2. Microclimate (Wind)

2.1 Spectator Player Wind Comfort Study, BMT FLUID MECHANICS

Project No. 431590

Anfield Expansion Project, Liverpool, UK

Spectator & Player Wind Comfort Study

(2nd April 2014)

For
Christal Management

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Anfield Expansion Project
Spectator & Player Comfort Study

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Background

A boundary layer wind tunnel study has been carried out by BMT Fluid Mechanics Ltd. (BMT) to assess the spectator and player wind comfort for the proposed Anfield Stadium Expansion in Liverpool, UK.

The study has provided an assessment of the wind environment at key pitch locations and seating areas within the proposed stadium in terms of spectator and player wind comfort and safety. More specifically, the study assesses the impact of the addition of a revised Main stand and a revised Anfield Road stand on the spectator and player comfort with respect to existing conditions.

The present report forms an assessment of comfort with respect to wind force.

Conclusions

The boundary layer wind tunnel study has assessed the player and spectator wind comfort for the proposed Anfield Expansion Project in Liverpool, UK.

The following conclusions have been drawn:

- In terms of the existing wind environment across the pitch and the spectator tiers, wind conditions are rated as suitable, in terms of safety, for all players and spectators throughout the year
- With the addition of the new Main stand (Phase 1) wind conditions are not significantly affected, and remain suitable for both spectator and sporting use
- With the addition of the new Anfield Road and new Main stands (Phase 2) wind conditions are not significantly affected, and remain suitable for both spectator and sporting use

Anfield Expansion Project
Spectator & Player Comfort Study

1. Introduction

A boundary layer wind tunnel study has been carried out by BMT Fluid Mechanics Ltd. (BMT) to assess the spectator and player wind comfort for the proposed Liverpool Stadium in Liverpool, UK.

The study has provided an assessment of the wind environment at key pitch locations and seating areas within the proposed stadium in terms of spectator and player wind comfort and safety. More specifically, the study assesses the impact of the addition of a revised Main stand and a revised Anfield Road stand on the spectator and player comfort with respect to existing conditions.

The present report forms an assessment of comfort with respect to wind force.

2. Site / Building Details

2.1. Location / Surrounding Area

The Anfield Stadium is located in Liverpool, UK. The immediate existing surrounding area generally consists of low-rise residential housing to the south, east and west, and open parkland in the north. An aerial view of the proposed site and surrounding area is shown in Figure 2.1.

2.2. Existing Stadium

The existing stadium consists of four stands, namely the Kop (at the southern aspect), the present Main stand (eastern aspect), the Anfield Road stand (northern aspect) and the Centenary Stand (western aspect).

2.3. Proposed Stadium Expansion

It is proposed that the stadium will expand over two phases, namely Phase 1, in which the present Main stand will be demolished and replaced with a larger Main stand; and Phase 2, where the present Anfield Road stand will then be demolished and replaced with a larger stand.

Figures 2.2 to 2.4 show the various stadium arrangements for the three cases in consideration.

3. Assessment Methodology

The assessment of environmental wind flows in the built environment lies outside the scope of BS EN 1991-1-4:2005, the current European Standard for wind actions on structures, which focuses on wind loading issues. In addition, there are no handbooks or engineering methods from which reliable assessments of the complex environmental wind flows that shape the wind conditions can be derived and numerical / computational methods such as computational fluid dynamics do not readily apply to turbulent wind flows in the built environment. As a result, a purposely-designed boundary layer wind tunnel study was required to provide a reliable quantification of the wind environment within the pitch and spectator tiers.

3.1. Wind Analysis

Details of the analysis carried out to determine the wind climate at the site are provided in BMT report 431590rep1v2.pdf (issued 10th March 2014). Details of the annual and seasonal climate wind analysis relevant to the site are presented in Appendix A.

3.2. Wind Tunnel and Model Details

Details of the model scale and construction, along with photos of the model and wind tunnel setup are presented in Appendix B. The model scale of 1:250 is large enough to allow a good representation of the details that are likely to affect the local and overall wind flows at full scale. In addition, this scale enables a good simulation of the turbulence properties of the wind to be achieved.

3.3. Measurement and Analysis

The technical details relating to the instrumentation, measurements and analysis for the wind environment study are described in Appendix C. The wind speeds within the stadium were measured for a full range of wind directions, in 22.5° increments. The wind environment was assessed at a total of 75 locations across the proposed stadium, comprising 35 locations on the pitch and 40 locations on the spectator tiers. Details of the measurement location schemes of the pitch and spectator tiers are shown in Figures 4.1 to 4.3.

The definition of wind direction is presented in Figure 2.1. The 0° wind direction has been chosen to coincide with the OS Grid north (90° east, 180° south, 270° west). The wind direction denotes the direction, which the wind is blowing *from*.

4. Results

4.1. Wind Speed-Up Factors

The measured wind speeds are converted into wind speed-up factors. These are defined as the ratio between the measured wind speeds at a height of ~1.5m above the ground and the wind speed at the reference height of 50m (the approximate overall height of the new Main stand).

4.2. Threshold Wind Speed Exceedance

Wind speed-up factors are processed in conjunction with wind statistics for the site to derive exceedances of threshold wind speeds relevant to comfort and safety criteria. These are presented in Figures 4.1 to 4.3 for the existing, Phase 1 and Phase 2 configurations respectively.

Details of the criteria adopted for the pitch and spectator tiers wind environment are provided in Appendix C. The assessment specifies the percentage of time each location investigated experiences wind speeds within the range deemed suitable for sports activities and outdoor seating as appropriate. Wind conditions are considered to be satisfactory when the probability of occurrence of wind speeds beneath threshold wind speeds appropriate for outdoor seating or sports activities respectively, is 95% or greater.

For the safety criteria, a wind speed greater than 15m/s occurring at least once per year is deemed unsafe, representing a wind speed with the potential to destabilise the less able members of the public such as the elderly and very young.

Figures 4.1 to 4.3 summarises the assessment on an annual basis for the pitch and spectator tiers.

Player and spectator comfort and safety ratings, for autumn, winter, spring and summer, are presented in electronic Appendix D.

4.3. Discussion

4.3.1. Existing Configuration

In terms of spectator comfort, wind conditions in all four stands are seen as relatively calm, being, at worst, suitable for at least 95% of the time (on an annual basis).

In terms of player comfort, wind conditions on the pitch are seen as very calm, being suitable for at least 99% of the time (on an annual basis).

4.3.2. Phase 1 Configuration

In terms of spectator comfort, with the addition of the new Main stand the wind conditions in the three existing stands are largely unchanged. Furthermore wind conditions within the new Main stand are relatively calm, being, at worst, suitable for at least 95% of the time (on an annual basis).

In terms of player comfort, wind conditions on the pitch are seen as very calm, being suitable for at least 98% of the time (on an annual basis).

4.3.3. Phase 2 Configuration

In terms of spectator comfort, with the addition of the new Main stand and the new Anfield Road stand the wind conditions in the remaining two existing stands are largely unchanged. Furthermore wind conditions within the new Main stand and new Anfield Road stand are relatively calm, being, at worst, suitable for at least 94% of the time (on an annual basis).

In terms of player comfort, wind conditions on the pitch are seen as very calm, being suitable for at least 98% of the time (on an annual basis).

5. Conclusions

The boundary layer wind tunnel study has assessed the player and spectator wind comfort for the proposed Anfield Expansion Project in Liverpool, UK.

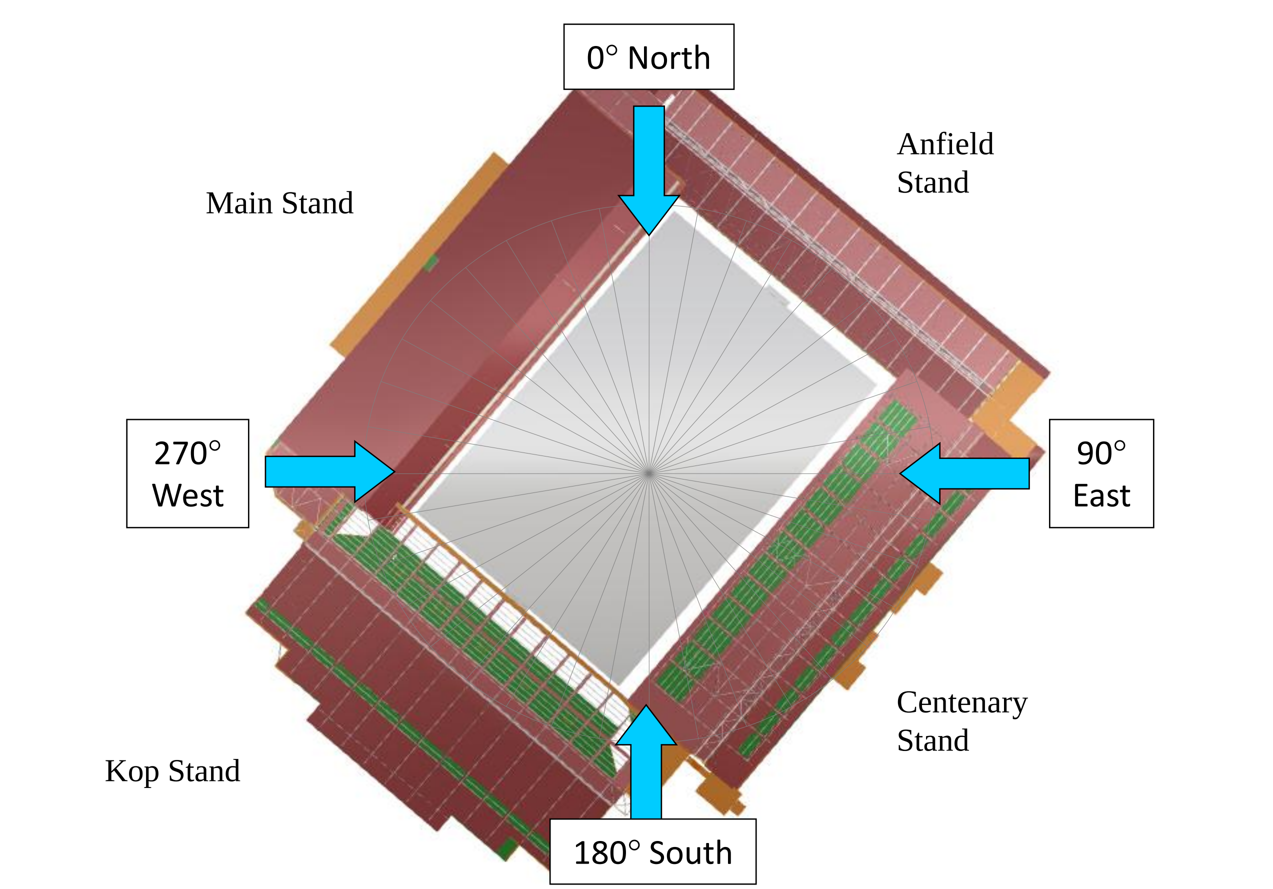
The following conclusions have been drawn:

- In terms of the existing wind environment across the pitch and the spectator tiers, wind conditions are rated as suitable, in terms of safety, for all players and spectators throughout the year
- With the addition of the new Main stand (Phase 1) wind conditions are not significantly affected, and remain suitable for both spectator and sporting use
- With the addition of the new Anfield Road and new Main stands (Phase 2) wind conditions are not significantly affected, and remain suitable for both spectator and sporting use

Figure 2.1: Aerial view of the surroundings of the proposed development site

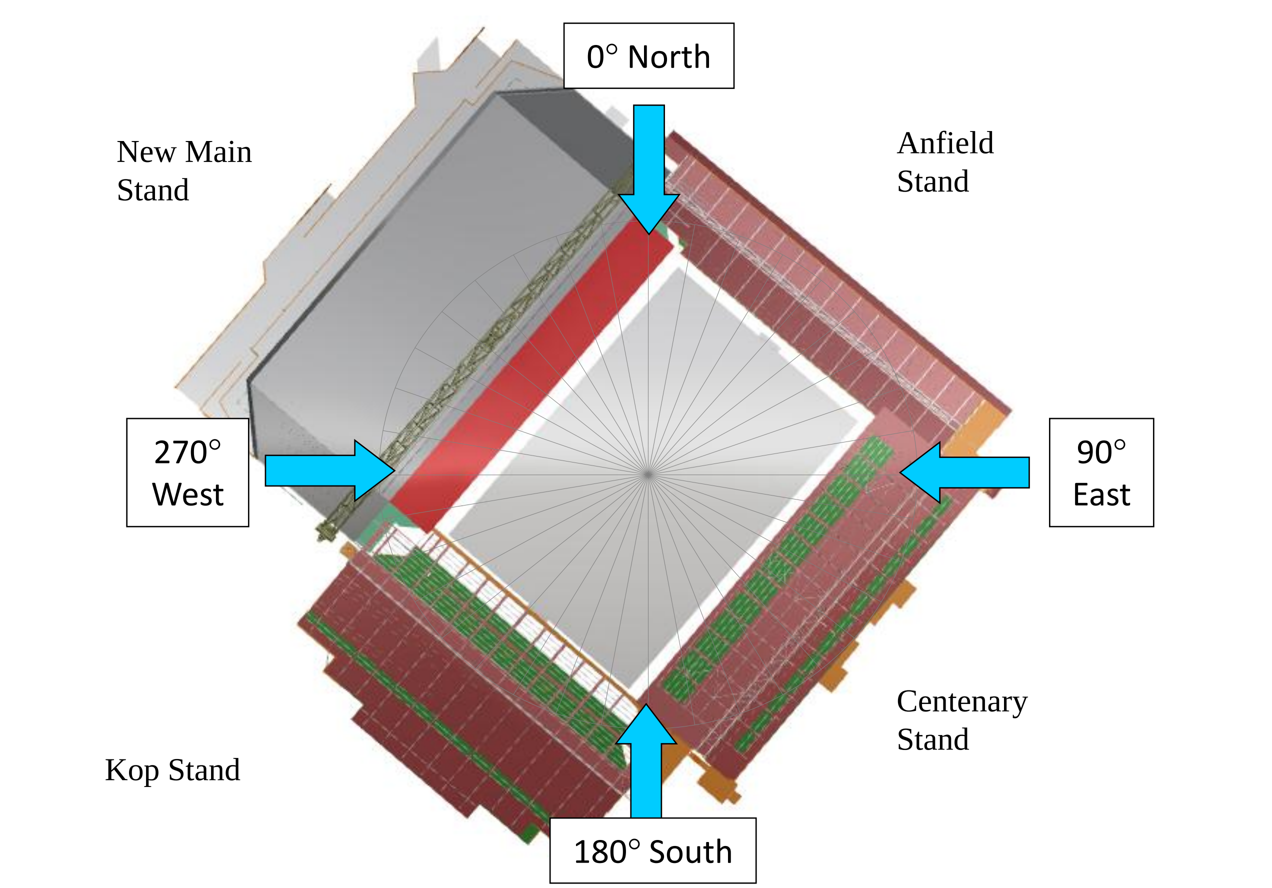
431590 – Liverpool Stadium Aerial View of Proposed Site	Status: Preliminary	Drawing No: 431590/ AV1	Prep: C. Dauge Date: 2-Apr-14

Figure 2.2: Existing configuration



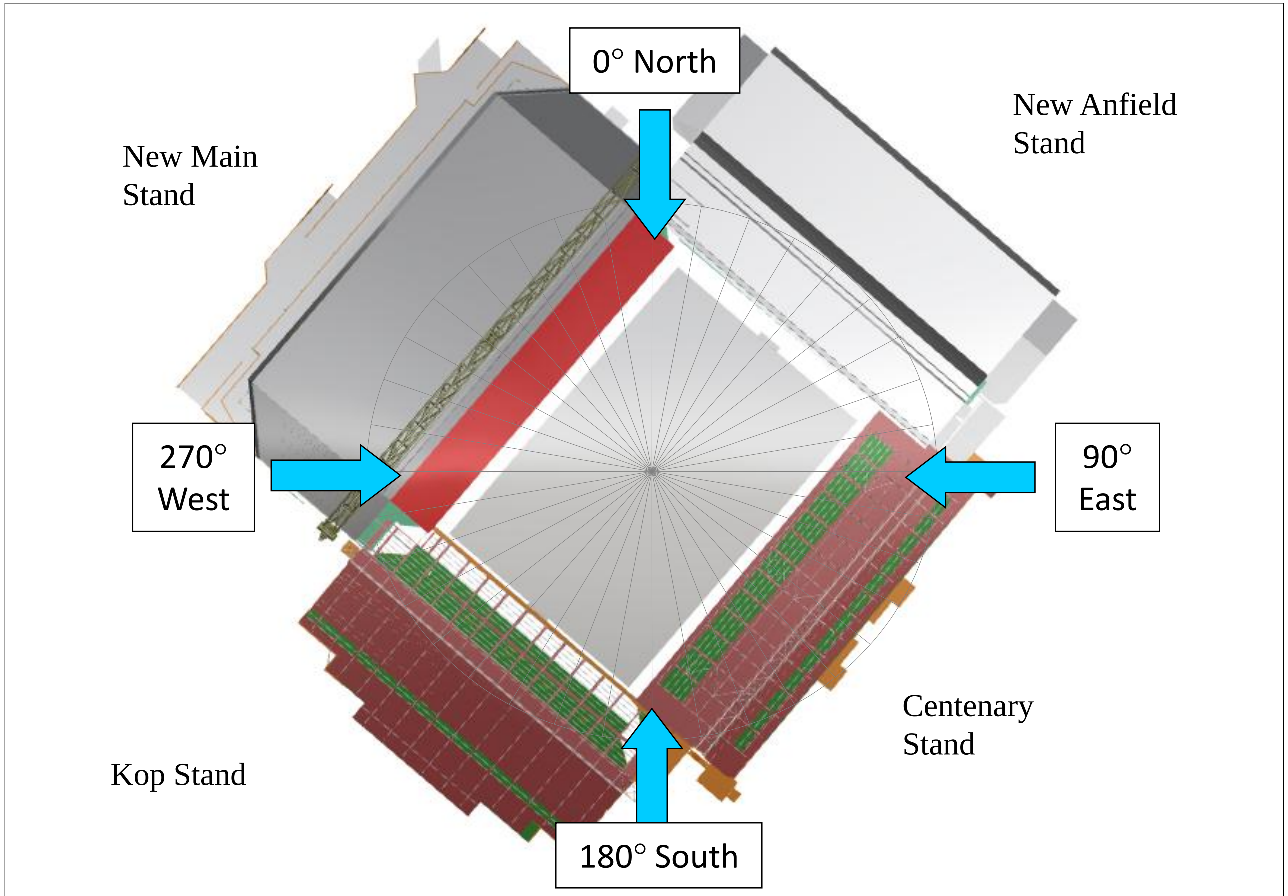
431590 – Liverpool Stadium Site Plan and Wind Directions – Existing configuration	Status: Preliminary	Drawing No: 431590/ WD1	Prep: C. Dauge Date: 2-Apr-14

Figure 2.3: Phase 1 Configuration



431590 – Liverpool Stadium Site Plan and Wind Directions – Phase 1	Status: Preliminary	Drawing No: 431590/ WD1	Prep: C. Dauge Date: 2-Apr-14

Figure 2.4: Phase 2 configuration



431590 – Liverpool Stadium Site Plan and Wind Directions – Phase 2	Status: Preliminary	Drawing No: 431590/ WD1	Prep: C. Dauge Date: 2-Apr-14	BMT Fluid Mechanics

Figure 4.1 - Player and Spectator Wind Comfort: Annual Assessment – Existing Configuration

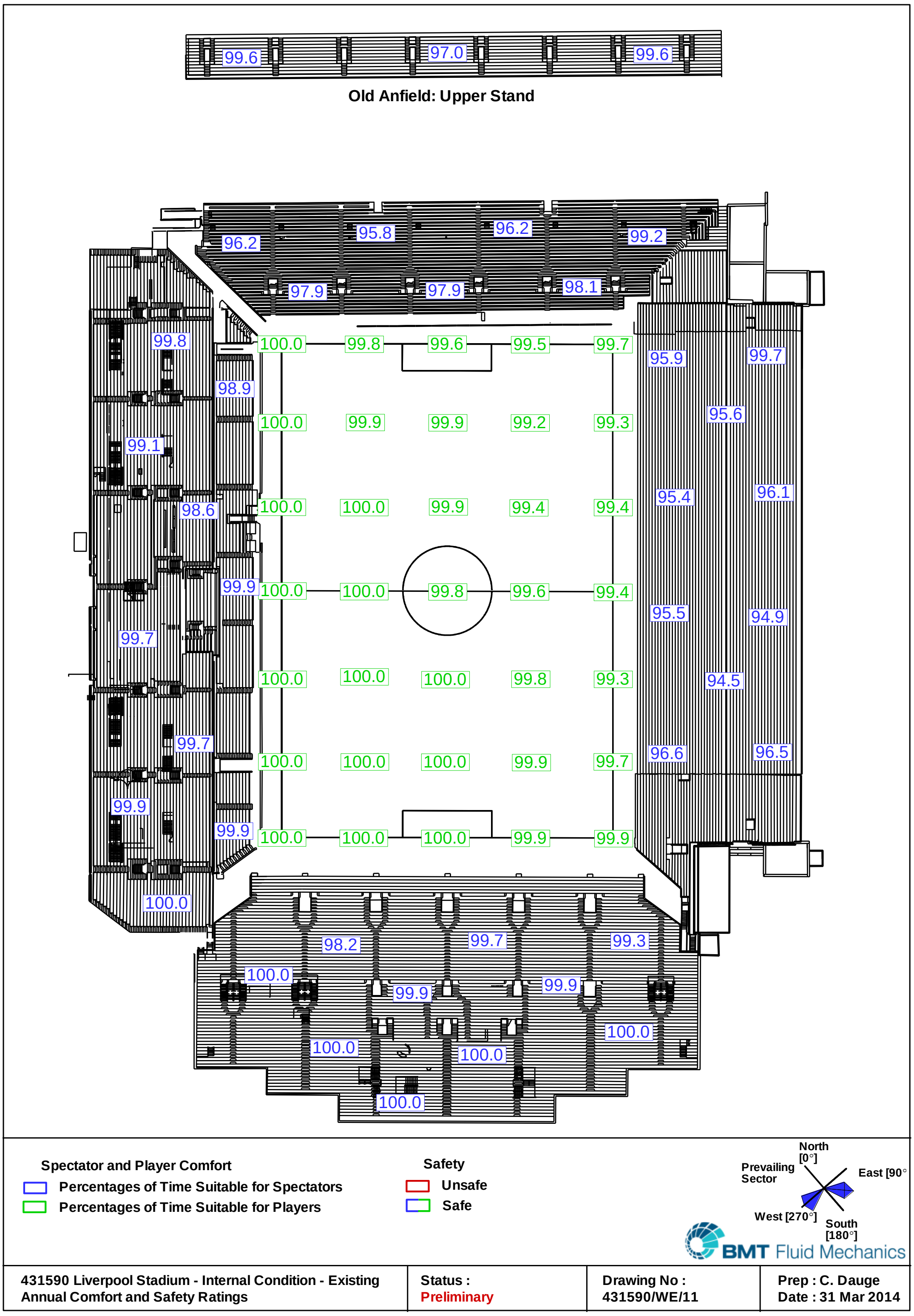
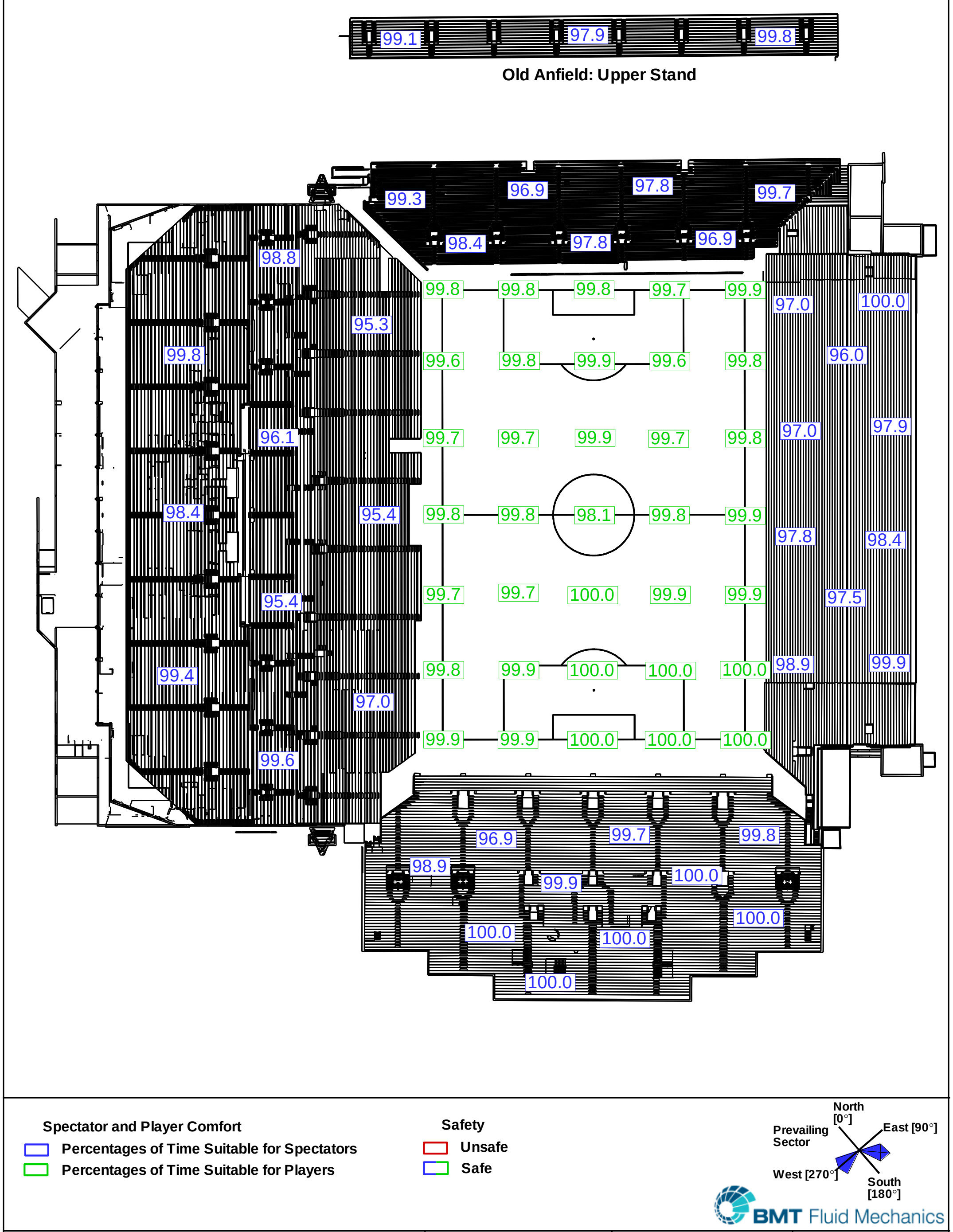
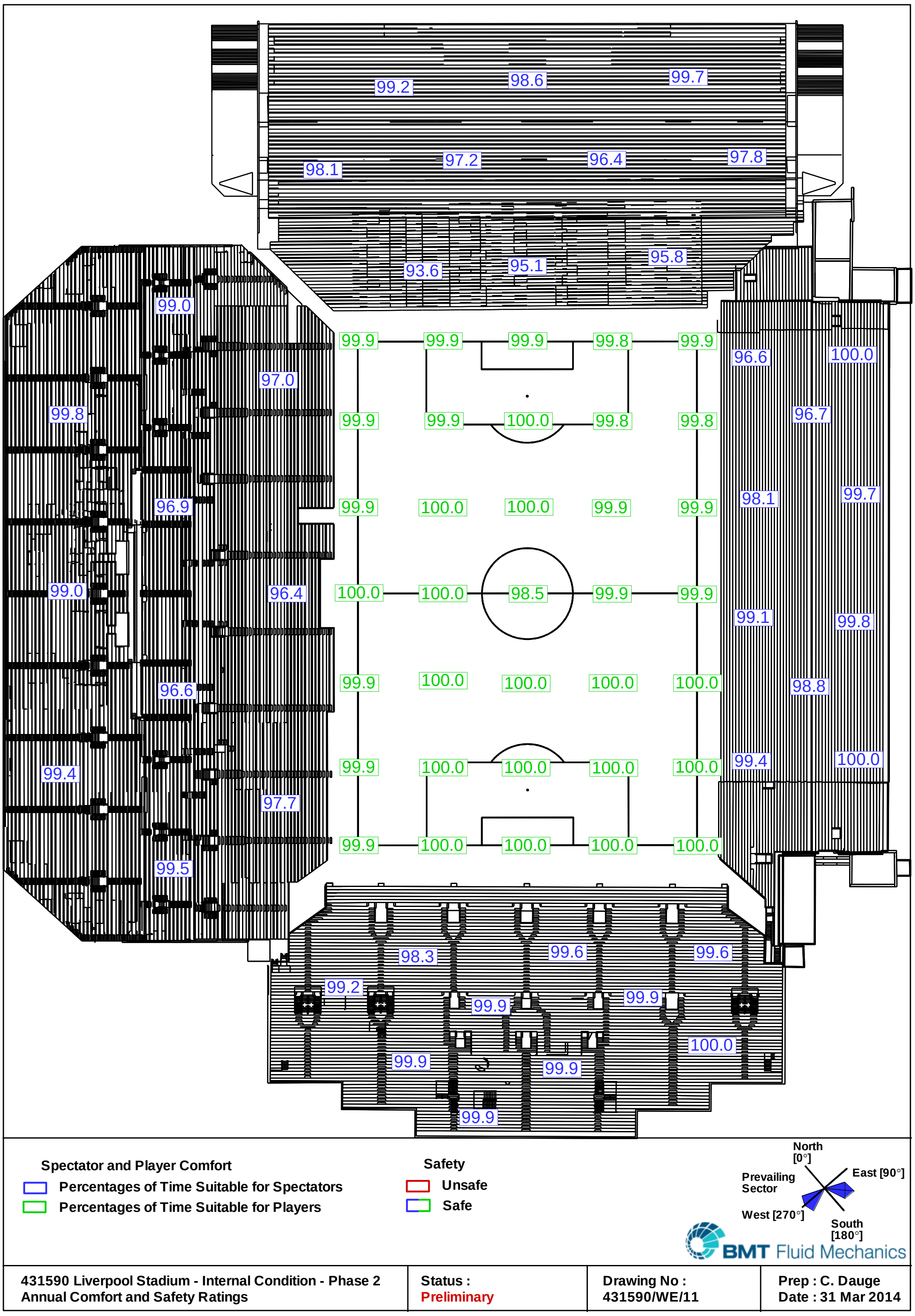


Figure 4.2 - Player and Spectator Wind Comfort: Annual Assessment – Phase 1



431590 Liverpool Stadium - Internal Condition - Phase 1 Annual Comfort and Safety Ratings	Status : Preliminary	Drawing No : 431590/WE/11	Prep : C. Dauge Date : 31 Mar 2014

Figure 4.3 - Player and Spectator Wind Comfort: Annual Assessment – Phase 2



APPENDIX A. SPECIFICATION OF WIND CLIMATE

A.1. ESDU Wind Analysis

A detailed wind analysis was carried out to determine the wind properties at the site. The wind analysis is based on the widely accepted Deaves and Harris log law wind model of the atmospheric boundary layer, as defined in ESDU (Engineering Sciences Data Unit) Item 01008, and has provided wind profiles describing the variation of wind speed and turbulence intensity with height for a full range of wind directions. From this analysis representative profiles were defined as targets for the atmospheric boundary layer simulation in the wind tunnel.

A.1.1. Roughness Changes for ESDU Wind Analysis

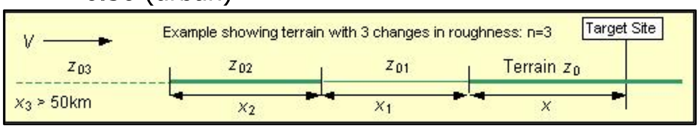
The wind analysis takes detailed account of the variation of the upwind terrain on each wind sector. The roughness changes used in the analysis for the current study are given in Table A.1 below.

Table A.1 - Terrain Roughness Changes from the Site

Wind Direction [deg]	z_0 [m]	x_0 [m]	z_{01} [m]	x01 [m]	z_{02} [m]	x02 [m]	z_{03} [m]	x03 [m]	z_{04} [m]	x04 [m]	z_{05} [m]
0	0.3	7,525	0.1	3,960	0.03						
30.0	0.3	7,525	0.03								
60.0	0.3	8,119	0.03	10,495	0.05	22,574	0.03				
90.0	0.3	6,931	0.08	15,248	0.03	17,228	0.3				
120.0	0.3	9,505	0.03								
150.0	0.3	12,871	water	2,970	0.03						
180.0	0.3	6,238	0.02	4,752	0.03						
210.0	0.3	1,188	0.5	2,970	water	2,376	0.3	3,168	0.02	12,871	0.03
240.0	0.3	1,089	0.5	2,178	water	990	0.2	11,881	water	7,129	0.03
270.0	0.3	1,980	0.5	990	water	1,782	0.3	3,762	water		
300.0	0.3	4,158	water								
330.0	0.3	9,109	0.03	5,545	0.05	3,960	water				

Where **x_0**: upwind fetch
z_0: roughness Groups length

N.B: **z_0** = water (sea)
0.03 (open terrain)
0.10 (sparsely built up suburban / country with trees)
0.30 (suburban)
0.50 (urban)



A.1.2. Wind Profile

Figure A.1 shows the variation of longitudinal turbulence intensity (Iu) with wind direction at reference height of 50m. The target profile selected for the boundary layer simulation is 180°.

Figure A.2 shows the variation of mean wind-speed (normalised by the mean wind speed at the reference height) with height for winds approaching the site from the four primary quarters. Also shown are the target wind profiles, for the boundary layer simulations, which are representative of conditions expected at the site.

Figure A.3 presents the profile of mean wind speed and longitudinal turbulence intensity used in the tests. The wind speed profiles are normalised by the mean wind speed at reference height. It can be seen that, over the range of heights of interest, the boundary layer simulation used in the tests was a good representation of that expected for the site at full scale which satisfies the experimental requirements of the American Society of Civil Engineering (ASCE Manuals and Reports on Engineering Practice No. 67), and the Quality Assurance Manual, AWEA-QAM-1-2001 by the Australasian Wind Engineering Society (AWES).

Figure A.1: Variation of longitudinal turbulence intensity (I_u) with wind direction at reference height, including reference turbulence levels

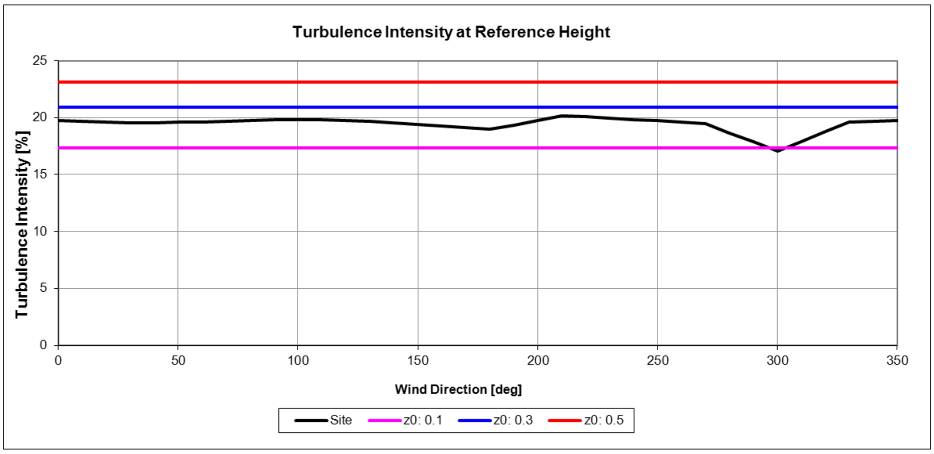


Figure A.2: Mean wind speed profiles (normalised to reference height) for each wind quarter

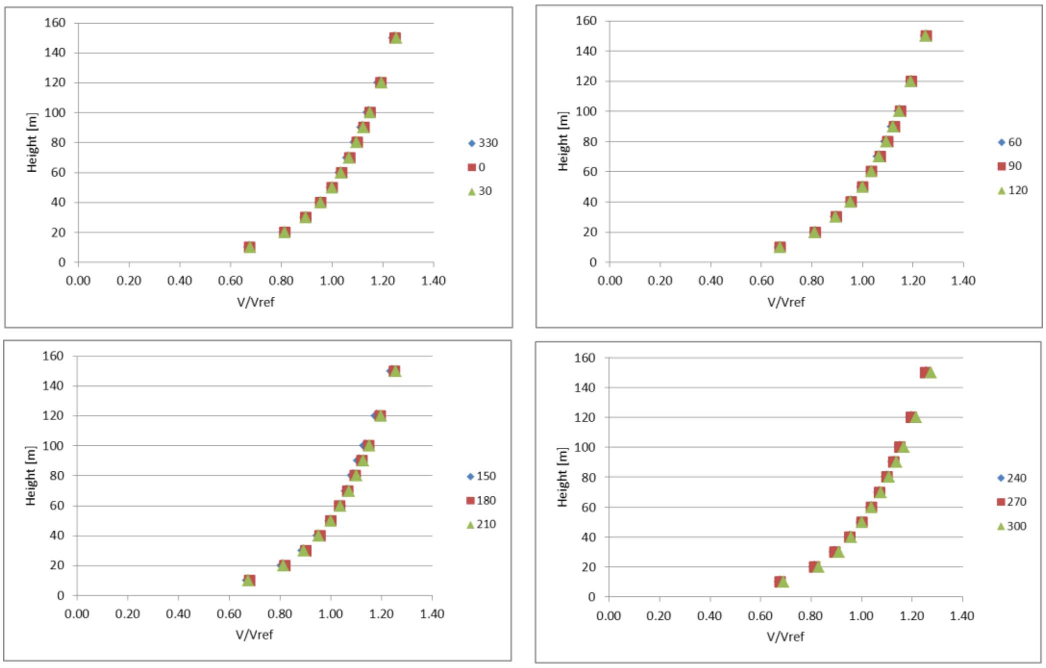
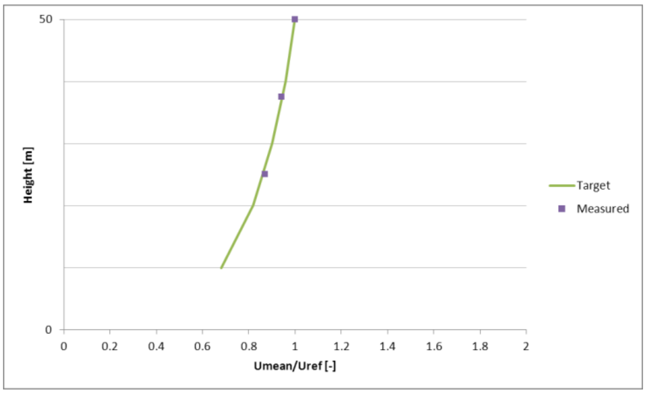
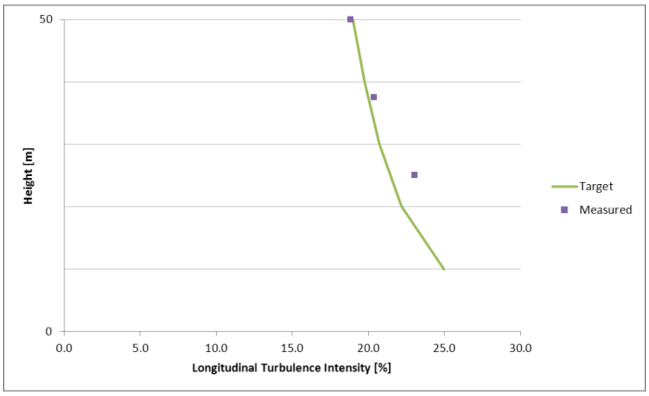


Figure A.3: Mean wind speed (Vmean/Vmean(ref)), gust wind speed (Vgust/Vmean(ref)) and longitudinal turbulence intensity profiles (Iu) used in the study

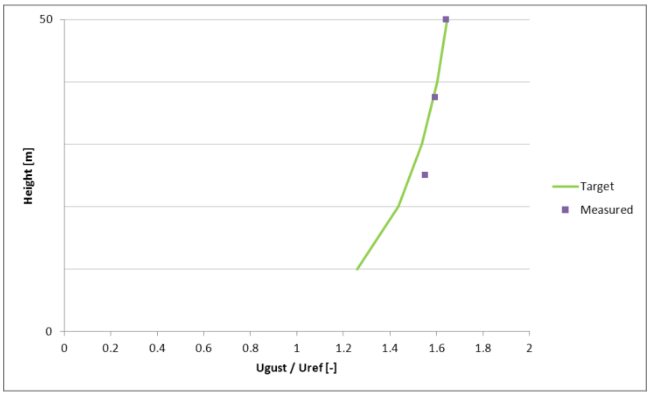
Vmean/Vmean(ref)



Iu [%]



Vgust/Vmean(ref)



A.2. Wind Frequency Data

Wind environment studies require that wind speed data obtained from a measurement station be transposed to the site of interest.

The wind speed history, provided by weather centres such as the UK Met Office, is reformatted into the number of observations of mean hourly wind speeds within each of several wind speed ranges, for each wind direction and for each month of the year. To facilitate the transposition of the wind data, the months are grouped into the seasons and a Weibull distribution is fitted to the wind speed distribution for each wind direction, for each season.

From the Weibull cumulative distribution the probability that, for a given wind direction, a wind speed, V, will be exceeded is given by:

$$P(>V) = e^{-(\frac{V}{c})^k}$$

where *c* is the dispersion parameter and k is the shape parameter.

To these parameters is further added the probability, *p*, of each wind direction occurring. Thus for each month of the year the probability that a specified wind speed is exceeded for a specified wind direction may be calculated.

The resulting weather centre wind data is transposed to open country terrain at sea-level, accounting for upwind terrain, topography and altitude for the weather centre. The 50-year return period design wind speed is calculated based on the wind data and from comparison with the basic design wind speed specified in BS EN 1991-1-4:2005 for the weather centre area, local topography and/or proximity effects can be corrected for. Values of *p*, *c* and *k* for the Aughton Liverpool Weather Centre, transposed to open-country terrain at 10m height above sea-level altitude are given in the Table A.2.

The open country wind data is then transposed to reference height at the site of the proposed development, accounting for upwind terrain and topography for the target site. The resulting annual and seasonal directional and wind speed probability distributions at reference height, at the proposed site, are given in Figures A.4 and A.5, respectively.

Table A.2 - Wind Frequency Statistics: data transposed to open terrain, Aughton Weather Centre WEIBULL COEFFICIENTS

Annual	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
p	3.22	3.49	3.70	3.64	4.71	7.74	10.77	8.29	5.14	5.64	6.26	9.19	9.54	8.78	6.19	3.71
c	3.39	3.96	4.48	4.59	4.79	4.47	4.79	4.88	4.97	5.91	6.47	6.40	6.18	5.69	4.99	3.62
k	1.54	1.70	2.09	2.11	2.13	2.28	2.09	2.17	2.14	2.15	2.27	2.31	2.05	1.96	1.92	1.63

Autumn	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
p	4.25	3.88	4.29	3.17	4.67	8.89	13.64	9.43	5.51	5.16	4.88	7.28	8.14	7.47	5.28	4.05
c	3.63	3.80	4.06	3.85	4.55	4.47	4.57	4.58	4.77	5.33	5.92	6.14	6.09	5.96	4.93	3.60
k	2.22	1.89	1.86	1.88	2.42	2.61	1.94	2.14	2.29	2.20	2.47	2.35	2.16	2.00	1.83	1.78

Winter	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
p	2.72	3.22	3.03	3.42	4.83	9.07	13.58	9.60	6.08	7.13	7.85	9.64	7.97	5.03	3.53	3.28
c	3.31	3.95	4.45	4.95	5.20	4.81	5.33	5.34	5.72	6.96	7.57	7.73	7.84	6.88	5.46	4.08
k	1.27	1.50	2.05	2.11	2.03	2.18	2.35	2.22	2.28	2.38	2.51	2.51	2.29	1.93	1.73	1.59

Spring	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
p	3.09	3.59	4.57	4.82	5.33	7.23	9.25	7.90	4.42	5.21	6.30	9.38	9.51	8.78	6.86	3.76
c	4.16	4.49	5.16	5.09	4.96	4.61	5.02	5.23	4.89	6.06	6.65	6.63	6.28	5.80	5.32	3.99
k	1.86	1.85	2.34	2.44	2.39	2.48	2.23	2.33	2.19	2.30	2.41	2.47	2.32	2.19	2.01	1.93

Summer	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
p	2.82	3.27	2.90	3.12	3.97	5.79	6.64	6.21	4.50	4.98	5.90	10.40	12.58	14.01	9.17	3.75
c	2.92	3.71	3.82	4.06	4.52	3.87	3.76	4.22	4.35	4.78	5.19	5.13	5.13	5.12	4.66	2.95
k	1.79	1.89	2.17	2.21	2.42	2.42	2.15	2.52	2.30	2.18	2.13	2.40	2.56	2.38	2.36	1.57

Figure A.4 - Annual & Seasonal Directional Probability Distribution at Site

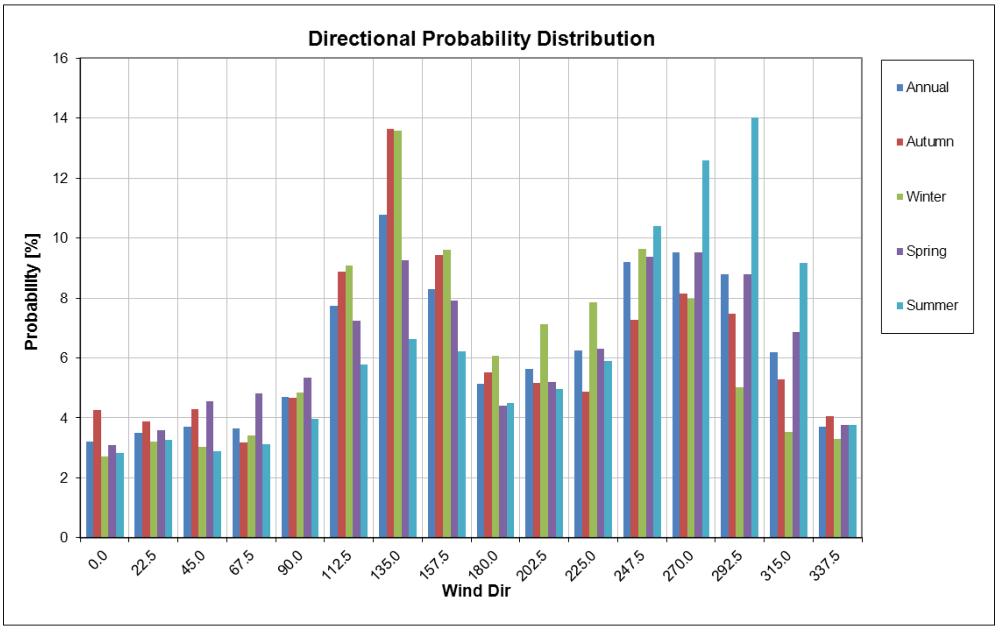
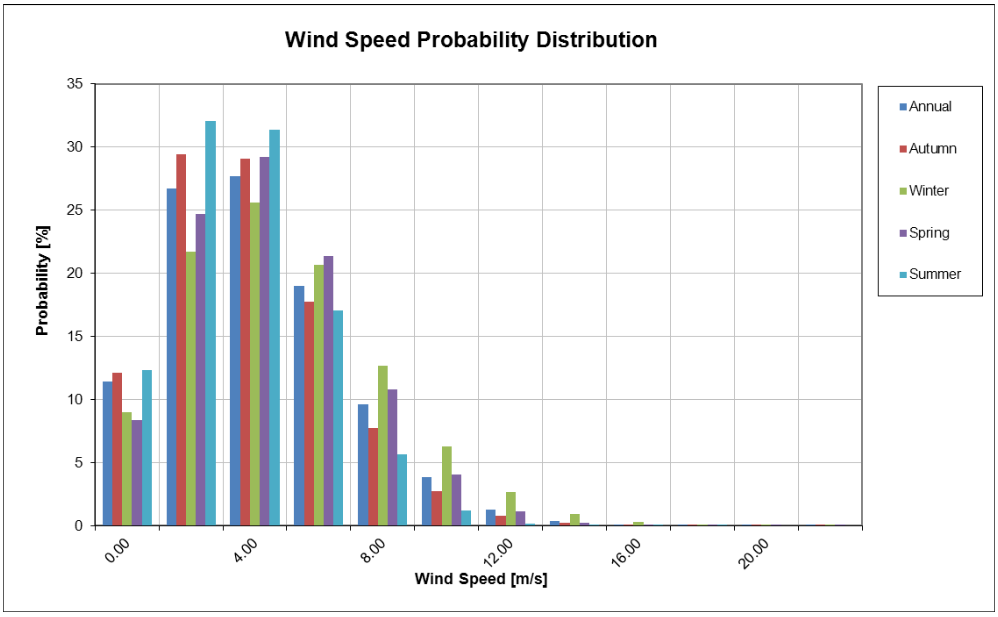


Figure A.5 - Annual & Seasonal Wind Speed Probability Distribution at Reference Height at Site



APPENDIX B. WIND TUNNEL & MODEL DETAILS

B.1. Wind Tunnel Specifications

All the tests were conducted in BMT's Boundary Layer Wind Tunnel which has a working section 4.8m wide, 2.4m high and 15m long with a 4.4m diameter multiple plate turntable and a remotely controlled 3-dimensional traversing system. The operating wind speed range is 0.2 – 45 m/s.

The turbulent boundary layer is set up using an arrangement of roughness elements distributed over the floor of the wind tunnel, vertical posts and a 2-dimensional barrier placed at the entrance to the test section according to the fetch.

B.2. Model

B.2.1. Information

The wind tunnel model of the proposed development was constructed based on drawing information supplied by KSS, the architect for the scheme, to BMT, as follows:

Date	Drawing	Date	Drawing
03/03/2014	PL1312.GA.102 Phase 1 Stadium Concourse.dwg	03/03/2014	Liverpool Football Club - Floorplans - Second Floor Level.dwg
03/03/2014	12609-ARCHExistingStadium-Survey-mesh.dwg	03/03/2014	Liverpool Football Club - Floorplans First Floor Level.dwg
03/03/2014	12609-ARCHExistingStadium-Survey-solid.dwg	03/03/2014	LOWER TIER ANFIELD ROAD FLOOR PLAN - LIVERPOOL FOOTBALL CLUB.dwg
03/03/2014	08727_KL1 ANFIELD STADIUM.dwg	03/03/2014	MAIN STAND FLOOR PLAN-LIVERPOOL FOOTBALL CLUB.dwg
03/03/2014	08727_KL2 ANFIELD STADIUM.dwg	03/03/2014	ROOF PLAN - LIVERPOOL FOOTBALL CLUB, ANFIELD.dwg
03/03/2014	08727_KL3 ANFIELD STADIUM (Provisional).dwg	03/03/2014	UPPER TIER ANFIELD ROAD FLOOR PLAN - LIVERPOOL FOOTBALL CLUB.dwg
03/03/2014	08727_KL4 ANFIELD STADIUM.dwg	03/03/2014	PL564.S.100 revAexisting le.dwg
03/03/2014	08727_KL5 ANFIELD STADIUM.dwg	03/03/2014	08727-3dT-ANFIELD STADIUM LIVERPOOL REV A.dwg
03/03/2014	08727-E-01 ANFIELD ELEVATIONS.dwg	03/03/2014	38870390_1 .. 04B0L6537 _170512_Mesh.dwg

Date	Drawing	Date	Drawing
03/03/2014	08727-IE KOP ANFIELD STADIUM.dwg	03/03/2014	38870390_1 .. 04B0L6537 _170512_Solids.dwg
03/03/2014	08727-L1- CENTENARY STAND.dwg	07/03/2014	12609-ARCHMaster-Anfield Road Stand.dwg
03/03/2014	08727-L2-CENTENARY STAND.dwg	07/03/2014	12609-ARCHMaster-Main stand.dwg
03/03/2014	08727-L3-CENTENARY STAND.dwg	07/03/2014	12609-ExistingStadiumSurvey.dwg
03/03/2014	08727-L4-CENTENARY STAND.dwg	07/03/2014	12609-ARCHMaster.dwg
03/03/2014	08727-L5-CENTENARY STAND.dwg	07/03/2014	12609-ARCH Master.dwg
03/03/2014	ELEVATIONS - LIVERPOOL FOOTBALL CLUB.dwg	11/03/2014	PL1312.LFC Stage D Phase 1 Masterplan.dwg
03/03/2014	Liverpool Football Club - Floorplans - Ground Floor Level.dwg	11/03/2014	PL1312.LFC Stage D Phase 2 Masterplan.dwg

The wind tunnel models representative of the surrounding building morphology were constructed based on information sourced from the public domain.

The models were reviewed and approved by the design team, prior to testing.

B.2.2. Scale

A model scale of *1:250* has been adopted. At this scale the model is large enough to allow a good representation of the details that are likely to affect the local and overall wind flows at full scale. In addition, this scale enables a good simulation of the turbulence properties of the wind to be achieved.

B.2.3. Construction

The model was constructed from a combination of materials such as hard foam, wood and perspex. The model incorporated all of the features that are likely to significantly affect the local wind flow around the development at full scale. The surrounding area was modelled to a radius of 550m from the centre of the site. The surrounding buildings and topography were represented to a sufficient level of detail to reproduce the wind flows at the location of the proposed development. Mature existing trees were represented in winter, or bare, format.

The model was mounted on a 4.4m diameter turntable of BMT's Boundary Layer Wind Tunnel.

B.2.4. Model Photos

Images of the wind tunnel model are presented as follows:

- Figures B.1 – B.3 - Wind Tunnel Models and Set-Up – Existing configuration
- Figures B.4 – B.6 - Wind Tunnel Models and Set-Up – Phase 1
- Figures B.7 – B.9 - Wind Tunnel Models and Set-Up – Phase 2

Figure B.1 - Wind Tunnel Models of the Proposed Development, Viewed from North, Wind Tunnel Set-Up, Existing

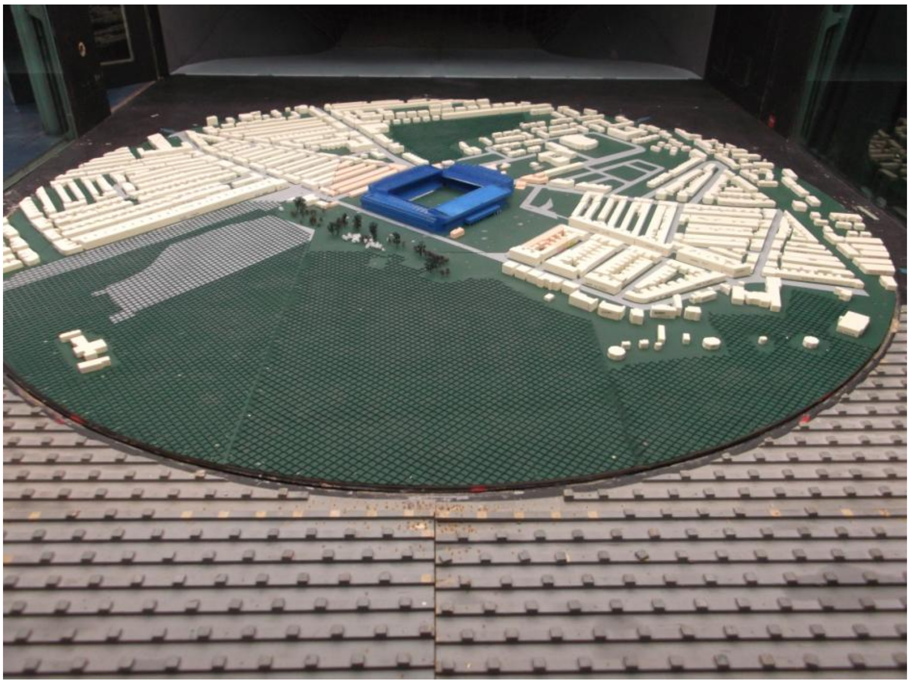


Figure B.2 - Wind Tunnel Models of the Proposed Development, Viewed from West, Wind Tunnel Set-Up, Existing Configuration

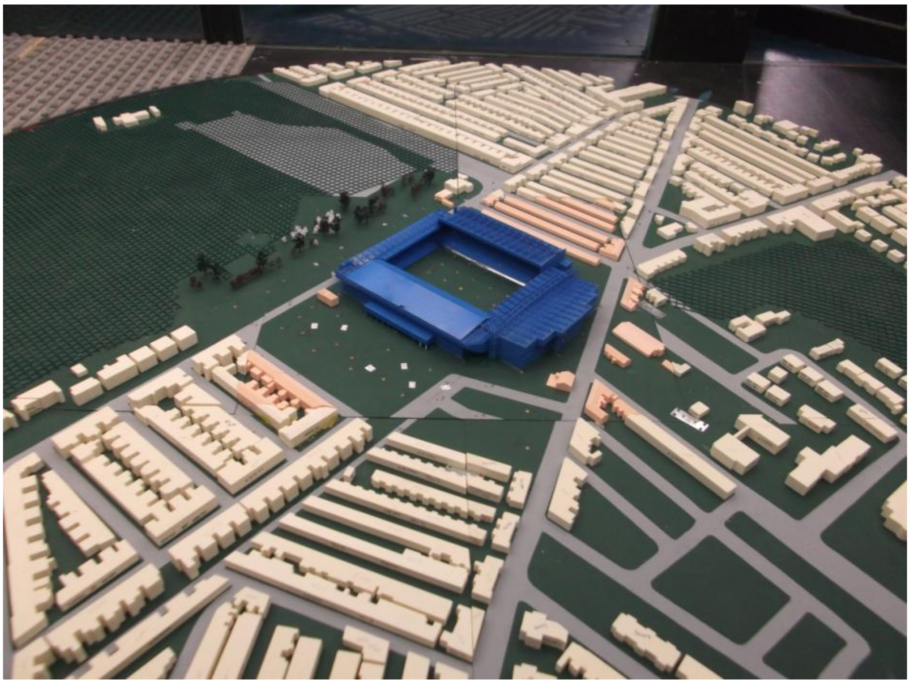


Figure B.3 - Wind Tunnel Models of the Proposed Development, Viewed from South, Wind Tunnel Set-Up, Close Up View, Existing Configuration

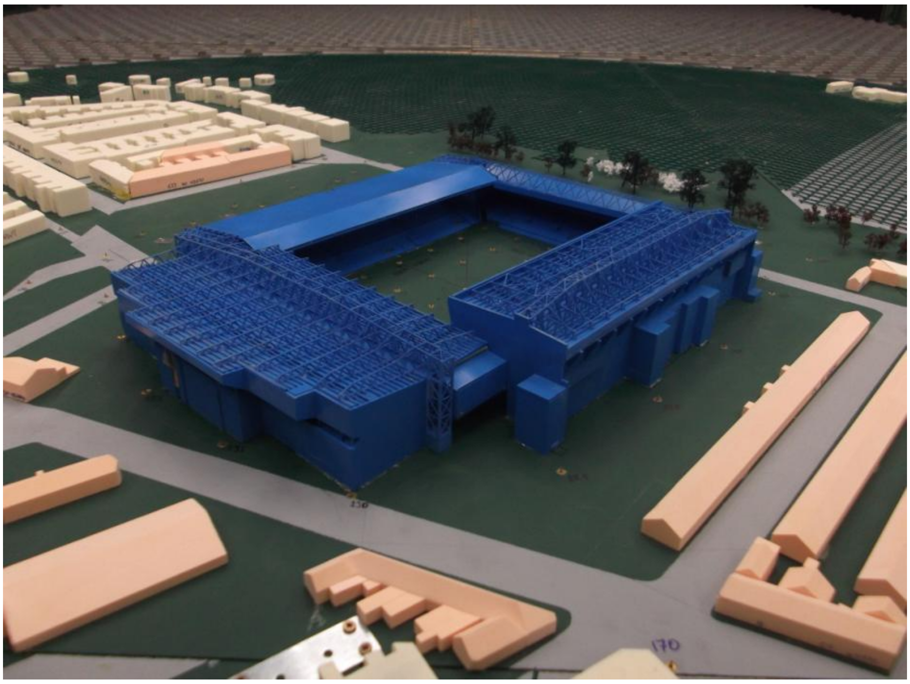


Figure B.4 - Wind Tunnel Models of the Proposed Development, Viewed from North, Wind Tunnel Set-Up, Phase 1

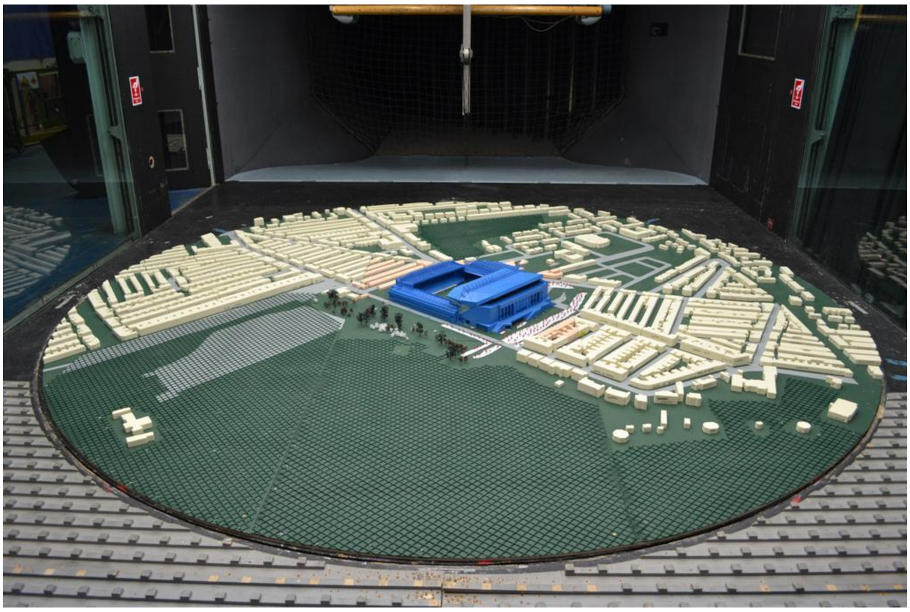


Figure B.5 - Wind Tunnel Models of the Proposed Development, Viewed from South, Wind Tunnel Set-Up, Phase 1

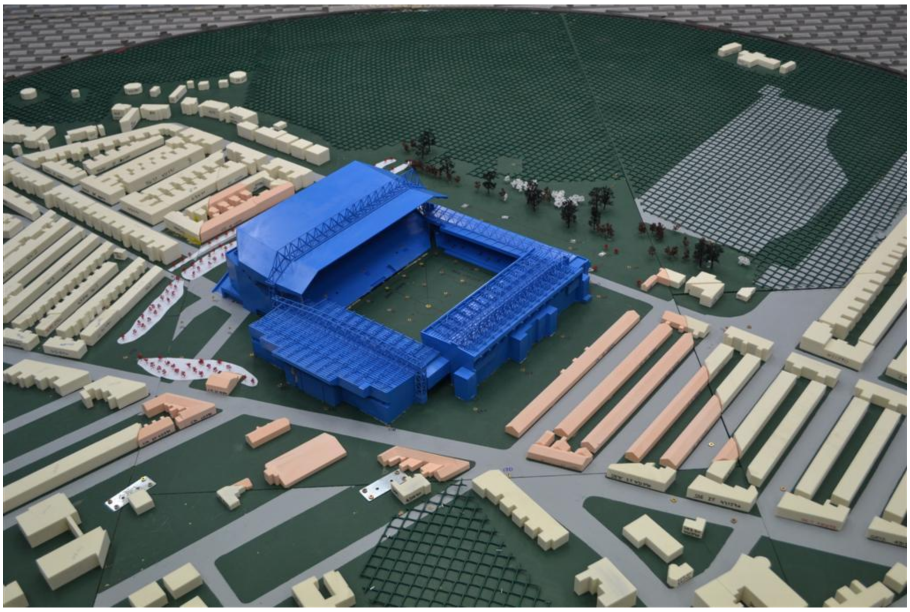


Figure B.6 - Wind Tunnel Models of the Proposed Development, Viewed from Northeast, Wind Tunnel Set-Up, Close Up View, Phase 1

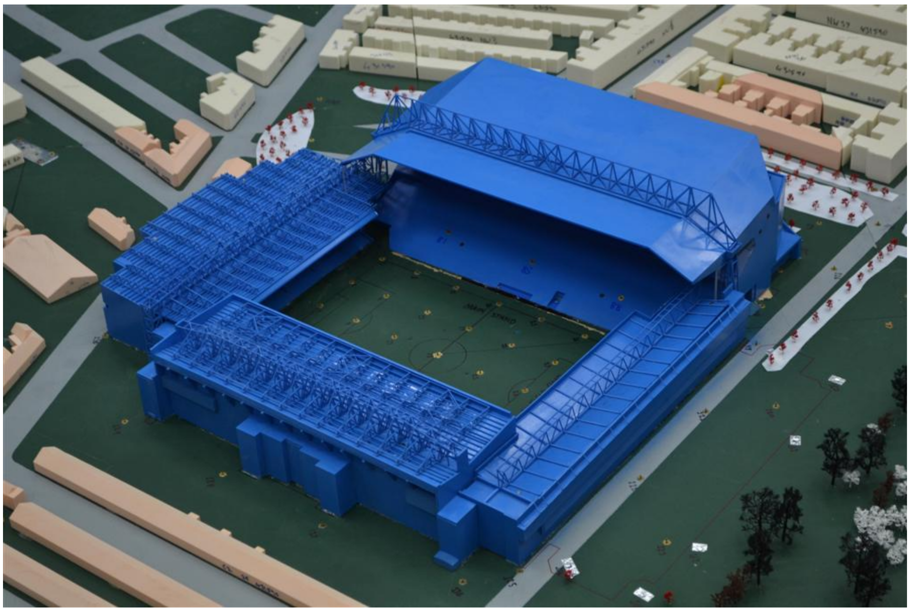


Figure B.7 - Wind Tunnel Models of the Proposed Development, Viewed from North, Wind Tunnel Set-Up, Phase 2

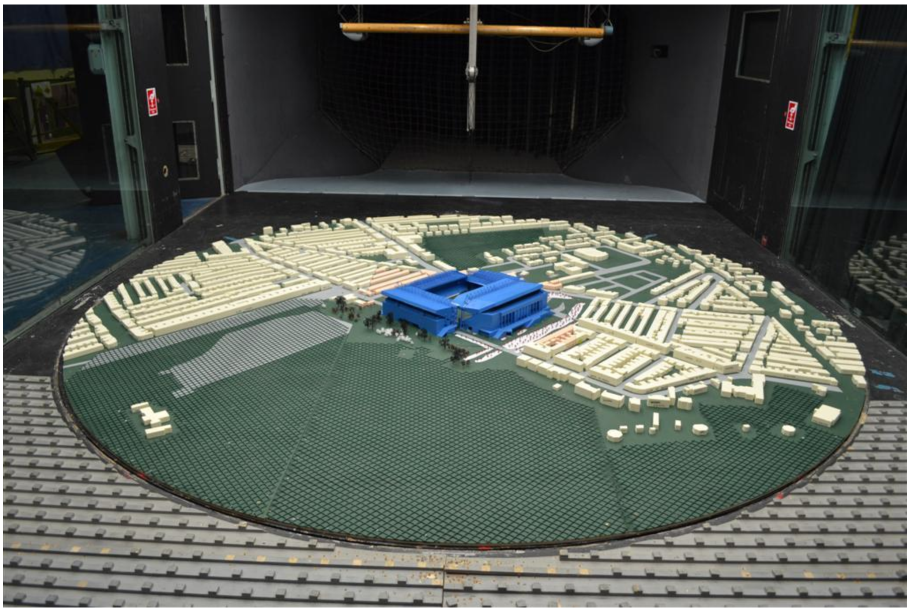


Figure B.8 - Wind Tunnel Models of the Proposed Development, Viewed from Southeast, Wind Tunnel Set-Up, Close Up View, Phase 2

Figure B.9 - Wind Tunnel Models of the Proposed Development, Viewed from South, Wind Tunnel Set-Up, Close Up View, Phase 2

APPENDIX C. EXPERIMENTAL TECHNIQUES FOR WIND ENVIRONMENT MEASUREMENTS

C.1. Physical Measurements

Wind speed measurements were made using so-called Irwin probes capable of measuring fluctuating pressure differences that are calibrated against wind speed. A system of probes running simultaneously was used to obtain results from up to 75 locations at a height corresponding to ~1.5m at full scale. Measurements were taken for a full range of wind directions in increments of 22.5°.

Data were recorded for a sufficient length of time to determine the mean and 3-second gust wind speeds.

Gusts in the wind flow may lead to additional discomfort beyond that caused by the mean wind speed. In order to assess this discomfort the gust wind speed is translated to an equivalent mean wind speed, the Gust Equivalent Mean or GEM, according to the following equation:

$$U_{GEM} = \frac{U_{GUST}}{1.85}$$

For each location the results were combined with local wind statistics to assess the wind environment in terms of the exceedance of threshold wind speeds that relate to comfort levels perceived during standard pedestrian activities.

C.2. Assessment Criteria: Seating Areas and Pitch

The assessment of spectator tiers and pitch wind environment is based on the threshold wind speeds adopted by the Lawson criteria.

The wind speed range deemed suitable for stadium seating areas is defined in Table C.1. The assessment specifies the percentage of time each seating area investigated experiences wind speeds within the ranges deemed suitable for outdoor seating.

The speed range deemed suitable for recreational/sports use, applicable to the pitch is defined in Table C.1. The assessment specifies the percentage of time each location investigated experiences wind speeds within the ranges deemed suitable for recreational/sports use.

For the safety criteria, a wind speed greater than 15m/s occurring at least once per year is deemed unsafe, representing a wind speed with the potential to destabilise the less able members of the public such as the elderly and very young.

Table C.2: Seating Area and Pitch - Assessment Criteria, Comfort

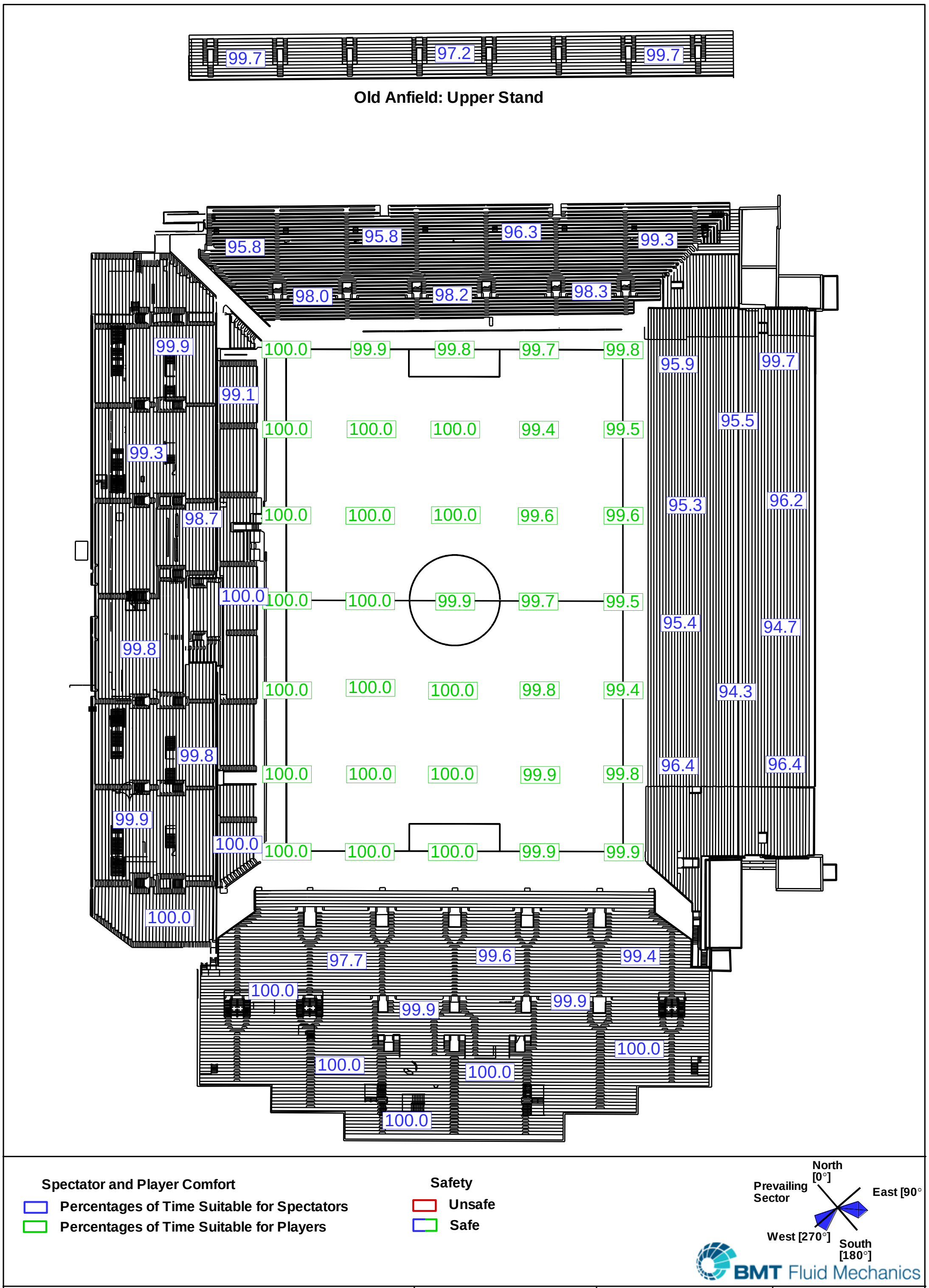
Wind Speed Range (m/s)	Suitability
0 – 4	Outdoor Seating
0 – 6	Recreational / Sports Use

APPENDIX D. SEASONAL RESULTS

The results for the seasonal player and spectator comfort and safety ratings derived from each measurement locations, are summarized in graphical format as follow, for each configuration:

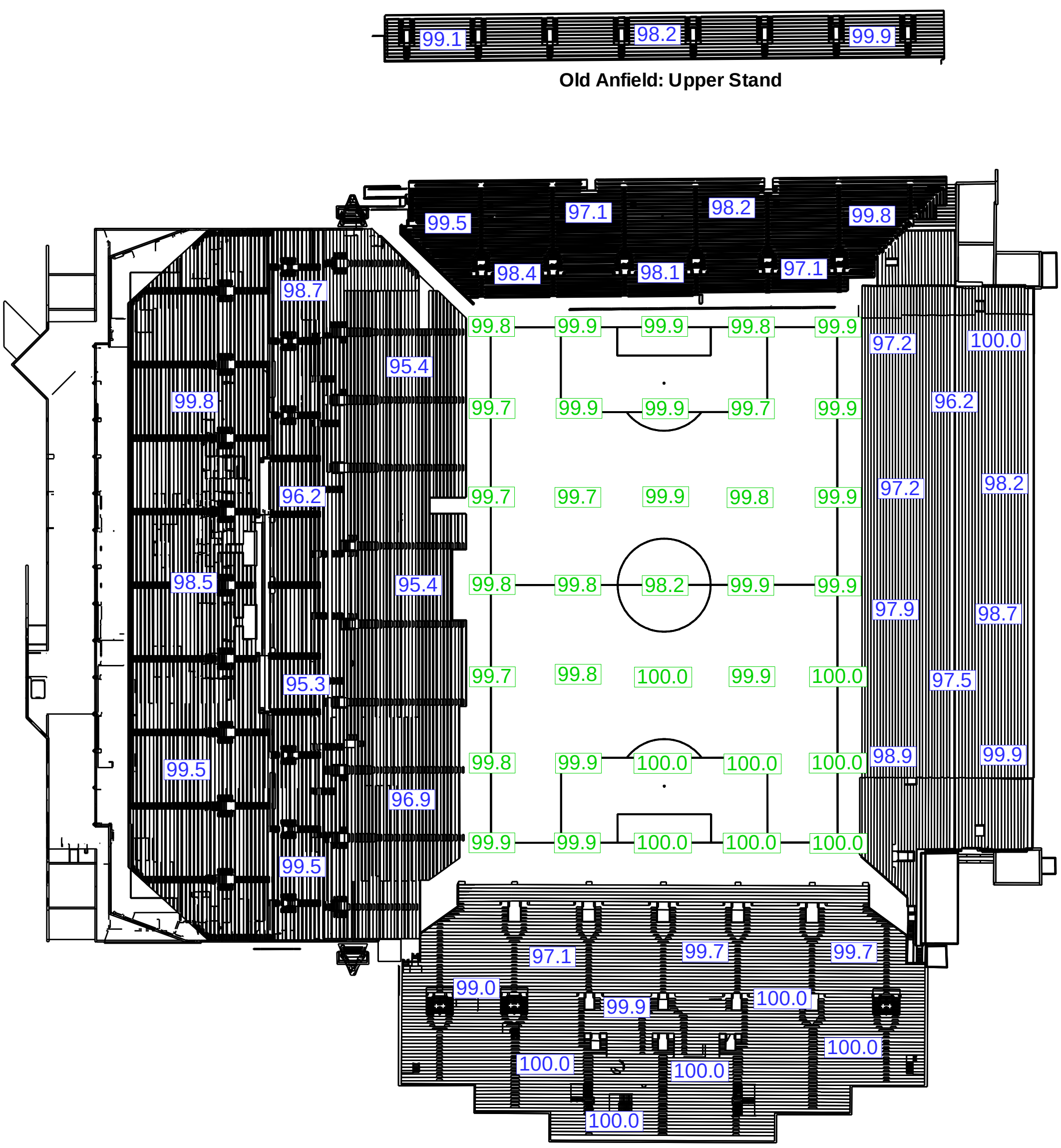
- Figures D.1.a to D.1.c present **spring seasonal** comfort
- Figures D.2.a to D.2.c present **summer seasonal** comfort
- Figures D.3.a to D.3.c present **autumn seasonal** comfort
- Figures D.4.a to D.4.c present **winter seasonal** comfort

Figure D.1.a - Pitch and Spectator Tiers Wind Environment – Spring Comfort and Safety Ratings – Existing configuration



431590 Liverpool Stadium - Internal Condition - Existing Spring Comfort and Safety Ratings	Status : Preliminary	Drawing No : 431590/WE/14	Prep : C. Dauge Date : 31 Mar 2014

Figure D.1.b - Pitch and Spectator Tiers Wind Environment – Spring Comfort and Safety Ratings – Phase 1



Spectator and Player Comfort

- Percentages of Time Suitable for Spectators
- Percentages of Time Suitable for Players

Safety

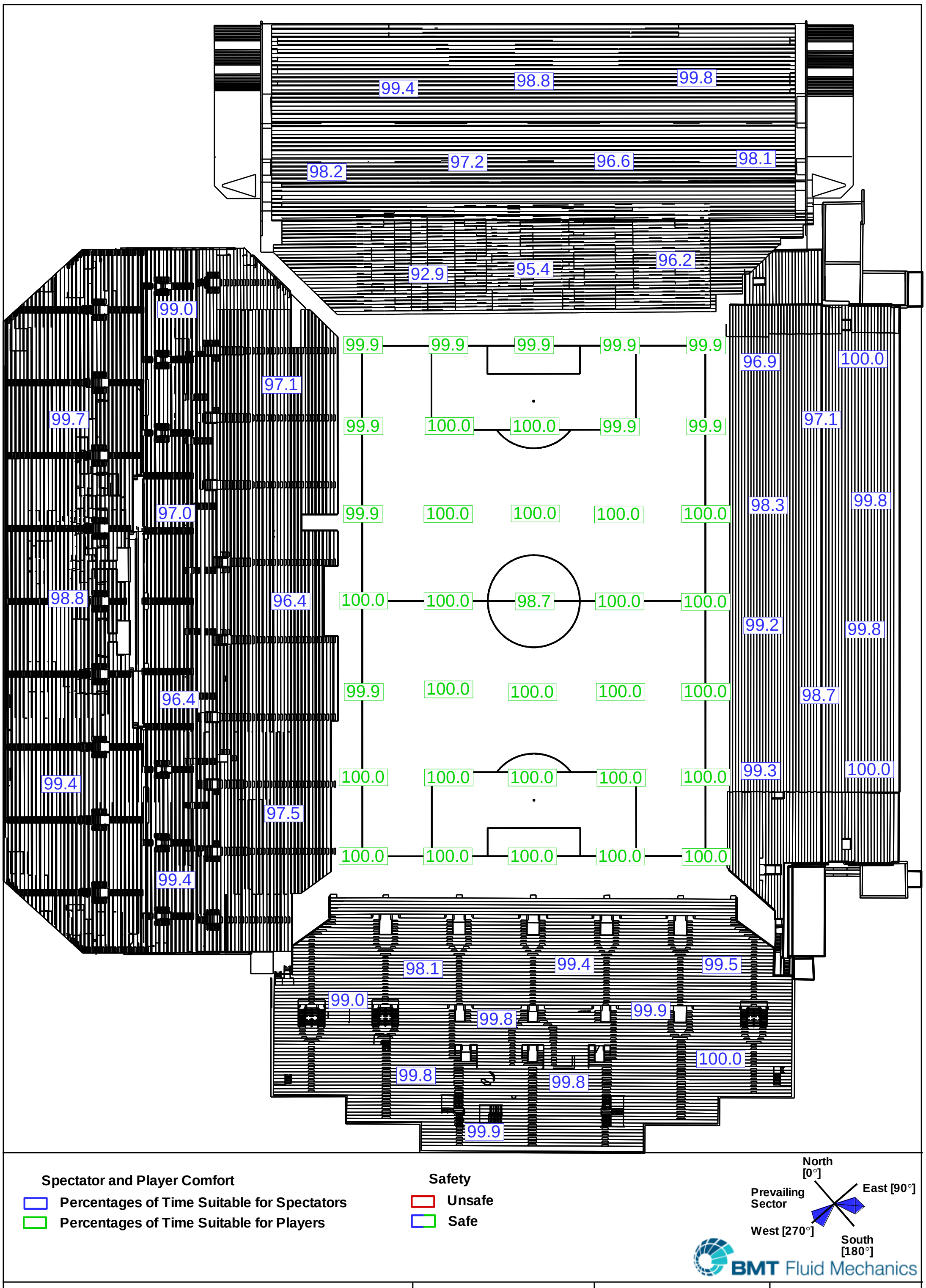
- Unsafe
- Safe

North [0°] East [90°] South [180°] West [270°] Prevailing Sector

BMT Fluid Mechanics

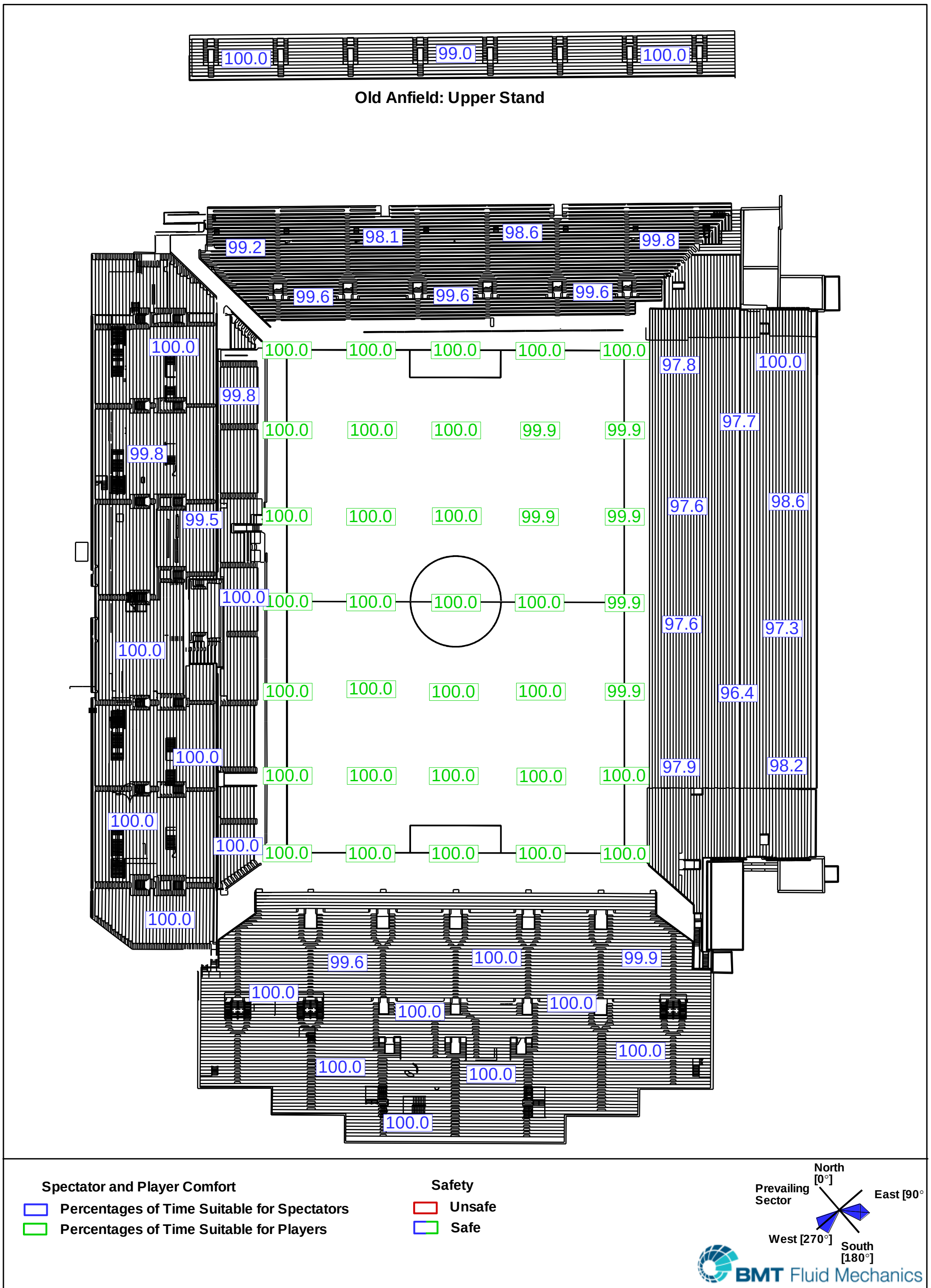
431590 Liverpool Stadium - Internal Condition - Phase 1 Spring Comfort and Safety Ratings	Status : Preliminary	Drawing No : 431590/WE/14	Prep : C. Dauge Date : 31 Mar 2014

Figure D.1.c - Pitch and Spectator Tiers Wind Environment – Spring Comfort and Safety Ratings – Phase 2



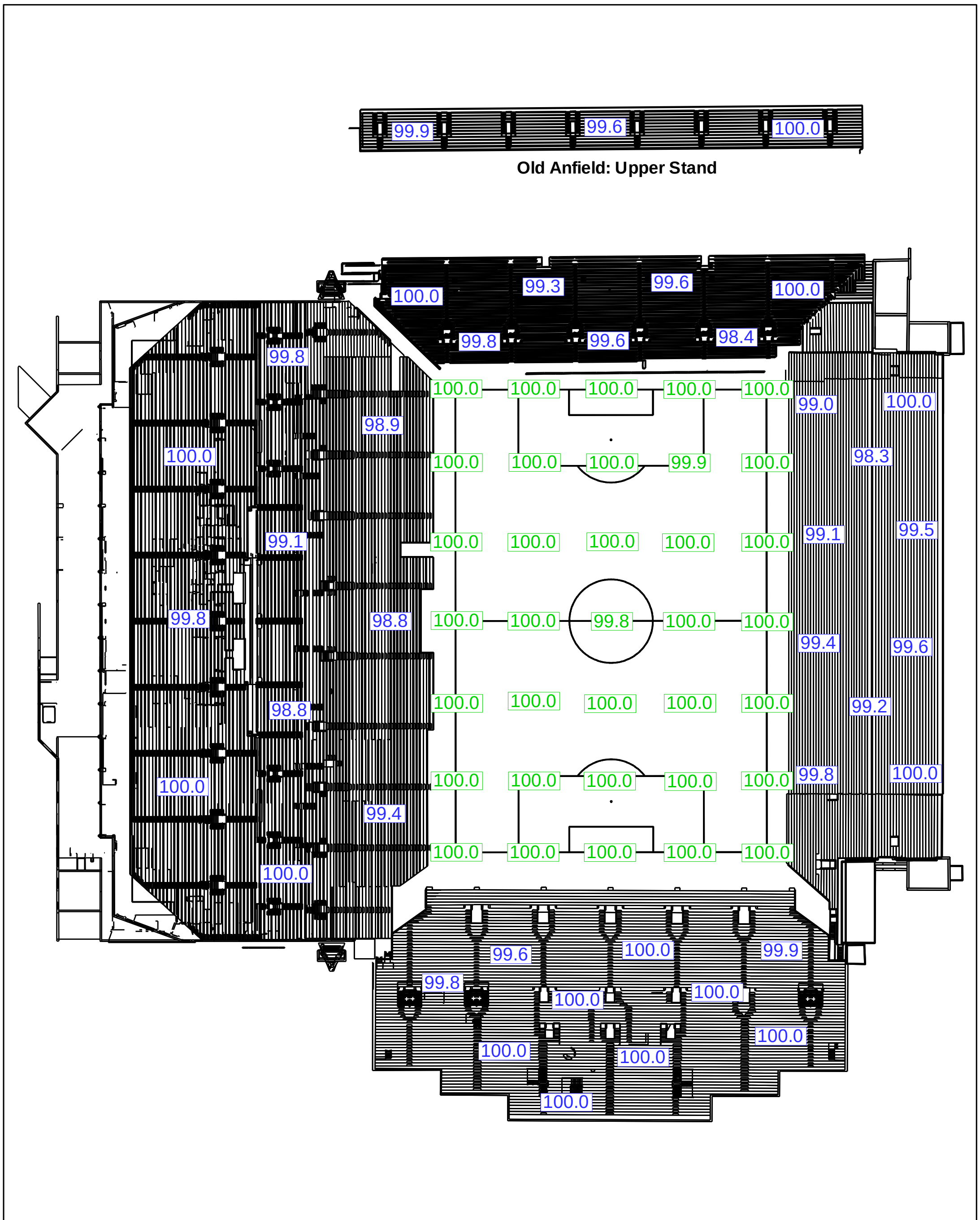
431590 Liverpool Stadium - Internal Condition - Phase 2 Spring Comfort and Safety Ratings	Status : Preliminary	Drawing No : 431590/WE/14	Prep : C. Dauge Date : 31 Mar 2014

Figure D.2.a - Pitch and Spectator Tiers Wind Environment – Summer Comfort and Safety Ratings – Existing Configuration



431590 Liverpool Stadium - Internal Condition - Existing Summer Comfort and Safety Ratings	Status : Preliminary	Drawing No : 431590/WE/15	Prep : C. Dauge Date : 31 Mar 2014

Figure D.2.b - Pitch and Spectator Tiers Wind Environment – Summer Comfort and Safety Ratings – Phase 1



Spectator and Player Comfort

- Percentages of Time Suitable for Spectators
- Percentages of Time Suitable for Players

Safety

- Unsafe
- Safe

North [0°] East [90°] South [180°] West [270°] Prevailing Sector

BMT Fluid Mechanics

431590 Liverpool Stadium - Internal Condition - Phase 1 Summer Comfort and Safety Ratings	Status : Preliminary	Drawing No : 431590/WE/15	Prep : C. Dauge Date : 31 Mar 2014

Figure D.2.c - Pitch and Spectator Tiers Wind Environment – Summer Comfort and Safety Ratings – Phase 2

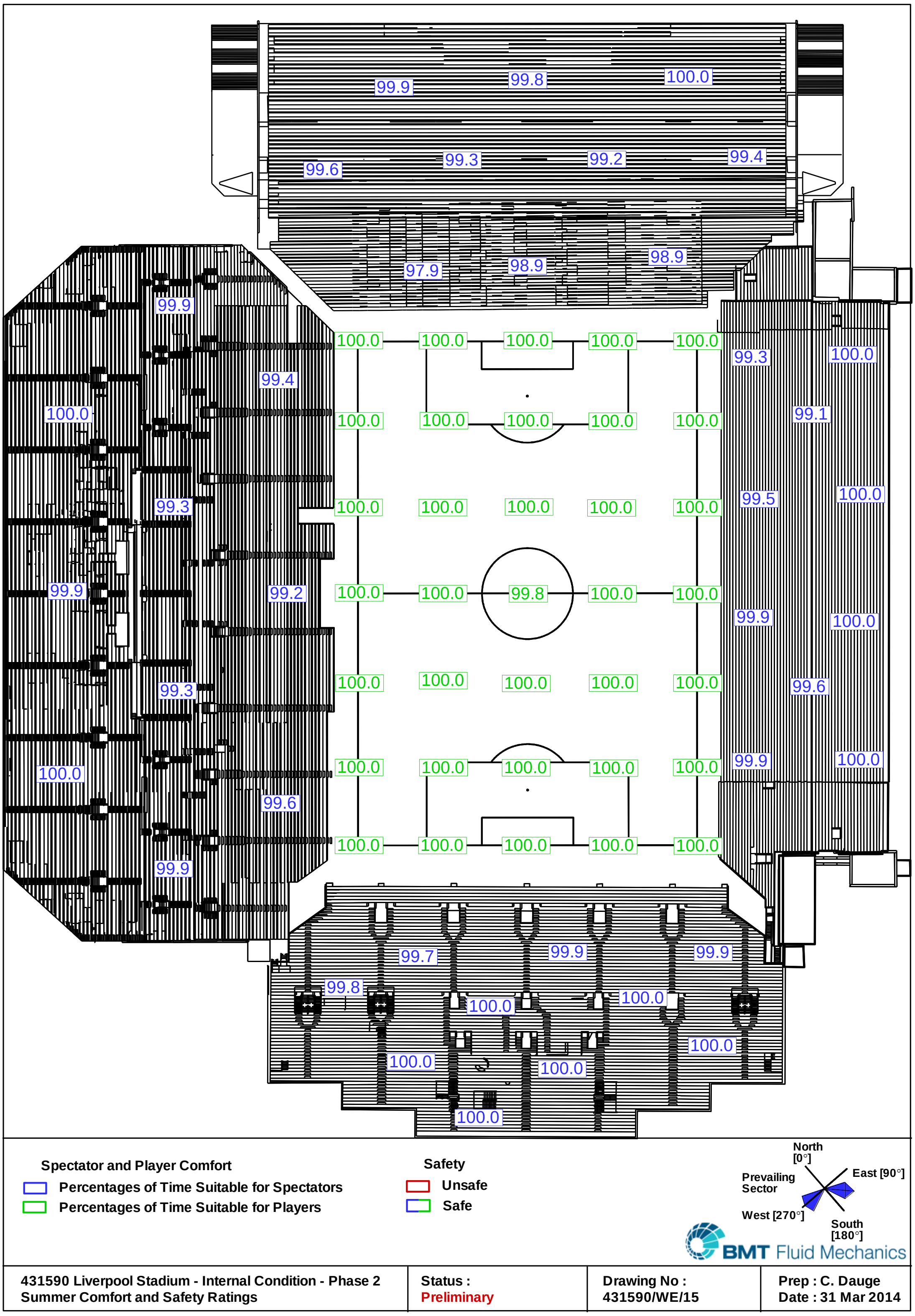
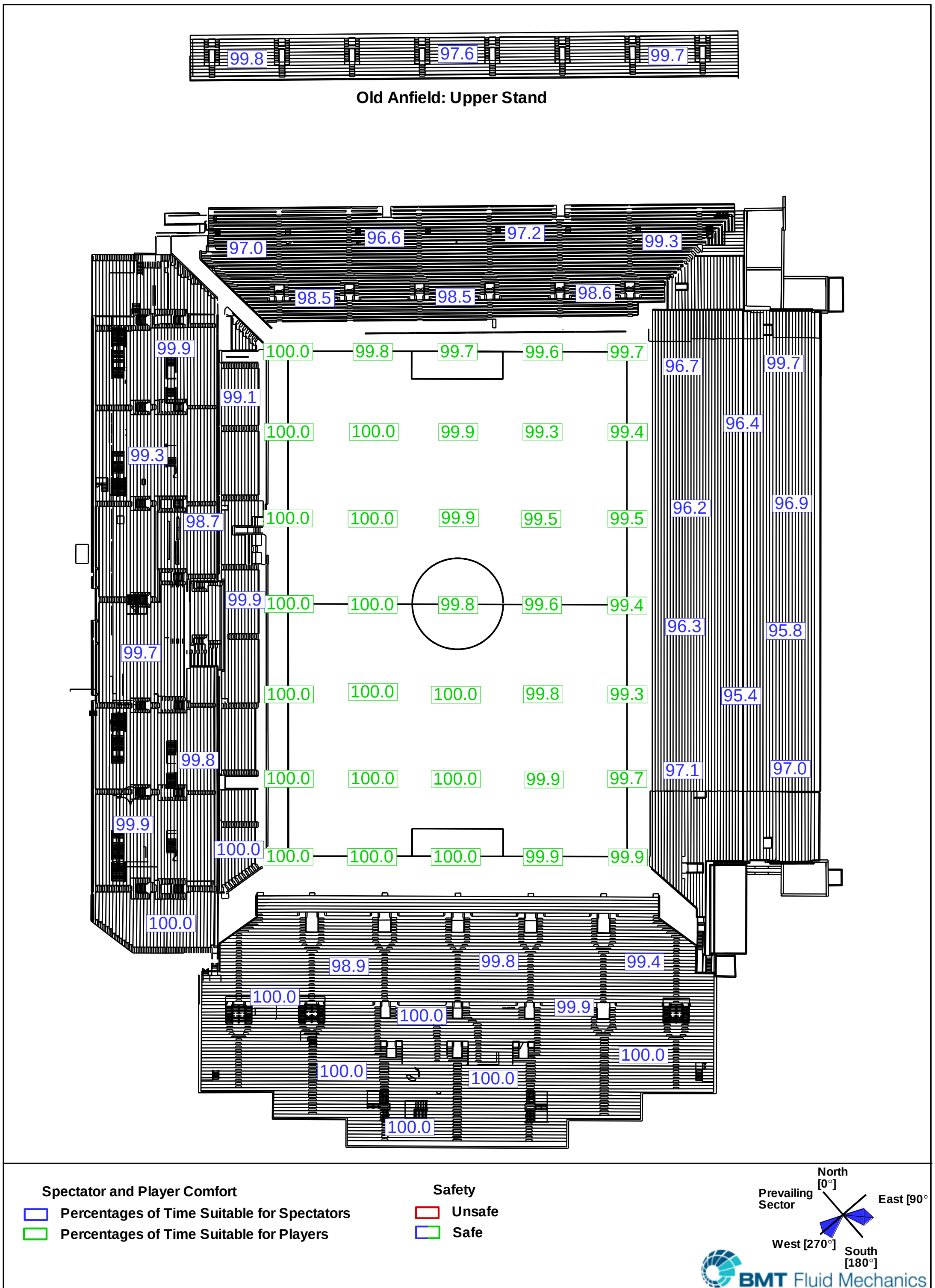
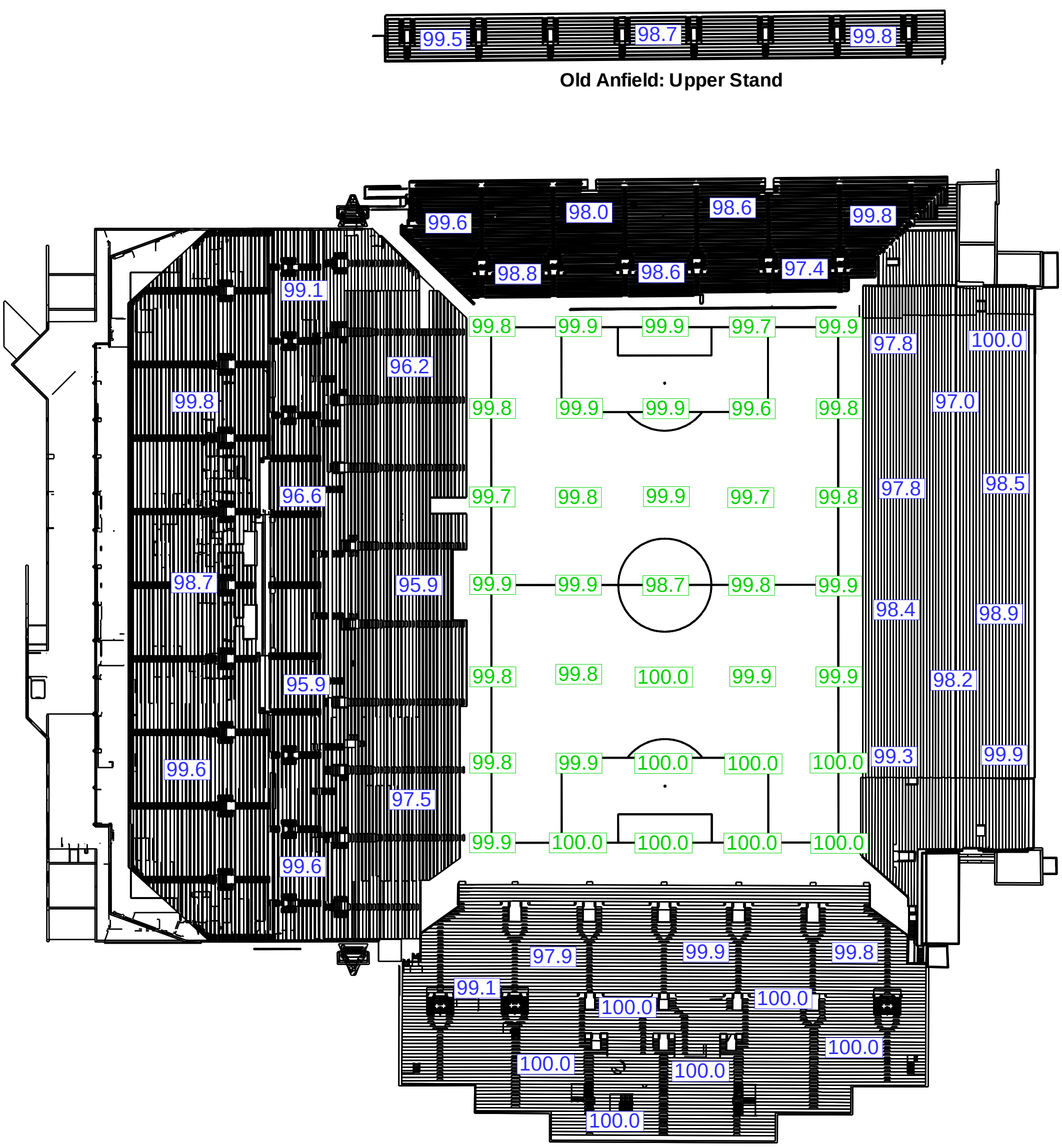


Figure D.3.a - Pitch and Spectator Tiers Wind Environment – Autumn Comfort and Safety Ratings – Existing Configuration



431590 Liverpool Stadium - Internal Condition - Existing Autumn Comfort and Safety Ratings	Status : Preliminary	Drawing No : 431590/WE/12	Prep : C. Dauge Date : 31 Mar 2014

Figure D.3.b - Pitch and Spectator Tiers Wind Environment – Autumn Comfort and Safety Ratings – Phase 1

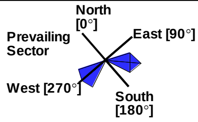


Spectator and Player Comfort

- Percentages of Time Suitable for Spectators
- Percentages of Time Suitable for Players

Safety

- Unsafe
- Safe



BMT Fluid Mechanics

431590 Liverpool Stadium - Internal Condition - Phase 1 Autumn Comfort and Safety Ratings	Status : Preliminary	Drawing No : 431590/WE/12	Prep : C. Dauge Date : 31 Mar 2014

Figure D.3.c - Pitch and Spectator Tiers Wind Environment – Autumn Comfort and Safety Ratings – Phase 2

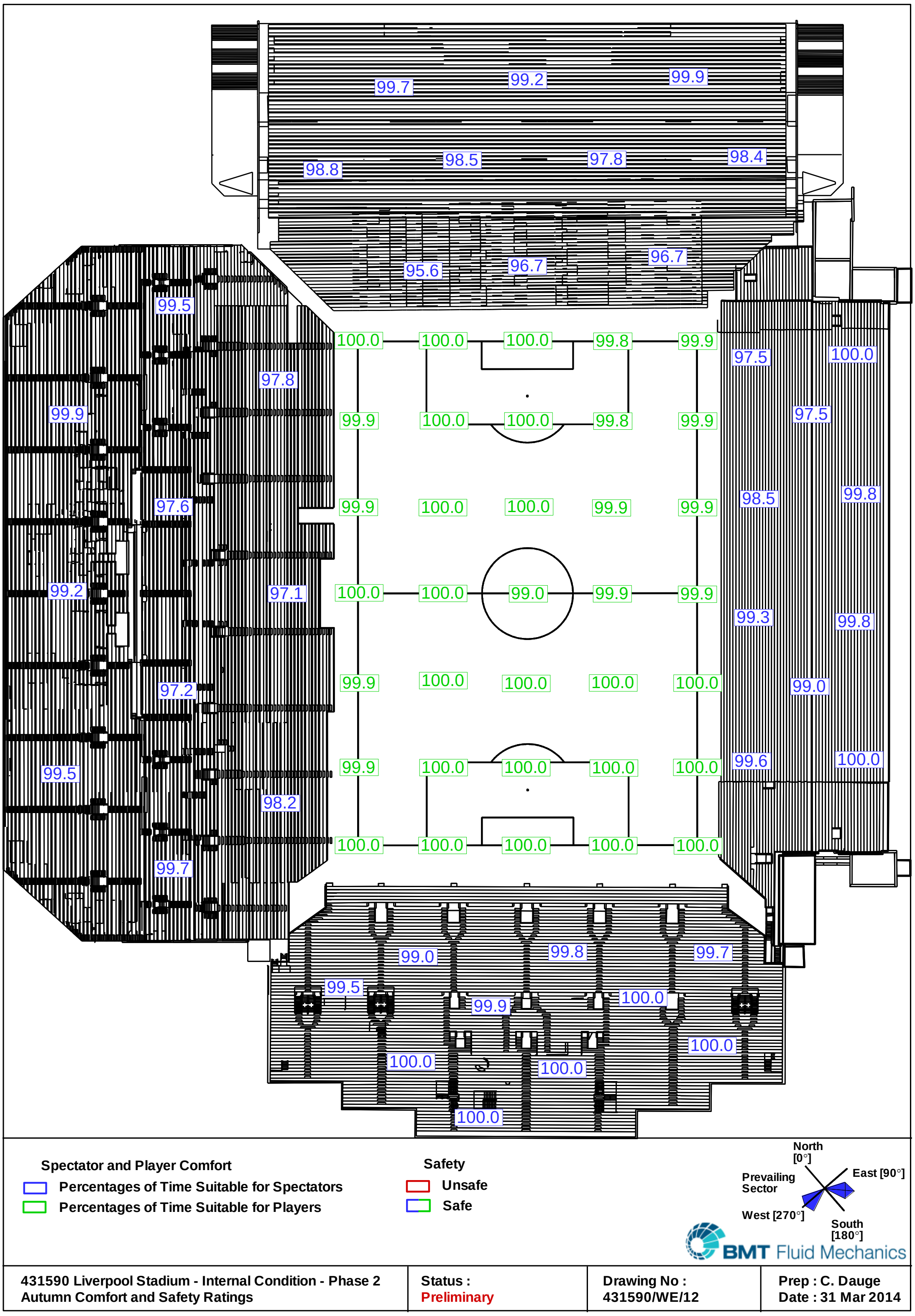
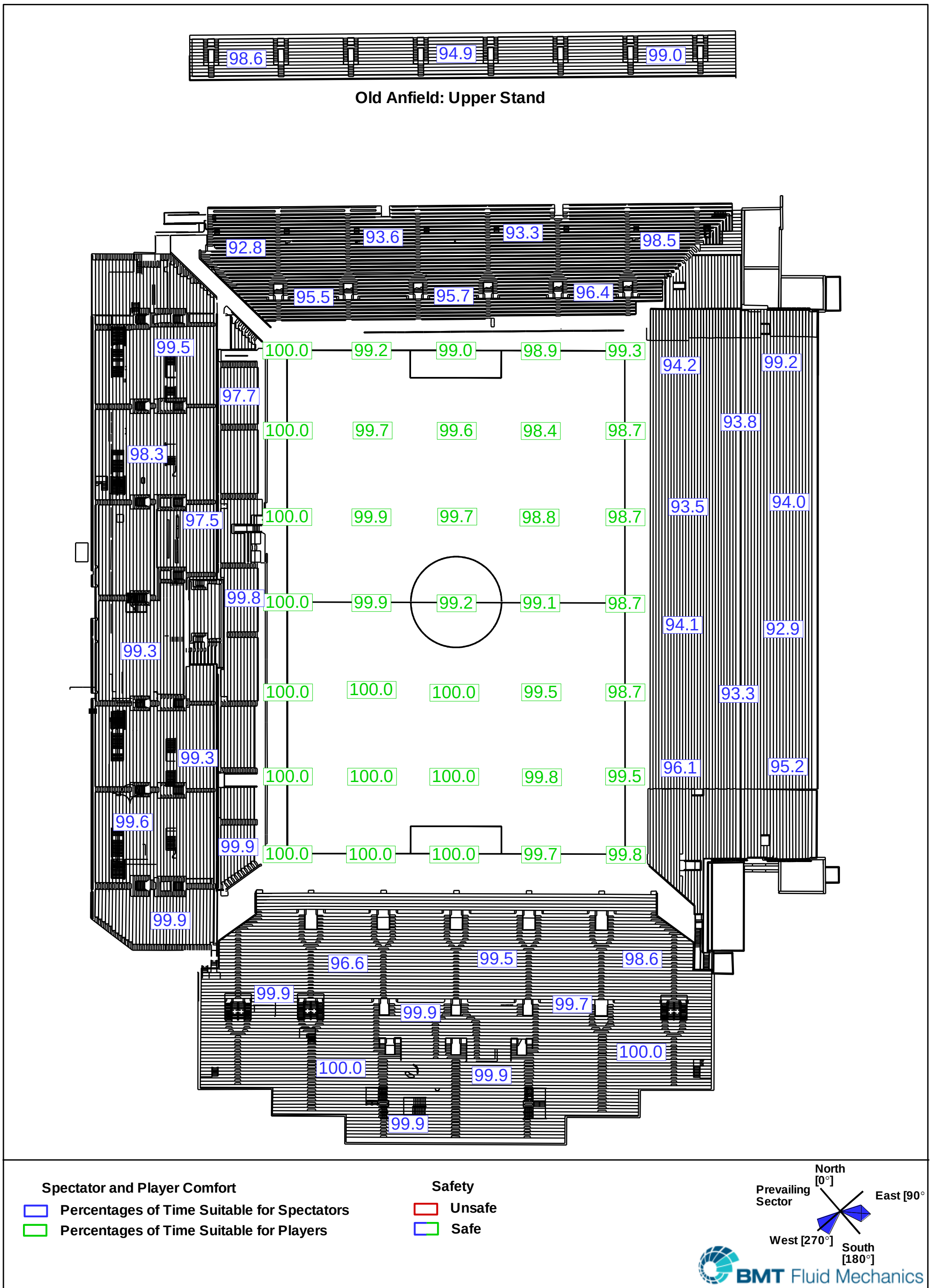
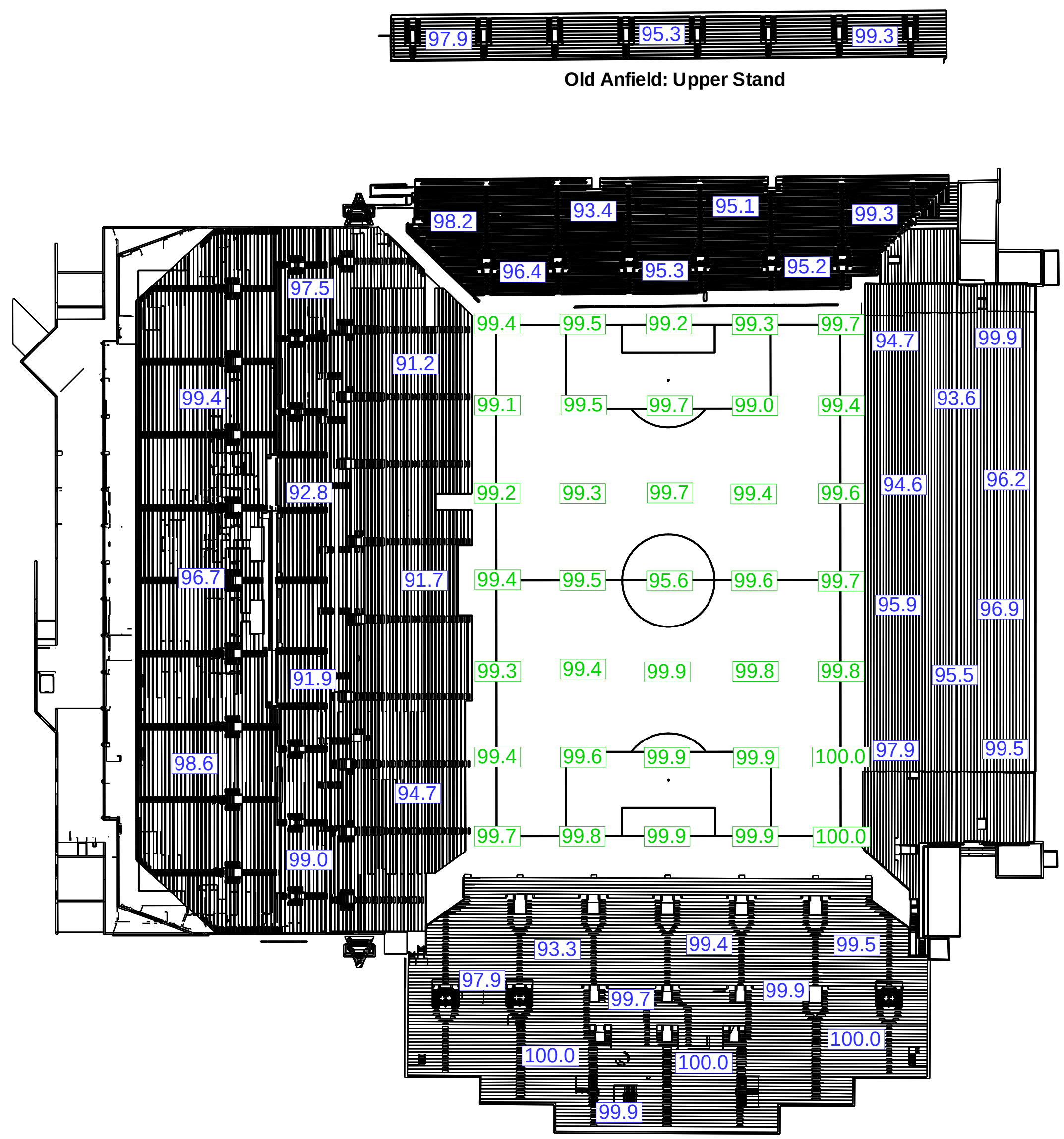


Figure D.4.a - Pitch and Spectator Tiers Wind Environment – Winter Comfort and Safety Ratings – Existing Configuration



431590 Liverpool Stadium - Internal Condition - Existing Winter Comfort and Safety Ratings	Status : Preliminary	Drawing No : 431590/WE/13	Prep : C. Dauge Date : 31 Mar 2014

Figure D.4.b - Pitch and Spectator Tiers Wind Environment – Winter Comfort and Safety Ratings – Phase 1



Spectator and Player Comfort
- Percentages of Time Suitable for Spectators
- Percentages of Time Suitable for Players

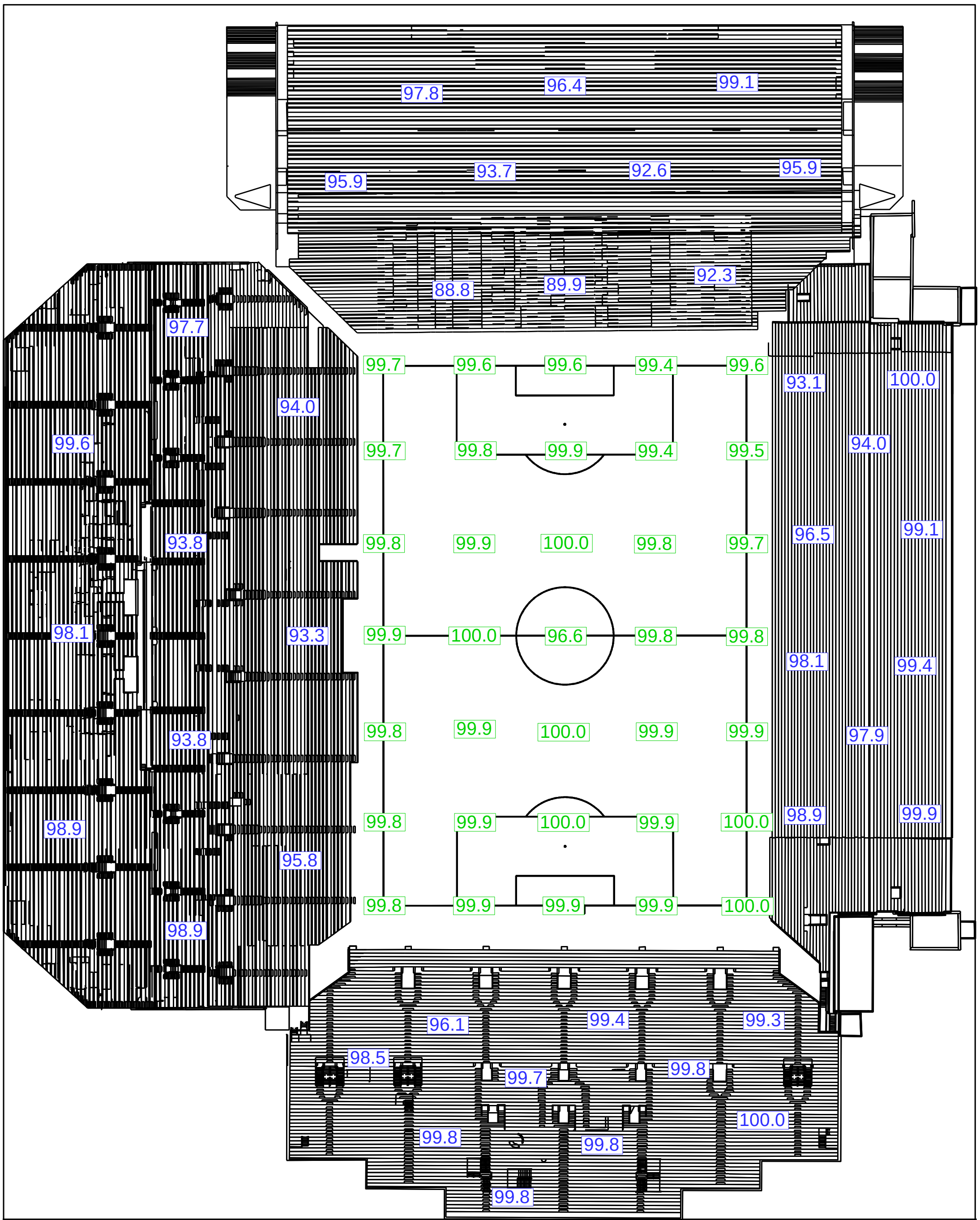
Safety
- Unsafe
- Safe

North [0°]
Prevailing Sector
East [90°]
West [270°]
South [180°]

BMT Fluid Mechanics

431590 Liverpool Stadium - Internal Condition - Phase 1 Winter Comfort and Safety Ratings	Status : Preliminary	Drawing No : 431590/WE/13	Prep : C. Dauge Date : 31 Mar 2014

Figure D.4.c - Pitch and Spectator Tiers Wind Environment – Winter Comfort and Safety Ratings – Phase 2



Spectator and Player Comfort

- Percentages of Time Suitable for Spectators
- Percentages of Time Suitable for Players

Safety

- Unsafe
- Safe

North [0°]
East [90°]
South [180°]
West [270°]
Prevailing Sector

BMT Fluid Mechanics

431590 Liverpool Stadium - Internal Condition - Phase 2 Winter Comfort and Safety Ratings	Status : Preliminary	Drawing No : 431590/WE/13	Prep : C. Dauge Date : 31 Mar 2014