



Stocktons

For

Liquid Business (Manchester) Limited

Wind Microclimate Report

0760483rep1v3

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Architectural Aerodynamics Ltd.

128 City Road

London

United Kingdom

EC1V 2NX

Submitted by:

Alex Turpitt

alex@architecturaero.com

Issue History

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Executive Summary

Background

A study has been carried out by Architectural Aerodynamics Ltd. (ArcAero) to assess the wind microclimate for the proposed Stocktons development in Manchester, United Kingdom.

The study has adopted wind tunnel testing to predict the strength of winds. Then using the industry standard Lawson criteria, it has established the suitability of wind conditions and the impact on the surrounding area, following the introduction of the proposed development.

Conclusions

The following conclusions have been drawn:

- Wind conditions throughout the existing site and surrounds satisfy the safety criteria for wind and generally satisfy the comfort criteria for all uses.
- With the introduction of the proposed development within existing surrounds, both comfort and safety criteria are generally met, though some exceptions exist. This is also the case with the introduction of cumulative surroundings.
- With the introduction of soft landscaping and mitigation measures, the safety criteria are met throughout the study area. Although some areas still exceed comfort criteria during windier seasons, primarily in winter, these exceedances are generally and / or localised marginal.

1 Introduction

A microclimate is defined 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 area as a whole. Wind microclimate assessments consider the wind conditions that would result upon the introduction of a new development into an existing space.

Such assessments predict the proportion of time an area will experience wind speeds in excess of threshold values associated with safe and comfortable use by pedestrians and occupants once the development is introduced. It can therefore be shown within the various parts of a new proposal and neighbouring properties whether wind conditions are suitable or unsuitable, and whether design adjustment or mitigation measures are required. It is for this purpose that wind microclimate assessments are undertaken.

This report summarises the results wind tunnel studies commissioned by Liquid Business (Manchester) Limited, to assess the wind microclimate for the proposed Stocktons development in Manchester, United Kingdom.

2 The Proposed Development

2.1 Site Location and Surrounding Area

The Stocktons development is bounded by Great Ancoats Street to the northeast, Store Street to the southeast, warehouses to the southwest and Ducie Street to the northwest.

Further afield are a mixture of low-, medium- and high-rise buildings typical of Manchester centre.

The proposed development will comprise a 47-storey residential block and 24-storey office accommodation on the same site.

2.2 Wind Assessment

Early-stage assessments were initially carried out in CFD before wind tunnel testing (WTT) was carried out to benchmark and validate the wind-related performance of the scheme, during which elements of mitigation were devised. This includes the soft landscaping and mitigation measures shown and described in Figure 2.1. Additional CFD modelling has been carried out post-wind tunnel testing to revisit and re-examine the effect of various mitigation measures.

2.3 Drawing Information Describing the Proposed Development

Assessment models have been constructed on the basis of the following drawings received from SimpsonHaugh:

Table 2-1 – Drawings for assessment

Drawing	Date
A_160824.fbx	19 th August 2024
A_160824_Slabs & Columns.fbx	19 th August 2024
B_190824.fbx	19 th August 2024
10359-SHP-Z0-A-G100-M3-XX-001 - Massing Models.dwg	25 th October 2024

The existing surrounding area was based upon information supplied by the design team and supplemented by Ordnance Survey details for the area. Cumulative surrounds were based upon information contained within the Manchester City Council planning portal.

2.4 Soft Landscaping and Wind Mitigation Measures

2.4.1 Wind Tunnel Testing

The development has been assessed, initially, in the absence of landscaping proposals or any wind mitigation measures, before landscaping and wind mitigation measures were introduced and their effectiveness verified. Soft landscaping and wind mitigation measures are as set out in Figure 2.1.

2.4.2 CFD Modelling

The development has been assessed with soft landscaping and wind mitigation measures in place. As with the wind tunnel modelling, soft landscaping proposals and wind mitigation measures are as set out in Figure 5.1.

2.5 Cumulative Schemes

Consented developments currently under construction have been included in the existing surrounds configuration are listed in Table 2-2.

Table 2-2 – Schemes under construction

Development Name	Planning Reference
Victoria House	122000/FO/2018
The Castings	127317/FO/2020
The Fairfax	121099/FO/2018
Store Street	126608/FO/2020
Sligo House	128911/FO/2020
One Port Street	132489/FO/2021
1NQ	135675/FO/2022

The proposed development was assessed in two surrounding contexts, namely existing surrounds and cumulative surrounds. Consented developments that have been additionally considered within the cumulative surrounds scenario are listed in Table 2-3.

Table 2-3 - Cumulative Schemes

Development Name	Planning Reference
Electric Park	128191/FO/2020
M1 Piccadilly	132626/FO/2022
Motto Hotel	135662/FO/2022
Eider House	115178/FO/2017

3 Assessment Methodology

3.1 Wind Tunnel Testing

Wind tunnel modelling was undertaken in the Imperial College 10x5 atmospheric boundary layer wind tunnel in London. The blockage ratio was within the 5% level recommended by the ASCE SEI (1) and AWES QAM (2) guidelines. Full details of the wind tunnel testing conducted for the study are presented in Appendix A of this report.

Modelling via wind tunnel testing has derived mean and gust equivalent mean wind speeds, in accordance with best industry practice. In doing so 16 wind directions were assessed, in 22.5° increments.

The industry standard criteria for wind microclimate assessments, the LDDC variant of the Lawson criteria (3), has been employed for the study.

3.2 CFD Modelling

CFD modelling has employed a RANS approach: full details of the CFD methodology are set out in Appendix C of this report. Salient highlights of this approach are:

- The Shear Stress Transport k- ω turbulence model has been employed.
- Architectural features of 0.5 metres or more have been captured within the geometry modelled.
- Cell sizes of as small as 0.2 metres were utilised to capture flow behaviour in critical locations.
- The region of interest closest to the ground (1.5 metres) incorporated 5 layers of cells.

Modelling via CFD has derived mean and gust equivalent mean wind speeds, in accordance with best industry practice. All assessment scenarios have considered 16 wind directions in 22.5° increments.

3.3 Wind Climate Analysis

Wind microclimate studies require that meteorological data is transposed from a nearby weather station with sufficient wind data to produce accurate wind frequency statistics. The current study uses data from Manchester Weather Station.

Full details of the wind climate relevant to the site, the wind properties approaching the site and the modelling of those wind properties in the wind tunnel models are provided in Appendix B of this report. All analysis of wind data and the atmospheric boundary layer has employed the methods of ESDU item 01008 (4), in accordance with best industry practice.

3.4 Assessment Scenarios

The wind tunnel model covered a radius of 450 metres from the site. All features which are likely to impact the wind flow within the study area have been replicated. The assessment

considered a full range of directions in 22.5° intervals, and considered the following configurations:

1. Existing site, existing surrounding conditions
2. Proposed development, existing surrounding conditions
3. Proposed development, existing surrounding conditions with proposed soft landscaping and wind mitigation measures
4. Proposed development, cumulative surrounding conditions

Details of the tunnel and model used for the wind tunnel study are presented in Appendix A of this report.

3.5 The LDDC Lawson Criteria

The industry standard criteria for wind microclimate assessments are commonly referred to in the UK as the Lawson criteria after one of their main authors. As with most other leading practitioners, ArcAero use the 'LDDC' variant of the Lawson Criteria (London Docklands Development Corporation (3)).

The LDDC variant 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 relatively simple and practical manner for the assessment of wind comfort and safety.

3.5.1 Safety

A wind speed of 15 m/s occurring once per year is rated as unsuitable, in terms of safety, with the potential to de-stabilise the less able members of the public including the elderly, cyclists and children.

3.5.2 Comfort

The LDDC variant of the Lawson criteria (3) prescribes that wind conditions are suitable for a given activity when the threshold is exceeded no more than 5% of the time. The value of 5% has been established as giving a reasonable allowance for extreme and relatively infrequent winds that are tolerable within each category.

Where certain activities are year-round, such as walking, entrance use or for waiting areas, comfort ratings are required to be met in all seasons. For more seasonal activities, such as outdoor recreation or for sitting spaces, the assessment focuses on relevant seasons where the expectation will exist for conditions to be suitable. The LDDC comfort threshold wind speed values are presented in Table 3-1.

Table 3-1 – LDDC Wind Comfort Thresholds

Threshold Wind Speed [m/s]	Comfort Rating / Activity	
4	C4	Long-term sitting
6	C3	Short-term sitting / standing

8	C2	Strolling
10	C1	Walking
> 10	C0	Uncomfortable

3.6 Pedestrian / Occupant Uses

In using the Lawson criteria to consider the suitability of spaces, in terms of comfort, it is necessary to identify the anticipated usage of the various areas and assign that usage to an assessment receptor. Each measurement location is assigned a pedestrian / occupant use, for each assessment scenario. This is presented in Appendix D.

4 Wind Tunnel Assessment - Results

4.1 Existing Site within Existing Surrounds

The results for the existing site conditions are presented graphically within Figure 4.1 and Figure 4.2 for worst-seasonal conditions, and within Figure 4.3 and Figure 4.4 for summer conditions.

4.1.1 Safety

Wind conditions throughout the existing site and surrounding areas satisfy the safety criteria for wind.

4.1.2 Comfort

Conditions within the existing site are expected to be generally suitable for existing pedestrian activities. This includes thoroughfares which are suitable for strolling or better, car parks that are suitable for strolling or better and entrances that are substantially suitable for standing or better. At elevated levels on the Oxygen Tower, balconies are suitable for at least short-term sitting in summer.

Minor exceptions at an entrance to Oxygen Tower (location 2) and at an entrance to an existing shop (location 77) which marginally exceed the comfort criteria, where conditions marginally exceed the criteria for standing in winter.

4.2 Proposed Development within Existing Surrounds

The results for the proposed development within existing surrounds are presented graphically within Figure 4.5 and Figure 4.6 for worst-seasonal, and within Figure 4.7 and Figure 4.8 for summer conditions.

4.2.1 Safety

All locations within the site and immediate surrounds meet the safety criteria with an exception at a thoroughfare on Ducie Street (location 69).

4.2.2 Comfort

4.2.2.1 Thoroughfares

In general, wind conditions within the site are suitable for strolling or better throughout the year and are thus suitable for thoroughfare use. One exception to this is at the east of Building B (location 56), being suitable only for fast walking during winter, falling just short of meeting the criteria by 1%. Others occur between Buildings A and B (locations 52-55), also marginally windy for strolling in winter.

4.2.2.2 Entrances

Wind conditions at entrances within the site are generally suitable for standing or better throughout the year. The entrance at the east of Building B (location 57) is marginally too windy in spring, this minor and seasonal exceedance is expected to be tolerable for users of the site.

4.2.2.3 *Recreational Spaces*

Wind conditions at recreational spaces within the site, at ground level and on the Building B terrace are generally too windy for comfortable recreational use.

4.2.2.4 *Outdoor Seating*

Wind conditions at the outdoor seatings at the northwest elevation of Building A (locations 50 and 92) are suitable only for short periods of sitting.

4.2.2.5 *Surrounding Area*

Within the wider surrounding area, wind conditions are generally suitable for existing pedestrian uses, including the use of thoroughfares, entrances, and car parks. Exceptions are predicted to exist at the following locations:

- Entrances along Ducie Street (locations 72, 75 and 77) are suitable only for strolling.
- An entrance on Ducie Street (location 68) is suitable only for strolling at best.
- A thoroughfare on Ducie Street (location 69) is generally only suitable for walking.

4.3 Proposed Development within Cumulative Surrounds

The results for the proposed development within cumulative surrounds are presented graphically within Figure 4.9 and Figure 4.10 for worst-seasonal and Figure 4.11 and Figure 4.12 for summer conditions respectively.

With the introduction of cumulative surrounds, the suitability of wind conditions remains materially similar to the existing surrounds scenario.

4.4 Proposed Development within Existing Surrounds with Soft Landscaping and Mitigation Measures

The results for the proposed development within existing surrounds with soft landscaping and mitigation measures are presented graphically within Figure 4.13 and Figure 4.14 for worst-seasonal and Figure 4.15 and Figure 4.16 for summer conditions respectively.

4.4.1 *Safety*

Wind conditions throughout the site and surrounding areas satisfy the safety criteria for wind.

4.4.2 *Comfort*

4.4.2.1 *Thoroughfares*

Wind conditions within the site are predominantly suitable for strolling or better throughout the year and are thus suitable for thoroughfare use. One minor exception occurs to the east of Building B (location 56) where conditions marginally exceed criteria in winter only. This minor and localised exceedance is considered tolerable.

4.4.2.2 *Entrances*

Wind conditions at entrances are predominantly suitable for standing or better throughout the year. One minor exceedance occurs at the east of Building B (location 57) where conditions

would be considered suitable for 93% of the time in spring, falling just short of the 95% requirement.

4.4.2.3 *Recreational Spaces*

Wind conditions within the recreational spaces on site are generally suitable for at least short periods of sitting /standing in summer and thus for comfortable recreational space use. Exceptions at locations 53 and 54, which are marginally windy suitable for strolling in summer.

At elevated level, wind conditions on the Building B terrace (locations 116, 117 and 118) are suitable for short-term sitting or better in summer.

4.4.2.4 *Outdoor Seating*

With mitigation, wind conditions at the outdoor seating at the northwest elevation of Building A are suitable for long periods of sitting in summer, and thus suitable for planned uses.

4.4.2.5 *Surrounding Area*

Within the wider surrounding area, wind conditions are generally suitable for existing pedestrian uses, including the use of thoroughfares, entrances, and car parks. Exceptions are predicted to exist at the following locations:

- Entrances along Ducie Street (locations 72 and 77) are suitable for strolling in winter.
- An entrance on Ducie Street (location 68) is suitable for strolling in winter.
- A thoroughfare on Ducie Street (location 69) is generally only suitable for walking.

5 CFD Assessment

5.1 Proposed Development with Soft Landscaping and Mitigation Measures within Existing Surrounds

Wind tunnel testing predicts a safety exceedance at the thoroughfare within Ducie Street (location 69) upon the introduction of the proposed development. This exceedance is driven by the presence of the proposed development. With the introduction of soft landscaping and mitigation measures, the safety exceedance at this location has been alleviated.

To explore this further, CFD was employed to examine the sensitivity of various mitigation options. This exercise has indicated how by varying the dimensions of different elements (as shown in Figure 5.1) affects the effectiveness of the mitigation.

For the different variations presented, the performance (in terms of safety) remains similar to the mitigation validated via wind tunnel testing (presented in Figure 2.1).

6 Conclusions

The following conclusions have been drawn:

- Wind conditions throughout the existing site and surrounds satisfy the safety criteria for wind and generally satisfy the comfort criteria for all uses.
- With the introduction of the proposed development within existing surrounds, both comfort and safety criteria are generally met, though some exceptions exist. This is also the case with the introduction of cumulative surroundings.
- With the introduction of soft landscaping and mitigation measures, the safety criteria are met throughout the study area. Although some areas still exceed comfort criteria during windier seasons, primarily in winter, these exceedances are generally and / or localised marginal.

7 References

1. Quality Assurance Manual - Wind Engineering Studies of Buildings. 2001. AWES-QAM-1-2001.
2. The American Society of Civil Engineers (ASCE) Manual of Practice No.67 for Wind Tunnel Studies. ASCE SEI 49/12.
3. Lawson, T.V. *The determination of the wind environment of a building complex before construction*. Bristol : University of Bristol, Department of Aeronautical Engineering, 1990.
4. ESDU (Engineering Science Data Unit). *Item 01008. Computer Program for wind speeds and turbulence properties: flat or hilly sites in terrain with roughness*. 2001.
5. F, Menter. *Zonal Two Equation $k-\omega$ Turbulence Models for Aerodynamic Flows*. 1993. AIAA Paper 93-2906.
6. F, Menter. *Turbulence Modelling for Engineering Flows*. s.l. : ANSYS Inc., 2011.
7. Richards, P.J. and Hoxey, R.P. *Appropriate boundary conditions for computational wind engineering models using the $k-\epsilon$ turbulence model*. s.l. : Journal of Wind Engineering and Industrial Aerodynamics, 1993. vol. 46 & 47, pg. 145 - 153.

8 Figures

Figure 2.1 – Soft landscaping and mitigation measures

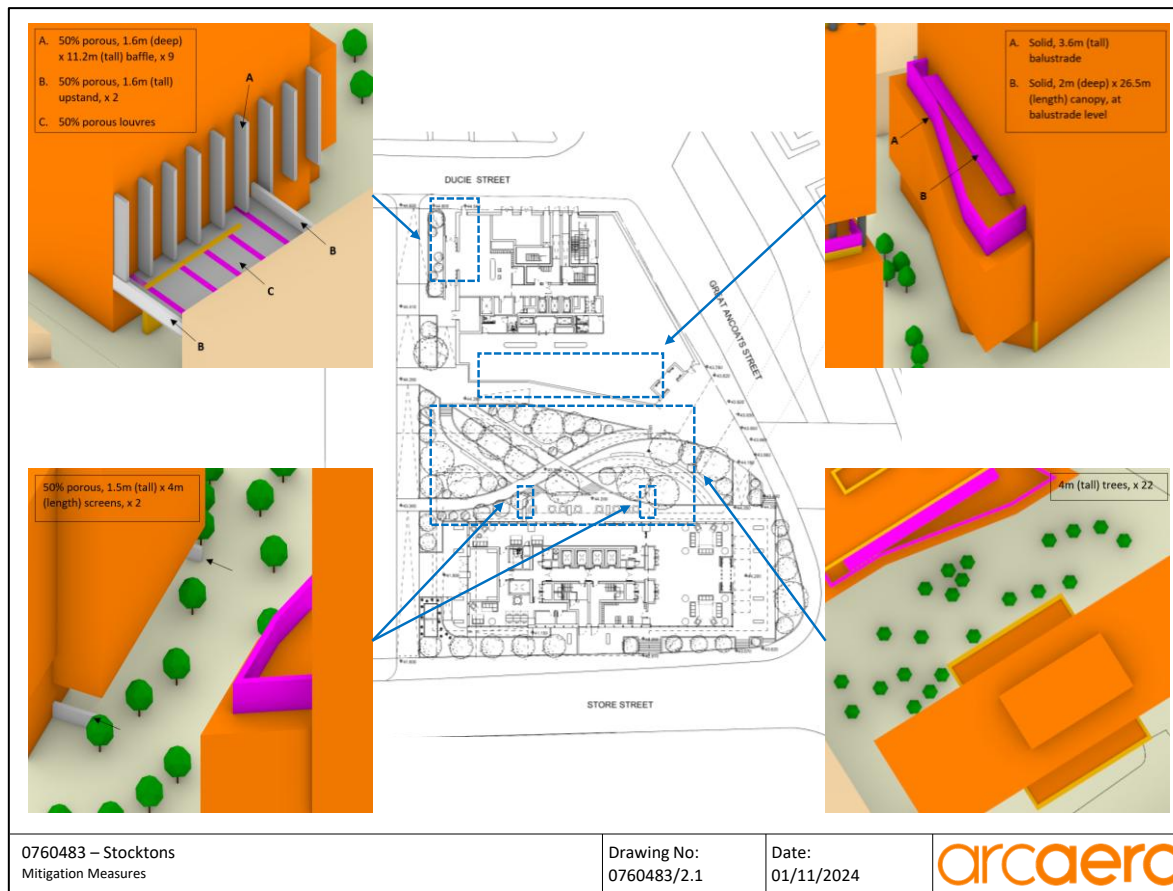


Figure 4.1 - Pedestrian wind conditions, existing site within existing surrounds, 'worst' season – ground level

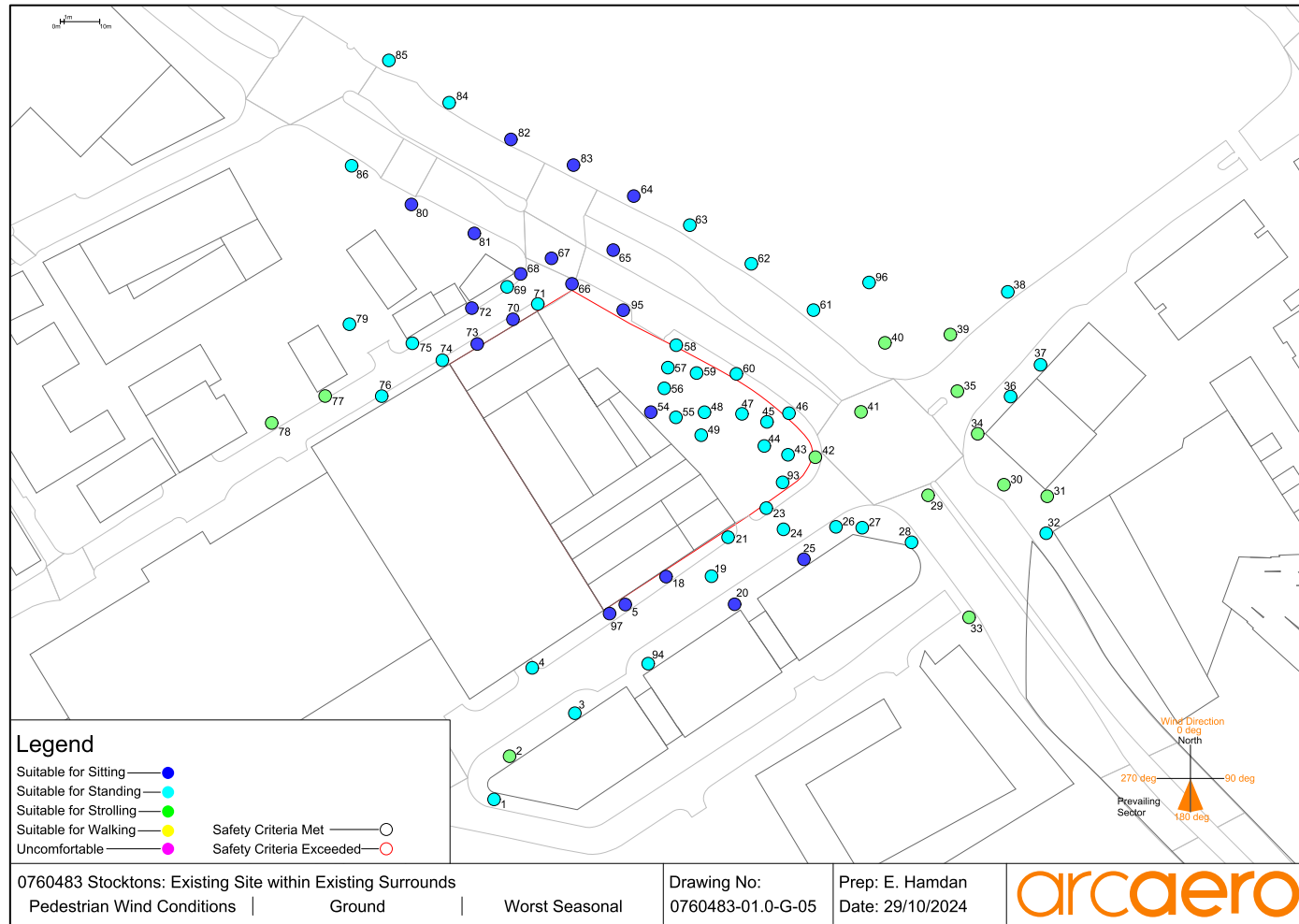


Figure 4.2 - Pedestrian wind conditions, existing site within existing surrounds, 'worst' season – elevated level



Figure 4.3 - Pedestrian wind conditions, existing site within existing surrounds, summer – ground level

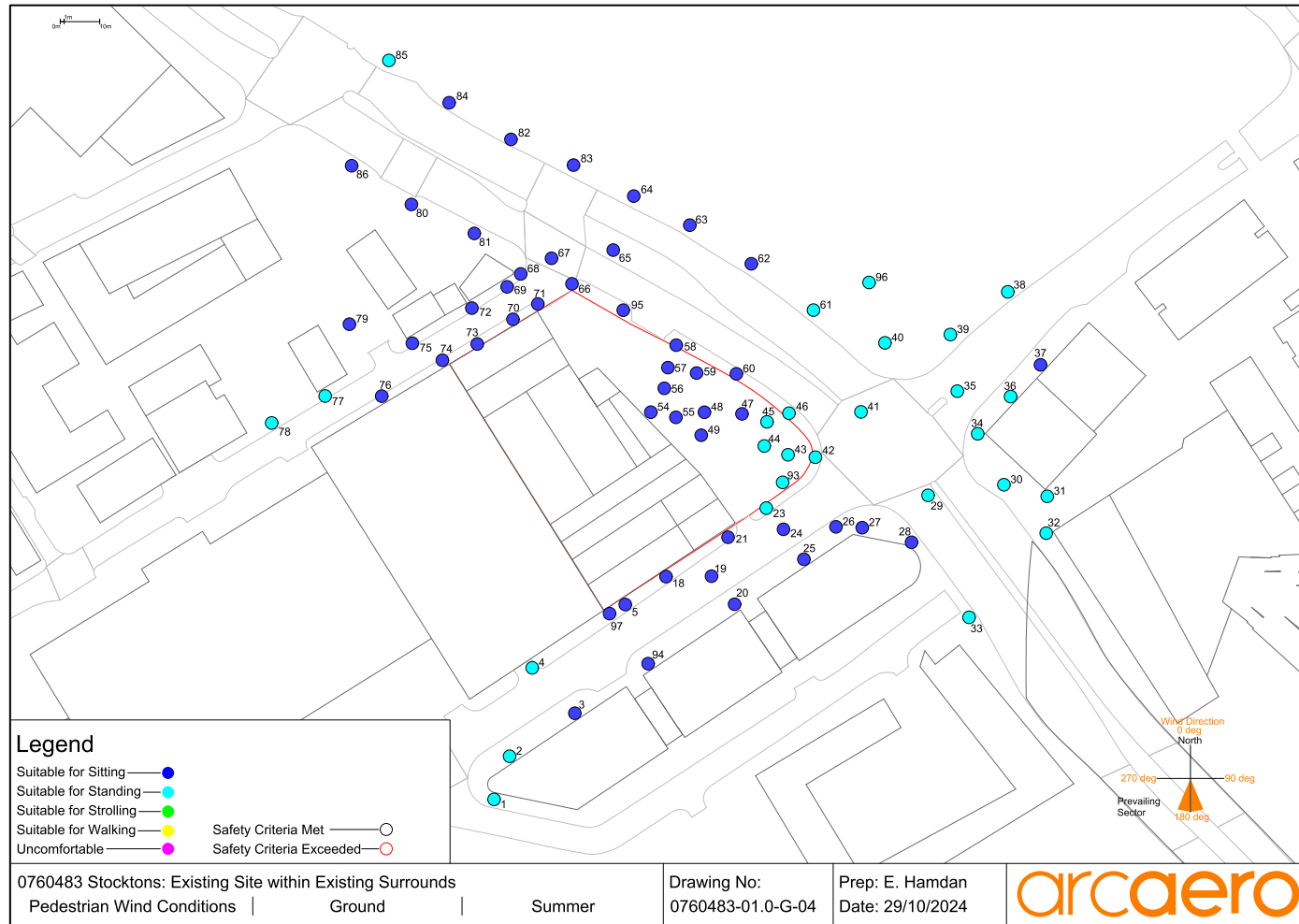


Figure 4.4 – Pedestrian wind conditions, existing site within existing surrounds, summer – elevated level



Figure 4.5 - Pedestrian wind conditions, proposed development within existing surrounds, 'worst' season – ground level

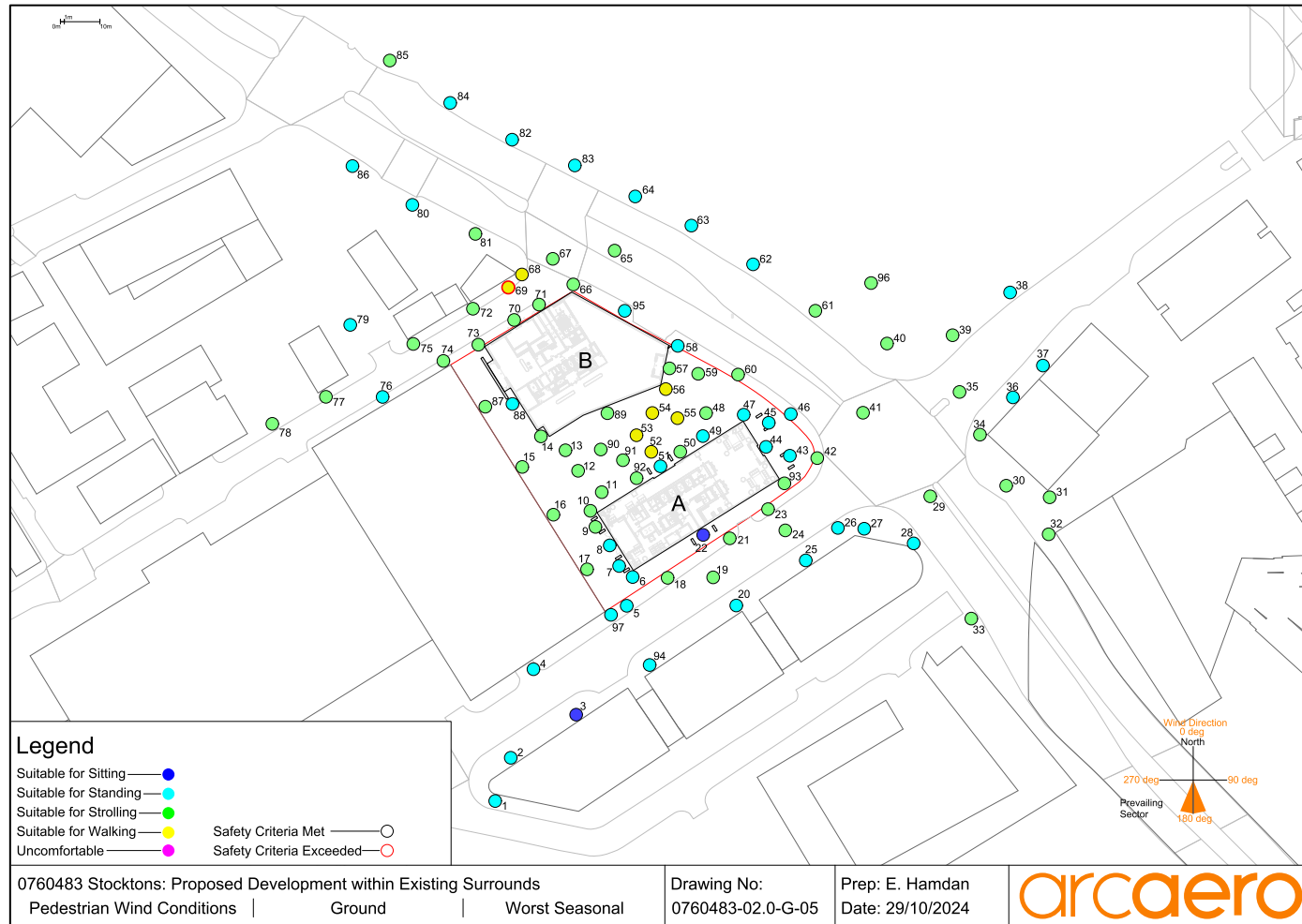


Figure 4.6 – Pedestrian wind conditions, proposed development within existing surrounds, 'worst' season – elevated level



Figure 4.7 - Pedestrian wind conditions, proposed development within existing surrounds, summer – ground level

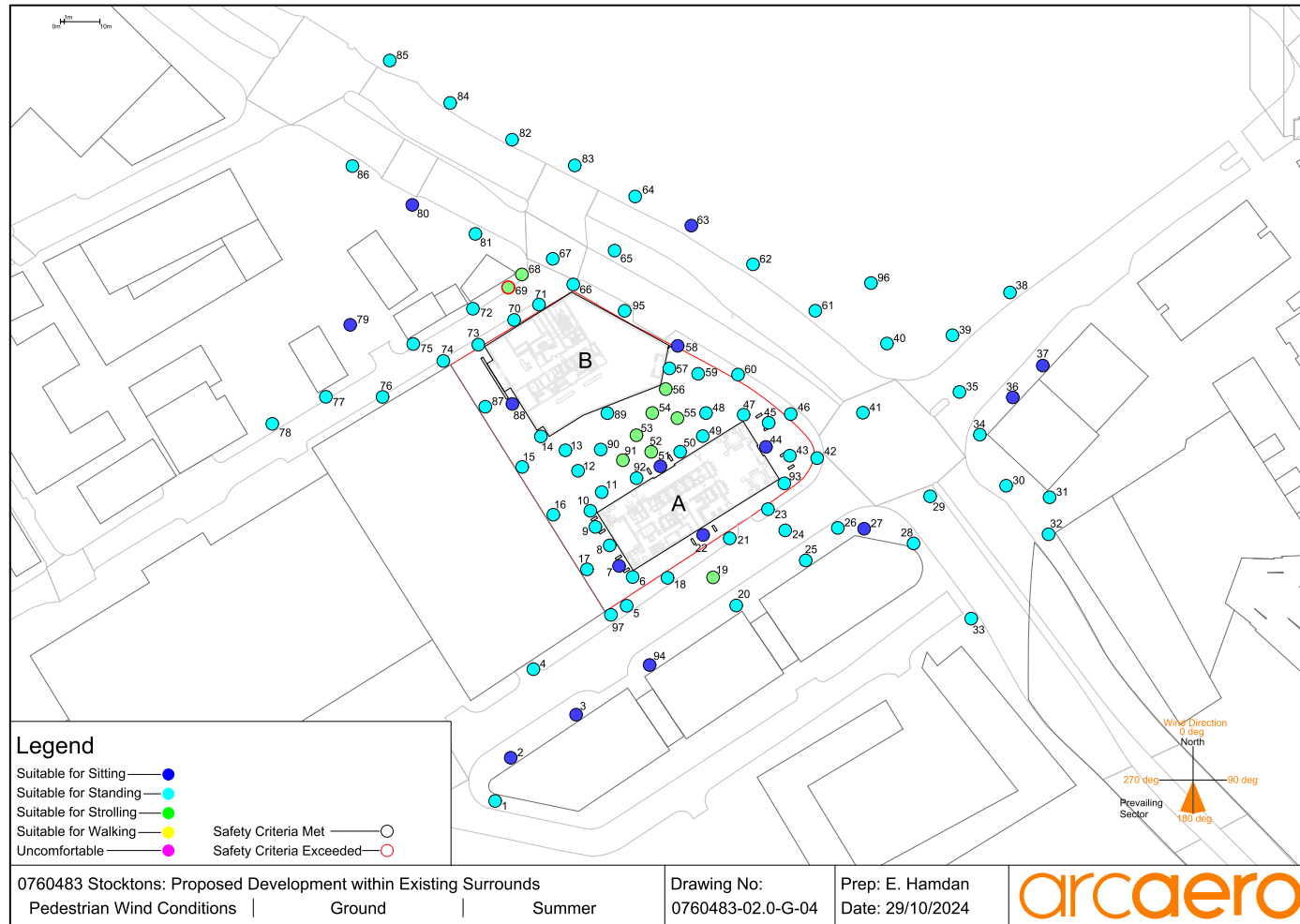


Figure 4.8 – Pedestrian wind conditions, proposed development within existing surrounds, summer – elevated level



Figure 4.9 - Pedestrian wind conditions, proposed development within cumulative surrounds, 'worst' season – ground level

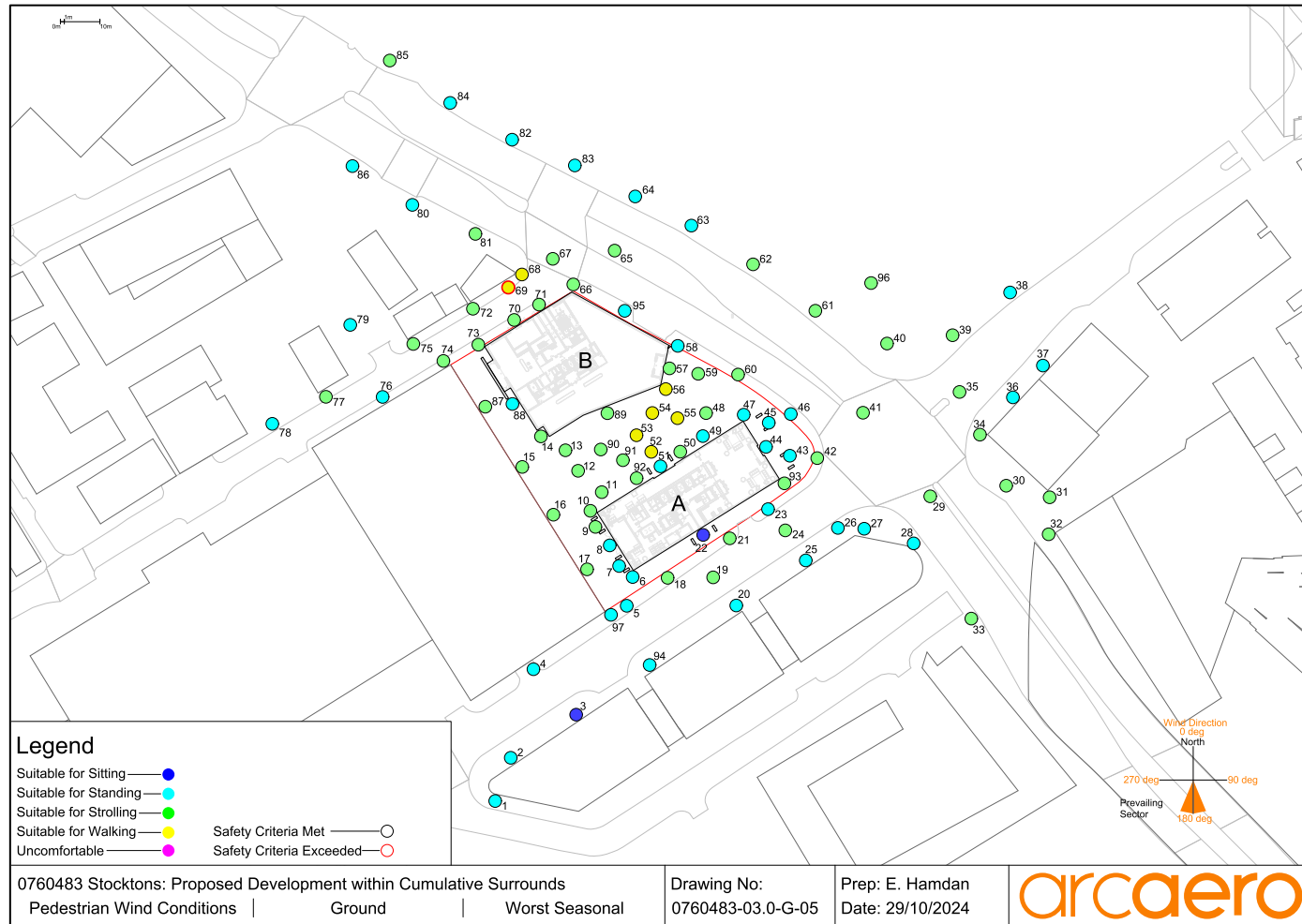


Figure 4.10 – Pedestrian wind conditions, proposed development within cumulative surrounds, 'worst' season – elevated level



Figure 4.11 – Pedestrian wind conditions, proposed development within cumulative surrounds, summer – ground level

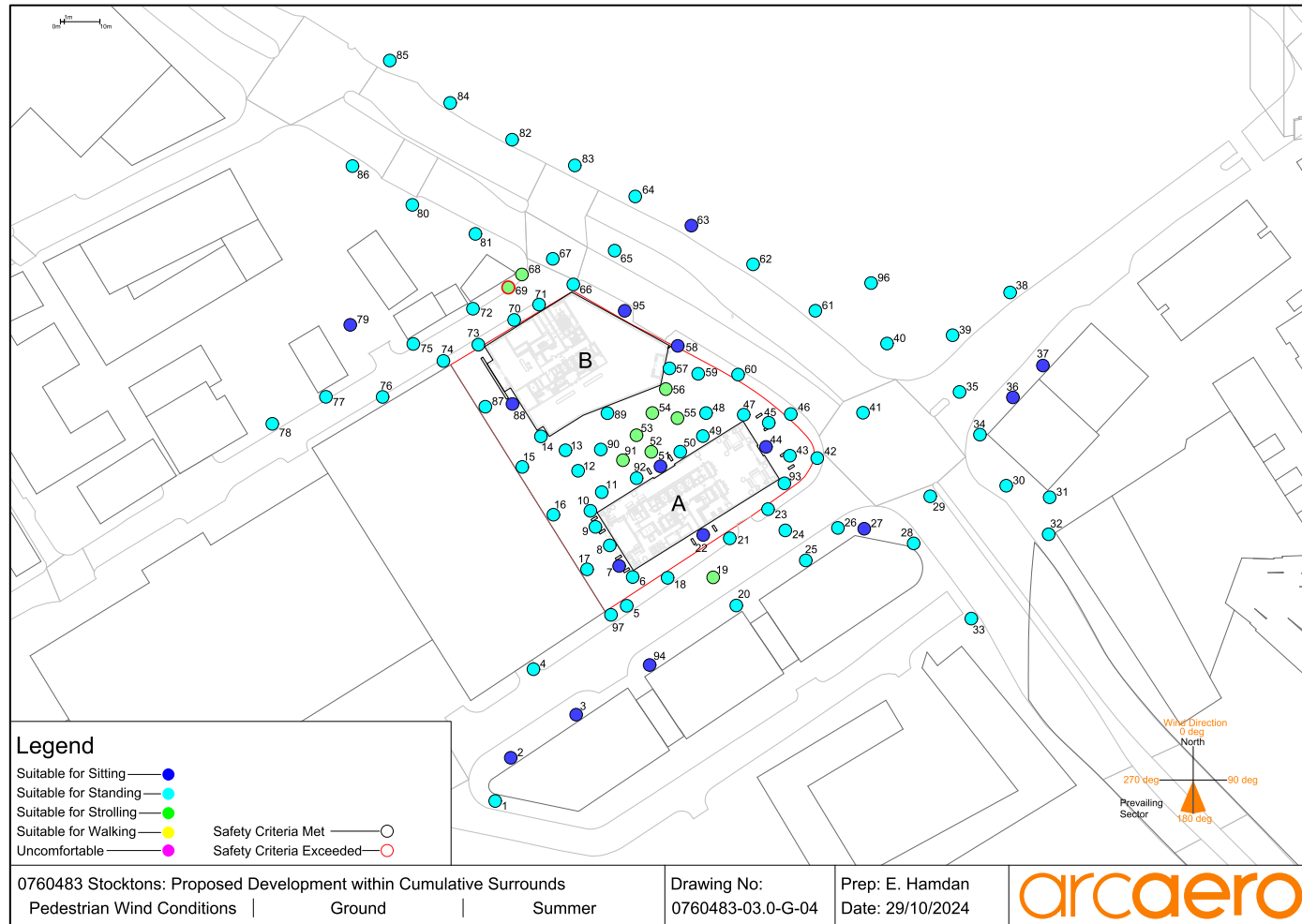


Figure 4.12 – Pedestrian wind conditions, proposed development within cumulative surrounds, summer – elevated level



Figure 4.13 – Pedestrian wind conditions, proposed development within existing surrounds, with soft landscaping and mitigation measures, ‘worst’ season – ground level

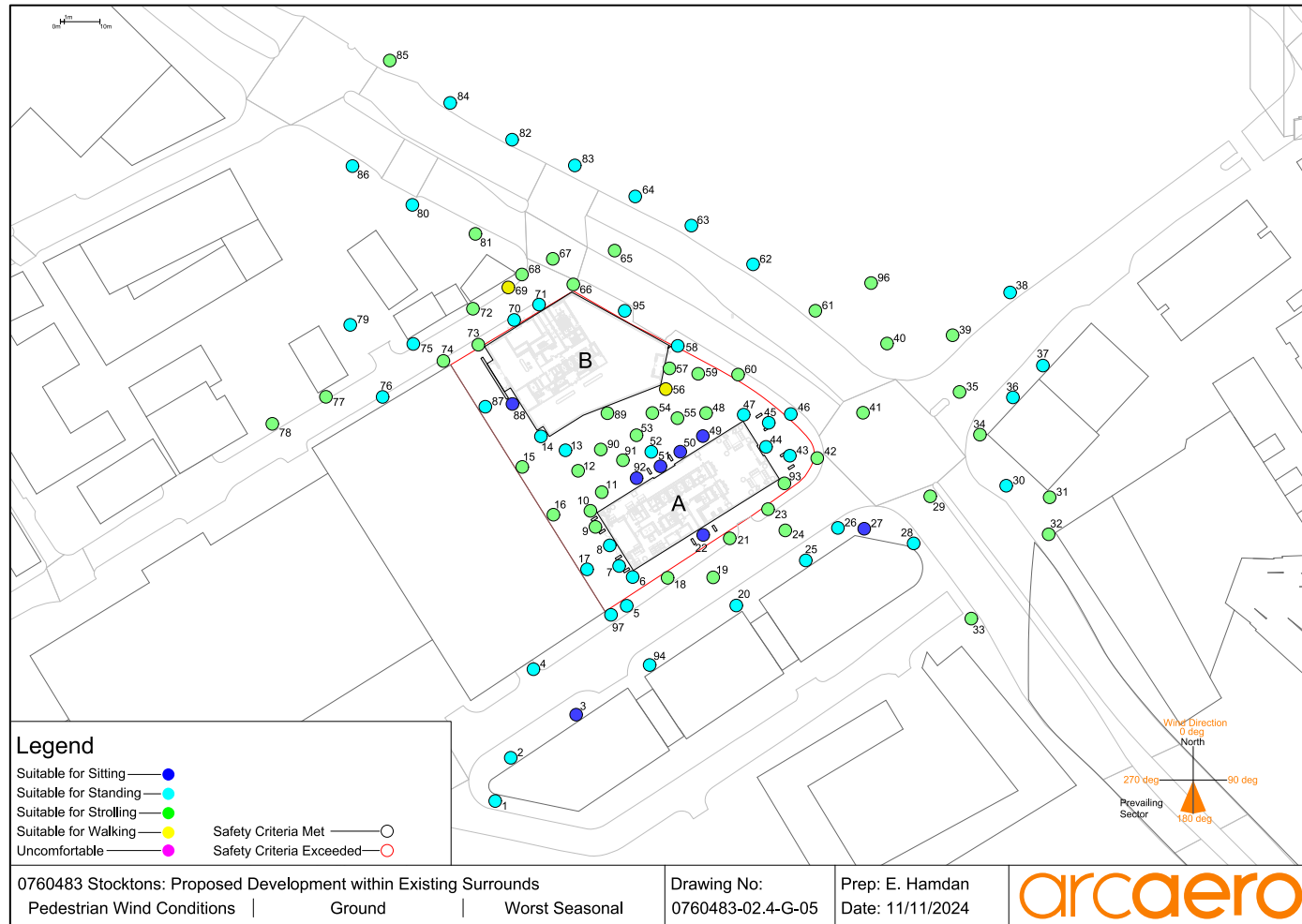


Figure 4.14 – Pedestrian wind conditions, proposed development within existing surrounds, with soft landscaping and mitigation measures, ‘worst’ season – elevated level



Figure 4.15 – Pedestrian wind conditions, proposed development within existing surrounds, with soft landscaping and mitigation measures, summer – ground level

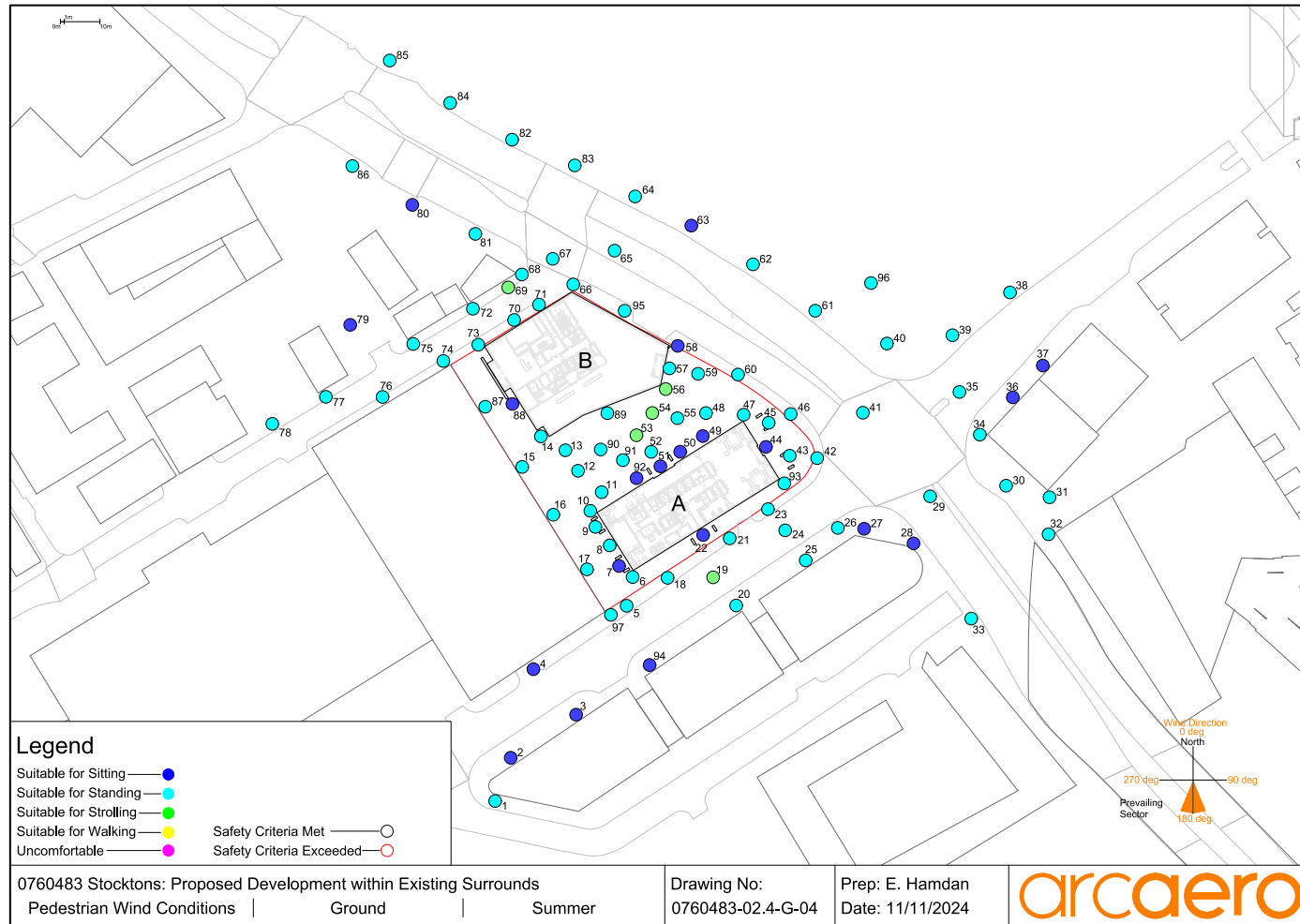
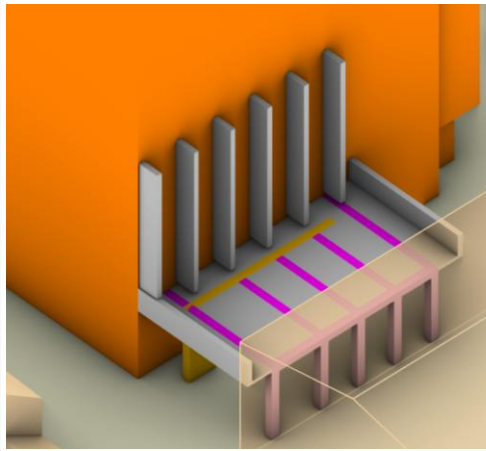
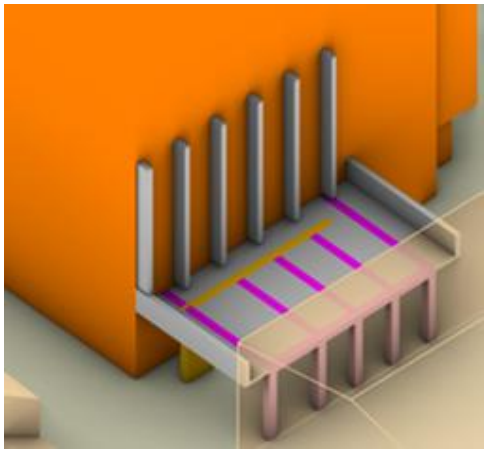
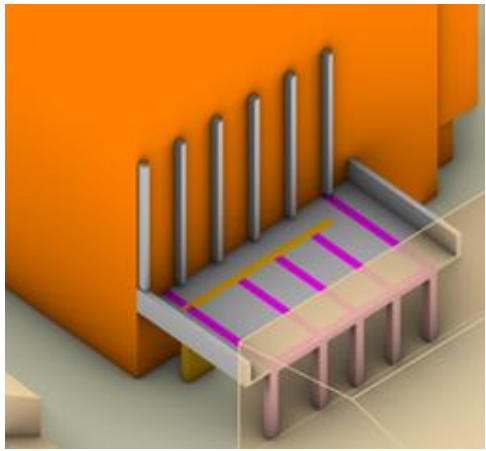


Figure 4.16 – Pedestrian wind conditions, proposed development within existing surrounds, with soft landscaping and mitigation measures, summer – elevated level



Figure 5.1 - Comparison of mitigation options in CFD

Option 1	Option 2	Option 3
		
A. 6x 50% porous, 1.6m (deep) x 11.2m (tall) baffle. B. 50% porous, 1.6m (tall) upstand on both ends of roof. C. 50% porous, entrance canopy structure	A. 6x 50% porous, 1.0m (deep) x 11.2m (tall) baffle. B. 50% porous, 1.6m (tall) upstand on both ends of roof. C. 50% porous, entrance canopy structure	A. 6x 50% porous, 0.6m (deep) x 11.2m (tall) baffle. B. 50% porous, 1.6m (tall) upstand on both ends of roof. C. 50% porous, entrance canopy structure

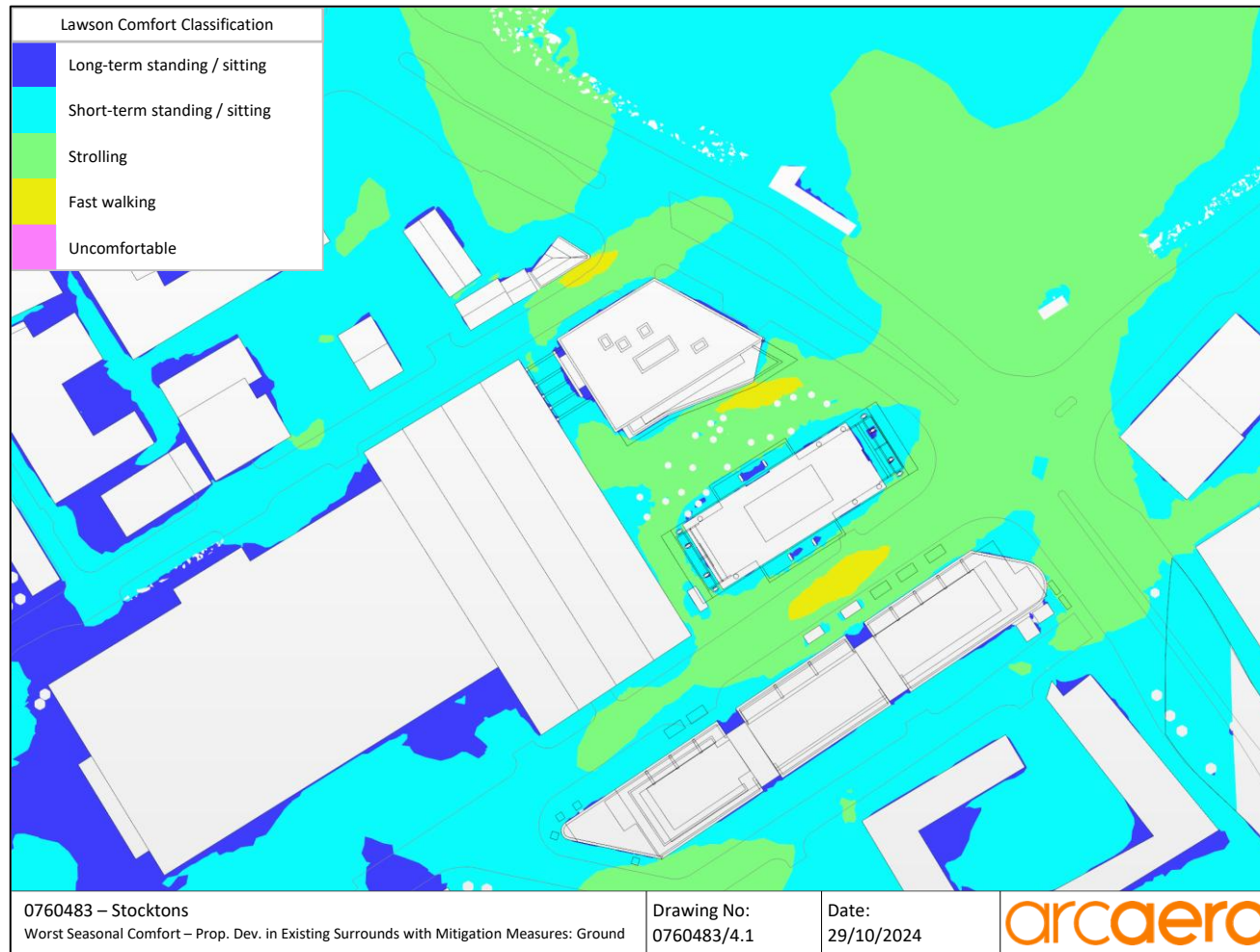
0760483 – Stocktons
Mitigation Options Comparison

Drawing No:
0760483/5.1

Date:
11/11/2024

arcaero

Figure 5.2 – Pedestrian wind conditions in CFD, proposed development within existing surrounds, with soft landscaping and mitigation measures, ‘worst’ season – ground level



Appendix A Wind Tunnel and Model

A.1 Atmospheric Boundary Layer Modelling

The study was conducted at the Imperial College 10' x 5' wind tunnel in London. This closed-loop facility provides a 20 metre long boundary layer test section and a 3.0 metre x 1.5 metre test section. The wind speed operating range is 0-40 m/s.

'Roughness blocks', a 2D fence and 3D posts were used to replicate the boundary layer. These elements are presented Figure A.1.

Figure A.1 - Boundary layer creation, Imperial College boundary layer wind tunnel, London.



A.2 Wind Tunnel Models

A 1:400 scale wind tunnel model was constructed from materials such as dense foam, wood and plastic. The wind microclimate was assessed at a total of 117 locations for the proposed development.

Photos of the wind tunnel model are presented as follows:

- Figure A.2 and Figure A.3: existing site conditions
- Figure A.4 and Figure A.5: proposed development within existing surrounds
- Figure A.6 and Figure A.7: proposed development within cumulative surrounds
- Figure A.8 and Figure A.9: close-ups of proposed development

Figure A.2 – Existing site conditions, viewed from north

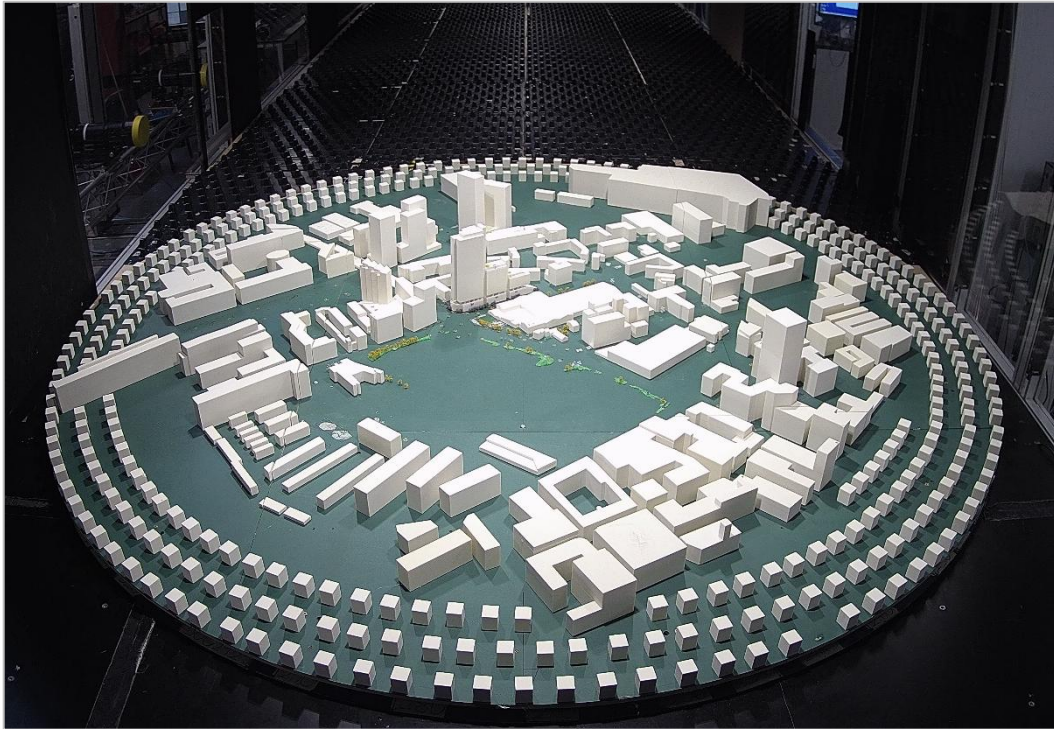


Figure A.3 - Existing site conditions, viewed from south

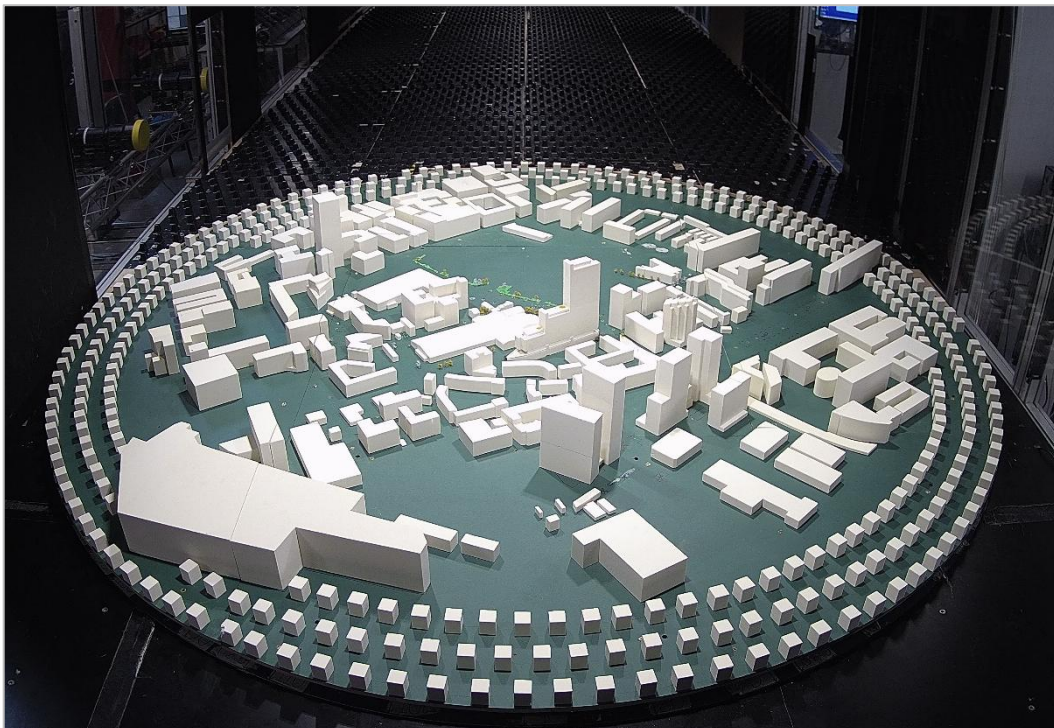


Figure A.4 - Proposed development within existing surrounds, viewed from north

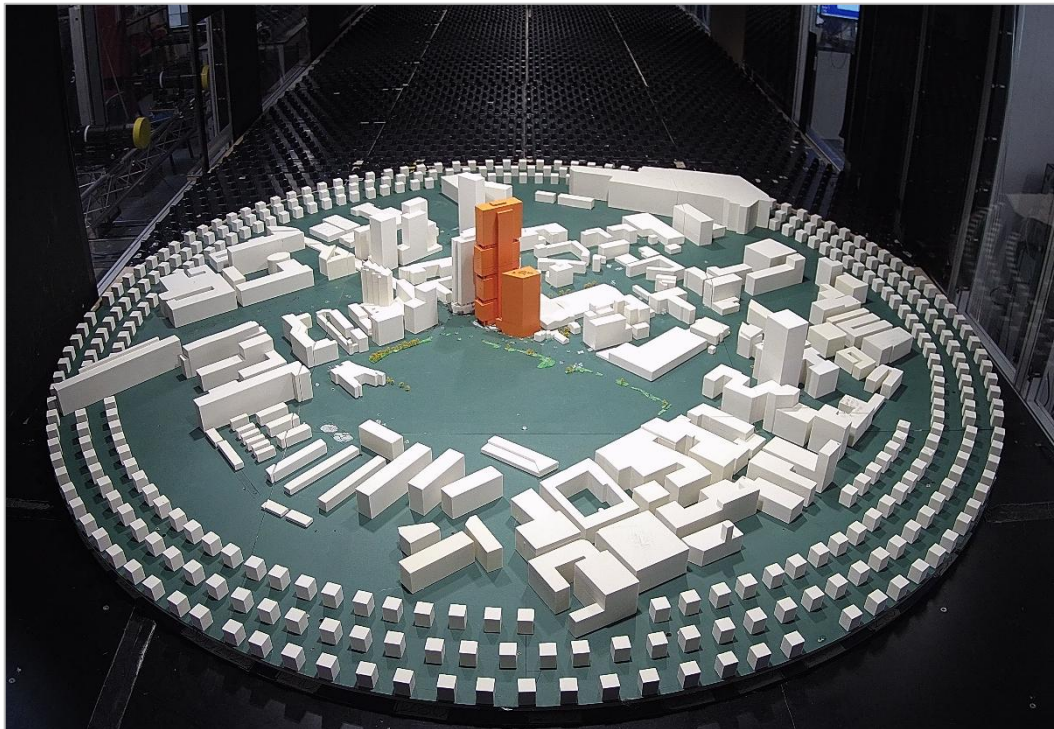


Figure A.5 - Proposed development within existing surrounds, viewed from south

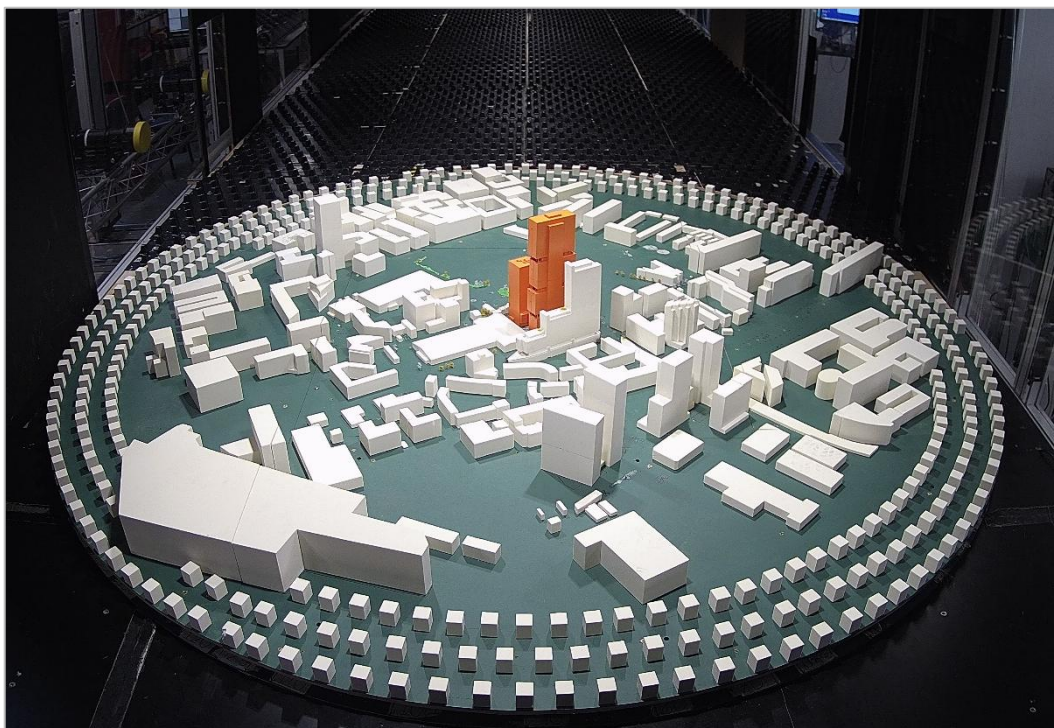


Figure A.6 – Proposed development within cumulative surrounds, viewed from north

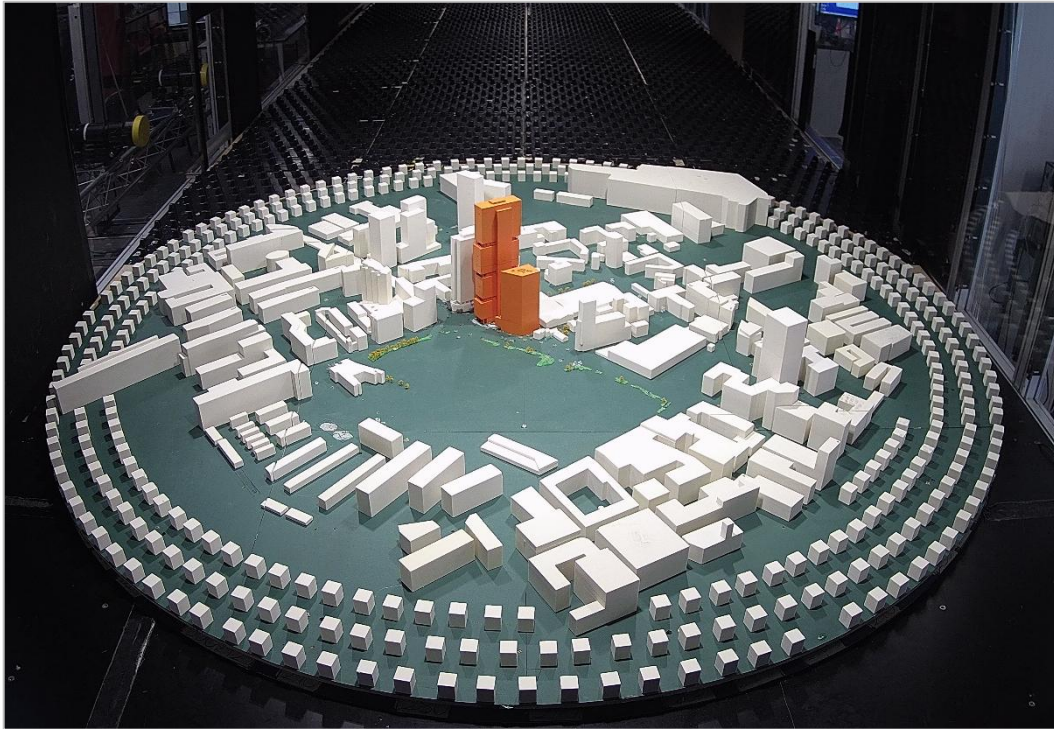


Figure A.7 – Proposed development within cumulative surrounds, viewed from south

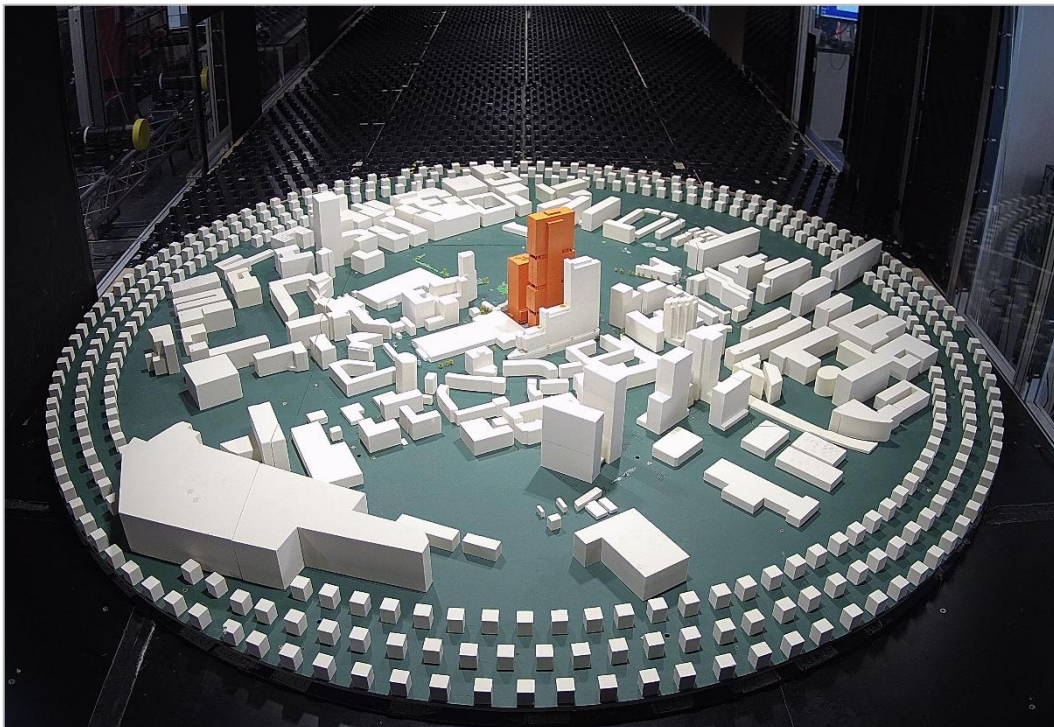


Figure A.8 – Close-up of the proposed development within existing surrounds, viewed from north



Figure A.9 – Close-up of the proposed development within existing surrounds, viewed from northeast



A.3 Data Acquisition

Wind speed measurements were made using ‘Irwin probes’, capable of measuring fluctuating pressure differences that are calibrated against wind speed. A system of probes running simultaneously was used to obtain results from approximately 117 locations at a height corresponding to 1.5m at full scale.

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

The gust wind speed is translated to an equivalent mean wind speed, the Gust Equivalent Mean or GEM, according to the following equation:

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

The results at each location were combined with wind statistics transposed to the site to assess the exceedance of threshold wind speeds that relate to comfort and safety in accordance with the Lawson criteria.

Appendix B Wind Climate Analysis

B.1 Wind Frequency Data, Manchester Weather Station

Wind microclimate studies require that wind speed data obtained from a measurement station be transposed to the site of interest. The current study employs wind data from Manchester Weather Station.

The wind speed history has been 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:

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

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

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

The resulting weather centre wind data is transposed to 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 the reference height at the site of the proposed development, accounting for upwind terrain, topography and altitude for the target site.

For the transposition of wind speed data from the weather station to open country, and from open country to the site, the methods set out in ESDU item 01008 (4) (the industry standard) have been employed.

The resulting annual and seasonal directional and wind speed probability distributions at the reference height of 150m, at the proposed site, are given in Figure B.2 to Figure B.6, respectively.

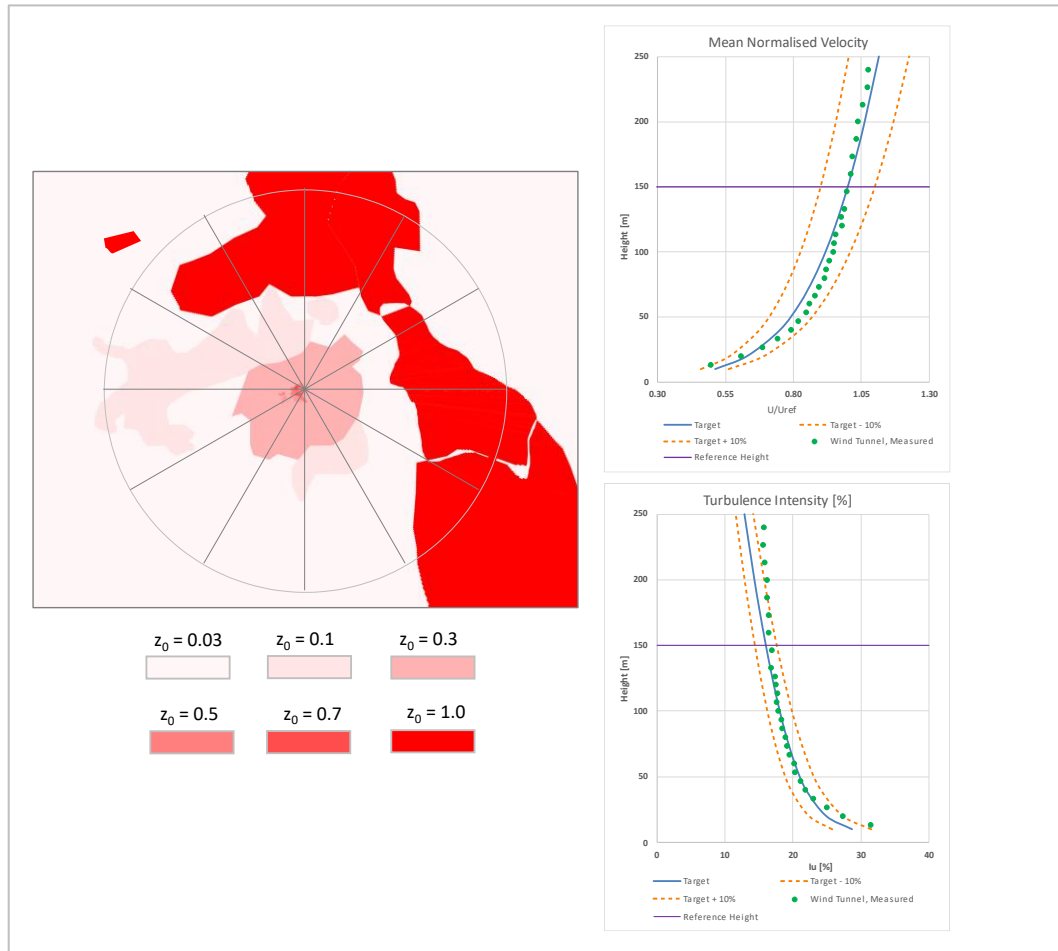
B.2 Wind Properties at the Site

A detailed analysis, based on the widely accepted Deaves and Harris model of the atmospheric boundary layer (ABL), as defined in ESDU Item 01008 (4), has been carried out to determine the wind properties at the site. From this analysis a representative profile was defined as a target for the ABL simulation in the wind tunnel.

Upon conducting the ESDU analysis, one wind profile was replicated in the wind tunnel to adequately account for wind blowing from all angles.

ArcAero's terrain analysis and resulting mean wind speed and turbulence intensity profiles are presented within Figure B.1.

Figure B.1 – Target mean wind speed and turbulence intensity profiles and wind tunnel profile



B.3 Wind Frequency Data

Wind microclimate studies require that meteorological data is transposed from a nearby weather station with sufficient wind data to produce accurate wind frequency statistics. The current study uses data from Manchester Weather Station. The cumulative wind speed probability distributions, transposed to building height at site are provided in Figure B.2 to Figure B.6.

Figure B.2 – Cumulative wind speed probability distribution at site, annual

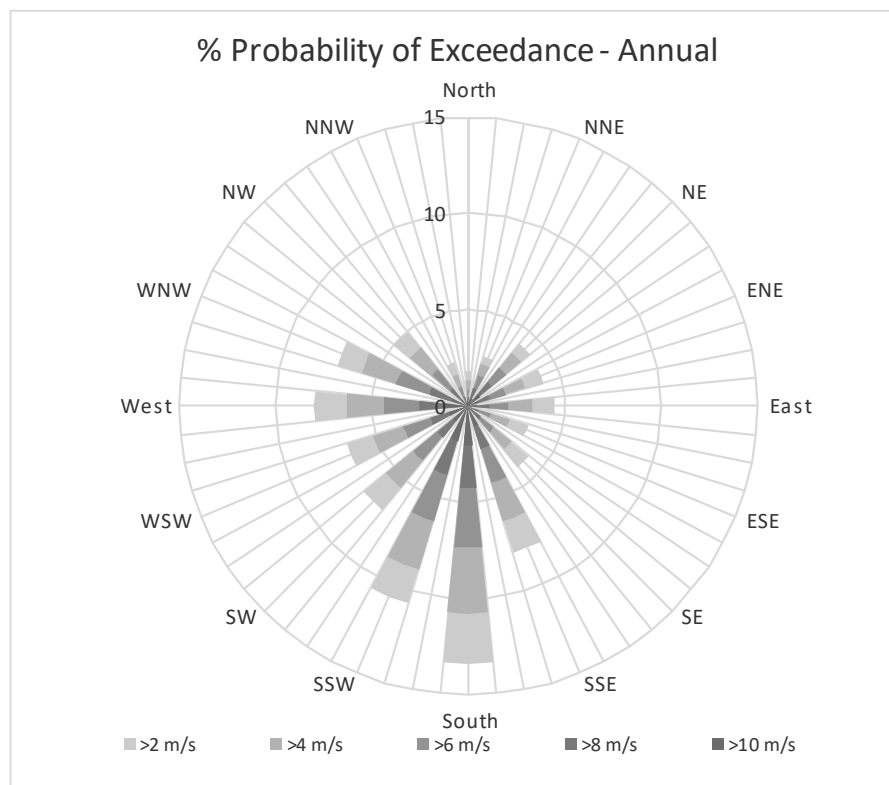


Figure B.3 – Cumulative wind speed probability distribution at site, spring

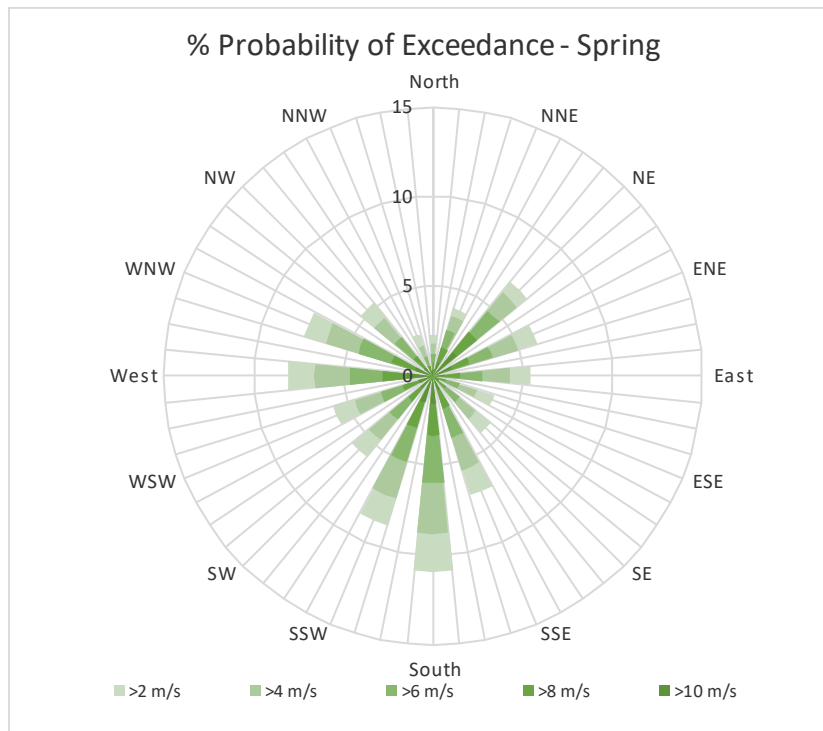


Figure B.4 – Cumulative wind speed probability distribution at site, summer

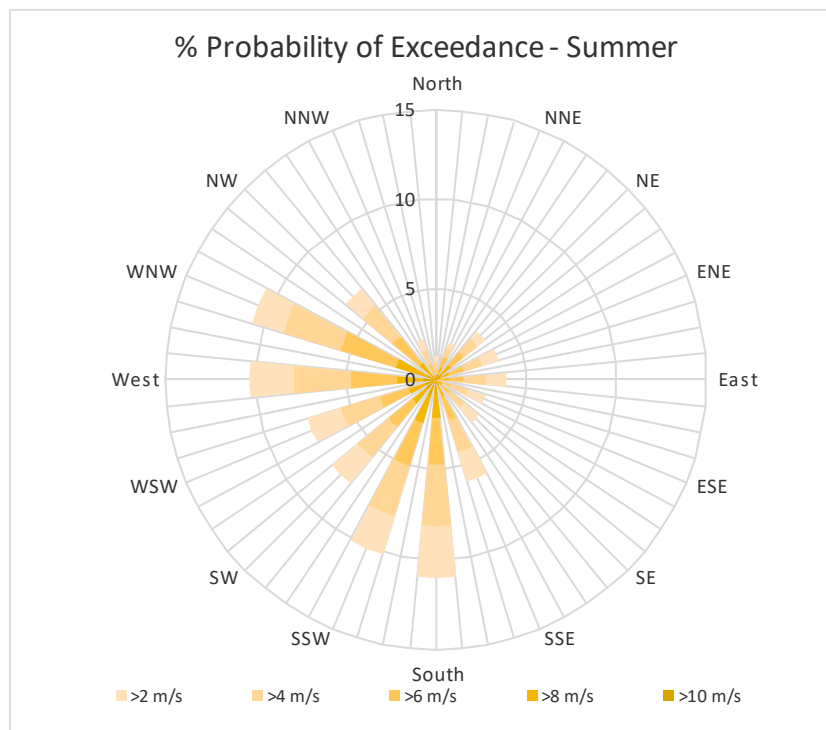


Figure B.5 – Cumulative wind speed probability distribution at site, autumn

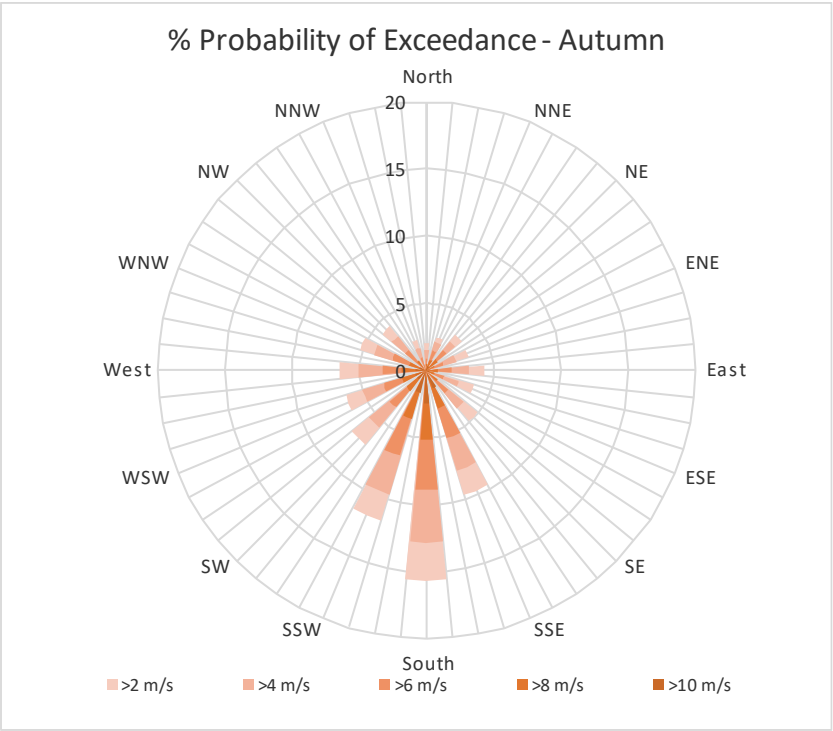
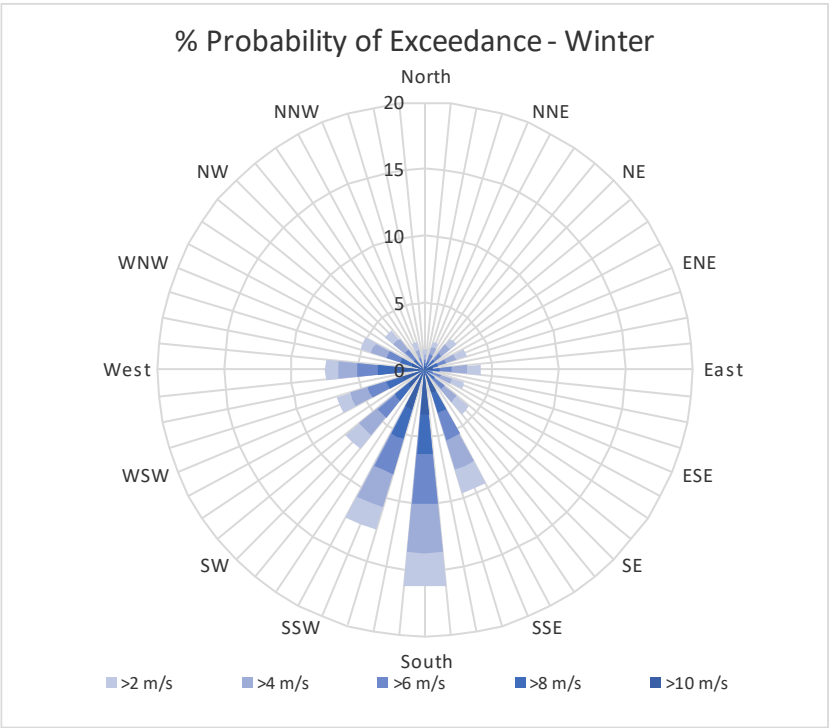


Figure B.6 – Cumulative wind speed probability distribution at site, winter



Appendix C CFD Modelling

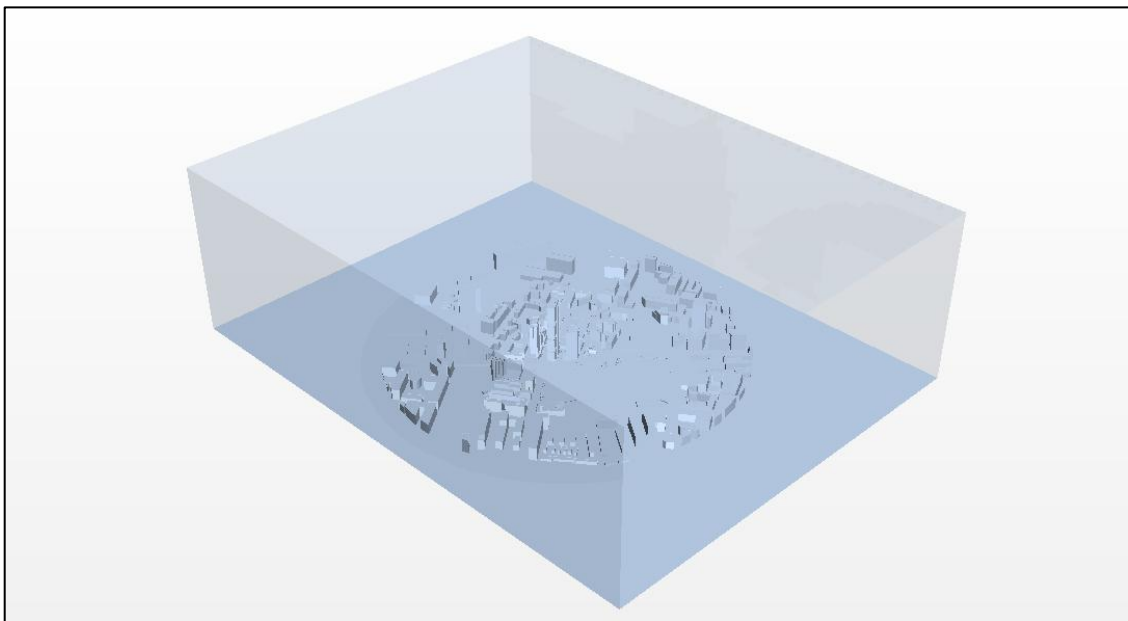
C.1 Spatial discretization

The computational domain was discretised using polyhedral cells for the core mesh, and low aspect-ratio prism cells adjacent to walls and the ground. Computational meshes were constructed for each of the three different study configurations.

The computational domain includes the proposed development site, with surrounding buildings and topographical features within a 450m radius represented explicitly. The full computational domain extends to 1500m in the along-wind direction, 1100m in the across-wind direction, and 450m vertically.

The proposed development and immediate vicinity were meshed down to a cell size of 0.2m in order to capture the detailed geometric features and resulting flow artefacts. The pedestrian ground level surfaces were meshed with a prism layer mesh of 5 layers, which, in the vicinity of the building rise up to a total height of 1.5m above the ground.

Figure C.1 - Computational Domain



C.2 Solution Method

The modelling of an incompressible fluid flow was completed with combinations of semi-implicit method for pressure-linked equations (SIMPLE) algorithms. The resulting flow turbulent features were modelled with introduction of the Shear Stress Transport (SST) $k-\omega$ turbulence model. This model was suggested by Menter (5) and is based on a two-equation eddy-viscosity approach, where the SST model formulation combines the use of a $k-\omega$ in the inner parts of the boundary layer, but also switches to a $k-\epsilon$ behaviour in the free-stream regions of the solutions. Further details for the selected turbulence model are provided in the work of Menter (6).

C.3 Initial and Boundary Conditions

The atmospheric boundary layer flow was simulated by implementing a logarithmic velocity profile model presented by Richards and Hoxey (7), with the following main assumptions:

- The vertical velocity component at the domain boundary is negligible
- The pressure gradient and shear stress are constant

The model implies the following equation for the mean inlet velocity at the CFD domain:

$$U(z) = \frac{U^*}{\kappa} \cdot \ln\left(\frac{z + z_0}{z_0}\right)$$

where:

- κ - is the von Karman's constant
- z - is the distance from the ground surface in vertical direction
- z_0 - is the ground surface roughness length in meters

The friction velocity U^* is calculated by the following equations:

$$U^* = \kappa \cdot \frac{U_{ref}}{\ln\left(\frac{z_{ref} + z_0}{z_0}\right)}$$

where:

- z_{ref} – is the reference height in metres
- U_{ref} - is the reference velocity in m/s measured at z_{ref}

The turbulent velocity fluctuations at the domain inlet are induced by the constant shear stress with height, maintained by the turbulent kinetic energy k equation below:

$$k(z) = \frac{(U^*)^2}{\sqrt{C_\mu}}$$

where:

- $C_\mu = 0.09$ - is a k - ϵ turbulence model constant

All surface boundary conditions were modelled as smooth walls with a no-slip condition. A no-slip wall boundary condition with a varying roughness length height based on the terrain analysis for the site was applied on the ground surface outside the explicit surrounds area of the domain.

C.4 Gust Equivalent Mean Calculation

The gusts in the wind flow is a major component that may lead to additional danger and discomfort to that caused by the mean wind flow. Thus, the gust wind speed is accounted by a calculation of the equivalent mean wind speed, considering the standard deviation of the mean wind speed, in particular the turbulent kinetic energy, k :

$$\sigma = \sqrt{(k * 2/3)}$$

The GEM is then calculated as:

$$U_{GEM} = \frac{U_{Mean} + 3.5\sigma}{k_g}$$

Where gust factor, $k_g = 1.85$

The final speedup used in the Lawson criteria is the worst case from U_{GEM} and U_{Mean} .

C.5 Digital Model

The digital model prepared for CFD analysis are presented within Figure C.2.

Figure C.2 – Digital model for CFD analysis



Appendix D Pedestrian / Occupant Uses

Figure D.1 – Existing site uses, ground level



Figure D.2 – Existing site uses, elevated level



Figure D.3 – Proposed development within existing surrounds uses, ground level

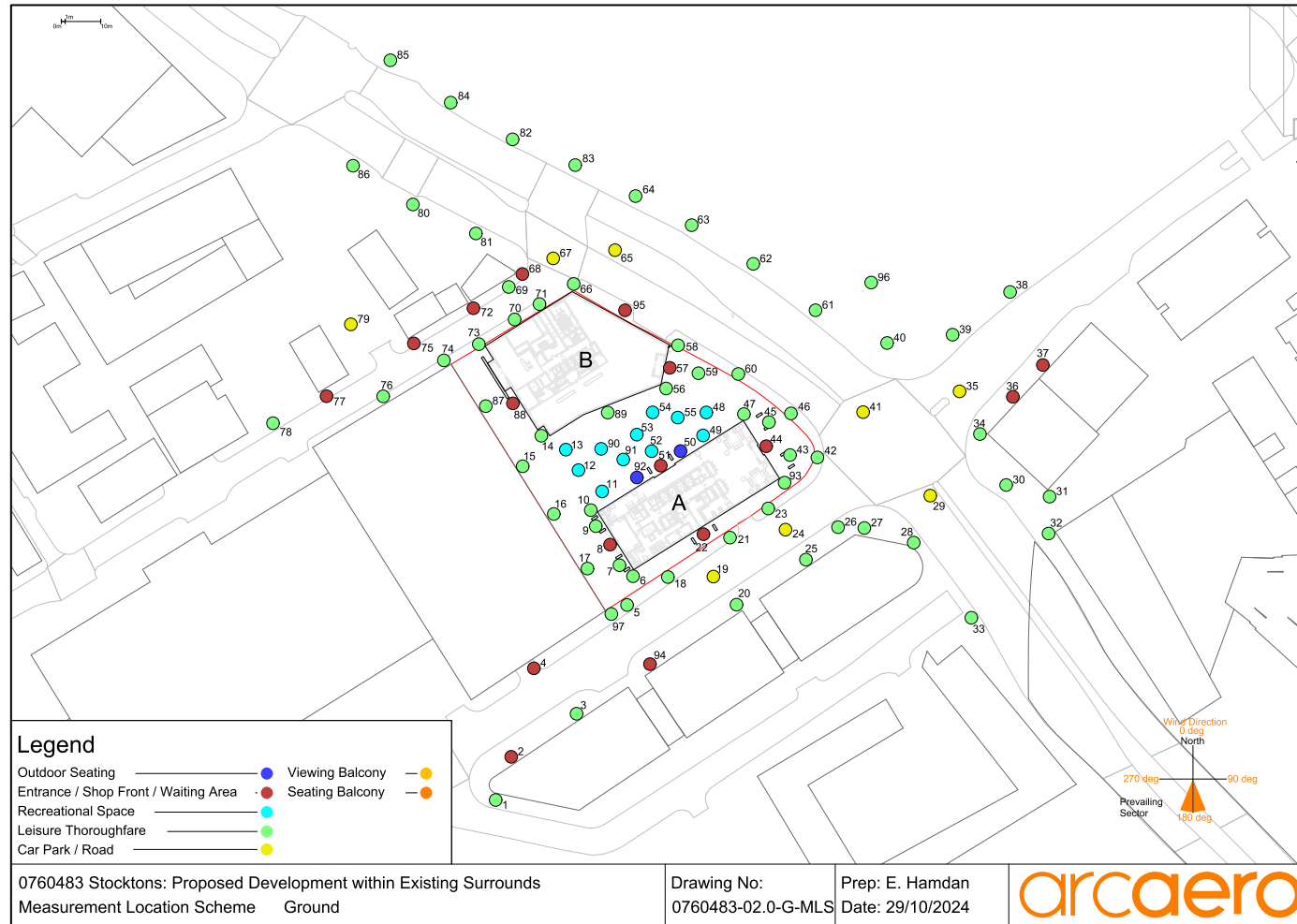


Figure D.4 - Proposed development within existing surrounds uses, elevated level

