Appendix 12.3: Pedestrian Level Wind Microclimate Assessment

Turley

FINAL REPORT

ANFIELD STADIUM

LIVERPOOL, UK

PEDESTRIAN LEVEL WIND MICROCLIMATE ASSESSMENT

RWDI #2000296 REV A
27 MARCH 2020

SUBMITTED TO

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VERSION HISTORY

RWDI Project #2000296	Anfield Stadium Liverpool, UK	
Report	**Releases**	**Dated**
Reports	Rev A	27 March 2020
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1 EXECUTIVE SUMMARY

The objective of this study was to determine the ground and elevated level wind environment within and around the proposed Anfield Road Stand of Anfield Stadium in Liverpool, UK.

This report presents a description of the methodology used for five configurations tested in the wind tunnel, namely:

- Configuration 1: Existing Site with Existing Surrounding Buildings and Existing Landscaping Scheme;
- Configuration 2: Proposed Scheme with Existing Surrounding Buildings and Existing Landscaping Scheme;
- Configuration 3: Proposed Scheme with Cumulative Surrounding Buildings and Existing Landscaping Scheme;
- Configuration 4: Proposed Scheme with Existing Surrounding Buildings, Existing and Proposed Landscaping Scheme; and
- Configuration 5: Proposed Scheme with Cumulative Surrounding Buildings, Existing and Proposed Landscaping Scheme

Configuration 1 tested the wind environment around Anfield Stadium with the existing Anfield Road Stand in place, in the context of the existing surrounding buildings and landscaping. Configurations 2 and 3 tested respectively the wind conditions around Anfield Stadium with the proposed Anfield Road Stand constructed, in the context of the existing and cumulative schemes; both configurations had the existing landscaping. Configurations 4 and 5 tested the wind conditions around Anfield Stadium with the proposed Anfield Road Stand constructed, in the context of the existing and cumulative surroundings; in both configurations the proposed landscaping scheme has been included, in addition to the existing landscaping.

The meteorological data for the Site indicates that the prevailing winds throughout the year are from the west (i.e. 225° to 315°). During the autumn and the winter seasons, winds are more frequent from the south-eastern quadrant; however, while winds from the west are less frequent during the winter, these tend to be the strongest throughout the year

Wind conditions around the Existing Site (Configuration 1) would range from suitable for sitting use to walking use during the windiest season. The windiest area of the baseline scenario is the northern corner of the Main Stand of Anfield Stadium, where several locations have walking use wind conditions during the windiest season and strong wind exceedances. Forty instances of strong winds exceeding 15 m/s for more than 2.2 hours per year would occur at several locations to the north of the Main Stand and along Anfield Road.

With the inclusion of the Proposed Scheme (Configuration 2) a similar number of strong winds exceedances would occur. However, the distribution and frequency of these strong winds is expected to change. Most notably the northern corner of the Main Stand would remain relatively windy but calmer than in the baseline scenario (Configuration 1), and there would be an increase in strong wind locations along Anfield Road and within Stanley Park.

Wind conditions at and surrounding the Proposed Scheme in the context of the cumulative schemes and with the existing landscaping in place (Configuration 3) would be largely similar to those in Configuration 2, with slightly calmer conditions to the north of the stadium.

Further wind tunnel tests have been conducted to develop an efficient wind mitigation strategy throughout a wind mitigation workshop held on March 19th 2020. Several wind mitigation options have been wind tunnel tested in order to provide a safe and comfortable wind environment at and surrounding the Proposed Scheme. Wind mitigation measures part of the proposed landscaping scheme which have been tested in both the context of the existing and cumulative surroundings with the existing landscaping scheme in place (respectively Configurations 4 and 5) are listed below:

- Six approximately 5m high deciduous trees along Anfield Road;
- Eighteen 50% porous screens (2m wide by 3m high) located at 3m above the ground;
- One 5m high 50% porous screen around the north-west entrances to the Proposed Scheme (leaving 2.5m of clearance from ground level); and
- A 2m high 50% porous fence around the OB area.

With the proposed landscaping scheme in place, wind conditions at and surrounding the Proposed Scheme would significantly improve, especially around the Main Stand. Wind conditions would generally range from suitable for sitting use to walking use during the windiest season, with walking use wind conditions around the north corner and to the south of the Main Stand. The extent of the strong winds would be substantially reduced along Anfield Road and within Stanley Park, with thirteen instances of strong winds exceeding 15 m/s for more than 2.2 hours per year.

With inclusion of the cumulative schemes (Configuration 5), wind conditions at and surrounding the Proposed Scheme would be largely consistent with those in Configuration 4, significantly calmer than the baseline scenario (Configuration 1).

Overall, the proposed landscaping scheme wind tunnel tested in Configurations 4 and 5 would significantly improve wind conditions to the north of the stadium, especially around the northern corner of the Main Stand, at the north-western corner of the Proposed Scheme, within Stanley Park and along Anfield Road. However, wind conditions at a few locations would be made worse compared to Configuration 1 (in terms of hours of exceedance) with the inclusion of the Proposed Scheme, or the intended use has changed (measurement locations 164 and 173 were thoroughfares in Configuration 1, while in Configurations 4 and 5 represent entrances), and further wind mitigation would be required:

- Strolling use wind conditions at entrances to the Proposed Scheme 164, 173, 175, and 232; and
- Strong winds at measurement locations 80, 164, 173, 177, 345, and 347.

Wind mitigation measures are required at these locations and surrounding the Proposed Scheme to provide a safe and comfortable wind environment. Architectural options will be considered and presented to LCC ahead of installation. It is anticipated that these will continue to accord with the principles set out under primary mitigation.

2 INTRODUCTION

RWDI was retained by Legends International to conduct a pedestrian level wind microclimate (PLW) assessment for the proposed Anfield Road Stand of Anfield Stadium in Liverpool, UK. This report presents the methodology employed by RWDI's.

Wind tunnel tests were conducted on a 1:300 scale model of the Proposed Scheme (referred to as the "Proposed Scheme" in this report). The investigation quantifies the wind conditions within and around the Site through comparison of the measured wind velocity and frequency of occurrence with the Lawson Comfort Criteria. Meteorological data for Liverpool, UK has been combined, analysed and adjusted to the Site conditions by modelling the effect of upstream terrain roughness on the wind velocities approaching the Site.

Measurements were taken at up to 410 locations for 36 wind directions, in 10° increments. The measurements covered pedestrian thoroughfares, entrances, bus stops, amenity areas and the stands/pitch of the Proposed Scheme. The analysis was conducted on a seasonal basis, however, the report focuses primarily on the windiest season (i.e. winter) and the summer season results, when pedestrian activity generally requires calmer conditions.

The following list details the five configurations tested in the wind tunnel:

- Configuration 1: Existing Site with Existing Surrounding Buildings and Existing Landscaping Scheme;
- Configuration 2: Proposed Scheme with Existing Surrounding Buildings and Existing Landscaping Scheme;
- Configuration 3: Proposed Scheme with Cumulative Surrounding Buildings and Existing Landscaping Scheme;
- Configuration 4: Proposed Scheme with Existing Surrounding Buildings, Existing and Proposed Landscaping Scheme; and
- Configuration 5: Proposed Scheme with Cumulative Surrounding Buildings, Existing and Proposed Landscaping Scheme

3 METHODOLOGY AND ASSESSMENT CRITERIA

Wind tunnel testing is a well-established and robust technique to assess the pedestrian wind microclimate of the Proposed Scheme. It provides the means to quantify the wind conditions at the Site and for the measurements to be classified in accordance with the Lawson Comfort Criteria (outlined in Sections 2.5-2.7). Wind tunnel investigations were conducted using a 1:300 scale model of the Proposed Scheme with existing and cumulative surrounding buildings and terrain covering a radius of 360m centred on the Site.

The basic methodology for quantifying the pedestrian level environment is outlined below:

1. Measure the wind speeds at pedestrian level in the wind tunnel relative to a reference wind speed;
2. Adjust standard meteorological data to account for conditions at the Site;
3. Combine these to obtain the expected frequency and magnitude of wind velocities at pedestrian level; and
4. Compare the results with the Lawson Comfort Criteria to 'grade' conditions around the Site.

3.1 Simulation of Atmospheric Winds

The wind is turbulent, or gusty, and this turbulence varies depending upon the Site. It is necessary to reflect these differences in the wind tunnel test. In addition, the atmospheric boundary layer is a shear flow which means that the mean wind speed increases with height.

Modelling these effects is achieved by a combination of spires and floor roughness elements to create a naturally-grown boundary layer that is representative of urban or open country conditions, as appropriate. The detailed contoured proximity model around the Site is used to fine-tune the flow and create conditions similar to those expected at full scale (as shown in Figure 1).

Figure 1: View from the south of the Proposed Scheme in the context of the existing surrounding buildings with the existing and proposed landscaping schemes in place (Configuration 4)

3.2 Measurement Technique

Wind speed measurements were made using Irwin probes. For pedestrian comfort studies, both the mean wind speed and the peak wind speed are measured at each location at a scaled height of 1.5m above ground level. The typical equivalent full-scale time period for measuring the mean wind speed is around 90 minutes, whereas the peak wind speed is taken as the wind speed exceeded for 1% of the time.

Wind speeds at each location were measured for 36 wind directions in 10° intervals, with 0° representing a wind blowing from the north and 90° a wind blowing from the east.

3.3 Scaling

The length scale of the model was 1:300 and the velocity scale was approximately 1:2 for strong winds. Consequently, the time scale for the tests was 1:150, or in other words 1 second in the wind tunnel is equivalent to 150 seconds at full scale. The sampling frequency for the data acquisition equipment is therefore adjusted for the time scale.

3.4 Meteorological Data

Approximately twenty years' worth of data were obtained from the meteorological station for Liverpool John Lennon Airport and was categorised by season as demonstrated in Figure 2 as wind roses. The radial axis indicates the percentage hours per season that the wind speed exceeds the particular velocity range. The seasons are defined as spring (March, April and May), summer (June, July and August), autumn (September, October and November) and winter (December, January and February).

The data has been corrected to standard conditions of 10m above open flat level country terrain, over which pedestrian level wind speeds are greatest. The meteorological station data is then adjusted to the Site conditions using the methodology set out in ESDU 01008[1]. Low to medium rise inner city environments increase the turbulence within the atmospheric boundary layer which reduces the mean wind speed, requiring terrain roughness factors to be specified and applied to the meteorological data to account for the variations in terrain surrounding the Site.

The meteorological data obtained for Liverpool indicates that the prevailing winds throughout the year are from the west (i.e. 225° to 315°). During the autumn and the winter seasons, winds are more frequent from the south-eastern quadrant, however, while winds from the west are less frequent during the winter, these tend to be the strongest throughout the year. The combination of meteorological data, Site altitude and velocity ratios permits the percentage of time that wind speeds are exceeded at ground level on the Site to be evaluated. The locations can then be assessed using the Lawson Comfort Criteria, as described below.

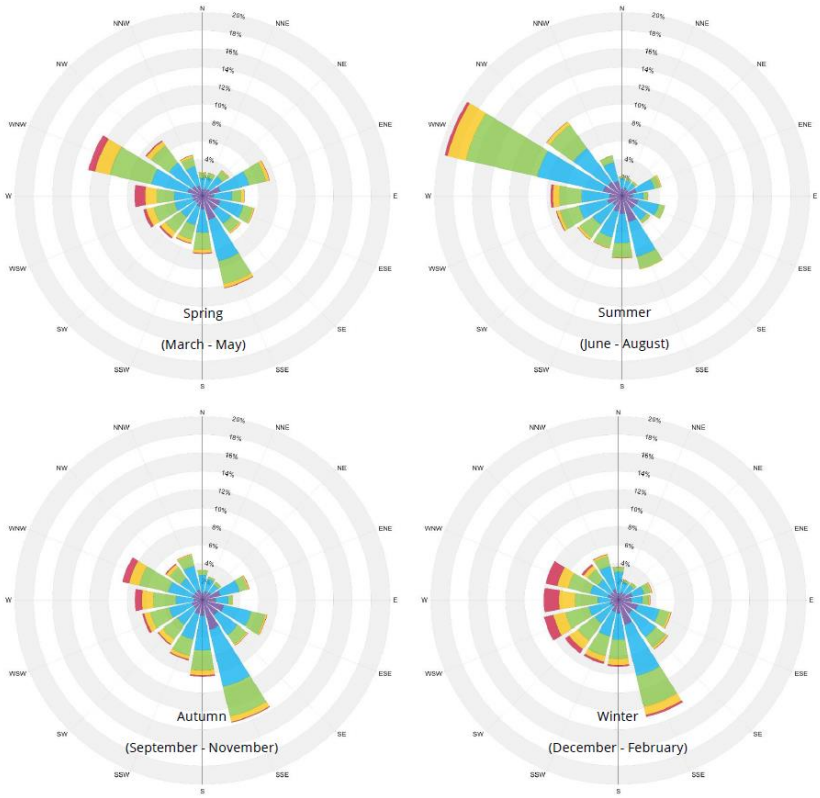

Figure 2: Directional Distribution (%) of Winds for Liverpool John Lennon Airport (1991-2011)

Table 1: ESDU Mean Factors at 120m above ground level

Wind Direction	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°
Mean Factor at 120 m	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Wind Direction	**120°**	**130°**	**140°**	**150°**	**160°**	**170°**	**180°**	**190°**	**200°**	**210°**	**220°**	**230°**
Mean Factor at 120 m	1.25	1.23	1.24	1.24	1.24	1.24	1.24	1.25	1.25	1.26	1.27	1.27
Wind Direction	**240°**	**250°**	**260°**	**270°**	**280°**	**290°**	**300°**	**310°**	**320°**	**330°**	**340°**	**350°**
Mean Factor at 120 m	1.27	1.27	1.27	1.37	1.38	1.38	1.39	1.37	1.30	1.27	1.26	1.26

3.5 Pedestrian Comfort

The assessment of the wind conditions requires a standard against which the measurements can be compared. This report uses the Lawson Comfort Criteria (Lawson, 2001) that have been established for over thirty years and have been widely used on building developments across the United Kingdom. The comfort criteria seek to define the reaction of an average pedestrian to the wind as described in Table 2. If the measured wind conditions exceed the threshold wind velocity for more than 5% of the time, then they are deemed unacceptable for the intended pedestrian activity. The expectation is that there may be complaints of nuisance or people will not use the area for its intended purpose.

The Criteria sets out four pedestrian activities and reflect the fact that less active pursuits require more benign wind conditions. The categories are sitting, standing, strolling and walking, in ascending order of activity level, with a fifth category for conditions that are uncomfortable for all pedestrian uses. In other words, the wind conditions in an area for sitting need to be calmer than a location that people merely walk past.

The distinction between strolling and walking is that in the strolling scenario pedestrians are more likely to take on a leisurely pace, with the intention of taking time to move through the area, whereas in the walking scenario pedestrians are intending to move through the area quickly and are therefore expected to be more tolerant of stronger winds.

The Criteria are derived for open air conditions and assume that pedestrians will be suitably dressed for the season.

The coloured key in Table 2 corresponds to the presentation of wind tunnel test results described in the results section of this report.

Table 2: Lawson Comfort Criteria

Key	Comfort Category	Threshold	Description

	Sitting	0-4 m/s	Light breezes desired for outdoor restaurants and seating areas where one can read a paper or comfortably sit for long periods
	Standing	4-6 m/s	Gentle breezes acceptable for main building entrances, pick-up/drop-off points and bus stops
	Strolling	6-8 m/s	Moderate breezes that would be appropriate for strolling along a city/town street, plaza or park
	Walking	8-10 m/s	Relatively high speeds that can be tolerated if one's objective is to walk, run or cycle without lingering
	Uncomfortable	>10 m/s	Winds of this magnitude are considered a nuisance for most activities, and wind mitigation is typically recommended

3.6 Desired Pedestrian Activity around the Proposed Scheme

Generally, for a mixed-use urban environment, such as the Site and surrounding area, the desired wind microclimate for the Proposed Scheme would typically need to have areas suitable for sitting, standing and strolling use.

The walking and uncomfortable classifications may be acceptable in isolated areas, but these classifications are also associated with occasional strong winds (which are described below) and so the aim has been to avoid conditions falling into these categories.

The target condition for seating in amenity areas is a wind microclimate that is suitable for sitting during the summer season. This is because these areas are more likely to be frequently used during the summer when pedestrians would expect to be able to sit comfortably. If an area is classified as suitable for sitting in the summer, the windier conditions that occur during the winter season usually mean that the area would be classified as suitable for standing in the windiest season, unless additional shelter was provided.

Wind conditions within the Stadium are desired to be suitable for a mix of sitting use to standing use during the windiest season. This is considered acceptable due to the more active purpose of the stands compared to a long-term seating area such as a café where sitting use wind conditions would be required.

Areas in proximity of building entrances, a wind environment suitable for standing or calmer is desired, as pedestrians will transition from the calm indoors to the windier outdoors throughout the year. The assessment for building entrances therefore focuses on the windiest season result.

Considered as entry points to a building which are not primary entrances and used for alternative purposes, like fire entrances or emergency exits, a wind environment for strolling or calmer is desired. The assessment focuses on the windiest season.

Wind conditions at bus stop locations are required to be suitable for standing use during the windiest season.

A pedestrian thoroughfare should be suitable for strolling during the windiest season. The assessment for pedestrian thoroughfares therefore focuses on the windiest season result.

Localised occurrence of walking conditions may be acceptable in areas with limited footfall, or service areas, as long as the strong wind criteria (see section 'Strong Winds') is not exceeded.

Crossings should be suitable for walking during the windiest season.

The Lawson Criteria does not specify criteria for acceptable wind conditions for cyclists; however, the occurrence of winds exceeding the strong winds threshold (as described below) would be considered unsuitable for cyclists.

3.7 Strong Winds

The Lawson Criteria also specifies a strong wind threshold when winds exceed 15m/s for more than 0.025% of the time (approximately 2.2 hours of the year) would have the potential to cause distress to pedestrians and cyclists. Exceedance of this threshold may indicate a need for remedial measures or a careful assessment of the expected use of that location; e.g. is it reasonable to expect older adults or young children to be present at the location on the windiest day of the year?

Wind Speeds that exceed 20m/s for more than 0.025% of the time (approximately 2.2 hours of the year) represent safety issue for all members of the population, which would require mitigation to provide an appropriate wind microclimate environment.

Strong winds are generally associated with areas which would be classified as acceptable for walking or conditions considered uncomfortable. In a mixed-use urban area, walking and uncomfortable conditions would not usually form part of the 'target' wind environment and would usually require mitigation due to pedestrian comfort considerations. This mitigation would also have the impact of reducing the frequency of, or even eliminate, any strong winds.

3.8 Occurrence of Strong Winds

Areas with occasional strong winds exceeding the 15m/s threshold are presented in the annual safety exceedances figures for each configuration. Strong winds in excess of 15m/s are considered a safety issue and will require mitigation, apart from where these conditions are pre-existing and occurring in the baseline.

Table 3: Annual Exceedance of Strong Winds

Location	Strong Wind Exceedance	Main Wind Direction (°)	Hours per Annum
Configuration 1: Existing Site with Existing Surrounding Buildings and Existing Landscaping Scheme			
80	S15	300	6.6
112	S15	290	4.5
114	S15	290	6.5
118	S15	280	5.4
123	S15	300	2.7
124	S15	290	5.4
125	S15	300	2.6
126	S15	300	8.2

127	S15	300	10.2
130	S15	290	9.5
131	S15	290	10.8
132	S15	290	13
133	S15	300	19.1
134	S20	300	4.5
134	S15	300	49.1
143	S15	290	8.5
145	S15	290	4.1
160	S15	290	6.5
161	S15	290	2.8
162	S15	290	3.9
163	S15	290	6
164	S15	290	8
165	S15	290	3
166	S15	290	4.4
167	S15	300	2.7
173	S15	290	4.1
174	S15	290	2.9
346	S15	290	11.6
347	S15	300	7.8
348	S15	290	21.8
349	S15	300	11.7
350	S15	300	27.5
351	S15	300	10.9
352	S15	300	10.1
353	S15	300	6.2
355	S15	300	8.4
356	S15	290	14.7
375	S15	290	7.9
376	S15	290	13
377	S15	290	5.6
378	S15	290	3.3
Configuration 2: Proposed Scheme with Existing Surrounding Buildings and Existing Landscaping Scheme			
80	S15	300	6.8

112	S15	280	4
114	S15	290	5.9
118	S15	280	4.4
124	S15	290	5.2
126	S15	290	6.2
127	S15	290	8.5
128	S15	290	3.3
130	S15	290	9
131	S15	290	11.9
132	S15	290	13.1
133	S15	290	6.3
134	S15	290	27.6
140	S15	290	2.8
143	S15	290	6.5
145	S15	290	2.8
159	S15	290	2.3
160	S15	290	6.1
161	S15	290	5
164	S15	290	3
174	S15	290	15.8
177	S15	290	10.4
183	S15	290	8.3
307	S15	280	2.2
346	S15	290	11
348	S15	290	18.5
349	S15	290	8
350	S15	290	17.5
351	S15	290	9.4
352	S15	290	10.5
353	S15	290	6
355	S15	290	5.8
356	S15	290	11.3
374	S15	290	2.7
375	S15	290	9.5
376	S15	290	9.5
377	S15	290	6.6

378	S15	290	5.2
Configuration 3: Proposed Scheme with Cumulative Surrounding Buildings and Existing Landscaping Scheme			
80	S15	300	6.5
112	S15	280	3.2
114	S15	290	4.7
118	S15	270	3.8
124	S15	290	3.8
126	S15	300	5
127	S15	290	6.9
130	S15	300	7.4
131	S15	300	9.3
132	S15	290	10.2
133	S15	290	4.8
134	S15	290	23.4
143	S15	290	5.1
160	S15	290	5
161	S15	290	4.2
164	S15	300	3.3
174	S15	290	11.8
177	S15	290	8
183	S15	290	5.8
346	S15	290	8.6
348	S15	290	16.6
349	S15	300	7.9
350	S15	300	16.4
351	S15	300	8.5
352	S15	300	8.6
353	S15	290	4.7
355	S15	290	5.3
356	S15	290	10.2
375	S15	300	7.5
376	S15	290	7.3
377	S15	300	5.2
378	S15	300	4
Configuration 4: Proposed Scheme with Existing Surrounding Buildings, Existing and Proposed Landscaping Scheme			

80	S15	300	6.8
112	S15	280	4.8
118	S15	280	2.6
133	S15	300	7.4
134	S15	290	17.9
164	S15	290	4.7
173	S15	290	3
177	S15	290	4.4
345	S15	300	2.3
347	S15	300	4.5
350	S15	290	5.2
355	S15	300	2.6
356	S15	280	2.8
Configuration 5: Proposed Scheme with Cumulative Surrounding Buildings, Existing and Proposed Landscaping Scheme			
80	S15	300	7.9
112	S15	280	3.8
133	S15	300	7.7
134	S15	300	18.4
164	S15	300	4.8
173	S15	300	2.8
177	S15	300	4
345	S15	300	2.4
347	S15	300	4.3
350	S15	300	5.1
355	S15	300	2.3
356	S15	300	2.7