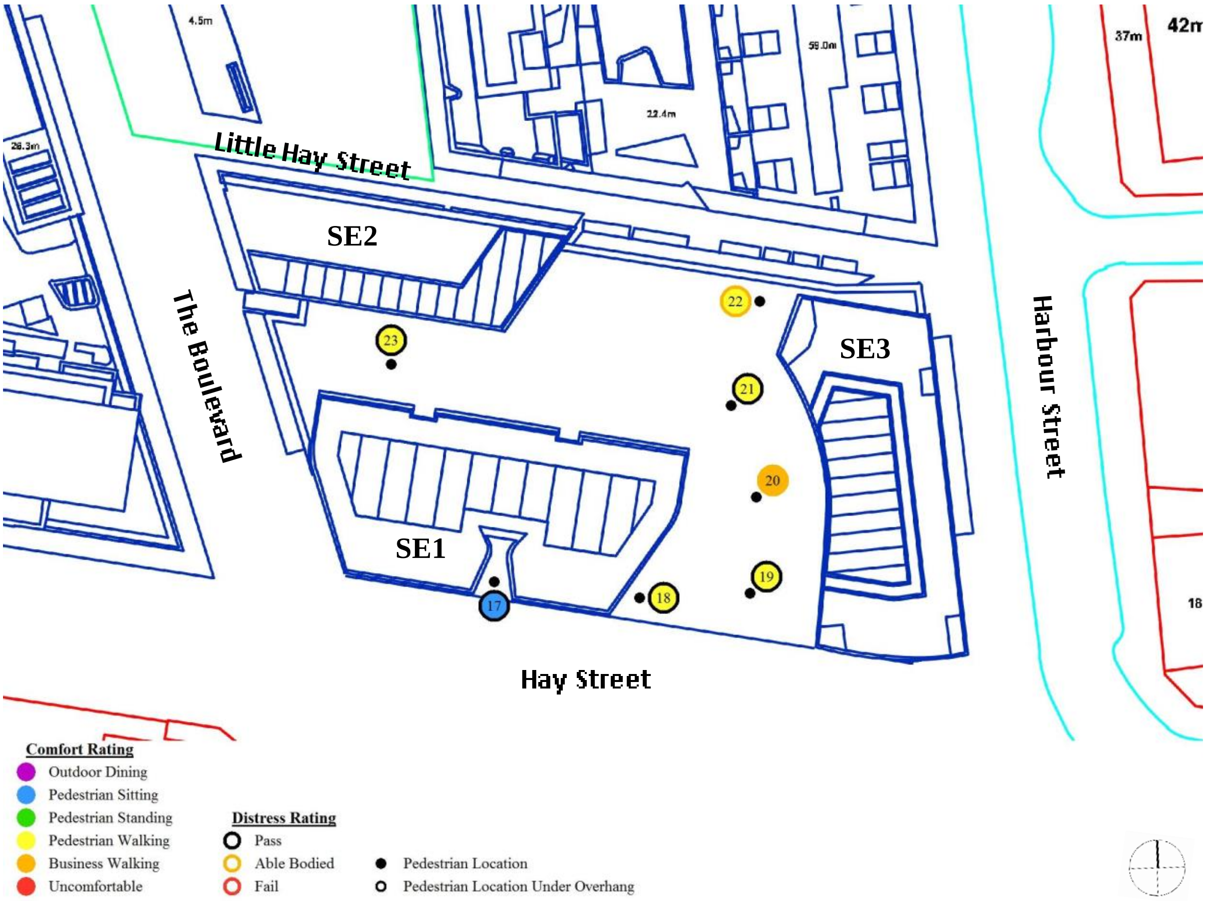

Figure 9: Pedestrian wind speed measurement locations with comfort/distress ratings – Podium

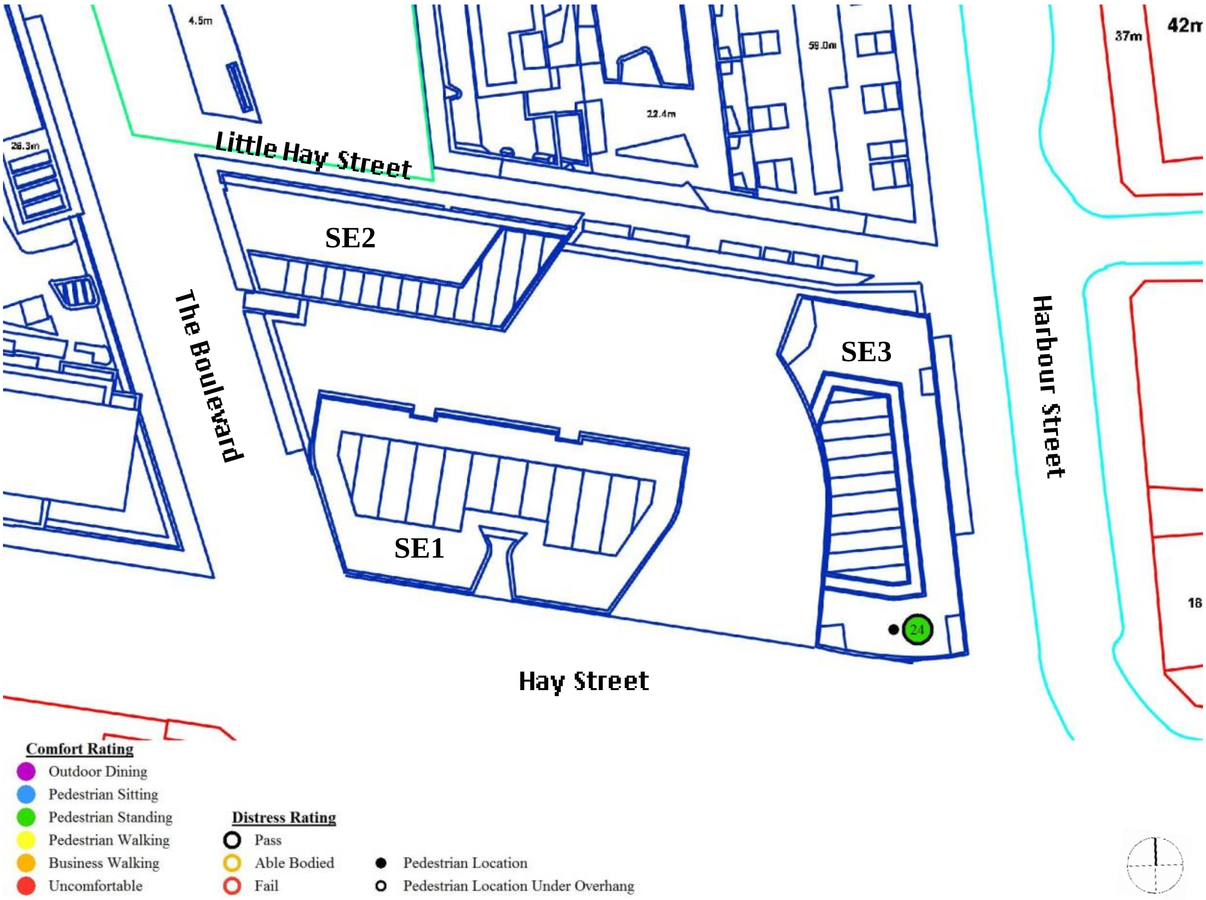

Figure 10: Pedestrian wind speed measurement locations with comfort/distress ratings – Roof

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Appendix 1: Additional photographs of the CPP wind tunnel model

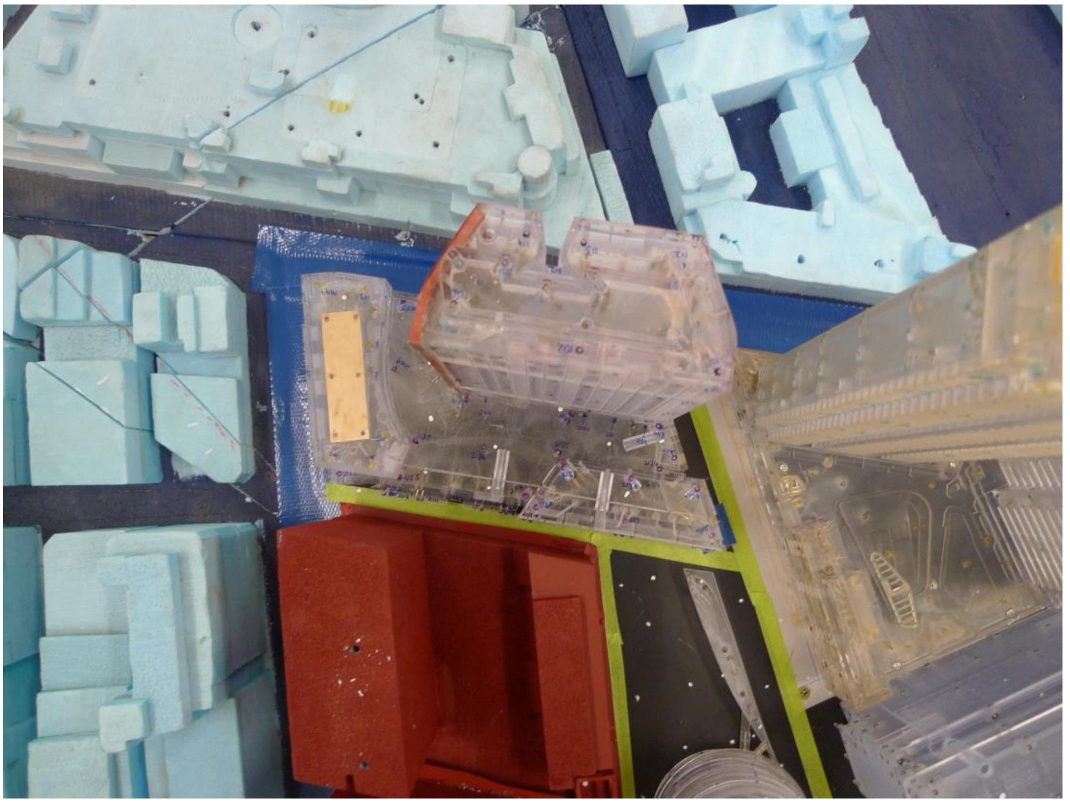


Figure 11: Darling Square – South East Plot Reduced Scheme development viewed from the top

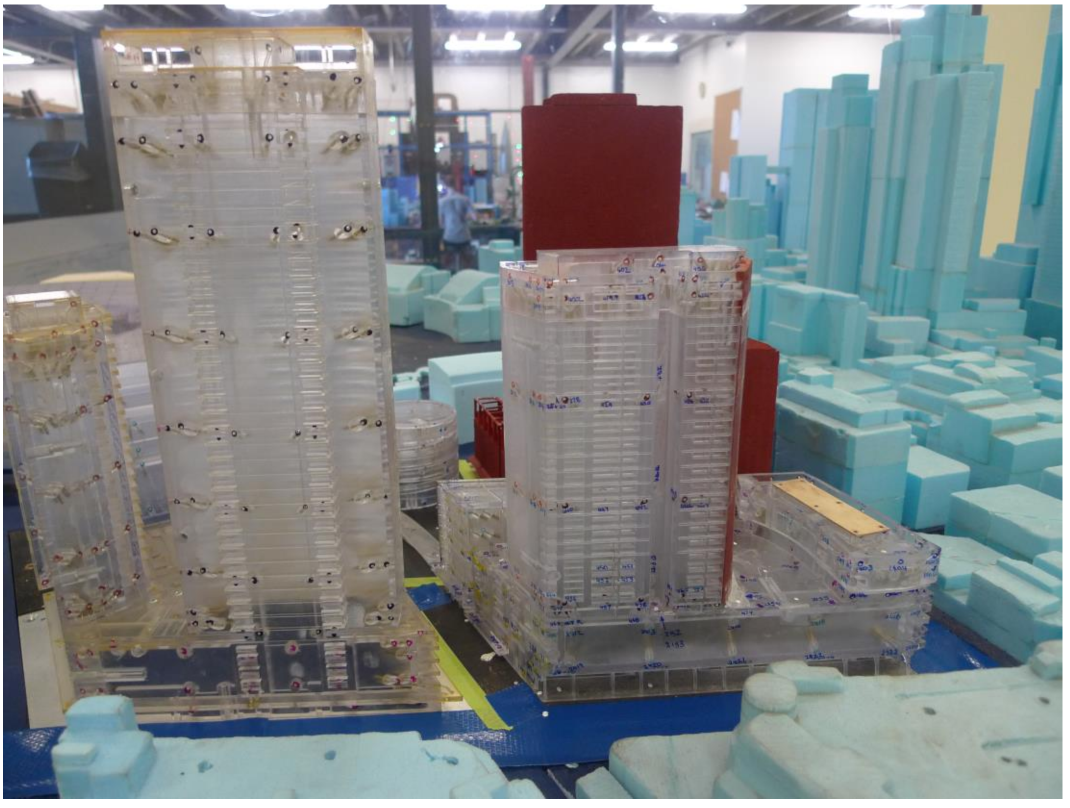
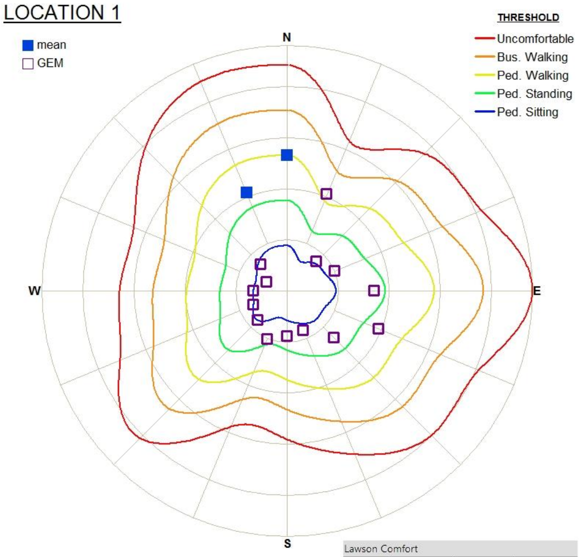


Figure 12: Darling Square – South East Plot Reduced Scheme development viewed from the south

Appendix 2: Directional Wind Results

LOCATION 1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	27.12	33.22	34.48
4	4.90	5.19	6.12
6	0.83	0.88	1.20
8	0.08	0.04	0.10
10	0.01	0.00	0.01

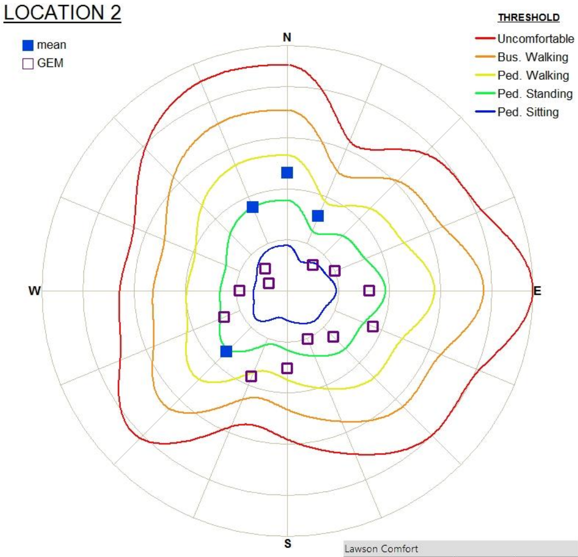
Lawson Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	3.9	4.0	4.2
Rating	Ped Sitting	Ped Sitting	Ped Standing

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.0	8.2	9.0
Rating	Pass	Pass	Pass

LOCATION 2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	37.21	40.79	43.34
4	7.55	7.89	8.85
6	0.62	0.62	0.78
8	0.05	0.05	0.07
10	0.00	0.00	0.00

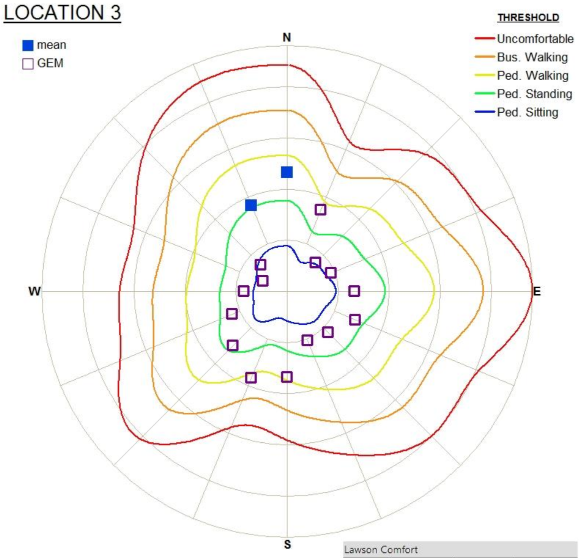
Lawson Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	4.3	4.4	4.5
Rating	Ped Standing	Ped Standing	Ped Standing

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	8.5	8.7	8.8
Rating	Pass	Pass	Pass

LOCATION 3



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	34.47	39.49	41.25
4	8.07	9.34	10.09
6	0.76	1.00	1.14
8	0.07	0.07	0.09
10	0.00	0.00	0.00

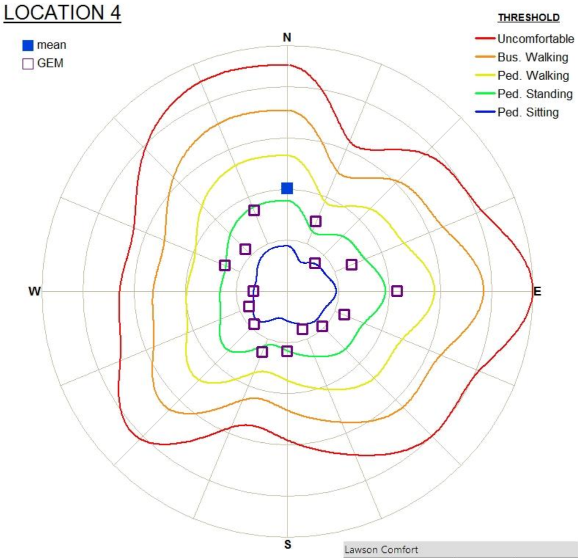
Lawson Comfort

(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)	8.8	8.9	9.0
Rating	Pass	Pass	Pass

LOCATION 4



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	19.96	35.83	36.05
4	1.31	4.17	4.26
6	0.08	0.18	0.19
8	0.00	0.00	0.00
10	0.00	0.00	0.00

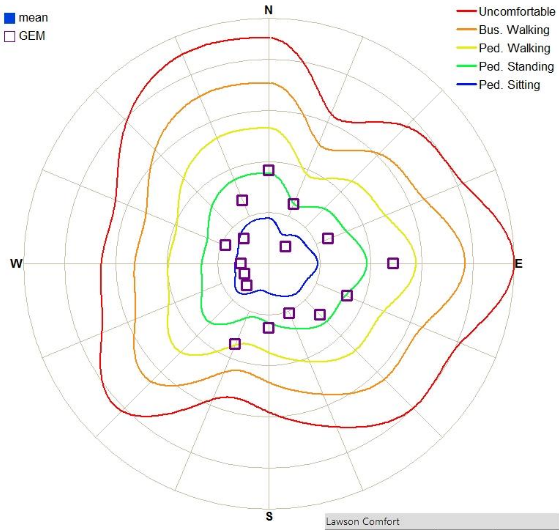
Lawson Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	3.1	3.9	3.9
Rating	Ped Sitting	Ped Sitting	Ped Sitting

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	6.8	7.0	7.1
Rating	Pass	Pass	Pass

LOCATION 5



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	19.64	35.58	35.58
4	1.45	4.99	4.99
6	0.07	0.36	0.36
8	0.00	0.02	0.02
10	0.00	0.00	0.00

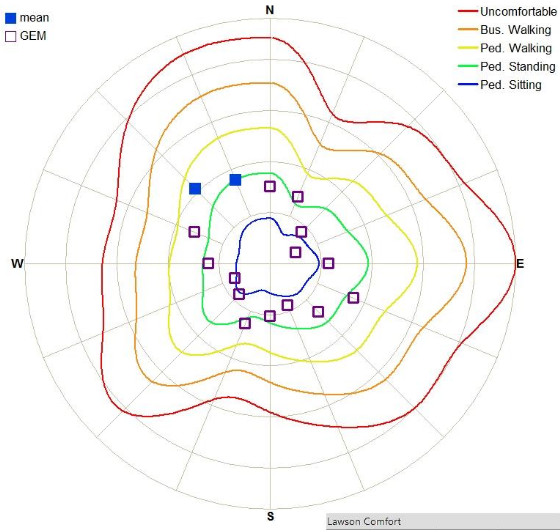
Lawson Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	3.1	4.0	4.0
Rating	Ped Sitting	Ped Sitting	Ped Sitting

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	6.6	8.1	8.1
Rating	Pass	Pass	Pass

LOCATION 6



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	25.47	38.53	40.46
4	2.60	3.55	3.90
6	0.37	0.31	0.42
8	0.06	0.03	0.06
10	0.01	0.00	0.01

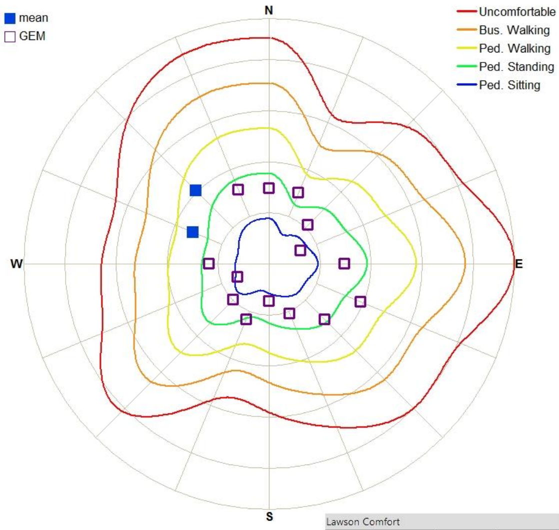
Lawson Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	3.4	3.7	3.8
Rating	Ped Sitting	Ped Sitting	Ped Sitting

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.2	8.1	9.2
Rating	Pass	Pass	Pass

LOCATION 7



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	28.29	37.27	38.36
4	2.57	3.85	4.06
6	0.34	0.33	0.39
8	0.05	0.03	0.05
10	0.01	0.00	0.01

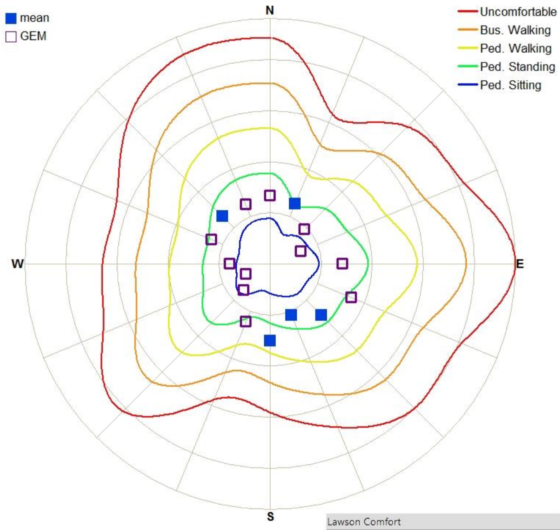
Lawson Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	3.4	3.8	3.8
Rating	Ped Sitting	Ped Sitting	Ped Sitting

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.0	8.2	9.0
Rating	Pass	Pass	Pass

LOCATION 8



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	31.49	33.46	34.44
4	4.00	4.01	4.48
6	0.16	0.14	0.19
8	0.01	0.01	0.01
10	0.00	0.00	0.00

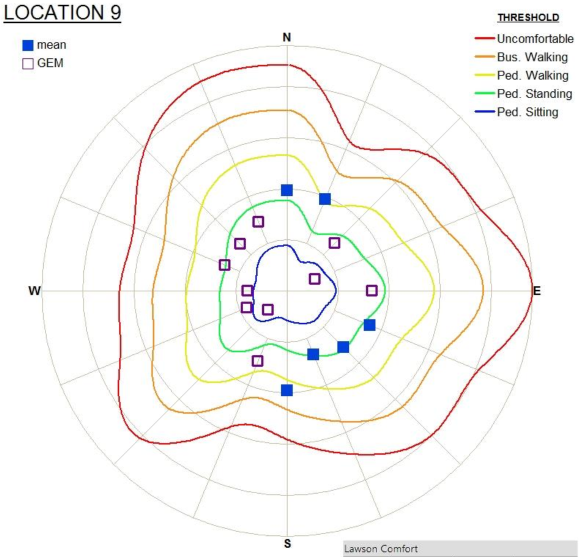
Lawson Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	3.8	3.8	3.9
Rating	Ped Sitting	Ped Sitting	Ped Sitting

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	7.4	7.2	7.4
Rating	Pass	Pass	Pass

LOCATION 9



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	41.54	43.45	45.54
4	10.91	9.98	12.16
6	1.84	1.15	1.96
8	0.11	0.05	0.11
10	0.01	0.00	0.01

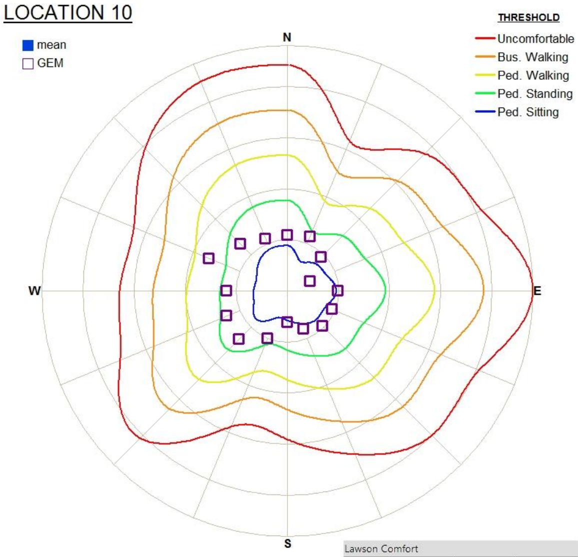
Lawson Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	5.0	4.7	5.0
Rating	Ped Standing	Ped Standing	Ped Standing

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.4	8.7	9.4
Rating	Pass	Pass	Pass

LOCATION 10



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	9.48	23.51	23.51
4	0.30	1.46	1.46
6	0.00	0.19	0.19
8	0.00	0.01	0.01
10	0.00	0.00	0.00

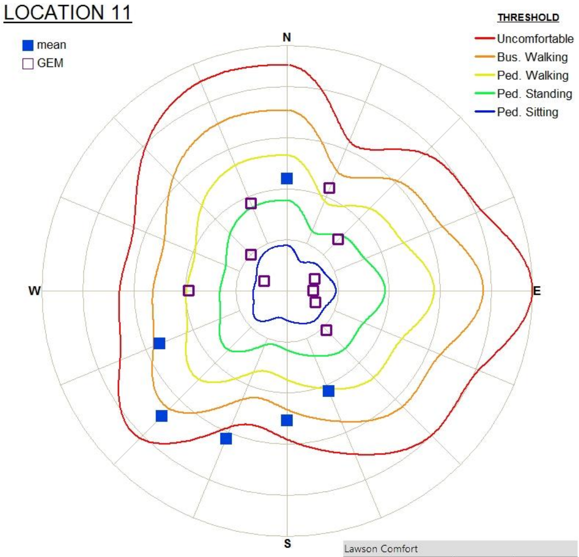
Lawson Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	2.4	3.1	3.1
Rating	Ped Sitting	Ped Sitting	Ped Sitting

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	5.4	7.6	7.6
Rating	Pass	Pass	Pass

LOCATION 11



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	46.36	53.62	54.61
4	23.88	23.70	26.34
6	9.91	7.02	10.55
8	2.84	1.31	2.91
10	0.68	0.24	0.69

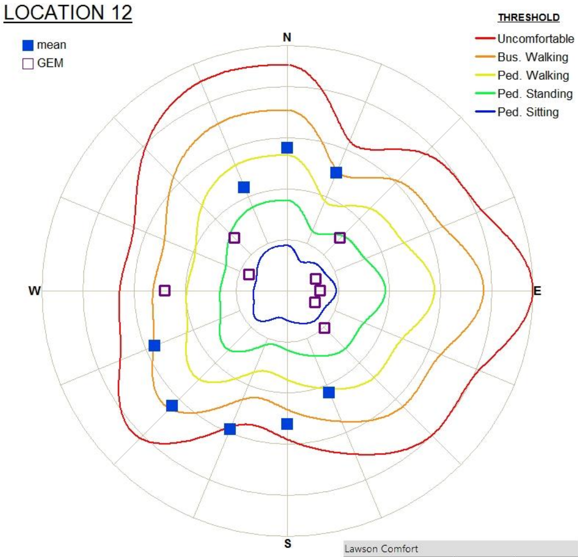
Lawson Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	7.0	6.4	7.1
Rating	Ped Walking	Ped Walking	Ped Walking

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	14.9	12.9	14.9
Rating	Pass	Pass	Pass

LOCATION 12



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	54.76	57.28	59.15
4	27.74	26.65	30.05
6	11.89	8.60	12.71
8	3.16	1.61	3.37
10	0.60	0.20	0.63

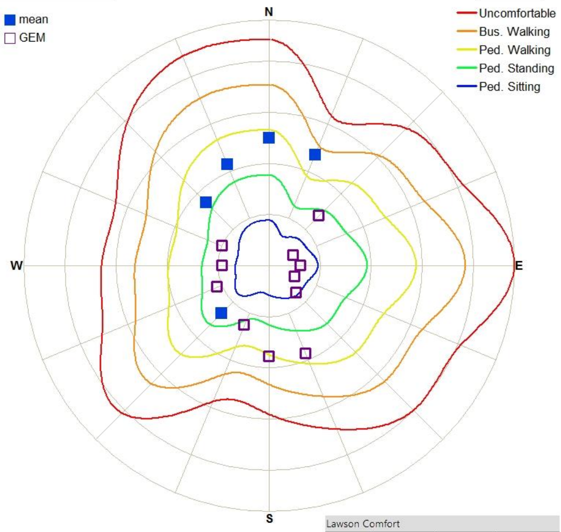
Lawson Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	7.3	6.7	7.4
Rating	Ped Walking	Ped Walking	Ped Walking

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	14.2	12.4	14.2
Rating	Pass	Pass	Pass

LOCATION 13

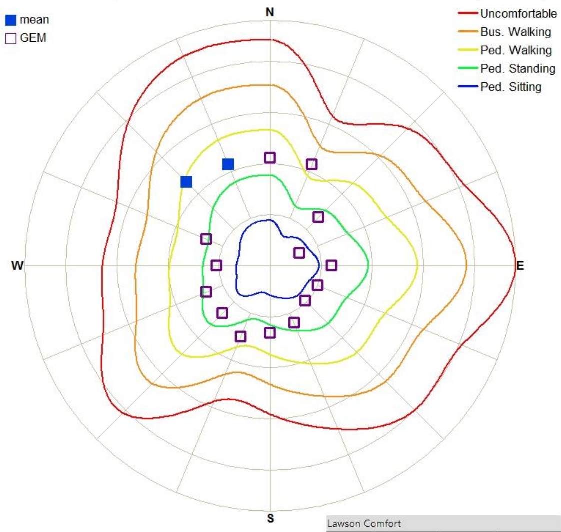


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	42.50	46.57	47.85
4	9.77	13.17	14.01
6	2.10	2.33	2.85
8	0.26	0.18	0.31
10	0.01	0.01	0.01

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.8	5.1	5.2
Rating	Ped Standing	Ped Standing	Ped Standing

Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.5	9.3	9.7
Rating	Pass	Pass	Pass

LOCATION 14

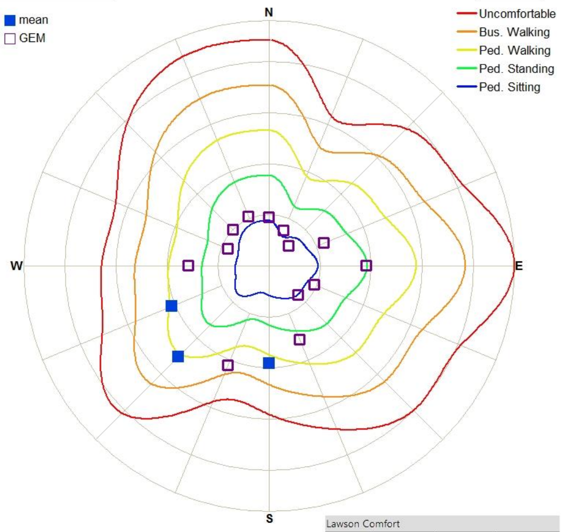


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	42.06	49.30	51.09
4	6.64	8.74	9.31
6	1.16	1.40	1.62
8	0.14	0.12	0.18
10	0.03	0.01	0.03

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.3	4.6	4.6
Rating	Ped Standing	Ped Standing	Ped Standing

Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	10.4	9.0	10.4
Rating	Pass	Pass	Pass

LOCATION 15

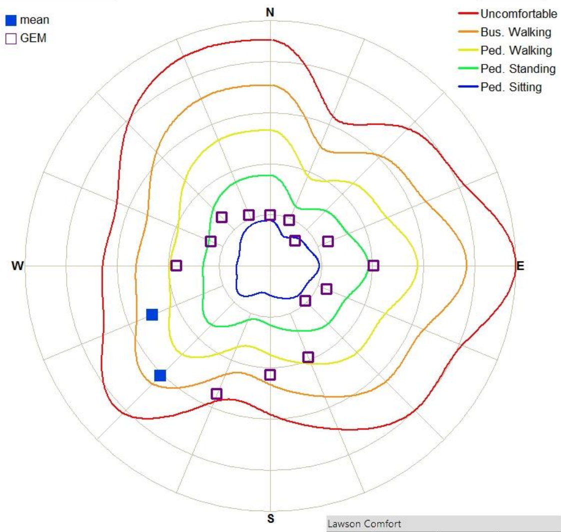


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	32.74	38.55	39.02
4	12.30	12.63	13.34
6	2.37	2.26	2.50
8	0.26	0.24	0.27
10	0.03	0.03	0.04

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

Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	10.3	10.3	10.4
Rating	Pass	Pass	Pass

LOCATION 16

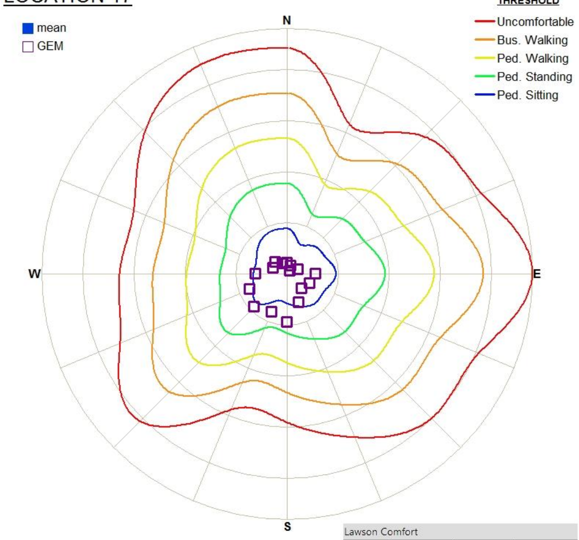


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	37.40	46.44	46.82
4	16.44	18.42	18.95
6	4.95	5.15	5.71
8	0.91	1.07	1.19
10	0.18	0.21	0.24

Lawson Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	5.9	6.0	6.1
Rating	Ped Standing	Ped Standing	Ped Walking

Lawson Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	12.4	12.9	12.9
Rating	Pass	Pass	Pass

LOCATION 17



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	2.31	8.57	8.57
4	0.00	0.09	0.09
6	0.00	0.00	0.00
8	0.00	0.00	0.00
10	0.00	0.00	0.00

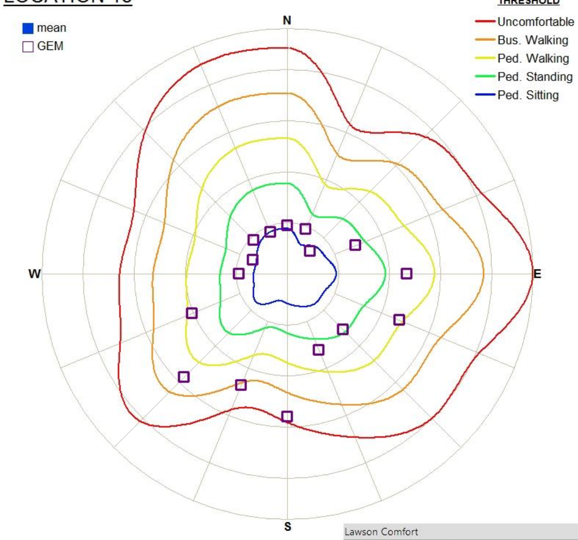
Lawson Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	1.7	2.3	2.3
Rating	Outdoor Dining	Ped Sitting	Ped Sitting

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	3.4	4.6	4.6
Rating	Pass	Pass	Pass

LOCATION 18



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	35.71	44.83	44.83
4	14.71	18.73	18.73
6	5.96	7.87	7.87
8	1.54	2.35	2.35
10	0.25	0.48	0.48

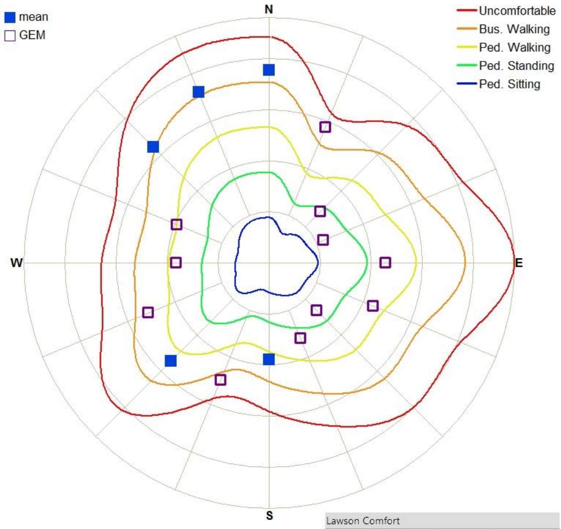
Lawson Comfort

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

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	12.6	13.5	13.5
Rating	Pass	Pass	Pass

LOCATION 19



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	71.39	76.33	77.51
4	29.39	29.18	32.71
6	8.70	9.08	10.23
8	2.60	2.31	3.05
10	0.59	0.47	0.70

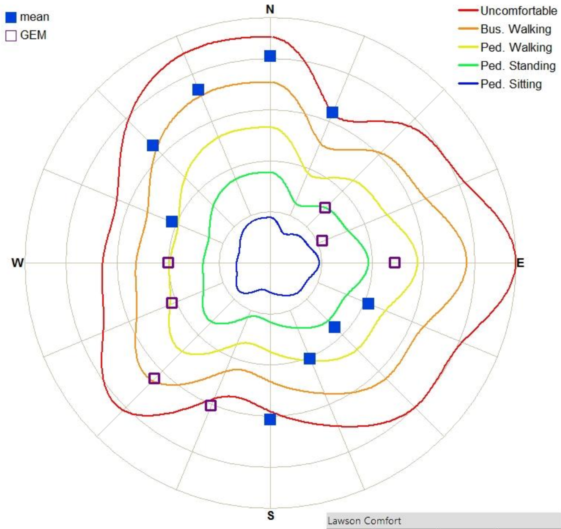
Lawson Comfort

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

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	14.9	13.4	14.9
Rating	Pass	Pass	Pass

LOCATION 20



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	77.77	78.49	81.65
4	37.28	34.39	40.89
6	17.05	14.88	18.56
8	7.09	4.91	7.67
10	2.03	1.21	2.25

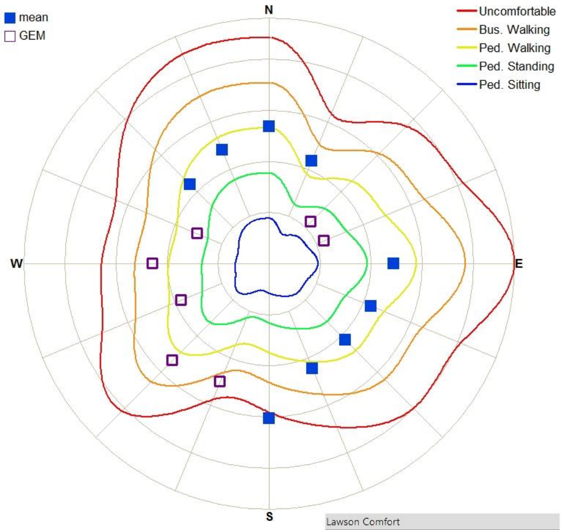
Lawson Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	8.5	7.9	8.7
Rating	Bus Walking	Ped Walking	Bus Walking

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	16.1	15.2	16.4
Rating	Able Body	Able Body	Able Body

LOCATION 21



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	70.07	67.73	73.44
4	29.41	26.88	31.99
6	11.27	9.25	12.25
8	3.54	2.45	3.82
10	0.92	0.46	0.97

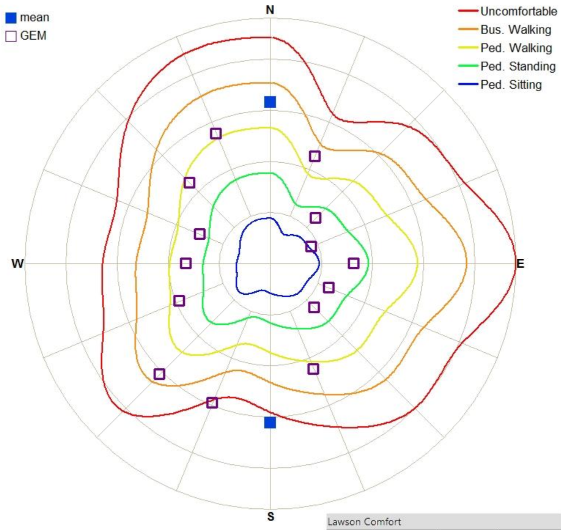
Lawson Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	7.4	6.9	7.5
Rating	Ped Walking	Ped Walking	Ped Walking

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	14.6	13.4	14.6
Rating	Pass	Pass	Pass

LOCATION 22



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	59.97	68.24	68.67
4	25.06	28.87	29.70
6	11.84	12.90	13.91
8	4.16	4.06	4.85
10	1.20	1.07	1.43

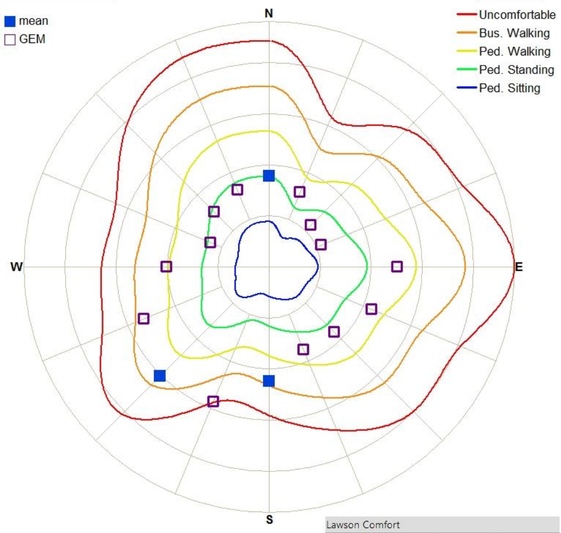
Lawson Comfort

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

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	15.0	15.0	15.4
Rating	Able Body	Pass	Able Body

LOCATION 23



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	53.04	61.50	61.75
4	18.86	23.81	24.25
6	6.14	6.68	7.17
8	1.37	1.47	1.60
10	0.26	0.32	0.34

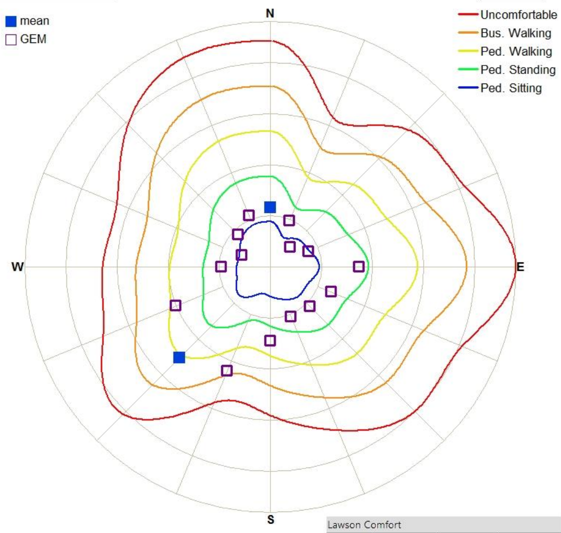
Lawson Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	6.2	6.3	6.5
Rating	Ped Walking	Ped Walking	Ped Walking

Lawson Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	13.0	13.5	13.6
Rating	Pass	Pass	Pass

LOCATION 24



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	28.92	35.65	35.76
4	5.65	7.80	7.81
6	0.84	1.39	1.39
8	0.12	0.23	0.23
10	0.01	0.04	0.04

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)	9.5	10.5	10.5
Rating	Pass	Pass	Pass