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MARO DEVELOPMENTS LTD

BRUNSWICK QUAY

WIND MICROCLIMATE ASSESSMENT

JULY 2018

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BRUNSWICK QUAY

WIND MICROCLIMATE ASSESSMENT

JULY 2018

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1 INTRODUCTION

1.1 Terms of Reference

1.1.1 WA was commissioned on behalf of Maro Developments Ltd, to undertake a Wind Microclimate Assessment (also called a pedestrian wind comfort assessment) of a proposed development scheme at the Brunswick Quay site in Liverpool, grid reference: 334708 388177.

1.1.2 This report has been produced with reference to current guidelines for pedestrian wind impact assessments, in particular the Commercial Quarter SPD (2006) and the City of London planning advice note 'Wind effects and tall buildings' dated July 2017.

1.1.3 The purpose of the Wind Microclimate Assessment is to satisfy the requirements of the National Planning Policy Framework and local planning policy as given in the Commercial Quarter SPD (2006). The National Planning Policy Framework (NPPF) sets out the Governments planning policies for England and how they are to be applied. The NPPF establishes a presumption in favour of sustainable development and seeks to establish streetscapes and buildings that are attractive and comfortable places to live, work and visit.

1.1.4 This assessment utilises Computational Fluid Dynamics (CFD) to model wind flows around the site and the buildings within approx. 500m of the site centre.

1.1.5 Mitigation and enhancement opportunities are also discussed, where appropriate.

1.2 Site Context

1.2.1 The site lies to the south of Liverpool City Centre, on the bank of the River Mersey. The Quay forms part of the southern edge of Brunswick Dock, and its primary road access is from Sefton Street, via Brunswick Way and Atlantic Way.

1.2.2 For the purposes of this report, 'The Site' refers to the area indicated within the red line development boundary, as approximately depicted in Figure 1.1, below.

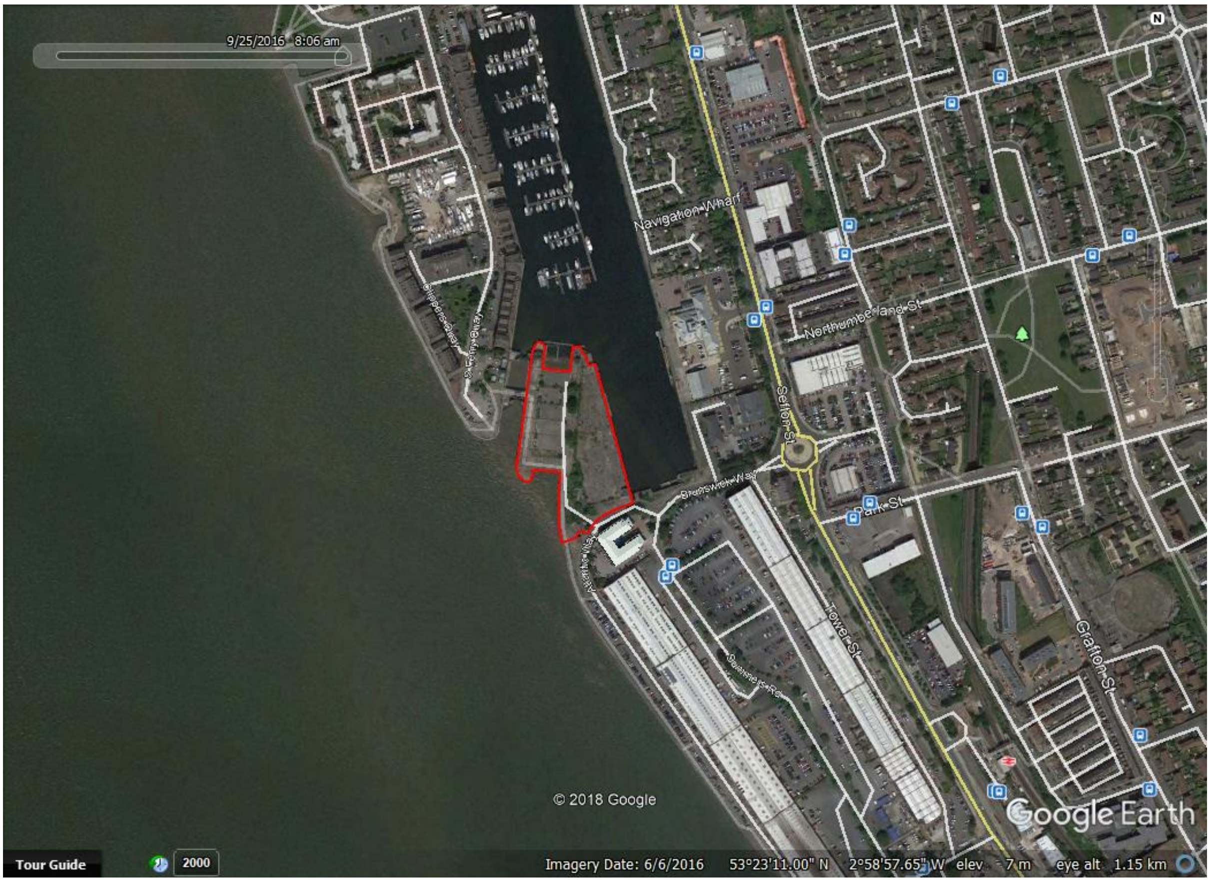


Figure 1.1: Approximate Site Boundary Overlaid on Aerial Imagery

(© 2018 Google)

1.3 Scope of Study

1.3.1 Simulations of the wind microclimate around the area of the proposed buildings were conducted to quantitively assess the effect on pedestrian comfort levels in and around the site.

1.3.2 This study aims to produce a model of the macro level wind regime around the buildings at Brunswick Quay site. The assessment was undertaken using computational fluid dynamics (CFD) techniques to model a 'virtual wind tunnel' and simulate conditions around the site. This report contains the methodology involved and results from these simulations.

1.3.3 Predicted wind speeds will be assessed against the Lawson Comfort Criteria and the proposed types of use planned for the various external areas of the site within the redline boundary.

1.3.4 The purpose of this report is to demonstrate acceptable wind conditions as a result of the proposed development only.

2 POLICY CONTEXT

2.1.1 This section outlines relevant legislation and policy related to pedestrian wind comfort.

2.2 National Planning Policy

2.2.1 There is no specific national legislation or policy in the National Planning Policy Framework dealing with microclimate. In general, there is little guidance at national level on wind effects. The National Planning Practice Guidance (NPPF) published online in March 2014 and establishes a presumption in favour of sustainable development. It seeks to establish streetscapes and buildings that are attractive and comfortable places to live, work and visit.

2.2.2 Paragraph 4.6(vi) of Historic England (previously English Heritage) Commission for Architecture and the Built Environment Guidance on Tall Buildings recommends that consideration be given to: *"The effect on the local environment, including microclimate, overshadowing and night time appearance, vehicle movements and the environment and those in the vicinity of the building."*

2.3 Local Planning Policy

2.3.1 The Unitary Development Plan (UDP) will gradually be replaced when the Liverpool Local Plan is adopted and until this time the UDP policies will still be used to determine planning applications. The Draft Local Plan is in the process of adoption.

2.3.2 Relevant policy on tall buildings is given in the Commercial Quarter SPD (2006). The Commercial District of the City Centre is identified as an area in which the development of tall buildings will be supported. The guidance emphasises the requirement that proposals for such development must be appropriate to their townscape context. They must also take account of potential impact on the local environment, in relation to micro-climate, external appearance, movement and access, etc.

2.3.3 Although not directly relevant, reference is also made to the City of London planning advice note 'Wind effects and tall buildings' dated July 2017 as this provides some of the most up to date guidance on urban wind modelling in the UK (see Appendix 1).

3 ASSESSMENT METHODOLOGY

3.1.1 To identify the likely effect of the proposed development on the pedestrian level wind environment, a 3D CFD model of the development and surrounding site was created. This section describes the methodology for the creation of this model and the inputs used.

3.1.2 Wind directions always indicate the direction that the wind blows from. For instance, a wind direction of 90 degrees denotes a wind blowing from the East.

3.2 Computational Fluid Dynamics

3.2.1 Simulations of the microclimate were conducted using OpenFOAM CFD software. CFD simulation of likely wind patterns requires the generation of a three-dimensional computer model of the site and surrounding buildings.

3.2.2 A 3D model of the buildings and site was provided by the client. This was used, along with a 3D LIDAR model of the surrounding urban area, obtained from Vertex Modelling (Level of Detail 2) to construct a 3D model using a number of 3D modelling packages including Trimble Sketchup and Ansys Spaceclaim.

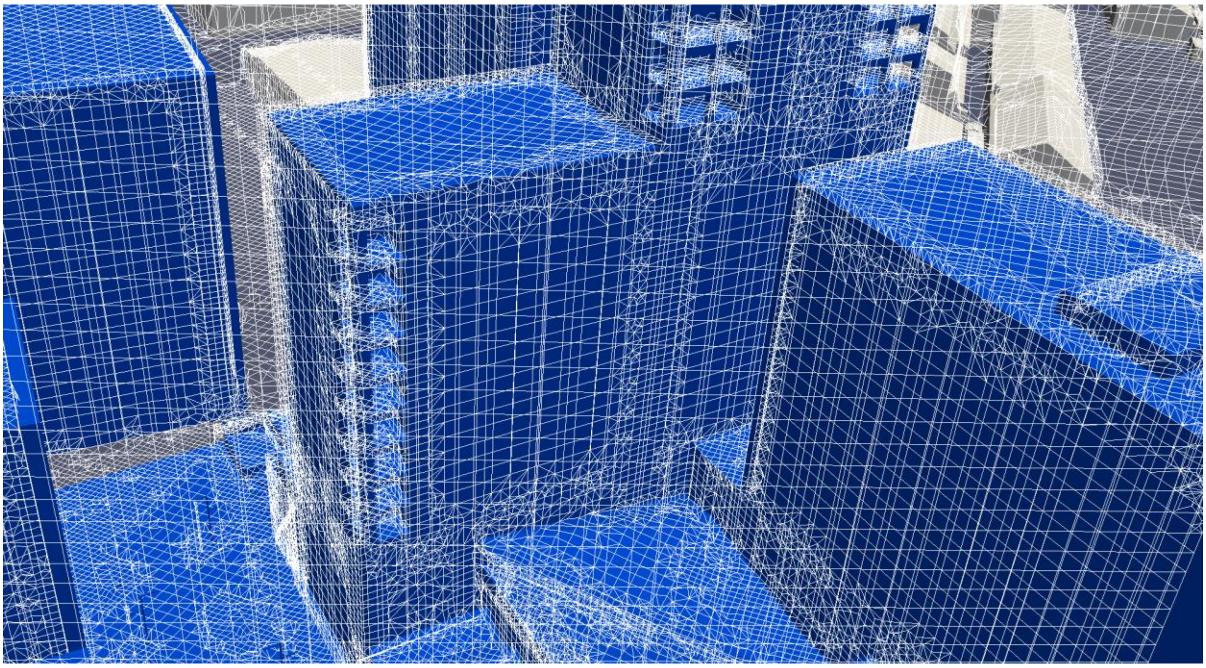


Figure 3.1: Example of Rendering of Mesh used in CFD Model

3.2.3 OpenFOAM CFD software was used to obtain a solution to the fundamental equations of fluid motion as applied to each cell in the model through intensely computational numerical processing. A computational 'mesh' was created to represent the geometry by dividing the domain into a large number of cell volumes. During the simulation, the values of each variable are determined in each cell of the mesh and so a comprehensive assessment of velocity and scalar variation within the calculation domain is obtained.

3.2.4 The dependent variables are as follows:

- Velocities in the three co-ordinate directions (X, Y, Z)
- Pressure (P)

- Turbulence Kinetic Energy (k)
- Turbulence Dissipation Rate (ε)
- Turbulence Specific Dissipation (ω)

3.2.5 To improve the resolution of the results, the mesh was concentrated in the areas of most interest (at pedestrian level around the proposed development) and around any significant small-scale flow features. This ensures greater accuracy of the variables under investigation.

3.3 Boundary Conditions

3.3.1 The modelling domain is circular with inlet and outlet boundary conditions specified for the relevant portions of the domain for the wind direction being modelled.

3.3.2 The inlet boundary condition is adjusted for each wind direction to account for the threshold wind speed for each wind direction at 10m above ground level (see Wind Data Analysis below for further details).

3.3.3 The atmospheric boundary layer (ABL) is also approximated for each wind direction. The atmospheric boundary layer is defined as the part of the atmosphere that is directly influenced by the earth's surface. Surface heating, surface roughness, and especially surface friction are the main actors on the ABL mechanism. The main consequence of this is that the earth continuously extracts momentum from the wind and the resulting flow is turbulent.

3.3.4 The effect of the ABL is approximated within OpenFOAM using the following equation:

$$U = \left[\frac{U^*}{K}\right] * ln\left[\frac{z - z_{Ground} + z_0}{z_0}\right]$$

Where: U^* is the frictional velocity;
K is Karman's Constant;
z_0 is the surface roughness length;
z is the vertical coordinate; and,
z_{Ground} is the minimum coordinate value in z-direction.

3.4 Building and Terrain Surfaces

3.4.1 No-slip wall functions for wind speed were applied to both the terrain and building surfaces as part of the modelling process. For the purposes of modelling porous structures and vegetation have been excluded but will be discussed as part of any mitigation strategy should one be required.

3.5 **Assessment Criteria**

3.5.1 The Town and Country Planning (Environmental Impact Assessment) Regulations 2011 (as amended) require the applicant to provide a 'description by the applicant or appellant of the forecasting methods used to assess the effects on the environment.' The methods used to interpret the results of the modelling, detailed above, and to forecast potential effects on the environment are detailed below.

3.5.2 This report is intended to assess the effects of changes in wind microclimate on pedestrian activities within and around the proposed development. The wind model covers an area that extends to 500m radius from the proposed development in order to capture all upstream and downstream effects although in reality the area of influence of the development on wind microclimate is unlikely to extend beyond 100m from the development boundary. The full computational domain is shown in Figure 3.2, below.

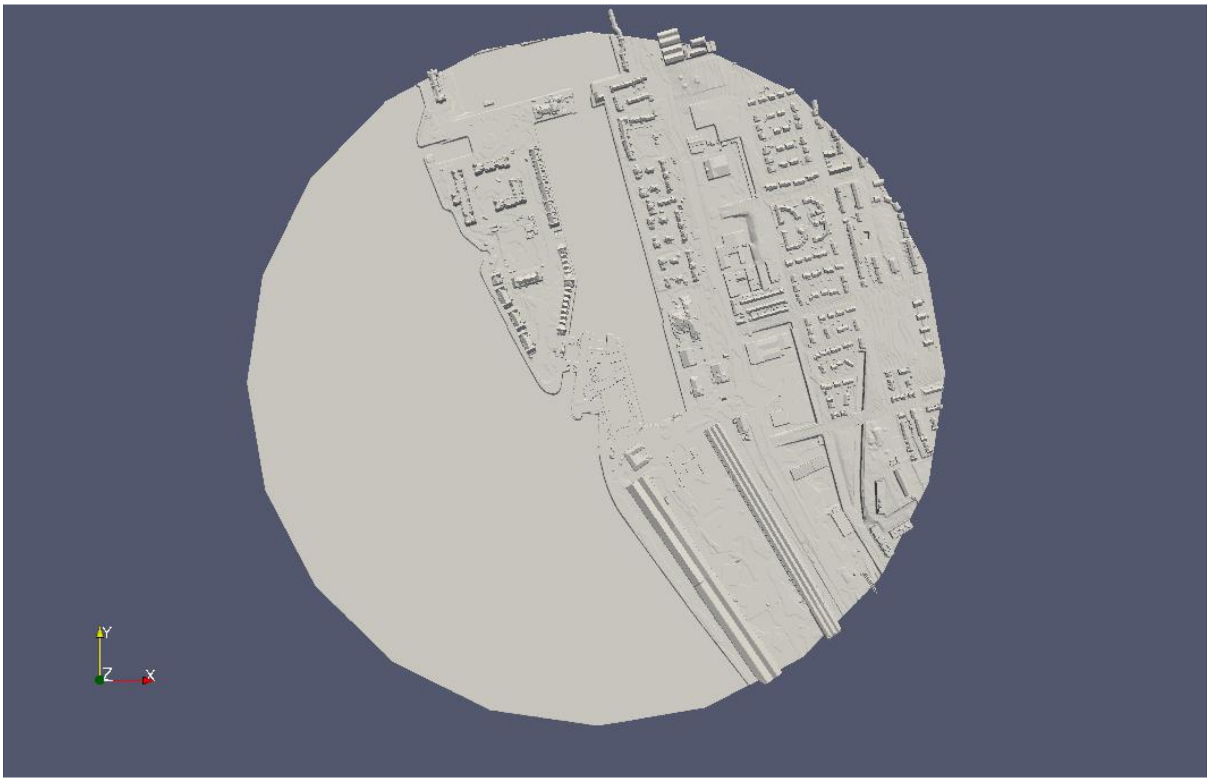


Figure 3.2: The CFD Modelling Domain

3.5.3 As such the receptors considered within this chapter are pedestrians carrying out their usual activities within the area of wind influence of the proposed development. These activities are broken down into categories as per the Lawson Criteria.

3.5.4 The Lawson Criteria provide threshold wind speeds which should not be exceeded 95% of the time for given pedestrian activities to be carried out comfortably. This report uses the London Docklands Development Corporation (LDDC) version of the criteria as outlined in the City of London planning advice note are used in this report and reproduced in Table 3.1, below.

Table 3.1: Lawsons LDDC Criteria - Comfort

Comfort Category	Threshold (m/s)	Description
Sitting	0-4	Light breezes desired for outdoor restaurants and seating areas where one can read a paper or sit for long periods.
Standing	4-6	Gentle breezes acceptable for main building entrances, pickup/drop-off points and bus stops.
Strolling	6-8	Breezes that would be appropriate for window shopping and strolling along a city/town centre street, plaza or park.
Business Walking	8-10	High speeds that can be tolerated if one's only objective is to walk, run or cycle without lingering
Uncomfortable	>10	Winds of this magnitude are considered a nuisance for most activities, and wind mitigation is required

3.5.5 In addition, a safety threshold is set for the wind speed exceeded once per year or 0.022% of the time from any wind direction (see Table 3.2).

Table 3.2: Lawsons LDDC Criteria - Safety

Comfort Category	Threshold (m/s)	Description
Unsafe	>15	Winds above this threshold will pose safety risks, particularly for more vulnerable pedestrians (elderly, cyclists, etc.)

3.6 Site Conditions

3.6.1 The Brunswick Quay site lies to the south of Liverpool City Centre, on the bank of the River Mersey. The Quay forms part of the southern edge of Brunswick Dock, and its primary road access is from Sefton Street, via Brunswick Way and Atlantic Way. Foot access to Clippers Quay is possible via the bridge at the lock gates and approach by water would also be possible to Brunswick Quay itself.

3.6.2 The area can be described as urban industrial in character with operational docklands to the north, light commercial/retail space to the south, the River Mersey to the west and the residential area of Toxteth beyond the dock to the east. Although the site itself is currently vacant there are a number of other buildings in relatively close proximity and one building immediately to the south which has received planning consent but has not yet completed construction. This will lead to a relatively complex wind environment with a highly variable degree of surface roughness.

3.7 Wind Data Analysis

3.7.1 Wind microclimate studies require that observational wind speed data, obtained from a reliable reference station, be transposed to the site of interest to understand the expected wind regime at that site.

3.7.2 Typically, historical wind speed data, accrued by meteorological weather stations such as the UK Met Office is acquired and refined into the required format. In this instance a series of wind speed frequency distributions (one for each 10° wind direction) is derived from the observations of minute-average wind speeds at the Crosby Met Station between 2008 and 2018. Frequency distributions are divided across 0.5m/s bins (see Table 3.3), and the probability of occurrence for each wind speed bin is established for each direction.

3.7.3 The wind speed probability density function is plotted for each direction and this allows a Weibull distribution to be fitted to each curve, after solving for the shape and scale factors (k and c respectively).

3.7.4 From the Weibull probability density function, for a given wind direction, the probability, p, of seeing a wind speed in a particular 0.5m/s wind speed bin is given by:

$$p = \frac{\frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right]}{2}$$

Where: v is the wind bin velocity (m/s),
c is the scale parameter (m/s); and,
k is the shape parameter.

3.7.5 In addition to these parameters, the probability, P, of each wind direction occurring may be calculated. Thus, the probability that a specified wind speed is exceeded for a specified wind direction may be calculated.

Row Labels	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	Grand Total
0			1	2	4	2	3	2	12	7	4	5	8	5	9	2		2	2	1			1	1	6	1	8	11	5	5	6	8	7	2	4		136
0.5	8	9	8	3	7	9	11	16	17	19	23	33	20	18	19	18	22	17	17	20	23	21	19	18	14	15	23	18	5	7	8	8	7	2	5	7	514
1	7	11	13	27	28	48	54	65	54	88	86	85	79	68	45	67	35	55	59	44	42	43	55	37	45	30	48	36	45	31	20	25	7	16	5	6	1509
1.5	12	26	39	67	114	158	155	188	186	217	236	200	171	112	113	89	70	68	74	76	57	74	66	67	74	68	65	62	80	86	74	62	46	29	12	12	3305
2	21	28	77	143	192	228	297	316	305	286	344	343	258	227	153	119	107	89	96	72	74	72	71	62	67	65	70	84	104	115	89	97	64	51	29	28	4843
2.5	16	45	108	169	247	282	285	292	272	290	321	396	373	299	189	177	157	128	134	99	82	66	74	99	99	85	78	109	131	143	130	123	90	59	65	34	5746
3	20	49	105	160	187	240	174	187	228	225	250	362	381	315	192	203	259	184	148	111	76	78	57	88	99	62	81	128	151	192	159	151	101	73	65	38	5579
3.5	20	75	118	109	136	133	127	144	179	194	209	321	344	356	272	319	329	176	180	112	95	106	73	103	92	62	89	124	145	186	203	182	132	88	81	51	5665
4	13	70	76	79	83	73	93	109	154	160	165	232	304	301	273	385	371	173	161	116	87	93	74	87	92	72	100	127	176	182	210	184	115	95	70	47	5202
4.5	10	54	59	66	74	61	86	91	142	123	120	153	239	248	253	398	443	190	131	125	138	140	119	114	122	97	94	157	167	224	210	198	136	95	74	45	5196
5	11	37	52	42	47	48	74	78	90	97	73	124	167	198	268	400	405	189	187	125	136	142	97	117	109	107	135	141	177	193	193	197	167	103	72	52	4850
5.5	14	35	35	26	41	42	46	84	88	59	69	104	137	157	228	415	395	178	138	139	154	162	148	125	147	149	165	174	197	229	206	199	157	99	62	43	4846
6	16	26	18	20	20	37	47	54	60	42	50	61	112	114	173	344	330	125	115	116	160	187	136	137	128	154	161	218	216	230	180	173	142	116	73	43	4334
6.5	7	26	7	10	25	30	36	57	56	28	25	43	81	83	174	334	319	138	109	110	156	174	174	132	137	133	184	220	217	244	172	141	133	81	63	37	4096
7	8	19	7	7	8	38	24	35	27	22	17	29	42	62	140	235	278	85	89	105	128	172	181	165	134	139	214	218	228	208	165	136	121	95	48	27	3656
7.5	7	12	2	4	7	21	29	20	20	7	8	23	31	36	96	198	183	69	74	94	102	176	183	176	139	145	211	252	214	198	161	127	81	84	38	24	3252
8	6	6	3	1	4	15	16	18	10	5	5	9	9	26	57	126	123	47	53	66	102	139	167	171	114	183	200	246	211	197	154	110	62	64	38	19	2782
8.5	5	1	2	1	2	16	13	11	5	3	3		12	25	42	95	88	39	44	68	101	166	180	174	126	180	237	223	195	154	147	90	63	57	34	24	2626
9	1				2	7	7	4	4	1	2		3	11	24	49	39	21	26	36	53	98	129	108	91	96	133	167	175	132	103	85	41	26	15	16	1705
9.5	4				1	8	9	9	2				5	12	21	61	52	12	20	70	65	127	129	119	89	177	252	198	179	124	110	86	78	56	24	11	2110
10	2					6	2	2					2	6	17	31	25	13	24	42	63	91	152	130	84	202	196	194	159	123	97	85	49	42	13	11	1863
10.5					3	3	2							5	10	28	18	8	17	47	58	90	119	100	112	149	172	173	156	110	93	57	44	42	9	4	1629
11	1						3	2						2	7	16	13	6	19	31	44	82	89	79	79	160	170	180	123	114	81	64	43	33	14	3	1458
11.5	1				5			1						1	6	7	11	4	10	33	41	71	87	66	63	141	127	137	145	87	74	45	24	19	5	2	1213
12	4	3		1	1		2							2	1	6	6	6	5	17	31	48	98	85	74	166	128	132	111	75	81	59	37	12	8	2	1201
12.5	1						1									3	1	2	4	14	21	40	67	43	60	116	97	109	97	51	61	32	25	19	11		875
13	3						1									1	4	4	3	11	19	33	66	52	54	114	89	107	101	55	37	25	14	9	4	4	810
13.5																	2	2	5	12	26	26	56	41	50	84	102	106	93	39	29	24	18	6	3	3	727
14																	1	3	6	6	16	29	41	24	62	97	84	94	79	31	37	10	11	3	3		637
14.5																1		1	2	3	5	20	30	15	45	97	61	66	67	29	32	11	8	5	1		499
15																			3	4	7	9	32	15	37	77	53	63	54	25	23	10	6	8	1		427
15.5																				4	4	11	10	16	25	71	43	53	55	19	13	12	5	5	1		347
16																				3	3	2	14	12	31	42	40	42	44	25	9	6	6	2			281
16.5																					5	7	10	9	15	45	39	44	27	22	2	3	5				233
17																					1	5	12	8	10	29	23	38	21	10	5	1					163
17.5																				1	1	7	8	7	14	21	24	25	20	10	3	2	2				145
18																						4	5	6	11	16	13	11	14	5	3	1	2				91
18.5																					1	2	4	2	11	10	12	11	18	8	2		1				82
19																						3	2	2	13	5	12	7	7	2	2	3	1				59
19.5																				1		1	1		6	4	3	7	7	3	2						35
20																						1		1	5	4	7	8		1	1						28
20.5																					1		1		1	2	2		1	1							9
21																						1	1		3	7		1		1							14
21.5																						1	1		2	5	2	4				1					16
22																						1	1	1	1	3	2										9
22.5																							2		1	2	1										6
23																										1	1										2
23.5																							1				2		1	1							5
24																							1			2		1									4
26																									1												1
27																									1												1
Grand Total	218	532	730	937	1238	1505	1597	1785	1911	1873	2010	2523	2778	2689	2782	4127	4086	2034	1955	1934	2178	2821	3044	2814	2795	3692	4053	4526	4418	3927	3387	2833	2051	1496	950	593	84822

Table 3.3: Raw data from the Reference Meteorological Station

3.7.6 A transposition function is then applied to the wind data observed at the reference station to convert it to be appropriate at the site, accounting for the surface roughness effects across the intervening terrain.

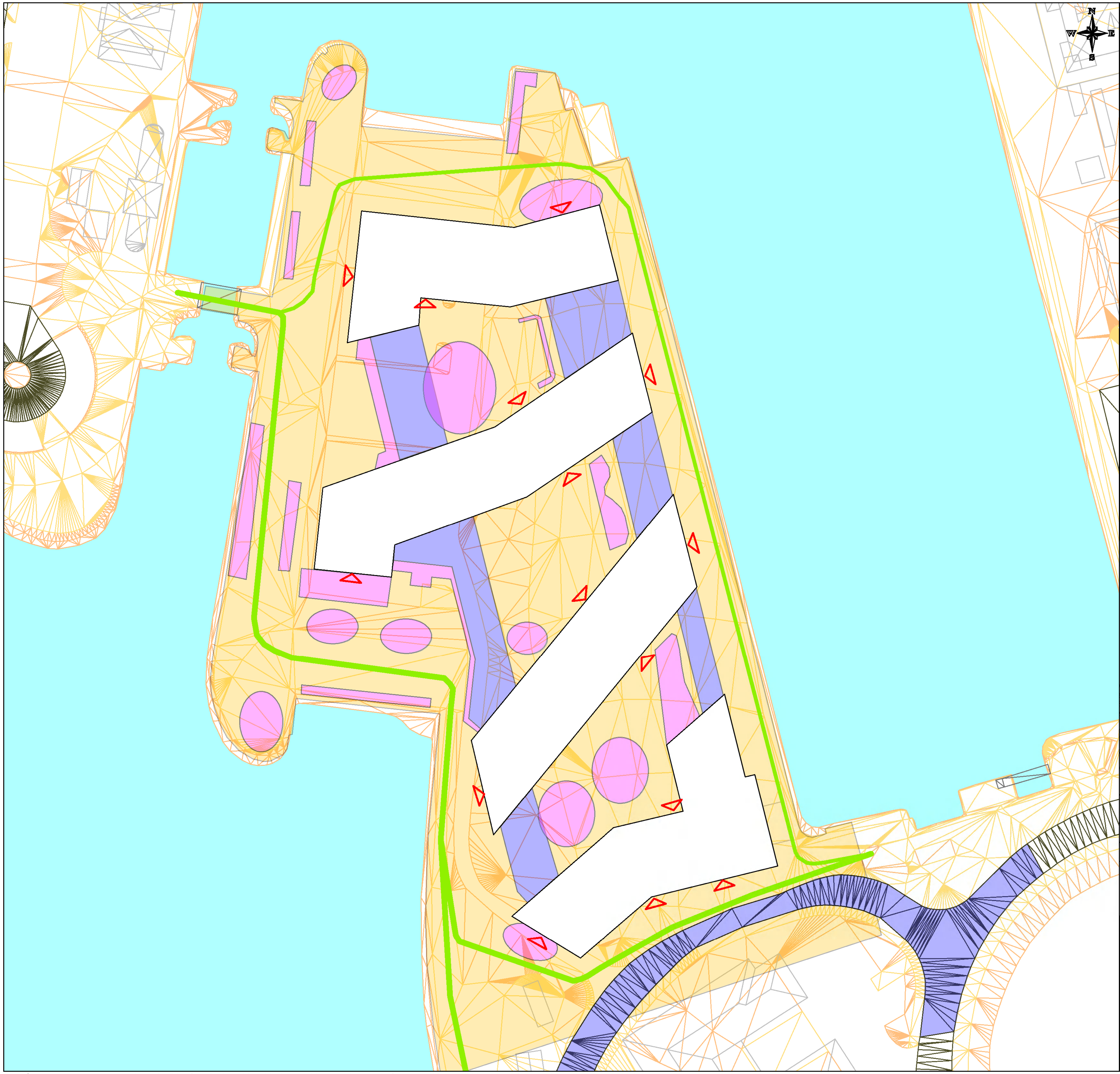
3.7.7 Values of P, c and k for the Crosby Meteorological Station for each direction, as used in the wind assessment calculation are given in Table 3.4. The data count displays the number of samples in each 10° bin.

Table 3.4: Weibull Factors

Reference Station				DataCount
Direction	Probability	Scale (c)	Shape (k)	
0	0.26%	5.23	1.73	218
10	0.63%	4.65	2.45	532
20	0.86%	3.89	2.67	730
30	1.10%	3.59	2.44	937
40	1.46%	3.61	1.99	1,238
50	1.77%	3.76	1.79	1,505
60	1.88%	3.79	1.76	1,597
70	2.10%	3.81	1.87	1,785
80	2.25%	3.79	2.10	1,911
90	2.21%	3.51	2.18	1,873
100	2.37%	3.44	2.16	2,010
110	2.97%	3.69	2.32	2,523
120	3.28%	4.09	2.40	2,778
130	3.17%	4.45	2.30	2,689
140	3.28%	5.26	2.43	2,782
150	4.87%	5.87	2.74	4,127
160	4.82%	5.84	2.81	4,086
170	2.40%	5.37	2.27	2,034
180	2.30%	5.57	2.03	1,955
190	2.28%	6.61	2.02	1,934
200	2.57%	7.30	2.15	2,178
210	3.33%	8.07	2.25	2,821
220	3.59%	8.92	2.32	3,044
230	3.32%	8.43	2.27	2,814
240	3.30%	8.90	1.97	2,795
250	4.35%	10.35	2.42	3,692
260	4.78%	9.75	2.37	4,053
270	5.34%	9.55	2.30	4,526
280	5.21%	9.07	2.16	4,418
290	4.63%	7.93	2.05	3,927
300	3.99%	7.69	2.08	3,387
310	3.34%	7.13	2.04	2,833
320	2.42%	7.11	2.07	2,051
330	1.76%	7.07	2.24	1,496
340	1.12%	6.35	2.19	950
350	0.70%	6.03	2.29	593

3.8 Pedestrian Activity

3.8.1 A plan showing the intended pedestrian uses of the areas on around the proposed development is shown in Figure 3.3. Where an area is to be used for multiple activities the activity with the lowest wind threshold is shown. Table 3.5 explains the pedestrian uses illustrated in Figure 3.3 and identifies the appropriate Lawson's LDDC criteria for each use.



1 : 1,000,000

0 metres 40

1 : 800 @ A3

BNG Ref:	334708 : 388177	OS 100km Grid:	SJ	Landranger Ref:	108
Lat : Long DD	53.3861° : -2.9818°	Lat : Long DMS	53° 23' 10.07'' : -2° 58' 54.46''		

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Drawn By:	S.Allen	Date:	20/06/2018
Checked By:	P.Evans	Date:	21/06/2018

Land Use Classes
Brunswick Quay
Liverpool

LANDUSE_V1_ST16666 | Figure 3.3

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Table 3.5: Legend of Pedestrian Uses & Equivalent LDDC Comfort Categories			
Legend	Description	Equivalent Lawson LDDC Comfort Categories	Threshold
	Seating	Sitting	0-4m/s
△	Entrances to Buildings	Standing	4-6m/s
	Public Spaces	Strolling	6-8m/s
	Around Buildings	Business Walking	8-10m/s
	Roads & Carparks	Business Walking	8-10m/s

3.8.2 Areas outside of the red line boundary and within the wind influence of the proposed development will also be reported on within the results. These areas consist of entrances, public spaces, around buildings and roads & car parks.

3.9 **Limitations and Assumptions**

3.9.1 In common with other forms of assessment such as the use of wind tunnels, there are various limitations to the accuracy of modelling that can be achieved that can be with computational fluid dynamics.

- Similar to wind tunnel testing, CFD modelling is not an exact science and each methodology has advantages and disadvantages;
- Absolute improvements cannot be guaranteed as it is a computational analysis;
- The CFD simulation is steady state and does not explicitly quantify gusting wind; however, a qualitative assessment of gusting will be provided.
- This study was carried out on a 3D model of the design proposal, dated 21st March 2018. The terrain model was obtained from Bluesky International Ltd. Minor variations have been made to the design of the proposal since that date and these will be discussed in context within the results.
- The consented development to the south of the proposed site is not currently available in the purchased terrain dataset. Due to its proximity to the development and its potential influence on localised wind speeds, it has been included by manually adding a model of its proposed design to the purchased dataset. If this building is built out other than in accordance with the plans we have seen then this will potentially affect the results of the CFD modelling.
- The biggest limiting factor, in this instance, has been the magnitude of the input wind speeds

4 BASELINE CONDITIONS

4.1.1 The Brunswick Quay site is currently vacant but it is known that the quay side is used by pedestrians and cyclists commuting along the river bank. To the best of our knowledge there have not been any problems arising from strong wind conditions affecting users of this route to date. It is, however, considered that, the wind speeds in the vicinity will, on occasion, far exceed the comfort thresholds and, quite likely, the safety thresholds as a result of natural wind flow.

4.1.2 The Crosby reference station itself shows wind speeds from some directions at the 95% exceedance level, far in excess of both Lawson's comfort and safety thresholds. This means that the design of the proposed building will not necessarily be responsible for the high wind speeds that the site is likely to exposed to, particularly from a westerly wind direction, but rather these will be symptomatic of its location on a river bank with near coastal wind speeds.

4.1.3 Lawson's criteria were originally designed for use in heavily urban areas. This location is urban to the east but highly exposed to winds travelling across the Irish Channel and over the River Mersey to the west. Whilst every effort will be made to ensure that the relevant thresholds are observed through suitable mitigation, a proportionate approach must be taken, with a degree of acceptance that this is a naturally windy location not the centre of an urban metropolis.

4.1.4 A Lawson LDDC Criteria Assessment is based upon fixed comfort values and not upon a change over the existing baseline but rather on whether an explicit threshold has been breached. To strictly apply the Lawson LDDC Criteria Assessment will require the building design and landscaping to not only not contribute to wind speed up through intelligent design but to actively decelerate the natural wind flow.

4.1.5 In some cases, active deceleration will be possible and indeed, necessary to ensure the safe use of facilities within the proposed development. However, it is also suggested that a pragmatic approach should be adopted in this situation as there are locations currently in use for the same activities as intended to be undertaken once the development is complete, which must have exposure to high winds at certain times. Such activities, particularly on the western boundary of the site, will be almost impossible to fully mitigate without enclosing the quayside completely and it is suggested that, provided safety is maintained at all times, it is more natural to expect a brisk breeze rather than a completely sheltered experience whilst on a quayside.

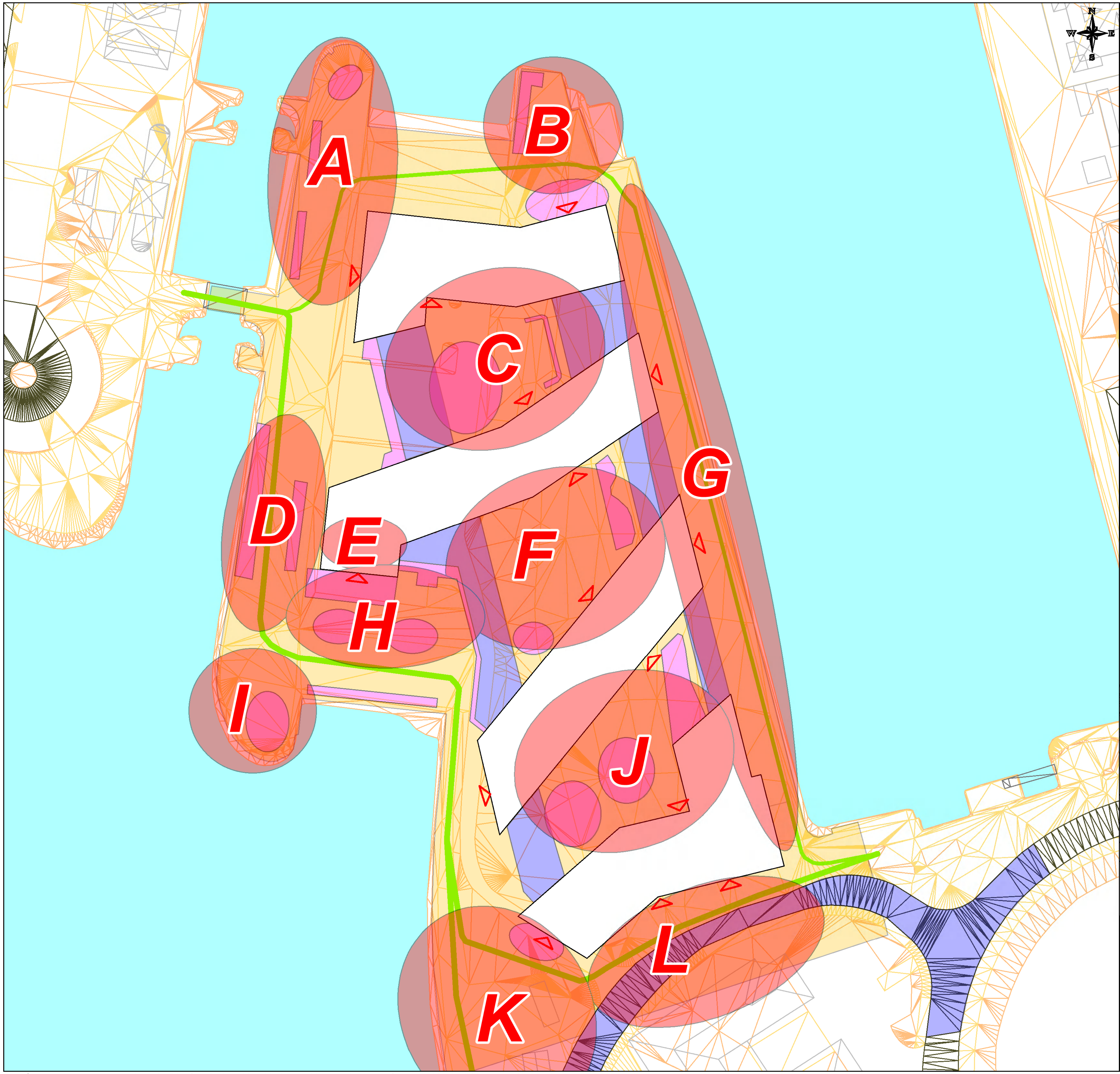
4.1.6 Should it be identified that thresholds outside of the redline boundary have been exceeded then, if it is not clear from the modelling already carried out, further analysis will be undertaken to determine whether or not the problem is caused by the development or not.

5 IDENTIFICATION AND EVALUATION OF EFFECTS

5.1 Introduction

5.1.1 Individual analysis has been undertaken for each of 36 wind directions around the compass, to assess the localised wind microclimate around the proposed development, based on 10^{o} directional approaches.

5.1.2 The detailed results obtained from the modelling of each wind direction are included in Appendix 1. These results have been compared with the proposed use categories for the site as specified by the Lawson LDDC criteria (Figure 3.3). It should be noted that the alphabetic notation used in the analysis below relates to particular locations, as identified on Figure 5.1, where specific effects are expected to manifest, and these effects are further defined in the discussion.



Entrance to Buildings
Building Rooftops
Seating
Public Spaces/Strolling
Business Walking
Roads and Carparks
Areas Of Interest

1 : 1,000,000

0 metres 40

1 : 800
@ A3

BNG Ref: 334708 : 388177	OS 100km Grid: SJ	Landranger Ref: 108
Lat : Long DD 53.3861° : -2.9818°	Lat : Long DMS 53° 23' 10.07'' : -2° 58' 54.46''	

maro developments | wardell armstrong

Wardell Armstrong LLP
Wheal Jane Earth Science Park
Baldhu, Truro, TR3 6EH

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Drawn By: S.Allen	Date: 20/06/2018
Checked By: P.Evans	Date: 21/06/2018

Areas of Interest Where Mitigation Is Expected to be Required Brunswick Quay, Liverpool

AREAS_INT_V1_ST16666 | Figure 3.4

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5.2 Mitigation Measures

5.2.1 The following mitigation measures correspond to the areas A-L identified in Figure 5.1, above.

Area A– Dockside to the NW of the development and Entrance

5.2.2 Area A exceeds the comfort criteria from a number of wind directions and multiple use classes. These are primarily where wind is carried into the site across the river, as shown in Figure 3.4 and Figure 3.5 (example case, with wind approaching from a bearing of 250^{o}). In most these instances wind speeds already exceed the comfort criteria and so the building itself is not causing any additional issues. However, for a number of the directions wind is accelerated around the corner of the northern most block further increasing wind speeds.

5.2.3 In this area we would recommend staggered screens or porous wind breaks similar to those shown in, below. The exact number and spacing of these will need to be developed alongside input from the rivers and harbours commission who own this area of the quayside. It is intended that mitigation would take the form of interpretation signage or artwork and would be constructed from materials that are sympathetic with the overall design language of the development.

5.2.4 We would also recommend that seating is not included in this area and that further screening is implemented around the entrance or a revolving door is utilised to improve safety in high wind conditions.

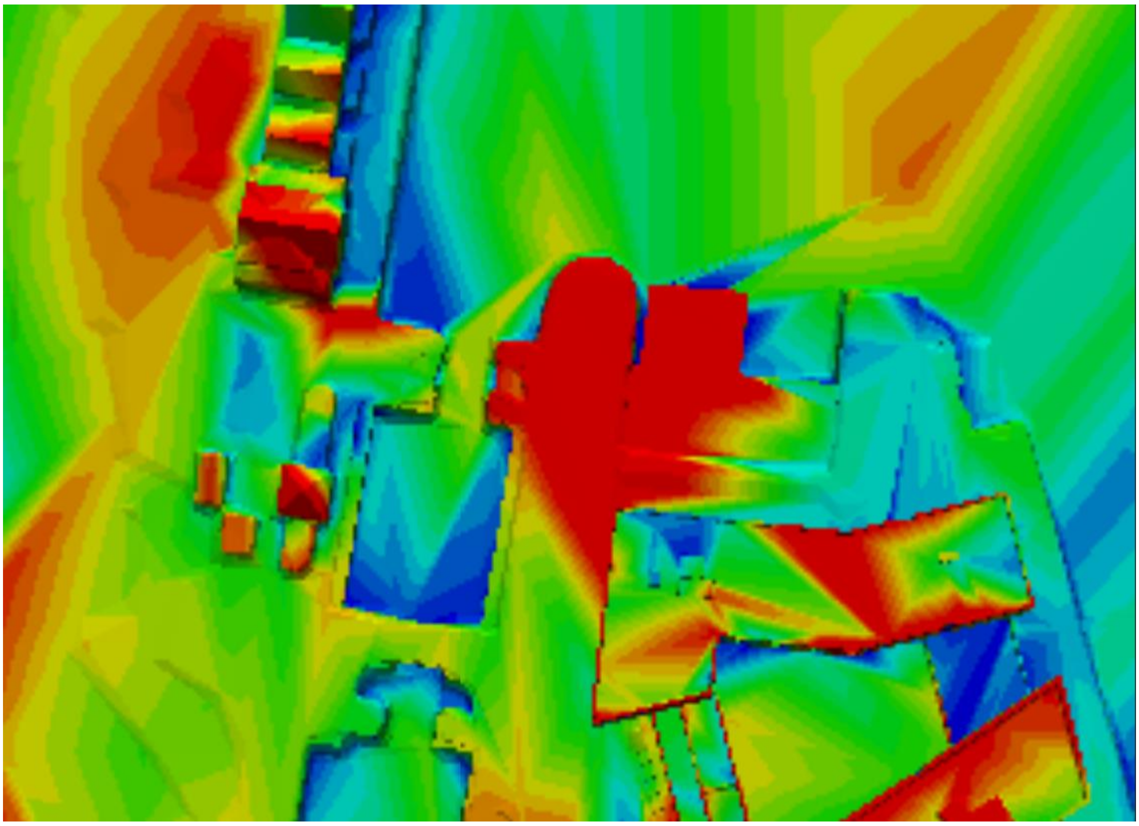


Figure 5.2: Wind Speed Effects - Wind Approaching from 250°

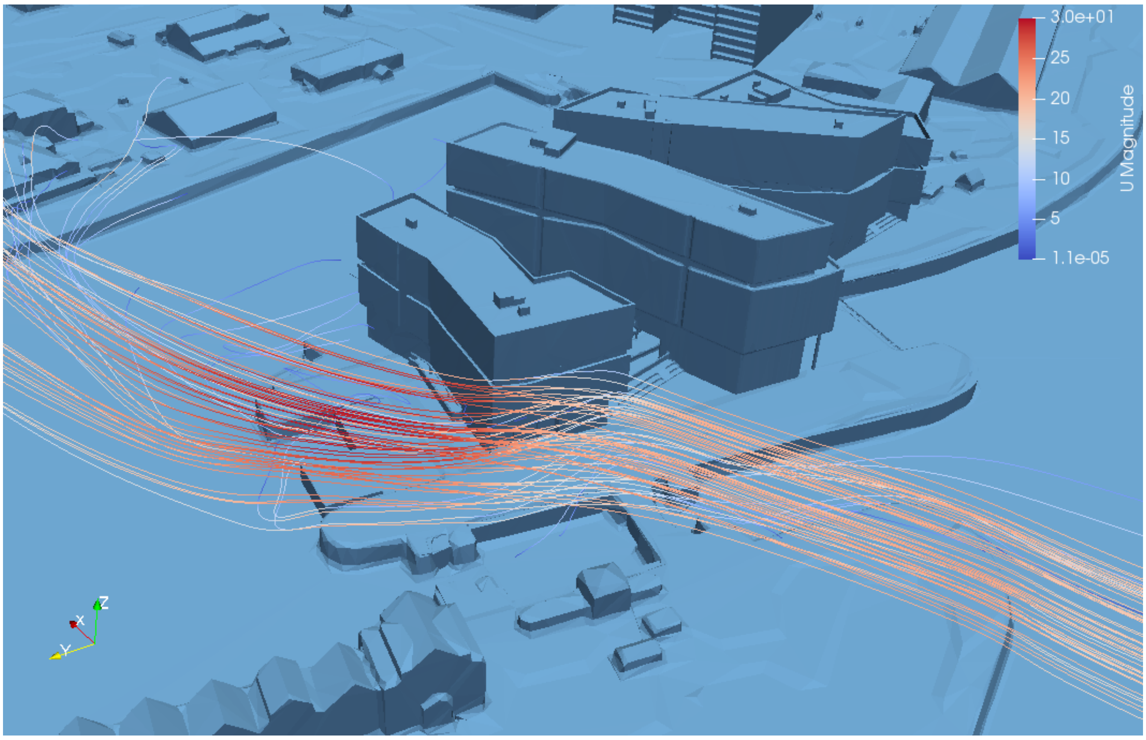


Figure 5.3: Streamlines Showing Wind Approaching from 250°

(Please note - this figure illustrates the trajectory of wind around Building A but the density of streamlines does not directly correlate to wind intensity at this location)

Figure 5.4: Example of Porous Wind Screen

(taken from London Guidance – see Appendix 1)

Figure 5.5: Example of Combining Form and Function - Public Art Wind Baffle

(taken from London Guidance – see Appendix 1)

Area B – Northern Quay, Seating Area and Entrance

5.2.5 Area B is primarily designated for seating and as open public space. As with area A the comfort criteria for these uses are exceeded from multiple wind directions but primarily where the wind is coming from either the NNE or SW. As with area A we would recommend a series of screens in this area. One set would be designed to break up the airflow prior to being escalated around the NE corner of the northern block and the second would be some form of solid screening between the seating areas and the water to the west. With mitigation in place this area will be suitable for all of the use types proposed.

Area C Northern Piazza,

Area F – Central Piazza and Children's Play Area and

Area J – Southern Piazza

5.2.6 All three Piazzas experience exceedances in the comfort criteria when the wind is blowing directly from the river and is being accelerated between the buildings. For all three of these areas we recommend a combination of porous screening and planting on the western end of each of the piazzas design due break up the wind flow as it enters the channels between the buildings. An example of the type of screening proposed is shown in Figure 5.6.

Figure 5.6: Example of Type of Screening Proposed for Piazza's

Areas D – Riverside Walk and Seating to the West of the Development and Area G - Eastern Dockside Walk and Entrances

5.2.7 Areas D and G are primarily designated as seating and public open space. It is worth noting that the proposed buildings have a limited effect on the wind flow in these areas and in general all of the comfort criteria exceedances, bar those relating to the entrances, are a direct result of strong winds being carried directly across or along the Mersey. Because of this, and as the areas are already popular for use a public open space, it is suggested that mitigation should be limited to some light screening or the use of a revolving door at the building entrances and some porous screens or planting adjacent to any proposed seating.

Area E – 8th Floor Roof Terrace

5.2.8 The 8th Floor roof terrace experiences exceedances in the comfort criteria once again when the wind is being blown directly from the Mersey. In this area we recommend solid glass screens around the perimeter of the terrace to eliminate any uncomfortable conditions.

Area G - Eastern Dockside Walk and Entrances

5.2.9 Exceedances in this area generally occur when the wind is blowing parallel to the dock either from the south or north. Theses winds interact with the corners of the buildings and cause exceedances at numerous points along the dockside walk. Mitigation here would be best achieved using a combination of staggered screens, porous screens and planting to break up wind flow.

Area H – Riverside Seating and Entrance and Area I – Riverside Pier

5.2.10 The exceedances in these areas also occur due to high wind speeds blowing in from the Mersey and are only lightly affected by the shape of the proposed buildings. Where seating is proposed we would recommend porous screens and planters to reduce incident wind speeds. There are also some large steps in area H that form architectural seating areas and we would suggest that mitigation is not required in these areas as if seating is required on windy days the screened areas would only be a few meters away. We would recommend some screening adjacent to the steps up to the entrance in area H and possibly a revolving door (Subject to further modelling) to ensure that the entrance can be used safely and comfortably.

Area K – Southern Riverside and Entrance and

Area L – Southern Roadside and Entrance

5.2.11 Some very high wind speeds have been modelled in these two areas, primarily as a result of interactions between the proposed development and the buildings directly to the south. In these locations we would suggest more porous screening and planting to break up winds blowing from the river, particularly focussed on the corners of the building.

5.3 Safety

5.3.1 In addition to the comfort criteria a number of the areas modelled also exceed the safety criteria of 20m/s for an able bodies person and 15m/s for an elderly person or a person with a disability. As with the comfort criteria these exceedances are mostly a direct result of the incident wind speeds and not the building itself, however the mitigation suggested above for the comfort criteria will also work to reduce the wind speeds below the safety criteria and will ensure that there are no safety criteria exceedances within the redline boundary.

6 CONCLUSIONS

6.1.1 The Lawson comfort criteria are exceeded in numerous locations throughout the proposed development, primarily when the wind is blowing directly from the river. This is directly as a result of relatively high wind speeds in this area and in most cases the proposed buildings are not having a significant effect on the wind speeds experienced.

6.1.2 A number of areas of mitigation have been suggested and once these have been designed and implemented we would not expect any further issues. In some instances, we would suggest that common sense prevails and users are allowed to make their own judgements about whether or not to use an area, particularly as the dockside is already popular with walkers and cyclists who will be experiencing the modelled conditions already.

APPENDICES

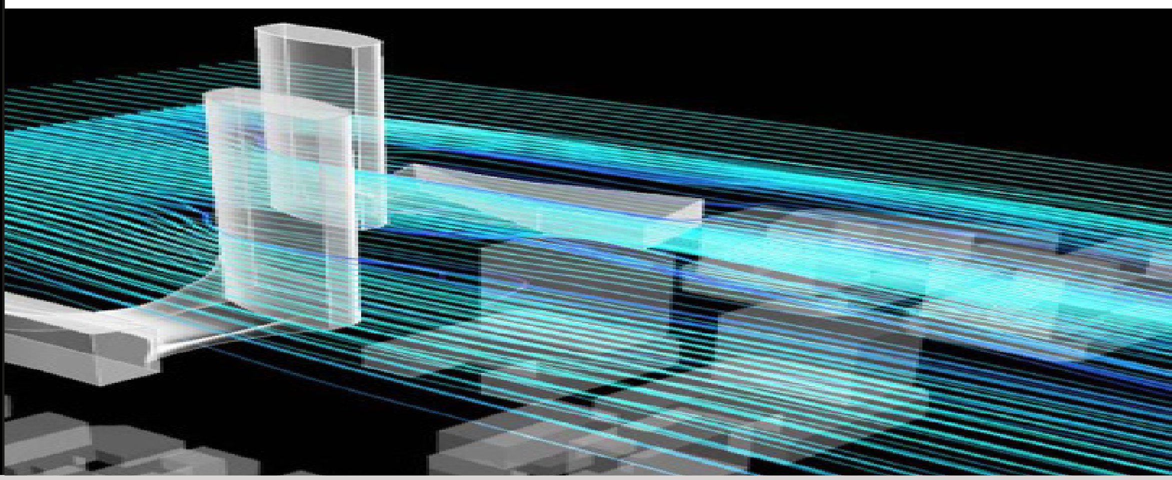
APPENDIX 1:

City of London Planning Advice Note 'Wind Effects and Tall Buildings', July 2017

Planning Advice Note

Wind Effects and Tall Buildings

Guidelines and best practice for assessing wind effects and tall buildings in the City of London



CITY OF LONDON

Planning Advice Note
July 2017

Wind Effects and Tall Buildings

Guidelines and best practice for assessing wind effects and tall buildings in the City of London

Contents

Carolyn Dwyer, BEng (Hons), DMS, CMILT, FCIHT
Director of the Built Environment
The City of London Corporation is the Local Authority for the financial and commercial heart of Britain, the City of London.

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Prepared by RWDI exclusively for the City of London

Introduction

This Planning Advice Note is one of a series of Advice Notes being prepared by the City Corporation covering microclimatic issues in the City of London. The Notes will provide clarity of advice on potential microclimatic impacts arising from development and how they need to be considered as part of the planning process.

The wind tunnel effect can occur where there are a cluster of tall buildings. Narrow areas or proximity between buildings creates low pressure causing the wind to accelerate at the base of buildings and around corners of buildings. Buildings with large frontages tend to be ones that are most sensitive to wind issues. This can cause localised wind issues and can sometimes result in safety hazards and uncomfortable wind conditions for pedestrians and cyclists. The potential for new buildings to create hazardous wind conditions should be assessed as part of the development proposal at the early planning stage; this will enable architects to address any potential impact at an early phase of design and will avoid the need to retrospectively mitigate adverse wind impacts.

This Planning Advice Note contributes to the City's key objectives to protect amenity, maintain a high quality public realm and ensure safety on the highways.

Policy Context

The planning policy framework, which comprises the context for the development of the advice note, is set out below. The framework includes the documents below as well as other documents produced by the City Corporation e.g. the Public Realm Supplementary Planning Document which gives guidance on the City's street scene and public realm.

City Corporation Corporate Plan

The overall vision seeks to support, promote and enhance the City of London as the world leader in international finance and business services. The relevant Key Policy Priority aims to support and promote the UK financial based services sector by encouraging quality developments in the built environment.

National Planning Policy

The National Planning Policy Framework (NPPF) sets out the Governments planning policies for England and how they are to be applied. The NPPF establishes a presumption in favour of sustainable development and seeks to establish a strong sense of place using streetscapes and buildings to create attractive and comfortable places to live, work and visit.

London Plan

The London Plan is the Mayor's spatial development strategy which forms part of the development plan for Greater London. The Mayor's vision is that London should excel among global cities, achieving the highest environmental standards and quality of life, and leading the world in its approach to tackling the urban challenges of the 21st century, particularly that of climate change. (Relevant London Plan policies are listed on Page 11).

City of London Local Plan

The Local Plan was adopted in 2015, and provides a spatial framework that brings together and co-ordinates a range of strategies prepared by the City Corporation, its partners and other agencies and authorities. The strategic objectives of the Plan include maintaining the City's position as the world's leading international financial and business centre, and seeking to promote a high quality of architecture and street scene appropriate to the City's position at the historic core of London. (Relevant Local Plan policies are listed on Page 11).

Guidance

When to carry out wind assessments

Buildings proposed on exposed sites with large frontages to southwest or northeast tend to be the ones that are most sensitive to wind issues. Also, building near frequently used areas (e.g. train stations) or those that may be used by vulnerable pedestrians (e.g. hospitals and schools) require careful attention. Therefore a degree of judgement has to be exercised, but the following general advice can provide a guideline for typical office or residential buildings. At the early stage of developing a scheme, bulk, height and massing options for the site need to be thoroughly assessed to avoid the need for retrospective mitigation measures.

10 to 14 Storeys	Desk-Based Assessment (see Appendix 1)
14 to 20 Storeys	Desk-Based Assessment + Computational (CFD) Simulations* (see Appendix 2)
Above 20 Storeys	Early Stage Wind Tunnel Testing + More Detailed CFD and/or Testing in Detailed Design (see Appendix 3)

(*) If the Computational Fluid Dynamics (CFD) study indicates the possibility of safety conditions, wind tunnel tests should be carried out to quantify and confirm the effectiveness of mitigation measures.

These guidelines have been prepared with the understanding that the average height of buildings in the City of London is approximately 6-8 storeys except in the eastern cluster where tall buildings are prevalent. Public spaces at high levels (e.g. terraces) fall into the same guidelines as above. Intelligent parapet and landscape design could be used to improve wind conditions on terraces.

Requirements of microclimate studies

The following items are the basic minimum requirements for any type of wind microclimate study;

1. Use of Lawson Criteria (LDDC version) to present the results, as shown in Table 1 over the page;

2. Consideration of minimum of 16 wind directions, and not just the prevailing south-westerly components;

3. Combination of long-term London weather statistics (ideally through processing at least 10 years of good quality weather data) with local wind flows obtained from wind tunnel tests or CFD;

4. Consideration of mean AND gust speeds, and reporting of both winter and summer conditions;

5. On a major scheme where it is anticipated there will be major issues, a separate wind tunnel and CFD analysis should be commissioned from two separate consultants. This is to ensure there is a robust assessment as possible. Every part of the public realm should be tested including roadways and open spaces;

6. Careful assessment and description of expected pedestrian uses (sitting, standing, walking, etc.) in different parts of the site;

7. Clear indication of mitigation requirements (size, location, porosity, etc.) with photos of wind tunnel models, sketches of proposed measures with dimensions and location plans.

The first five items relate to the technical quality and robustness of the study. Items 6 to 7 allow clear understanding of the impacts by planners, and are therefore as critical as the technical aspects.

Table 1. Lawson's LDDC criteria

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 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	Breezes that would be appropriate for window shopping and strolling along a city/town centre street, plaza or park.
Business Walking	8-10 m/s	High speeds that can be tolerated if one's only 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 required.

Safety Category	Threshold **	Description
Unsafe	>15 m/s	Winds above this threshold will pose safety risks, particularly for more vulnerable pedestrians (elderly, cyclists, etc.).

(*) Comfort threshold is set for the wind speed that is exceeded 5% of the time from all wind directions.

(**) Safety threshold is set for the wind speed exceeded once a year (0.022% of the time) from any wind direction.

Mitigation Options

A cluster of tall buildings can offer shelter to one another and push the windy areas to the edge of the cluster. This is not unlike a group of penguins sheltering one another in winter.

Therefore the tall exposed buildings at the edge of a cluster will be most problematic from a microclimate perspective. Buildings proposed on the southwest edge of the cluster will be particularly exposed to the prevailing south-west winds, and those on the northeast edge will be exposed to the cold north-easterly winds.

For very tall towers, it is necessary to require wind studies at a very early stage of design to ensure that the adverse wind effects can be mitigated through positive massing adjustments.

A group of penguins sheltering one another in winter

Massing modifications are the most effective form of mitigation for wind effects, but requires very early-stage input from a qualified wind engineer. The City prefers wind mitigation measures to be incorporated on the building as opposed to within the public realm.

The following solutions can be effective forms of mitigation, however some can also have substantial architectural and planning impacts;

Canopies - Solid canopies are effective against down drafted winds, porous canopies tend to be effective against funnelled or skew winds. They require projection rights. Canopies of over 5m cantilever size may also require substantial structural support.

Solid canopies tend to be effective against down drafted winds

Porous Screens - These are most effective when placed near building corners or near entrances, to reduce local flow speeds. Also used on the soffit of passageways. The size of screen needs to be comparable to the size of the area to be sheltered, and hence typically applied for small localized problems.

Porous screens can reduce wind speed

Fins - Regular pattern of fins/sunshades on an entire facade will be ineffective, as the main flow skips over the fins, with small-scale circulations created between each fin. Therefore they are most effective at ground-level, to offer localized reduction in surface-level wind speeds. They can create pockets where rubbish gather, or cause security concerns.

Trees and hedges - Much like the penguin effect described previously, trees and hedges are most effective when grouped together to create a meaningful obstacle to wind. They can be highly effective in reducing wind speeds on the ground, but need to be semi-mature when planted and continuously maintained. The height and crown size of trees need to be stated in any microclimate assessment, and the planted trees should be sized accordingly. Evergreen trees are more effective than deciduous counterparts, but London’s climate tends to be more suited to deciduous tree types.

Public Art/Porous Screens On the Ground - Often taking the form of art features, porous screens can serve a similar purpose to trees, but require minimal maintenance.

Public art to mitigate the effect of wind

Contacts

Please phone the General Planning Enquiries desk for information on wind effects and tall building issues.

Phone
020 7332 1710

Email
plans@cityoflondon.gov.uk

Contact Address
Department of the Built Environment
Guildhall
PO Box 270
London
EC2P 2EJ

Policies

Relevant London Plan policies relating to the microclimate

5.3 Sustainable Design and Construction
7.5 Public Realm
7.6 Architecture
7.7 Location and Design of Tall and Large Buildings

Relevant City of London Local Plan policies relating to the microclimate

CS 3 Safety and Security
CS 10 Design
CS 14 Tall Buildings
CS 15 Sustainable Development and Climate Change
DM 10.1 New Development
DM 10.4 Environmental Enhancement
DM 10.7 Daylight and Sunlight

Appendix 1 – Desk Studies

A qualified wind engineer with over 5 years of wind tunnel experience will be able to identify the key wind-related problems in an early-stage desk study. These studies involve the following;

- Knowledge of the prevailing wind climate in London;
- Evaluation of proposed building massing with respect to the neighbouring buildings and prevailing wind directions;
- Consideration of intended pedestrian uses at the site.

This information will be used by the wind engineer to predict the general flow pressure fields around the site, based on his/her experience of testing similar schemes using the wind tunnel or CFD. Downdrafts, funnelling, wise effect, horse-shoe vortices and other critical flow features can often be predicted. Flow features and windy areas should be graphically represented (as illustrated below) and suggestions for mitigation options or further wind studies should be clearly stated in the desk study report.

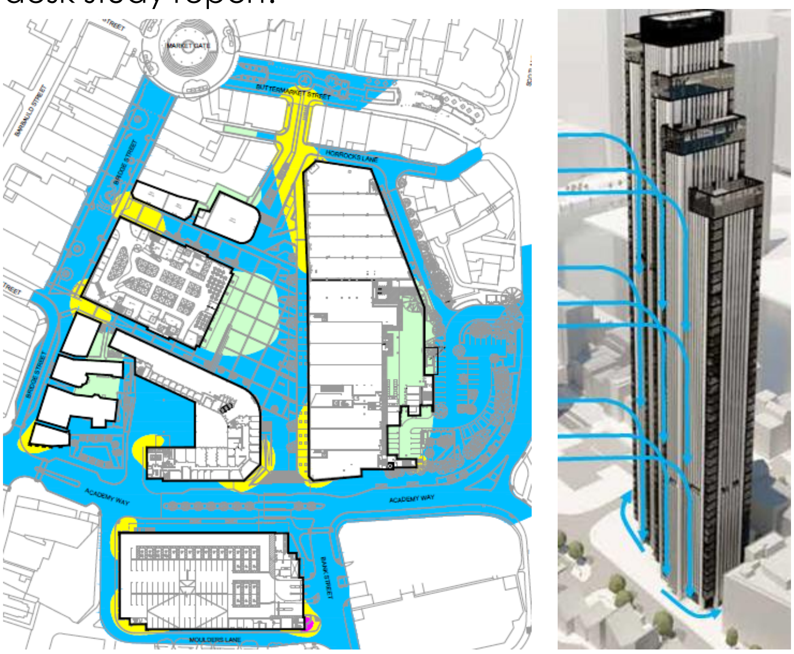


Figure 1.1
(a) Typical contour plot from a desk study indicating the comfort levels using Lawson LDDC criteria.
(b) Main flow features expected around a tower, simplified in a desk study.

Appendix 2 –Desk Studies Enhanced With CFD

Computational Fluid Dynamics (CFD) is an emerging tool that can provide a good understanding of wind flows around a development. While CFD can reliably predict mean flows, it does not always provide a good prediction of gusts which can be important for pedestrian safety. When the capabilities of CFD are used by an experienced wind engineer, it is possible to highlight critical wind issues, provide initial predictions of comfort conditions, and also spot areas where CFD simulations may not fully represent the reality. CFD results can either be used to provide visual representations of the predominant flow patterns, or be combined with long-term weather statistics in the same way as wind tunnel data to provide Lawson comfort ratings.

Ideally CFD studies would include direct representation of gusts, but this is often very costly and time consuming to achieve. So in areas where turbulence may be important (e.g. in the wake regions behind buildings, or areas with funnelling) care should be taken when interpreting CFD results. For buildings above 25 storeys it is preferable to carry out unsteady (transient) CFD simulations.

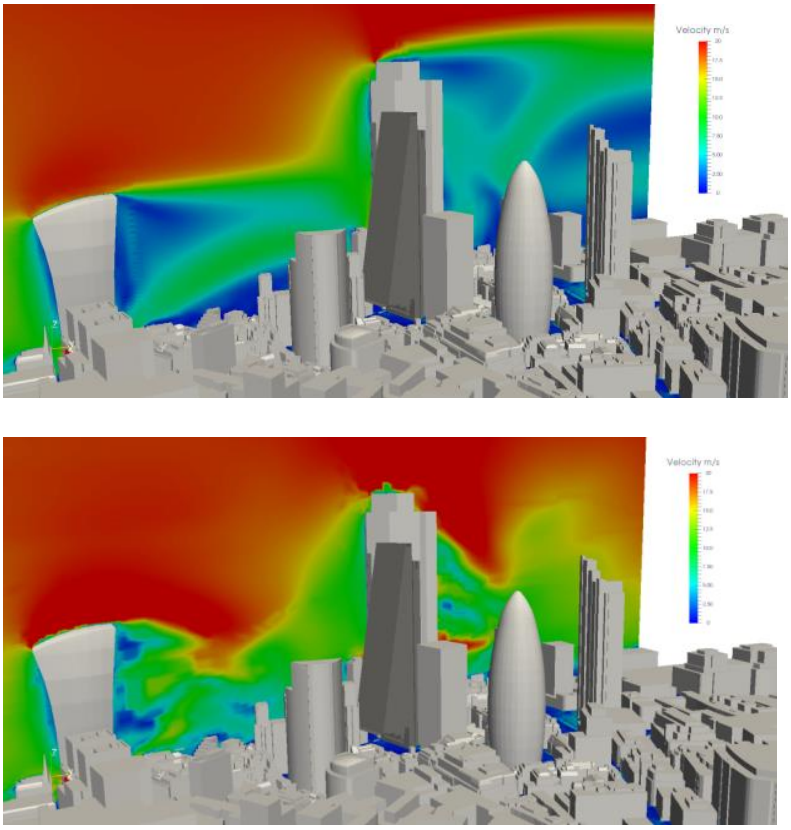


Figure 2.1
(a) Typical mean-flow prediction by CFD (RANS analysis).
(b) Prediction of gusts using CFD (LES analysis, snapshot in time).

Appendix 3 – Wind Tunnel Studies

Wind tunnel studies are the most established tool for evaluating wind effects, as they have been in use for over 50 years. It can also be the most effective tool if multiple configurations need to be tested for a full range of wind directions, or if multiple tests are required to develop mitigation options. Nevertheless, there are certain aspects of wind tunnel testing which require careful attention in order to ensure that the results are fully representative.

The wind tunnel test involves the use of discrete sensors to measure local wind speeds. The placement of these sensors should be done with care, to capture the windiest parts of the site, as well the most frequently used (e.g. entrances, main walking routes, etc.). Around building corners it is advised to place a minimum of two to three sensors to adequately capture the accelerated flow effects for all wind directions.

The data from the wind tunnel provides an understanding of local building-induced effects, but to obtain Lawson comfort ratings the wind tunnel data needs to be combined with weather statistics. This is not a trivial task, as 10 or more years of data from reliable sources (generally airports) need to be carefully filtered, and statistically analysed to provide the necessary information (typically probability functions, using Weibull coefficients) for a robust analysis. Amalgamated sample-year data from sources such as CIBSE – which are not calibrated for wind effects – should not be used.

Finally, whether a wind tunnel study is used or not, the true effects of wind on the development need to be very clearly provided in the wind engineering reports. This includes the details of any wind mitigation, such as size, location, porosity, etc. Assuming that wind mitigations form part of the design is not a good excuse to avoid describing these details. There are other test details, such as blockage, boundary-layer development, instrumentation, etc., which will not be described herein, but can be found in published resources. Most established wind tunnel facilities will ensure that the test procedures meet or exceed those described in BS6399, Eurocode, ASCE and other codified sources.

Figure 3.1

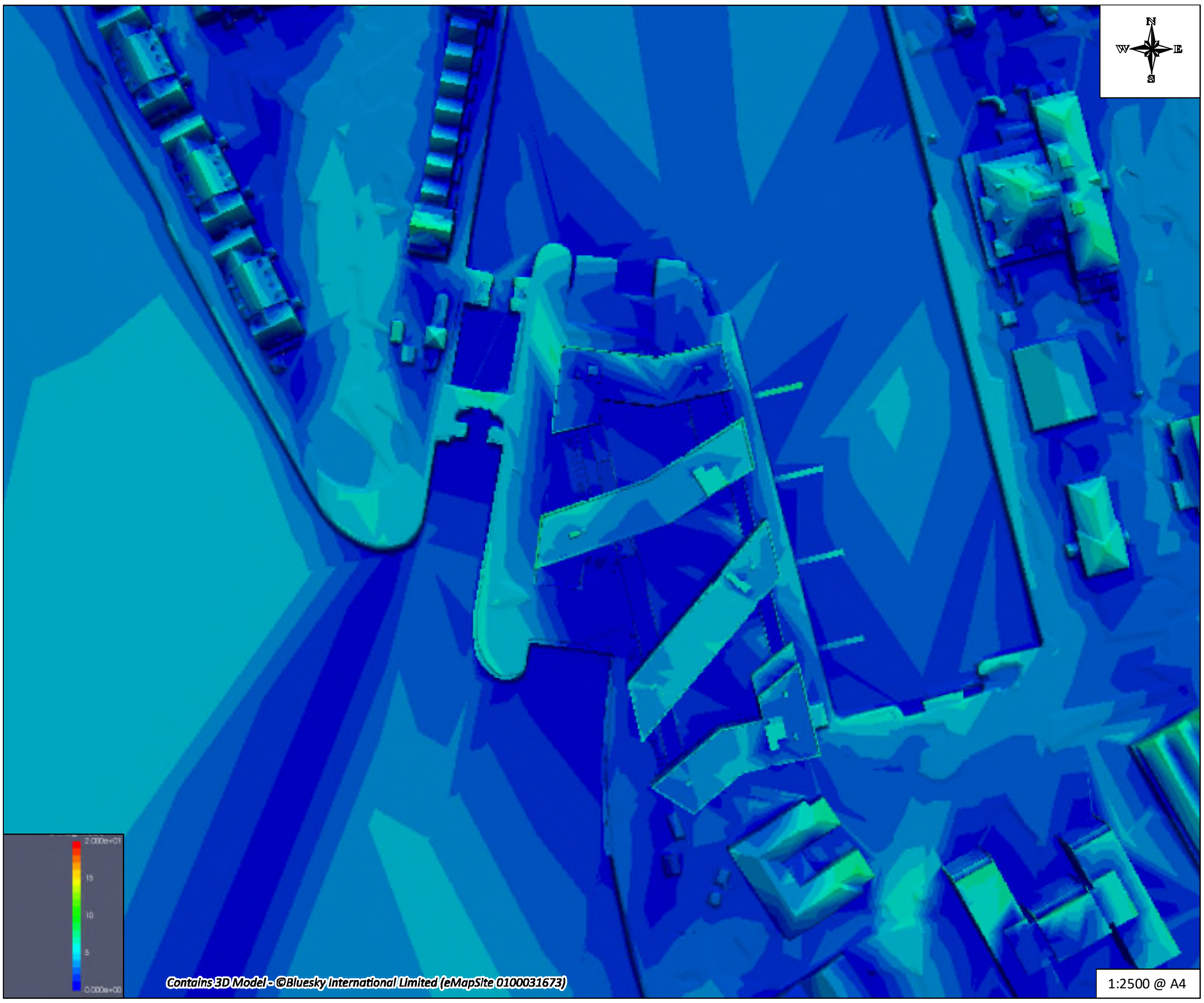
(a) Typical wind tunnel test setup.

(b) Irwin probe sensors typically used to measure the pedestrian-level wind speeds.

APPENDIX 2:

Results of Modelling Outputs

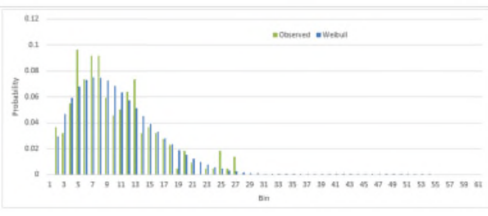
Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 0°/360°



Statistics on Wind Data

Wind Direction	0.0°
Probability of occurrence	0.26%
Scale Factor (c)	5.23
Shape Factor (k)	1.73
No. data points	218
Roughness (site)	0.5
Average Wind Speed (*ref*)	4.66
Average Wind Speed (site)	2.98
Max Wind Speed (*ref*)	12.86
Max Wind Speed (site)	8.22
Exceedence Probability	5.000%
Wind Speed (*ref*)	9.86
Wind Speed (site)	6.30
Exceedence Probability	0.022%
Wind Speed (*ref*)	23.14
Wind Speed (site)	14.79

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

Notes:

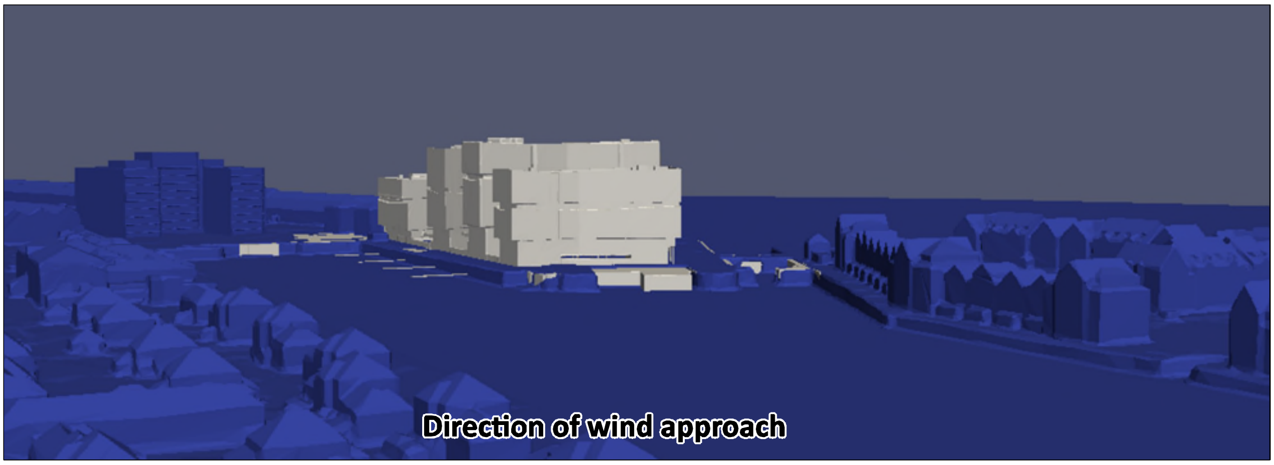
Wardell Armstrong LLP
Wheal Jane Earth Science Park
Baldhu, Truro, Cornwall, TR3 6EH
Tel: +44 (0) 1872 560738
email: info@wardell-armstrong.com
web: www.wardell-armstrong.com

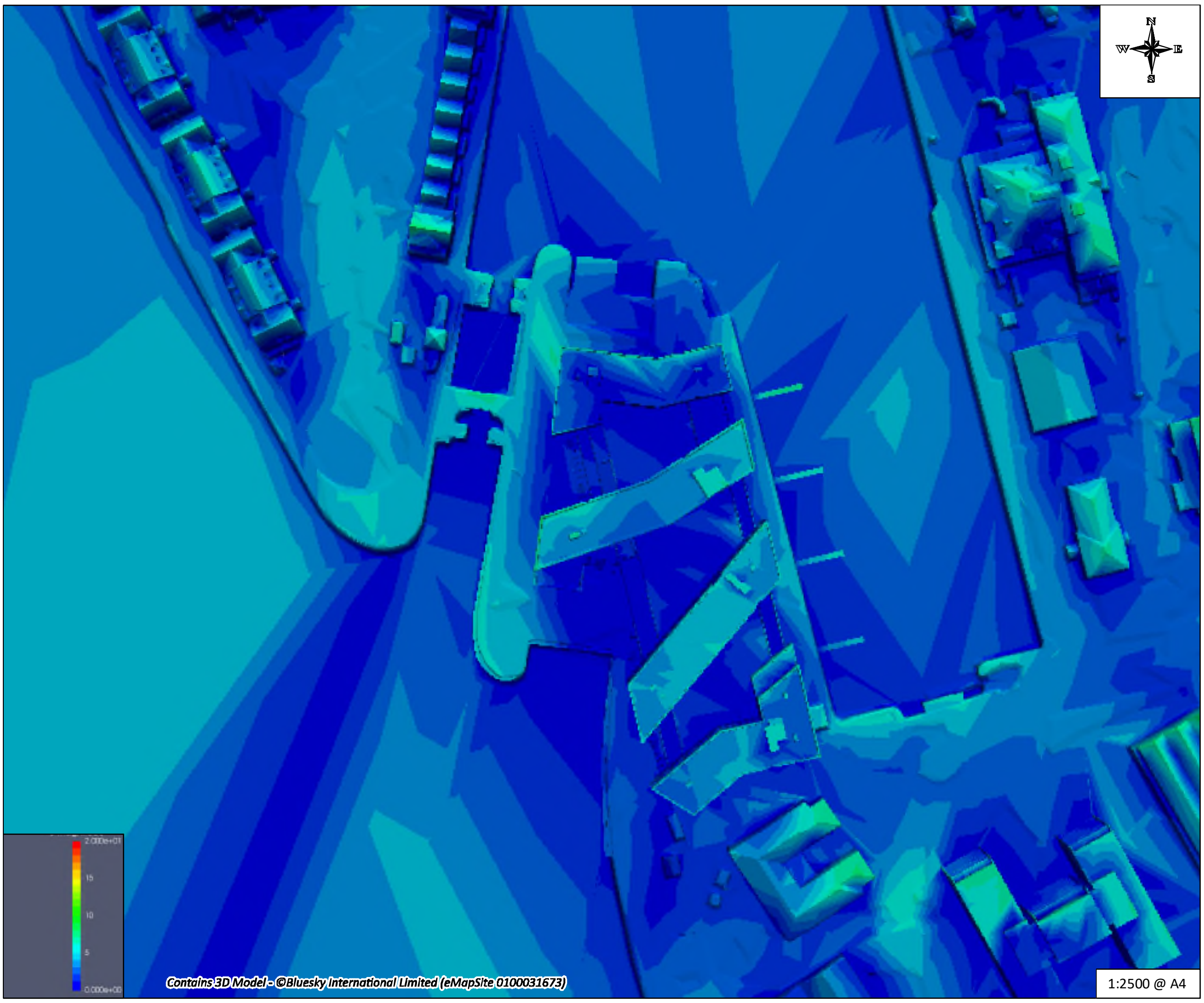
Drawn By:	S.Allen	Date:	21/06/2018
Checked By:	P.Evans	Date:	21/06/2018

CFD Model of Wind Flow at 0°
Brunswick Quay
Liverpool

WIND_000_v001_ST16666 | Appendix 2.01

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 10°

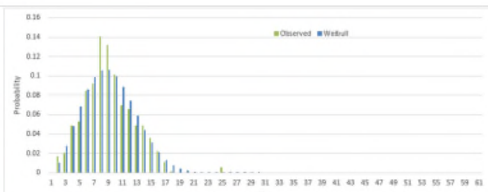




Statistics on Wind Data

Wind Direction	10.0°
Probability of occurrence	0.63%
Scale Factor (c)	4.65
Shape Factor (k)	2.45
No. data points	532
Roughness (site)	0.5
Average Wind Speed (ref)	4.33
Average Wind Speed (site)	2.64
Max Wind Speed (ref)	12.02
Max Wind Speed (site)	7.08
Exceedence Probability	5.000%
Wind Speed (ref)	7.28
Wind Speed (site)	4.65
Exceedence Probability	0.022%
Wind Speed (ref)	21.34
Wind Speed (site)	14.29

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

Notes:

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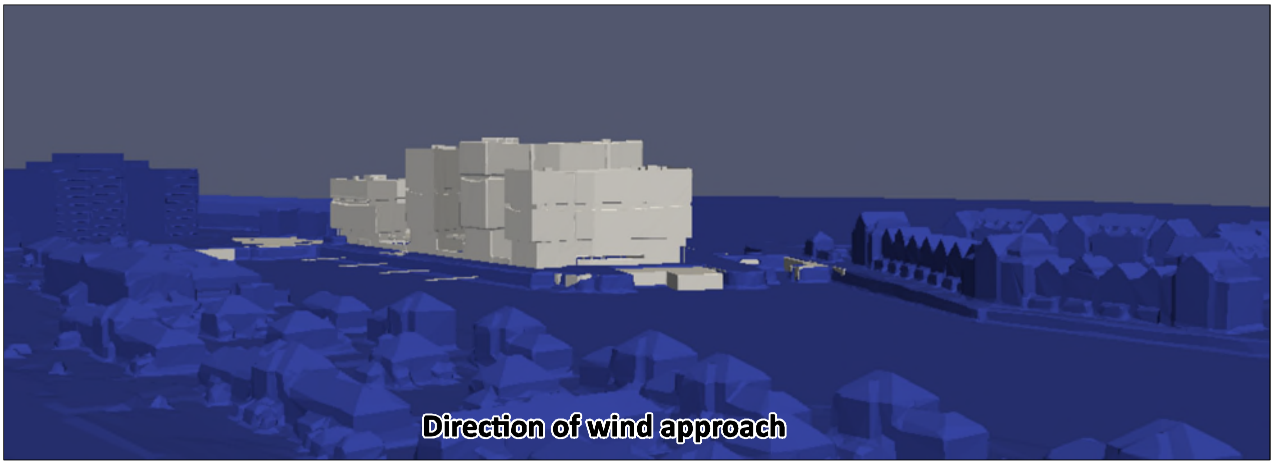
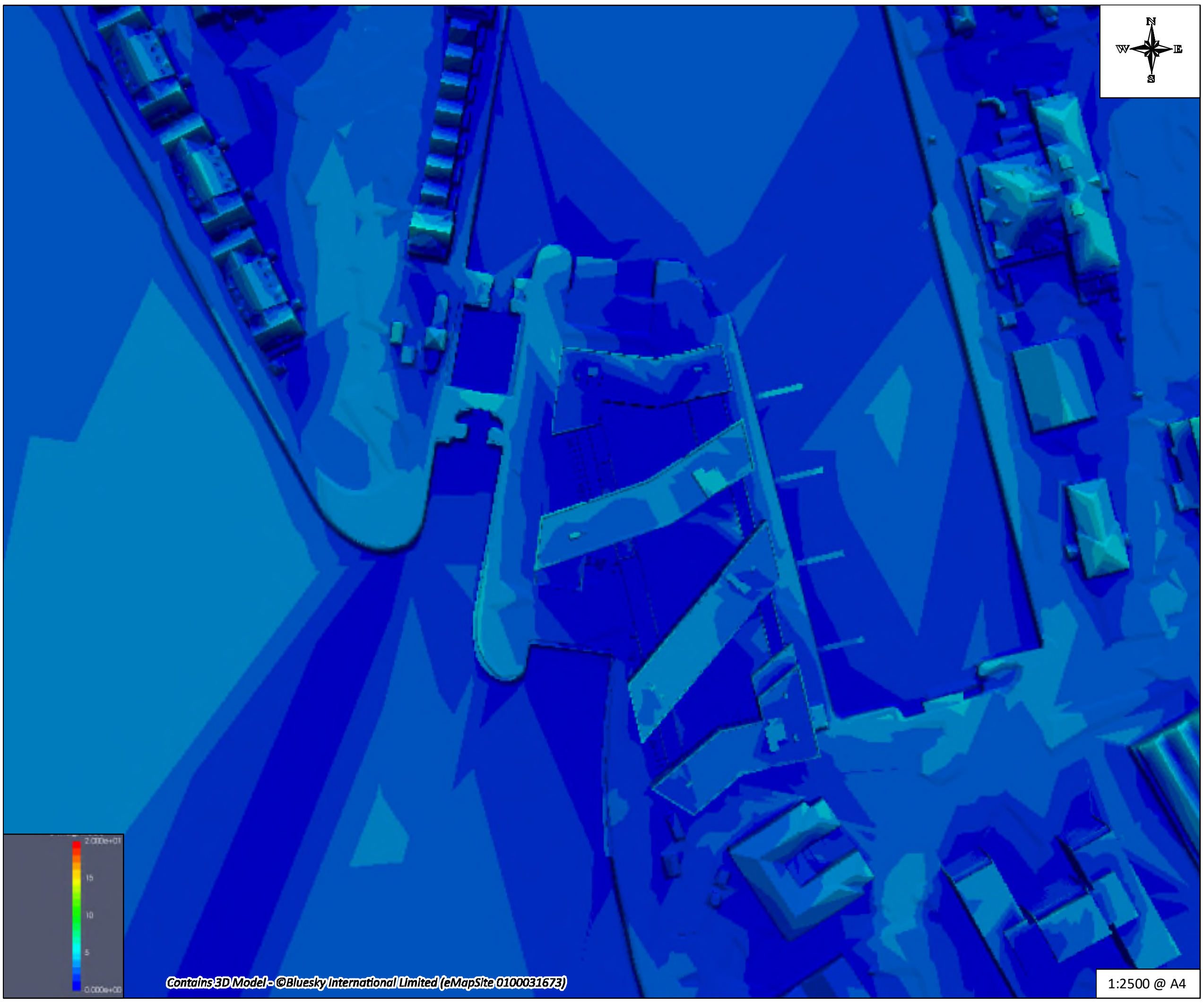
CFD Model of Wind Flow at 10°
Brunswick Quay
Liverpool

WIND_010_v001_ST16666 | Appendix 2.02

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 20°

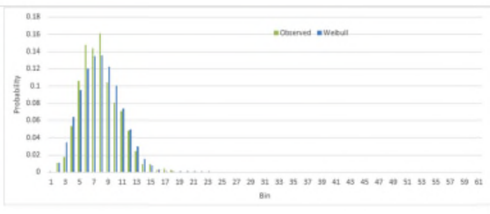




Statistics on Wind Data

Wind Direction	20.0°
Probability of occurrence	0.86%
Scale Factor (c)	3.89
Shape Factor (k)	2.67
No. data points	730
Roughness (site)	0.5
Average Wind Speed (ref)	3.46
Average Wind Speed (site)	2.23
Max Wind Speed (ref)	8.55
Max Wind Speed (site)	5.46
Exceedence Probability	5.000%
Wind Speed (ref)	5.87
Wind Speed (site)	3.75
Exceedence Probability	0.022%
Wind Speed (ref)	21.14
Wind Speed (site)	14.79

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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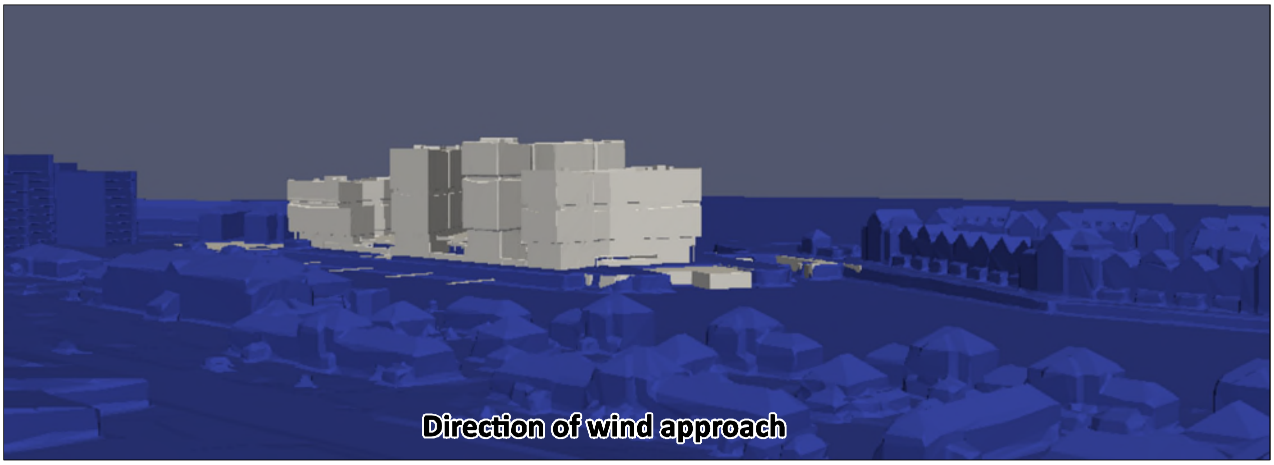
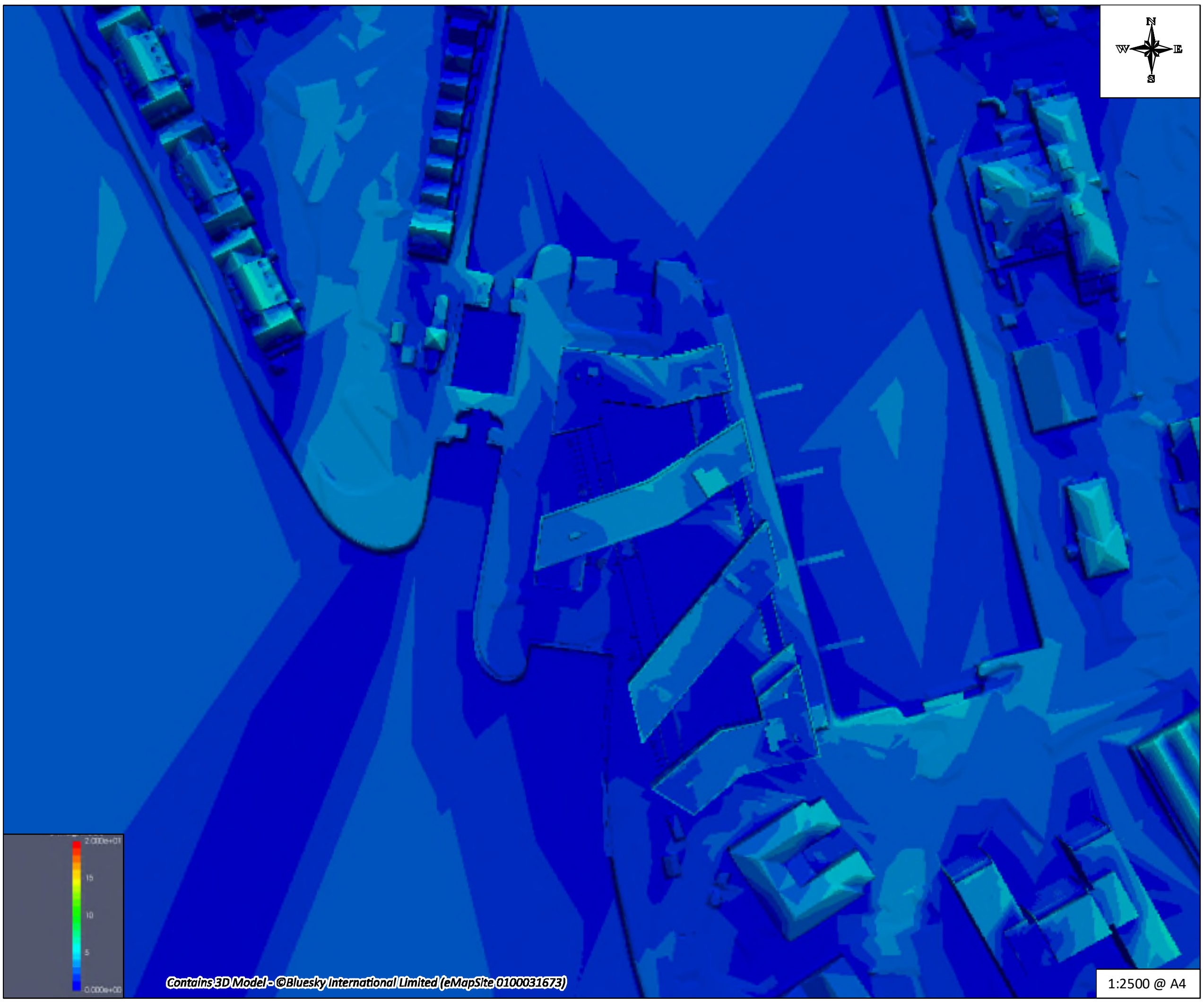
CFD Model of Wind Flow at 20°
Brunswick Quay
Liverpool

WIND_020_v001_ST16666 | Appendix 2.03

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 30°

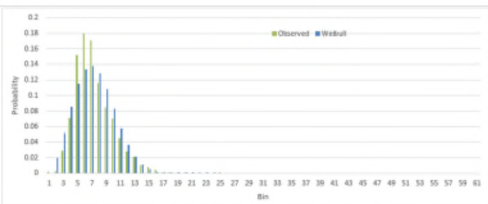




Statistics on Wind Data

Wind Direction	30.0°
Probability of occurrence	3.30%
Scale Factor (c)	3.59
Shape Factor (k)	2.44
No. data points	937
Roughness (site)	0.5
Average Wind Speed (ref)	3.38
Average Wind Speed (site)	2.03
Max Wind Speed (ref)	12.02
Max Wind Speed (site)	7.08
Exceedence Probability	5.000%
Wind Speed (ref)	5.62
Wind Speed (site)	3.59
Exceedence Probability	0.022%
Wind Speed (ref)	21.34
Wind Speed (site)	14.29

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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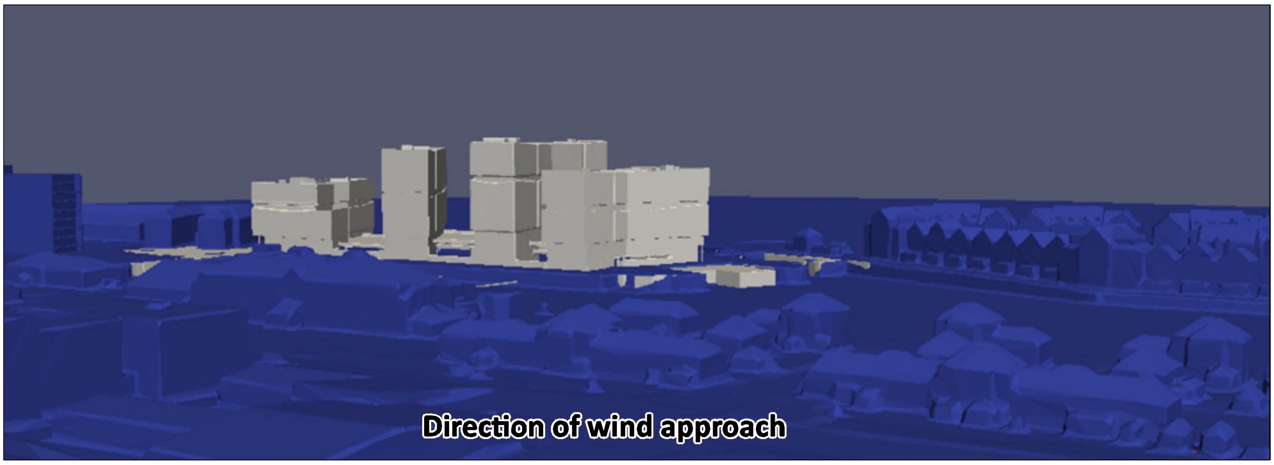
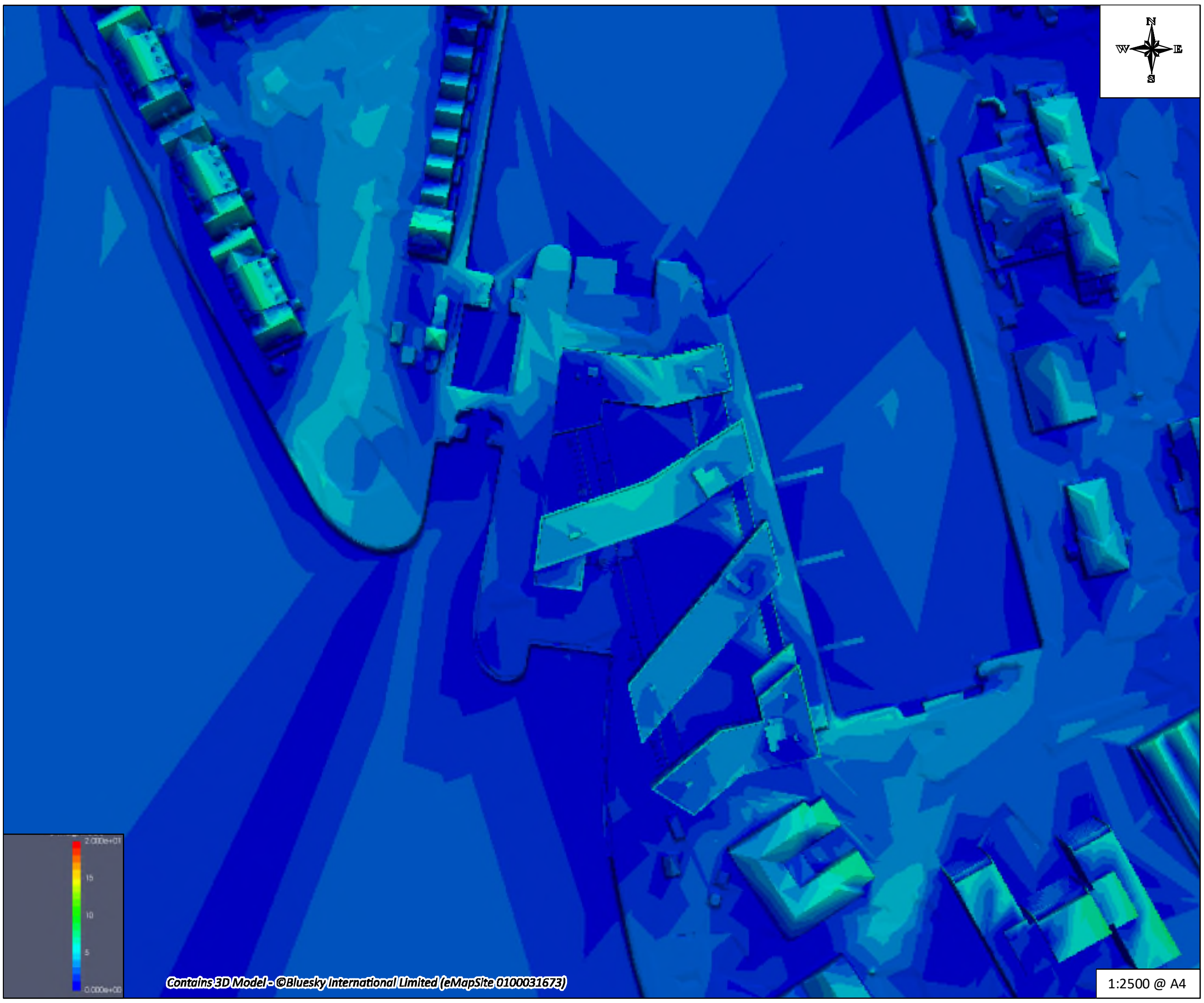
CFD Model of Wind Flow at 30°
Brunswick Quay
Liverpool

WIND_030_v001_ST16666 | Appendix 2.04

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 40°

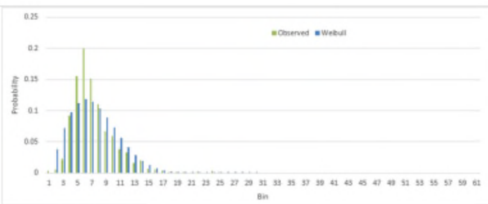




Statistics on Wind Data

Wind Direction	40.0°
Probability of occurrence	1.46%
Scale Factor (c)	3.40
Shape Factor (k)	1.99
No. data points	1238
Roughness (site)	0.5
Average Wind Speed (ref)	3.20
Average Wind Speed (site)	2.04
Max Wind Speed (ref)	11.78
Max Wind Speed (site)	7.51
Exceedence Probability	5.000%
Wind Speed (ref)	6.27
Wind Speed (site)	4.00
Exceedence Probability	0.077%
Wind Speed (ref)	21.14
Wind Speed (site)	14.79

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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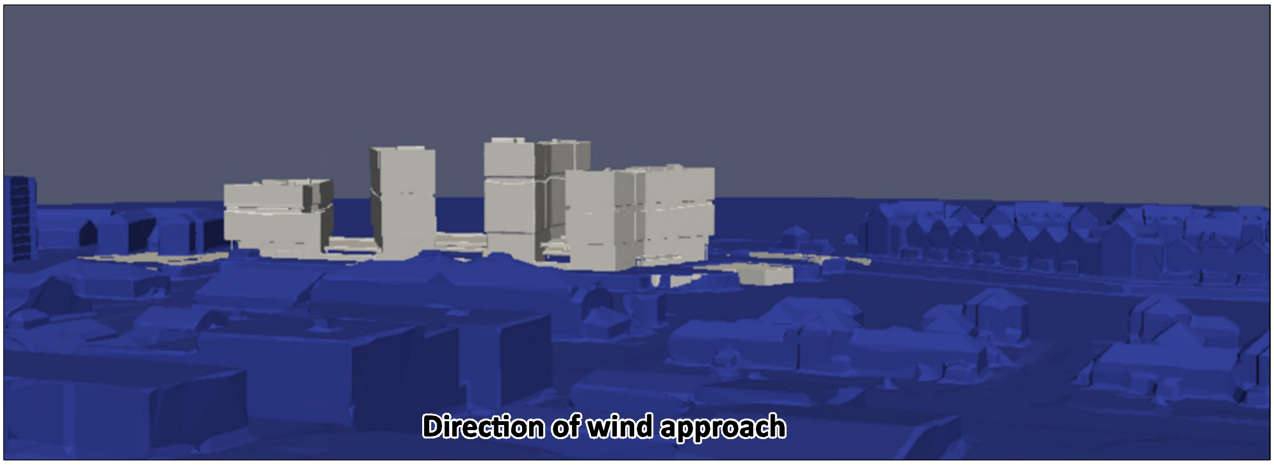
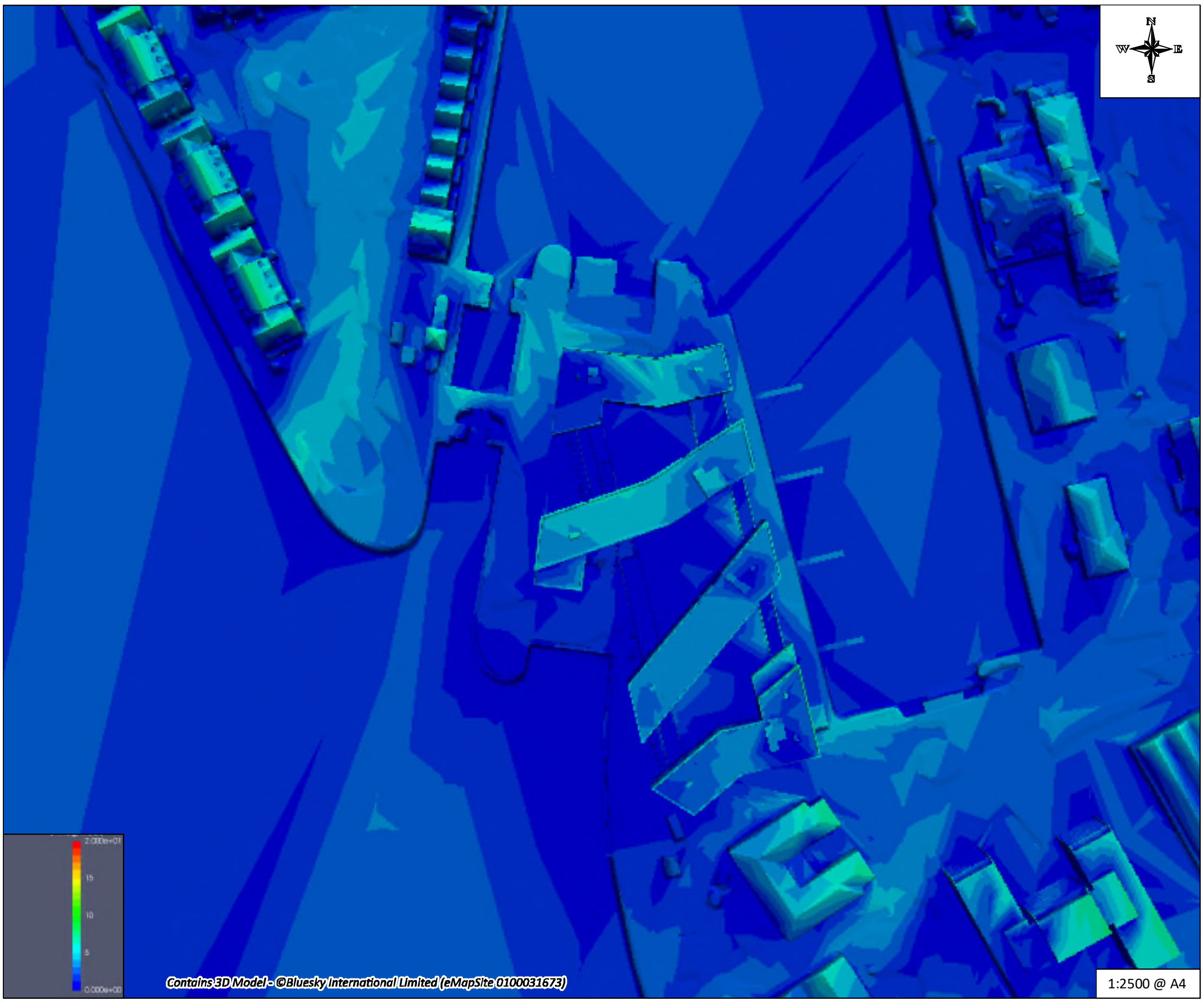
CFD Model of Wind Flow at 40°
Brunswick Quay
Liverpool

WIND_040_v001_ST16666 | Appendix 2.05

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 50°

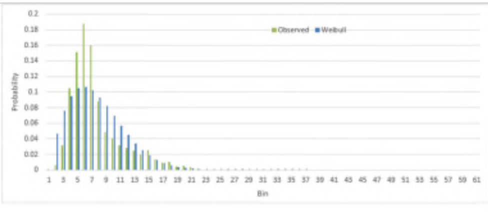




Statistics on Wind Data

Wind Direction	50.0°
Probability of occurrence	1.77%
Scale Factor (c)	3.76
Shape Factor (k)	1.79
No. data points	1505
Roughness (site)	0.5
Average Wind Speed (ref)	3.35
Average Wind Speed (site)	2.14
Max Wind Speed (ref)	10.49
Max Wind Speed (site)	6.70
Exceedence Probability	5.000%
Wind Speed (ref)	6.94
Wind Speed (site)	4.44
Exceedence Probability	0.077%
Wind Speed (ref)	21.14
Wind Speed (site)	14.79

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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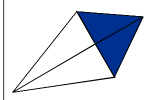
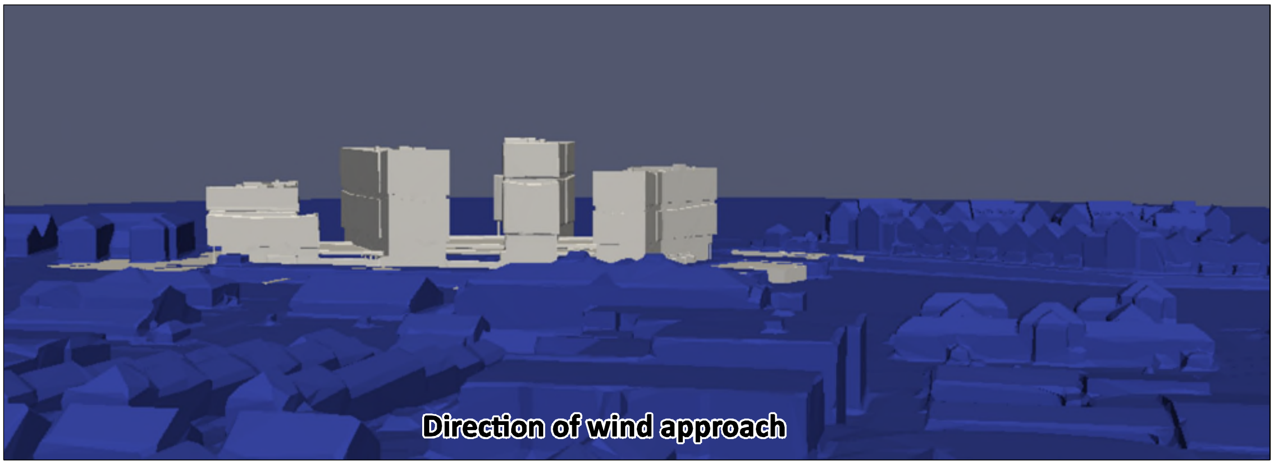
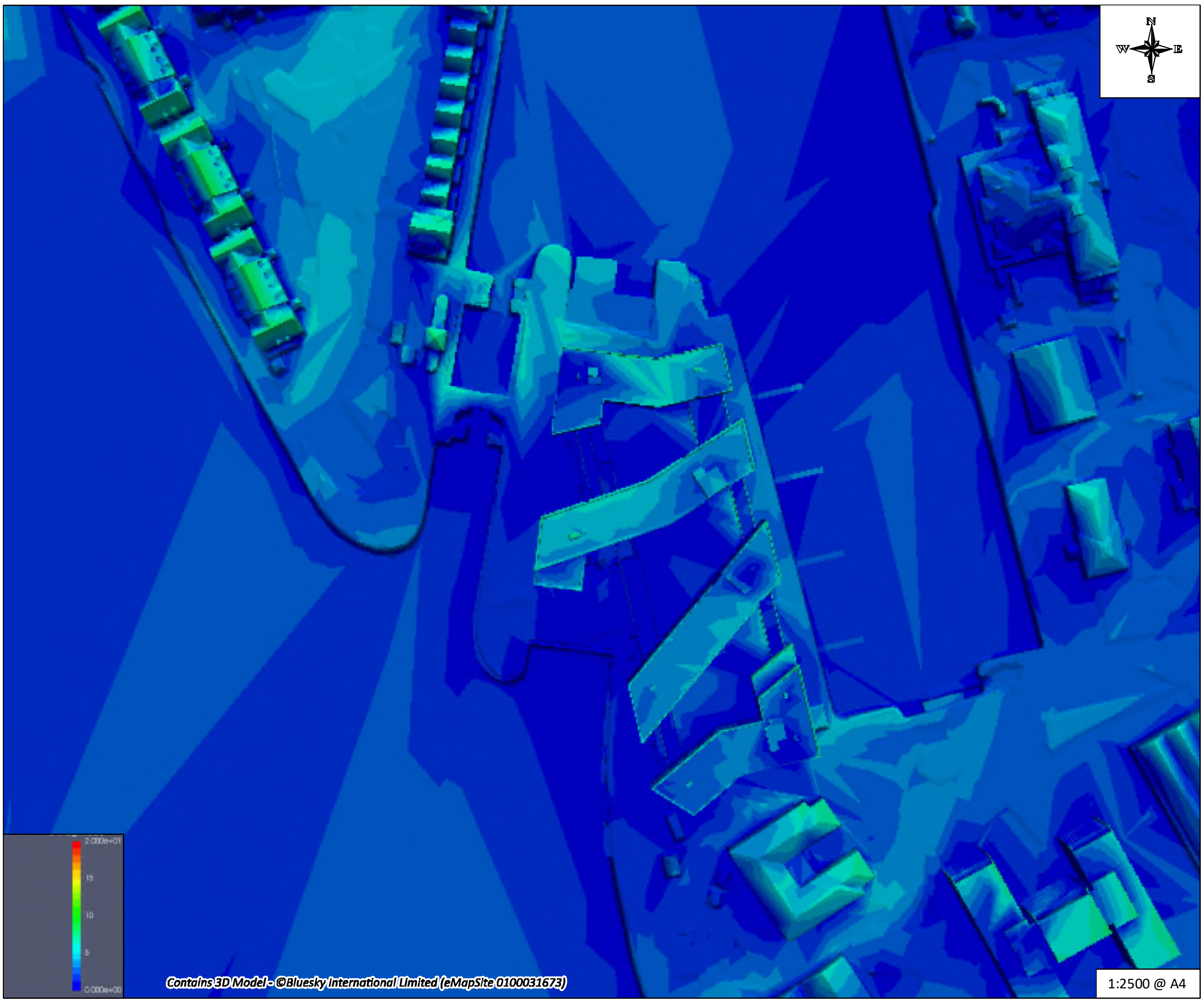
CFD Model of Wind Flow at 50°
Brunswick Quay
Liverpool

WIND_050_v001_ST16666 | Appendix 2.06

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 60°



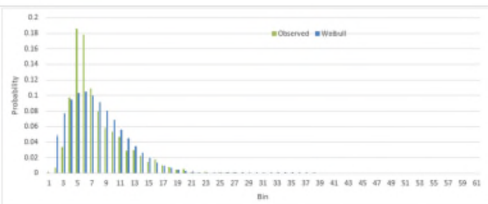




Statistics on Wind Data

Wind Direction	60.0°
Probability of occurrence	3.08%
Scale Factor (c)	3.79
Shape Factor (k)	1.76
No. data points	3597
Roughness (site)	0.5
Average Wind Speed (ref)	3.37
Average Wind Speed (site)	2.16
Max Wind Speed (ref)	12.86
Max Wind Speed (site)	8.22
Exceedence Probability	5.000%
Wind Speed (ref)	7.07
Wind Speed (site)	4.52
Exceedence Probability	0.022%
Wind Speed (ref)	21.34
Wind Speed (site)	14.79

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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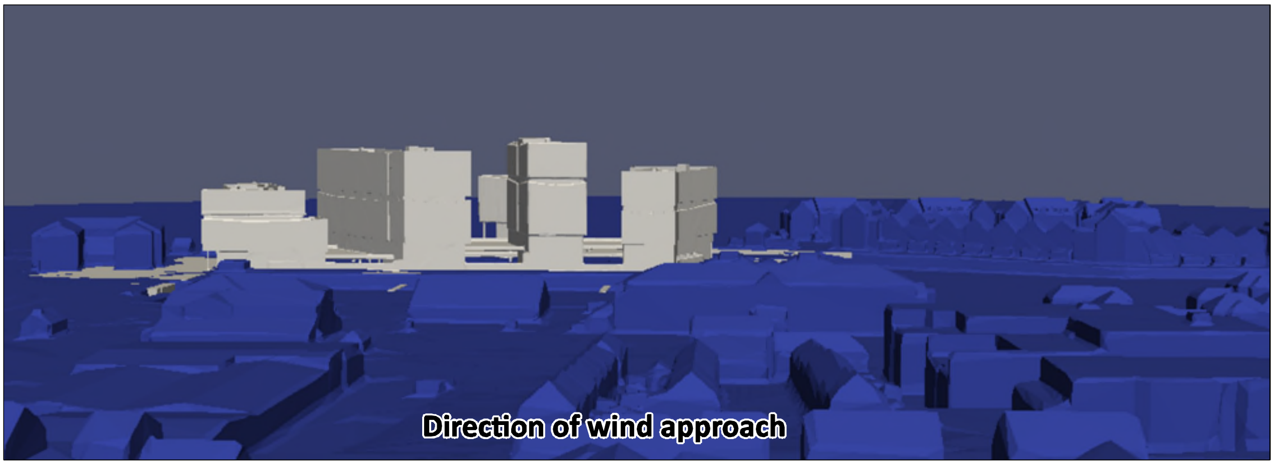
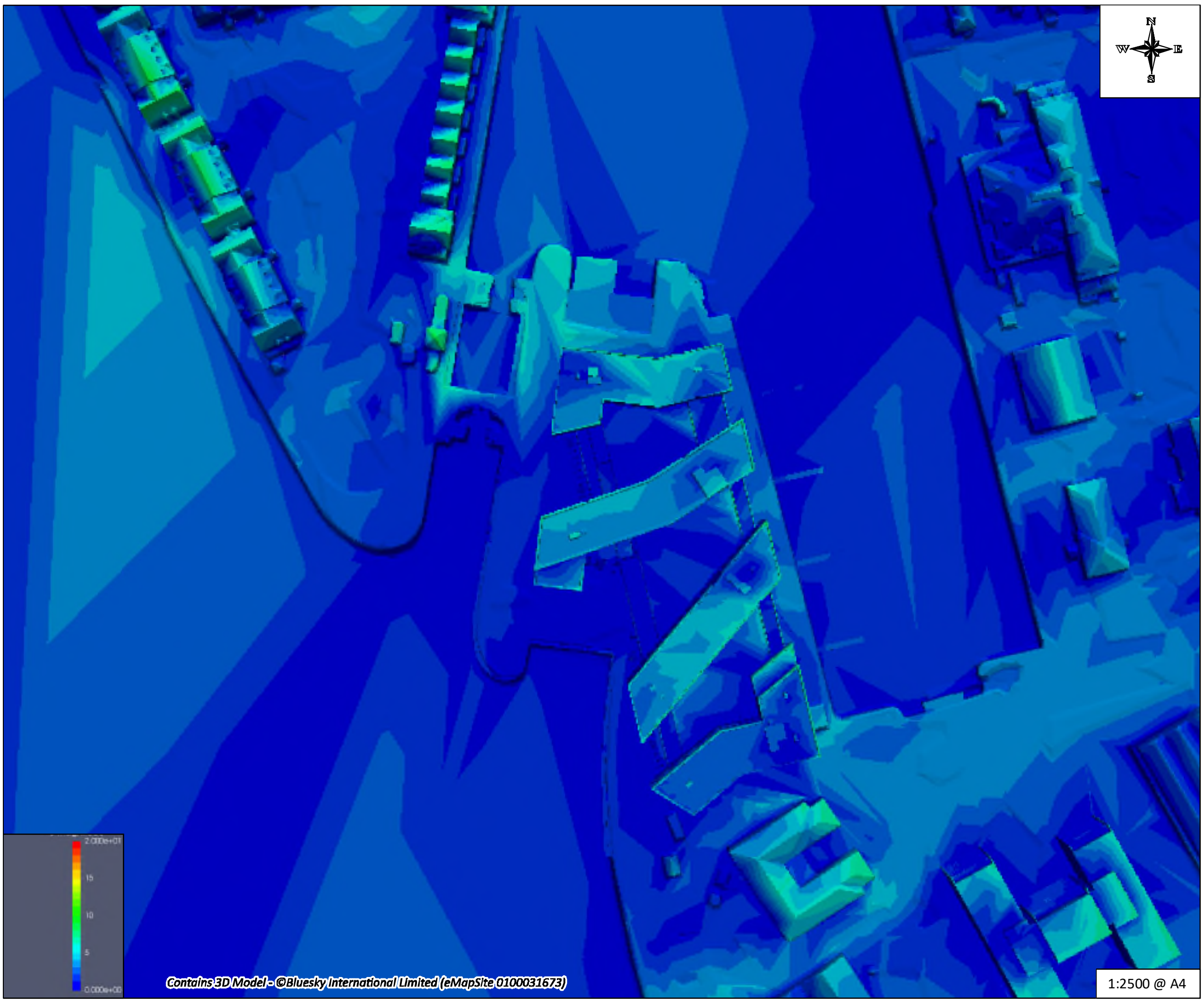
CFD Model of Wind Flow at 60°
Brunswick Quay
Liverpool

WIND_060_v001_ST16666 | Appendix 2.07

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 70°

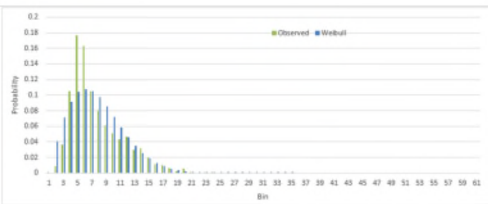




Statistics on Wind Data

Wind Direction	70.0°
Probability of occurrence	2.30%
Scale Factor (c)	3.83
Shape Factor (k)	1.87
No. data points	1,785
Roughness (site)	0.5
Average Wind Speed (ref)	3.38
Average Wind Speed (site)	2.16
Max Wind Speed (ref)	11.71
Max Wind Speed (site)	7.49
Exceedence Probability	5.000%
Wind Speed (ref)	6.86
Wind Speed (site)	4.38
Exceedence Probability	0.022%
Wind Speed (ref)	21.14
Wind Speed (site)	14.79

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

Notes:

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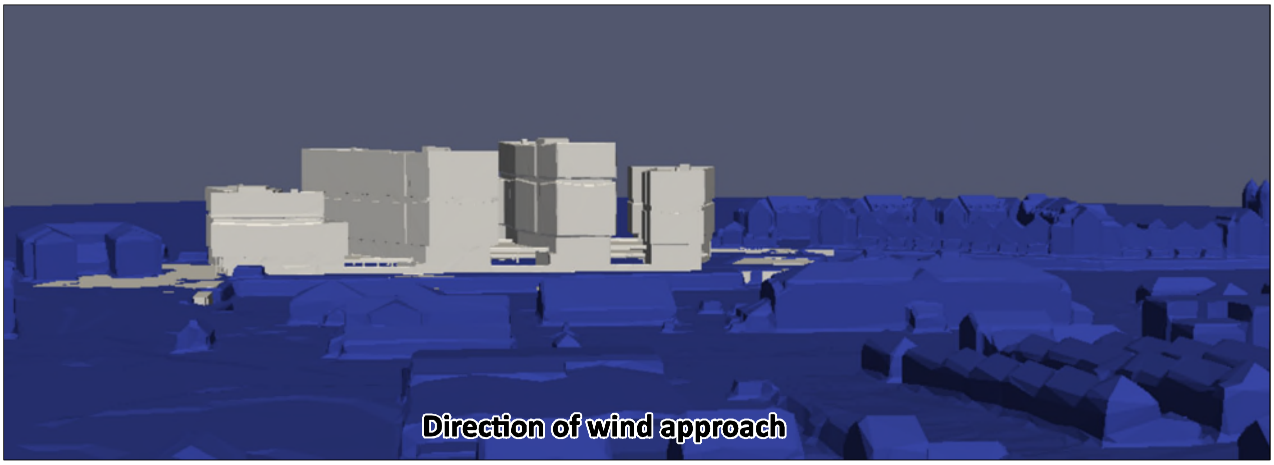
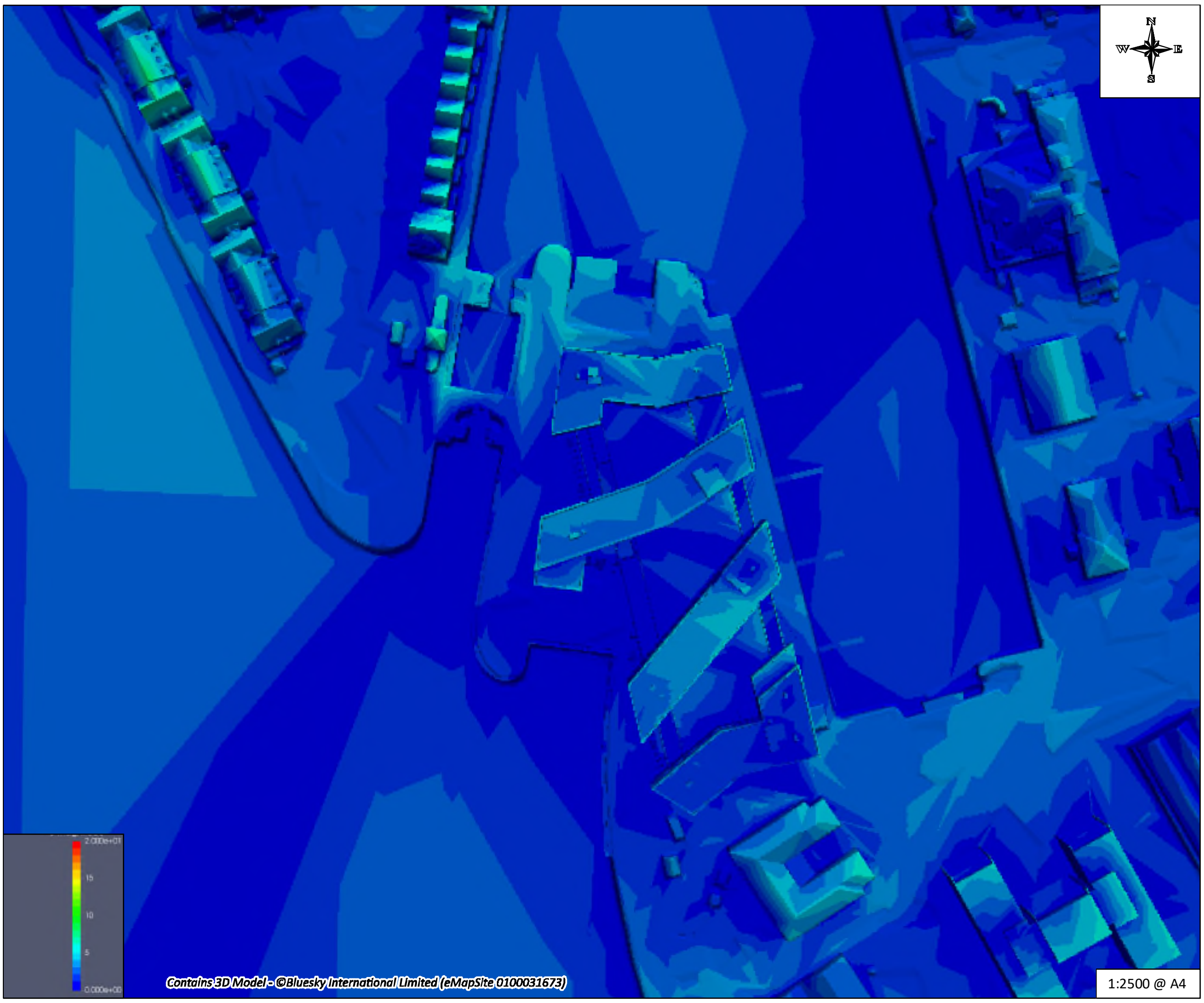
CFD Model of Wind Flow at 70°
Brunswick Quay
Liverpool

WIND_070_v001_ST16666 | Appendix 2.08

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 80°

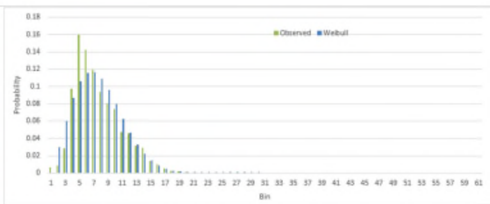




Statistics on Wind Data

Wind Direction	80.0°
Probability of occurrence	2.25%
Scale Factor (c)	3.79
Shape Factor (k)	2.30
No. data points	3933
Roughness (site)	0.5
Average Wind Speed (ref)	3.36
Average Wind Speed (site)	2.34
Max Wind Speed (ref)	9.53
Max Wind Speed (site)	6.08
Exceedence Probability	5.000%
Wind Speed (ref)	6.39
Wind Speed (site)	4.08
Exceedence Probability	0.077%
Wind Speed (ref)	21.14
Wind Speed (site)	14.79

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

Notes:

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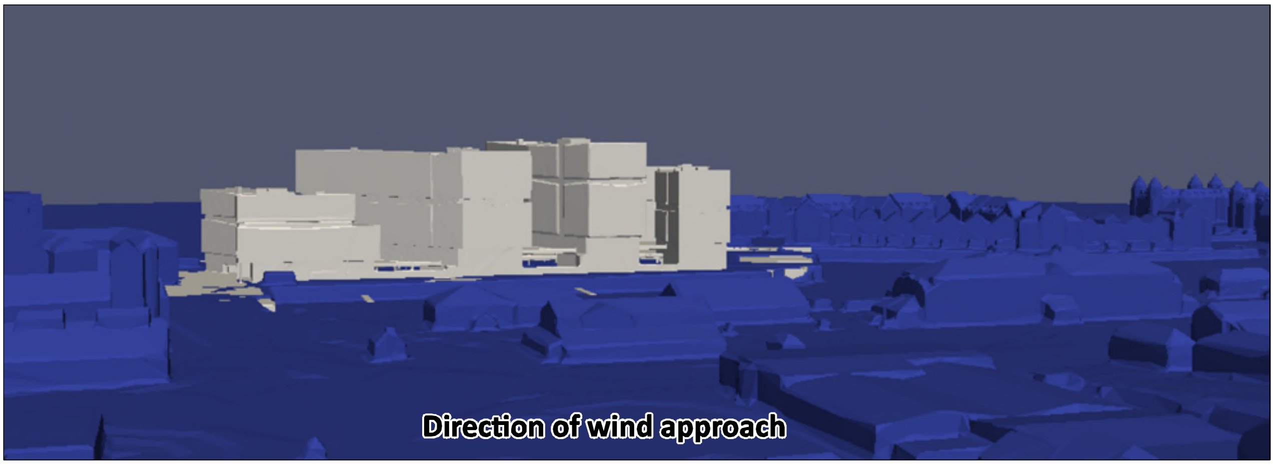
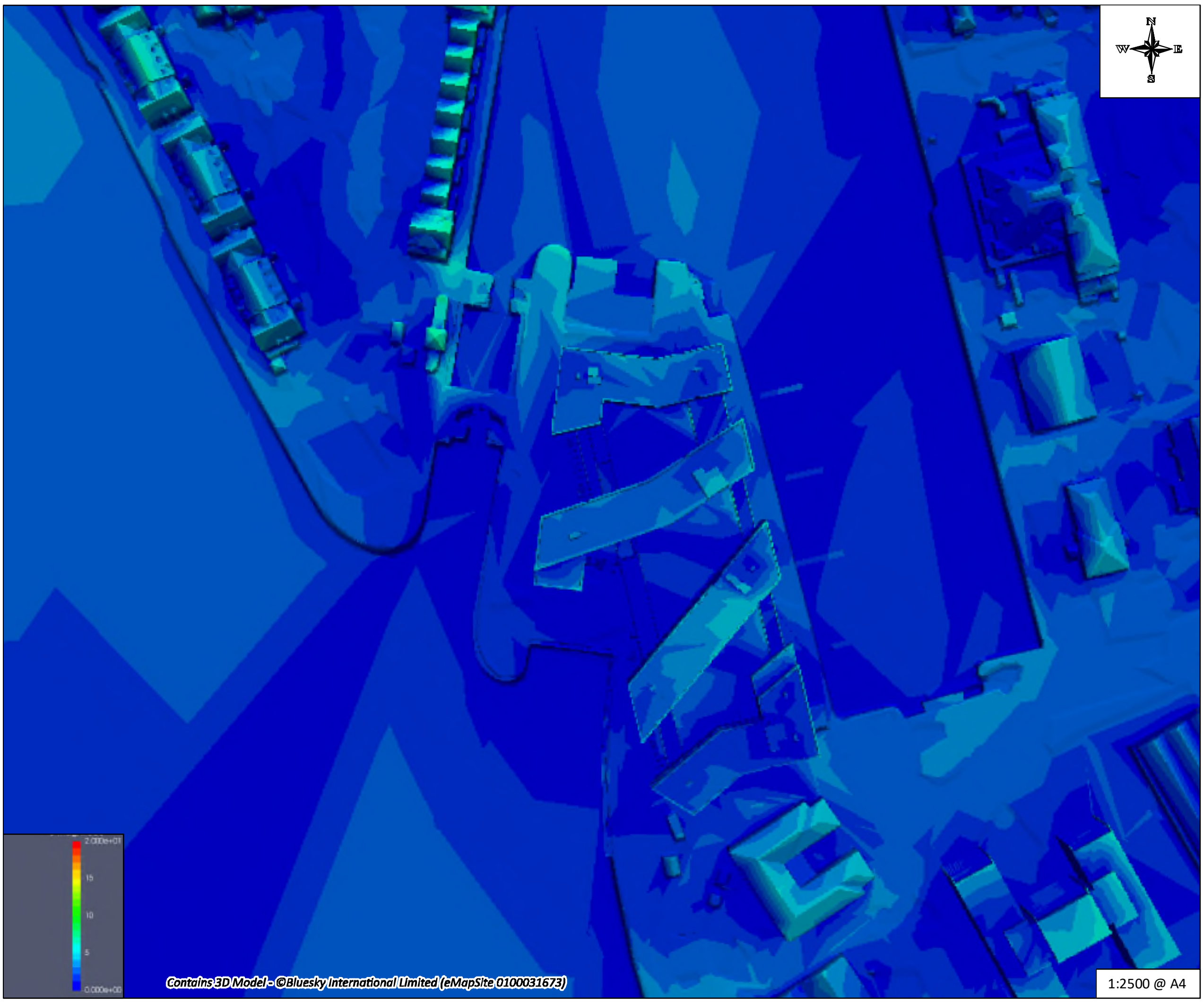
CFD Model of Wind Flow at 80°
Brunswick Quay
Liverpool

WIND_080_v001_ST16666 | Appendix 2.09

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 90°

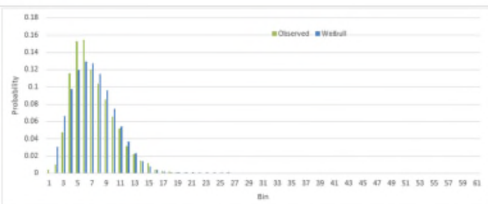




Statistics on Wind Data

Wind Direction	90.0°
Probability of occurrence	2.23%
Scale Factor (c)	3.53
Shape Factor (k)	2.38
No. data points	1871
Roughness (site)	0.5
Average Wind Speed (ref)	3.13
Average Wind Speed (site)	1.98
Max Wind Speed (ref)	8.81
Max Wind Speed (site)	5.64
Exceedence Probability	5.000%
Wind Speed (ref)	5.80
Wind Speed (site)	3.70
Exceedence Probability	0.022%
Wind Speed (ref)	21.34
Wind Speed (site)	14.29

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

Notes:

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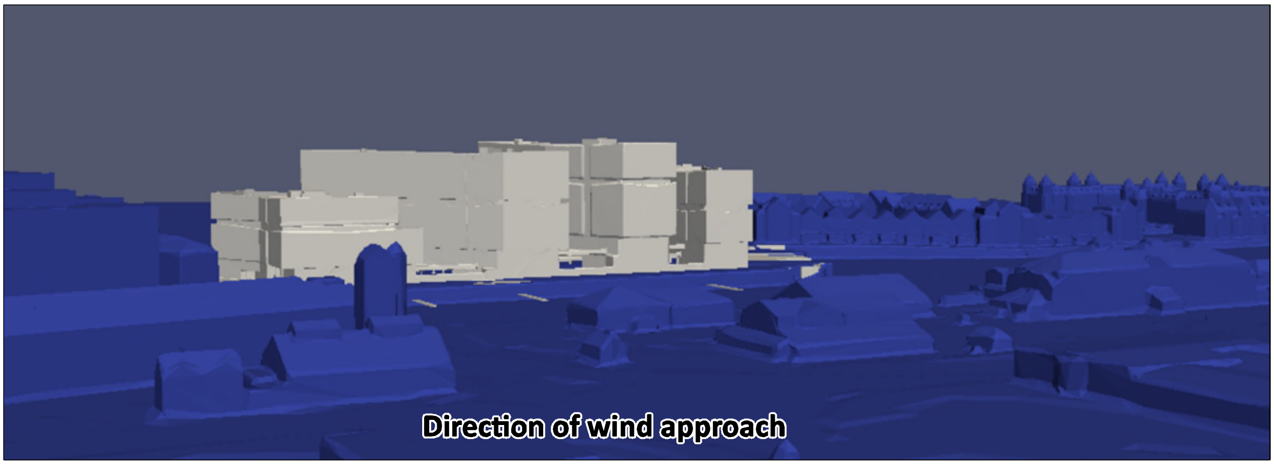
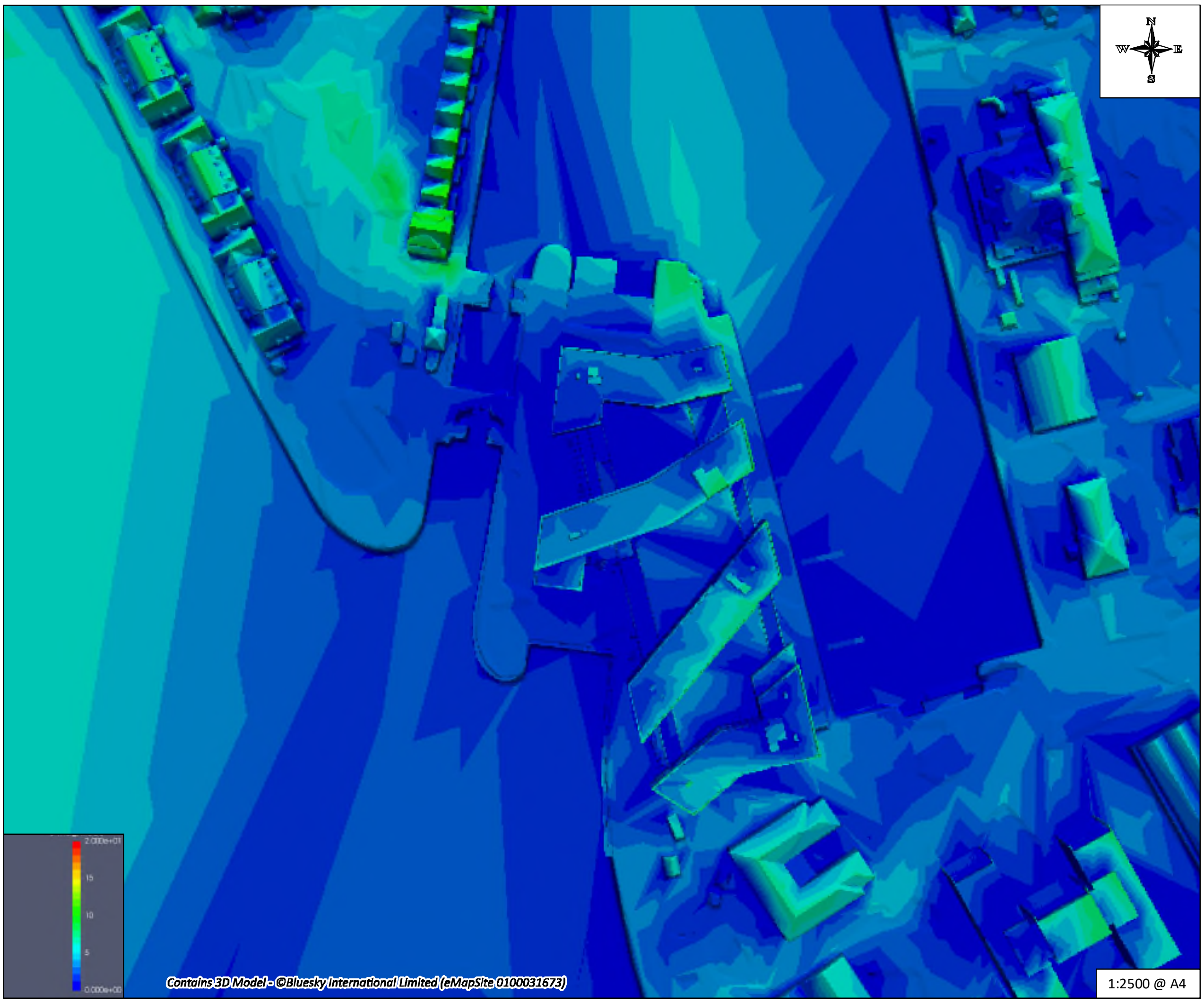
CFD Model of Wind Flow at 90°
Brunswick Quay
Liverpool

WIND_090_v001_ST16666 | Appendix 2.10

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 100°

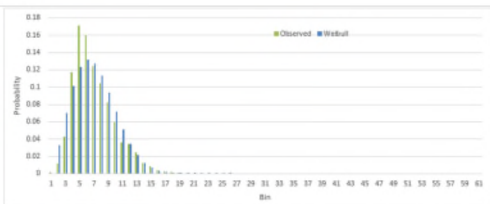




Statistics on Wind Data

Wind Direction	100.0°
Probability of occurrence	2.17%
Scale Factor (c)	3.44
Shape Factor (k)	2.16
No. data points	2010
Roughness (site)	0.5
Average Wind Speed (ref)	3.04
Average Wind Speed (site)	3.04
Max Wind Speed (ref)	9.33
Max Wind Speed (site)	9.33
Exceedence Probability	5.000%
Wind Speed (ref)	5.73
Wind Speed (site)	5.73
Exceedence Probability	0.022%
Wind Speed (ref)	21.34
Wind Speed (site)	21.34

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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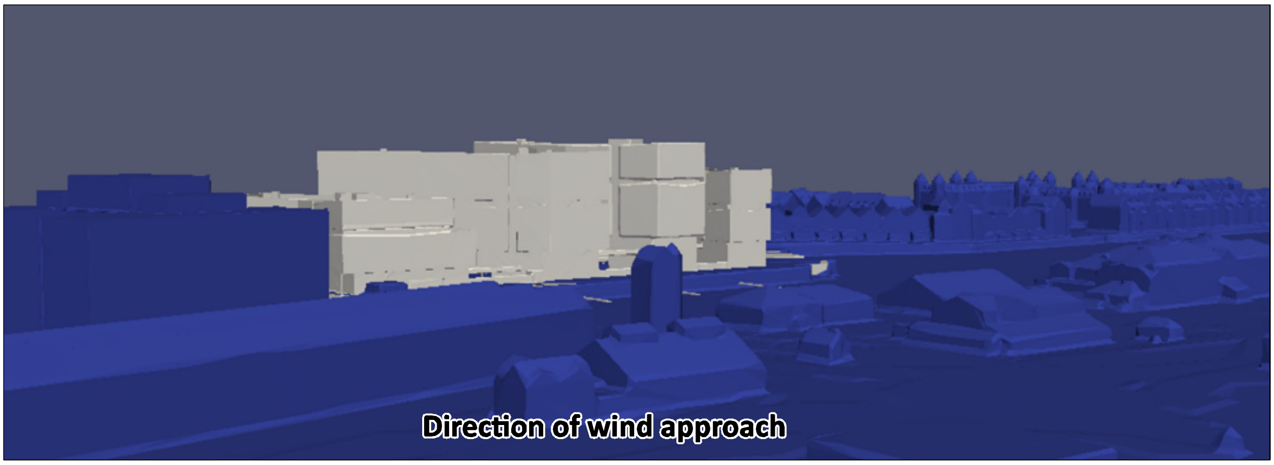
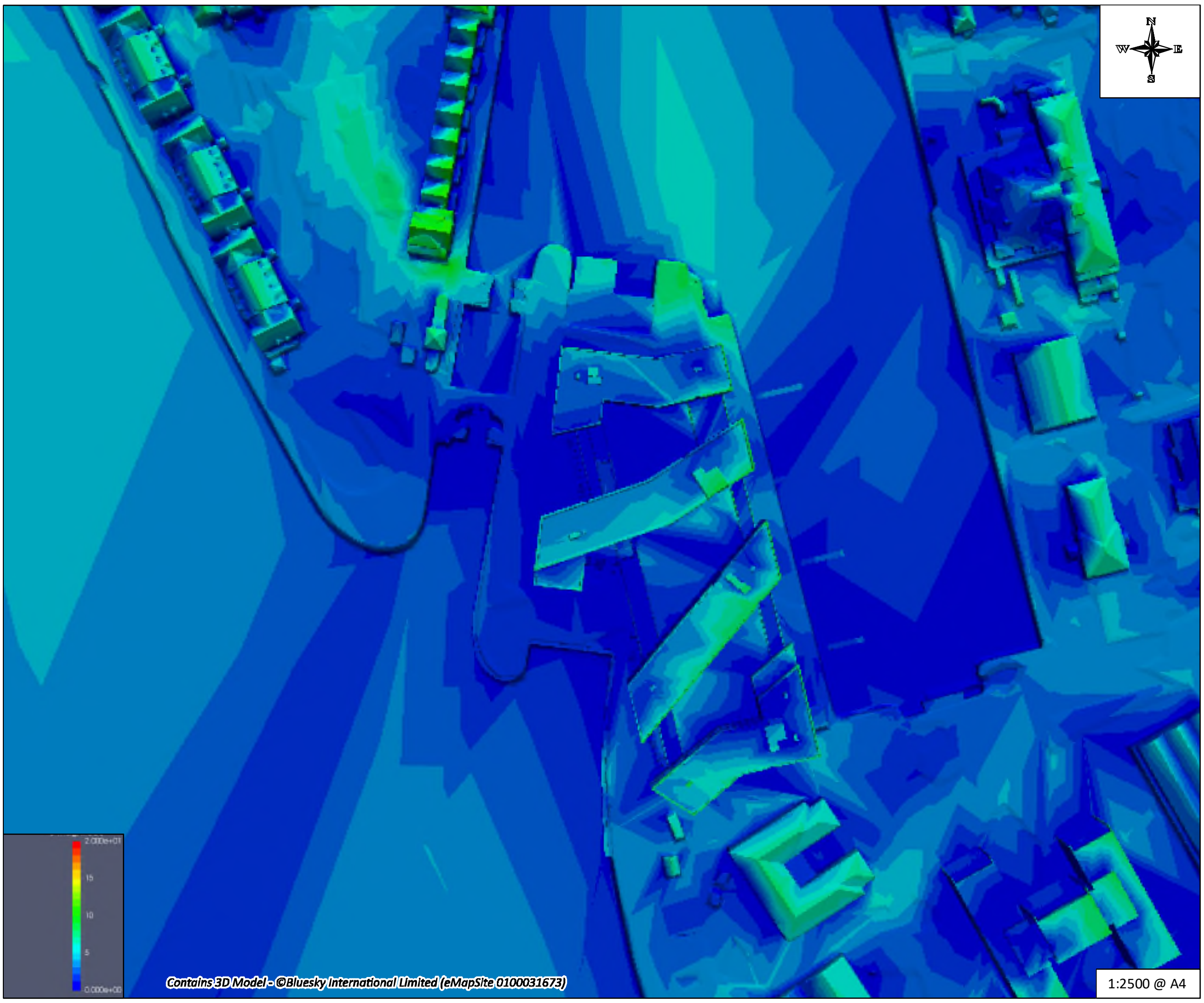
CFD Model of Wind Flow at 100°
Brunswick Quay
Liverpool

WIND_100_v001_ST16666 | Appendix 2.11

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 110°

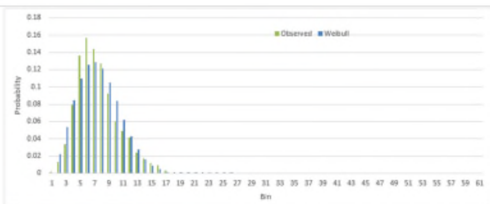




Statistics on Wind Data

Wind Direction	110.0°
Probability of occurrence	2.97%
Scale Factor (*c*)	3.69
Shape Factor (*k*)	2.12
No. data points	2523
Roughness (site)	0.5
Average Wind Speed (*ref*)	3.27
Average Wind Speed (site)	3.27
Max Wind Speed (*ref*)	8.23
Max Wind Speed (site)	8.23
Exceedence Probability	5.000%
Wind Speed (*ref*)	5.93
Wind Speed (site)	5.93
Exceedence Probability	0.022%
Wind Speed (*ref*)	23.34
Wind Speed (site)	23.34

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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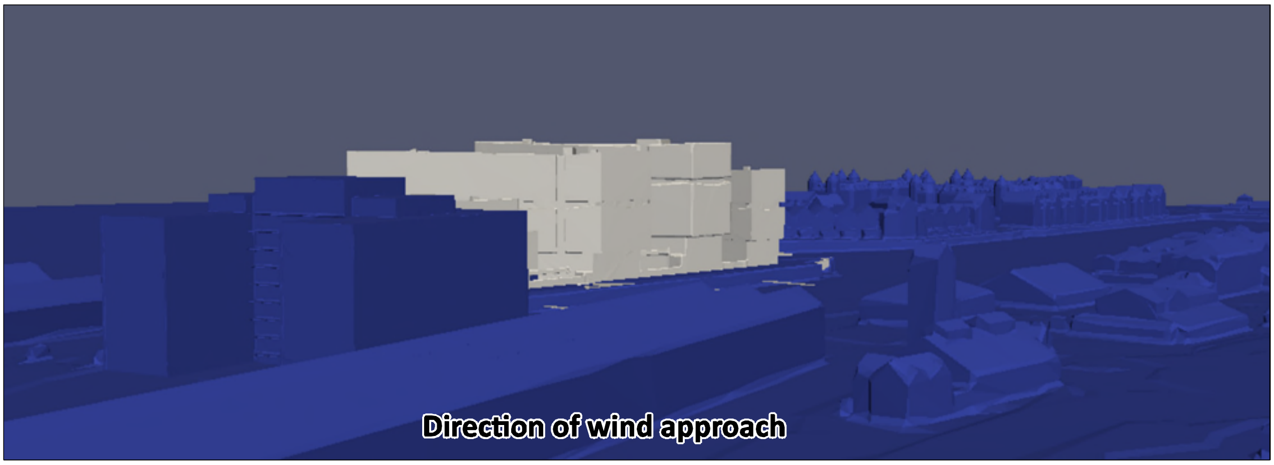
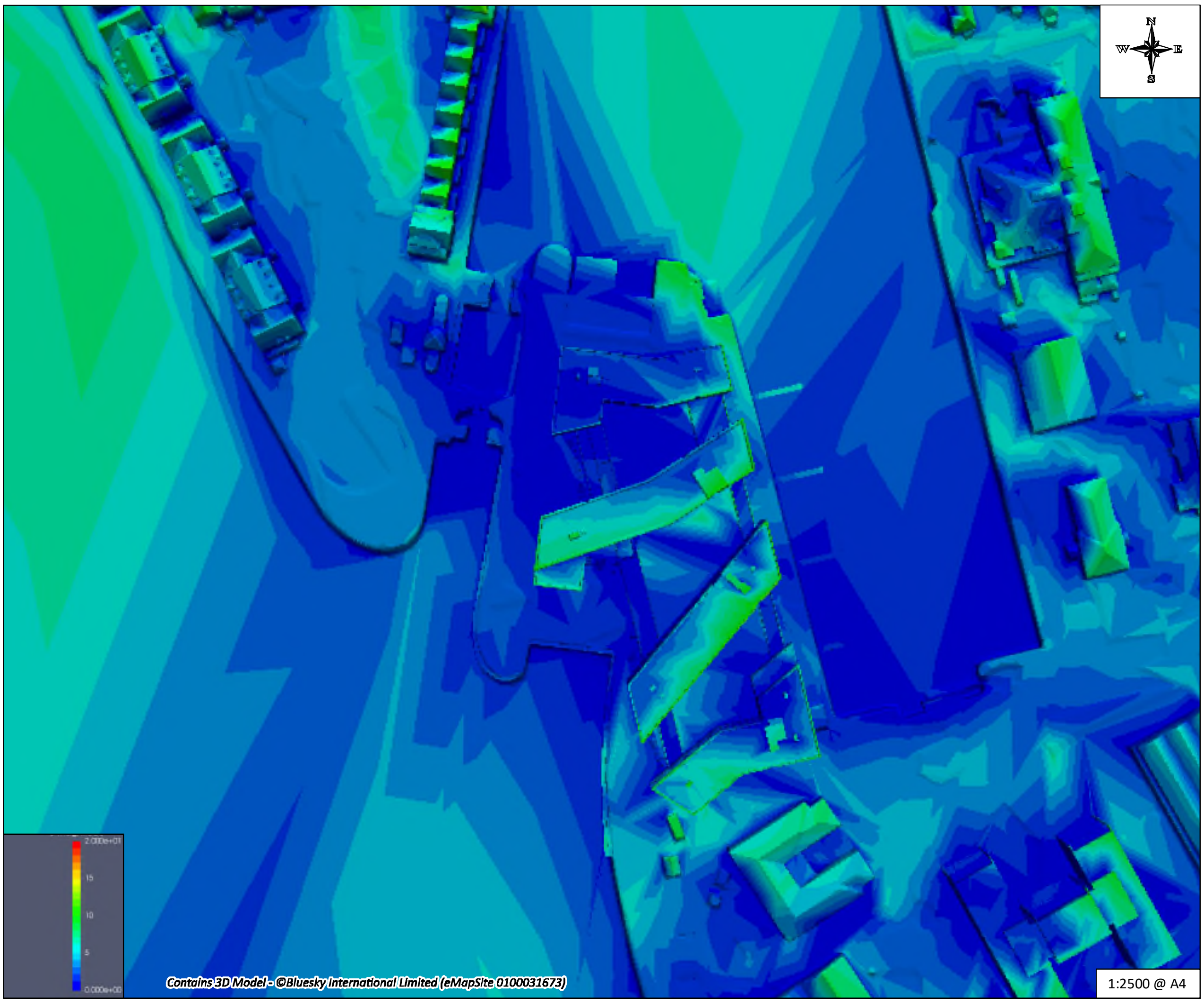
CFD Model of Wind Flow at 110°
Brunswick Quay
Liverpool

WIND_110_v001_ST16666 | Appendix 2.12

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 120°

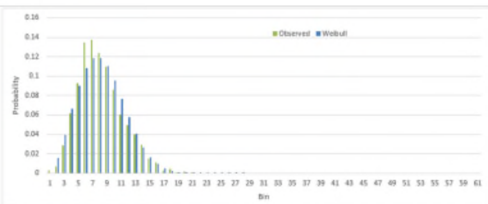




Statistics on Wind Data

Wind Direction	120.0°
Probability of occurrence	3.28%
Scale Factor (c)	4.09
Shape Factor (k)	2.40
No. data points	2278
Roughness (site)	0.5
Average Wind Speed (ref)	3.62
Average Wind Speed (site)	3.62
Max Wind Speed (ref)	9.77
Max Wind Speed (site)	9.77
Exceedence Probability	5.000%
Wind Speed (ref)	6.46
Wind Speed (site)	6.46
Exceedence Probability	0.022%
Wind Speed (ref)	23.34
Wind Speed (site)	23.34

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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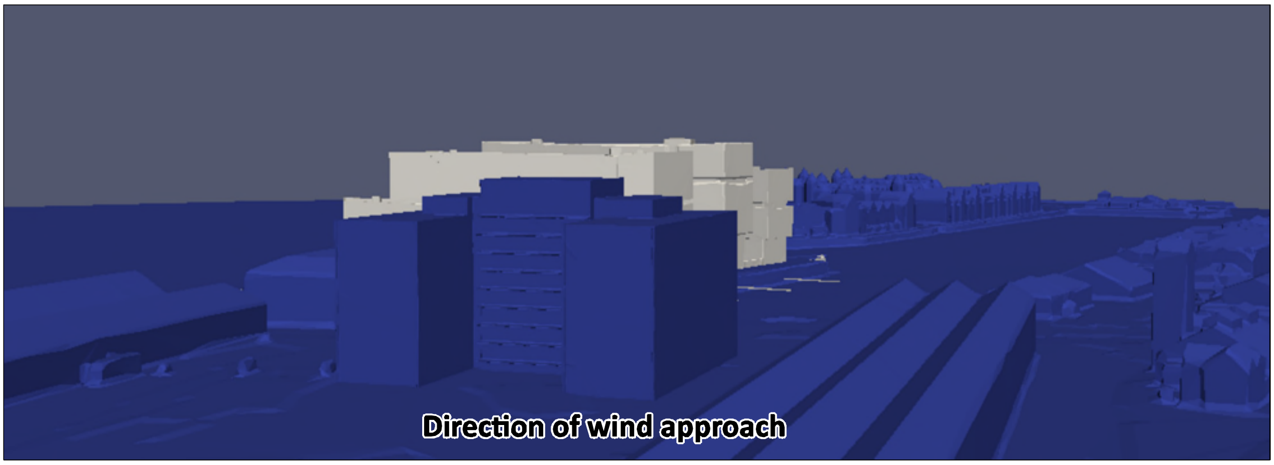
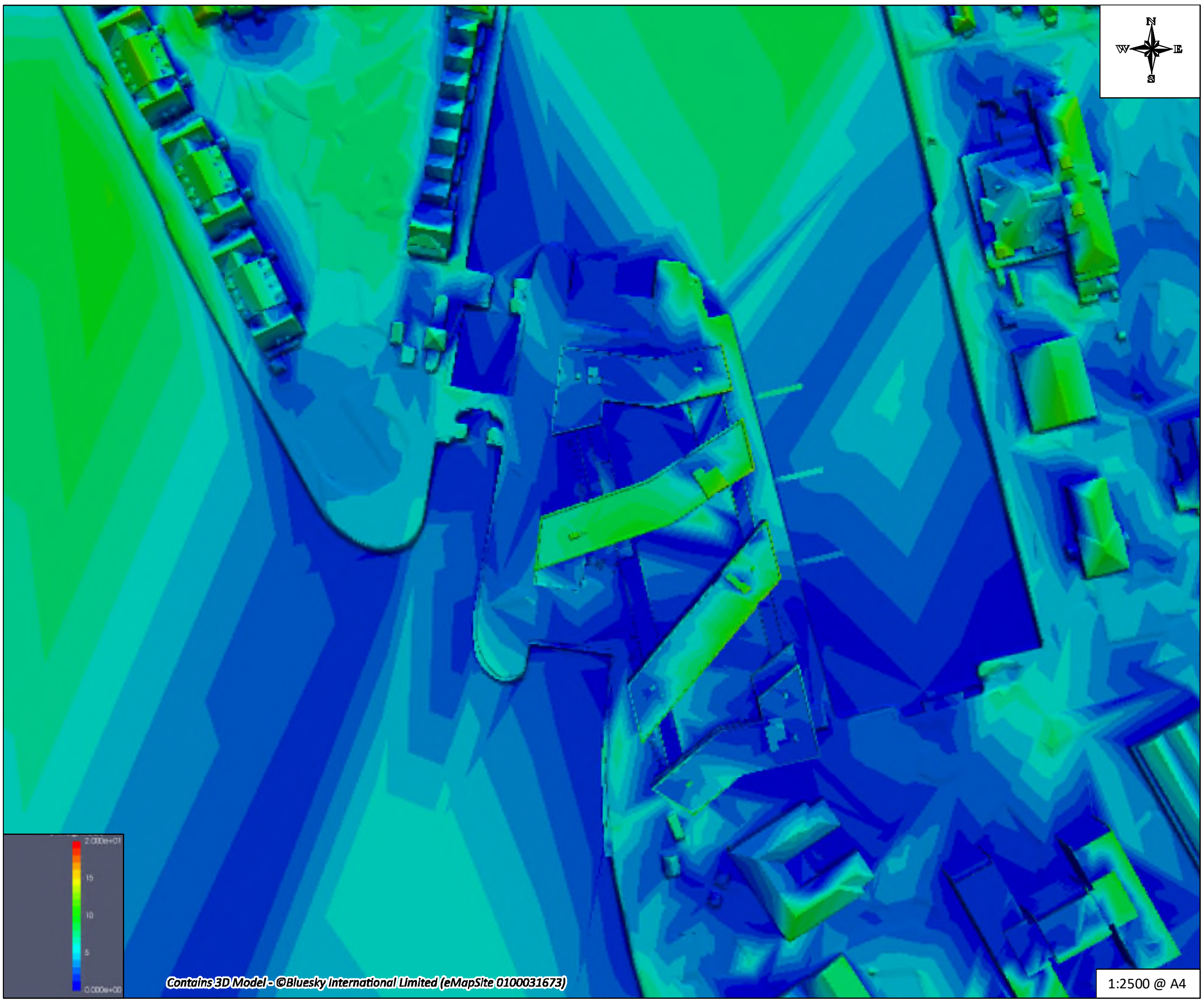
Drawn By:	S.Allen	Date:	21/06/2018
Checked By:	P.Evans	Date:	21/06/2018

CFD Model of Wind Flow at 120°
Brunswick Quay
Liverpool

WIND_120_v001_ST16666 | Appendix 2.13

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 130°

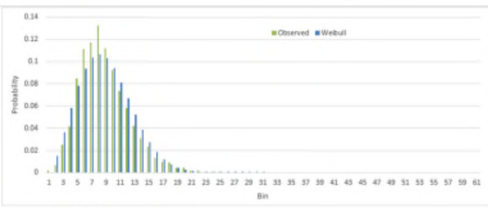




Statistics on Wind Data

Wind Direction	130.0°
Probability of occurrence	3.17%
Scale Factor (c)	4.45
Shape Factor (k)	2.30
No. data points	2689
Roughness (site)	0.5
Average Wind Speed (ref)	3.94
Average Wind Speed (site)	3.94
Max Wind Speed (ref)	11.81
Max Wind Speed (site)	11.81
Exceedence Probability	5.000%
Wind Speed (ref)	7.17
Wind Speed (site)	7.17
Exceedence Probability	0.022%
Wind Speed (ref)	21.14
Wind Speed (site)	21.14

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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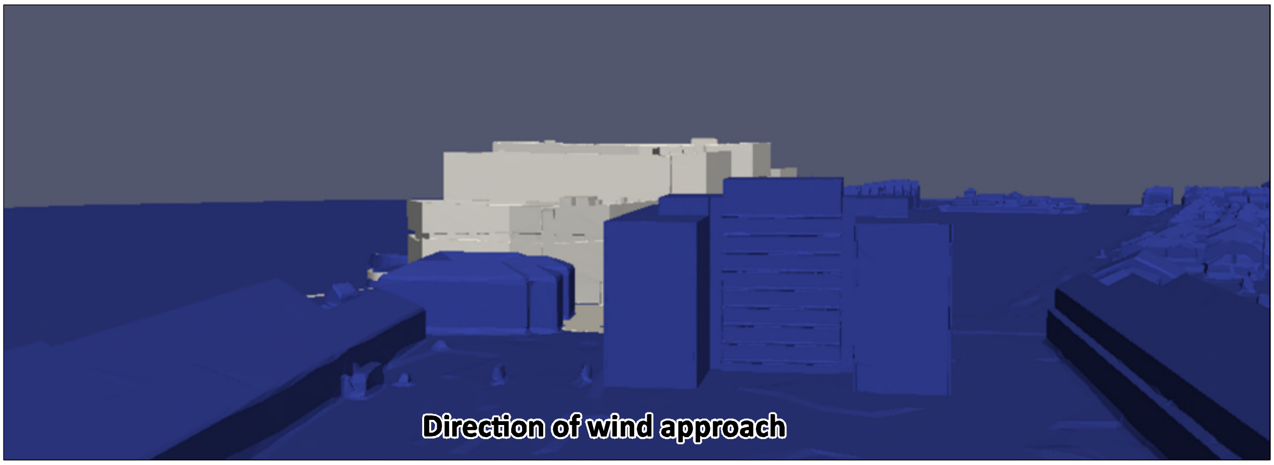
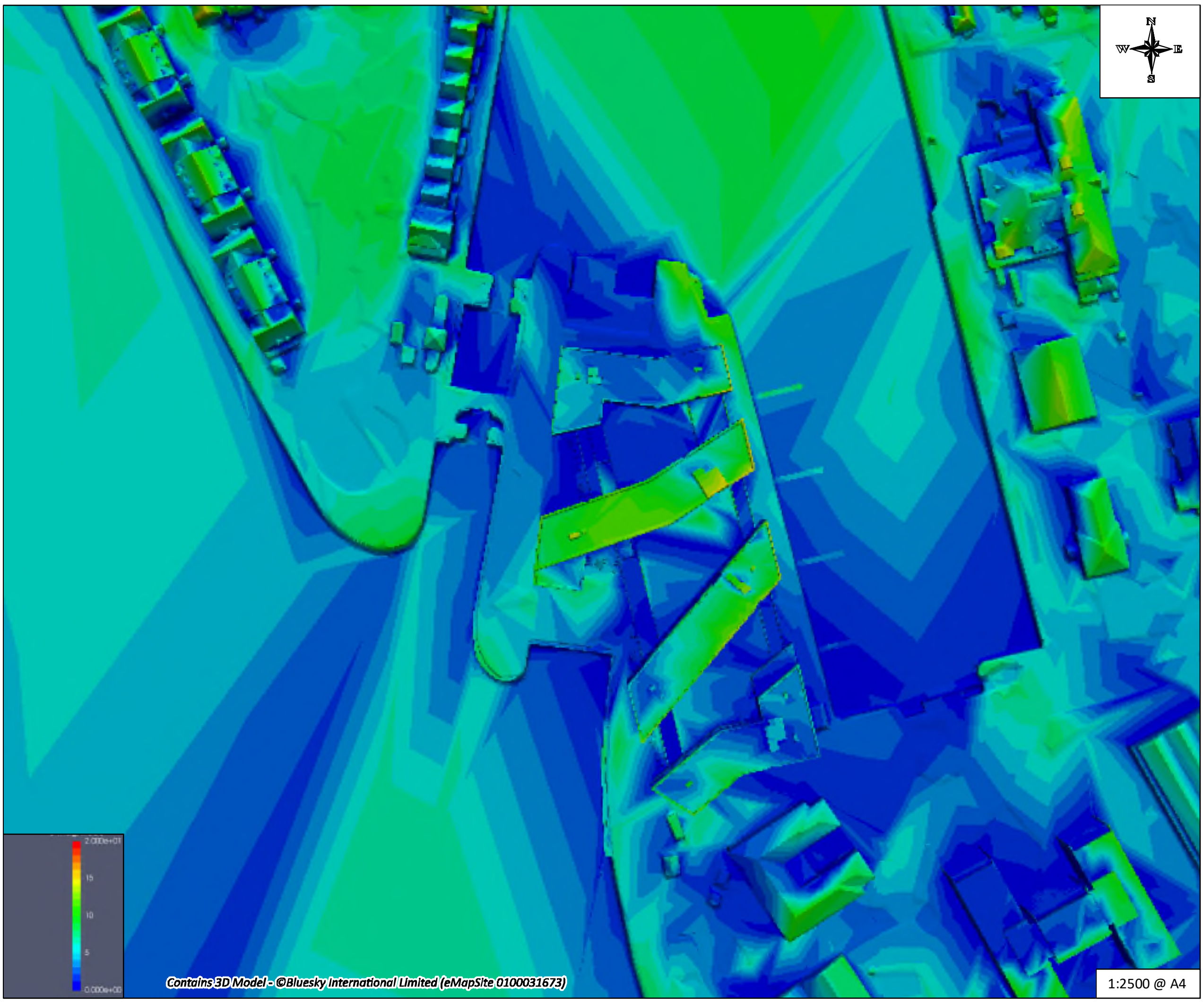
CFD Model of Wind Flow at 130°
Brunswick Quay
Liverpool

WIND_130_v001_ST16666 | Appendix 2.14

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 140°

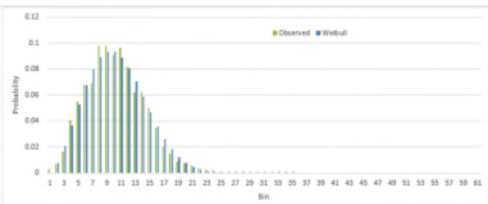




Statistics on Wind Data

Wind Direction	140.0°
Probability of occurrence	3.26%
Scale Factor (c)	5.26
Shape Factor (k)	2.43
No. data points	2,802
Roughness (site)	0.5
Average Wind Speed (ref)	4.66
Average Wind Speed (site)	4.66
Max Wind Speed (ref)	33.83
Max Wind Speed (site)	33.83
Exceedence Probability	5.000%
Wind Speed (ref)	8.25
Wind Speed (site)	8.25
Exceedence Probability	0.022%
Wind Speed (ref)	23.34
Wind Speed (site)	23.34

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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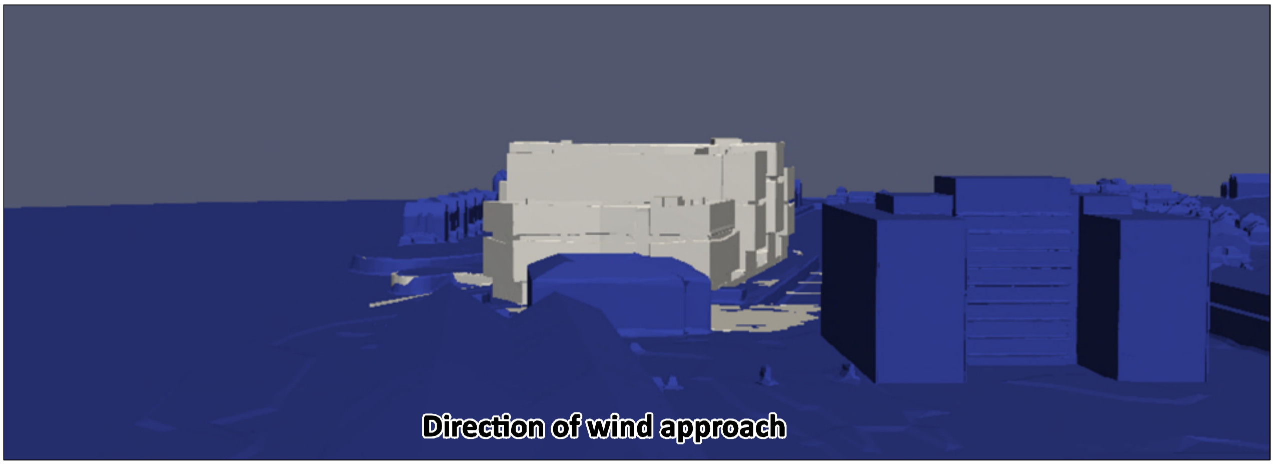
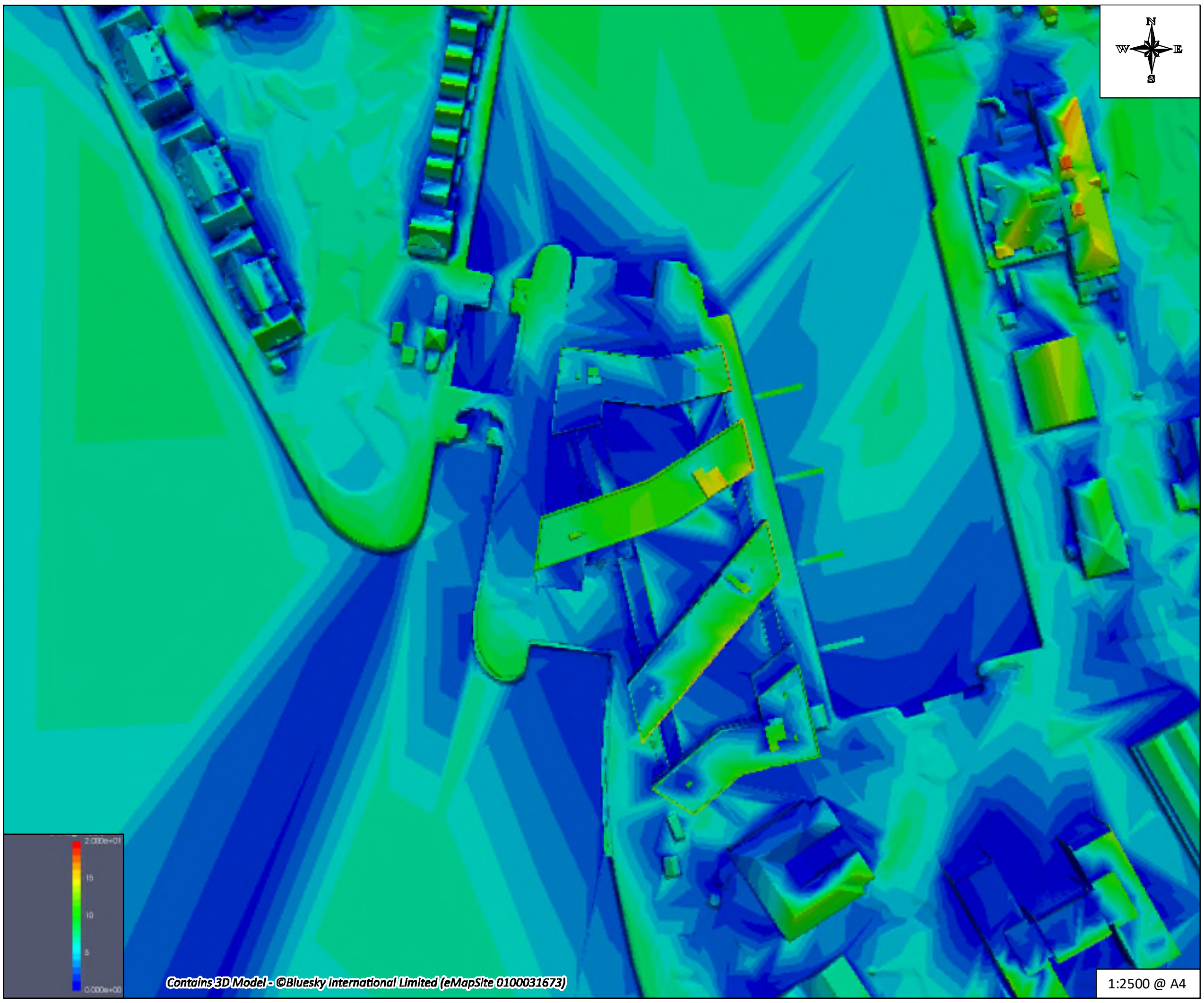
CFD Model of Wind Flow at 140°
Brunswick Quay
Liverpool

WIND_140_v001_ST16666 | Appendix 2.15

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 150°

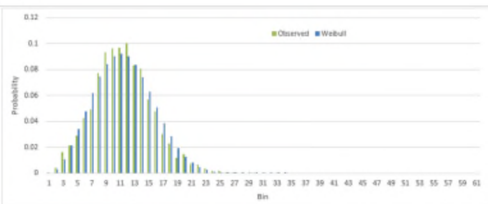




Statistics on Wind Data

Wind Direction	150.0°
Probability of occurrence	4.87%
Scale Factor (c)	5.87
Shape Factor (k)	2.74
No. data points	4327
Roughness (site)	0.5
Average Wind Speed (ref)	5.21
Average Wind Speed (site)	5.21
Max Wind Speed (ref)	14.70
Max Wind Speed (site)	14.70
Exceedence Probability	5.000%
Wind Speed (ref)	8.77
Wind Speed (site)	8.77
Exceedence Probability	0.027%
Wind Speed (ref)	21.14
Wind Speed (site)	21.14

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

Notes:

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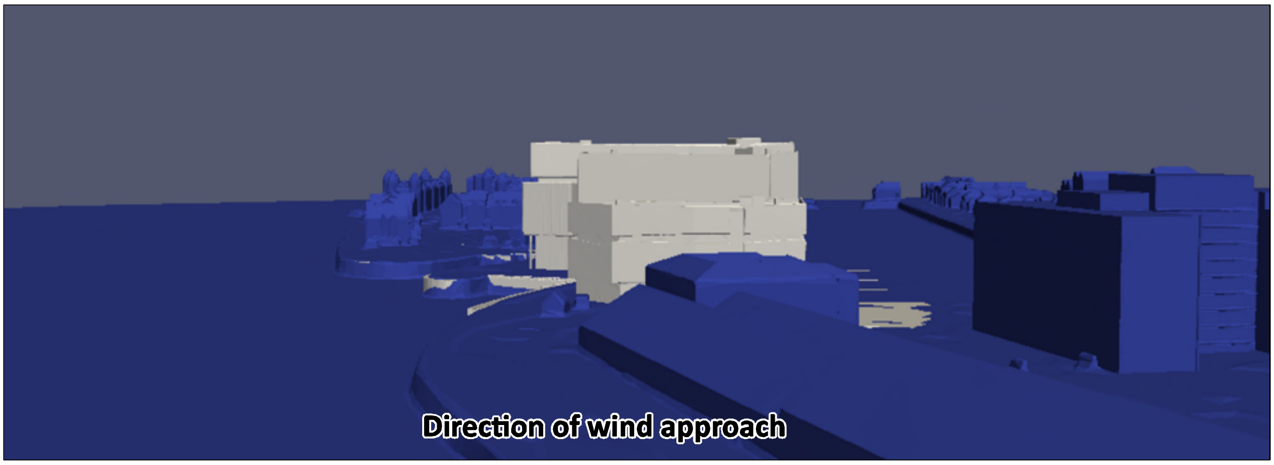
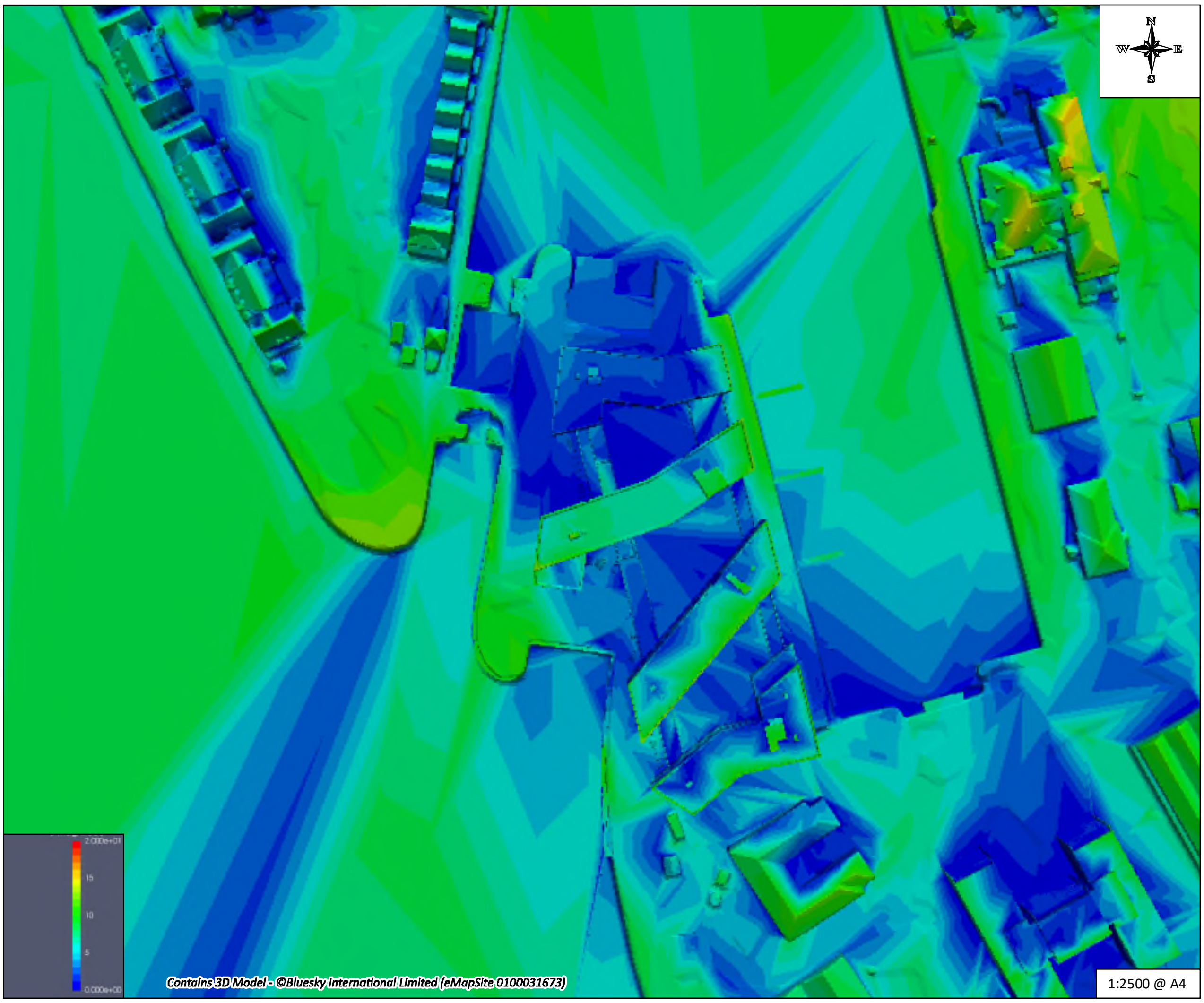
CFD Model of Wind Flow at 150°
Brunswick Quay
Liverpool

WIND_150_v001_ST16666 | Appendix 2.16

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 160°

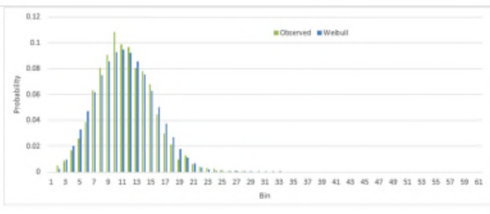




Statistics on Wind Data

Wind Direction	[illegible]
Probability of occurrence	4.30%
Scale Factor (c)	5.84
Shape Factor (k)	2.03
No. data points	4086
Roughness (site)	0.5
Average Wind Speed (ref)	5.20
Average Wind Speed (site)	5.20
Max Wind Speed (ref)	13.84
Max Wind Speed (site)	13.84
Exceedence Probability	5.000%
Wind Speed (ref)	8.64
Wind Speed (site)	8.64
Exceedence Probability	0.022%
Wind Speed (ref)	21.14
Wind Speed (site)	21.14

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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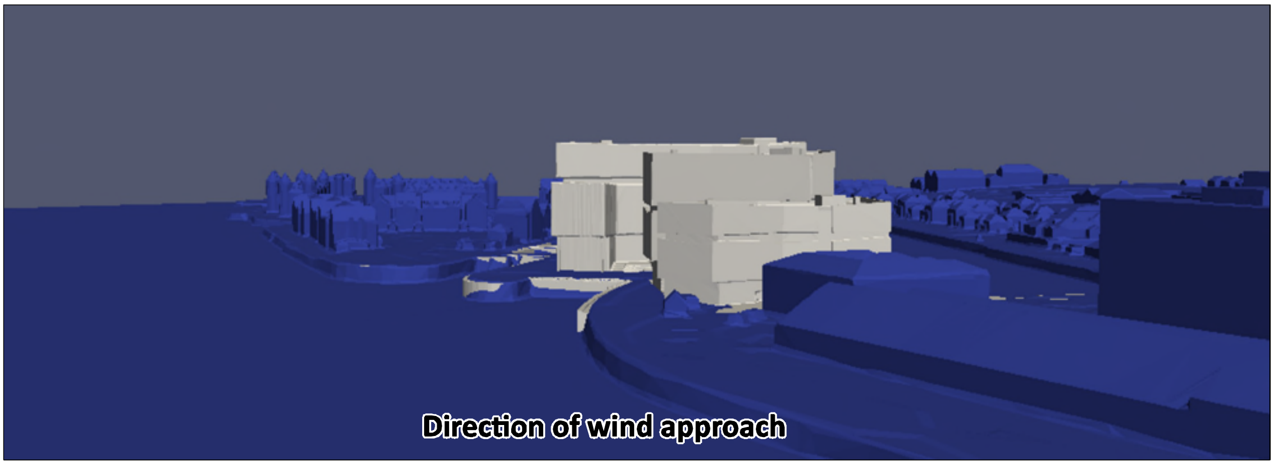
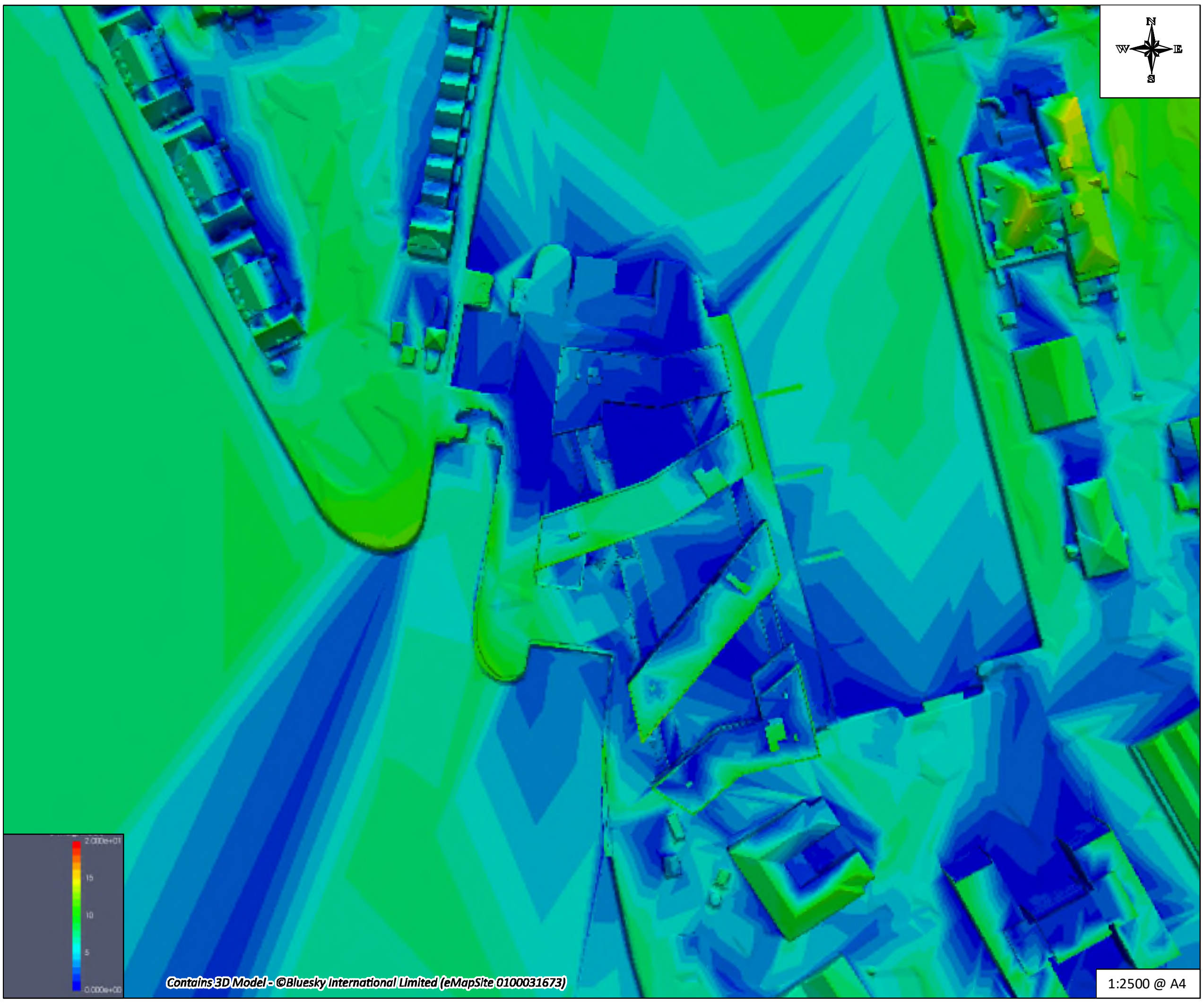
CFD Model of Wind Flow at 160°
Brunswick Quay
Liverpool

WIND_160_v001_ST16666 | Appendix 2.17

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 170°

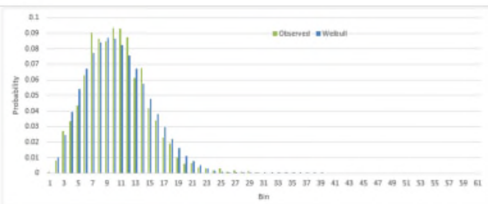




Statistics on Wind Data

Wind Direction	170.0°
Probability of occurrence	2.40%
Scale Factor (c)	5.37
Shape Factor (k)	2.27
No. data points	2014
Roughness (site)	0.003
Average Wind Speed (ref)	4.76
Average Wind Speed (site)	4.76
Max Wind Speed (ref)	34.67
Max Wind Speed (site)	34.67
Exceedence Probability	5.000%
Wind Speed (ref)	8.71
Wind Speed (site)	8.71
Exceedence Probability	0.022%
Wind Speed (ref)	23.34
Wind Speed (site)	23.34

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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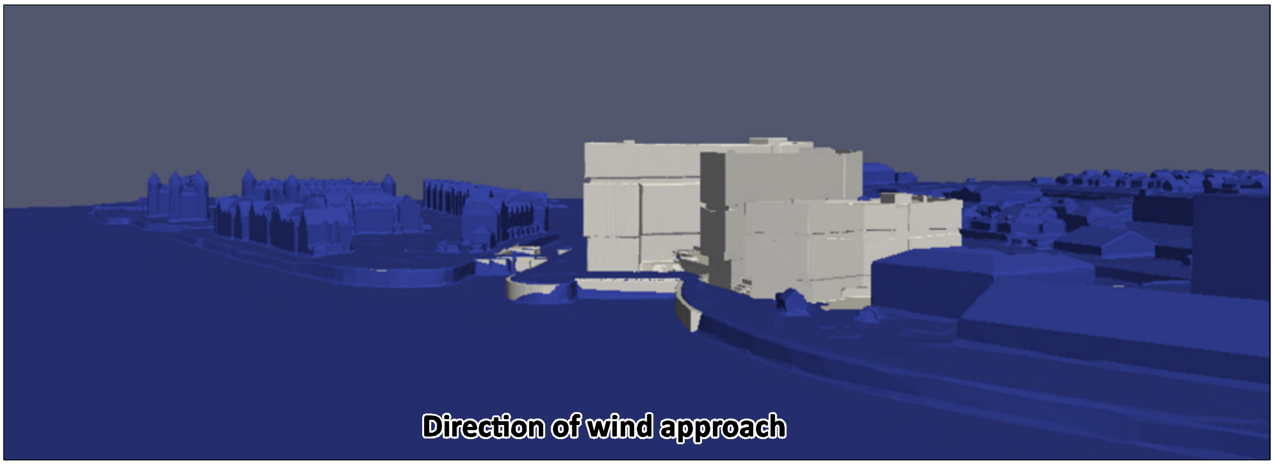
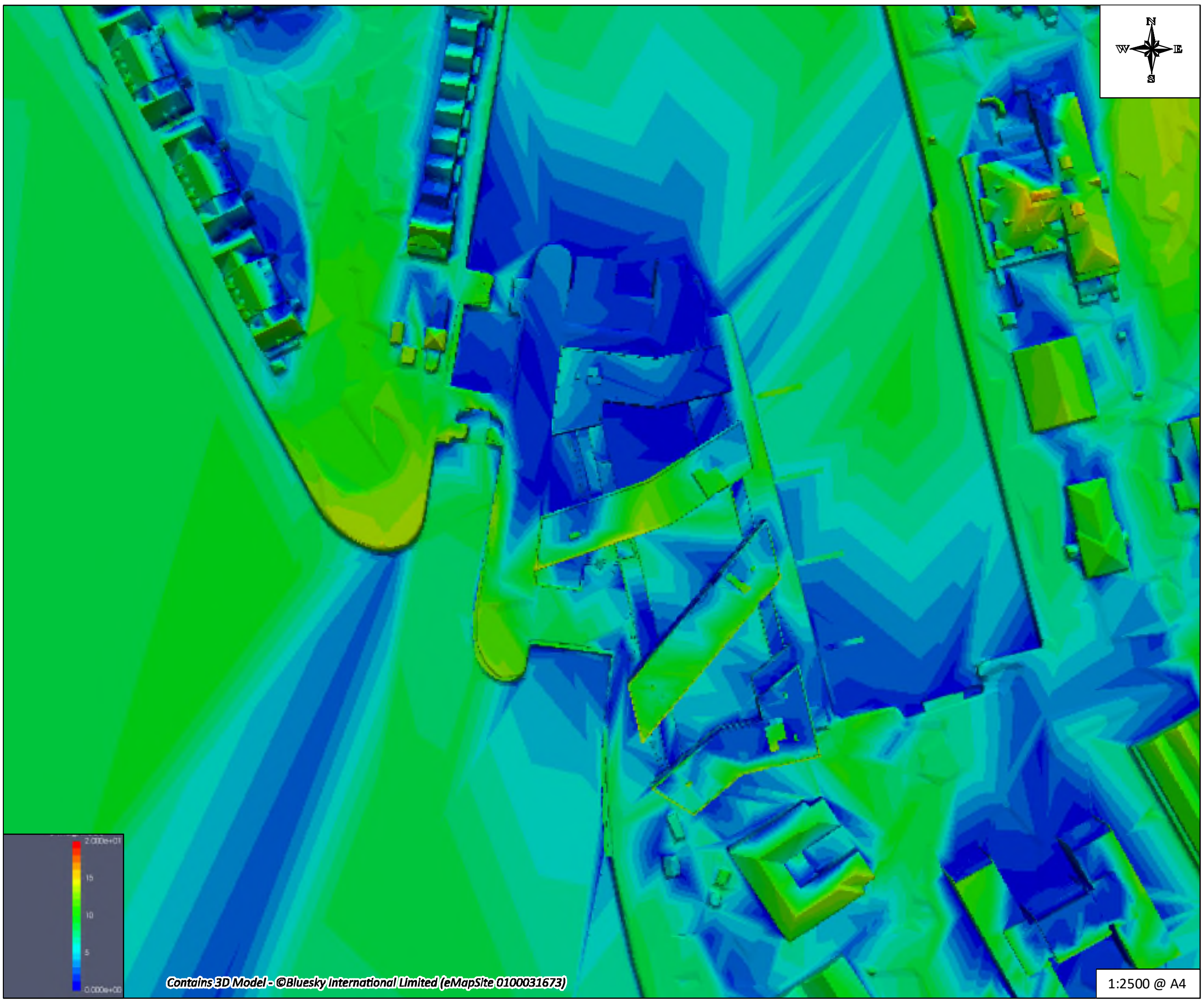
CFD Model of Wind Flow at 170°
Brunswick Quay
Liverpool

WIND_170_v001_ST16666 | Appendix 2.18

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 180°

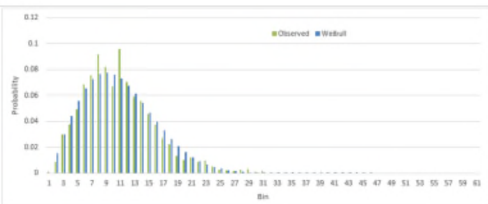




Statistics on Wind Data

Wind Direction	180.0°
Probability of occurrence	2.30%
Scale Factor (c)	5.57
Shape Factor (k)	2.03
No. data points	1955
Roughness (site)	0.003
Average Wind Speed (ref)	4.93
Average Wind Speed (site)	4.93
Max Wind Speed (ref)	14.92
Max Wind Speed (site)	14.92
Exceedence Probability	5.000%
Wind Speed (ref)	9.57
Wind Speed (site)	9.57
Exceedence Probability	0.022%
Wind Speed (ref)	21.14
Wind Speed (site)	21.14

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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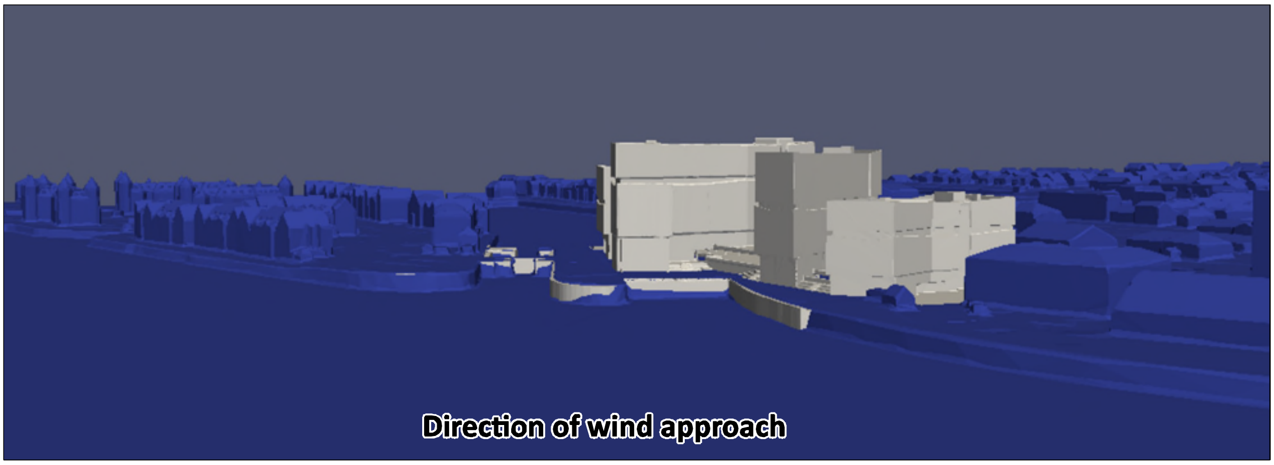
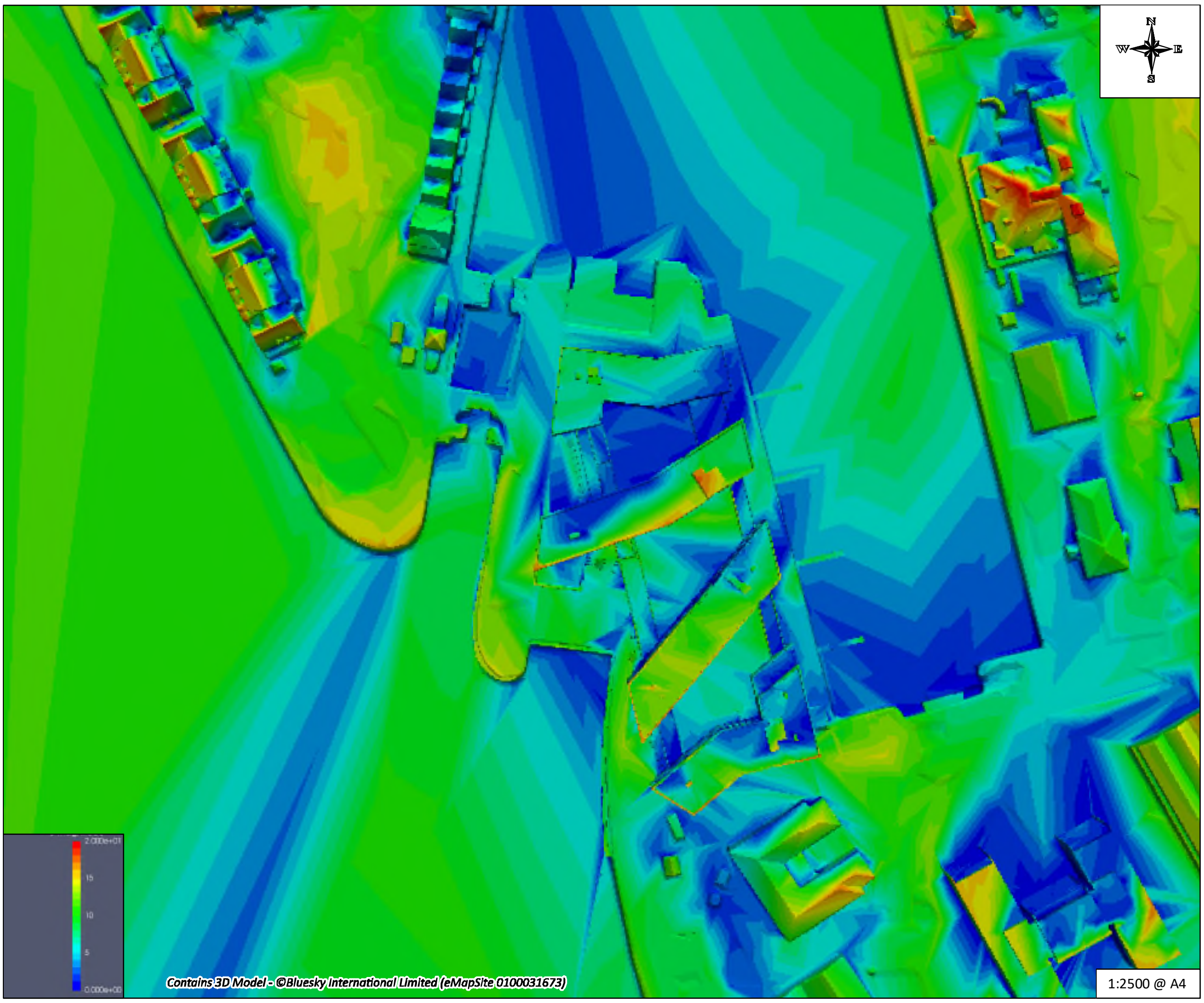
CFD Model of Wind Flow at 180°
Brunswick Quay
Liverpool

WIND_180_v001_ST16666 | Appendix 2.19

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 190°

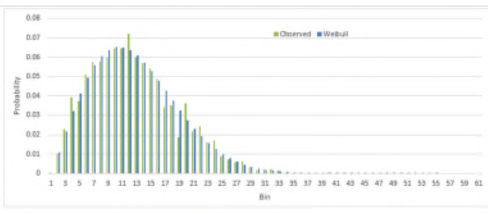




Statistics on Wind Data

Wind Direction	190.0°
Probability of occurrence	2.28%
Scale Factor (c)	6.60
Shape Factor (k)	2.07
No. data points	3934
Roughness (site)	0.001
Average Wind Speed (ref)	5.86
Average Wind Speed (site)	5.86
Max Wind Speed (ref)	19.67
Max Wind Speed (site)	19.67
Exceedence Probability	5.000%
Wind Speed (ref)	11.38
Wind Speed (site)	11.38
Exceedence Probability	0.07?%
Wind Speed (ref)	21.14
Wind Speed (site)	21.14

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

Notes:

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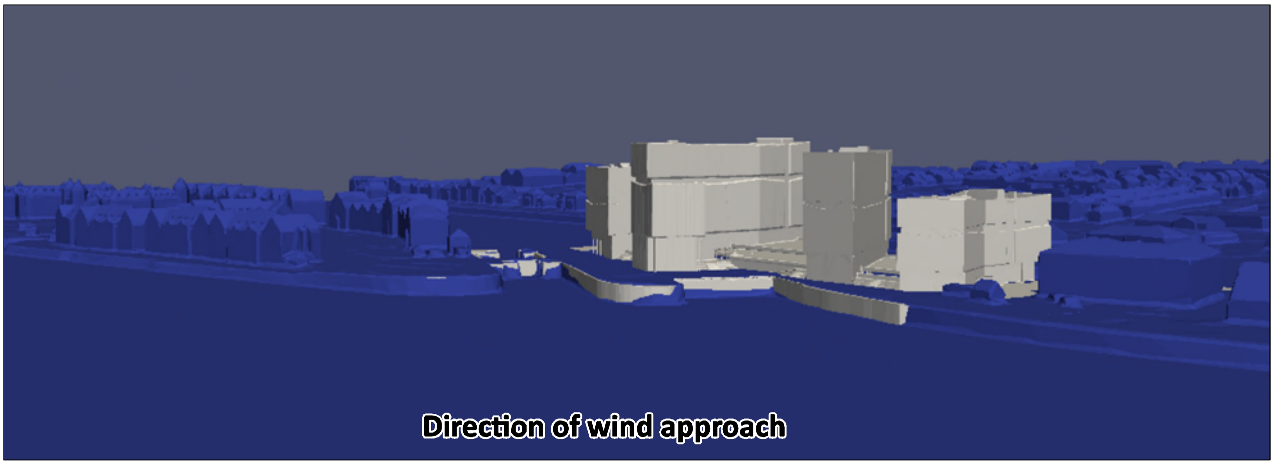
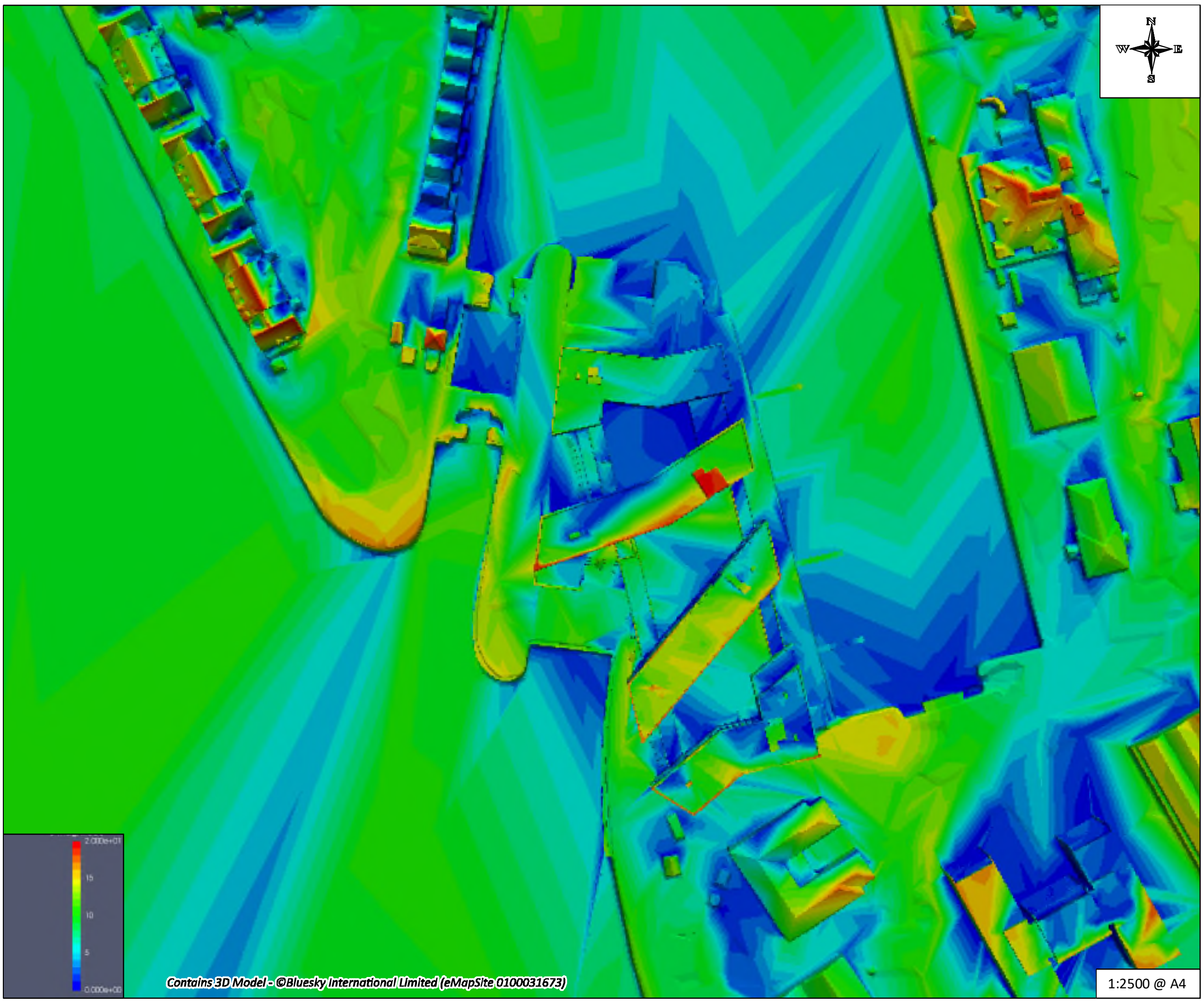
CFD Model of Wind Flow at 190°
Brunswick Quay
Liverpool

WIND_190_v001_ST16666 | Appendix 2.20

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 200°

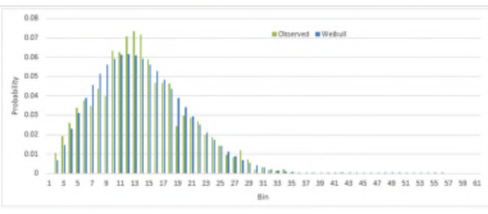




Statistics on Wind Data

Wind Direction	200.0°
Probability of occurrence	2.57%
Scale Factor (c)	7.30
Shape Factor (k)	2.35
No. data points	2378
Roughness (site)	0.001
Average Wind Speed (ref)	3.46
Average Wind Speed (site)	3.46
Max Wind Speed (ref)	20.61
Max Wind Speed (site)	20.61
Exceedence Probability	5.000%
Wind Speed (ref)	12.16
Wind Speed (site)	12.16
Exceedence Probability	0.077%
Wind Speed (ref)	21.34
Wind Speed (site)	21.34

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

Notes:

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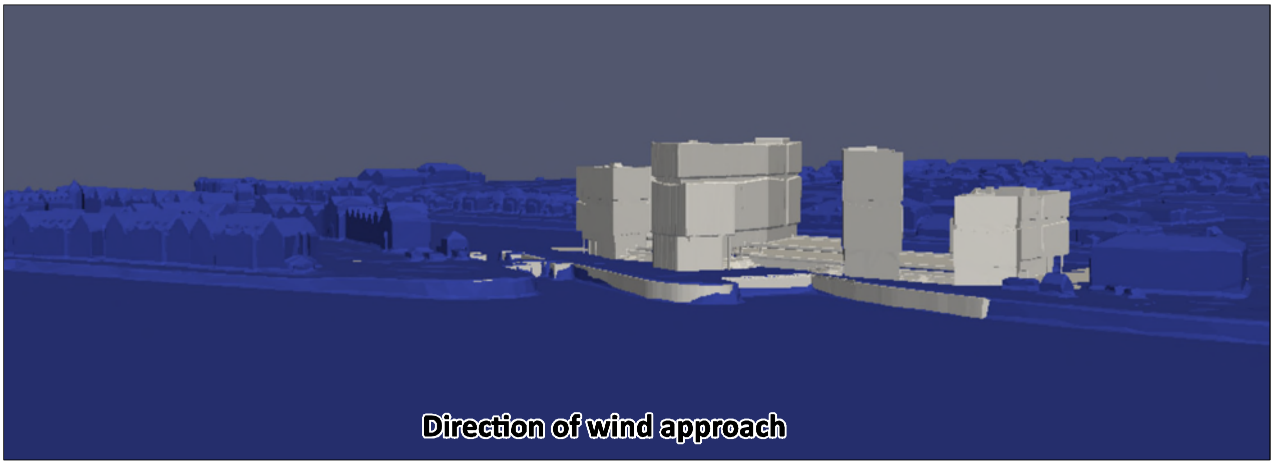
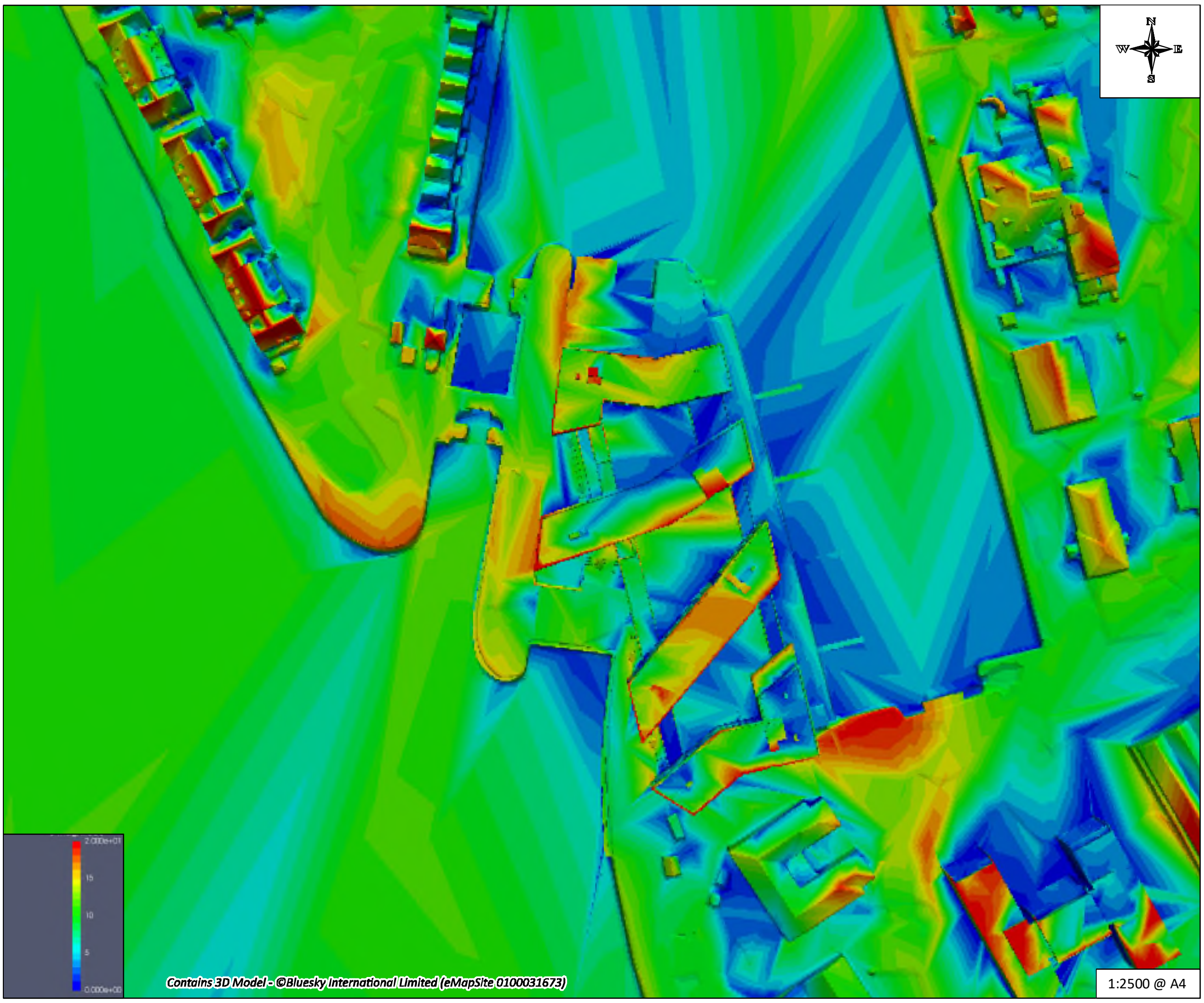
CFD Model of Wind Flow at 200°
Brunswick Quay
Liverpool

WIND_200_v001_ST16666 | Appendix 2.21

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 210°

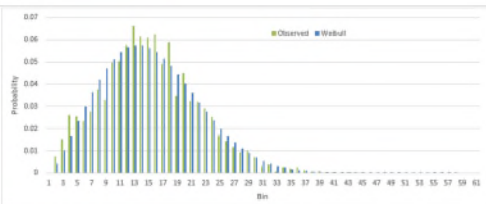




Statistics on Wind Data

Wind Direction	210.0°
Probability of occurrence	3.33%
Scale Factor (c)	8.07
Shape Factor (k)	2.25
No. data points	2823
Roughness (site)	0.003
Average Wind Speed (ref)	7.15
Average Wind Speed (site)	7.15
Max Wind Speed (ref)	21.87
Max Wind Speed (site)	21.87
Exceedence Probability	5.000%
Wind Speed (ref)	11.16
Wind Speed (site)	11.16
Exceedence Probability	0.022%
Wind Speed (ref)	21.14
Wind Speed (site)	21.14

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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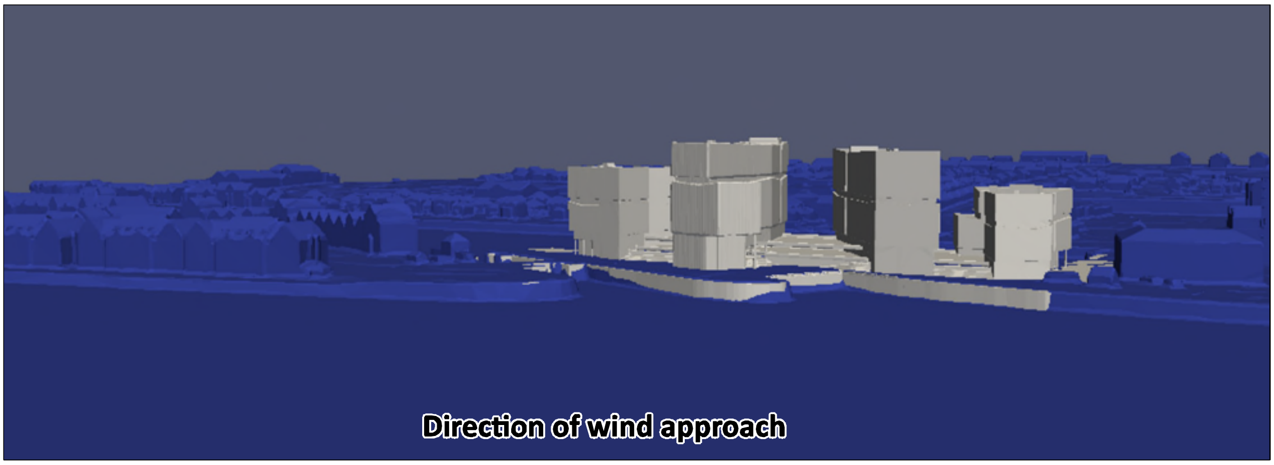
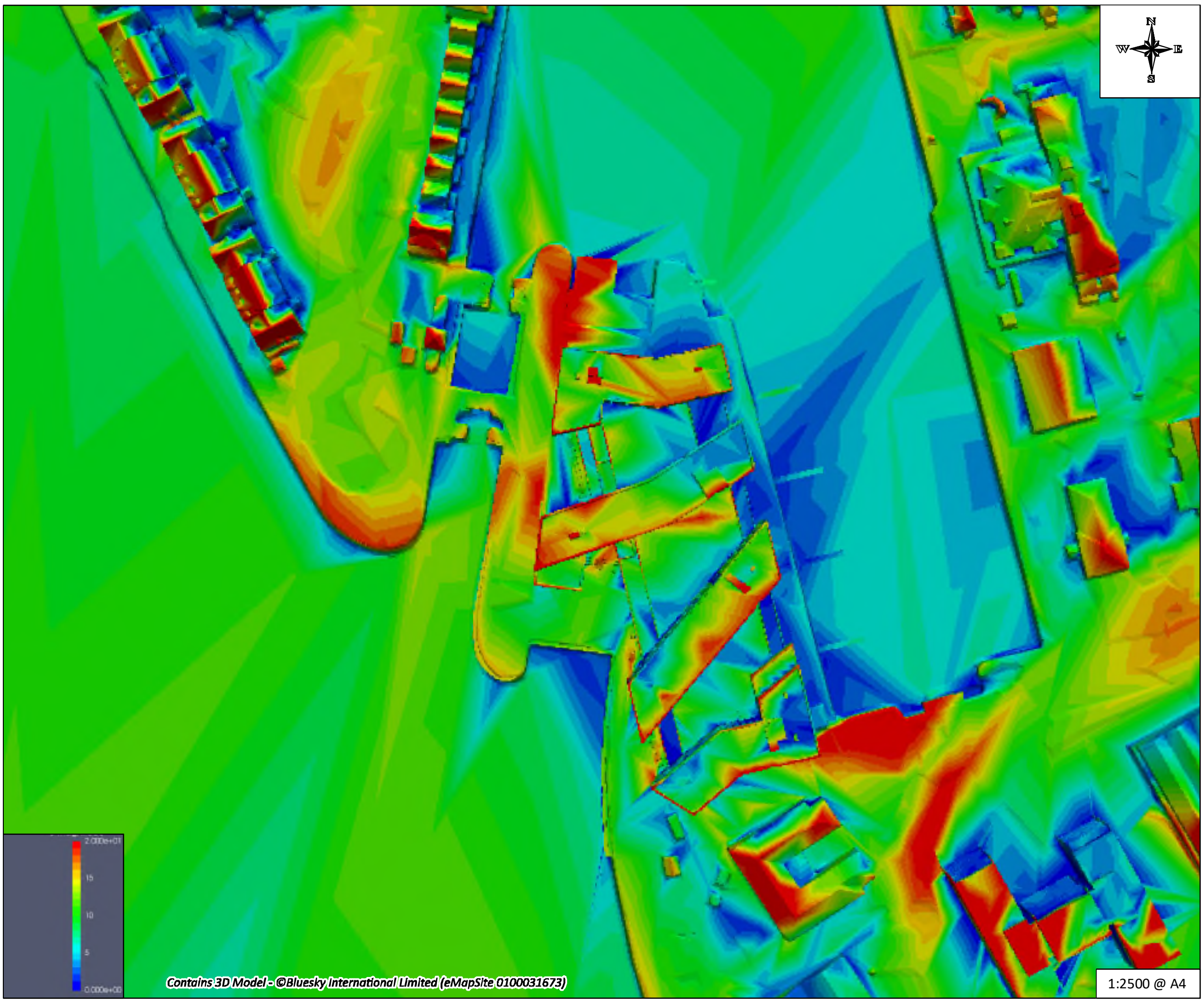
CFD Model of Wind Flow at 210°
Brunswick Quay
Liverpool

WIND_210_v001_ST16666 | Appendix 2.22

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 220°

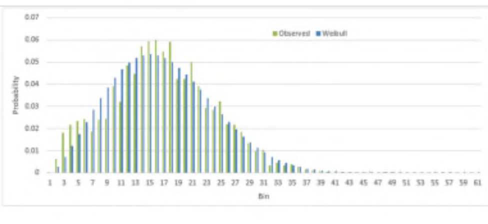




Statistics on Wind Data

Wind Direction	220.0°
Probability of occurrence	3.59%
Scale Factor (c)	8.92
Shape Factor (k)	2.12
No. data points	3044
Roughness (site)	0.003
Average Wind Speed (ref)	7.90
Average Wind Speed (site)	7.90
Max Wind Speed (ref)	24.00
Max Wind Speed (site)	24.00
Exceedence Probability	5.000%
Wind Speed (ref)	14.13
Wind Speed (site)	14.13
Exceedence Probability	0.022%
Wind Speed (ref)	23.34
Wind Speed (site)	23.34

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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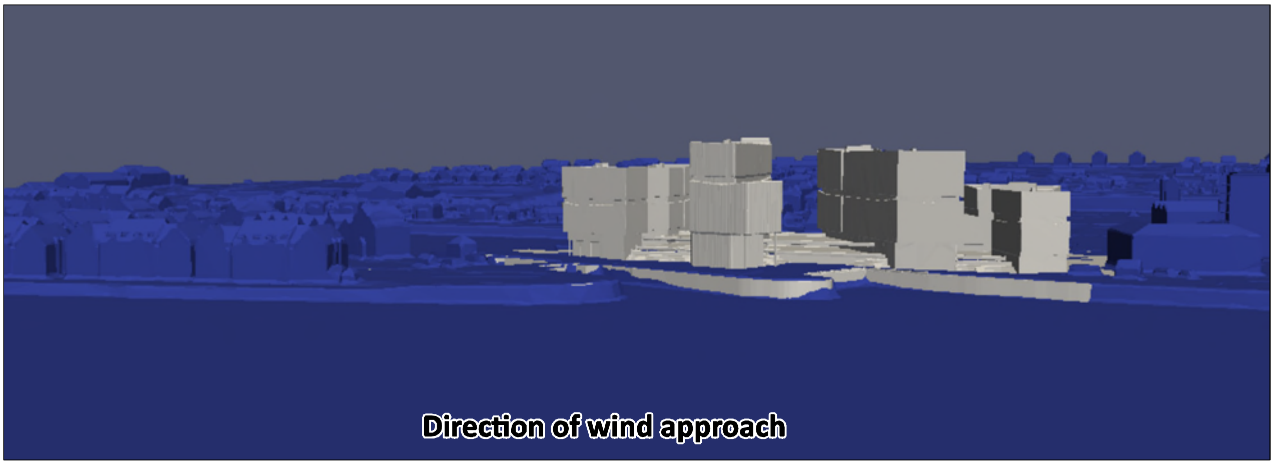
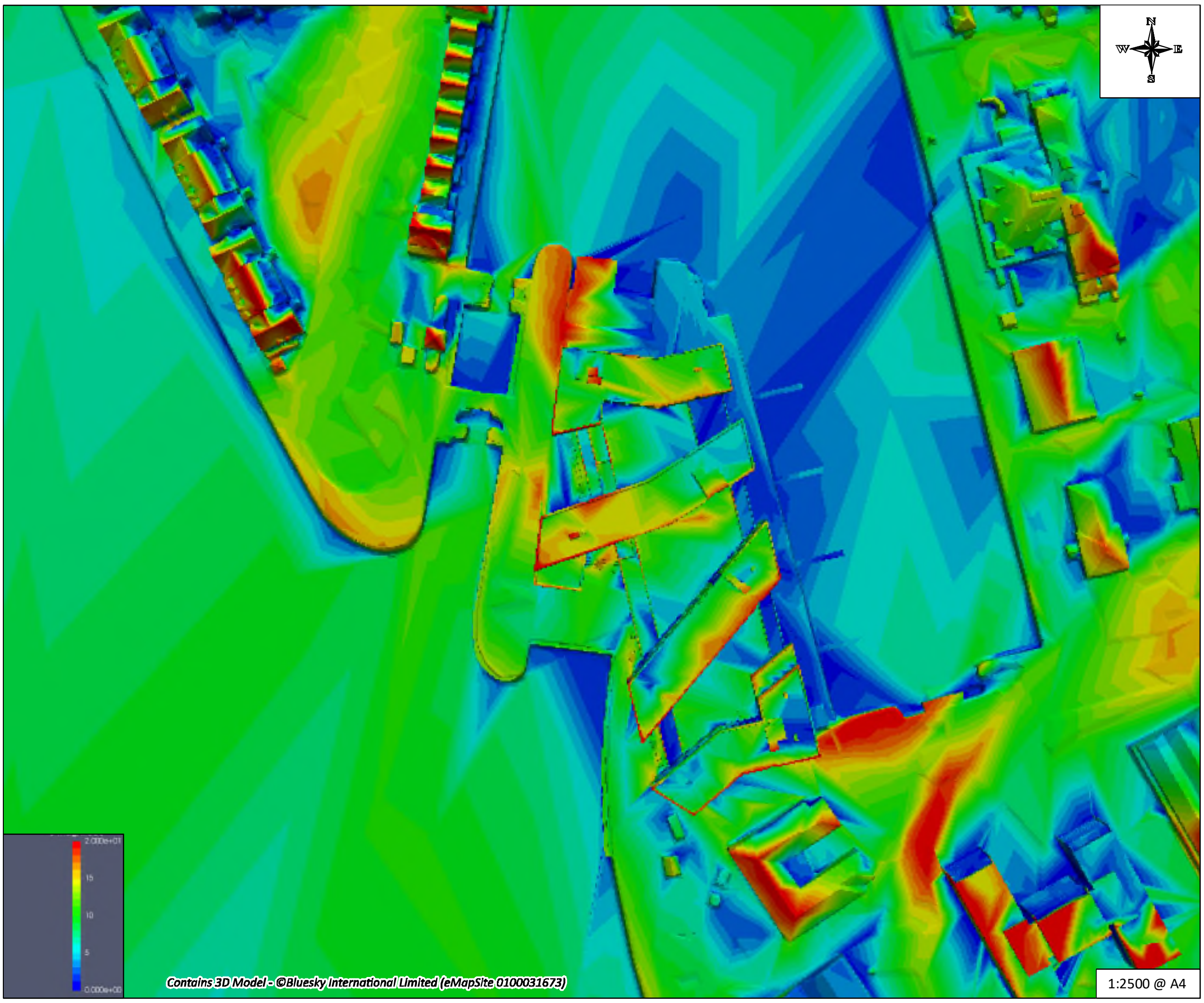
CFD Model of Wind Flow at 220°
Brunswick Quay
Liverpool

WIND_220_v001_ST16666 | Appendix 2.23

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 230°

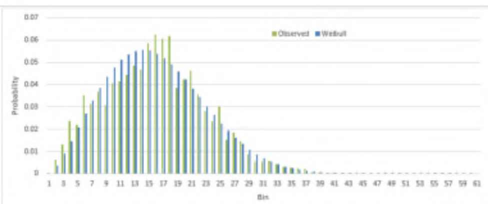




Statistics on Wind Data

Wind Direction	230.0°
Probability of occurrence	3.32%
Scale Factor (c)	8.43
Shape Factor (k)	2.27
No. data points	2804
Roughness (site)	0.003
Average Wind Speed (ref)	7.47
Average Wind Speed (site)	7.47
Max Wind Speed (ref)	22.07
Max Wind Speed (site)	22.07
Exceedence Probability	[illegible]%
Wind Speed (ref)	13.67
Wind Speed (site)	13.67
Exceedence Probability	0.0[illegible]%
Wind Speed (ref)	21.34
Wind Speed (site)	21.34

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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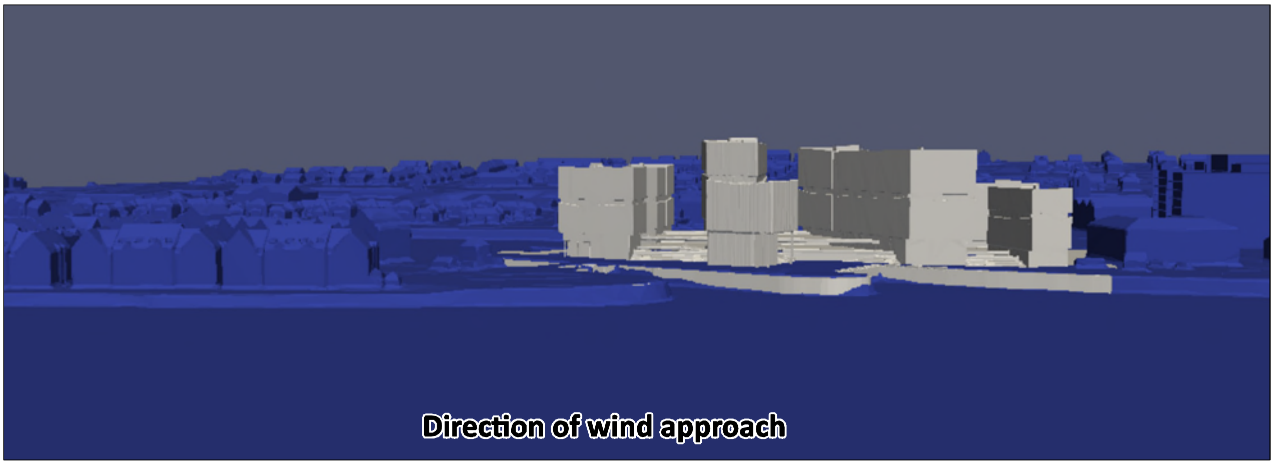
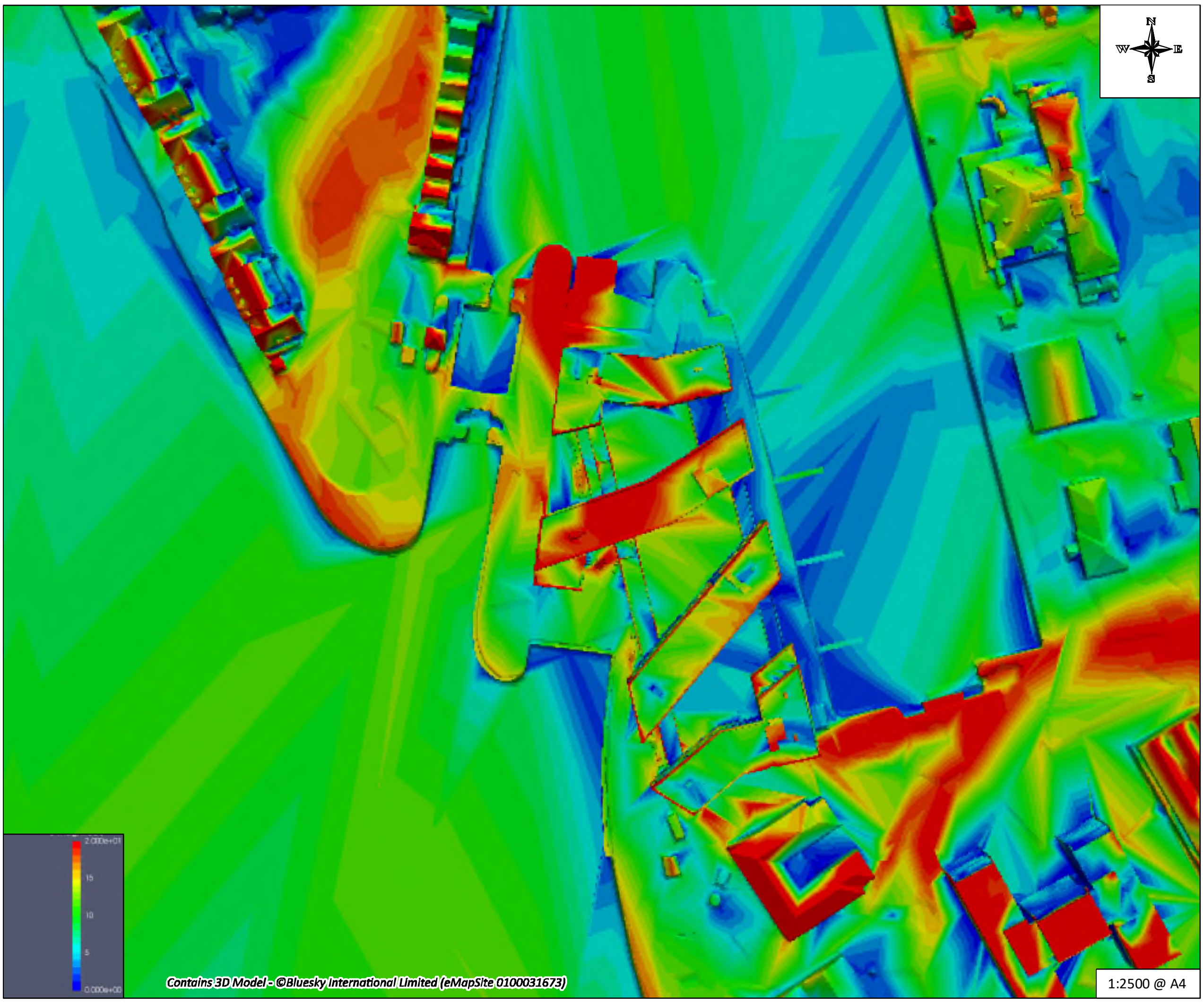
Checked By:	P.Evans	Date:	21/06/2018

CFD Model of Wind Flow at 230°
Brunswick Quay
Liverpool

WIND_230_v001_ST16666 | Appendix 2.24

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 240°

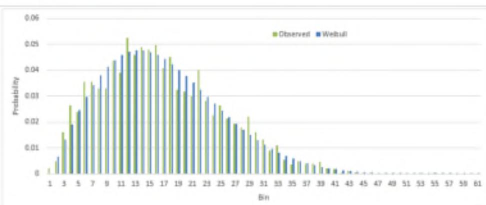




Statistics on Wind Data

Wind Direction	240.0°
Probability of occurrence	3.30%
Scale Factor (c)	8.90
Shape Factor (k)	1.97
No. data points	2295
Roughness (site)	0.003
Average Wind Speed (ref)	7.89
Average Wind Speed (site)	7.89
Max Wind Speed (ref)	26.79
Max Wind Speed (site)	26.79
Exceedence Probability	5.000%
Wind Speed (ref)	15.55
Wind Speed (site)	15.55
Exceedence Probability	0.077%
Wind Speed (ref)	23.34
Wind Speed (site)	23.34

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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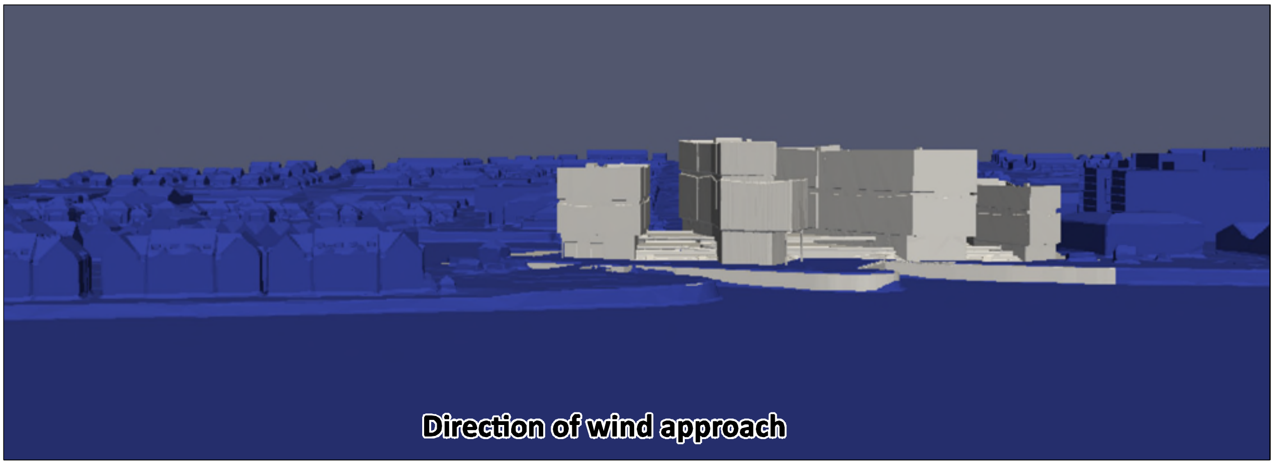
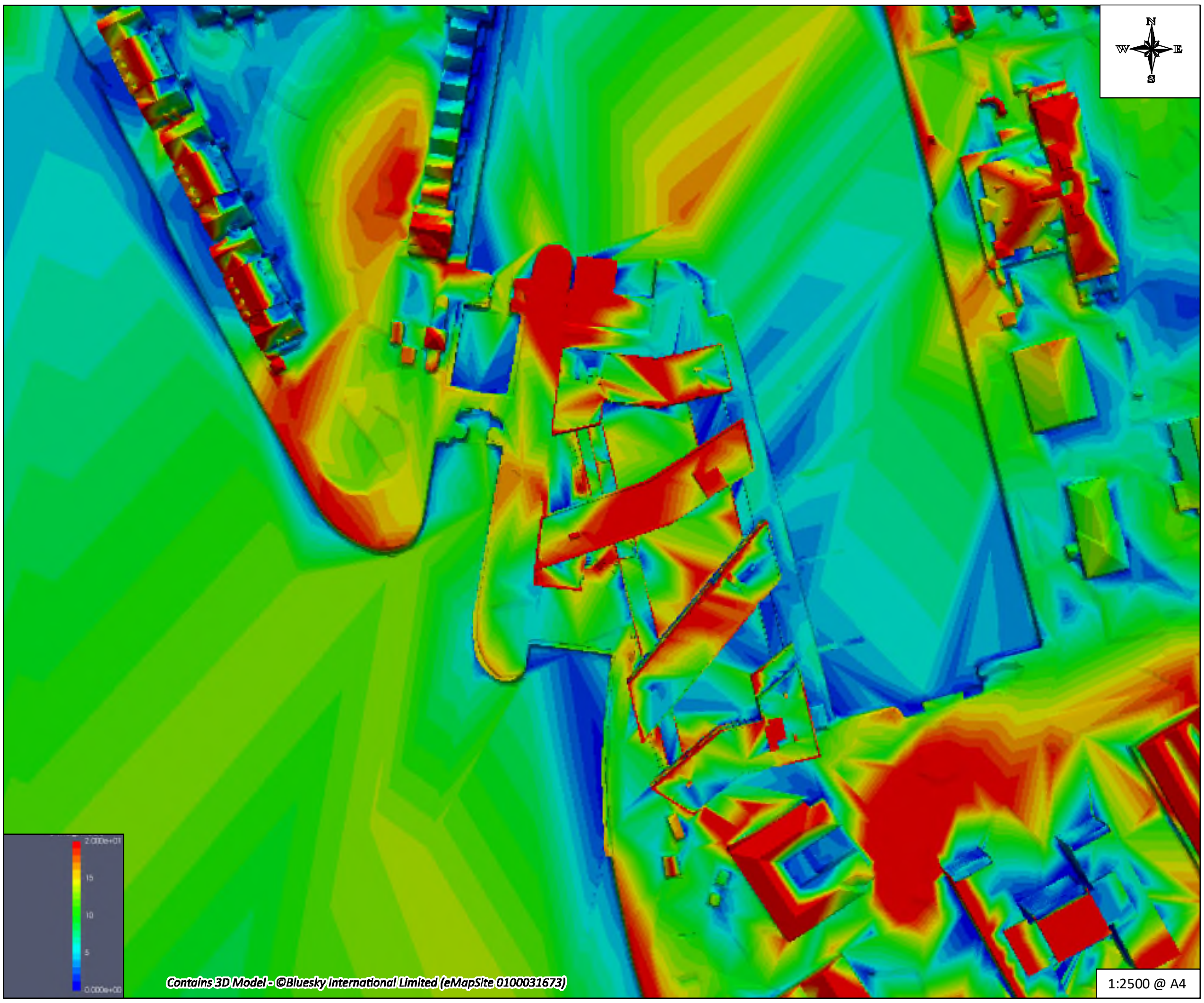
Drawn By:	S.Allen	Date:	21/06/2018
Checked By:	P.Evans	Date:	21/06/2018

CFD Model of Wind Flow at 240°
Brunswick Quay
Liverpool

WIND_240_v001_ST16666 | Appendix 2.25

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 250°

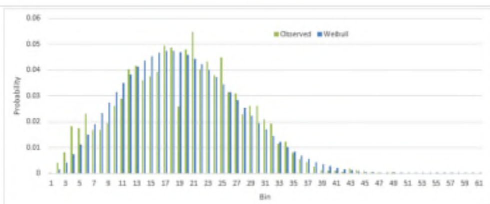




Statistics on Wind Data

Wind Direction	250.0°
Probability of occurrence	4.15%
Scale Factor (c)	10.35
Shape Factor (k)	2.42
No. data points	3697
Roughness (site)	0.001
Average Wind Speed (ref)	9.17
Average Wind Speed (site)	9.17
Max Wind Speed (ref)	24.38
Max Wind Speed (site)	24.38
Exceedence Probability	5.000%
Wind Speed (ref)	16.28
Wind Speed (site)	16.28
Exceedence Probability	[illegible]
Wind Speed (ref)	21.34
Wind Speed (site)	21.34

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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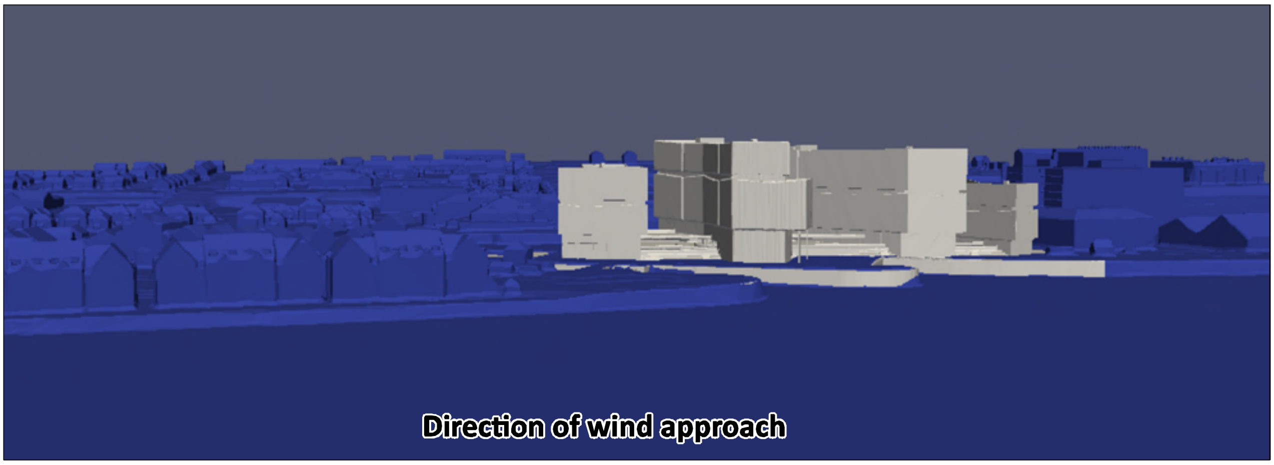
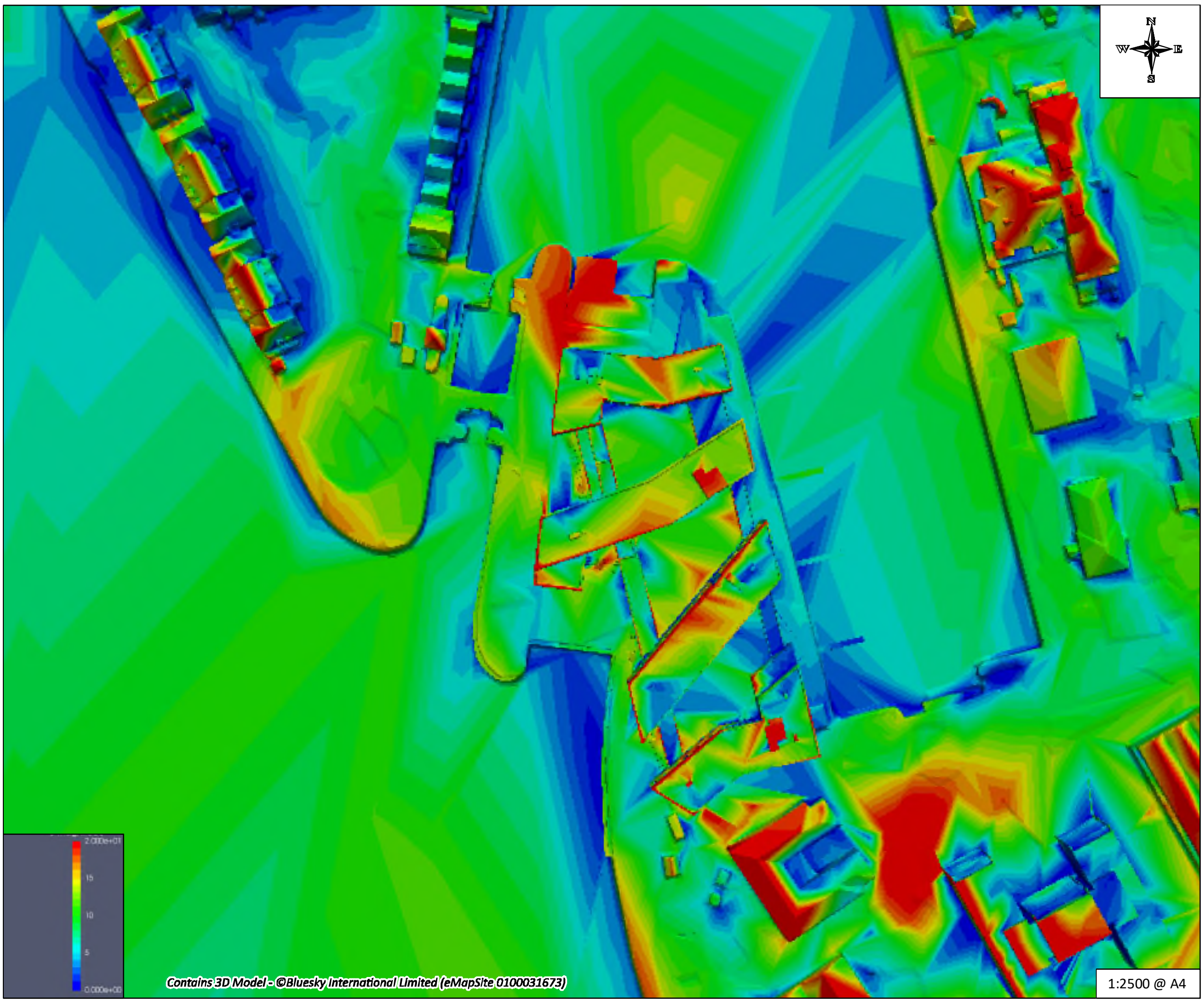
CFD Model of Wind Flow at 250°
Brunswick Quay
Liverpool

WIND_250_v001_ST16666 | Appendix 2.26

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 260°

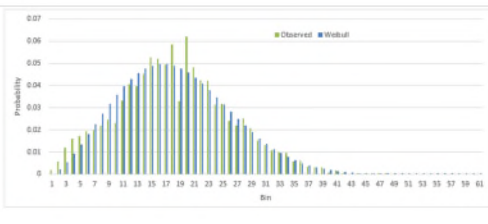




Statistics on Wind Data

Wind Direction	260.0°
Probability of occurrence	4.78%
Scale Factor (c)	9.75
Shape Factor (k)	2.17
No. data points	4053
Roughness (site)	0.003
Average Wind Speed (ref)	8.64
Average Wind Speed (site)	8.64
Max Wind Speed (ref)	23.66
Max Wind Speed (site)	23.66
Exceedence Probability	5.000%
Wind Speed (ref)	15.48
Wind Speed (site)	15.48
Exceedence Probability	0.022%
Wind Speed (ref)	23.34
Wind Speed (site)	23.34

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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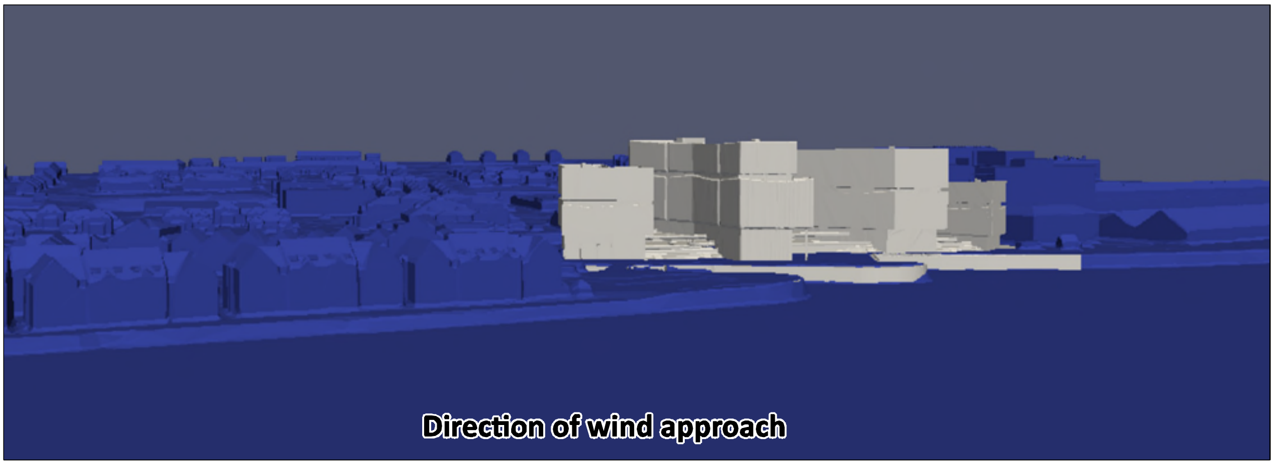
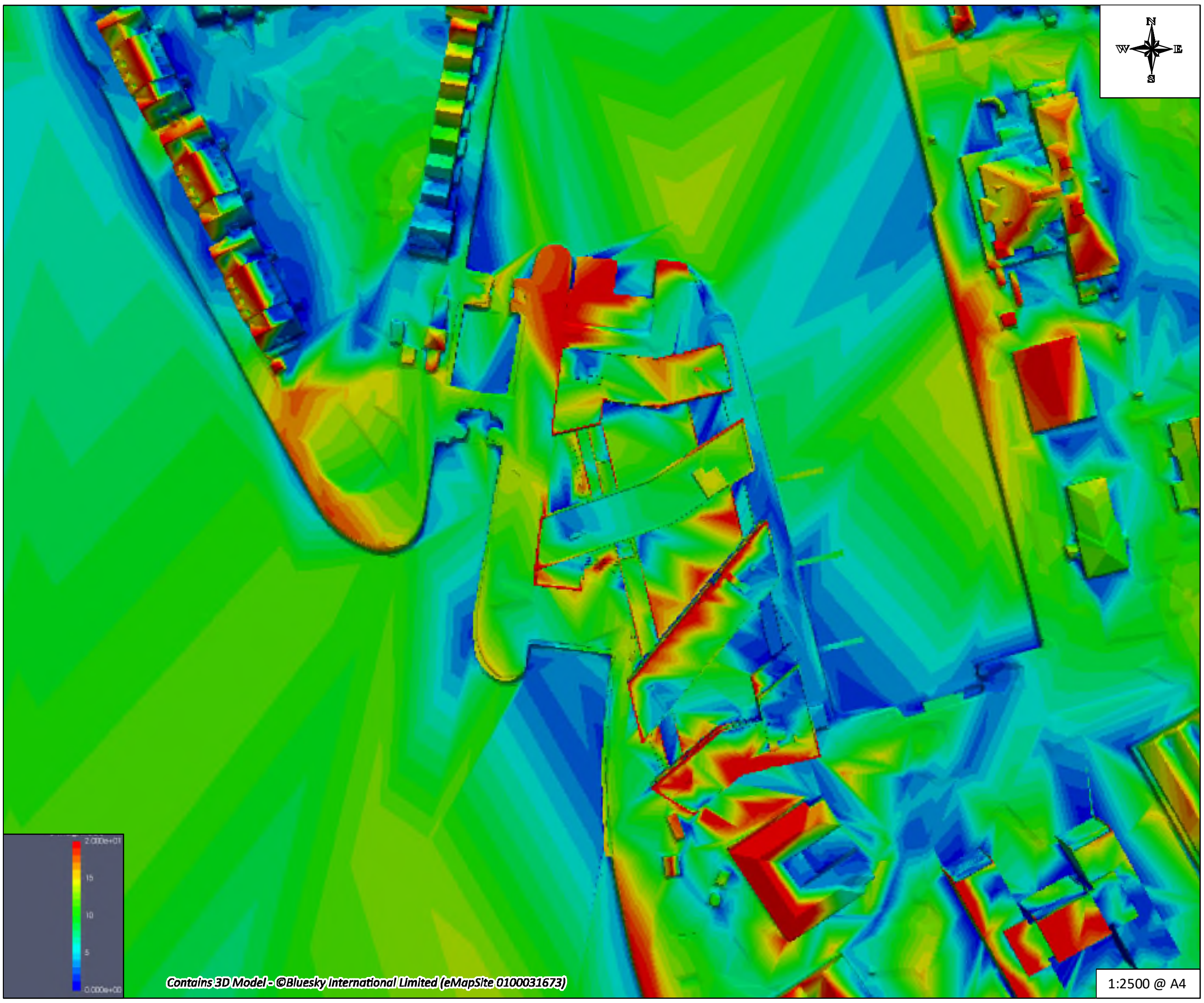
CFD Model of Wind Flow at 260°
Brunswick Quay
Liverpool

WIND_260_v001_ST16666 | Appendix 2.27

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 270°

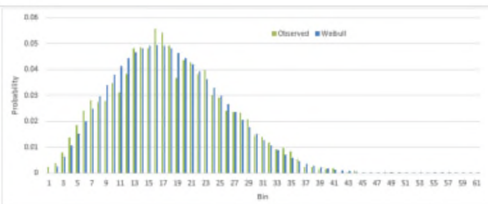




Statistics on Wind Data

Wind Direction	270.0°
Probability of occurrence	5.34%
Scale Factor (c)	9.55
Shape Factor (k)	2.30
No. data points	4576
Roughness (site)	0.001
Average Wind Speed (ref)	8.46
Average Wind Speed (site)	8.46
Max Wind Speed (ref)	21.94
Max Wind Speed (site)	21.94
Exceedence Probability	5.000%
Wind Speed (ref)	15.39
Wind Speed (site)	15.39
Exceedence Probability	0.077%
Wind Speed (ref)	21.34
Wind Speed (site)	21.34

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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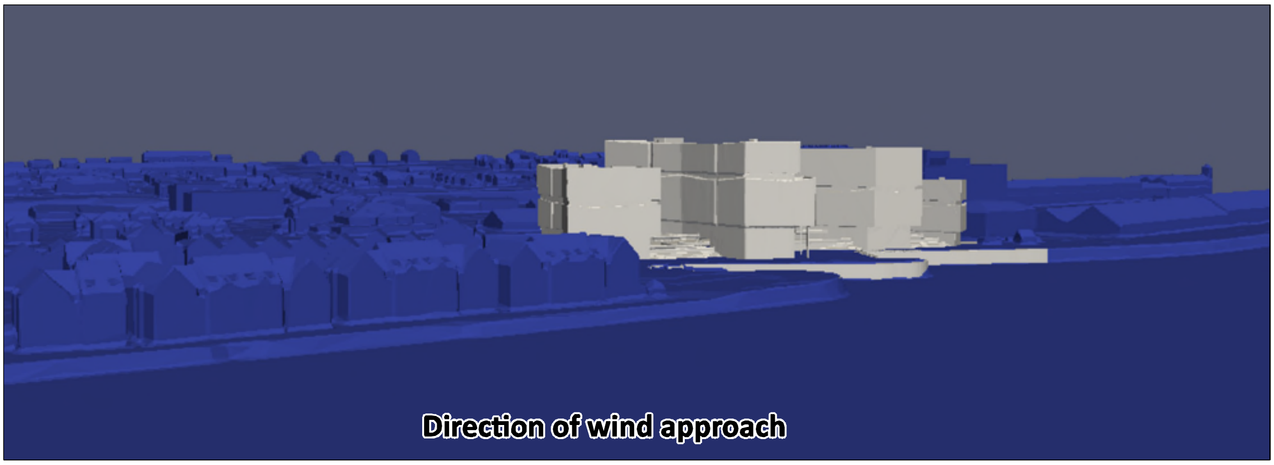
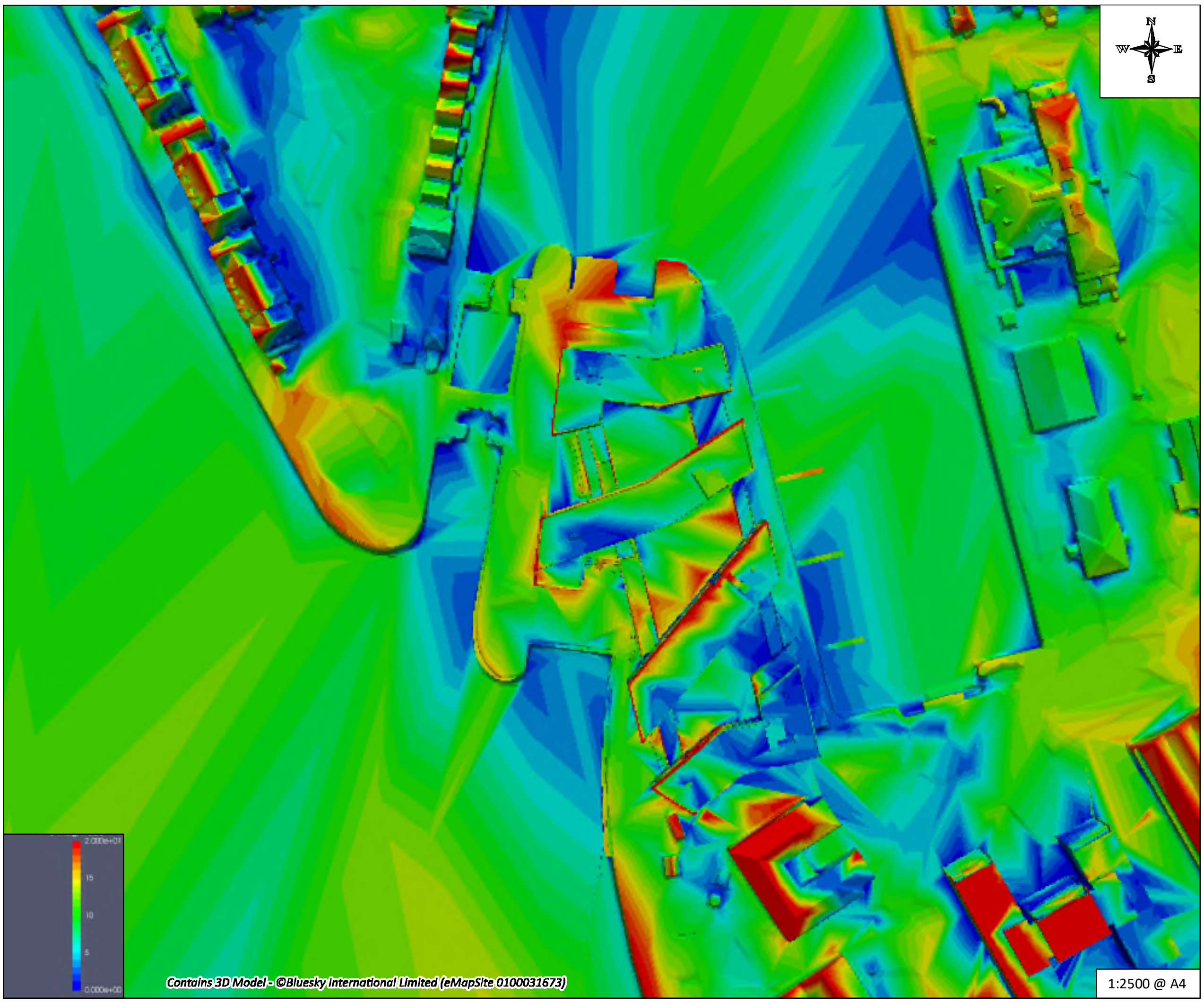
CFD Model of Wind Flow at 270°
Brunswick Quay
Liverpool

WIND_270_v001_ST16666 | Appendix 2.28

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 280°

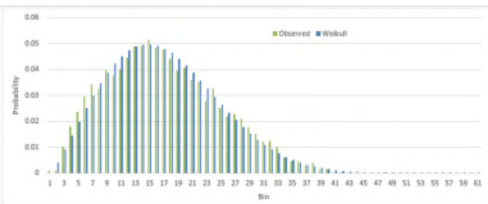




Statistics on Wind Data

Wind Direction	280.0°
Probability of occurrence	5.23%
Scale Factor (c)	9.07
Shape Factor (k)	2.36
No. data points	4938
Roughness (site)	0.003
Average Wind Speed (ref)	8.04
Average Wind Speed (site)	8.04
Max Wind Speed (ref)	23.47
Max Wind Speed (site)	23.47
Exceedence Probability	5.000%
Wind Speed (ref)	35.07
Wind Speed (site)	35.07
Exceedence Probability	0.022%
Wind Speed (ref)	23.34
Wind Speed (site)	23.34

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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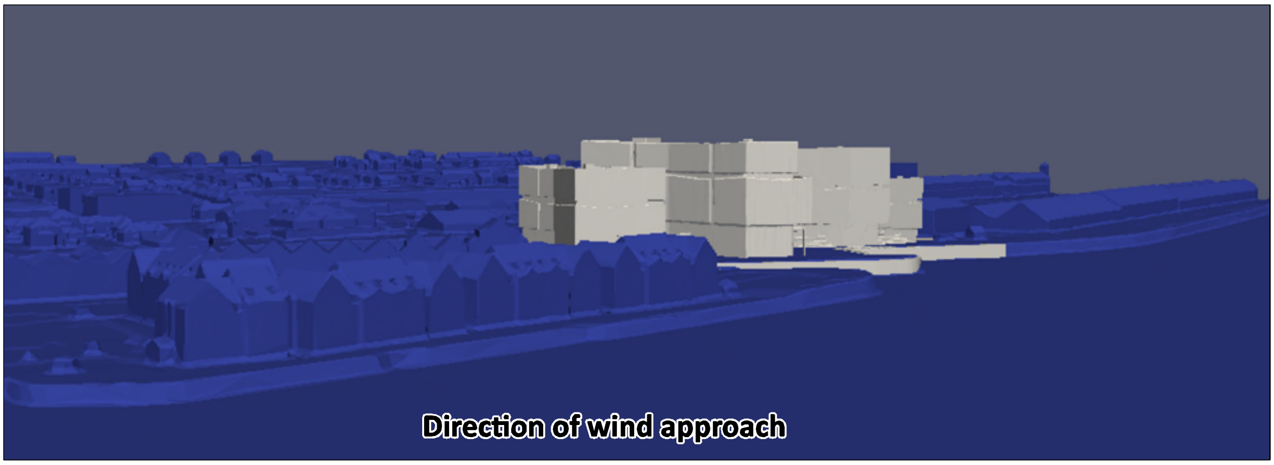
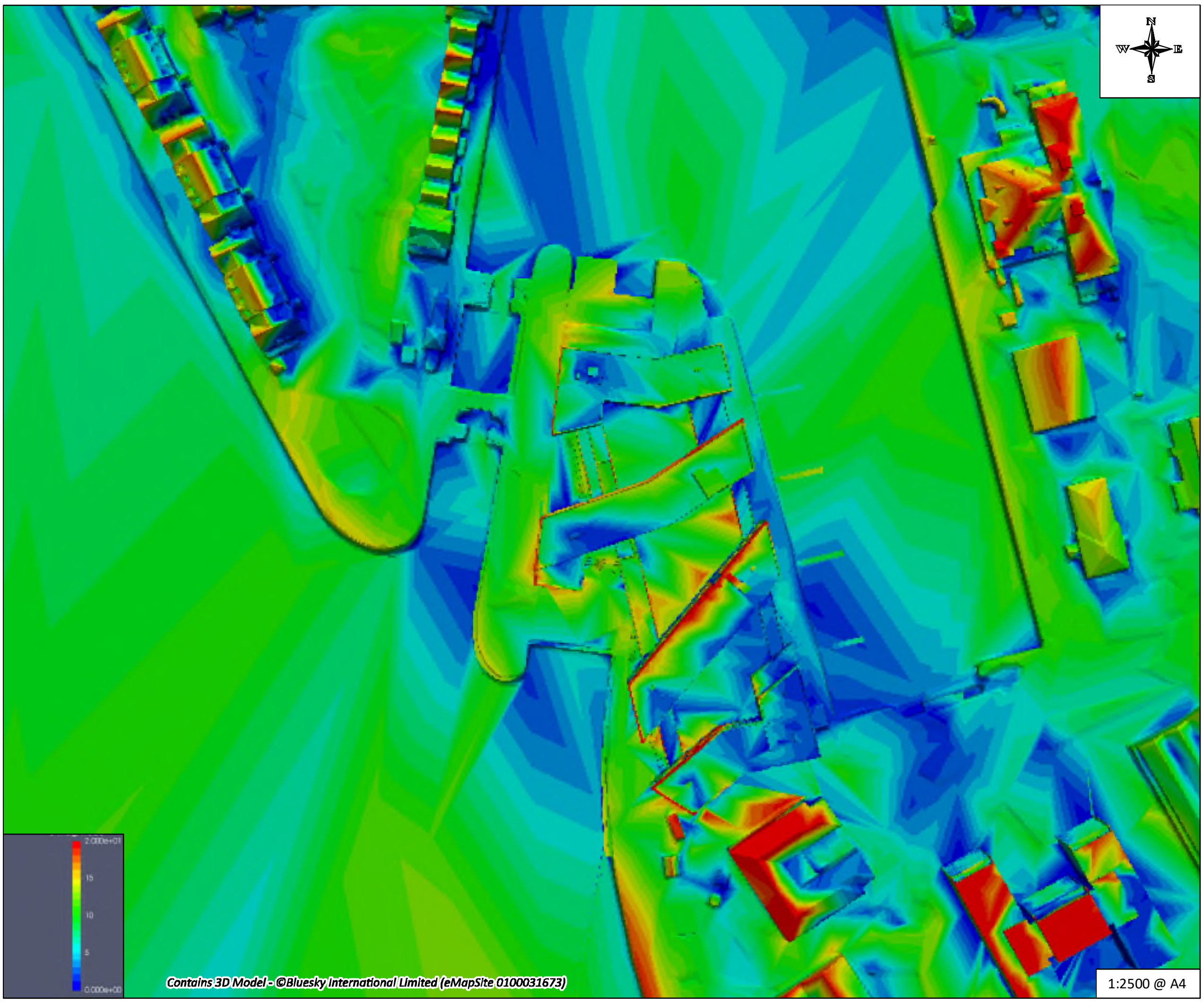
CFD Model of Wind Flow at 280°
Brunswick Quay
Liverpool

WIND_280_v001_ST16666 | Appendix 2.29

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 290°

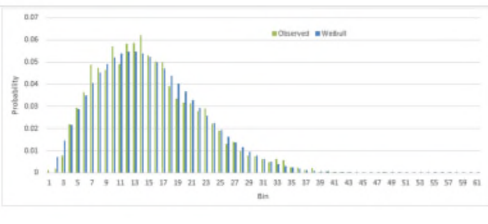




Statistics on Wind Data

Wind Direction	290.0°
Probability of occurrence	4.63%
Scale Factor (c)	7.93
Shape Factor (k)	2.05
No. data points	2927
Roughness (site)	0.003
Average Wind Speed (ref)	7.03
Average Wind Speed (site)	7.03
Max Wind Speed (ref)	21.27
Max Wind Speed (site)	21.27
Exceedence Probability	5.000%
Wind Speed (ref)	11.50
Wind Speed (site)	11.55
Exceedence Probability	0.022%
Wind Speed (ref)	21.14
Wind Speed (site)	21.14

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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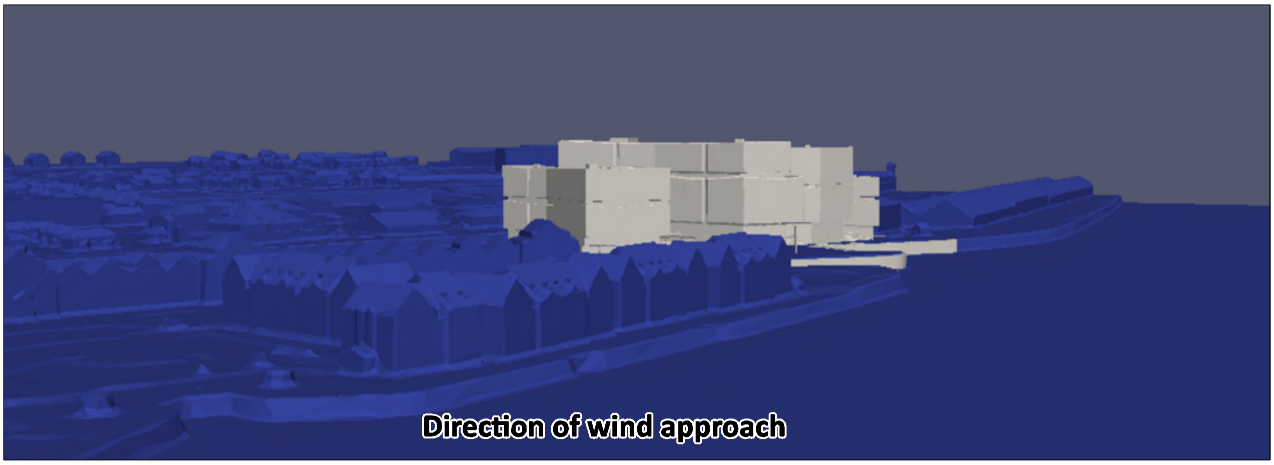
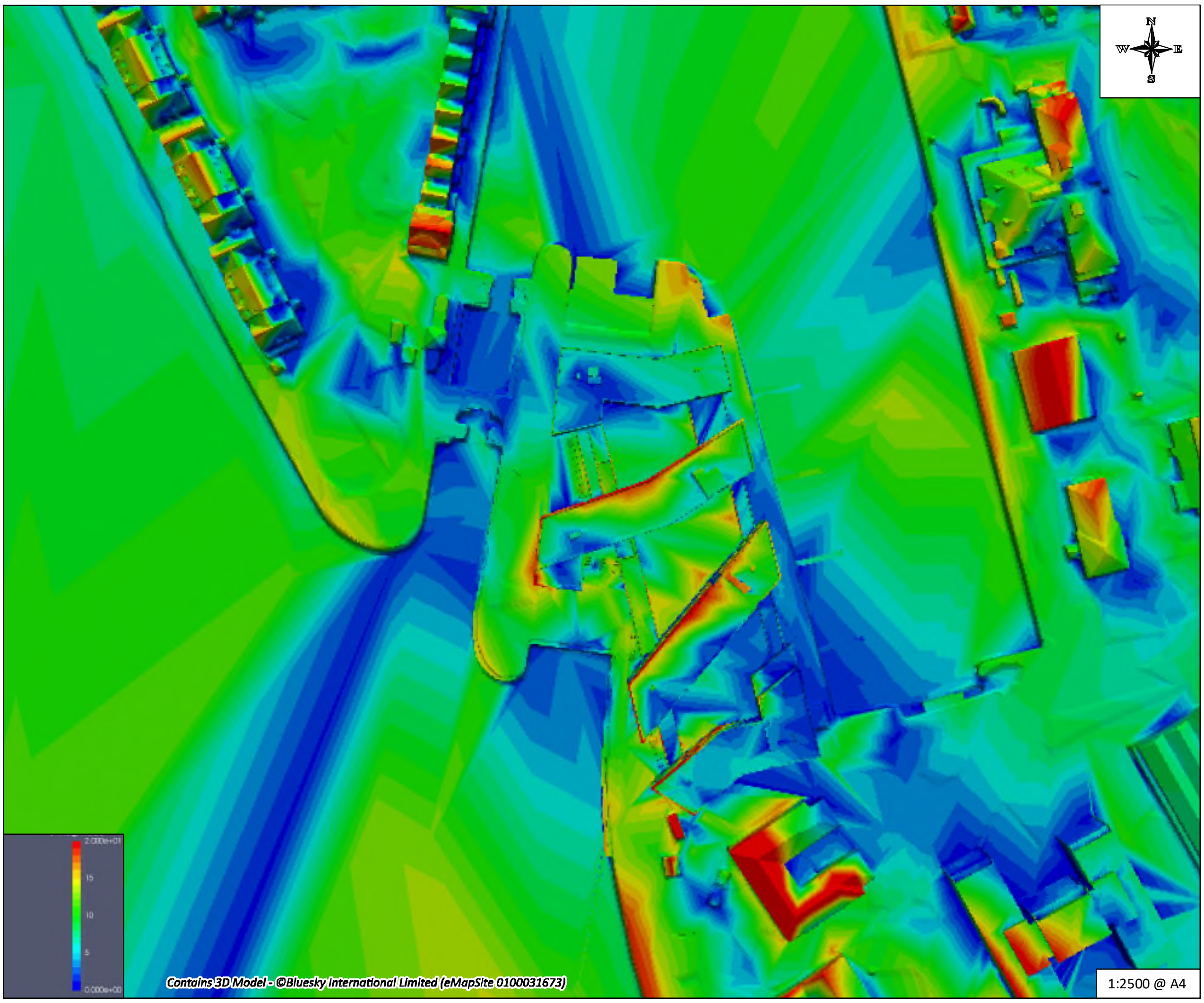
CFD Model of Wind Flow at 290°
Brunswick Quay
Liverpool

WIND_290_v001_ST16666 | Appendix 2.30

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 300°

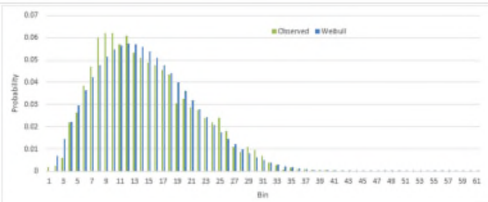




Statistics on Wind Data

Wind Direction	300.0°
Probability of occurrence	3.99%
Scale Factor (c)	7.09
Shape Factor (k)	2.08
No. data points	3387
Roughness (site)	0.001
Average Wind Speed (ref)	6.30
Average Wind Speed (site)	6.30
Max Wind Speed (ref)	19.84
Max Wind Speed (site)	19.84
Exceedence Probability	5.000%
Wind Speed (ref)	11.02
Wind Speed (site)	11.02
Exceedence Probability	0.077%
Wind Speed (ref)	21.34
Wind Speed (site)	21.34

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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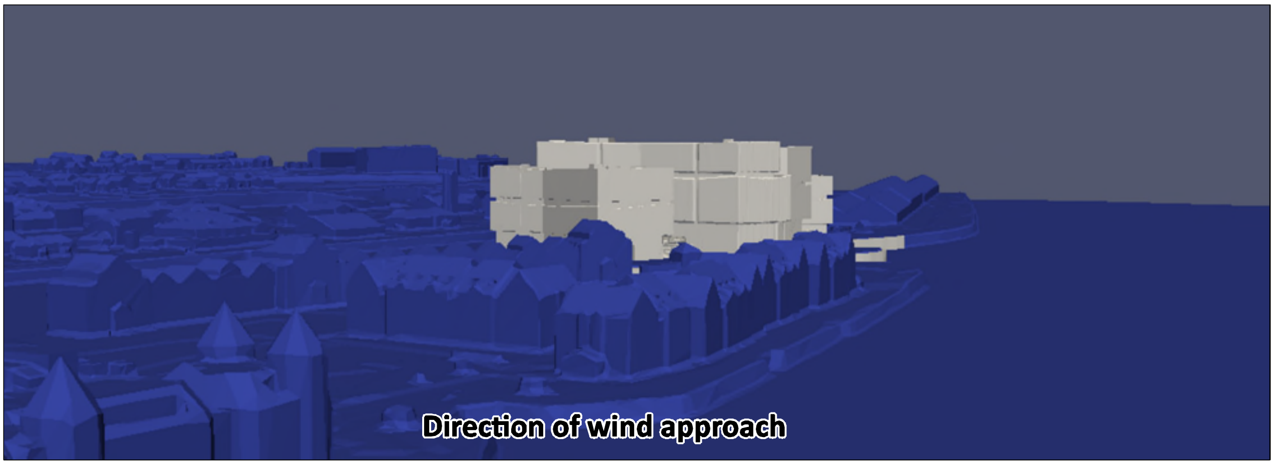
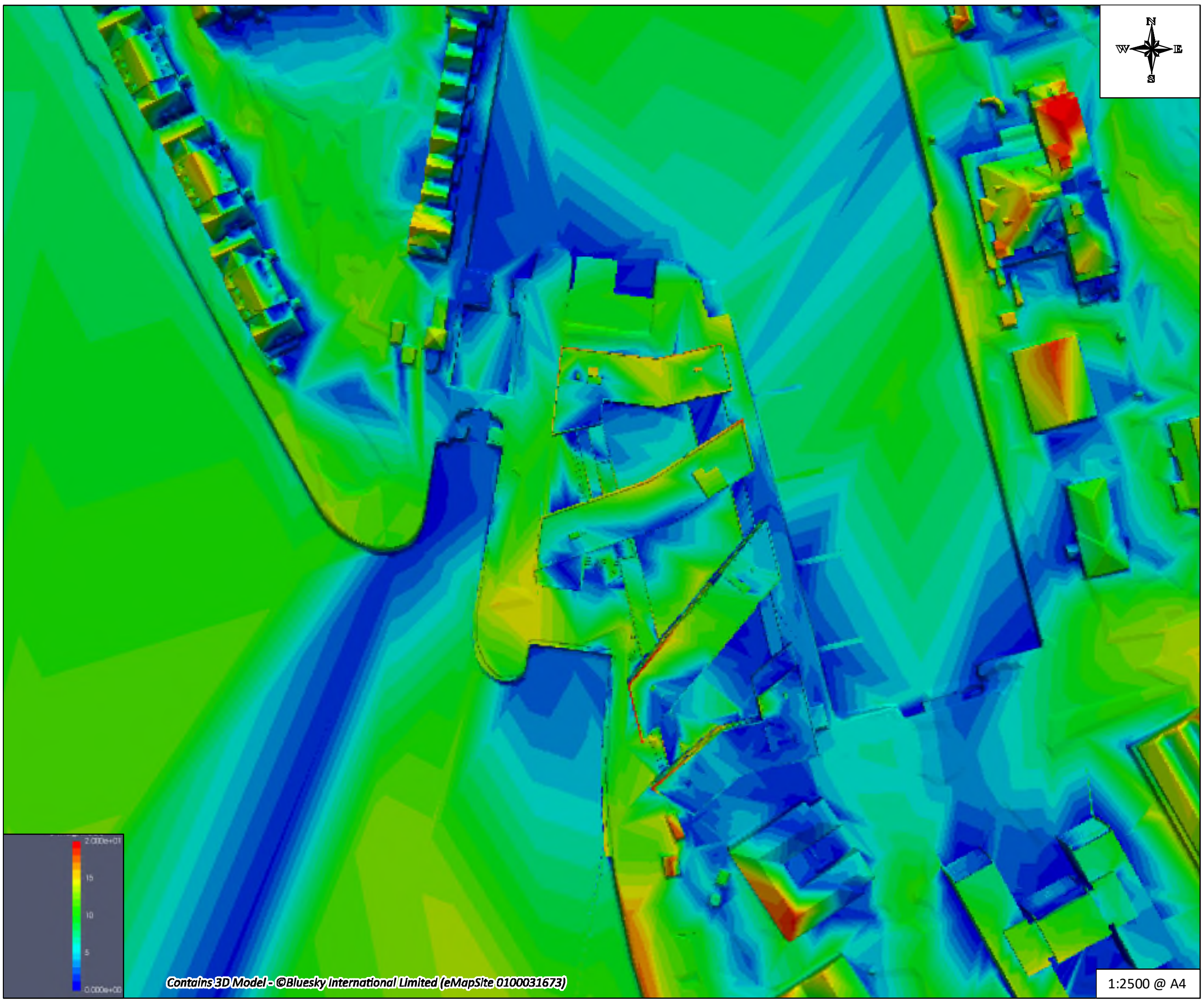
Checked By:	P.Evans	Date:	21/06/2018

CFD Model of Wind Flow at 300°
Brunswick Quay
Liverpool

WIND_300_v001_ST16666 | Appendix 2.31

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 310°



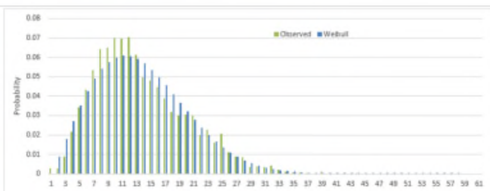


1:2500 @ A4

Statistics on Wind Data

Wind Direction	310.0°
Probability of occurrence	3.14%
Scale Factor (c)	7.13
Shape Factor (k)	2.04
No. data points	2831
Roughness (site)	0.001
Average Wind Speed (ref)	6.32
Average Wind Speed (site)	6.32
Max Wind Speed (ref)	21.38
Max Wind Speed (site)	21.38
Exceedence Probability	5.000%
Wind Speed (ref)	12.23
Wind Speed (site)	12.23
Exceedence Probability	0.07%
Wind Speed (ref)	21.14
Wind Speed (site)	21.14

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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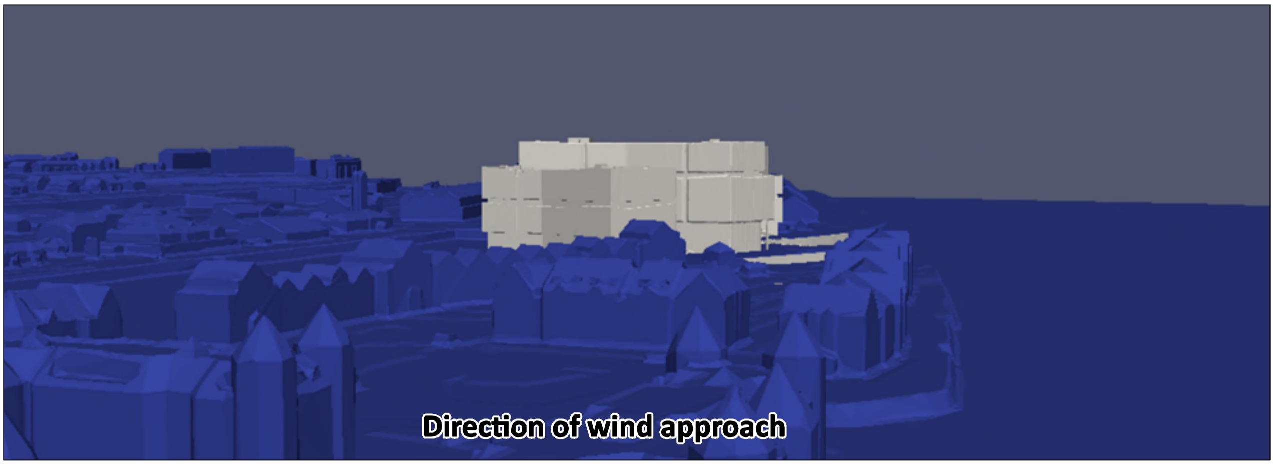
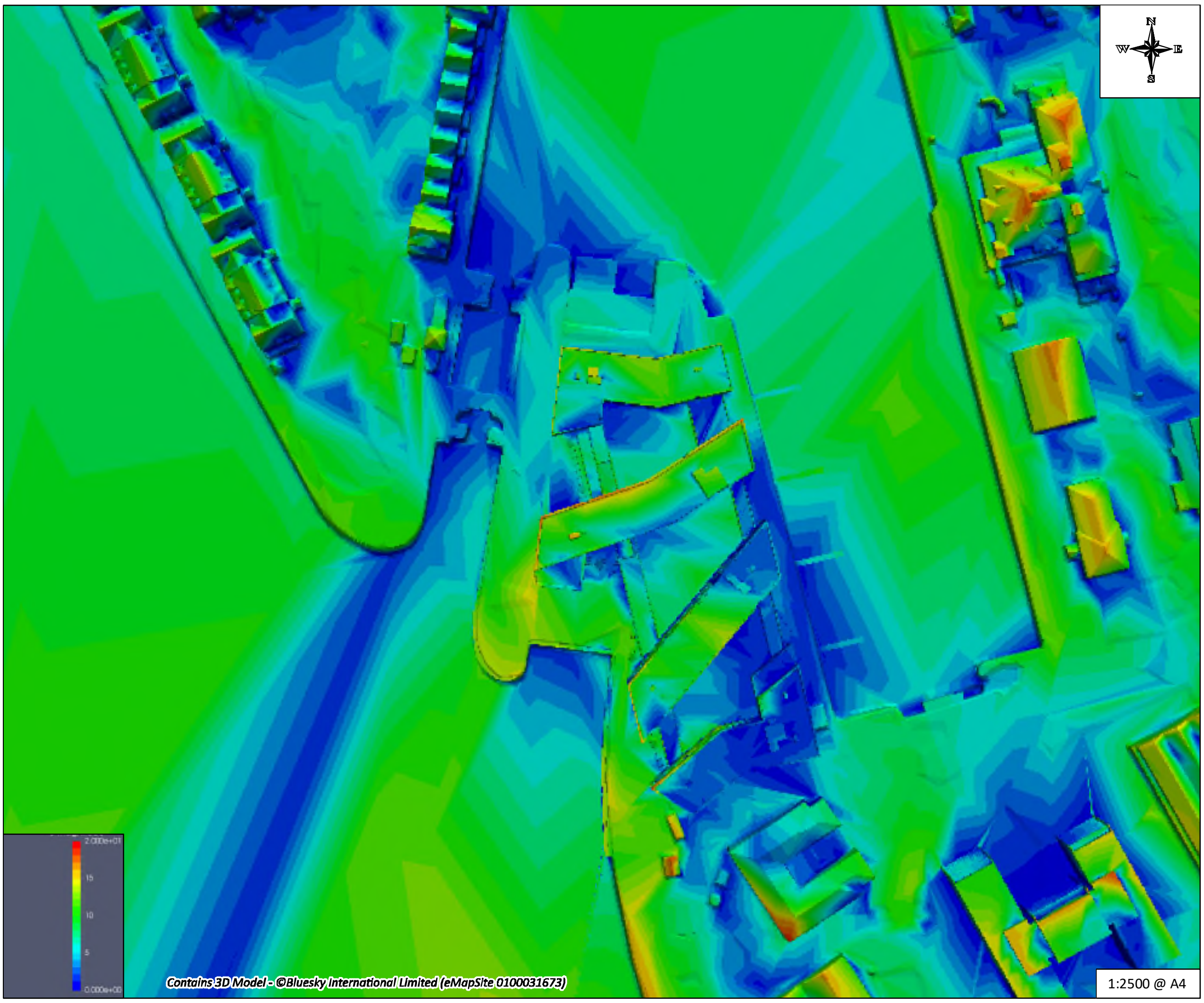
Checked By:	P.Evans	Date:	21/06/2018

CFD Model of Wind Flow at 310°
Brunswick Quay
Liverpool

WIND_310_v001_ST16666 | Appendix 2.32

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 320°

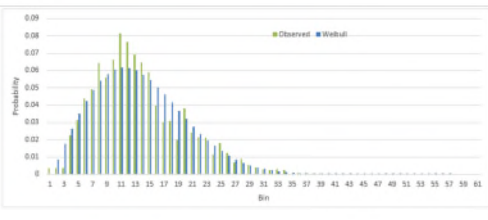




Statistics on Wind Data

Wind Direction	[illegible]
Probability of occurrence	2.40%
Scale Factor (c)	7.33
Shape Factor (k)	2.07
No. data points	2053
Roughness (site)	0.003
Average Wind Speed (ref)	6.30
Average Wind Speed (site)	6.30
Max Wind Speed (ref)	18.88
Max Wind Speed (site)	18.88
Exceedence Probability	5.000%
Wind Speed (ref)	12.08
Wind Speed (site)	12.08
Exceedence Probability	0.022%
Wind Speed (ref)	23.34
Wind Speed (site)	23.34

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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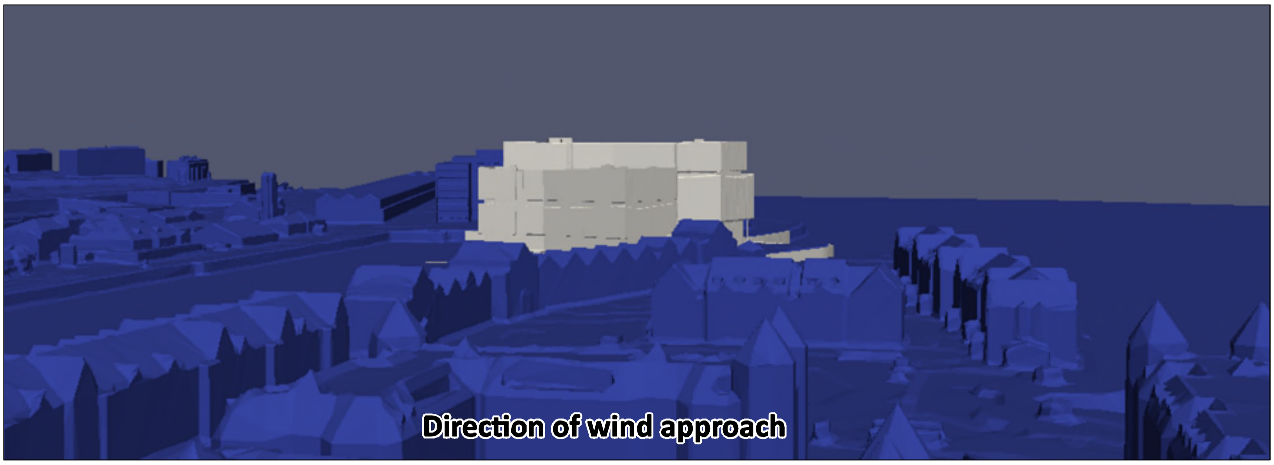
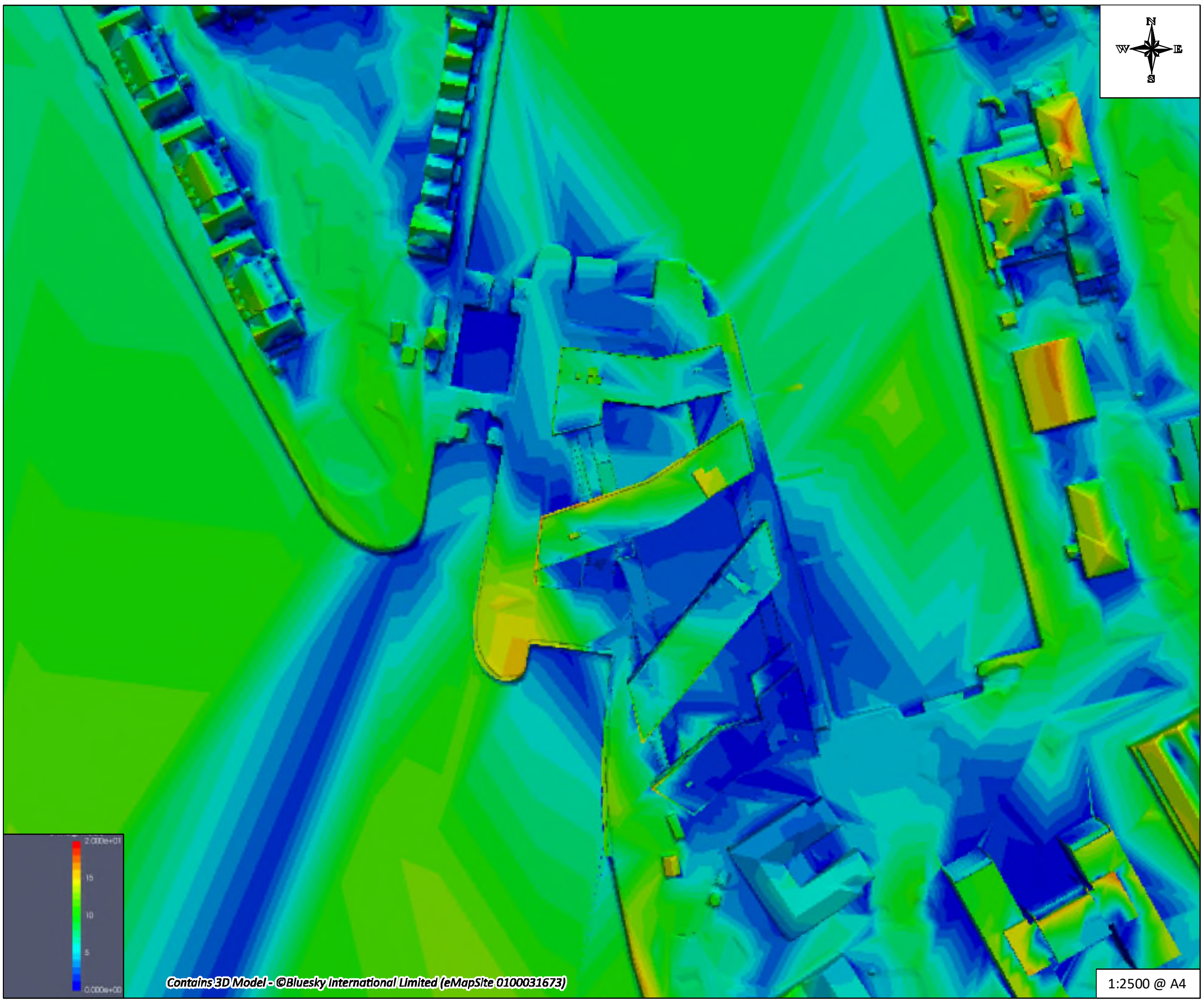
CFD Model of Wind Flow at 320°
Brunswick Quay
Liverpool

WIND_320_v001_ST16666 | Appendix 2.33

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 330°

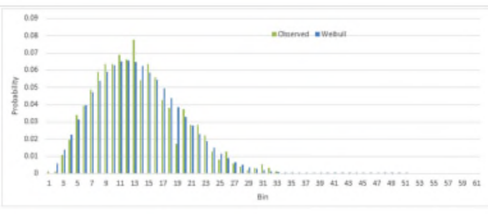




Statistics on Wind Data

Wind Direction	330.0°
Probability of occurrence	1.78%
Scale Factor (c)	7.07
Shape Factor (k)	2.28
No. data points	3496
Roughness (site)	0.001
Average Wind Speed (ref)	6.26
Average Wind Speed (site)	6.26
Max Wind Speed (ref)	16.16
Max Wind Speed (site)	16.16
Exceedence Probability	5.000%
Wind Speed (ref)	11.55
Wind Speed (site)	11.55
Exceedence Probability	0.075%
Wind Speed (ref)	21.14
Wind Speed (site)	21.14

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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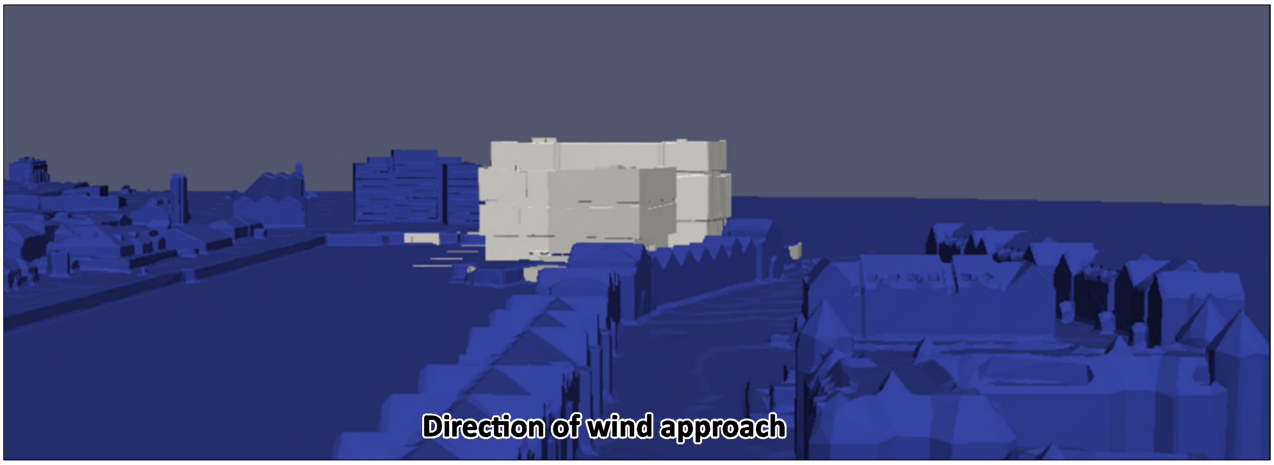
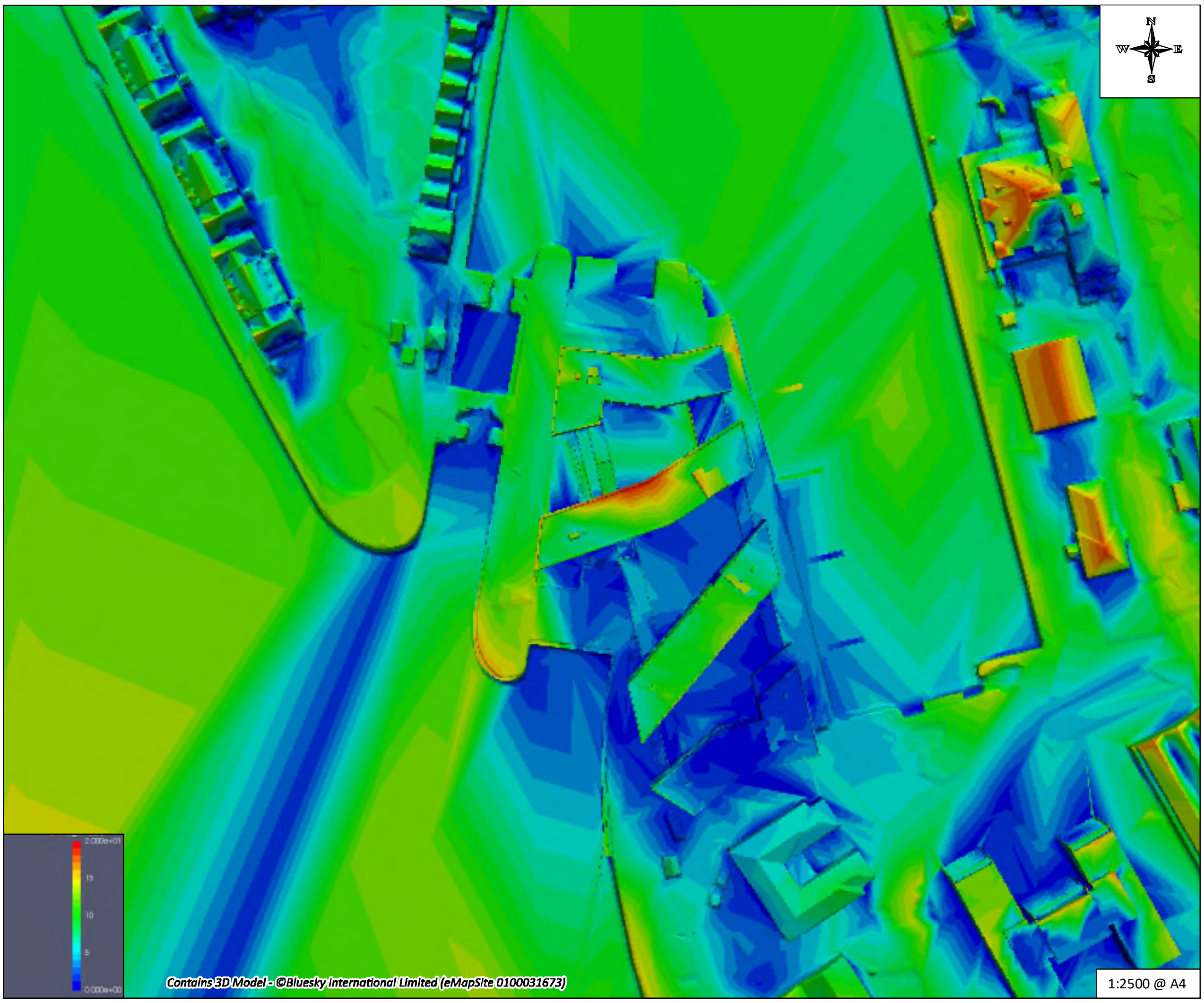
CFD Model of Wind Flow at 330°
Brunswick Quay
Liverpool

WIND_330_v001_ST16666 | Appendix 2.34

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 340°

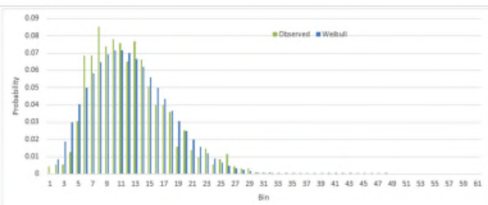




Statistics on Wind Data

Wind Direction	340.0°
Probability of occurrence	3.12%
Scale Factor (c)	6.15
Shape Factor (k)	2.39
No. data points	950
Roughness (site)	0.003
Average Wind Speed (ref)	5.63
Average Wind Speed (site)	6.67
Max Wind Speed (ref)	15.27
Max Wind Speed (site)	18.11
Exceedence Probability	5.000%
Wind Speed (ref)	10.49
Wind Speed (site)	12.44
Exceedence Probability	0.022%
Wind Speed (ref)	23.34
Wind Speed (site)	27.45

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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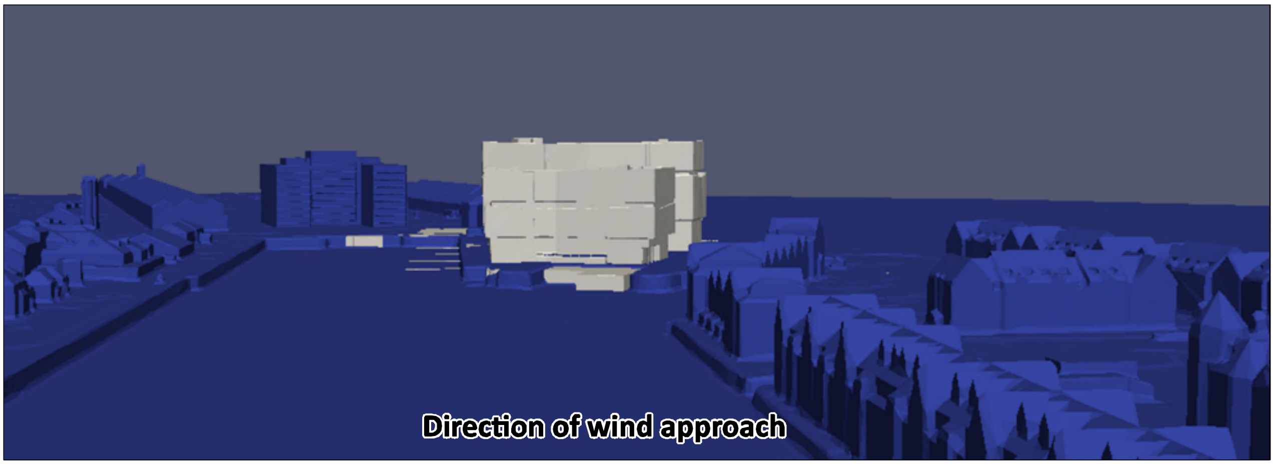
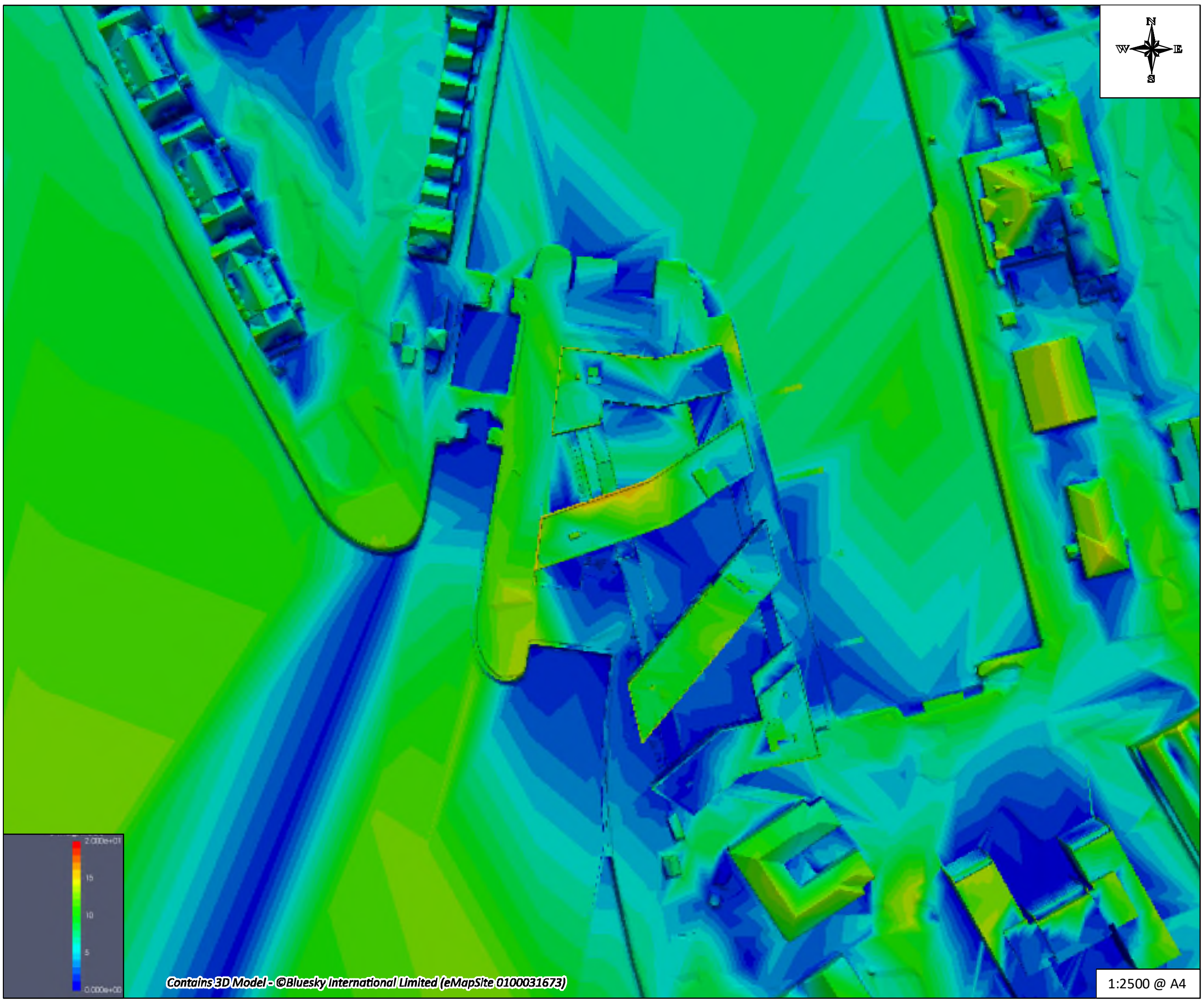
CFD Model of Wind Flow at 340°
Brunswick Quay
Liverpool

WIND_340_v001_ST16666 | Appendix 2.35

Brunswick Quay Development
Wind Microclimate Assessment
Wind Direction: 350°

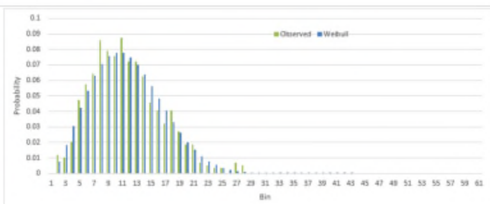




Statistics on Wind Data

Wind Direction	350.0°
Probability of occurrence	0.70%
Scale Factor (c)	6.03
Shape Factor (k)	2.29
No. data points	593
Roughness (site)	0.001
Average Wind Speed (ref)	5.34
Average Wind Speed (site)	6.34
Max Wind Speed (ref)	13.44
Max Wind Speed (site)	15.94
Exceedence Probability	5.000%
Wind Speed (ref)	9.75
Wind Speed (site)	11.56
Exceedence Probability	0.020%
Wind Speed (ref)	21.14
Wind Speed (site)	27.45

Comparison of Observed & Modelled Wind Data



All wind speeds measured at 10m AGL

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Drawn By:	S.Allen	Date:	21/06/2018
Checked By:	P.Evans	Date:	21/06/2018

CFD Model of Wind Flow at 350°
Brunswick Quay
Liverpool

WIND_350_v001_ST16666 | Appendix 2.36

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