HOARE LEA

# Clarendon Centre. Oxford.
## Clarendon LP GP Limited.

**BUILDING PHYSICS**
WIND MICROCLIMATE
DESKTOP ASSESSMENT
REVISION A – 07 JANUARY 2021

STAGE 2

## Audit sheet.

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# Executive summary.

Hoare Lea has been appointed by Clarendon LP GP Limited to carry out a wind microclimate desktop study of the Proposed Development at Clarendon Centre, Oxford.
This report focuses on the wind desktop assessment, consisting of a semi-quantitative analysis of expected wind conditions and comfort scenarios for the fruition of open spaces in and around the Proposed Development. This study includes a quantitative modelling involving Computational Fluid Dynamics (CFD) that analysed two prevailing wind directions and has complemented the desktop assessment. No wind tunnel study has been conducted on the proposed design. Further details of the desktop approach are outlined in the methodology section of this study.

A number of point of interests (receptors) have been identified in all external spaces relevant to pedestrian wind comfort, a total of 14 key locations were established for consideration in this study; all points of interest were located at pedestrian level in the internal alleys and courtyards designed around the three proposed buildings.

The wind assessment has been conducted in accordance with the Lawson Criteria LCC assessment which establishes the probability of exceedance of assigned wind thresholds for each location considered.

The thresholds are established according to the use of the space and are described in detail in Section 3.

The analysis overall found the following:

1. The site is partially sheltered to prevailing wind from the west and south west quadrants.
2. The urban grid of the existing surrounding buildings is characterised by compact blocks and narrow gaps between buildings that therefore do not allow wind acceleration at ground level. The two main surrounding streets Queen St. and Cornmarket St. both (15m wide) are oriented respectively East-West and North West to South East. Queen Street is mostly exposed to the prevailing wind form 240°.
3. In the pedestrian areas and courtyards within the Proposed Development only two location were found to exceed slightly the required windiness thresholds for the expected activity type.

The CFD study conducted on two prevailing wind directions 210° and 240° analysed in detail the expected wind accelerations within the site and confirmed that the geometry of the development does not cause concerning accelerations the wind in the internal pedestrian areas and connected courtyards. Minor adverse conditions in two sitting areas have been however confirmed, for which local mitigations are recommended.

Mitigation options are discussed and summarized in Section 8. These relate largely to small-scale mitigation strategies which make use of landscaping, screens, low-level vegetation and balustrades.

# 1. Introduction.

Hoare Lea has been appointed by Clarendon LP GP Limited to carry out a wind microclimate desktop study of the Proposed Development at Clarendon Centre, Oxford. The Proposed Development will replace the existing buildings that today constitute the Clarendon Commercial Shopping Centre. This will be partially demolished or refurbished and three new independent buildings, will be built. They will provide commercial spaces as well as, retail, offices, a student accommodation, residential apartments and a laboratory,

The Proposed Development is located in the centre of Oxford. The three new buildings will be identified in this report as Phase 1 (on the south West), Phase 2 (on the North) and Phase 3 (on the South East). All buildings will have approximately similar height and their geometry will blend with the existing geometry and features of the surrounding blocks.

The current guideline document for the assessment of wind environment for pedestrian comfort is Building Research Establishment (BRE) Digest 520 (P., 2011). This document stresses that there are no statutory requirements and the methodologies proposed in the document are regarded as good practice.

The effect of the Proposed Development on the local wind environment is assessed focussing on the likely effect of the buildings on pedestrian comfort and safety, in consideration of the proposed use of the area, for example outdoor seating or circulation areas. The proposed massing, location and local wind data is considered.

The Desktop Wind Analysis is a semi-quantitative assessment, using well-founded principles for estimating wind flow around buildings. The approach enables areas which are likely to be at risk of experiencing increased wind speed to be identified for the purposes of a pedestrian wind comfort assessment. Further details of the desktop analysis are outlined in the methodology section of this report.

Detailed quantitative modelling involving Computational Fluid Dynamics (CFD) has analysed prevailing wind conditions and will be discussed in this report. Physical modelling using a wind tunnel is not carried out as part of this assessment.

## 2. Site description.

The site is located at the centre of Oxford (Figure 1 and Figure 2). The terrain is mostly flat with minor variations in height. The Pedestrian level in the site is approximately at 60m above sea level.

The Proposed Development hosts offices, residential units, retail and commercial spaces and a laboratory. The units at ground floor are mostly commercial and retail. It is understood that the existing buildings on the site will be refurbished or partially demolished leaving the space for the new Proposed Development.

The site is surrounded by a dense, almost compact, grid of low-rise buildings, max 4 storey height. Towers and spires belonging to nearby churches and historical buildings characterise the surroundings. Existing trees are limited and far away from the site. The main streets are 15m wide and surround the site on the South and towards the East. The other minor streets in the surroundings are much narrower instead and for this reason they do not allow the wind to accelerate at pedestrian level.


Figure 1:Location of the Proposed Development site, satellite view.


Figure 2:Location of the Proposed Development site, aerial view.

# 3. Site analysis.

Four different activity categories are suggested for a typical desktop wind study, each of them reflective of the activity held. The four categories include: sitting; standing/entrance, strolling and walking.

Sitting category is the most stringent of the Lawson Criteria assessment and they are representative of an elevated comfort requirement. This category aims to guarantee the comfort of a person undertaking a very light or a sedentary activity. This low level of “body activity” leads the person to be highly sensitive to the external weather condition and so more sensitive to wind.

The second category, standing/entrances, is more relaxed than the sitting category. It is representative of people moving from a sheltered area into an exposed area. This change in the environmental conditions can create a level of discomfort as they become more sensitive to adverse wind conditions.

Strolling spaces is the default category for pedestrian areas in the vicinity of a development. A ‘walking’ category is less stringent in its wind microclimate requirements but requires the client to demonstrate that this area will be used solely as a walkthrough, such as pedestrian islands or access routes i.e. there is no reason for pedestrians to linger in said area.

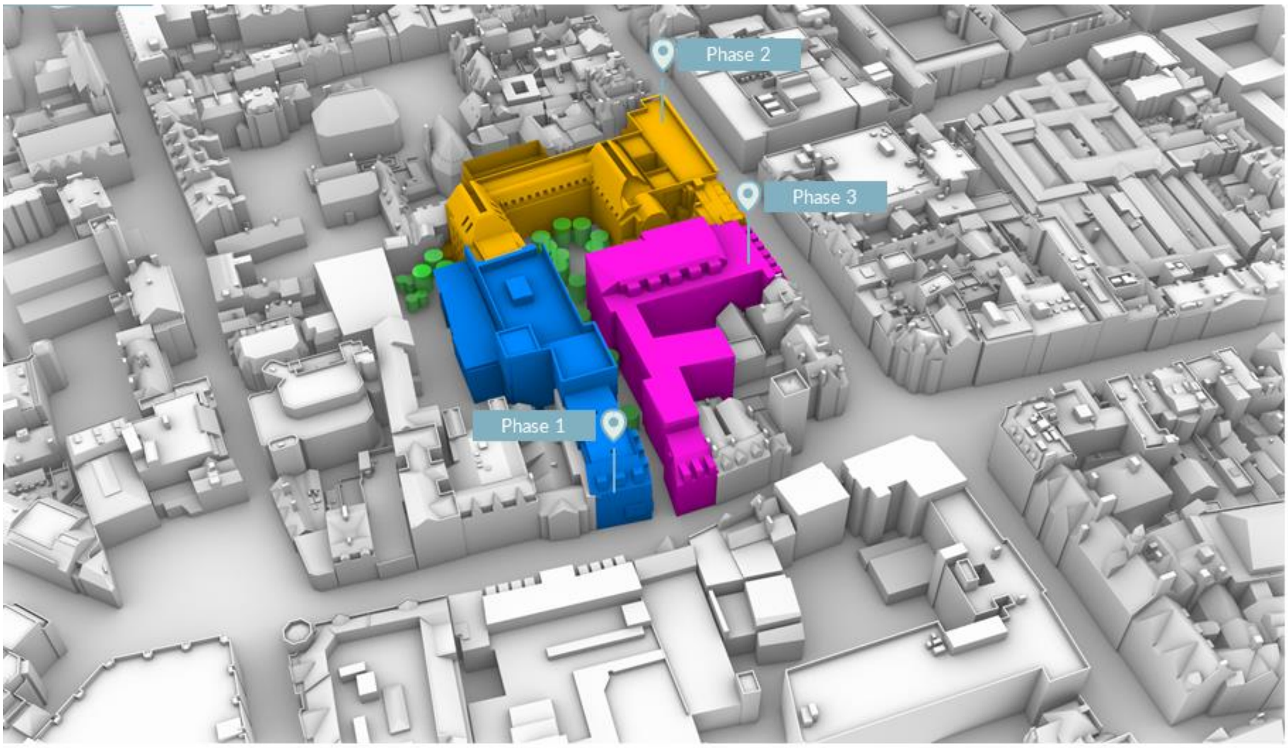



Figure 3: Rendering of the massing of the Proposed Development within the existing site.

### 3.1 Pedestrian level and internal courtyards.

The internal pedestrian area, that can be accessed from Queen St. and from Cornmarket St., provides access to the main internal square and to a courtyard on the west of the site. Both the internal square and the courtyard offer a communal space with trees, benches and an integrated landscape where café and restaurant can provide external seating for the customers.

Targeted sitting, standing and strolling areas have been highlighted in the Figure 4 below. Fast Walking activity is non contemplated in this context.

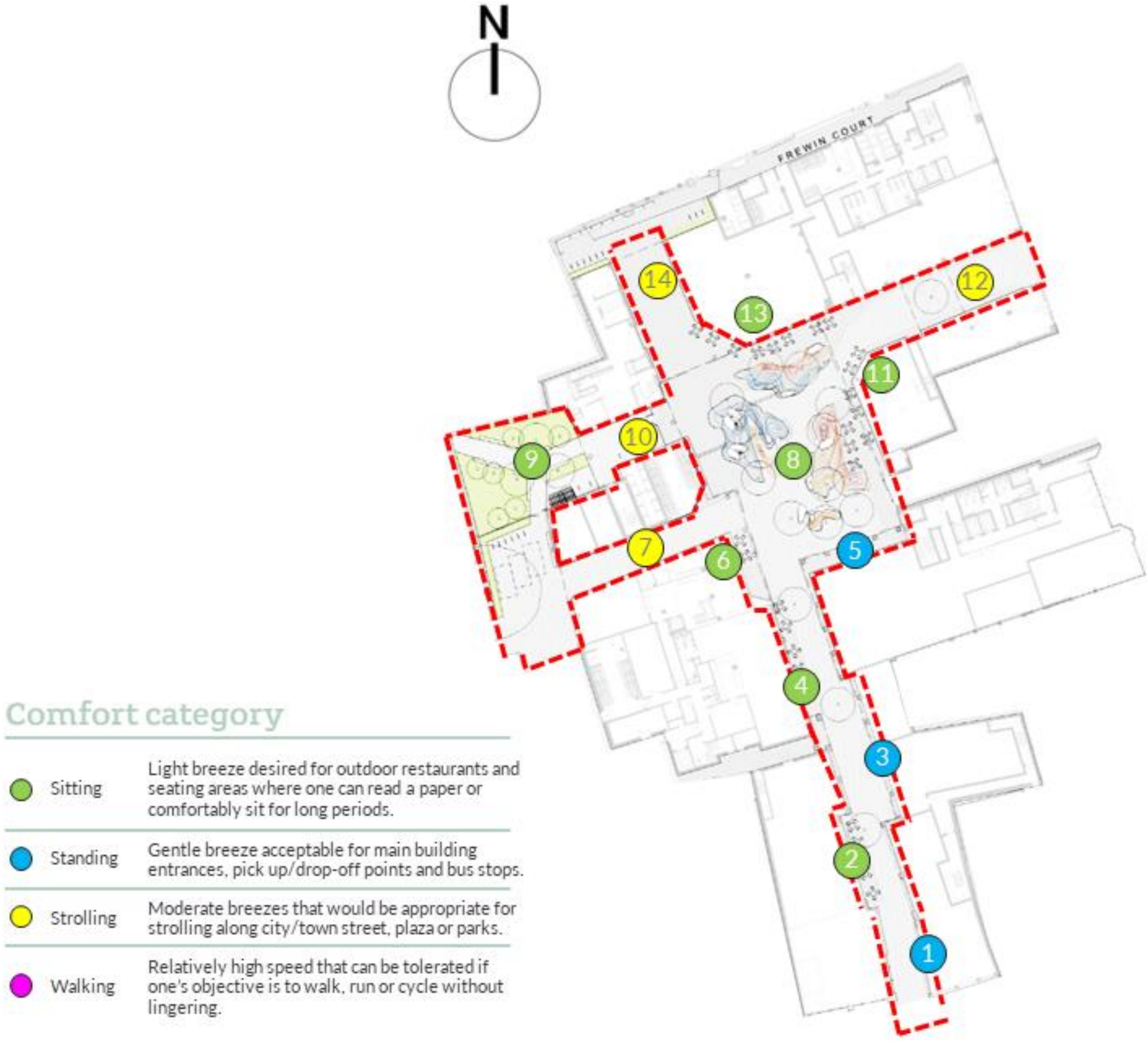



Figure 4: Pedestrian level layout of proposed activities.

### 3.2 Key locations considered and targeted comfort categories.

Following identification of all external spaces relevant to pedestrian wind comfort, a total of 14 key locations were established for consideration in this study; All the locations are at pedestrian level. The position of the points is reported in the table below:

Table 1 The position of the location points.

| Image | Description |
|---|---|
|  | Location 1: Standing area (Phase 3)<br>Location 2: Sitting area (Phase 1)<br>Location 3: Standing area (Phase 3)<br>Location 4: Sitting area (Phase 1)<br>Location 5: Standing area and entrance (Phase 3)<br>Location 6: Sitting area (Phase 3)<br>Location 7: Covered passage (Phase 1)<br>Location 8: Sitting area (Main square)<br>Location 9: Sitting area (Courtyard)<br>Location 10: Covered passage (between Phase 1 and 2)<br>Location 11: Sitting area (Phase 3)<br>Location 12: Covered passage (between Phase 2 and 3)<br>Location 13: Sitting area (Phase 2)<br>Location 14: Covered passage (Phase 2) |

# 4. Methodology.

This wind microclimate study is limited to assessing the effects on pedestrians and excludes effects on receptors other than people (e.g. ecology) as these are not covered by the current guidance documents.

It should be noted that, according to guidance in BRE Digest 520 (1), the baseline conditions for a wind microclimate study is for the site with no buildings present. The Proposed Development site contains some structures in its present state, which are not reflected in the baseline.

The current study is a visual desktop study using 'coarse' speed-up factors and does not involve computational or physical modelling.

The wind microclimate study is generally carried out in four stages;

- Stage 1. Analysis of most appropriate weather station wind data.
- Stage 2. Adjustment of weather station data to local site conditions.
- Stage 3. Accounting for effects of building massing.
- Stage 4. Comparison against baseline and assessment of need for mitigation.

The following subsections describe these stages in more detail.

## 4.1 Analysis of most appropriate weather station data.

The most appropriate weather station is identified, and wind velocity and frequency of occurrence tables are analysed for a 10 year period minimum. The Weibull distribution parameters are calculated (J.V. Seguro, 2000) and used to produce cumulative probability wind data tables. A further calculation is made using the Deaves and Harris (3) methodology to produce mean wind speed profiles. More information on these calculations can be found in Appendix A: Weibull parameters and Appendix B: The Deaves and Harris model.

## 4.2 Adjustment of weather station data to local site conditions.

Wind probability data for the weather station is adjusted for the site conditions taking into consideration differences in terrain roughness and topology. Deaves and Harris methodology is used once again to make this adjustment. The result is adjusted wind speed profiles, wind rose and cumulative wind probability plots specific to the site. At this stage an adjustment for height to pedestrian level (1.5m from ground) is also made. The analysis results in the production of a baseline model for the site irrespective of local building geometry considerations.

## 4.3 Accounting for effects of building massing.

At this stage, key locations for pedestrian comfort around the building are identified and the effect of the proposed building massing on local wind conditions is taken into account. Each location is analysed separately. Speed-up factors based on local building geometry are estimated for northerly, southerly, easterly and westerly wind directions and then interpolated for all other wind directions. They are then factored into the local wind speed calculations, and a probability of exceedance of each Beaufort scale number is calculated. This can then be used in a Lawson Criteria assessment for each of the key locations included in this study.

Guidance from BRE Digest 520 (P., 2011) and Gandemer (J., 1977) has been taken for the appropriate selection of the speed up factors. It is noted that although these factors have been developed based on wind tunnel observations of a number of buildings, no wind tunnel study or CFD study has been undertaken at this stage for the Proposed Development and therefore the selection of appropriate speed-up factors retains a level of subjectivity. Appendix C: Guidance on wind flow characteristics provides a summary of the main effects considered and the basis for estimating speed-up factors.

The resultant wind speeds are then assessed against the Beaufort scales and Lawson Criteria described below.

(a) Benchmarks: The Beaufort scale.

The Beaufort scale (Lawson, 2001) relates wind speed to observed conditions at sea or land.

Table 2 shows the Beaufort scale applicable on land.

**Table 2: The Beaufort scale (on land)**

| Beaufort Number | Description | Wind Speed (m/s) | Wind effect (on land) |
|---|---|---|---|
| B0 | Calm | 0 - 0.45 | Smoke rises vertically |
| B1 | Light Air | 0.45 - 1.55 | Direction shown by smoke drift but not by wind vanes |
| B2 | Light Breeze | 1.55 - 3.35 | Wind felt on face; leaves rustle; wind vane moved by wind |
| B3 | Gentle Breeze | 3.35 - 5.6 | Leaves and small twigs in constant motion; light flags extended |
| B4 | Moderate Breeze | 5.6 - 8.25 | Raises dust and loose paper; small branches moved. |
| B5 | Fresh Breeze | 8.25 - 10.95 | Small trees in leaf begin to sway; crested wavelets form on inland waters. |
| B6 | Strong Breeze | 10.95 – 14.1 | Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty. |
| B7 | Near Gale | 14.10 - 17.2 | Whole trees in motion; inconvenience felt when walking against the wind. |
| B8 | Gale | 17.2 - 20.8 | Twigs break off trees; generally impedes progress. |
| B9 | Strong Gale | 20.8 - 24.35 | Slight structural damage (chimney pots and slates removed). |
| B10 | Storm | 24.35 - 28.4 | Seldom experienced inland; trees uprooted; considerable structural damage |
| B11 | Violent Storm | 28.4 - 32.4 | Very rarely experienced; accompanied by widespread damage. |
| B12 | Hurricane | 32.4 + | Devastation |

The benchmark recommended for pedestrian comfort in the UK is the Lawson Criteria (Lawson, 2001) shown in

Table 3, which describes the wind speeds that are ‘acceptable’ or ‘unacceptable’ for different activities.

The criteria are activity-specific. For example, higher wind speeds or gusts are considered ‘acceptable’ in this index in areas where the public is merely walking through rather than sitting. For pedestrians ‘walking’, conditions are considered ‘unacceptable’ if wind speeds exceed 10m/s more than 5% of the time.

Should the use of the space be different to that stated in this report or be changed at a later date this may have a significant effect on the wind microclimate requirements for said space.

Table 3: Lawson criteria assessment (for each activity category, thresholds cannot be exceeded more than 5% of the time). The Standing category also includes entrances and exits.

| Key | Comfort Category | Threshold | Description |
|---|---|---|---|
| 🟢 (light green) | Sitting | 0-4 m/s | Light breezes desired for outdoor restaurants and seating areas where one can read a paper or comfortably sit for long periods |
| 🔵 (light blue) | Standing | 4-6 m/s | Gentle breezes acceptable for main building entrances, pick-up/drop-off points and bus stops |
| 🟡 (yellow) | Strolling | 6-8 m/s | Moderate breezes that would be appropriate for strolling along a city/town street, plaza or park |
| 🟣 (magenta) | Walking | 8-10 m/s | Relatively high speeds that can be tolerated if one's objective is to walk, run or cycle without lingering |
| 🔴 (red) | Uncomfortable | >10 m/s | Winds of this magnitude are considered a nuisance for most activities, and wind mitigation is typically recommended |

In addition to the Lawson criteria assessment a minimum safety criteria is utilized as indicative of the risk to vulnerable peoples and/or cyclists for all locations included in this study. This states that for all wind directions a 15m/s wind velocity cannot be exceeded more than 1% of the time.

### 4.4 Comparison against baseline and assessment of need for mitigation.

The results for each location are compared to the Baseline conditions. The deviation between actual and required wind conditions can be assessed as 'Substantial', 'Moderate' or 'Minor', and as 'Adverse' or 'Beneficial' as per criteria shown in Table 4. It is noted that although this table comments on the need for mitigation, recommendations on mitigations in this document shall be made based on the Lawson Criteria (

Table 3) as this takes into account the proposed use of each location.

Finally, the results of the building massing assessment are analysed and recommendations are made for wind mitigation.

Table 4: The significance criteria

| Significance criteria | Description of criteria |
|---|---|
| Substantial Beneficial | Substantial reduction in risk of increased local wind speed, turbulence and gustiness compared to baseline wind conditions. |
| Moderate Beneficial | Moderate reduction in risk of increased local wind speed, turbulence or gustiness compared to baseline wind conditions. |
| Minor Beneficial | Minor reduction in risk of increased local wind speed, turbulence or gustiness compared to baseline wind conditions. |
| Negligible | No appreciable change in local wind comfort conditions compared to baseline wind conditions. |
| Minor Adverse | Minor increase in risk of increased local wind speed, turbulence or gustiness compared to baseline wind condition. Some mitigation measures may be recommended. |
| Moderate Adverse | Moderate increase in risk of increased local wind speed, turbulence or gustiness compared to baseline wind conditions. Mitigation measures should be considered. |
| Substantial Adverse | Substantial increase in risk of increased local wind speed, turbulence and gustiness compared to baseline wind conditions. Likely to lead to unacceptable wind conditions for pedestrians. Mitigation measures required. |

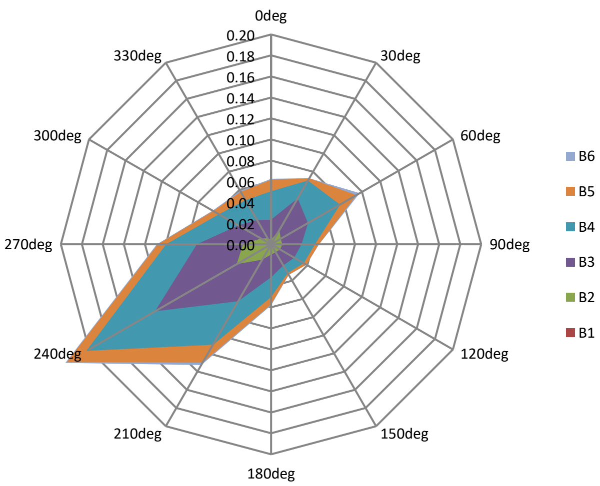
## 5. Weather conditions at most appropriate weather station.

The most appropriate weather station to the site with quality data available is Brize Norton, about 21km to the West from the site (see Figure 5).

Brize Norton weather station is at location:

- Latitude: 51 Deg 75 Min N
- Longitude: 01 Deg 58 min W
- Altitude: 81 m above sea level


Figure 5: Location of Brize Norton weather station relative to the site.




The wind rose for Brize Norton weather station at the reference height (10m above ground level) is shown in Figure 6.

Each outer edge of the coloured sections represents the probability of wind velocities being equal or below each specified Beaufort numbers.

The areas in this graph show that, for most of the time, wind speeds are in the B3, B4 and B5 range (i.e. 3.35m/s to 8.25m/s) with a predominant wind direction from south west (240° SW).

Figure 6: Annual wind rose for Brize Norton weather station at reference height (10m).

Figure 7 shows the probability density function curves for Brize Norton. The variation between high probability wind and less probable winds can be observed. As the graph below shows, wind from 240° is more common throughout the year.

Given that the Proposed Development is expected to be occupied all year round, this wind study for ground level areas has been carried out using wind data for the whole year.

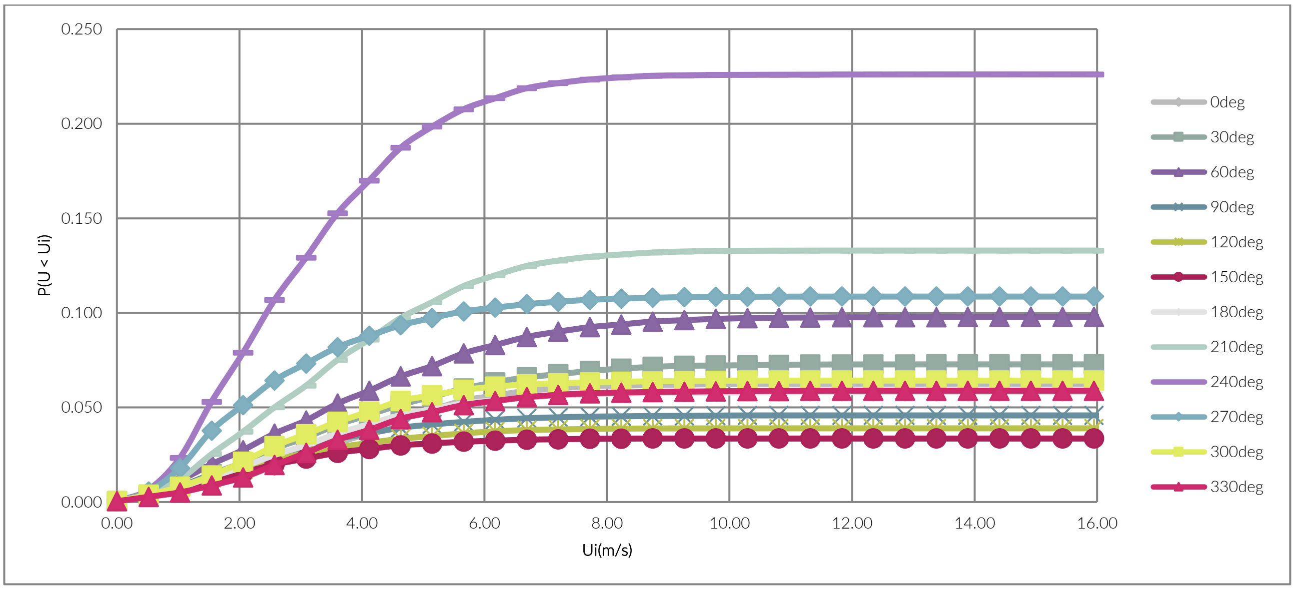



Figure 7: Cumulative probability density curves by direction for Brize Norton (annual).

# 6. Wind conditions at site.

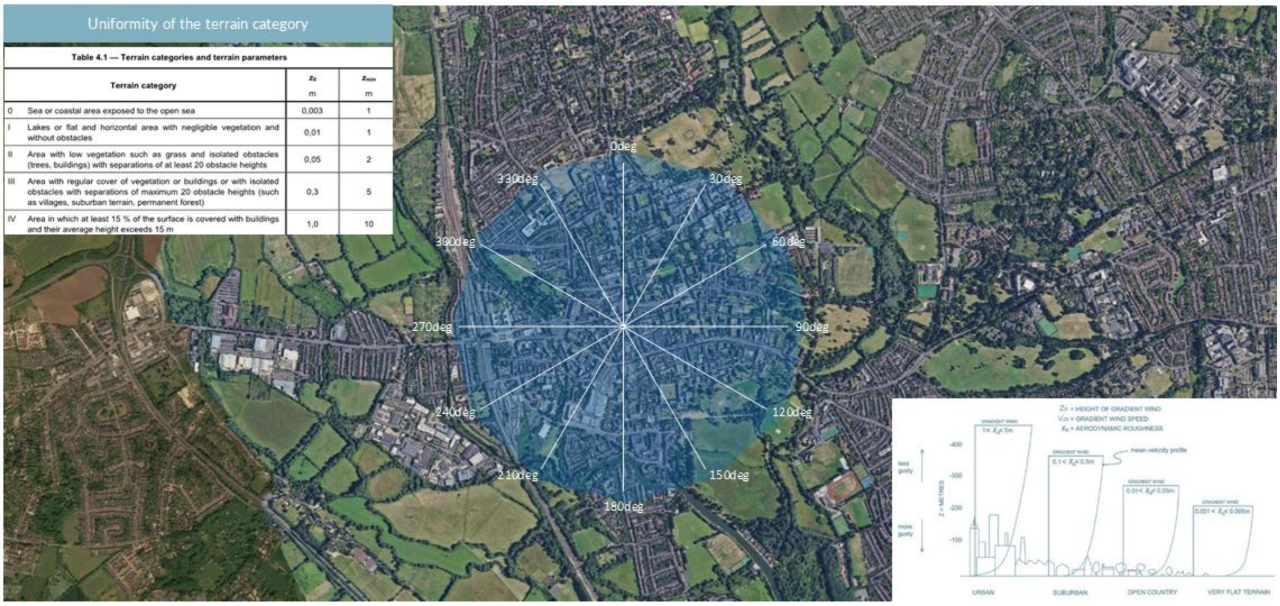
The mean wind speed (referenced at 10m above ground level) at the Proposed Development site depends on the local topography, ground roughness and nearby obstacles. Wind data must be corrected for terrain as the collective height of the surrounding buildings exert a drag on the wind that is much higher than the drag exerted by open terrain. Therefore, surface wind speeds are lower at city locations than in open countryside.

To obtain the mean wind speed profile at the Proposed Development site from observations at Brize Norton weather station, the Deaves and Harris model was used (Drew D., 2013). This is done by first generating a wind profile for Brize Norton and then translating this to site. This gives us wind speeds at the site at all heights of interest and requires the following assumptions to be made;

- The site is assumed to be surrounded by a flat and horizontal area with negligible vegetation and obstacle.
- The wind speed of the free stream at Brize Norton is the same as the wind speed over the Proposed Development site. The height of the free stream was estimated at 383m above the ground and was calculated using Drew et al (Drew D., 2013).
- The surface roughness ($z_o$) in Brize Norton is equal to 0.05 as described in Eurocode 1 (British Standards, 2010).
- Brize Norton is a terrain category ($T_{cat}$) 2, corresponding to an area with low vegetation or isolated obstacles, as described in Eurocode 1 (British Standards, 2010). This means that at heights below 2m ($Z_{min}$) wind speeds can be assumed to be constant.
- The change in altitude from Brize Norton to the site is small and has a minimal effect on the velocity profiles. Therefore, it has not been taken into consideration for this study.

The terrain surrounding the Proposed Development could be classified as Type 3. For this terrain category the wind speed could be considered constant below 5m and the roughness value is considered to be 0.3. This assumption is shown in Figure 8 (up to 1km radius).

Extrapolating down to the pedestrian zone (1.5m height above ground level) gives a mean wind speed at site of 1.44m/s. This is the calculated mean speed that would be experienced if there were no buildings at the site location but with the existing surrounding city context. This approach follows methodologies outlined in BRE Digest 520.



Uniformity of the terrain category

Table 4.1 — Terrain categories and terrain parameters

| | Terrain category | $z_0$ m | $z_{min}$ m |
|---|---|---|---|
| 0 | Sea or coastal area exposed to the open sea | 0,003 | 1 |
| I | Lakes or flat and horizontal area with negligible vegetation and without obstacles | 0,01 | 1 |
| II | Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights | 0,05 | 2 |
| III | Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest) | 0,3 | 5 |
| IV | Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m | 1,0 | 10 |



Figure 8: Site view and wind rose showing the subdivision of the site based on the wind rose sectors.

Figure 9 shows the variation of mean wind speed with height at both Brize Norton Station and the Proposed Development site (Category 3). The mean wind speed for Brize Norton at a height of 5m above ground level is 3.02m/s. Adjusting for terrain this translates to a mean wind speed for site of 1.44m/s for the investigated site. This means that the investigated site may experience a lower average wind speed (47% circa lower than the weather station).

Using the adjusted mean wind velocity profiles for site, it was possible to calculate roughness and height amplification factors for sector and use these to produce a compounded wind rose for the site (shown in Figure 9). This shows that at pedestrian level (1.5m above ground level) the wind velocities are mostly in the range of levels B2, B3 and B4 of the Beaufort scale. A considerable reduction on the B5 wind speed level could be noticed against the weather station data.

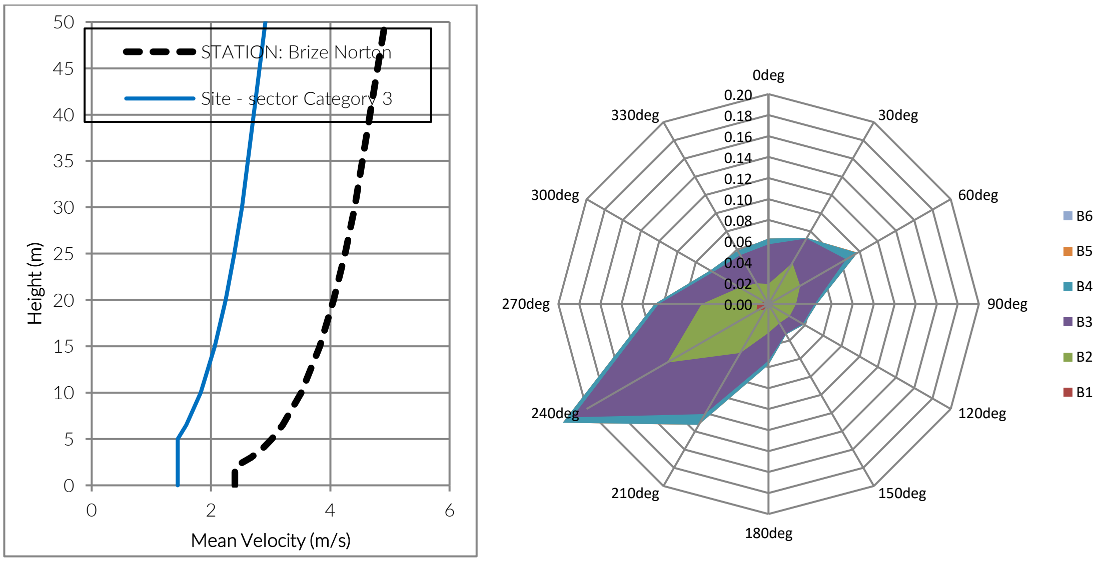



Figure 9: Mean wind velocity profiles and annual wind rose at pedestrian height (1.5m) for the investigated site.

Based on this assessment of the wind conditions on the site it was possible to produce a Lawson Criteria assessment for site with no building present. This is shown in Table 5. This assessment was produced using the adjusted wind conditions for the site but without taking into consideration the local wind effects caused by the buildings' masses. This baseline also assumes there is no building currently on the site.

The Table 5 shows that minimum safety requirements wind conditions on the site are met. This initial analysis also confirms all the comfort criteria are acceptable, even the more demanding 'sitting' condition. These results apply to pedestrian level (1.5m from ground). At more elevated levels, where mean wind speeds increase, conditions would be less favourable.

Table 5: Wind microclimate assessment for the proposed development site with no building present

| Category | Acceptable |
|---|---|
| Sitting | YES |
| Standing/Entrances | YES |
| Strolling | YES |
| Walking | YES |
| Safety | YES |

# 7. Effect of Proposed Development on local wind microclimate.

The following sections outline the findings from the Lawson criteria assessment and minimum safety requirements for the development. In the categories observed 'sitting' is the most sensitive activity examined. 'walking' is the least sensitive activity. In addition, the minimum safety requirement indicates when wind poses a risk to vulnerable pedestrians or cyclists.

## 7.1 Ground floor locations.

### 7.1.1 Location 1: Standing area (Phase 3)

This location refers to the south entrance to the site and identifies the region near to Phase 3 building.

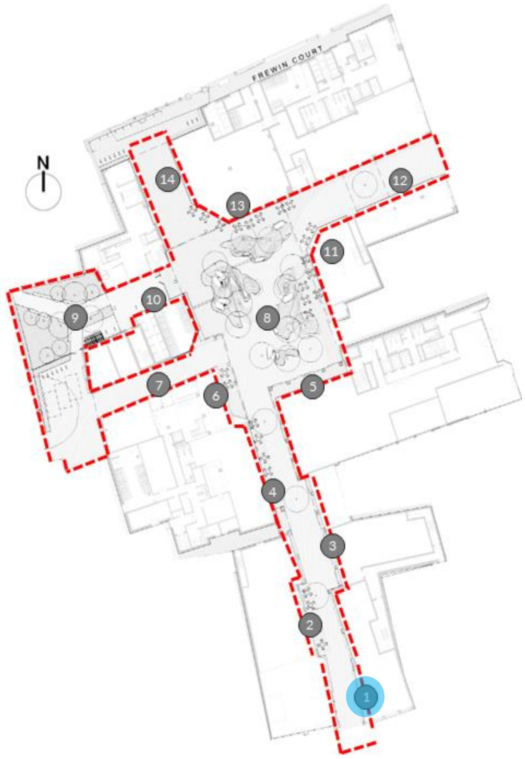



Table 6 shows the results of the Lawson Criteria assessment for this location, indicating that wind conditions are 'Acceptable' for the standing activity considered.

This entrance to the development is on the corner between the internal pedestrian area and Queen Street. The velocity of the prevailing winds from 210° and 240° is expected to be amplified by the "corner acceleration" phenomena and downwash for the façade on Queen Street. The orientation and design of the pedestrian access to the site makes it prone to wind funnelling when the wind direction is 150° or 180°. These wind directions are however not frequent during the year. All other wind directions do not have a substantial impact on this location.

The significance of the effect of wind on pedestrians at Location 1 is calculated as 'Negligible' for the Standing/Entrances category. This location is however not suitable for a "Sitting" category.

No mitigation is required if the category is kept as "Standing/Entrance".

Table 6: Wind microclimate assessment results for Location 1

| Category | Acceptable |
|---|---|
| Sitting | NO |
| Standing/Entrances | YES |
| Strolling | YES |
| Walking | YES |
| Safety | YES |

### 7.1.2 Location 2: Sitting area (Phase 1)

This location is intended to be representative of the sitting area on the west side of the pedestrian path nearby the recessed wall of Phase 1 building. The amenity category has been identified as external sitting area for a probable café or restaurant.

Table 7 shows the results of the Lawson Criteria assessment for this location. Wind conditions are 'acceptable' for the considered activity.

This location is in a favourable position, far away from the corner accelerations that Location 1 will be instead subject to. The main wind that could cause funnelling and influence this location is from the South-East quadrant. Its frequency during the year is however low.

Location 2 is also sheltered by the geometry of the recessed wall, therefore offering an extra protection for outdoors activity like sitting.

Prevailing winds from the 210° and 240° quadrants will have minor influence on this location.

The results of the study showed that the significance of the effect of wind on pedestrians at this location can be defined as 'Negligible'. The designated category Sitting is therefore acceptable.

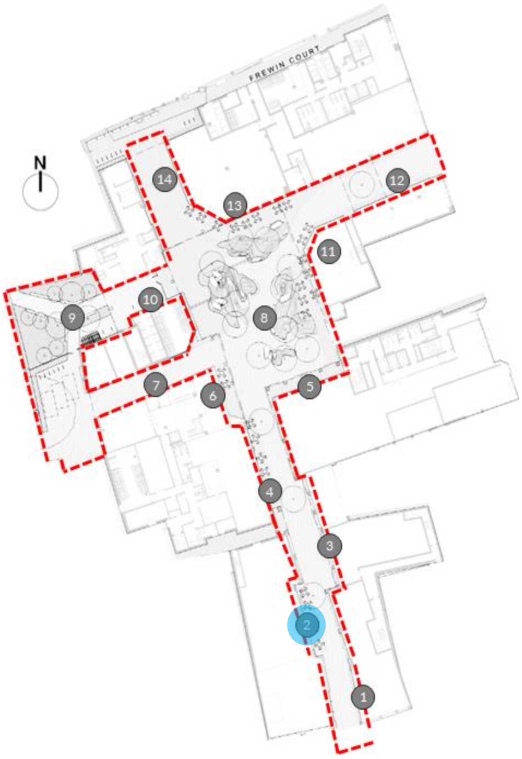



Table 7: Wind microclimate assessment results for Location 2

| Category | Acceptable |
|---|---|
| Sitting | YES |
| Standing/Entrances | YES |
| Strolling | YES |
| Walking | YES |
| Safety | YES |

### 7.1.3 Location 3: Standing area (Phase 3)

This location refers to the standing/entrance area on the Phase 3 building along the internal pedestrian area of the development.

In the same way as the previous locations, this space is relatively sheltered from prevailing winds. The standing area is protected and the only wind direction that has been deemed as relevant is from South-East. The distance of this location from the south entrance to the site makes it less exposed to wind accelerations caused by the South -Easterly winds.

The significance of the effect of wind on pedestrians at this location is classified as 'Minor Beneficial' and the Lawson Criteria assessment for the location shows that Standing/Entrance is acceptable as per Table 8. No mitigation is required.

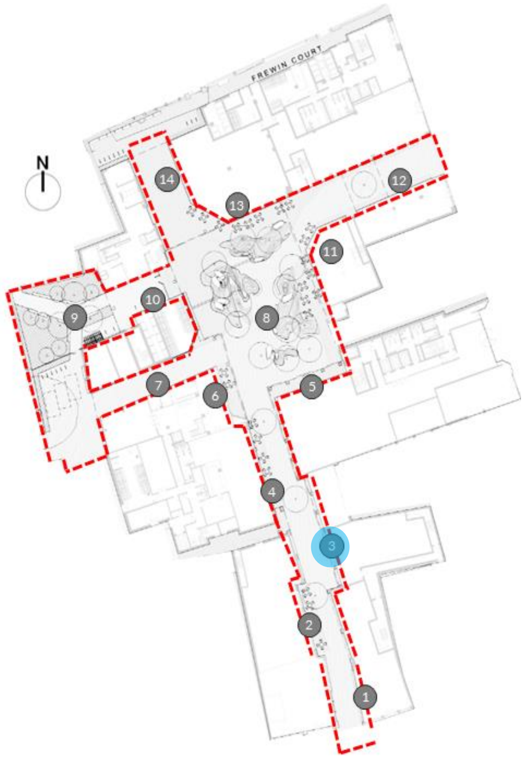



Table 8: Wind microclimate assessment results for Location 3

| Category | Acceptable |
|---|---|
| Sitting | YES |
| Standing/Entrances | YES |
| Strolling | YES |
| Walking | YES |
| Safety | YES |

### 7.1.4 Location 4: Sitting area (Phase 1)

This location refers to the second sitting area on the side of Phase 1 building.

Location 4 is right in a centre of the pedestrian path and relatively sheltered from prevailing winds. Minor tunnelling could increase the wind speed in this area due to the narrowing of the pedestrian path, however the probability of wind form the South-East sector is low.

The significance of the effect of wind on pedestrians at this location can therefore be defined as 'Negligible' and the results of the Lawson Criteria assessment for this location show that sitting is 'acceptable', as per Table 9. No mitigation is required.

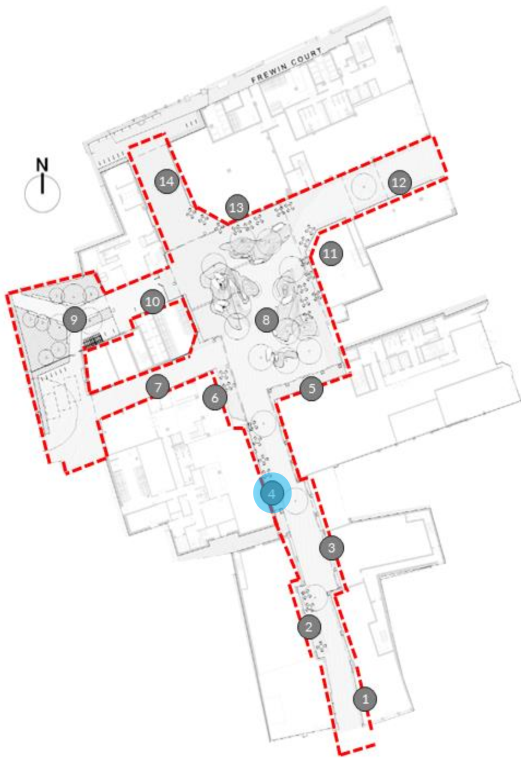



Table 9: Wind microclimate assessment results for Location 4

| Category | Acceptable |
|---|---|
| Sitting | YES |
| Standing/Entrances | YES |
| Strolling | YES |
| Walking | YES |
| Safety | YES |

### 7.1.5 Location 5: Standing area and entrance (Phase 3)

This location refers to the entrance to Phase 3 building from the internal square.

The location is sheltered from the prevailing winds and by possible funnelling that can happen in the pedestrian path along the South-Easterly axis. Wind from the north could influence this entrance, but its recessed position under the '*pilotis*', as well as the adoption of a revolving door visible in the architectural drawings, eliminates every possible discomfort caused by northerly wind entering the main square.

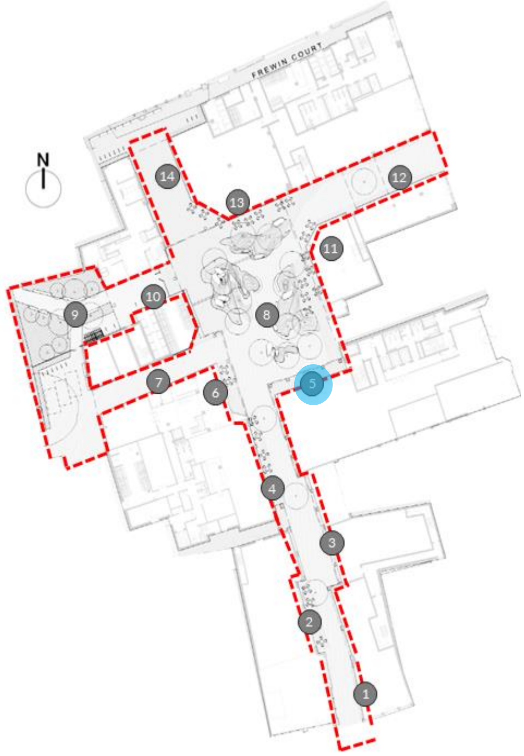


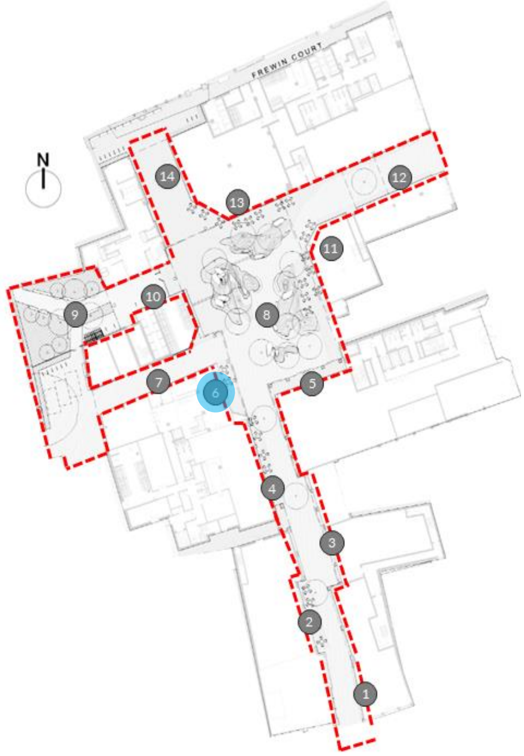

Table 10 shows the results of the Lawson Criteria assessment for this location. Wind conditions are 'acceptable' for the 'Standing' category for 'entrances'. The significance of the effect of wind on pedestrians at this location can therefore be defined as 'Minor Beneficial''. No further mitigation is required at this location.

Table 10: Wind microclimate assessment results for Location 5

| Category | Acceptable |
|---|---|
| Sitting | YES |
| Standing/Entrances | YES |
| Strolling | YES |
| Walking | YES |
| Safety | YES |

### 7.1.6 Location 6: Sitting area (Phase 3)

Location 6 refers to the sitting area on the South-West corner of the internal square.




This location could become exposed to winds funnelling inside the square from the South East and from the South West. Especially on the very corner location minor accelerations could be experienced in prevailing wind conditions. Nonetheless the location is relatively sheltered due to its recessed position on the façade of Phase 1 building.

Table 11 shows the results of the Lawson Criteria assessment. The wind conditions are 'acceptable' for the sitting activity considered. The significance of the effect of wind on pedestrians at this location has been calculated as 'Negligible'. No mitigation is required at this location.

Table 11: Wind microclimate assessment results for Location 6

| Category | Acceptable |
|---|---|
| Sitting | YES |
| Standing/Entrances | YES |
| Strolling | YES |
| Walking | YES |
| Safety | YES |

### 7.1.7 Location 7: Entrance to development (Covered passage of Phase 1)

This location refers to one of the main entrances into the scheme and its located in the covered passage under Phase 1 building, connecting the square with the courtyard.

The location and orientation of this passage increases the likelihood of higher wind velocity in prevailing wind conditions, however the analysis shows its suitability for standing/entrance, as shown in Table 12.

The significance of the effect of wind on pedestrians at this location has been defined as 'Minor Beneficial' for 'Standing/Entrances'. No mitigation is required at this location.

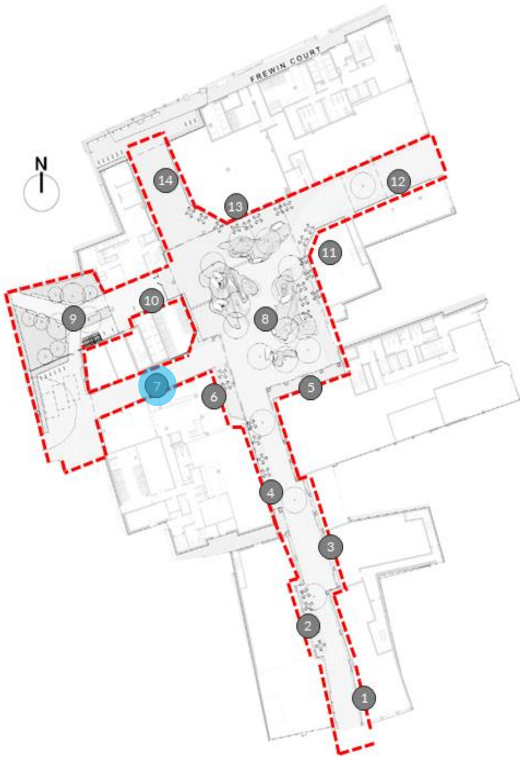



Table 12: Wind microclimate assessment results for Location 7

| Category | Acceptable |
|---|---|
| Sitting | NO |
| Standing/Entrances | YES |
| Strolling | YES |
| Walking | YES |
| Safety | YES |

### 7.1.8 Location 8: Sitting area (Main square)

Location 8 is at the centre of the square and it is sheltered by the proposed trees. This location will be influenced by the easterly and westerly prevailing winds channelling in the passages under the building. However, the trees are expected to offer a good mitigation.

Table 13 shows the results of the Lawson Criteria assessment for this location. The wind conditions are 'acceptable' for all activities considered ('sitting'). The significance of the effect of wind on pedestrians at this location can therefore be defined as 'Negligible'. No further mitigation is required at this location.

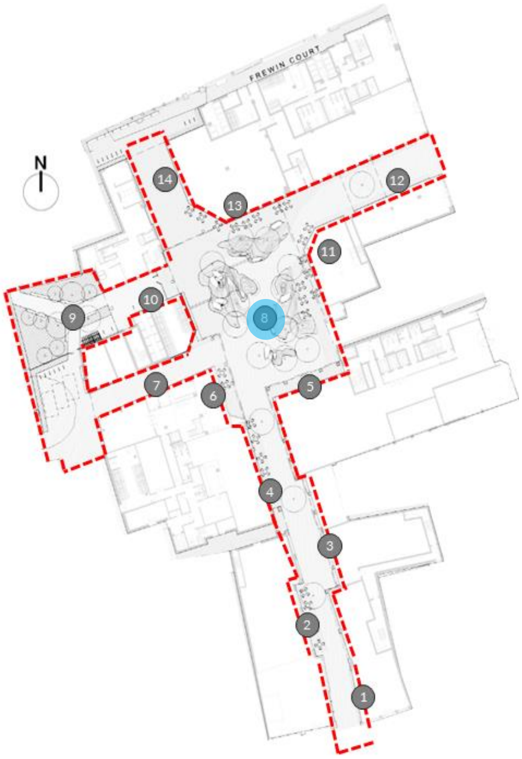



Table 13: Wind microclimate assessment results for Location 8

| Category | Acceptable |
|---|---|
| Sitting | YES |
| Standing/Entrances | YES |
| Strolling | YES |
| Walking | YES |
| Safety | YES |

### 7.1.9 Location 9: Sitting area (Courtyard)

This location is representative of the central area of the courtyard on the west of the proposed development. In a similar way to Location 8, also this location is surrounded by the proposed trees that are part of the landscape design. Due to its position near to a sheltered North-West side, the location is sheltered from prevailing winds, however, it is in line with the East-West axis that leads to Cornmarket St. For this reason, it may be subject to airflow accelerations when the wind from 60° and 90° funnels into this passage. Since these winds are not as frequent as the westerly winds during the year, their effect will be marginal on the overall comfort assessment of this location.

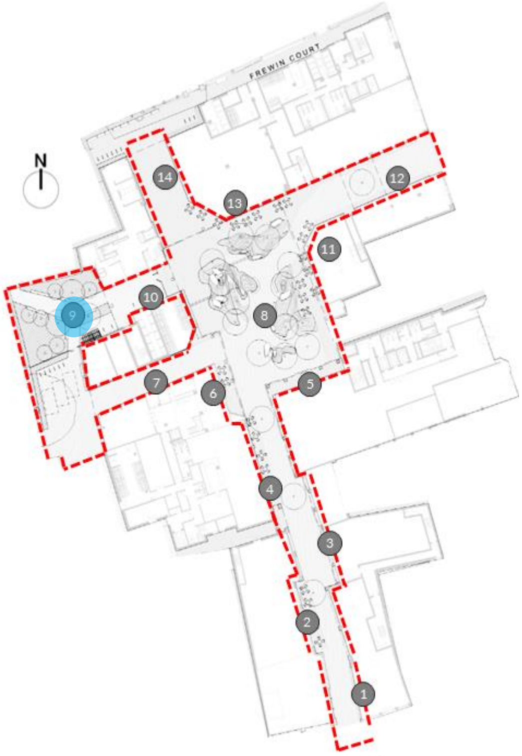


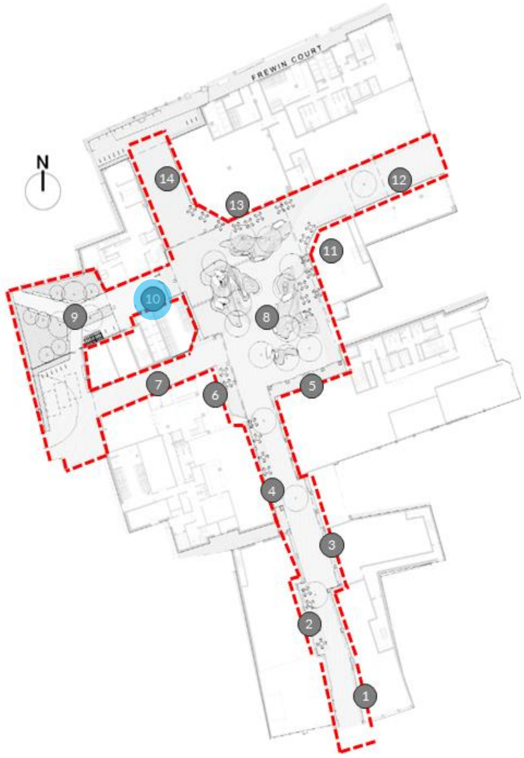

Table 14 shows the results of the Lawson Criteria assessment indicating that the proposed activity will experience 'acceptable' wind conditions. The significance of the effect of wind on pedestrians can therefore be defined as 'Minor Beneficial'. No further mitigation is required.

Table 14: Wind microclimate assessment results for Location 9

| Category | Acceptable |
|---|---|
| Sitting | YES |
| Standing/Entrances | YES |
| Strolling | YES |
| Walking | YES |
| Safety | YES |

### 7.1.10 Location 10: Covered passage (between Phase 1 and 2)

Location 10 identifies the walking path between the square and the courtyard. As discussed before for location 9, also this location will be potentially influenced by Easterly winds funnelling under the buildings from the entrance on Comarket Street. Its more central position will mean that accelerations due to Westerly winds can be experienced too.




The Location 10 is sheltered from all other winds. The assessment conducted in accordance with the Lawson Criteria shows that the wind conditions are 'acceptable' for 'standing/entrances' (Table 15). The significance of the effect of wind on pedestrians is defined as 'Minor Beneficial'.

No mitigation is required at this location.

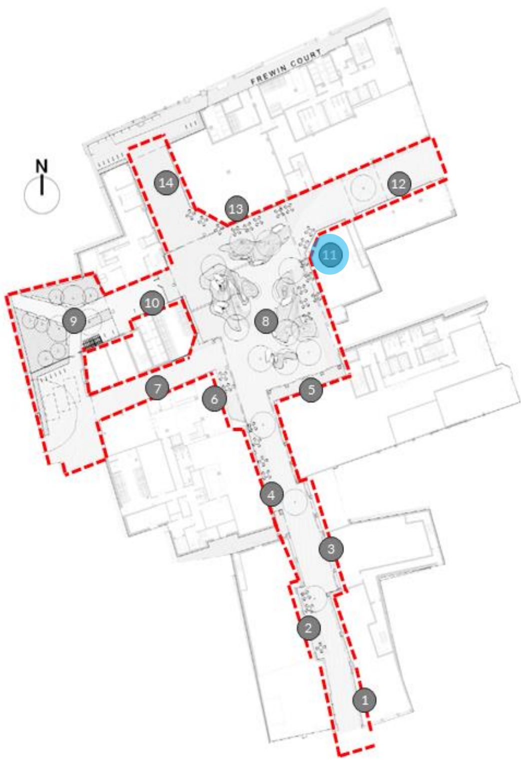
Table 15: Wind microclimate assessment results for Location 10

| Category | Acceptable |
|---|---|
| Sitting | NO |
| Standing/Entrances | YES |
| Strolling | YES |
| Walking | YES |
| Safety | YES |

### 7.1.11 Location 11: Sitting area and possible Entrance to the (Phase 3)

Location 11 refers to the sitting area in the North-Easterly corner of the square adjacent to the passage towards Cornmarket Street.

This location can experience corner acceleration with Easterly and Westerly winds funnelling into the passage to Cornmarket Street.




The trees in the square will mitigate wind accelerations from the West however the two table sets near the 45 degrees corner wall will be exposed to funnelling and corner accelerations during Easterly wind conditions. This location is sheltered from all other wind directions.

Table 16 shows the results of the Lawson Criteria assessment relative to the 45 degrees corner area.

Considering the above potential issues, it is likely that the sitting area positioned in this corner will experience 'Minor Adverse' wind conditions for the proposed sitting activity, that will require location mitigations.

If instead the 45 degrees corner will become an entrance to the development, as recently discussed with the design team, Location 11 will experience "Minor beneficial" conditions, therefore requiring no mitigations.

The sitting area immediately south of the corner of Location 11 is not influenced by negative accelerations and will be sheltered by the proposed trees and landscape. No further mitigation is needed in this southern region of Location 11.

Table 16: Wind microclimate assessment results for Location 11

| Category | Acceptable |
|---|---|
| Sitting | NO |
| Standing/Entrances | YES |
| Strolling | YES |
| Walking | YES |
| Safety | YES |

### 7.1.12 Location 12: Covered passage (Phase 2)

Location 12 identifies the walking path between Comarket Street and the internal square. As discussed before for location 10, also this location will be potentially influenced by Easterly and Westerly winds.

The Locations 12 is sheltered from all other wind directions. The assessment conducted in accordance with the Lawson Criteria shows that the wind conditions are 'acceptable' for the proposed activity (strolling). Sitting in this area will not be recommended, while standing/entrance will be acceptable.

No mitigation is required at this location.

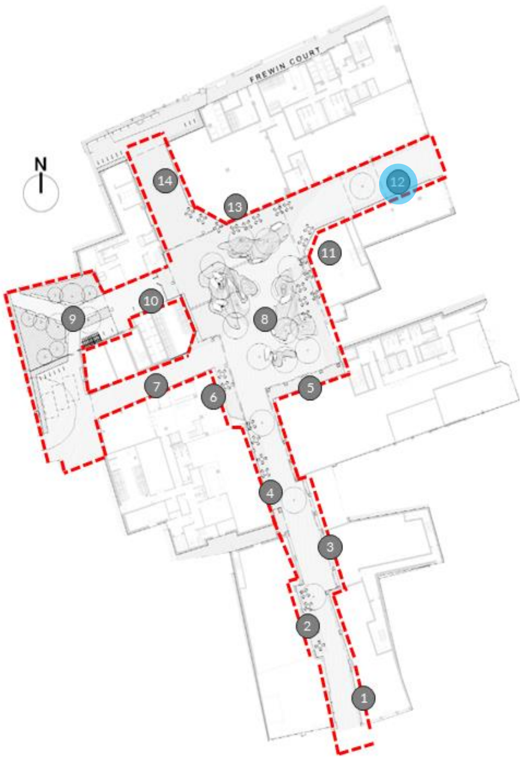



Table 17: Wind microclimate assessment results for Location 12

| Category | Acceptable |
|---|---|
| Sitting | NO |
| Standing/Entrances | YES |
| Strolling | YES |
| Walking | YES |
| Safety | YES |

### 7.1.13 Location 13: Sitting area (Phase 2)

This location explores the wind conditions for the sitting area in the North region of the square.

The sitting area stretches around a corner where the influence of various wind direction can be felt. Minor accelerations can be expected especially during Easterly and Westerly prevailing winds. The proximity of this location to the North access to the development makes it eventually prone to accelerations due to funnelling wind also from the North; but this phenomenon is not expected to be significant as the adjacent Frewin Court is relatively narrow and sheltered. The proposed landscape design and trees will protect location 13 from Southerly wind accelerations due to funnelling inside the pedestrian area and the square.

As highlighted in Table 18 the assessment conducted for this location highlights the potential of local discomfort in the whole sitting area indicated in the plan. The location may require minor mitigations in the form of small planters or porous screens. The significance of the effect of wind on pedestrians at this location can therefore be defined as 'Minor Adverse'.

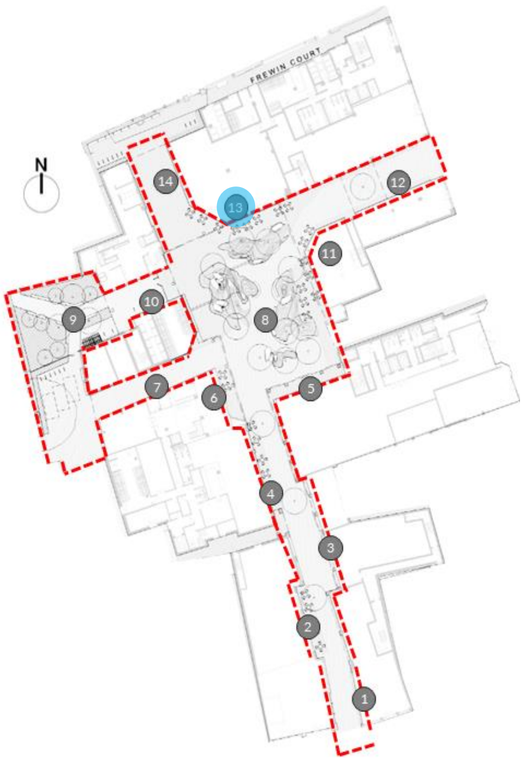



Table 18: Wind microclimate assessment results for Location 13

| Category | Acceptable |
|---|---|
| Sitting | NO |
| Standing/Entrances | YES |
| Strolling | YES |
| Walking | YES |
| Safety | YES |

### 7.1.14 **Location 14: Covered passage (Phase 2)**

Location 14 refers to the north access to the pedestrian area of the development, under Phase 2 building.

This location will be sheltered from all prevailing wind directions and it is expected to experience only minor accelerations due to funnelling wind from the South and from the North (that as discussed earlier, will not be producing relevant accelerations). The South funnelling wind will be partially mitigated by the trees.

Table 19 shows the results of the Lawson Criteria assessment where wind conditions are expected to be 'acceptable' for the proposed 'strolling' activity.

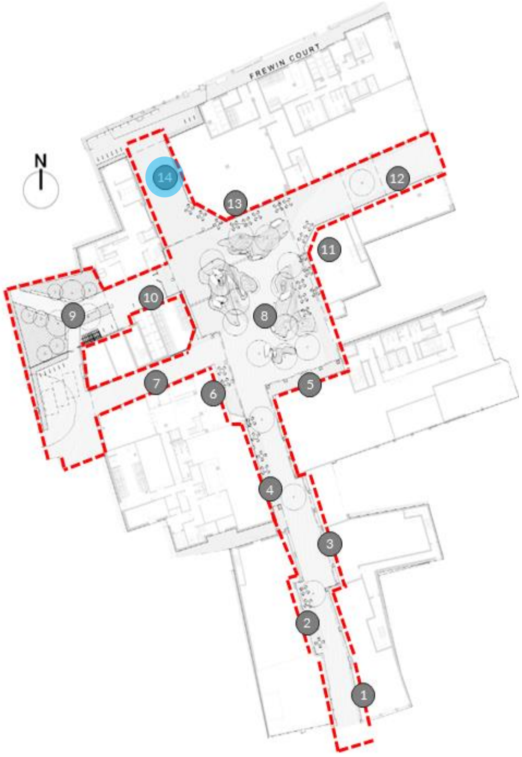



Table 19: Wind microclimate assessment results for Location 14

| Category | Acceptable |
|---|---|
| Sitting | YES |
| Standing/Entrances | YES |
| Strolling | YES |
| Walking | YES |
| Safety | YES |

# 8. Proposed Mitigation Options.

A total of 2 locations were found to have wind conditions which are ‘unacceptable’ for their intended use and therefore mitigations are to be considered. Suggested mitigation options are provided below. Where landscaping strategies are developed the ‘acceptable’ outcome will depend on the suitability of the strategy undertaken and will require final review by the wind engineer.

## 8.1 Pedestrian level.

The locations 11 and 13 present a similar geometrical context and same utilisation category. Both locations are also influenced by similar wind directions that are likely to produce acceleration in proximity to the 45-degree corners where café’-restaurant tables are indicated. The analysis conducted using the Lawson criteria has shown that these locations will experience “Minor adverse” conditions for sitting, and therefore some form of local mitigation will be required.

Table 20: Summary of locations that require mitigations (Ground floor)

| Location No | Location Name | Category Required | Significance Criteria | Assessment result | Mitigation |
|---|---|---|---|---|---|
| 11 * | Corner seating area in Phase 3 | Sitting | Minor Adverse | Unacceptable | Recommended |
| 13 | Corner seating area in Phase 2 | Sitting | Minor Adverse | Unacceptable | Recommended |

* It must be noted that the corner in location 11, that is currently reported as a sitting area in the architectural drawings, will be probably serve as one of the entrances to Phase 2 building. If this is the final intention of the designer, the Location 11 will then be suitable for this type of category and no mitigations will be required.


**Minor Adverse**

**Mitigation options are required**

1. Where possible low level vegetation should be planted adjacent to seating areas. Shrubs should be at least 1.3m in height including the height of the planter where available.
2. Trees, positioned upwind, are another possible option and they should be at least 3m in height.

Figure 10: Proposed mitigation (area identified by the pink dot denotes necessary landscaping).

# 9. CFD analysis.

The Computational Fluid Dynamic analysis has been conducted to provide a more in-depth comprehension of the wind phenomena on site. The study focused on the two prevailing wind directions (210° and 240°). Detailed insight into the air flow characteristics around the site have been reported. The CFD analysis was carried out on a steady state basis with an 'averaged' turbulence model and therefore do not take safety or gustiness effects into account.

Figure 11 shows the extend of the model used for the CFD. This model represents the computational domain where the wind is simulated and visualised using coloured contour maps and streamlines (streamlines are a geometrical representation of wind behaviour that is based on the assumption that the lines are always tangent to the wind path in each point of the trajectory).

The three phases of the Proposed Development are represented at the centre of the computational domain that extends for a radius of 400 meters around the proposed development. This radius allows for the inclusion of a significant region of the surrounding buildings and terrain, therefore increasing the accuracy of the modelling results.

The proposed trees inside the development have been modelled in 3D and included as part of the CFD study. The dimension and position of the trees have been coordinated with the Landscape Architect firm, Farrer Huxley, and the following sizes are applied to the model:

- Single stem trees: 30-35cm girth, 5.5-6.5m high and 2.5m clear stem.
- Multi stem (in courtyard only): 3.5-4.0m high.

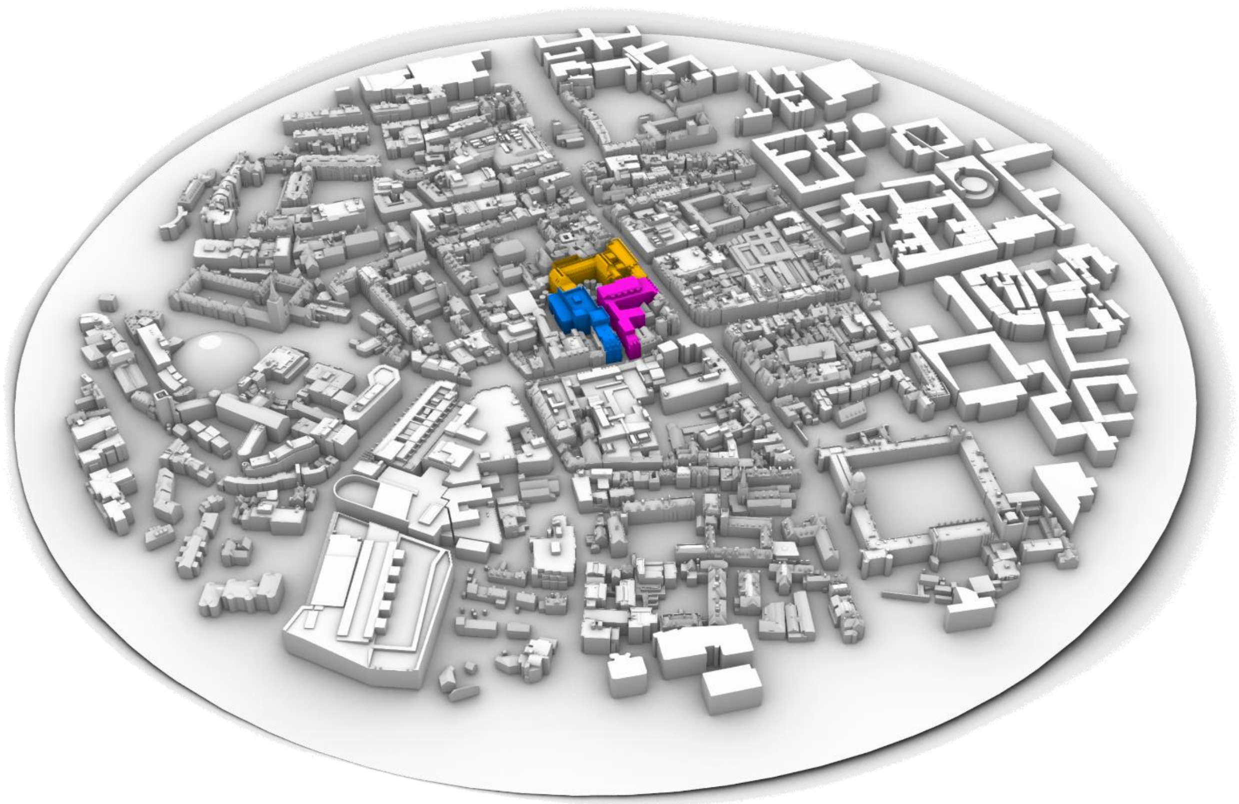


Figure 11: 3D model of the computational domain representing the site and Proposed Development three phases.

The CFD study assumes a reference velocity of 10m/s at inlet (located at the edges of the circumference of the computational domain). The reference velocity is not illustrative of all annual wind conditions on site, but only serves for the purpose of normalising the results for comparison of each wind direction effects. Therefore, the velocity maps below will need to be interpreted by looking at the areas where wind can accelerate due to the geometry of the proposed development. In particular, areas where the velocity accelerates abruptly compared to nearby regions, need to be taken into consideration.

Velocity magnitude are reported on a plane positioned at 1.5m above the ground. This height of the plane is recommended in order to capture the effect of the wind on people in sitting and standing positions.

### 9.1 South West wind from 210°.

Figure 12 shows the velocity on the 1.5m plane when wind blows from the South West with an angle of 210°. The higher acceleration of the wind is visible in the south corner of the site, just at the entrance of the pedestrian access on Queen Street (Location 1). However, the shape of the proposed development does not amplify much the wind speed at this location and therefore accelerations could only represent a minor adverse condition for sitting. Considering that the proposed activity in Location 1 is standing, no comfort issues are expected, as discussed in the wind desktop analysis.

Other minor accelerations have been identified also in the nearby regions of the internal pedestrian path, in proximity to Locations 2, 3, and 4.

These locations are likely to be more sheltered ad protected than Location 1, so no concerns are raised, and conclusion of the Desktop analysis are confirmed.

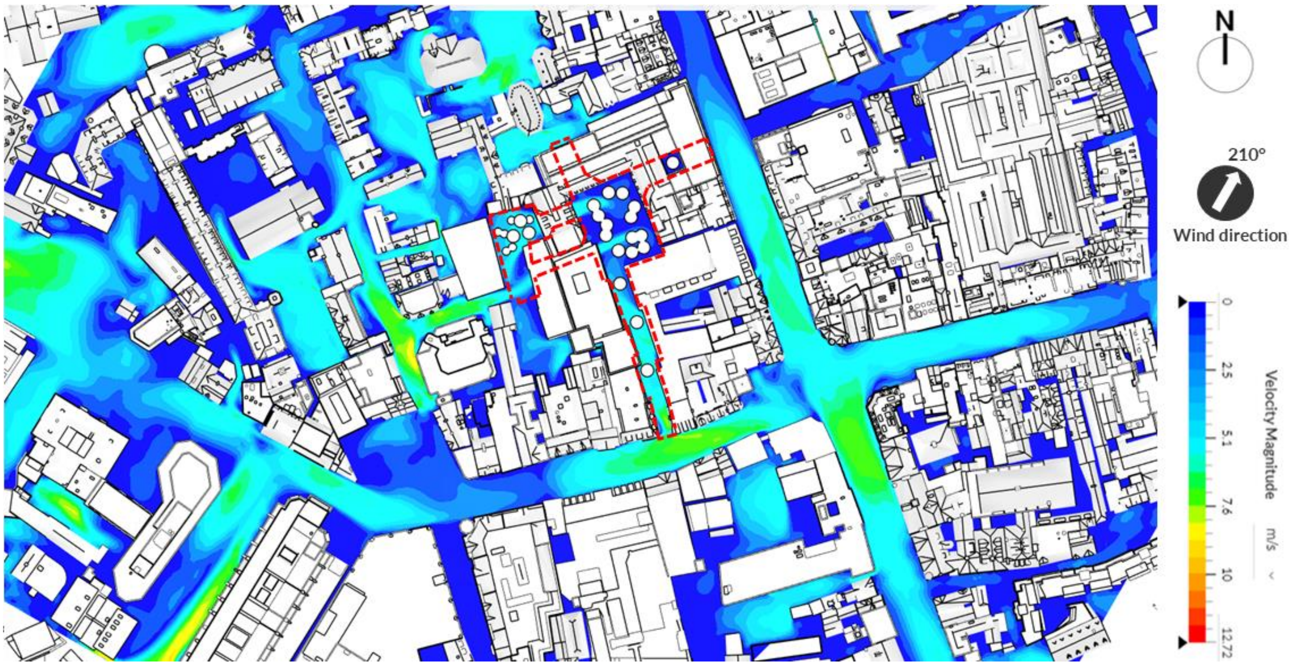



Figure 12: Velocity map on the site, produced by a 210° wind.

Figure 13 and Figure 14 show the wind streamlines respectively from a perspective view and from the top. Incoming wind intercepts the façade of Phase 1 building on Queen Street and gets “downwashed” towards location 1 where it reaches the ground and enters the pedestrian area. As shown by the streamlines coloured by velocity, the accelerations are mostly minor and only affect the Location 1. Trees along the pedestrian path mitigate the intensity of the wind reducing its velocity further before it reaches the square.

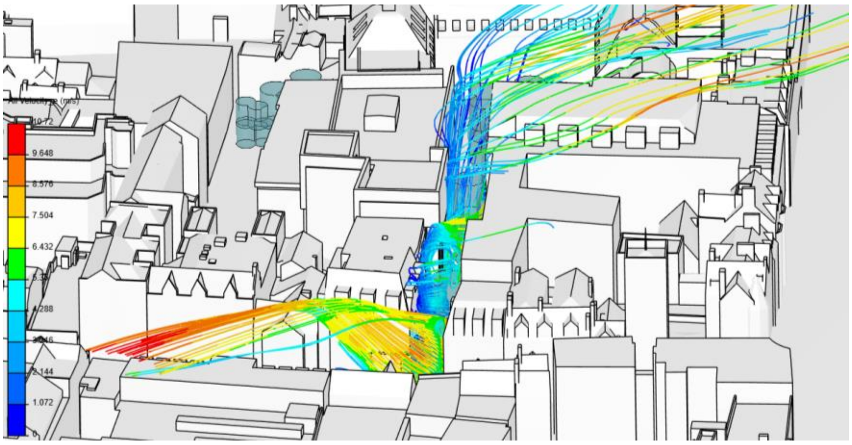



Figure 13: 210° wind streamlines, perspective view.

Figure 14: 210° wind streamlines, top view.

## 9.2 South West wind from 240°.

Figure 15 shows the velocity magnitude on the site when prevailing wind from 240° is simulated. The accelerations in Location 1 are the predominant ones on the whole pedestrian area. However, with this wind condition other minor accelerations are also identified in the pedestrian connection between the courtyard and the square (Location 10). Because both locations assume a “Standing” or “Walking” activity, the recorded accelerations are not expected to penalise comfort for these categories, as discussed in the wind desktop analysis.

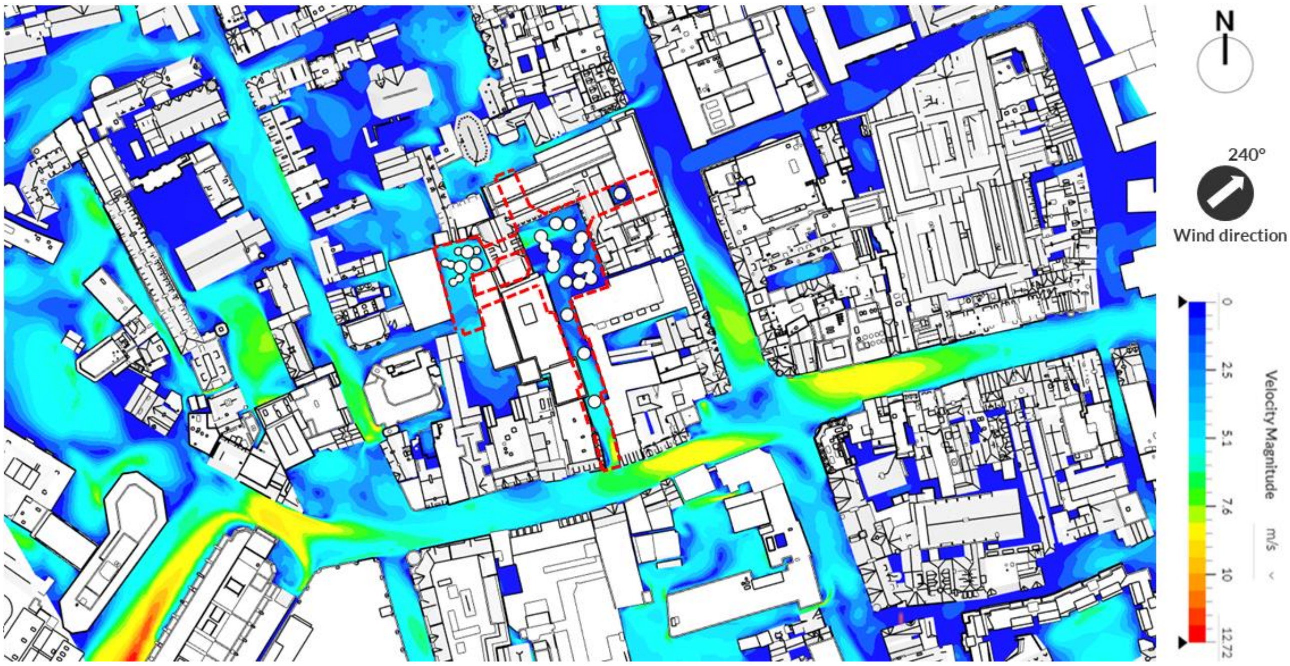



Figure 15: Velocity map on the site, produced by a 240° wind.

The 3D view of the streamlines in Figure 16 helps to understand the important role of the trees in the courtyard. Trees are modelled as porous elements that will slow down the acceleration of the flow as it passes through the crown.

In the case of the 240° wind in the square, the trees can reduce the velocity and disperse the flow streamlines. The expected accelerations of the flow near the corners of Phase 1 and Phase 2 building (location 11 and 13) is shown in Figure 17. This figure helps to visualise the velocity in the square and in the connection passages under the Phase 1 and 2 buildings.

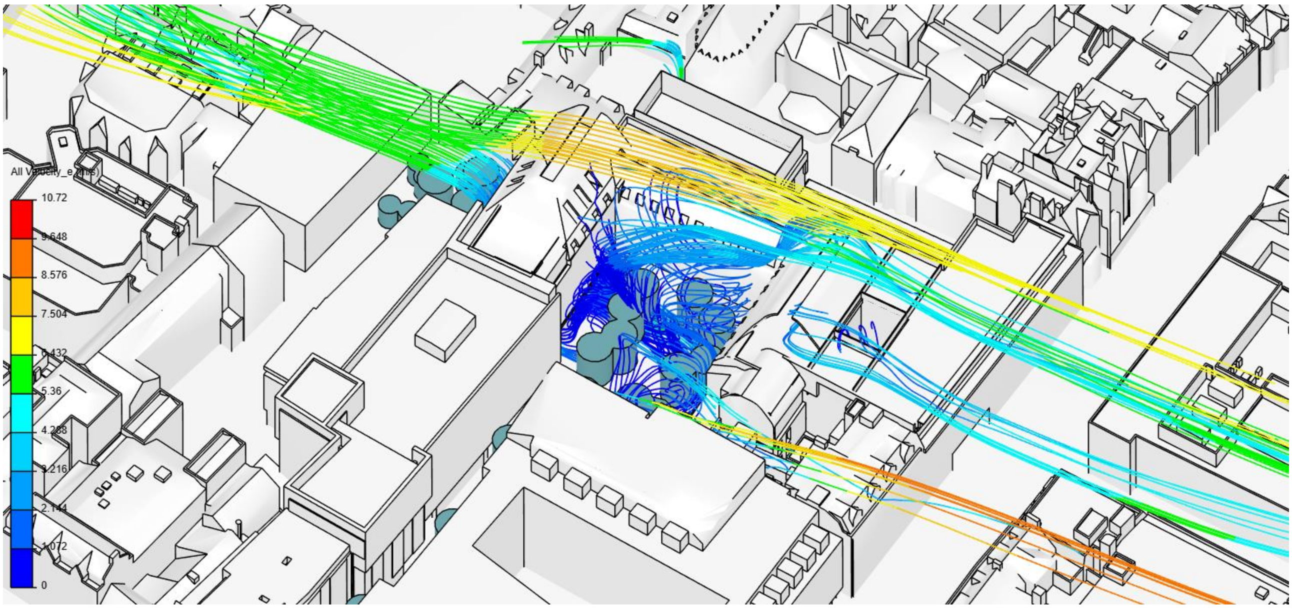



Figure 16: Streamlines in the internal square, 240° wind.

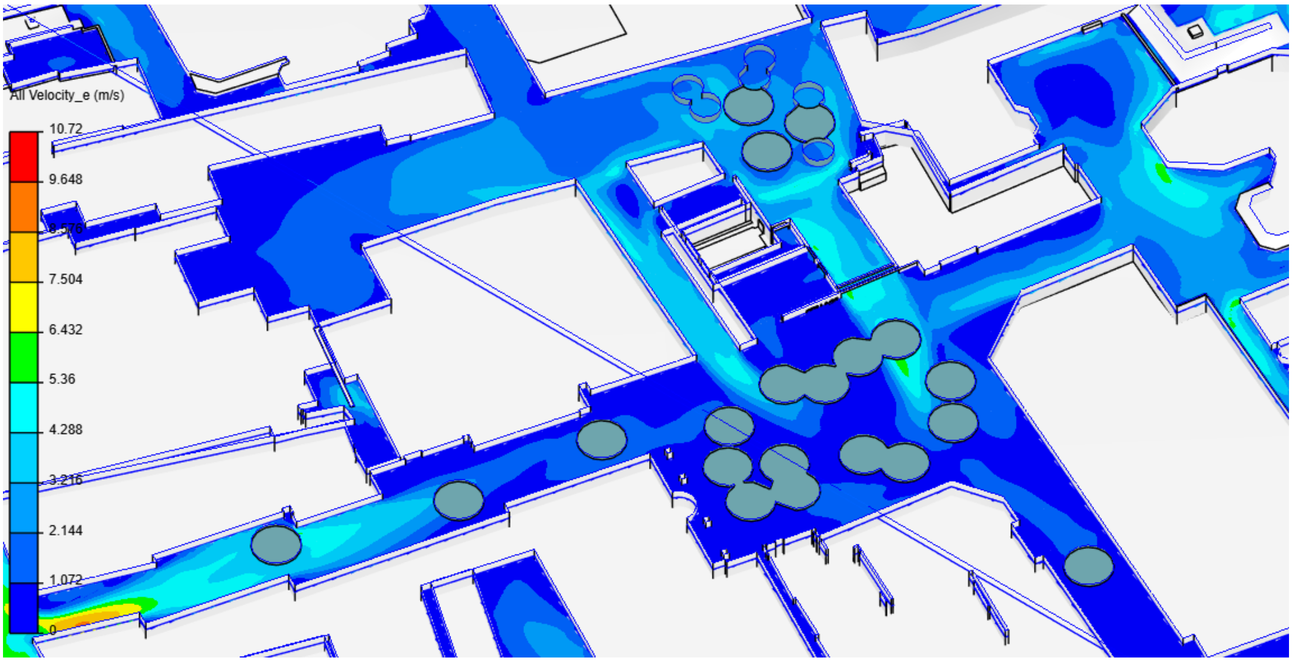



Figure 17: Contour map of velocity showing accelerations in the internal square and in the access from Queen Street, 240° wind.

### 9.3 CFD conclusions

As highlighted in the explanation of results above, the CFD simulation confirms the expected behaviour of the wind flow within the development for the 210° and 240° prevailing winds, complementing the findings of the Lawson Desktop assessment discussed previously.

The CFD analysis of two wind directions does not capture all the details of the airflow in the site and does not represent a full pedestrian wind comfort assessment. Therefore, conclusions on outdoors discomfort or safety cannot be drawn by processing only these two datasets. However, the study has given useful insights on the response of the proposed geometry exposed to prevailing South Westerly winds.

The CFD identified minor areas of acceleration near corners and narrow passages, when simulating the 210° and 240°. These findings have been already captured in the Desktop analysis and do not conflict with previous comments.

## 10. Overall Summary and Conclusions.

The analysis overall found the following:

1. A total of 14 locations were considered.
2. The development site is in part sheltered to prevailing winds from south west and from the east.
3. Two locations were found to have unacceptable wind conditions for the identified sitting activity.
4. Mitigation recommendations have been provided and are summarized for all relevant areas in Proposed Mitigation Options.

Figure 18 below presents a visual summary of the findings for each location (considering also the effect of proposed landscape design).

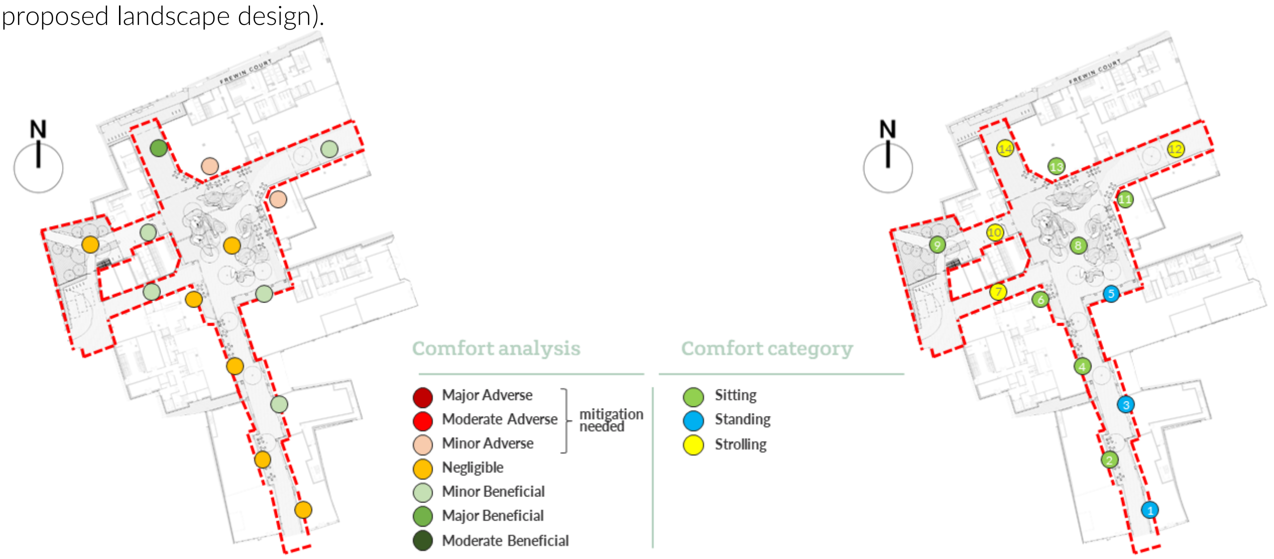



Figure 18: Summary of significance criteria results for areas at pedestrian level (only 'adverse' conditions require mitigation)

## 11. References.

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# Appendix A: Weibull parameters.

The Weibull distribution is a two-parameter function commonly used to fit the wind speed frequency distribution. This family of curves has been shown to give a good fit to measured wind speed data. The Weibull function provides a convenient representation of the wind speed data for wind energy calculation purposes.

The Weibull parameters k and c can be calculated using the modified Maximum Likelihood method for wind data in frequency distribution format. Whereby:

$$k = \left( \frac{\sum_{i=1}^{n} vi^{k} \ln(vi)\, P(vi)}{\sum_{i=1}^{n} vi^{k}\; P(vi)} - \frac{\sum_{i=1}^{n} \ln(vi)\, P(vi)}{P\,(v \geq 0)} \right)^{-1} \quad (1)$$

$$c = \left( \frac{1}{P(v \geq 0)} \sum_{i=1}^{n} vi^{k}\, P(vi) \right)^{\frac{1}{k}} \quad (2)$$

$v_i$ = Wind speed central to bin $i$

$n$ = Number of wind speed bins

$P(v_i)$ = Frequency with which he wind speed falls within bin $i$

$P(v \geq 0)$ = Probability that the wind speed equals or exceeds zero

Equation (1) must be solved iteratively, after which Equation (2) can be solved explicitly.

## Appendix B: The Deaves and Harris model.

The Deaves and Harris model provides a method to calculate the wind velocity variation with height. It meets both the upper and lower boundary conditions and is therefore applicable to the entire boundary layer, not just the surface layer. The Deaves and Harris wind speed profile is given by:

$$U(z) = \frac{u_*}{k}\left[\ln\left(\frac{z}{z_o}\right) + 5.75\left(\frac{z}{h}\right) - 1.88\left(\frac{z}{h}\right)^2 - 1.33\left(\frac{z}{h}\right)^3 + 0.25\left(\frac{z}{h}\right)^4\right] \qquad (3)$$

Whereby:

$\mathrm{h}$ = height of the neutral boundary layer in metres

$z$ = height in metres from ground level

$u_*$ = surface friction velocity

$\mathrm{k}$ = the von Karman constant

# Appendix C: Guidance on wind flow characteristics.

As documented in BRE Digest 520, the characteristics that are most likely to create uncomfortable wind conditions at pedestrian levels are identified below as well as regions where high levels of windiness commonly occur.

### C.1 Downwash from tall buildings.

When the wind approaches a large (tall and wide) façade head-on, the flow splits at a height of 0.66-0.75 of the height of the building and tries to find a path in order to move around the building. This is shown in Figure C-0-1. The point at which the flow splits is called the 'stagnation point'. Some air will flow over the top and around the sides, but some will be washed downwards towards the street level at the speed at which it approached the stagnation point. The speed-up factor generated will be in the region of 1.2 to 2 depending on building height.

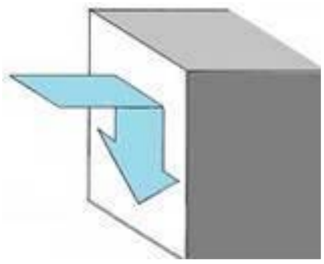

Figure C-0-1: Illustration of 'downwash'

### C.2 Downwash between two buildings.

Downwash from tall buildings may be amplified if there is a lower building upwind. Air that is washed downwards approaches the ground and cannot continue moving downwards. Therefore it must change its direction. If there is a building immediately upwind blocking the oncoming wind at low level, the wind is able to travel back in the opposite direction to the oncoming wind due to the shelter of the upwind building. On reaching the upwind building the wind must again change its direction and moves up to join the oncoming wind stream. This parcel of air rotates in the gap between the buildings and a stable vortex can be maintained. Wind speed-up factors at the base of the building can reach a value of 2 depending on the height of the downstream building.

### C.3 Corner streams.

If there is no building upwind of the building causing the downwash, the air cannot go back the way it came against the oncoming wind. Therefore it is confined on the windward face where it forms a circulation region in the lower area of the windward face near the ground. The windward vortex is continually being pushed by more downwash from above, so it tries to move around the building, circulating as it goes. This circulation region looks like a corkscrew and is quite turbulent. As air moves around the corners, as shown in Figure C-2, wind speed-up factors at the base of the building can reach a value from 2 to 2.5 for very tall buildings.

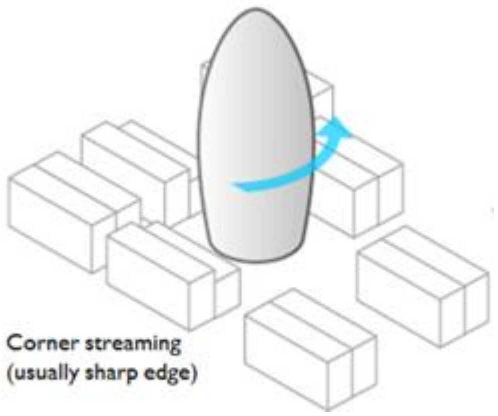


Figure C-2: Illustration of 'corner streaming'

### C.4 Funnelling.

Funnelling occurs when large amounts of air are directed through narrow gaps, with few or no alternative routes around them, as shown in Figure C-3. Examples are passageways through large buildings at ground level or where buildings are angled 90° or less towards the oncoming wind with a narrow gap between them. Funnelling can increase wind speeds by a factor of up to 1.3 (against wind speeds normally seen at pedestrian height), depending on the size of the gap relative to the size of the adjacent buildings.

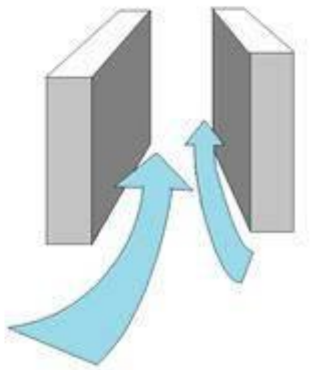

Figure C-3: Illustration of 'funnelling'

### C.5 Entrances to buildings.

Building entrances are particularly sensitive to wind as people are moving from the still environment of the building into the potentially windy outdoor environment. Entrances should therefore be protected from the effects of wind speed up and ideally located in more sheltered areas.

HOARE LEA

**ENRICO CROBU**
PRINCIPAL BUILDING PHYSICS ENGINEER

+44 20 3668 7272
enricocrobu@hoarelea.com

HOARELEA.COM

Western Transit Shed
12-13 Stable Street
London
N1C 4AB
England