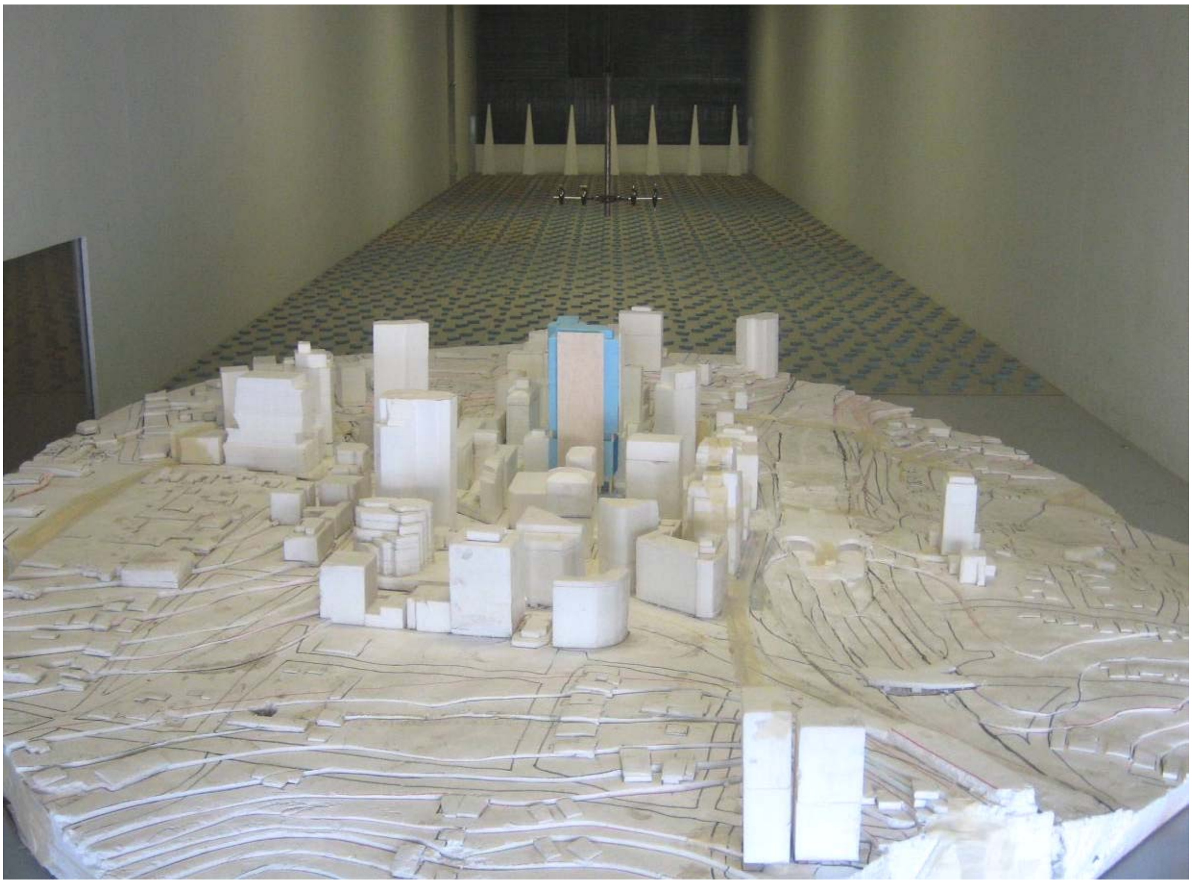

Environment Wind Effects Report

for the proposed development at

100 Mount Street, North Sydney

April 21, 2009

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2	21/04/2009	Updated Figures	KP	-	AB

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Table of Contents

1.0 Executive Summary

This report presents the results of a detailed investigation into the wind environment impact in relation to the proposed development at 100 Mount Street, located in North Sydney. Wind speed measurements were carried out using a 1:400 scale model of the development. A surrounds model incorporating the neighbouring buildings and local land topography was placed around the model of the proposed development. The surrounds model extends to a radius of 500m from the site.

Testing was performed using Windtech's boundary layer wind tunnel facility, which has a 3.0m wide work section and has a fetch length of 14m.

Peak gust wind speeds were measured and related to reference velocities at a height of 200m upstream of the proximity model. Wind speed velocity coefficients representing the local wind speeds are derived from the wind tunnel and are combined with the meteorological data for this region to provide the equivalent full-scale wind speeds. These wind speed measurements are compared with criteria for long and short duration stationary activities and for pedestrian comfort, based on annual maximum peak wind speeds and weekly maximum Gust Equivalent Mean (GEM) wind speeds, and where appropriate against the existing site wind conditions.

The results of this study indicate that wind conditions for most of the outdoor areas of the site, including all ground level areas, will require treatments to be implemented to be acceptable for their intended uses. Many treatments have been investigated in this study to treat the adverse winds affecting the outdoor areas of the proposed development. A set of treatments have been recommended in this report to ameliorate these effects, and are summarised as follows:

- Strategic placement of 1.2m high impermeable balustrades within and around the Ground Level of the development site.
- The addition of an awning above the street level along the eastern and southern aspects of the development.
- Maintaining existing 1.5m high shrub at the corner of Denison and Mount Streets and 1.2m high Garden Wall at the corner of Denison and Spring Streets.
- Densely foliating tree capable of growing to a height of 3 metres with a 3 metre canopy on Spring Street.
- Densely foliating trees capable of growing to a height of 5 metres with a 6 metre canopy on Mount and Walker Streets, and a 6 metre high tree with a 8 metre canopy on the corner of Walker and Mount Street
- 1.5m high impermeable balustrades along the perimeter of the Level 8 Roof Garden terrace areas.
- 1.5m high impermeable balustrade along the perimeter of the Level 20 Sky Garden terrace area, setback from the edge.

With the recommended treatments included into the final design of the development, the wind conditions within and around the proposed development site will be acceptable for their intended uses.

2.0 Model Description

2.1 Model of the Study Building and Surrounds

Wind speed measurements were carried out using a 1:400 scale model of the development. A surrounds model incorporating the neighbouring buildings and local land topography was placed around the study building model. The surrounds model extends to a radius of 500m from the site. Photographs of the wind tunnel model with the proposed and existing development are presented in Figures 1a to 1g.

In this study two different surrounds and study building configurations were considered. There were:

1. The existing surrounds and the existing study building;
2. The existing surrounds and the proposed study building;

The model was placed in a suburban terrain boundary layer wind flow based on the Deaves and Harris (1978) model. The reference wind speeds were corrected for changes in the upstream building morphology and land topography.

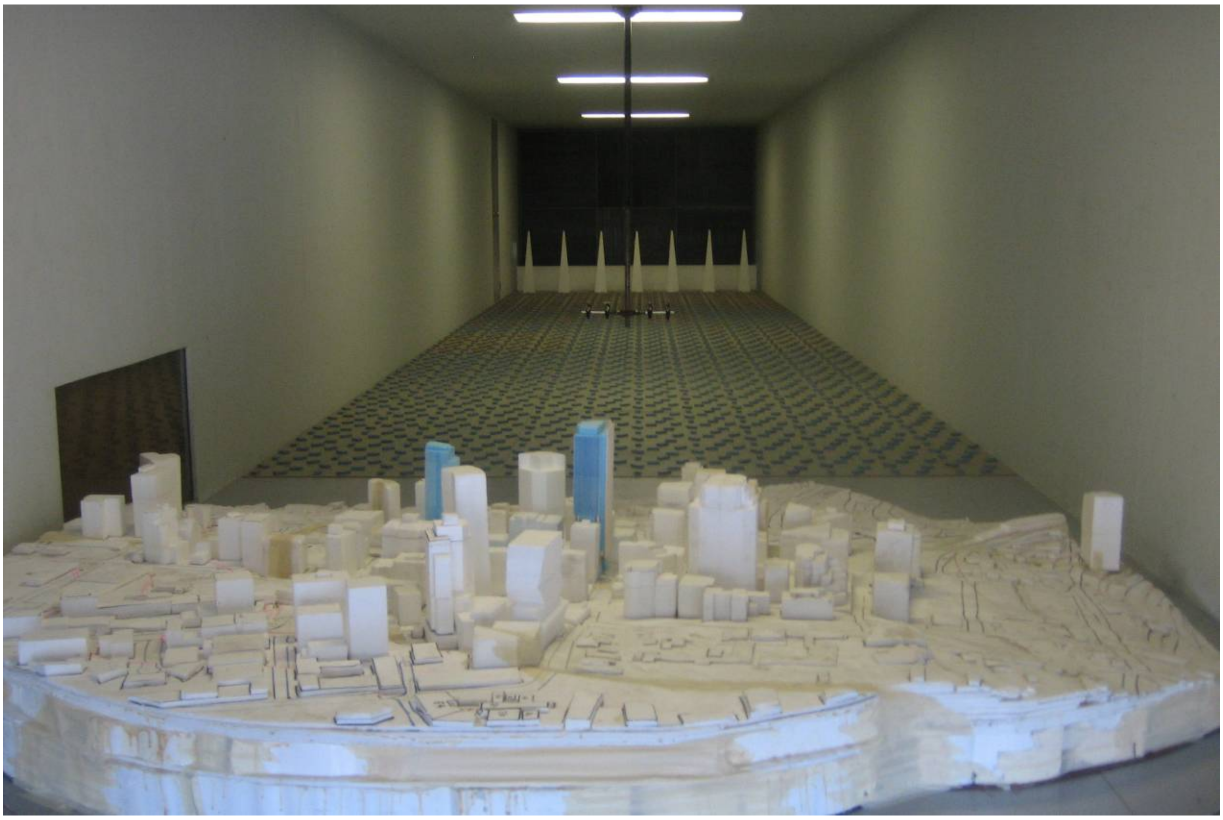

Figure 1a: Photograph of the Model in the Wind Tunnel
(view from the West – with the inclusion of the proposed development)

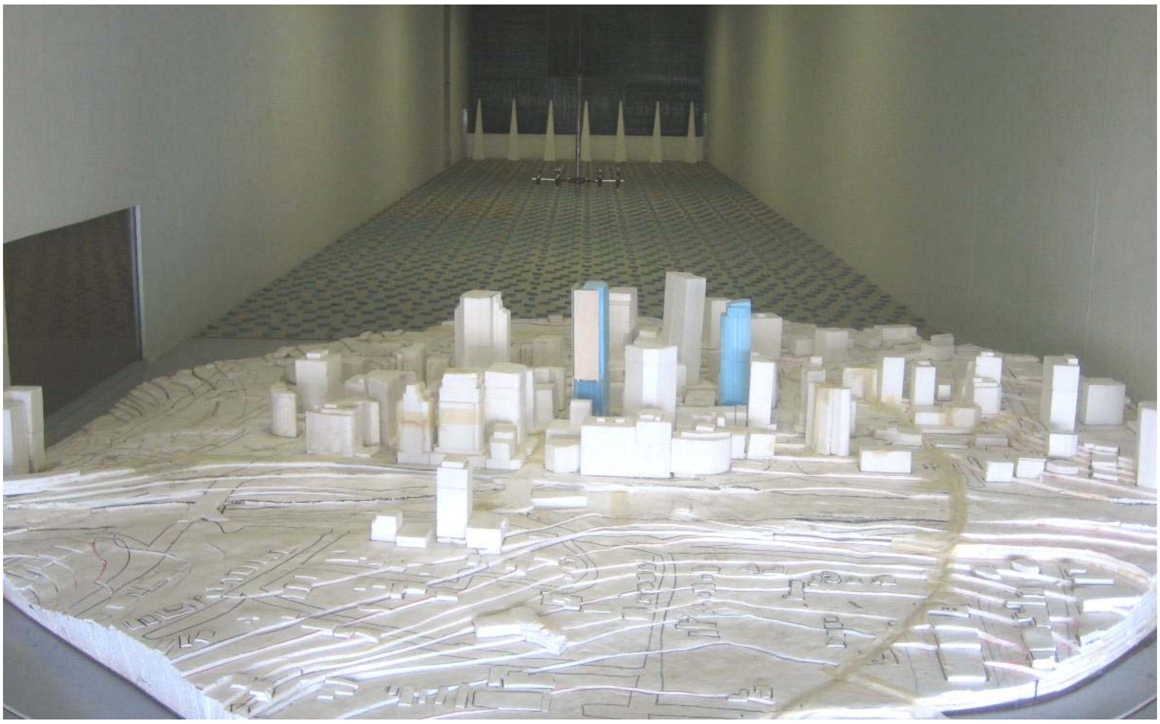

Figure 1b: Photograph of the Model in the Wind Tunnel
(view from the East - with the inclusion of the proposed development)

Figure 1c: Photograph of the Model in the Wind Tunnel
(view from the North - with the inclusion of the proposed development)

Figure 1d: Photograph of the Model in the Wind Tunnel (close-up view of the proposed development, from the East)

Figure 1e: Photograph of the Model in the Wind Tunnel (close-up view of the proposed development, from the North)

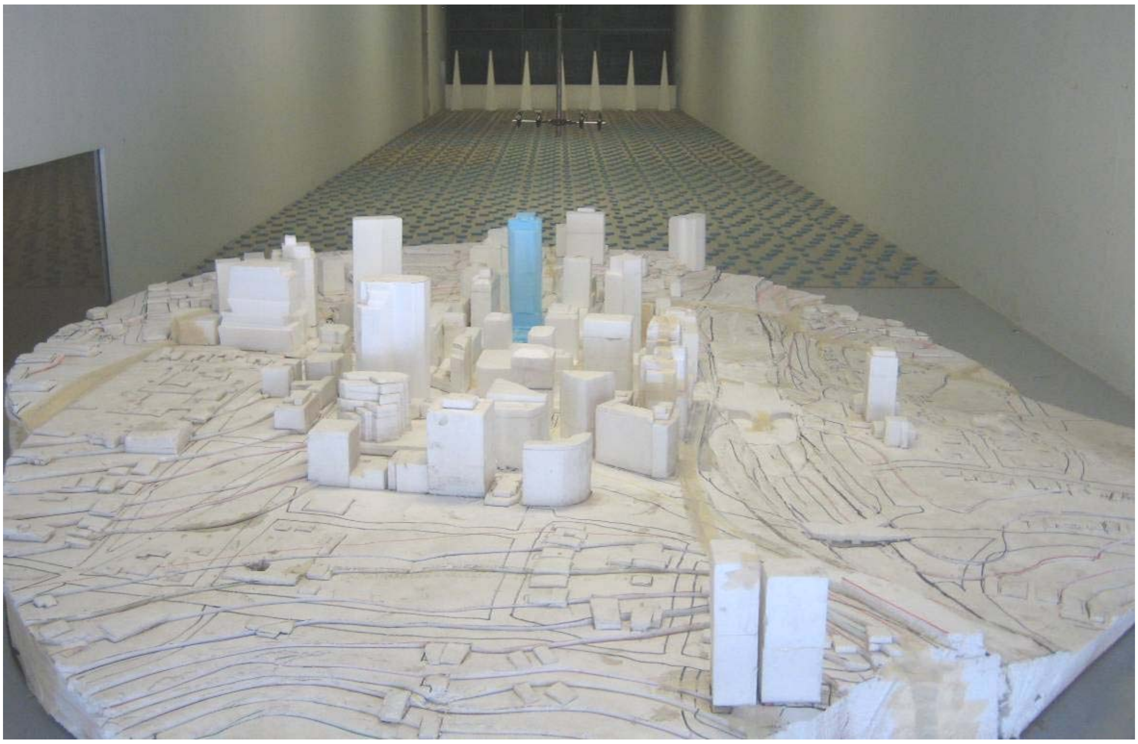

Figure 1f: Photograph of the Model in the Wind Tunnel
(view from the South – existing site model)

Figure 1g: Photograph of the Model in the Wind Tunnel
(view from the East – existing site model)

2.2 Wind Climate Model

The tower reference height used for this study is 150m. The boundary layer wind flows matched the model scale and the overall surrounding terrain characteristics beyond the 500m radius of the physical surrounds model tested in the wind tunnel for each wind direction tested. For the fetch beyond the extent of the surround model the wind profiles are simulated based on the Deaves and Harris model (1978). The wind profile shape is calculated based on an analysis of the surrounding terrain for each wind direction tested. Figure 2 shows an aerial image of the site and surrounds for a radius of 40h from the site, where h is the reference height of the tower. Hence, for this project, the fetch length is 6.0km. The terrain types indicated in Figure 2 are classified as open, suburban or urban.

The length of each terrain type, and the distance each terrain type is from the site, is analysed for each wind direction tested. When the wind travels from one terrain type to another, the mean velocity profile does not change instantly. A lag occurs, and is measured as a distance by the following formula, which is adapted from Davenport et al (1997):

$$x_i = z_{0,r}\left[\frac{z}{0.3z_{0,r}}\right]^{1.25} \qquad (2.1)$$

where x_i is the lag length caused by the change in terrain type.

z is the height above ground.

$z_{0,r}$ is the larger of the two roughness lengths of the two terrain types (see Table 1).

The wind profile for each wind direction is calculated using the lag distance equation above, and the site terrain analysis data measured from the image shown in Figure 2.

For example, for wind coming from 67.5 degrees (an east-north-easterly wind), it is assumed that the approaching wind profile at the edge of the study zone (6.0km from the site for this study) is the standard Deaves and Harris (1978) open terrain profile, since this is coming from over water and open terrain. The wind continues over the open terrain until, approximately 4.2km from the site, the wind reaches the suburban terrain of Balmoral. This is where the Deaves and Harris (1978) suburban terrain is most appropriate. The wind profile then begins to adapt from the open terrain profile to the suburban terrain profile as it passes over Mosman, Cremorne and Neutral Bay. However, by the lag distance equation, at a height of 250m above ground, the profile requires 6.7km to fully change to the standard Deaves and Harris (1978) suburban terrain profile. Hence, by the time the wind reaches the site, at a height of 250m above ground, the profile is only 63% developed into the suburban wind profile from the open wind profile. At the building height, it is 100% developed into the suburban wind profile. The wind profile plot in Appendix B for wind angle 67.5 degrees shows that, by the time the wind reaches the site, the profile has already adapted to the standard suburban terrain profile for heights below the building height, and above this it is still adapting into the suburban terrain profile from the open terrain profile. The wind profiles used for this study are shown in Appendix B of this report for each wind direction tested.

Table 1: Mean and Gust Terrain and Height Multipliers and Turbulence Intensity at Building Height, and the Corresponding Roughness Length for the Standard Deaves & Harris Profiles (1978) (150m)

Terrain Description	$\overline{M}_{(z,cat)}$ at BH	$M_{(z,cat)}$ at BH	Turbulence Intensity	Roughness Length (m) $z_{0,r}$
Flat	0.97	1.31	0.095	0.002
Open	0.89	1.27	0.117	0.020
Suburban	0.78	1.21	0.150	0.200
Dense Urban	0.62	1.11	0.210	2.000

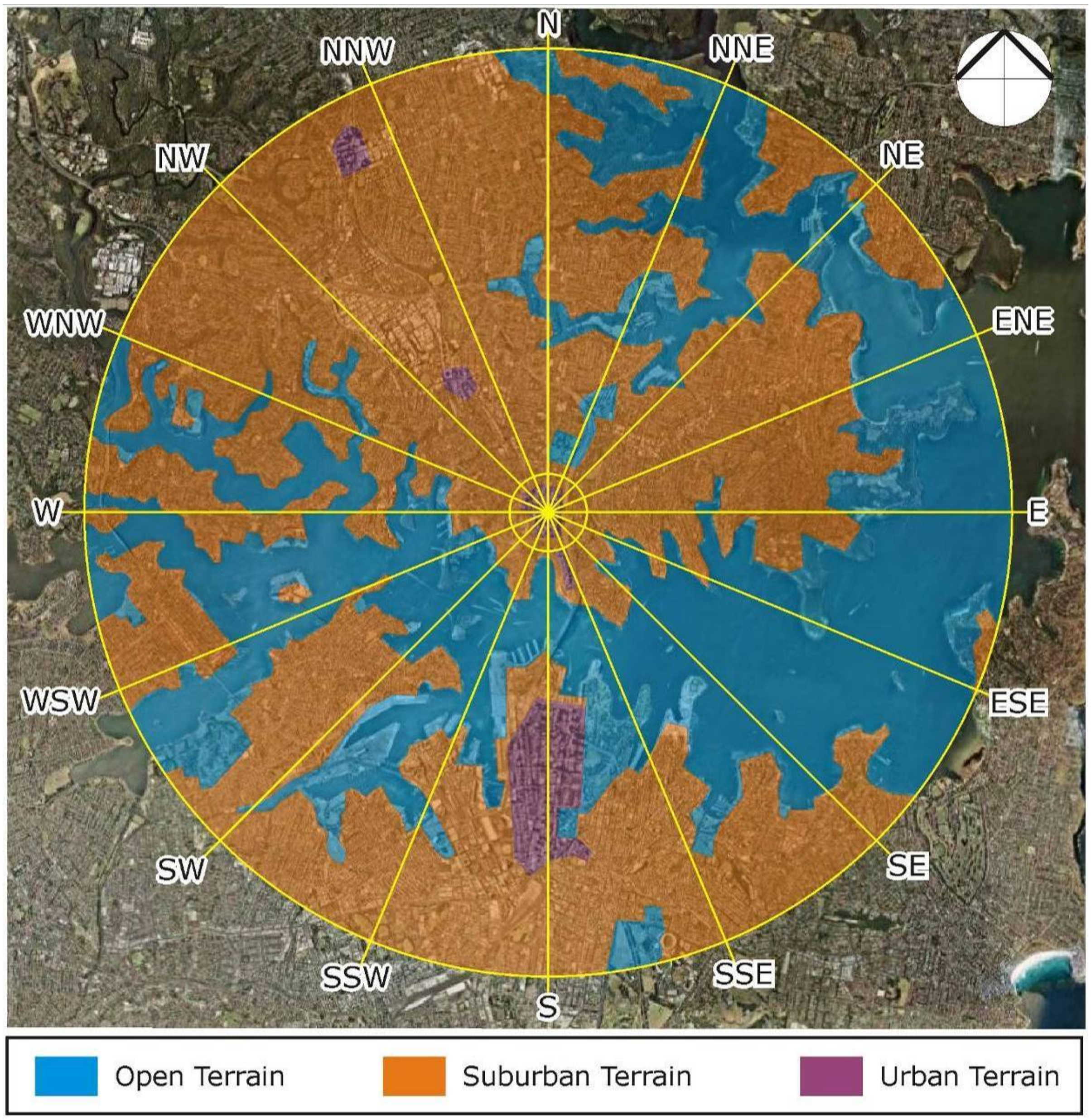

Figure 2: Aerial Image of the Site and Surrounds – 6.0km Radius (terrain category types also indicated)

3.0 Test Procedure

Testing was performed in Windtech's blockage tolerant boundary layer wind tunnel facility. No correction is required for blockage effects. The mean free stream wind speed at the reference height in the tunnel is approximately 11 m/sec. This corresponds to a velocity scale range of approximately 1:1.2 to 1:2.0 for the annual maximum peak wind speeds. Hence the sample length in the model scale of 12 seconds is equivalent to a range of approximately 39 minutes to 65 minutes in full-scale for the annual maximum peak wind speeds, which is suitable for this type of study.

A detailed analysis involving sixteen wind directions at 22.5 degrees intervals was carried out. This procedure provides comprehensive information about the wind environment to be expected for the various wind directions.

The freestream and test-location air currents were monitored using a pair of Dantec hot wire probe anemometers. The probe support was set vertically as much as possible. This ensures that the measured wind speeds are independent of wind direction along the horizontal plane. In addition, care was taken in the alignment of the probe wire and in avoiding wall-heating effects.

The output from both probes was obtained using a National Instruments 12-bit data acquisition card. The signal was low-pass filtered at 32 Hz and results in peak gust being the equivalent of the 2 to 3 second gust on which the criteria are based. A sample rate of 1000 samples per second was used, which is more than adequate for the given frequency band.

The mean and the maximum 3 second duration peak gust coefficients were obtained. The largest qualifying single peak was taken as the maximum gust velocity. To ensure that the largest measured peak is not a 'false' peak, the maximum peak would not qualify if it is more than 25% greater than the average of the second and third largest peaks. Any non-qualifying peak is replaced by the average of the second and third largest peaks. The measured mean and gust wind speeds are compared against the appropriate criteria for each of the outdoor areas tested.

For each of the sixteen wind directions, peak gust and mean wind speeds were measured at selected points at a full-scale height of approximately 1.5m and were normalised by the mean value at a reference scale height of 200m up-wind of the model. The reference velocity measurements are used to relate the mean and peak wind speed measurements to actual mean and gust velocities, based on available meteorological data for Sydney.

The directional distributions of the statistical mean hourly wind speeds for Sydney, corrected for suburban terrain (Terrain Category 3, as defined by AS/NZS 1170.2:2002) and a reference height of 200m are shown in Figure 3.

The meteorological data for Sydney was analysed statistically from frequency of occurrence tables prepared by the National Climate Centre, which are based on continuous data collected at 3 hour intervals over 53 years, ending March 1992. Data was collected from the Sydney Airport Observation Office at a height of 6 metres.

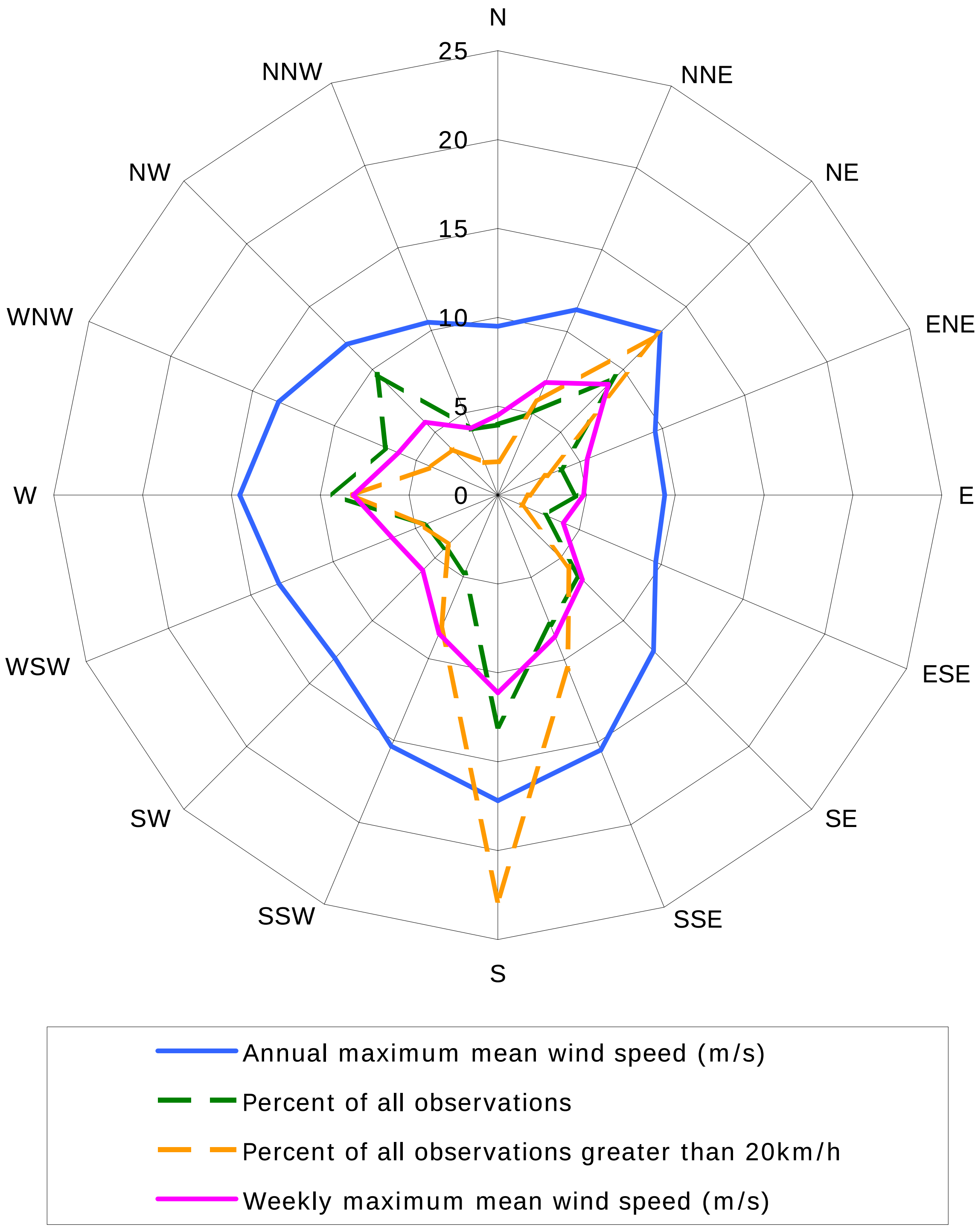

Figure 3: Reference Wind Speeds and Frequencies for Sydney (based on 3 hourly mean observations at Kingsford Smith Airport, from 1939 to 1992, corrected for 10m height in open terrain)

4.0 Environmental Wind Speed Criteria

The three principal wind directions affecting this development prevail from the North-East, South and West. Table 2 is a summary of the principal time of occurrence of these winds. A full set of wind roses for the Sydney region, obtained from Sydney Airport (1939 to 2000) at 9am and 3pm for each month throughout the year, are attached in Appendix C of this report.

Table 2: Principle Time of Occurrence of Wind for the Sydney Region

Month	Wind Direction		
	North-Easterly	Southerly	Westerly
January	X	X	
February	X	X	
March	X	X	
April		X	X
May			X
June			X
July			X
August			X
September		X	X
October	X	X	
November	X	X	
December	X	X	

The acceptability of wind in any area is dependent upon its use. For example, people walking or window-shopping will tolerate higher wind speeds than those seated at an outdoor restaurant. The following table (see Table 3), developed by Penwarden (1975), is a modified version of the Beaufort Scale, and describes the effects of various wind intensities on people. Note that the applicability column related to wind conditions occurring frequently (approximately once per week on average). Higher ranges of wind speeds can be tolerated for rarer events.

Table 3: Summary of Wind Effects on People (after Penwarden, 1975)

Type of Winds	Beaufort Number	Mean Wind Speed (m/s)	Effects
Calm, light air	1	0 - 1.5	Calm, no noticeable wind
Light breeze	2	1.6 - 3.3	Wind felt on face
Gentle breeze	3	3.4 - 5.4	Hair is disturbed, Clothing flaps
Moderate breeze	4	5.5 - 7.9	Raises dust, dry soil and loose paper - Hair disarranged
Fresh breeze	5	8.0 – 10.7	Force of wind felt on body
Strong breeze	6	10.8 – 13.8	Umbrellas used with difficulty, Hair blown straight, Difficult to walk steadily, Wind noise on ears unpleasant.
Near gale	7	13.9 – 17.1	Inconvenience felt when walking.
Gale	8	17.2 -20.7	Generally impedes progress, Great difficulty with balance.
Strong gale	9	20.8 – 24.4	People blown over by ***gusts***.

Lawson (1973) quotes that Beaufort 4 wind speeds (6 to 8m/s means) would be acceptable if it is not exceeded for more than 4% of the time; and a Beaufort 6 (11 to 14m/s means) as being unacceptable if it is exceeded more than 2% of the time.

4.1 Davenport's Criteria for Mean Wind Speeds

Davenport (1972) had also come up with a set of criteria in terms of the Beaufort Scale and for various return periods. The values presented in Table 4 below are based on a frequency of exceedance of once per week (a probability of exceedance of 5%).

Table 4: Criteria by Davenport (1972)

Classification	Human Activities	95 Percentile Maximum Mean (once per week)
Walking Fast	Acceptable for walking, main public accessways	10 m/s > *u* > 7.5 m/s
Strolling, Skating	Slow walking, etc.	7.5 m/s > *u* > 5.5 m/s
Short Exposure Activities	Generally acceptable for walking & short duration stationary activities such as window-shopping, standing or sitting in plazas.	5.5 m/s > *u* > 3.5 m/s
Long Exposure Activities	Generally acceptable for long duration stationary activities such as in outdoor restaurants & theatres and in parks.	3.5 m/s > *u*

4.2 Lawson's Criteria for Mean Wind Speeds

Later, Lawson (1975) came up with a set of criteria very similar to those of Davenport's. These are presented in Tables 5a and 5b, below.

Table 5a: Safety Criteria by Lawson (1975)

Classification	Human Activities	Annual Maximum Mean
Safety (all weather areas)	Accessible by the general public	15 m/s
Safety (fair weather areas)	Private outdoor areas such as balconies, terraces etc	20 m/s

Table 5b: Comfort Criteria by Lawson (1975)

Classification	Human Activities	95 Percentile Maximum Mean (once per week)
Business Walking	Objective Walking from A to B	10 m/s > *u* > 8m/s
Pedestrian Walking	Slow walking, etc.	8 m/s > *u* > 6 m/s
Short Exposure Activities	Pedestrian Standing or sitting for a short time	6 m/s > *u* > 4 m/s
Long Exposure Activities	Pedestrian sitting for a long duration	4 m/s > *u*

4.3 Melbourne's Criteria for Peak Wind Speeds

Melbourne (1978) introduced a set of criteria for the assessment of environmental wind conditions. These criteria were developed for temperatures in the range from 10^{o}C to 30^{o}C and for people suitably dressed for outside temperature conditions. These criteria are based on peak gust wind speeds. Melbourne's criteria are outlined in Table 5 below. This set of criteria tends to be more conservative than criteria suggested by other researchers such as those indicated in Figure 4.

Table6: Criteria by Melbourne (1978)

Classification	Human Activities	Annual Maximum Gust
Limit for safety	Completely unacceptable: people likely to get blown over.	*u* > 23m/s
Marginal	Unacceptable as main public accessways.	23 m/s > *u* > 16 m/s
Comfortable Walking	Acceptable for walking, main public accessways	16 m/s > *u* > 13 m/s
Short Exposure Activities	Generally acceptable for walking & short duration stationary activities such as window-shopping, standing or sitting in plazas.	13 m/s > *u* > 10 m/s
Long Exposure Activities	Generally acceptable for long duration stationary activities such as in outdoor restaurants and theatres and in parks.	10 m/s > *u*

4.4 Comparison of the Various Wind Speed Criteria

The criteria mentioned in Table 6, as well as other criteria, are compared on a probabilistic basis in Figure 4, below.

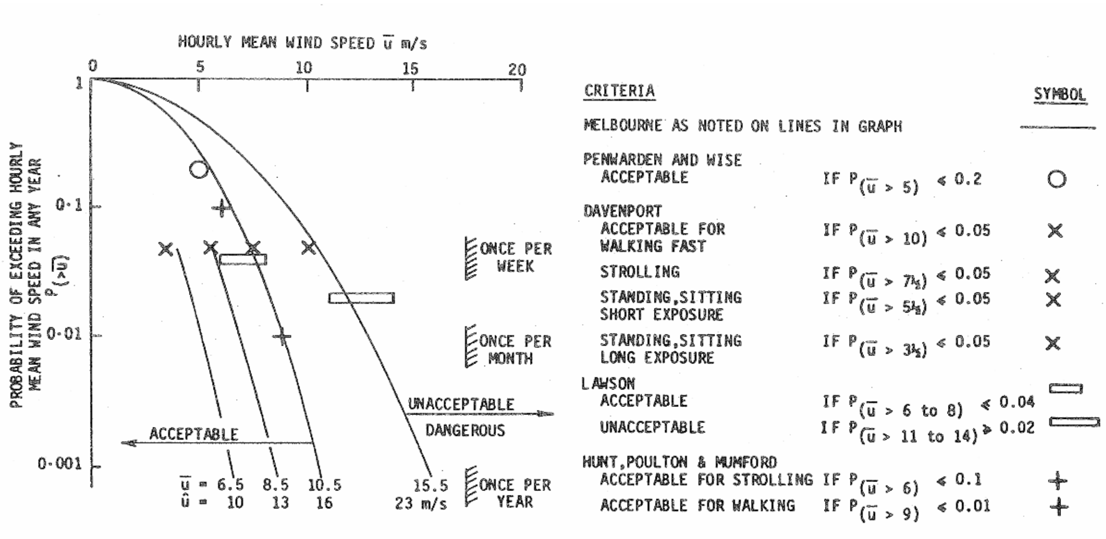

Figure 4: Comparison of Various Mean and Gust Wind Environment Criteria, assuming 15% turbulence and a Gust Factor of 1.5 (after Melbourne, 1978)

However, a comparative study presented by Ratcliff and Peterka (1990) based on measurements taken from a total of 246 locations in various urban situations tends to indicate that the criteria suggested by Melbourne (1978) can be considerably more conservative than the other criteria set out above. The results are in indicated in Figure 5. This agrees with our own observations (Rofail, 2007). This discrepancy in the criteria by Melbourne is due to the assumption of a fixed 15% turbulence intensity for all areas, which in our experience tends to be at the lower end of the range of turbulence intensities.

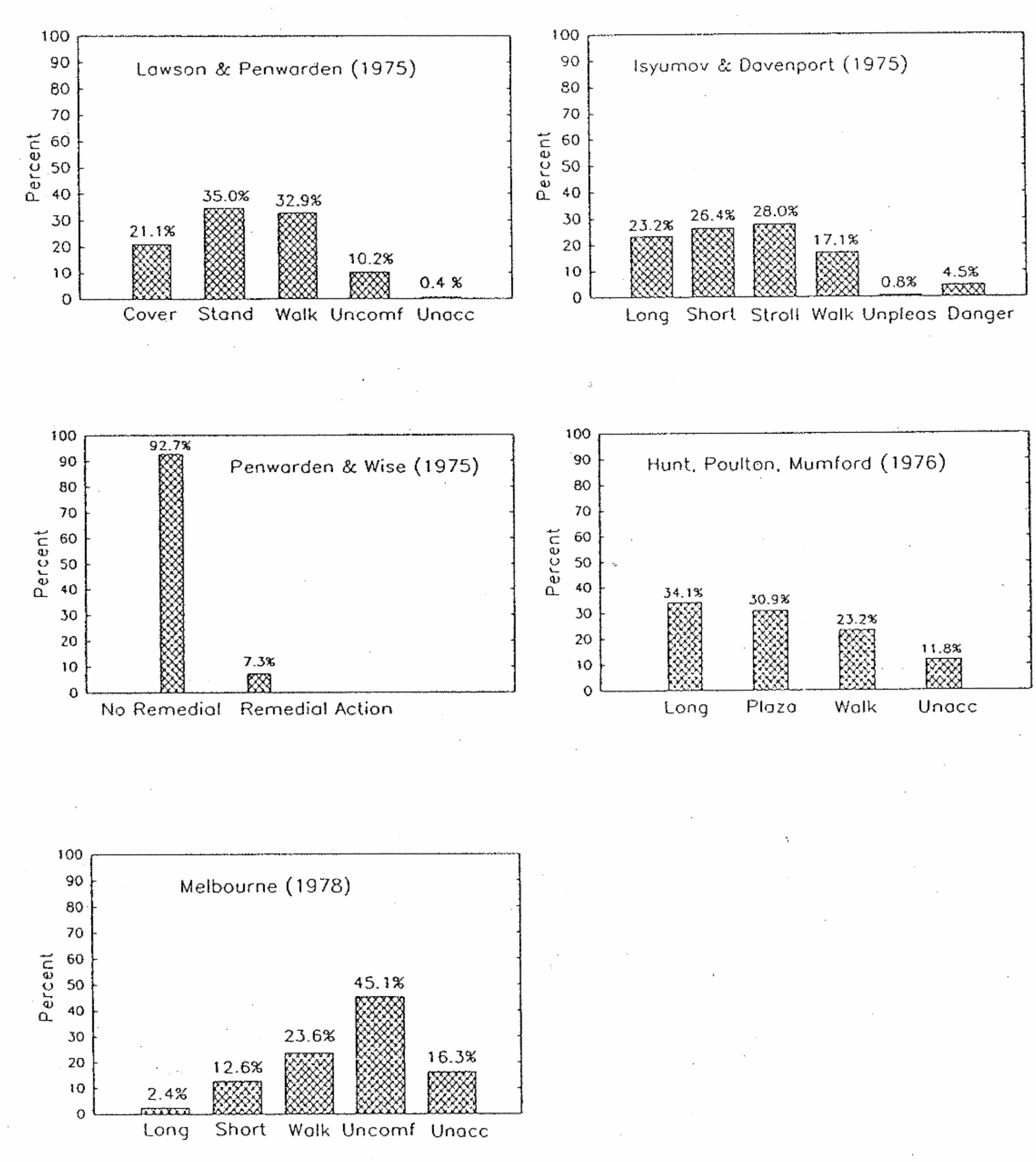

Figure 5: Distribution of Pedestrian Wind Comfort over Five Criteria for 246 locations examined in the Wind Tunnel (after Ratcliff & Peterka, 1990)

4.5 Wind Speed Criteria for the North Sydney CBD

For this study, the local wind climate has been compared against the existing wind conditions and the annual maximum peak wind speed criteria, as required by the North Sydney Development Control Plan (DCP). These are partly based on criteria by Melbourne (1978). The wind comfort criteria used for this study are as follows;

- Wind conditions for all pedestrian accessible ground level areas within and around the proposed development should not exceed 13m/s for the annual maximum peak wind speeds (as specified in the North Sydney DCP) , or if they do they should not exceed the existing wind conditions.
- Wind conditions for private balconies and terraces of the proposed development should satisfy the safety limit of 23m/s for the annual maximum peak wind speeds. If a terrace is used frequently as a communal area for all occupants of the development, the comfortable walking criterion of 7.5m/s for the weekly maximum Gust Equivalent Mean (GEM) wind speeds should also be satisfied.

Note that the abovementioned Gust Equivalent Mean (GEM) wind speed (defined below), in conjunction with the Davenport criteria (see Section 4 of this report), has proven over time and through field observations to be the most reliable indicator of pedestrian comfort. The most reliable source of data for field observation results are obtained when undertaking remedial wind environment studies. Note that the Safety Limit criterion by Melbourne (1978) of 23m/s for annual maximum peak wind speeds is also applied to all areas. This criterion is used for most areas of Australia and around the world, unless stipulated otherwise by the local government authority.

Notes:

- The GEM is defined as the maximum of the following:
    - Mean wind speed
    - Gust wind speed divided by a gust factor of 1.85
- The gust wind speed is defined as 3.5 standard deviations from the mean.
- Long Exposure criterion applies typically to outdoor dining areas in restaurants, amphitheatres, etc.
- Short Exposure criterion applies typically to areas where short duration stationary activities are involved (less than 1 hour). This includes parks and landscaped areas, swimming pool, window shopping, waiting and drop-off areas.
- Comfortable Walking criterion applies typically to main pedestrian thoroughfares.
- Fast walking criterion applies typically to infrequently used laneways, balconies, private terraces etc.
- In all areas, the wind conditions are also checked against the safety limit.

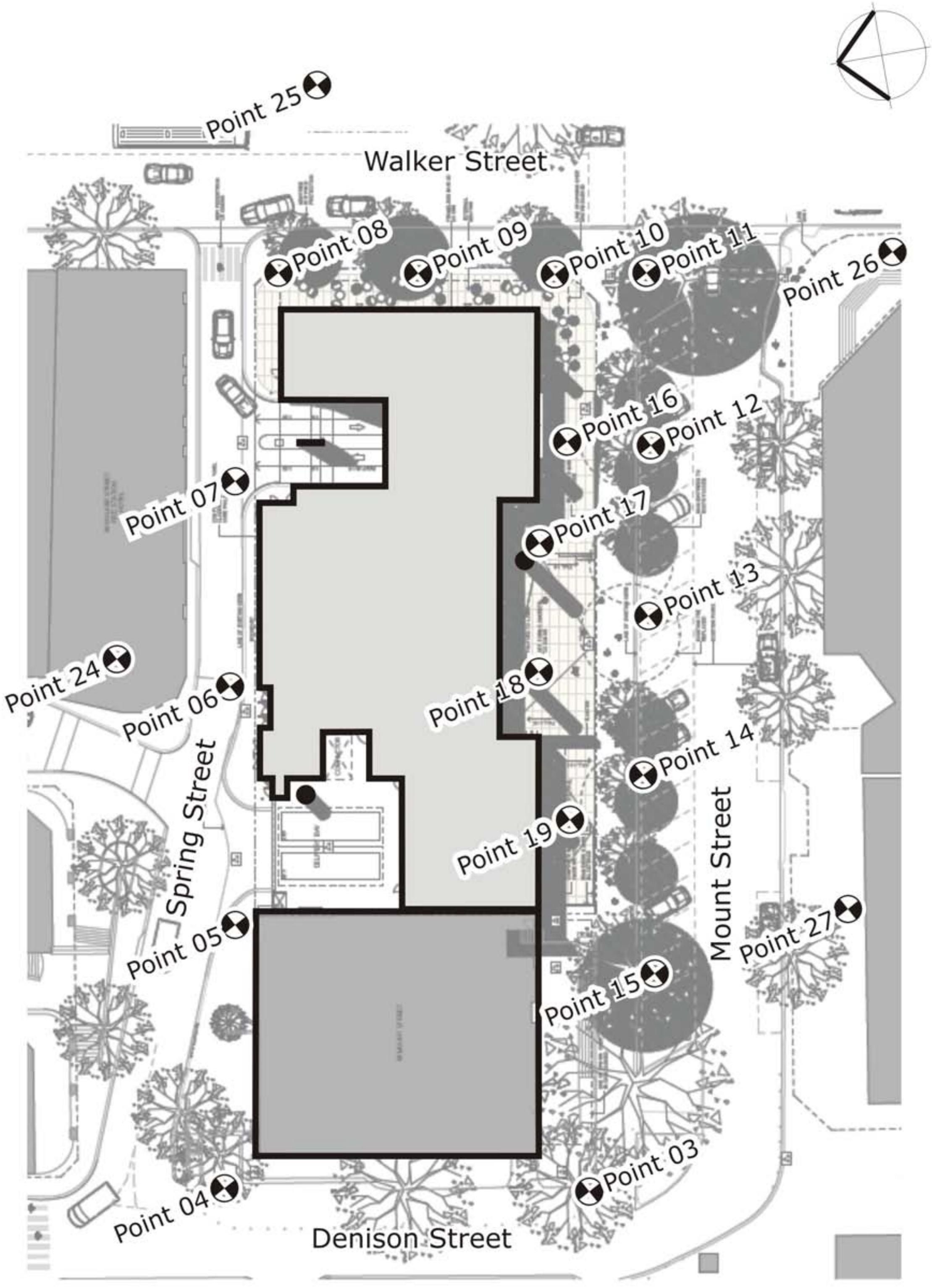

Figure 6a: Study Point Locations - Ground Level