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WESTERN SYDNEY STADIUM

Wind Engineering – Environmental Wind Report

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Bringing ideas to life

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Document prepared by:

Aurecon Australasia Pty Ltd

ABN 54 005 139 873

Level 5, 116 Military Road
Neutral Bay NSW 2089

PO Box 538
Neutral Bay NSW 2089
Australia

T +61 2 9465 5599
F +61 2 9465 5598
E sydney@aurecongroup.com
W aurecongroup.com

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Author signature		Approver signature	
Name	Richard Jones	Name	Matt Magraith
Title	Wind Engineer	Title	Technical Director

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1 Introduction

Figure 1: Internal view within the stadium

1.1 Project Understanding

Project involves the demolition of the existing stadium and construction of a new stadium to seat 30,000. Structure of the stadium is relatively simple with regularly spaced trusses supporting the seating platforms and a cantilevered truss with a tensioned membrane to the underside. Openings at ground level and to the rear of the seating platform.

1.2 Assessment Background

This report provides an assessment of environmental wind comfort and safety for critical patron areas at the proposed Western Sydney Stadium. Stadium structures must be designed such that they not only provide sufficient shielding from weather, but also a pleasant space to focus on the event being held.

In this assessment we analysed wind speeds at pedestrian height across all relevant locations around the stadium. Computational Fluid Dynamic (CFD) methods were used in this assessment which involved combining a 3D model of the stadium with an analysis of local meteorological data obtained from the nearest Bureau of Meteorology (BOM) station.

1.3 Assessment Scope

Assessment of pedestrian-level wind comfort and safety was based on the following scope of works:

- Obtain and analyse hourly meteorological data from the closes/most representative BOM station
- Complete an 8-directional wind frequency analysis
- Create 3D model of the proposed Western Sydney Stadium from architectural drawings and Revit models provided at the time of modelling
- Predict wind speeds across patron locations for an environmental wind speed of 10m/s at 10m height above ground level (ABL)
- Identify appropriate patron wind comfort and safety classifications
- Combine predicted wind speeds obtained from CFD modelling with the 8-directional wind frequency analysis to determine patron wind comfort and safety classifications.
- Assess patron comfort and safety classifications against relevant criteria
- Assess playing field wind effects
- Provide mitigation advice based on CFD/statistical results.

1.4 Architectural Sources

A simplified model of the proposed Western Sydney Stadium was developed using an architectural Revit model and drawings provided by Populous (Populous, 2016/17).

Alterations to this design were made for the roof leading edge (eyebrow), specifically the area between the roof and the leading edge was opened, the leading edge angle increased to 7 degrees and the angle between the trailing edge of the eyebrow and the leading edge of the roof membrane was set to 45 degrees. These design changes occur in locations that have minimal impact on patron wind comfort and safety.

The design of the curved display screen on the North Eastern corner of the stadium was unknown at the time of modelling. This feature was therefore assumed to provide no wind resistance in an effort to give conservative environmental wind results.

A ‘plinth’ was necessary for ease of modelling the lower bowl (below ground/concourse level). This feature provides an approximation to terrain effects near the stadium.

Figure 2: Plaza surrounding the stadium where pedestrian impacts are important

2 Wind Environment

2.1 Climatic Wind Conditions

Climatic wind conditions near the Western Sydney Stadium were obtained by statistical analysis of the nearby Bankstown Airport weather station. In this environmental wind analysis, results from steady CFD simulation over the proposed structure are scaled by the statistical properties of the wind in order to estimate the probability of local wind criteria exceedance. Wind speed probability is commonly modelled using the Weibull distribution. Coefficients for the Weibull wind speed distribution at Bankstown Airport are given in Table 1 below. Further details regarding these values can be found in the meteorology report associated with this project (Aurecon 2017).

Table 1: Weibull parameters for each wind direction

Direction	A	k	C
N	0.03	1.30	2.43
NE	0.09	1.92	3.89
E	0.1	1.86	4.21
SE	0.15	1.83	4.93
S	0.15	1.34	3.58
SW	0.18	1.27	2.69
W	0.17	1.27	3.05
NW	0.14	1.41	3.11

2.2 Local Wind Effects

A schematic illustration of the wind flow pattern around a single wide high rise building is presented in Figure 3.

As the wind flow approaches the building, it gradually diverges. Part of the flow is deviated over the building (1) and part of it flows around the building (2). At the windward facade, a stagnation point with maximum pressure is situated at approximately 70% of the building height. From this point, the flow is deviated to the lower pressure zones of the facade: upwards (3), side-wards (4) and downwards (5).

The considerable amount of air flowing downwards produces a vortex at ground level (6) called standing vortex, frontal vortex or horseshoe vortex. The main flow direction of the standing vortex near ground level is opposite to the direction of the approach flow. Where both flows meet, a stagnation point with low wind speed values is created at the ground in front of the building (7). The standing vortex stretches out sideways and sweeps around the building corners where flow separation occurs and corner streams with high wind speed values are created (8). The corner streams subsequently merge into the general flow around the corners (9).

At the leeward side of the building, an under-pressure zone is created. As a result, backflow or recirculation flow occurs (10,13). A stagnation zone is marked downstream of the building at ground level where the flow directions are opposite and low wind speeds exist (11; end of the recirculation zone). Beyond the stagnation zone, the flow resumes its normal direction but wind speeds stay low for a considerable distance behind the building (i.e. the far wake) (12).

The backflow is also responsible for the creation of slow rotating vortices behind the building (13). Between these vortices and the corner streams (9), a zone with a high velocity gradient exists (the shear layer) that comprises small, fast rotating vortices (16). The shear layers originate at the building corners where flow separation occurs (Blocken and Carmeliet, 2004).

Wind effects, particularly downwash, are worsened with increased surface area exposed to incident winds.

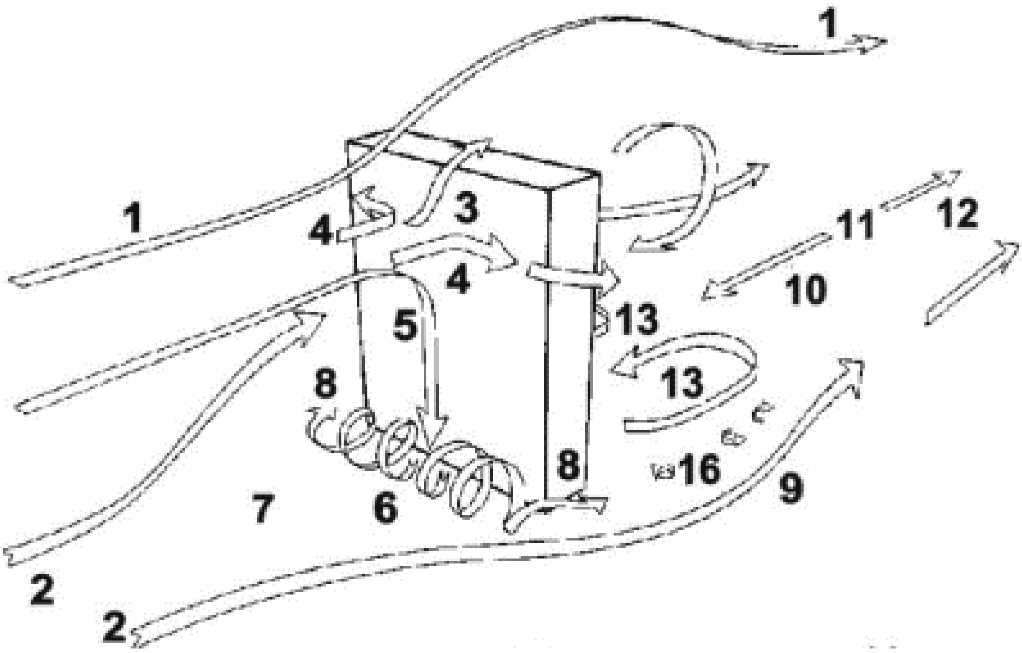

Figure 3: Wind effects around a building (Blocken and Carmeliet, 2004)

The terrain surrounding Western Sydney Stadium is shown in Figure 4 and is marked with a circle of radius 400m. Very few buildings can be seen in the immediate vicinity of the stadium, with the exception of the East and North East where suburban housing approaches O'Connell St. This housing will provide some low level protection to the stadium structure, however the upper bowl and roof structure will be relatively unaffected by the buildings in immediate vicinity.

Figure 4: Aerial image of Western Sydney Stadium and surroundings (source: Google Earth). Yellow circle indicates a radius of 400m.

3 Assessment Criteria

3.1 Patron Comfort

The Lawson comfort criteria (Lawson and Penwarden, 1975 amended with input from Isyumov and Davenport, 1975) are often used for wind comfort assessment in outdoor areas and are defined in Table 2. The commonly used Beaufort scale is also provided for comparison in Table 3. The Davenport criteria are used to assess wind force only and do not allow for variations in ambient temperature, solar radiation, and other environmental variables.

The comfort criteria (Lawson, 1978) are based on the exceedance of the threshold wind speeds occurring less than 5% of the time (approximately once per month during daylight hours). The value of 5% has been established as giving a reasonable allowance for extreme and relatively infrequent winds that are tolerable within each category. For example, if the mean hourly wind speed at a particular location is less than 4 m/s for 95% of the time then that location is classified as C4. On the Beaufort scale, 4 m/s is described as a gentle breeze. At the other extreme, if the wind speed exceeds 8 m/s more than 5 % of the time but exceeds 10 m/s less than 5% of the time, then category C1 applies and the location would be considered windy though not necessarily unsafe. The Beaufort description of this would be a fresh breeze. A wind speed in excess of 10 m/s more than 5% of the time would incur a category of C1+.

Table 2: Lawson/Davenport Comfort Criteria

Comfort rating	Description	Mean hourly wind speed	Appropriate Area Usage	Description of Wind Effects
C1+	Uncomfortable for all users	>10 m/s	Uncomfortable for all uses	▪ Umbrellas difficult to use ▪ Hair blown straight
C1	Fast or business walking	10 m/s	Areas where people are not expected to linger	▪ Force of wind felt on body
C2	Leisurely walking	8 m/s	General walking or sightseeing	▪ Dust and papers raised ▪ Hair disarranged
C3	Short period sitting/standing	6 m/s	Bus stops, building entrances	▪ Light leaves and twigs in motion ▪ Lightweight flags extend
C4	Long period sitting/standing	4 m/s	Reading a newspaper, eating and drinking	▪ Light wind felt on face ▪ Leaves rustle

Table 3: Beaufort scale

Beaufort Number	Description	Mean Hourly Wind Speed [m/s]	Effect
0	Calm	0 - 0.3	Smoke rises vertically
1	Light air	0.3 – 1.6	No noticeable wind
2	Light breeze	1.6 – 3.6	Wind felt on face
3	Gentle breeze	3.6 – 5.5	Hair disturbed, clothing flaps, newspaper difficult to read
4	Moderate breeze	5.5 – 8.0	Raises dust and loose paper. Hair disarranged
5	Fresh breeze	8.0 – 10.8	Force of wind felt on body, danger of stumbling
6	Strong breeze	10.8 – 13.9	Umbrellas difficult to use, difficult to walk steadily, wind noise unpleasant
7	Near gale	13.9 – 17.2	Inconvenient to walk
8	Gale	17.2 – 20.8	Impedes pedestrian progress, difficult balancing in gusts
9	Strong Gale	20.8 – 24.5	People blown over

3.2 Patron Safety

For the safety criteria, once per annum during daylight hours equates to a seasonal threshold exceedance of 0.023 %. A mean hourly wind speed greater than 15 m/s but less than 20 m/s occurring once a year is classified as unsuitable for general public which includes elderly, cyclists and children. Able bodied users are those determined to experience distress when the wind speed exceeds 20 m/s once per year. Such safety criteria indicate the potential for danger during normal pedestrian activity, for example, a pedestrian crossing on a busy road, where the consequences of being blown over would be very serious. Other examples include access ways to hospitals and schools where the local pedestrian population is unlikely to cope safely with extreme winds. Referring again to the Beaufort scale, S2 would be classified as gale force, S1 as strong gale force.

Safety rating	Description	Mean hourly wind speed
S1	Unsuitable for able bodied	20 m/s
S2	Unsuitable for general public	15 m/s

3.3 Playing Field Wind Effects

The aerodynamic characteristics of ball flight play a pivotal role in sports such as rugby. Limited data is available on wind effects on rugby ball flight, however notable contributions from Ball (2010), Djamovski et. al. (2012), Alam et. al. (2006, 2008, 2010, 2012) and Polster and Ross (2010) give some guidance on the possible effects of crosswind.

A number of wind tunnel experiments were undertaken at varying yaw angle by Alam et. al. (2012) using a Summit rugby ball (produced by Heritage Sports Australia). Drag coefficients ranged between approximately 0.14 at zero yaw and 0.68 at 70 degrees yaw with variation between these values being a function of both yaw angle and Reynolds number (wind speed). Note that drag coefficients are Reynolds number dependent and will reduce with reducing velocity at higher yaw angles. These tests were conducted with a static ball and did not consider any tumbling or spin.

As an example of possible crosswind effects the following is a basic calculation of displacement of the rugby ball during flight. Typical ball speed during a 45m punt or a field goals is approximately 25m/s (Ball, 2010) giving a flight time (*t*) of approximately 1.8 seconds. Assuming a crosswind of 6m/s a vector sum gives a velocity of 25.7m/s (92.5km/h) at 14 degrees yaw. The drag coefficient (C_D) under these conditions is approximately 0.2 (Alam, 2012). The ball is likely to experience a crosswind displacement (*s*) of approximately

$$F = C_D(0.5\rho V^2 A) = 2.11\ [\mathrm{N}]$$

$$F_{side} = 2.11 \times \frac{6}{25} = 0.492\ [N]$$

$$a_{side} = \frac{F_{side}}{m} = 1.23\ [\mathrm{m/s^2}]$$

$$s = 0.5at^2 = 1.99\ [\mathrm{m}]$$

Where the frontal (circular) cross sectional area is A=0.0266m^2 corresponding to diameter 184mm (Alam, 2012), ρ is air density assumed to be 1.2 [kg/m^3] and m=400g is the rugby ball mass (Ball, 2010). Similar calculations for crosswinds of 10 and 15m/s result in side-displacements of 4.69 and 12.5m, respectively.

According to the World Rugby (2017) rules the distance between goal posts is 5.6m, indicating there is potential for crosswind effects to affect player performance. Assessment criteria are however difficult to define, since crosswind effects are not necessarily detrimental to play and may in fact be used to advantage by players and coaches (Cottrell, 2017). Comment on the effect of predicted statistical wind environment on play is included in Section 5.2 below.

4 Modelling Methods

4.1 Geometry and Meshing

The proposed Western Sydney Stadium geometry was modelled from provided architectural models (Populous 2016) as described in Section 1.4 above.

CFD divides (meshes) the volume surrounding all modelled geometry into discrete 3D elements (cells), over which the governing equations of fluid motion are solved. Smaller cell sizing is required in regions of expected flow field variation and where there are areas of complex geometry. To keep calculation time to a manageable level cell count must be judiciously managed. Therefore, geometry was simplified and fine details removed where appropriate (e.g. staircase hand railing). Images of the simplified geometry can be seen in Figures 4, 5 and 6 below.

The computational domain dimensions were chosen as a compromise between establishment of adequate free-field atmospheric boundary layer flow, resolution of surrounding structures and a manageable cell count. The final domain was set to an octagon shape of 400m radius and 100m height surrounding Western Sydney Stadium. The domain was meshed using the hexahedral dominant meshing tool, snappyHexMesh. Maximum cell sizes were 5m cubes in the far-field, while the smallest cells of approximately 300mm cubes were required near stadium surfaces in order to adequately resolve the frame geometry and fluid volume between bowl and roof components (see Figure 7). Total cell count was 8.1 million cells.

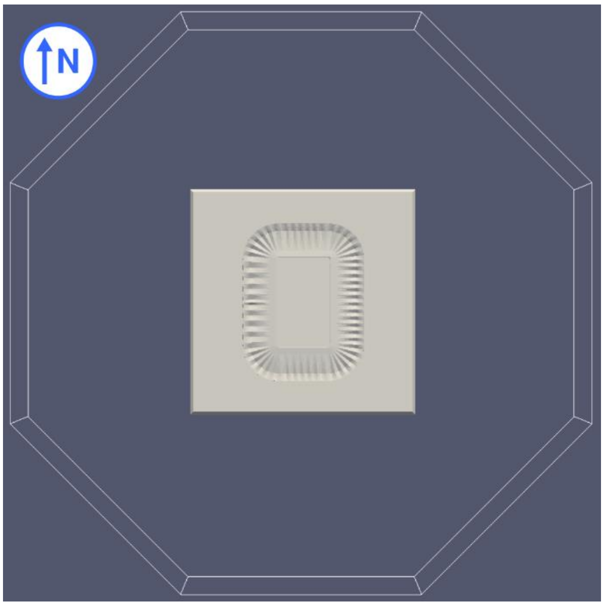

Figure 5: Plan view of Western Sydney Stadium geometry and domain

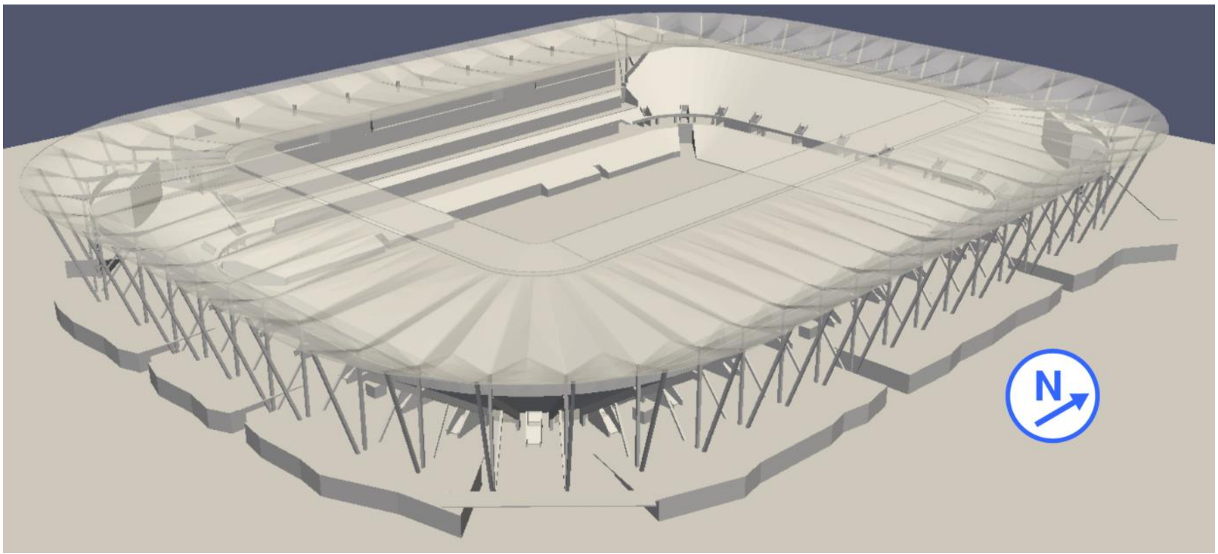

Figure 6: South East view of Western Sydney Stadium geometry and domain

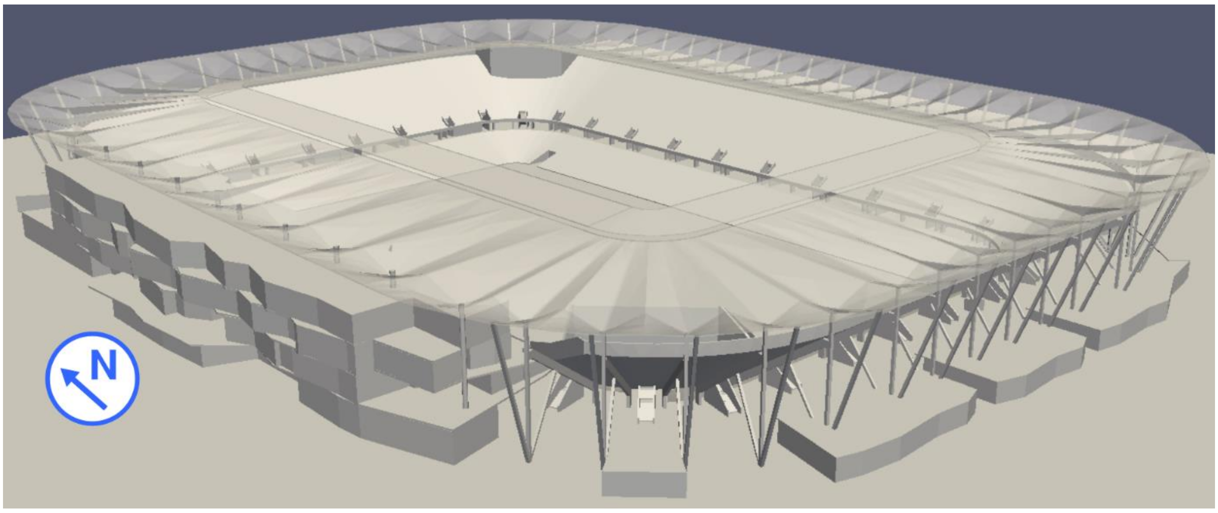

Figure 7: South West view of Western Sydney Stadium geometry and domain

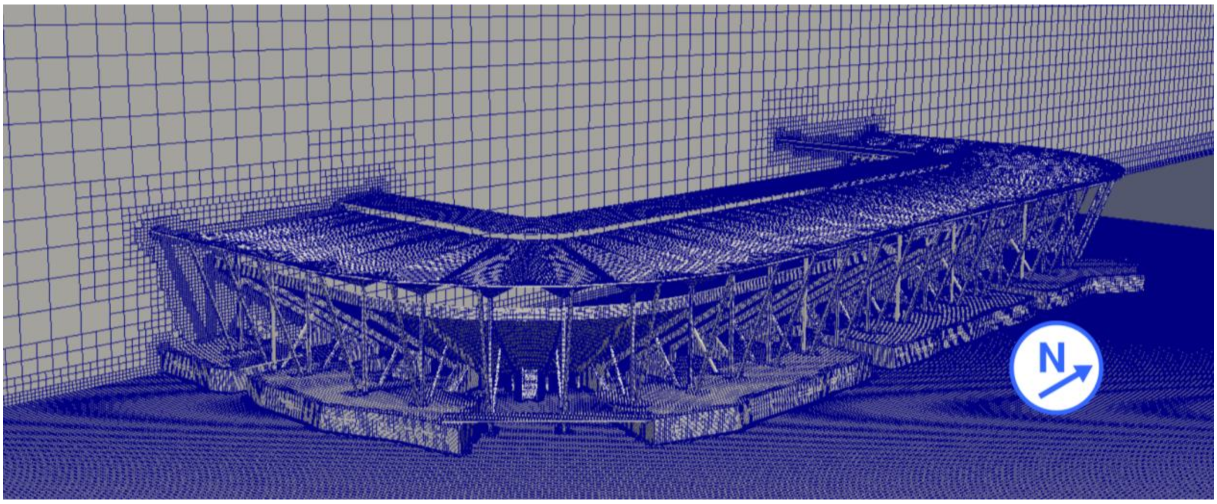

Figure 8: Cutting plane and wall surfaces displaying mesh resolution

4.2 Wind Modelling

Simulation of the Atmospheric Boundary Layer (ABL) requires the basic characteristics of the natural wind to be modelled. A suitable model of the atmospheric boundary layer is incorporated in the Australian Wind Actions Standard, AS 1170.2 (Standards Australia, 1989 and 2011) based on the work of Melbourne (1981) and Deaves and Harris (1978). This model uses a logarithmic law to describe the mean wind speed profile as a function of the aerodynamic roughness length which, in turn, is related to the surrounding terrain category (TC). Terrain categories and associated roughness lengths are defined in Table 3. Western Sydney Stadium is surrounded predominantly by suburban housing in all directions (Aurecon 2017) and the terrain category for all directions is therefore TC 3.

Table 4: Terrain categories used to simulate approach flows (Standards Australia, 2011)

Terrain Category	Definition	Aerodynamic Roughness Length [m]
1	Very exposed open terrain such as treeless flat plains, rivers, canals and lakes	0.002
2	Open grassland with no more than two well scattered obstructions per hectare of height generally 1.5 to 5m. Includes farmland and clear land with isolated trees.	0.02
3	Numerous closely spaced obstructions with heights generally 3 to 10m, such as suburban housing.	0.2
4	Numerous large, high (10-30m) closely spaced obstructions. Includes large city centres and well-developed industrial complexes.	2

Aurecon have implemented the Deaves and Harris ABL model in OpenFOAM, closely following all recommendations of Richards and Hoxey (1993) including upper boundary shear stress. The upper boundary turbulent gradients are also defined following the equations outlined in Sumner and Masson (2012). These equations were implemented for the k-epsilon class of turbulence models and the realizable k-epsilon model (Shih et. al. 1994) was used for the wind simulation.

A steady Reynolds averaged simulation was then conducted for all eight cardinal directions. The atmospheric boundary layer reference velocity was set to 10m/s at a 10m height for all directions. Simulations were run to convergence where three sampled velocity points distributed throughout the domain converged to steady state, while all momentum and turbulent equation residuals were less than 7×10^{-5} and the pressure equation residual less than 7×10^{-4}. Local and global continuity errors were less than 1.5×10^{-7} and 1.3×10^{-9} respectively. A selection of wind results are shown in Figures 8, 9 and 10 below.

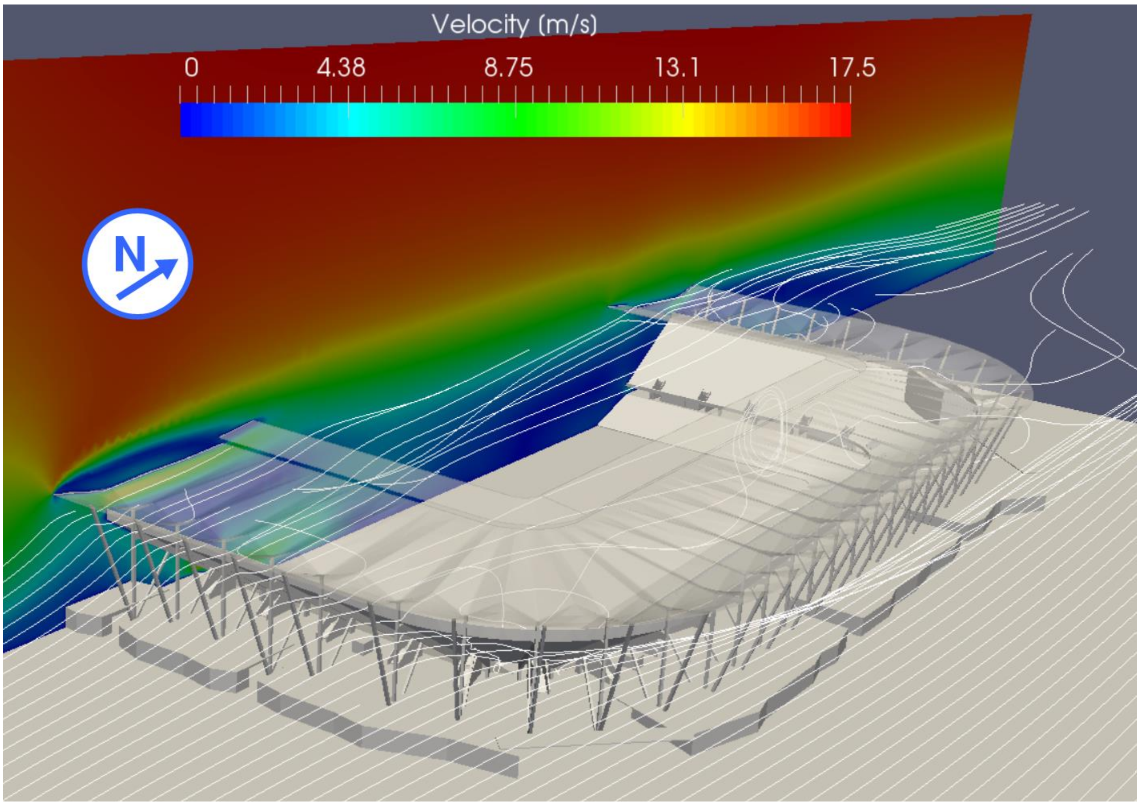

Figure 9: Cutting plane and streamlines for Southerly wind results, viewed from the South East

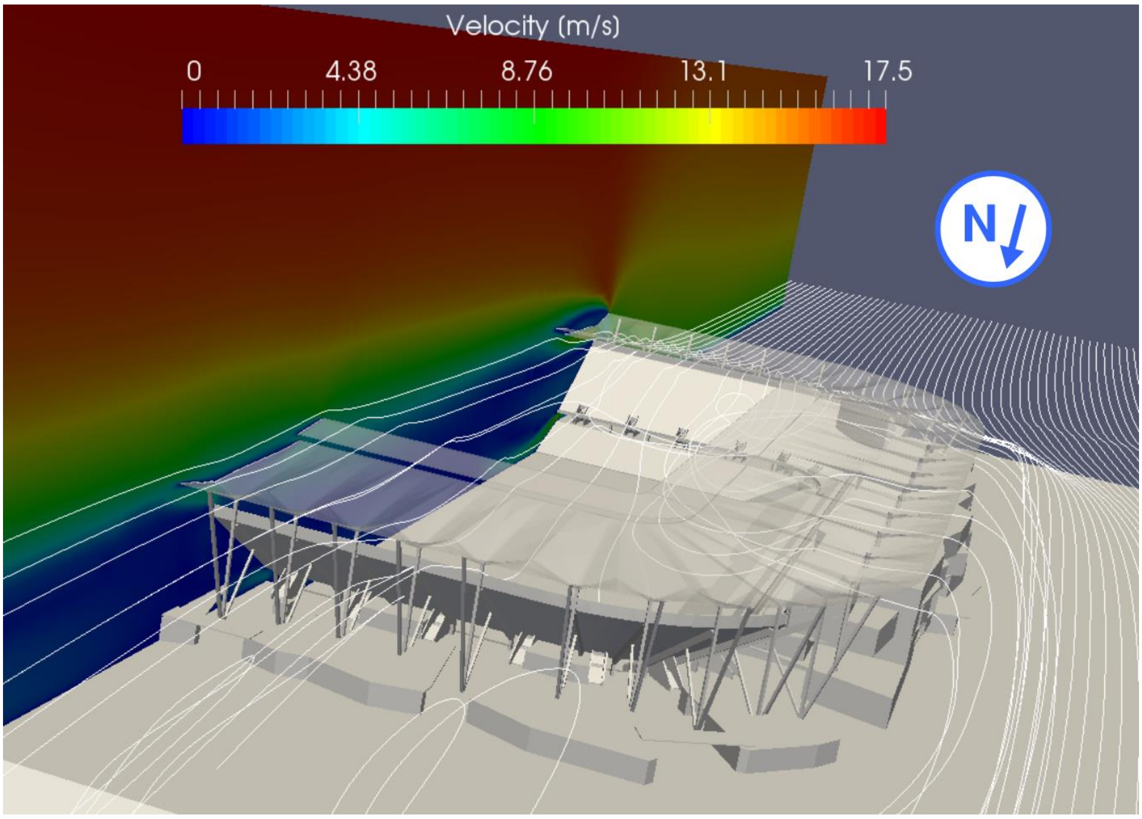

Figure 10: Cutting plane and streamlines for Southerly wind results, viewed from the North West

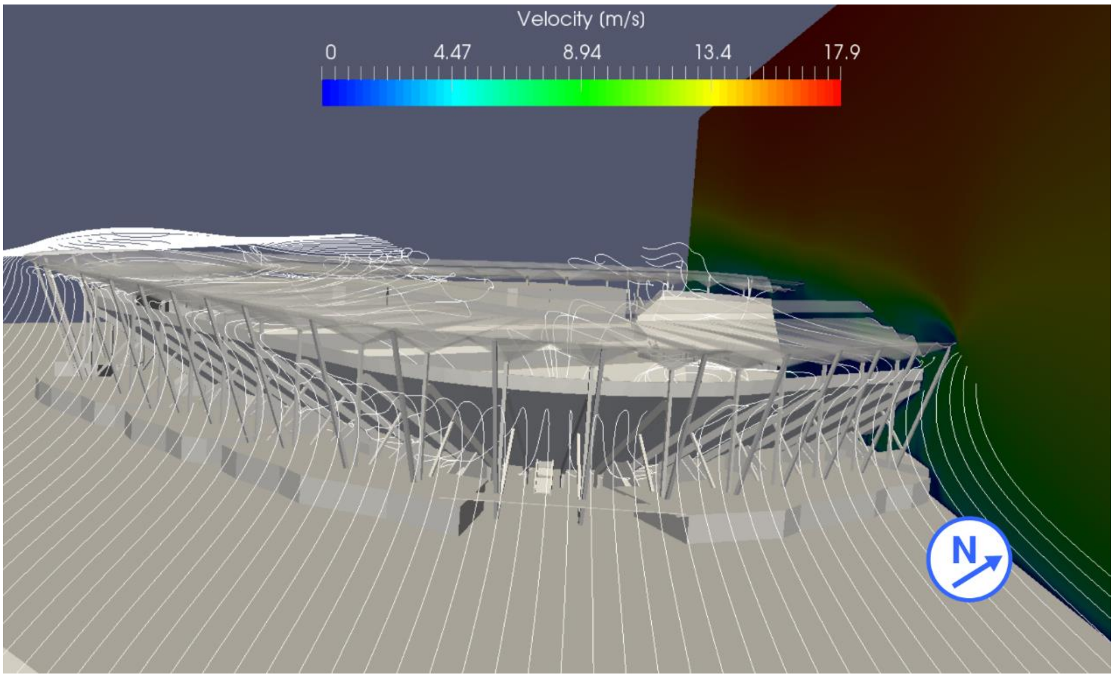

Figure 11: Cutting plane and streamlines for South Easterly wind results, viewed from the South East

4.3 Environmental Wind Statistical Analysis

The steady velocity fields for all cardinal directions were then scaled by the reference velocity and the probability of exceedance for each Davenport velocity criteria (Section 3.1) calculated across the computational domain using the corresponding Weibull probability coefficients (Section 2.1). The contribution to probability of exceedance is summed for each direction, giving an overall probability of exceedance. Where this probability exceeds 5% the corresponding comfort criteria is applied. A similar procedure is followed for the Davenport safety criteria (Section 3.2), where the probability exceedance criteria was 0.023%. Results from this procedure are given in Chapter 5 below.

5 Results and Assessment

5.1 Patron Wind Environment

The environmental wind comfort and safety criteria fields were sampled across the domain at a 1.5m height (patron height) above the each area of interest. Images of these results are shown in Figures 12 to 19 below.

Figure 12 shows the wind comfort criteria across the public spaces surrounding the stadium. All areas are categorised as suitable for either long or short period sitting/standing. This aligns with the potential use cases for these areas and indicates and further activities through the area are not likely to be impacted by an adverse wind environment. Similarly Figure 13 indicates wind safety criteria are not exceeded across these public spaces.

Figure 14, 15 and 16 show wind comfort and safety criteria are satisfied for intended usage across the playing field and upper bowl seating.

Figure 17 illustrates wind comfort criteria across the lower bowl seating areas and the concourse area within the stadium. At concourse level the wind environment is determined to fall within the comfort levels for the intended use. More specifically, patrons are expected to use the concourse area primarily for short period standing and leisurely walking between facilities. Similarly, Figure 16 shows wind environment safety criteria were found to be compliant throughout the playing field and upper bowl seating areas of the stadium.

For the lower bowl seating area the intended use is long period sitting. Figure 17 shows the predicted wind environment exceeds the comfort criteria in limited areas near the top seats, based on the intended use. The flow features that lead to these results are a consequence of a channelling effect between the upper and lower bowl geometries. A marker of this flow feature can be seen in Figure 11 where the streamlines are directed down the upper bowl surface where fluid velocity is accelerated through the open areas between stairwells. Figure 18 shows that these flow features also result in non-compliance with wind environment safety criteria was predicted in the same locations. However, it should be noted that the comfort criteria are based on a 5% exceedance (once per month), while safety criteria are based on 0.23% exceedance (once per year). Given the transient usage of the stadium, these standard ratings may not appropriately reflect a need for mitigation.

In the event that a mitigation strategy is required to reduce adverse wind effects within the stadium a solid or porous balustrade can be installed at the top of lower bowl seating areas. These balustrades would be required to provide sufficient blockage as to create a low speed bluff body wake region where patron seating is located. Locations of the suggested balustrades are illustrated in Figure 19.

The solid balustrade mitigation strategy is tested in Section 5.3 and found to achieve the desired reduction of environmental wind conditions for patron comfort and safety. However, this mitigation strategy has the following disadvantages:

- Cost impact will be significant
- Pitch turf ventilation requirements (Aurecon 2017) are significantly affected on the East (although somewhat improved for the West side of the pitch given deflection of wind by the balustrade)
- Visual impact (minimised with a transparent balustrade), although the view of the game for fans standing immediately behind the balustrade is unlikely to be affected
- May pose an emergency egress issue

Given the compromises to turf health and visual amenity, and the cost impact relative to the duration in which patron comfort is compromised, we consider it would not be unreasonable to proceed without balustrades.

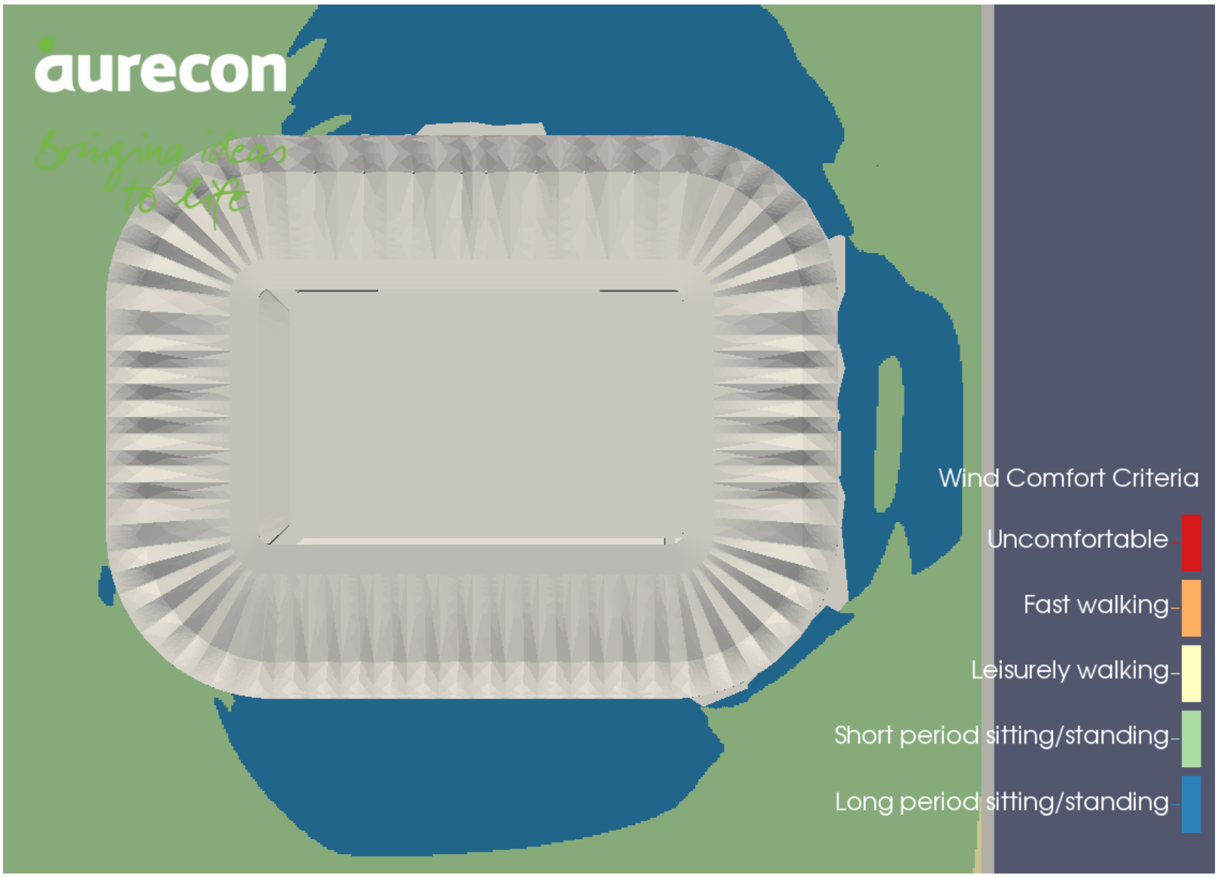

Figure 12: Wind comfort criteria over a cutting plane 1.5m above the concourse area surrounding the stadium

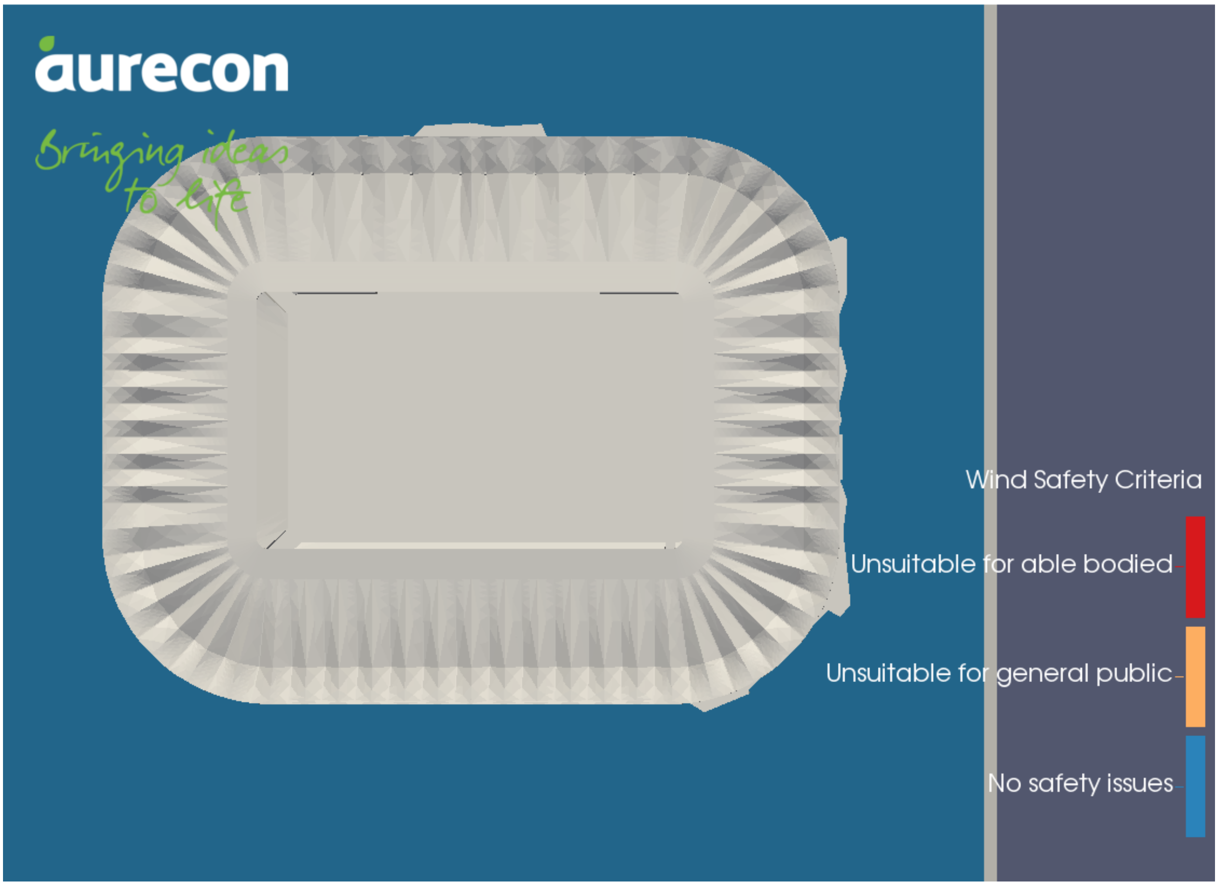

Figure 13: Wind safety criteria over a cutting plane 1.5m above the concourse area surrounding the stadium

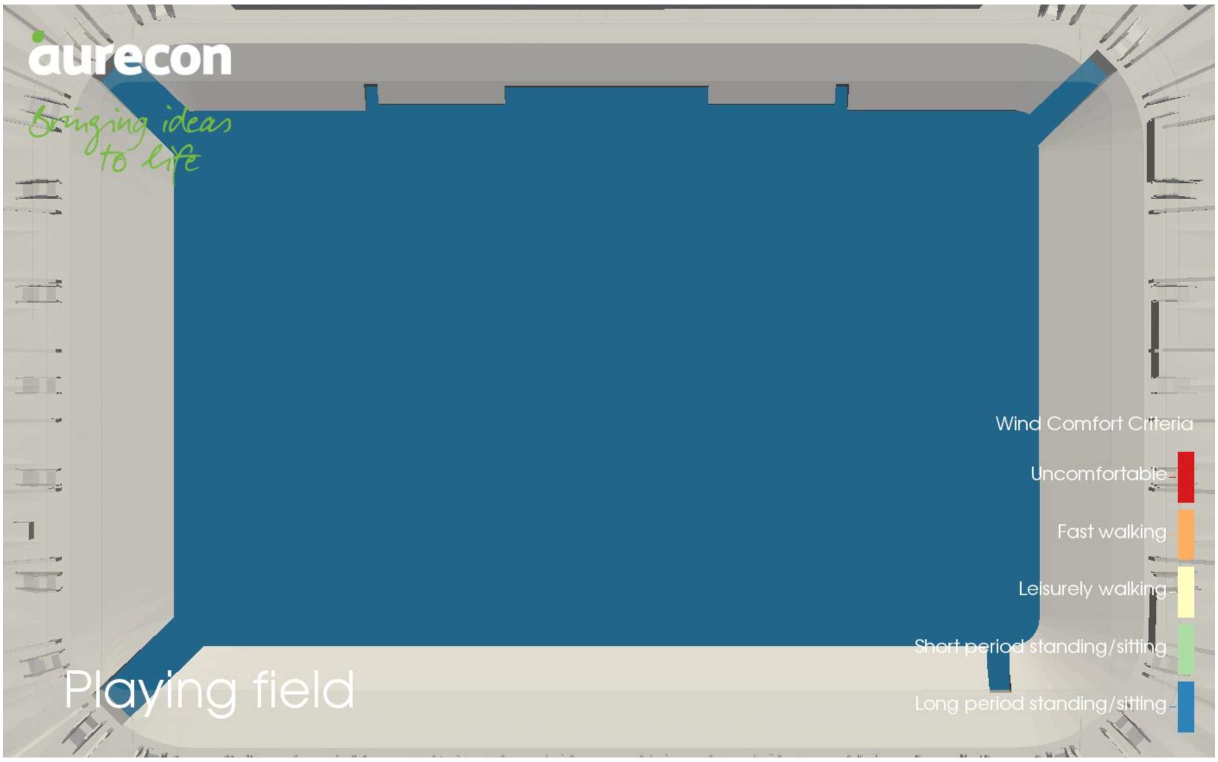

Figure 14: Wind comfort criteria over a cutting plane 1m above the playing field

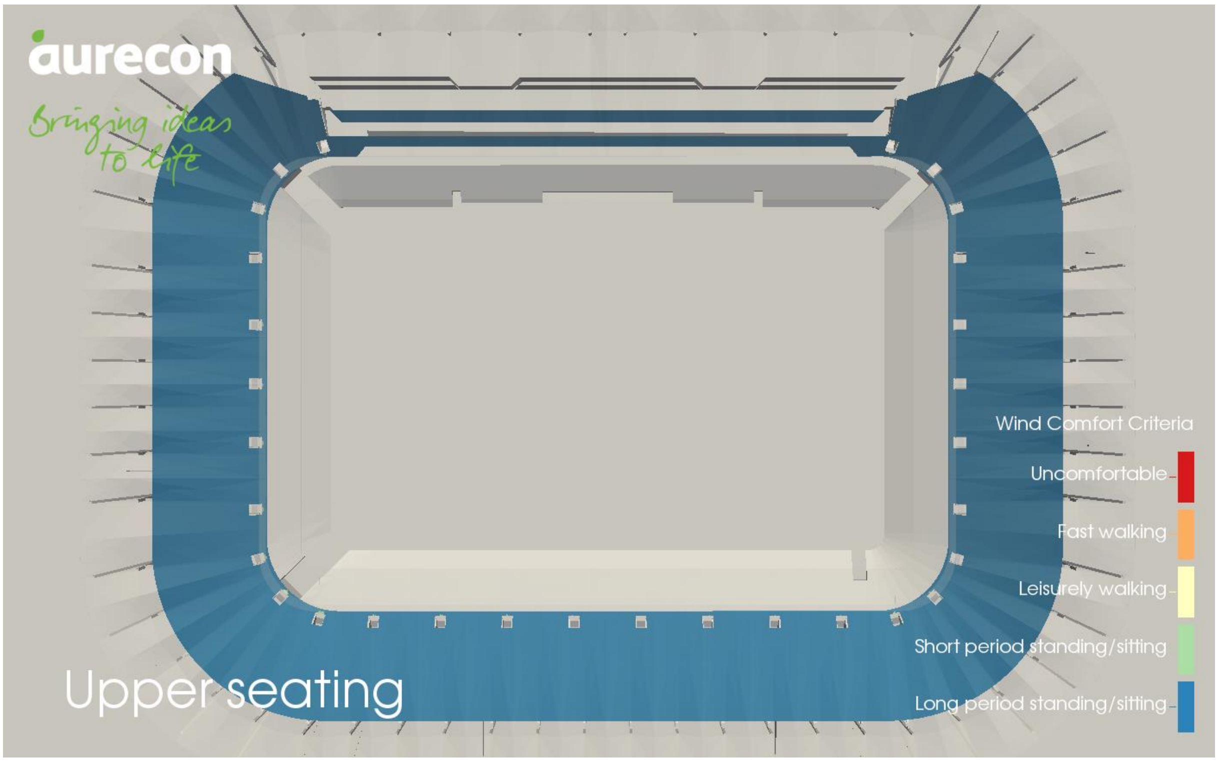

Figure 15: Wind comfort criteria over a cutting plane 1.5m above the upper bowl seating

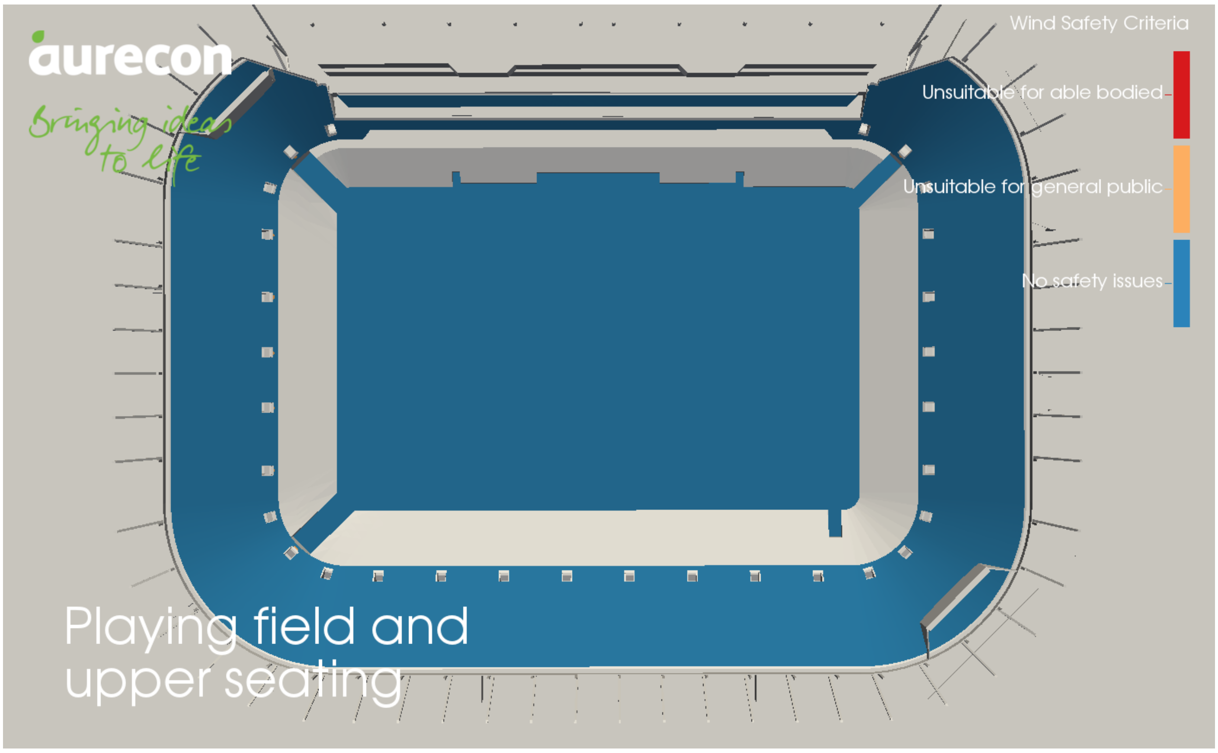

Figure 16: Wind safety criteria over a cutting plane 1.5m above the upper bowl seating and playing field areas.

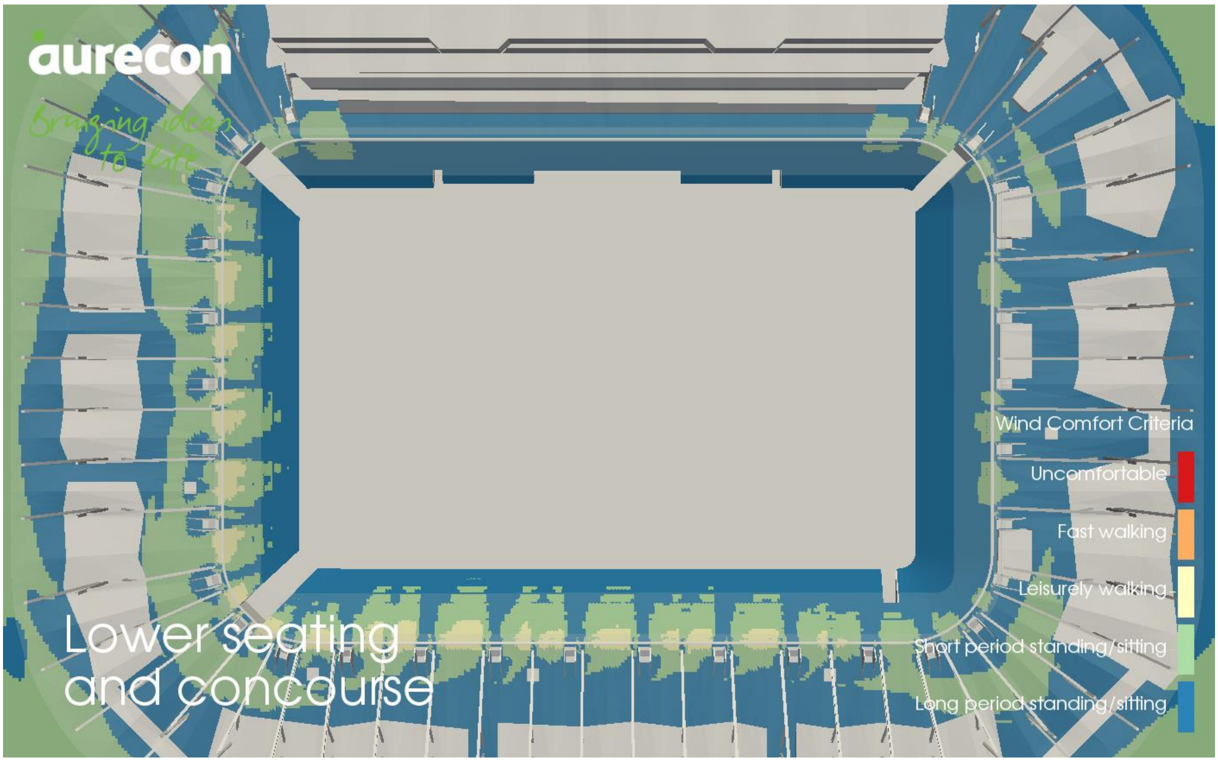

Figure 17: Wind comfort criteria over a cutting plane 1.5m above the concourse and lower bowl seating areas

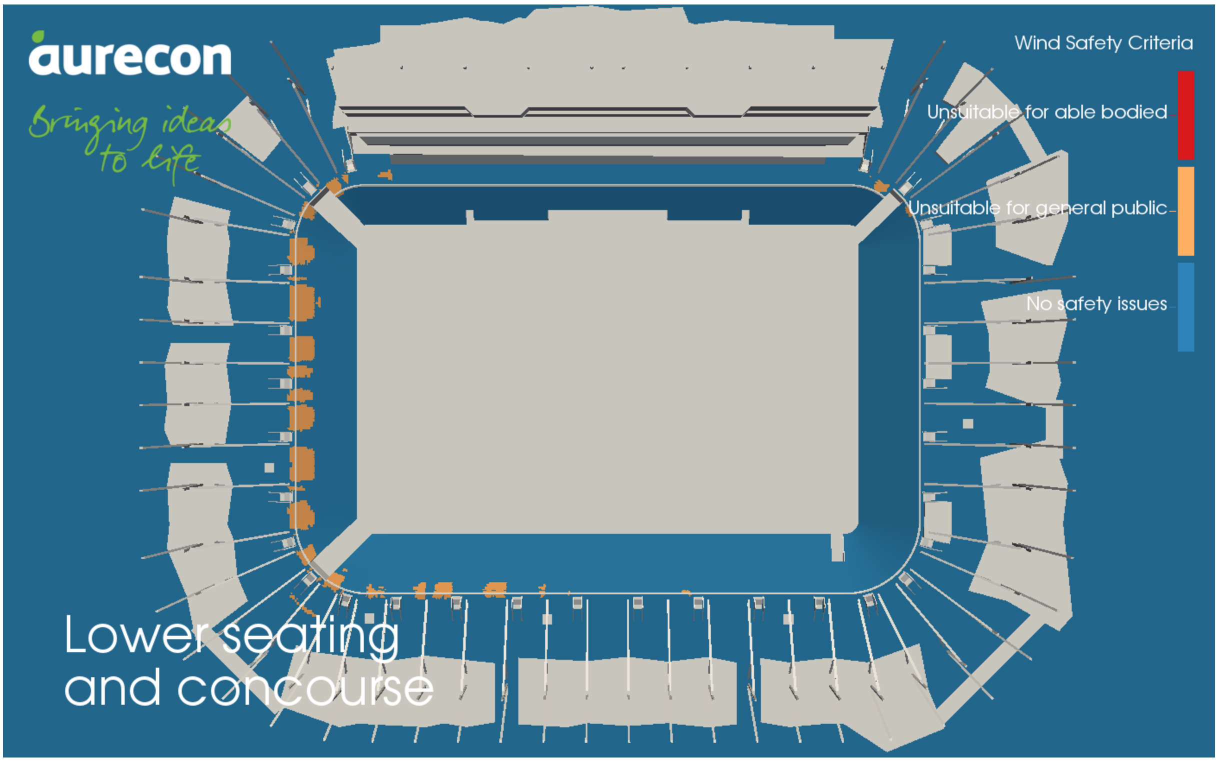

Figure 18: Wind safety criteria over a cutting plane 1.5m above the lower bowl seating and concourse areas.

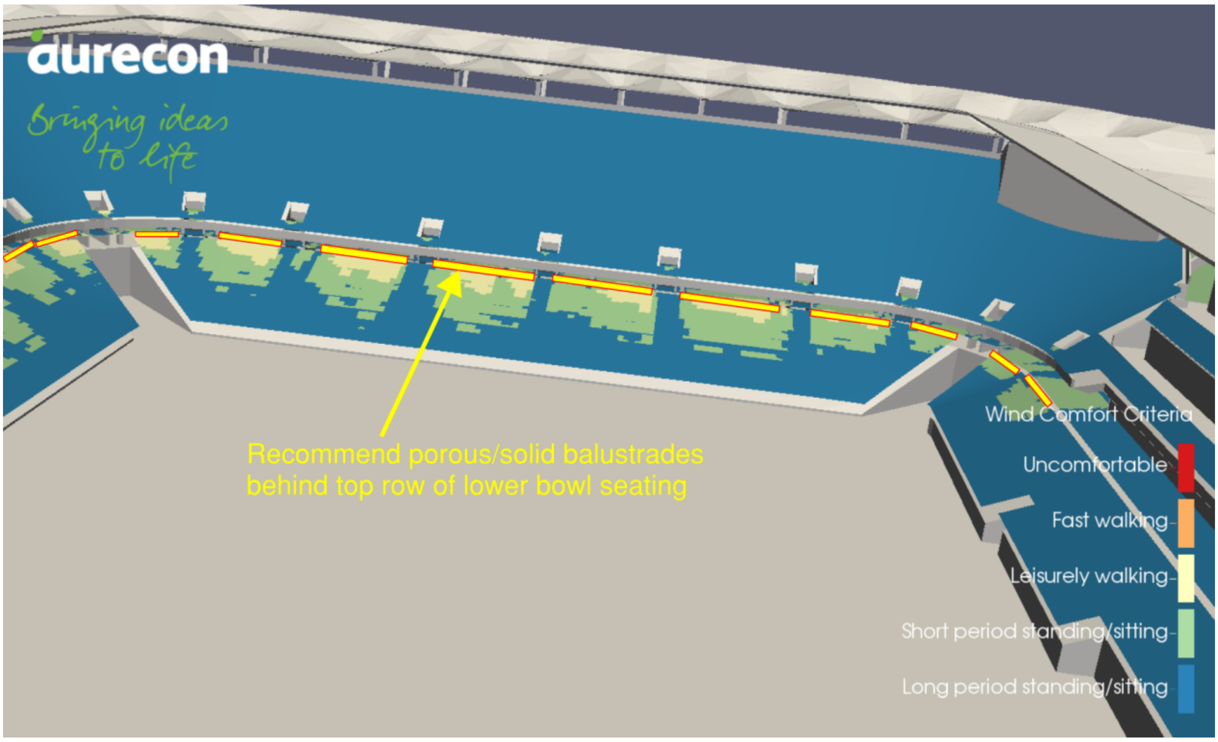

Figure 19: South view of stadium interior, displaying wind comfort criteria over a cutting plane 1.5m above the seating bowls and concourse areas. Recommended design changes are also shown.

5.2 Playing Field Wind Effects

Probability results from the patron wind comfort analysis were reused in an effort to examine the effect of crosswinds on playing conditions. As discussed in Section 3.3 crosswinds have potential to effect ball trajectories and a small but noticeable deviation in flight path is predicted when subject to a 6m/s crosswind.

Horizontal cutting planes of wind speed probability for 6m/s wind speed through the stadium playing area are shown in Figures 20 to 27. There are some predicted low probability exceedances of 6m/s near the corners of the playing field between 1.5 and 5m height while the majority of the playing field experiences calm winds. At 25m height and above there are more significant probabilities of exceeding 6m/s, however the rugby ball is not expected to exceed these heights in the course of regular play. It should be noted that the wind effects on play at low heights are expected to reduce further as a result of the patron comfort and safety mitigation strategies listed in the above section.

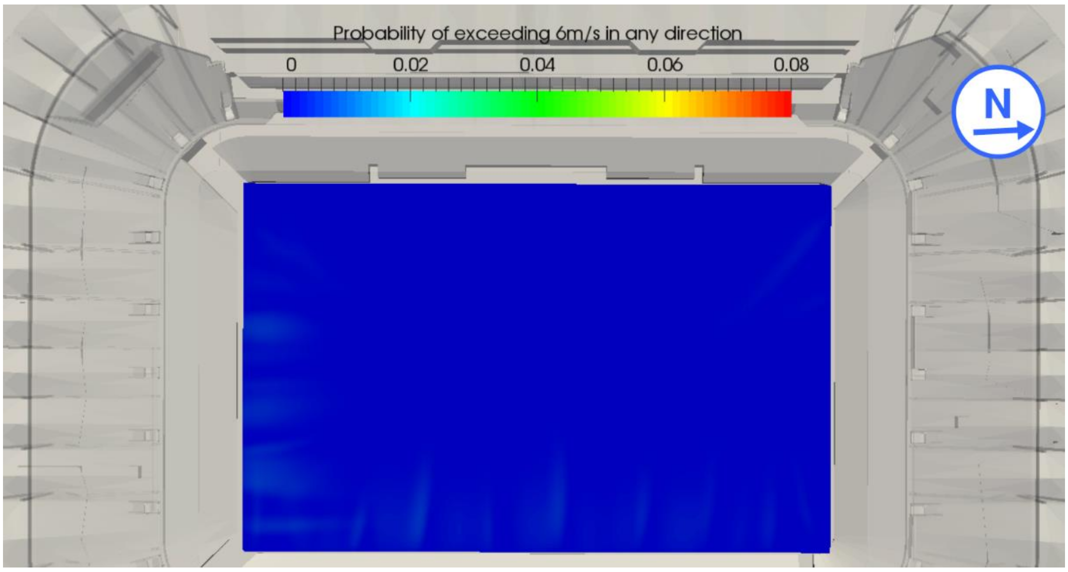

Figure 20: Horizontal cutting plane of probability of exceeding 6m/s at 1.5m above the playing field

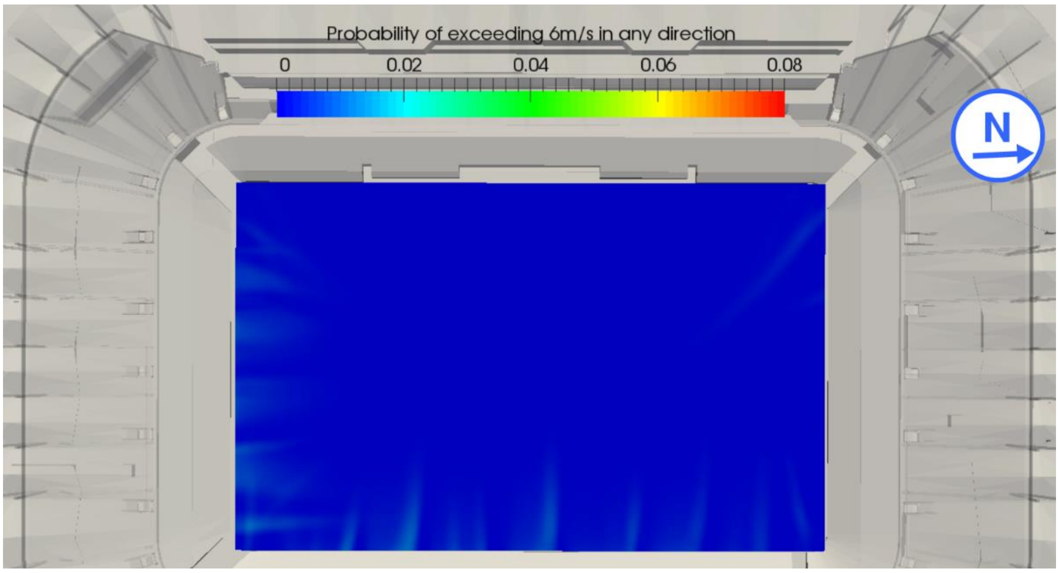

Figure 21: Horizontal cutting plane of probability of exceeding 6m/s at 2.5m above the playing field

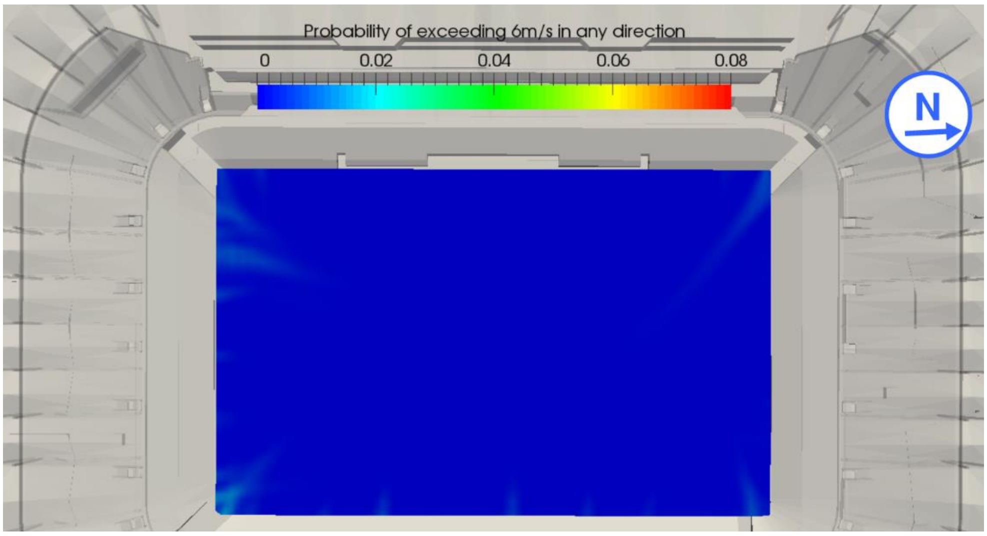

Figure 22: Horizontal cutting plane of probability of exceeding 6m/s at 5m above the playing field

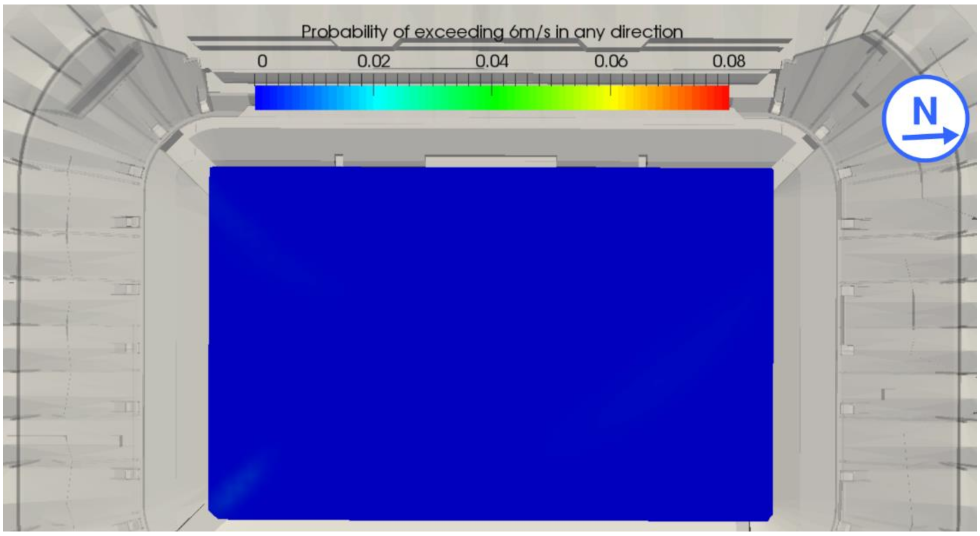

Figure 23: Horizontal cutting plane of probability of exceeding 6m/s at 10m above the playing field

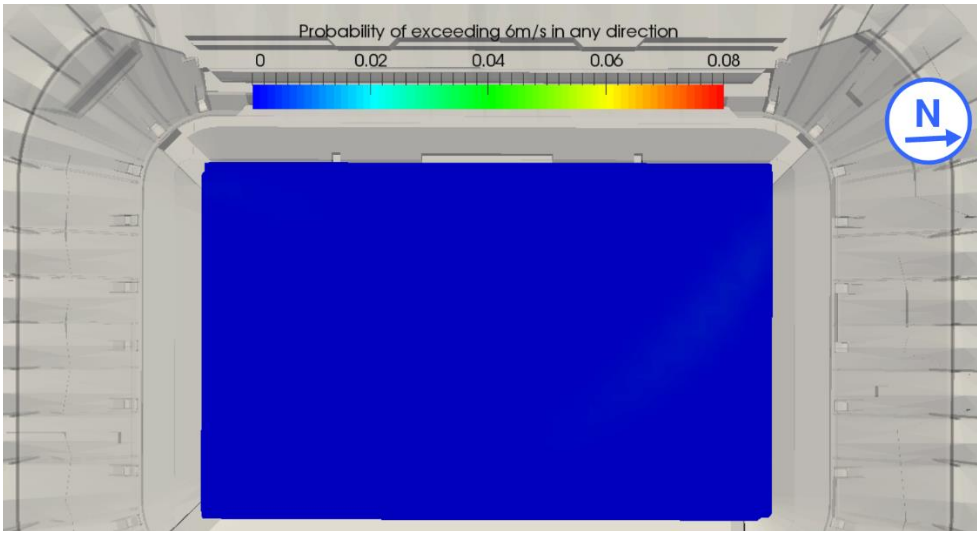

Figure 24: Horizontal cutting plane of probability of exceeding 6m/s at 15m above the playing field

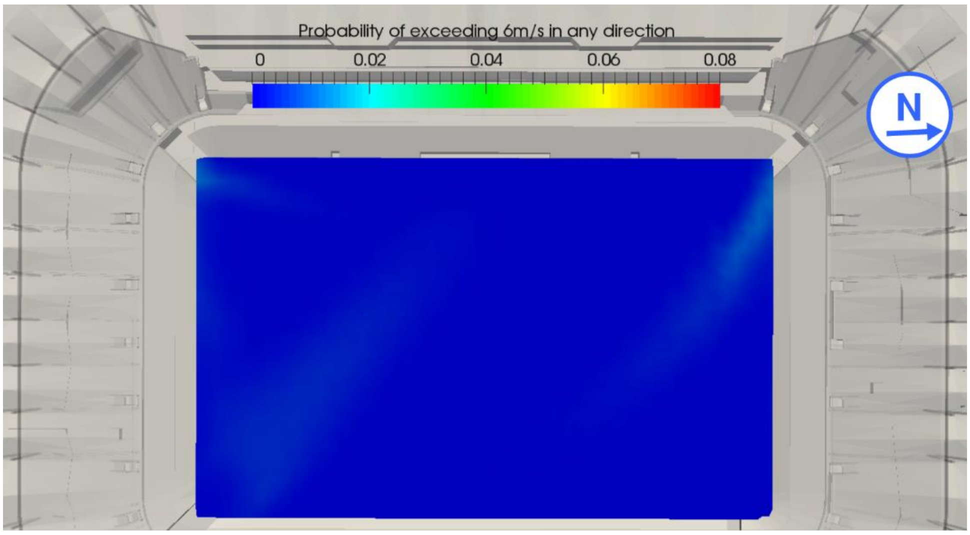

Figure 25: Horizontal cutting plane of probability of exceeding 6m/s at 20m above the playing field

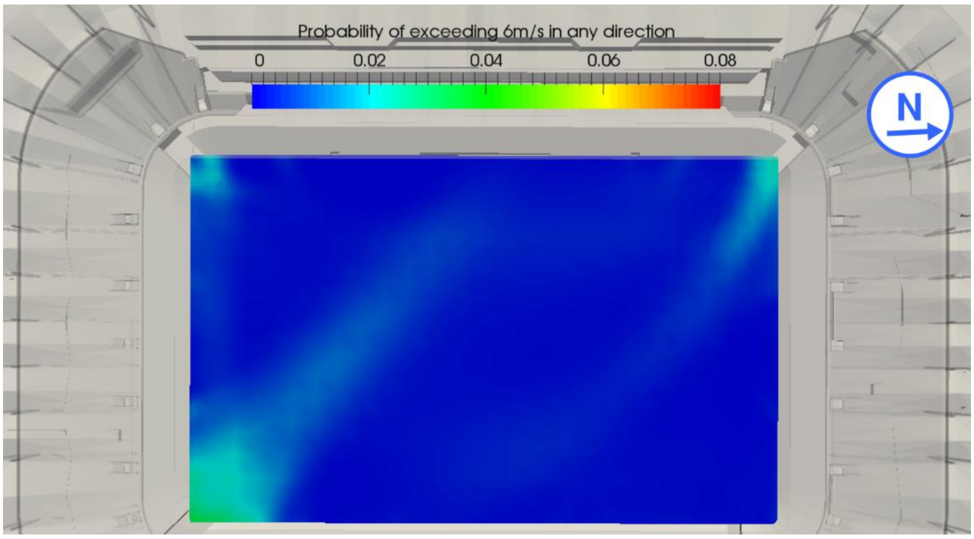

Figure 26: Horizontal cutting plane of probability of exceeding 6m/s at 25m above the playing field

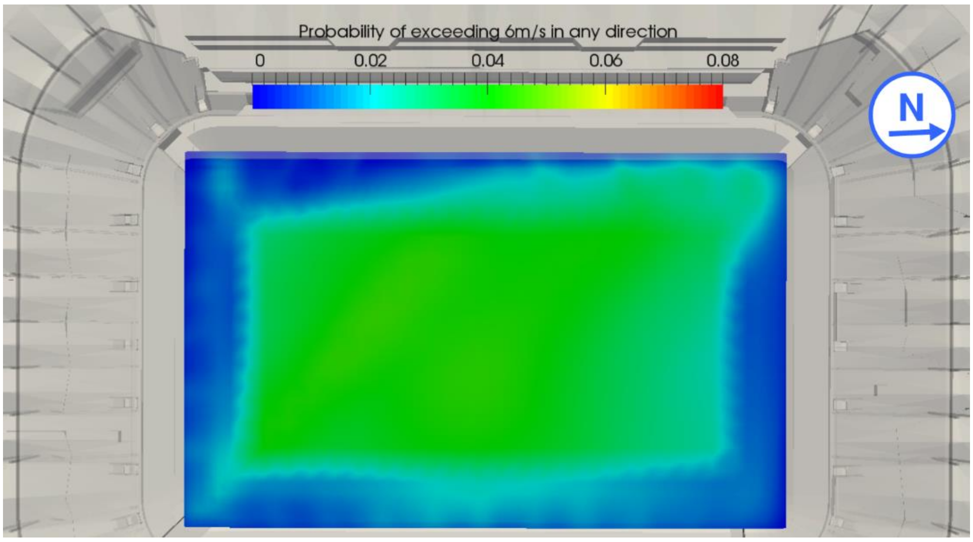

Figure 27: Horizontal cutting plane of probability of exceeding 6m/s at 30m above the playing field

5.3 The Effect of Concourse Balustrades

The effect of adding balustrades to mitigate patron wind safety and discomfort concerns was tested using the same modelling procedure described above. A solid 1200mm height balustrade was placed near the top of the lower bowl seating as illustrated in Figure 28.

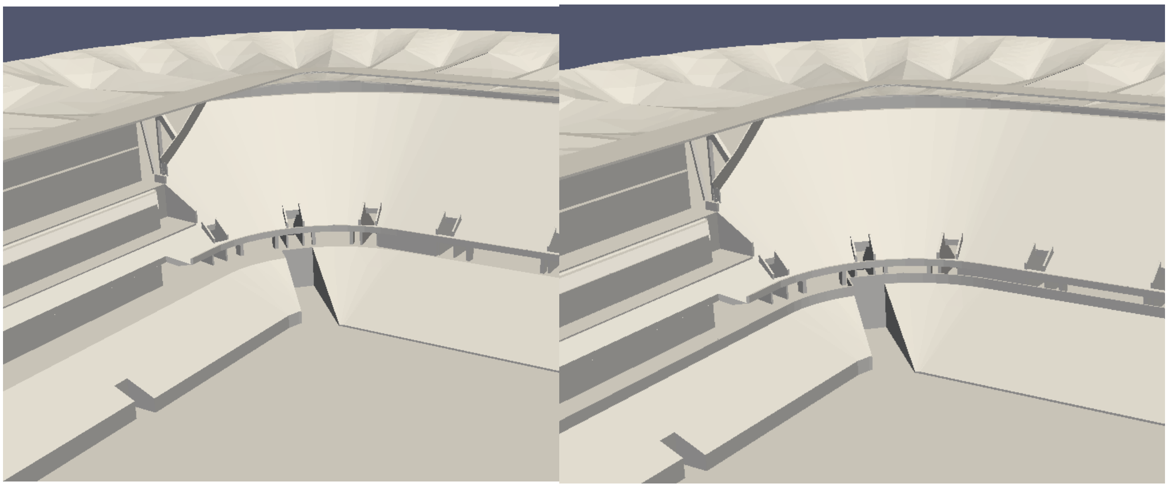

Figure 28: Original stadium geometry (left) and with proposed concourse level balustrades (right).

Patron comfort and safety contour plots are shown in Figures 29 to 32 below. Here it is clear the addition of the proposed balustrades reduces wind discomfort and safety concerns. However as discussed in the Pitch Health Report (Aurecon 2017), the reduction in velocity over the pitch area due to the addition of solid balustrades is expected to have a detrimental effect on turf ventilation and growth.

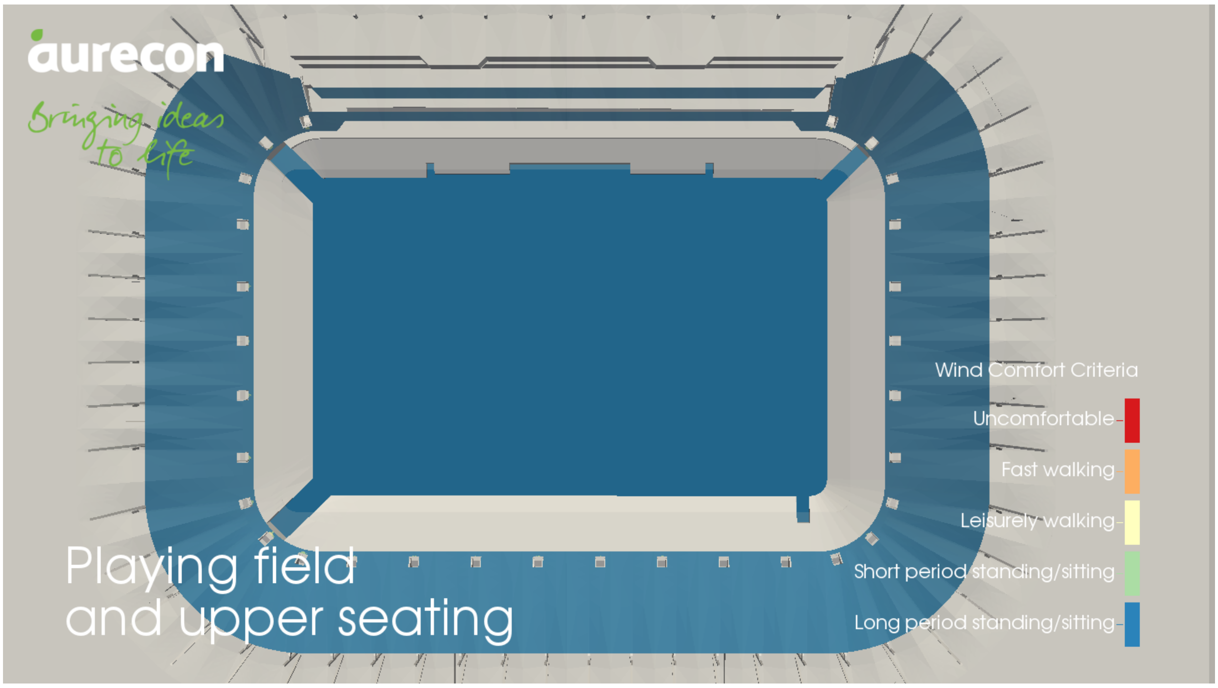

Figure 29: Stadium with solid balustrades wind comfort criteria at 1.5m above the upper bowl seating and playing field.

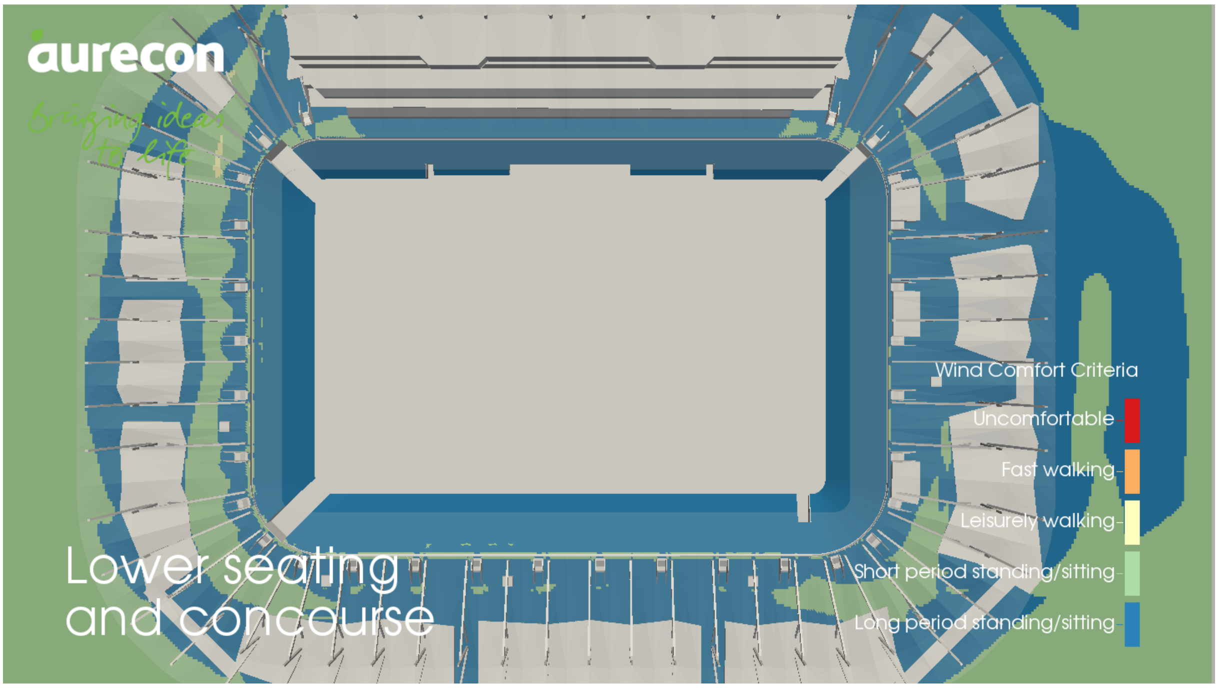

Figure 30: Stadium with solid balustrades wind comfort criteria at 1.5m above the lower bowl seating and concourse.

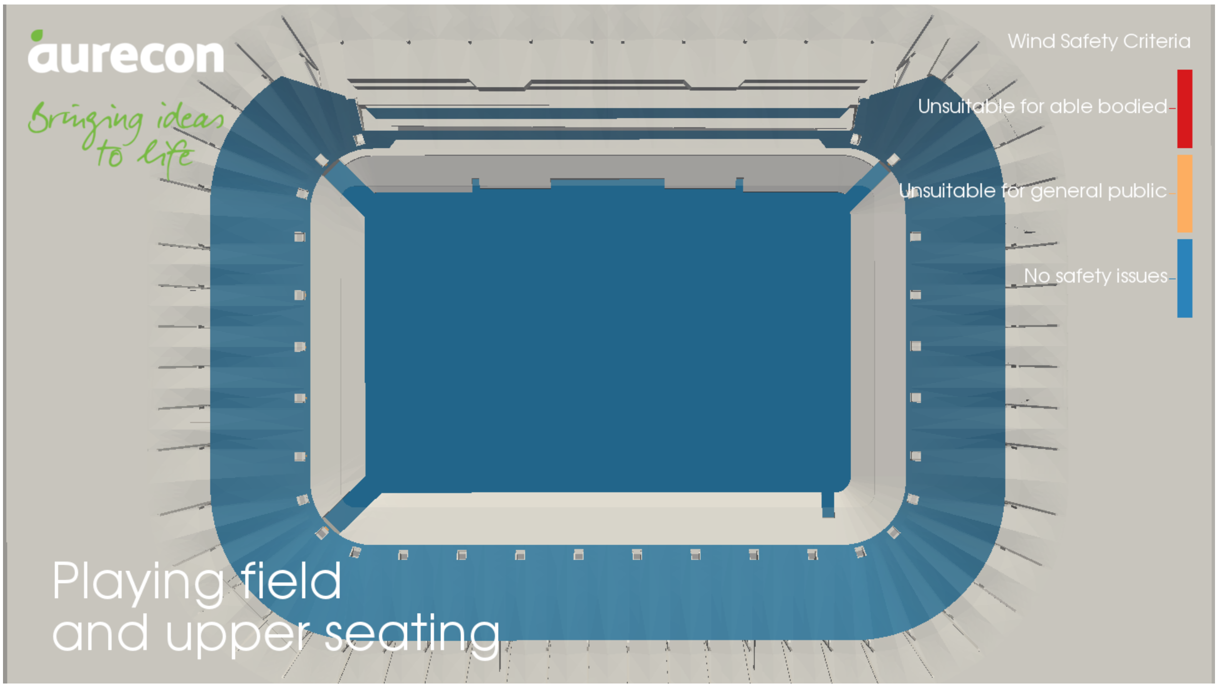

Figure 31: Stadium with solid balustrades wind safety criteria at 1.5m above the upper bowl seating and playing field.

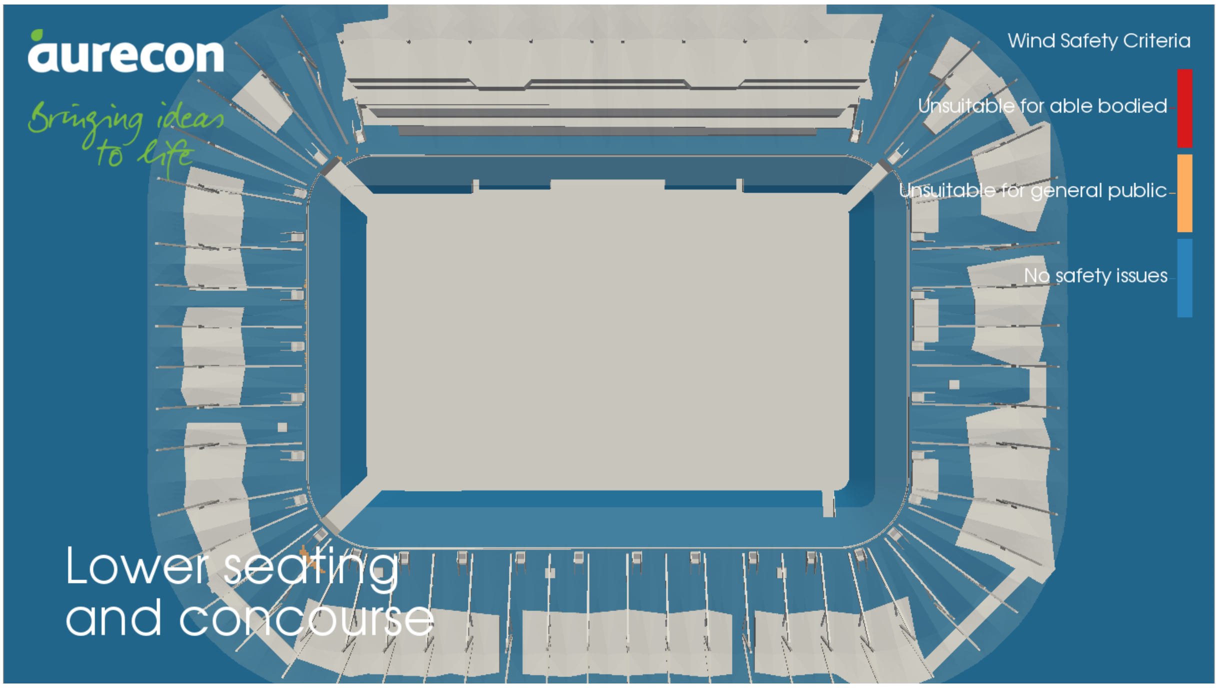

Figure 32: Stadium with solid balustrades wind comfort criteria at 1.5m above the lower bowl seating and concourse.

6 Conclusion

A study was conducted of the environmental wind for the proposed Western Sydney Stadium. Local meteorological conditions were obtained from the nearest BOM station and a statistical analysis of the wind environment was completed. South Easterly, South and South Westerly winds were found to occur with the highest frequency and magnitude.

A suitable 3D model of the proposed Western Sydney Stadium was created and CFD investigations of the local wind environment conducted. Results were scaled to account for the statistical wind behaviour in this locale. Areas of the proposed stadium where patrons frequented were assessed for compliance with wind comfort and safety criteria, with reference to their intended use.

Satisfactory wind comfort and safety criteria were predicted throughout the public concourse areas surrounding the stadium.

Some patrons sitting in the upper rows of the lower bowl seating were predicted to experience discomfort during long period sitting and possible wind safety issues. However the frequency of exceedance criteria based on 24hr wind data may not indicate mitigation is required given the infrequent usage of the stadium seating. A mitigation strategy was suggested, involving the installation of balustrades behind the top row of the lower bowl seating. The balustrades must be constructed of solid or porous material that effectively blocks or reduces wind speed in the lower bowl seating area. This mitigation strategy was shown to achieve the desired reduction in wind effects. However, given the compromises to turf health and visual amenity, and the cost impact relative to the duration in which patron comfort is compromised, we consider it would not be unreasonable to proceed without balustrades.

Mean wind speed probability results were analysed for crosswind effects on rugby ball flight. There were no significant areas of concern within 25m (height) of the playing field. Some lower probability crosswind effects near ground level are likely to be reduced further by the patron wind comfort mitigation strategy.

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Aurecon Australasia Pty Ltd
ABN 54 005 139 873
Level 5, 116 Military Road
Neutral Bay NSW 2089
PO Box 538
Neutral Bay NSW 2089
Australia

T +61 2 9465 5599
F +61 2 9465 5598
E sydney@aurecongroup.com
W aurecongroup.com