Pall Mall

Liverpool, UK

Wind Microclimate Study

27th June 2019

For
Kier Property Developments
Limited and CTP Limited

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Pall Mall
Liverpool, UK

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EXECUTIVE SUMMARY

This report summarises the results of a numerical study, commissioned by Kier Property Developments Limited and CTP Limited, carried out to assess the impact of the Pall Mall located in Liverpool, UK.

The study provides an assessment of the wind environment in terms of comfort and safety using the industry standard Lawson Criteria, which enables the pedestrian level wind environment at the site to be quantified in terms of suitability for current and planned usage. It considers three site configurations:

- Existing site conditions
- Proposed development, within the context of existing surrounds
- Proposed development, within the context of future surrounds

The numerical simulations combine the pedestrian level wind speeds at key areas in and around the site with long-term wind frequency statistics to determine the probability of local wind speeds exceeding comfort and safety thresholds for a range of common pedestrian activities based on the industry standard Lawson Criteria. This defines the type of activities for which the wind conditions would be safe and/or comfortable.

The following observations were drawn from the wind microclimate study:

- For all the assessed configurations, wind conditions are generally suitable in terms of both pedestrian comfort and safety for their intended use throughout the year
- With the introduction of the proposed development, a limited number of locations are associated with increased wind acceleration and reduced comfort levels for long-term sitting, but still suitable for waiting areas, recreation, and short-term sitting. These areas are located northeast to the new Block A building however this is within the acceptable rating

Pall Mall
Liverpool, UK

1. Introduction

This report summarises the results of a numerical study, commissioned by Kier Property Developments Limited, and CTP Limited, carried out to assess the impact of the Pall Mall located in Liverpool, UK. The proposed development site is to be located near the intersection between Pall Mall and Tithebarn Street.

Numerical simulations have enabled the pedestrian level wind environment at the site to be quantified and classified in terms of suitability for several types of usage, based on the industry standard Lawson Criteria for pedestrian comfort and safety. The study combines the pedestrian level wind speeds at key areas in and around the site with long-term wind frequency statistics to determine the probability of local wind speeds exceeding comfort and safety thresholds for a range of common pedestrian activities. This defines the type of activities for which the wind conditions would be safe and/or comfortable.

The study considers three site configurations:

- Existing site conditions
- Proposed development, within the context of existing surrounds
- Proposed development, within the context of future surrounds

The study was carried out by BMT for Kier Property Developments Limited, and CTP Limited. The scope of work was based on the proposal prepared by BMT dated 1st October 2018 [1].

2. The Assessment of Wind Microclimate

The UK Met Office defines microclimate as the distinctive climate of a small-scale area. The weather variables in a microclimate, such as wind, may be different to the conditions prevailing over the wider area.

Wind microclimate assessments consider the wind conditions which would result due to the introduction of a new development into an existing space. Such assessments predict the proportion of time an area will experience wind speeds exceeding threshold values for pedestrian safety and stability, and threshold values associated with a series of typical activities such as walking, waiting for buses or sitting within a café, restaurant, or bar outlet. It can be shown within a proposed new development and the neighbouring properties, whether wind conditions are suitable or unsuitable, and whether design adjustments and/or mitigation measures are required. It is for this purpose wind microclimate assessments are undertaken.

The industry standard criteria for such assessments is commonly referred to as the Lawson Criteria and emerged during a period of substantial research by eminent wind engineers of the time, many of whom individually presented proposals for criteria within wind engineering literature, including Davenport [2] in 1972. Lawson presented what has become the University of Bristol variant of the Lawson Criteria in 1973 [3], prior to a collaborative initiative which produced the London Docklands Development Corporation (LDDC) variant of the Lawson Criteria [4].

The LDDC variant of the Lawson Criteria applies a single percentage probability of exceedance of a range of wind speeds and associates different wind speeds to different types of usage. This offers a practical approach for the assessment of wind comfort and safety. The LDDC variant of the Lawson Criteria is used to characterise the wind comfort and safety in this study. Details of the wind climate analysis used to determine the percentage probability for the range of wind speeds at the site is presented in APPENDIX A.

3. Study Area

3.1. Site Location and Surrounding Area

The proposed development site is to be located near the intersection between Pall Mall and Tithebarn Street.

The site location is presented within the context of the wider surrounding area in Figure 1. Figure 2 presents the 3D model of the existing site condition used in the study.

3.2. Proposed Development

With Liverpool's stock of Grade A office floorspace dwindling, Kier Property Developments Limited, and CTP Limited are involved in a £200 million redevelopment of Pall Mall. The first phase will deliver an office-led scheme totalling approximately 400,000 square foot of space with retail and leisure uses, and a landscaped public realm. This study focuses on Block A as part of this upgrade, represented in Figure 3 in the context of the existing surrounds.

The assessment supports a hybrid planning application: a detailed application for Building A and public realm, and an outline application for four further buildings. It assesses the impact of the detailed design of Building A (identified in Figure 3 which will be subject to a detailed application.

3.3. Consented Future Surrounds

The consented future surrounds at this point are illustrated in Figure 4. This image presents the 3D model of the proposed development in the context of the consented future surrounds. This assessment considers the outline application as part of the future scenario, with the assessment based on the layout and scale parameters currently proposed. The future scenario includes committed developments which are identified in Figure 4.

3.4. Soft Landscaping and Wind Mitigations

The soft landscape was omitted in the numerical assessment to represent the worst-case scenario during winter seasons.

4. Assessment Methodology

4.1. Atmospheric Boundary Layer Assessment

The assessment of environmental wind flows in the built environment lies outside the scope of internationally recognised wind codes, which focus on wind loading issues. In addition, there are no handbooks or engineering methods from which reliable assessments of the complex environmental wind flows which shape the pedestrian level wind conditions can be derived.

As a result, a purposely-designed atmospheric boundary layer Computational Fluid Dynamics (CFD) study was carried out to provide a reliable quantification of the pedestrian level wind environment within the following key areas:

- Pedestrian access routes
- Entrances
- Recreational areas

The study combines wind speed-up factors at key areas in and around the site with long-term wind frequency statistics to determine the probability of local wind speeds exceeding comfort and safety thresholds for a range of common pedestrian activities. The threshold wind speeds are based on the industry standard Lawson Criteria [3]. The wind speed-ups are derived through a full-scale atmospheric boundary layer CFD model for a full range of wind directions. The wind statistics are transposed from the nearest suitable weather centre and applied directly at the site.

4.2. Wind Climate Analysis

Details of the annual and seasonal wind analyses relevant to the site are presented in APPENDIX A.

4.3. CFD Software and Model Details

Details of the software and full-scale numerical model used in this study are presented in APPENDIX B.

4.4. Wind Direction

Wind environment simulations were completed for a full range of wind directions in increments of 22.5°. The wind direction denotes the direction from which the wind is blowing. A wind direction of 0° denotes wind coming from north (90° east, 180° south, 270° west).

4.5. Safety

At each of the investigated areas, the suitability of pedestrian level wind environment in terms of safety is assessed based on the Lawson Criteria [3] for pedestrian safety. Safety is determined for the 'able-bodied' and for the 'general public'. For the general public, the safety threshold is exceeded when a wind speed of 15 m/s occurs once per year or more. At 15 m/s the wind has the potential to de-stabilise the less-able members of the public including the elderly, cyclists, and children. Able-bodied users are more likely to be capable against extreme pedestrian level winds and thus experience distress at a higher threshold wind speed of 20 m/s. The safety threshold for the able-bodied is exceeded when a wind speed of 20 m/s occurs once per year or more.

Safety Rating	**Threshold Wind Speed**	**Threshold Upcrossing Rate** [5]
Unsuitable for the General Public	15 m/s	<= 1.0
Unsuitable for the Able-Bodied	20 m/s	<= 1.0

4.6. Comfort

The suitability of the pedestrian level wind environment at each investigated area in terms of comfort for various activities is assessed based on the Lawson Criteria [3] for pedestrian comfort. The assessment takes full account of seasonal variations in wind conditions and pedestrian activities. For example, conditions for recreational activities focus on summer, but also consider spring and autumn, whilst conditions for pedestrian thoroughfare, access or waiting (for example bus stops) consider all seasons, with winter generally being the critical season. The activities considered, and their relation to the Lawson comfort criteria, are summarised as follows:

Suitability		**Lawson Comfort Criteria**
Outdoor seating	For long periods of sitting such as for an outdoor café / bar, a private balcony	'Long-term sitting' in summer
Entrances, waiting areas, shop fronts	For pedestrian ingress / egress at a building entrance / shop front, window shopping, or short periods of sitting or standing such as at a bus stop, taxi rank, meeting point, etc.	'Short-term standing / sitting' in all seasons
Recreational spaces	For outdoor leisure uses such as a park, children's play area, etc.	'Short-term standing / sitting' from spring through autumn

Suitability		Lawson Comfort Criteria
Leisure Thoroughfare / Strolling	For access to and passage through the development and surrounding area	'Leisure Thoroughfare / Strolling' in all seasons
Pedestrian Transit / Thoroughfare (A-B)	For access to and passage through the development and surrounding area	'Pedestrian Transit / Thoroughfare (A-B)' in all seasons

Comfort Rating	Threshold Wind Speed	Exceedance Time [3]
Uncomfortable for All Uses	10 m/s	> 5 %
Pedestrian Transit (A-B)	10 m/s	<= 5%
Strolling / Recreational Spaces / Short Periods of Standing / Sitting	8 m/s	<= 5%
Entrances / Shop Fronts / Waiting Areas	6 m/s	<= 5%
Long Term Sitting	4 m/s	<= 5%

4.7. Results

Results are provided for the following configurations:

- Existing site conditions
- Proposed development within the context of existing surrounds
- Proposed development within the context of future surrounds

The derived wind speeds are converted into wind speed-up factors. These are defined as the ratio between the measured wind speeds at a height of 1.5 m above the ground and the wind speed at a reference height of 60 m.

Wind speed-up results from the numerical simulations are presented in graphical form, as velocity ratio contours and are presented in APPENDIX C. The contours are plotted on a plane 1.5 m above the ground surface.

Wind speed-up factors are processed in conjunction with wind statistics for the site to derive the exceedance of threshold wind speeds relevant to the comfort and safety criteria detailed in Section 4.6.

The results are summarised in graphical format in terms of comfort and safety contours in Figure 5 to Figure 13.

5. Results

5.1. Existing Site Conditions

The annual safety plot for the existing site conditions is presented in Figure 5. Both the worst seasonal comfort ratings and the summer comfort ratings are presented in Figure 6 and Figure 7 respectively.

The existing site of the development is adjacent to a recreational area / park and the Exchange Station. It is situated in a built-up area amongst many higher rise buildings which shelter the site from the prevailing winds. As such, the existing site is expected to experience relatively calm wind conditions.

Wind conditions at all areas in and around the existing site are generally suitable, in terms of both pedestrian safety and comfort, for their intended uses. There are some areas of reduced wind comfort levels / safety issues observed at the pedestrian passages between Fazakerley Street and Union Street, and the corner of Brook Street and Old Hall Street. This is due to the downwash winds creating a channelling effect between the higher rise buildings.

5.2. Proposed Development, within the Context of Existing Surrounds

5.2.1. Safety

With the introduction of the proposed development, within the context of existing surrounds, wind conditions generally remain unchanged and suitable in terms of pedestrian safety, around the proposed development.

The annual safety plot for the proposed site conditions, within the context of the existing surrounds is presented in Figure 8.

5.2.2. Comfort

Wind conditions at the locations around the proposed development ground level generally rate as suitable in terms of pedestrian comfort, for their intended use for both the summer and the worst seasonal (winter) assessments.

The inclusion of Block A within the proposed development site causes an increase in wind speed acceleration and reduced comfort levels for a limited number of locations, reducing suitability from long term sitting to waiting areas. These are located northeast to the new Block A building however this is within the acceptable rating.

Both the worst seasonal comfort ratings and summer comfort ratings are presented in Figure 9 and Figure 10 respectively.

5.3. Proposed Development, within the Context of Future Surrounds

5.3.1. Safety

With the introduction of the proposed development, within the context of future surrounds, wind conditions generally remain suitable in terms of pedestrian safety, at all areas in and around the proposed development.

The annual safety plot for the proposed site conditions, within the context of the future surrounds is presented in Figure 11.

5.3.2. Comfort

Wind conditions at the locations around the proposed development ground level generally rate as suitable in terms of pedestrian comfort, for their intended use for both the summer and the worst seasonal assessments.

With the addition of the future surrounds, the pedestrian comfort levels around the site change their suitability from long term sitting to waiting areas however this is within the acceptable rating.

Both the worst seasonal comfort ratings and summer comfort ratings are presented in Figure 12 and Figure 13 respectively.

6. Observations and Recommendations

The following observations were drawn from the wind microclimate study:

- For all the assessed configurations, wind conditions are generally suitable in terms of both pedestrian comfort and safety for their intended use throughout the year
- With the introduction of the proposed development, a limited number of locations are associated with increased wind acceleration and reduced comfort levels for long-term sitting, but still suitable for waiting areas, recreation, and short-term sitting. These areas are located northeast to the new Block A building however this is within the acceptable rating

7. References

[1] BMT, "Proposal No. Q533742: Pall Mall Exchange, Liverpool, UK," 1st October 2018.

[2] Davenport, A.G., "An Approach to Human Comfort Criteria for Environmental Wind Conditions.," *Colloqium on Building Climatology, Stockholm,* September 1972.

[3] Lawson, T.V, "The Wind Environment of Buildings: A Logical Approach to the Establishment of Criteria," *University of Bristol, Department of Aeronautical Engineering, TVL/7301,* 1973.

[4] Lawson, T.V, "The determination of the wind environment of a building complex before construction.," *University of Bristol, Department of Aeronautical Engineering, TVL/9025,* 1990.

[5] Blocken, B. and Carmeliet, J., "Pedestrian wind environment around buildings: Literature review and practical examples," *Journal of Thermal Envelope and Building Science,* pp. 107-159, October 2004.

[6] ESDU (Engineering Science Data Unit) Item 01008, "Computer program for wind speeds and turbulence properties: flat or hilly sites in terrain with roughness," 2001.

[7] BMT, "E-mail Sent from BMT, "600312/SC - Pall Mall Liverpool - Schedule Update (Week 3)"," 17th May 2019.

[8] Kier Property, "E-mail Received from Oliver Butler, "[External] RE: Wind mitigation model update"," 10th May 2019.

[9] Richards, P.J. and Hoxey, R.P., "Appropriate boundary conditions for computational wind engineering models using the k-ε turbulence model," *Journal of Wind Engineering and Industrial Aerodynamics,* vol. 46 & 47, pp. 145-153, 1993.

[10] Melbourne, W.H., Criteria For Environmental Wind Conditions, Journal of Industrial Aerodynamics, 3, 241-249, 1978.

8. Figures

8.1. General Site Figures

Figure 1 - Site Location

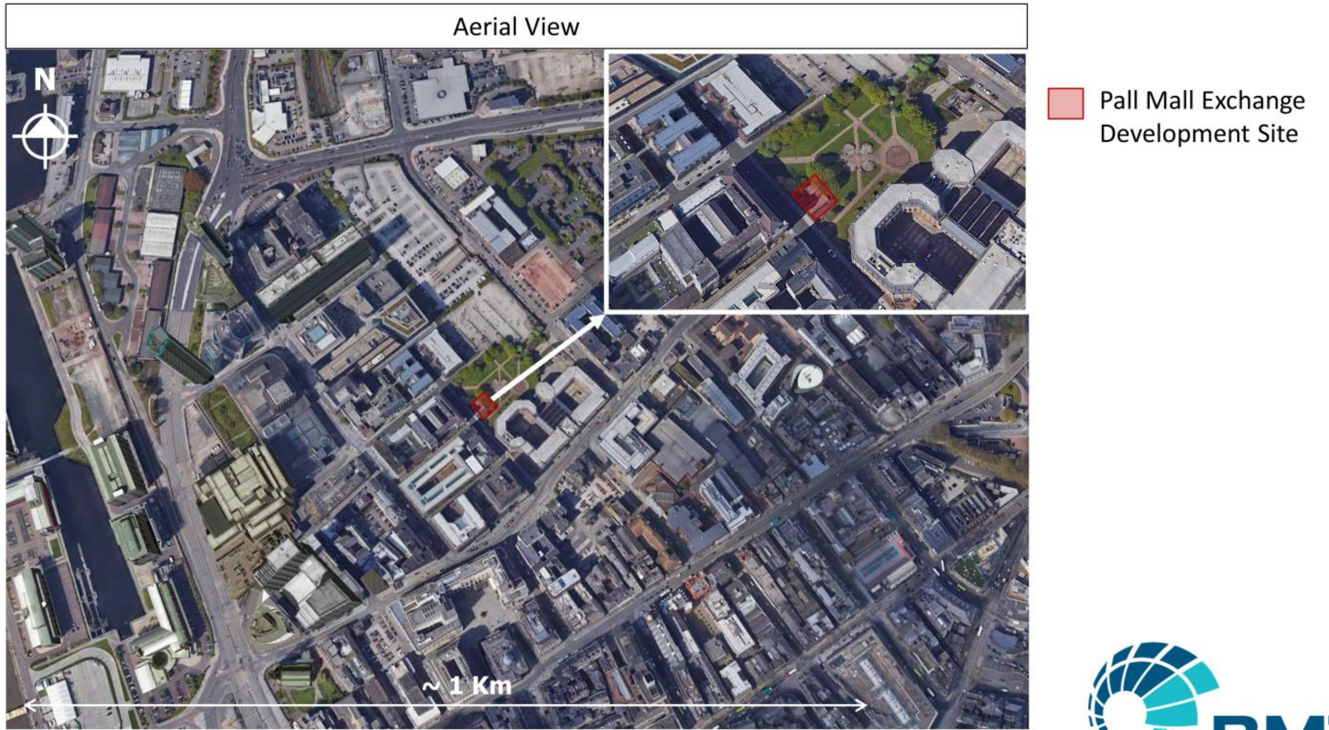


Figure 2 - 3D model: Existing Site Conditions

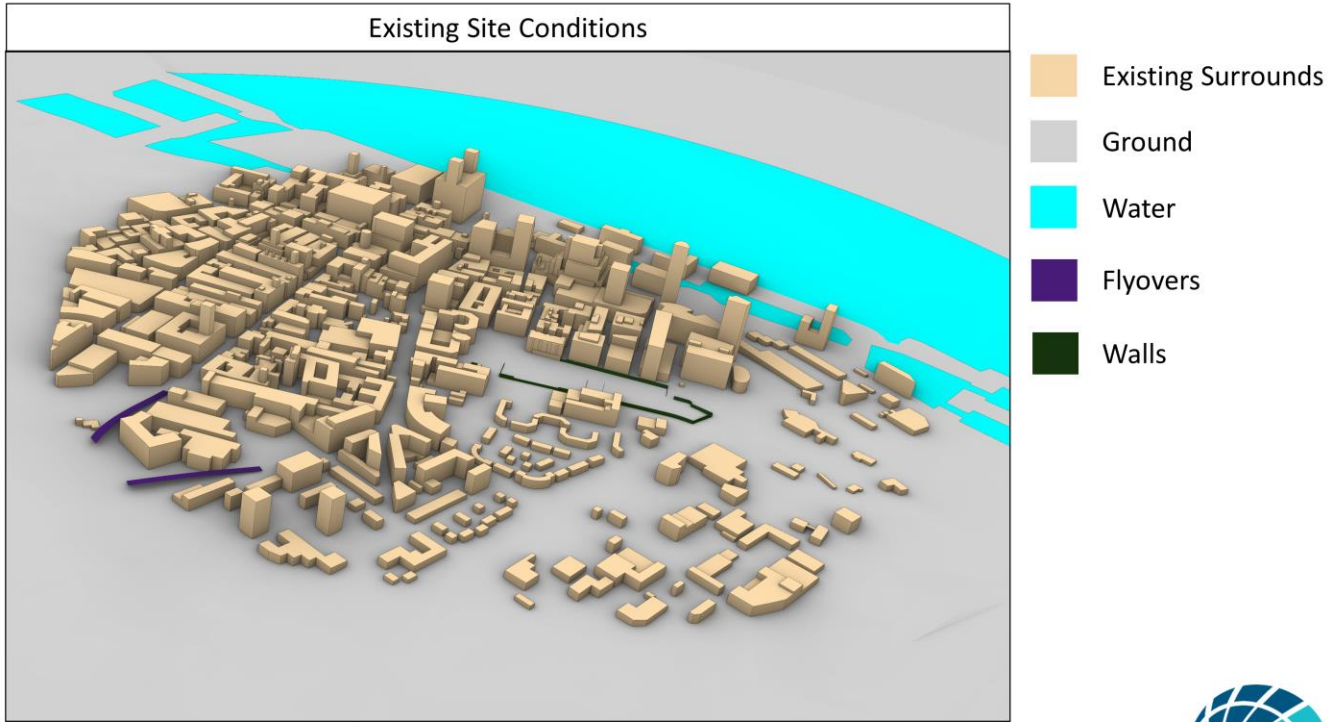


Figure 3 - 3D model: Proposed Development in the context of the Existing Surrounds

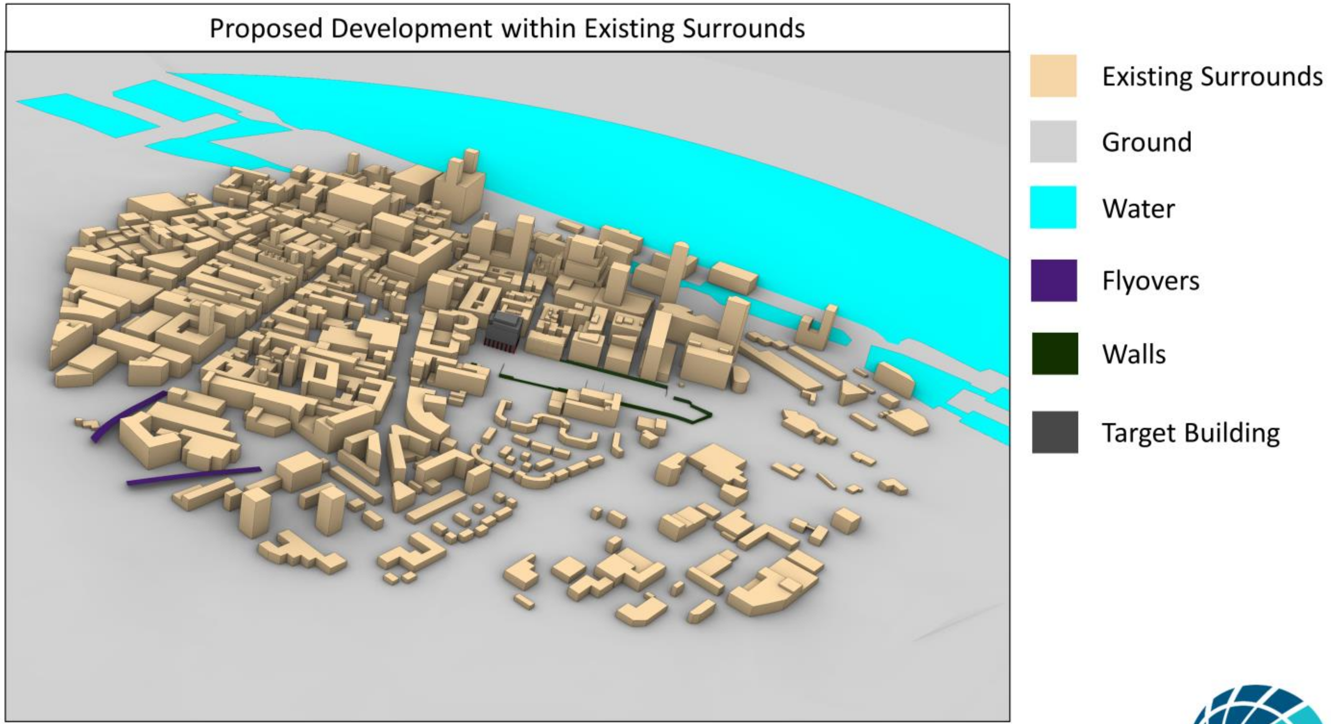
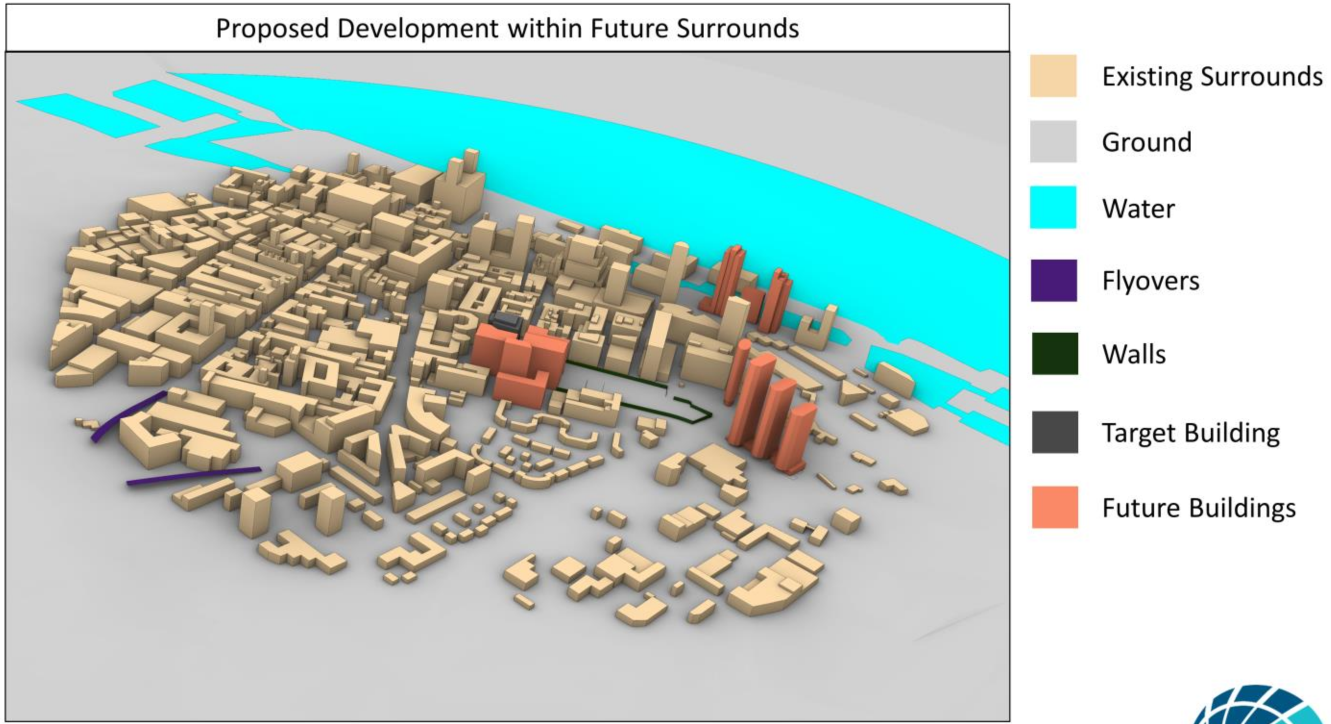


Figure 4 - 3D model: Proposed Development in the context of the Future Surrounds

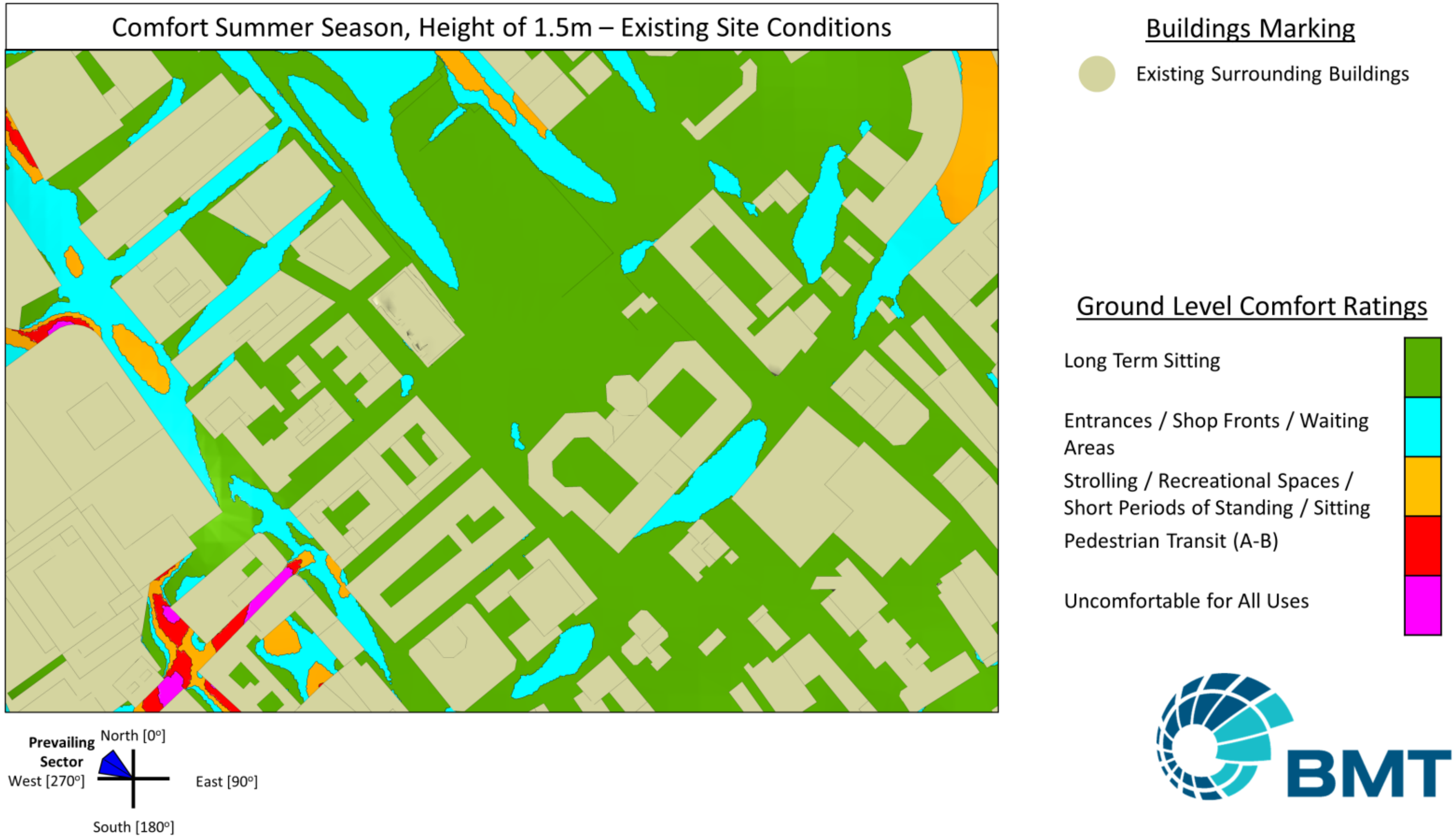


8.2. Wind Microclimate Results - Existing Site Conditions

Figure 5 - Safety Ratings: Existing Site Conditions

Figure 6 - Worst Seasonal Comfort Ratings: Existing Site Conditions

Figure 7 - Summer Comfort Ratings: Existing Site Conditions



8.4. Wind Microclimate Results - Proposed Development, within Existing Surrounds

Figure 8 - Safety Ratings: Proposed Site, within Existing Surrounds

Figure 9 - Worst Seasonal Comfort Ratings: Proposed Site, within Existing Surrounds

Figure 10 - Summer Comfort Ratings: Proposed Site, within Existing Surrounds

8.5. Wind Microclimate Results - Proposed Development, within Future Surrounds

Figure 11 - Safety Ratings: Proposed Site, within Future Surrounds

Figure 12 - Worst Seasonal Comfort Ratings: Proposed Site, within Future Surrounds

Figure 13 - Summer Comfort Ratings: Proposed Site, within Future Surrounds

APPENDIX A. WIND CLIMATE ANALYSIS

A.1. ESDU Wind Analysis

A detailed analysis was carried out to determine the wind properties at the site. The wind analysis is based on the widely accepted Deaves and Harris model of the Atmospheric Boundary Layer (ABL), as defined in ESDU Item 01008 [6], and has provided wind profiles describing the variation of wind speed and turbulence intensity with height and wind direction.

A.2. Wind Frequency Data

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

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

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

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

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

The resulting weather station wind data is transposed to a standard reference terrain category, 'open country terrain', at sea-level, accounting for upwind terrain, topography and altitude for the weather centre.

The open country wind data is then transposed to reference height at the site of the proposed development, accounting for upwind terrain, topography and altitude for the target site. The resulting annual and seasonal directional and wind speed probability distributions at the reference height of 60 m, at the proposed site, are given in Figure A.1 to Figure A.5.

Values of *p*, *c,* and *k* for the Liverpool Airport (Lennon) weather station, transposed to open-country terrain at 10 m height above sea-level altitude are given in Table A.1.

Figure A.1 - Wind speed probability distribution at site (60 m reference height): Annual

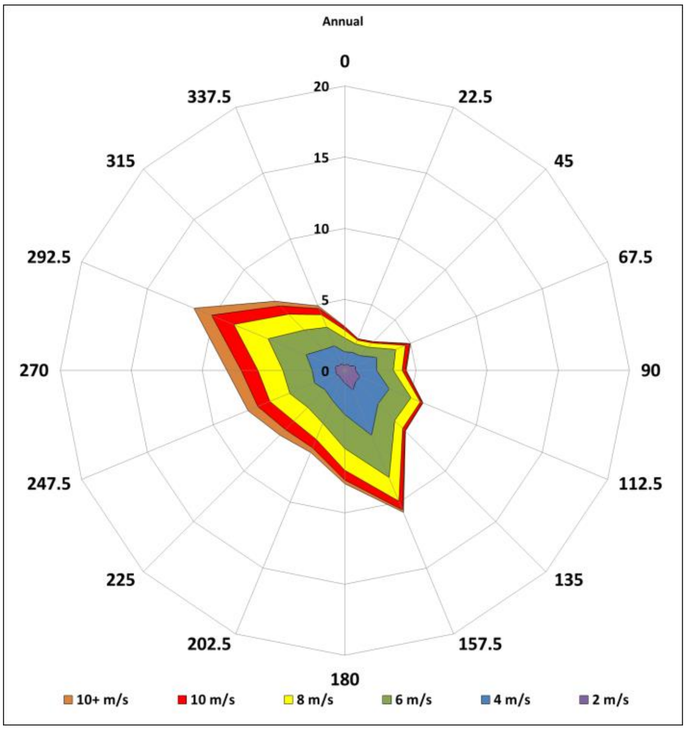


Figure A.2 - Wind speed probability distribution at site (60 m reference height): Spring

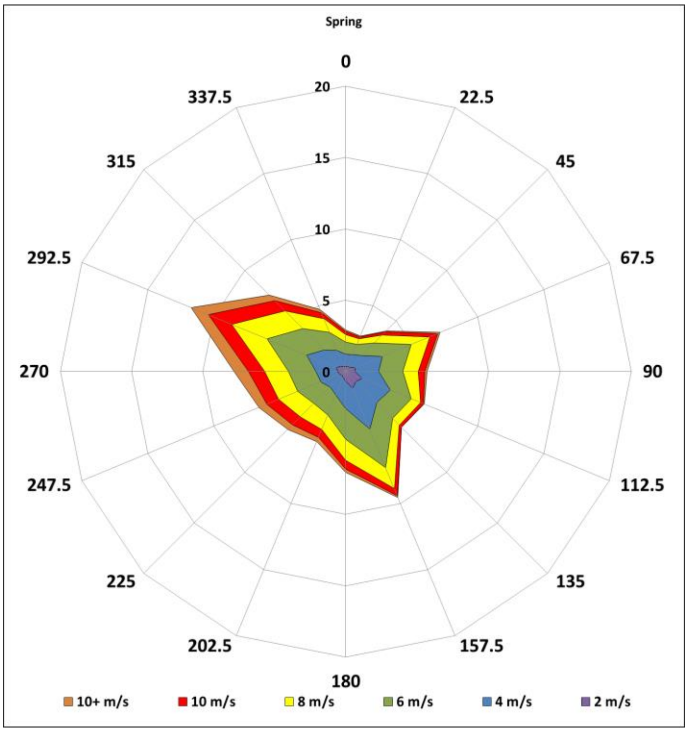


Figure A.3 - Wind speed probability distribution at site (60 m reference height): Summer

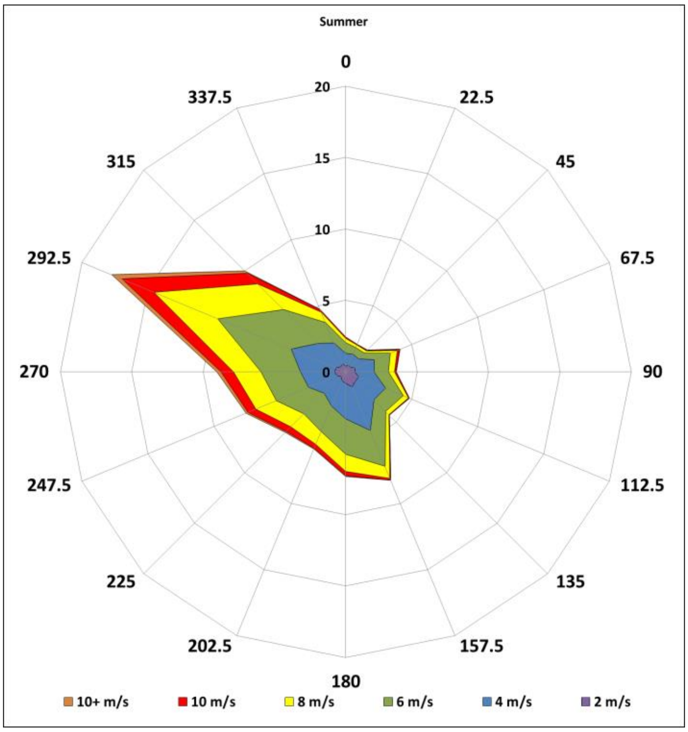


Figure A.4 - Wind speed probability distribution at site (60 m reference height): Autumn

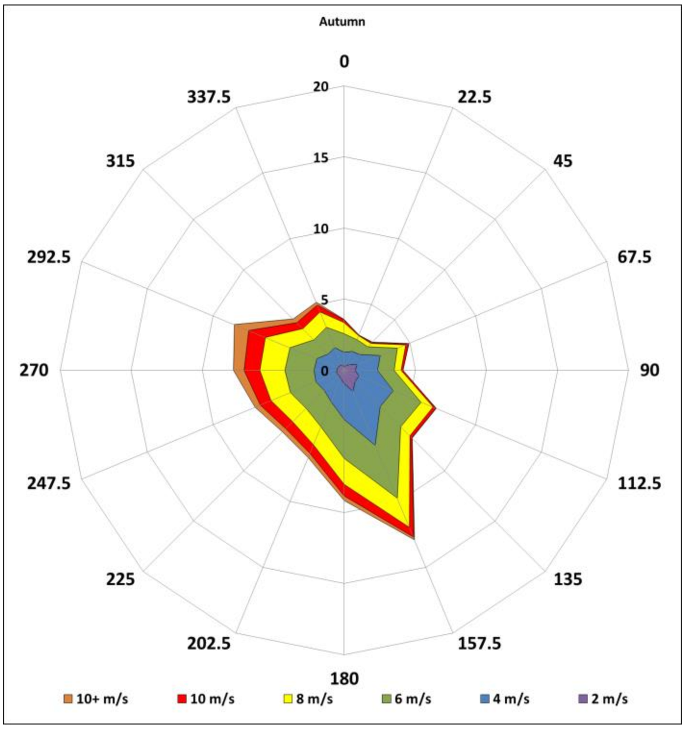


Figure A.5 - Wind speed probability distribution at site (60 m reference height): Winter

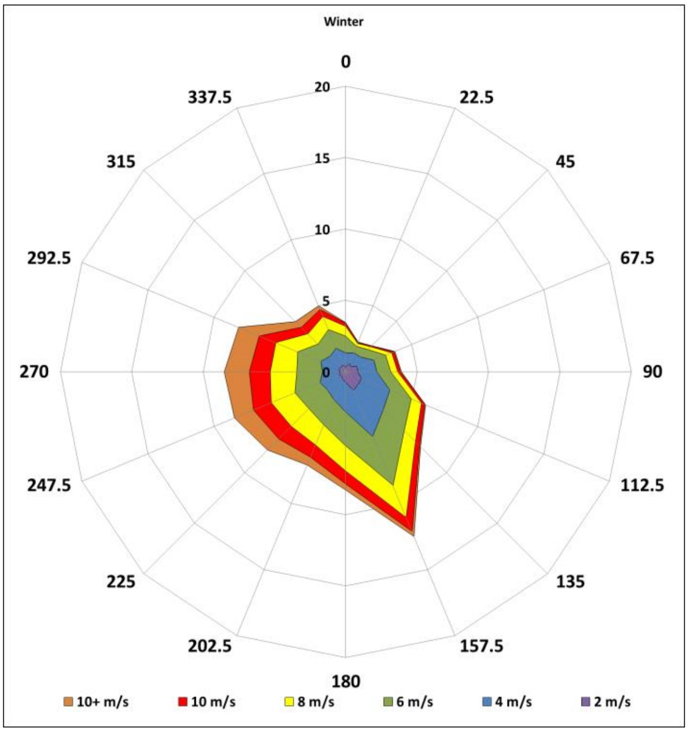


Table A.1 - Wind Frequency Statistics: Corrected Liverpool Airport (Lennon) Weather Station Data transformed to z0 = 0.03 m Weibull Coefficients

Annual	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
p	3.1	2.43	2.89	5	4.33	5.95	6	10.78	7.95	6.21	6.42	7.34	8.29	11.49	6.91	4.91
c	5.24	4.36	4.73	4.92	4.77	4.38	4.49	5.08	5.6	5.9	6.5	6.54	6.94	7.03	6.36	5.68
k	2.2	1.85	2	1.95	1.87	1.96	1.97	2.06	2.11	2.04	2.11	1.99	2.05	2.16	2.18	2.05

Autumn	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
p	3.57	2.69	2.78	4.94	4.14	7	6.76	12.91	9.15	6.64	6.16	6.8	7.79	8.38	5.11	5.17
c	5.48	4.47	4.43	4.51	4.39	4.55	4.56	5.13	5.66	5.86	6.12	6.21	6.77	7.17	6.32	5.97
k	2.64	2.28	1.94	1.85	1.99	2.14	2.11	2.16	2.13	2.1	2.19	2.16	2.18	2.15	2.1	2.26

Winter	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
p	3.46	2.24	2.56	3.71	3.91	6.04	7.42	12.51	8.28	7.06	7.75	8.44	8.52	8.14	4.95	5
c	5.41	3.98	4.3	4.38	4.53	4.49	4.82	5.57	6.03	6.51	7.36	7.62	8.12	7.79	6.67	5.95
k	2.37	1.66	2.07	1.67	1.74	1.89	1.93	2.1	2.14	2.11	2.17	2.08	2.18	1.99	1.93	2.04

Spring	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
p	2.92	2.69	4.03	7.16	5.69	5.94	5.53	9.53	7.07	5.3	5.75	6.57	7.83	11.71	7.59	4.69
c	5.43	4.98	5.49	5.55	5.47	4.38	4.46	5.04	5.72	6.1	6.66	6.62	7.05	6.99	6.53	5.95
k	2.06	1.95	2.24	2.17	2.09	1.89	1.99	2.13	2.2	2.11	2.26	2.15	2.05	2.19	2.26	2.17

Summer	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
p	2.43	2.07	2.14	4.12	3.53	4.83	4.3	8.23	7.33	5.85	6.02	7.56	9.05	17.76	10	4.77
c	4.56	3.97	4.19	4.62	4.43	4.04	3.91	4.45	4.97	5.05	5.62	5.55	5.82	6.55	6.1	4.98
k	2.19	1.89	1.95	2.01	2.01	2.13	2.08	2.39	2.35	2.24	2.4	2.31	2.25	2.69	2.64	2.23

APPENDIX B. COMPUTATIONAL FLUID DYNAMICS MODEL

B.1. Analysis Software

The multi-purpose CFD software ANSYS CFX (Version 19.2) was used for the study. CFX is regarded as a market-leading product that has been thoroughly validated both in-house and by external specialists for wind flow analysis.

B.2. Atmospheric Boundary Layer CFD Model

A total of 48 transient atmospheric boundary layer CFD simulations were carried out for the three configurations, covering the full 360^{o} with a wind angle increment of 22.5^{o}. The k-ω Shear Stress Transport (SST) turbulent model was used in the analysis for all cases.

The k-ω SST turbulence model accounts for the transport of the turbulent shear stress and gives highly accurate predictions of the onset and the amount of flow separation under adverse pressure gradients.

B.2.1. Model Geometry and Computational Domain

The CFD model including the target buildings and existing surround buildings were constructed based on 3D and 2D data, supplied by Kier Property Developments Limited, and CTP Limited in [7] and [8].

The computational mesh was generated in the atmosphere bounded by the buildings, the ground, and the outer boundaries. The computational domain extended at least 5 characteristic lengths in each direction to avoid any boundary influence on the flow solution.

B.2.2. Computational Mesh

A computational mesh consisting of 28 million tetrahedral and hexahedral elements was constructed. The computational mesh presented in Figure B.1 was used for the analysis. Cells were concentrated around the proposed development as shown in Figure B.2.

Figure B.1 - Perspective far-field view of the computational mesh

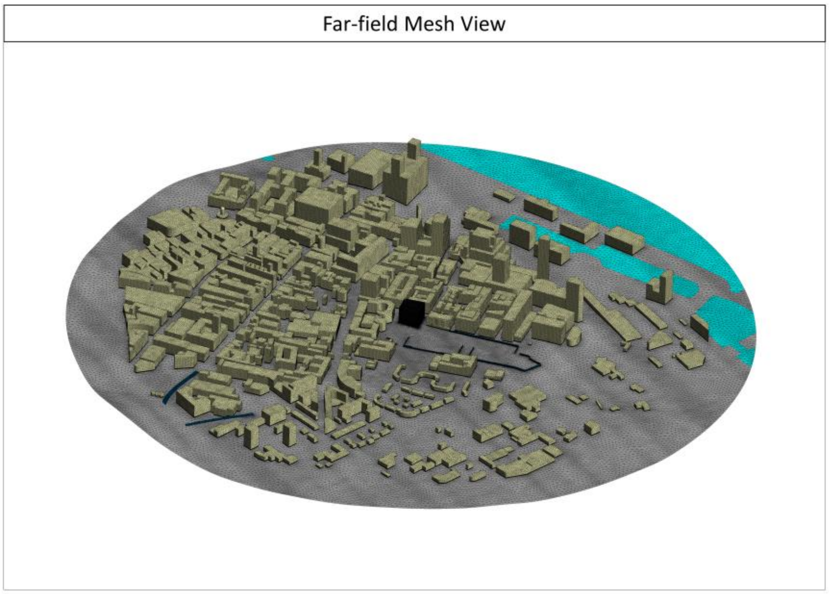
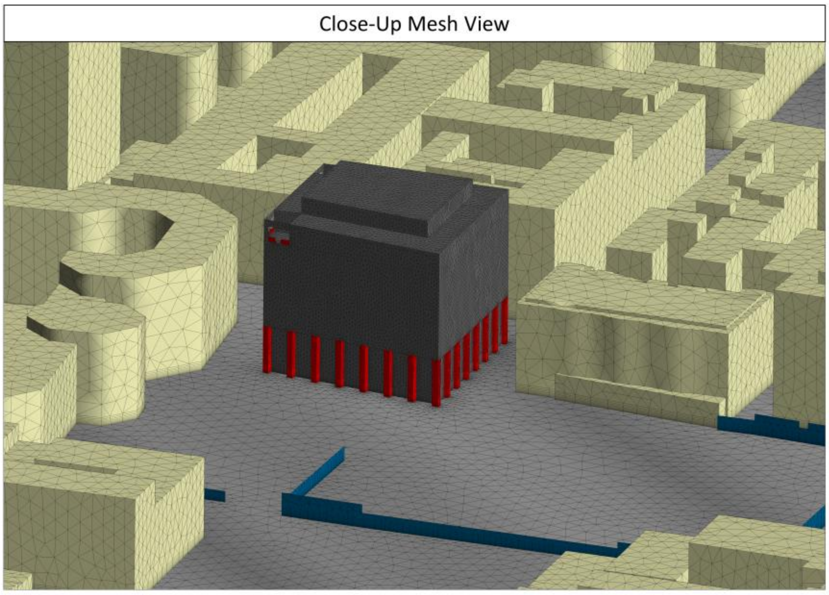


Figure B.2 - Perspective close-up view of the computational mesh



B.2.3. Atmospheric Boundary Layer

The atmospheric boundary layer was simulated using a logarithmic velocity profile consistent with the model presented by Richards and Hoxey [9]. It assumes that:

- The vertical velocity is zero
- The pressure is constant
- The shear stress is constant

This implies the following relationships for the velocity and turbulence quantities:

$$U = \frac{u^*}{a_k}\ln\left(\frac{z}{z_0}\right) \qquad k = \frac{{u^*}^2}{\sqrt{C_\mu}} \qquad \varepsilon = \frac{{u^*}^3}{a_k(z+z_0)}$$

Where: u^* is the friction velocity

a_k is the von Karman's constant

U is the mean velocity

z is the height

z_0 is the aerodynamic surface roughness of the ground

k is the turbulent kinetic energy

C_μ is a constant equal to 0.09

ε is the turbulence eddy dissipation

The friction velocity was calculated from a specified reference velocity U_{ref} at a reference height Z_{ref} as follows:

$$u^* = a_k \frac{U_{ref}}{\ln\left(\frac{Z_{ref} + z_0}{z_0}\right)}$$

B.2.4. Boundary conditions

A no-slip wall boundary condition (u, v, w = 0) with a varying appropriate roughness (based on the terrain analysis carried out in site wind analysis presented in APPENDIX A) was applied on the ground. All other surfaces were modelled as smooth walls with a no-slip condition.

B.2.5. Gust Equivalent Mean (GEM)

Gusts in the wind flow may lead to additional danger and discomfort beyond that caused by the mean wind speed. In order to assess this danger and/or discomfort, the gust wind speed is translated to an equivalent mean wind speed. The standard deviation of the wind speed was calculated by using the turbulent kinetic energy in Eq.1. The Gust Equivalent Mean or GEM is given in Eq.2 [10].

$$\sigma = \sqrt{(k * 2/3)} \qquad \text{Eq.1}$$

$$U_{GEM} = U + 3.5\sigma \qquad \text{Eq.2}$$

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

APPENDIX C. VELOCITY RATIOS

Figure D.1 - Velocity Ratio Contours at 1.5 m above Ground: Existing Site Conditions

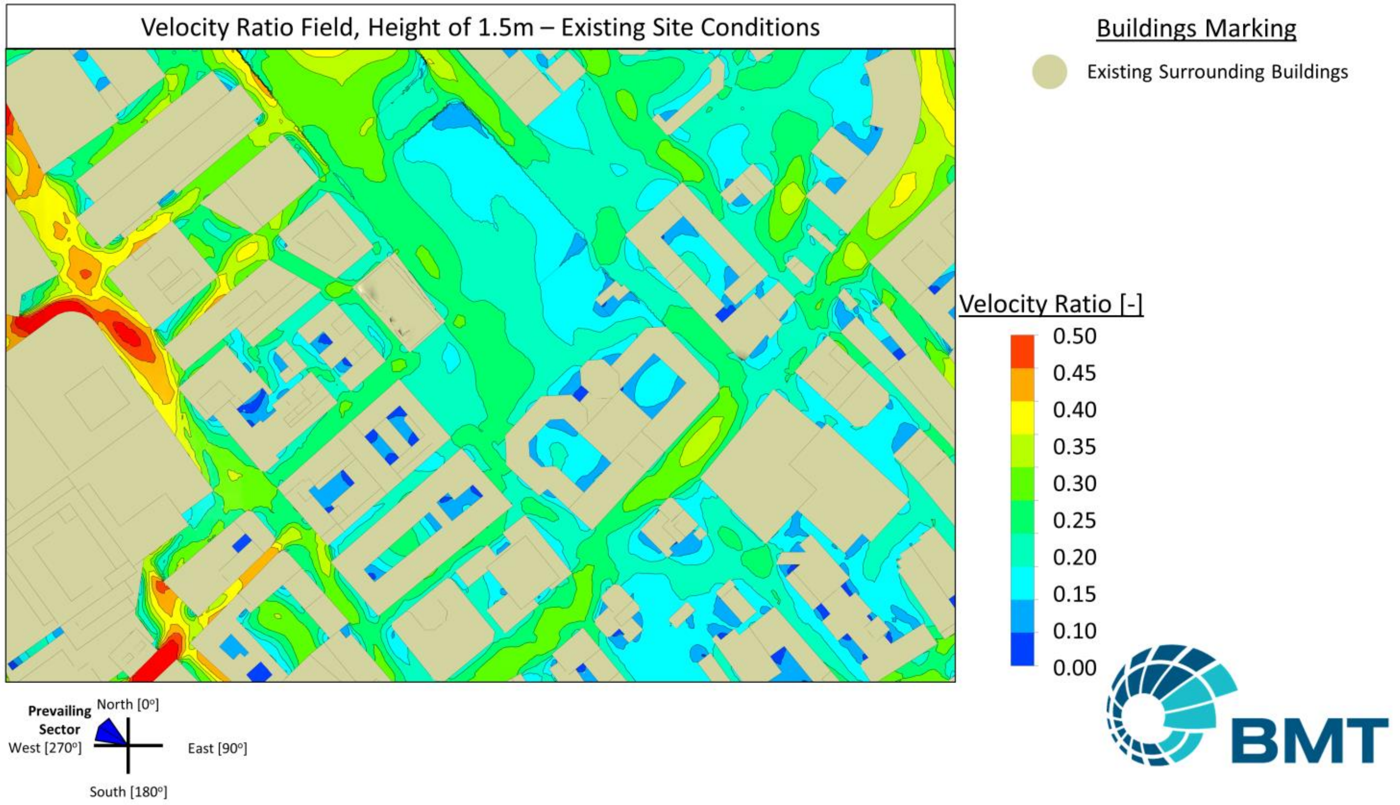


Figure D.2 - Velocity Ratio Contours at 1.5 m above Ground: Proposed Site, within Existing Surrounds

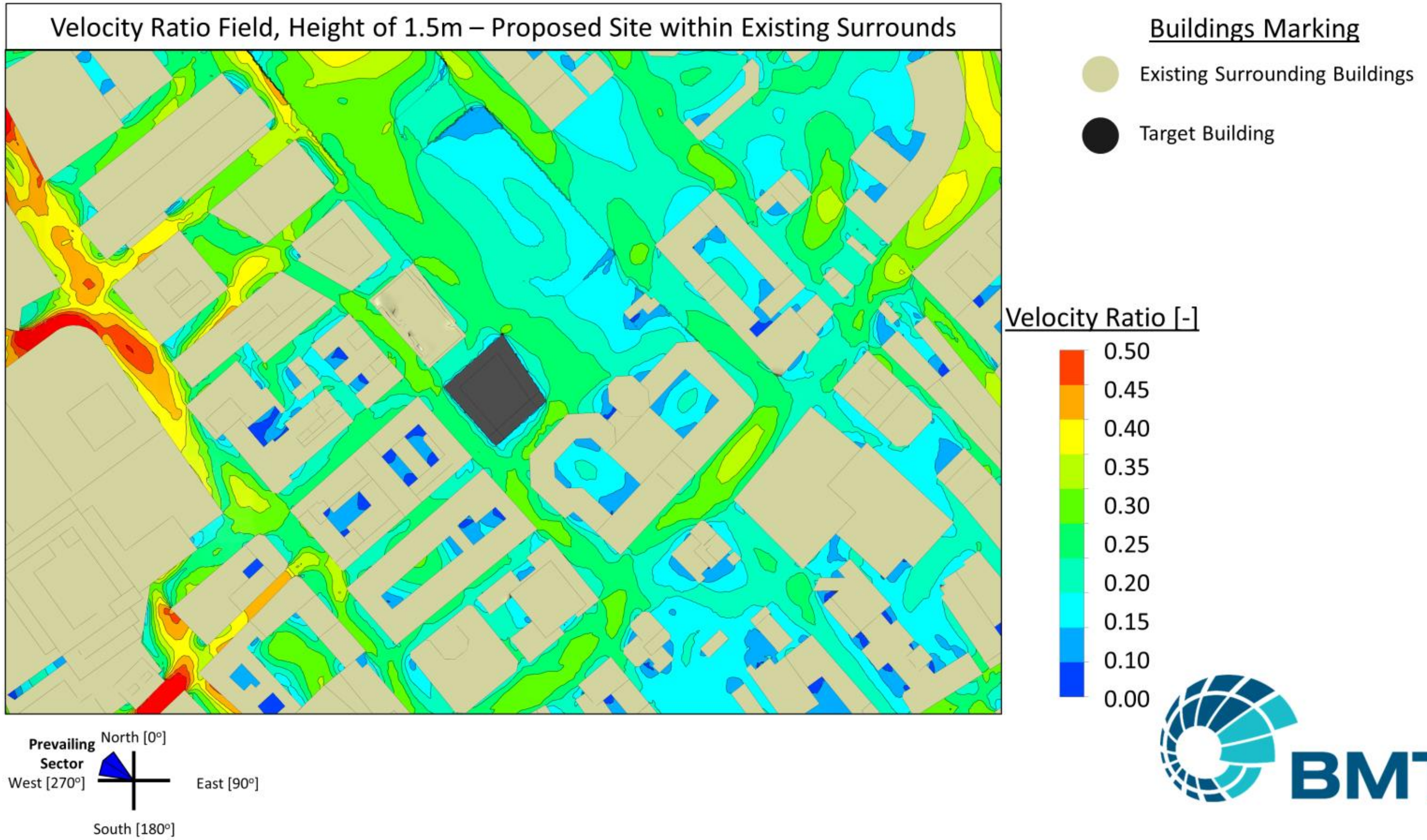


Figure D.3 - Velocity Ratio Contours at 1.5 m above Ground: Proposed Site, within Future Surrounds