BMT Fluid Mechanics

Project No. 432087

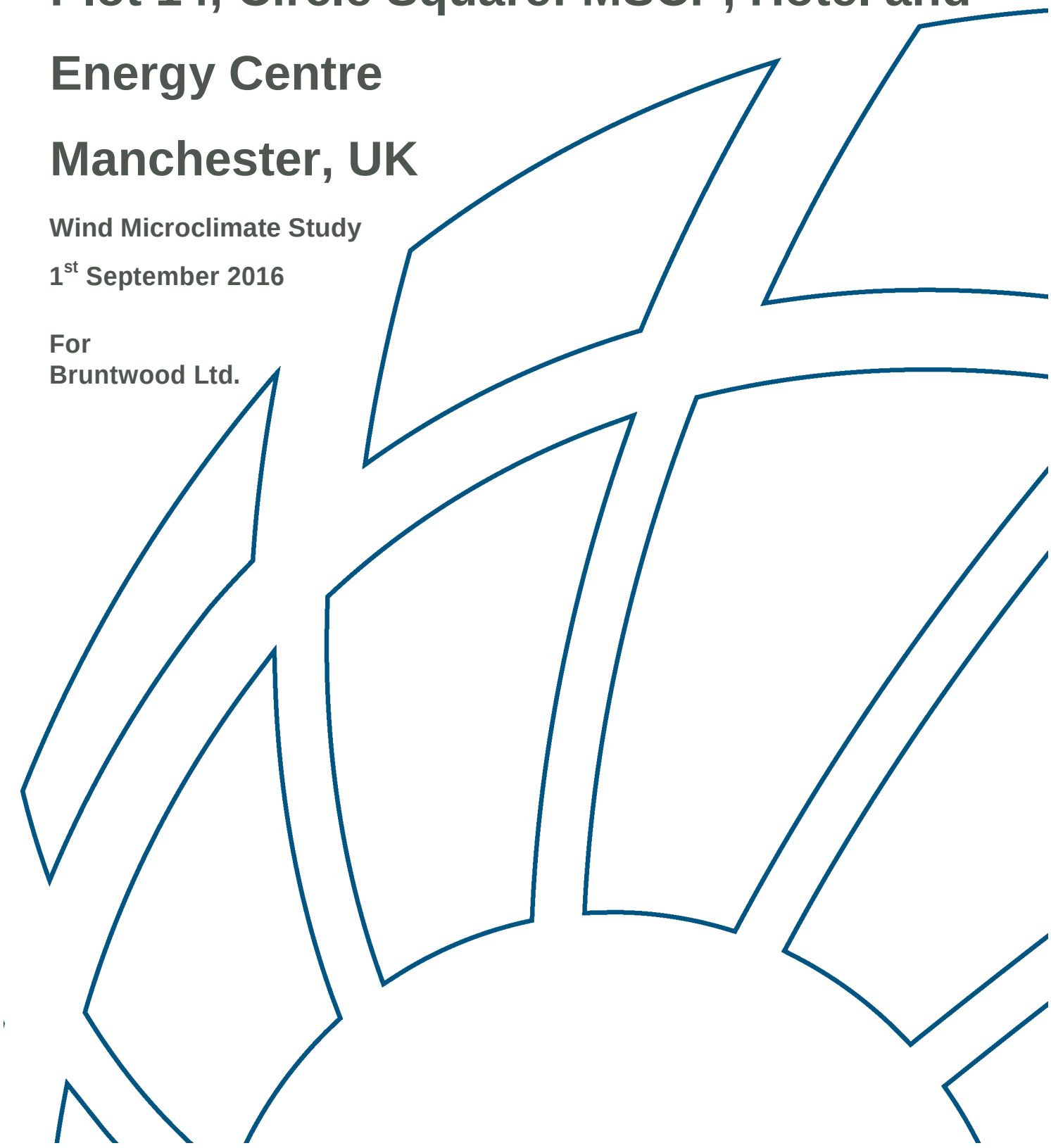
Plot 14, Circle Square: MSCP, Hotel and Energy Centre

Manchester, UK

Wind Microclimate Study

1st September 2016

For
Bruntwood Ltd.



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	Name:	Signature:	Date:
Prepared by:	**Mr Y.J. Pang**	----------	----------
Checked by:	**Mr M. Lee**	----------	----------
Approved by:	**Mr S. Cammelli**	----------	----------

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Plot 14, Circle Square: MSCP, Hotel and Energy Centre Manchester, UK Wind Microclimate Study

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EXECUTIVE SUMMARY

Background

This report is an addendum to the Wind Microclimate Study report (BMTFM report 431955rep1v5, dated 13th January 2016) prepared by BMT Fluid Mechanics, in relation the Phase 1B Proposals.

A boundary layer wind tunnel study has been carried out by BMT Fluid Mechanics Ltd. (BMT) to assess the wind microclimate for the revised proposals for Plot 14 of the Circle Square Masterplan at the former BBC Site, Oxford Road, Manchester. Plot 14 forms part of Phase 1B of this regeneration project.

The boundary layer wind tunnel study has enabled the pedestrian level wind environment 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 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

The boundary layer wind tunnel study has assessed the wind microclimate for the proposed development. On the basis of the wind tunnel modelling, the following conclusions have been drawn:

- Wind conditions in and around the proposed development in all three configurations tested are generally suitable in terms of pedestrian safety and comfort, for the intended use.
- A single exception, only in terms of pedestrian comfort, on the "Proposed development within the complete masterplan and the consented future surrounding conditions with landscaping" configuration, occurs on an entrance on the west façade of the development. As this location is a fire escape and is used only in emergencies, wind conditions would be considered tolerable for its proposed usage.

Plot 14, Circle Square: MSCP, Hotel and Energy Centre Manchester, UK Wind Microclimate Study

1. Introduction

This report summarises the results of a boundary layer wind tunnel study, commissioned by Bruntwood Ltd, to assess the wind environment for the revised proposals for Plot 14 of the Circle Square Masterplan at the former BBC Site, Oxford Road, Manchester. Plot 14 forms part of Phase 1B of this regeneration project.

The boundary layer wind tunnel study has enabled the pedestrian level wind environment 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 proposed development in the context of existing surrounds, approved future surrounds and the completed masterplan.

2. The Assessment of Wind Microclimate

The UK Met Office defines a 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 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 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. It is this approach that BMT adopts.

3. Study Area

3.1. Site Location & Surrounding Area

The proposed development site is located in Manchester, UK. The site is bounded by Cloak Street to the north, Princess Street to the east, the Mancunian Way to the south, and Oxford House to the west.

At present the area immediately surrounding the proposed development principally comprises a mixture of low rise commercial and residential developments. Further afield, the wider surrounding area largely consists of the urban greater Manchester area.

The site location is presented within the context of the wider surrounding area in Figure 3.1. Figure 3.2 presents a site plan of the proposed development.

Three configurations of the surrounding area are considered in the current study, namely:

- Proposed development in the context of existing surrounding conditions
- Proposed development in the context of the consented future surrounding conditions
- Proposed development within the complete masterplan and the consented future surrounding conditions

3.2. Revised Plot 14 Proposals

The proposed development comprises of a seven storey hotel, located on top of a multi storey car park on Plot 14 of the masterplan. The multi storey car park has a height of about 36m, and the hotel has a height of about 60m.

3.3. Soft Landscaping

The wind environment has been assessed for the proposed development with current soft landscaping proposals. As illustrated graphically within Figure 3.3, the soft landscaping modelled comprised the following:

- ~7.5m trees lining the northwest façade of the MSCP development
- ~7.5m trees lining the passages in between the masterplan buildings and earlier phases of the Circle Square development
- ~10.5m trees in between Buildings 2 and 4 and Buildings 7 and 8

- ~5.4m trees alongside the west and south bank of the canal towards the north of the development

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 and numerical / computational methods such as computational fluid dynamics do not readily apply to turbulent wind flows in the built environment.

As a result, a purposely-designed boundary layer wind tunnel study was used 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. 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

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

The model scale of 1:300 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.

4.4. Measurement and Analysis

The technical details relating to the instrumentation, measurements and analysis for the wind environment 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 environment was assessed at a total of 67 locations for the proposed development, with 62 locations at ground level and 5 locations on top of the podium. Details of proposed pedestrian activities, assumed in the assessment, are also provided in Appendix C.

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

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 the 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 following configurations:

- Proposed development in the context of existing surrounding conditions
- Proposed development in the context of consented future surrounding conditions
- Proposed development within the complete masterplan and the consented future surrounding conditions

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 1.5m above the ground and the wind speed at the reference height of 60m, the highest roof height within the site relative to the wind tunnel model datum level.

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.

6. Assessment

6.1. Approach to Assessment

6.1.1. Safety

At each area investigated, the suitability of the pedestrian level wind environment 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 environment in terms of comfort for various activities is assessed based on the Lawson criteria 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 autumn and spring, 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:

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 to 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

6.1.3. Mitigation Requirements

The assessment considers the requirement for mitigation schemes at each location based on proposed pedestrian activities listed in Appendix C. Areas that **require** mitigation schemes in order to create a wind environment sufficiently safe and comfortable for proposed uses are highlighted.

6.2. Proposed development in the context of existing surrounding conditions with landscaping

The introduction of the proposed development into the existing surrounding conditions represents an obstruction to prevailing southerly winds; however, as the development does not protrude significantly from its surroundings, the wind conditions on site are expected to be suitable, in terms of pedestrian comfort, for their intended uses.

The results of the assessment for the proposed development in the context of existing surrounding conditions are summarised in graphical format in Figures 6.1a and 6.1b.

6.2.1. Safety

With the introduction of the proposed development within the context of existing surrounding conditions, wind conditions at all locations in and around the site are rated as suitable, in terms of pedestrian safety, for all users.

6.2.2. Comfort

6.2.2.1. Thoroughfares

Wind conditions at all thoroughfares in and around the proposed development within the context of existing surrounding conditions are rated as suitable, in terms of pedestrian comfort, for the intended use.

6.2.2.2. Entrances

Wind conditions at all entrances in and around the proposed development within the context of existing surrounding conditions are rated as suitable, in terms of wind comfort, for use as pedestrian ingress / egress from the buildings.

6.2.2.3. Recreational Spaces

Wind conditions within general recreational spaces in and around the proposed development within the context of existing surrounding conditions are suitable, in terms of pedestrian comfort, for their intended uses.

6.3. Proposed development in the context of Phase 1B and other consented future surrounding conditions with landscaping

The introduction of the wider Phase 1B proposals and other consented future surrounds buildings is largely expected to provide the development with further shielding from the wind, but result in slightly windier conditions towards the northwest of the site of the proposed development.

The results of the assessment for the proposed development in the context of consented future surrounding conditions are summarised in graphical format in Figures 6.2a and 6.2b.

6.3.1. Safety

With the introduction of the wider Phase 1B proposals and other consented future surrounding conditions, wind conditions at all locations in and around the site remain suitable, in terms of pedestrian safety, for all users.

6.3.2. Comfort

6.3.2.1. Thoroughfares

Wind conditions at all thoroughfares in and around the proposed development remain suitable, in terms of pedestrian comfort, for the intended use.

6.3.2.2. Entrances

Wind conditions at all entrances in and around the proposed development remain suitable, in terms of wind comfort, for use as pedestrian ingress / egress from the buildings.

6.3.2.3. Recreational Spaces

Wind conditions within general recreational spaces in and around the proposed development remain suitable, in terms of pedestrian comfort, for their intended uses.

6.4. Proposed development within the complete masterplan and the consented future surrounding conditions with landscaping

The further addition of the masterplan buildings the consented future surrounds buildings is expected to allow for some further shielding from the wind, away from the site of the proposed development. However, due to the proximity of the masterplan buildings, wind funnelling is expected to occur, resulting in windier conditions along the façade of the proposed development.

The results of the assessment for the proposed development in the context of the complete masterplan and the consented future surrounding conditions are summarised in graphical format in Figures 6.3a and 6.3b.

6.4.1. Safety

With the introduction of the masterplan, wind conditions at all locations in and around the site remain suitable, in terms of pedestrian safety, for all users.

6.4.2. Comfort

6.4.2.1. Thoroughfares

Wind conditions at all thoroughfares in and around the proposed development remain suitable, in terms of pedestrian comfort, for the intended use.

6.4.2.2. Entrances

Wind conditions at the vast majority of entrances in and around the proposed development remain suitable, in terms of wind comfort, for use as pedestrian ingress / egress from the buildings, with the exception of an entrance on the western façade of the proposed development [Location 45]. Wind conditions at this location are comfortable for pedestrian strolling throughout the year, but only suitable as an entrance from spring to autumn. As the location is a fire escape and is used only in emergencies, wind conditions would be considered tolerable for its proposed usage.

6.4.2.3. Recreational Spaces

Wind conditions within general recreational spaces in and around the proposed development remain suitable, in terms of pedestrian comfort, for their intended uses.

7. Conclusions

The boundary layer wind tunnel study has assessed the wind microclimate for the revised Plot 14 proposals. On the basis of the wind tunnel modelling, the following conclusions have been drawn:

- Wind conditions in and around the proposed development in all three configurations tested are generally suitable in terms of pedestrian safety and comfort, for the intended use.
- A single exception, only in terms of pedestrian comfort, on the "Proposed development within the complete masterplan and the consented future surrounding conditions with landscaping" configuration, occurs on an entrance on the west façade of the development. As this location is a fire escape and is used only in emergencies, wind conditions would be considered tolerable for its proposed usage.

8. References

[1] Davenport, A.G. *An Approach to Human Comfort Criteria for Environmental Wind Conditions*. Colloqium 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.

[5] BMT Fluid Mechanics Report 431955rep1v5. *Former BBC Site, Manchester, UK: Wind Microclimate Study*. 2016.

Figure 3.1: Site location

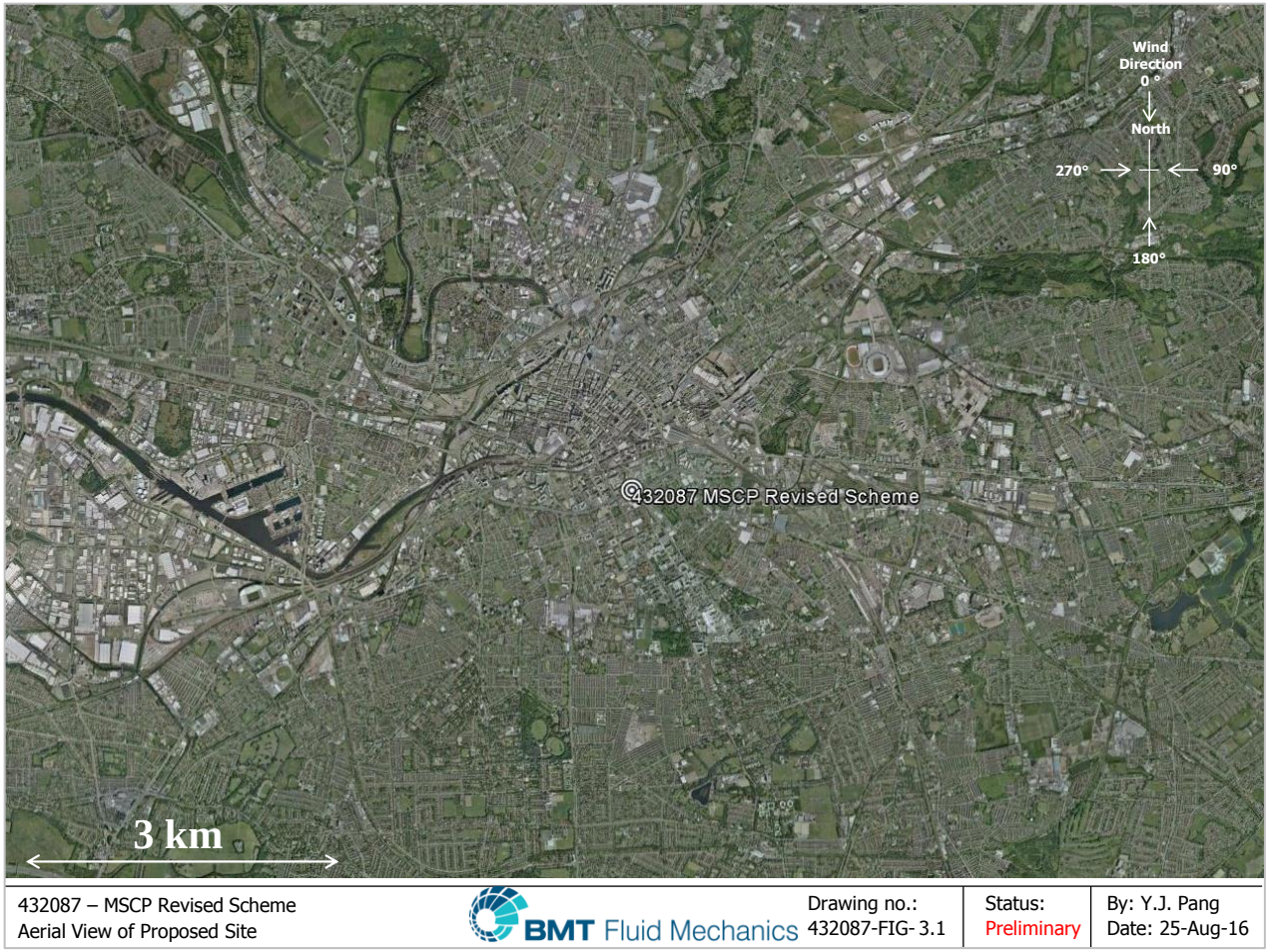


Figure 3.2: Site Plan of the proposed development

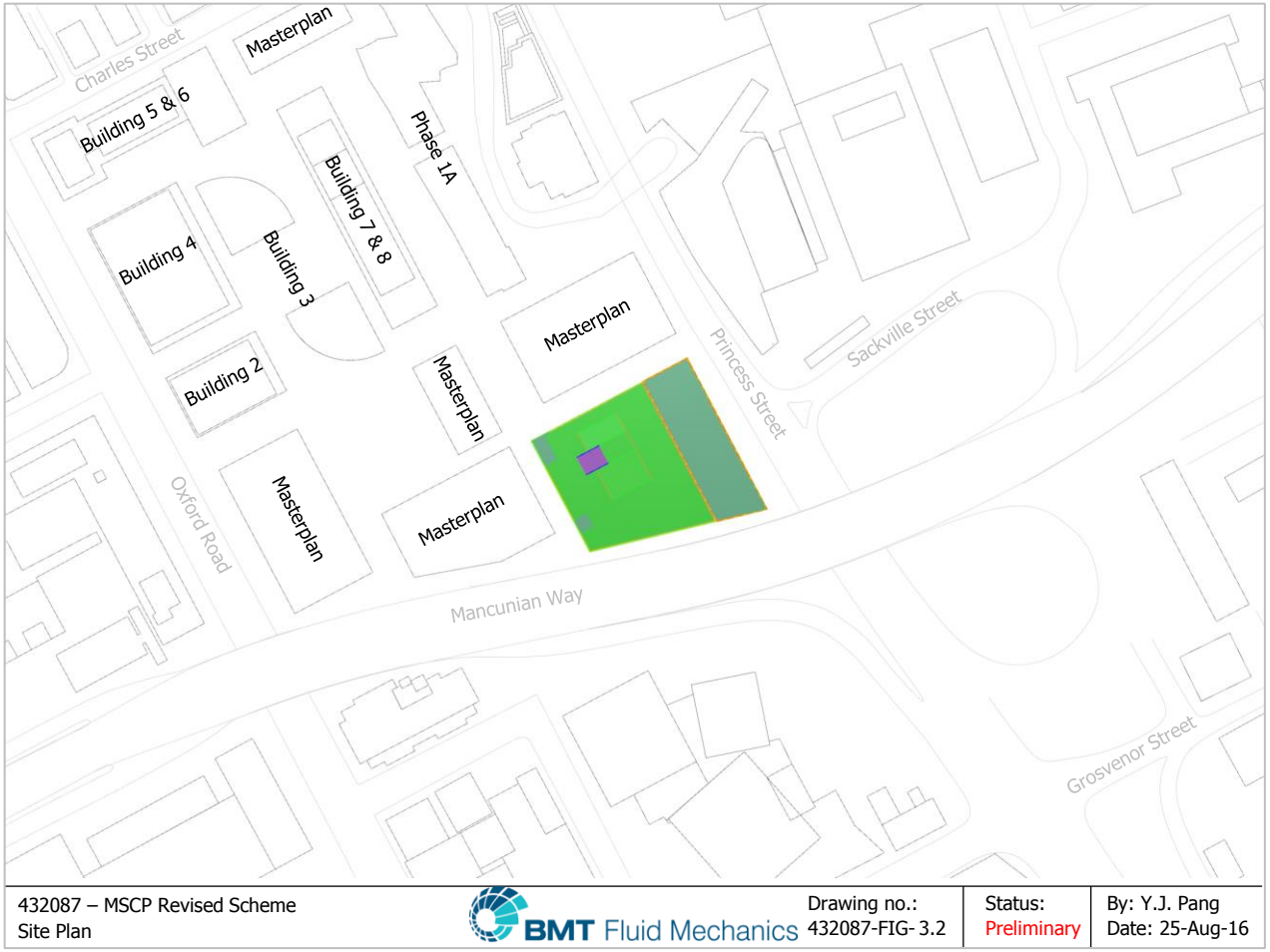


Figure 3.3: Soft landscaping proposal

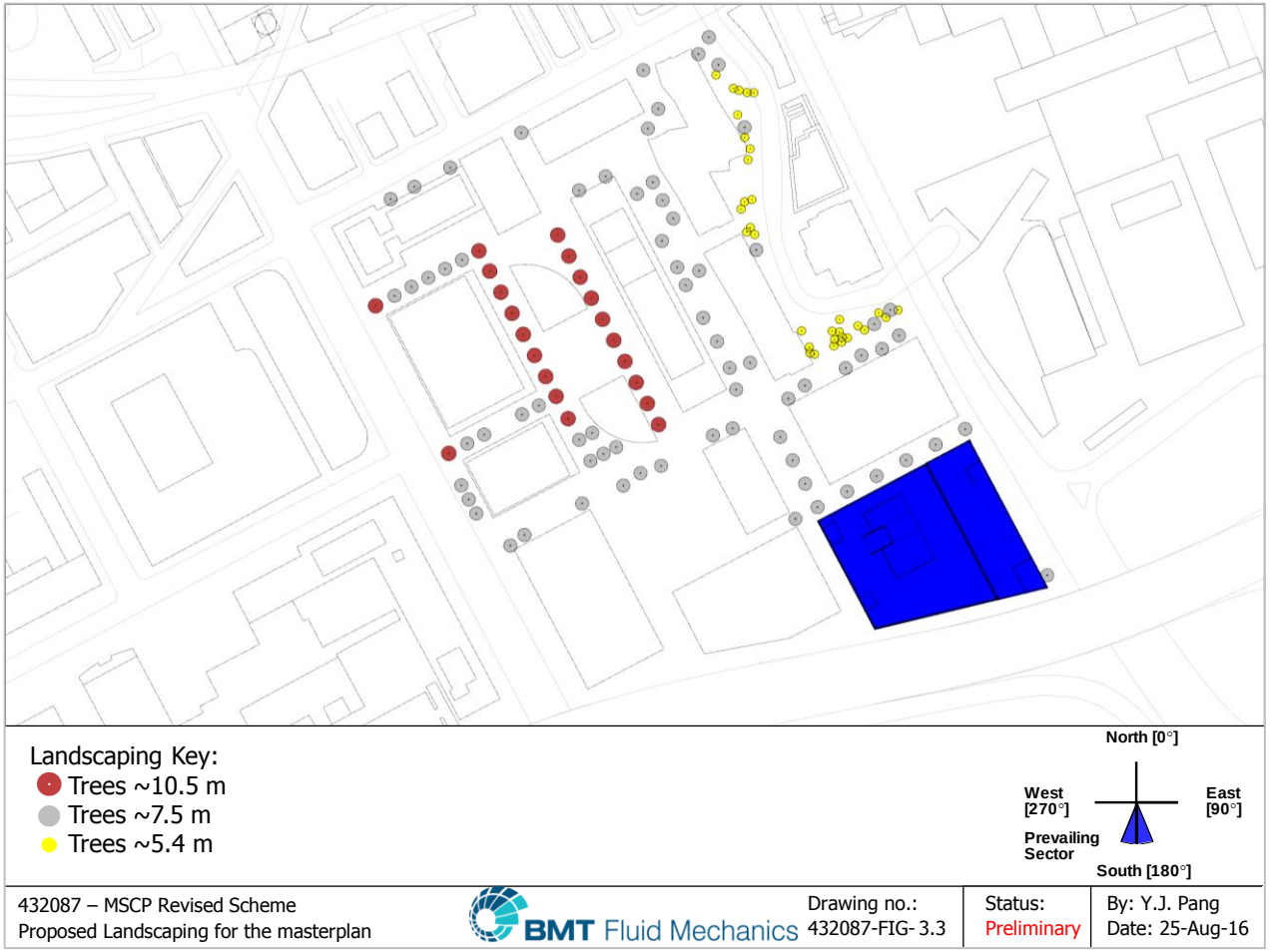


Figure 6.1a: Ground wind microclimate summary, proposed development in the context of existing surrounding conditions with landscaping

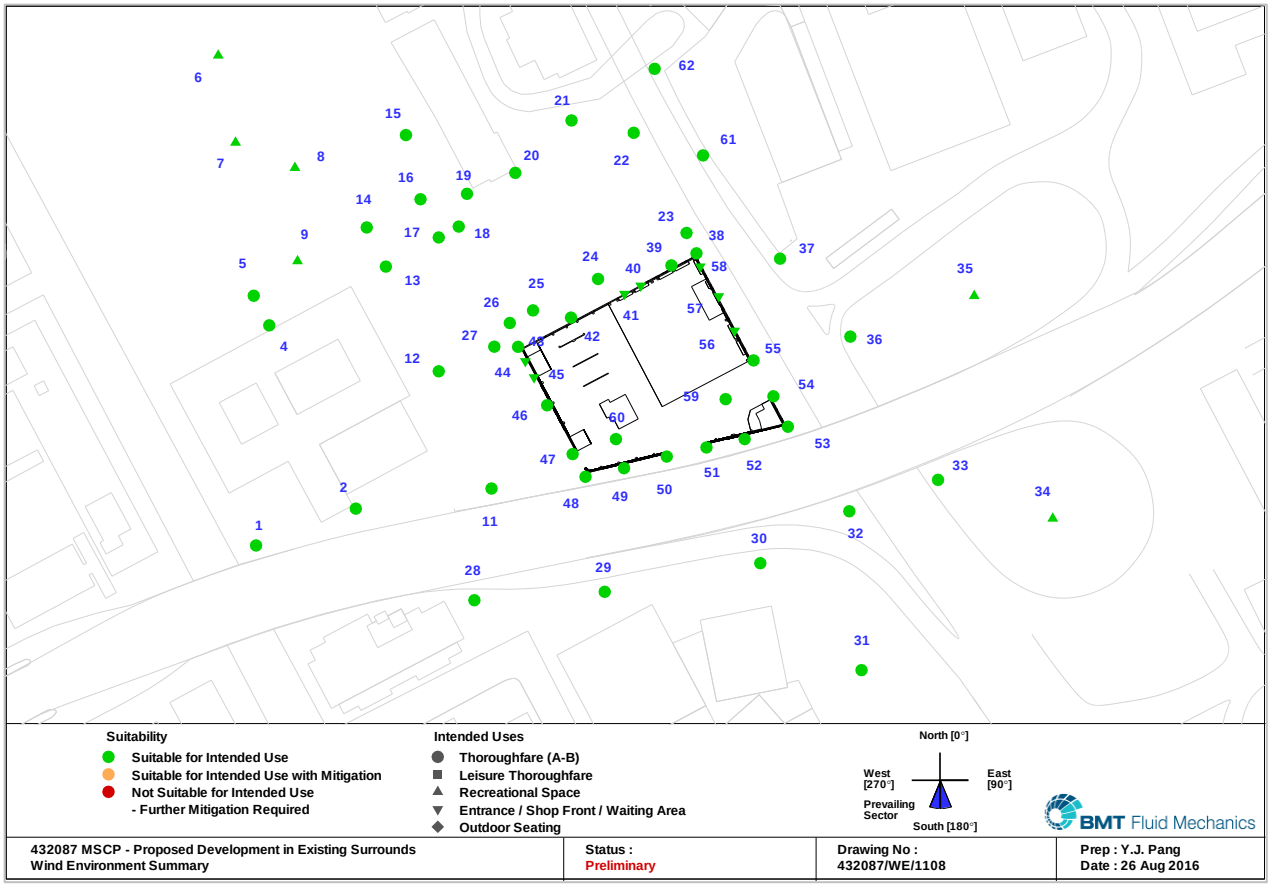


Figure 6.1b: Podium wind microclimate summary, proposed development in the context of existing surrounding conditions with landscaping

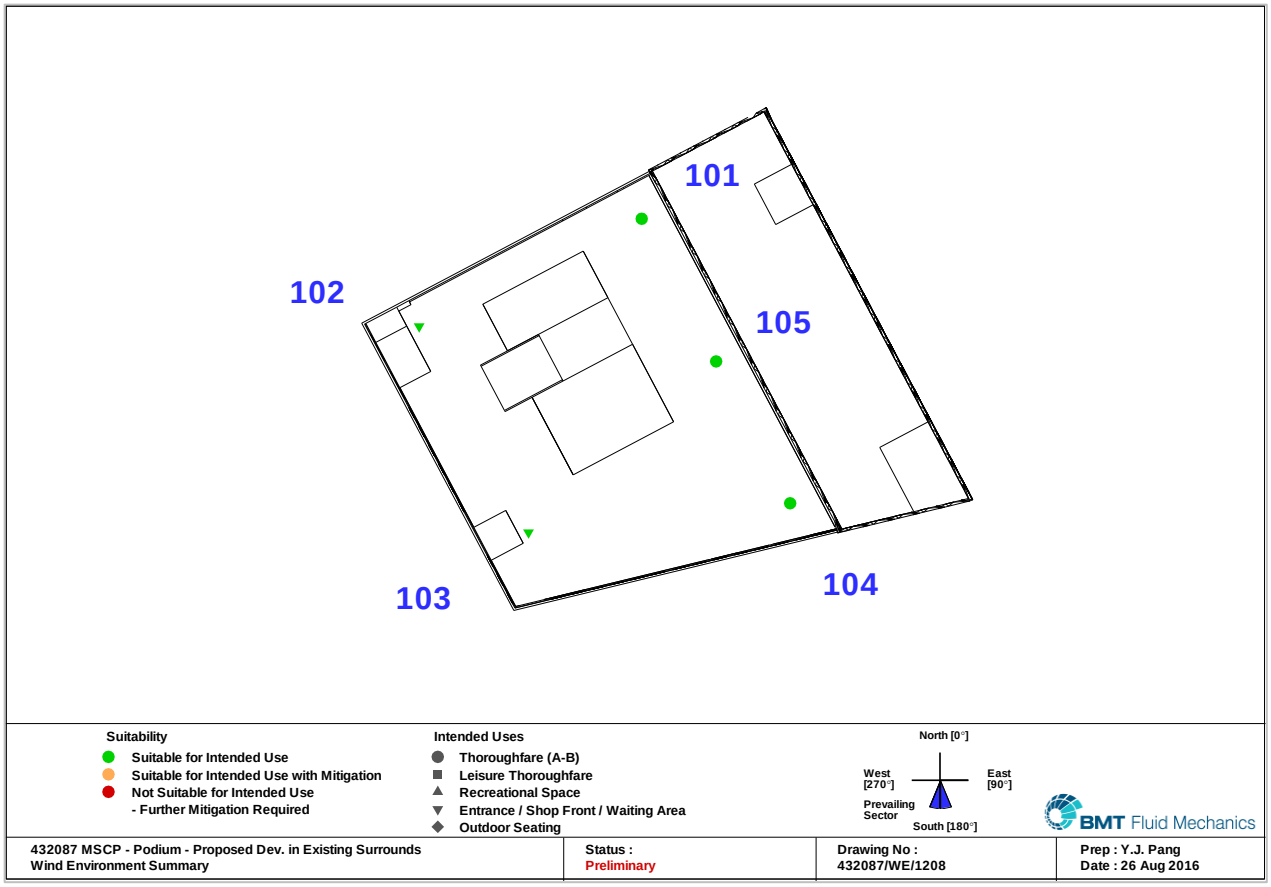


Figure 6.2a: Ground wind microclimate summary, proposed development in the context of wider Phase 1B Proposals and other consented future surrounding conditions with landscaping

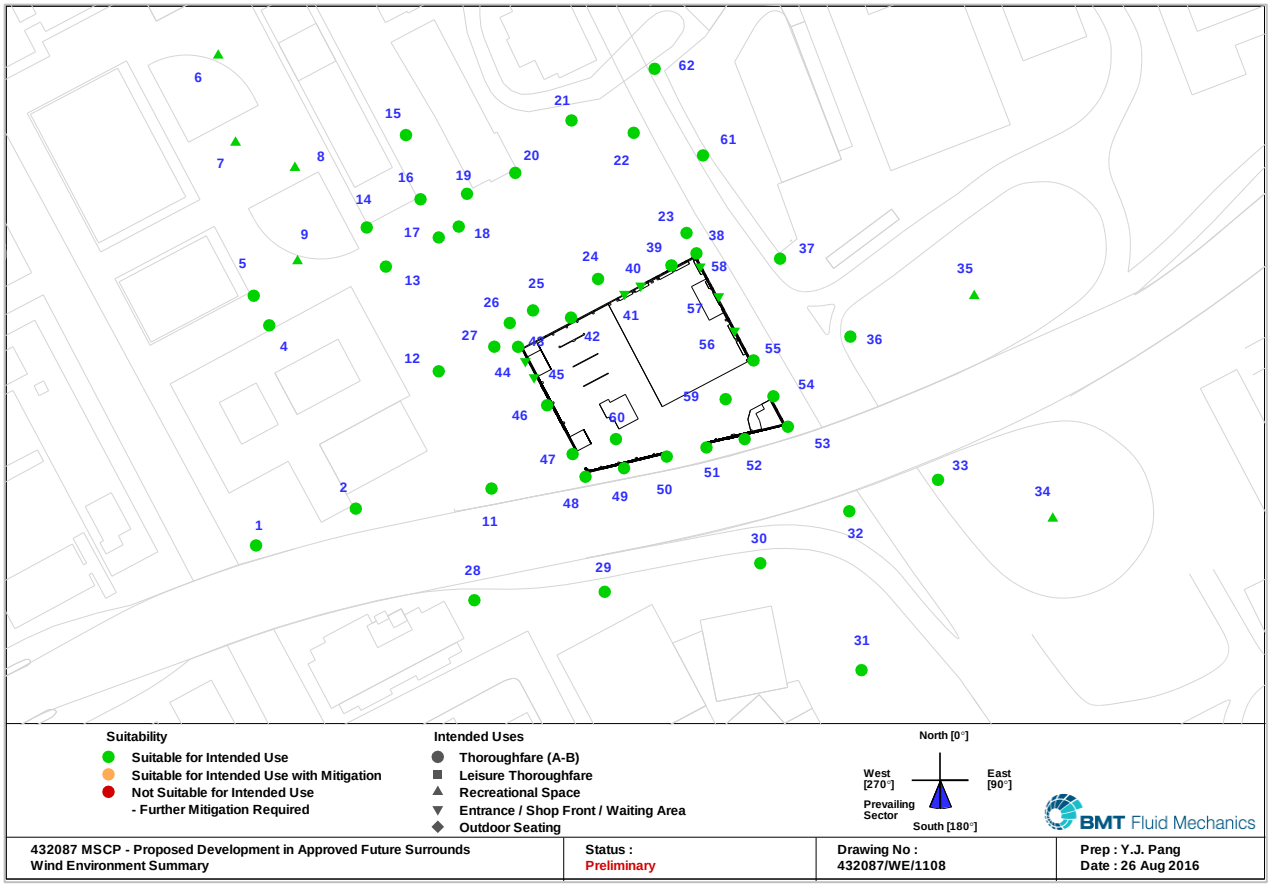


Figure 6.2b: Podium wind microclimate summary, proposed development in the context of wider Phase 1B Proposals and other consented future surrounding conditions with landscaping

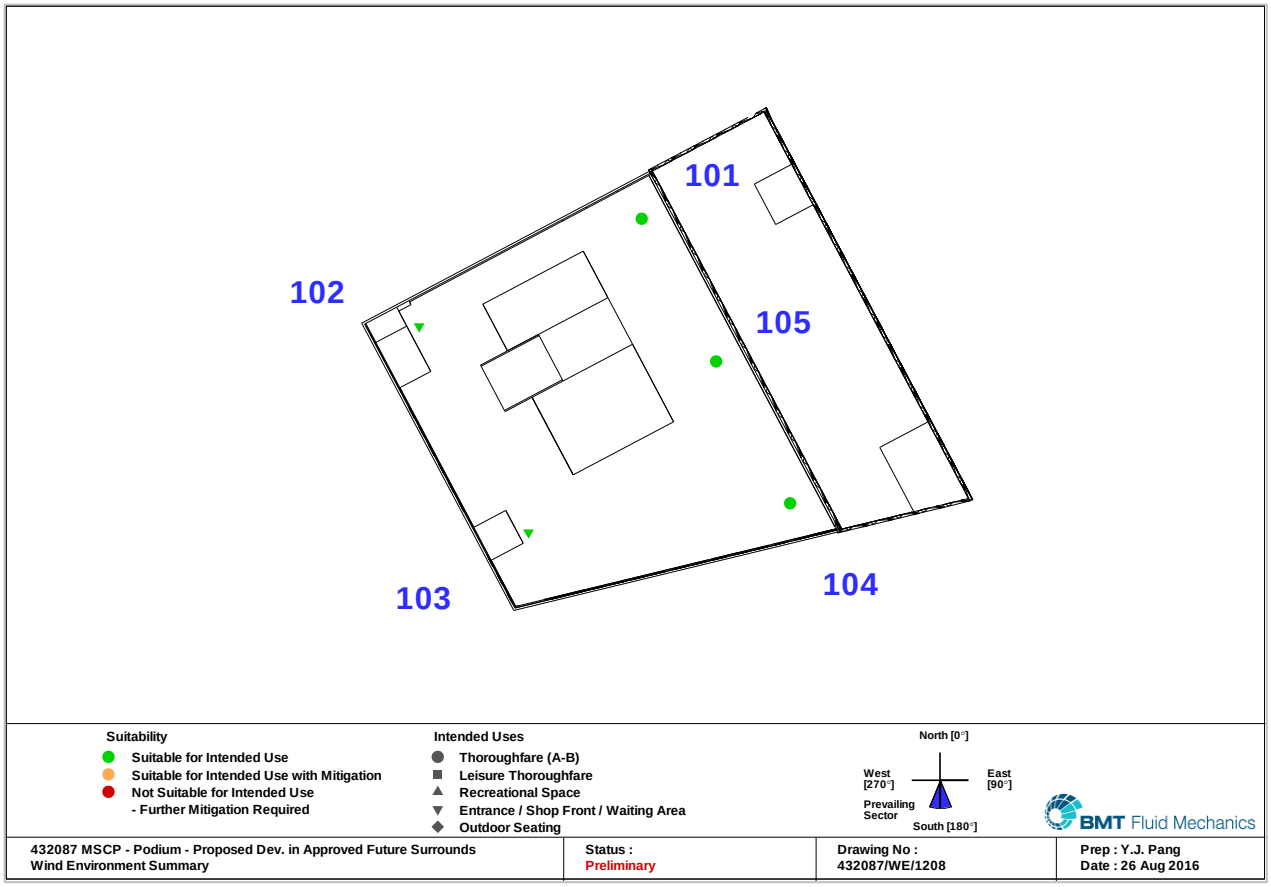


Figure 6.3a: Ground wind microclimate summary, proposed development in the context of the complete masterplan and the consented future surrounding conditions with landscaping

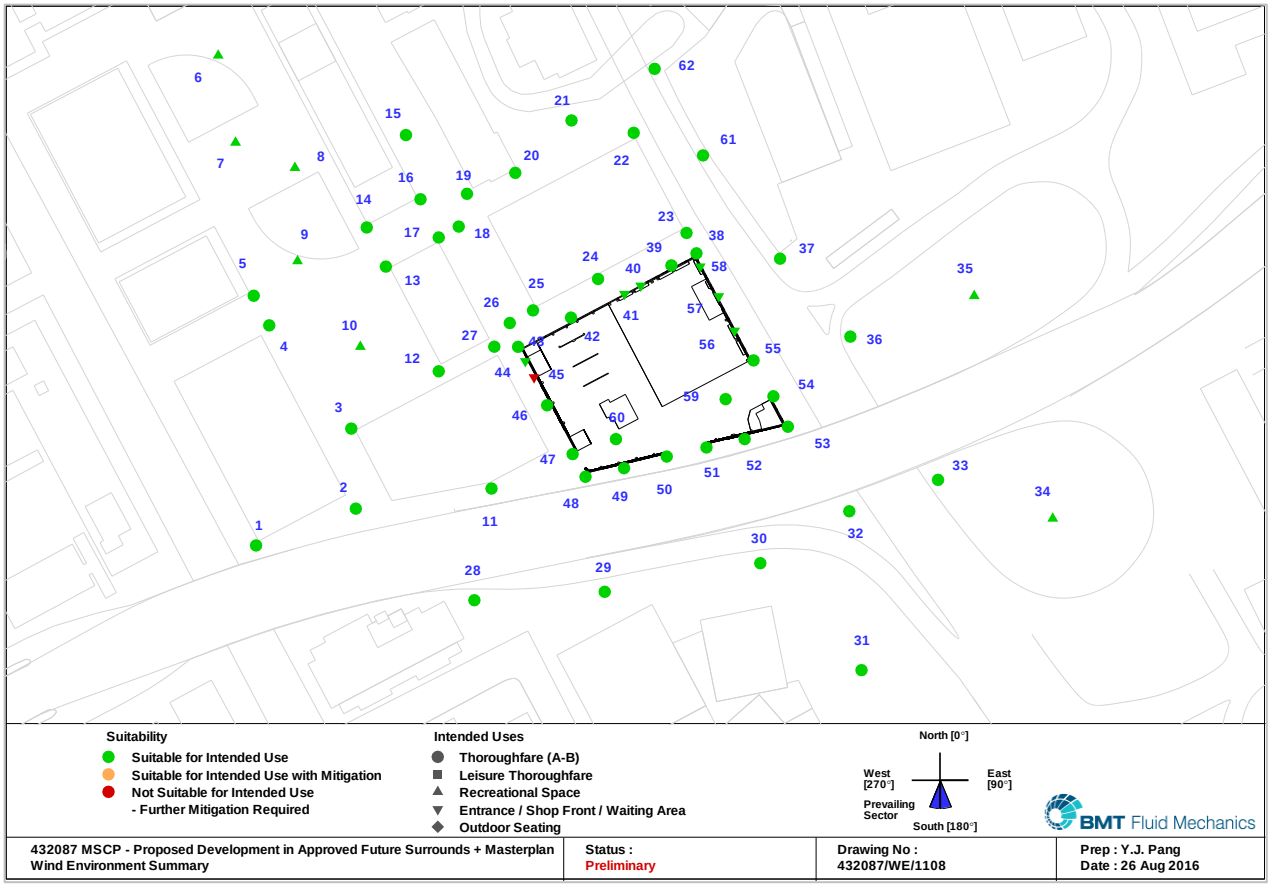
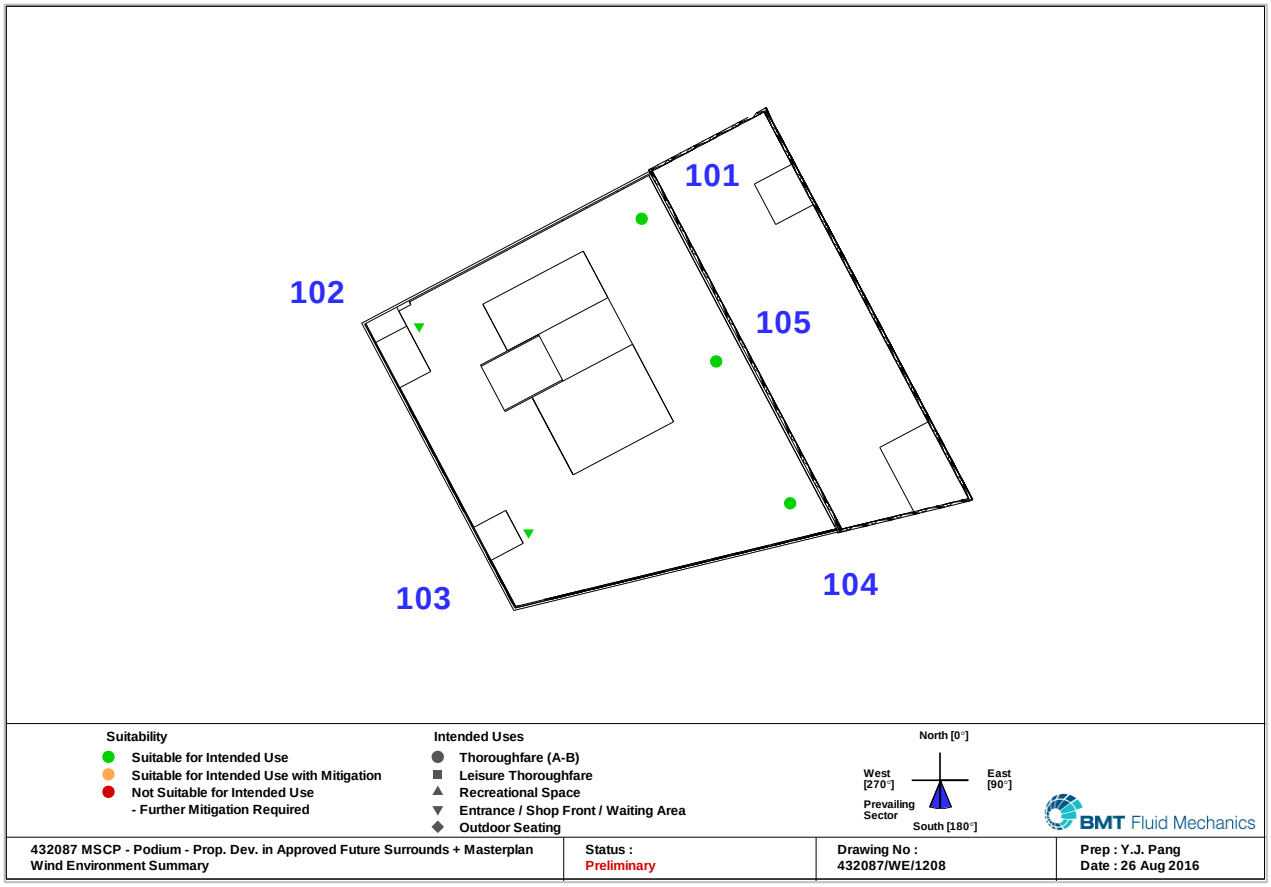


Figure 6.3b: Podium wind microclimate summary, proposed development in the context of the complete masterplan and the consented future surrounding conditions with landscaping



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.

A.1.1. Terrain Roughness Changes for ESDU Wind Analysis

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

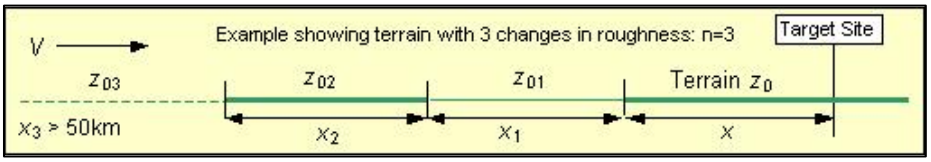
Table A.1: Terrain roughness changes from the site

Wind Dir	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		
330°	0.5	1,800	0.3	6,100	0.03				

Where
x_0 = upwind fetch
z_0 = roughness length

z0

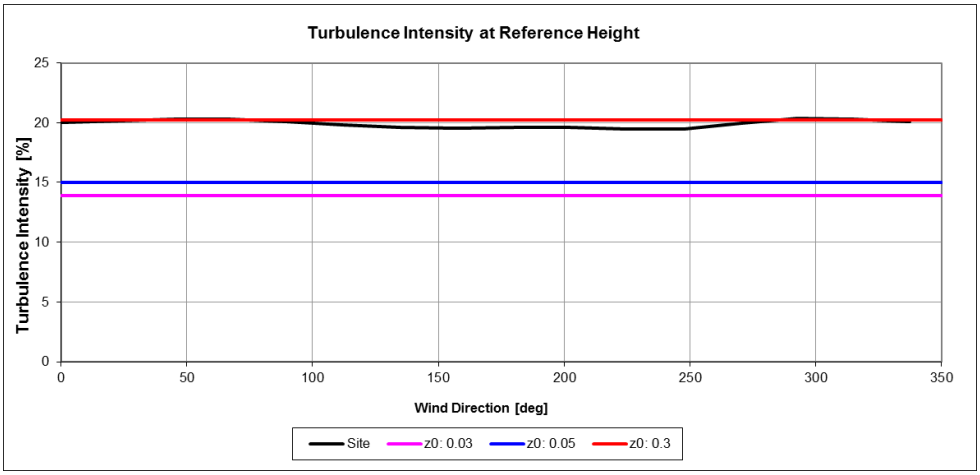
water	=	sea, lakes, estuaries
0.03	=	open country
0.1	=	sparse suburban
0.3	=	suburban
0.5	=	urban
0.7 / 1.0	=	city centre



A.2. Wind Properties at the Site

Figure A.1 shows the variation of longitudinal turbulence intensity with wind direction at a reference height of 60m.

Figure A.1: Variation of turbulence intensity with wind direction at 60m height, including reference turbulence levels



Due to the similarity of wind properties with wind direction, one target profile has been selected for the boundary layer simulation.

The target profile selected for the boundary layer simulation is 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 60m) 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 a reference height of 60m

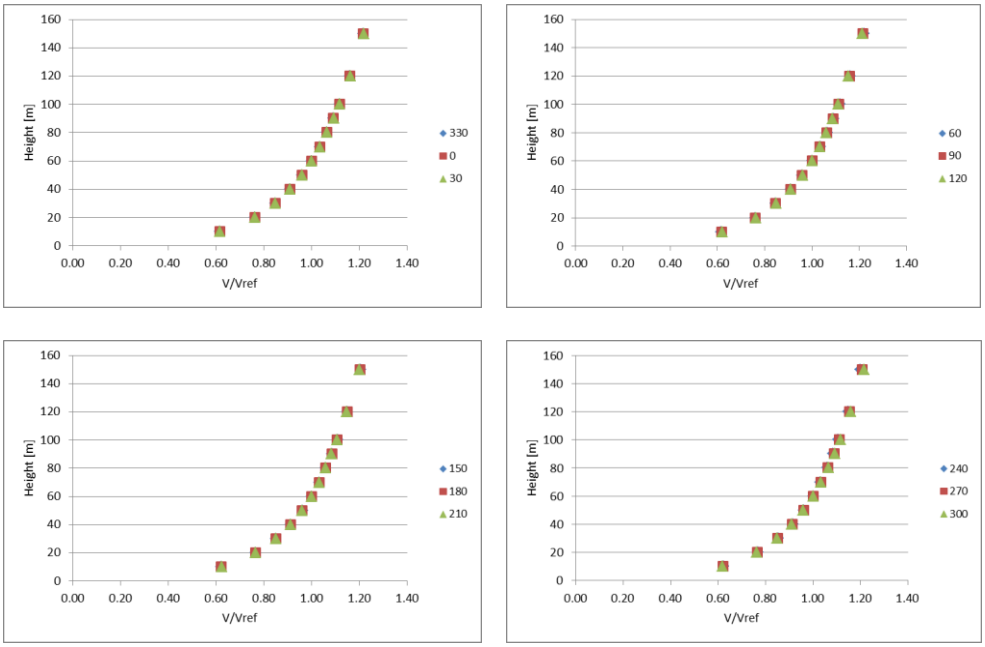


Figure A.3: Variation of longitudinal turbulence intensity with wind direction a reference height of 60m

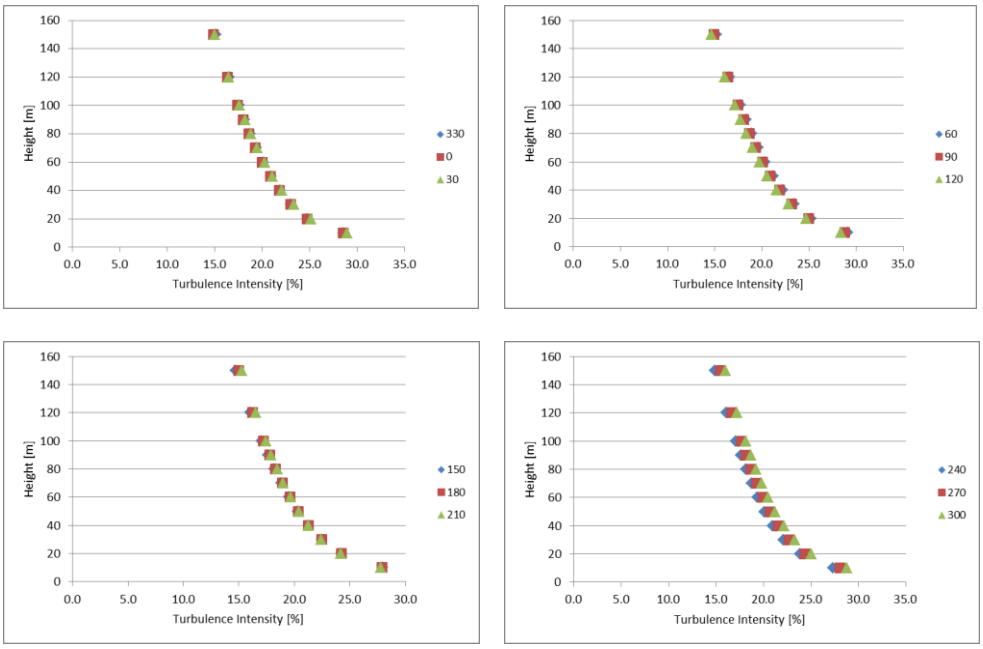
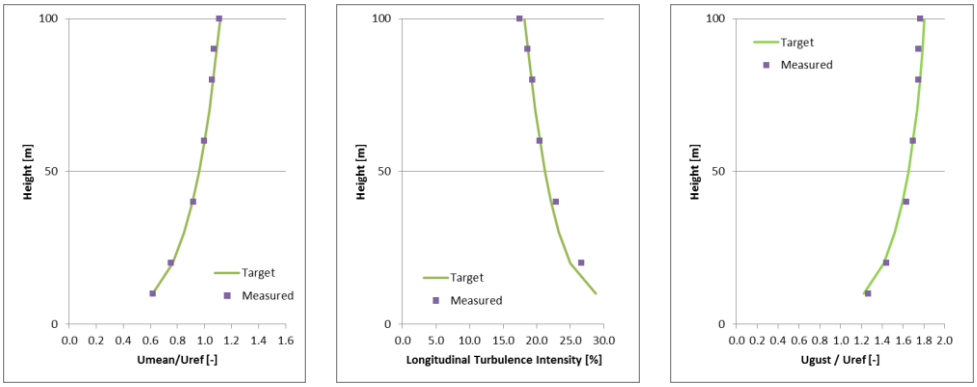


Figure A.4 presents the variation of mean wind speed, longitudinal turbulence intensity and gust wind speed used in the tests. The wind speed profiles are normalised by the mean wind speed at a reference height of 60m.

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 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 a reference height of 60m, at the proposed site, are given in Figures A.5a to A.5e, respectively.

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

Figure A.5a: Directional Windspeed Probability Distribution at Site: Annual (at 60m height)

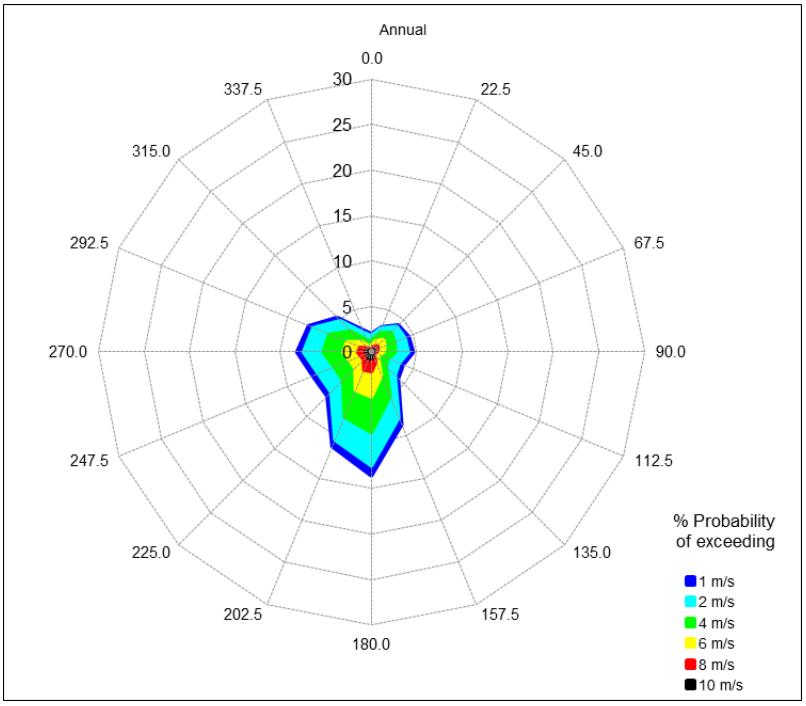


Figure A.5b: Directional Windspeed Probability Distribution at Site: Spring (at 60m height)

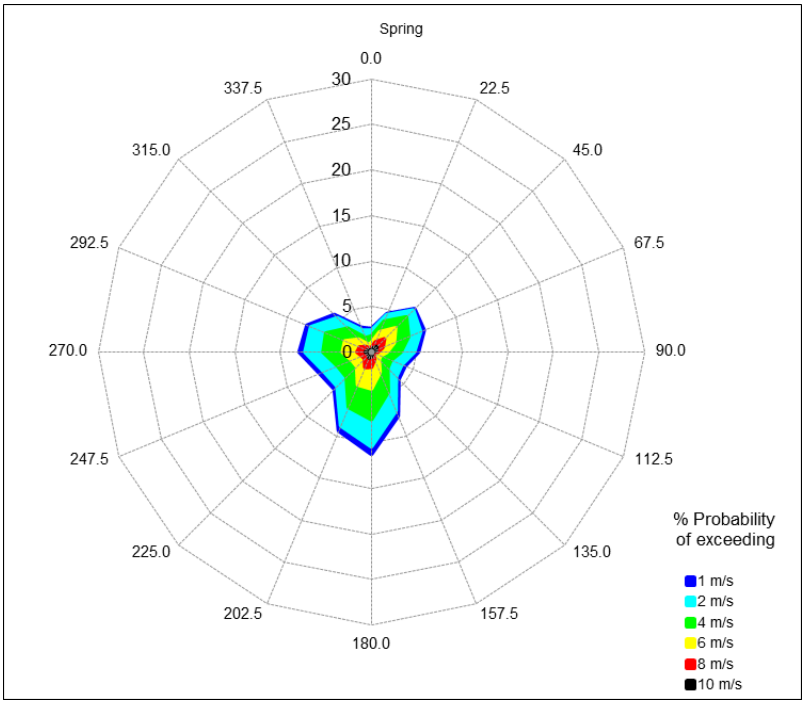


Figure A.5c: Directional Windspeed Probability Distribution at Site: Summer (at 60m height)

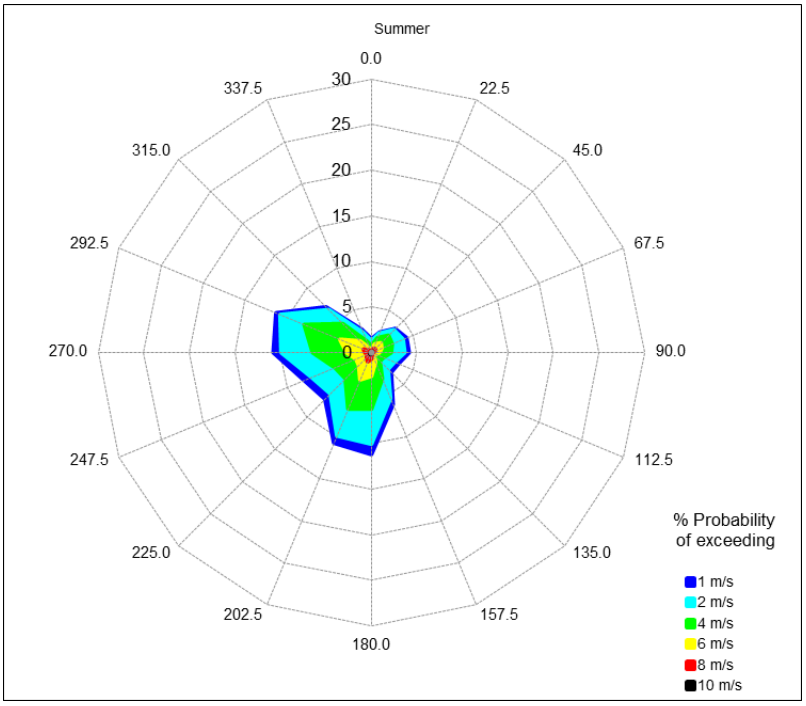


Figure A.5d: Directional Windspeed Probability Distribution at Site: Autumn (at 60m height)

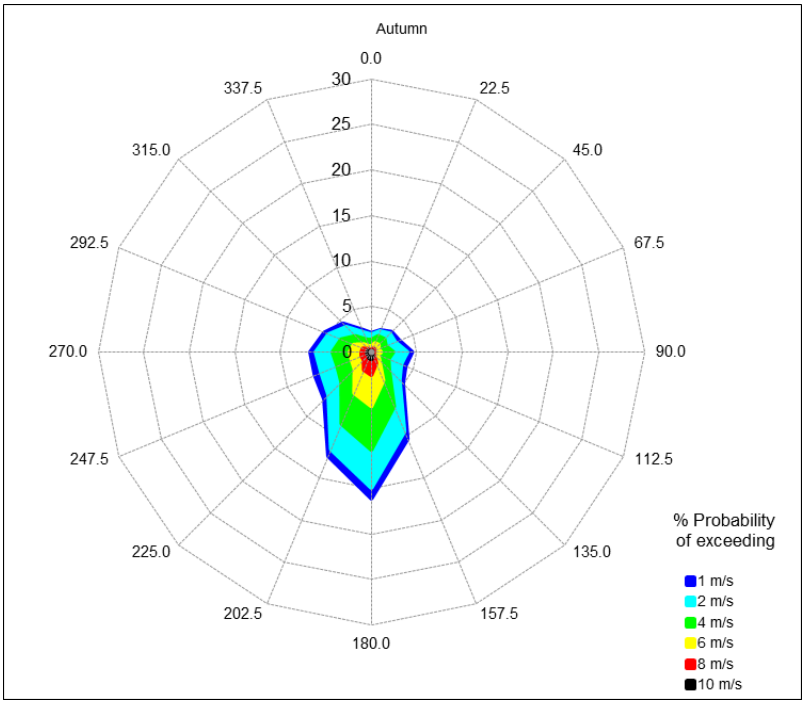


Figure A.5e: Directional Windspeed Probability Distribution at Site: Winter (at 60m height)

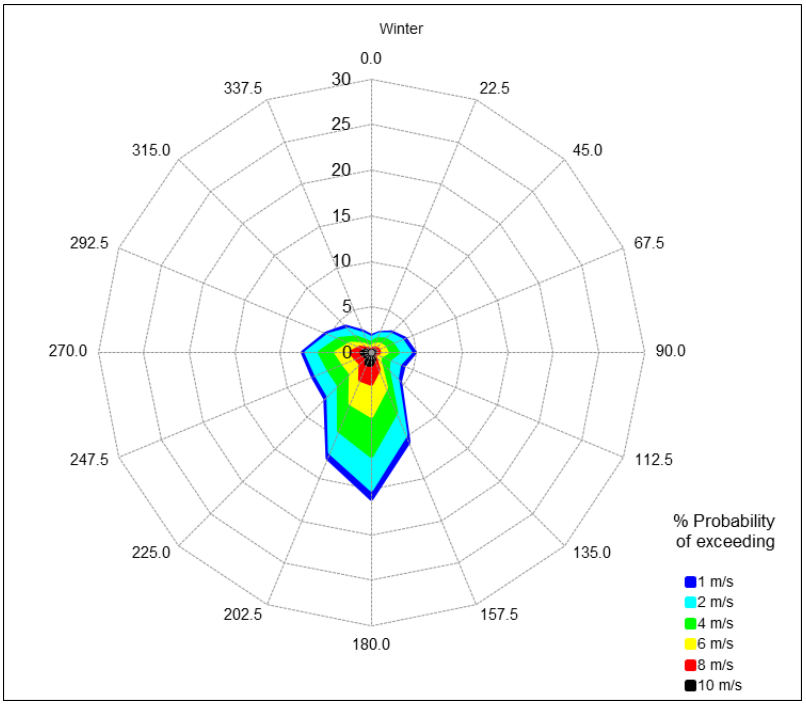


Table A.2: Wind frequency statistics: corrected Manchester Airport weather centre data transformed to z0=0.03m Weibull Coefficients

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	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

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

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

APPENDIX B. WIND TUNNEL & MODEL DETAILS

B.1. Wind Tunnel Specifications

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

A turbulent boundary layer, representative of the conditions at the site, is set up using an arrangement of roughness elements distributed over the floor of the wind tunnel and a 2-dimensional barrier with square posts or spires at the entrance to the test section.

B.2. Model

B.2.1. Information For Model Construction

The model of the proposed development was constructed based on drawing information supplied by Feilden Clegg Bradley Studios, the architects for the scheme, as follows:

Drawing	Date
1829-FCB-A-ZZ-ZZ-M3-MSCP+HOTEL.dwg	08/08/2016

The model of the existing surrounding area was based on OS superplan data supplemented by a site survey conducted by BMT using publically 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 450m from the centre of the site. The surrounding buildings and topography were represented to a sufficient level of detail to reproduce the wind flows at the location of the proposed development.

The model was mounted on a 3.0m diameter baseboard and installed on the 4.4m diameter turntable of BMT's Boundary Layer Wind Tunnel.

B.2.4. Model Photos

Images of the wind tunnel model are presented as follows:

- Figure B.1 - close-up of proposed development
- Figure B.2 - close-up of proposed development
- Figure B.3 - proximity model: existing surrounding conditions
- Figure B.4 - proximity model: consented future surrounding conditions
- Figure B.5 - proximity model: consented future with masterplan

Figure B.1: Close-up of the proposed development

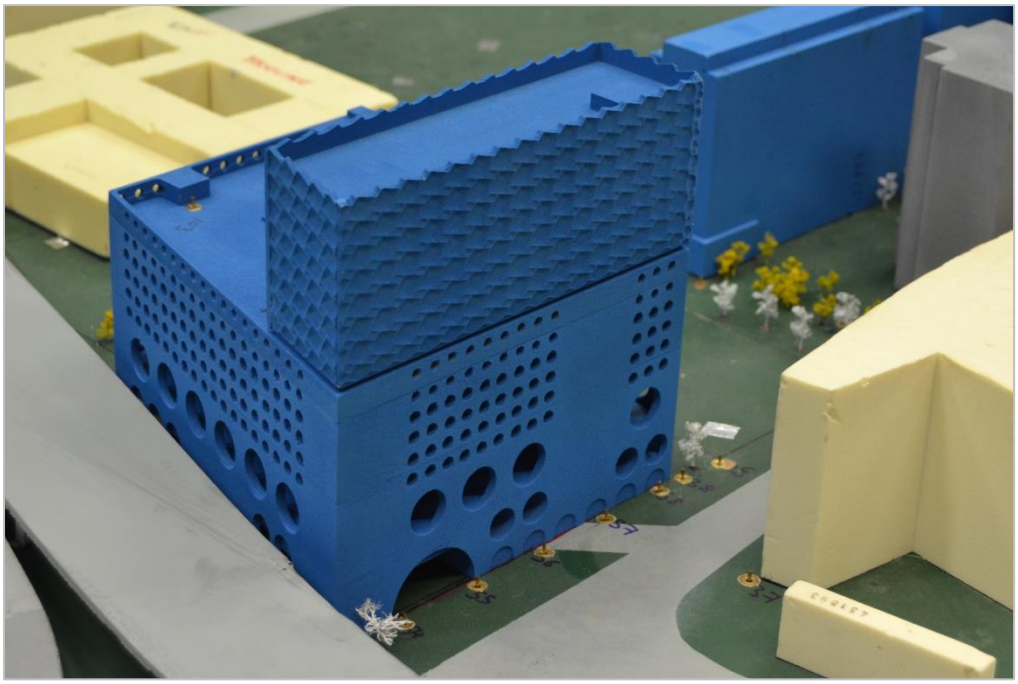


Figure B.2: Close-up of the proposed development

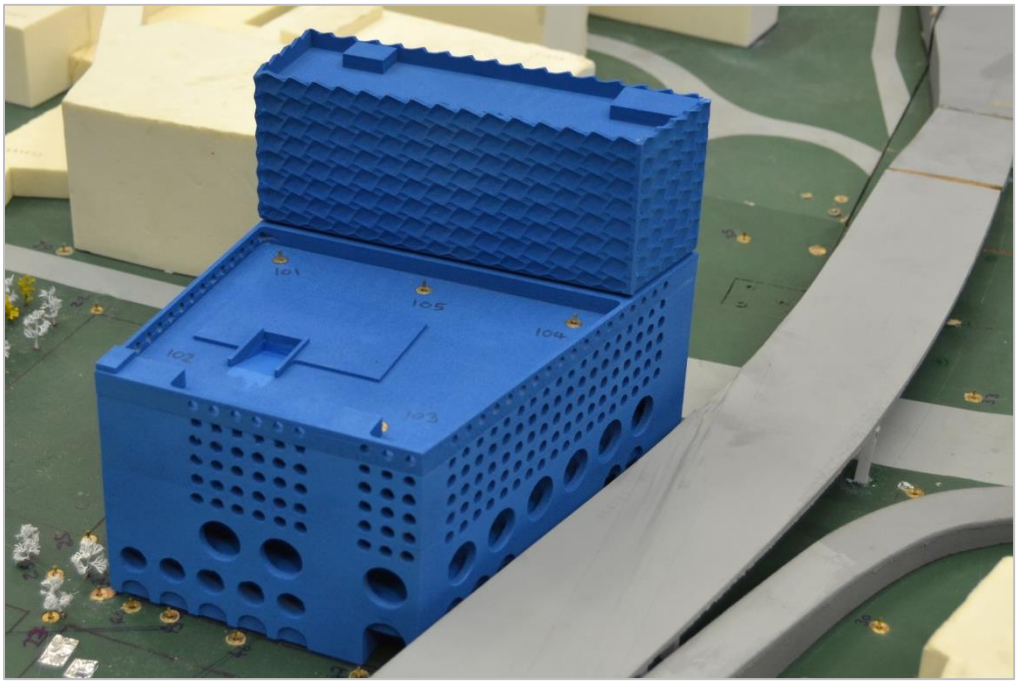


Figure B.3: Proximity model: existing surrounding conditions

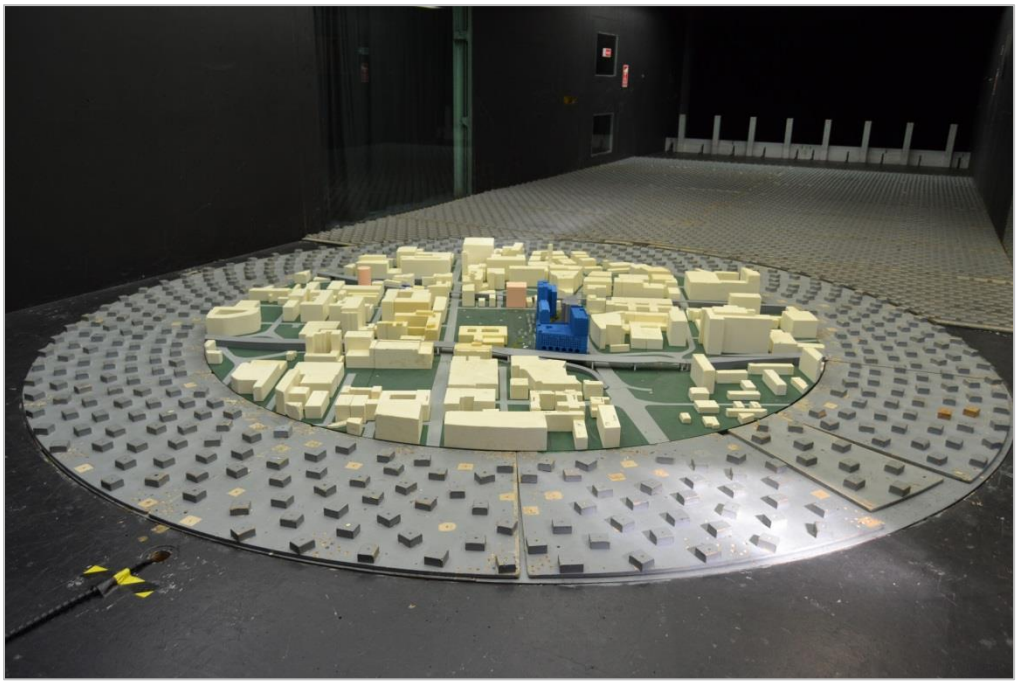


Figure B.4: Proximity model: Phase 1B and consented future surrounding conditions

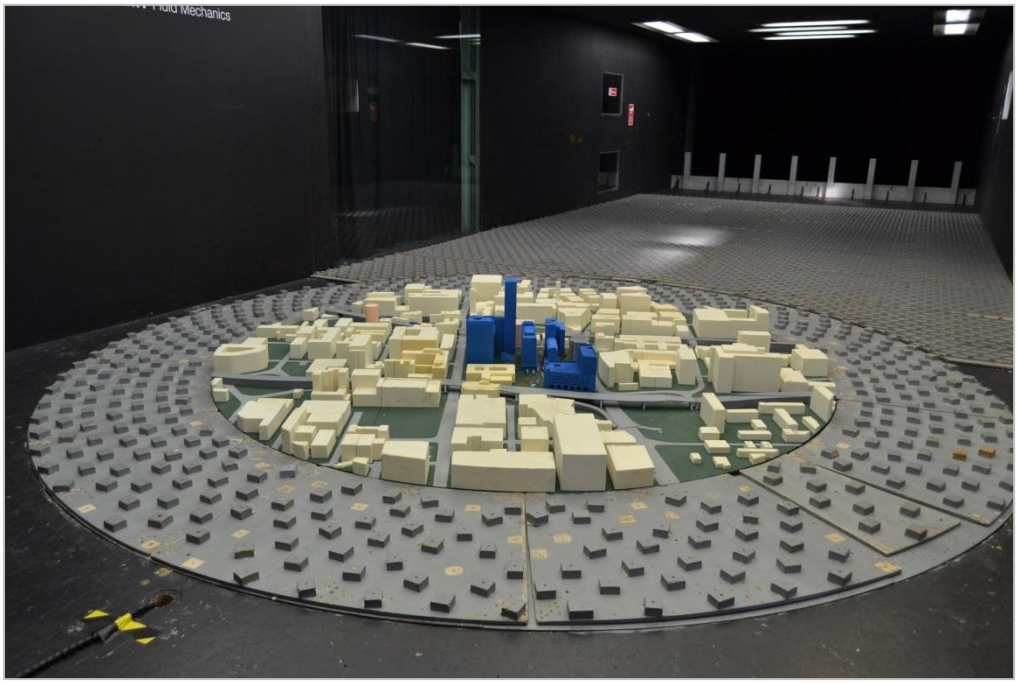


Figure B.5: Proximity model: Phase 1B and consented future surrounding conditions, with masterplan



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 up to 67 locations at a height corresponding to 1.5m at full scale. Measurements were taken for a full range of wind directions in increments of 22.5°.

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

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

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

For each location the results were combined with local wind statistics to assess the wind 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. BMT 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 / Activity		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 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 general public	Less able and cyclists find conditions physically difficult
> 20 m/s	S1	Unsuitable for able-bodied	Able-bodied persons find conditions difficult. Physically impossible to remain standing during gusts.

C.3. Pedestrian Activities

Tables C.3a, C.3b and C.3c present the potential pedestrian uses assumed for each of the corresponding measurement locations presented in Figures 6.1a to 6.3b for the proposed development within the context of

- existing surrounds
- consented future surrounds
- consented future surrounds and complete masterplan

Table C.3a: Pedestrian uses – proposed development, existing surrounds

Location	Intended Use	Location	Intended Use
1	Thoroughfare (A-to-B)	36	Thoroughfare (A-to-B)
2	Thoroughfare (A-to-B)	37	Thoroughfare (A-to-B)
4	Thoroughfare (A-to-B)	38	Thoroughfare (A-to-B)
5	Thoroughfare (A-to-B)	39	Thoroughfare (A-to-B)
6	Recreational Space	40	Entrance / Shop Front / Waiting Area
7	Recreational Space	41	Entrance / Shop Front / Waiting Area
8	Recreational Space	42	Thoroughfare (A-to-B)
9	Recreational Space	43	Thoroughfare (A-to-B)
11	Thoroughfare (A-to-B)	44	Entrance / Shop Front / Waiting Area
12	Thoroughfare (A-to-B)	45	Entrance / Shop Front / Waiting Area
13	Thoroughfare (A-to-B)	46	Thoroughfare (A-to-B)
14	Thoroughfare (A-to-B)	47	Thoroughfare (A-to-B)
15	Thoroughfare (A-to-B)	48	Thoroughfare (A-to-B)
16	Thoroughfare (A-to-B)	49	Thoroughfare (A-to-B)
17	Thoroughfare (A-to-B)	50	Thoroughfare (A-to-B)
18	Thoroughfare (A-to-B)	51	Thoroughfare (A-to-B)
19	Thoroughfare (A-to-B)	52	Thoroughfare (A-to-B)
20	Thoroughfare (A-to-B)	53	Thoroughfare (A-to-B)
21	Thoroughfare (A-to-B)	54	Thoroughfare (A-to-B)
22	Thoroughfare (A-to-B)	55	Thoroughfare (A-to-B)
23	Thoroughfare (A-to-B)	56	Entrance / Shop Front / Waiting Area
24	Thoroughfare (A-to-B)	57	Entrance / Shop Front / Waiting Area
25	Thoroughfare (A-to-B)	58	Entrance / Shop Front / Waiting Area
26	Thoroughfare (A-to-B)	59	Thoroughfare (A-to-B)
27	Thoroughfare (A-to-B)	60	Thoroughfare (A-to-B)
28	Thoroughfare (A-to-B)	61	Thoroughfare (A-to-B)
29	Thoroughfare (A-to-B)	62	Thoroughfare (A-to-B)
30	Thoroughfare (A-to-B)	101	Thoroughfare (A-to-B)
31	Thoroughfare (A-to-B)	102	Entrance / Shop Front / Waiting Area
32	Thoroughfare (A-to-B)	103	Entrance / Shop Front / Waiting Area
33	Thoroughfare (A-to-B)	104	Thoroughfare (A-to-B)
34	Recreational Space	105	Thoroughfare (A-to-B)
35	Recreational Space		

Table C.3b: Pedestrian Uses – proposed development, consented future surrounds

Location	Intended Use	Location	Intended Use
1	Thoroughfare (A-to-B)	36	Thoroughfare (A-to-B)
2	Thoroughfare (A-to-B)	37	Thoroughfare (A-to-B)
4	Thoroughfare (A-to-B)	38	Thoroughfare (A-to-B)
5	Thoroughfare (A-to-B)	39	Thoroughfare (A-to-B)
6	Recreational Space	40	Entrance / Shop Front / Waiting Area
7	Recreational Space	41	Entrance / Shop Front / Waiting Area
8	Recreational Space	42	Thoroughfare (A-to-B)
9	Recreational Space	43	Thoroughfare (A-to-B)
11	Thoroughfare (A-to-B)	44	Entrance / Shop Front / Waiting Area
12	Thoroughfare (A-to-B)	45	Entrance / Shop Front / Waiting Area
13	Thoroughfare (A-to-B)	46	Thoroughfare (A-to-B)
14	Thoroughfare (A-to-B)	47	Thoroughfare (A-to-B)
15	Thoroughfare (A-to-B)	48	Thoroughfare (A-to-B)
16	Thoroughfare (A-to-B)	49	Thoroughfare (A-to-B)
17	Thoroughfare (A-to-B)	50	Thoroughfare (A-to-B)
18	Thoroughfare (A-to-B)	51	Thoroughfare (A-to-B)
19	Thoroughfare (A-to-B)	52	Thoroughfare (A-to-B)
20	Thoroughfare (A-to-B)	53	Thoroughfare (A-to-B)
21	Thoroughfare (A-to-B)	54	Thoroughfare (A-to-B)
22	Thoroughfare (A-to-B)	55	Thoroughfare (A-to-B)
23	Thoroughfare (A-to-B)	56	Entrance / Shop Front / Waiting Area
24	Thoroughfare (A-to-B)	57	Entrance / Shop Front / Waiting Area
25	Thoroughfare (A-to-B)	58	Entrance / Shop Front / Waiting Area
26	Thoroughfare (A-to-B)	59	Thoroughfare (A-to-B)
27	Thoroughfare (A-to-B)	60	Thoroughfare (A-to-B)
28	Thoroughfare (A-to-B)	61	Thoroughfare (A-to-B)
29	Thoroughfare (A-to-B)	62	Thoroughfare (A-to-B)
30	Thoroughfare (A-to-B)	101	Thoroughfare (A-to-B)
31	Thoroughfare (A-to-B)	102	Entrance / Shop Front / Waiting Area
32	Thoroughfare (A-to-B)	103	Entrance / Shop Front / Waiting Area
33	Thoroughfare (A-to-B)	104	Thoroughfare (A-to-B)
34	Recreational Space	105	Thoroughfare (A-to-B)
35	Recreational Space		

Table C.3c: Pedestrian Uses – proposed development, consented future surrounds and complete masterplan

Location	Intended Use	Location	Intended Use
1	Thoroughfare (A-to-B)	35	Recreational Space
2	Thoroughfare (A-to-B)	36	Thoroughfare (A-to-B)
3	Thoroughfare (A-to-B)	37	Thoroughfare (A-to-B)
4	Thoroughfare (A-to-B)	38	Thoroughfare (A-to-B)
5	Thoroughfare (A-to-B)	39	Thoroughfare (A-to-B)
6	Recreational Space	40	Entrance / Shop Front / Waiting Area
7	Recreational Space	41	Entrance / Shop Front / Waiting Area
8	Recreational Space	42	Thoroughfare (A-to-B)
9	Recreational Space	43	Thoroughfare (A-to-B)
10	Recreational Space	44	Entrance / Shop Front / Waiting Area
11	Thoroughfare (A-to-B)	45	Entrance / Shop Front / Waiting Area
12	Thoroughfare (A-to-B)	46	Thoroughfare (A-to-B)
13	Thoroughfare (A-to-B)	47	Thoroughfare (A-to-B)
14	Thoroughfare (A-to-B)	48	Thoroughfare (A-to-B)
15	Thoroughfare (A-to-B)	49	Thoroughfare (A-to-B)
16	Thoroughfare (A-to-B)	50	Thoroughfare (A-to-B)
17	Thoroughfare (A-to-B)	51	Thoroughfare (A-to-B)
18	Thoroughfare (A-to-B)	52	Thoroughfare (A-to-B)
19	Thoroughfare (A-to-B)	53	Thoroughfare (A-to-B)
20	Thoroughfare (A-to-B)	54	Thoroughfare (A-to-B)
21	Thoroughfare (A-to-B)	55	Thoroughfare (A-to-B)
22	Thoroughfare (A-to-B)	56	Entrance / Shop Front / Waiting Area
23	Thoroughfare (A-to-B)	57	Entrance / Shop Front / Waiting Area
24	Thoroughfare (A-to-B)	58	Entrance / Shop Front / Waiting Area
25	Thoroughfare (A-to-B)	59	Thoroughfare (A-to-B)
26	Thoroughfare (A-to-B)	60	Thoroughfare (A-to-B)
27	Thoroughfare (A-to-B)	61	Thoroughfare (A-to-B)
28	Thoroughfare (A-to-B)	62	Thoroughfare (A-to-B)
29	Thoroughfare (A-to-B)	101	Thoroughfare (A-to-B)
30	Thoroughfare (A-to-B)	102	Entrance / Shop Front / Waiting Area
31	Thoroughfare (A-to-B)	103	Entrance / Shop Front / Waiting Area
32	Thoroughfare (A-to-B)	104	Thoroughfare (A-to-B)
33	Thoroughfare (A-to-B)	105	Thoroughfare (A-to-B)
34	Recreational Space		

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:

- Figures D.1a to D.1f present **annual safety** ratings for each configuration, for ground and podium levels
- Figures D.2a to D.2f present **summer season comfort** ratings for each configuration, for ground and podium levels
- Figures D.3a to D.3f present **worst seasonal comfort** ratings for each configuration, for ground and podium levels

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.1a: Ground annual safety ratings, proposed development in the context of existing surrounding conditions with landscaping

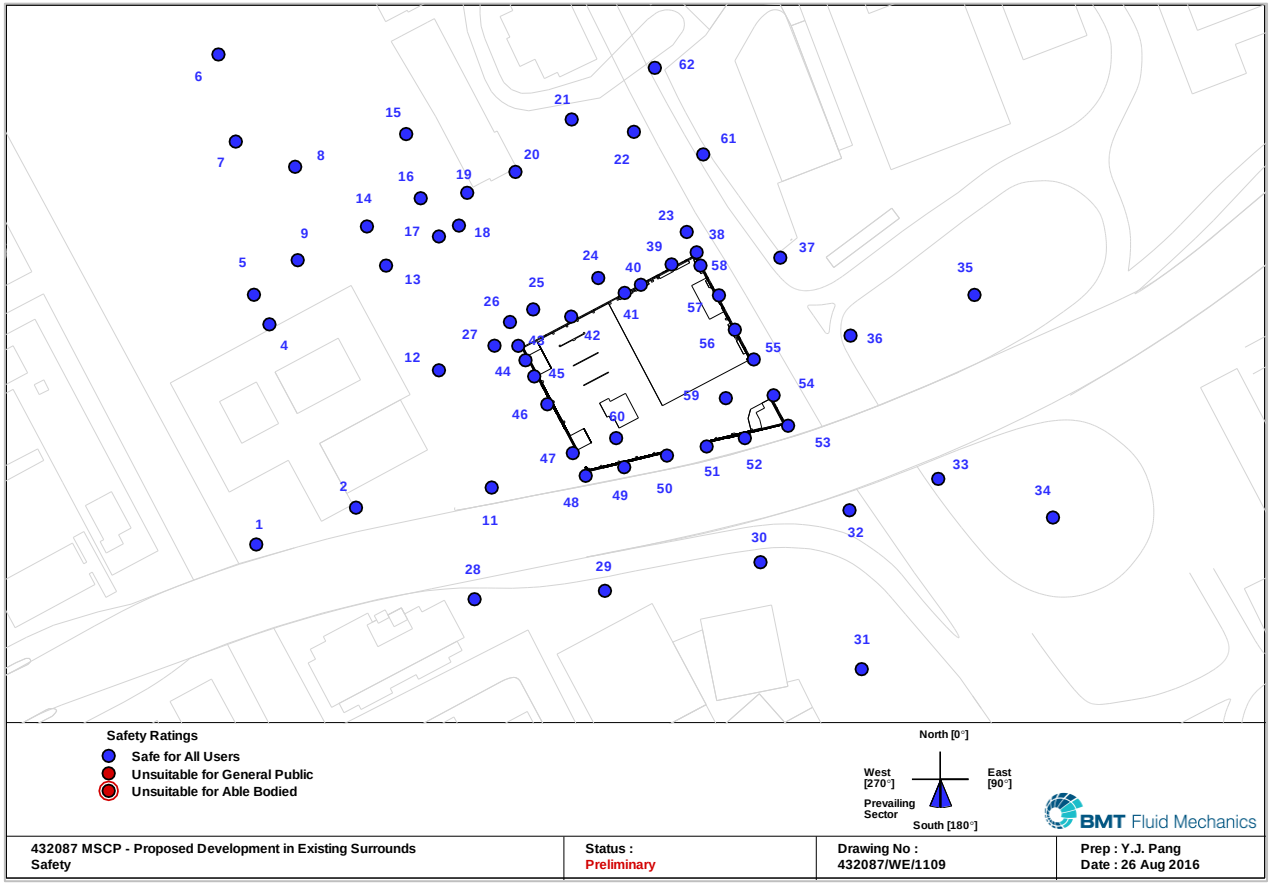


Figure D.1b: Podium annual safety ratings, proposed development in the context of existing surrounding conditions with landscaping

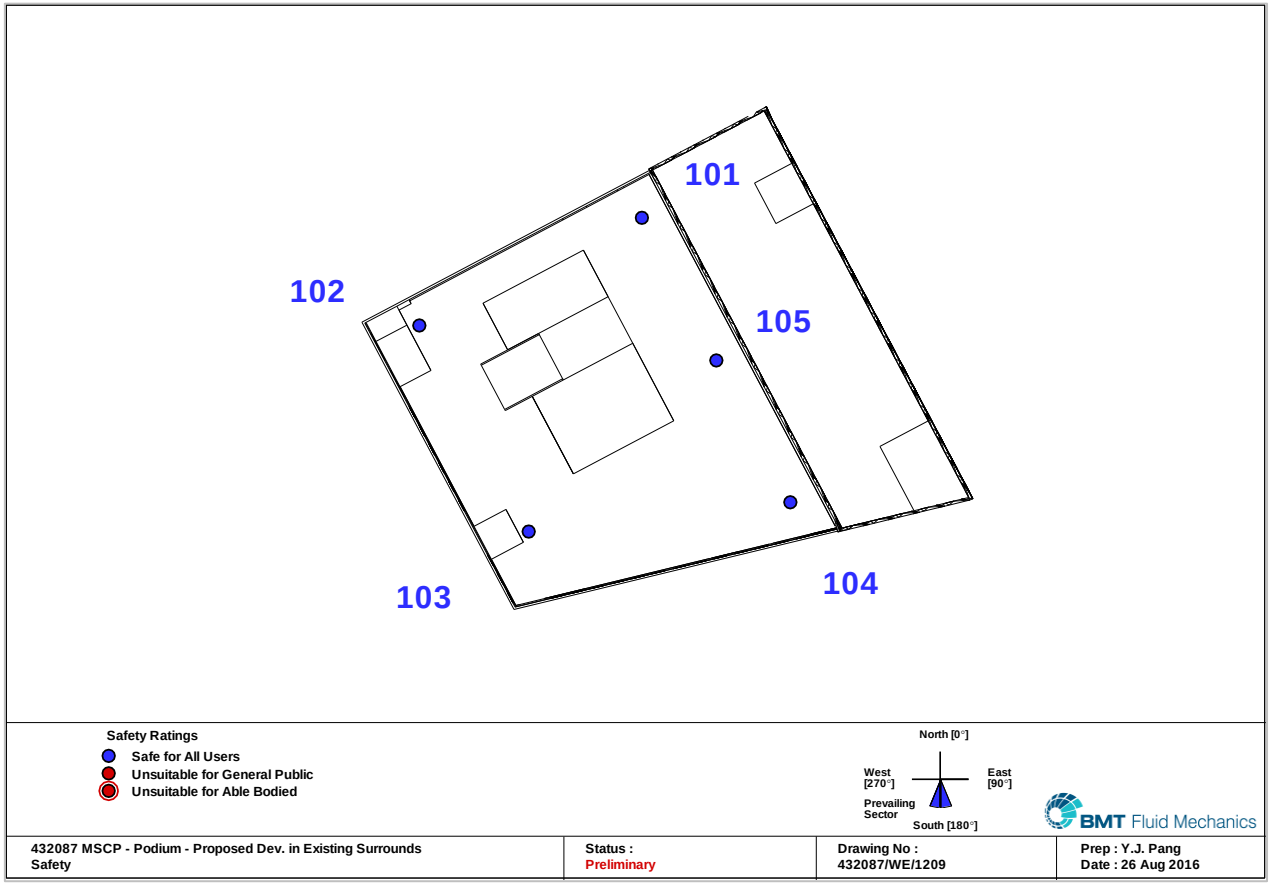


Figure D.1c: Ground annual safety ratings, proposed development in the context of wider Phase 1B Proposals and other consented future surrounding conditions with landscaping

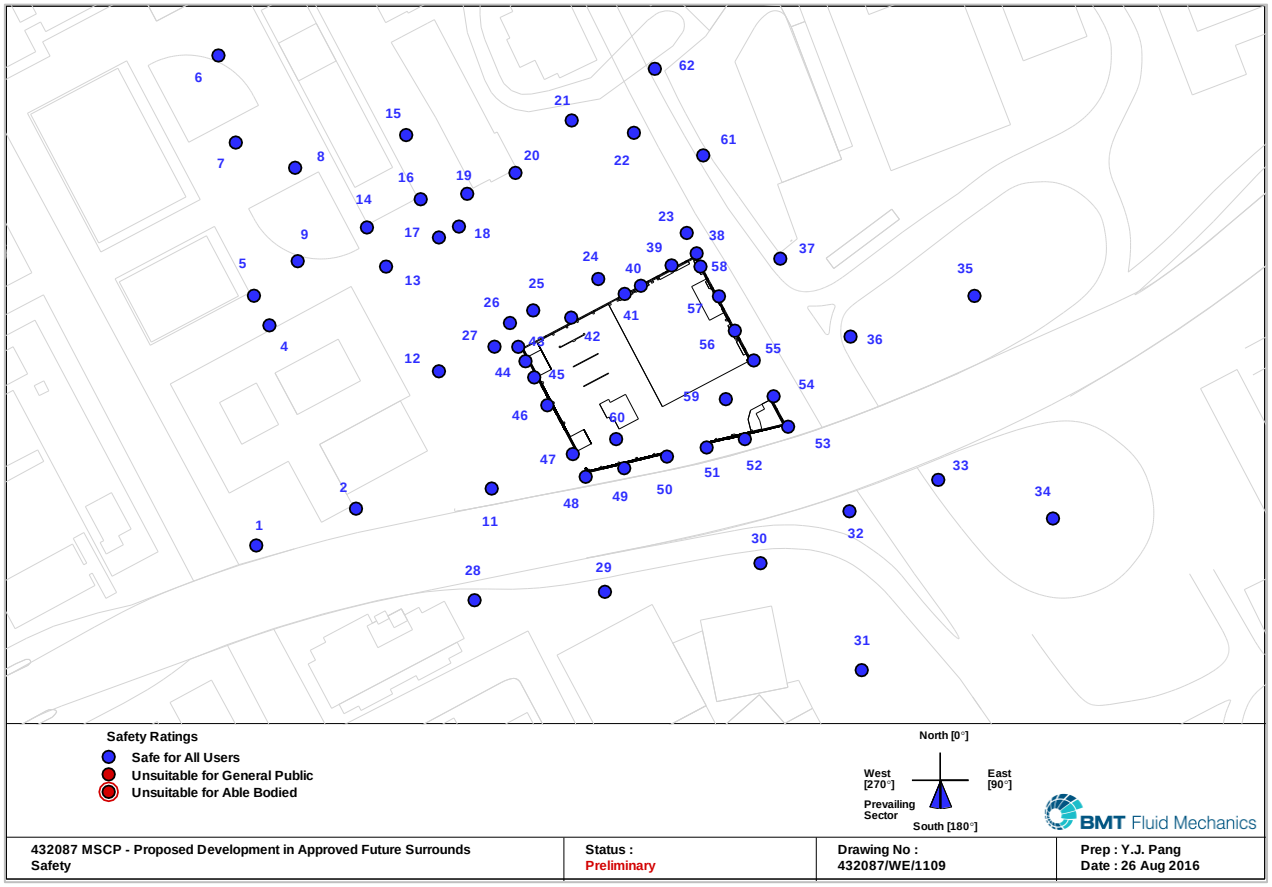


Figure D.1d: Podium annual safety ratings, proposed development in the context of wider Phase 1B Proposals and other consented future surrounding conditions with landscaping

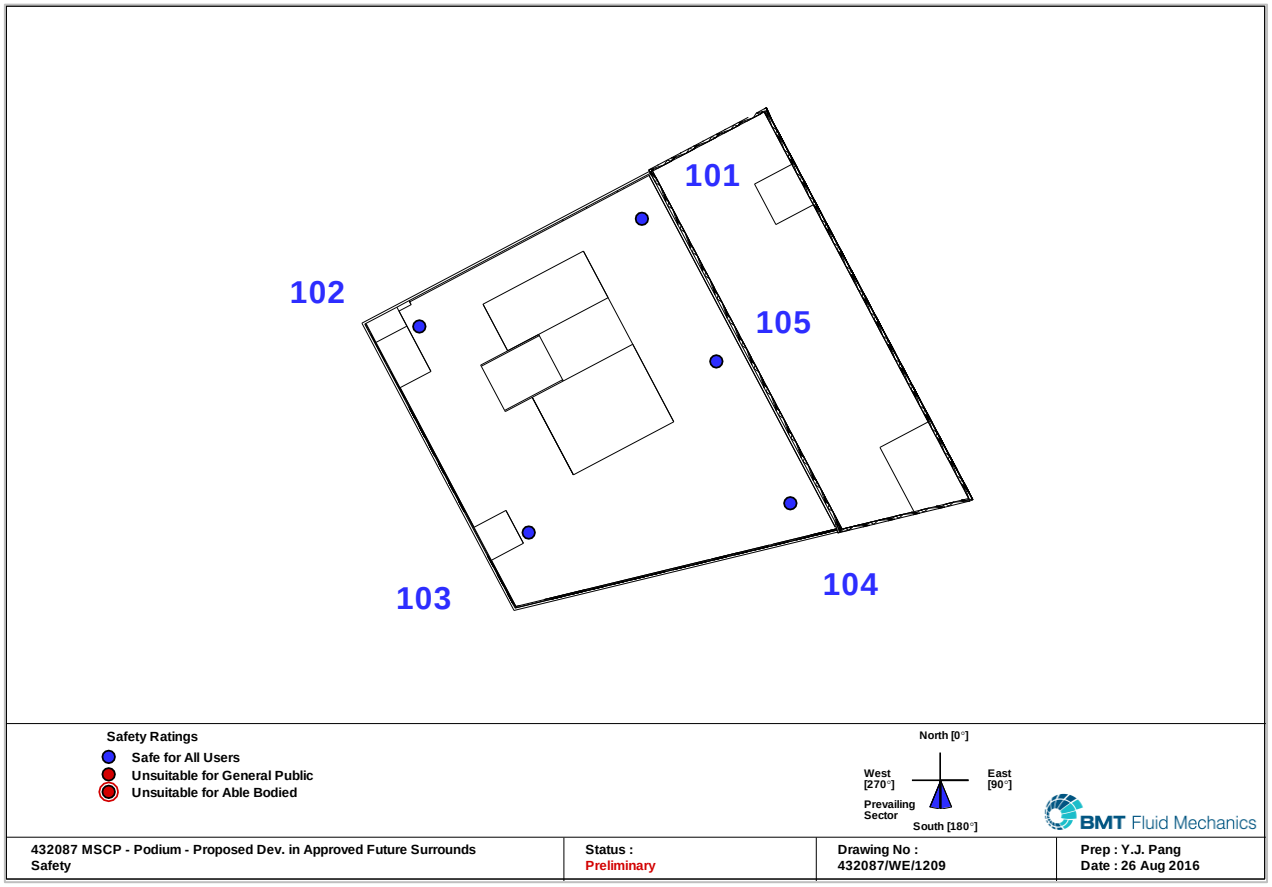


Figure D.1e: Ground annual safety ratings, proposed development in the context of consented future surrounding conditions with masterplan and with landscaping

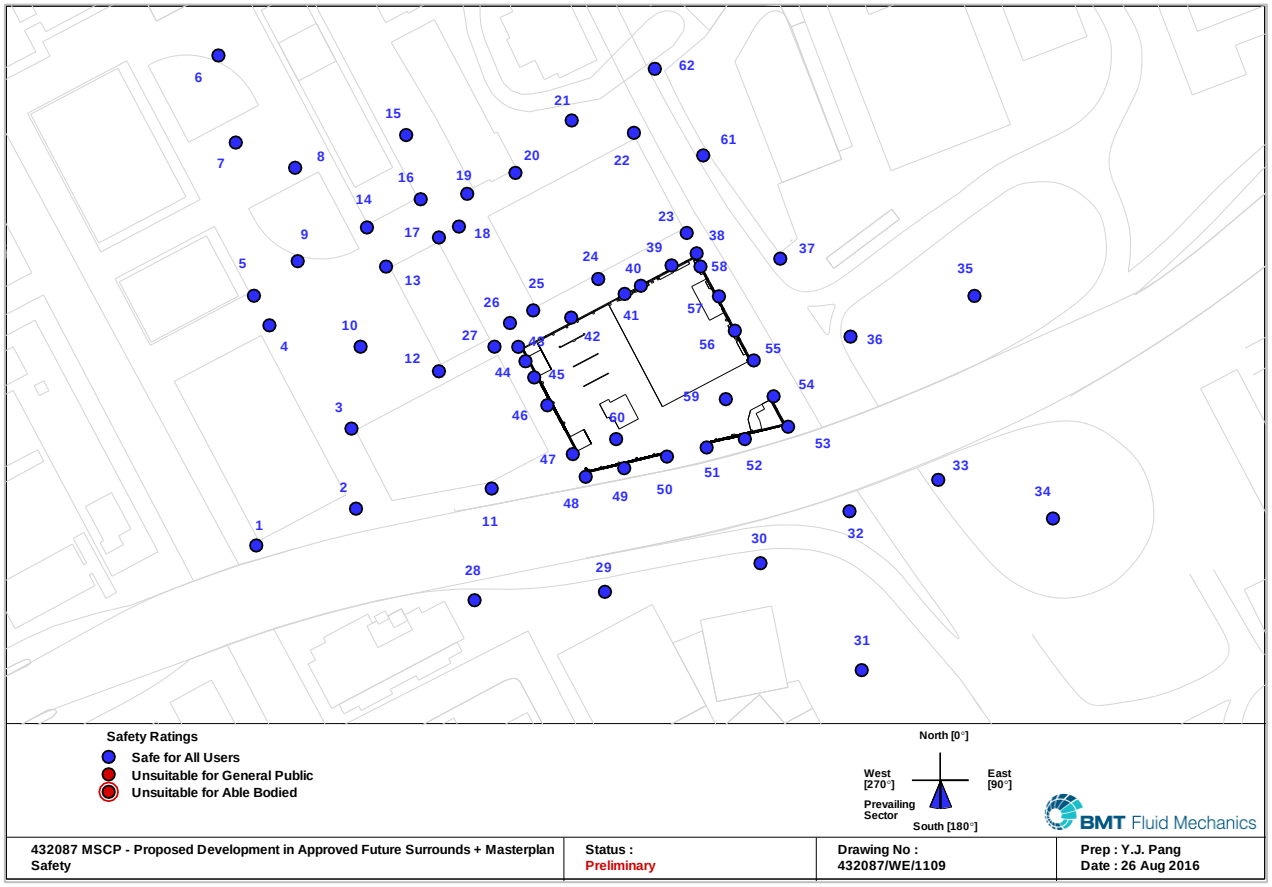


Figure D.1f: Podium annual safety ratings, proposed development in the context of consented future surrounding conditions with masterplan and with landscaping

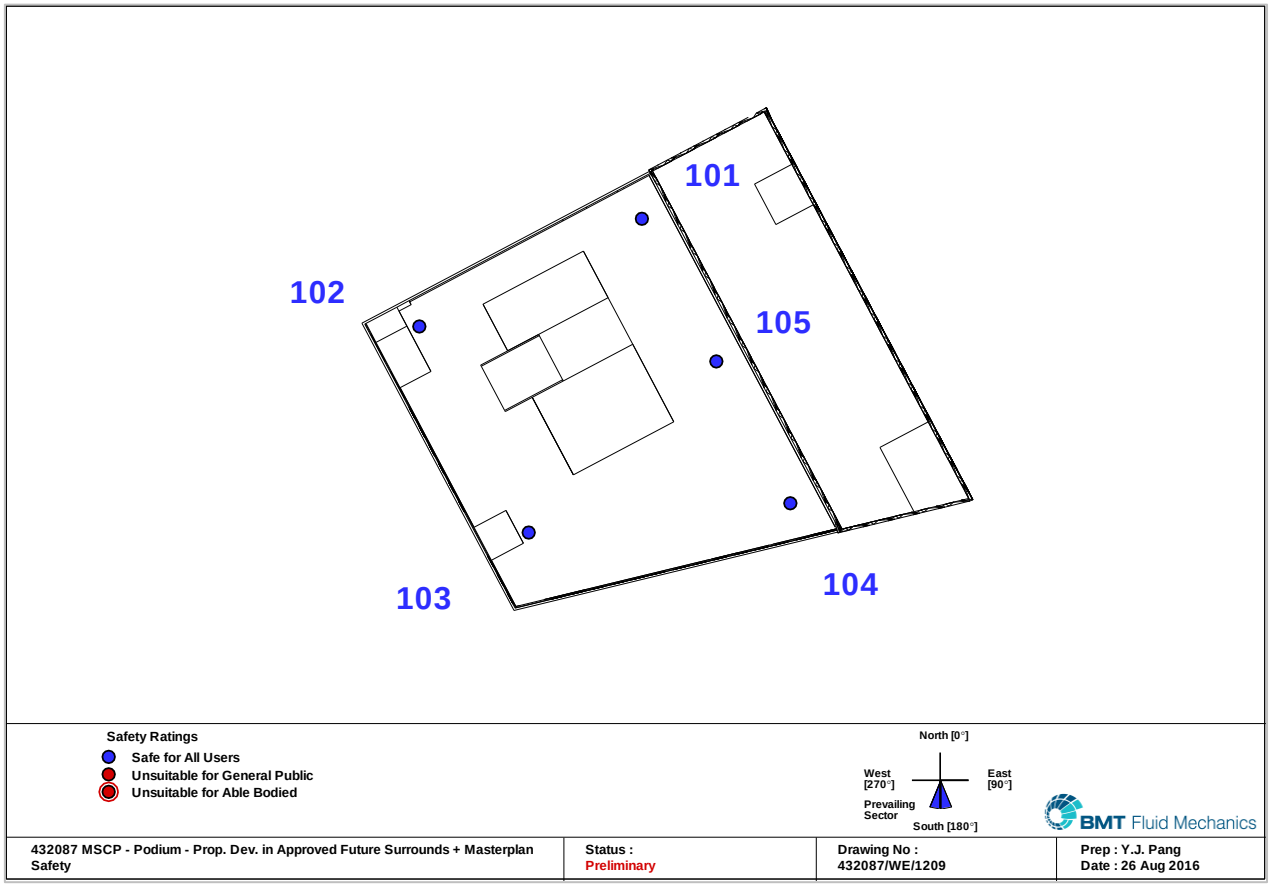


Figure D.2a: Ground summer comfort ratings, proposed development in the context of existing surrounding conditions with landscaping

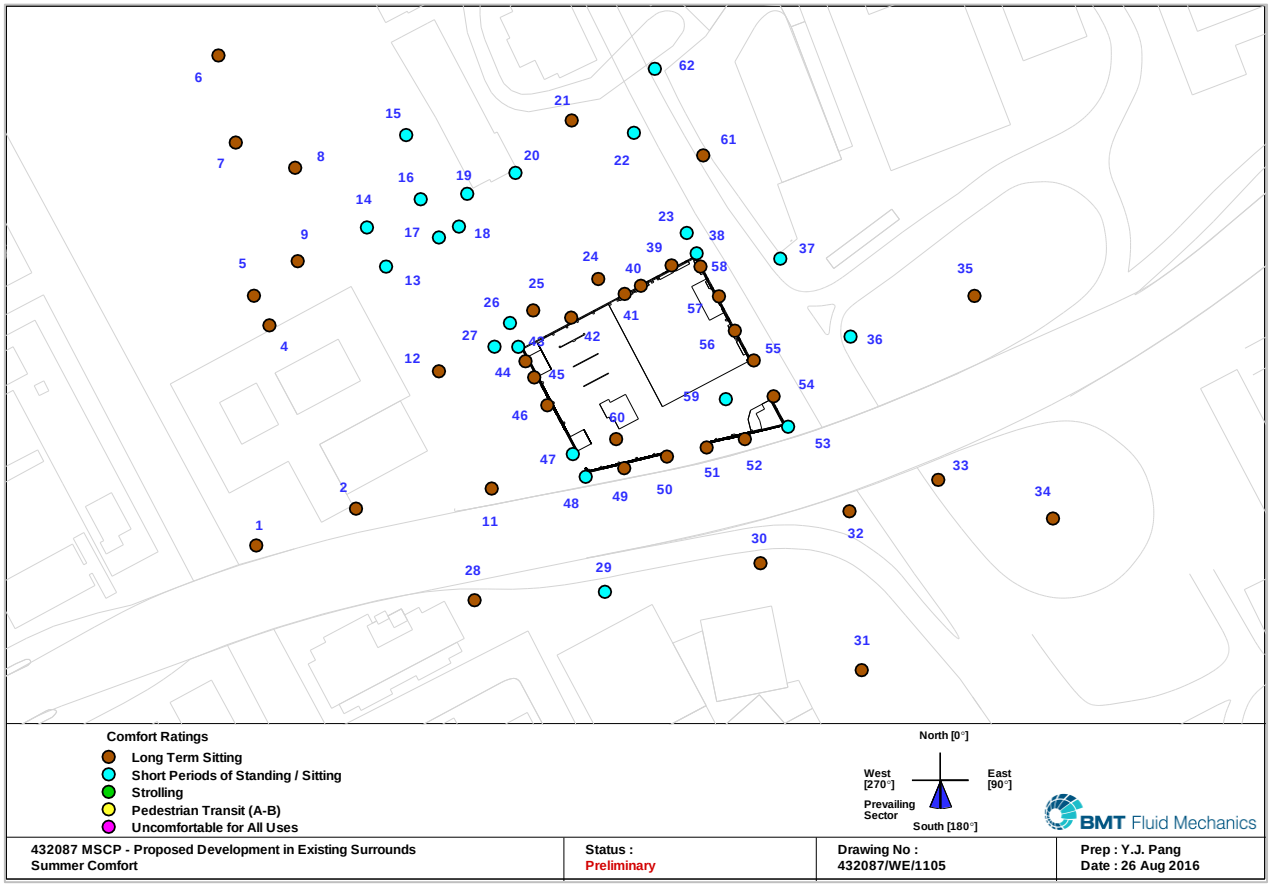


Figure D.2b: Podium summer comfort ratings, proposed development in the context of existing surrounding conditions with landscaping

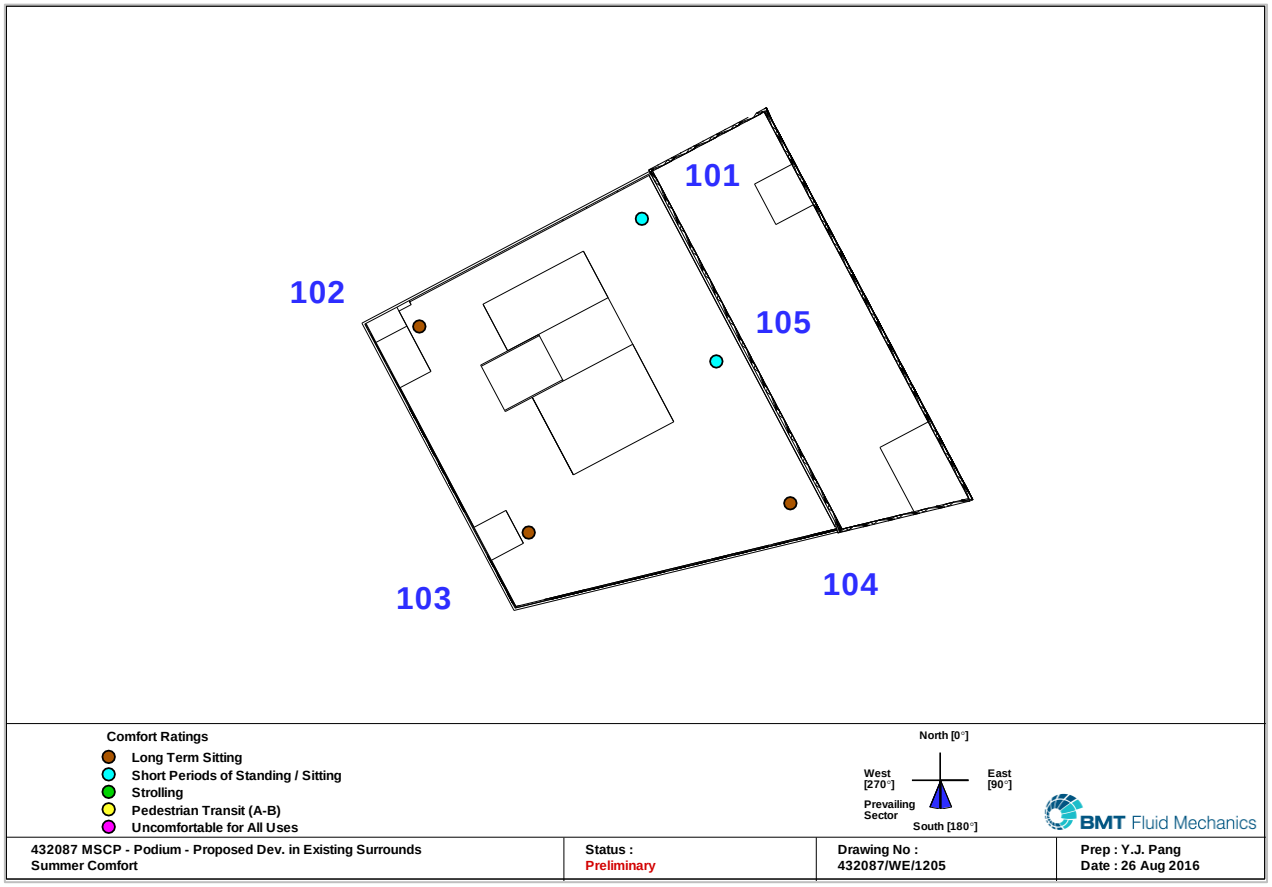


Figure D.2c: Ground summer comfort ratings, proposed development in the context of wider Phase 1B Proposals and other consented future surrounding conditions with landscaping

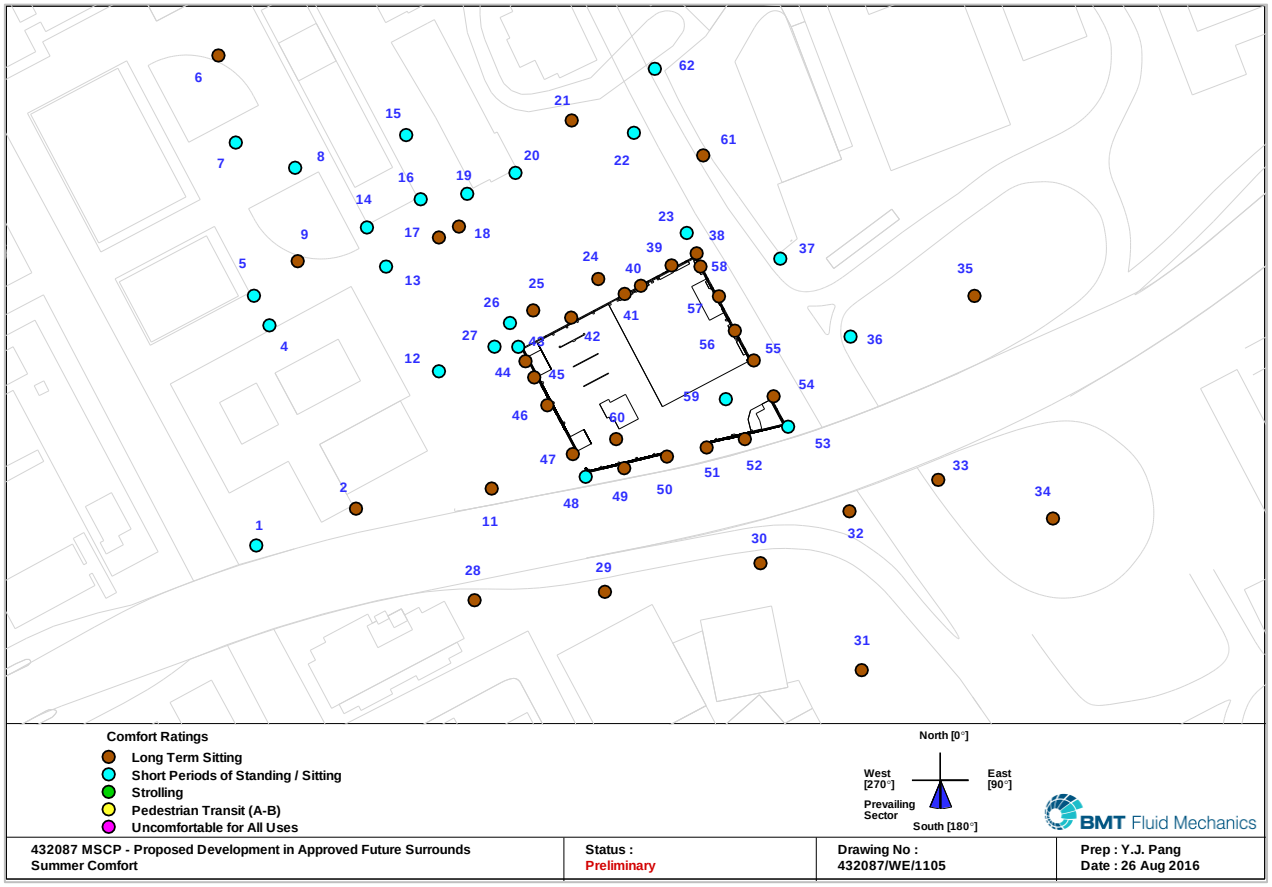


Figure D.2d: Podium summer comfort ratings, proposed development in the context of wider Phase 1B Proposals and other consented future surrounding conditions with landscaping

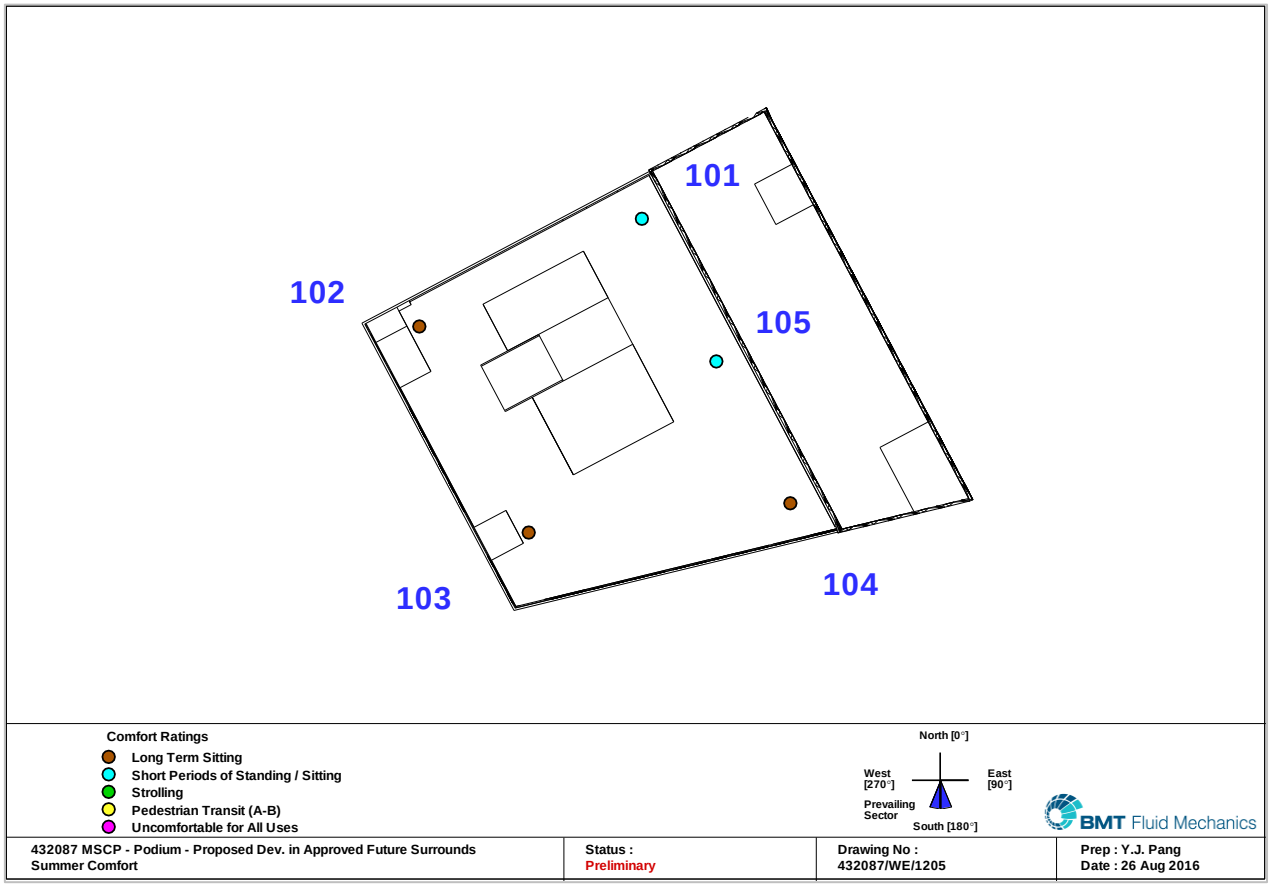


Figure D.2e: Ground summer comfort ratings, proposed development in the context of consented future surrounding conditions with masterplan and with landscaping

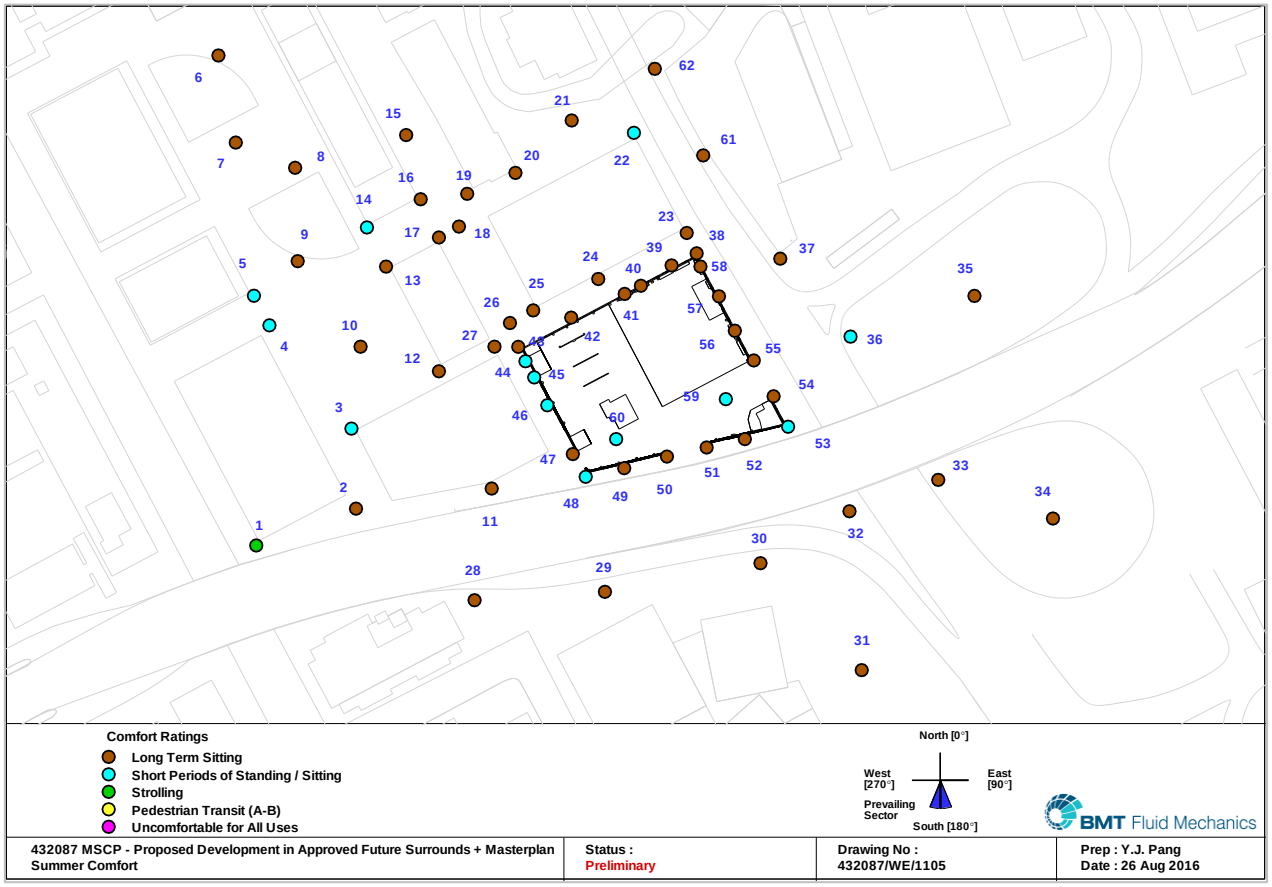


Figure D.2f: Podium summer comfort ratings, proposed development in the context of consented future surrounding conditions with masterplan and with landscaping

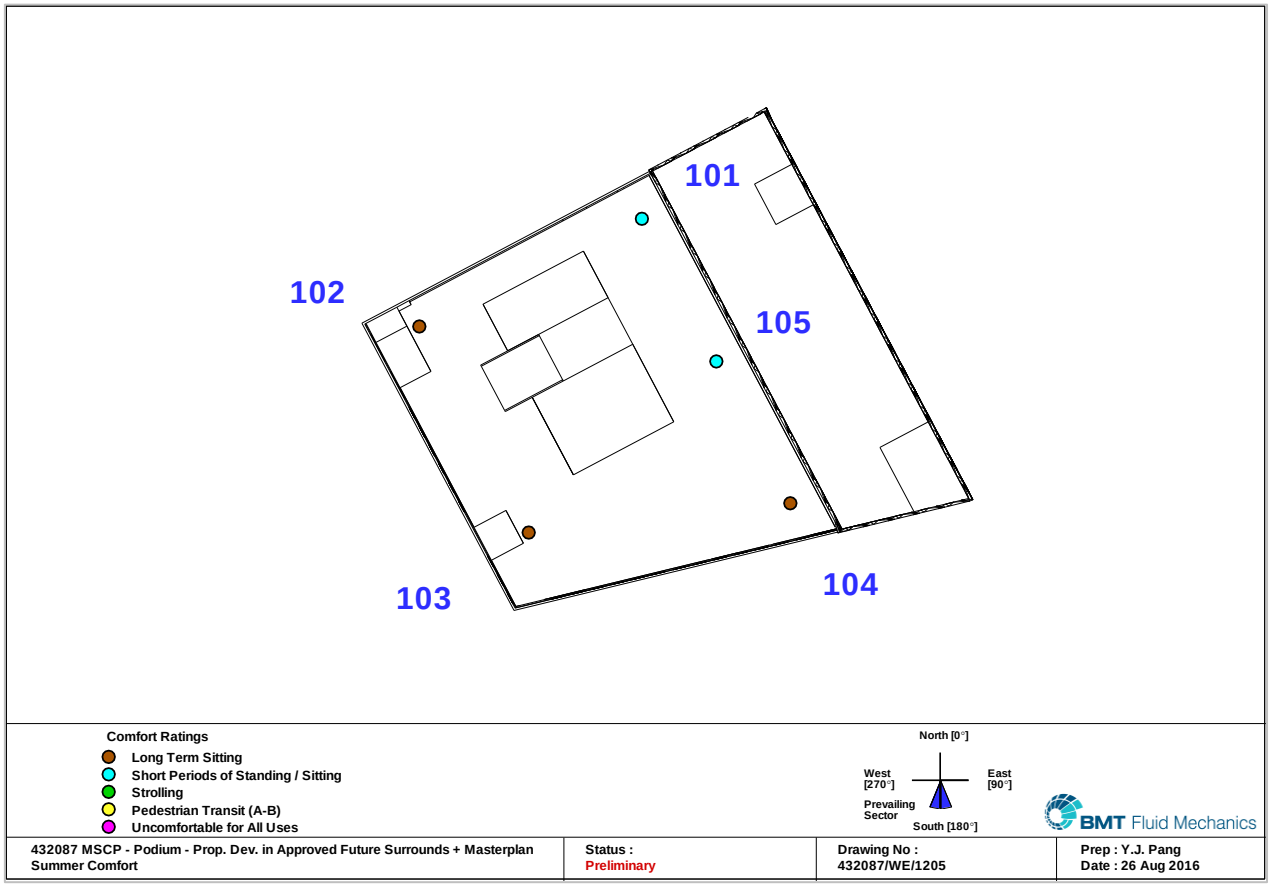


Figure D.3a: Ground worst seasonal comfort ratings, proposed development in the context of existing surrounding conditions with landscaping

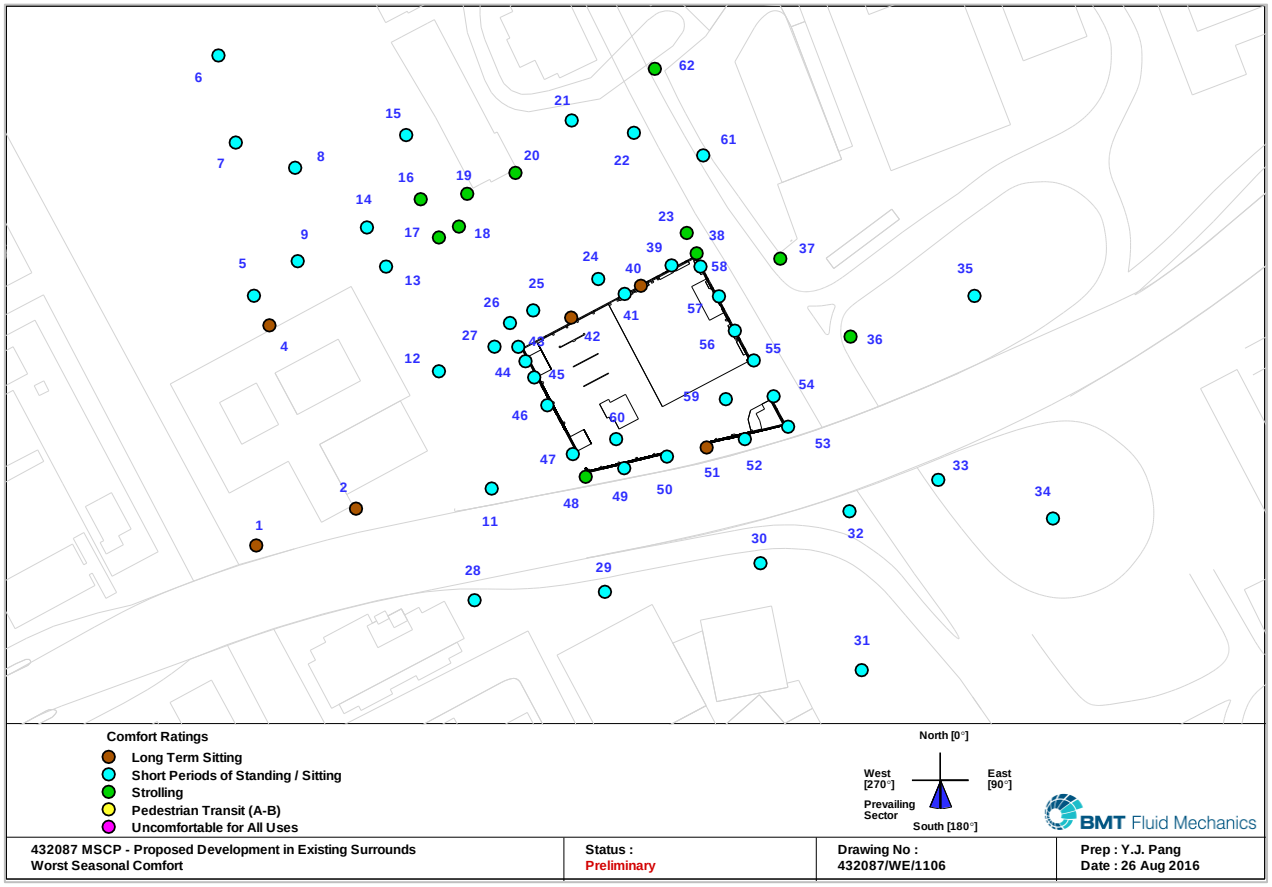


Figure D.3b: Podium worst seasonal comfort ratings, proposed development in the context of existing surrounding conditions with landscaping

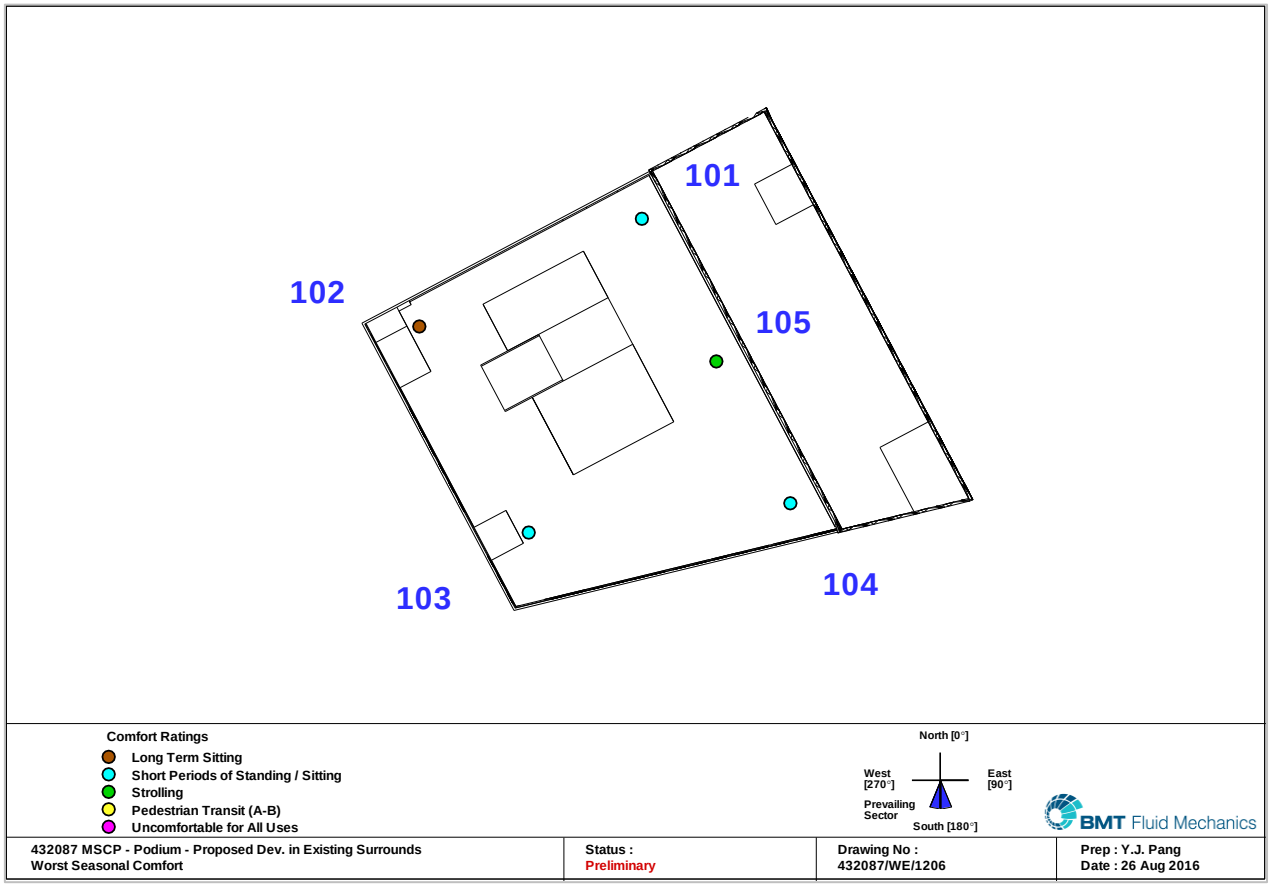


Figure D.3c: Ground worst seasonal comfort ratings, proposed development in the context of wider Phase 1B Proposals and other consented future surrounding conditions with landscaping

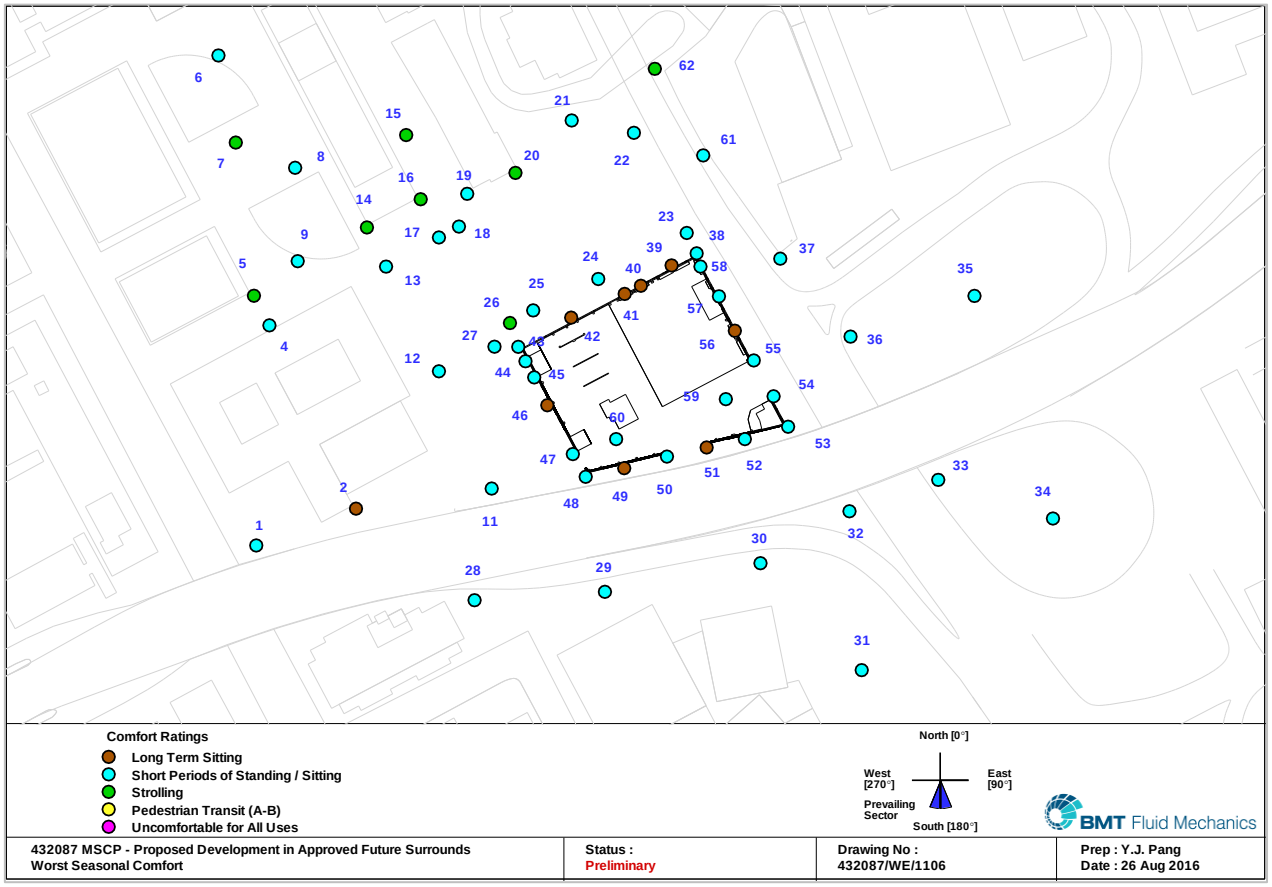


Figure D.3d: Podium worst seasonal comfort ratings, proposed development in the context of wider Phase 1B Proposals and other consented future surrounding conditions with landscaping

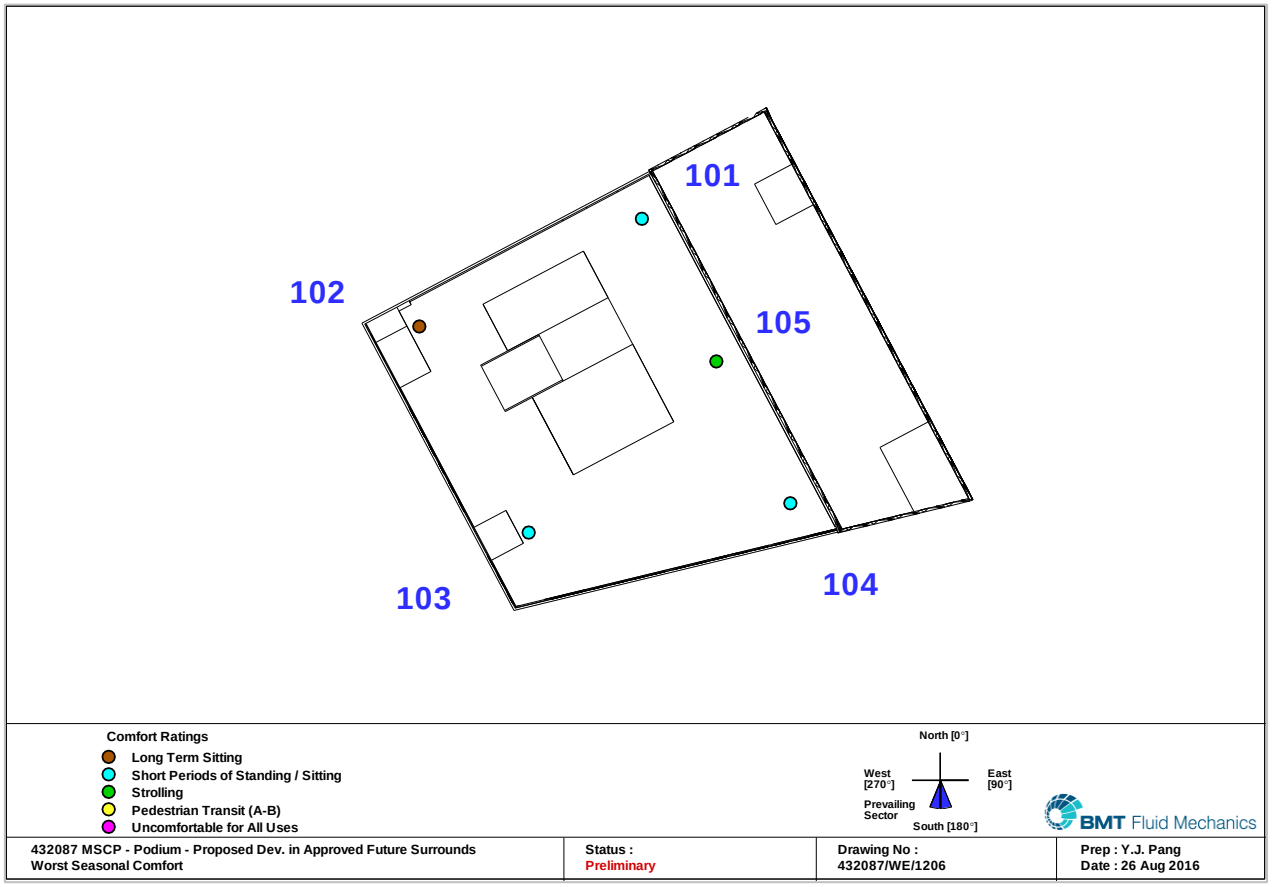


Figure D.3e: Ground worst seasonal comfort ratings, proposed development in the context of consented future surrounding conditions with masterplan and with landscaping

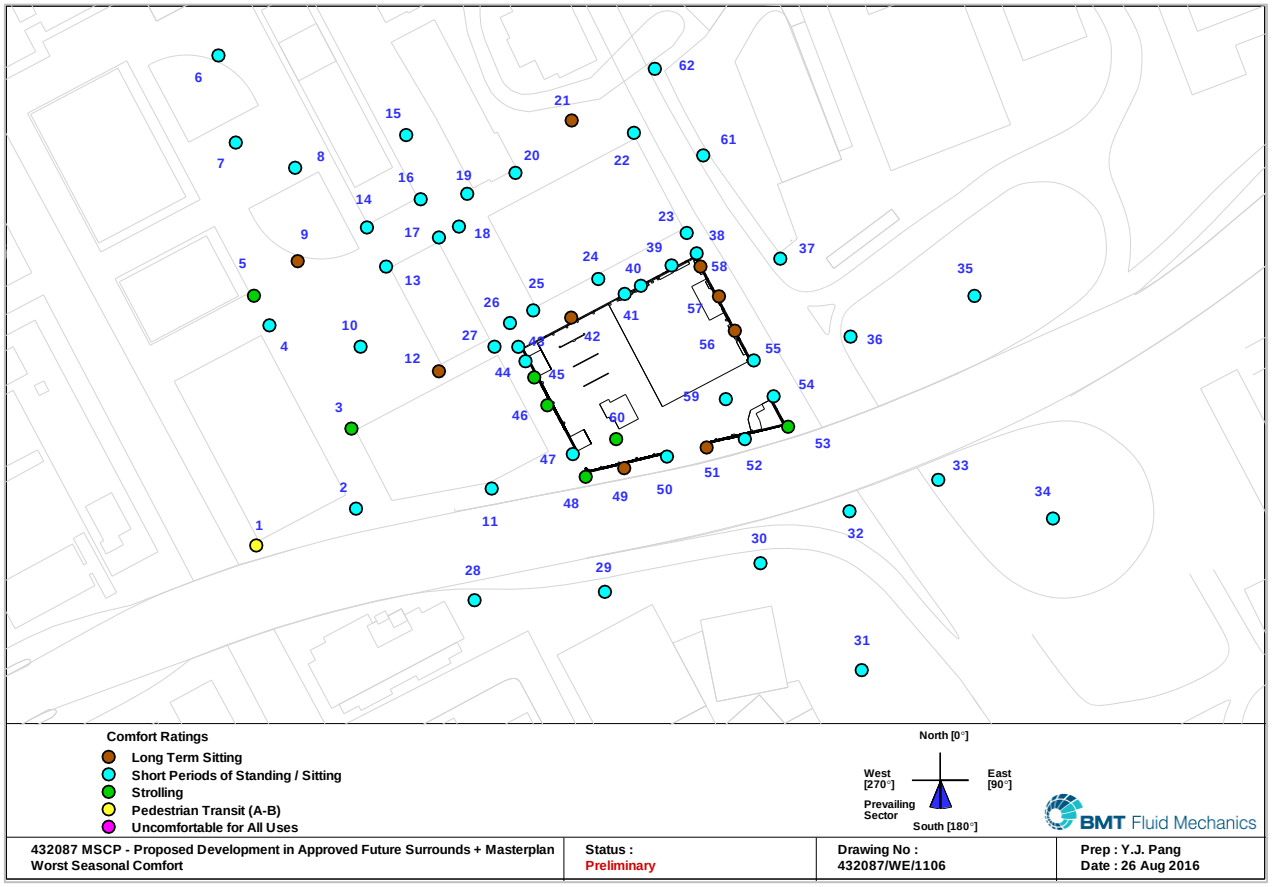


Figure D.3f: Podium worst seasonal comfort ratings, proposed development in the context of consented future surrounding conditions with masterplan and with landscaping

