SYDNEY FOOTBALL STADIUM REDEVELOPMENT

STATE SIGNIFICANT DEVELOPMENT APPLICATION

Concept Proposal and Stage 1 Demolition

SSDA 9249

APPENDIX I:

Wind Considerations for Stadium Design

NSW GOVERNMENT

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Sydney Football Stadium – wind engineering

Dear Ms. O'Neill,

Please find herein some commentary outlining the Sydney wind climate and stadia design considerations from an environmental wind comfort and wind loading perspective.

Sydney 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 1997 to 2016 are presented in Figure 1 to Figure 3. The arms of the wind rose point in the direction from where the wind is coming from. The anemometer is located about 9 km to the south-south-west of the site. The directional wind speeds measured at the anemometer are considered representative of the wind conditions at the site.

Figure 1 shows the wind rose for the entire year as well as specific time periods throughout the day, which are more associated with the use of the stadium and surrounding areas. It is evident that strong winds come from the north-east, south, and west quadrants with lighter winds in the early morning increasing throughout the day.

Seasonal wind roses are presented in Figure 2, and temperature wind roses in Figure 3. It is evident summer winds occur mainly from the south quadrant and the north-east. 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-scale 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 north-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.

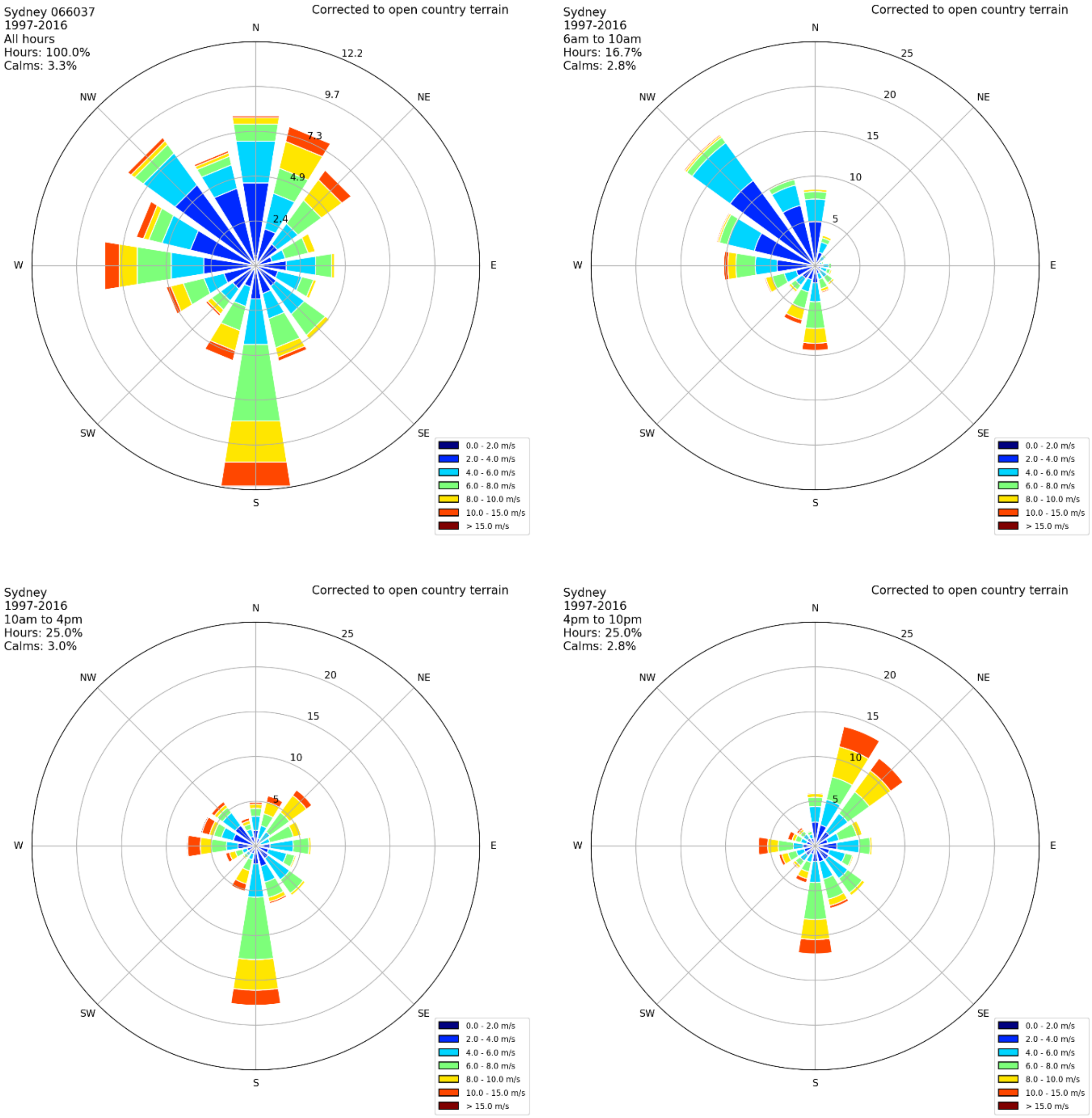

Figure 1: Sydney Airport temporal wind roses

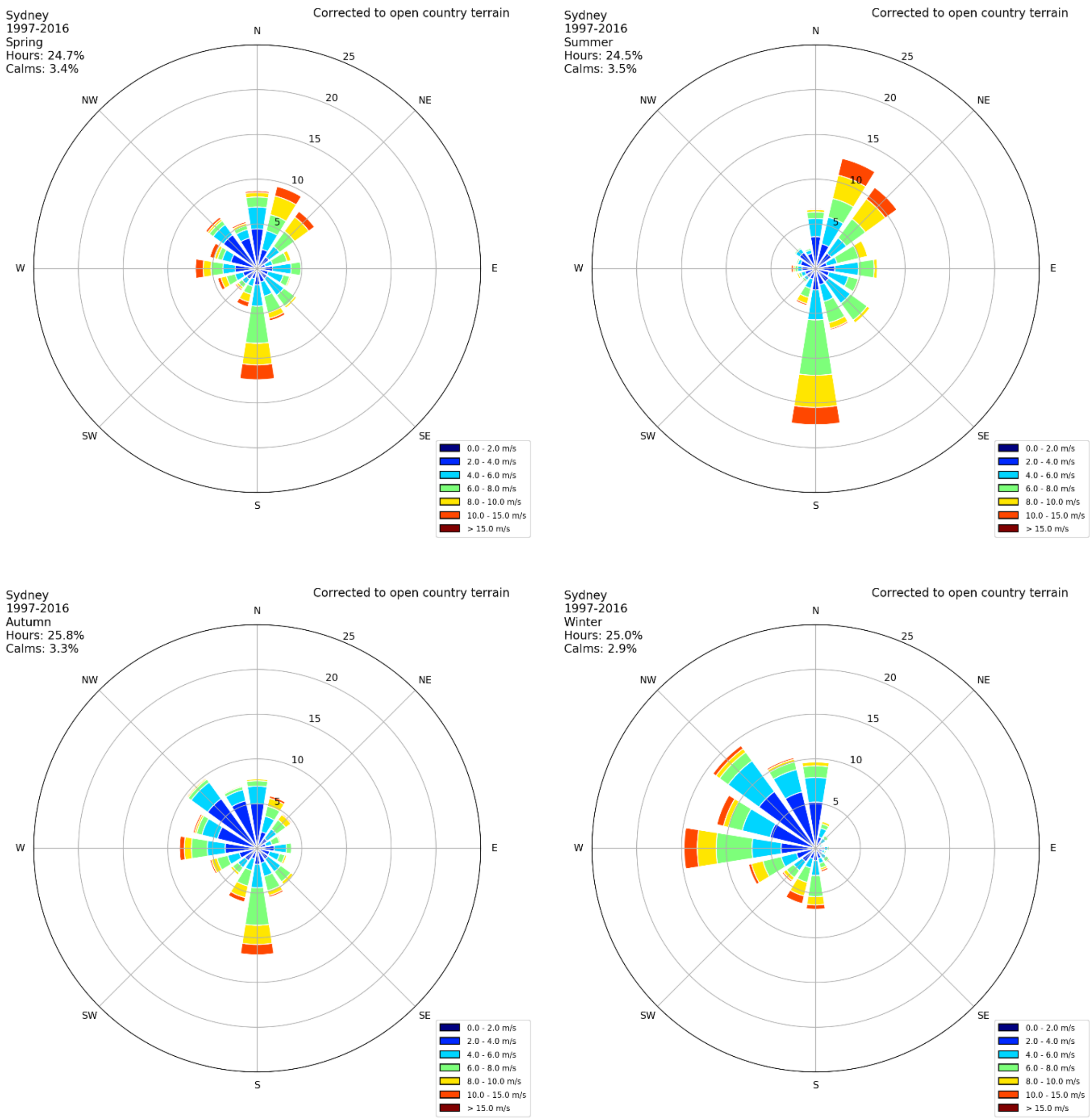

Figure 2: Sydney Airport seasonal wind roses

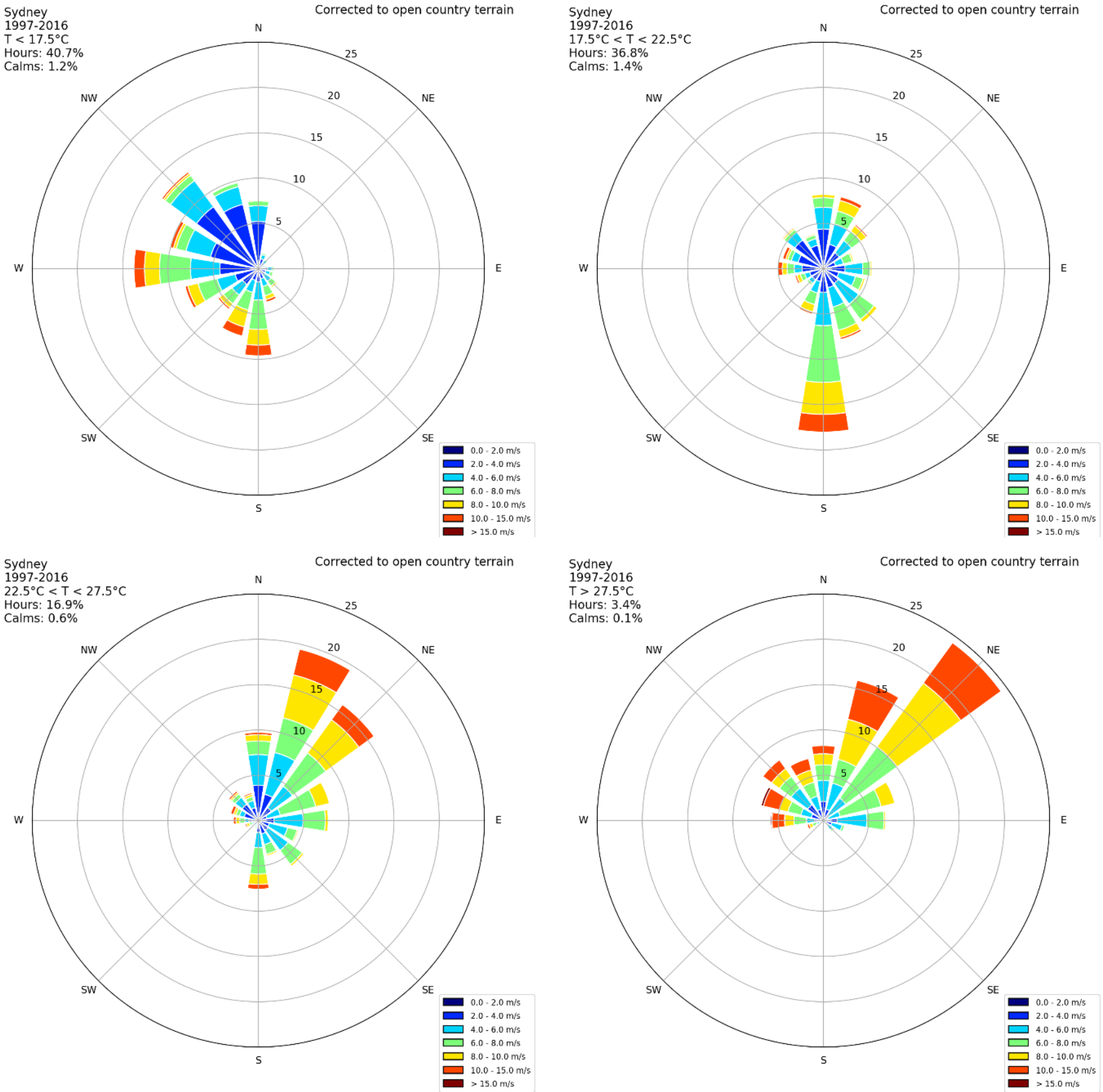

Figure 3: Sydney Airport temperature range wind roses

Sydney wind-driven rain climate

Rain occurs in Sydney for approximately 5% of the time. Directional wind driven rain statistics recorded at Sydney Airport are presented in Table 1 for rainfall intensity and in Table 2 for wind speed. It is evident that about 45% of the rain comes from the south quadrant, and the remaining 55% is evenly distributed around the other quadrants.

The rain associated wind speed at 10 m height at Sydney Airport is typically above 2 m/s. About 80% of the associated wind speed is spread evenly between 2 and 10 m/s, with a decreasing percentage at higher velocities. The combined wind speed and rainfall intensity distribution of rain events is presented in Table 3 showing that the majority of rain events have low rainfall intensity with a relatively high wind speed. There is a relatively constant distribution of time for medium intensity rainfall and mean wind speed.

Due to the increased density of buildings around the stadium compared with the airport, for all wind directions the mean wind speed at the site would be expected to be slightly lower, and the turbulence higher than recorded at the airport. The mean wind speed governs the constant wetting of an area, whereas the turbulence governs the maximum extent of rain ingress.

Wind driven rain ingress depends on the rainfall intensity, and the local wind speed and direction; these parameters control the particle size distribution, and the particle velocities in both the vertical and horizontal directions. The greater the rainfall intensity, the larger the particle size. The terminal velocity of individual rain particles is dependent on their size. When the local wind speed is in excess of the terminal velocity the shape of the rain particle changes, reducing the terminal velocity and forcing the rain particle to move more with the wind flow direction. Small lighter particles accelerate quickly reaching terminal velocity, or the local wind speed, from stationary in under 5 s. When rain particles hit a surface, they can break up into smaller sized particles that are more easily transported on the wind.

Table 1: Distribution of rainfall intensity with wind direction expressed as a percent of time

Rainfall rate	Wind direction																	
mm/30 mins	CALM	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
0-1	0.7	5.4	3.3	2.4	2.0	3.6	3.2	3.9	5.9	13.7	9.4	4.6	3.3	4.1	2.5	2.7	2.3	**73.0**
1-2	0.1	0.8	0.5	0.5	0.5	0.7	0.9	1.0	1.4	2.7	1.8	0.9	0.7	0.6	0.4	0.3	0.3	**14.2**
2-4	0.0	0.3	0.2	0.3	0.4	0.7	0.4	0.6	0.8	1.7	0.8	0.5	0.4	0.3	0.2	0.2	0.2	**8.3**
5-10	0.0	0.2	0.1	0.2	0.1	0.3	0.2	0.2	0.4	0.7	0.3	0.2	0.2	0.2	0.1	0.1	0.1	**3.6**
>10	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	**1.0**
TOTAL	**0.8**	**6.8**	**4.1**	**3.5**	**3.0**	**5.4**	**4.9**	**5.8**	**8.6**	**18.9**	**12.4**	**6.2**	**4.7**	**5.2**	**3.2**	**3.4**	**2.9**	**100**

Table 2: Distribution of rain events with wind speed and direction expressed as a percent of time

Wind speed	Wind direction																	
/m/s	CALM	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
0-2	0.8	0.5	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.2	0.3	0.2	**4.3**
2-4		2.7	1.1	1.0	0.7	1.1	0.7	0.7	0.9	1.5	1.2	1.2	1.4	1.9	1.8	1.8	1.5	**21.2**
4-6		2.3	1.3	0.9	0.9	1.5	1.2	1.3	1.4	2.9	2.2	1.5	1.6	1.5	0.6	0.9	0.8	**22.9**
6-8		0.9	0.8	0.9	0.7	1.4	1.5	1.6	2.0	4.1	2.8	1.6	0.9	0.7	0.3	0.3	0.3	**20.8**
8-10		0.3	0.4	0.4	0.3	1.0	1.0	1.4	1.9	4.2	2.9	1.1	0.3	0.4	0.2	0.0	0.1	**15.8**
10-12		0.0	0.2	0.2	0.1	0.2	0.4	0.7	1.1	3.1	1.8	0.5	0.1	0.2	0.1	0.0	0.0	**8.9**
>12		0.0	0.0	0.0	0.1	0.0	0.1	0.2	1.1	2.9	1.3	0.2	0.1	0.1	0.0	0.0	0.0	**6.2**
TOTAL	**0.8**	**6.8**	**4.1**	**3.5**	**3.0**	**5.4**	**4.9**	**5.8**	**8.6**	**18.9**	**12.4**	**6.2**	**4.7**	**5.2**	**3.2**	**3.4**	**2.9**	**100**

Table 3: Distribution of rain events with wind speed and rainfall intensity expressed as a percent of time

Wind speed	Rainfall intensity /(mm/30 min)					
/m/s	0-1	1-2	2-4	4-10	>10	Total
0	0.70%	0.052%	0.022%	0.0074%	0%	**0.78%**
0-2	2.8%	0.46%	0.16%	0.12%	0.0074%	**3.5%**
2-4	17%	2.4%	1.4%	0.73%	0.13%	**21%**
4-6	17%	3.3%	1.8%	0.84%	0.24%	**23%**
6-8	15%	2.9%	1.9%	0.78%	0.19%	**21%**
8-10	11%	2.4%	1.4%	0.63%	0.10%	**16%**
10-12	6.1%	1.4%	1.0%	0.33%	0.074%	**8.9%**
>12	3.8%	1.3%	0.70%	0.33%	0.089%	**6.2%**
Total	**73%**	**14%**	**8.3%**	**3.8%**	**0.82%**	**100%**

Wind-driven rain is an issue for the existing stadium, which is open to the prevailing wind driven rain direction from the south. The pitch of the roof, extent of coverage, and opening around the outer perimeter of the stadium under the roof encourages wind to carry rain across spectators.

To minimise rain ingress, it is beneficial to have the inner edge of the roof at approximately the same height around the entire stadium, increase the spectator coverage, and increase the solidity of the perimeter cladding.

Environmental 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.
Freshbreeze	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. 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 particularly in a stadium environment.

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.

Air speed has a large impact on thermal comfort and is generally welcome during hot summer conditions. The current Sydney City Council DCP (2012) wind controls are based on the work of Melbourne (1978). For people appropriately dressed for the outside temperature conditions ranging from 10° to 30°C, these criteria are based on the annual maximum wind gust, which is defined as the peak 3 s gust wind speed occurring in an hour for 0.1% of the time from any wind direction, are as follows:

1. Safety criterion >23 m/s.
2. Acceptable for walking if the annual maximum gust is less than 16 m/s.
3. Acceptable for short-term stationary activities (window shopping, standing or sitting in plazas) if the annual maximum gust is less than 13 m/s.
4. Acceptable for long-term stationary activities (outdoor restaurants) if the annual maximum gust is less than 10 m/s.

The area around the SFS is not an active frontage as defined in Sydney City Council DCP (2012) and therefore the assessment criterion in the area surrounding the site is for an annual maximum gust wind speed of 16 m/s.

Inside the stadium, the required environmental conditions will depend on the intended use of the space and suggested criteria are described in Table 5 to maintain the same format as the Sydney City Council DCP. All locations should meet the safety criterion.

Table 5 Recommended criteria for various spaces

Activity	Comfort criterion (annual maximum gust wind speed)
Access around stadium	2. Walking (<16 m/s)
Queuing for tickets, food outlets	3. Short-term stationary activities (<13 m/s)
Outdoor eating	4. Long-term stationary activities (10 m/s)
Spectating (Denoon et al. 2000)	Spectator activities (<11.5 m/s)

Wind flow across the pitch level is important for the health of the grass. There are no known minimum criteria for grass health, but from working with landscape architects, it would require to be windier than the long-term stationary activities criterion. Consideration should be given in the stadium design to the conflicting environmental requirements of spectators, competitors, and the health of the grass, which may require event and non-event modes of operation.

General flow patterns

The wind conditions in and around the stadium are influenced by the surrounding buildings and topography, the orientation of the stadium, the openness of the façade, and the design of the roof. The larger and more solid the building, the more flow will be directed around the outside of the structure and less through the stadium. The general overall rounded form of the building encourages flow to pass horizontally around and over the structure rather than inducing significant downwash that would adversely influence pedestrians.

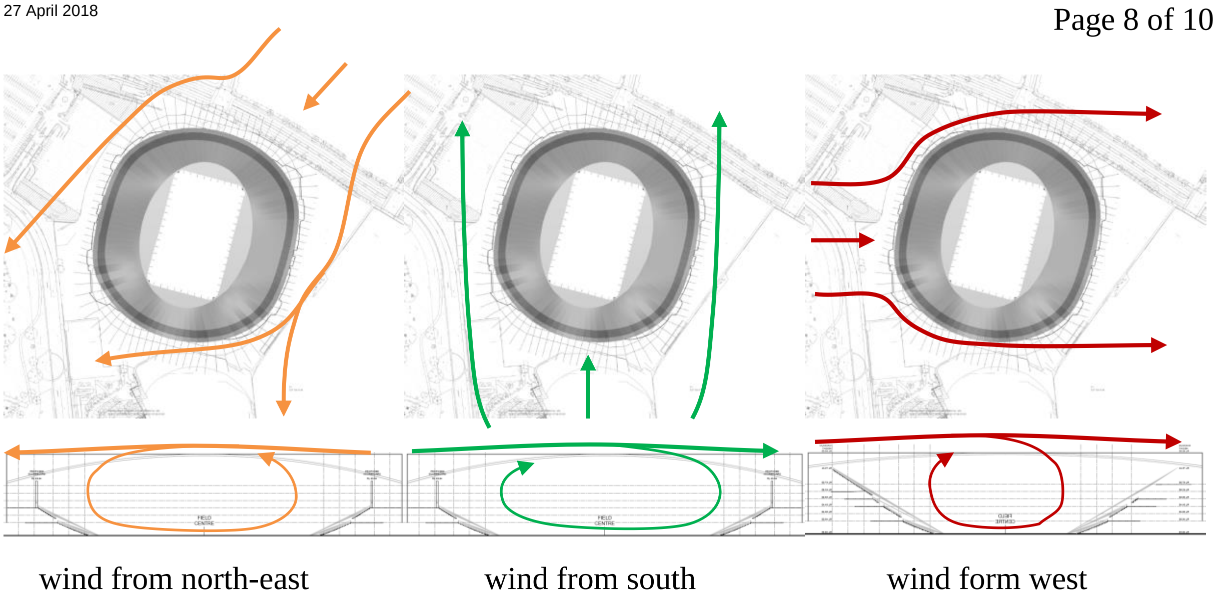

Figure 4 Indicative global flow patterns around sealed stadium

Flow through the stadium is controlled by the number and size of all external openings, including the roof opening. As wind passes around a structure, a pressure distribution is generated resulting in flow through the structure from areas of high to low pressure, Figure 5. The size and location of the narrowest cross-section along the flow path controls the overall magnitude of flow through the stadium, whereas the internal layout governs the local flow pattern. The fastest flows will be experienced at the narrowest cross section along the flow path; where the green streamlines in Figure 5 come close together; such as internal doorways and vomitories if the area of the openings in the façade are greater than the areas of the internal openings. Upstream of the constriction wind conditions will be relatively calm, decelerating with distance downstream of the constriction. Typically, the jet is experienced for about 10-15 m downstream of the constriction and this area should be used as a transient space. The shape of the opening has an impact of the flow direction of the jet and can be used to direct flow to the pitch; compare the impact of the relative position of the upper tier on the direction of the jet outflow through the lower tier between Figure 5 and Figure 6.

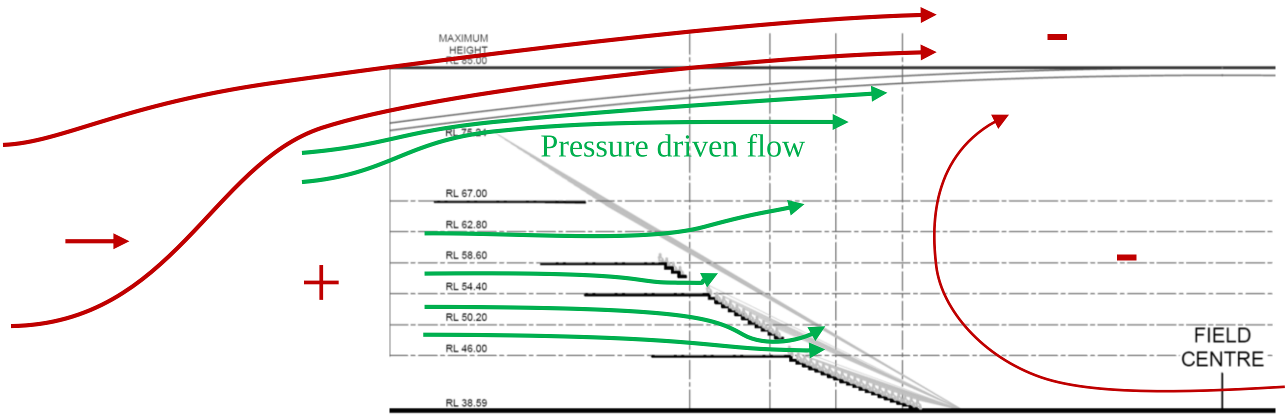

Figure 5 Flow schematic through open stadium

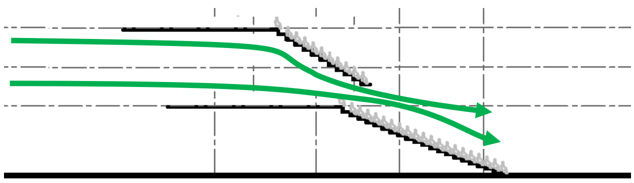

Figure 6 Flow schematic with displaced upper tier

Wind conditions

The existing wind conditions around the site are generally classified as suitable for pedestrian standing, with some windier locations to the north-west and south-west suitable for walking caused by uninterrupted winds from the west quadrant accelerating around the stadium. Inside the stadium, wind conditions can be uncomfortable for spectators during the prevailing wind form the south. Despite the significant shielding provided by the SCG to the south, these strong wind events are primarily caused by the saddle shape of the roof combined with the open sections of the façade between the top of the stand and underside of the roof, which encourages flow across the seating space.

The site is reasonably well protected by the SCG to the south, and topography to the north-east. The wind conditions around a similar-sized curved stadium would be expected to be similar to existing conditions. The wind conditions inside the stadium will be governed by the geometric design of the roof, openness of the façade, and internal layout. Note that windier conditions will be experienced at the narrowest cross-sectional area along the flow path and appropriate consideration should be taken over the use of these spaces.

If the façade behind the rear of the stand closest to the underside of the roof is open, a solid wall should be provided to the rear of the seating area of at least 2 m above seat level, to offer protection to pedestrians from wind and wind-driven rain.

Wind Loading

The governing loading on the roof is typically from wind loading. The critical loading pattern on the roof will be highly dependent on the structural supporting system. Note that the wind loading provided in Appendix D of Standards Australia (2011) is for an cantilever roof design system on a single isolated stand. The curved nature of the stadium, and the interference effects from the stand on the opposite side of the pitch has a significant impact on the design loading. General techniques to reduce the wind loading on a stadium roof are to vent the leading edge rather than having a solid roof at the edge, and to vent the outer façade just below the roof. The height of the sub-roof vent should be a minimum of 1% of the overall height of the façade.

The dynamic response of a large roof is generally small. However, if the roof is lightweight with low inertia, there is the potential for dynamic overshoot to sudden impulse wind loading events. This often occurs for roofs on opposite side of the stadium.

Impact of the SFS on the SCG

The close proximity of the stadia will cause wind flow interference effects. The increase in massing of the south elevation of the SFS would be expected to encourage slightly more flow through the gap between the stadia. The concourse to the rear of the north stand and the seats tot eh west of the north stand would be expected to become slightly windier during winds from the west, but calmer for winds from north-east. The overall general comfort conditions would not be expected to change. There are no safety concerns from a wind perspective.

As most of the design cases for the roof structure were associated with winds form the south, the proposed SFS is not expected to increase the wind loading.

Post-competition wind studies

Wind-tunnel testing should be conducted on the final geometry of the stadium during detailed design to determine the appropriate wind loads for the final structural system. In addition, the wind climate in and around the stadium for pedestrian comfort, and pitch health should be quantified through wind-tunnel testing, or a suitably calibrated numerical model.

I hope this is of assistance, please do not hesitate to contact me on (02) 9320 9921, if you have any questions regarding any aspect of this report.

Yours sincerely,

Graeme Wood
Associate Principal

REFERENCES

Denoon, R., Kwok, K.C.S., Wood, G.S., Phillips, A.G., Issues on the Design of Sports Stadia for Environmental Wind Effects, Wind and Structures into the 21st Century, Cheju, Korea, 2000.

Standards Australia (2011), Structural Design Actions; Part 2: Wind actions, AS/NZS1170.2:2011.