APPENDIX 11.1

WIND MICROCLIMATE STUDY (MARCH 2019)

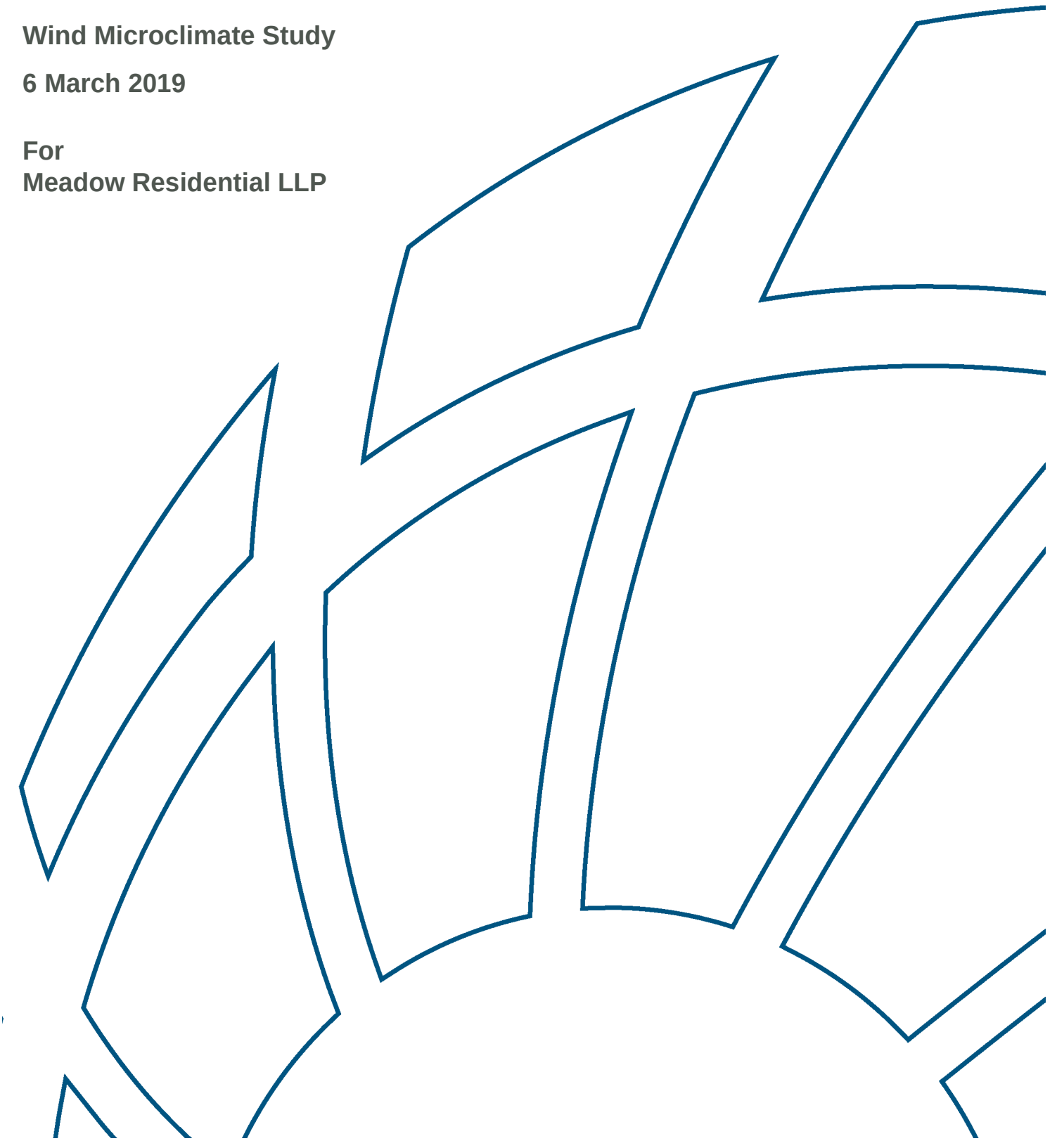
Pentavia Retail Park

London, UK

Wind Microclimate Study

6 March 2019

For
Meadow Residential LLP



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Pentavia Retail Park
London, UK
Wind Microclimate Study

Contents

EXECUTIVE SUMMARY

Background

A boundary layer wind tunnel study has been carried out by BMT to assess the wind microclimate for the proposed Pentavia Retail Park development in London, UK.

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 current and 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 existing site are suitable, in terms of both pedestrian safety and comfort, for their current usage throughout the year.
- With the introduction of the proposed development within the context of existing surrounds, wind conditions in and around the site are suitable, in terms of both pedestrian safety and comfort, for their intended usage.
- With the introduction of the cumulative surrounds, wind conditions in and around the proposed development remain similar to the existing surrounds and are suitable, in terms of safety and comfort, for the general public throughout the year.
- With the introduction of the proposed soft landscaping, wind conditions remain suitable, both in terms of pedestrian comfort and safety, for the intended use by the general public and are further improved in some areas of the development.

Pentavia Retail Park
London, UK
Wind Microclimate Study

1. Introduction

This report summarises the results of a boundary layer wind tunnel study, commissioned by Meadow Residential LLP, to assess the wind environment for the proposed Pentavia Retail Park development in London, UK.

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 current and 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 and cumulative surrounds.

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 London, UK. The site is bounded by Bunns Lane to the north, Watford Way to the east and M1 Motorway to the west.

At present the area immediately surrounding the proposed development principally comprises low-rise residential buildings, which give way to open country to the north and suburban London to the south.

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

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

- Existing surrounding conditions
- Cumulative surrounding conditions

3.2. Proposed Development

The proposed development comprises of 26 blocks between approximately 16m and 57m tall. These blocks are divided into two rows running parallel north/south, compromising of 12 and 14 blocks respectively, which enclose a central amenity space.

Figure 3.2 presents a site plan of the proposed development.

3.3. Soft Landscaping

The wind environment has been assessed for the proposed development both with and without current soft landscaping proposals, as indicated in the drawing information "X LAND.dwg" (received on 26th February 2019) provided by Outerspace. As illustrated graphically within Figure 3.3, the soft landscaping modelled comprised the following:

- 4m-4.5m tall trees
- 5m-6m tall trees
- 8m tall trees

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, including the rooftop terraces
- Balconies

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 157 locations for the proposed development, with 109 locations at ground level and 48 locations at elevated levels. 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:

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

The results of existing site conditions are based on wind tunnel studies conducted in September 2016 and reproduced for ease of reference here.

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 36m.

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 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:

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. Existing Site Conditions

The existing site is slightly sheltered by existing surrounding buildings for winds approaching from all directions. As such, it does not represent an obstruction to wind.

The results of the assessment for existing site conditions are summarised in graphical format in Figure 6.1.

6.2.1. Safety

Within the context of existing site, wind conditions at all assessed locations are rated as suitable, in terms of pedestrian safety, for use by the general public.

6.2.2. Comfort

Within the context of existing site, wind conditions at all assessed locations are rated as suitable, in terms of pedestrian comfort, for the uses (i.e. pedestrian access routes / entrances and recreational area).

6.3. Proposed Development in Existing Surrounds

With the exception of Block A, the proposed development protrudes partially above the surrounding context. Correspondingly, the strength of downdrafts will be limited and strong acceleration around corners limited to the northern and southern extremities of the site.

The results of the assessment for the proposed development within existing surrounds are summarised in graphical format in Figures 6.2a to 6.2d.

6.3.1. Safety

With the introduction of the proposed development within the context of existing surrounds, wind conditions in and around the proposed development are suitable, in terms of pedestrian safety, for the general public throughout the year.

6.3.2. Comfort

With the introduction of the proposed development, wind conditions in and around the proposed development rate as suitable, in terms of pedestrian comfort, for the intended uses, which include a mixture of leisure thoroughfare, recreational spaces and outdoor seating.

6.4. Proposed Development in Cumulative Surrounds

The cumulative surrounds consist of additional low-rise residential buildings that have been introduced to the west and south-west of the proposed development. However, as the cumulative surrounds are similar in height to the existing context, the exposure of the proposed development remains unchanged. Consequently, wind conditions at all assessed locations remain similar to the existing surrounds and are suitable, in terms of safety and comfort, for the intended use by the general public throughout the year.

The results of the assessment for the proposed development within cumulative surrounds are summarised in graphical format in Figures 6.3a to 6.3d.

6.5. Proposed Development in Existing Surrounds with Soft Landscaping

With the introduction of the proposed soft landscaping, described in section 3.3, wind conditions remain suitable, both in terms of pedestrian comfort and safety, for the intended use by the general public and are further improved in some areas of the development. It should be noted that, as the wind conditions are largely similar in cumulative surrounds, it is expected that the impact of the soft landscaping in the cumulative surrounds scenario will be the same.

The results of the assessment for the proposed development in existing surrounds with soft landscaping are summarised in graphical format in Figures 6.4a to 6.4d.

The assessment assumes that the rooftop terraces are intended for general recreational use, for which wind conditions are considered suitable, in terms of pedestrian comfort. Where outdoor seating is required, and thus the more stringent long-term sitting criteria must be met in summer, for the rooftop areas where conditions would not already be suitable it has been demonstrated within the wind tunnel studies that suitable shelter can be created using any one of the following mitigation options:

1. 1.8m high 50% porous parapets around the perimeter of the roof;
2. 1.8m high solid parapets around the perimeter of the roof;
3. 1.0m high, 1m wide hedging around the perimeter of the roof.

The results presented within Appendix D, for the proposed development in existing surrounds with soft landscaping, include the 50% porous parapets around the perimeter of the rooftop terraces. However, the results are similar for any of the options presented above and critically are suitable for long term sitting in summer at all rooftop terraces.

7. 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 existing site are suitable, in terms of both pedestrian safety and comfort, for their current usage throughout the year.
- With the introduction of the proposed development within the context of existing surrounds, wind conditions in and around the site are suitable, in terms of both pedestrian safety and comfort, for their intended usage.
- With the introduction of the cumulative surrounds, wind conditions in and around the proposed development remain similar to the existing surrounds and are suitable, in terms of safety and comfort, for the general public throughout the year.
- With the introduction of the proposed soft landscaping, wind conditions remain suitable, both in terms of pedestrian comfort and safety, for the intended use by the general public and are further improved in some areas of the development.

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.

Figure 3.1: Site location

Figure 3.2: Site plan of the proposed development

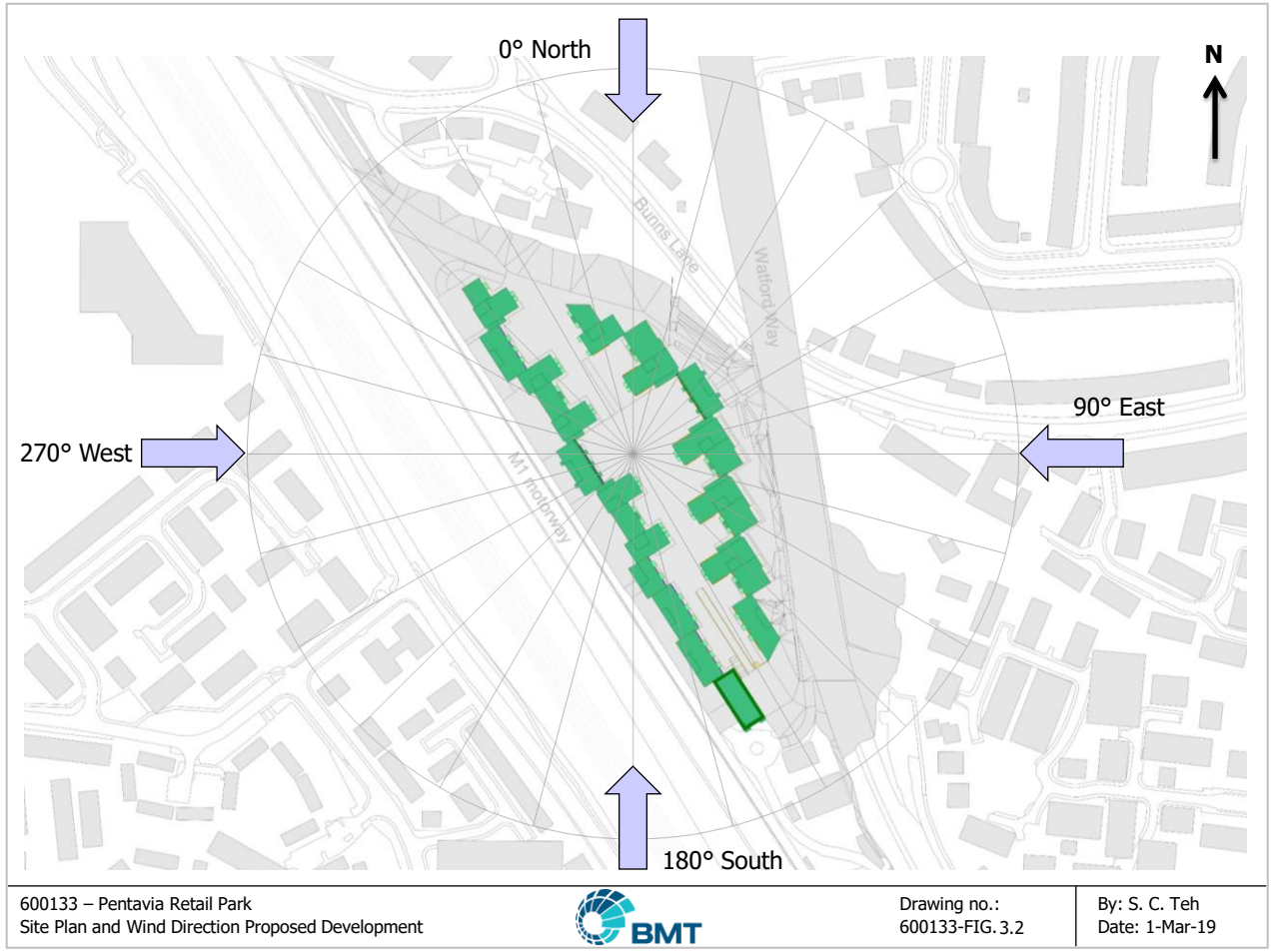


Figure 3.3: Soft landscaping proposals

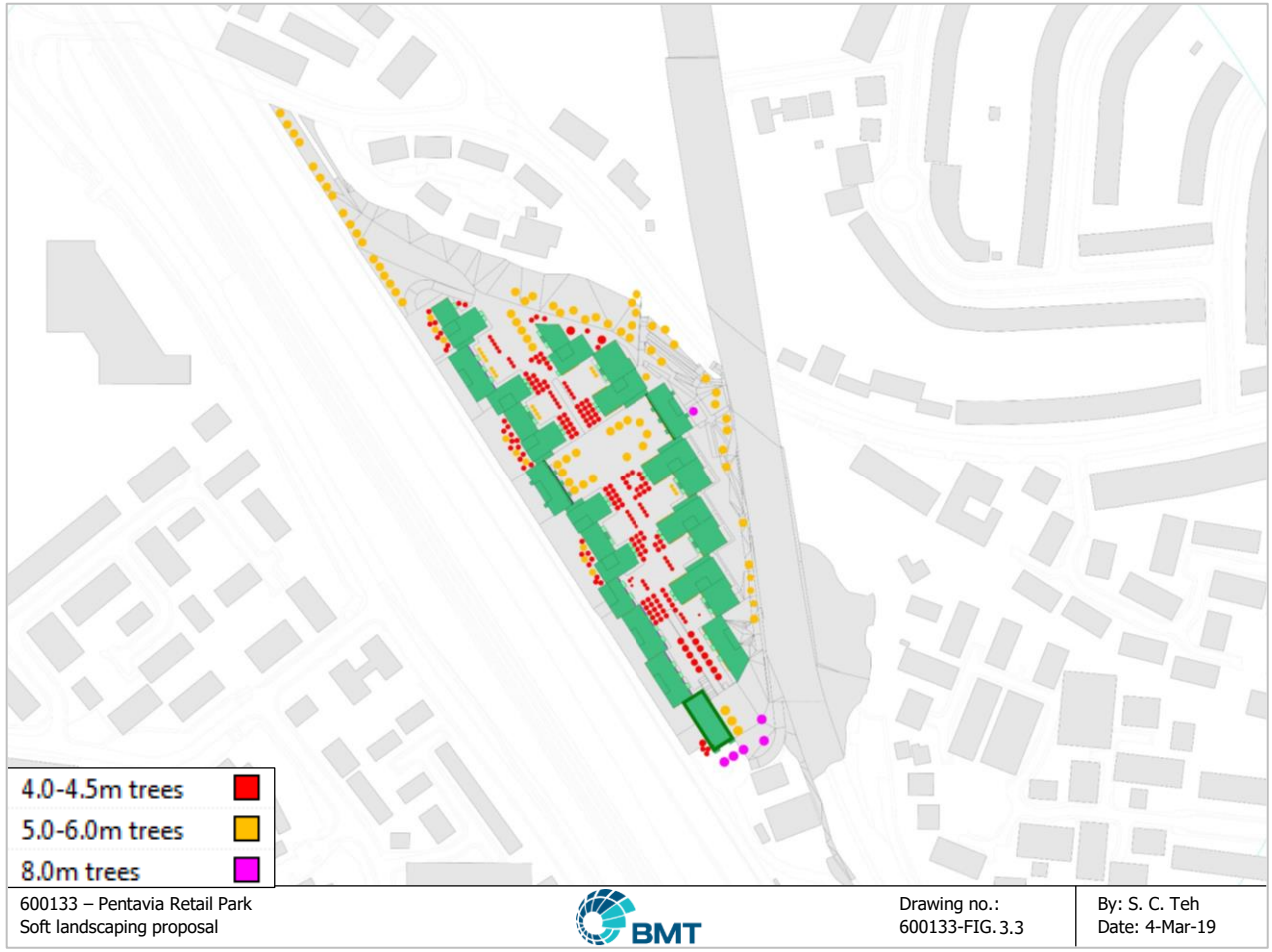


Figure 6.1: Wind microclimate summary, existing site, ground level

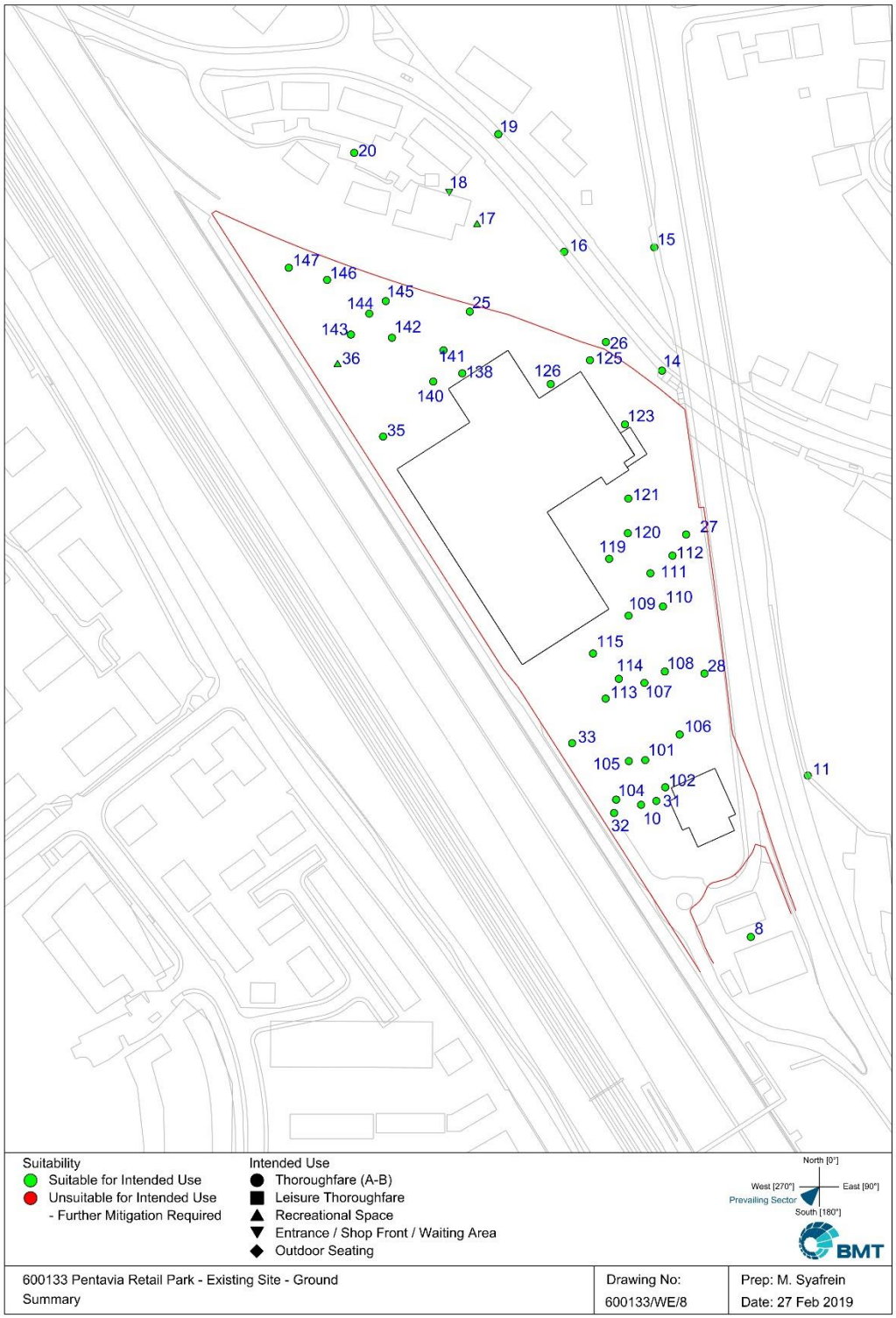


Figure 6.2a: Wind microclimate summary, proposed development within existing surrounds, lower ground level

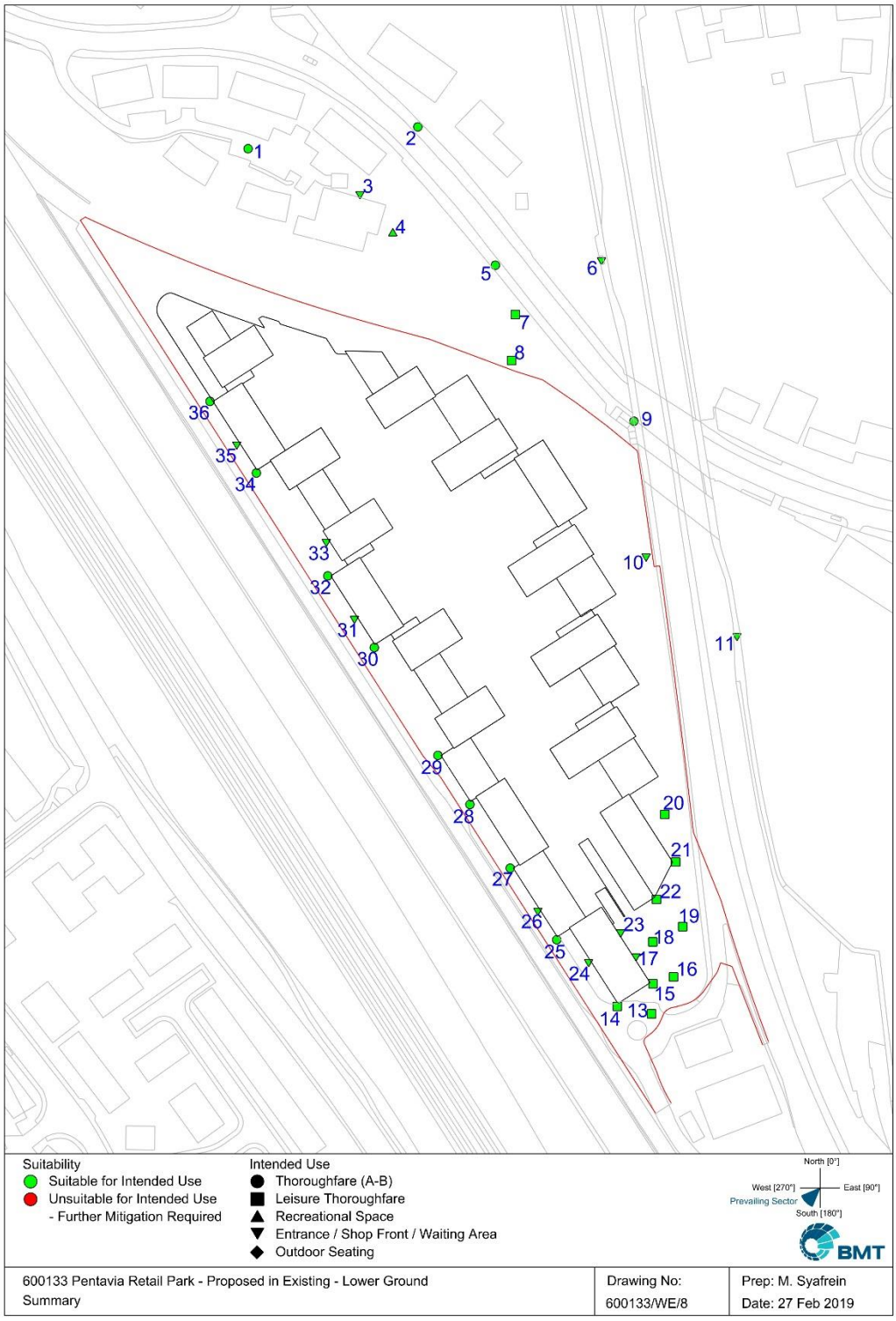


Figure 6.2b: Wind microclimate summary, proposed development within existing surrounds, upper ground level

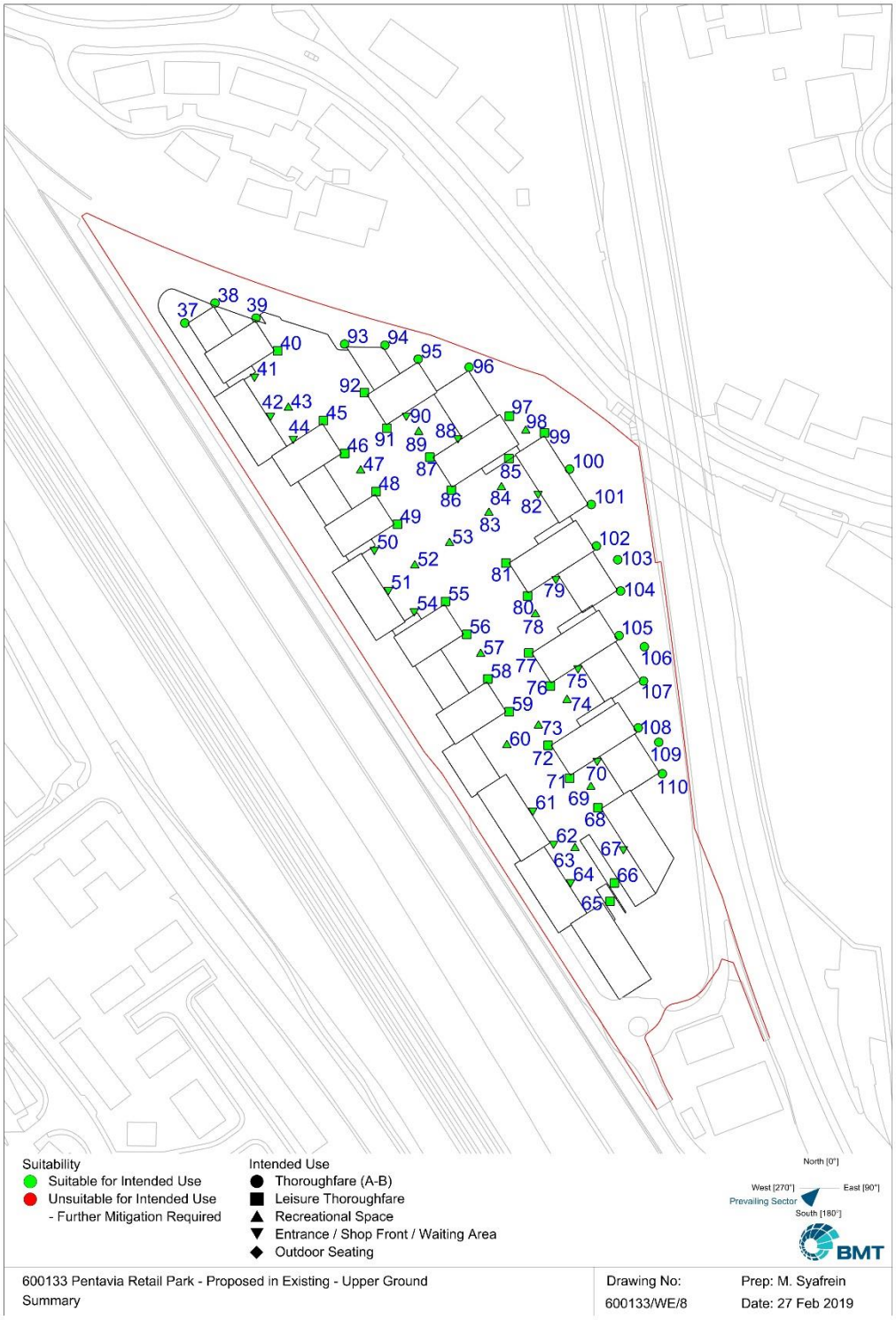


Figure 6.2c: Wind microclimate summary, proposed development within existing surrounds, terrace level

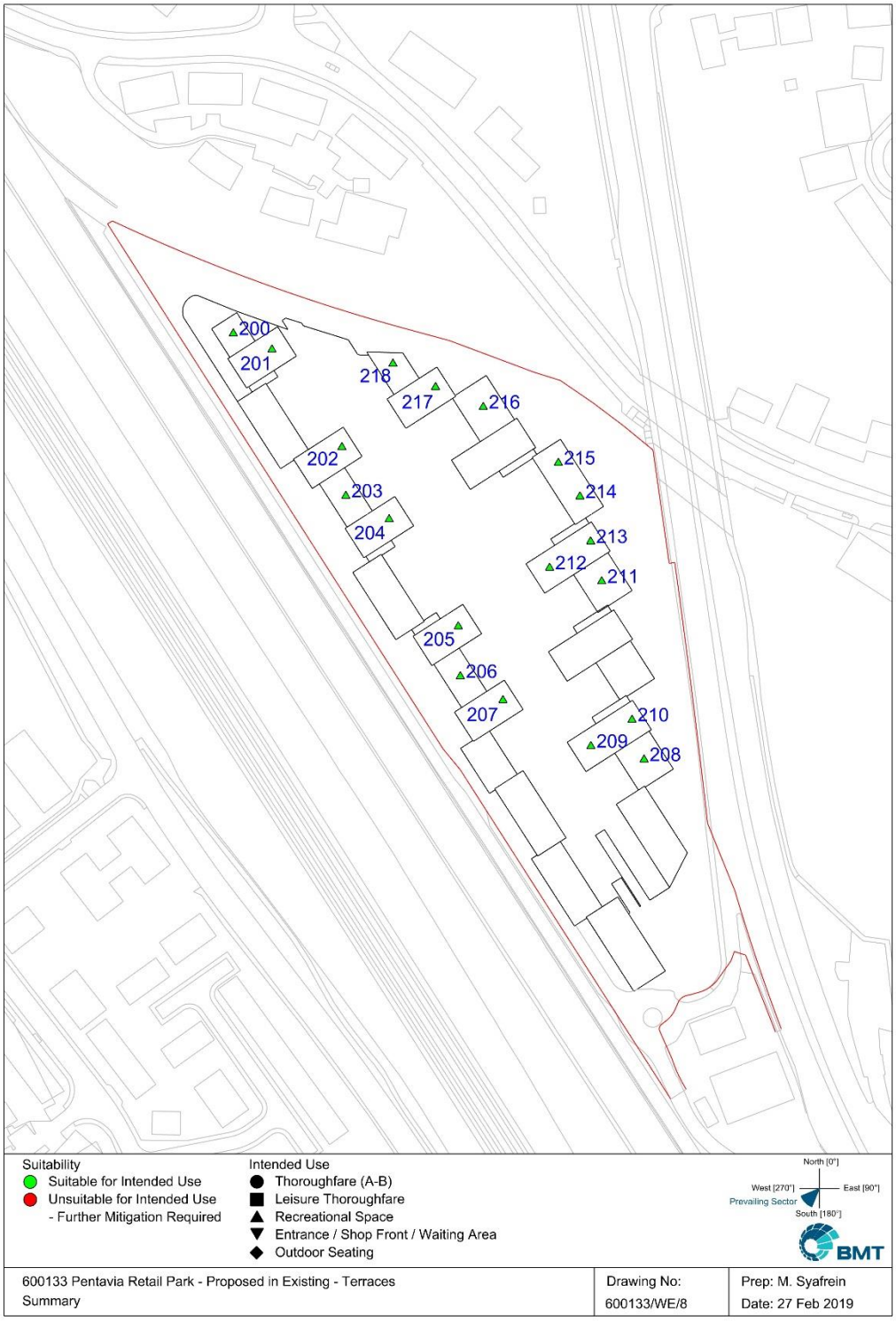


Figure 6.2d: Wind microclimate summary, proposed development within existing surrounds, balconies

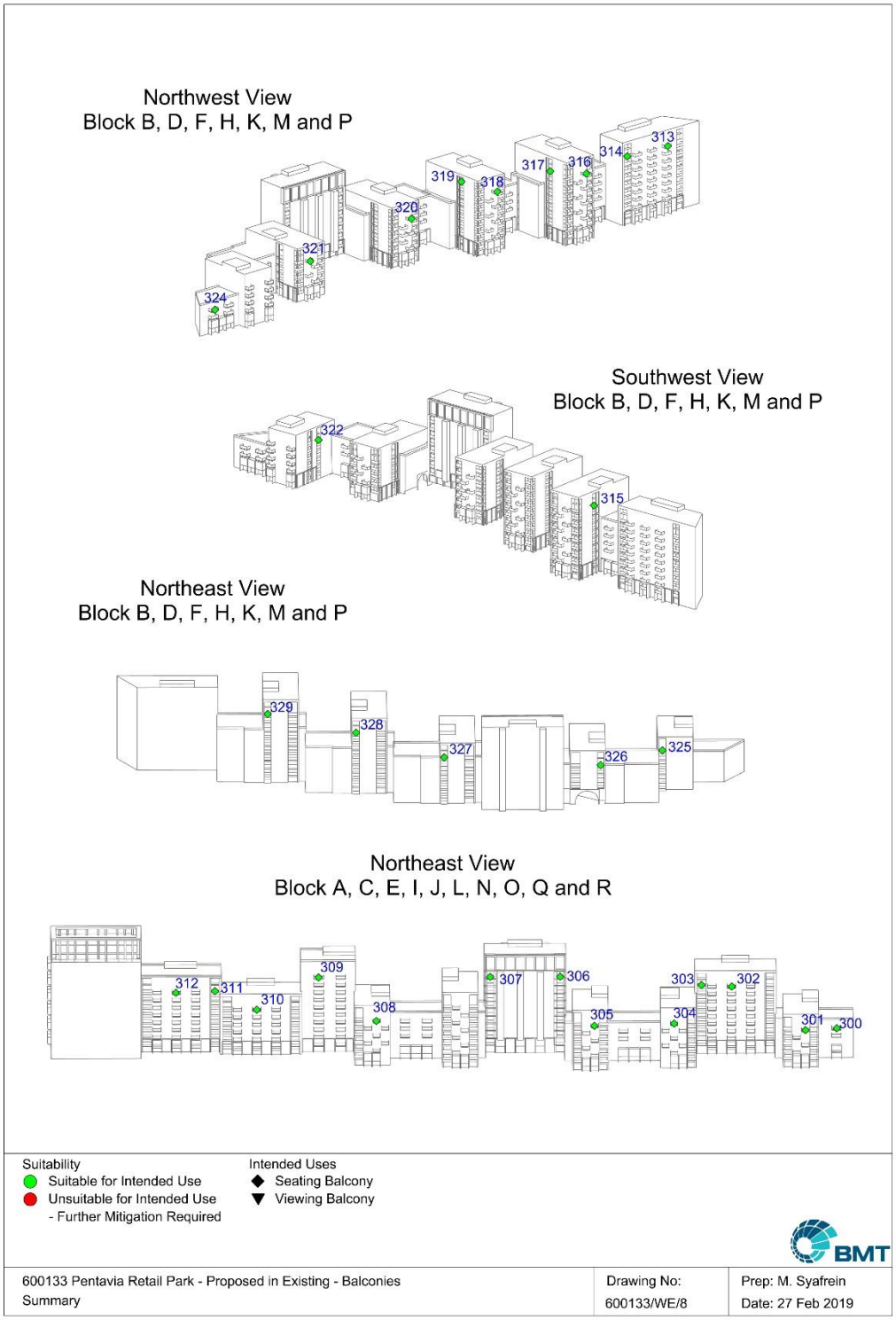


Figure 6.3a: Wind microclimate summary, proposed development within cumulative surrounds, lower ground level

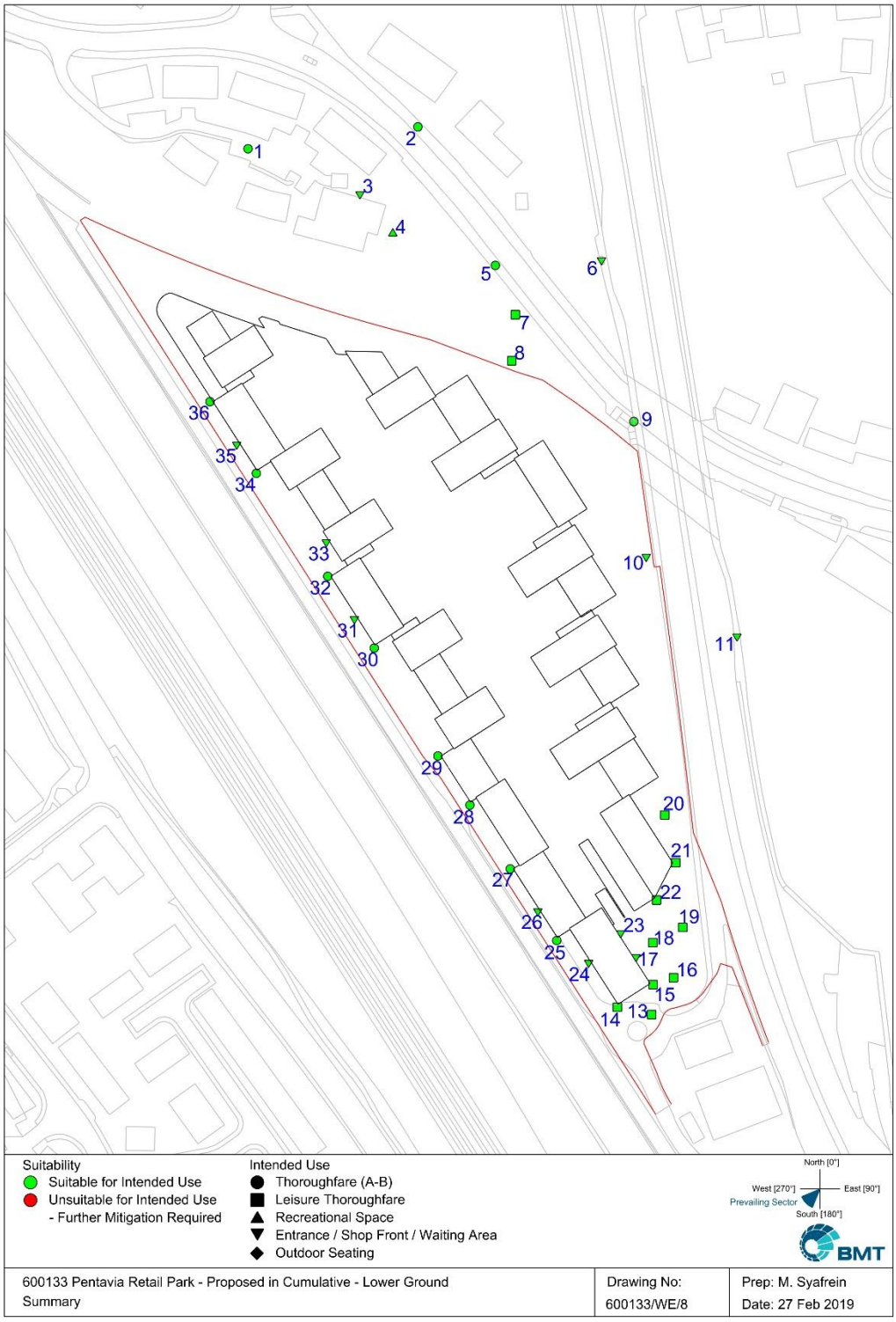


Figure 6.3b: Wind microclimate summary, proposed development within cumulative surrounds, upper ground level

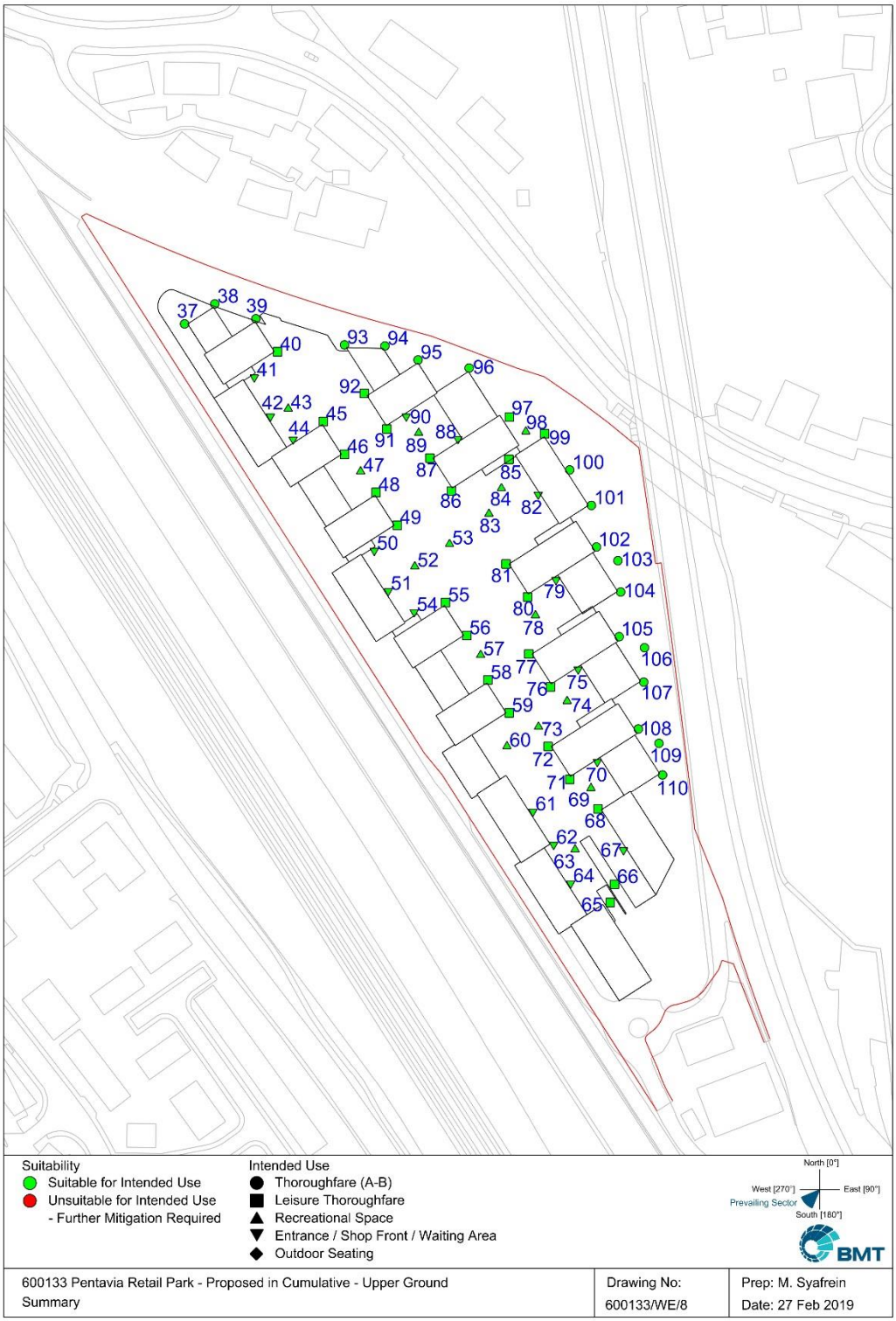


Figure 6.3c: Wind microclimate summary, proposed development within cumulative surrounds, terrace level

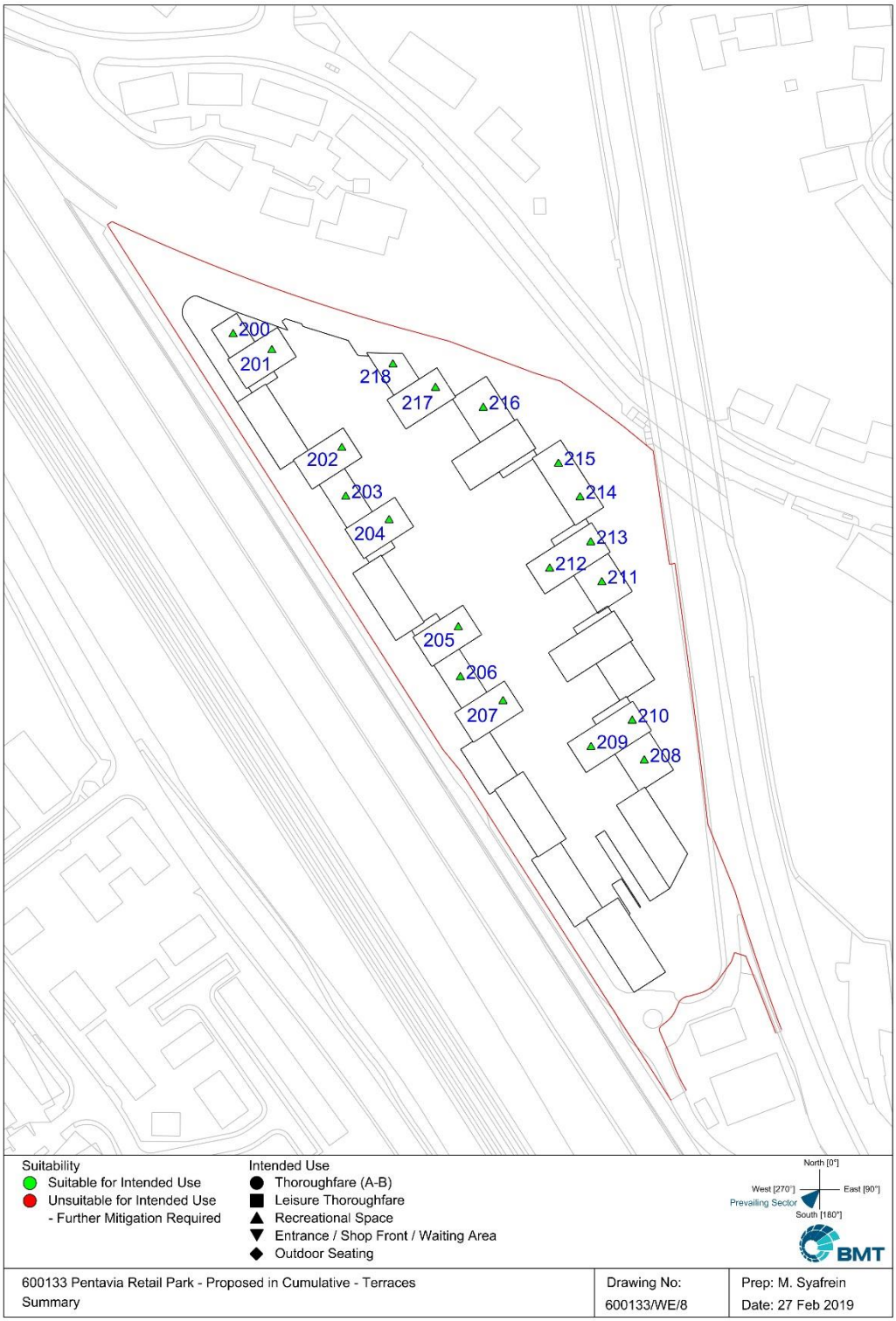


Figure 6.3d: Wind microclimate summary, proposed development within cumulative surrounds, balconies

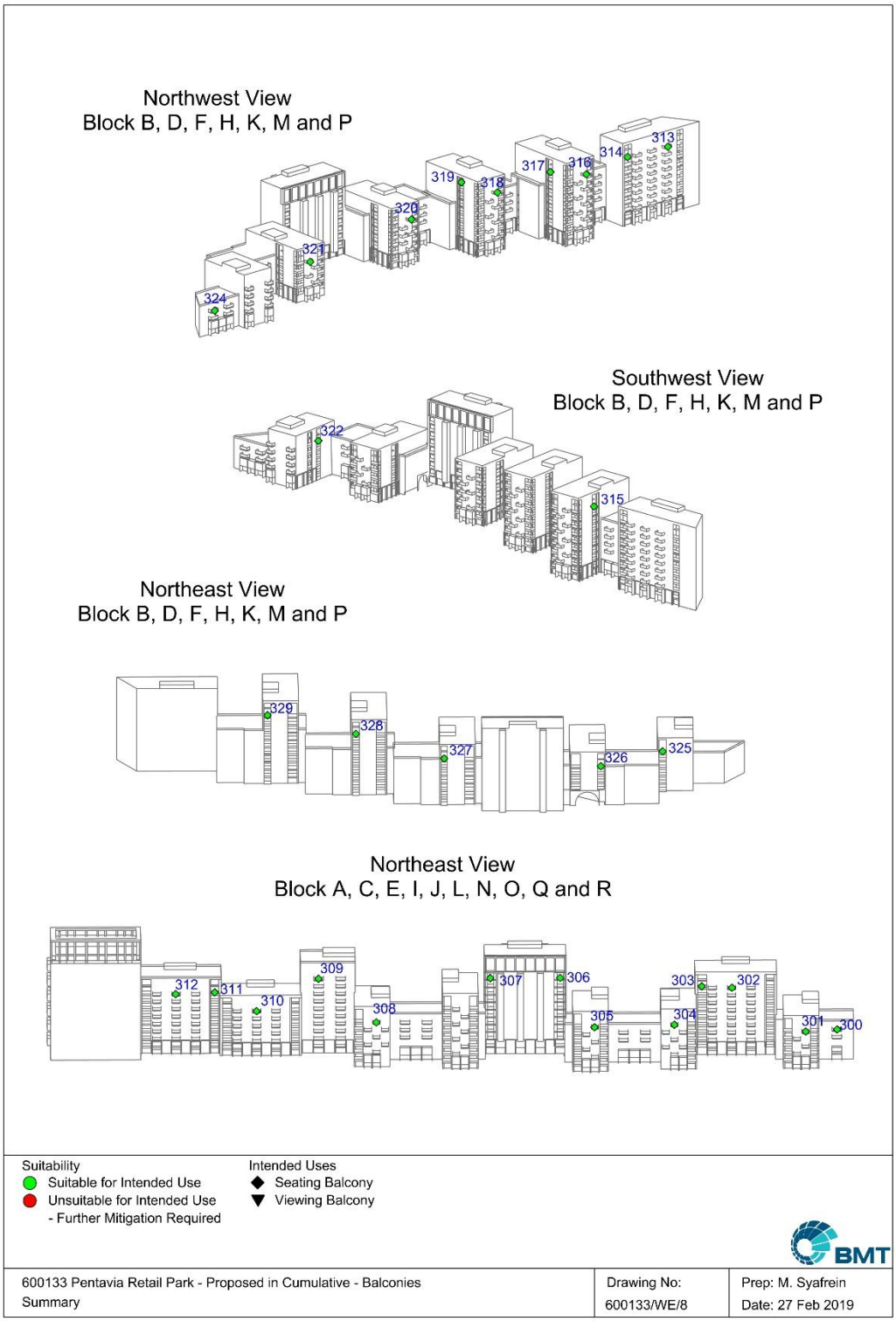


Figure 6.4a: Wind microclimate summary, proposed development within existing surrounds with soft landscaping, lower ground level

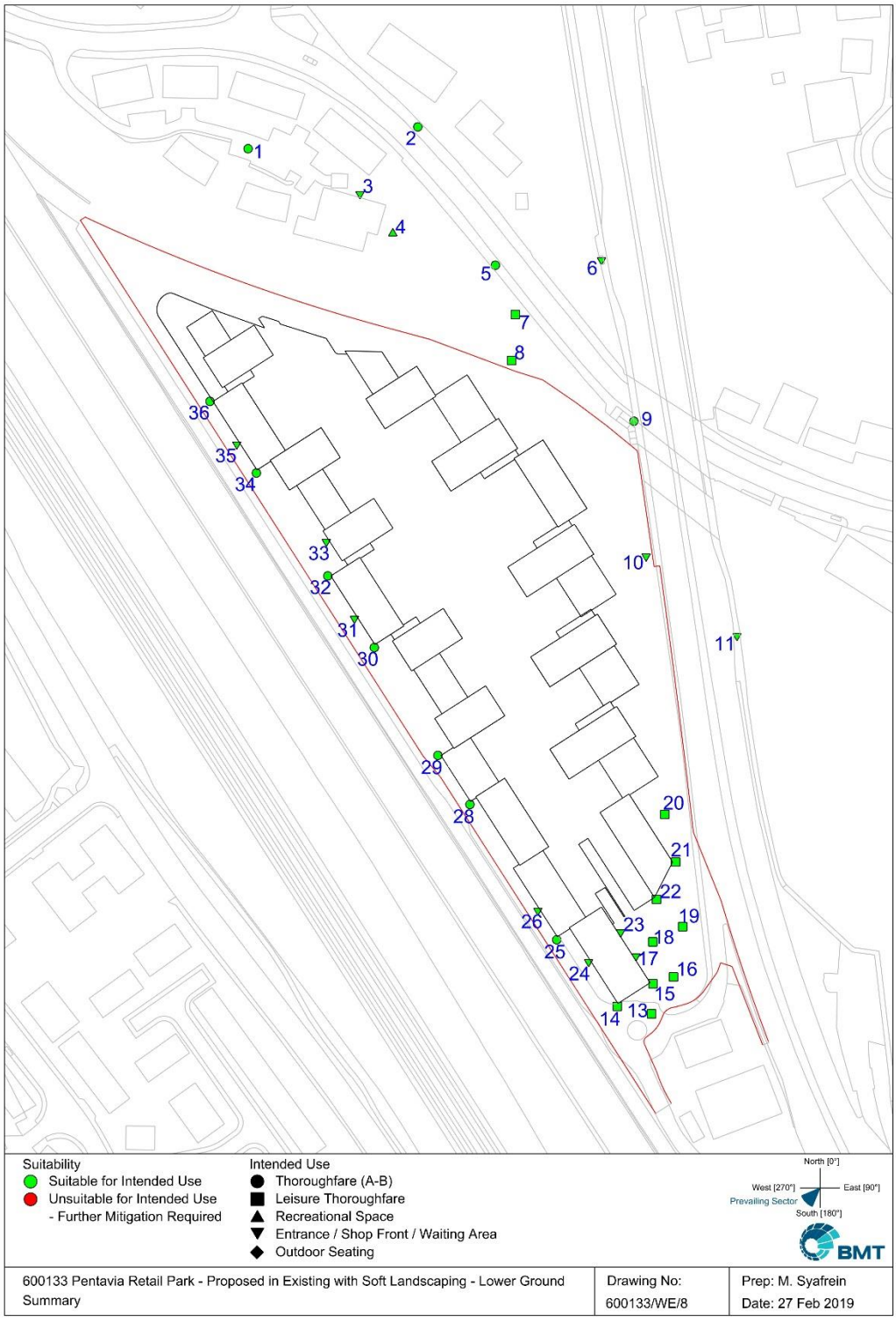


Figure 6.4b: Wind microclimate summary, proposed development within existing surrounds with soft landscaping, upper ground level

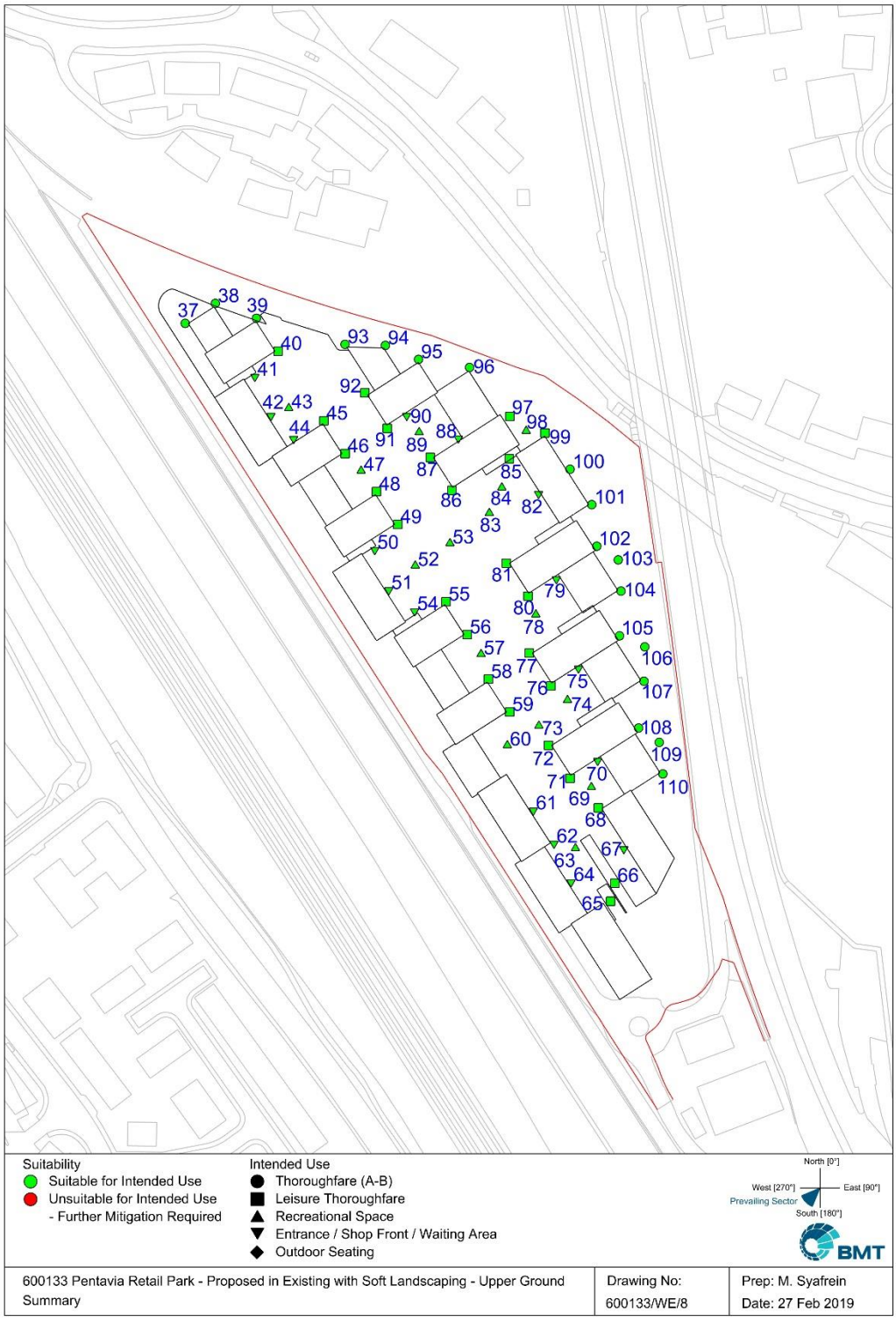


Figure 6.4c: Wind microclimate summary, proposed development within existing surrounds with soft landscaping, terrace level

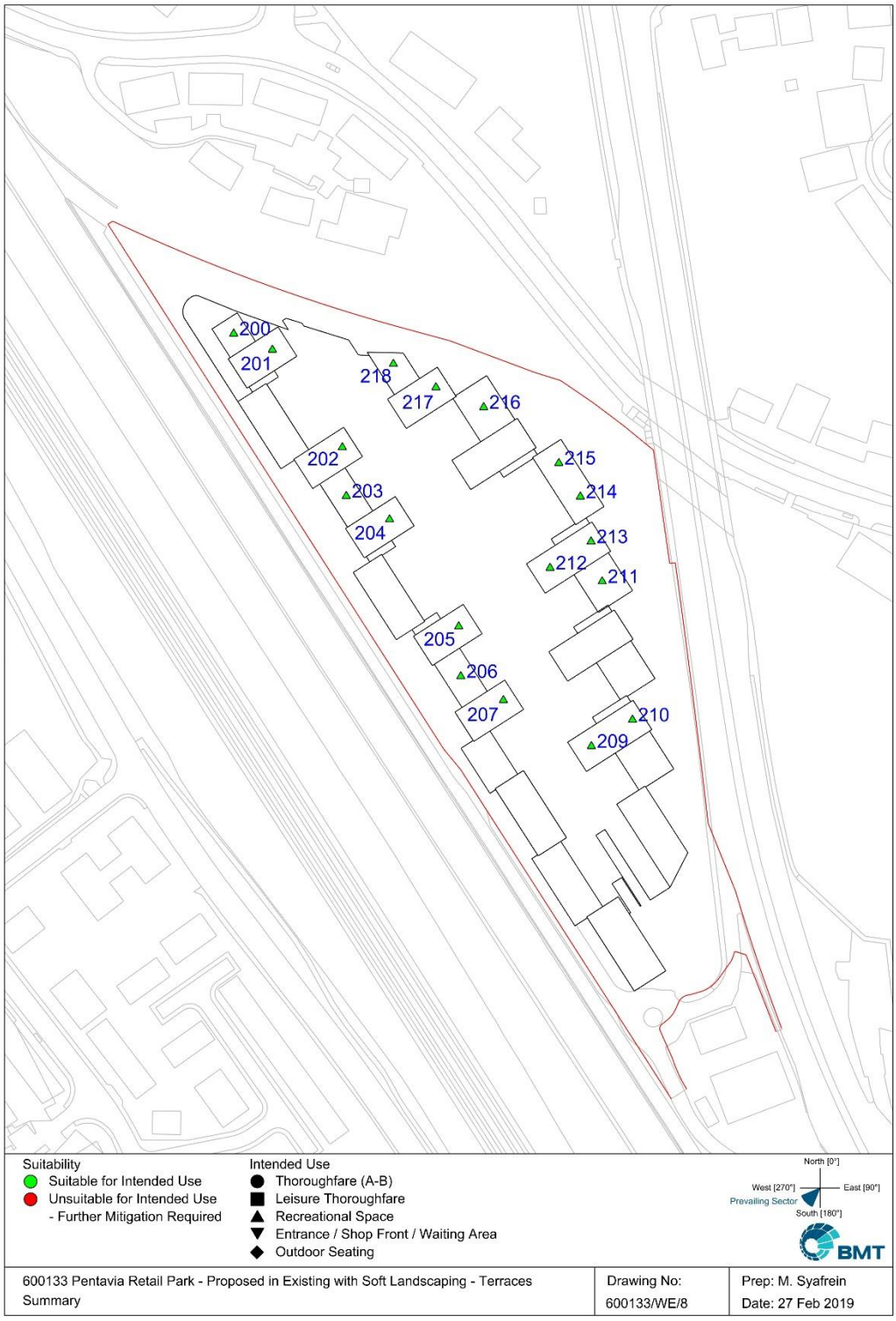
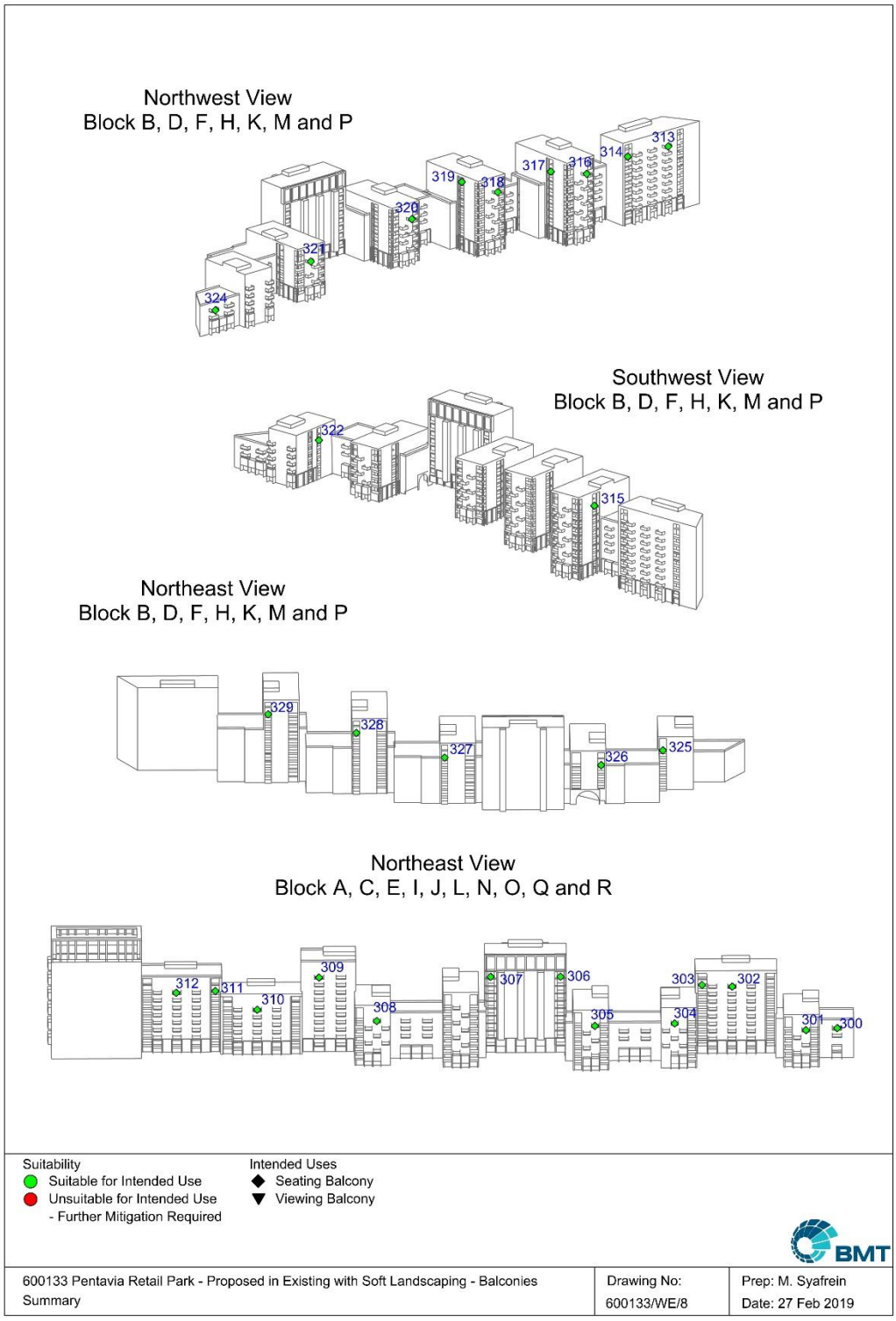


Figure 6.4d: Wind microclimate summary, proposed development within existing surrounds with soft landscaping, balconies



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

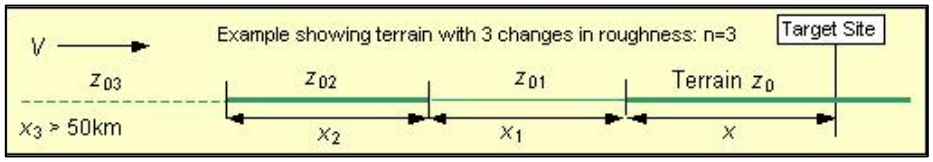
The wind analysis takes detailed account of the variation of the upwind terrain on each wind sector. The roughness changes used in the analysis for the current study are given in Table A.1 below.

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]	x_{04} [m]	z_{05} [m]
0°	0.3	300	0.053	300	0.3	500	0.109	1,000	0.03		
30°	0.3	1,500	0.03	2,600	0.136	1,600	0.03				
60°	0.3	2,300	0.05	1,600	0.2	4,900	0.109	4,300	0.03		
90°	0.3	700	0.07	500	0.3	24,200	0.03				
120°	0.3	900	0.05	700	0.3	38,000	0.03				
150°	0.3	1,300	0.152	500	0.3	8,600	0.574	6,300	0.3	17,200	0.03
180°	0.3	34,600	0.03								
210°	0.3	3,700	0.136	1,300	0.3	29,400	0.03				
240°	0.3	20,000	0.03								
270°	0.3	1,100	0.109	200	0.3	15,200	0.03				
300°	0.3	3,600	0.07	3,100	0.14	9,500	0.03				
330°	0.3	4,100	0.109	3,100	0.03						

Where
x_0 = upwind fetch
z_0 = roughness length

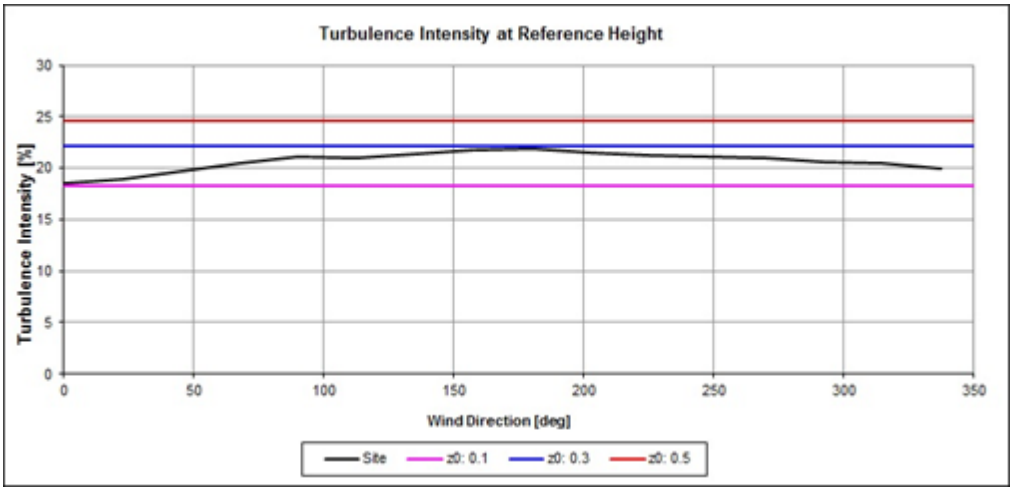
z0		
water	=	sea, lakes, estuaries
0.03	=	open country
0.1	=	sparse suburban
0.3	=	suburban
0.5	=	urban



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 36m.

Figure A.1: Variation of turbulence intensity with wind direction at 36m 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 36m) 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 36m

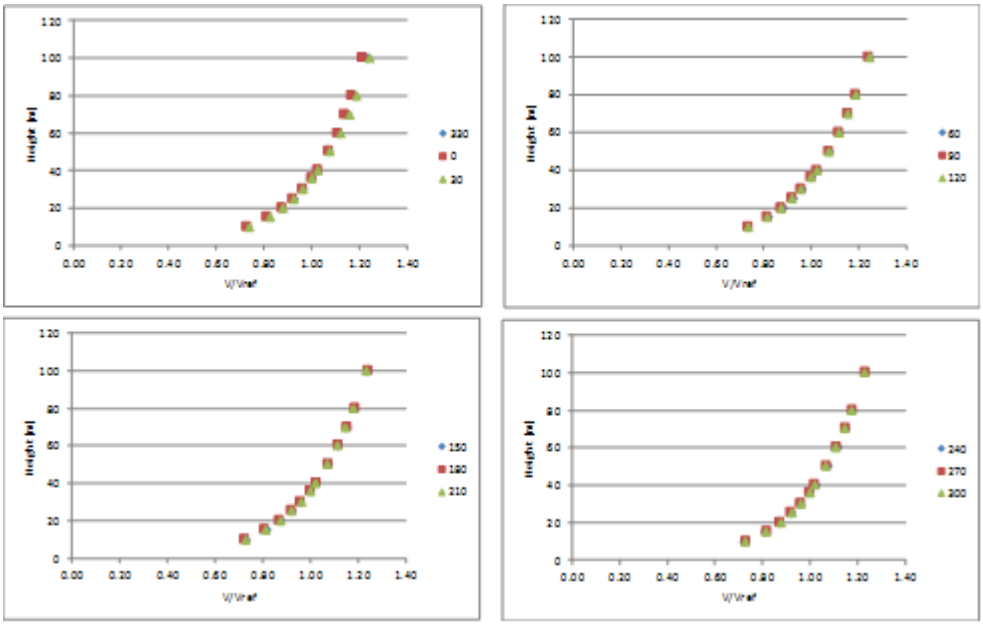


Figure A.3: Variation of longitudinal turbulence intensity with wind direction a reference height of 36m

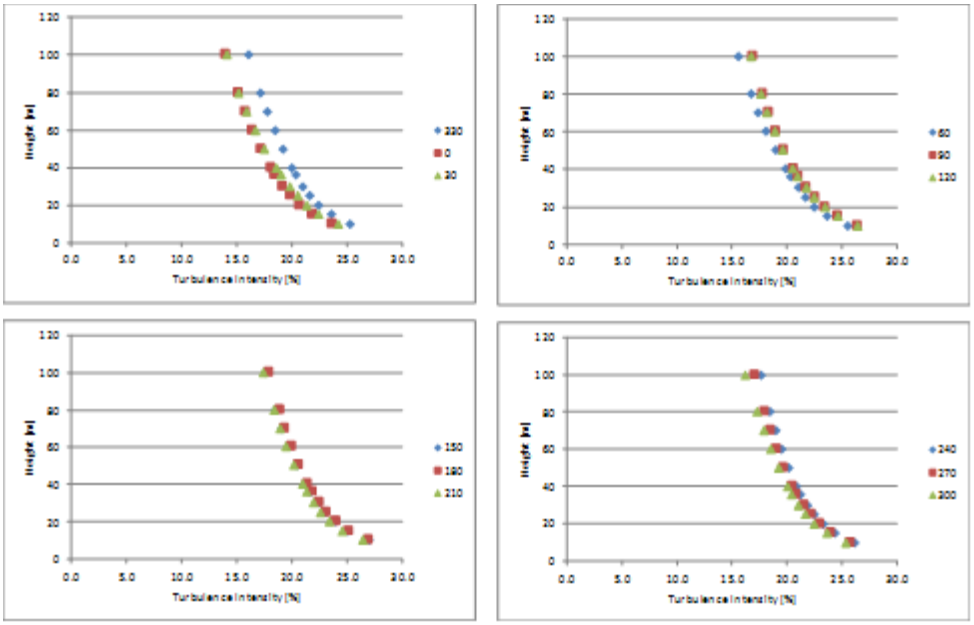
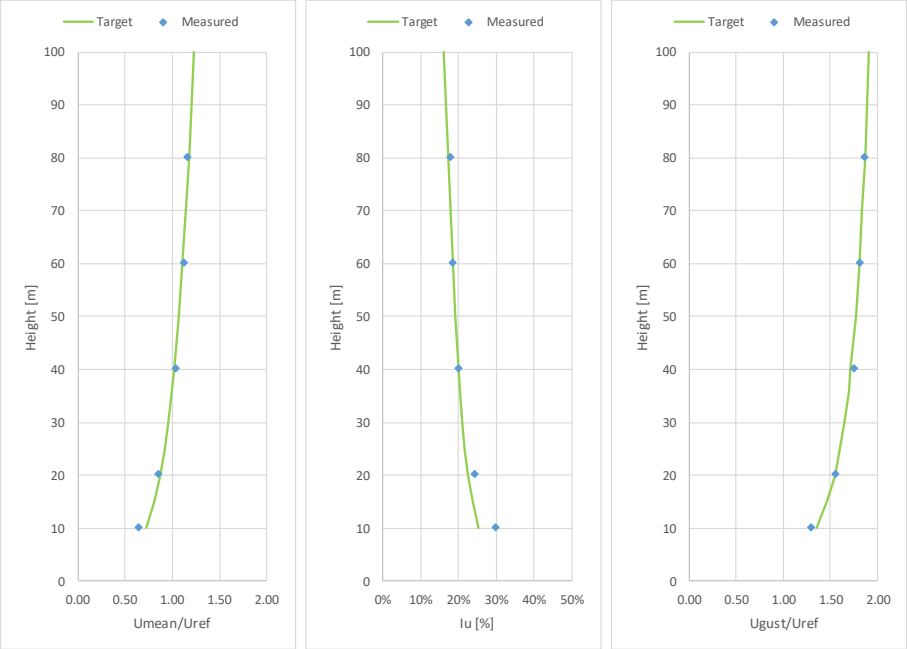


Figure A.4 presents the variation of mean wind speed, longitudinal turbulence intensity and gust wind speed used in the tests. The wind speed profiles are normalised by the mean wind speed at a reference height of 36m.

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 36m, at the proposed site, are given in Figures A.5a to A.5e, respectively.

Values of *p*, *c* and *k* for the London Heathrow 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 36m height)

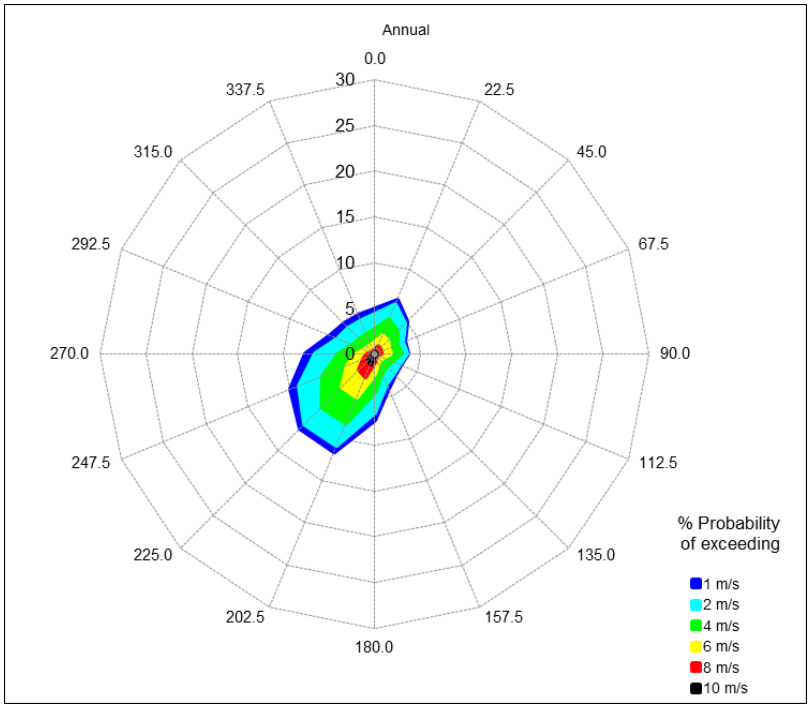


Figure A.5b: Directional Windspeed Probability Distribution at Site: Spring (at 36m height)

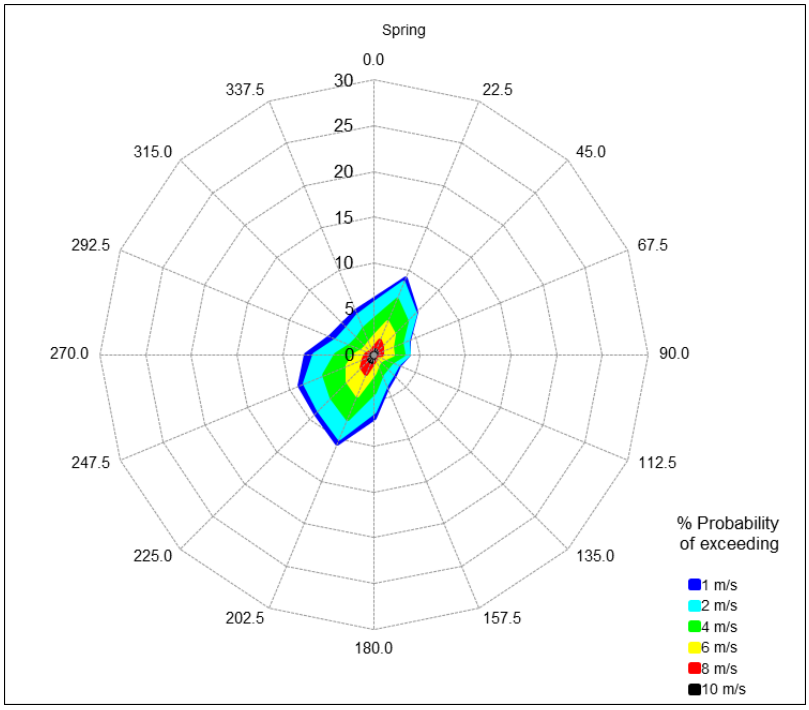


Figure A.5c: Directional Windspeed Probability Distribution at Site: Summer (at 36m height)

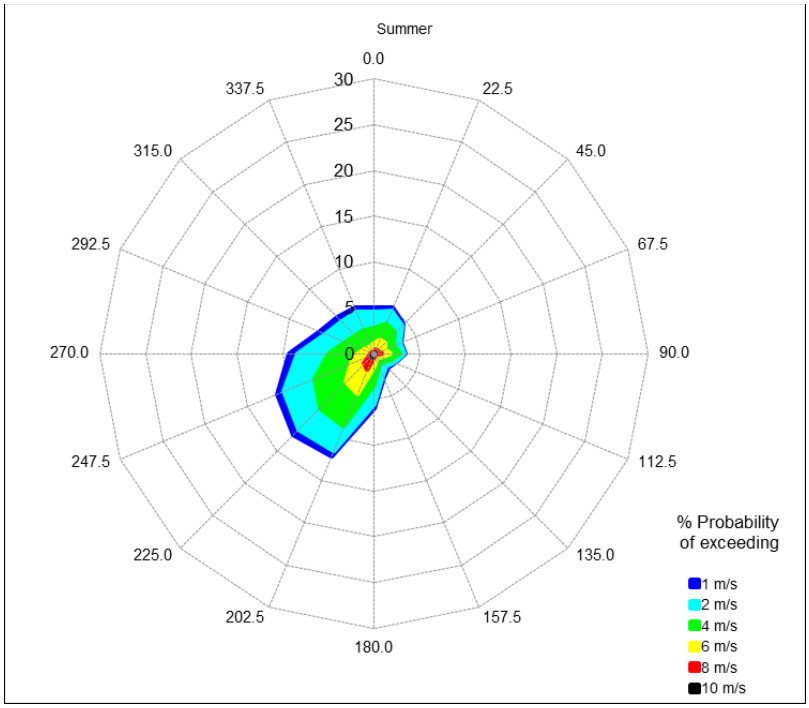


Figure A.5d: Directional Windspeed Probability Distribution at Site: Autumn (at 36m height)

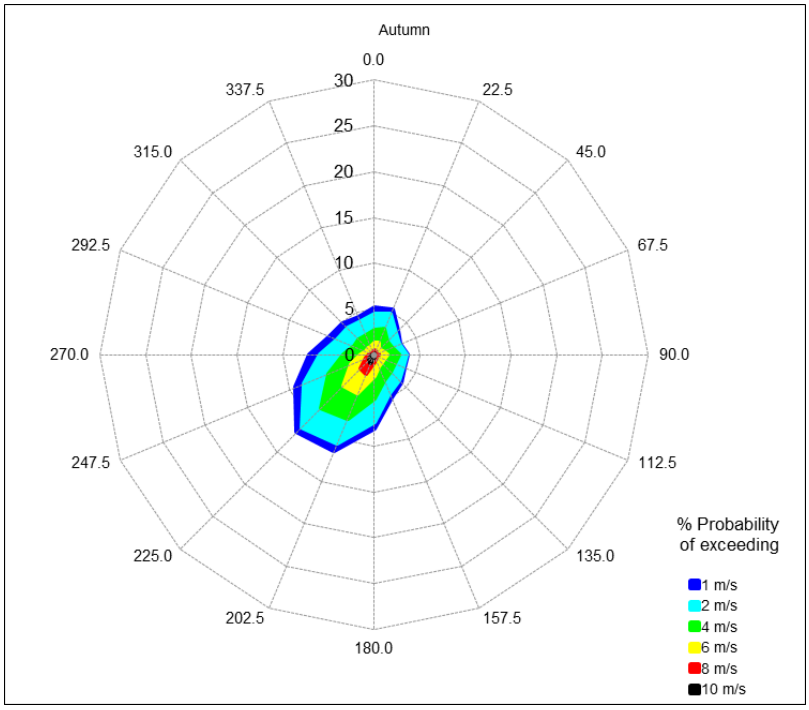


Figure A.5e: Directional Windspeed Probability Distribution at Site: Winter (at 36m height)

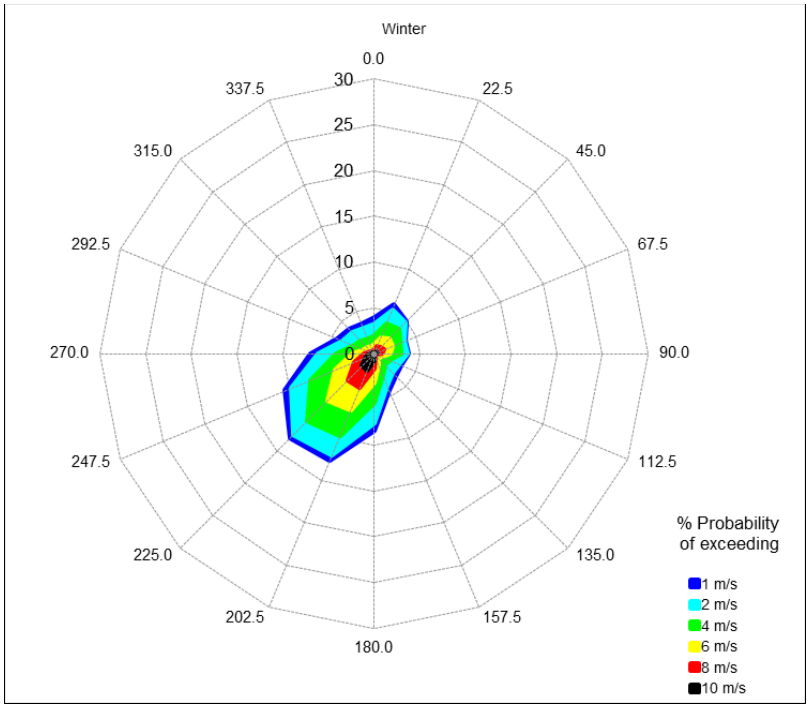


Table A.2: Wind frequency statistics: corrected London Heathrow weather centre data transformed to z0=0.03m Weibull Coefficients

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	5.28	6.57	5.05	3.56	3.73	3.14	3.35	4.14	7.58	11.87	11.82	10.28	8.08	5.67	5.03	4.85
c	3.77	4.26	4.84	5.52	5.59	4.92	4.44	4.43	4.56	5.42	5.43	4.79	4.06	3.70	3.58	3.62
k	1.88	2.06	2.38	2.46	2.68	2.48	2.18	1.94	1.84	2.01	2.13	1.97	1.74	1.69	1.79	1.91

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	5.44	5.53	3.78	3.17	3.74	3.71	4.37	5.19	8.42	11.76	12.16	9.66	7.66	5.75	5.08	4.59
c	3.60	3.82	3.90	4.81	5.11	4.82	4.52	4.49	4.54	5.11	5.16	4.51	3.70	3.42	3.55	3.63
k	1.86	2.09	2.31	2.48	2.70	2.55	2.24	2.11	2.01	1.92	2.19	1.99	1.72	1.74	1.89	2.09

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	4.27	6.06	5.06	3.71	3.87	3.29	3.57	4.52	8.74	12.86	13.22	10.77	7.37	4.79	4.10	3.79
c	3.56	4.12	5.25	6.22	5.59	4.51	4.00	4.54	5.10	6.10	6.25	5.58	4.59	3.96	3.82	3.59
k	1.60	1.85	2.47	2.74	2.42	2.19	1.96	1.76	1.82	2.06	2.29	2.06	1.65	1.60	1.76	1.70

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	6.26	9.20	6.67	4.10	3.87	3.01	3.23	4.01	7.13	10.63	9.24	9.04	7.77	5.49	5.03	5.35
c	4.21	4.72	5.19	5.66	5.76	5.09	4.67	4.48	4.52	5.45	5.49	4.94	4.29	3.92	3.76	3.95
k	2.06	2.24	2.61	2.65	3.01	2.60	2.31	2.08	2.05	2.20	2.20	2.22	1.85	1.64	1.79	1.97

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	5.12	5.49	4.66	3.25	3.45	2.56	2.24	2.88	6.07	12.26	12.72	11.67	9.52	6.64	5.85	5.62
c	3.69	4.17	4.65	5.20	5.84	5.27	4.50	4.17	4.33	5.07	4.87	4.43	4.01	3.76	3.57	3.51
k	2.27	2.49	2.55	2.45	2.87	2.78	2.15	2.15	2.40	2.43	2.35	2.57	2.34	2.19	2.27	2.35

APPENDIX B. WIND TUNNEL & MODEL DETAILS

B.1. Wind Tunnel Specifications

All the tests were conducted in the lower section of Imperial College's 10x5 Wind Tunnel which has a working section 3.1m wide, 1.5m high and 20m long with a 3.0m diameter turntable and a remotely controlled 3-dimensional traversing system. The operating wind speed range is 0 – 40m/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 shark 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 the 3D model, "A_44032_MH_3D Mill Hill.dwg" (received 13th February 2019) supplied by AFK Studios, the architects for the scheme.

The model of the existing surrounding area was based on OS superplan data supplemented by a site survey conducted by BMT using publicly available information.

The models of the consented cumulative surrounding development were based on information supplied by the design team.

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.

B.2.4. Model Photos

Images of the wind tunnel model are presented as follows:

- Figure B.1 - close-up 1: proposed development
- Figure B.2 - close-up 2: proposed development
- Figure B.3 - proximity model: existing surrounding conditions
- Figure B.4 - proximity model: cumulative surrounding conditions
- Figure B.5 - wind tunnel set-up, viewed from downstream

Figure B.1: Close-up of the proposed development, viewed from south east

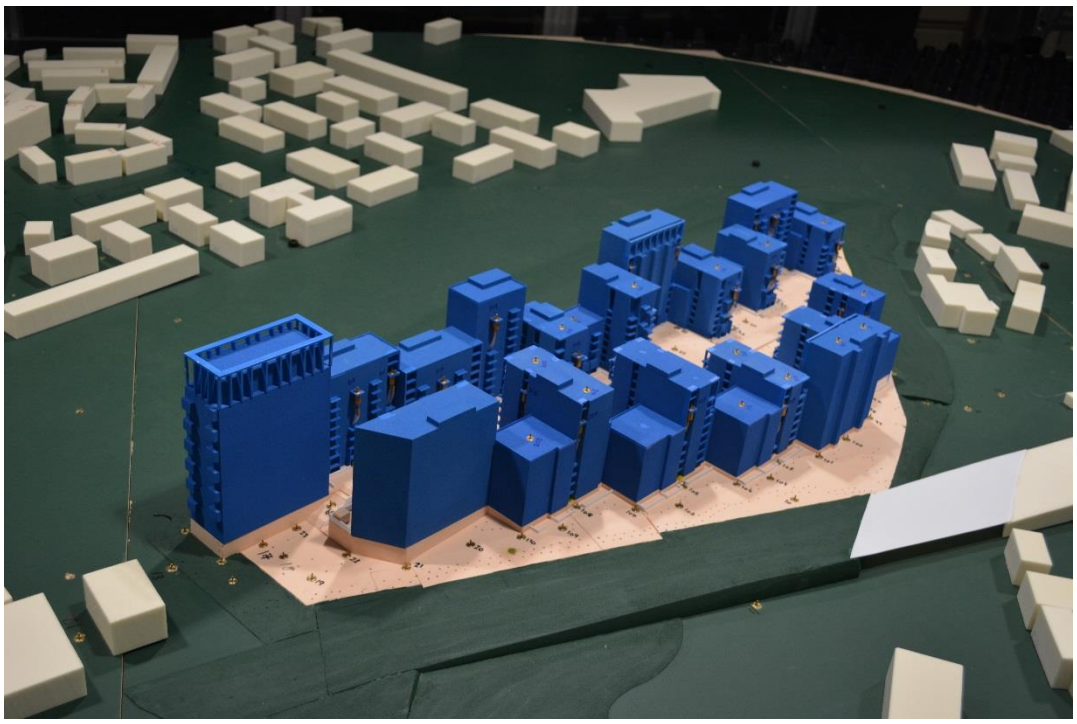


Figure B.2: Close-up of the proposed development, viewed from south west

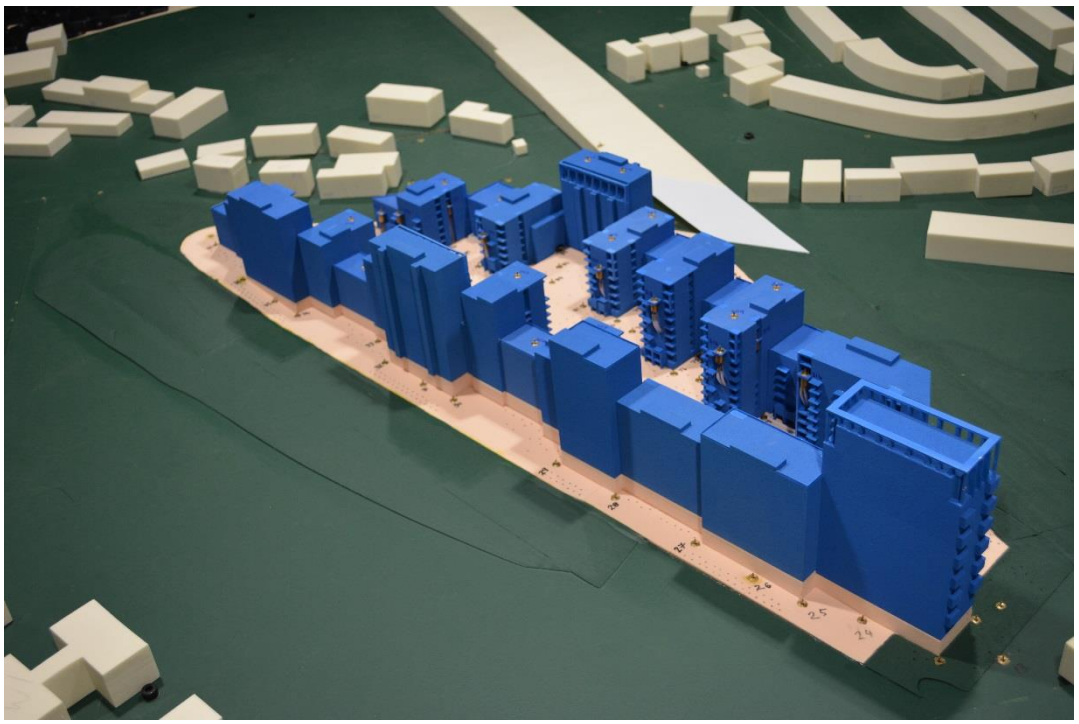


Figure B.3: Proximity model: existing surrounding conditions, viewed from north

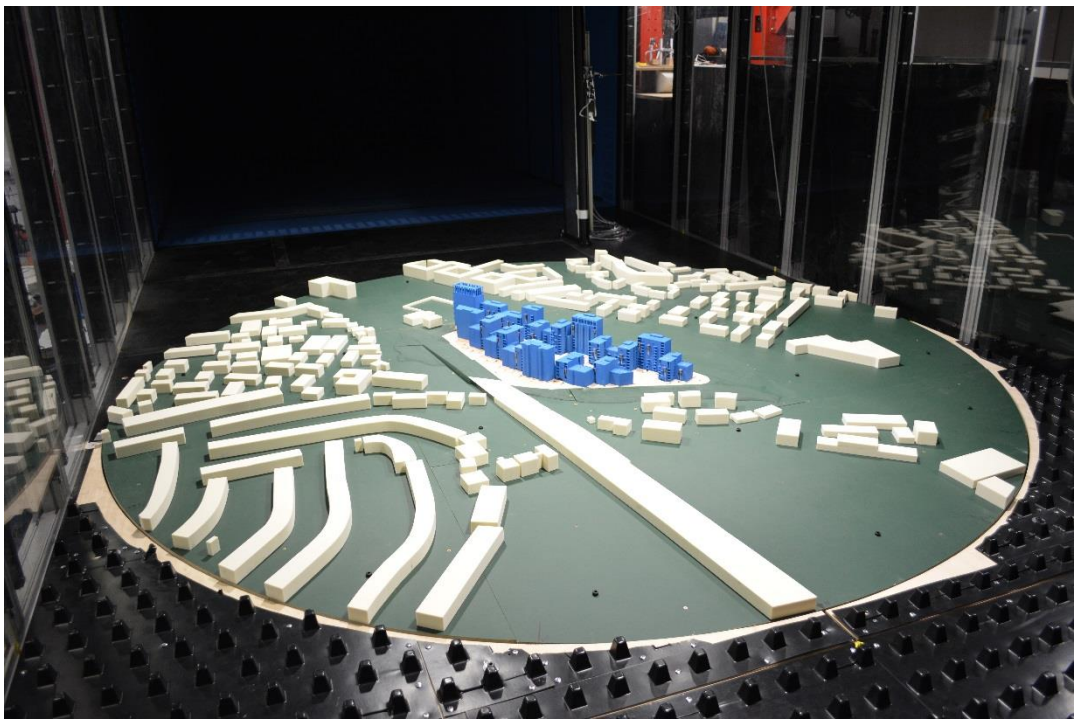


Figure B.4: Proximity model: cumulative surrounding conditions, viewed from north

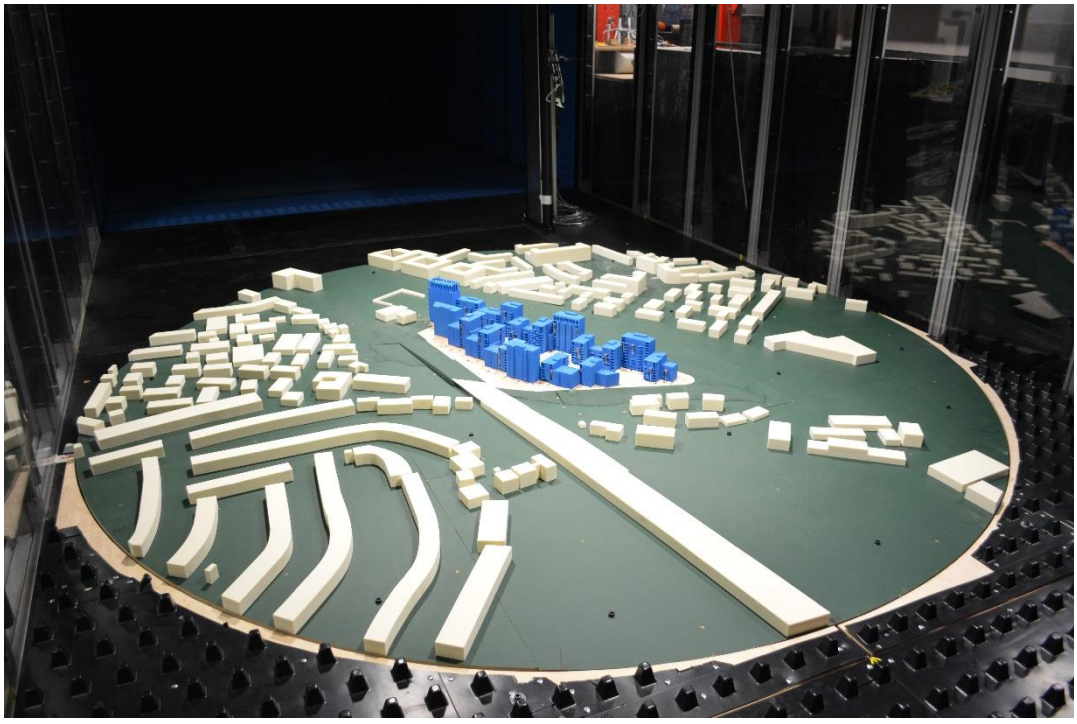


Figure B.5: Wind tunnel set-up, viewed from downstream

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 157 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 and C.3b present the pedestrian uses assumed for each of the corresponding measurement locations presented in Figures 6.1 to 6.3c.

- Table C.3a presents the pedestrian uses for the existing site conditions
- Table C.3b presents the potential uses at each measurement location for the proposed development within the context of
    - existing surrounds
    - cumulative surrounds

Table C.3a: Pedestrian uses – existing site conditions

Loc'n	Intended Use	Loc'n	Intended Use
8	Thoroughfare (A-to-B)	107	Thoroughfare (A-to-B)
10	Thoroughfare (A-to-B)	108	Thoroughfare (A-to-B)
11	Thoroughfare (A-to-B)	109	Thoroughfare (A-to-B)
14	Thoroughfare (A-to-B)	110	Thoroughfare (A-to-B)
15	Thoroughfare (A-to-B)	111	Thoroughfare (A-to-B)
16	Thoroughfare (A-to-B)	112	Thoroughfare (A-to-B)
17	Recreational Space	113	Thoroughfare (A-to-B)
18	Entrance	114	Thoroughfare (A-to-B)
19	Thoroughfare (A-to-B)	115	Thoroughfare (A-to-B)
20	Thoroughfare (A-to-B)	119	Thoroughfare (A-to-B)
25	Thoroughfare (A-to-B)	120	Thoroughfare (A-to-B)
26	Thoroughfare (A-to-B)	121	Thoroughfare (A-to-B)
27	Thoroughfare (A-to-B)	123	Thoroughfare (A-to-B)
28	Thoroughfare (A-to-B)	125	Thoroughfare (A-to-B)
31	Thoroughfare (A-to-B)	126	Thoroughfare (A-to-B)
32	Thoroughfare (A-to-B)	138	Thoroughfare (A-to-B)
33	Thoroughfare (A-to-B)	140	Thoroughfare (A-to-B)
35	Thoroughfare (A-to-B)	141	Thoroughfare (A-to-B)
36	Recreational Space	142	Thoroughfare (A-to-B)
101	Thoroughfare (A-to-B)	143	Thoroughfare (A-to-B)
102	Thoroughfare (A-to-B)	144	Thoroughfare (A-to-B)
104	Thoroughfare (A-to-B)	145	Thoroughfare (A-to-B)
105	Thoroughfare (A-to-B)	146	Thoroughfare (A-to-B)
106	Thoroughfare (A-to-B)	147	Thoroughfare (A-to-B)

Table C.3b: Pedestrian Uses – proposed development in existing and cumulative surrounds

Loc'n	Intended Use	Loc'n	Intended Use
1	Thoroughfare (A-to-B)	43	Recreational Space
2	Thoroughfare (A-to-B)	44	Entrance
3	Entrance	45	Leisure Thoroughfare
4	Recreational Space	46	Leisure Thoroughfare
5	Thoroughfare (A-to-B)	47	Recreational Space
6	Waiting Area	48	Leisure Thoroughfare
7	Leisure Thoroughfare	49	Leisure Thoroughfare
8	Leisure Thoroughfare	50	Entrance
9	Thoroughfare (A-to-B)	51	Entrance
10	Waiting Area	52	Recreational Space
11	Waiting Area	53	Recreational Space
13	Leisure Thoroughfare	54	Entrance
14	Leisure Thoroughfare	55	Leisure Thoroughfare
15	Leisure Thoroughfare	56	Leisure Thoroughfare
16	Leisure Thoroughfare	57	Recreational Space
17	Entrance / Shop Front	58	Leisure Thoroughfare
18	Leisure Thoroughfare	59	Leisure Thoroughfare
19	Leisure Thoroughfare	60	Recreational Space
20	Leisure Thoroughfare	61	Entrance
21	Leisure Thoroughfare	62	Entrance
22	Leisure Thoroughfare	63	Recreational Space
23	Entrance / Shop Front	64	Entrance
24	Entrance	65	Leisure Thoroughfare
25	Thoroughfare (A-to-B)	66	Leisure Thoroughfare
26	Entrance	67	Entrance
27	Thoroughfare (A-to-B)	68	Leisure Thoroughfare
28	Thoroughfare (A-to-B)	69	Recreational Space
29	Thoroughfare (A-to-B)	70	Entrance
30	Thoroughfare (A-to-B)	71	Leisure Thoroughfare
31	Entrance	72	Leisure Thoroughfare
32	Thoroughfare (A-to-B)	73	Recreational Space
33	Entrance	74	Recreational Space
34	Thoroughfare (A-to-B)	75	Entrance
35	Entrance	76	Leisure Thoroughfare
36	Thoroughfare (A-to-B)	77	Leisure Thoroughfare
37	Thoroughfare (A-to-B)	78	Recreational Space
38	Thoroughfare (A-to-B)	79	Entrance
39	Thoroughfare (A-to-B)	80	Leisure Thoroughfare
40	Leisure Thoroughfare	81	Leisure Thoroughfare
41	Entrance	82	Entrance
42	Entrance	83	Recreational Space

Loc'n	Intended Use	Loc'n	Intended Use
84	Recreational Space	211	Recreational Space
85	Leisure Thoroughfare	212	Recreational Space
86	Leisure Thoroughfare	213	Recreational Space
87	Leisure Thoroughfare	214	Recreational Space
88	Entrance	215	Recreational Space
89	Recreational Space	216	Recreational Space
90	Entrance	217	Recreational Space
91	Leisure Thoroughfare	218	Recreational Space
92	Leisure Thoroughfare	300	Seating Balcony
93	Thoroughfare (A-to-B)	301	Seating Balcony
94	Thoroughfare (A-to-B)	302	Seating Balcony
95	Thoroughfare (A-to-B)	303	Seating Balcony
96	Thoroughfare (A-to-B)	304	Seating Balcony
97	Leisure Thoroughfare	305	Seating Balcony
98	Recreational Space	306	Seating Balcony
99	Leisure Thoroughfare	307	Seating Balcony
100	Thoroughfare (A-to-B)	308	Seating Balcony
101	Thoroughfare (A-to-B)	309	Seating Balcony
102	Thoroughfare (A-to-B)	310	Seating Balcony
103	Thoroughfare (A-to-B)	311	Seating Balcony
104	Thoroughfare (A-to-B)	312	Seating Balcony
105	Thoroughfare (A-to-B)	313	Seating Balcony
106	Thoroughfare (A-to-B)	314	Seating Balcony
107	Thoroughfare (A-to-B)	315	Seating Balcony
108	Thoroughfare (A-to-B)	316	Seating Balcony
109	Thoroughfare (A-to-B)	317	Seating Balcony
110	Thoroughfare (A-to-B)	318	Seating Balcony
200	Recreational Space	319	Seating Balcony
201	Recreational Space	320	Seating Balcony
202	Recreational Space	321	Seating Balcony
203	Recreational Space	322	Seating Balcony
204	Recreational Space	324	Seating Balcony
205	Recreational Space	325	Seating Balcony
206	Recreational Space	326	Seating Balcony
207	Recreational Space	327	Seating Balcony
208	Recreational Space	328	Seating Balcony
209	Recreational Space	329	Seating Balcony
210	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.1m present **annual safety** ratings for each configuration, for ground, terraces and balconies
- Figures D.2a to D.2m present **summer season comfort** ratings for each configuration, for ground, terraces and balconies
- Figures D.3a to D.3m present **worst seasonal comfort** ratings for each configuration, for ground, terraces and balconies

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: Annual safety ratings, existing site configuration, ground level

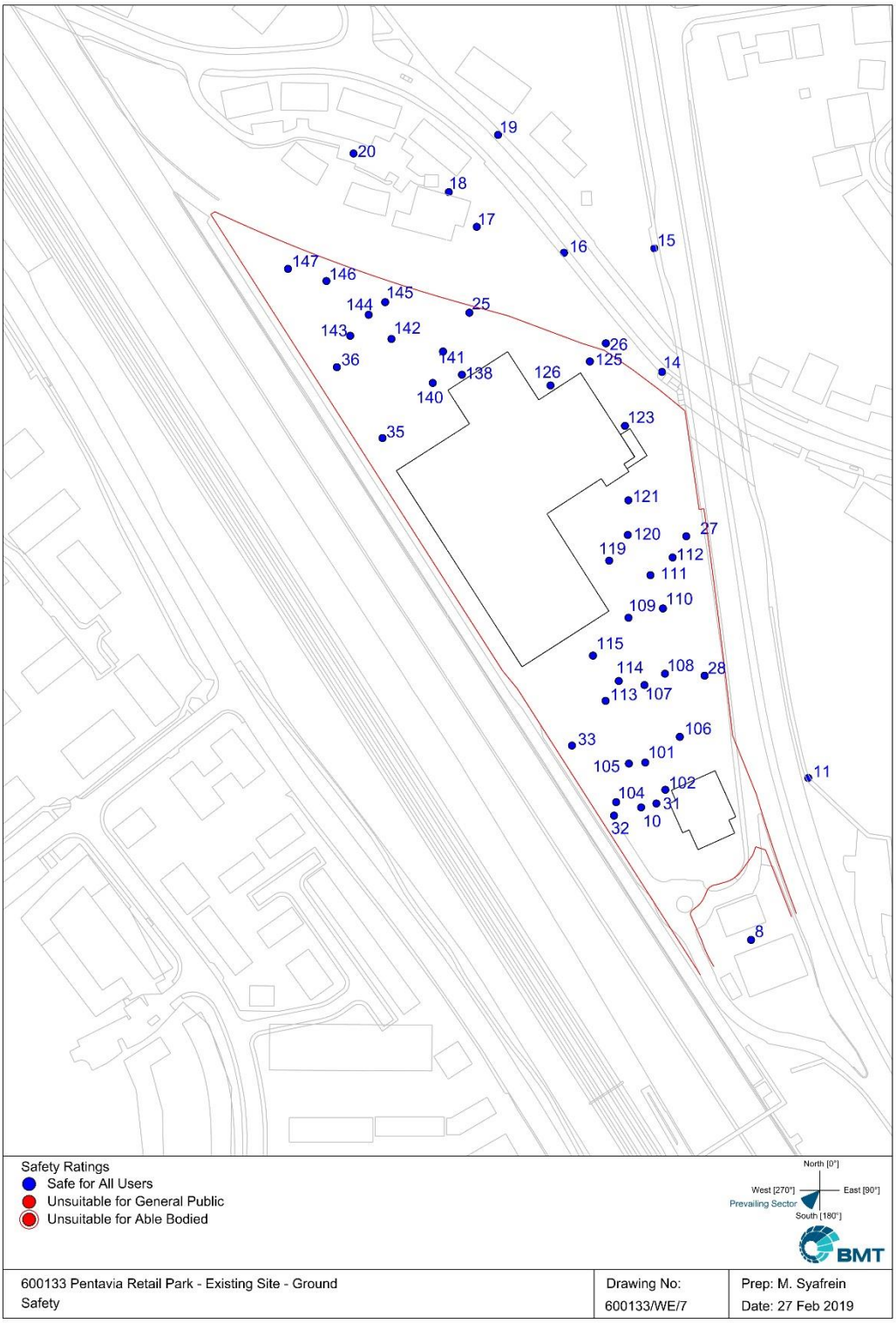


Figure D.1b: Annual safety ratings, proposed development within existing surrounds, lower ground level

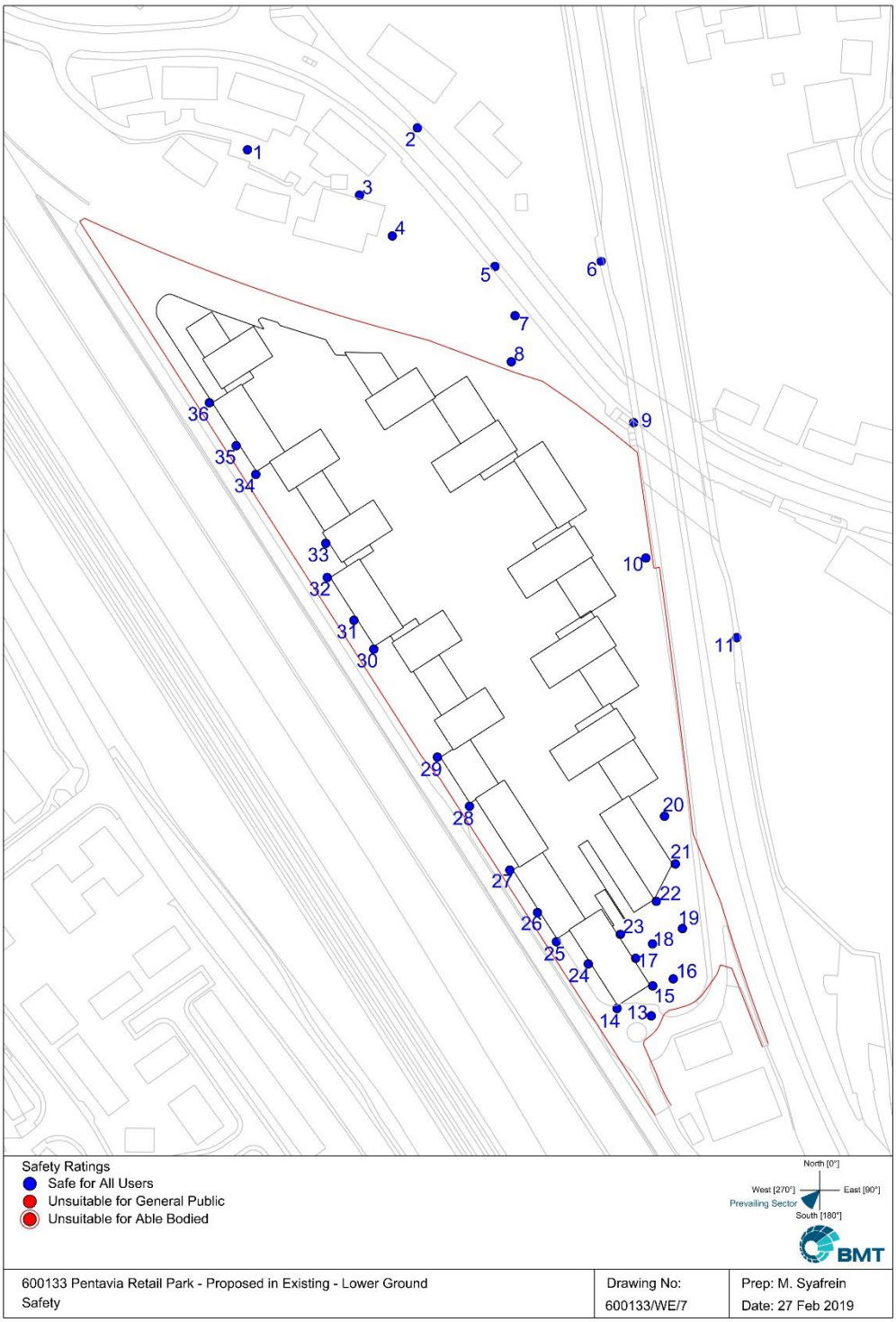


Figure D.1c: Annual safety ratings, proposed development within existing surrounds, upper ground level

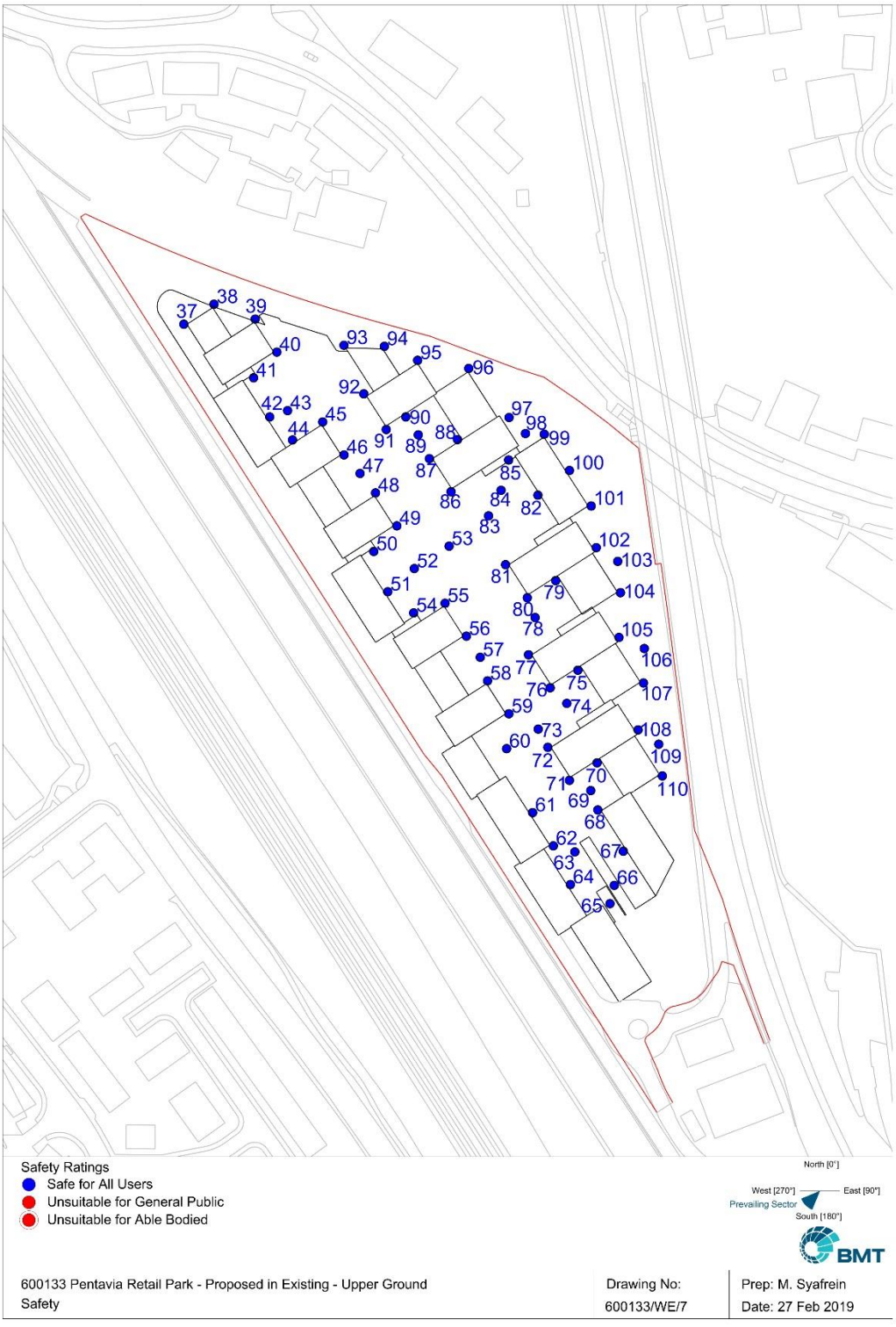


Figure D.1d: Annual safety ratings, proposed development within existing surrounds, terrace level

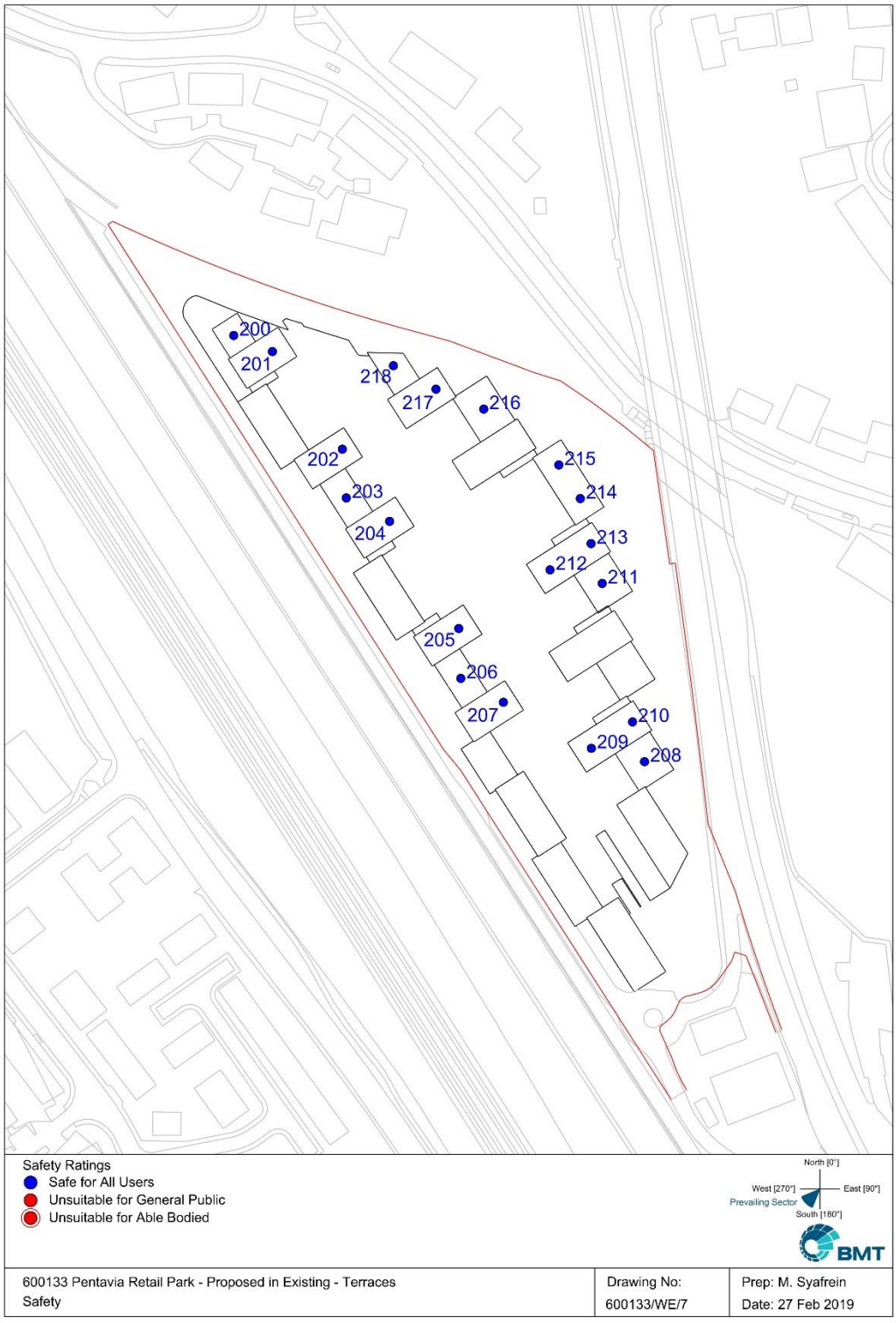


Figure D.1e: Annual safety ratings, proposed development within existing surrounds, balconies

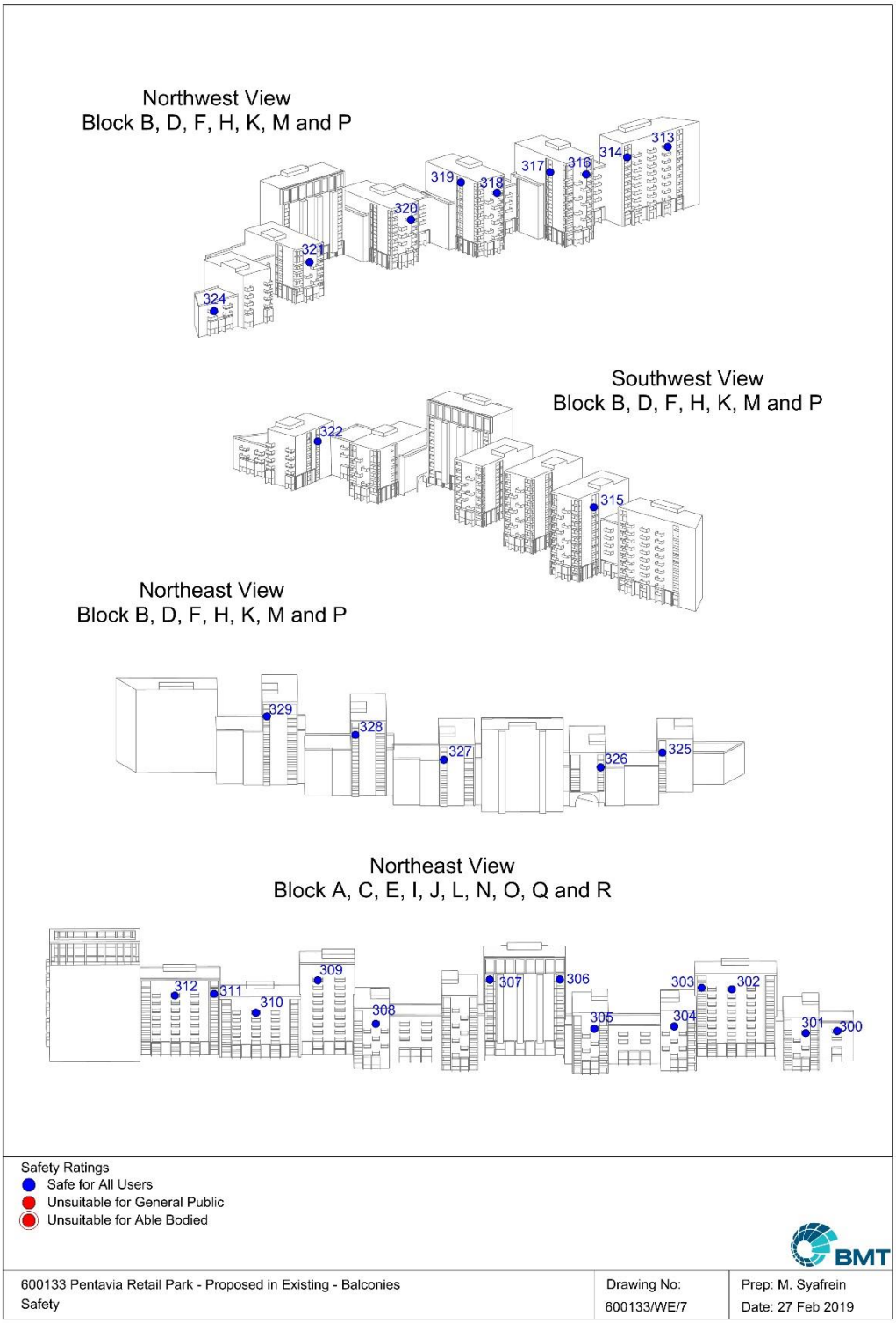


Figure D.1f: Annual safety ratings, proposed development within cumulative surrounds, lower ground level

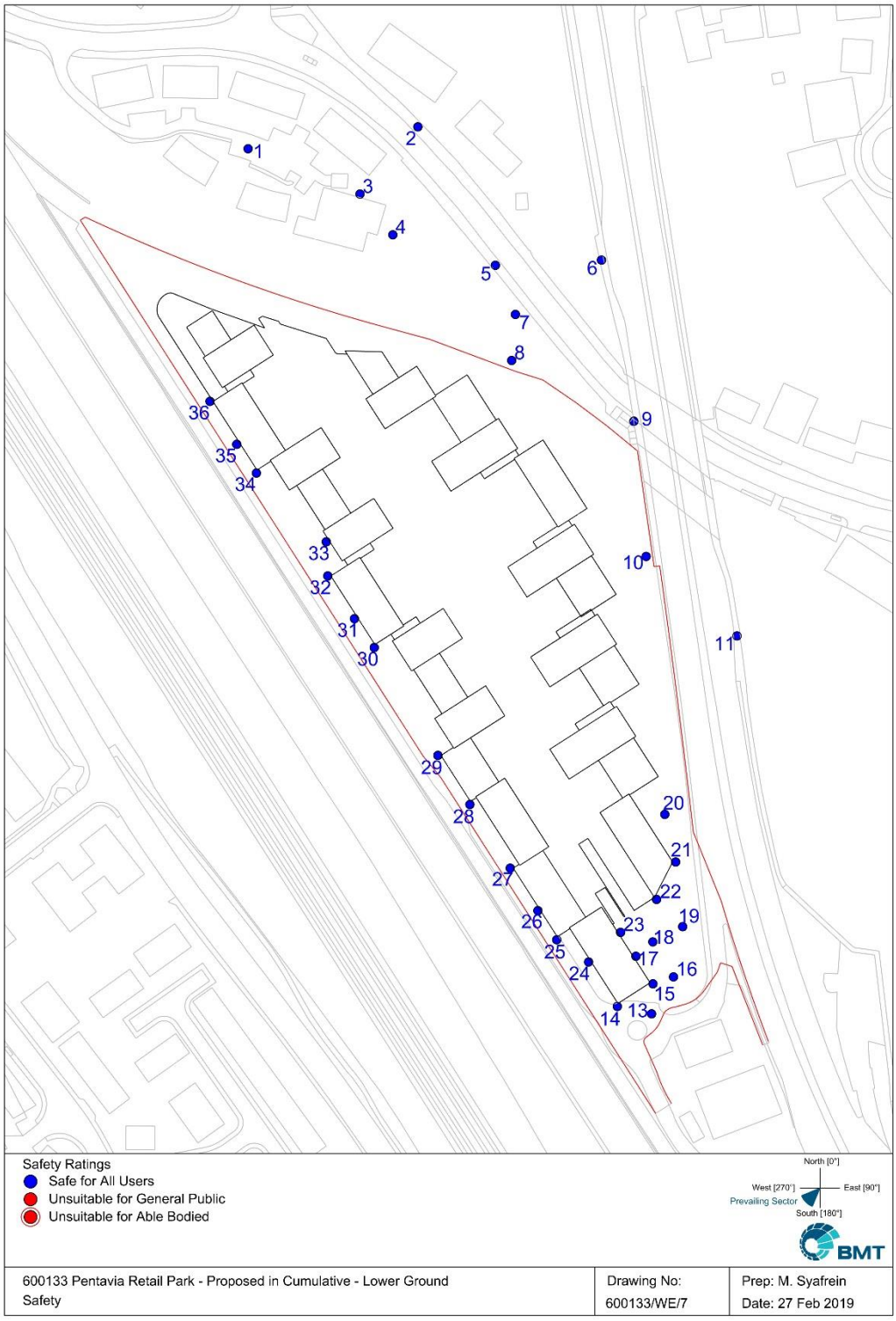


Figure D.1g: Annual safety ratings, proposed development within cumulative surrounds, upper ground level

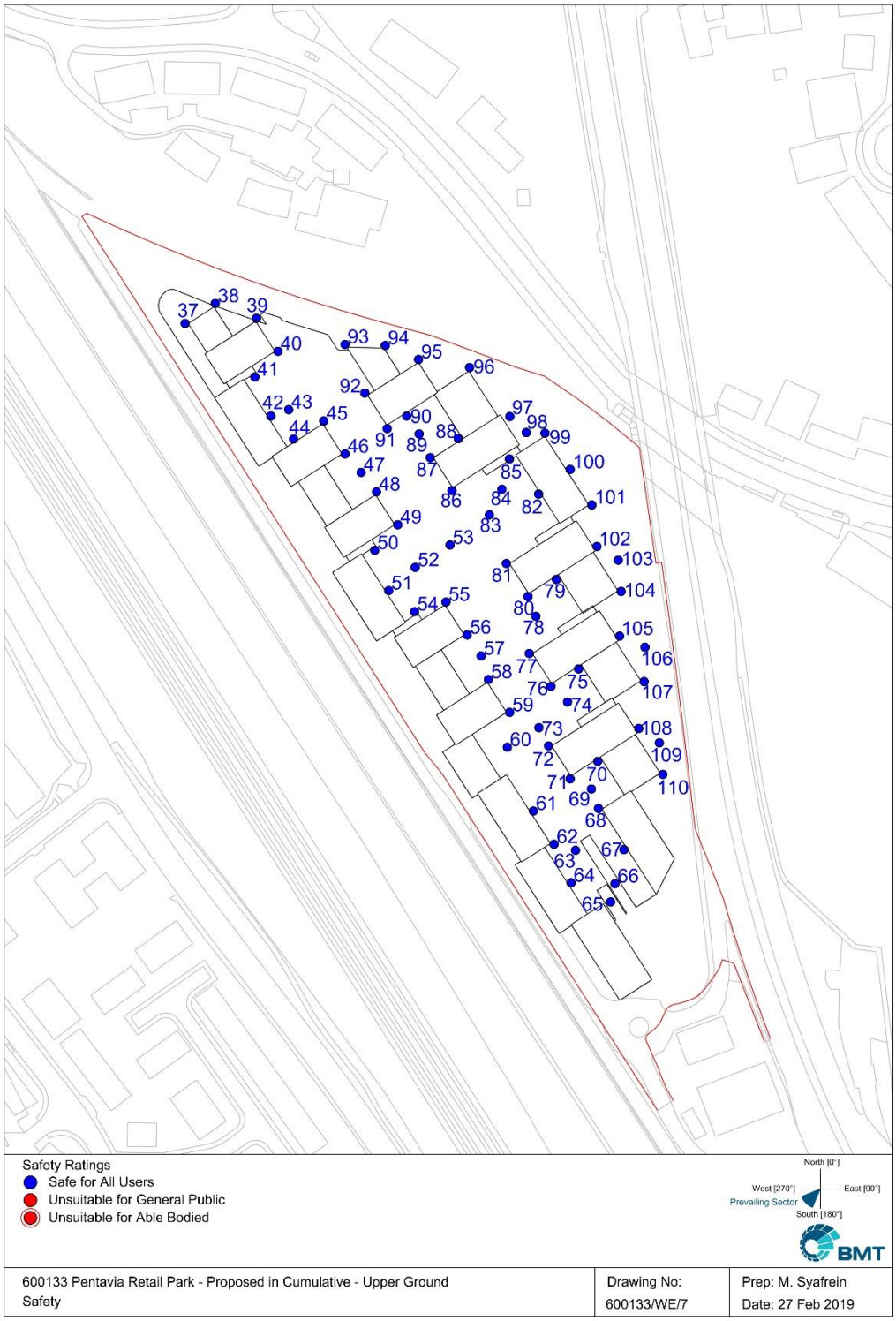


Figure D.1h: Annual safety ratings, proposed development within cumulative surrounds, terrace level

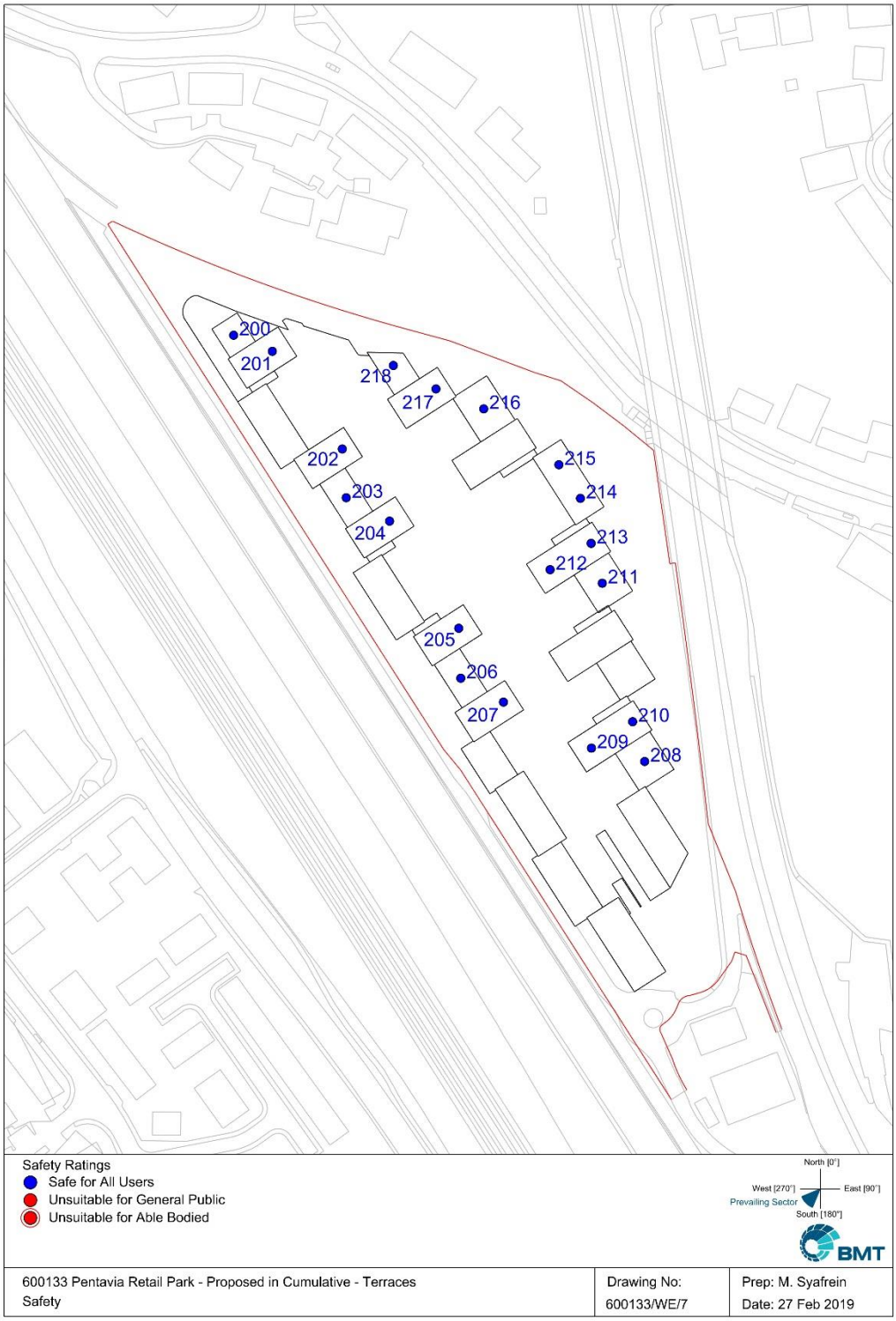


Figure D.1i: Annual safety ratings, proposed development within cumulative surrounds, balconies

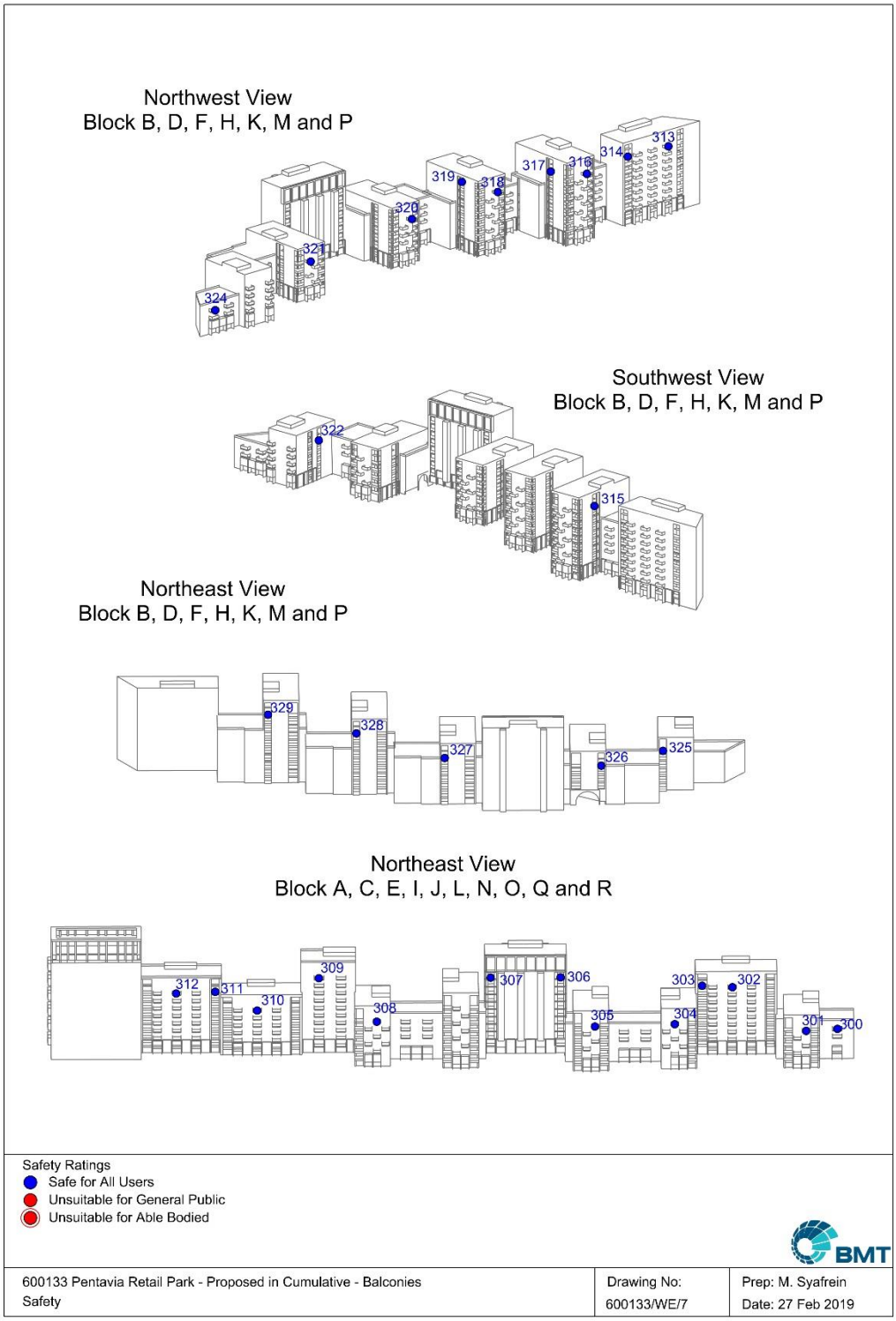


Figure D.1j: Annual safety ratings, proposed development within existing surrounds with soft landscaping, lower ground level

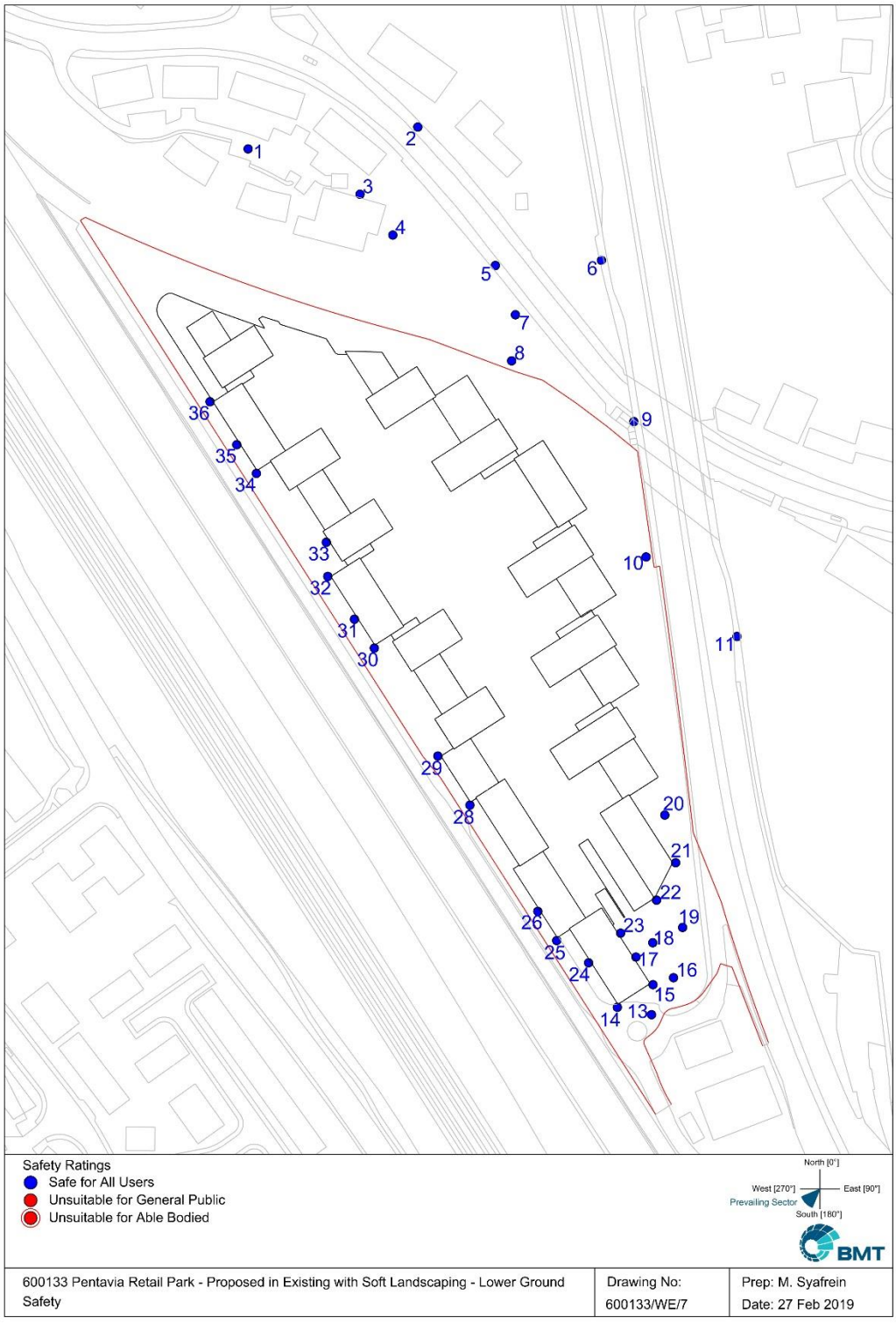


Figure D.1k: Annual safety ratings, proposed development within existing surrounds with soft landscaping, upper ground level

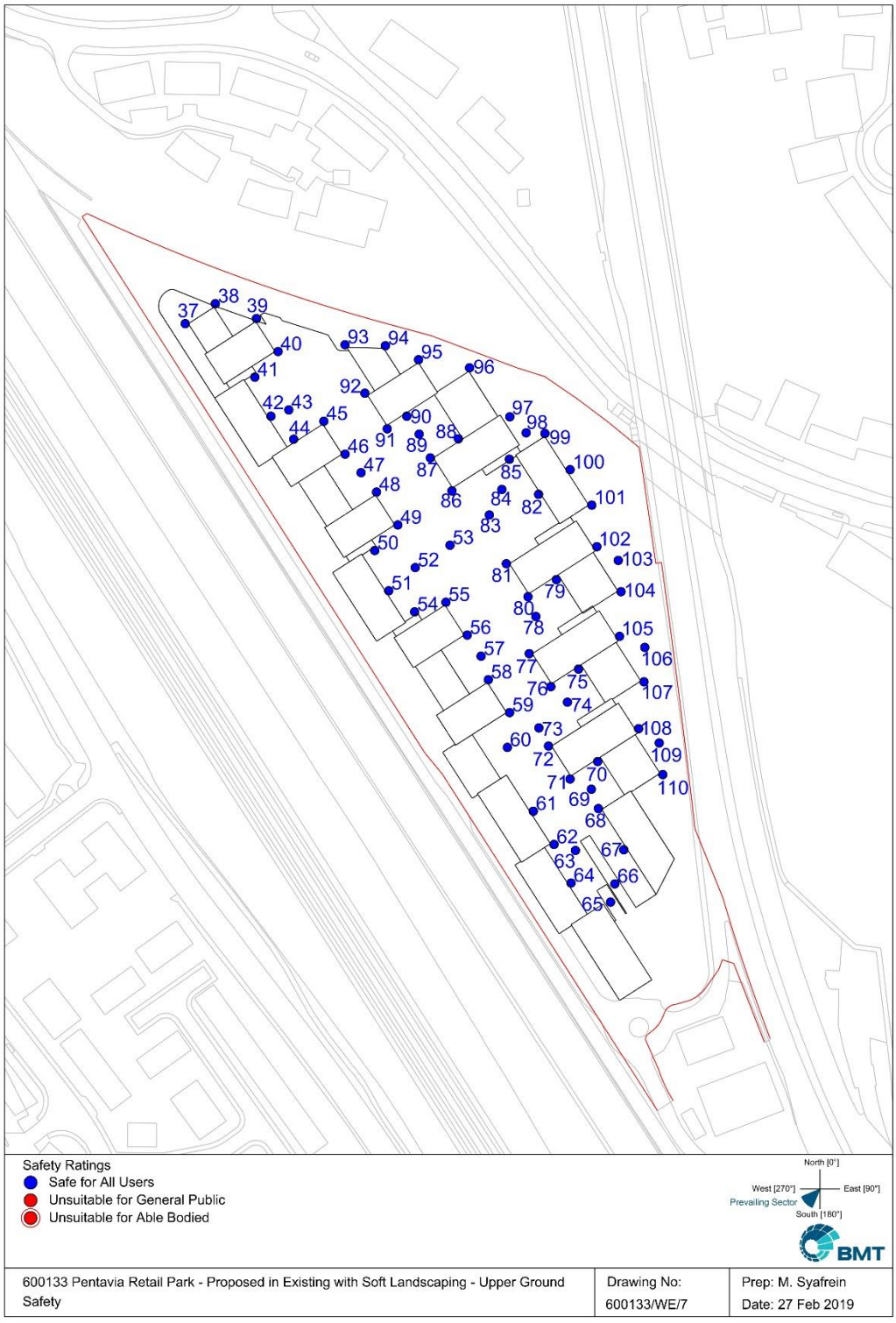


Figure D.1l: Annual safety ratings, proposed development within existing surrounds with soft landscaping, terrace level

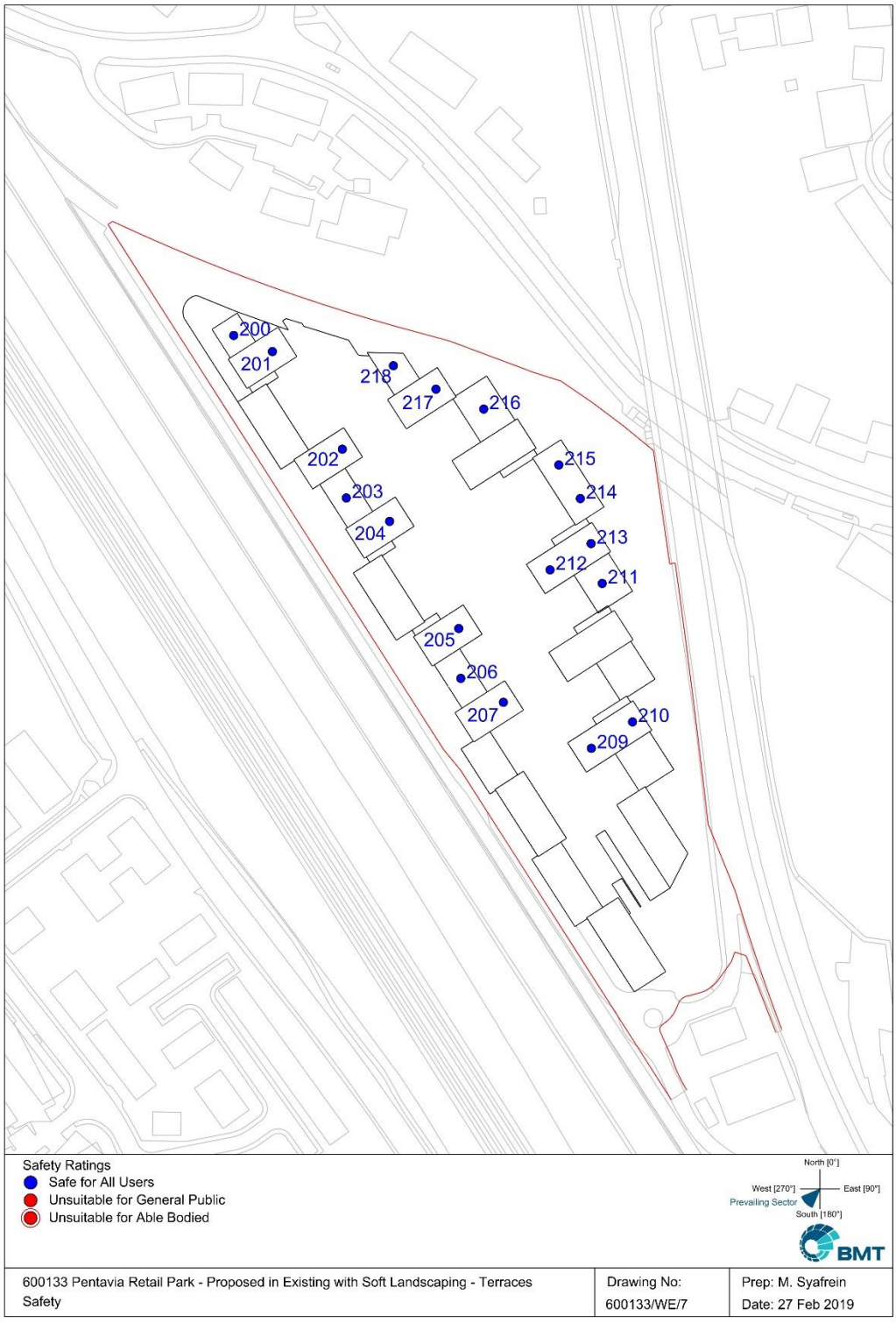


Figure D.1m: Annual safety ratings, proposed development within existing surrounds with soft landscaping, balconies

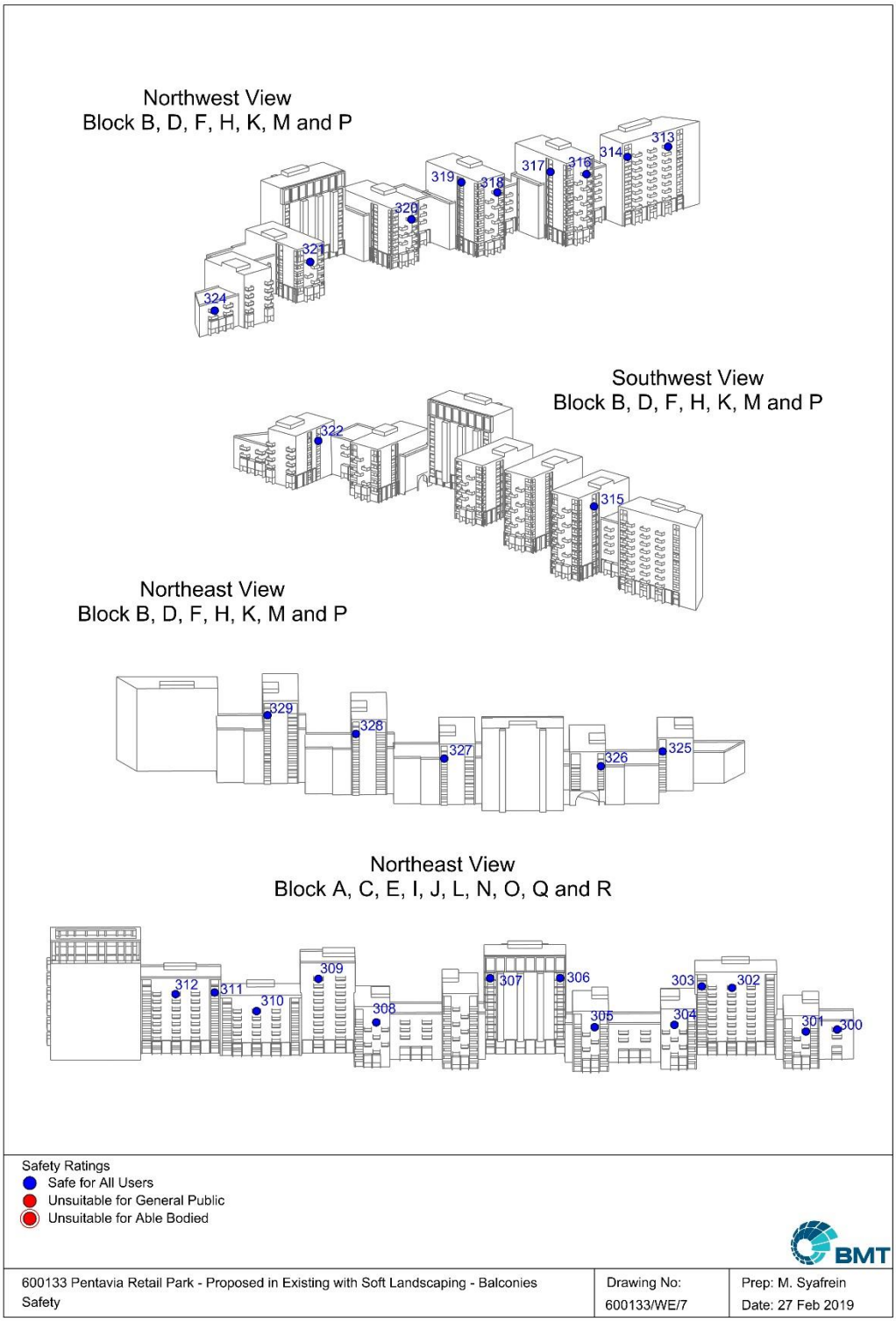


Figure D.2a: Summer comfort ratings, existing site, ground level

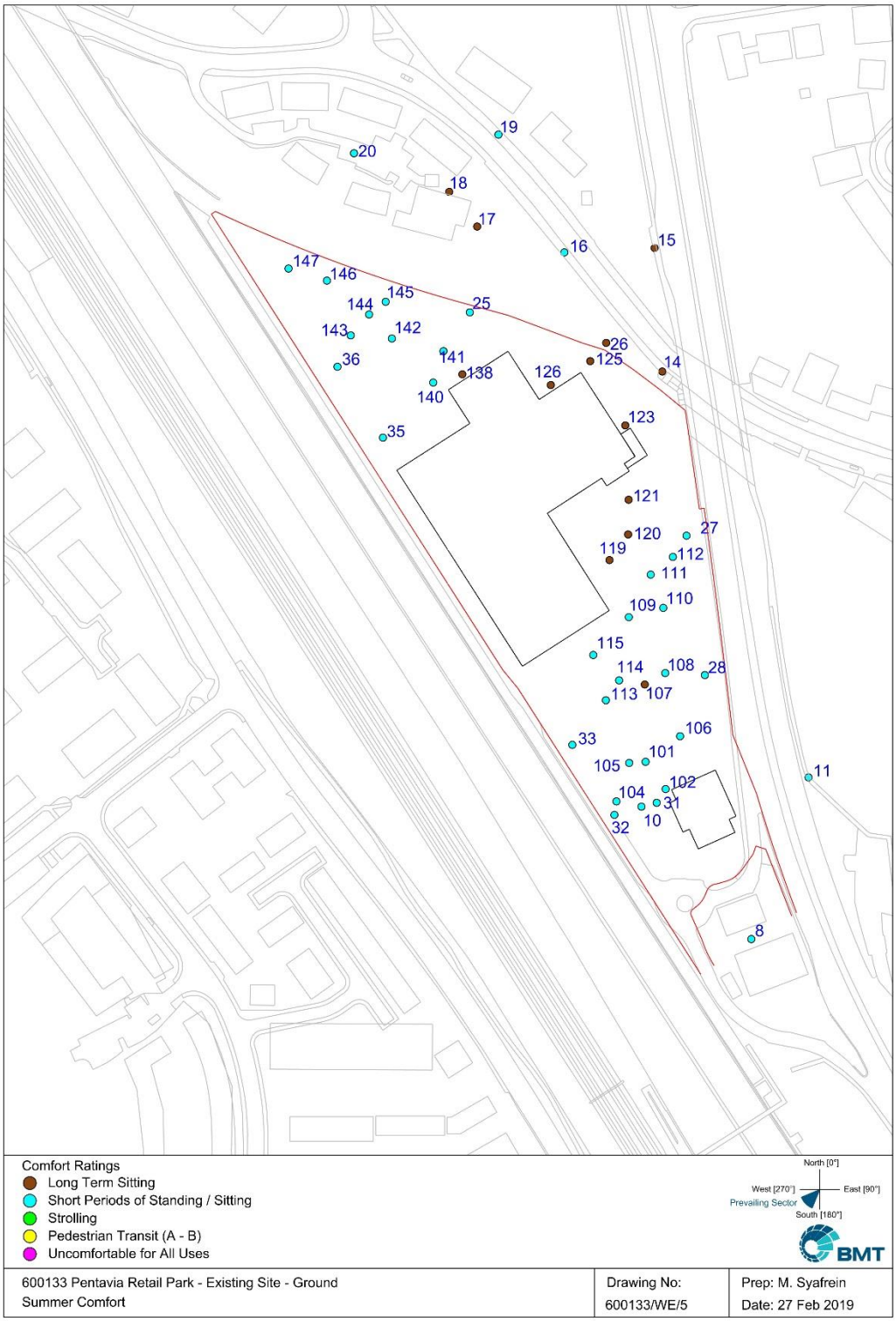


Figure D.2b: Summer comfort ratings, proposed development within existing surrounds, lower ground level

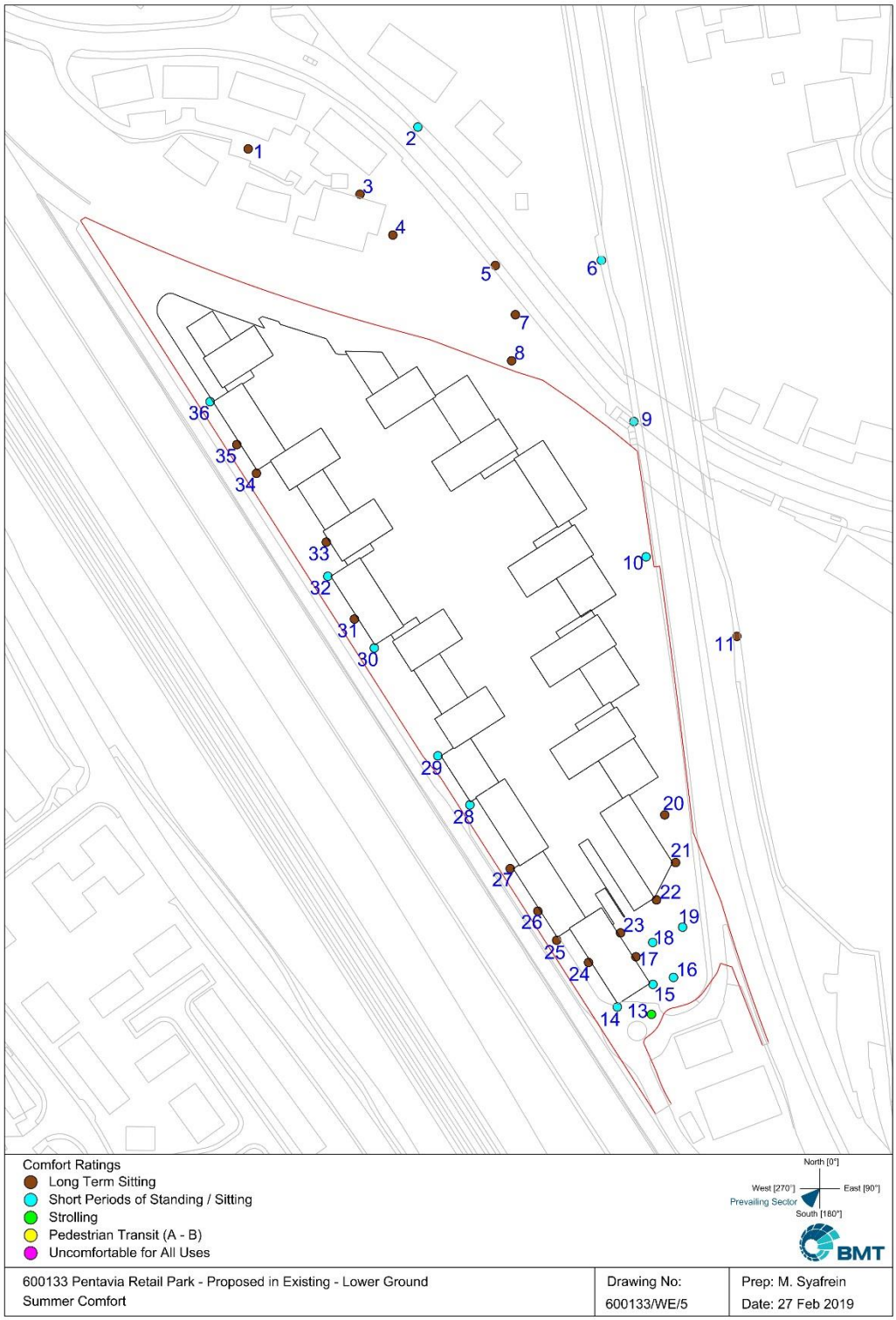


Figure D.2c: Summer comfort ratings, proposed development within existing surrounds, upper ground level

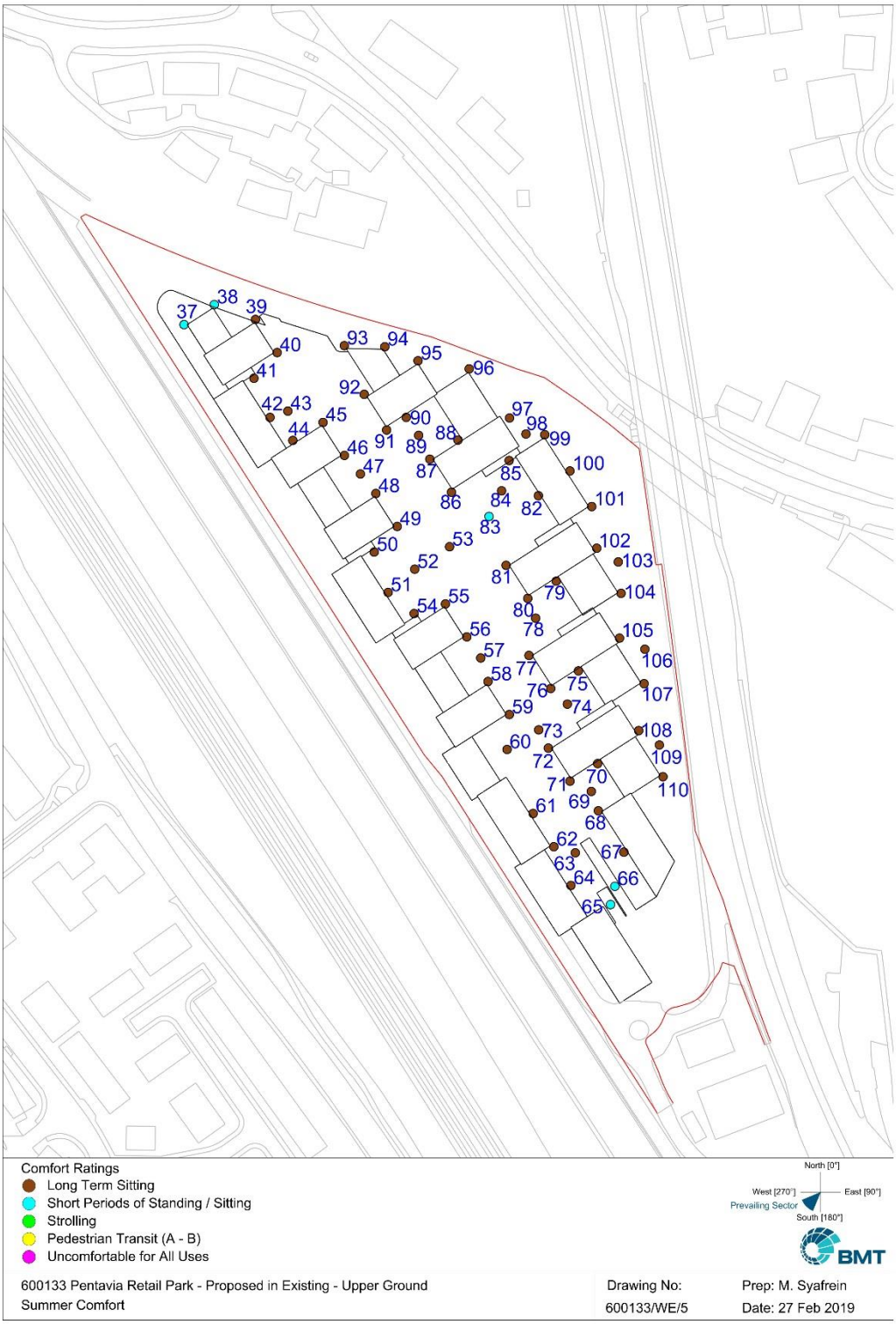


Figure D.2d: Summer comfort ratings, proposed development within existing surrounds, terrace level

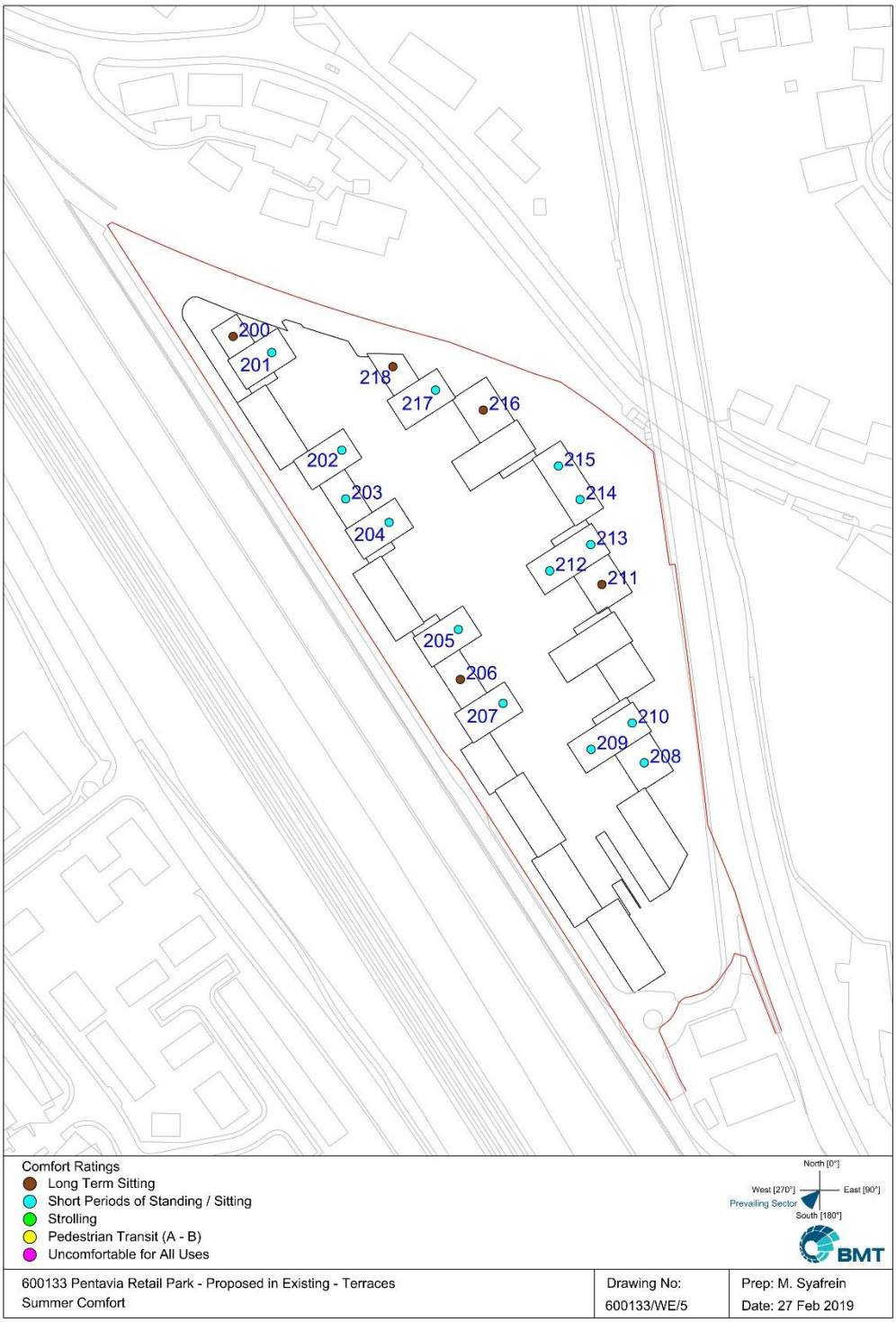


Figure D.2e: Summer comfort ratings, proposed development within existing surrounds, balconies

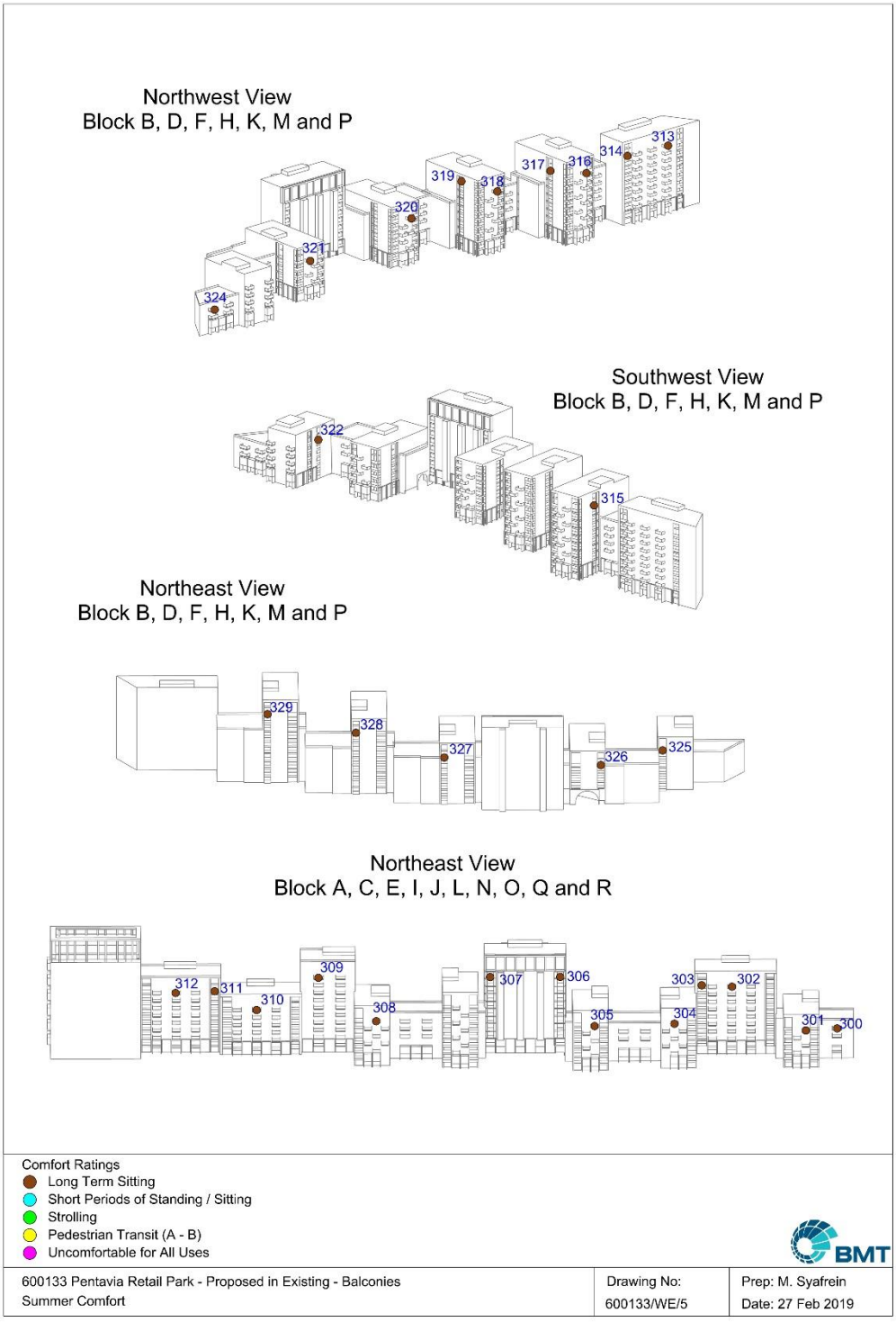


Figure D.2f: Summer comfort ratings, proposed development within cumulative surrounds, lower ground level

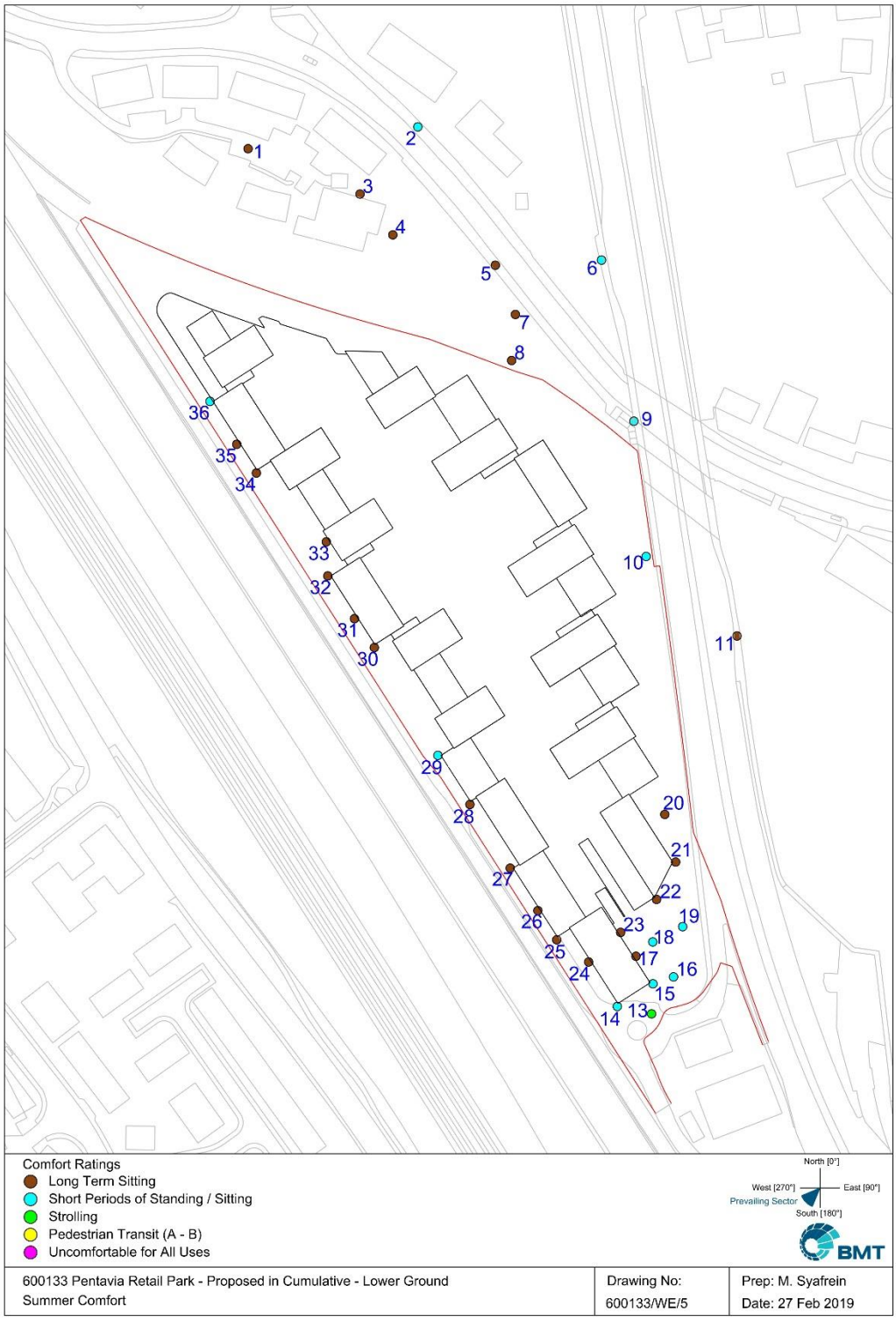


Figure D.2g: Summer comfort ratings, proposed development within cumulative surrounds, upper ground level

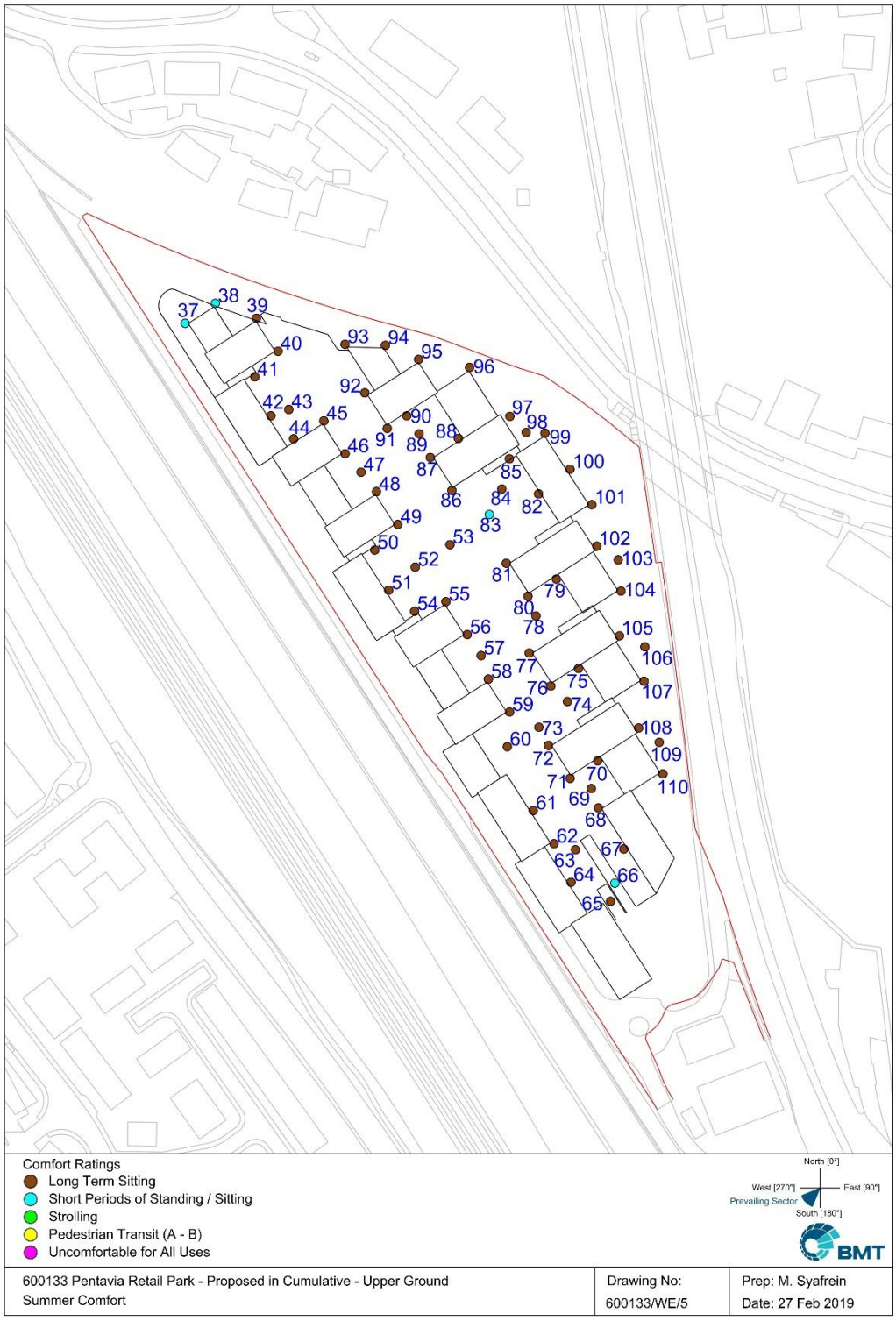


Figure D.2h: Summer comfort ratings, proposed development within cumulative surrounds, terrace level

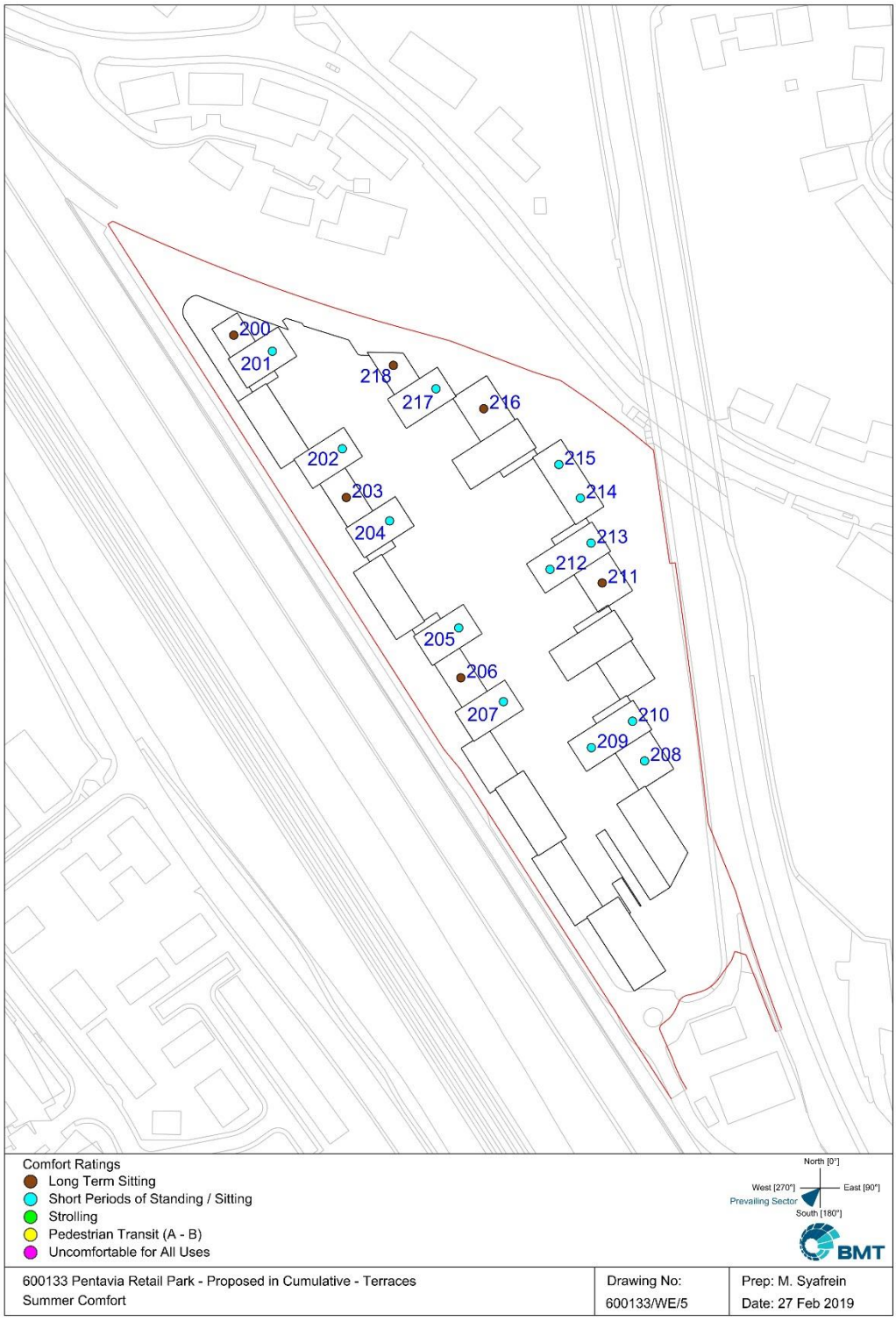


Figure D.2i: Summer comfort ratings, proposed development within cumulative surrounds, balconies

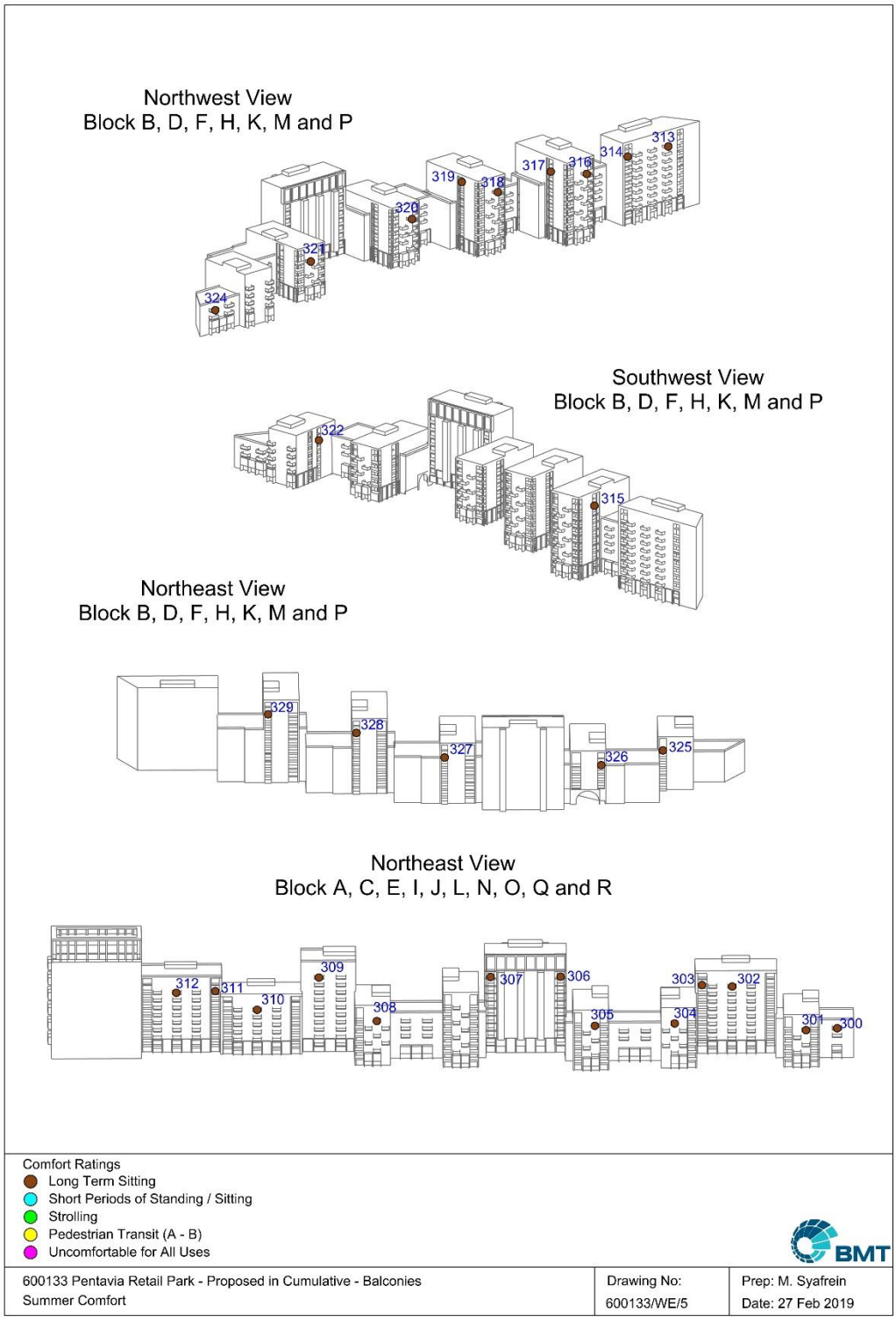


Figure D.2j: Summer comfort ratings, proposed development within existing surrounds with soft landscaping, lower ground level

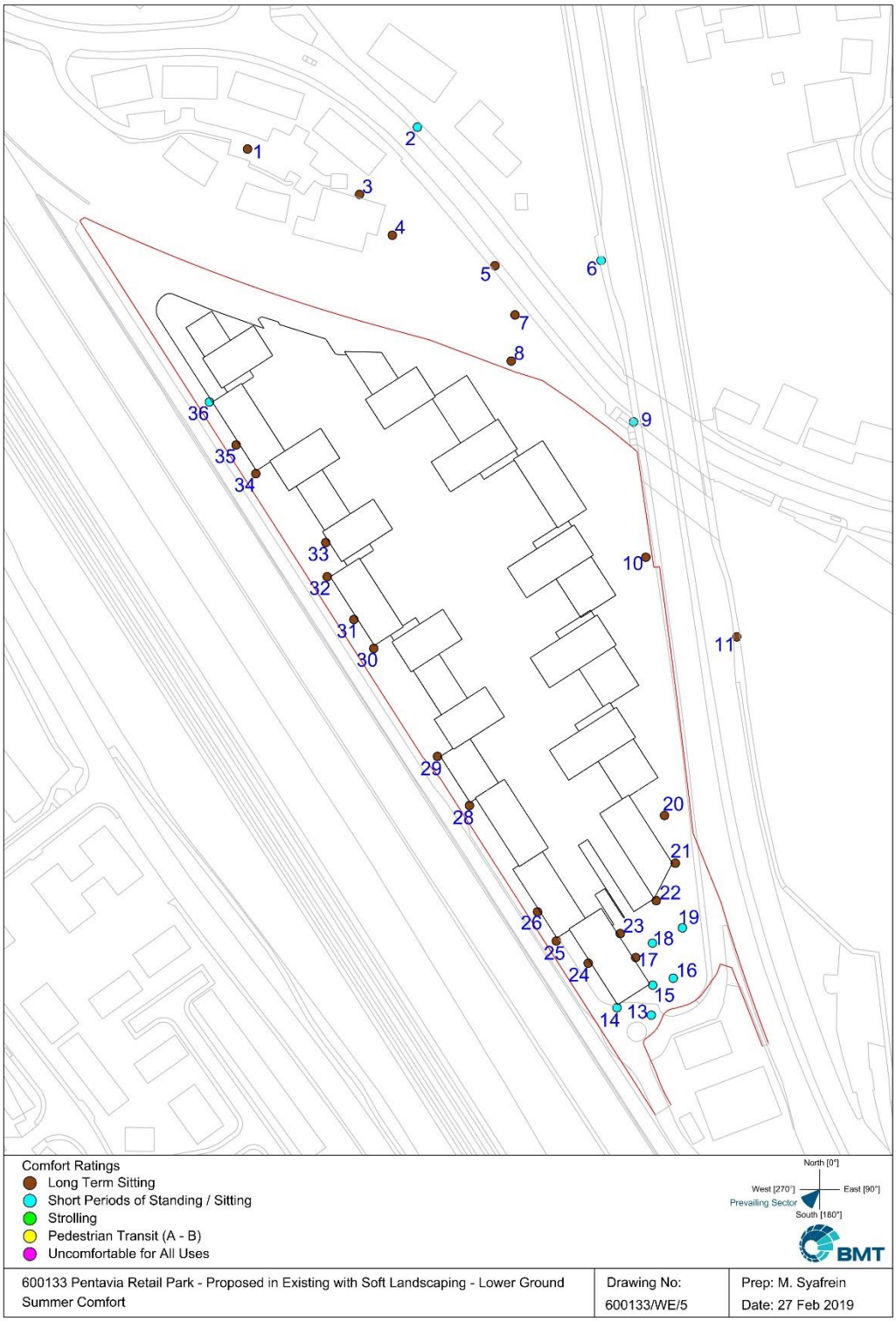


Figure D.2k: Summer comfort ratings, proposed development within existing surrounds with soft landscaping, upper ground level

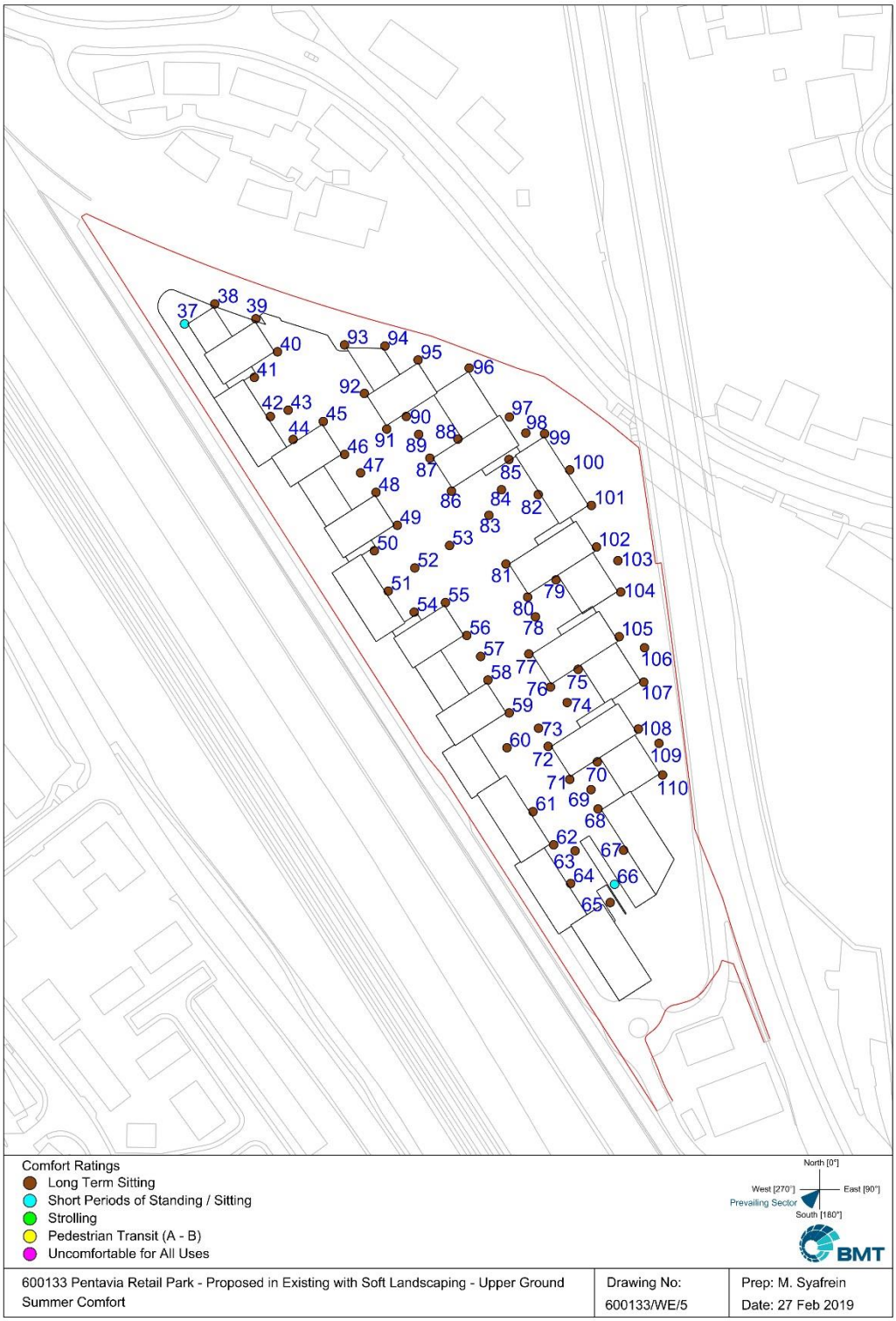


Figure D.2l: Summer comfort ratings, proposed development within existing surrounds with soft landscaping, terrace level

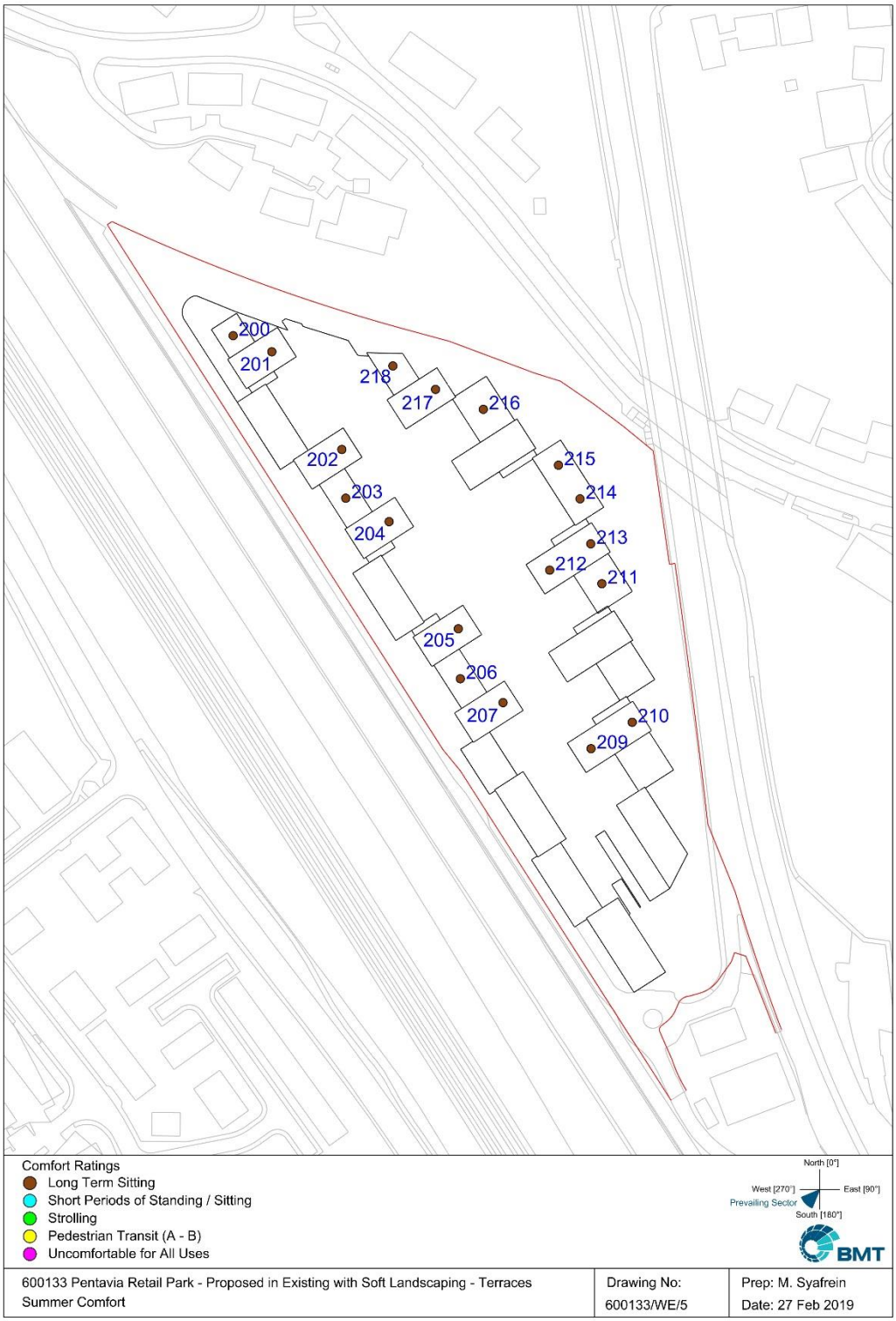


Figure D.2m: Summer comfort ratings, proposed development within existing surrounds with soft landscaping, balconies

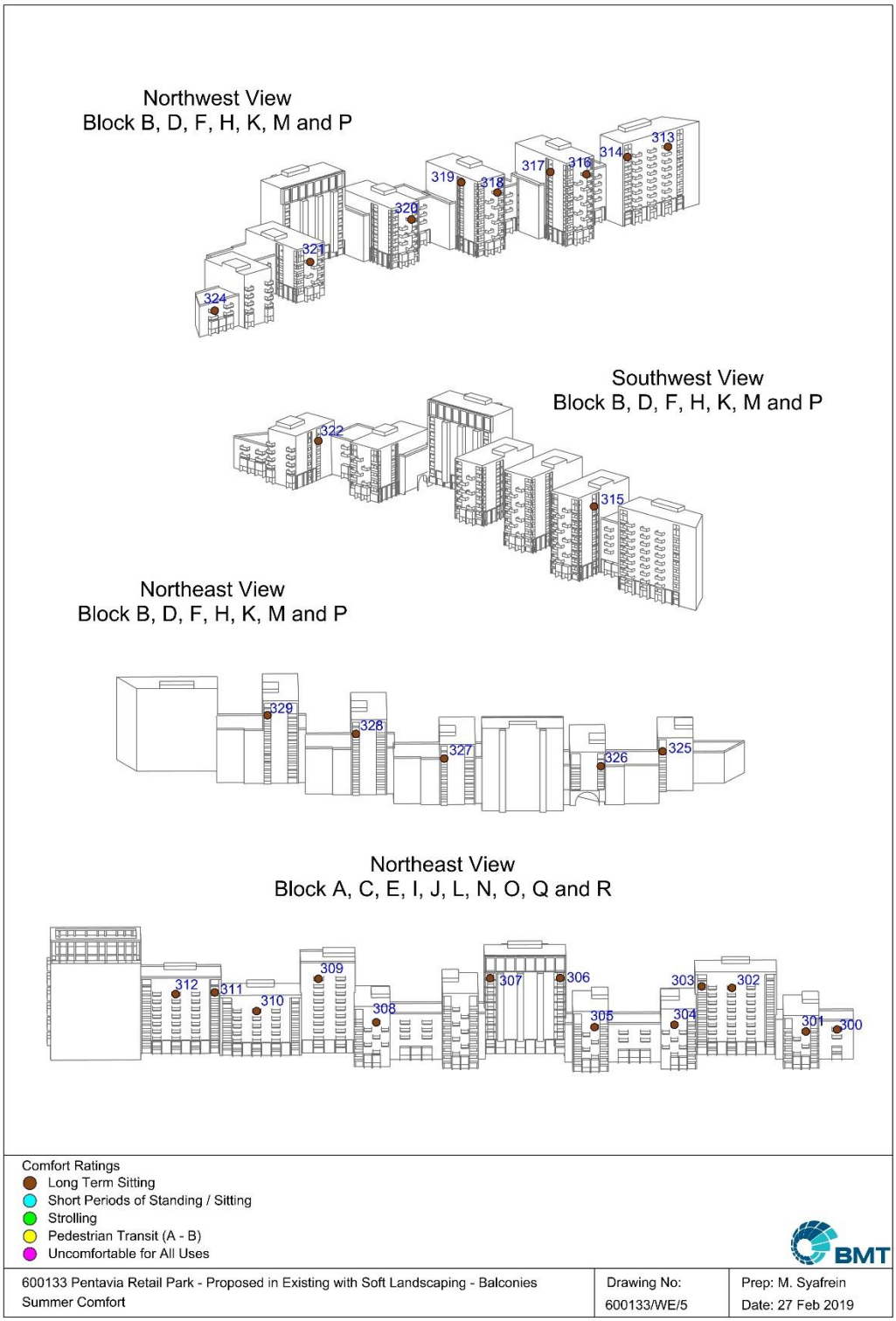


Figure D.3a: Worst-seasonal comfort ratings, existing site, ground level

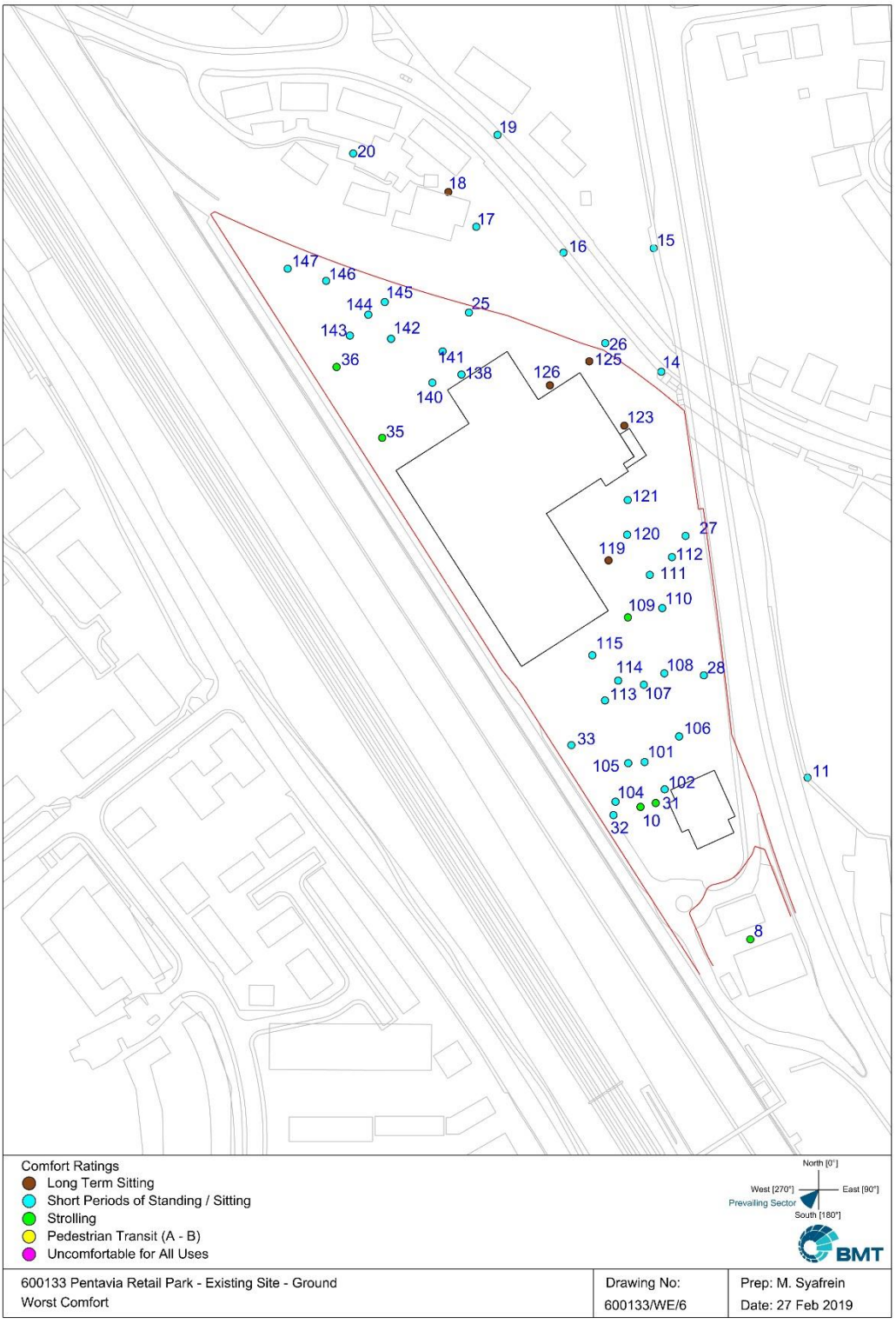


Figure D.3b: Worst-seasonal comfort ratings, proposed development within existing surrounds, lower ground level

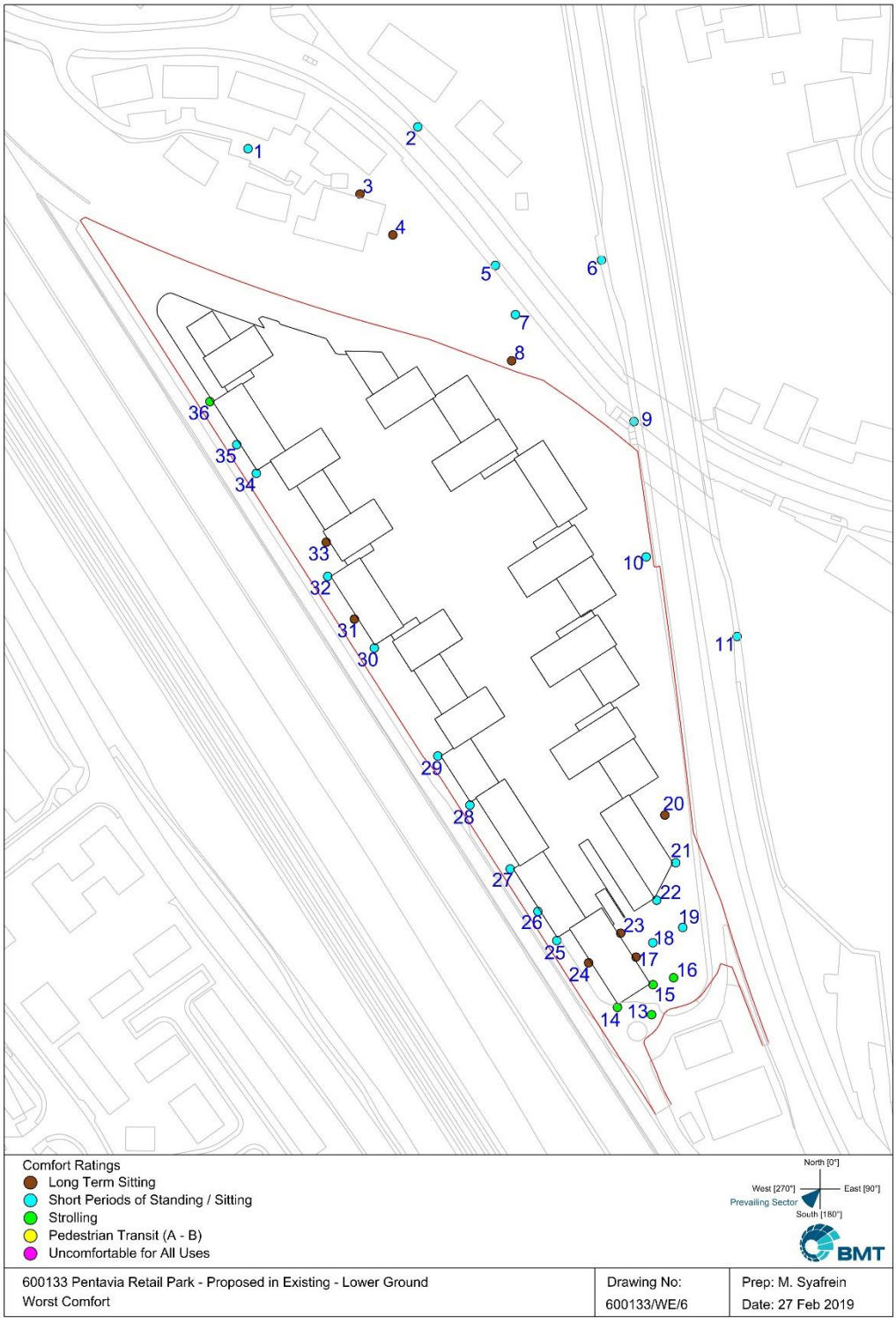


Figure D.3c: Worst-seasonal comfort ratings, proposed development within existing surrounds, upper ground level

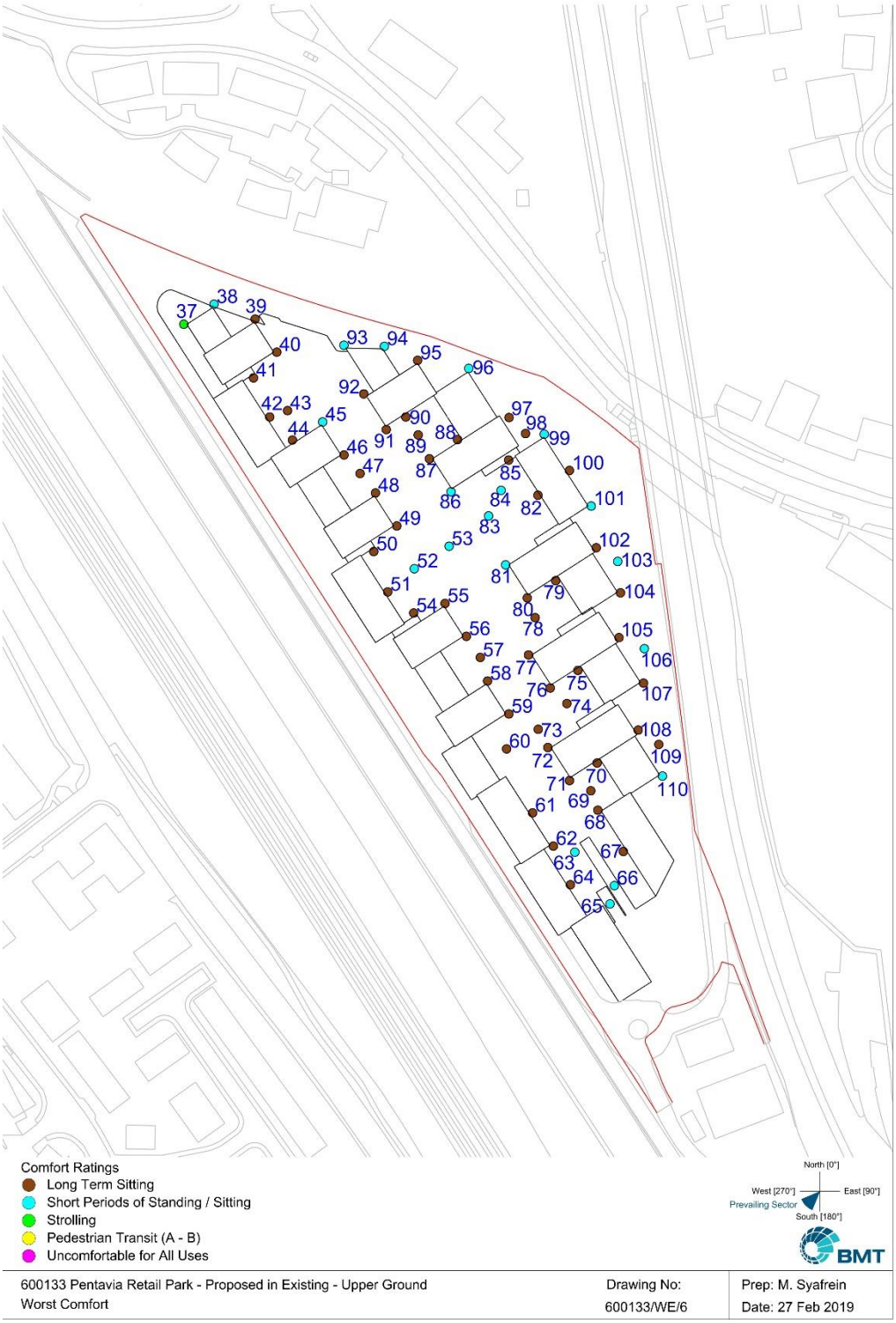


Figure D.3d: Worst-seasonal comfort ratings, proposed development within existing surrounds, terrace level

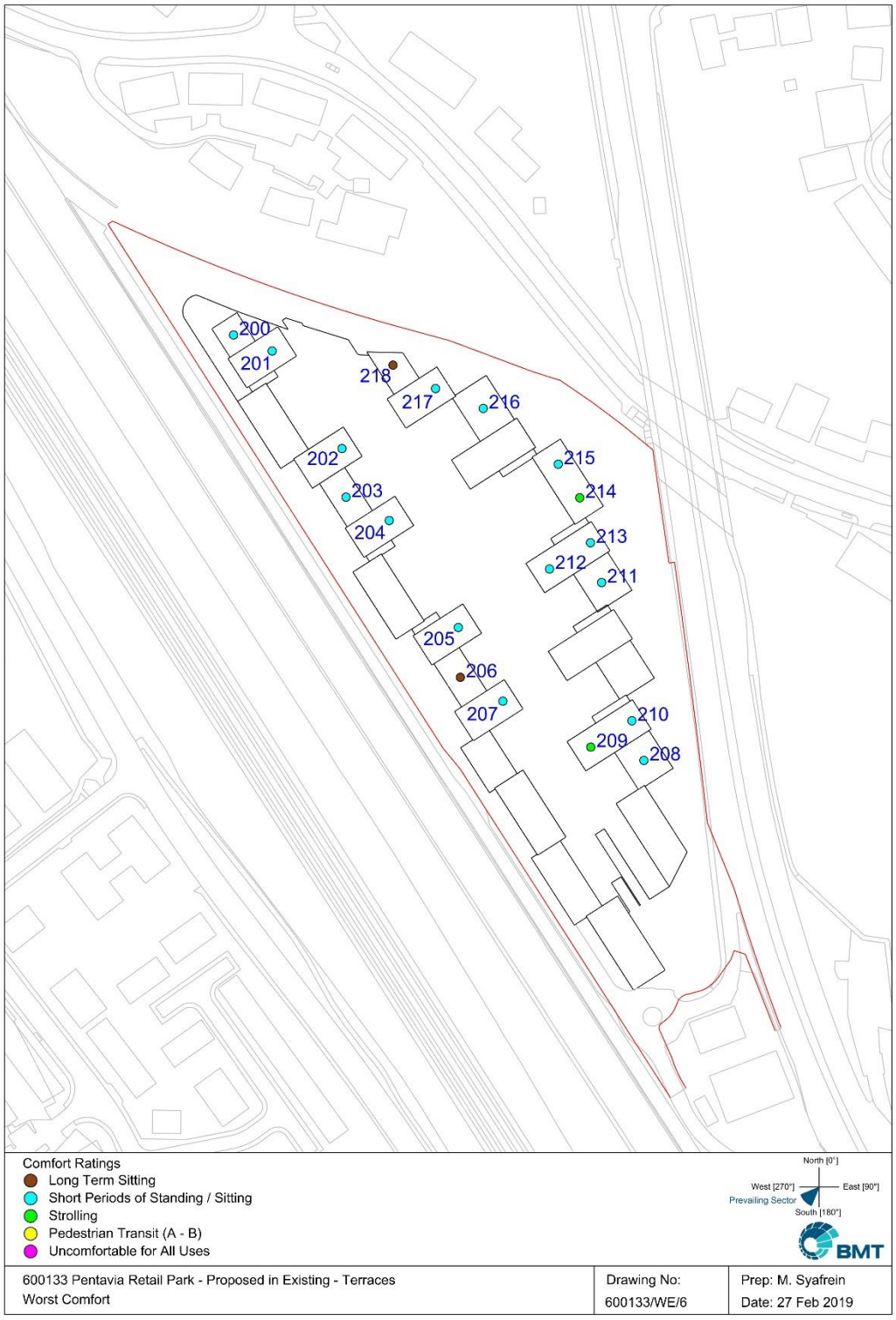


Figure D.3e: Worst-seasonal comfort ratings, proposed development within existing surrounds, balconies

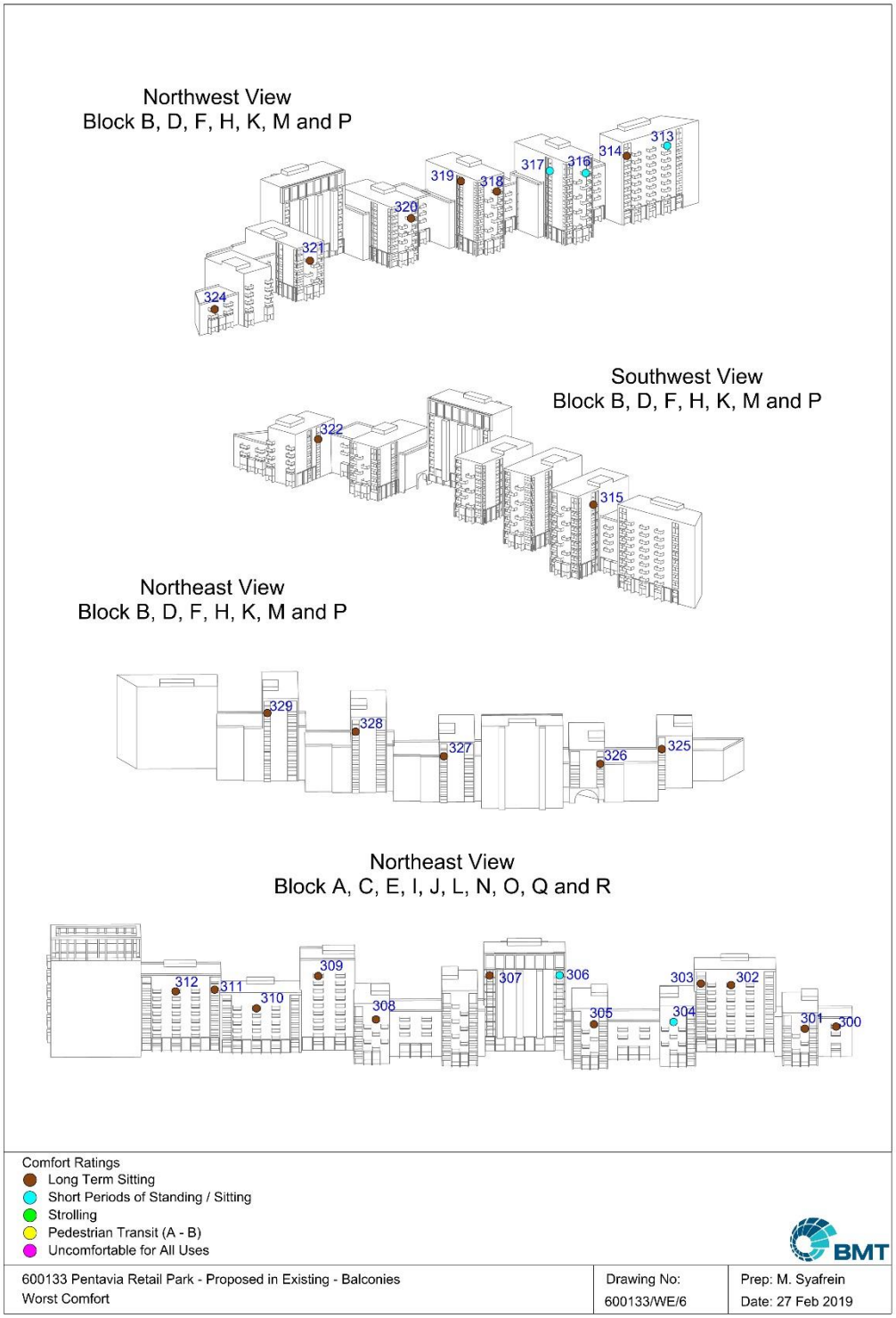


Figure D.3f: Worst-seasonal comfort ratings, proposed development within cumulative surrounds, lower ground level

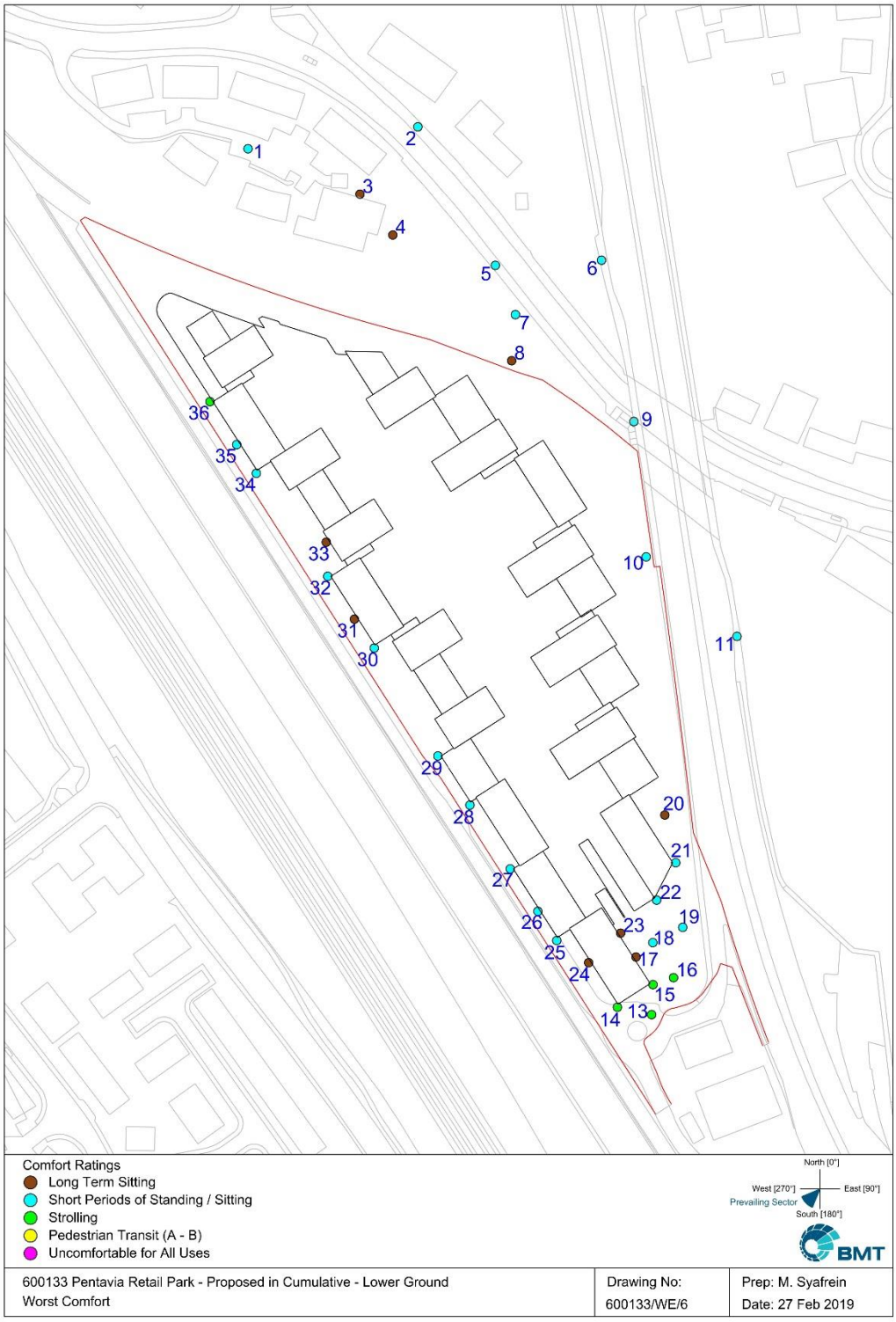


Figure D.3g: Worst-seasonal comfort ratings, proposed development within cumulative surrounds, upper ground level

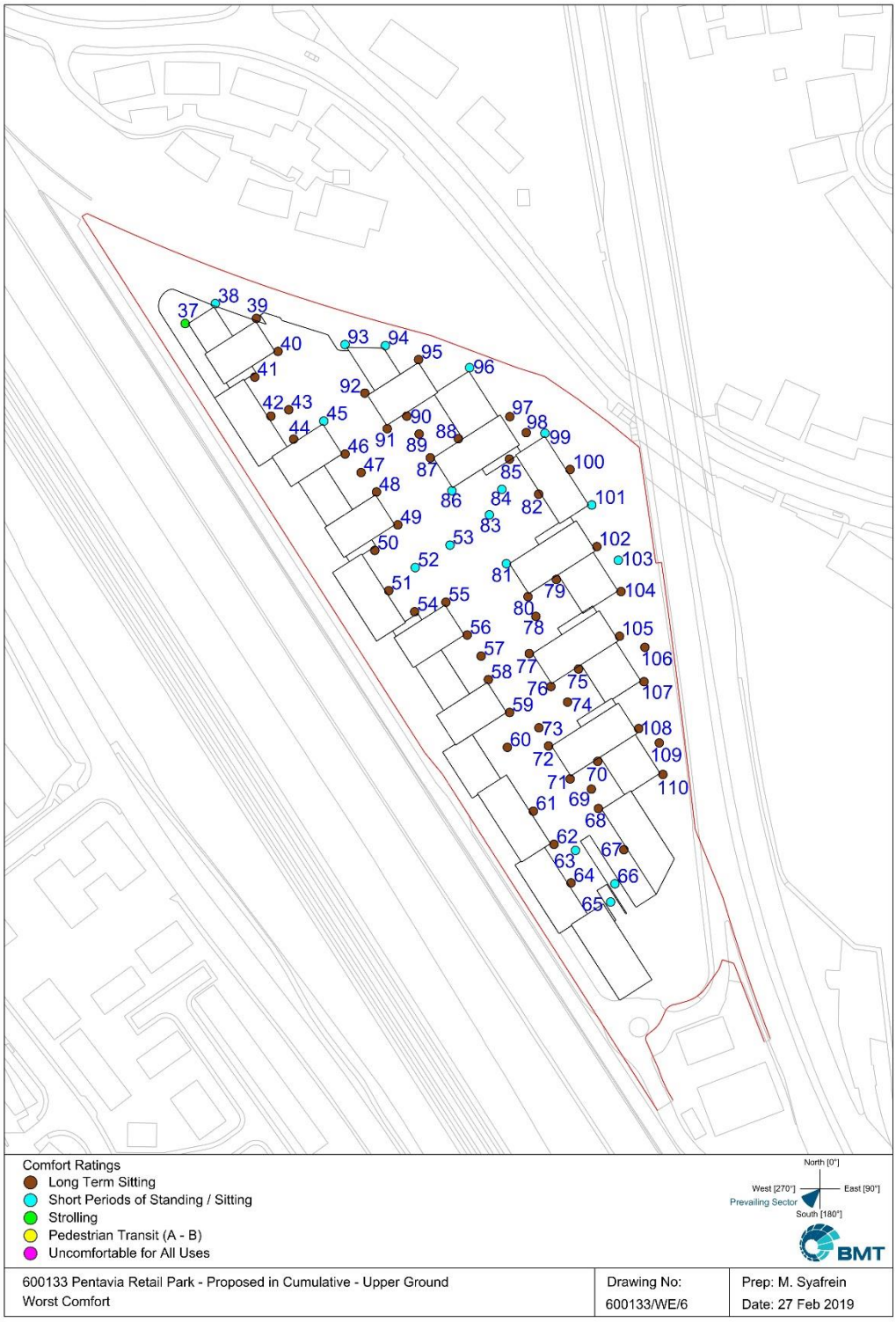


Figure D.3h: Worst-seasonal comfort ratings, proposed development within cumulative surrounds, terrace level

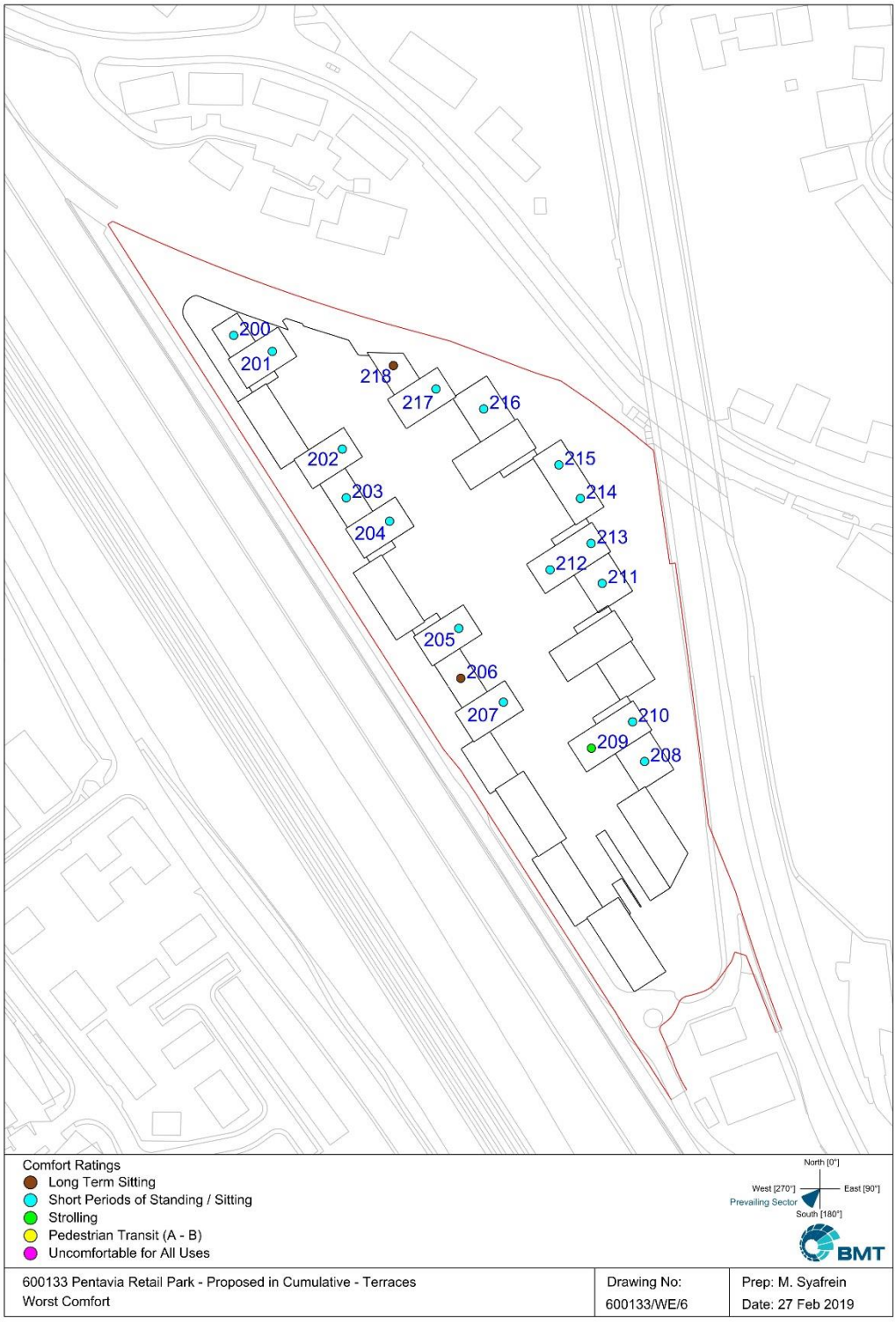


Figure D.3i: Worst-seasonal comfort ratings, proposed development within cumulative surrounds, balconies

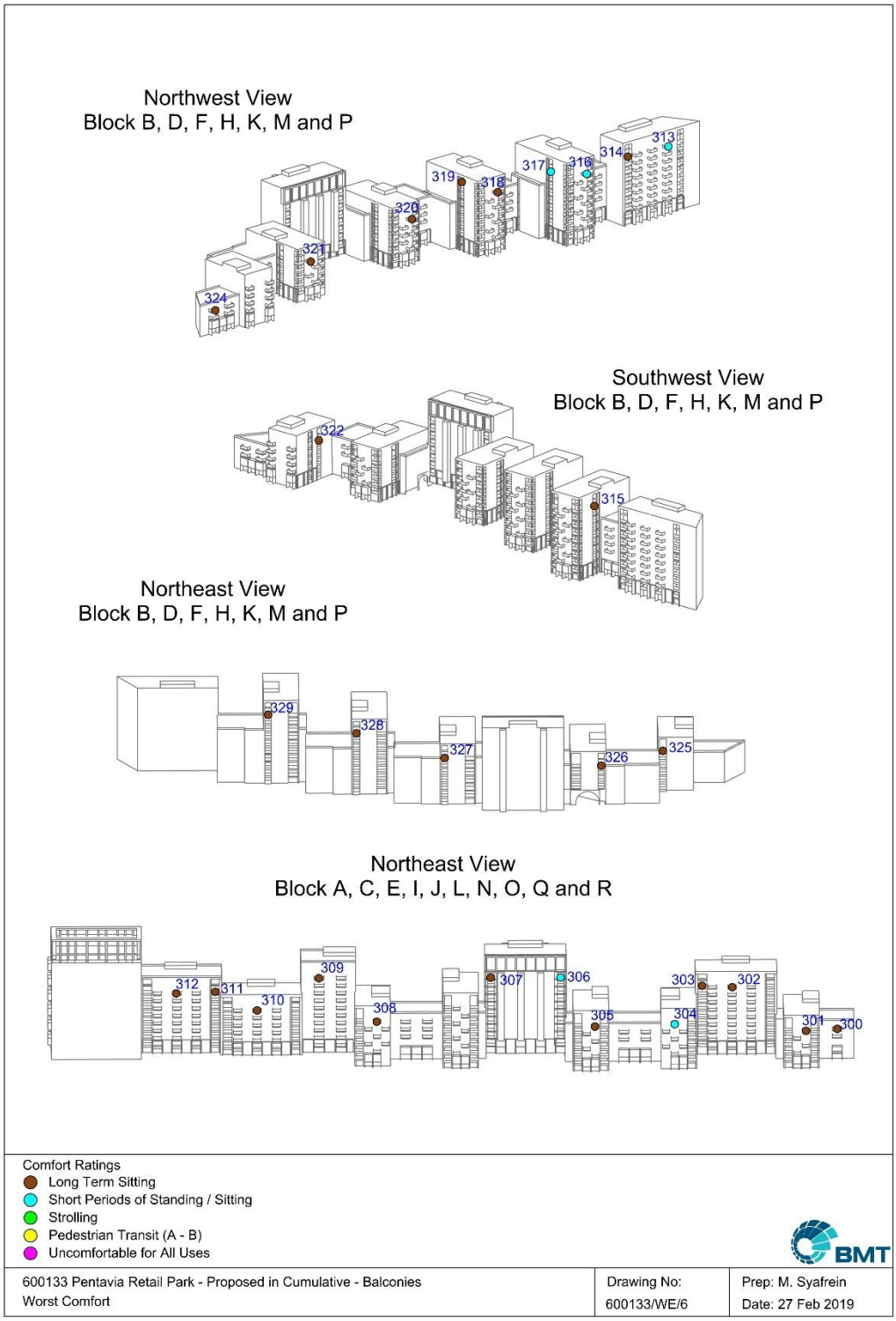


Figure D.3j: Worst-seasonal comfort ratings, proposed development within existing surrounds with soft landscaping, lower ground level

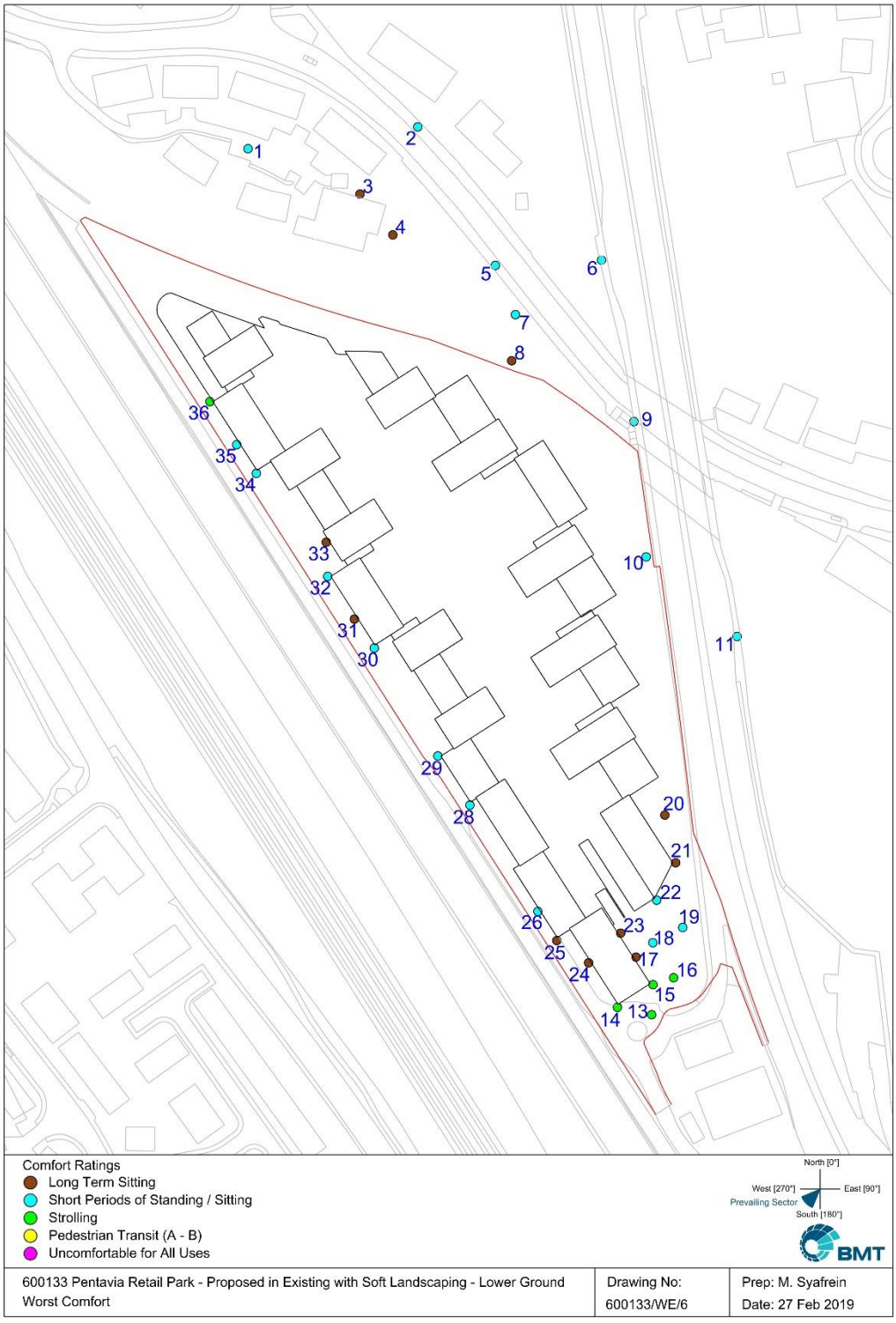


Figure D.3k: Worst-seasonal comfort ratings, proposed development within existing surrounds with soft landscaping, upper ground level

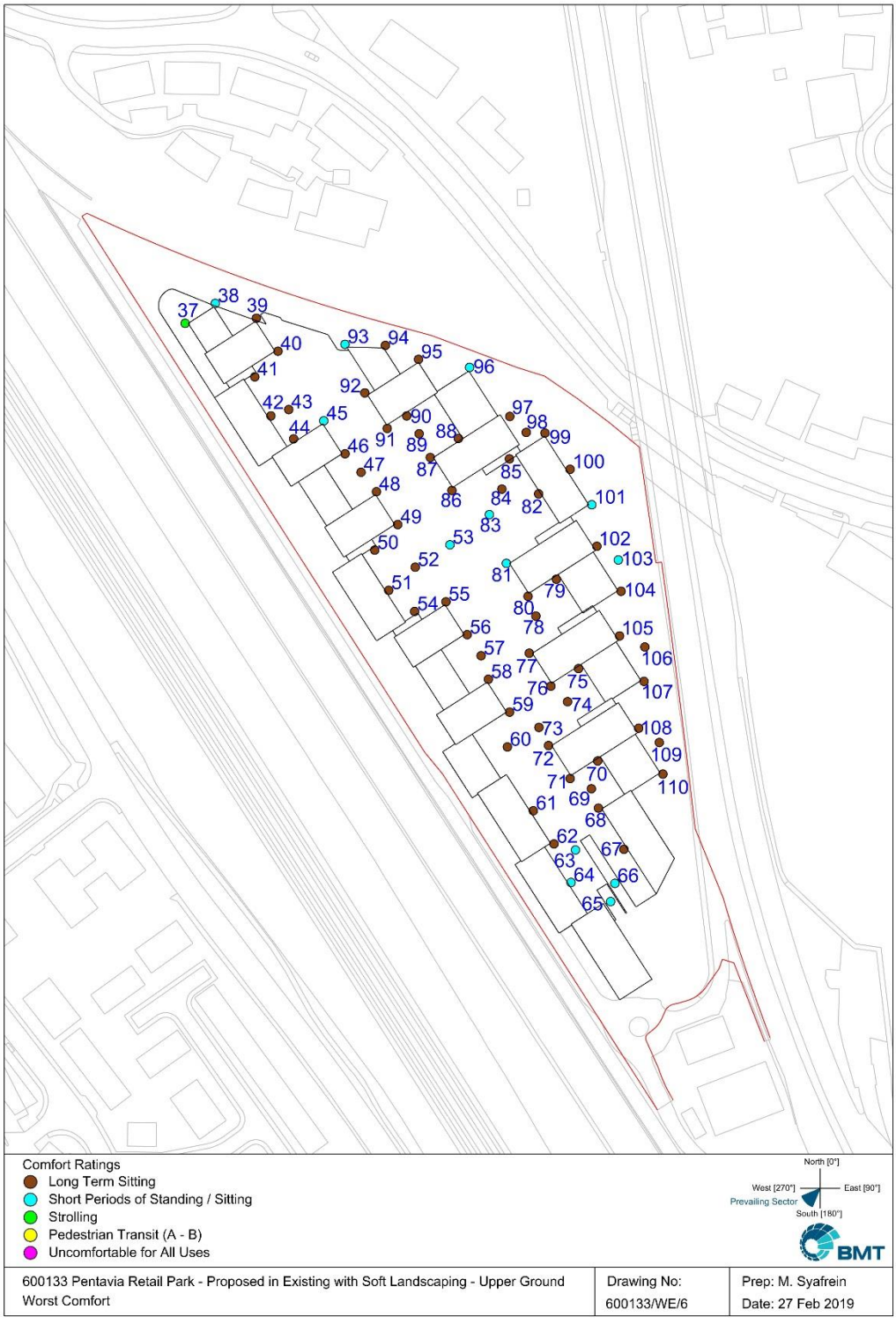


Figure D.3l: Worst-seasonal comfort ratings, proposed development within existing surrounds with soft landscaping, terrace level

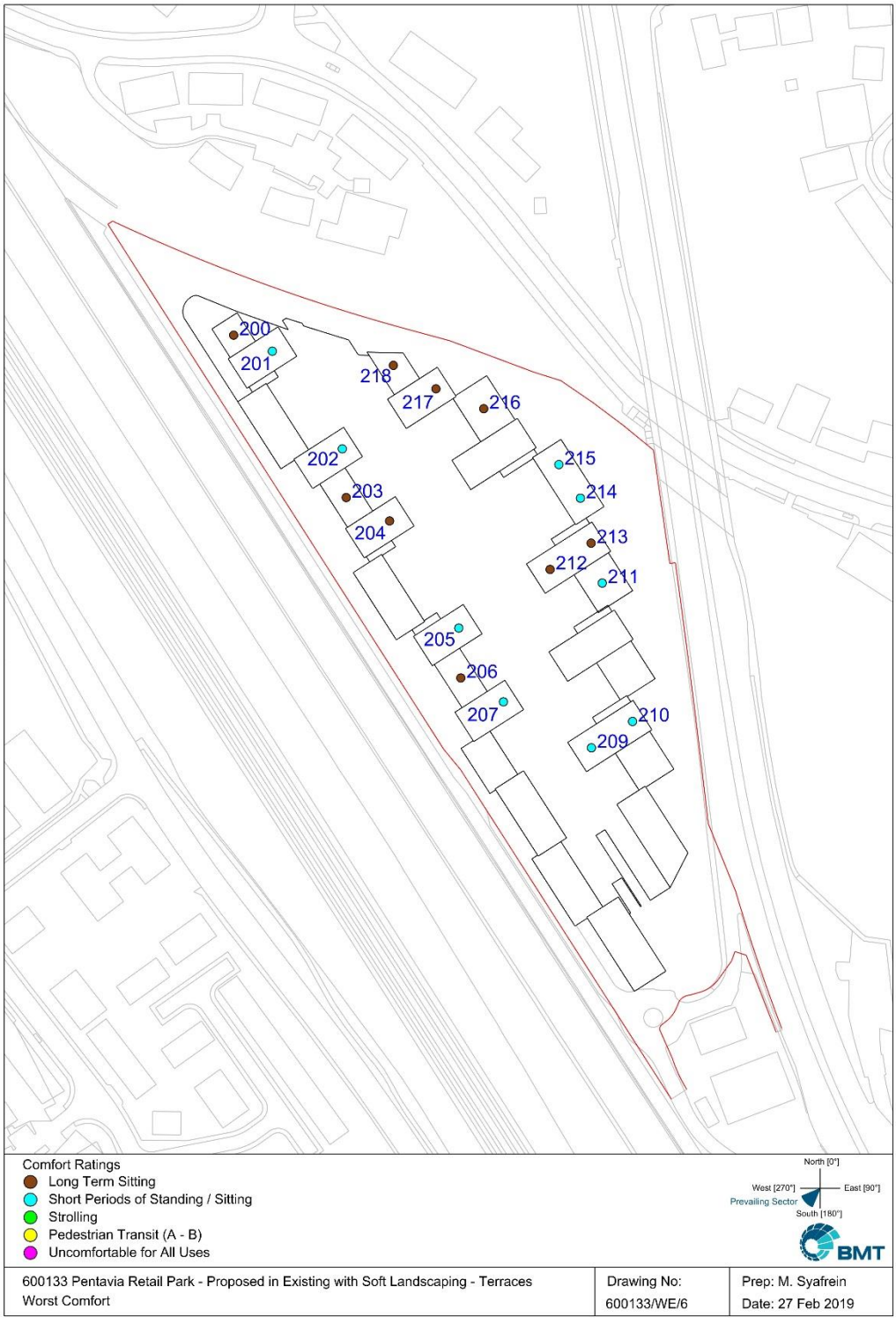


Figure D.3m: Worst-seasonal comfort ratings, proposed development within existing surrounds with soft landscaping, balconies