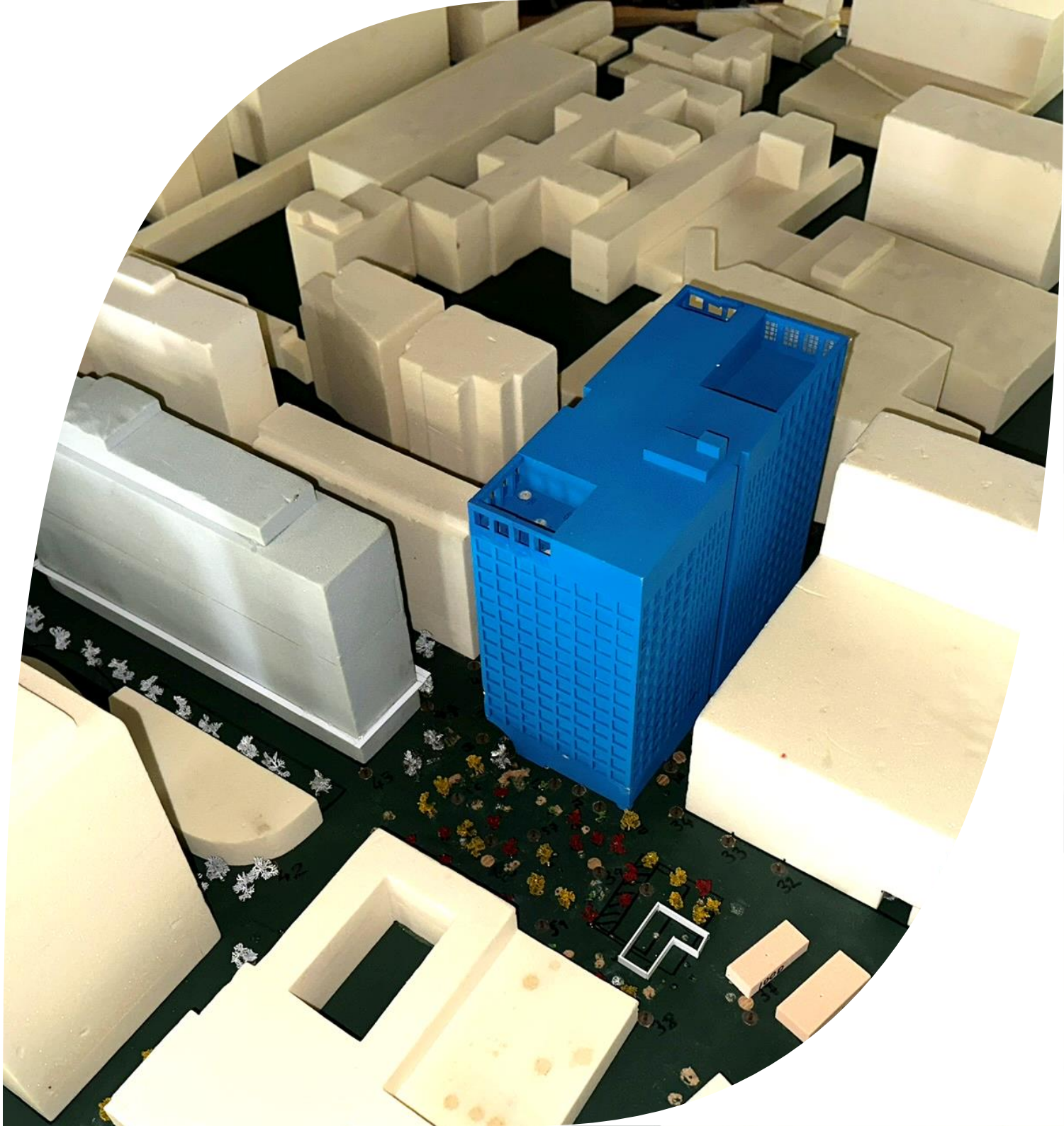
NOVA
FLUID MECHANICS

No.3 Circle Square
Manchester, UK

Wind Microclimate Addendum

5th August 2024



No.3 Circle Square Manchester, UK

Wind Microclimate Addendum

For: Bruntwood

Doc. No.	Version	Date	Comments
75019rep6v1	1	8th September 2023	First issue
75019rep6v2	2	12th September 2023	Updated based on client comments
75019rep6v3	3	29th February 2024	Clarification of changes relative to approved scheme
75019rep6v4	4	5th August 2024	Updated based on comments from Deloitte

Author: Dr D. Hankin

Approver: Ms A. Bagnara

© Copyright NOVA Fluid Mechanics Ltd 2024
4 Vicarage Road, Teddington, England, TW11 8EZ
enquiries@novafluidmechanics.com

The information contained in this report is commercial in confidence and must not be transmitted to a third party without the prior written agreement of NOVA Fluid Mechanics Ltd.

Contents

1. Introduction....4
2. The Assessment of Wind Microclimate....4
3. Study Area....5
4. Assessment Methodology....6
5. Results....7
6. Assessment....7
7. Conclusions....10
8. References....10
APPENDIX A. Wind Climate Analysis....16
APPENDIX B. Wind Tunnel & Model Details....24
APPENDIX C. Measurements and Analysis....26
APPENDIX D. Comfort and Safety Ratings....29

Executive Summary

Background

A boundary layer wind tunnel study has been carried out by NOVA Fluid Mechanics Ltd to assess the wind microclimate for the proposed amendments to the soft landscaping scheme for No.3 of the wider Circle Square Masterplan development in Manchester, UK.

The boundary layer wind tunnel study has enabled the pedestrian level wind microclimate at the site to be quantified and classified in terms of suitability for planned usage, based on the industry standard Lawson criteria for pedestrian comfort and safety.

The study considers the Approved Development in the context of existing surrounding conditions with the proposed amendments to the soft landscaping scheme and is provided as an addendum to the original report (NOVA Report 75019rep5v2, dated 22nd June 2022) submitted in support of the approved planning application (Ref: 134288/FO/2022). In terms of the wind microclimate, the principle changes relative to the approved scheme are the removal of a number of trees along Princess Street and Newman Street, in conjunction with changes to the type, location and number of trees within the park space following detailed design development.

The study combines measured 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 comfortable.

Conclusions

On the basis of the wind tunnel modelling, the following conclusions have been drawn:

- Wind conditions around the Approved Development in existing surrounds with the proposed amendments to the soft landscaping scheme remain suitable, in terms of pedestrian safety and comfort, for intended uses at the vast majority of locations.
- Whilst there are some minor localised exceedances, in terms of comfort only, wind conditions remain similar to the approved soft landscaping scheme and are still expected to be tolerable, if not entirely suitable for the intended uses.

The results are consistent with the original wind assessment submitted in support of the approved planning application. Whilst the outdoor seating on the south-west corner has improved to become suitable, the outdoor seating within the park space to the west now slightly exceed the criteria, but are more likely to benefit from increased foliage during summer months (compared to the predominantly bare winter-time trees modelled). Furthermore, the service entrance on Cloak Street is now only suitable for a mixture of entrance and leisurely thoroughfare, but this is considered tolerable given the intended use. The remaining wintertime exceedances on the thoroughfares around the corners are similar to the approved scheme. In conclusion, the impact of the proposed amendments is considered to be acceptable, with only minor residual exceedances, in terms of comfort only, which given the intended uses are considered to be tolerable.

No.3 Circle Square – Wind Microclimate Study

1. Introduction

This report summarises the results of a boundary layer wind tunnel study, commissioned by Bruntwood, to assess the wind microclimate for the proposed amendments to the soft landscaping scheme for No.3 of the wider Circle Square Masterplan development in Manchester, UK.

The boundary layer wind tunnel study has enabled the pedestrian level wind microclimate at the site to be quantified and classified in terms of suitability for planned usage, based on the industry standard Lawson criteria for pedestrian comfort and safety.

The study considers the Approved Development in the context of existing surrounding conditions with the updated soft landscaping proposals and is provided as an addendum to the original report (NOVA Report 75019rep5v2, dated 22nd June 2022) submitted in support of the approved planning application (Ref: 134288/FO/2022). In terms of the wind microclimate, the principle changes relative to the approved scheme are the removal of a number of trees along Princess Street and Newman Street, in conjunction with changes to the type, location and number of trees within the park space following detailed design development.

2. The Assessment of Wind Microclimate

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 for safety and stability and threshold values associated with a series of typical activities such as walking, awaiting a bus or sitting within a café, restaurant or bar outlet. It can therefore be shown within the various parts of a new development proposal and the neighbouring properties, whether wind conditions are suitable or unsuitable, and whether or not design adjustment or mitigation measures are required. It is for this purpose that wind microclimate assessments are undertaken.

The industry standard criteria for such assessments are 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[1] in 1972. Lawson himself presented what has become the ‘University of Bristol’ variant of the Lawson criteria in 1973[2], prior to a collaborative initiative that produced the London Docklands Development Corporation (LDDC) variant of the Lawson criteria[3].

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

3. Study Area

3.1. Site Location & Surrounding Area

The Approved Development is located in Manchester, UK. The Site is bound by Newman Street (formerly Brancaster Road) to the north, Princess Street to the east, Premier Inn and MSCP, and Mancunian Way to the south and Manchester Technology Centre to the West.

At present the area immediately surrounding the Site consists of mid-rise buildings and student accommodation. Further afield, the wider surrounding area largely consists of the urban greater Manchester area giving way to open country.

The site location is presented within the context of the wider surrounding area in Figure 3.1.

A single configuration of the surrounding area was considered in the current study, namely the existing surrounding conditions, as no relevant consented schemes were identified within the wind tunnel model radius.

3.2. Approved Development

The Approved Development comprises a Ground + 14 storey office development with ground floor commercial uses on what was known as Plot 12 of the Circle Square Masterplan. It also includes Symphony Gardens, a landscaped outdoor garden area providing places to sit, walk and enjoy. The overall height of the development is approximately 65 m.

Planning permission was granted in November 2022 (Ref: 134288/FO/2022).

Figure 3.2 presents a site plan of the Approved Development.

3.3. Proposed Amendments - Soft Landscaping

The wind microclimate has been assessed for the Approved Development with the proposed amendments to the soft landscaping scheme. As illustrated graphically within Figure 3.3, the modelled soft landscaping comprised of the following:

- 3 x ~7.5 m tall evergreen trees along Newman Street;
- 4 x ~7.5 m tall deciduous trees along Newman Street;
- 1 x ~4.5 m tall evergreen multi-stem west of the main entrance;
- 14 x ~5.4 m tall deciduous trees along Newman Street, Cloak Street and within the park space;
- 10 x ~4.5 m tall deciduous trees within the park space;
- 1 x ~4.5 m tall evergreen tree on the north corner of the park space;
- 7 x ~3.5 m tall deciduous multi-stems within the park space;
- 2 x ~3.0 m tall deciduous multi-stems within the park space;
- 3 x ~2.5 m tall deciduous multi-stems within the park space;
- 1 x ~3.0 m tall evergreen multi-stem on the north corner of the park space; and
- 7 x ~2.0 m tall evergreen multi-stems within the park space.

In addition, the model also incorporated the soft landscaping for the wider masterplan, comprising 60 x ~7.5 m tall deciduous trees and 33 x ~5.4 m tall deciduous trees, as well as three existing ~10.5 m tall deciduous trees to the south of the Mancunian Way underpass along Princess Street, illustrated graphically within Figure 3.4.

4. Assessment Methodology

4.1. Boundary Layer Wind Tunnel Studies

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 that shape the pedestrian level wind conditions can be derived.

A detailed quantification of the local wind microclimate requires a purposely designed boundary layer wind tunnel study, such that wind conditions can classified in terms of suitability for planned usage, based on the industry standard Lawson criteria, and wind mitigation measures developed and validated as required.

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[2]. The wind speed-ups are measured in the model-scale boundary layer wind tunnel testing for a full range of wind directions. The wind statistics are transposed from the nearest suitable weather centre to apply directly at the site.

4.2. Wind Climate Analysis

Details of the annual and seasonal climate wind analysis relevant to the site are presented in Appendix A.

4.3. Wind Tunnel and Model Details

The wind tunnel model was built at a scale of 1:300, which is large enough to allow a good representation of the details that are likely to affect the local and overall wind flows at full scale. In addition, this scale enables a good simulation of the turbulence properties of the wind to be achieved.

Details of the model scale and construction, along with photos of the model and wind tunnel setup are presented in Appendix B.

4.4. Measurement and Analysis

The technical details relating to the instrumentation, measurements and analysis for the wind microclimate study along with the assessment criteria to which they are compared (Lawson criteria) are described in Appendix C.

The Lawson criteria define the type of activities for which the wind conditions would be safe and comfortable. An area that has relatively low wind speeds and would be comfortable for recreational use (involving standing or sitting) would also be suitable for uses that tolerate higher wind speeds such as walking.

The wind microclimate was assessed at a total of 57 locations, which were reviewed and approved by the design team prior to testing. Details of proposed pedestrian activities, assumed in the assessment, are also provided in Appendix C.

Measurements were taken for a full range of wind directions in increments of 22.5°.

4.5. Wind Direction

The 0° wind direction has been chosen to coincide with north (90° east, 180° south, 270° west). The wind direction denotes the direction, which the wind is blowing *from*.

5. Results

5.1. General

Results are provided for the Approved Development in existing surrounds with the proposed amendments to the soft landscaping scheme.

5.2. Wind Speed-Up Factors

The measured wind speeds are converted into wind speed-up factors. These are defined as the ratio between the measured wind speeds at a height of 1.5 m above the ground and the wind speed at the reference height of 65 m.

5.3. Threshold Wind Speed Exceedance

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

5.4. Annual and Seasonal Assessments

The results of the wind speed measurements are summarised in graphical format in Appendix D, in terms of comfort and safety ratings derived for each pedestrian level measurement location.

The annual safety plots indicate those locations that exceed safety thresholds for the general public or able bodied, with a red dot indicating an exceedance of the threshold.

The comfort plots indicate the suitability of each location in terms of wind comfort rating, with the dots colour coded according to usage, for both the summer season and the worst season (being the worst conditions for a given location across all four seasons).

6. Assessment

6.1. Approach to Assessment

6.1.1. Safety

At each area investigated, the suitability of the pedestrian level wind microclimate in terms of safety is assessed based on the Lawson criteria for pedestrian safety (see Appendix C). Safety is determined for the ‘able-bodied’ and for the ‘general public’. For the general public a wind speed of 15 metres-per-second occurring once per year is rated as unsafe, with 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 of defending themselves against extreme pedestrian level winds and thus experience distress at a higher threshold wind speed of 20 metres-per-second, once per year.

6.1.2. Comfort

At each area investigated, the suitability of the pedestrian level wind microclimate in terms of comfort for various activities is assessed based on the Lawson criteria[3] for pedestrian comfort (see Appendix C). 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 (example bus stops) consider all seasons, with winter usually being the critical season. The activities considered, and their relation to the Lawson comfort criteria, are summarised as follows:

Activity	Comfort Rating	Season	Examples
”Thoroughfare (A-B)”	Pedestrian Transit	All seasons	Local areas around tall buildings where people are not likely to linger. For access to and passage through the development and surrounding area.
”Leisure thoroughfare”	Strolling	All seasons	General areas of walking and sightseeing. For recreational passage through the development and surrounding area.
“Viewing Balcony”	Short Periods of Standing / Sitting	Summer	For short periods of sitting and standing on balconies.
”Recreational space”		Spring through autumn	For leisure uses including parks, gardens, children’s play areas, terraces, bench seating, etc.
”Entrance / shop front / waiting area”		All seasons	For pedestrian ingress/egress at a building entrance, or short periods of sitting or standing such as at a bus stop, taxi rank, meeting point, etc.
”Outdoor seating” / ”Seating Balcony”	Long-term Sitting	Summer	For long periods of sitting such as for an outdoor café/bar/restaurant, event seating, etc.

6.2. Approved Development in Existing Surrounds

The proposed amendments to the soft landscaping scheme, which is similar to the scheme originally assessed, include a general reduction in the height of the trees being offset by the substitution of multi-stem and evergreen varieties. Consequently, wind conditions generally remain suitable for the intended uses, and similar to those originally assessed.

The results of the assessment for the Approved Development in existing surrounds with the proposed amendments to the soft landscaping scheme are summarised in Figure 6.1.

6.2.1. Safety

Wind conditions in and around the Approved Development in existing surrounds with the proposed amendments to the soft landscaping scheme are suitable, in terms of pedestrian safety, for all users.

6.2.2. Comfort

6.2.2.1. Thoroughfares

With the introduction of the proposed amendments to the soft landscaping scheme, wind conditions along the vast majority of thoroughfares in and around the Site remain suitable for the intended use, being comfortable for leisurely thoroughfare as a minimum throughout the year.

However, wind conditions around the north-east corner of the MSCP [Location 26], the south-east corner of the Vita Living building to the north-west [Location 44] and to the east of the entrance at the north-west corner of the Approved Development [Location 17] exceed the criteria in winter only (suitable 92.6-93.9% of the time, against a threshold of 95%), being suitable for pedestrian transit, but as the majority of the area is suitable for at least leisurely

thoroughfare use throughout the year this would still be considered tolerable for the intended use in these areas.

6.2.2.2. Entrances

With the introduction of the proposed amendments to the soft landscaping scheme, wind conditions at the designated entrances to the Approved Development and surrounding buildings are suitable, in terms of pedestrian comfort, for ingress / egress and thus entrance use.

A single exception to this occurs at the service entrances to the Approved Development from the eastern end of Cloak Street [Location 5], which are suitable for entrance use in summer, but otherwise suitable for leisurely thoroughfare only. However, based on the expected usage, this is considered to still be tolerable.

6.2.2.3. Recreational Spaces

With the introduction of the proposed amendments to the soft landscaping scheme, wind conditions within the recreational spaces around the Approved Development are suitable, in terms of pedestrian comfort, for short periods of sitting or standing from spring to autumn, and thus are suitable for their intended use.

6.2.2.4. Outdoor Seating

With the introduction of the proposed amendments to the soft landscaping scheme, wind conditions within the vast majority outdoor seating areas around the Approved Development are suitable, in terms of pedestrian comfort, for long-term sitting in summer, and thus their intended use.

The only exception being in the centre of the park space [Locations 40 & 56], where wind conditions slightly exceed the criteria for long-term sitting in summer (suitable 94.4% and 94.2% of the time, respectively, against a threshold of 95%), being suitable for short-term sitting / standing only. Noting that the trees will provide additional shelter at this time of year compared to the predominantly bare winter-time trees modelled, it is expected that wind conditions will be at least tolerable, if not entirely suitable.

7. Conclusions

The boundary layer wind tunnel study has assessed the wind microclimate for the proposed amendments to the soft landscaping scheme for the Approved Development. On the basis of the wind tunnel modelling, the following conclusions have been drawn:

- Wind conditions around the Approved Development in existing surrounds with the proposed amendments to the soft landscaping scheme remain suitable, in terms of pedestrian safety and comfort, for intended uses at the vast majority of locations.
- Whilst there are some minor localised exceedances, in terms of comfort only, wind conditions remain similar to the approved soft landscaping scheme and are still expected to be tolerable, if not entirely suitable for the intended uses.

These results are consistent with the original wind assessment submitted in support of the approved planning application (NOVA Report 75019rep5v2, dated 22nd June 2022). Whilst the outdoor seating on the south-west corner has improved to become suitable, the outdoor seating within the park space to the west now slightly exceed the criteria, but are more likely to benefit from increased foliage during summer months (compared to the predominantly bare winter-time trees modelled). Furthermore, the service entrance on Cloak Street is now only suitable for a mixture of entrance and leisurely thoroughfare, but this is considered tolerable given the intended use. The remaining wintertime exceedances on the thoroughfares around the corners are similar to the approved scheme. In conclusion, the impact of the proposed amendments is considered to be acceptable, with only minor residual exceedances, in terms of comfort only, which given the intended uses are considered to be tolerable.

8. References

[1] Davenport, A.G. An Approach to Human Comfort Criteria for Environmental Wind Conditions. Colloquium on Building Climatology, Stockholm, September 1972

[2] 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.

[3] 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.

[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

Figure 3.1: Site location

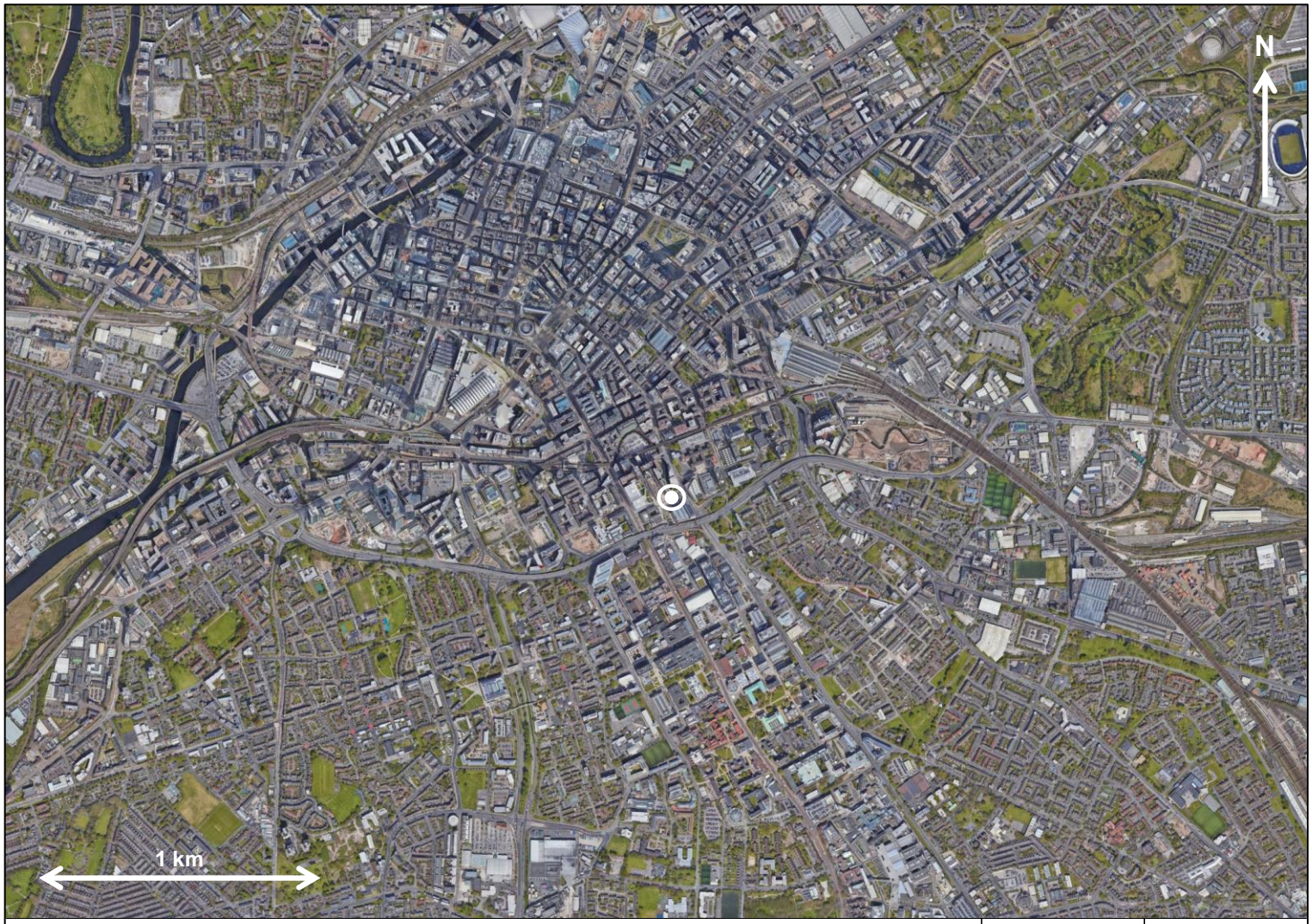


Figure 3.2: Site plan of the Approved Development

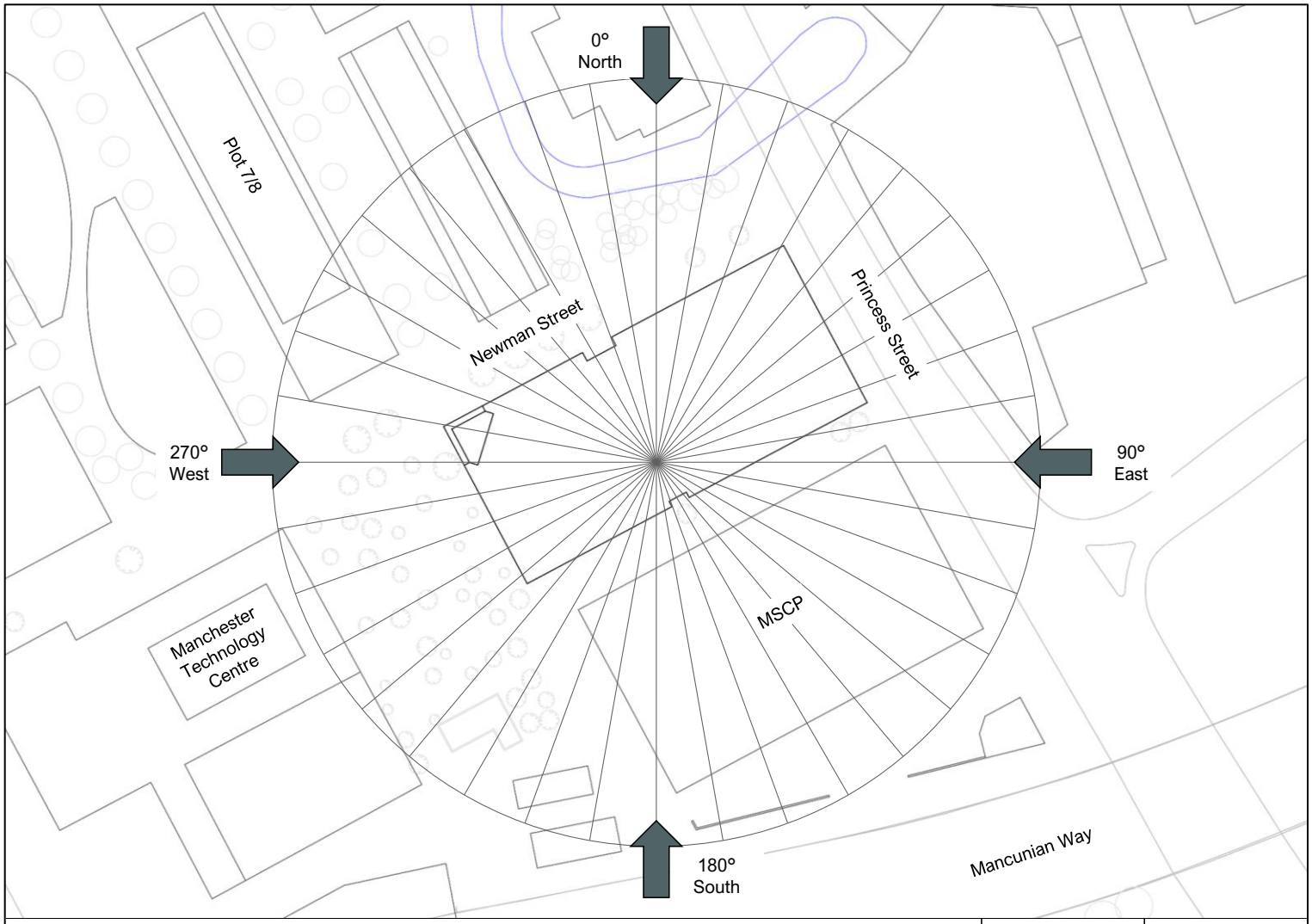


Figure 3.3: Proposed amendments to the soft landscaping scheme

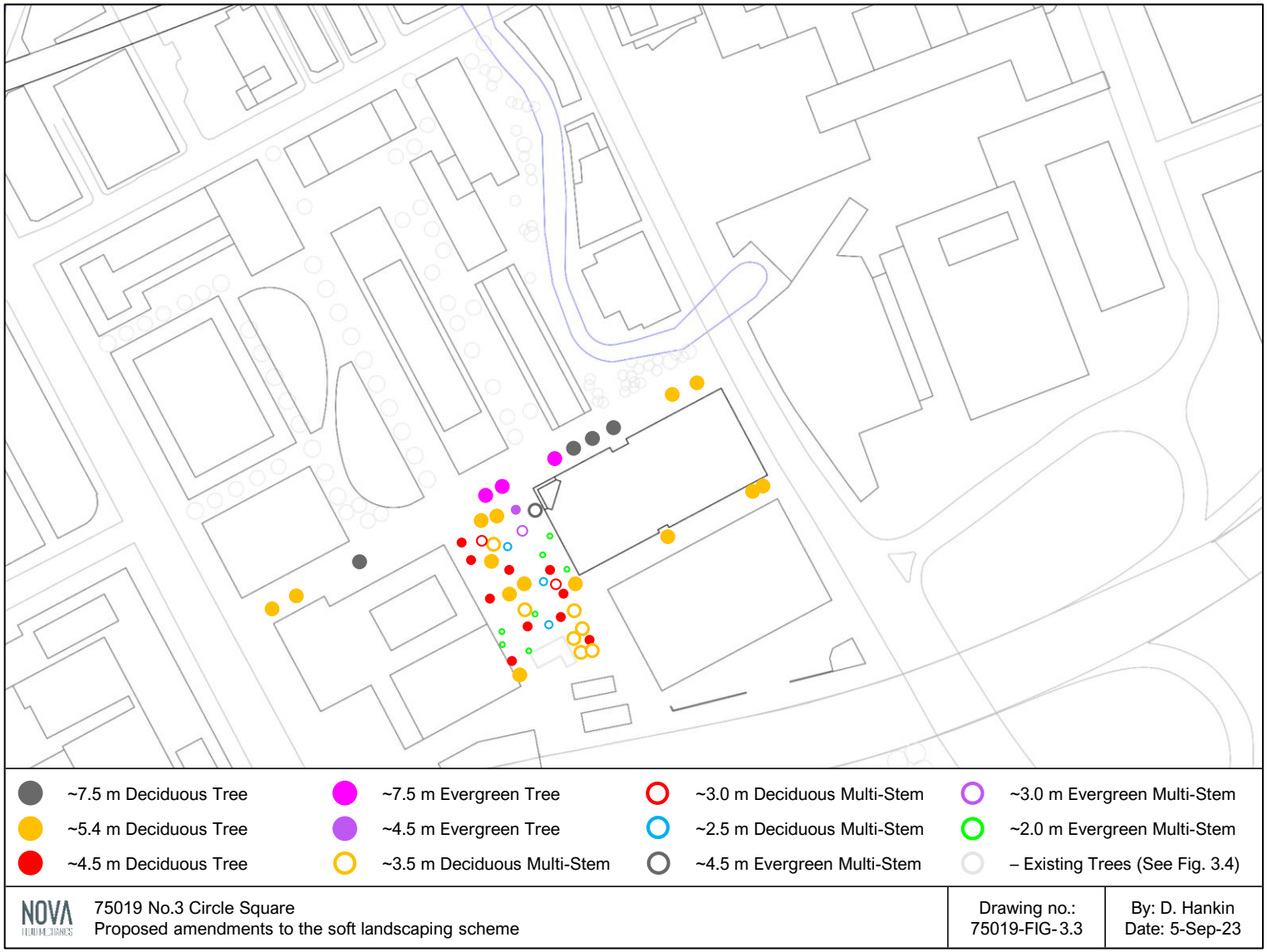


Figure 3.4: Existing soft landscaping

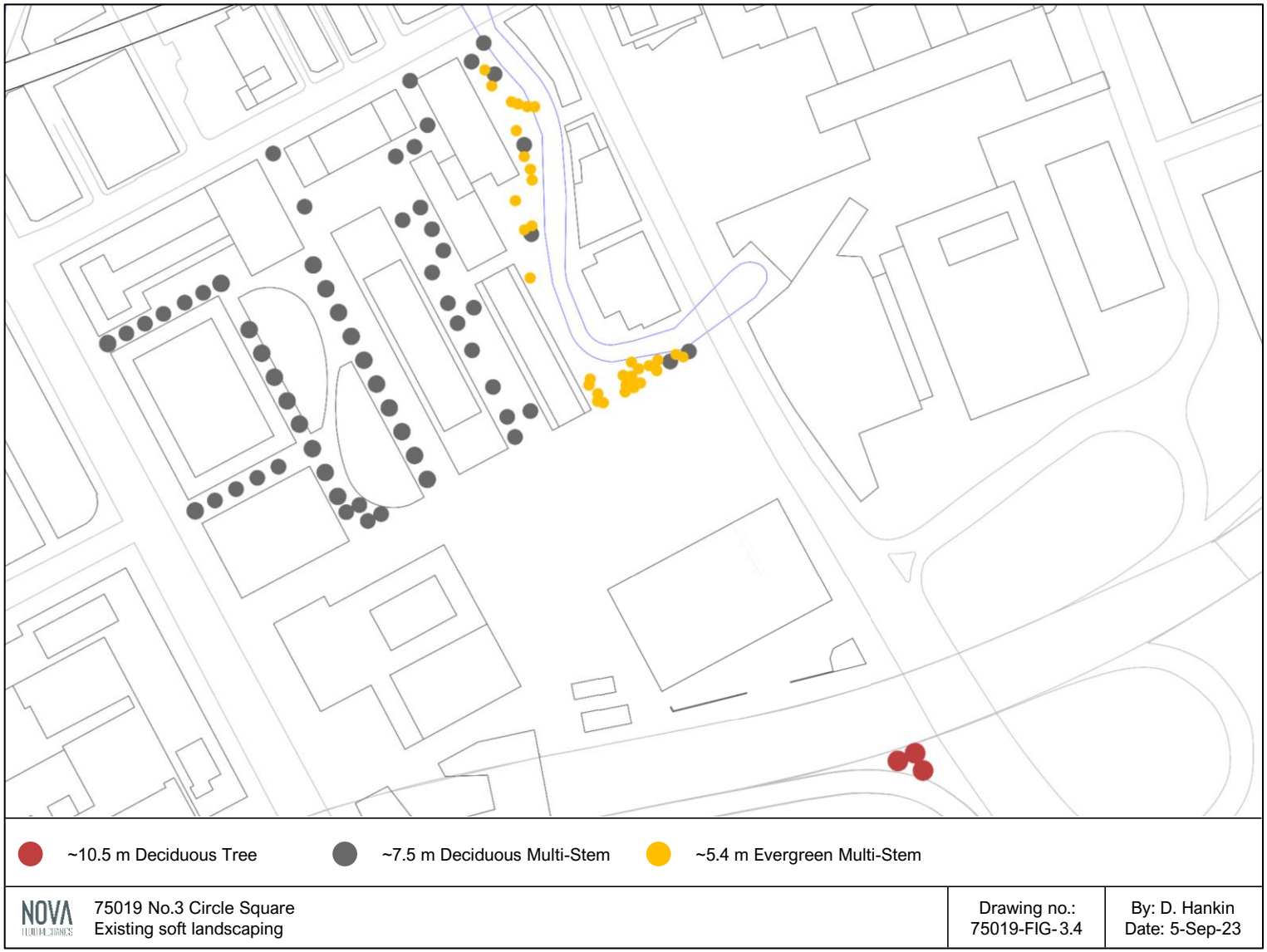
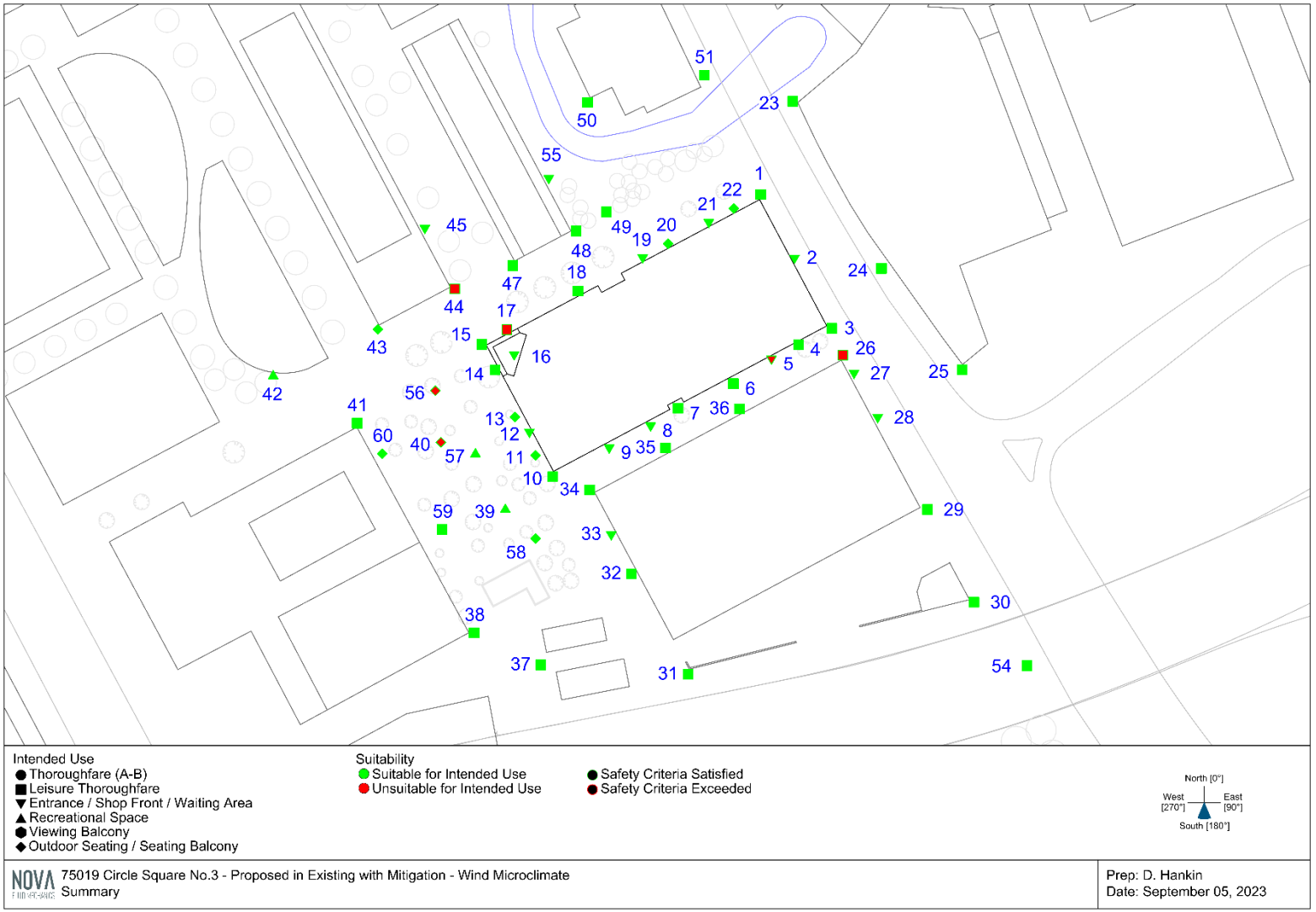


Figure 6.1: Wind microclimate summary, approved in existing



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[4], and has provided wind profiles describing the variation of wind speed and turbulence intensity with height and wind direction. From this analysis representative profiles were defined as targets for the ABL simulation in the wind tunnel.

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

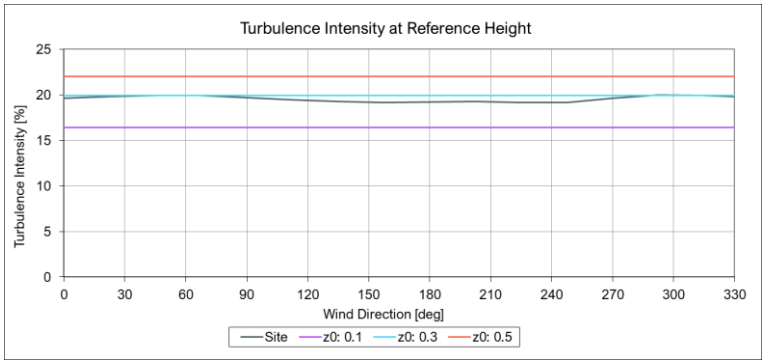
Table A.1: Terrain roughness changes from the site

Wind Dir'n	z_0 [m]	x_0 [m]	z_{01} [m]	x_{01} [m]	z_{02} [m]	x_{02} [m]	z_{03} [m]	x_{03} [m]	z_{04} [m]
0°	0.5	1,800	0.3	6,100	0.03				
30°	0.5	1,500	0.3	8,700	0.03				
60°	0.5	1,500	0.3	10,000	0.03	9,400	0.05	6,100	0.03
90°	0.5	800	0.3	11,100	0.03	8,500	0.05	21,700	0.03
120°	0.5	400	0.3	10,700	0.03				
150°	0.5	300	0.3	10,100	0.03				
180°	0.5	300	0.3	11,500	0.03				
210°	0.5	300	0.3	13,200	0.03				
240°	0.5	500	0.3	8,800	0.03				
270°	0.5	1,200	0.3	7,800	0.05	13,700	0.1	12,700	0.03
300°	0.5	1,900	0.3	8,600	0.1	10,300	0.03		
330°	0.5	2,000	0.3	5,300	0.05	13,000	0.03		

A.2. Wind Properties at the Site

Figure A.1 shows the variation of longitudinal turbulence intensity with wind direction at the reference height of 65 m.

Figure A.1: Variation of turbulence intensity with wind direction at 65 m height, including reference turbulence levels



Due to the low variation of wind properties with wind direction, one target profile has been selected for the boundary layer simulation, being that for 300°.

Figures A.2 and A.3 show the variation of mean wind-speed (normalised by the mean wind speed at the reference height of 65 m) and turbulence intensity with height for winds approaching the site from the four primary quarters.

Figure A.2: Variation of mean wind speed normalised by mean wind speed at the reference height of 65 m

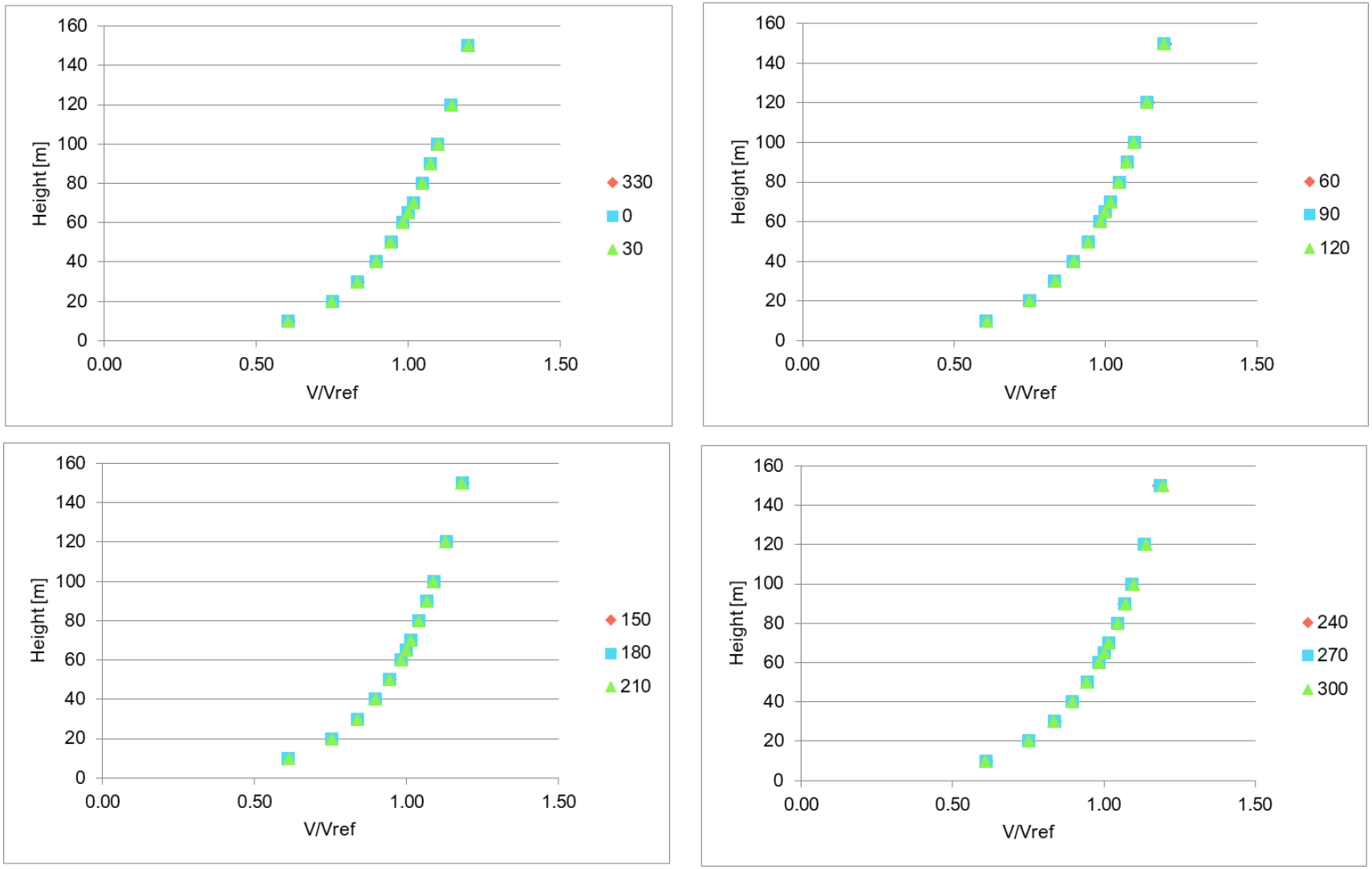


Figure A.3: Variation of longitudinal turbulence intensity with wind direction the reference height of 65 m.

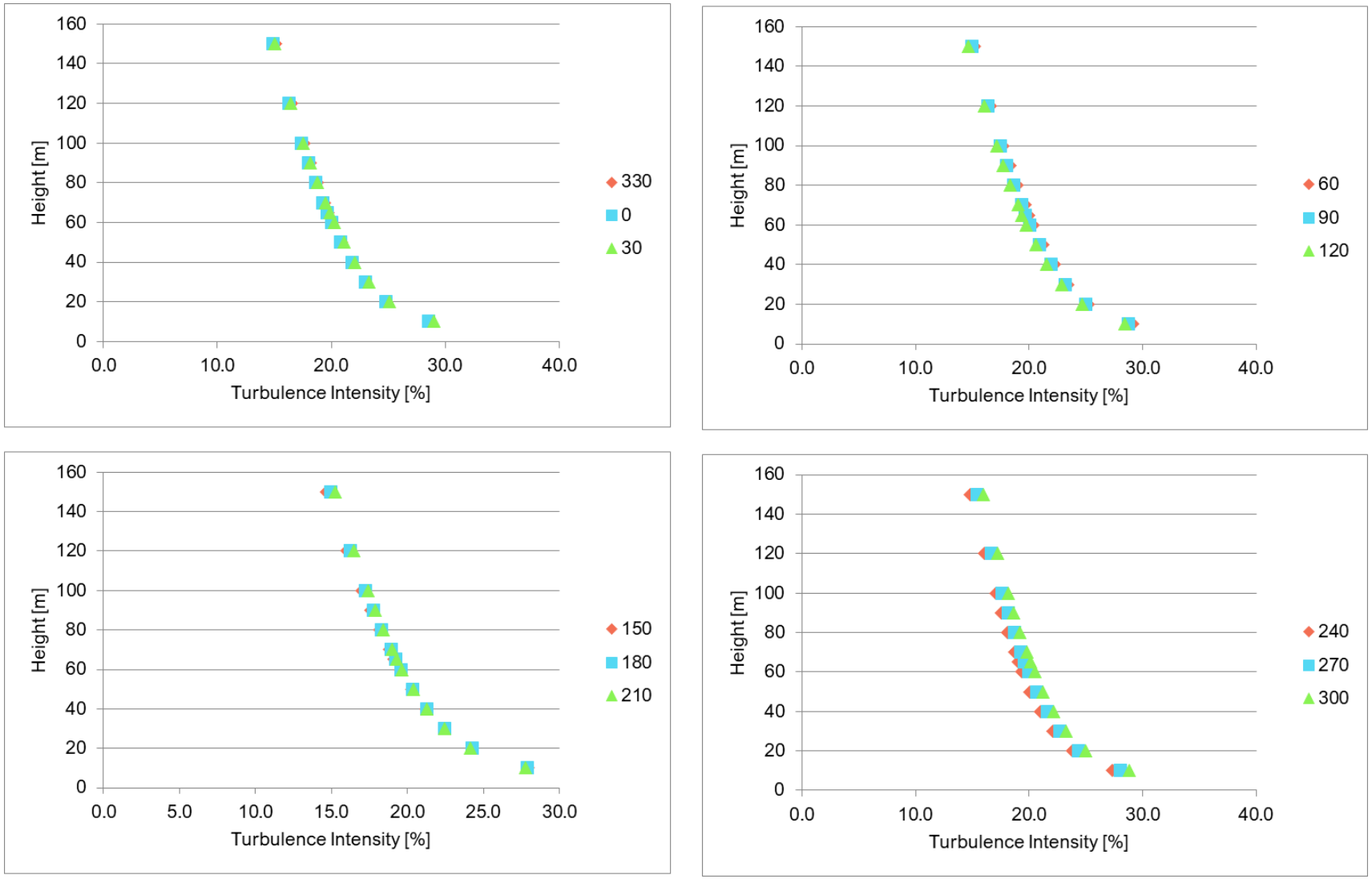
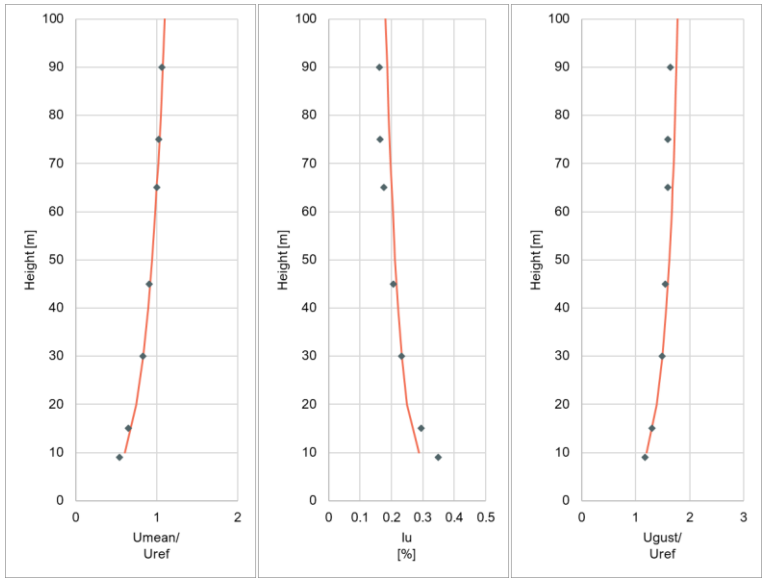


Figure A.4 presents the variation of mean wind speed, longitudinal turbulence intensity and gust wind speed used in the tests. The wind speed profiles are normalised by the mean wind speed at the reference height of 65 m.

Figure A.4: Mean wind speed ($U_{mean}/U_{mean}(ref)$), longitudinal turbulence intensity profiles (I_u) and gust wind speed ($U_{gust}/U_{mean}(ref)$) modelled in the study



It can be seen that, over the range of heights of interest, the boundary layer simulations used in the tests were a good representation of the profiles expected for the site at full scale.

A.3. Wind Frequency Data

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

The wind speed history, provided by weather centres such as the UK Met Office or the National Oceanic & 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 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. The resulting annual and seasonal directional and wind speed

probability distributions at the reference height of 65 m, at the proposed site, are given in Figures A.5a to A.5e, respectively.

Values of *p*, *c* and *k* for the Manchester weather centre transposed to open-country terrain at 10 m height above sea-level altitude are given in Table A.2.

Figure A.5a: Directional wind speed probability distribution at site: annual (at 65 m height)

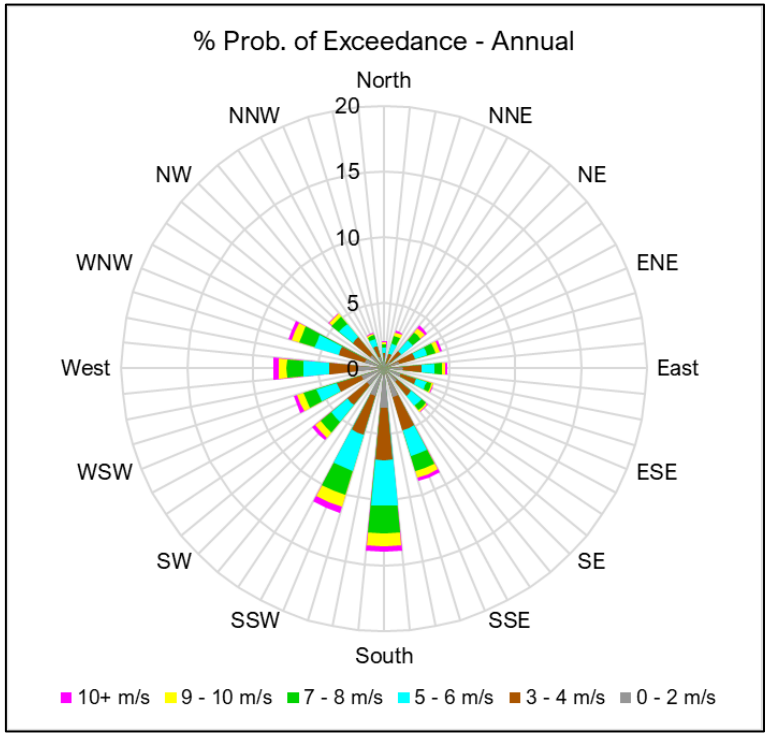


Figure A.5b: Directional wind speed probability distribution at site: spring (at 65 m height)

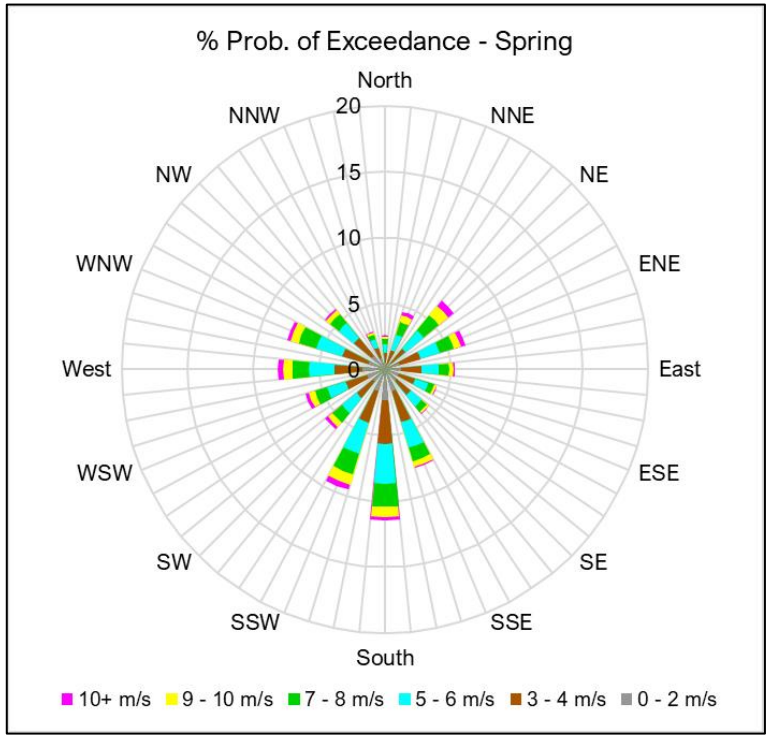


Figure A.5c: Directional wind speed probability distribution at site: summer (at 65 m height)

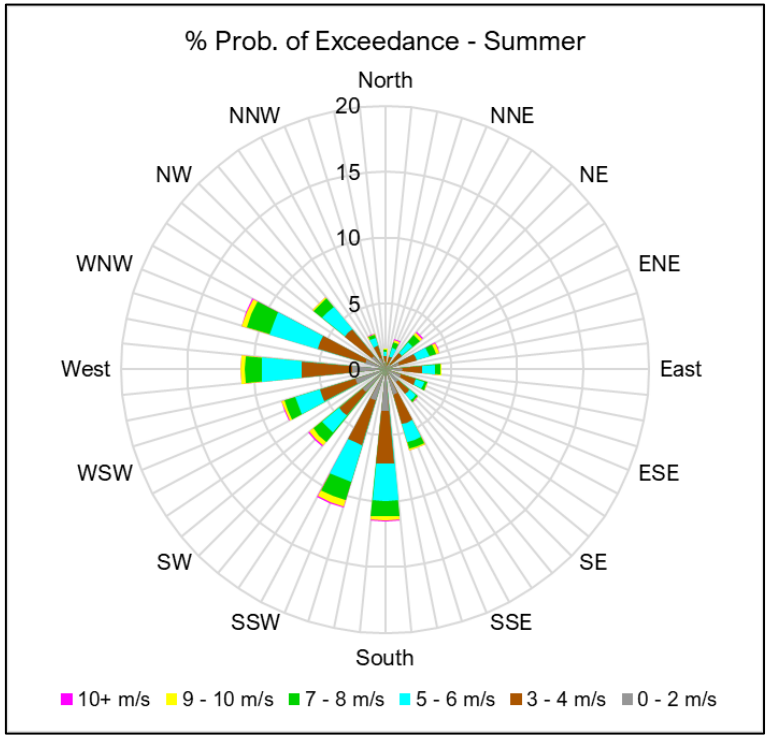


Figure A.5d: Directional wind speed probability distribution at site: autumn (at 65 m height)

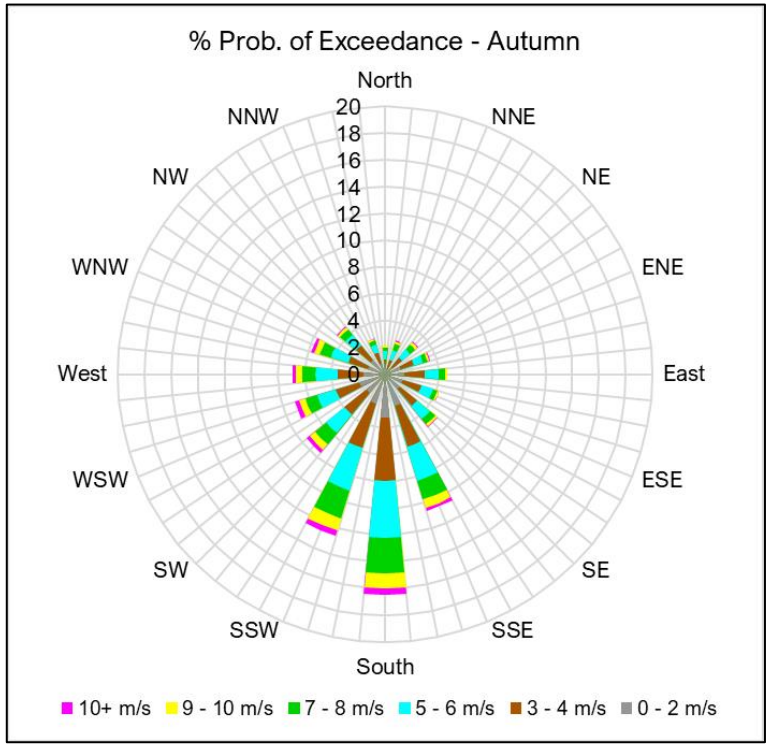


Figure A.5e: Directional wind speed probability distribution at site: winter (at 65 m height)

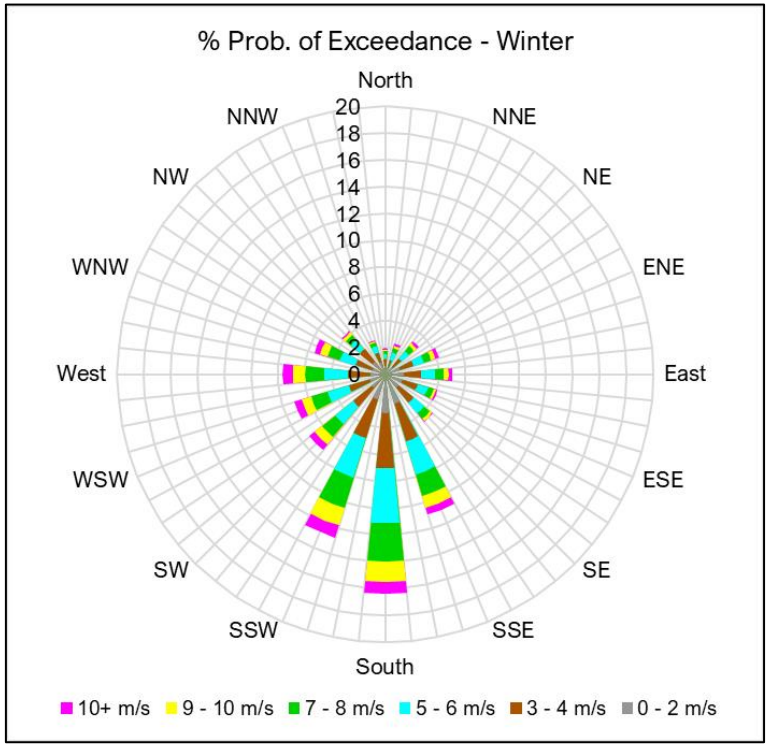


Table A.2: Wind frequency statistics: corrected Manchester weather station data transformed to z_0=0.03m

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	2.07	3.01	4.24	4.61	4.81	3.95	4.32	8.94	13.92	11.46	7.07	7.20	8.44	7.63	5.50	2.83
c	4.85	5.82	5.88	5.11	4.63	4.20	4.35	4.85	5.14	5.45	5.15	5.10	5.28	5.44	4.81	4.39
k	1.81	2.34	2.17	1.80	1.81	1.86	1.95	1.94	2.05	2.08	1.92	1.86	1.89	2.08	2.06	1.76

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	2.61	4.58	6.74	6.39	5.29	4.11	4.36	7.81	11.46	9.54	5.88	6.33	8.14	7.76	5.95	3.04
c	5.39	6.28	6.57	5.72	4.98	4.57	4.62	4.86	5.14	5.54	5.34	5.24	5.46	5.61	5.09	4.72
k	2.08	2.53	2.48	2.06	2.04	2.12	2.12	2.15	2.15	2.14	2.04	1.94	1.94	2.24	2.06	1.82

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	1.59	2.42	3.73	4.32	4.29	3.37	3.24	6.42	11.52	10.98	7.53	8.26	10.98	11.40	7.14	2.82
c	4.16	5.57	5.51	4.74	4.25	3.80	3.68	4.06	4.37	4.81	4.49	4.32	4.62	5.16	4.73	4.08
k	1.72	2.40	2.44	2.00	2.08	2.02	1.99	2.13	2.17	2.23	1.90	2.09	2.37	2.82	2.67	2.12

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	2.13	2.62	3.22	3.54	4.68	4.23	5.08	10.66	16.45	12.60	7.57	7.07	6.94	5.78	4.65	2.78
c	4.92	5.51	5.19	4.29	4.33	4.09	4.42	4.92	5.22	5.40	5.09	4.95	5.14	5.32	4.57	4.53
k	2.27	2.51	2.02	1.71	1.97	2.02	2.05	2.05	2.14	2.19	1.93	1.69	1.94	1.89	1.85	1.93

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	1.94	2.38	3.23	4.20	5.00	4.08	4.62	10.95	16.37	12.76	7.30	7.09	7.66	5.53	4.21	2.67
c	4.71	5.47	5.46	5.27	5.05	4.39	4.55	5.36	5.66	6.03	5.76	6.00	6.40	6.05	4.79	4.41
k	1.54	1.96	1.83	1.66	1.72	1.69	1.91	1.95	2.09	2.11	2.00	2.00	2.05	1.94	1.78	1.65

APPENDIX B. WIND TUNNEL & MODEL DETAILS

B.1. Wind Tunnel Specifications

All the tests were conducted in the Boundary Layer Wind Tunnel at STU which has a working section 2.6 m wide, 1.6 m high and 26.3 m long with a 2.4 m diameter turntable and a remotely controlled 3-dimensional traversing system. The operating wind speed range is 0 – 32 m/s.

A turbulent boundary layer, representative of the conditions at the site, is set up using turbulence inducing elements at the entrance to the test section and an arrangement of roughness elements distributed over the floor of the wind tunnel.

B.2. Model

B.2.1. Information for Model Construction

The model of the approved development was constructed based on the architecture plans provided by Deloitte, received 29th March 2022.

The model of the surrounding area was based on a site survey using publicly available information.

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

B.2.2. Scale

A model scale of 1:300 has been adopted. At this scale the model is large enough to allow a good representation of the details that are likely to affect the local and overall wind flows at full scale. In addition, this scale enables a good simulation of the turbulence properties of the wind to be achieved.

B.2.3. Construction

The model was constructed from a combination of materials such as hard foam and wood. The model incorporated all of the features that are likely to significantly affect the local wind flow around the development at full scale. The surrounding area was modelled to a radius of 300 m from the centre of the site. The surrounding buildings were represented to a sufficient level of detail to reproduce the wind flows at the location of the proposed development.

Deciduous trees were represented in winter, or bare, format in order to obtain conservative results, but it is presumed that trees planted as part of the development will be a species which is robust, and offers a worthwhile degree of alleviation of accelerated winds, i.e. the trees retain a substantial level of solidity during winter (lots of twigs and branches).

B.2.4. Model Photos

Images of the wind tunnel model are presented as follows:

- Figures B.1 & B.2: Approved Development in existing surrounds
- Figures B.3 & B.4: Close-ups of Approved Development

Figure B.1: Approved development in existing surrounds viewed from the south-west.

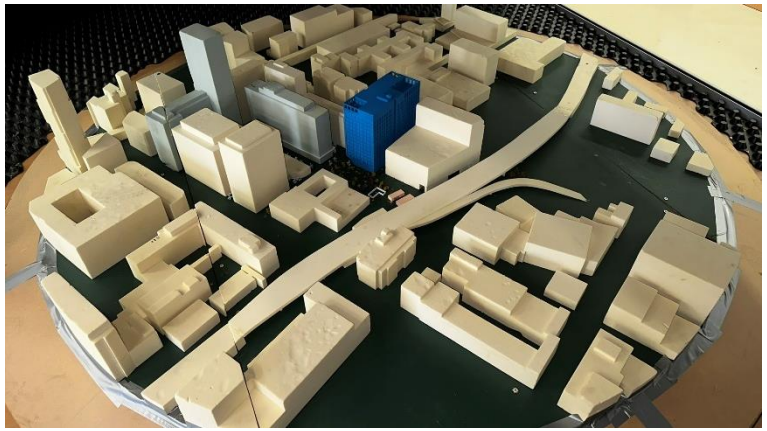


Figure B.2: Approved development in existing surrounds viewed from the north-west.



Figure B.3: Close-up of approved development viewed from the south-west.

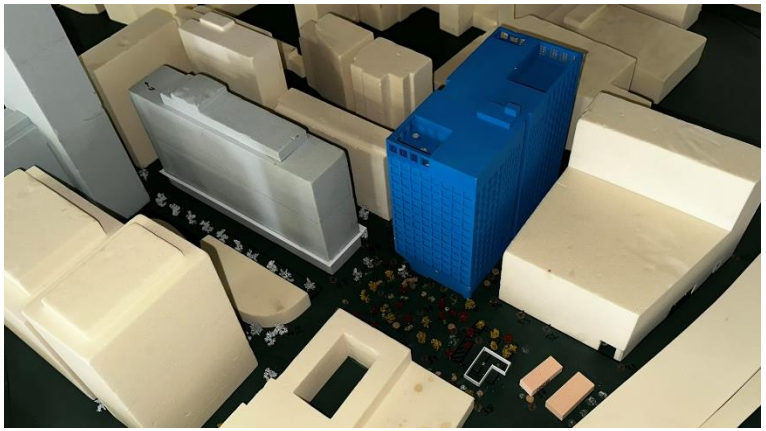


Figure B.4: Close-up of approved development viewed from above.



APPENDIX C. MEASUREMENTS AND ANALYSIS

C.1. Wind Speed Measurements

Wind speed measurements were made using so-called 'Irwin probes', capable of measuring fluctuating pressure differences that are calibrated against wind speed. A system of probes running simultaneously was used to obtain results from 57 locations at a height corresponding to 1.5 m at full scale. Measurements were taken for a full range of wind directions in increments of 22.5°.

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

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

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

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

C.2. Assessment Criteria

The accepted, UK industry standard, Lawson criteria for pedestrian comfort and safety are applied in the study. NOVA adhere to the LDDC variant of the Lawson criteria[3].

Details of the comfort criteria are presented in Table C.1 and are based on the exceedance of the threshold wind speeds, based on the mean-hourly value and on the gust equivalent mean value, occurring less 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.

Table C.1: Lawson comfort criteria – LDDC variant[3]

Threshold Wind Speed	Comfort Rating		Examples
4 m/s	C4	Long-term standing / sitting	Reading a newspaper and eating and drinking
6 m/s	C3	Short-term standing / sitting	Appropriate for bus stops, window shopping and building entrances
8 m/s	C2	Leisure thoroughfare / strolling	General areas of walking and sightseeing
10 m/s	C1	Pedestrian transit / thoroughfare (A-B)	Local areas around tall buildings where people are not likely to linger
> 10 m/s	C0	Uncomfortable for all uses	Uncomfortable for all pedestrian activities

Details of the safety criteria are presented in Table C.2 and are based on the exceedance of threshold wind speeds, again both the mean-hourly value and on the gust equivalent mean value, occurring once per annum.

A wind speed greater than 15 metres-per-second occurring once a year is classified as unsuitable for the general public and represents a wind speed with the potential to destabilise the less able members of the public such as the elderly, cyclists and children.

Able-bodied users are those determined to experience distress when the wind speed exceeds 20 metres-per second once per year.

Table C.2: Lawson safety criteria – LDDC variant[3]

Threshold Wind Speed	Safety Rating		Qualifying Comments
> 15 m/s	S2	Unsuitable for the general public	Less able and cyclists find conditions physically difficult
> 20 m/s	S1	Unsuitable for the able-bodied	Physically impossible for able-bodied to remain standing during gusts.

C.3. Pedestrian Activities

Table C.3 presents the pedestrian uses assumed for each of the corresponding measurement locations presented in Figure 6.1, for the approved development in existing surrounds.

Table C.3: Pedestrian uses – approved development

Loc'n	Usage	Loc'n	Usage	Loc'n	Usage
1	Leisure thoroughfare	20	Outdoor seating	39	Recreational space
2	Entrance	21	Entrance	40	Outdoor seating
3	Leisure thoroughfare	22	Outdoor seating	41	Leisure thoroughfare
4	Leisure thoroughfare	23	Leisure thoroughfare	42	Recreational space
5	Entrance	24	Leisure thoroughfare	43	Outdoor seating
6	Leisure thoroughfare	25	Leisure thoroughfare	44	Leisure thoroughfare
7	Leisure thoroughfare	26	Leisure thoroughfare	45	Entrance
8	Entrance	27	Entrance	47	Leisure thoroughfare
9	Entrance	28	Entrance	48	Leisure thoroughfare
10	Leisure thoroughfare	29	Leisure thoroughfare	49	Leisure thoroughfare
11	Outdoor seating	30	Leisure thoroughfare	50	Leisure thoroughfare
12	Entrance	31	Leisure thoroughfare	51	Leisure thoroughfare
13	Outdoor seating	32	Leisure thoroughfare	54	Leisure thoroughfare
14	Leisure thoroughfare	33	Entrance	55	Entrance
15	Leisure thoroughfare	34	Leisure thoroughfare	56	Outdoor seating
16	Entrance	35	Leisure thoroughfare	57	Recreational space
17	Leisure thoroughfare	36	Leisure thoroughfare	58	Outdoor seating
18	Leisure thoroughfare	37	Leisure thoroughfare	59	Leisure thoroughfare
19	Entrance	38	Leisure thoroughfare	60	Outdoor seating

APPENDIX D. COMFORT AND SAFETY RATINGS

The results of the wind speed measurements are summarised in graphical format in terms of comfort and safety ratings derived for each measurement location, as follows:

- Figure D.1 presents **annual safety** ratings for each configuration
- Figures D.2 presents **summer comfort** ratings for each configuration
- Figures D.3 presents **worst seasonal comfort** ratings for each configuration

The presentations listed above show the worst case between the results derived using wind speed-up factors based on the mean and gust equivalent mean (GEM) wind speeds (see Appendix C).

Figure D.1: Annual safety ratings, approved in existing

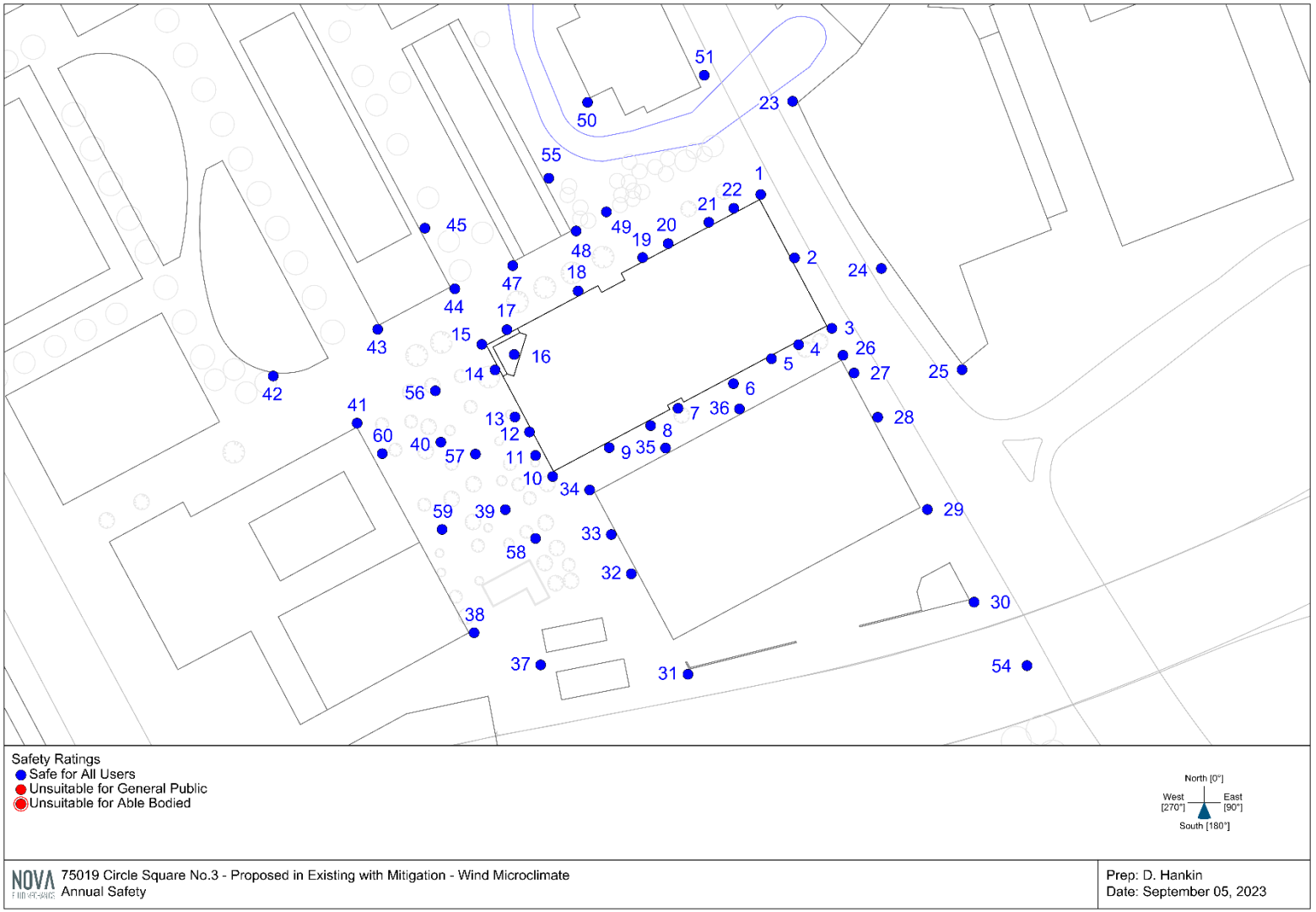


Figure D.2: Summer comfort ratings, approved in existing

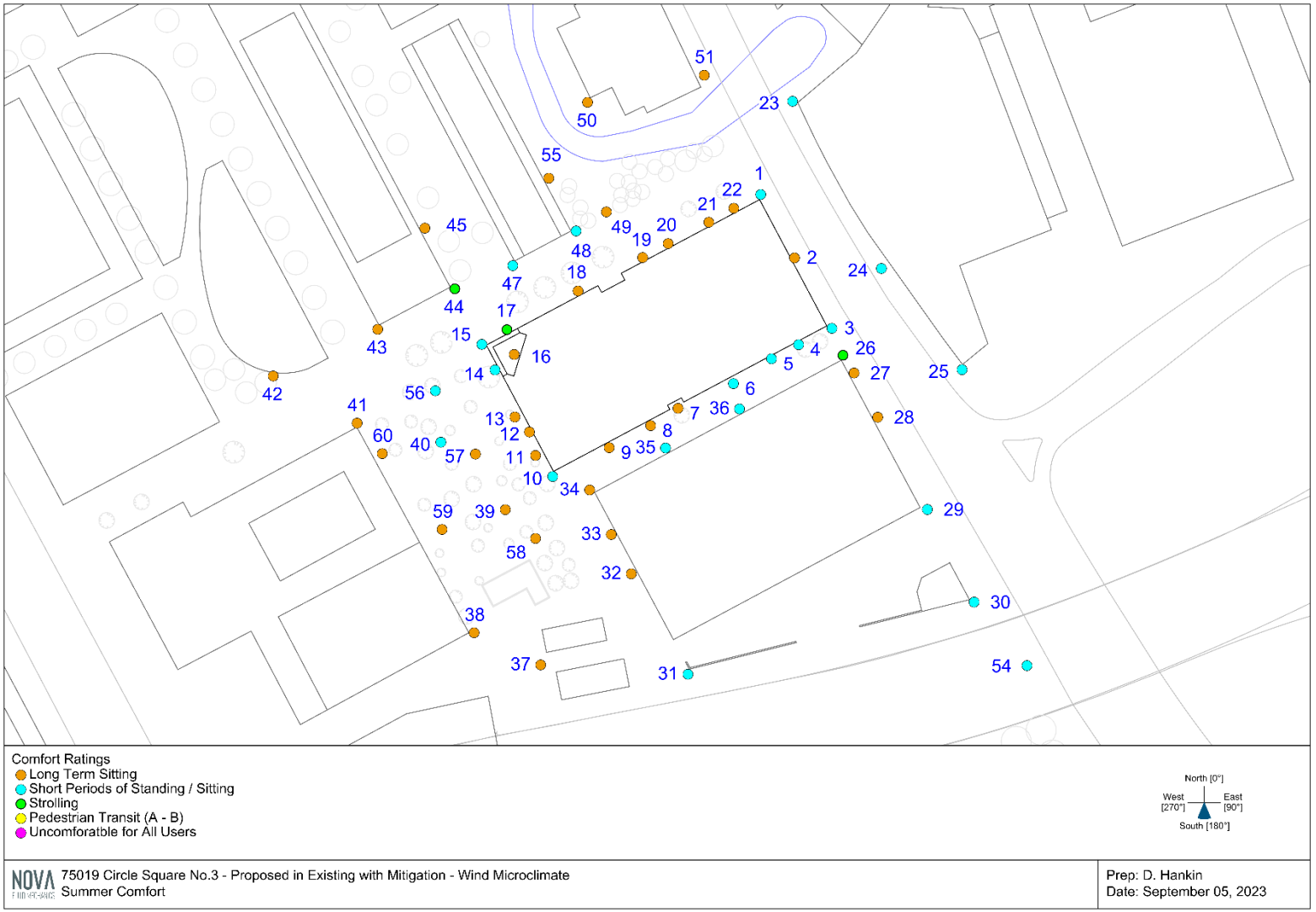


Figure D.3: Worst seasonal comfort ratings, approved in existing

