Frasers Property Australia and Dexus Funds Management Limited

Western Gateway Sub-Precinct Proposal: Block B

14-30 Lee Street, Haymarket NSW 2000

Environmental Wind Assessment

Wind

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Job number 265869-00

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Executive summary

Arup have been commissioned by Frasers Property Australia and Dexus Funds Management Limited to provide a quantitative assessment of the proposed development at Western Gateway Sub-Precinct Proposal: Block B on the pedestrian level wind conditions for comfort and safety in and around the site.

This report provides discussion on the impact of proposed buildings in the Western Gateway sub-precinct on the measured wind conditions in and around the site. The wind tunnel testing report conducted around the Western Gateway sub-precinct Block B, in the existing and two potential building configurations, is presented in Appendix 4.

Generally, the inclusion of any large buildings on the fringe of a City markedly changes the local wind environment. The first isolated building typically creates the largest change in wind conditions with the windiest locations at the building corners. Subsequent large developments alter the overall wind flow pattern making some areas calmer and others windier, particularly at the outer corners of the compound shape and between closely spaced towers. As the precinct continues to expand, Henry Deane Plaza tends to become calmer while the windier locations are moved to the perimeter of the developed area. Ideally the ‘final’ developed built-up profile, including the proposed Central Precinct Over Station Development (OSD), would have the tallest buildings towards the middle tapering in height to the fringes to the south and east.

Compared with the existing wind conditions, the inclusion of only Block B generally increases the local serviceability wind speeds across the precinct by about one criterion level assuming Blocks A and C remain as is. The pedestrian wind comfort conditions across the precinct are generally classified as suitable for pedestrian standing, which is considered suitable for this area. Development of more sedentary areas would be close to the buildings where it is significantly easier to ameliorate local wind conditions. The areas most affected are on the east boundary of Block B where there would be little pedestrian access through the affected areas until completion of the proposed OSD. Upon completion of the OSD, the wind conditions around the Western Gateway sub-precinct would be expected to improve.

Certain locations in this part of the city are currently exposed to prevailing strong wind directions and exceed the safety criterion. Depending on the design and orientation of the proposed buildings in the Western Gateway sub-precinct, the wind conditions are expected to worsen locally. The areas most affected are again to the east of the precinct, where in the current configuration there would be limited reason to access these spaces. Upon completion of the OSD, the wind conditions around the Western Gateway sub-precinct would be expected to improve.

With the inclusion of Blocks A and B, the wind conditions generally improve in the open space of Henry Deane Plaza due to the additional shielding to prevailing wind directions and the constriction of flow in the gap between Blocks A and B.

The opening of this gap from 13 m to 24 m is likely to improve the wind conditions in this area between two Blocks but slightly increase the wind conditions across the open plaza. The mitigation strategies to improve wind conditions in and around the site are discussed below.

Mitigation Strategies

Prior to any development of the OSD, for locations to the north-east of Block B, the wind directions causing strong winds are from the south. Winds from this direction impinge on the broad south-east façade of Block B, inducing downwash that is accelerated around the north-east corner. Potential mitigation strategies to improve the wind conditions in this area include:

- Restrict pedestrian access to the area until the OSD development is advanced;
- Review the built form of the tower and podium particularly in the north-east corner;
- Include a temporary roof/canopy between Blocks A and B.

These mitigation strategies would be developed through the design process and reviewed following future developments in the surrounding area, such as the OSD, which would be expected to markedly improve the wind conditions in this area.

Potential amelioration measures to improve wind conditions in the open plaza would include local landscaping to provide local shielding and a downstand façade below and/or an upstand façade over potential enclosed temporary roof between Blocks A and B.

Incorporating these mitigation measures would be expected to improve wind conditions in and around the site, including the open plaza and the transient space between Blocks A and B, and have the potential to satisfy the criteria for the intended use of space.

- **Potential future OSD developments**

Any potential future over station developments to the south of the site have the potential to provide shielding to the site and improve wind conditions in the open plaza and between Blocks A and B.

A combination of these strategies has the potential to satisfy the wind comfort and safety criteria for the precinct. However, the benefit of any changes would require confirmation through numerical or physical modelling.

- **Separation between Blocks A and B**

Increasing separation would be expected to make wind conditions between Block A and B better at the expense of slightly increasing wind conditions at the open plaza, as it allows more wind flow from the south to penetrate through the gap and across open plaza. Since the wind tunnel testing was conducted, the separation between Blocks A and B has increased from 13 m to 24 m. This increase would be expected to improve the wind conditions in between the two blocks.

- **Redesign of tower and podium**

For winds from the south and south-east, a review of the tower and podium design on the north-east corner to divert the accelerated and downwash flow over the podium level and discharge the flow over the open plaza at higher levels. The review of the tower and podium design is an option that could be further considered during the design excellence phase.

- **Temporary roof between Blocks A and B**

A roof spanning between Blocks A and B would prevent the remaining portion of downwash reaching the ground level. This could be included as a temporary measure prior to the development of the OSD. As the surrounding area is further developed, including the OSD, the wind conditions between Blocks A and B would be expected to improve depending on the massing and orientation of the future developments. Any roof structure installed could be removed at a later date once the OSD was complete and the pedestrian connection Blocks A and B became operational, if the OSD design was shown to suitably improve the wind conditions in the relevant spaces.

Under this temporary condition, the higher the roof, the better the protection for the open plaza provided that a vertical downstand would be installed below and to the east of the roof. Hence, it would be recommended to install the proposed roof as high as possible, however to avoid pressure driven flow a vertical downstand is required to the east of the roof between Blocks A and B. The smaller the gap under the downstand, the better the wind conditions. For winds from the south, wind speeds at the location of the downstand would slightly increase, but would expand and decelerate with distance from the downstand. The relative elevation difference to the east and west of the gap would help dissipating the high wind speeds and generally improve the wind conditions. If a lower-level roof is employed, it would be recommended to include an upstand façade to the north-west edge of the roof to direct flow over the plaza. Hence, the wind would expand and decelerate before reaching the open plaza.

- **Local landscaping**

Local amelioration is expected to be required for any sitting areas in the open plaza and around the development to provide local shielding. These would typically take the form of permanent or temporary vertical screens perpendicular to the façade. To improve the wind conditions in the central area of the open plaza, local landscaping would be recommended.

Contents

1 Introduction

Dexus CPA Pty Ltd (Dexus) and Frasers Property Australia (Frasers Property) (the Consortium) is seeking to build "a vibrant new business district and revitalise the face of Sydney's busiest transport interchange" (Project Vision) at 14-30 Lee Street, Haymarket, otherwise known as the Site or Block B within the Western Gateway Sub-Precinct, as illustrated in Figure 1.

Figure 1: Central Precinct (White), Western Gateway Precinct (Orange shading), Block B (Red Outline)

The Western Gateway sub-precinct is made up of three landholdings as illustrated in Figure 1:

- Block A – land predominately occupied by the YHA Hostel;
- Block B – the Dexus / Frasers Property site subject of this report;
- Block C – land on which the Adina Hotel and Henry Deane Plaza are located.

Figure 2: Western Gateway landholdings

To facilitate redevelopment of the Western Gateway sub-precinct, the existing planning controls are required to be amended. This report supports a submission to the Secretary of the Department of Planning, Industry and Environment (‘the DPIE’) which seeks to amend the height and density controls within the *Sydney Local Environmental Plan 2012* (Sydney LEP 2012).

The request to amend the planning controls follows the Minister for Planning and Public Spaces recent declaration identifying the Central Station Precinct as a State Significant Precinct (SSP). The Western Gateway, located within the Central Precinct SSP, is earmarked as a sub-precinct within the proposed SSP boundary for early consideration for rezoning.

Transport for New South Wales (TfNSW) is developing a vision for the growth and development of this precinct and is preparing a Strategic Framework to guide future detailed planning of the Central Precinct. The Strategic Framework will be placed on exhibition for public comment concurrently with the rezoning of the Western Gateway.

1.1 Project Objectives

The proposed rezoning forms part of a broader planning process being pursued by the Consortium to realise a shared vision and set of objectives for the Western Gateway and the Central Precinct more broadly. The overall Project objectives for Block B is to:

- High tech jobs – Deliver creative workspace that builds the Sydney Innovation and Technology Precinct and underpins Sydney’s enduring global competitiveness.
- Transport connectivity – Redefine the experience of over 20 million pedestrians who walk through Henry Deane Plaza every year with world

class public realm and connectivity.

- A revitalised precinct – Transform Central into an exciting place with lively retail and dining options, supporting Sydney's day and night time economy.
- Infrastructure for the future – Enable wider renewal of Central by delivering underground smart building services, waste and utility infrastructure necessary for an integrated and sustainable precinct.

Figure 3: Block B within the Western Gateway Sub-Precinct (existing)

1.2 The Project

The Consortium intends to develop up to 155,000 m^2 of commercial and retail GFA within a podium, two towers, lower and upper ground plane over a three level basement. The Project comprises:

- two commercial towers comprising 46,000 m^2 and 42,000 m^2 located above the podium with floorplates of approx. 1,850 m^2 and 2,000 m^2 GFA,
- a podium comprising 61,500 m^2 GFA,
- a retail offering of approx. 5,500 m^2 accessible from lower and upper ground levels, including food and beverage catering to station, visitors and Western Gateway commercial occupants providing an activated frontage and interface to Henry Deane Plaza. This includes an activated Lee Street frontage and lobby located at upper ground level, providing access to the commercial office podium levels and towers above,
- three levels of basement car parking to accommodate:
    - 48 service vehicle and loading dock parking and distribution area within an Integrated Distribution Facility (IDF),
    - service vehicle, loading dock and distribution area for all stakeholders within the Western Gateway,
    - provision for emergency, maintenance and service vehicle parking and distribution area for future Central Over Station Development (OSD within the IDF),
    - 121 parking spaces for Block B occupants,

    - provision for Block A and C vehicle access via the Block B,
    - bicycle parking and end of trip facilities for staff, and
    - bicycle parking spaces for customers/visitors.
- podium and tower rooftops designed for passive activation and gatherings for occupants of the Project to utilise and appreciate the views of the city and harbour,
- redeveloped public space and stairs from Block B to future Central Precinct Over Station Development (OSD) providing an east-west pedestrian connection to and from the Western Gateway Sub-Precinct, and
- integration with a redeveloped Henry Deane Plaza to accommodate the increased pedestrian movement from existing and future pedestrian connections to various modes of transport.

To prepare Block B for future development, an increase in building height and floor space controls is sought. These proposed amendments to the Sydney LEP 2012 align with State, regional and local strategic planning objectives and initiatives.

This report should be read in conjunction with the Planning Statement prepared by MG Planning, and the other appended technical reports.

1.3 Site Ownership

The Consortium’s Proposal relates to land located at 14-30 Lee Street, Haymarket. It is legally described as Lots 12, 14 and 15 in DP 1062447. Legal descriptions of each parcel within Block B are detailed below.

Title Details	Legal Description
Lot 12 in DP 1062447	The proprietor of the fee simple is Rail Corporation of New South Wales. The proprietor of the leasehold estate of the land and the buildings on the land created by lease AA651830 expiring on 30 June 2099 is Dexus CPA Pty Ltd A.C.N. 160 685 156.
Lot 14 in DP 1062247	The proprietor of the fee simple is Rail Corporation of New South Wales. The proprietor of the leasehold estate of the land and the buildings on the land created by lease AA651832 expiring on 30 November 2100 is Henry Deane Building Nominees Pty Ltd A.C.N. 081 941 951
Lot 15 in DP 1062447	The proprietor of the fee simple is Rail Corporation of New South Wales. The proprietor of the leasehold estate of the land and the buildings on the land created by lease AA651833 expiring on 31 March 2101 is Gateway Building Nominees Pty Ltd A.C.N. 081 951 822.

1.4 Site Location

Located close to Central Station, Block B comprises land fronting Lee Street, Haymarket and is bounded by Henry Deane Plaza to the north, the railway corridor to the east, the Sydney Buses layover to the south and Lee Street and Railway Square to the west. Together it constitutes an area of approximately 9,632m2 at ground level, with a dimension from north to south of approximately 103-143 metres and approximately 74-81 metres from east to west (Figure 4).

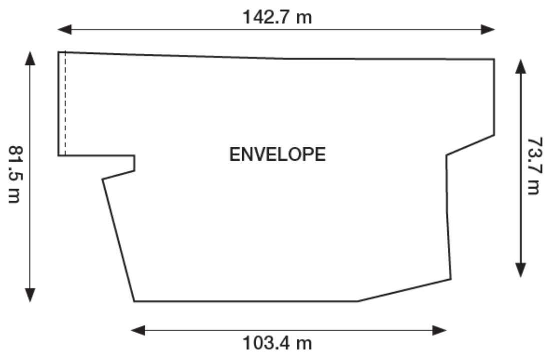


Figure 4: Block B site boundary Source: Woods Bagot & SOM architects

Henry Deane Plaza (located on the lower datum) is centrally located within the Western Gateway and primarily funnels pedestrians between Devonshire Street tunnel, accessed from the Site's eastern boundary, and Lee Street tunnel, Railway Square, and tertiary institutions to the west.

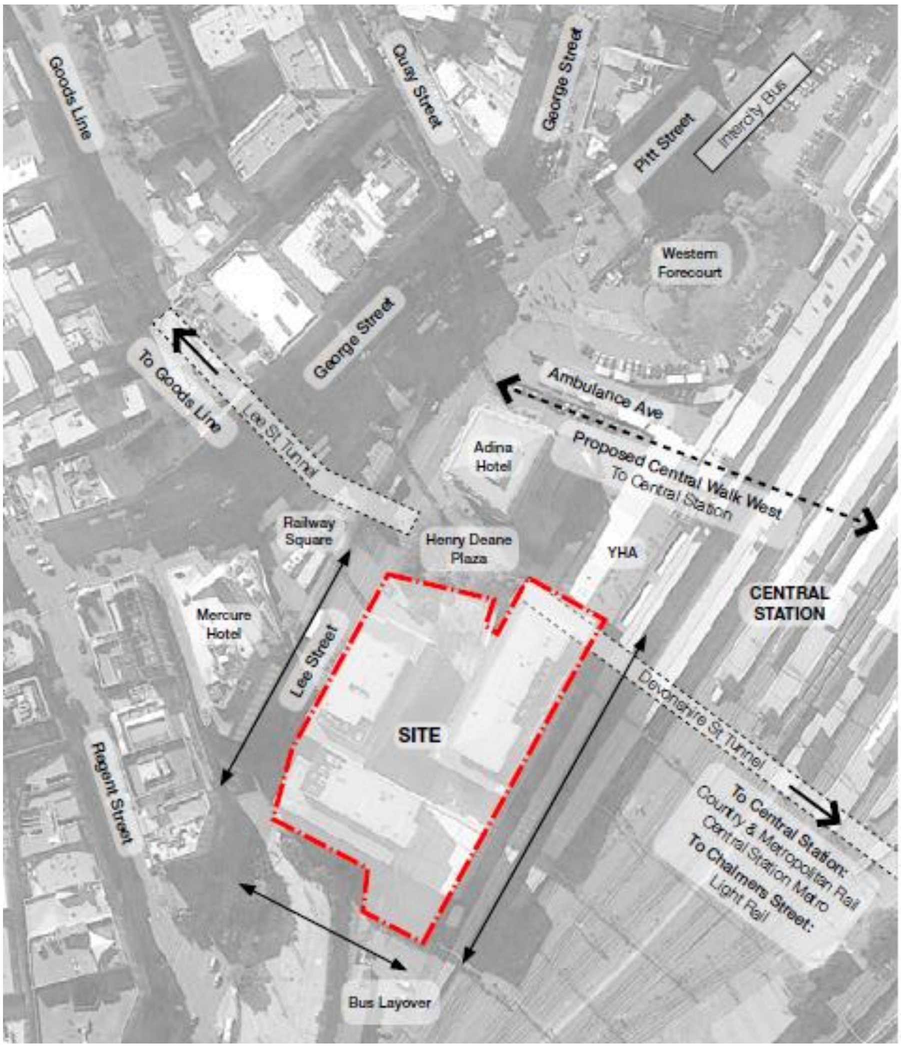


Figure 5: Block B site boundary Source: Woods Bagot & SOM architects

The upper level of Block B flanks Henry Deane Plaza to the north and south (part of Block C). The State heritage listed Adina Hotel (part of Block C) and Sydney

Railway Square Youth Hostel (YHA) (Block A) are located north of Henry Deane Plaza. South of Henry Deane Plaza is dominated by more contemporary office buildings of approximately 20 years age which are occupied by State and Commonwealth agencies including Transport for NSW, Department of Immigration and Border Protection, Department of Foreign Affairs and Trade and Corrective Services NSW.

A range of food and beverage outlets and service retail tenancies are located across both the lower and upper levels across the Western Gateway precinct.

2 Wind assessment

The Consortium engaged Arup to provide a quantitative environmental wind assessment for the proposed Western Gateway Sub-Precinct Proposal: Block B. This report discusses the relevant results of the wind tunnel testing study conducted on the development and interpretive discussion on the impact of the proposed buildings on the pedestrian level wind comfort and safety.

2.1 Modelling

Wind tunnel testing was conducted in three primary configurations, Figure 6 and Figure 7:

1. Existing condition
2. With initial design of proposed Block B
3. With initial design of proposed Blocks A and B

The construction of the physical models was based on the 3d model received from the architect. No landscaping or awnings were included in the original 3d models, which would locally slightly improve the wind conditions. Moreover, the proposed Central Precinct Over Station Development (OSD) is not modelled in the wind tunnel. Including this has the potential to improve wind conditions in the open plaza and in between Blocks A and B.

The wind-tunnel testing programme conducted by CPP was in accordance with the requirements of AWES (2019) and appropriate for the investigation. Appropriate wind speed and turbulence profiles, and test locations were used in the testing. In the existing configuration, measurements were taken at 11 locations, and at 18 locations for the other proposed configurations. Testing was conducted for 16 wind directions and integrated with the Sydney wind climate.

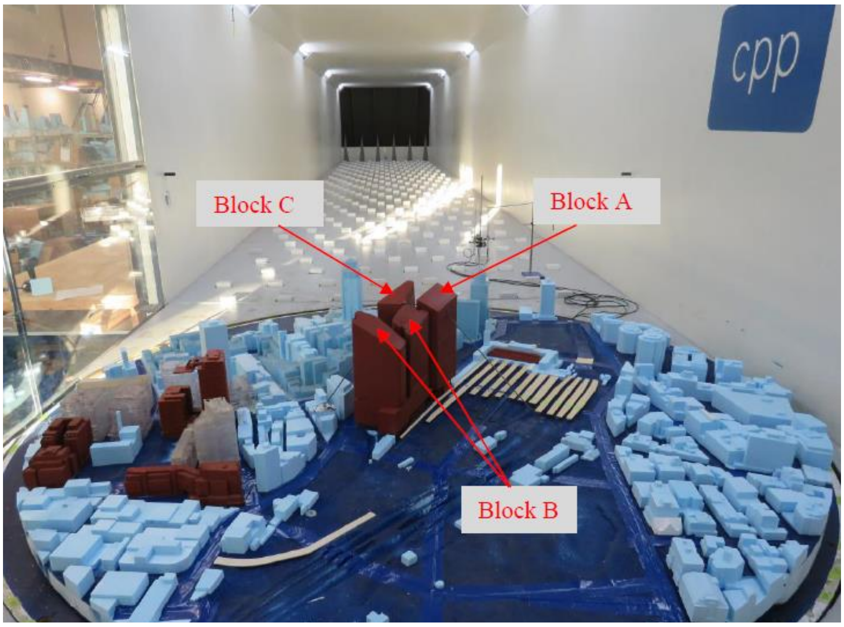
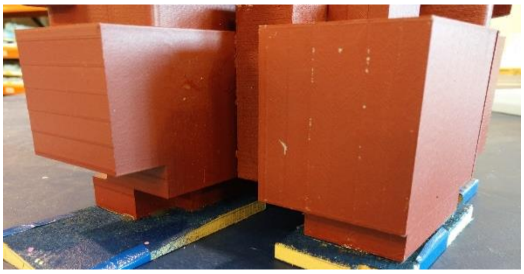
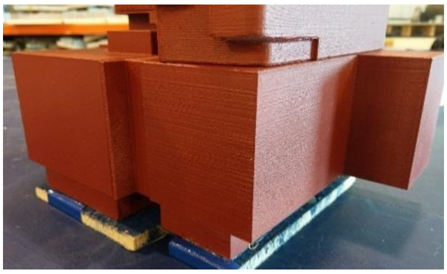


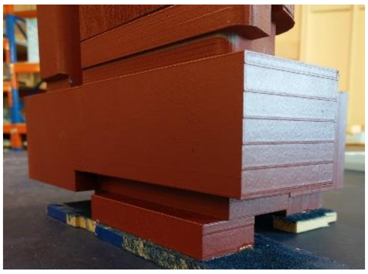
Figure 6: Photograph of the constructed model and surrounding in the wind tunnel



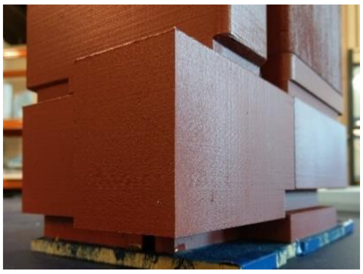
Viewed from north-west



Viewed from south-west



Viewed from north-east



Viewed from south-east

Figure 7: Photographs of lower levels of Block B

2.2 Local wind climate

Weather data recorded at Sydney Airport by the Bureau of Meteorology has been analysed for this project. The analysis is summarised in Appendix 1. Strong prevailing winds for the site are from the north-east, south, and west quadrants. This wind assessment is based on these wind directions. A general description on flow patterns around buildings is given in Appendix 2.

2.3 Specific wind controls

Wind comfort is generally measured in terms of wind speed and rate of change of wind speed, where higher wind speeds and gradients are considered less comfortable. Air speed has a large impact on thermal comfort and are generally welcome during hot summer conditions. There have been many wind comfort criteria proposed, and a general discussion is presented in Appendix 3. The criteria used in this study are based on the work of Lawson (1990) described in Table 1 and Figure 18. The Lawson criteria are in line with the draft City of Sydney DCP.

Table 1 Pedestrian comfort criteria for various activities

Comfort (max. of mean or GEM wind speed exceeded 5% of the time)	
<2 m/s	Dining
2-4 m/s	Sitting
4-6 m/s	Standing
6-8 m/s	Walking
8-10 m/s	Objective walking or cycling
>10 m/s	Uncomfortable
Safety (max. of mean or GEM wind speed exceeded 0.022% of the time)	
<15 m/s	General access
<20 m/s	Able-bodied people (less mobile or cyclists not expected)

2.4 Discussion of results

The primary findings of the study are summarised in Figure 8, which list the locations selected for investigation along with the target and measured comfort and safety classifications.

Location	Target	Existing			With Block B			With Blocks A and B		
	Comfort rating, 5% exceedance wind speed (m/s)	Comfort rating, 5% exceedance wind speed (m/s)	Meets target Y/N	Safety rating, 0.022% exceedance wind speed (m/s)	Comfort rating, 5% exceedance wind speed (m/s)	Meets target Y/N	Safety rating, 0.022% exceedance wind speed (m/s)	Comfort rating, 5% exceedance wind speed (m/s)	Meets target Y/N	Safety rating, 0.022% exceedance wind speed (m/s)
1	>6 to 8	4.2	Y	8.2	4.6	Y	9.7	4.7	Y	9.7
2	>6 to 8	7.0	Y	15.3	8.8	N	18.4	9.1	N	19.0
3	>6 to 8	n/a		n/a	5.2	Y	10.6	5.3	Y	10.9
4	>6 to 8	5.4	Y	10.9	5.0	Y	8.9	5.4	Y	9.8
5	>6 to 8	3.4	Y	6.3	4.9	Y	10.4	6.8	N	13.7
6	>6 to 8	4.5	Y	9.0	7.4	Y	13.4	7.0	Y	13.3
7	>4 to 6	3.7	Y	9.0	4.4	Y	8.1	4.9	Y	10.5
8	>6 to 8	n/a		n/a	5.2	Y	9.8	4.9	Y	9.3
9	>6 to 8	3.0	Y	5.7	4.9	Y	9.5	5.7	Y	10.9
10	>6 to 8	3.6	Y	6.4	4.2	Y	8.4	3.7	Y	7.3
11	>6 to 8	n/a		n/a	9.0	N	18.9	10.3	N	20.8
12	>6 to 8	n/a		n/a	5.4	Y	12.4	7.3	Y	14.6
13	>6 to 8	n/a		n/a	5.2	Y	10.3	8.3	N	17.4
14	>6 to 8	n/a		n/a	5.3	Y	11.6	7.3	Y	15.6
15	>6 to 8	6.5	Y	13.2	10.0	N	20.7	9.3	N	19.2
16	>6 to 8	6.0	Y	11.2	7.2	Y	14.3	6.9	Y	13.0
17	>6 to 8	6.0	Y	11.2	6.7	Y	12.7	7.0	Y	12.8
18	>6 to 8	n/a		n/a	6.0	Y	12.3	6.2	Y	13.3
19	>6 to 8	n/a		n/a	5.8	Y	12.0	5.4	Y	10.3

LEGEND

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

Figure 8: Summary of wind tunnel results

A visual summary of the wind comfort classifications in and around the site for the various configurations based on City of Sydney DCP 2012 comfort criteria are shown in Figure 9; the number on the plot shows the location, the inner and outer colours represent the comfort and safety classifications for each location. Based on the results, the majority of locations would be classified as suitable for standing and walking type activities meeting the target comfort classifications. With Block A, Locations 2, 11, and 15 are in excess of the walking criterion and would require amelioration.

Based on Lawson safety criteria, any location exceeding 15 m/s for 0.022% of the time would be classified as unsuitable for this type of public access. Locations 2, 11, 13, 14, and 15 are all in this category. These locations are discussed in the remainder of this section.

Location 2

The wind conditions at Location 2, to the south-west corner of Block B do not meet the safety criterion in all configurations tested. The wind directions causing the exceedances are from the south and north-west quadrants producing downwash as described in Appendix 2. The wind conditions at this location could be ameliorated in the final built form through a combination of measures such as:

- changing the southern tower setback to the podium edge,
- changing the orientation or including articulation of the south façade,
- inclusion of awnings around the Lee Street corner, and
- remove the colonnade along Lee Street.

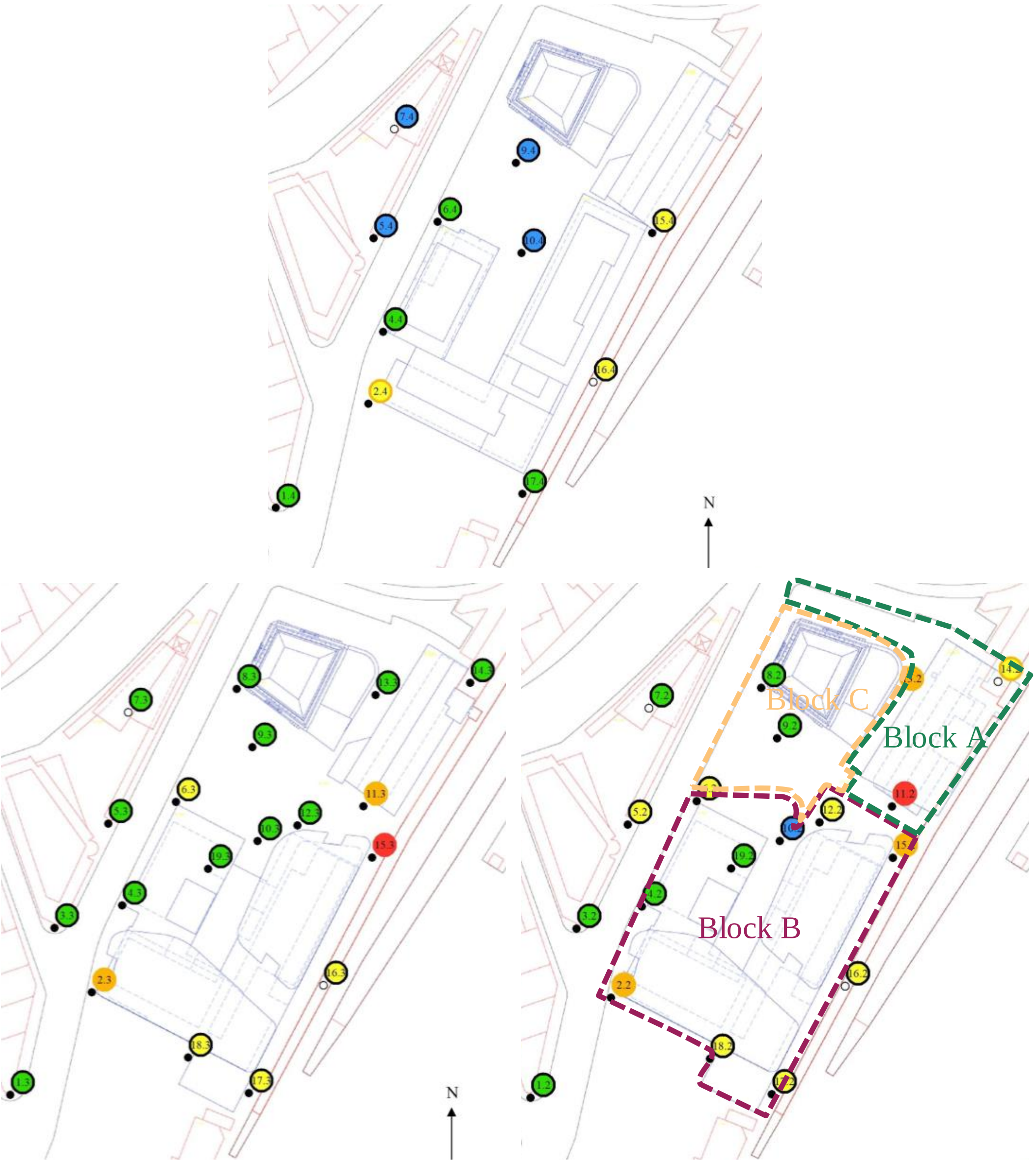


Figure 9: Wind speed measurements in configuration with ratings: existing (T), with Block B (BL), with Blocks A and B (BR)

Locations 11 and 15

With the inclusion of Blocks A and B, the wind conditions at Locations 11 and 15, to the north of Block B, are windy during winds from the south and north-west quadrants. The location of the strongest winds in this areas is a function of the massing, orientation, and separation between Blocks A and B. With any of the large towers constructed, the wind conditions in this area are in excess of the required comfort and safety criteria. Depending on the incident wind direction, the flow mechanisms causing the strong wind events are a combination of downwash flow, horizontal wind accelerating along the east façade and expanding into the laneway, and channelled flow between the towers. Prior to finalisation of the OSD, pedestrian access to this area could be limited. Development of the Bus Layover development to the immediate south of Block B, and the OSD would provide significant shielding to the Western Gateway sub-precinct thereby improving the wind conditions. Until completion of these developments, potential temporary amelioration measure could include:

- increasing the Block B tower setback from the north-east corner of the podium,
- include a tower setback along the north and east façades of Tower 2,
- decrease the length of the east façade,
- include a temporary canopy across the open plaza to the north to disrupt the downwash flow,
- remove the colonnade to the north,
- increase the separation between Blocks A and B to more than the modelled 13 m (although this would be expected to increase the wind speed across Henry Deane Plaza), and
- restrict pedestrian access to the area between Blocks A and B.

Locations 13 and 14

Locations to 13 and 14 to the north of Block A are primarily impacted by the design of Block A. With only Block B, these locations are classified as suitable for pedestrian standing and meet the target classifications for the area. The design of Block A would be the major factor in improving the wind conditions in these areas, although the amelioration measures discussed for Locations 11 and 15 would still be beneficial to the wind environment.

3 References

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Appendix 1: Wind climate

The wind frequency and direction information measured by the Bureau of Meteorology anemometer at a standard height of 10 m at Sydney Airport from 1995 to 2017 have been used in this analysis, Figure 10. The arms of the wind rose point in the direction from where the wind is coming from. The anemometer is located about 8 km to the south of the site. The directional wind speeds measured here are considered representative of the wind conditions at the site.

It is evident from Figure 10 that strong prevailing winds are organised into three main groups which centre at about the north-east, south, and west quadrants.

Strong summer winds occur mainly from the south and north-east quadrants. Winds from the south are associated with large synoptic frontal systems and generally provide the strongest gusts during summer. Moderate intensity winds from the north-east tend to bring cooling relief on hot summer afternoons typically lasting from noon to dusk. These are small-scales temperature driven effects; the larger the temperature differential between land and sea, the stronger the wind.

Winter and early spring strong winds typically occur from the south-west, and west quadrants. West quadrant winds provide the strongest winds affecting the area throughout the year and tend to be associated with large scale synoptic events that can be hot or cold depending on inland conditions.

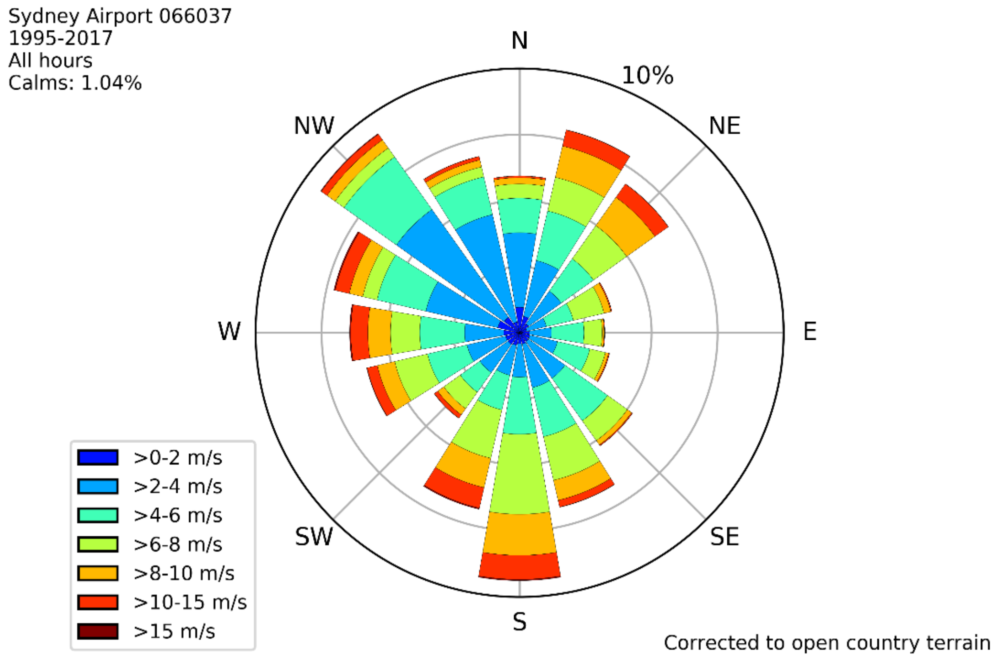

Figure 10: Wind rose showing probability of time of wind direction and speed

Appendix 2: Wind flow mechanisms

An urban environment generates a complex wind flow pattern around closely spaced structures, hence it is exceptionally difficult to generalise the flow mechanisms and impact of specific buildings as the flow is generated by the entire surrounds. However, it is best to start with an understanding of the basic flow mechanisms around an isolated structure.

Isolated building

When the wind hits an isolated building, the wind is decelerated on the windward face generating an area of high pressure, Figure 11, with the highest pressure at the stagnation point at about two thirds of the height of the building. The higher pressure bubble extends a distance from the building face of about half the building height or width, whichever is lower. The flow is then accelerated down and around the windward corners to areas of lower pressure, Figure 11. This flow mechanism is called **downwash** and causes the windiest conditions at ground level on the windward corners and along the sides of the building.

Rounding the building corners or chamfering the edges reduces downwash by encouraging the flow to go around the building at higher levels. However, concave curving of the windward face can increase the amount of downwash. Depending on the orientation and isolation of the building, uncomfortable downwash can be experienced on buildings of greater than about 6 storeys.

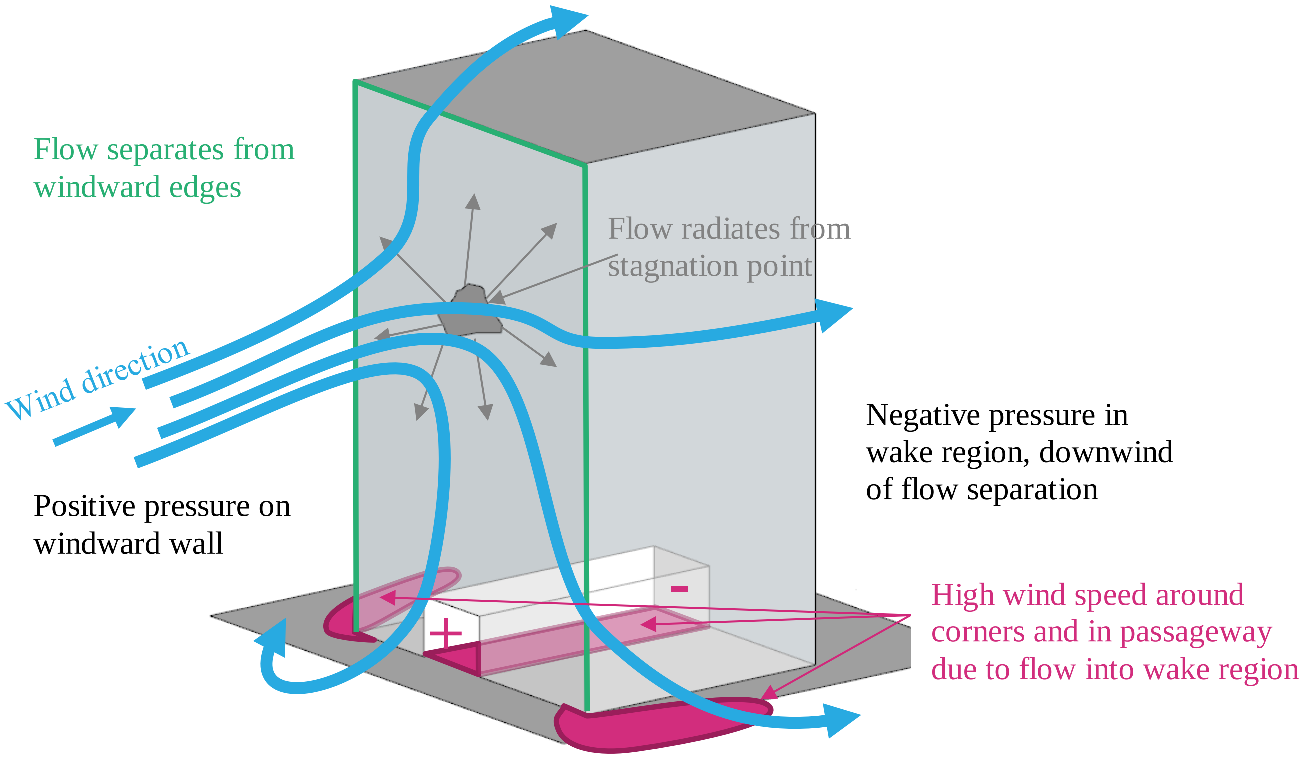

Figure 11: Schematic wind flow around tall isolated building

Techniques to mitigate the effects of downwash winds at ground level include the provision of horizontal elements, the most effective being a podium to divert the downward flow away from pavements and building entrances, but this will generate windy conditions on the podium roof, Figure 11. Generally, the lower the podium roof and deeper the setback from the podium edge to the tower improves the ground level wind conditions. The provision of an 8 m setback on an isolated building is generally sufficient to improve ground level conditions, but is highly dependent on the building isolation, orientation to prevailing wind directions, shape and width of the building, and any plan form changes at higher level.

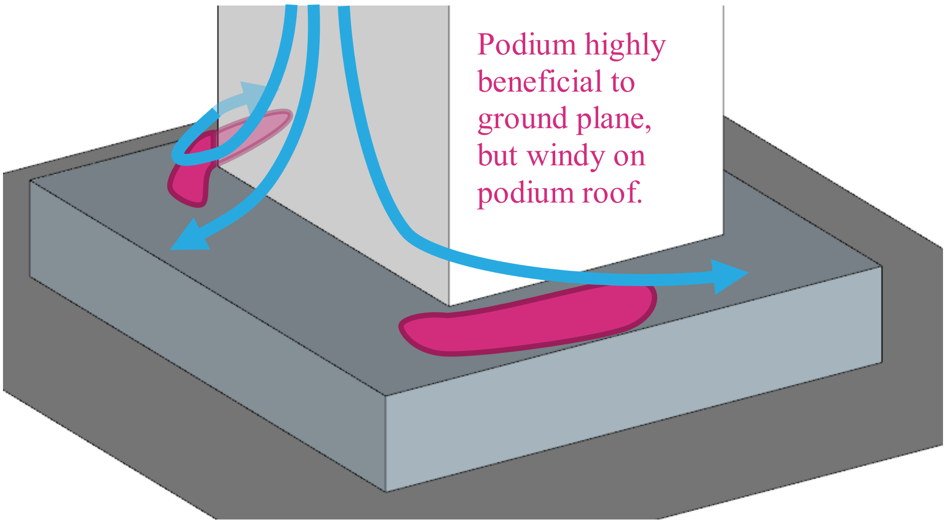

Figure 12: Schematic flow pattern around building with podium

Awnings along street frontages perform a similar function as a podium, and generally the larger the horizontal projection from the façade, the more effective it will be in diverting downwash flow, Figure 13. Awnings become less effective if they are not continuous along the entire façade, or on wide buildings as the positive pressure bubble extends beyond the awning resulting in horizontal flow under the awning.

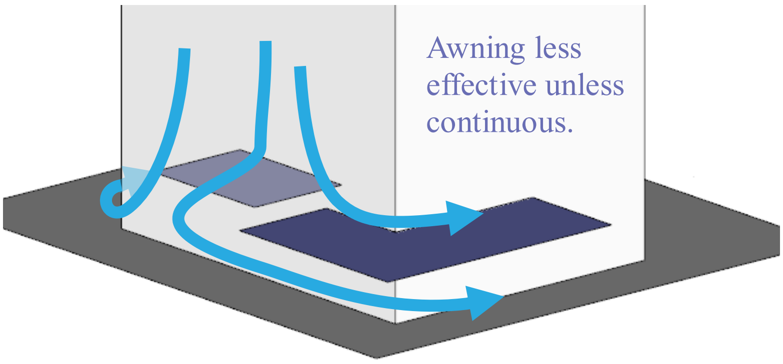

Figure 13: Schematic flow pattern around building with awning

It should be noted that colonnades at the base of a building with no podium generally create augmented windy conditions at the corners due to an increase in the pressure differential, Figure 14. Similarly, open through-site links through a building cause wind issues as the environment tries to equilibrate the pressure generated at the entrances to the link, Figure 11. If the link is blocked, wind conditions will be calm unless there is a flow path through the building, Figure 15. This area is in a region of high pressure and therefore the is the potential for internal flow issues. A ground level recessed corner has a similar effect as an undercroft, resulting in windier conditions, Figure 15.

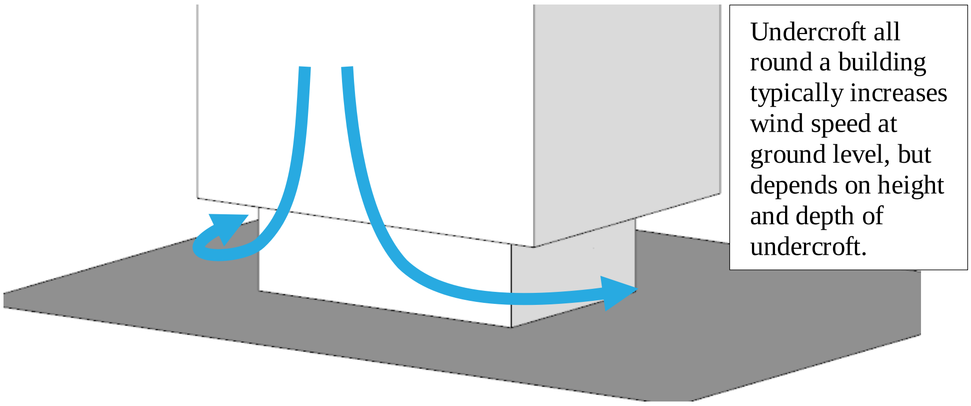

Figure 14: Schematic of flow patterns around isolated building with undercroft

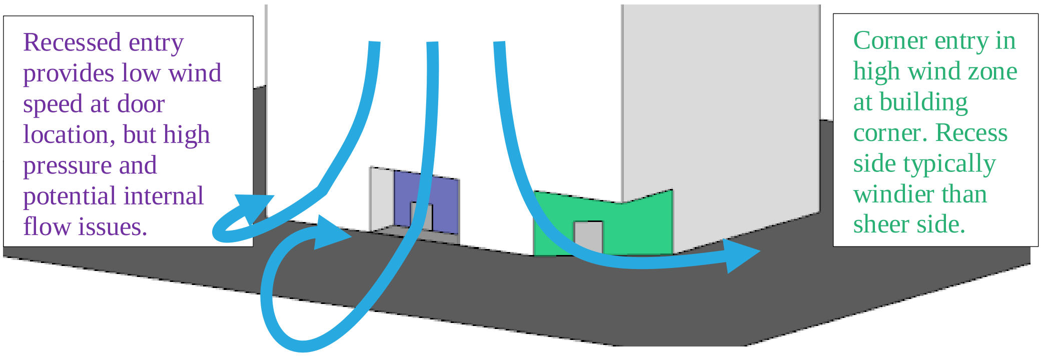

Figure 15: Schematic of flow patterns around isolated building with ground articulation

Multiple buildings

When a building is located in a city environment, depending on upwind buildings, the interference effects may be positive or negative, Figure 16. If the building is taller, more of the wind impacting on the exposed section of the building is likely to be drawn to ground level by the increase in height of the stagnation point, and the additional negative pressure induced at the base. If the upwind buildings are of similar height then the pressure around the building will be more uniform hence downwash is typically reduced with the flow passing over the buildings.

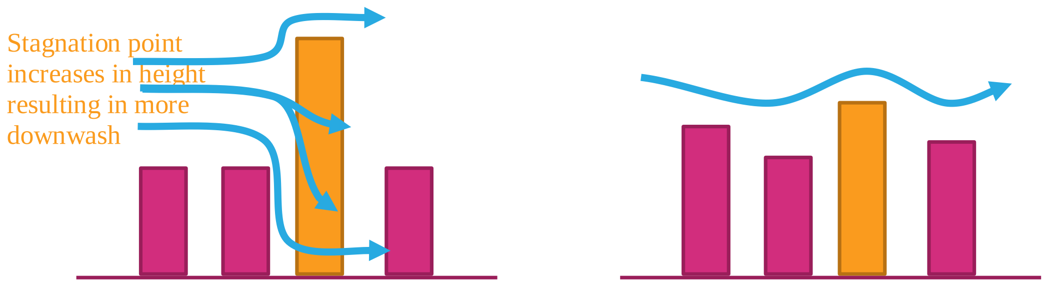

Figure 16: Schematic of flow pattern interference from surrounding buildings

The above discussion becomes more complex when three-dimensional effects are considered, both with orientation and staggering of buildings, and incident wind direction, Figure 17.

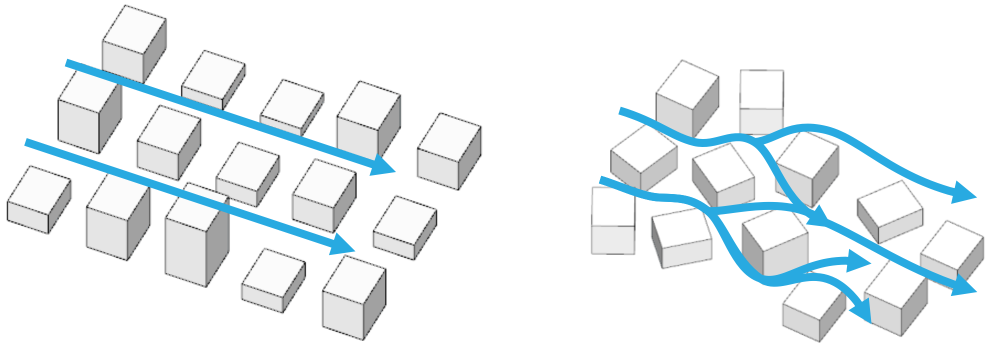

Figure 17: Schematic of flow patterns through a grid and random street layout

Channelling occurs when the wind is accelerated between two buildings, or along straight streets with buildings on either side, Figure 17(L), particularly on the edge of built-up areas where the approaching flow is diverted around the city massing and channelled along the fringe by a relatively continuous wall of building facades. This is generally the primary mechanism driving the wind conditions for this perimeter of a built-up area, particularly on corners, which are exposed to multiple wind directions. The perimeter edge zone in a built-up area is typically about two blocks deep. Downwash is more important flow mechanism for the edge zone of a built-up area with buildings of similar height.

As the city expands, the central section of the city typically becomes calmer, particularly if the grid pattern of the streets is discontinued, Figure 17(R). When buildings are located on the corner of a central city block, the geometry becomes slightly more important with respect to the local wind environment.

Appendix 3: Wind speed criteria

Primary controls that are used in the assessment of how wind affects pedestrians are the wind speed, and rate of change of wind speed. A description of the effect of a specific wind speed on pedestrians is provided in Table 2. It should be noted that the turbulence, or rate of change of wind speed, will affect human response to wind and the descriptions are more associated with response to mean wind speed.

Table 2. Summary of wind effects on pedestrians

Description	**Speed (m/s)**	**Effects**
Calm, light air	0–2	Human perception to wind speed at about 0.2 m/s. Napkins blown away and newspapers flutter at about 1 m/s.
Light breeze	2–3	Wind felt on face. Light clothing disturbed. Cappuccino froth blown off at about 2.5 m/s.
Gentle breeze	3–5	Wind extends light flag. Hair is disturbed. Clothing flaps.
Moderate breeze	5–8	Raises dust, dry soil. Hair disarranged. Sand on beach saltates at about 5 m/s. Full paper coffee cup blown over at about 5.5 m/s.
Fresh breeze	8–11	Force felt on body. Limit of agreeable wind on land. Umbrellas used with difficulty. Wind sock fully extended at about 8 m/s.
Strong breeze	11–14	Hair blown straight. Difficult to walk steadily. Wind noise on ears unpleasant. Windborne snow above head height (blizzard).
Near gale	14–17	Inconvenience felt when walking.
Gale	17–21	Generally impedes progress. Difficulty with balance in gusts.
Strong gale	21–24	People blown over by gusts.

Local wind effects can be assessed with respect to a number of environmental wind speed criteria established by various researchers. These have all generally been developed around a 3 s gust, or 1 hour mean wind speed. During strong events, a pedestrian would react to a significantly shorter duration gust than a 3 s, and historic weather data is normally presented as a 10 minute mean.

Despite the apparent differences in numerical values and assumptions made in their development, it has been found that when these are compared on a probabilistic basis, there is some agreement between the various criteria. However, a number of studies have shown that over a wider range of flow conditions, such as smooth flow across water bodies, to turbulent flow in city centres, there is less general agreement among. The downside of these criteria is that they have seldom been benchmarked, or confirmed through long-term measurements in the field, particularly for comfort conditions. The wind criteria were all developed in temperate climates and are unfortunately not the only environmental factor that affects pedestrian comfort.

For assessing the effects of wind on pedestrians, neither the random peak gust wind speed (3 s or otherwise), nor the mean wind speed in isolation are adequate. The gust wind speed gives a measure of the extreme nature of the wind, but the mean wind speed indicates the longer duration impact on pedestrians. The extreme gust wind speed is considered to be suitable for safety considerations, but not necessarily for serviceability comfort issues such as outdoor dining. This is because the instantaneous gust velocity does not always correlate well with mean wind speed, and is not necessarily representative of the parent distribution. Hence, the perceived 'windiness' of a location can either be dictated by strong steady flows, or gusty turbulent flow with a smaller mean wind speed.

To measure the effect of turbulent wind conditions on pedestrians, a statistical procedure is required to combine the effects of both mean and gust. This has been conducted by various researchers to develop an equivalent mean wind speed to represent the perceived effect of a gust event. This is called the 'gust equivalent mean' or 'effective wind speed' and the relationship between the mean and 3 s gust wind speed is defined within the criteria, but two typical conversions are:

$$U_{GEM} = \frac{(U_{mean} + 3 \cdot \sigma_u)}{1.85} \text{ and } U_{GEM} = \frac{1.3 \cdot (U_{mean} + 2 \cdot \sigma_u)}{1.85}$$

It is evident that a standard description of the relationship between the mean and impact of the gust would vary considerably depending on the approach turbulence, and use of the space.

A comparison between the mean and 3 s gust wind speed criteria from a probabilistic basis are presented in Figure 18 and Figure 20. The grey lines are typical results from modelling and show how the various criteria would classify a single location. City of Auckland has control mechanisms for accessing usability of spaces from a wind perspective as illustrated in Figure 18 with definitions of the intended use of the space categories defined in Figure 19.

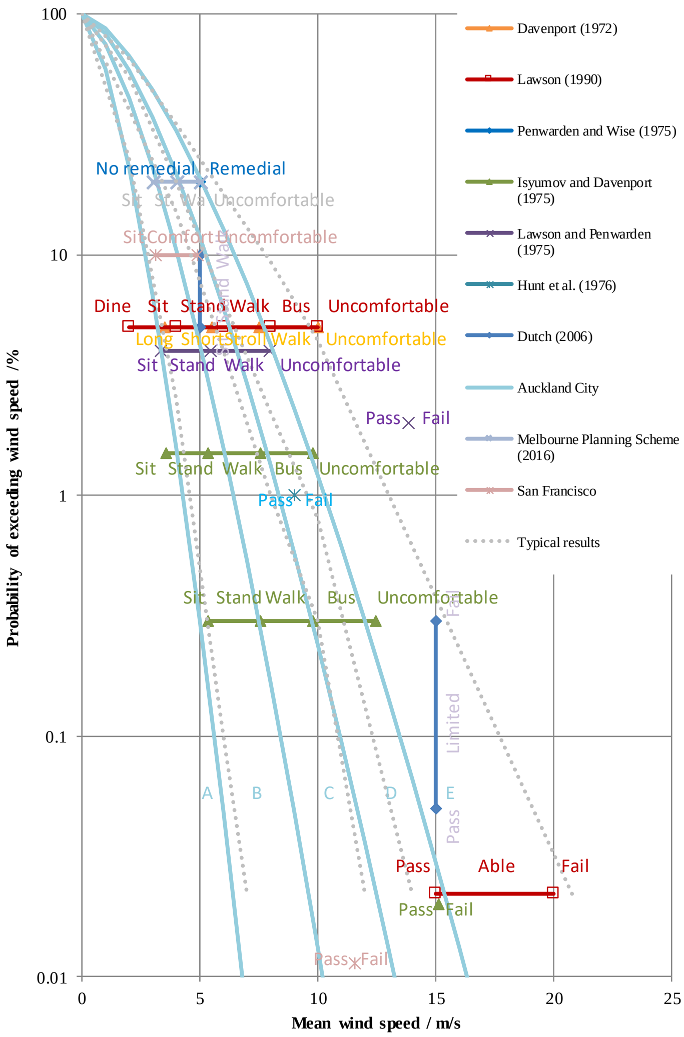

Figure 18: Probabilistic comparison between wind criteria based on mean wind speed

Category A	Areas of pedestrian use or adjacent dwellings containing significant formal elements and features intended to encourage longer term recreational or relaxation use i.e. public open space and adjacent outdoor living space
Category B	Areas of pedestrian use or adjacent dwellings containing minor elements and features intended to encourage short term recreation or relaxation, including adjacent private residential properties
Category C	Areas of formed footpath or open space pedestrian linkages, used primarily for pedestrian transit and devoid of significant or repeated recreational or relaxational features, such as footpaths not covered in categories A or B above
Category D	Areas of road, carriage way, or vehicular routes, used primarily for vehicular transit and open storage, such as roads generally where devoid of any features or form which would include the spaces in categories A - C above.
Category E	Category E represents conditions which are dangerous to the elderly and infants and of considerable cumulative discomfort to others, including residents in adjacent sites. Category E

Figure 19: Auckland Utility Plan (2016) wind categories

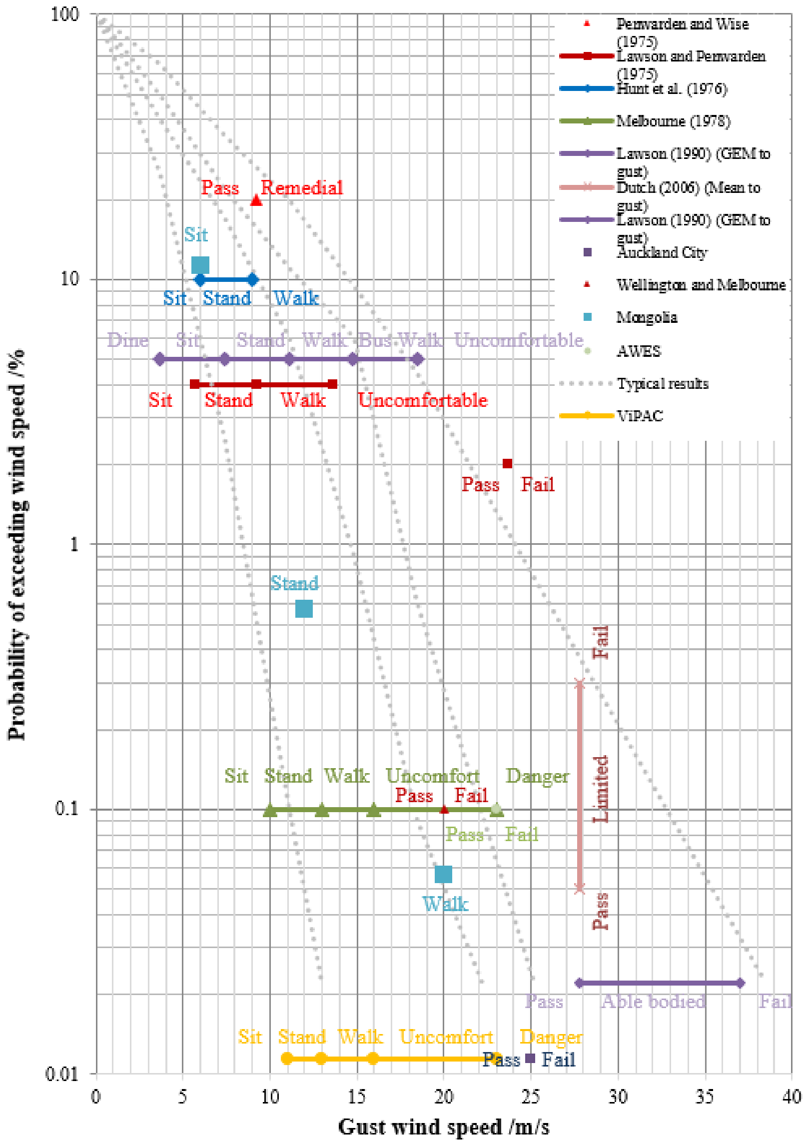

Figure 20: Probabilistic comparison between wind criteria based on 3 s gust wind speed

Appendix 4: CPP Wind tunnel test report

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CERMAK
PETERKA
PETERSEN

WIND ENGINEERING AND AIR QUALITY CONSULTANTS

Final Report

Pedestrian Wind Tunnel Tests for:
Western Gateway Sub-Precinct: Block B
14-30 Lee Street, Haymarket
Sydney

Prepared for:
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September 2019

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EXECUTIVE SUMMARY

A wind tunnel study of the proposed Western Gateway Sub-Precinct: Block B development to be located in Sydney was conducted to assess the pedestrian wind environment in and around the development site. 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 an Suburban Approach as defined in Standards Australia (2011).

Measurements of winds likely to be experienced by pedestrians were made with a hot-film anemometer at 19 locations for 16 wind directions each. These points were tested around the development in the proposed configuration, focusing on access routes, entrances, and outdoor seating areas. Measurements were taken in an additional surrounds configuration, at the same locations, to include the proposed Block A tower to the immediate north of the development site. A subset of 11 locations were tested in the existing configuration for comparison. The measurements were combined with site specific wind statistics to produce results of wind speed versus the percentage of time that wind speed is exceeded for each location.

The wind environment around the development was found to be generally suitable for pedestrian walking and standing style activities from a comfort perspective with reference to the Lawson criteria in the two proposed configurations. In both proposed configurations three to four locations were found to exceed the pedestrian walking criterion, one of which was rated as uncomfortable under the Lawson comfort criteria in one of the proposed configurations. Up to five locations failed the Lawson distress criteria in the proposed configurations. It is recommended to add wind mitigation measures to reduce the wind speed particularly near building corners and through site links. The addition of tower setbacks at podium level and awnings over the pedestrian areas can be effective measures to reduce the amount of downwash flow affecting pedestrians at ground level.

DOCUMENT VERIFICATION

Date	Revision	Prepared by	Checked by	Approved by
09/08/19	Initial release	JP	AVD	AVD
26/08/19	Minor revision	JP	JP	JP
11/09/19	Final Report	JP	AVD	AVD

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LIST OF SYMBOLS

D	Characteristic dimension (building height, width, etc.), m
n	Mean velocity profile power law exponent
T_u	Turbulence intensity, U_{rms}/U
U	Local mean velocity, m/s
U_{ref}	Reference mean velocity at reference height z_{ref}, m/s
U_{pk}	Peak wind speed in pedestrian studies, m/s
U_{rms}	Root-mean-square of fluctuating velocity, m/s
z	Height above surface, m
ν	Kinematic viscosity of approach flow, m²/s
$\sigma(\ )$	Standard deviation of $(\ ), = (\ )'_{\mathrm{rms}}$
ρ	Density of approach flow, kg/m³
$(\ )_{\mathrm{max}}$	Maximum value during data record
$(\ )_{\mathrm{min}}$	Minimum value during data record
$(\ )_{\mathrm{mean}}$	Mean value during data record
$(\ )_{\mathrm{rms}}$	Root mean square about the mean

1 INTRODUCTION

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

Techniques have been developed which permit boundary layer wind tunnel modelling of buildings to determine wind velocities in pedestrian areas. This report includes wind tunnel test procedures, test results, and discussion of acquired test results. Table 1 summarises the model configurations, test methods, and data acquisition parameters used. All the data collection was performed in accordance with Australasian Wind Engineering Society (2001), and American Society of Civil Engineers (1999, 2010). While analytical methods such as computational fluid dynamics (CFD) have some utility in the field of pedestrian wind comfort, they are not yet capable of reliably and accurately predicting gust wind speeds for assessment of wind conditions from a safety perspective.

Table 1: Parameters and configurations for data acquisition.

General Information	
Model scale	1:400
Surrounding model radius (full-scale)	570 m
Reference height (full-scale)	200 m AGL
Approach Terrain Category	Suburban Approach (Terrain Category 3)
Testing Configurations	
Configuration 1 (test locations labelled X.1)	Proposed Western Gateway Sub-Precinct Blocks A & B with existing and approved surrounding buildings, as shown in Figure 10. Pedestrian winds measured at 19 locations for 16 wind directions at 22.5° increments from 0° (north).
Configuration 2 (test locations labelled X.2)	Proposed Western Gateway Sub-Precinct Block B with existing and approved surrounding buildings, as shown in Figure 11. Pedestrian winds measured at 19 locations for 16 wind directions at 22.5° increments from 0° (north).
Configuration 3 (test locations labelled X.3)	Existing site with existing and approved surrounding buildings, as shown in Figure 12. Pedestrian winds measured at 10 locations for 16 wind directions at 22.5° increments from 0° (north).

2 THE WIND TUNNEL TEST

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

The wind tunnel test was performed in the boundary layer wind tunnel shown in Figure 1. The wind tunnel test section is 3.0 m wide, by 2.4 m high with a porous slatted roof for passive blockage correction. This wind tunnel has a 21 m long test section, the floor of which is covered with roughness elements, preceded by vorticity generating fence and spires. The spires, barrier, and roughness elements were designed to provide a modelled atmospheric boundary layer approximately 1.2 m thick with a mean velocity and turbulence intensity profile similar to that expected to occur in the region approaching the modelled area. The approach wind characteristics used for the model test are shown in Figure 2 and are explained more fully in Section 4.1.1.

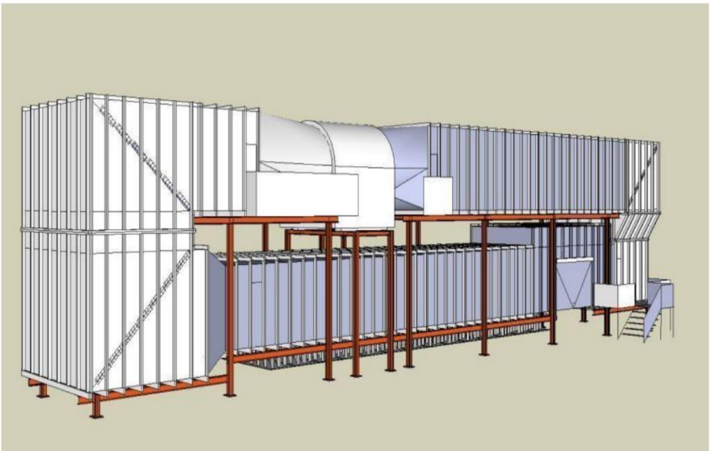

Figure 1: Schematic of the closed-circuit wind tunnel.

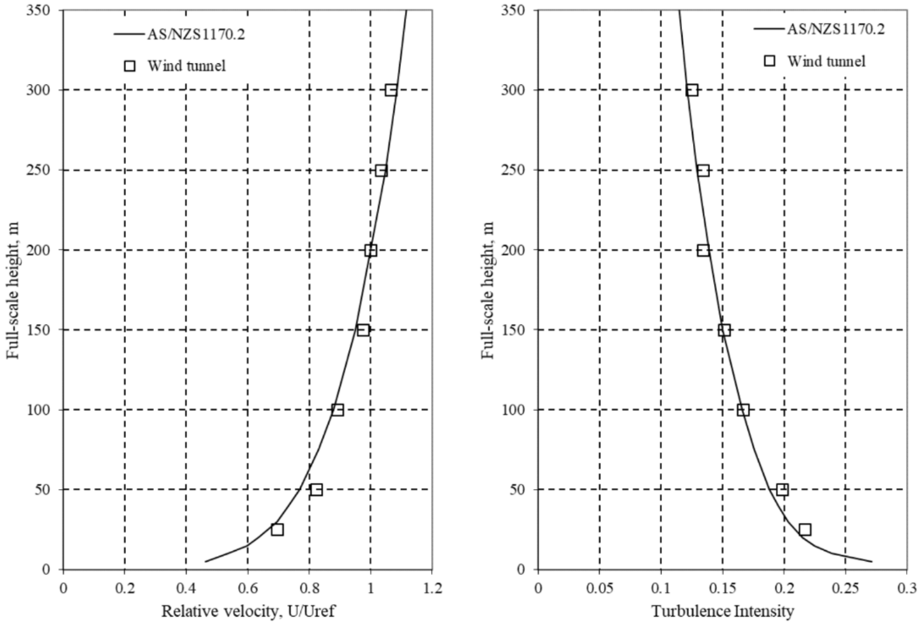

Figure 2: Mean velocity and turbulence profiles (Terrain Category 3) approaching the model.

A model of the proposed development and surrounds to a radius of 570 m was constructed at a scale of 1:400, which was consistent with the modelled atmospheric flow, permitted a reasonable test model size with an adequate portion of the adjoining environment to be included in a proximity model, Figure 3, and was within wind tunnel blockage limitations. Significant variations in the building surface were formed into the model. The models were mounted on the turntable located near the downstream end of the wind tunnel test section, Figure 4. The turntable permitted rotation of the modelled area for examination of velocities from any approach wind direction. Additional photos of the test models are included in Appendix 1.

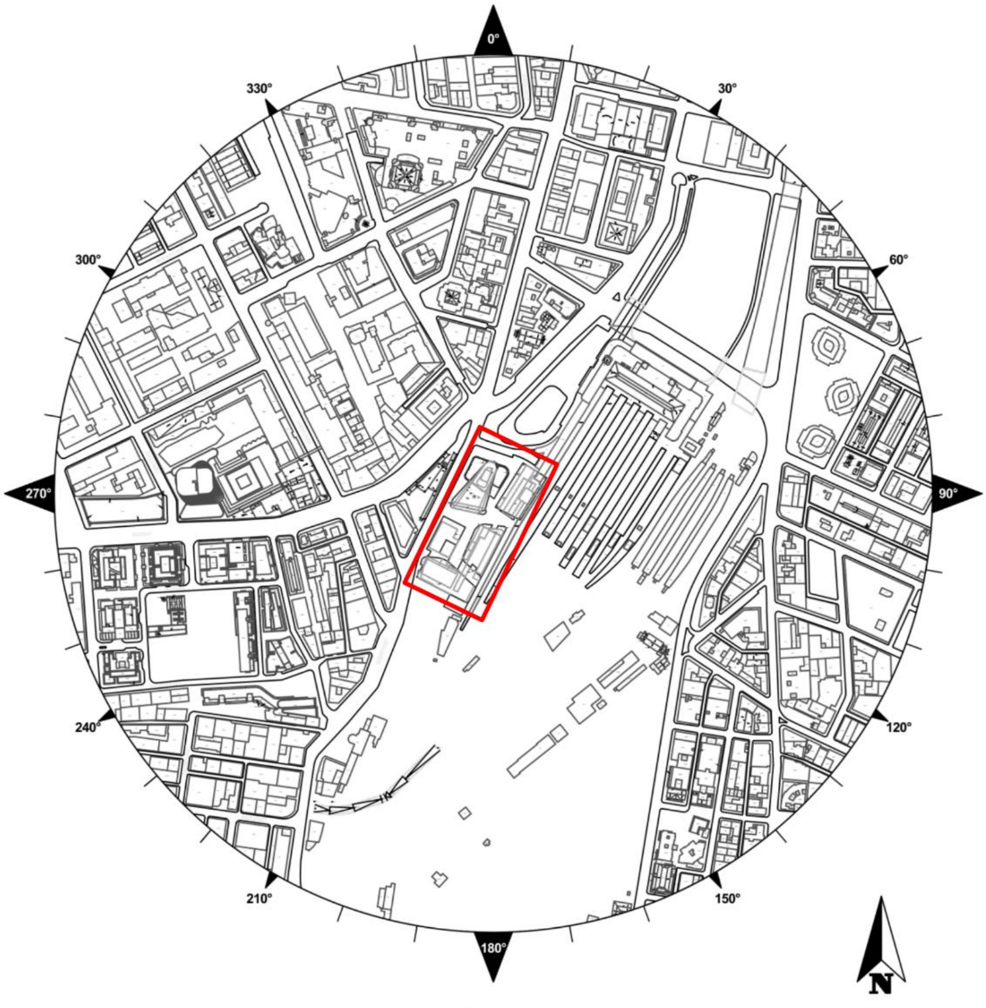

Figure 3: Project location and turntable layout with proposed Western Gateway Sub-Precinct highlighted.

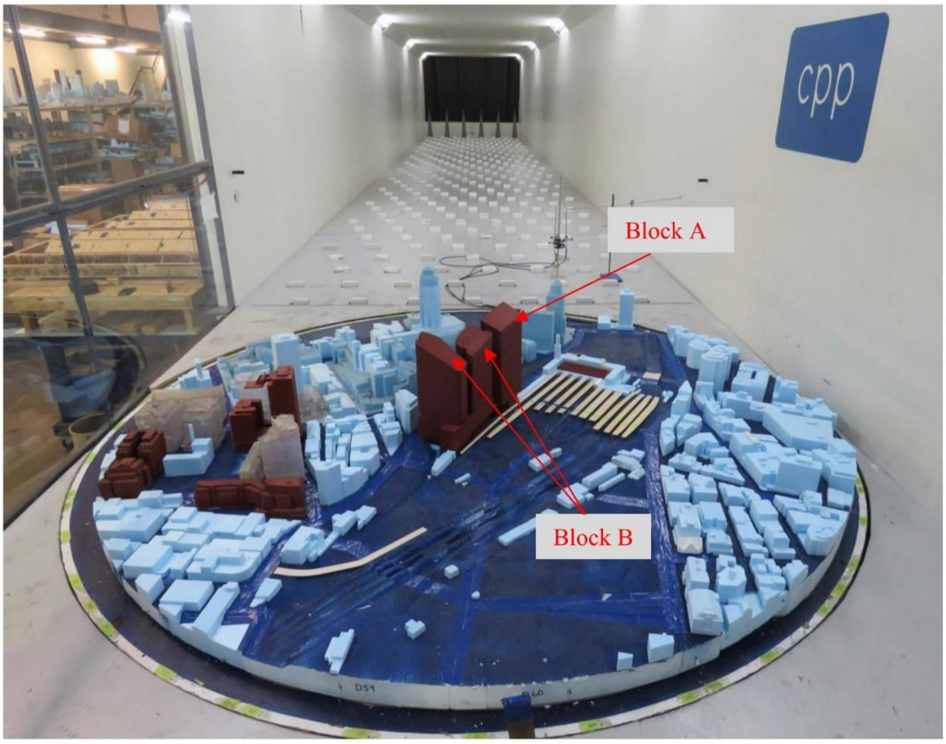

Figure 4: Proposed Western Gateway Sub-Precinct model in the wind tunnel viewed from the south.

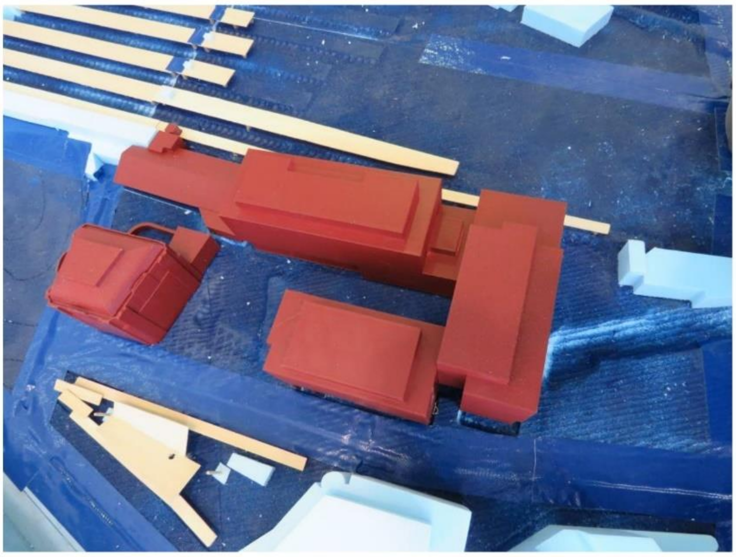

Figure 5: Close up of the Western Gateway Sub-Precinct model in the wind tunnel viewed from the west (Configuration 3, existing).

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 5% of the time, allowing planners to judge the usability of locations for various intended purposes ranging from "Business Walking" to "Pedestrian sitting". The level and severity of these comfort categories can vary based on individual preference, so calibration to the local wind environment is recommended when evaluating the Lawson ratings. The criteria also include a distress rating, for safety assessment, which is based on occasional (once or twice per year) wind speeds[1]. In both cases, the wind speed used is the larger of a mean or gust equivalent-mean (GEM) wind speed. The GEM is defined as the peak gust wind speed divided by 1.85; this is intended to account for locations where the gustiness is the dominant characteristic of the wind. Assessment using the Lawson criteria provides a similar classification as using once per annum gust criteria, but also provides significantly more information regarding the serviceability wind climate.

Table 2: Summary of Lawson criteria.

Comfort (maximum of mean or gust equivalent mean (GEM[†]) wind speed exceeded 5% of the time)	
< 4 m/s	Pedestrian Sitting (considered to be of long duration)
4 - 6 m/s	Pedestrian Standing (or sitting for a short time or exposure)
6 - 8 m/s	Pedestrian Walking
8 - 10 m/s	Business Walking (objective walking from A to B or for cycling)
> 10 m/s	Uncomfortable[1]
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.

[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.

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 proposed development the parts of Lee Street, Broadway, and Regent Street closest to Railway Square are classified as active frontages. The draft amendments of the DCP require a wind speed of 8 m/s not to be exceeded for more than 5% of the time during daylight hours, i.e. between 6 am and 10 pm, aligning with the pedestrian walking criterion by Lawson. There are few locations in Sydney that would meet the current DCP criteria without shielding to improve the wind conditions. From discussions with Council the current DCP 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, while the 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. 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. The Lawson comfort criteria align with the draft amendments of the City of Sydney DCP.

4 DATA ACQUISITION AND RESULTS

4.1 Velocities

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

4.1.1 Velocity Profiles

Mean velocity and turbulence intensity profiles for the boundary layer flow approaching the model are shown in Figure 2. Turbulence intensities are related to the local mean wind speed. These profiles have the form as defined in Standards Australia (2011) and are appropriate for the approach conditions.

4.1.2 Pedestrian Winds

Block B is located at the southern end of the Sydney CBD, in Haymarket at 14-30 Lee Street within the Western Gateway Sub-Precinct directly to the west of Sydney Central Station, Figure 3, and is mostly surrounded by low to medium-rise buildings to the south and east, with mostly mid-rise buildings to the west, and the high-rise buildings of the CBD to the north of the site.

For this report, wind speed measurements were recorded at 19 locations, as described in Table 1, to evaluate pedestrian wind comfort and safety in and around the project site shown in Figure 7 to Figure 9. Velocity measurements were made at the model scale equivalent of 1.5 to 2.1 m above the surface for 16 wind directions at 22.5° intervals. Locations were chosen to determine the degree of pedestrian wind comfort and safety at building corners where relatively severe conditions are frequently found, near building entrances and passageways, and at upper level outdoor locations.

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

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

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

To enable a quantitative assessment of the wind environment in the region, the wind tunnel data were combined with wind frequency and direction information measured by the Bureau of Meteorology at a standard height of 10 m at Sydney Airport from 1995 to 2017, Figure 6.

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

The criteria of Lawson consider the integration of the velocity measurements with local wind climate statistical data summarised in Figure 6 to rate each location. From the cumulative wind speed distributions for each location, the percentage of time each of the Lawson comfort rating wind speeds are exceeded are presented in tabular form under the polar plots in Appendix 2. In addition to the rating wind speeds, the percentage of time that 2 m/s is exceeded is also reported. This has been provided as it has been found that the limiting wind speed for long-term stationary activities such as fine outdoor dining should be about 2 to 2.5 m/s rather than 4 m/s.

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

The tables in Appendix 2 additionally provide the wind speed exceeded 5% and 0.022% of the time for direct comparison with the Lawson comfort and distress criteria, and the associated Lawson ratings for both mean and GEM wind speeds. A colour coded summary assessment of pedestrian wind comfort and safety with respect to the Lawson criteria is presented in Figure 7 to Figure 9 for each test location. The implications of the results are discussed in Section 5.

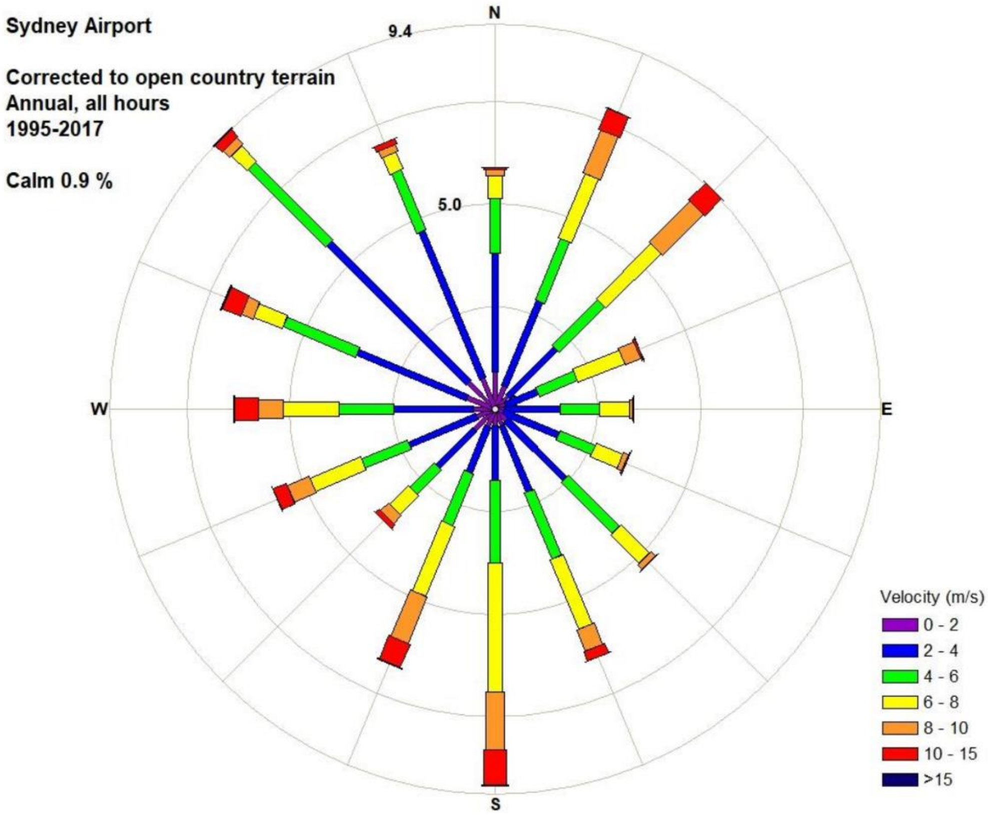

Figure 6: Wind rose for Sydney Airport.

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

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

5 DISCUSSION

The wind climatology chart of Figure 6 indicates that the most frequent strong winds are from the south and to a lesser degree from the west and north-east quadrants. The locations tested around the Western Gateway Sub-Precinct are susceptible to winds from these directions, depending on the relative position of the location tested to the geometry of the proposed development and surrounds. The influence of wind direction on the suitability of a location for an intended purpose can be ascertained from the polar plots in Appendix 2. The polar plots show the severity, distribution, and frequency of steady winds and gusts from 16 directions at 22.5° intervals.

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

The primary conclusions of the pedestrian study can be understood by reviewing the colour coded images of Figure 7 to Figure 9, which depict the locations selected for investigation along with the Lawson comfort and distress criteria ratings. The central colour indicates the comfort rating for the location, and the colour of the outer ring indicates whether the location passes or exceeds the distress criterion, Table 2. Interpretation of these wind levels can be aided by the description of the effects of wind of various magnitudes on people found in Table 3.

Note that testing was performed without existing and proposed trees, and other plantings to provide a worst-case assessment; heavy landscape planting typically reduces the wind speeds by less than 10%. However, landscaping cannot be relied on to provide sufficient shielding from winds that potentially pose a safety risk due to their vulnerabilities. Mitigation measures are likely to be required for orange and red locations and may be necessary for other locations depending on the intended use of the space. Although conditions may be classified as acceptable, there may be certain wind directions that cause regular strong events, and these can be determined by an inspection of the polar plots in Appendix 2.

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

Location	Target	Wind Tunnel Results								
		Configuration 1 (Block A and B towers)			Configuration 2 (Block A tower)			Configuration 3 (existing)		
	Comfort rating, 5% exceedance wind speed (m/s)	Comfort rating, 5% exceedance wind speed (m/s)	Meets target Y/N	Safety rating, 0.022% exceedance wind speed (m/s)	Comfort rating, 5% exceedance wind speed (m/s)	Meets target Y/N	Safety rating, 0.022% exceedance wind speed (m/s)	Comfort rating, 5% exceedance wind speed (m/s)	Meets target Y/N	Safety rating, 0.022% exceedance wind speed (m/s)
1	>6 to 8	4.7	Y	9.7	4.6	Y	9.7	4.2	Y	8.2
2	>6 to 8	9.1	N	19.0	8.8	N	18.4	7.0	Y	15.3
3	>4 to 6	5.3	Y	10.9	5.2	Y	10.6	n/a		n/a
4	>6 to 8	5.4	Y	9.8	5.0	Y	8.9	5.4	Y	10.9
5	>4 to 6	6.8	N	13.7	4.9	Y	10.4	3.4	Y	6.3
6	>6 to 8	7.0	Y	13.3	7.4	Y	13.4	4.5	Y	9.0
7	>4 to 6	4.9	Y	10.5	4.4	Y	8.1	3.7	Y	9.0
8	>6 to 8	4.9	Y	9.3	5.2	Y	9.8	n/a		n/a
9	>6 to 8	5.7	Y	10.9	4.9	Y	9.5	3.0	Y	5.7
10	>6 to 8	3.7	Y	7.3	4.2	Y	8.4	3.6	Y	6.4
11	>6 to 8	10.3	N	20.8	9.0	N	18.9	n/a		n/a
12	>6 to 8	7.3	Y	14.6	5.4	Y	12.4	n/a		n/a
13	>6 to 8	8.3	N	17.4	5.2	Y	10.3	n/a		n/a
14	>6 to 8	7.3	Y	15.6	5.3	Y	11.6	n/a		n/a
15	>6 to 8	9.3	N	19.2	10.0	N	20.7	6.5	Y	13.2
16	>6 to 8	6.9	Y	13.0	7.2	Y	14.3	6.0	Y	11.2
17	>6 to 8	7.0	Y	12.8	6.7	Y	12.7	6.0	Y	11.2
18	>6 to 8	6.2	Y	13.3	6.0	Y	12.3	n/a		n/a
19	>6 to 8	5.4	Y	10.3	5.8	Y	12.0	n/a		n/a

LEGEND

Comfort Criteria
- Outdoor Dining
- Pedestrian Sitting
- Pedestrian Standing
- Pedestrian Walking
- Business Walking
- Uncomfortable

Safety Criteria
- Passes safety criteria
- Able bodied
- Fails safety criteria

The wind conditions in Configuration 1 with the proposed Block B indicative scheme as well as the Block A tower are presented in Figure 7. Wind conditions in the vicinity of the Western Gateway Sub-Precinct are classified as suitable for pedestrian standing or walking under the Lawson comfort criteria in most locations with locations near the building corners to the south-west and east of the site exceeding the walking criteria and some locations exceeding the Lawson distress criterion. The Western Gateway Sub-Precinct is exposed to the east and south, and the broad facades and combined massing of the proposed towers would cause significant downwash flow for wind from these directions which accelerates around the tower corners upon reaching ground level, causing windy conditions in the areas around Locations 2 and 15. These locations are classified as suitable for business walking type activities under the Lawson comfort criterion. Location 11 in the through site link between the eastern Block B tower and the proposed Block A tower is rated as uncomfortable and fails the Lawson distress criterion. Reference to the polar plots in Appendix 2 indicates that wind conditions at Location 11 are dominated by winds from the south-east and north-west quadrants. As these winds reach the development site downwash is generated from the proposed tower facades which is driven through the narrow pathway between the towers by the pressure differential between the windward and leeward sides of the development. The relatively higher wind speeds experienced at Location 11, when compared to Location 9 or 12, are considered the result of the smaller cross-sectional area in the vicinity of Location 11Figure 7. Locations 2, 13, 14, and 15 exceed the Lawson distress criterion with an able-bodied rating.

In Configuration 2 without the Block A tower the wind conditions to the north and west of Block A, Locations 12-14, are significantly calmer than in Configuration 1, Figure 8. Conversely, for Location 15 the wind conditions deteriorate slightly with the removal of the Block A tower reducing the deceleration of flow that was present for approaching winds from the south quadrant. Reference to the polar plots in Appendix 2 indicate that Location 15 sits on the threshold wind speed for the uncomfortable Lawson comfort classification. The remainder of the test locations show similar wind conditions as in Configuration 1 with the Block A tower present.

Location 19 on the podium roof of the proposed Block B development is rated as suitable for pedestrian standing in both proposed configurations.

The existing wind conditions were tested for a subset of the test locations. Conditions were found to be generally calmer than in the proposed configurations. Areas on Railway Square (Locations 5 and 7) and Henry Deane Plaza (Locations 9 and 10) are rated as suitable for pedestrian sitting in the existing configuration. The north-east and south-west corners of Block B, Locations 2 and 15, are also found to be the most windy areas in the existing configuration, however the conditions are calmer than in the proposed configurations, with both locations being rated as suitable for pedestrian walking type activities from a comfort perspective, Figure 9. Location 2 also exceeds the Lawson distress criterion in the existing configuration; all other locations pass the distress criterion.

Wind conditions on the station platform close to Block B, Location 16, are rated as suitable for Pedestrian Walking in all three test configurations.

To mitigate the strong wind conditions near building corners and in the space north-east of Block B in the proposed configurations, the recommended approach would be to introduce measures to reduce the amount of downwash flow, generated from the building facades, reaching ground level. The introduction of tower setbacks at podium level to the east and south or the extension of the podium to the south to create an appropriate tower setback would assist in diverting some of the downwash flow at podium level, thereby benefitting the wind conditions at ground level. Additionally, an awning above the pedestrian areas on these buildings sides and wrapping around the corner would protect pedestrians underneath from the direct effects of any downwash flow.

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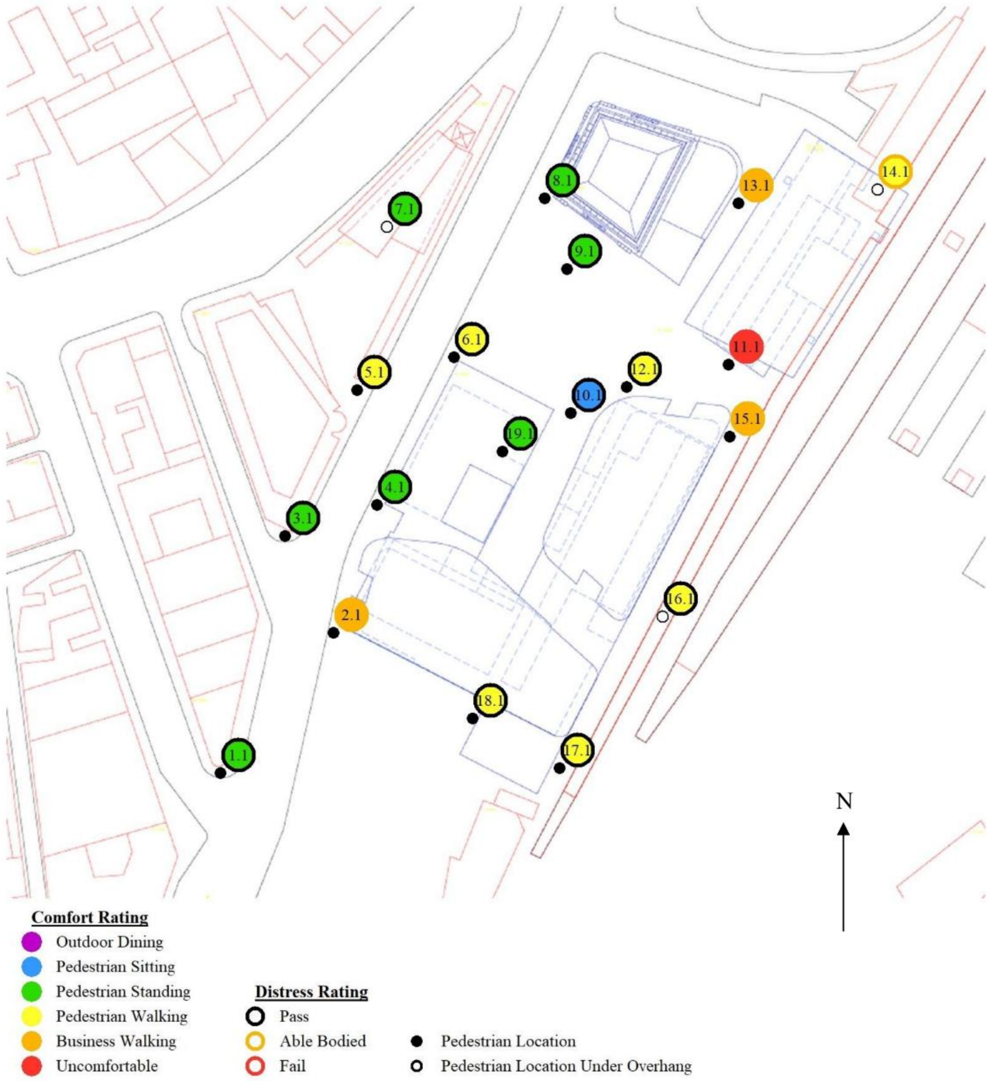

Figure 7: Pedestrian wind speed measurement locations with comfort/distress ratings – Configuration 1.

19

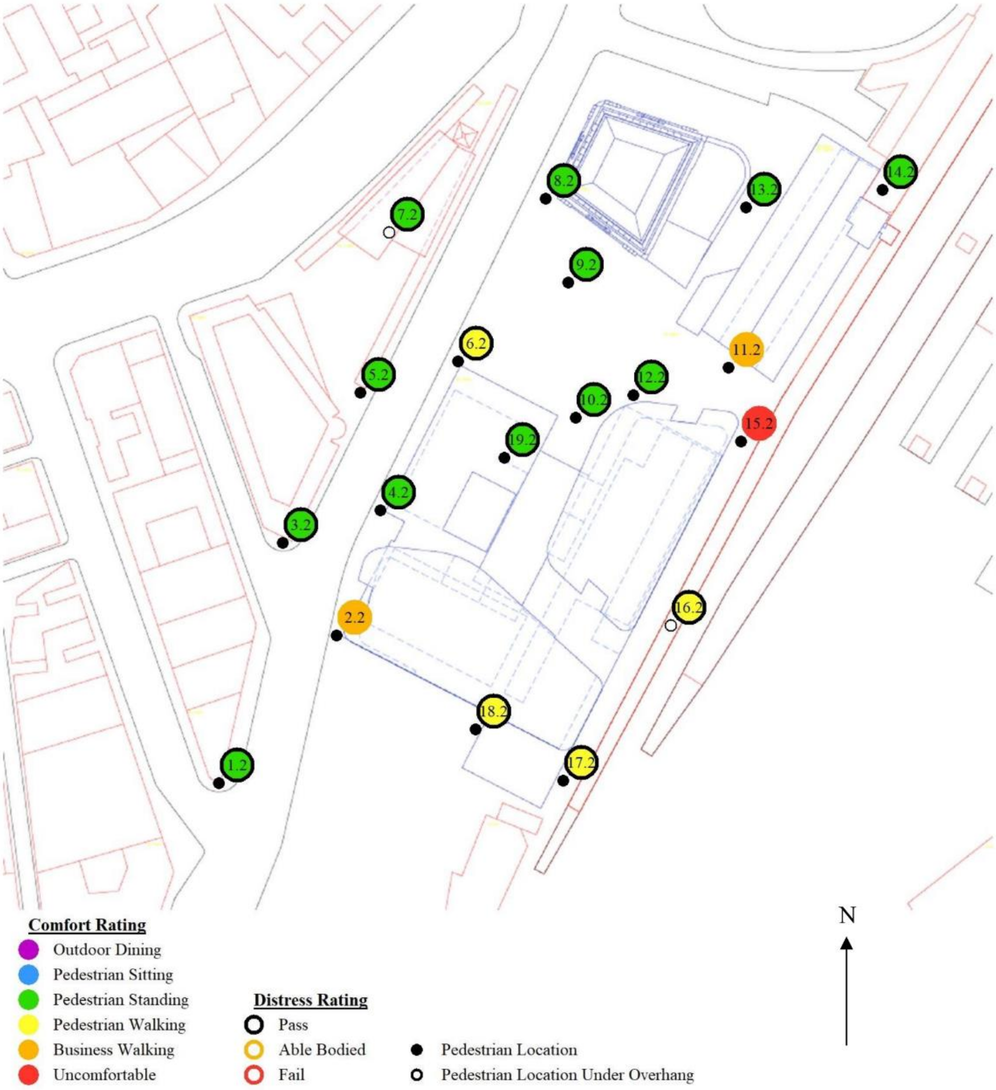

Figure 8: Pedestrian wind speed measurement locations with comfort/distress ratings – Configuration 2.

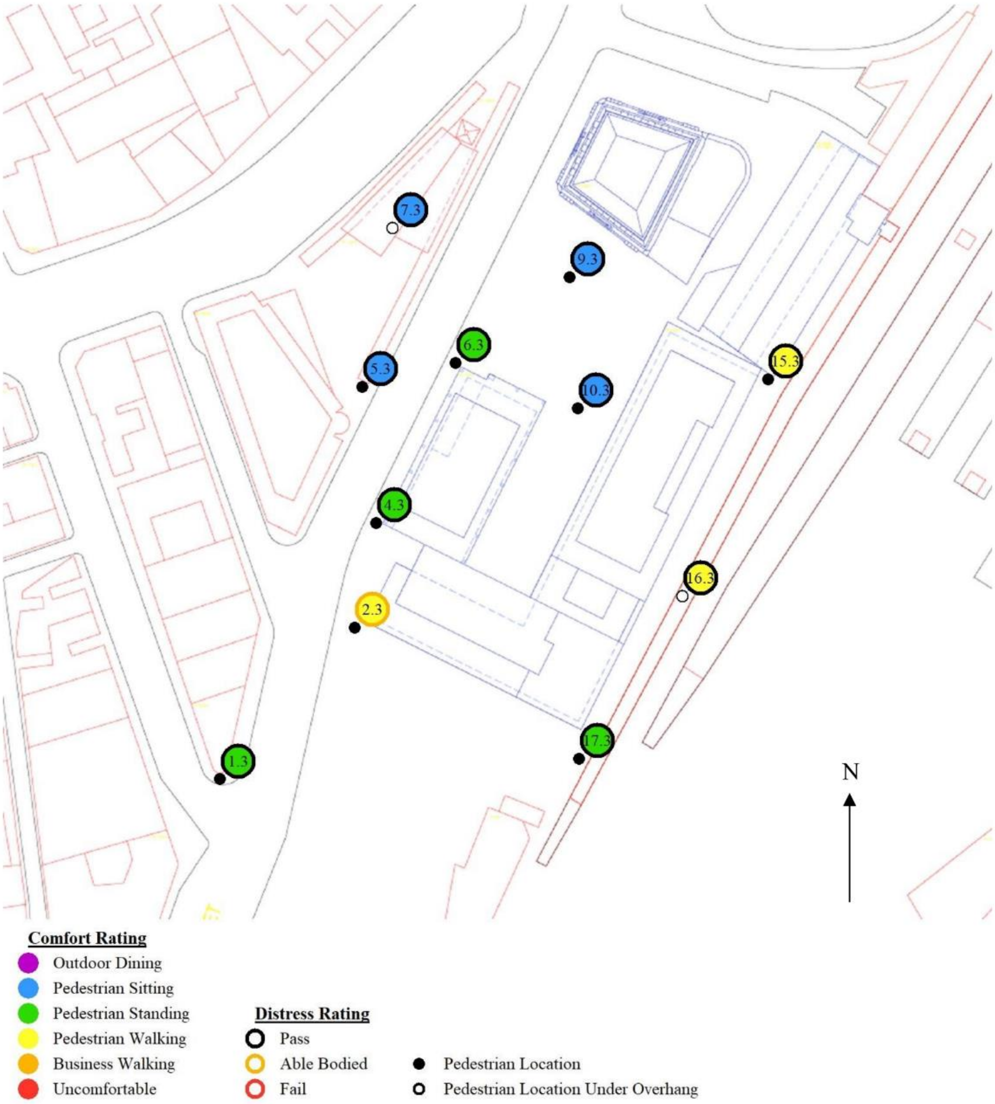

Figure 9: Pedestrian wind speed measurement locations with comfort/distress ratings – Configuration 3.

6 CONCLUSION

A wind tunnel investigation of the pedestrian level wind environment in and around the proposed Block B development of the Western Gateway Sub-Precinct has been conducted. Testing was conducted in two proposed configurations with and without the proposed Block A tower to the immediate north of the site. The wind environment at ground level near the development site was found to be generally suitable for pedestrian standing and walking in most areas.

Areas near the building corners to the north-east and south-west of the site are significantly windier, with several locations exceeding the Lawson distress criterion in the proposed configurations. Block B is rather exposed to unimpeded winds approaching from the south and east quadrants. It is recommended to add wind mitigation measures to reduce the wind speeds experienced at ground level, particularly near building corners and through site links. The addition of tower setbacks at podium level and awnings over the pedestrian areas can be effective measures to reduce the amount of downwash flow affecting pedestrians at ground level.

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Appendix 1: Additional photographs of the CPP wind tunnel model

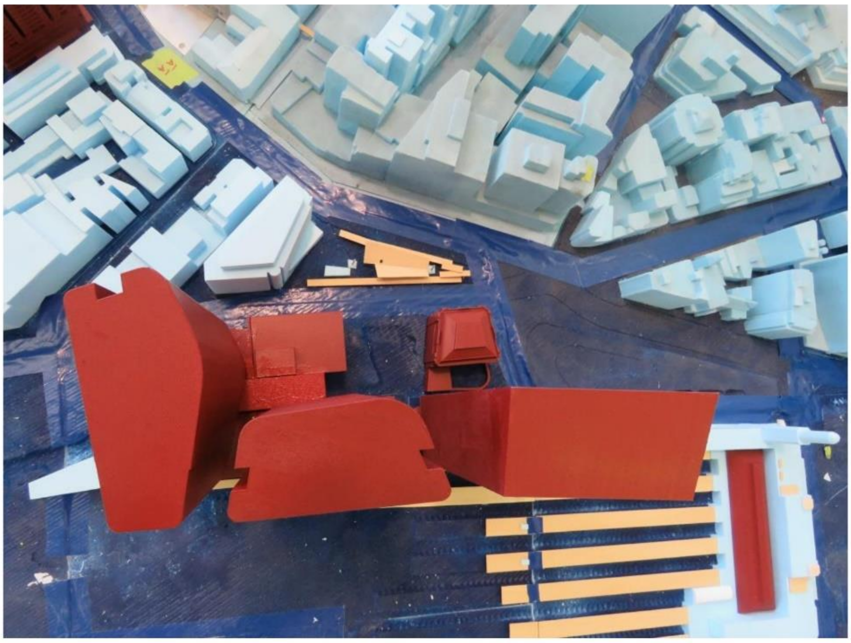


Figure 10: Close-up of the wind tunnel model in Configuration 1 viewed from above.

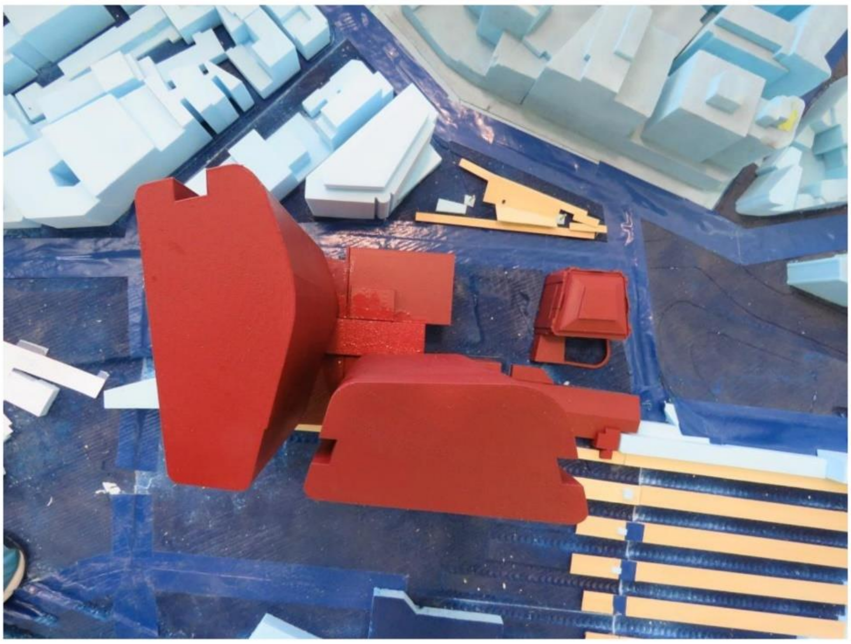


Figure 11: Close-up of the wind tunnel model in Configuration 2 viewed from above.

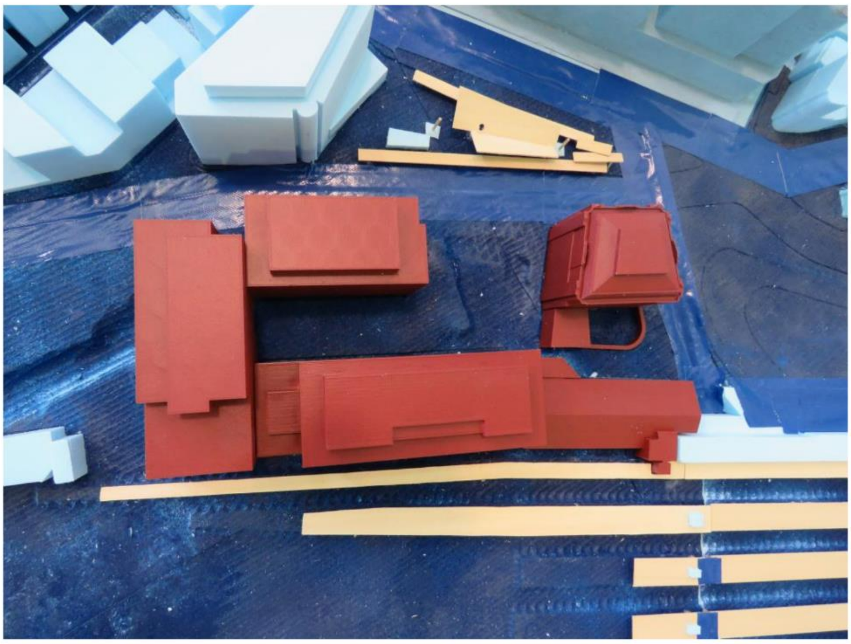
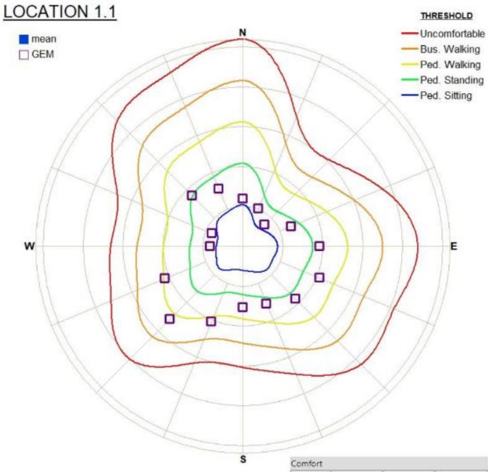


Figure 12: Close-up of the wind tunnel model in Configuration 3 viewed from above.

Appendix 2: Directional wind results

LOCATION 1.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	30.01	44.94	44.94
4	4.96	10.01	10.01
6	0.45	1.43	1.43
8	0.04	0.16	0.16
10	0.00	0.02	0.02

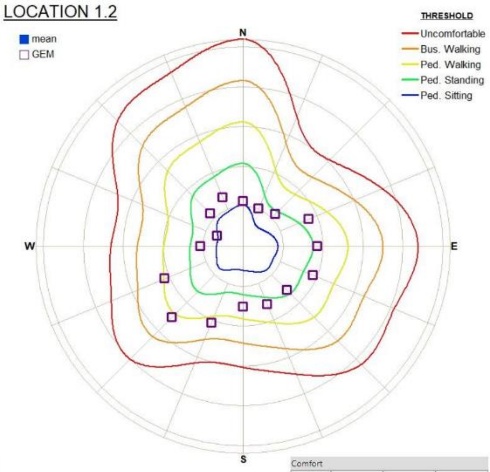
Comfort

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

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	8.3	9.7	9.7
Rating	Pass	Pass	Pass

LOCATION 1.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	31.13	44.27	44.27
4	4.75	9.56	9.56
6	0.50	1.31	1.31
8	0.05	0.15	0.15
10	0.00	0.02	0.02

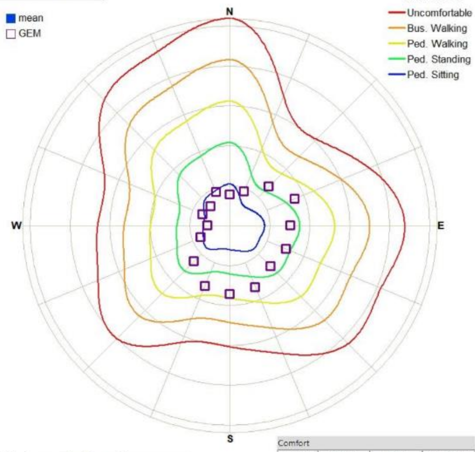
Comfort

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

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	8.5	9.7	9.7
Rating	Pass	Pass	Pass

LOCATION 1.3



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	22.31	34.47	34.47
4	2.64	6.46	6.46
6	0.15	0.51	0.51
8	0.00	0.03	0.03
10	0.00	0.00	0.00

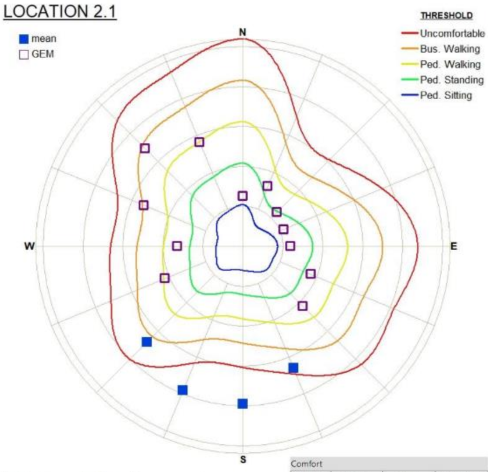
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	3.5	4.2	4.2
Rating	Ped Sitting	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	7.2	8.2	8.2
Rating	Pass	Pass	Pass

LOCATION 2.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	54.26	67.63	68.59
4	26.38	28.13	30.66
6	15.55	11.07	16.30
8	7.79	3.91	8.01
10	3.47	1.19	3.56

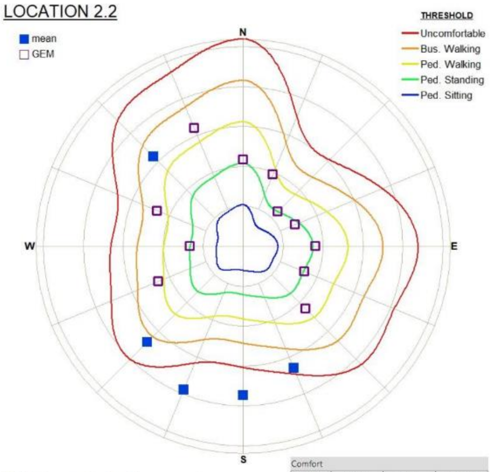
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	9.0	7.5	9.1
Rating	Bus Walking	Ped Walking	Bus Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	18.9	15.5	19.0
Rating	Able Body	Able Body	Able Body

LOCATION 2.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	57.46	70.73	71.98
4	26.86	28.64	31.59
6	15.39	10.49	16.10
8	7.14	3.41	7.35
10	3.00	0.86	3.05

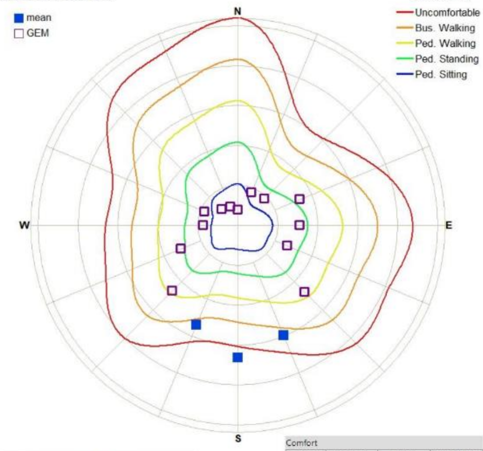
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	8.7	7.2	8.8
Rating	Bus Walking	Ped Walking	Bus Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	18.4	14.7	18.4
Rating	Able Body	Pass	Able Body

LOCATION 2.3



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	30.43	42.47	42.85
4	17.10	17.96	19.03
6	9.06	6.72	9.21
8	3.04	1.91	3.06
10	0.99	0.45	0.99

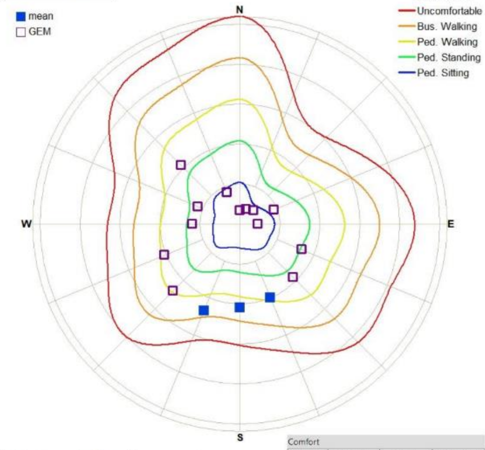
Comfort

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

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	15.3	13.4	15.3
Rating	Able Body	Pass	Able Body

LOCATION 3.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	30.49	39.44	40.12
4	12.00	12.27	14.15
6	2.64	2.42	3.06
8	0.38	0.32	0.45
10	0.05	0.04	0.06

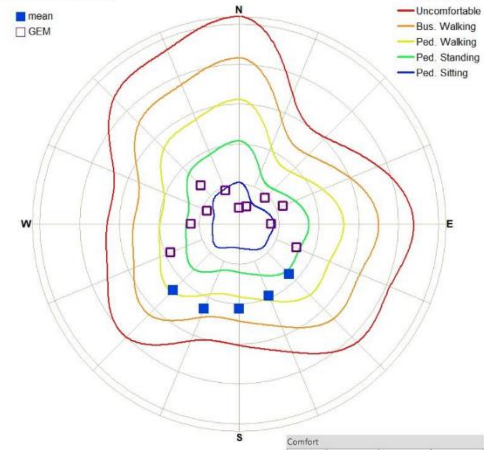
Comfort

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

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	10.7	10.5	10.9
Rating	Pass	Pass	Pass

LOCATION 3.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	29.17	38.89	39.41
4	11.72	11.18	12.72
6	2.58	2.10	2.67
8	0.38	0.26	0.38
10	0.05	0.03	0.05

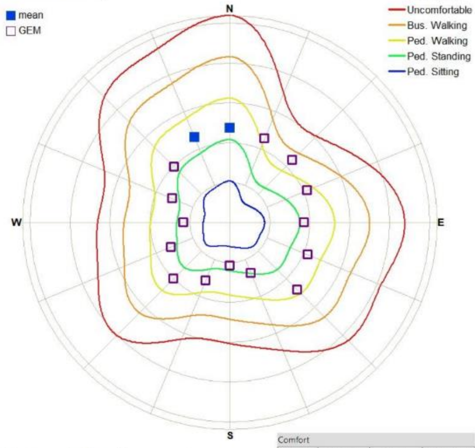
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	5.1	5.0	5.2
Rating	Ped Standing	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	10.6	10.2	10.6
Rating	Pass	Pass	Pass

LOCATION 4.1

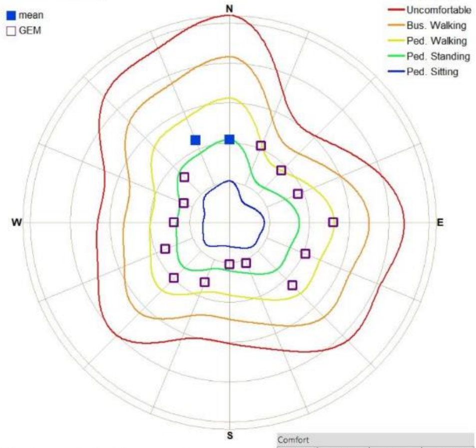


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	41.75	58.96	59.20
4	9.08	16.18	16.29
6	1.42	2.94	2.97
8	0.10	0.32	0.32
10	0.00	0.02	0.02

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.7	5.4	5.4
Rating	Ped Standing	Ped Standing	Ped Standing

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	8.9	9.8	9.8
Rating	Pass	Pass	Pass

LOCATION 4.2

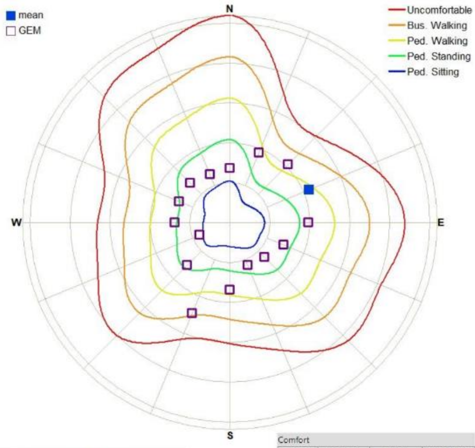


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	39.91	54.58	54.63
4	6.46	14.39	14.41
6	0.61	1.52	1.53
8	0.04	0.10	0.10
10	0.00	0.01	0.01

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

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	8.4	8.9	8.9
Rating	Pass	Pass	Pass

LOCATION 4.3



% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	31.75	46.51	46.54
4	8.42	14.77	14.86
6	1.19	2.87	2.89
8	0.11	0.41	0.41
10	0.00	0.05	0.05

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.6	5.3	5.4
Rating	Ped Standing	Ped Standing	Ped Standing

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.0	10.9	10.9
Rating	Pass	Pass	Pass

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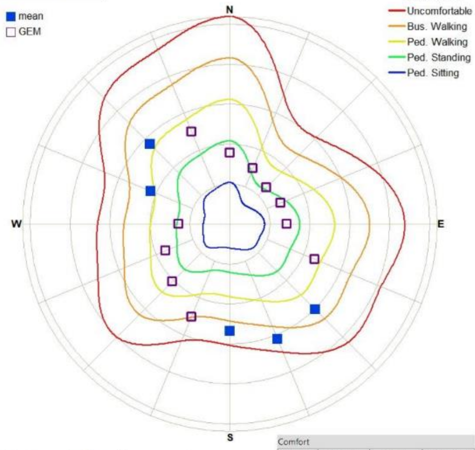
LOCATION 5.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	57.73	64.29	65.40
4	20.99	22.91	24.83
6	7.84	6.44	8.84
8	2.01	1.38	2.24
10	0.44	0.22	0.49

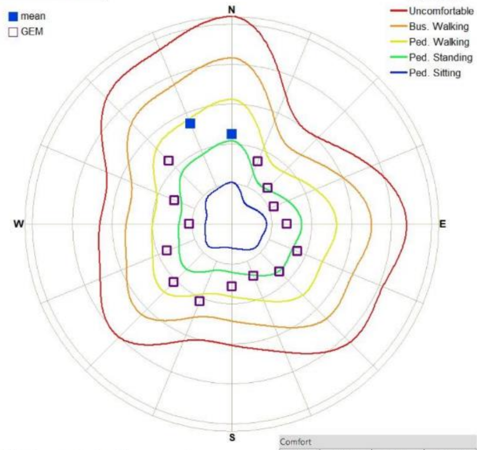
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	6.6	6.3	6.8
Rating	Ped Walking	Ped Walking	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	13.7	12.5	13.8
Rating	Pass	Pass	Pass

LOCATION 5.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	40.22	55.80	56.42
4	4.80	11.38	11.61
6	0.73	1.58	1.63
8	0.15	0.21	0.25
10	0.03	0.03	0.04

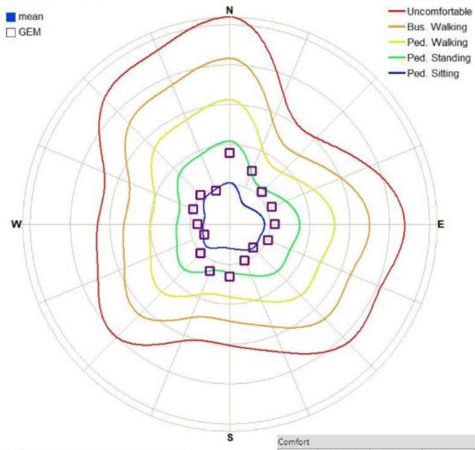
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	3.9	4.8	4.9
Rating	Ped Sitting	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	10.2	10.1	10.4
Rating	Pass	Pass	Pass

LOCATION 5.3



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	12.41	29.22	29.22
4	0.17	2.08	2.08
6	0.00	0.04	0.04
8	0.00	0.00	0.00
10	0.00	0.00	0.00

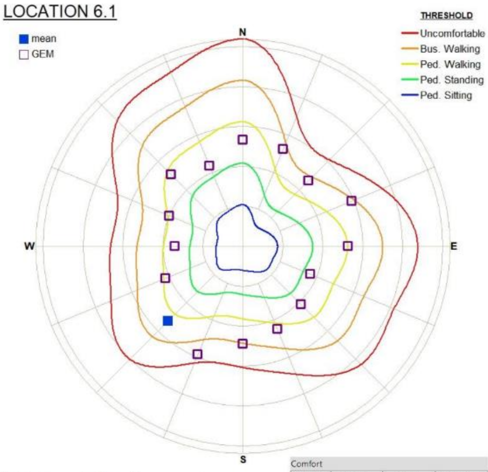
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	2.5	3.4	3.4
Rating	Ped Sitting	Ped Sitting	Ped Sitting

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	4.8	6.3	6.3
Rating	Pass	Pass	Pass

LOCATION 6.1

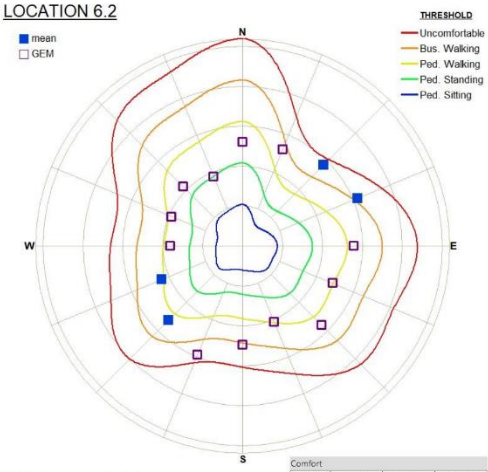


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	61.41	72.12	72.23
4	22.71	33.11	33.24
6	6.49	10.92	11.02
8	1.09	2.30	2.32
10	0.18	0.37	0.37

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	6.3	7.0	7.0
Rating	Ped Walking	Ped Walking	Ped Walking

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	12.4	13.2	13.3
Rating	Pass	Pass	Pass

LOCATION 6.2

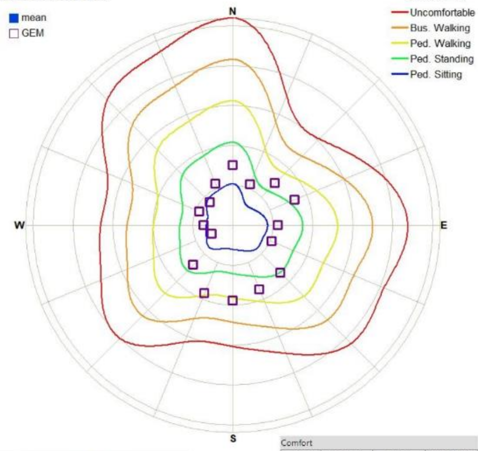


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	63.52	71.15	71.84
4	27.83	34.43	35.68
6	9.95	11.64	13.29
8	2.31	2.52	3.30
10	0.44	0.46	0.60

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	7.0	7.1	7.4
Rating	Ped Walking	Ped Walking	Ped Walking

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	13.0	13.2	13.4
Rating	Pass	Pass	Pass

LOCATION 6.3

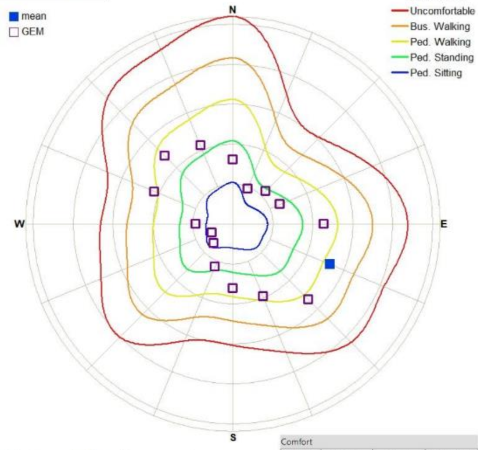


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	20.68	37.80	37.80
4	2.84	8.70	8.70
6	0.17	1.05	1.05
8	0.00	0.09	0.09
10	0.00	0.00	0.00

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	3.5	4.5	4.5
Rating	Ped Sitting	Ped Standing	Ped Standing

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	7.3	9.0	9.0
Rating	Pass	Pass	Pass

LOCATION 7.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	29.06	49.92	49.96
4	5.23	11.51	11.61
6	0.77	2.04	2.09
8	0.12	0.32	0.33
10	0.02	0.04	0.04

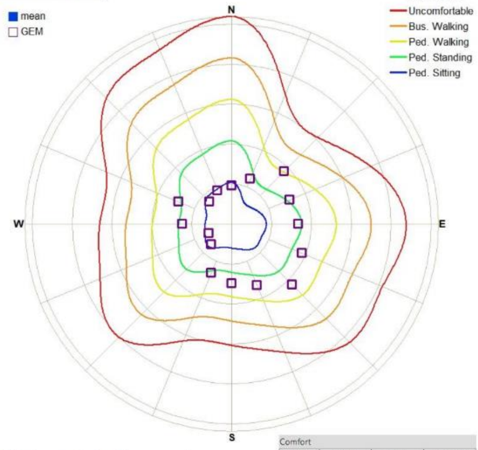
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	4.0	4.9	5.0
Rating	Ped Standing	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.7	10.5	10.5
Rating	Pass	Pass	Pass

LOCATION 7.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	23.17	41.54	41.54
4	2.46	8.32	8.32
6	0.10	0.72	0.72
8	0.00	0.03	0.03
10	0.00	0.00	0.00

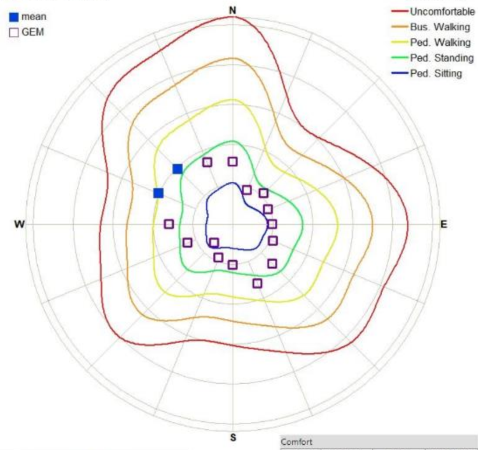
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	3.4	4.5	4.5
Rating	Ped Sitting	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	6.7	8.1	8.1
Rating	Pass	Pass	Pass

LOCATION 7.3



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	17.69	37.37	37.64
4	2.11	3.79	3.88
6	0.49	0.57	0.61
8	0.08	0.08	0.09
10	0.01	0.00	0.01

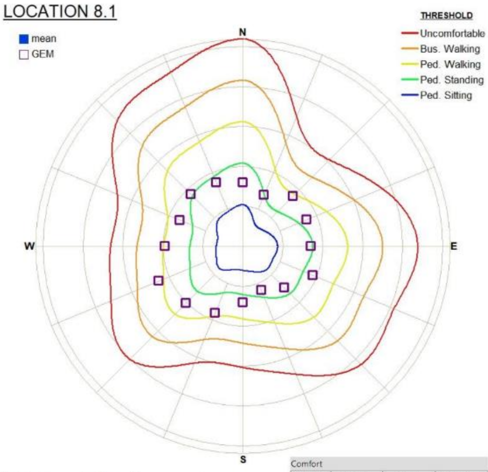
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	3.0	3.7	3.7
Rating	Ped Sitting	Ped Sitting	Ped Sitting

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	8.9	8.8	9.0
Rating	Pass	Pass	Pass

LOCATION 8.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	33.38	54.38	54.38
4	4.36	12.82	12.82
6	0.35	1.62	1.62
8	0.02	0.13	0.13
10	0.00	0.01	0.01

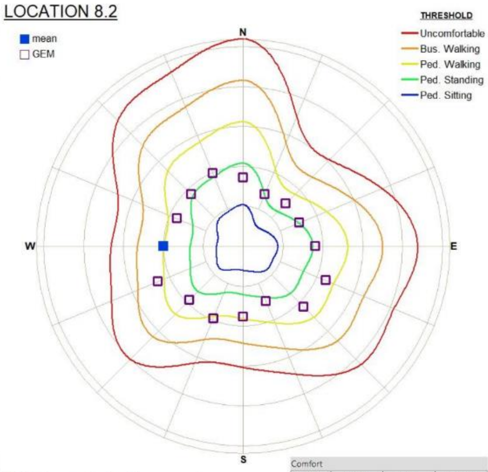
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	3.9	4.9	4.9
Rating	Ped Sitting	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	8.0	9.3	9.3
Rating	Pass	Pass	Pass

LOCATION 8.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	42.98	59.47	59.52
4	5.38	15.75	15.81
6	0.64	2.21	2.23
8	0.05	0.21	0.21
10	0.00	0.02	0.02

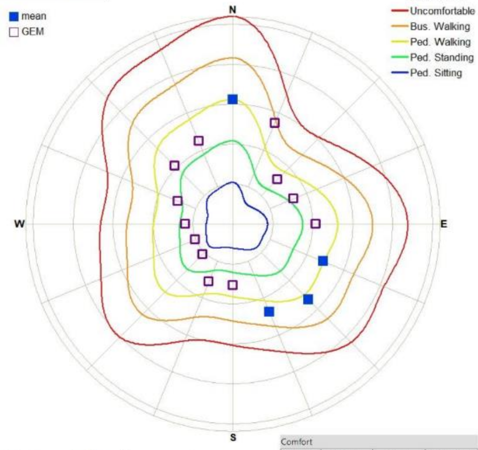
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	4.0	5.2	5.2
Rating	Ped Standing	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	8.6	9.8	9.8
Rating	Pass	Pass	Pass

LOCATION 9.1

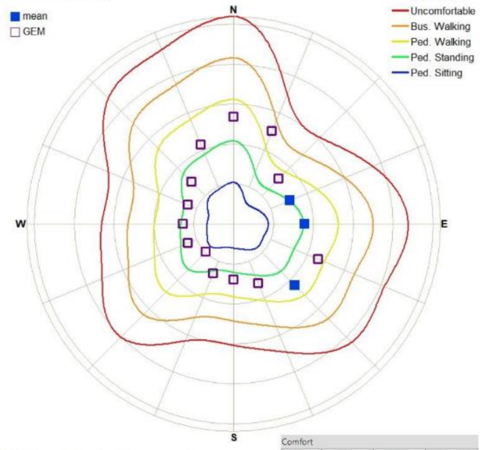


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	51.91	60.47	61.07
4	14.38	17.40	18.81
6	2.77	3.30	3.95
8	0.34	0.51	0.61
10	0.03	0.05	0.06

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	5.3	5.5	5.7
Rating	Ped Standing	Ped Standing	Ped Standing

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	10.3	10.6	10.9
Rating	Pass	Pass	Pass

LOCATION 9.2

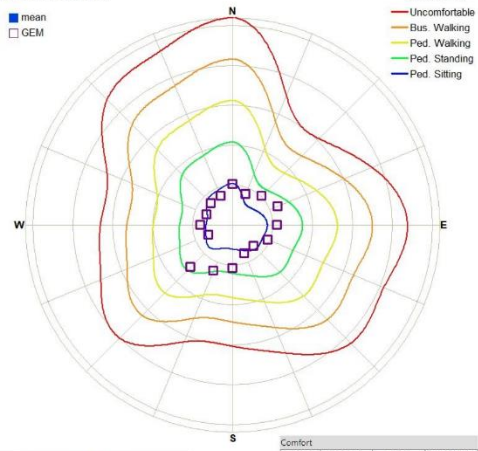


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	43.76	54.24	54.45
4	8.50	12.18	12.36
6	0.97	1.88	1.90
8	0.05	0.18	0.19
10	0.00	0.01	0.01

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	4.5	4.9	4.9
Rating	Ped Standing	Ped Standing	Ped Standing

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	8.6	9.5	9.5
Rating	Pass	Pass	Pass

LOCATION 9.3

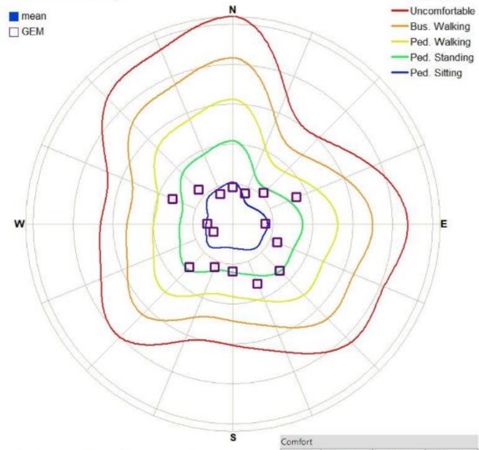


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	9.68	20.95	20.95
4	0.08	0.78	0.78
6	0.00	0.01	0.01
8	0.00	0.00	0.00
10	0.00	0.00	0.00

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	2.4	3.0	3.0
Rating	Ped Sitting	Ped Sitting	Ped Sitting

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	4.4	5.7	5.7
Rating	Pass	Pass	Pass

LOCATION 10.1

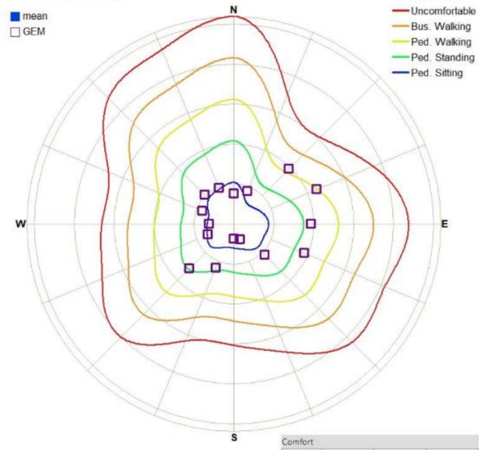


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	8.73	31.73	31.73
4	0.17	3.26	3.26
6	0.00	0.20	0.20
8	0.00	0.00	0.00
10	0.00	0.00	0.00

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	2.3	3.7	3.7
Rating	Ped Sitting	Ped Sitting	Ped Sitting

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	4.8	7.3	7.3
Rating	Pass	Pass	Pass

LOCATION 10.2

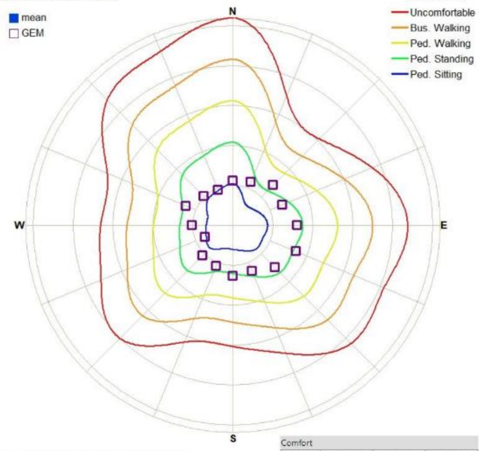


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	11.29	24.28	24.28
4	2.27	6.23	6.23
6	0.09	0.79	0.79
8	0.00	0.05	0.05
10	0.00	0.00	0.00

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	3.1	4.2	4.2
Rating	Ped Sitting	Ped Standing	Ped Standing

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	6.7	8.4	8.4
Rating	Pass	Pass	Pass

LOCATION 10.3

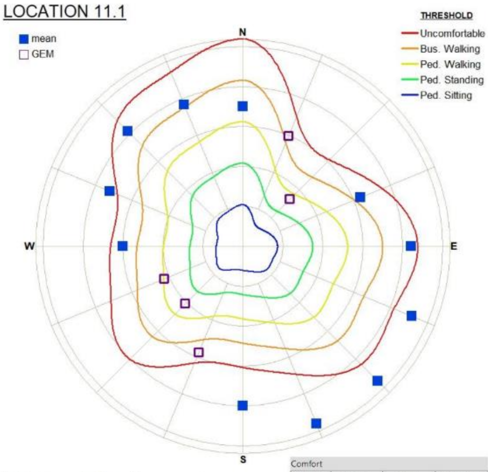


% of time in excess of wind speed V			
V (m/s)	MEAN	GEM	COMBINED
2	17.30	35.28	35.28
4	0.28	2.86	2.86
6	0.00	0.07	0.07
8	0.00	0.00	0.00
10	0.00	0.00	0.00

Comfort			
(5%)	MEAN	GEM	COMBINED
V (m/s)	2.7	3.6	3.6
Rating	Ped Sitting	Ped Sitting	Ped Sitting

Safety			
(0.022%)	MEAN	GEM	COMBINED
V (m/s)	4.7	6.5	6.5
Rating	Pass	Pass	Pass

LOCATION 11.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	81.30	81.79	85.81
4	50.48	44.95	54.49
6	26.77	20.98	29.20
8	13.53	6.86	14.49
10	5.93	1.91	6.14

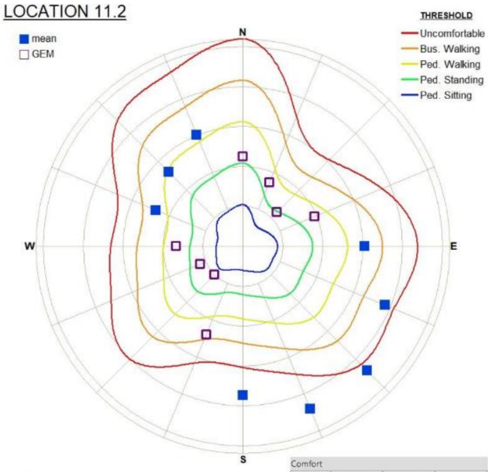
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	10.3	8.4	10.3
Rating	Uncomfortable	Bus Walking	Uncomfortable

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	20.8	16.2	20.8
Rating	Fail	Able Body	Fail

LOCATION 11.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	62.89	67.14	69.18
4	29.60	29.43	33.62
6	16.29	12.36	17.41
8	7.93	3.72	8.15
10	3.20	1.02	3.24

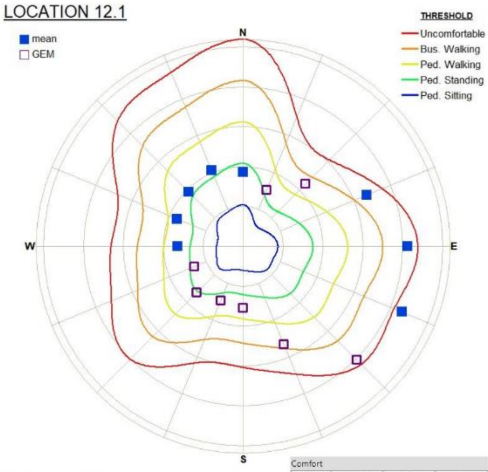
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	9.0	7.5	9.0
Rating	Bus Walking	Ped Walking	Bus Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	18.9	15.2	18.9
Rating	Able Body	Able Body	Able Body

LOCATION 12.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	58.15	59.86	63.17
4	19.23	23.68	26.03
6	7.37	8.22	10.15
8	2.59	1.90	3.36
10	0.49	0.35	0.62

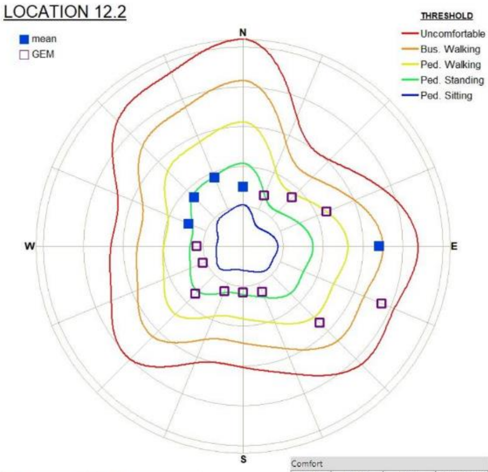
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	6.8	6.7	7.3
Rating	Ped Walking	Ped Walking	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	14.5	13.5	14.6
Rating	Pass	Pass	Pass

LOCATION 12.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	41.81	49.38	51.07
4	8.94	13.02	13.52
6	2.37	3.16	3.49
8	0.37	0.54	0.60
10	0.08	0.13	0.14

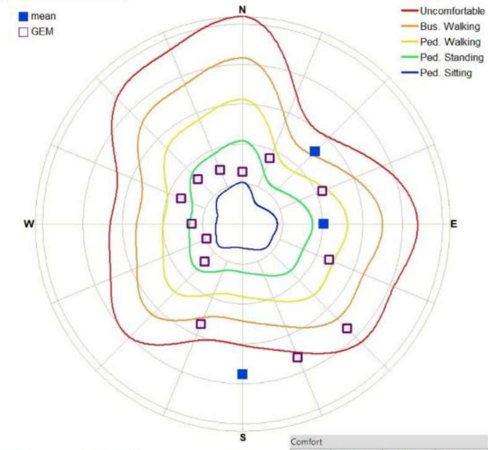
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	4.8	5.3	5.4
Rating	Ped Standing	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	11.4	12.2	12.4
Rating	Pass	Pass	Pass

LOCATION 13.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	48.32	58.03	58.29
4	23.22	30.18	30.94
6	11.83	13.85	15.66
8	4.56	4.62	6.08
10	1.77	1.31	2.12

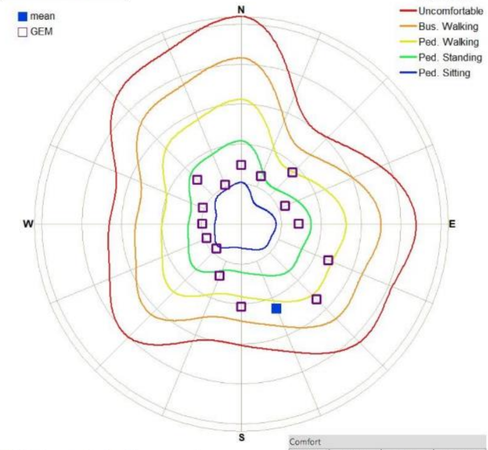
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	7.7	7.8	8.3
Rating	Ped Walking	Ped Walking	Bus Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	17.3	15.9	17.4
Rating	Able Body	Able Body	Able Body

LOCATION 13.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	29.23	46.13	46.13
4	8.47	14.44	14.45
6	1.45	2.52	2.53
8	0.16	0.28	0.29
10	0.02	0.03	0.03

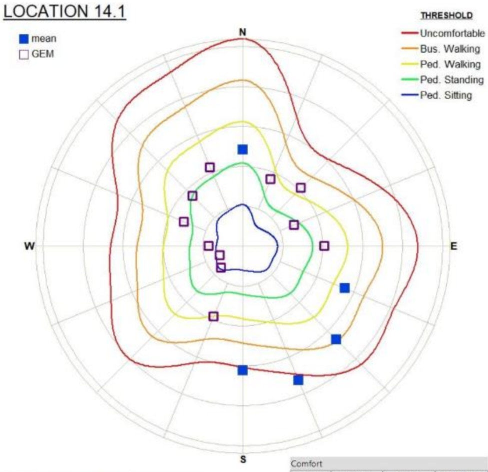
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	4.7	5.2	5.2
Rating	Ped Standing	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.8	10.2	10.3
Rating	Pass	Pass	Pass

LOCATION 14.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	51.14	57.01	57.73
4	23.03	24.47	26.71
6	9.40	6.93	10.56
8	3.29	1.35	3.43
10	0.98	0.23	0.99

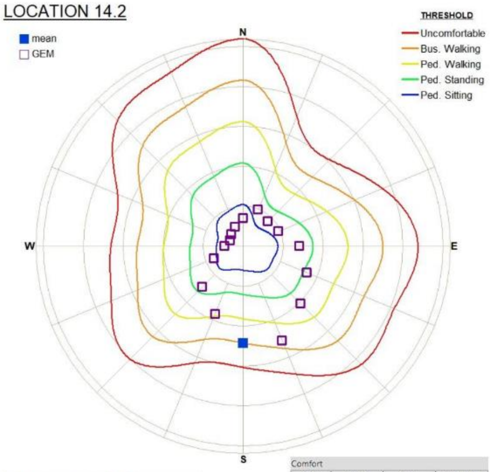
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	7.2	6.4	7.3
Rating	Ped Walking	Ped Walking	Ped Walking

Safety

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

LOCATION 14.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	24.02	34.30	34.34
4	10.13	12.45	12.60
6	2.60	3.04	3.20
8	0.56	0.62	0.69
10	0.07	0.08	0.09

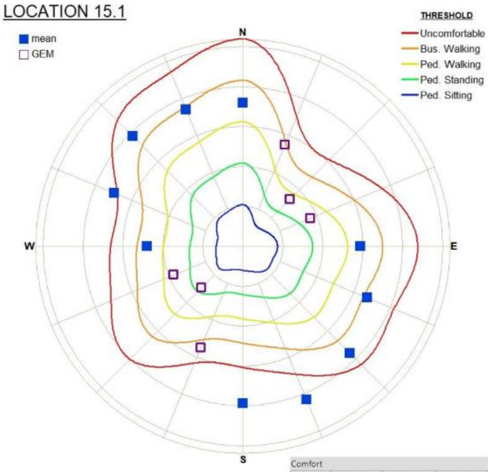
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	5.0	5.3	5.3
Rating	Ped Standing	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	11.2	11.4	11.6
Rating	Pass	Pass	Pass

LOCATION 15.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	80.03	78.72	82.59
4	42.98	39.23	46.50
6	20.72	16.55	22.16
8	9.05	5.17	9.51
10	3.65	1.57	3.75

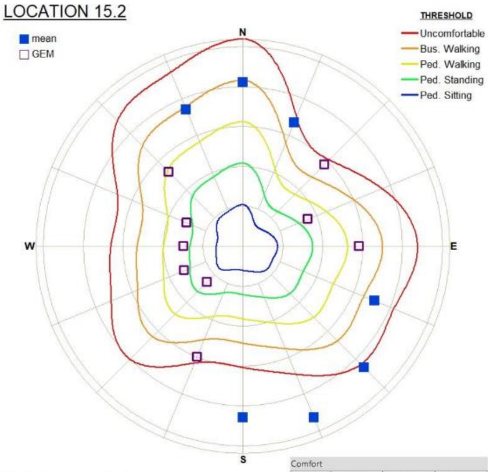
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	9.2	8.0	9.3
Rating	Bus Walking	Ped Walking	Bus Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	19.2	15.9	19.2
Rating	Able Body	Able Body	Able Body

LOCATION 15.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	71.13	75.36	77.03
4	40.67	39.79	44.26
6	23.09	21.14	25.73
8	11.50	7.75	12.94
10	4.83	2.20	5.24

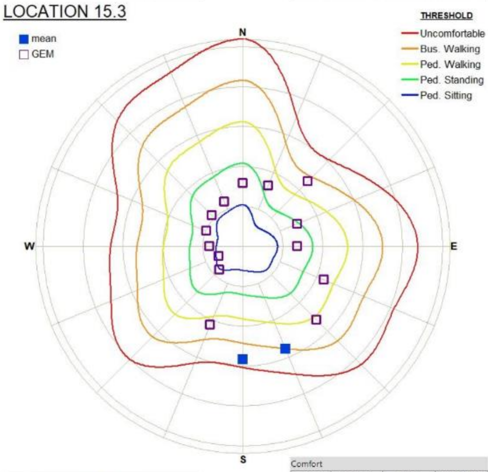
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	9.8	8.6	10.0
Rating	Bus Walking	Bus Walking	Uncomfortable

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	20.7	16.5	20.7
Rating	Fail	Able Body	Fail

LOCATION 15.3



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	40.08	47.24	47.32
4	17.12	21.53	21.81
6	5.32	6.81	7.32
8	1.46	1.51	1.80
10	0.34	0.26	0.37

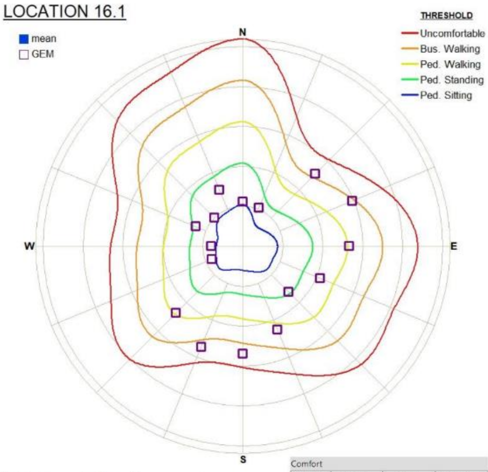
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	6.0	6.3	6.5
Rating	Ped Walking	Ped Walking	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	13.2	12.7	13.2
Rating	Pass	Pass	Pass

LOCATION 16.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	36.17	48.96	48.96
4	17.39	24.27	24.27
6	5.60	9.20	9.20
8	1.16	2.16	2.16
10	0.20	0.42	0.42

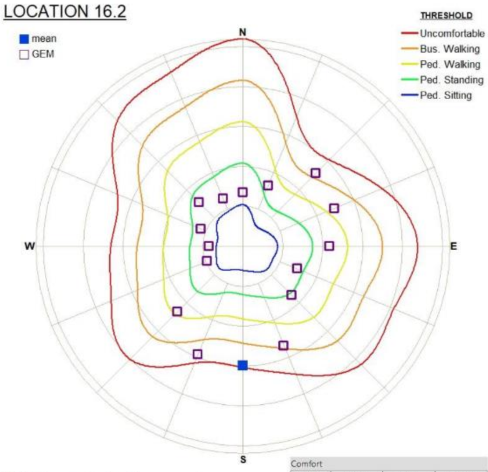
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	6.1	6.9	6.9
Rating	Ped Walking	Ped Walking	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	12.3	13.0	13.0
Rating	Pass	Pass	Pass

LOCATION 16.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	37.89	52.32	52.40
4	19.62	25.11	25.37
6	7.74	10.01	10.61
8	2.27	2.76	3.09
10	0.59	0.62	0.78

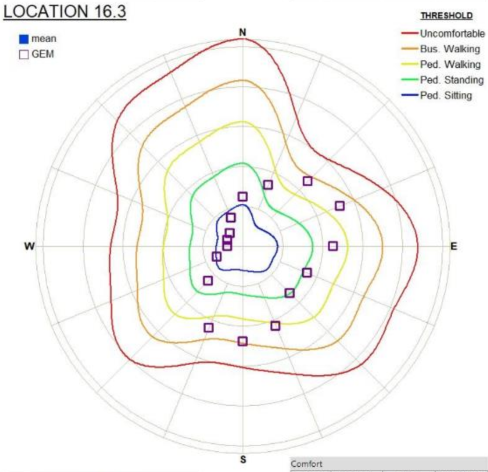
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	6.7	7.1	7.2
Rating	Ped Walking	Ped Walking	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	14.1	13.8	14.3
Rating	Pass	Pass	Pass

LOCATION 16.3



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	32.97	43.54	43.54
4	10.38	20.40	20.40
6	1.77	5.39	5.39
8	0.16	0.88	0.88
10	0.01	0.10	0.10

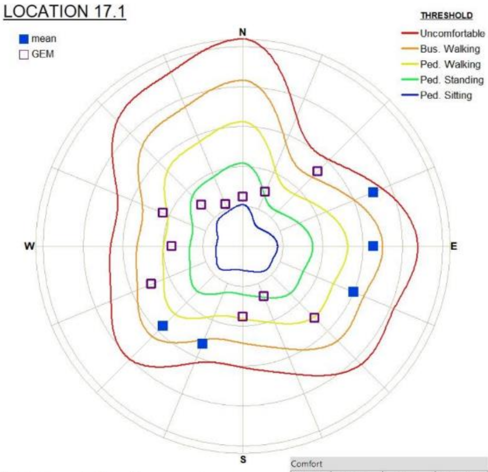
Comfort

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

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	9.3	11.2	11.2
Rating	Pass	Pass	Pass

LOCATION 17.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	50.96	59.96	60.28
4	20.98	25.97	26.60
6	8.67	8.86	10.04
8	2.05	1.79	2.36
10	0.34	0.28	0.39

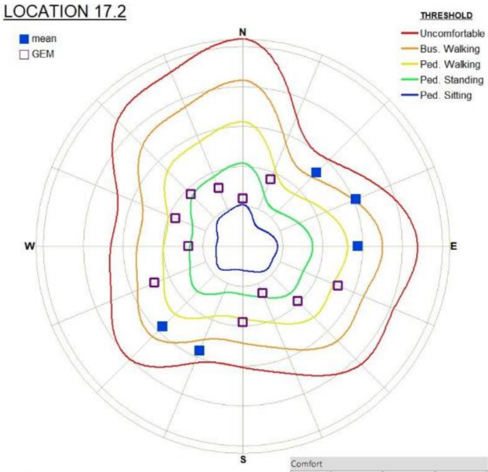
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	6.8	6.7	7.0
Rating	Ped Walking	Ped Walking	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	12.6	12.2	12.8
Rating	Pass	Pass	Pass

LOCATION 17.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	49.69	61.18	61.60
4	20.73	24.98	25.80
6	7.62	7.13	8.63
8	1.64	1.19	1.77
10	0.32	0.17	0.33

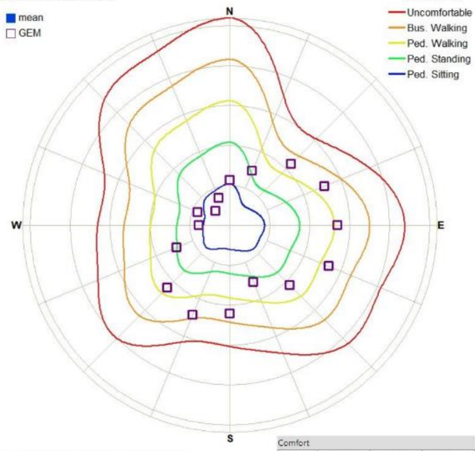
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	6.6	6.4	6.7
Rating	Ped Walking	Ped Walking	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	12.7	11.9	12.7
Rating	Pass	Pass	Pass

LOCATION 17.3



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	36.35	48.91	48.91
4	12.12	21.07	21.07
6	2.26	5.06	5.06
8	0.26	0.78	0.78
10	0.03	0.09	0.09

Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	5.1	6.0	6.0
Rating	Ped Standing	Ped Standing	Ped Standing

Safety

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

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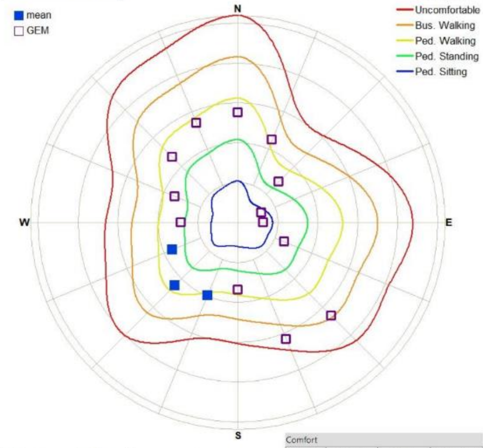
LOCATION 18.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	53.09	61.00	61.52
4	15.53	20.90	21.71
6	3.05	5.80	6.00
8	0.48	1.15	1.18
10	0.07	0.26	0.27

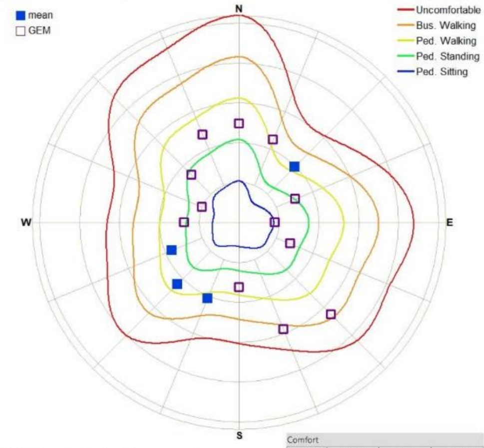
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	5.4	6.2	6.2
Rating	Ped Standing	Ped Walking	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	11.6	13.3	13.3
Rating	Pass	Pass	Pass

LOCATION 18.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	51.76	58.68	59.54
4	17.08	20.39	22.01
6	2.76	4.90	5.47
8	0.27	0.74	0.83
10	0.02	0.14	0.15

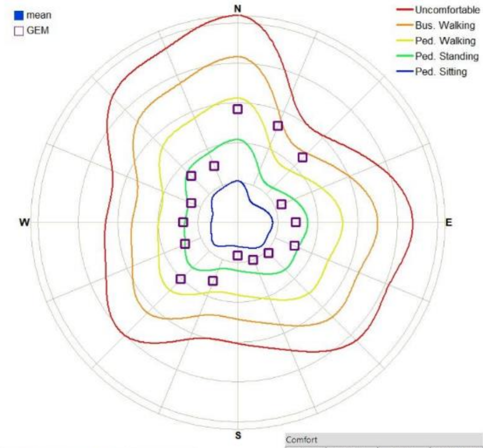
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	5.4	5.9	6.0
Rating	Ped Standing	Ped Standing	Ped Walking

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	10.1	12.3	12.3
Rating	Pass	Pass	Pass

LOCATION 19.1



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	21.97	45.99	45.99
4	4.36	12.18	12.18
6	0.45	3.31	3.31
8	0.02	0.48	0.48
10	0.00	0.03	0.03

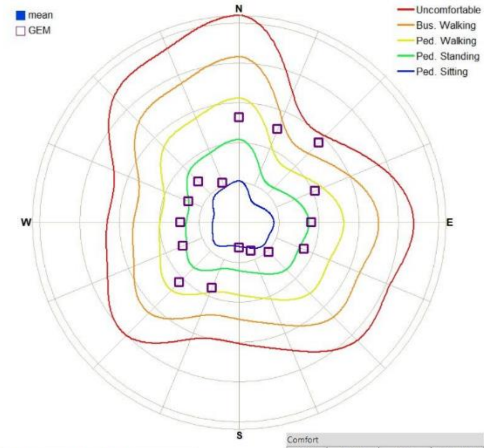
Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	3.8	5.4	5.4
Rating	Ped Sitting	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	7.8	10.3	10.3
Rating	Pass	Pass	Pass

LOCATION 19.2



% of time in excess of wind speed V

V (m/s)	MEAN	GEM	COMBINED
2	27.52	44.09	44.09
4	6.51	15.15	15.15
6	1.09	4.80	4.80
8	0.08	1.19	1.19
10	0.00	0.23	0.23

Comfort

(5%)	MEAN	GEM	COMBINED
V (m/s)	4.3	5.8	5.8
Rating	Ped Standing	Ped Standing	Ped Standing

Safety

(0.022%)	MEAN	GEM	COMBINED
V (m/s)	8.6	12.0	12.0
Rating	Pass	Pass	Pass

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