Ethos Urban

Bon Marche and Science Precinct, University of Technology Sydney

Environmental Wind Assessment

Wind

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Job number 259272-51

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Executive summary

Arup have been commissioned by Ethos Urban to provide a quantitative assessment of the proposed Bon Marche and Science Precinct, University of Technology Sydney on the pedestrian level wind conditions for comfort and safety in and around the site.

Arup have provided the wind tunnel testing report and discussion on the impact of the proposed control envelope and articulated scheme on pedestrian wind comfort and safety in and around the proposed development. Based on the wind tunnel testing report and re-analysis of data to align with the City of Sydney assessment criteria, the majority of locations around the site on the pedestrian level would be expected to be classified as suitable for pedestrian standing and walking type activities. It was shown that for the proposed and articulated designs, the wind conditions at most locations are similarly classified. The measured wind conditions were generally found to be similar to the existing conditions with a few locations on the border of the non-active frontage criterion. With the inclusion of the development, certain areas become windier, and others calmer depending on the wind direction. These conditions would be considered suitable for the intended use of the space. All locations on the ground plane around the proposed development for all designs pass the safety criterion.

It is evident that changes to the proposed control massing scheme would slightly affect the local wind climate and testing of the final architectural scheme would be recommended.

Contents

1 Introduction

Ethos Urban have engaged Arup to provide a quantitative environmental wind assessment for the proposed development at Bon Marche and Science Precinct, University of Technology Sydney. This report outlines the wind tunnel testing study conducted on the precinct and subsequent analysis related to pedestrian wind comfort and safety on the ground level surrounding the development.

2 Wind assessment

2.1 Modelling

Wind tunnel testing was conducted in three configurations: existing, proposed control envelope, and potential articulated scheme, Figure 1.

The proposed control envelope, Figure 1(M), is a building with the total height of approximately 75 m along Harris Street. A tower sits on a podium and is set back 3 m from the east façade of the podium. The southern end of the tower aligns with the north edge of the original existing heritage building. A 3.5 m deep setback is made at Harris Street footpath level and extends from the Heritage façade to Thomas Street.

A further articulated scheme, Figure 1(B), has also been studied, which adds a cantilevered section over the heritage building, notional full sky garden at the podium roof level, as well as indicative passageways made at street level connecting Harris Street and Alumni Green for more specific testing. As the building geometry is not finalised, this test was conducted to show the potential implications on the surrounding wind climate with reasonably large geometric changes. This articulated geometry was chosen to produce the widest variation in results. Photographs of the wind tunnel testing models are included in Figure 1 and Appendix 3.

The proposed control envelope represents the final envelope for approval that is sought by UTS as part of its Section 75W Modification Application (Mod 6) to the Broadway Precinct Concept Plan. The originally submitted envelope, which was the subject of previous assessment by Arup (August 2018) has been amended in response to submissions made during the public exhibition period.

The wind-tunnel testing programme conducted by Vipac was in accordance with the requirements of AWES 2019, and considered appropriate for the investigation. Appropriate wind profiles and test locations were used in the testing. Measurements were taken at 30 points at pedestrian level in and around the site as shown in Figure 2, where the red points are at ground level, blue on the podium roof/skygarden level, and green on the roof. Testing was conducted at 10º wind direction intervals.

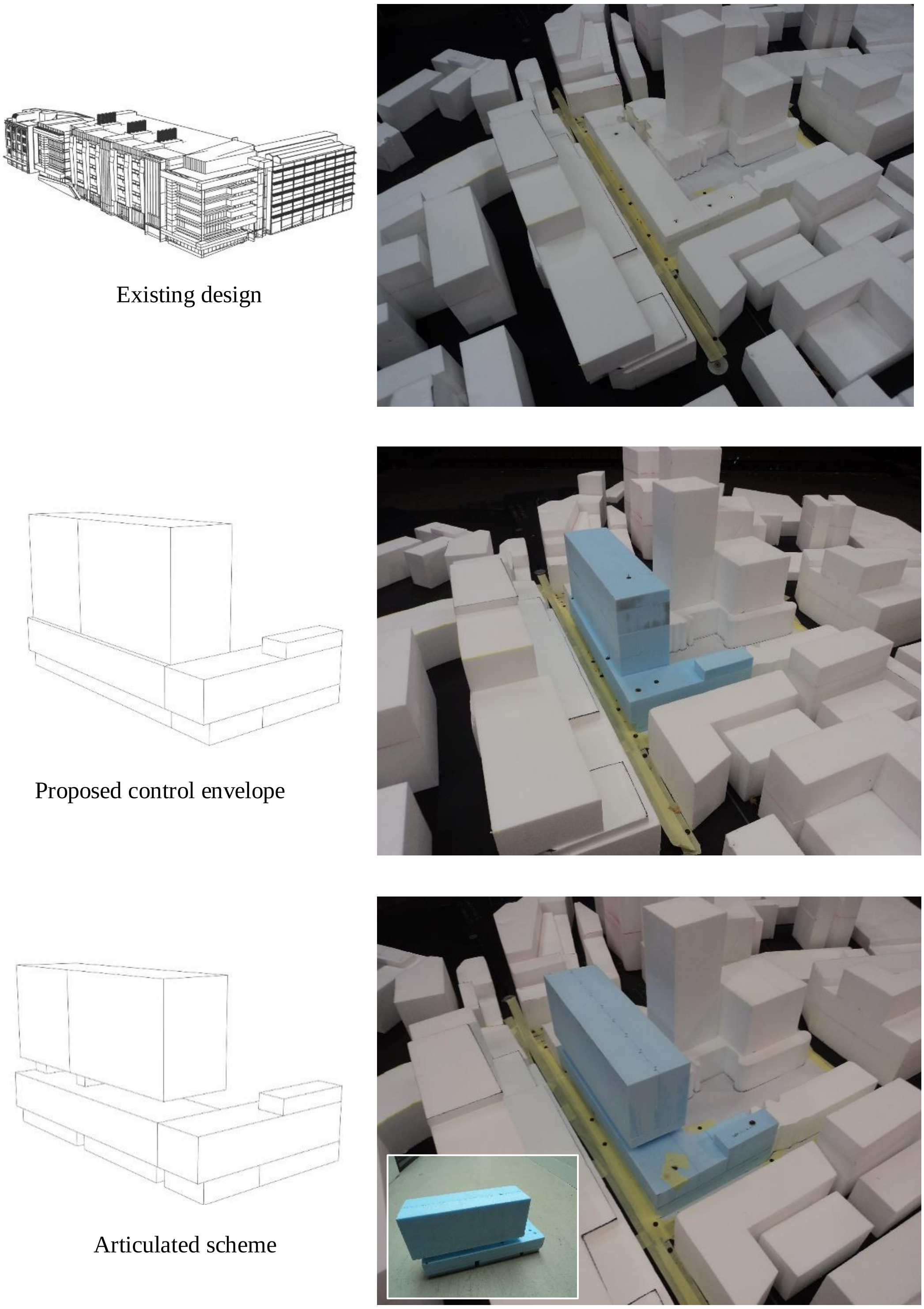

Figure 1: Schematic design and wind tunnel model for Existing design (T), Proposed control envelope (M), and Articulated scheme (B)

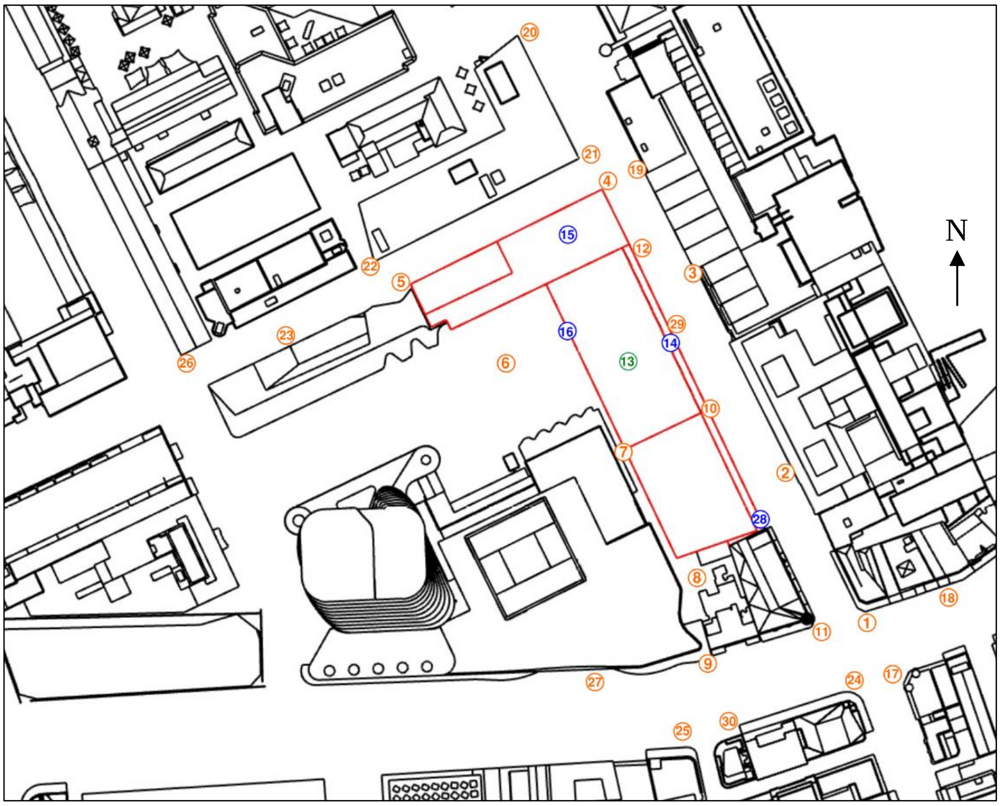

Figure 2: Testing points in and around the site

2.2 Wind assessment criteria

Vipac measured wind speeds at 30 locations and assessed wind conditions around the site based on their own comfort criteria. The wind assessment criteria used in the Vipac report are based on the directional maximum peak 3 s gust wind speeds occurring in an hour, once per annum, Table 1. This corresponds to a probability of 1 hour per annum event, 1/8760~0.0114%.

Table 1: Summary of wind effects on pedestrians based on Vipac criteria

Annual maximum 3 s gust speed	Result on perceived pedestrian comfort
> 23 m/s	**Unsafe** (frail pedestrians knocked over)
< 20 m/s	Acceptable for **fast walking** (waterfront or particular walking areas)
< 16 m/s	Acceptable for **walking** (steady steps for most pedestrians)
< 13 m/s	Acceptable for **standing** (window shopping, vehicle drop-off, queuing)
< 11 m/s	Acceptable for **sitting** (outdoor café, gardens, park benches)

The current City of Sydney (2012) DCP specifies wind effects not to exceed 10 m/s for active frontages, and 16 m/s for all other streets, Figure 3. There are few locations in Sydney that would meet the ‘active frontage’ criterion without significant shielding to improve the wind conditions.

From discussions with Council this reference wind speed is a once per annum gust wind speed similar to the wind criteria in City of Sydney 2004 DCP, but is meant to be interpreted as a comfort level criterion to promote outdoor activities and is not intended to be used as a distress requirement. The once per annum gust wind speed criterion used in the City of Sydney (2012) DCP is based on the work of Melbourne (1978), which is for the probability of the gust occurring in an hour of data for 0.1% of the time for any direction, or two peak storm events in a year. The 10 m/s level is classified as generally acceptable for pedestrian sitting, and the 16 m/s for pedestrian walking. The Melbourne criterion gives the 'once per annum gust wind speed', and uses this as an estimator of the general conditions at a site. The probabilistic comparison between the Vipac and City of Sydney (Melbourne) criteria based on a peak 3 s gust wind speed occurring in an hour is presented in Figure 15. The wind-tunnel data were re-analysed to account for the change in wind speed and probability between the Vipac and City of Sydney criteria.

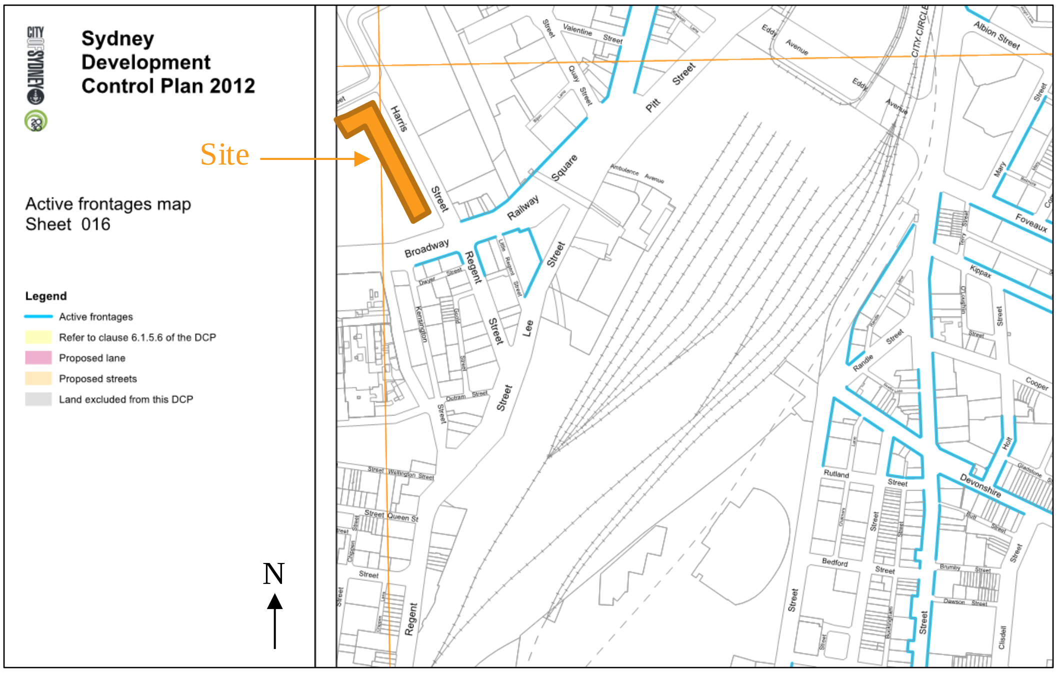

Figure 3: Active frontage map from City of Sydney DCP 2012

Table 2: Summary of wind effects on pedestrians based on Melbourne (1978) criteria

Max. 3 s gust wind speed occurring in an hour for 0.1% of the time in any wind direction	Result on perceived pedestrian comfort
> 23 m/s	**Unsafe** (frail pedestrians knocked over)
< 16 m/s	Acceptable for **walking** (steady steps for most pedestrians)
< 13 m/s	Acceptable for **standing** (window shopping, vehicle drop-off, queuing)
< 10 m/s	Acceptable for **sitting** (outdoor café, gardens, park benches)

Figure 4 shows a polar plot of directional wind speeds for a typical testing location overlayed with Melbourne wind comfort criteria indicated as dashed lines. The distance from the centre to a marker is an indication of wind speed and the direction to which a marker points, shows the wind direction. If a marker sits in between two criteria, it is classified as the upper bound for that particular direction. The classification of wind condition for the location is then determined based on the highest wind criteria amongst all markers for that particular model.

For example from Figure 4, for the proposed control envelope, the marker pointing to the direction between W and WNW determines the criteria which shows the wind conditions would exceed the walking criteria. For the articulated scheme, the marker pointing to W (i.e. winds from west) determines the criteria which is at the boundary of walking criteria. For the existing design, the marker pointing to S determines the criteria which is at the boundary of walking standing.

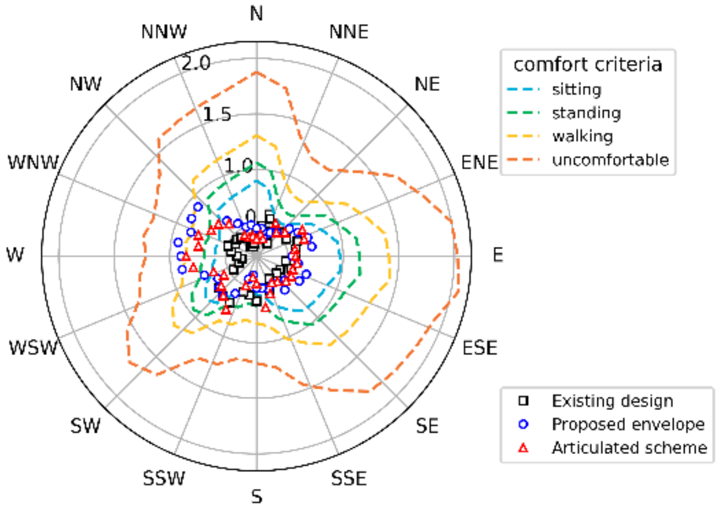

Figure 4: Comparison of directional wind speeds at a typical location with Melbourne criteria

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 the analysis to determine the probabilistic wind climate to transfer the data from the Vipac to the City of Sydney criteria. All the points have been reanalysed based on 0.1% exceedance wind speed and compared with the City of Sydney DCP 2012 criteria.

For assessing the effects of wind on pedestrians, neither the random peak gust wind speed, nor a mean wind speed in isolation are considered adequate. The gust wind speed gives a measure of the fluctuating turbulent nature of the wind, but the mean wind speed indicates the longer duration impact on pedestrians. The gust wind speed may be suitable for safety considerations, but not necessarily for serviceability comfort issues such as outdoor dining comfort. 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.

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 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, which is typically a factor of between 1.5 and 2, with a value of 1.85 generally used.

A comparison between various mean wind speed criteria from a probabilistic basis are presented in Figure 5 for a particular measured location. The horizontal coloured lines show the criteria with the symbols marking the upper wind speed for that type of activity. The solid coloured lines are typical results from wind tunnel testing, and where the results line cuts the criteria lines indicates the comfort classification for that location. For example, in Figure 5, the proposed control envelope (blue line) intersects with Lawson criteria (red horizontal line) in between siting and standing criteria; Therefore, the point is classified as suitable for standing type activities—based on the upper wind speed Lawson criteria. City of Auckland has control mechanisms for accessing usability of spaces from a wind comfort perspective as illustrated with the grey lines in Figure 5. It is evident that the Auckland comfort criteria are based on other assessment criteria as the lines cross similar points on the other criteria lines, but have the added benefit that they assess the location at all probabilities, which is exceptionally useful for planning. The City of Auckland safety criterion is specified as a once per annual maximum peak 3 s gust wind speed of 25 m/s, which is similar to a 0.1% of the time exceedance maximum 3 s gust wind speed of 23 m/s.

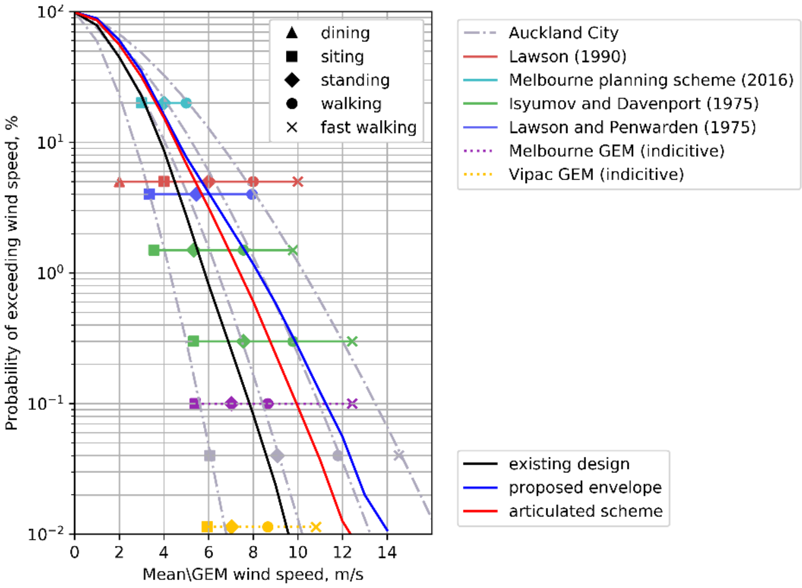

Figure 5: Probabilistic comparison between environmental criteria based on mean/GEM wind speeds

2.3 Discussion of results

The primary findings of the study are summarised in Table 3, which list the locations selected for investigation of pedestrian wind comfort, along with the comfort ratings achieved. A visual summary of the wind comfort classifications in and around the site for the existing design, proposed control envelope, and articulated scheme based on City of Sydney comfort criteria are shown in Figure 6 to Figure 8, respectively. The majority of locations would be classified as suitable for standing and walking type activities. All locations would pass internationally recognised wind safety criteria.

Table 3: Summary of target criteria and wind tunnel results

Description / Location		Target	Wind tunnel results					
		DCP 2012 criteria, 0.1% exceedance of gust wind speed (m/s)	Existing design		Proposed control envelope		Articulated scheme	
			DCP 2012 criteria, 0.1% exceedance of gust wind speed (m/s)	Meet Target	DCP 2012 criteria, 0.1% exceedance of gust wind speed (m/s)	Meet Target	DCP 2012 criteria, 0.1% exceedance of gust wind speed (m/s)	Meet Target
Ground Plane	1	10	16.3	N	14.5	N	15.8	N
	2	16	14.3	Y	14.6	Y	16.6	N
	3	16	12.7	Y	17.2	N	16.2	N
	4	16	12	Y	12.9	Y	11.9	Y
	5	16	10.6	Y	11.9	Y	12.3	Y
	6	16	14.4	Y	16.4	N	14.7	Y
	7	16	10.3	Y	11.3	Y	11	Y
	8	16	7.8	Y	11.5	Y	10.1	Y
	9	16	11.7	Y	11.4	Y	13.9	Y
	10	16	8.5	Y	10.4	Y	10.4	Y
	11	16	12.7	Y	12.1	Y	13.5	Y
	12	16	7.2	Y	11.1	Y	10.1	Y
	17	10	12.5	N	11.4	N	10.3	N
	18	10	13.8	N	12.6	N	14.2	N
	19	16	12	Y	12.4	Y	10.5	Y
	20	16	13.3	Y	12.4	Y	15.3	Y
	21	16	13.9	Y	11.7	Y	12.4	Y
	22	16	11.8	Y	13.1	Y	13.9	Y
	23	16	14.9	Y	13.1	Y	14.2	Y
	24	10	8.5	Y	10.5	N	11.6	N
	25	16	15.5	Y	15	Y	14.6	Y
	26	16	10.1	Y	9.9	Y	10.7	Y
	27	16	14.3	Y	13.9	Y	13.7	Y
	29	16	6.3	Y	10.5	Y	10.9	Y
	30	10	13.5	N	13.9	N	13.7	N
Sky Garden (Podium roof)	14		-		12.7		13.2	
	15		-		15.4		13.6	
	16		-		-		20.4	
	28		-		-		9.6	
Rooftop	13		-		18.8		19.3	

10 m/s	Pedestrian Siting (active frontage)
13 m/s	Pedestrian Standing
16 m/s	Pedestrian Walking (other streets)
23 m/s	Uncomfortable
>23	Dangerous

The 'Target' column in Table 3 is based on Figure 3. It is noted that in the existing design, the majority locations meet the intended target classification except for Location 1, on the north-east corner of Broadway and Harris Street.

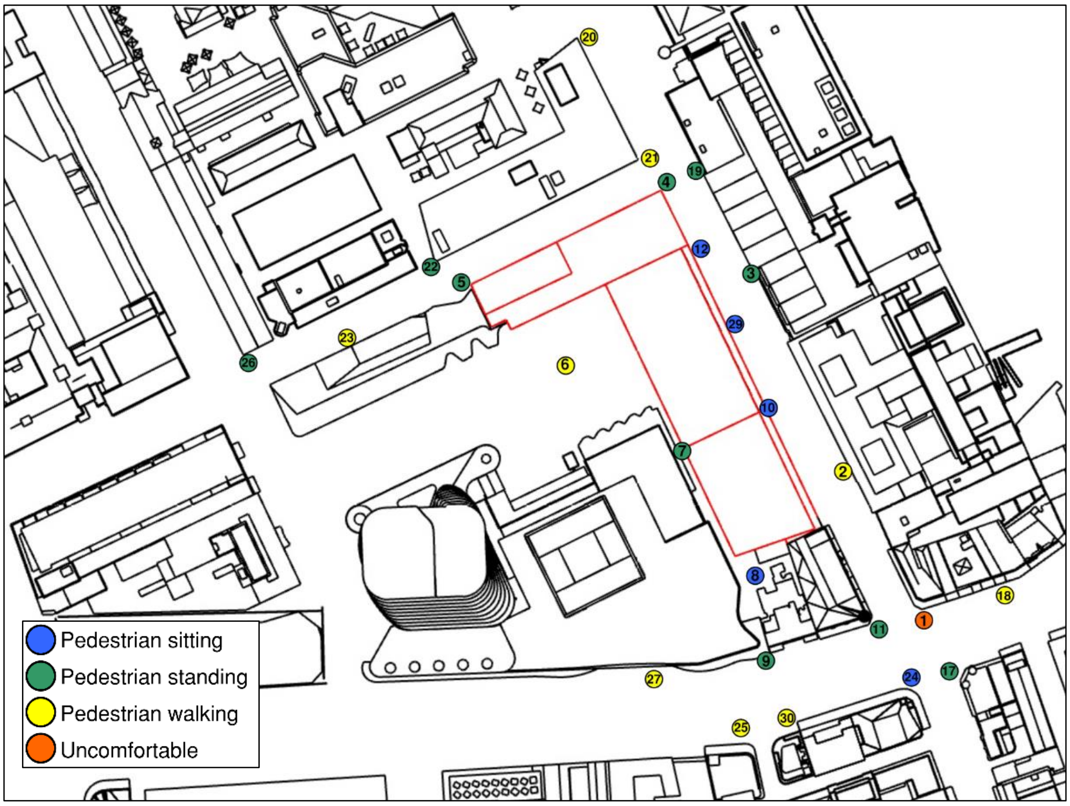

Figure 6: Pedestrian wind speed measurement location with comfort ratings — Existing design

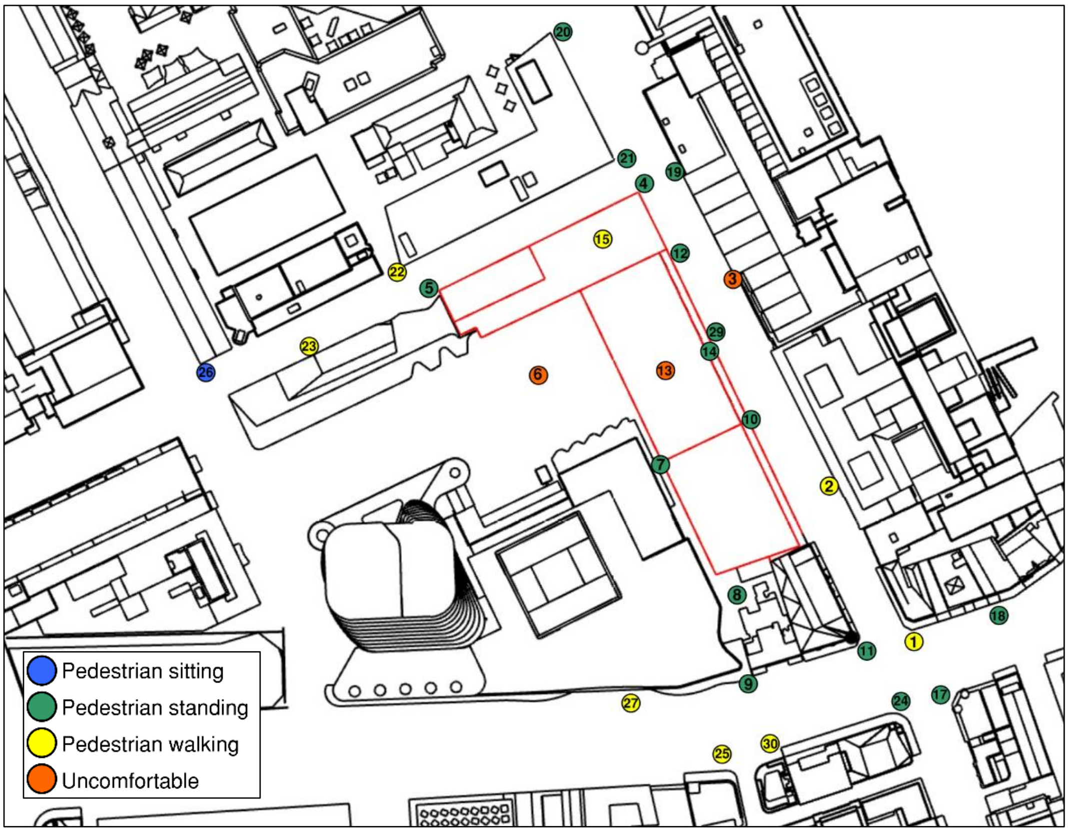

Figure 7: Pedestrian wind speed measurement location with comfort ratings — Proposed control envelope

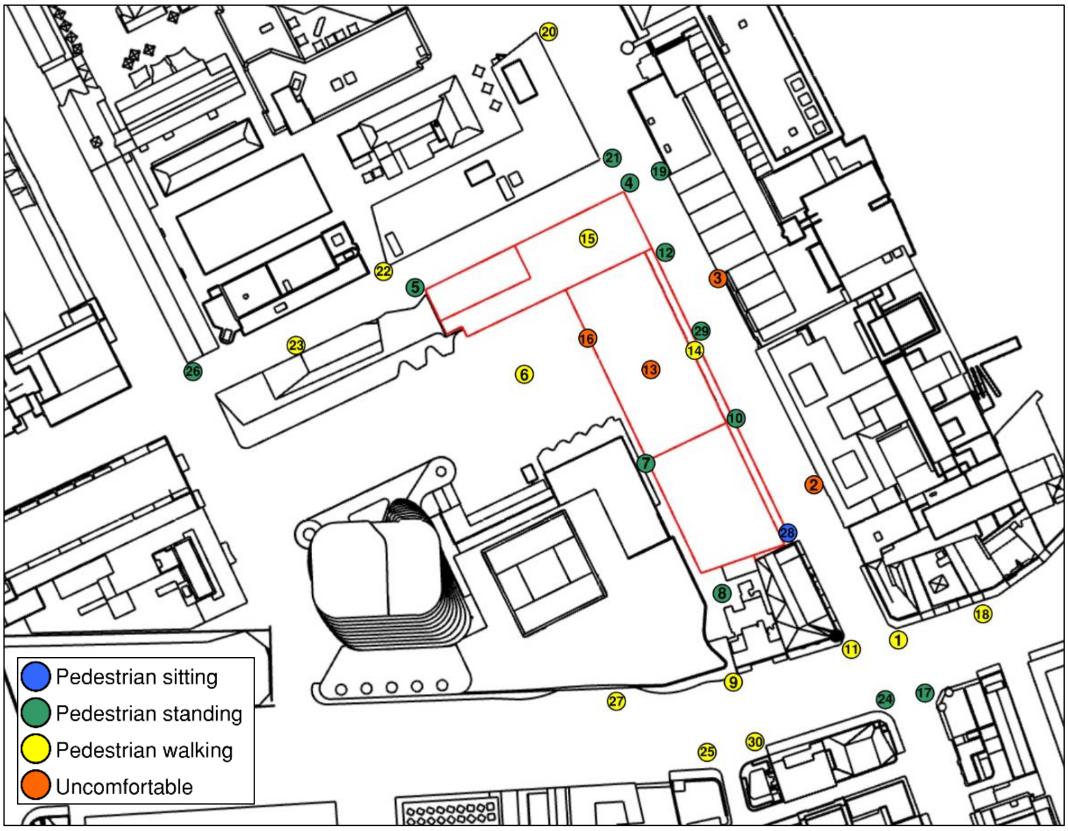

Figure 8: Pedestrian wind speed measurement location with comfort ratings — Articulated scheme

The strongest wind conditions at ground level were measured at Location 3 on the east side of Harris Street for winds from the west in the proposed control configuration, Figure 9(L). The change in wind conditions from the existing to proposed control configuration is caused by wind accelerating around the north side of the proposed tower component of the development, impinging on the buildings to the east and being redirected along Harris Street. It is evident from the measurements that this location would slightly exceed the walking criterion for one wind direction from the west quadrant. The wind conditions here would be similar to those currently experienced at Location 1 on the corner of Broadway and Harris Street, Table 3. The measured wind speeds for winds from the west in the articulated scheme are generally lower than the proposed control envelope, indicating that the sky garden helps mitigate the wind conditions along Harris Street for winds from the west, as it allows the flow to pass through the gap rather than diverted to pedestrian level.

The wind conditions at Location 2 is similar in the proposed control envelope and existing design and would tend to increase in the articulated scheme to the boundary of walking criteria. This is caused by the winds from the south impinging on the south façade of the cantilevered section which would then create downwash discharging to the opposite side of Harris Street at Location 2.

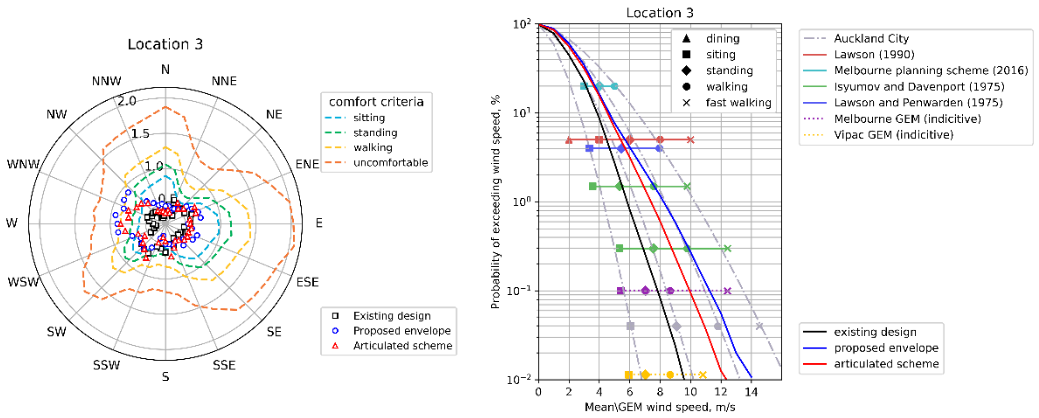

Figure 9: Wind condition at Location 3 compared with directional Melbourne criteria (L), and with integrated pedestrian wind criteria (R)

As described in the Section 2.2, the wind tunnel results have been directionally integrated and analysed on a probabilistic basis to compare with other well-established pedestrian comfort criteria commonly used across the world, Figure 9(R). With reference to the Auckland criterion, it is evident that above 1% of the time, the wind conditions at Location 3 would be classified as suitable for pedestrian walking, and at lower probabilities follows the criteria line. This indicates that the lower probabilities are not a reliable predictor of the more general wind conditions.

It is shown in Figure 10(R) that the wind conditions at Location 6 in Alumni Green would be classified as suitable for pedestrian standing type activities for the three models tested when compared with Lawson criteria, and suitable for walking relative to the Auckland criteria. This is considered suitable for this open public space. It is worth to note that the wind conditions for the existing design and proposed control envelope would be similar and would get better in the articulated scheme when compared with Lawson criteria, Figure 10(R).

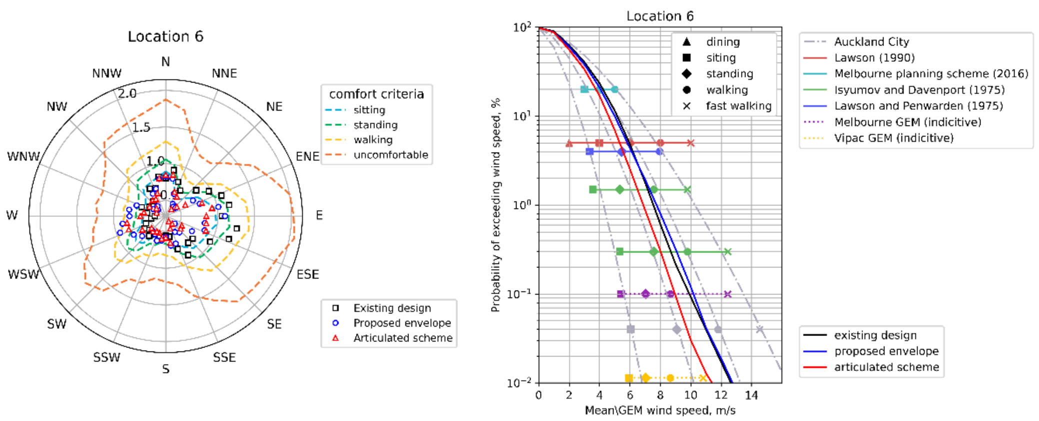

Figure 10: Wind condition at Location 6 compared with directional Melbourne criteria (L), and with integrated pedestrian wind criteria (R)

For Location 8, in the courtyard to the west of the heritage terraces, the proposed configurations would be classified as suitable for siting to standing type activities, Figure 11(R). These would satisfy the intended use of space.

The local amelioration incorporated at the detailed design stage, especially at podium level, would be expected to slightly impact the current classification of the wind conditions in and around the site. Therefore, mitigating strategies to reduce wind conditions in and around the site to a level acceptable for City of Sydney DCP could be achieved during the detailed design stage once the final geometry of the building is developed.

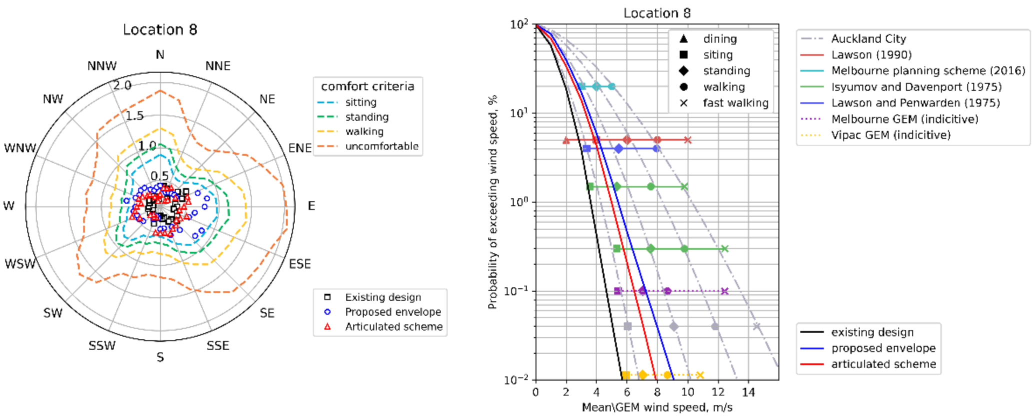

Figure 11: Wind condition at Location 8 compared with Melbourne criteria, directional (L), and with various pedestrian wind criteria, integrated (R)

The results at Location 1, on the east corner of Broadway and Harris Street, shows wind conditions in the existing design exceed the current DCP walking criteria. Both the proposed control envelope and articulated scheme indicate improved wind conditions at this location and is classified as suitable for pedestrian walking. None of the active frontage testing points (Locations 1, 17, 18, 24, and 30) meet the DCP criteria for all tested configurations; except location 24 in the existing design. The proposed control envelope and articulated scheme would generally make the condition in these locations less windy.

Based on the wind tunnel results for the tested models, we would expect that if the proposed control envelope changes to accommodate only the sky garden (without tower cantilevered section and with tower setback from the podium’s east façade), the wind conditions around the site on pedestrian level would be similar to the articulated scheme. Aligning the tower’s south façade to be in line with podium would make the wind conditions at Location 2 slightly reduced and shifted to the north. Also, the tower setback from podium’s east façade would make wind conditions in along the Harris Street slightly better for winds from the east quadrant.

As expected, the proposed control and articulated designs had a minimal impact on most locations further out of the site.

3 Summary

Arup have provided a quantitative assessment of the impact of the existing, proposed, and articulated designs on pedestrian wind comfort in and around the site.

Arup have provided the wind tunnel testing report conducted on the development, accompanied with an interpretative discussion on the impact of the proposed development on pedestrian wind comfort. The wind-tunnel data has been assessed against a range of environmental wind assessment criteria including those prescribed by the City of Sydney. It was shown that for the proposed and articulated designs the wind conditions at most locations are similarly classified. Location 3 on the east side of Harris Street would meet the non-active frontage walking criteria for all wind directions except one direction from west. For the articulated scheme, measured wind speeds at this location are lower than the proposed envelope, suggesting that the porous podium roof assists with mitigating wind conditions at this location. Location 2 in the articulated scheme and Location 6 in the proposed control envelope would have wind conditions at the boundary of walking criteria which would be similar to Location 1 in the existing design.

The measured wind conditions were generally found to be similar to the existing conditions with a few locations on the border of the non-active frontage criterion. The added massing changes the flow pattern around the site, resulting in some locations becoming more windy, and others calmer. It is considered that wind conditions generated by the general massing of the development would produce an environment suitable for the intended use of the space. It is evident that changes to the proposed control massing scheme would slightly affect the local wind climate and testing of the final architectural scheme would be recommended. All locations in and around the proposed development would pass the safety criterion.

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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 12. 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 12 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.

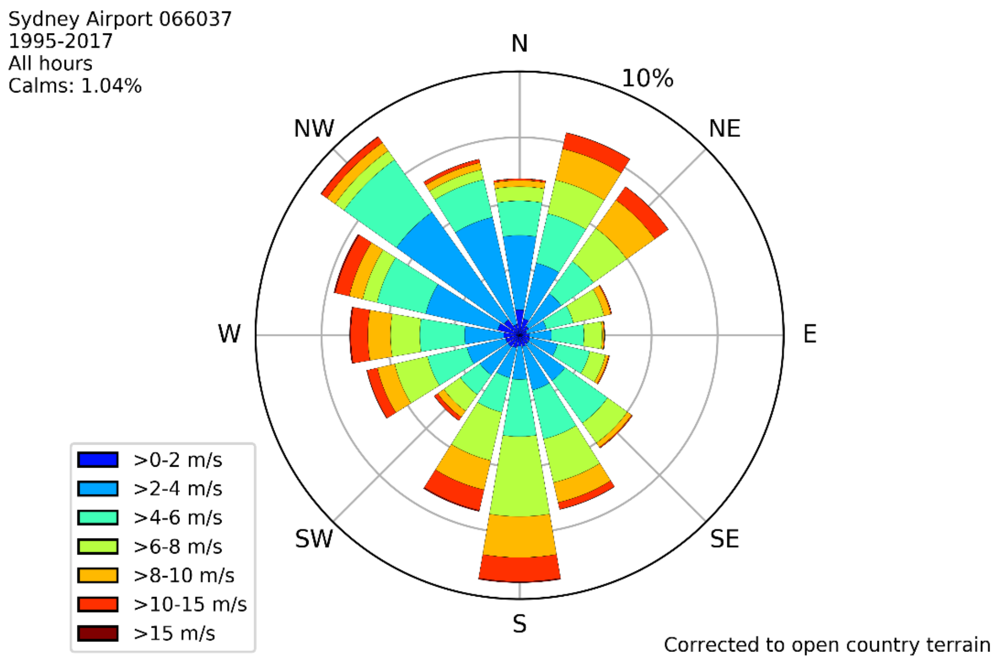

Figure 12: Wind rose showing probability of time of wind direction and speed

Appendix 2: 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 4. 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 4 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 13 and Figure 15. 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 13 with definitions of the intended use of the space categories defined in Figure 14.

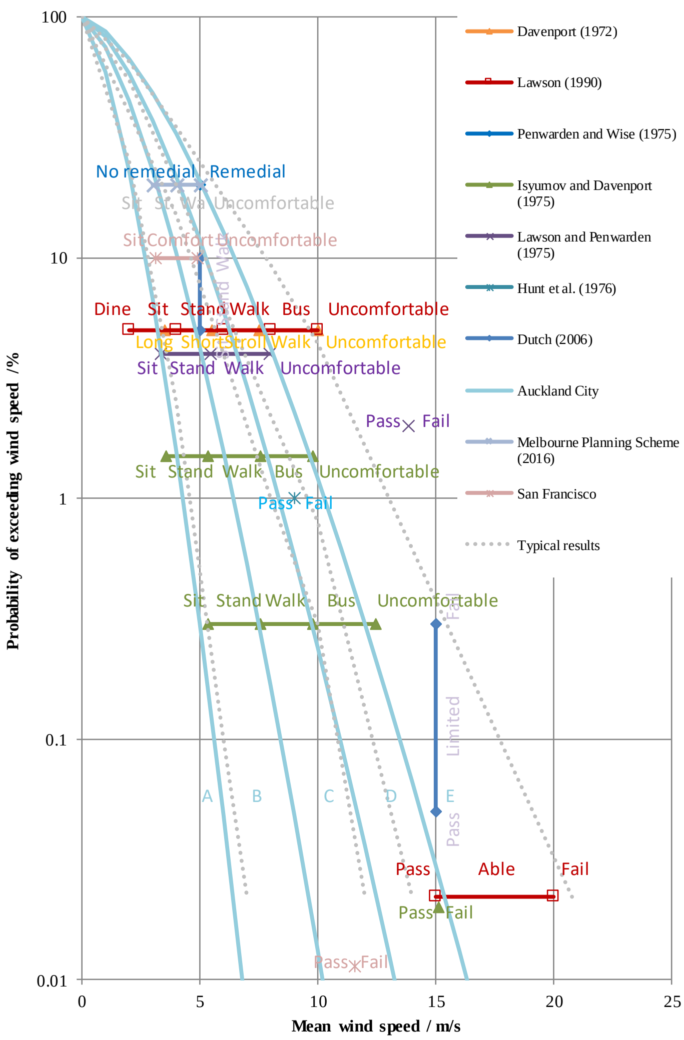

Figure 13: Probabilistic comparison between wind criteria based on mean wind speed

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 14: Auckland Utility Plan (2016) wind categories

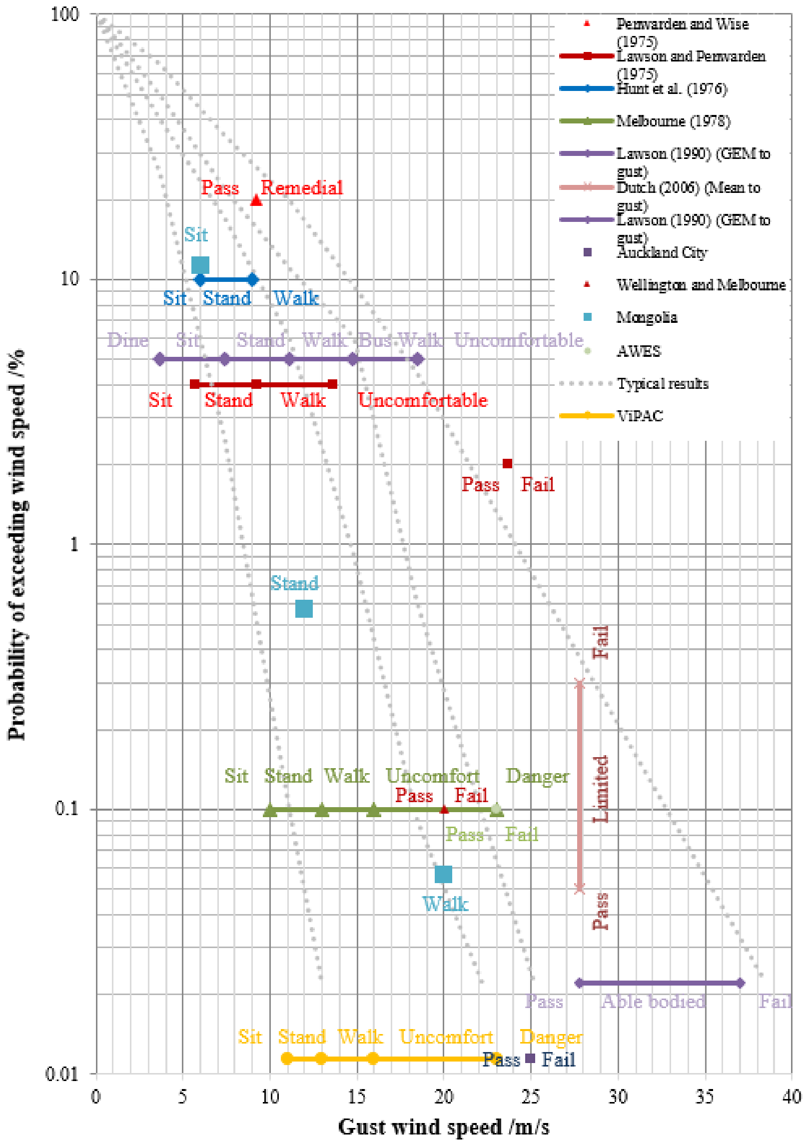

Figure 15: Probabilistic comparison between wind criteria based on 3 s gust wind speed

Appendix 3: Photographs of tested models

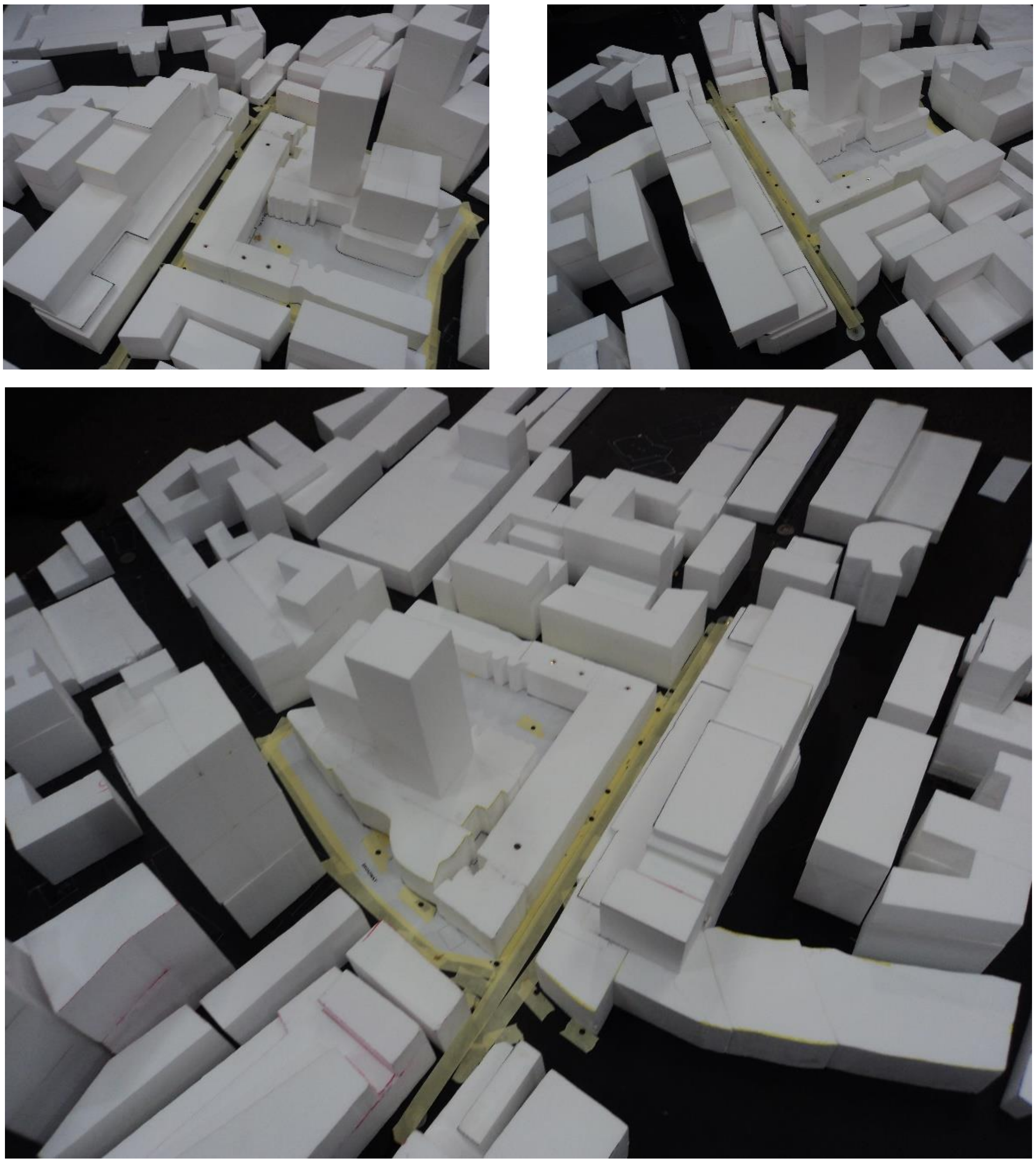

Figure 16: Closed-up photographs of the wind tunnel model: Existing design

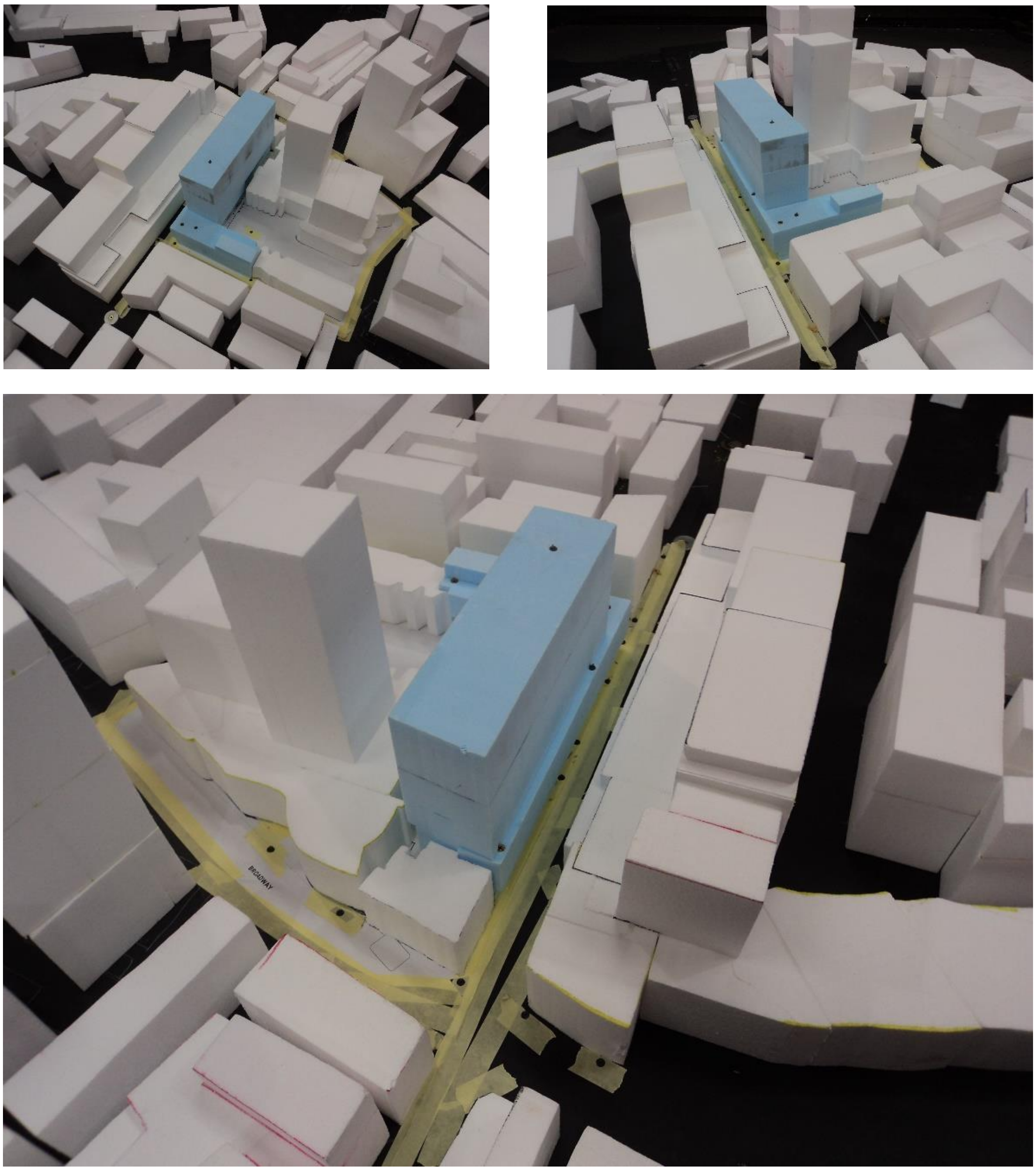

Figure 17: Closed-up photographs of the wind tunnel model: Proposed envelope

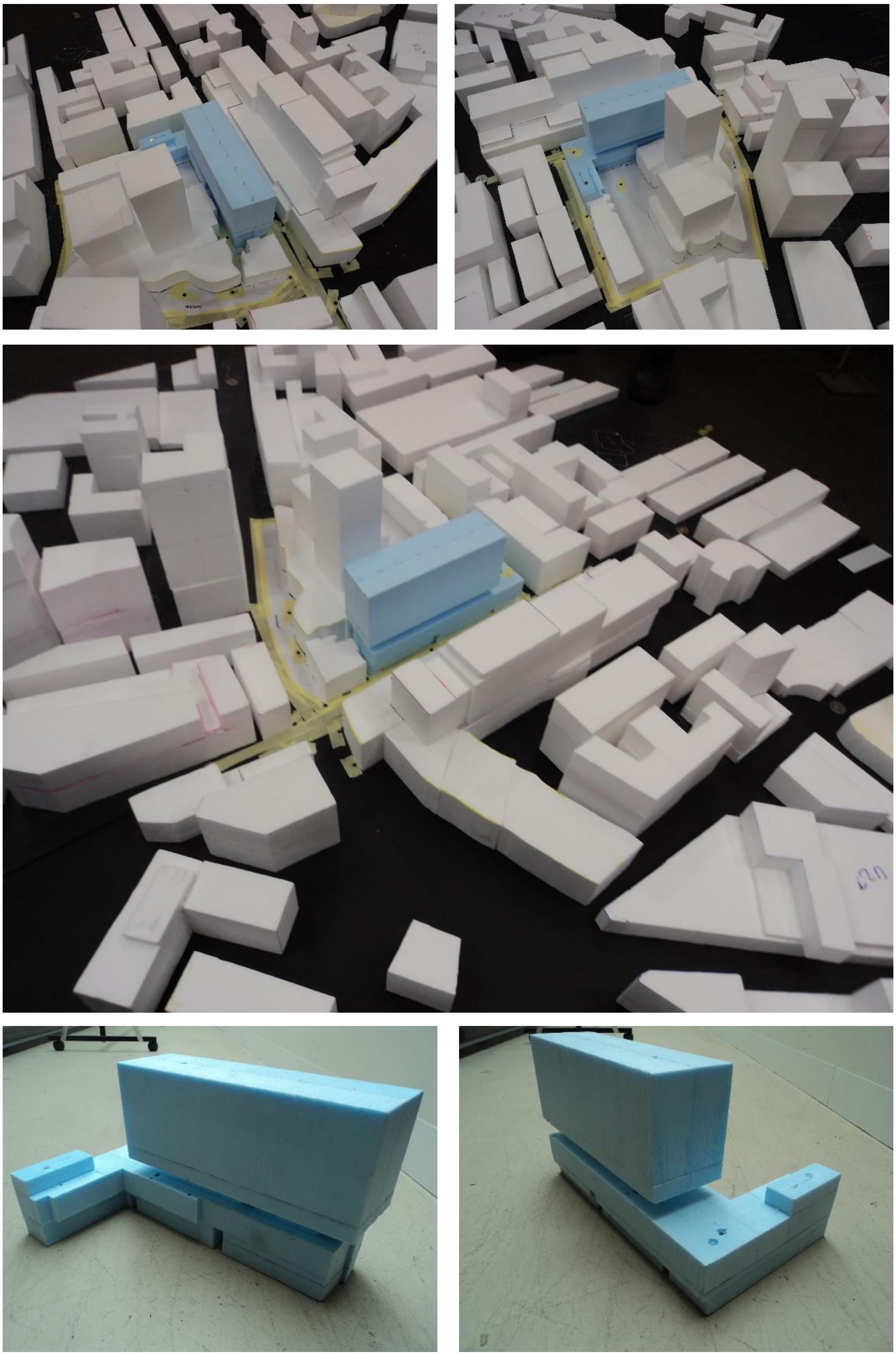

Figure 18: Closed-up photographs of the wind tunnel model: Articulated scheme

Appendix 4: Reference documents

In preparing the assessment, the following documents have been referenced to understand the building massing and features.

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Final Envelope with passages_Rhino Export.3dm	18/02/2019 9:08 AM

Appendix 5: Wind tunnel testing report

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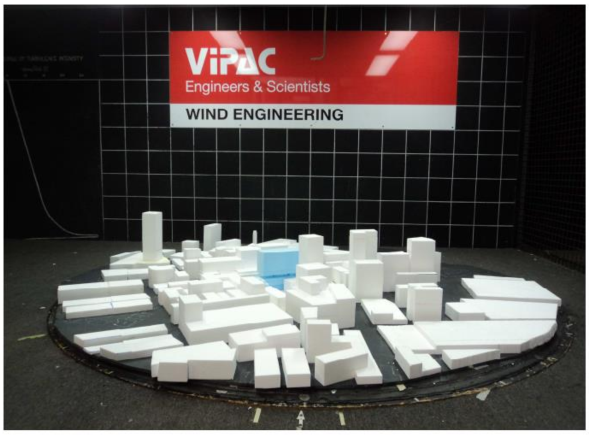
Vipac Engineers & Scientists

Arup Australia Pty Ltd

UTS Bon Marche Science Precinct

Pedestrian Level Winds - Wind Tunnel Test



30N-19-0027-TRP-6758281-1

14 March 2019

Melbourne • Sydney • Adelaide • Brisbane

VIPAC

Arup Australia Pty Ltd
UTS Bon Marche Science Precinct
Pedestrian Level Winds - Wind Tunnel Test

Report Title: Pedestrian Level Winds - Wind Tunnel Test
Job Title: UTS Bon Marche Science Precinct

DOCUMENT NO: 30N-19-0027-TRP-6758281-1	**REPORT CODE:** TRP
PREPARED FOR:	**PREPARED BY:**
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	Wind Group Leader	

REVISION HISTORY

Revision No.	Date Issued	Reason/Comments
0	6/03/2019	Initial Issue
1	14/03/2019	Minor amendment
2		

DISTRIBUTION

Copy No.______	**Location**	
1	Project	
2	Client (PDF Format)	Uncontrolled Copy
3		

KEYWORDS:

EXECUTIVE SUMMARY

Vipac Engineers & Scientists Ltd (VIPAC) has been commissioned by **Arup Australia Pty Ltd** to perform an assessment of pedestrian level winds for the proposed redevelopment at **UTS Bon Marche Science Precinct, Sydney**.

The model was constructed to drawings supplied by **Arup** in **Feb 2019**. The proposed development and surrounding buildings covering a circular area of approximately **500 m** radius were modelled at a **1:400** scale. The approaching mean and turbulent flows of Terrain Category 3 and 3.5 were modelled in the wind tunnel, as per AS/NZS 1170.2:2011.

The wind tunnel tests were carried out in the Boundary Layer Wind Tunnel Facility owned and operated by Vipac in Melbourne during March 2019.

A list of the drawings used to construct the wind tunnel test model and the updated drawings are provided in Appendix A of this report.

The findings of the wind tunnel assessment are summarised as below:

- With the proposed design and amended scheme, the adjacent footpaths fulfil the recommended walking comfort criterion. Some footpaths across the street (near Location 3) have wind speeds exceeding the walking criterion for a few wind directions, but met the “fast walking” criterion.
- The podium roof near Location 16 had unsafe wind conditions for the amended scheme. The rooftop had elevated wind conditions for both configurations. Wind control measures are necessary to be considered for these spaces.

As a general statement, educating residents about wind conditions at high level terraces during high-wind events and tying down loose lightweight furniture are highly recommended.

TABLE OF CONTENTS

1 INTRODUCTION

Vipac Engineers & Scientists Ltd was commissioned by **Arup Australia Pty Ltd** to carry out an assessment of the likely wind conditions for the proposed development at **UTS Bon Marche Science Precinct, Sydney** based on wind tunnel testing.

The proposed design is the redevelopment to the existing building at the intersection of Harris and Thomas Streets. The proposed design has an approximate height of 80 m from ground level. The site is bounded by Harris Street to the east, Thomas Street to the north, and existing developments to the other directions.

The site plan of the proposed development is shown in Figure 1 and the satellite image of the proposed development site is shown in Figure 2.

This report details the pedestrian level wind assessment results of the tests carried out on a 1:400 scale model of the proposed development in Vipac's Boundary Layer Wind Tunnel in Melbourne, during March 2019. The results show the wind effects in ground level public areas adjacent to the development as proposed.

The pedestrian wind environment study of the development was conducted using Omni-directional pressure sensor techniques to predict wind velocities. The study investigated safety and comfort in ground level pedestrian access-ways adjacent to the project.

The model was constructed to drawings supplied by **Arup** in **Feb 2019**. Figure 3 and Figure 4 shows east elevation proposed and amended perspective view. Figure 5 to Figure 7 show the 1:400 scaled models in the wind tunnel. Complete lists of the drawings used to construct the model are provided in Appendix A of this report.

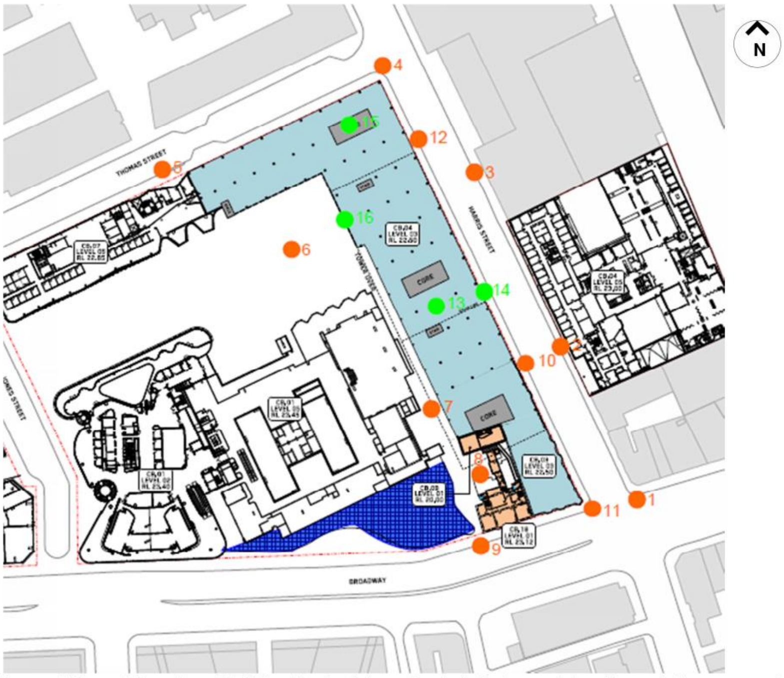


Figure 1: Proposed Ground Floor plan of UTS Bon Marche Science Precinct, Sydney and Arup Suggested measurement locations

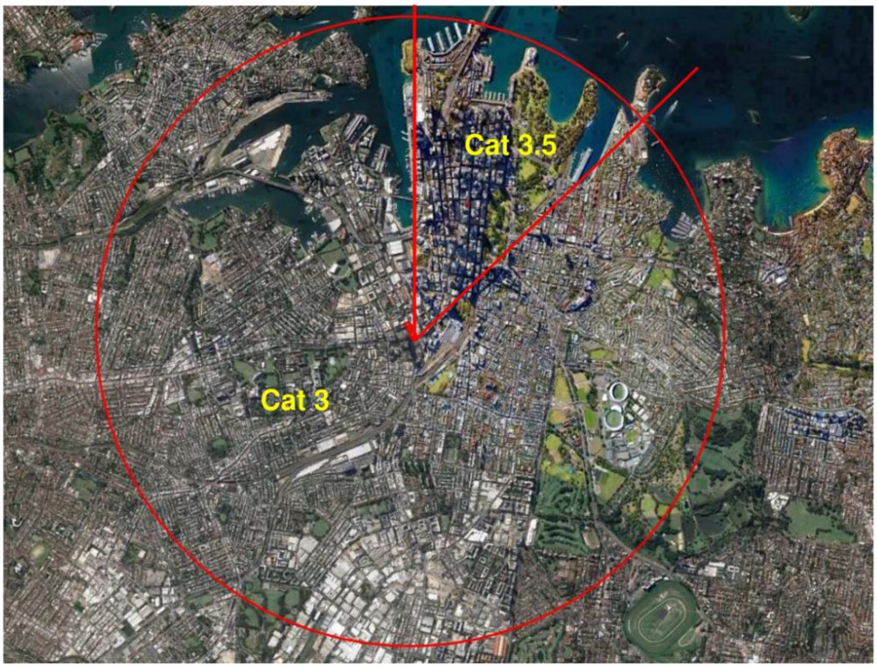
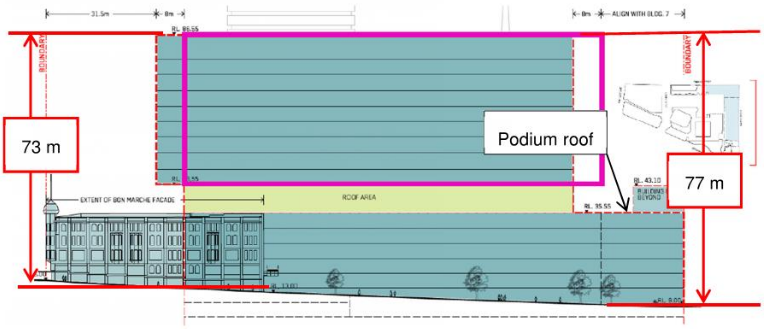


Figure 2: Satellite image of the proposed development site and surrounding terrain.



East elevation

Figure 3: East Elevation with the approximate height of the tower overlaid in meters (m)

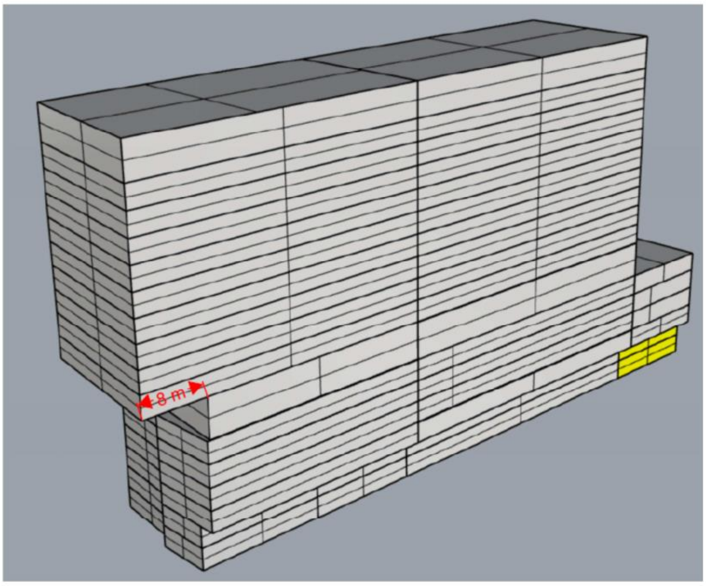


Figure 4: Perspective view of the amended scheme

Figure 5: Overall view from the north of the 1:400 scale model of the proposed redevelopment in the wind tunnel

Figure 6: Close up view from the North East of the 1:400 scale model of the proposed redevelopment in the wind tunnel

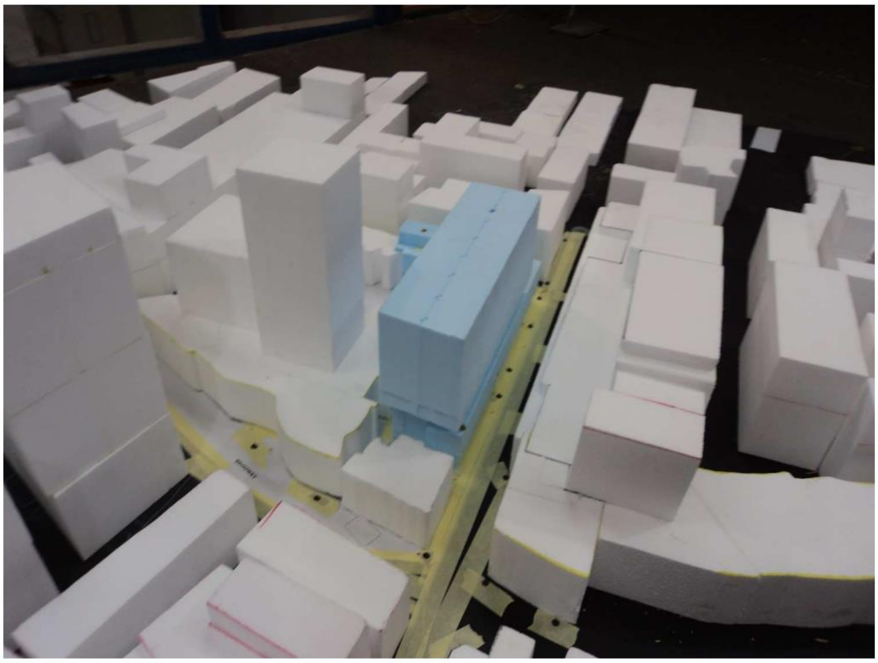


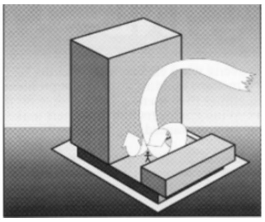
Figure 7: Close up view from the South East of the 1:400 scale model of the amended scheme in the wind tunnel

1.1. ENVIRONMENTAL WIND EFFECTS

Atmospheric Boundary Layer

As wind flows over the earth it encounters various roughness elements and terrain such as water, forests, houses and buildings. To varying degrees, these elements reduce the mean wind speed at low elevations and increase air turbulence. The wind above these obstructions travels with un-attenuated velocity, driven by atmospheric pressure gradients. The resultant increase in wind speed with height above ground is known as a wind velocity profile. When this wind profile encounters a tall building, some of the fast moving wind at upper elevations is diverted down to ground level resulting in local adverse wind effects.

The terminology used to describe the wind flow patterns around the proposed Development is based on the aerodynamic mechanism, direction and nature of the wind flow.

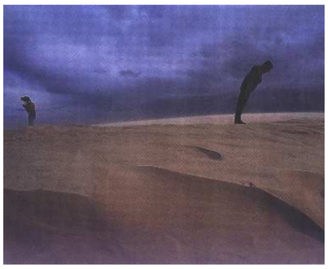


Downwash – refers to a flow of air down the exposed face of a tower. A tall tower can deflect a fast moving wind at higher elevations downwards.

Corner Accelerations – when wind flows around the corner of a building it tends to accelerate in a similar manner to airflow over the top of an aeroplane wing.

Flow separation – when wind flowing along a surface suddenly detaches from that surface and the resultant energy dissipation produces increased turbulence in the flow. Flow separation at a building corner or at a solid screen can result in gusty conditions.

Flow channelling – the well-known "street canyon" effect occurs when a large volume of air is funnelled through a constricted pathway. To maintain flow continuity the wind must speed up as it passes through the constriction. Examples of this might occur between two towers, in a narrowing street or under a bridge.



Direct Exposure – a location with little upstream shielding for a wind direction of interest. The location will be exposed to the unabated mean wind and gust velocity. Piers and open water frontage may have such exposure.

2 REGIONAL WIND CLIMATE

The mean and gust wind speeds have been recorded in the Sydney area for over 30 years. These data have been analyzed and the directional probability distribution of wind speeds has been determined. The directional distribution of hourly mean wind speed at the reference height (about 500 m), with a probability of occurring once per year (i.e. 1 year return period) is shown in Figure 8. The wind data at this free stream height is common to all Sydney city sites and may be used as a reference to assess ground level wind conditions at the site.

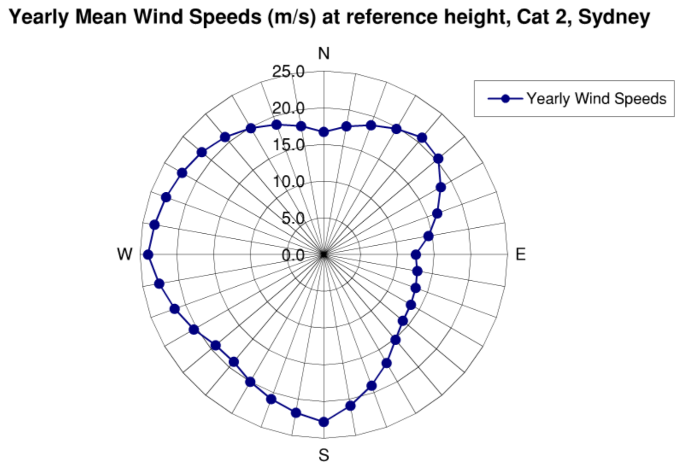


Figure 8: Directional distribution of annual return period mean hourly wind velocities (m/s) at the reference height for Sydney

3 ASSESSMENT CRITERIA

Vipac's assessment criteria for pedestrian wind comfort are based on some consensus of international opinion. A set of annual maximum peak 3-second gust velocities is derived from meteorological data for the geographical location under consideration, for each wind direction to be assessed. For all of these possible wind directions and speeds, the regions where each of the wind speed criteria may be exceeded are then considered.

Most people will consider a site unacceptable for a given activity if the mean and/or gust velocities in that area during the annual maximum wind event exceed the annual maximum wind speed criterion for that activity. The site would also be likely to be considered excessively windy for that activity during more moderate winds.

The threshold gust velocity criteria are:

Table 1: Gust Velocity Criteria - Recommended Wind Speeds for Comfort and Safety

Annual Maximum Gust Speed	Result on Perceived Pedestrian Comfort
>23m/s	Unsafe (frail pedestrians knocked over)
<20m/s	Acceptable for **fast walking** (waterfront or particular walking areas)
<16m/s	Acceptable for **walking** (steady steps for most pedestrians)
<13m/s	Acceptable for **standing** (window shopping, vehicle drop off, queuing)
<11m/s	Acceptable for **sitting** (outdoor cafés, gardens, park benches)

In a similar manner, a set of hourly mean velocity criteria with a 0.1% probability of occurrence are also applicable to ground level areas in and adjacent to the proposed Development. An area should be within both the relevant mean and gust limits in order to satisfy the particular human comfort and safety criteria in question.

The threshold mean velocity criteria are:

Table 2: Mean Velocity Criteria - Recommended Wind Speeds for Comfort and Safety

Mean wind speed exceeded 0.1% of the time	Result on Perceived Pedestrian Comfort
>15m/s	Unsafe (frail pedestrians knocked over)
<13m/s	Acceptable for **fast walking** (waterfront or particular walking areas)
<10m/s	Acceptable for **walking** (steady steps for most pedestrians)
<7m/s	Acceptable for **standing** (window shopping, vehicle drop off, queuing)
<5m/s	Acceptable for **sitting** (outdoor cafés, gardens, park benches)

The Development Control Plan 2012 for Sydney specifies that the streets adjacent to the development are to be considered as other streets (Figure 9) where the following wind criteria apply (section 3.2.6):

- *Development must not create a ground level environment where additional generated wind speeds exceed:*
  - *10 metres per second for active frontages as shown on the Active frontages map; and*
  - *16 metres per second for all other streets.*

It is noted the above 16 m/s for other streets corresponds to Vipac Walking criterion.

Figure 9 Proposed development site in Street zone division of DCP 2012

3.1. APPLICABLE CRITERIA

The following table lists the specific areas adjacent to the development and the corresponding recommended criteria. We have combined our general criteria with the requirements from DCP 2012. (see Figure 10).

Table 3: Recommended application of criteria

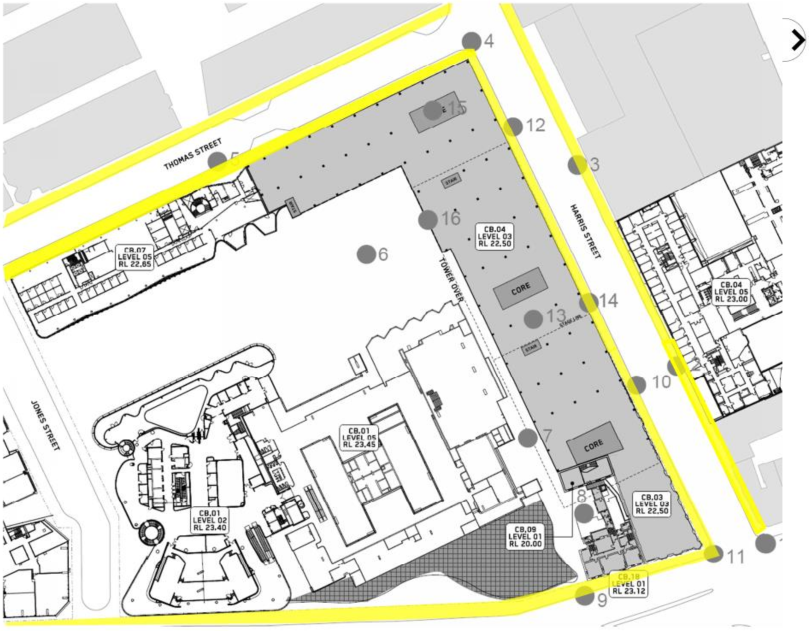
Area	Specific location	Recommended Criteria
Public Footpaths and Access ways	Around the proposed development on Thomas Street and Harris Street (Figure 9)	Within Walking
Terraces	Podium roof and roof top	Within Walking(See discussion below)

TERRACE / BALCONY AND ROOFTOP AREAS RECOMMENDED CRITERION DISCUSSION

Communal Terraces are proposed on podium roof and rooftop. Vipac recommends as a minimum that balcony/rooftop terrace areas meet the criterion for walking since:

- these areas are not public spaces;
- the use of these areas is optional;
- many similar developments in Melbourne and other Australian capital cities experience wind conditions on balconies and elevated deck areas in the vicinity of the criterion for walking.

However, it should be noted that meeting the walking criterion on elevated recreation areas will be no guarantee that occupants will find wind conditions in these areas acceptable at all times.



Recommended to fulfil Walking

Figure 10: Plan view of the ground level of the proposed development with the recommended wind criteria overlaid.

4 WIND TUNNEL SIMULATION

4.1 SIMILARITY REQUIREMENTS

The validity of wind tunnel testing relies on the similarity between model and full-scale parameters. This requires undistorted length scaling (ie. geometric similarity), similarity of flow parameters (i.e. kinematic similarity) and finally similarity of pressures and forces.

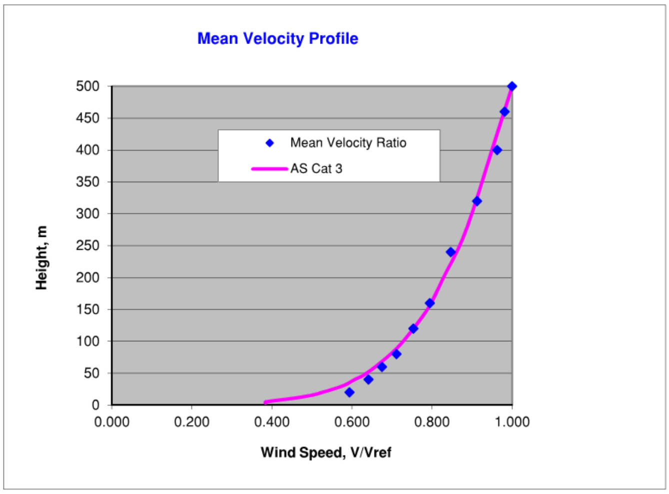
Complete similarity is usually impossible to obtain because of the competing requirements of the various non-dimensional parameters, (e.g. Reynolds Number, Rossby Number and Richardson Number). Some requirements (i.e. Reynolds Number equality) can be waived for sharp edged structures immersed in a neutrally stable atmospheric boundary layer and geometric and kinematic similarity suffice. These are the requirements specified in Section C1.4, AS/NZS 1170.2 Supplement 1: 2011 [4] and are employed in this study.

4.2 APPROACH WIND SIMULATION

The wind effects tests were carried out in the 3m wide × 2m tall × 16m long Boundary Layer Wind Tunnel at Vipac Engineers and Scientists Ltd in Melbourne. The Boundary Layer Wind Tunnel is designed to simulate the flow incident on a proposed development by modelling the upstream terrain characteristic roughness. To this end, an estimate of the upstream terrain properties for the Development has been made and reproduced in the wind tunnel.

The approaching mean and turbulent flows of the Terrain Category 3 and 3.5 Atmospheric Boundary Layer was modelled based on Australia Standard AS 1170.2-2011 (Figure 2). The wind tunnel calibration velocity and turbulence intensity profiles for Terrain Category 3 for the azimuth directions of 50º-360º and Terrain Category 3.5 for all other directions are shown in Figure 11 and Figure 12. These represent the wind velocity and turbulence intensity profiles approaching the model of the development. Closer to the ground the wind moves more slowly but with increased turbulence. The simulated approach is indicative of full-scale planetary boundary layer velocity and turbulence intensity profiles.

The velocity correction factors (0.93 for Cat 3.5 and 0.98 for Cat 3 profiles) were used to ensure that the roof height wind speeds match the expected full-scale values.



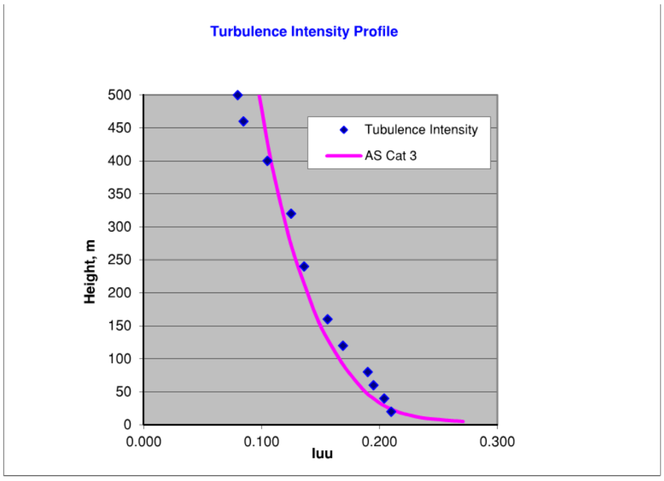
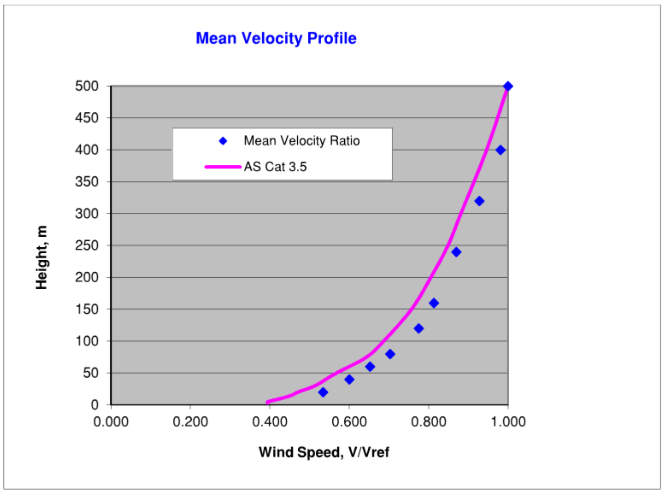


Figure 11: Mean Velocity and Turbulence Intensity Profiles for Terrain Category 3 (1:400 scale).



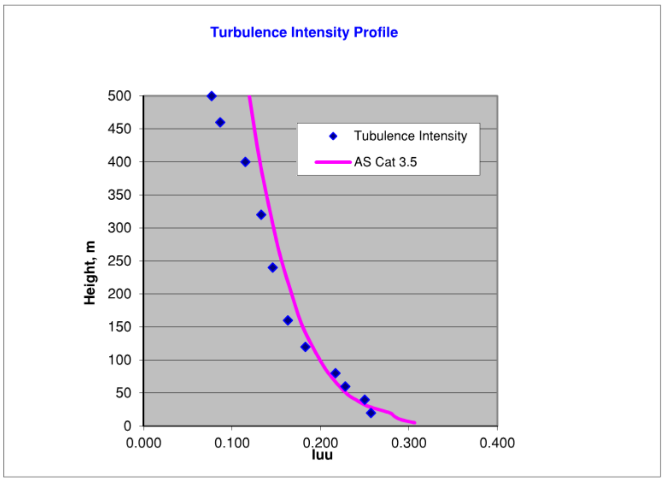


Figure 12: Mean Velocity and Turbulence Intensity Profiles for Terrain Category 3.5 (1:400 scale).

5 TEST PROCEDURE

The pedestrian wind environment in the footpath areas adjacent to the development were assessed using omnidirectional pressure sensor tests (point method) [4].

5.1 OMNIDIRECTIONAL PRESSURE SENSORS

Velocity measurements were made using Irwin sensors (omnidirectional pressure sensors) installed at various locations in the adjacent ground level footpath areas, selected podium roof and rooftop terraces and some areas neighbouring the proposed Development.

The distribution of Irwin sensors has allowed the determination of the variation in velocity over the surface of the model sufficient to capture the changes in velocity distribution that can typically occur over such areas. The resolution of measurement locations is in accordance with that prescribed in the Wind Tunnel Testing Quality Assurance Manual of the Australasian Wind Engineering Society.

PVC tubes with 1.5 mm internal diameter linked the Irwin sensors to pressure transducer device using a tuned arrangement to prevent harmonic fluctuations.

Velocity measurements were obtained at 10° wind azimuth increments starting from 0° (N) for a full 360° circle. The sampling time is determined based on the similarity criteria and corresponds to a total time of one hour in full scale. Statistical analysis was carried out on the signals for the mean and standard deviation. All velocity coefficients derived from the wind tunnel were converted to velocities by integrating the data with the Sydney wind climate and corresponding to a 1-year return period design wind speeds.

6 PEDESTRIAN LEVEL WIND ASSESSMENT

The pedestrian level wind assessment of the adjacent footpath areas of the proposed development was determined using omnidirectional pressure sensor test.

A total of 30 sensors were used to determine the adjacent wind environment - 16 sensors according to Arup recommended measurement locations on the surrounding footpaths and podium/rooftop areas (Locations 1-12 at ground level; Location 13 on the rooftop; Locations 14, 15 and 16 on the podium roof). Another 14 sensors (Locations 17 to 30) were added at the footpaths across the street and further away from the proposed site. The tests were conducted for full 360° with 10° resolution.

The test sensor locations (overlaid on the plans) are shown in Figure 13.

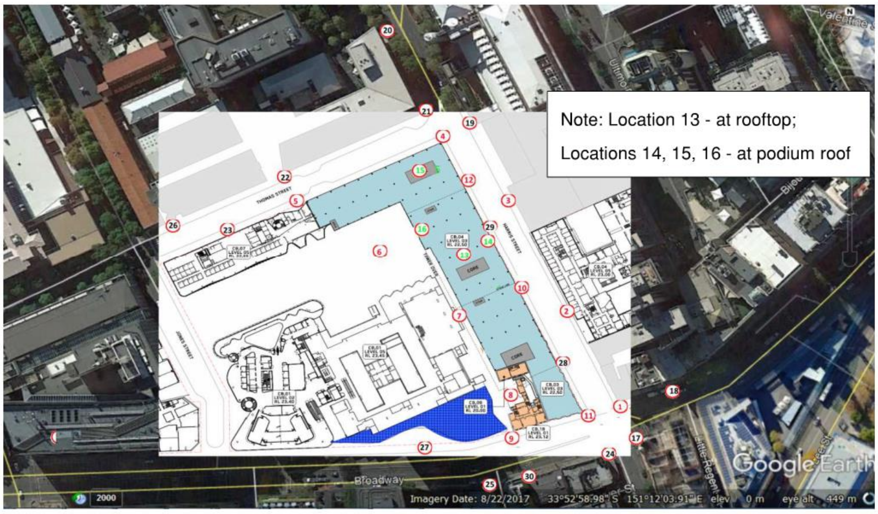


Figure 13: Sensor Numbers and Locations of the proposed development and surroundings.

7 RESULTS AND DISCUSSION

The pedestrian wind environment in the footpath areas adjacent to the development was assessed using omnidirectional pressure sensor test. The results of omnidirectional pressure sensor tests are presented as polar plots for the gust wind speeds and are shown in Appendix B of this report. Figure 14 shows an example of these plots for Location 15. In the Figure, the colour circles represent the velocities for the different criteria and the three sets of data points represent the test predicted gust velocity for the 36 directions. The required criterion is labelled under the plot title.

The plot shows that Proposed Design and Amended Scheme would have significant different wind conditions on the podium roof near Location 15.

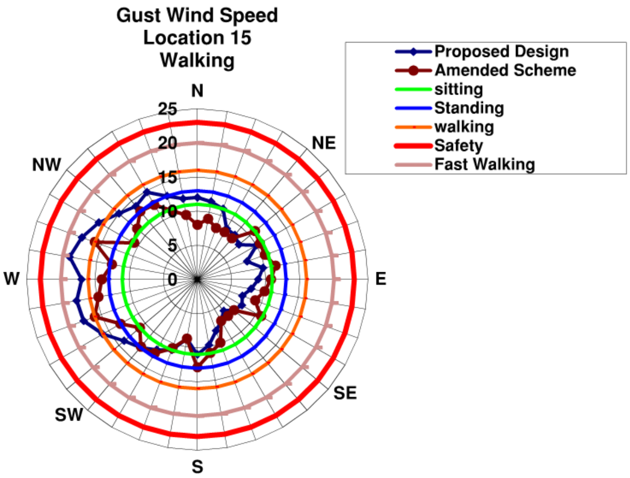


Figure 14: Polar plot of test predicted wind gusts overlaid with different criteria (Location 15)

Two main tests (**safety and comfort**) were conducted during the testing.

For the comfort test, three configurations were tested, namely:

- Configuration 1: The proposed Design;
- Configuration 2: The amended scheme; and
- Configuration 3: The existing building at the site.

All tests were conducted without street landscaping.

Based on the tests conducted, the following points were observed.

1) Safety test

Test showed that all ground level test locations met the safety criterion for all wind directions with the proposed design. The podium rooftop near Location 16 had wind levels exceeding the safety criterion for the amended scheme and requires mitigation solutions to reduce wind levels to within safety and comfort criteria levels.

2) Comfort test

GROUND FLOOR

Footpath adjacent to the proposed development: With the proposed design in both Configurations 1 and 2, wind conditions at most footpaths around the proposed development met the wind comfort criterion for walking. The maximum velocity was observed at Location 3 which has one wind direction with speeds exceeding the walking criterion for the amended scheme and a few wind directions in the westerly sector exceeding the walking criterion for the proposed scheme.

Locations 1, 17, 18, 24, 25 and 30 are located in Active frontage Streets at which 10 m/s wind speed limit is required in DCP 2012 Sydney. At these locations, wind speeds exceeded 10 m/s limit for most directions. However, both the proposed design and amended scheme would have similar wind conditions to the existing conditions. As such, the proposed redevelopment would not create additional adverse wind effects to these areas.

PODIUM ROOF

Location 16 measured gust wind speeds over the safety criterion for the amended scheme. High parapet or balustrade (≥1.8 m) and windscreens might be necessary to rectify this at detail design stage.

TOWER ROOFTOP

The tower rooftop had high wind conditions for both configurations, reaching the safety criterion for some westerly directions. High parapet or balustrade (≥1.8 m) and localized windscreens or landscaping could be considered as wind control measures at detail design stage.

7.1 RECOMMENDATIONS

Tests showed that wind conditions at all ground level locations generally met the recommended criteria. Vipac makes no recommendations to ground floor pedestrian level winds.

However, for the amended scheme, the podium roof near Location 16 would experience unsafe high wind conditions. High parapet or balustrade (≥1.8 m) and windscreens might be needed to rectify this at the detail design stage.

The tower rooftop would have high wind conditions for both Configurations, and wind control measures would be necessary to be considered at detail design stage.

8 CONCLUSIONS

Vipac has carried out an assessment of the pedestrian level winds for the proposed redevelopment at **UTS Bon Marche Science Precinct, Sydney** based on a scaled wind tunnel test.

The wind environments in the adjacent ground level footpath areas of the proposed development were tested. Some locations neighbouring the proposed building and across streets were also tested.

Wind conditions in these areas have been assessed based on internationally accepted comfort and safety criteria. The following conclusions are drawn from this analysis:

- With the proposed design and amended scheme, the adjacent footpaths fulfil the recommended walking comfort criterion. Some footpaths across the street (near Location 3) have wind speeds exceeding the walking criterion for a few wind directions, but met the “fast walking” criterion.
- The podium roof near Location 16 had unsafe wind conditions for the amended scheme. The rooftop had elevated wind conditions for both configurations. Wind control measures are necessary to be considered for these spaces.

As a general statement, educating residents about wind conditions at apartment balconies/terraces during high-wind events and tying down loose lightweight furniture are highly recommended.

This Report has been Prepared

For

Arup Australia Pty Ltd

By

VIPAC ENGINEERS & SCIENTISTS LTD.

9 REFERENCES

1) Australian/New Zealand Standard 1170.2:2002, Wind actions
2) Melbourne, W. H., "Criteria for Environmental Wind Conditions", Jour. Industrial Aerodynamics, Vol. 3, 241-249,1978
3) Simiu E, Scanlan R, "*Wind Effects on Structures*". Wiley-Interscience
4) Aynsley R., Melbourne W., Vickery B., *Architectural Aerodynamics* Applied Science Publishers

Appendix A DRAWING LISTS

Drawings Received: Feb 2019

Name	Date modified
Site Model + Envelope	14/02/2019 1:46 PM
Final Site+Envelope_DWG Export	14/02/2019 1:46 PM
Amended configuration-UTS Bon Marche	14/02/2019 4:13 PM
measuring points - UTS Bon Marche	14/02/2019 4:13 PM
Test points	14/02/2019 4:13 PM

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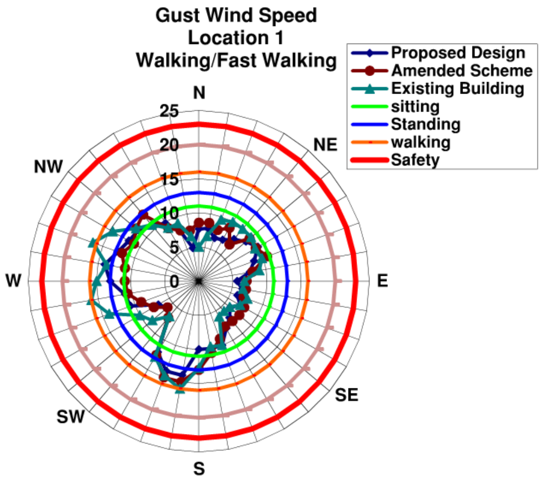
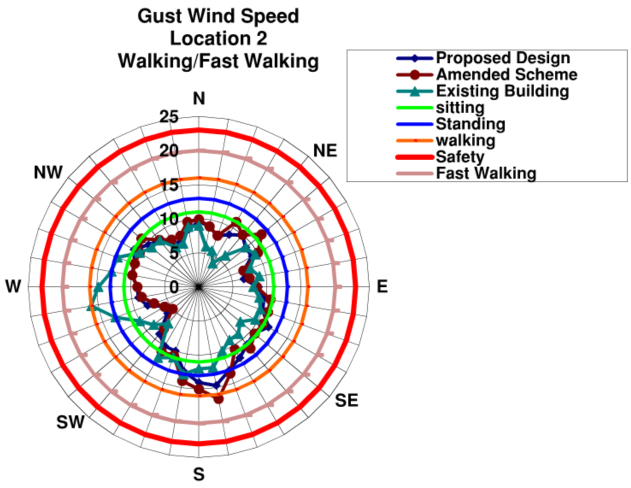
Pedestrian Level Winds - Wind Tunnel Test

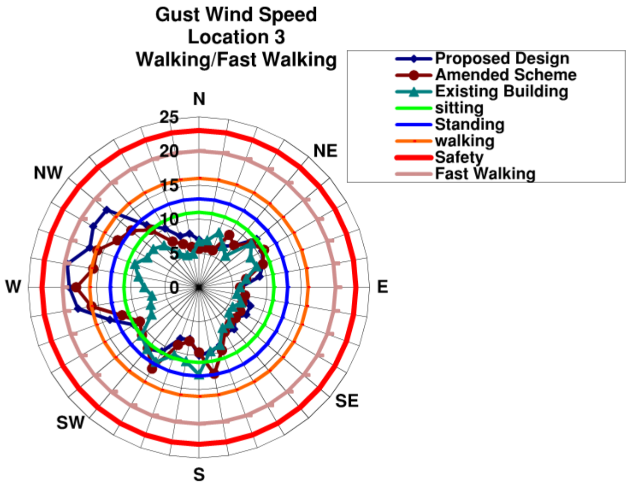
Appendix B WIND SPEED POLAR PLOTS

Note: Only Gust Wind speeds are presented.

No Street Trees were modelled during the test.




Gust Wind Speed
Location 2
Walking/Fast Walking
Proposed Design
Amended Scheme
Existing Building
sitting
Standing
walking
Safety
Fast Walking
N
NE
E
SE
S
SW
W
NW
0
5
10
15
20
25


Gust Wind Speed
Location 3
Walking/Fast Walking
Proposed Design
Amended Scheme
Existing Building
sitting
Standing
walking
Safety
Fast Walking
N
NE
E
SE
S
SW
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NW
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15
20
25

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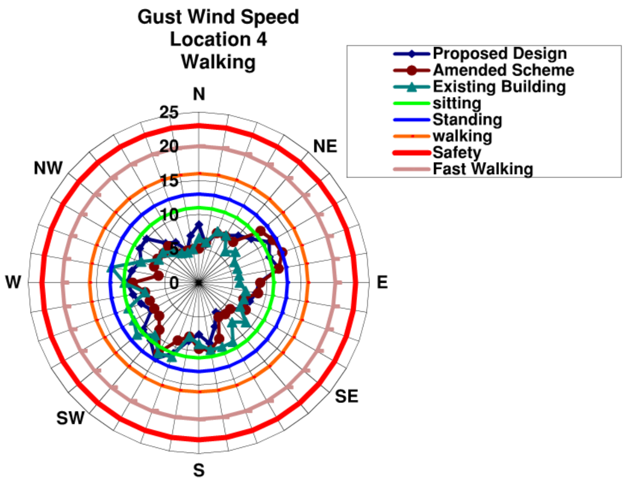

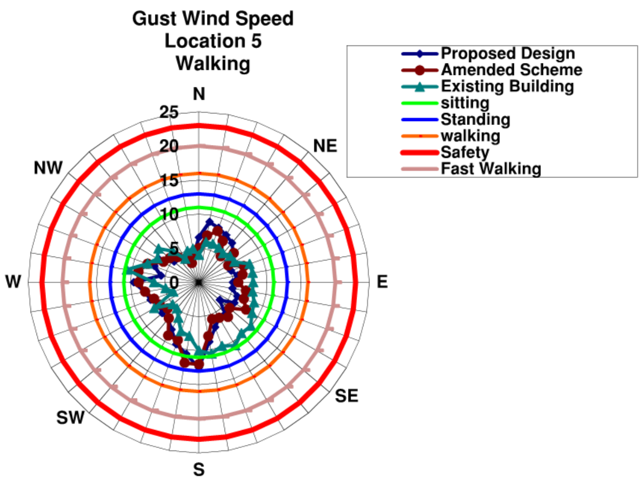

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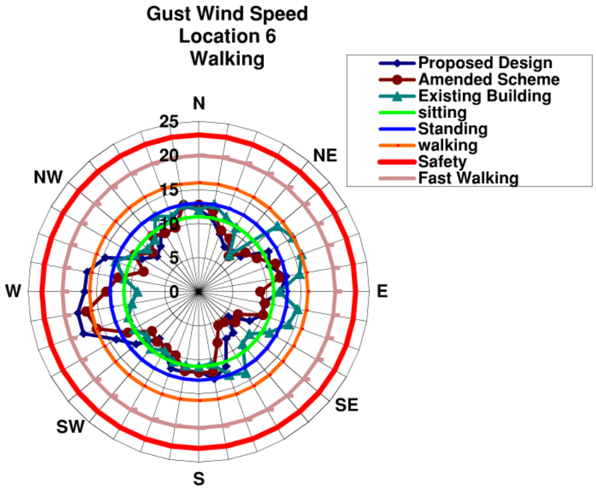
Gust Wind Speed
Location 6
Walking
Proposed Design
Amended Scheme
Existing Building
sitting
Standing
walking
Safety
Fast Walking
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SE
S
SW
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NW
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20
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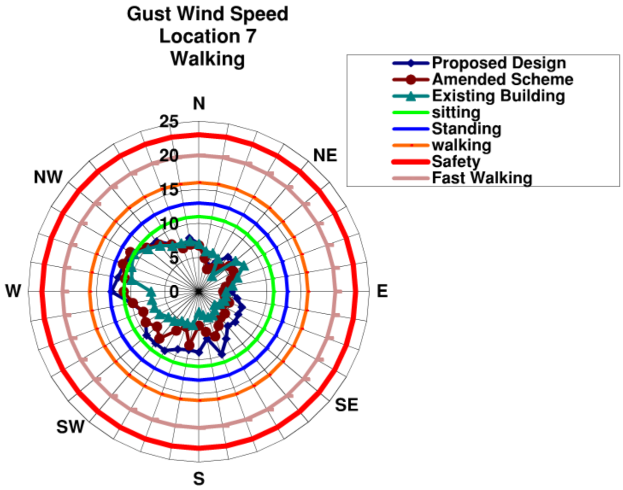
Gust Wind Speed
Location 7
Walking
Proposed Design
Amended Scheme
Existing Building
sitting
Standing
walking
Safety
Fast Walking
N
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E
SE
S
SW
W
NW
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5
10
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20
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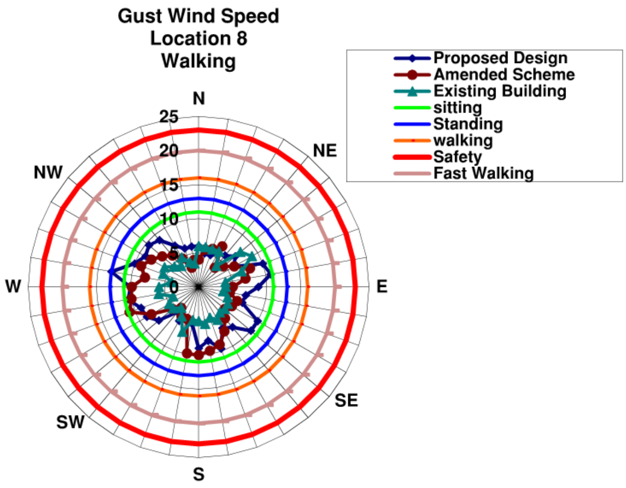
Gust Wind Speed
Location 8
Walking
Proposed Design
Amended Scheme
Existing Building
sitting
Standing
walking
Safety
Fast Walking
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E
SE
S
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W
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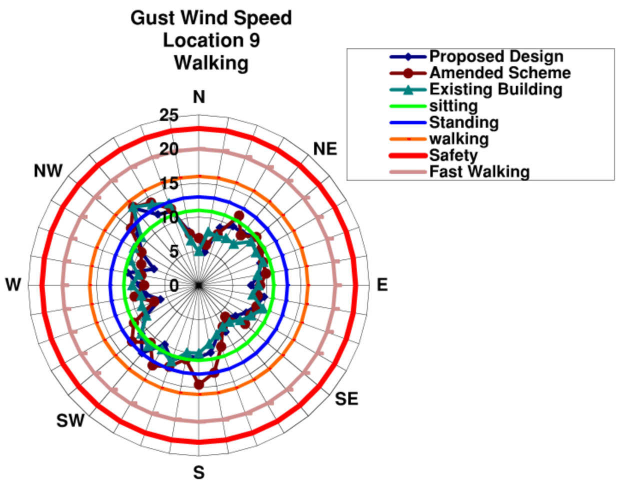
Gust Wind Speed
Location 9
Walking
Proposed Design
Amended Scheme
Existing Building
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Standing
walking
Safety
Fast Walking
N
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E
SE
S
SW
W
NW
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20
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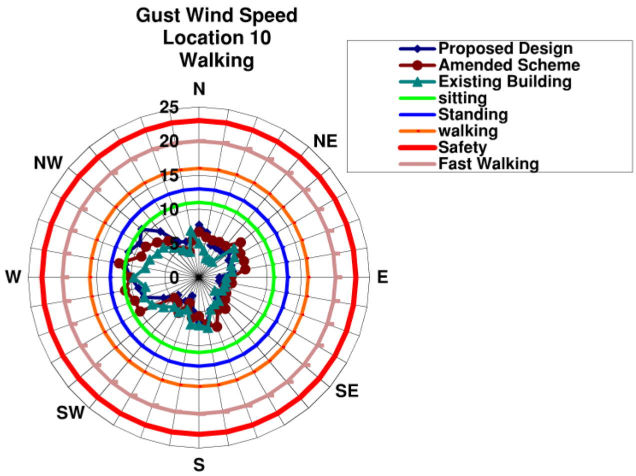
Gust Wind Speed
Location 10
Walking
Proposed Design
Amended Scheme
Existing Building
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Standing
walking
Safety
Fast Walking
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SE
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SW
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NW
25
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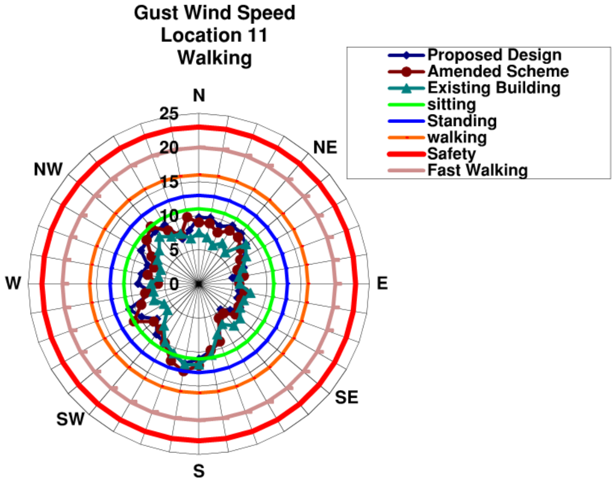
Gust Wind Speed
Location 11
Walking
Proposed Design
Amended Scheme
Existing Building
sitting
Standing
walking
Safety
Fast Walking
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NE
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NW
25
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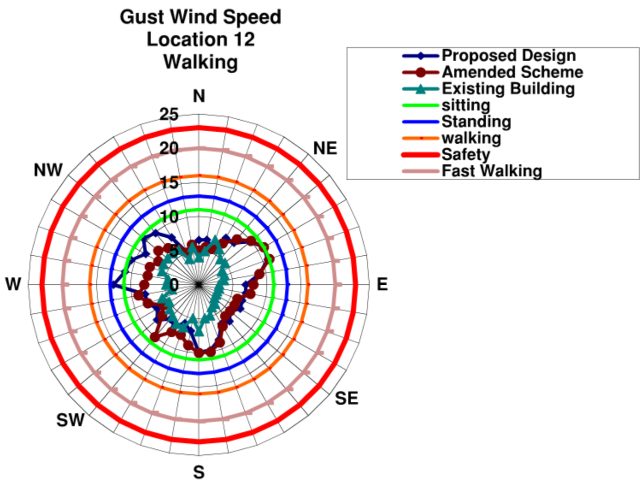
Gust Wind Speed
Location 12
Walking
Proposed Design
Amended Scheme
Existing Building
sitting
Standing
walking
Safety
Fast Walking
N
NE
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SW
W
NW
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15
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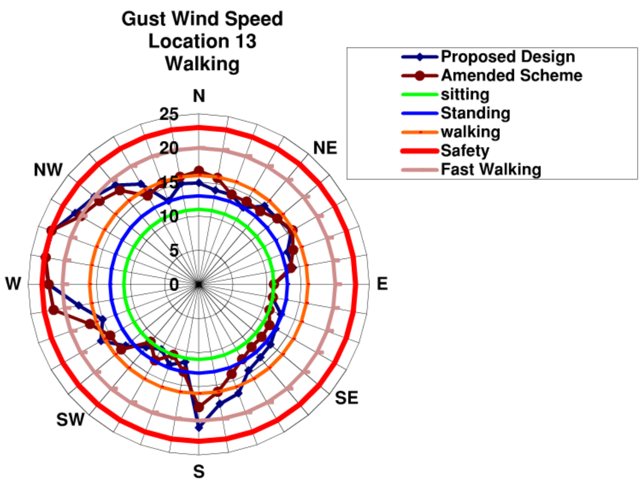
Gust Wind Speed
Location 13
Walking
Proposed Design
Amended Scheme
sitting
Standing
walking
Safety
Fast Walking
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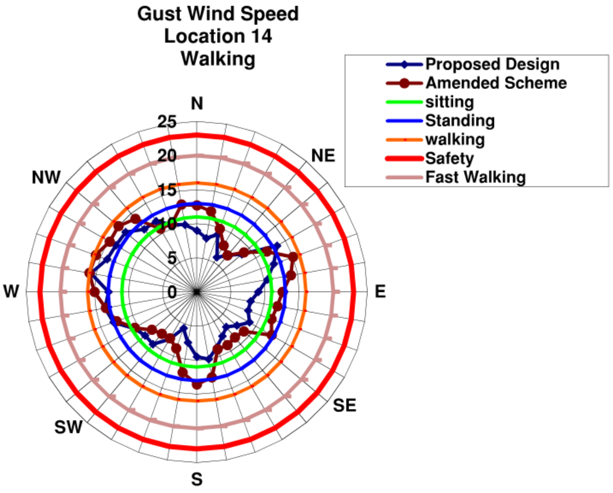

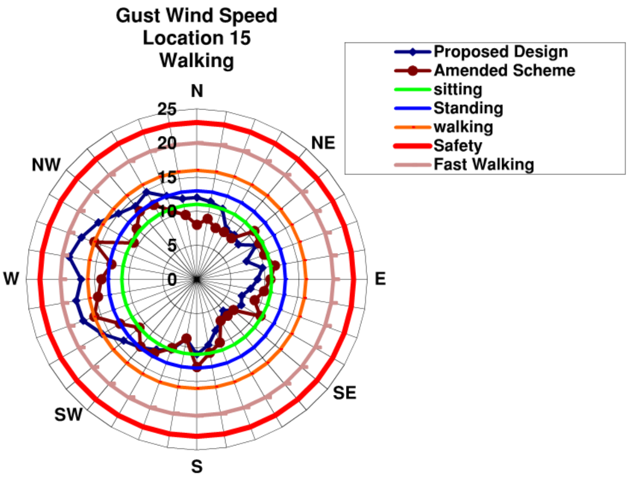

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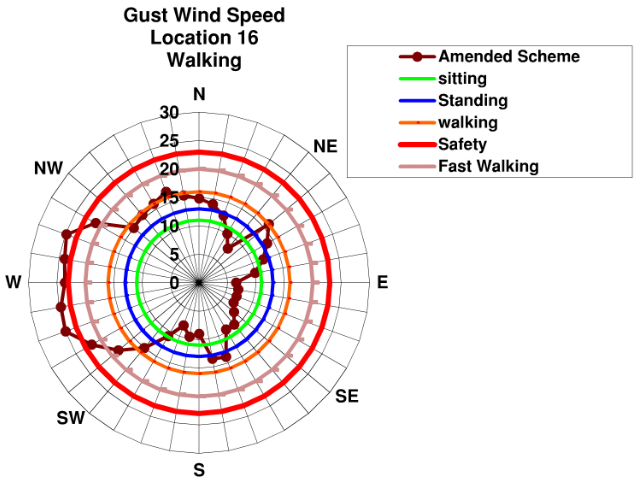
Gust Wind Speed
Location 16
Walking
Amended Scheme
sitting
Standing
walking
Safety
Fast Walking
N
NE
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SW
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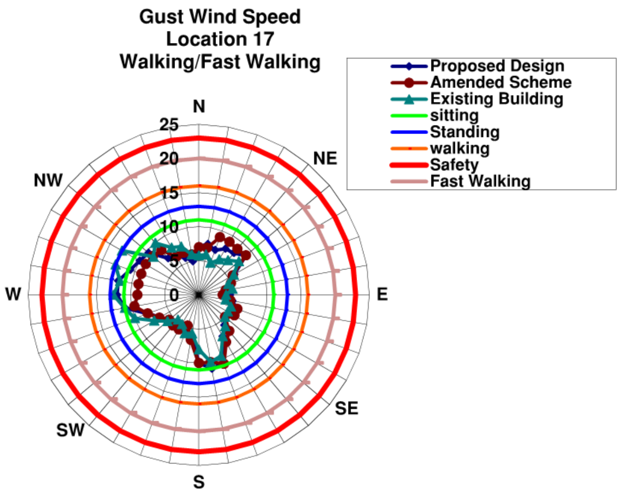
Gust Wind Speed
Location 17
Walking/Fast Walking
Proposed Design
Amended Scheme
Existing Building
sitting
Standing
walking
Safety
Fast Walking
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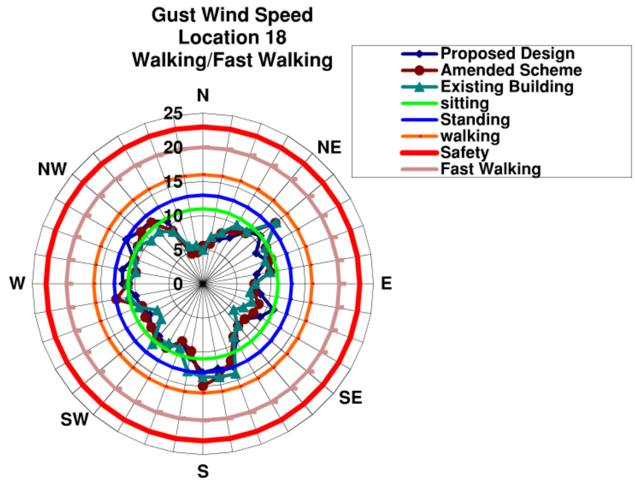
Gust Wind Speed
Location 18
Walking/Fast Walking
Proposed Design
Amended Scheme
Existing Building
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Standing
walking
Safety
Fast Walking
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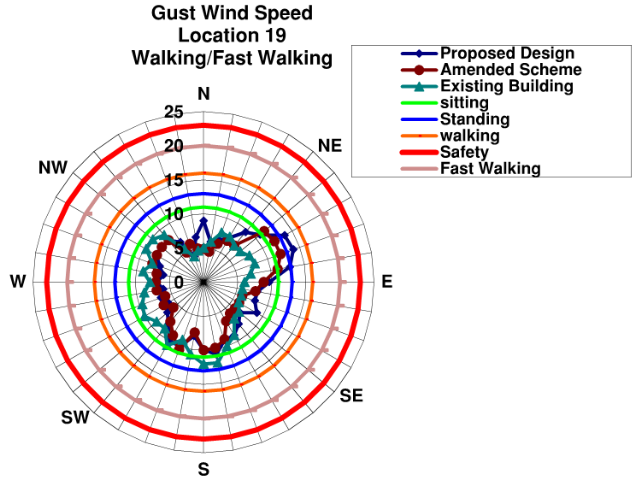
Gust Wind Speed
Location 19
Walking/Fast Walking
Proposed Design
Amended Scheme
Existing Building
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Standing
walking
Safety
Fast Walking
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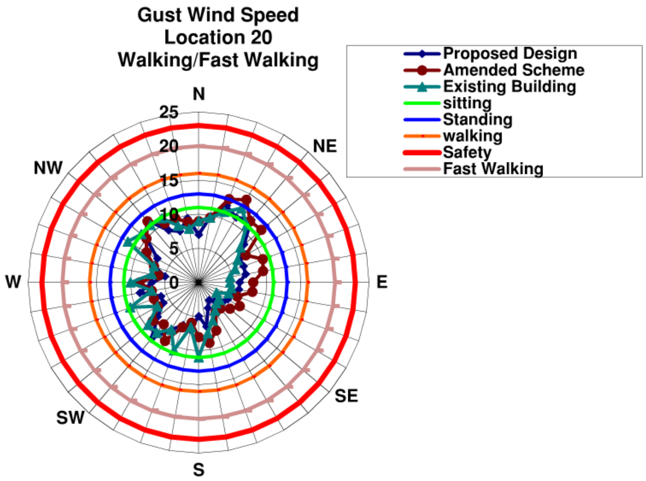
Gust Wind Speed
Location 20
Walking/Fast Walking
Proposed Design
Amended Scheme
Existing Building
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Standing
walking
Safety
Fast Walking
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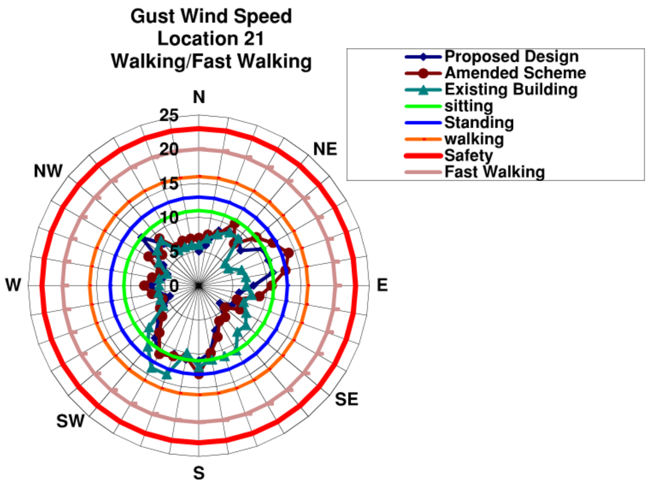
Gust Wind Speed
Location 21
Walking/Fast Walking
Proposed Design
Amended Scheme
Existing Building
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Standing
walking
Safety
Fast Walking
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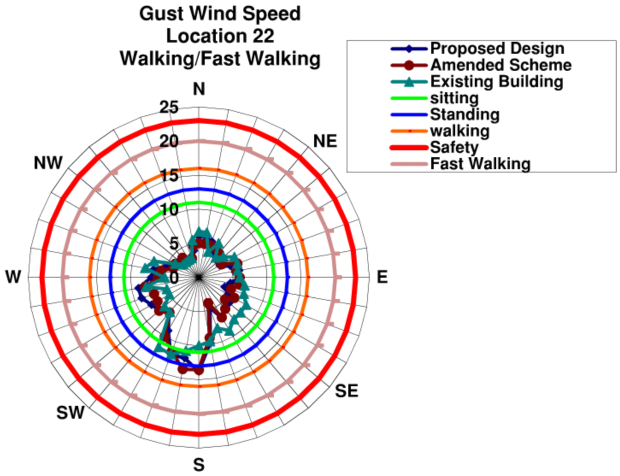
Gust Wind Speed
Location 22
Walking/Fast Walking
Proposed Design
Amended Scheme
Existing Building
sitting
Standing
walking
Safety
Fast Walking
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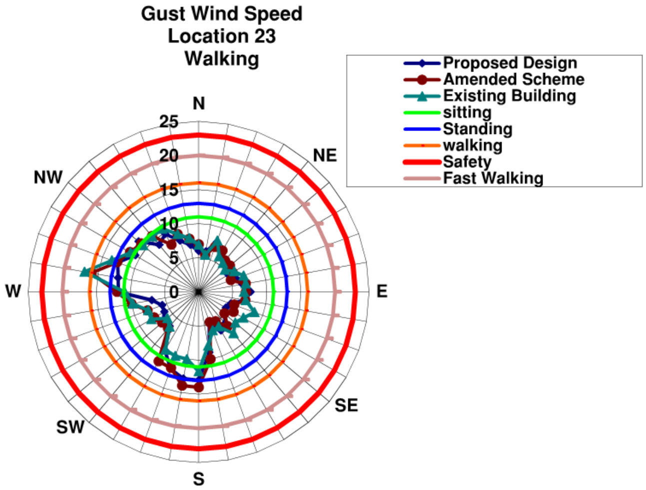
Gust Wind Speed
Location 23
Walking
Proposed Design
Amended Scheme
Existing Building
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Standing
walking
Safety
Fast Walking
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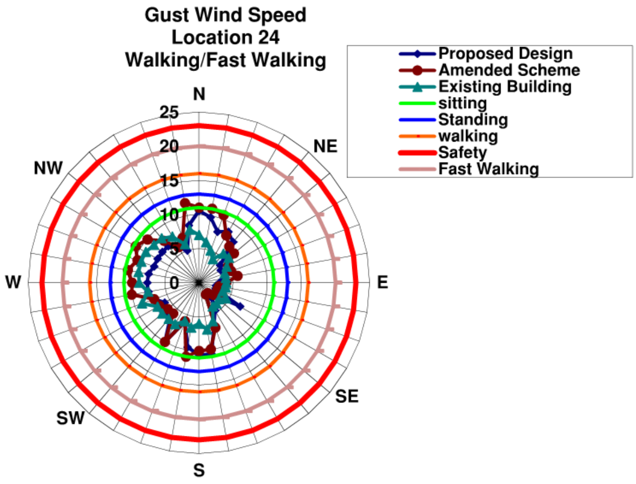
Gust Wind Speed
Location 24
Walking/Fast Walking
Proposed Design
Amended Scheme
Existing Building
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Standing
walking
Safety
Fast Walking
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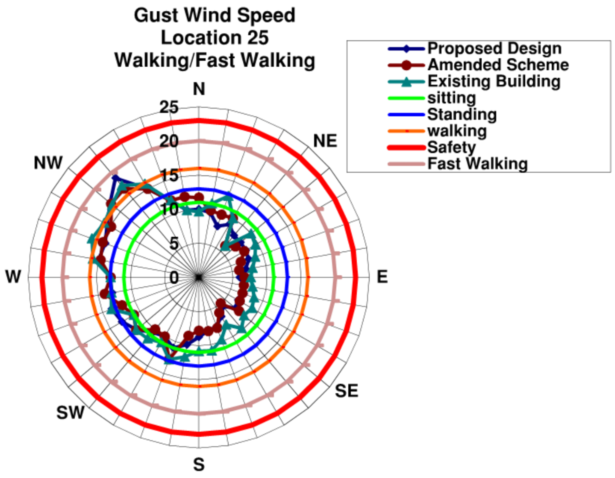
Gust Wind Speed
Location 25
Walking/Fast Walking
Proposed Design
Amended Scheme
Existing Building
sitting
Standing
walking
Safety
Fast Walking
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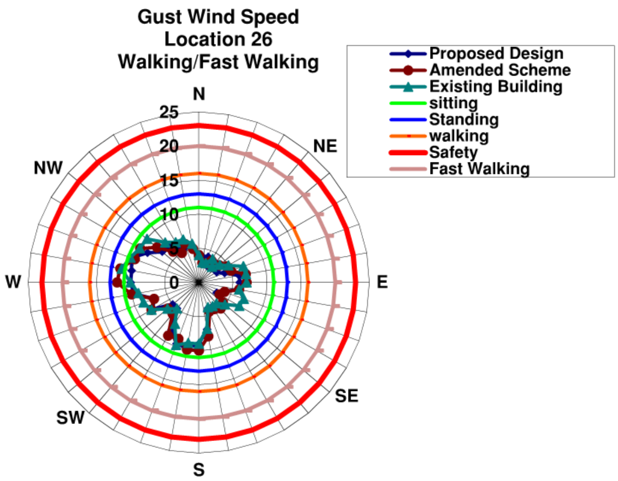
Gust Wind Speed
Location 26
Walking/Fast Walking
Proposed Design
Amended Scheme
Existing Building
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Standing
walking
Safety
Fast Walking
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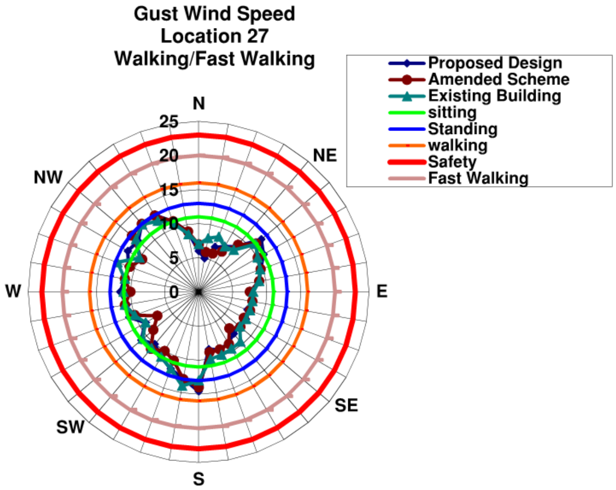
Gust Wind Speed
Location 27
Walking/Fast Walking
Proposed Design
Amended Scheme
Existing Building
sitting
Standing
walking
Safety
Fast Walking
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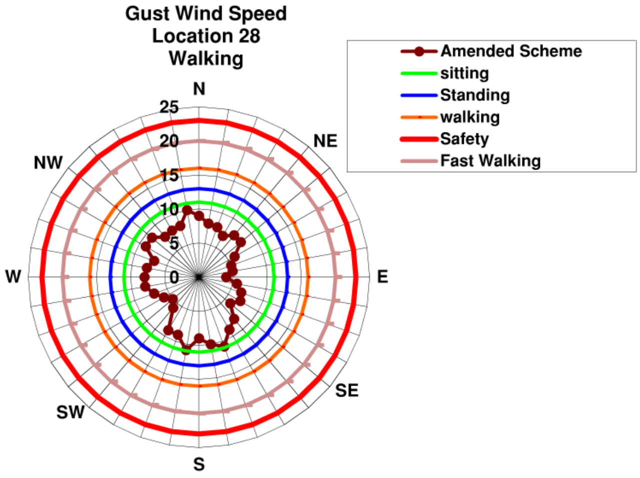

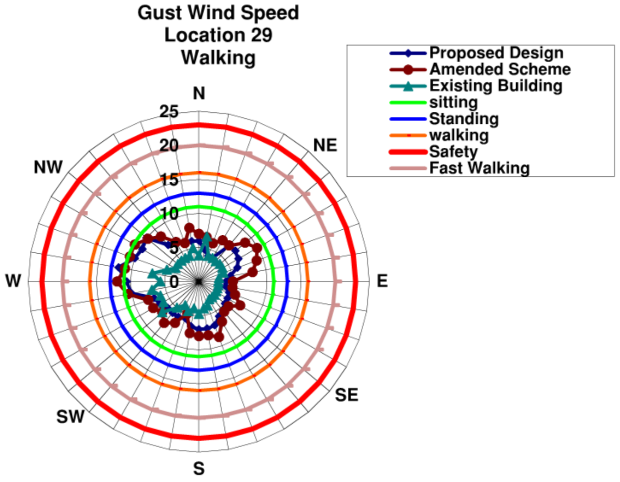

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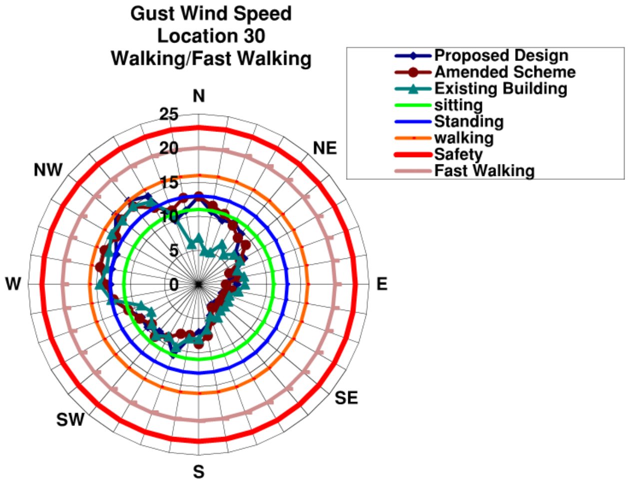

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