REPORT N^{O} 70023367-122

122 OLD HALL STREET

WIND ASSESSMENT

October
2016

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Wind Assessment Report

Project no: 70023367-122

Date: October 2016

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1 INTRODUCTION

1.1.1 WSP | Parsons Brinckerhoff (WSP | PB) has been commissioned by Old Hall Street Ltd to undertake a wind environment assessment of the proposed development at the 122 Old Hall Street site in Liverpool. This report summarises the results of the wind assessment at pedestrian level within the site and its surroundings. Full details of the assessment are provided in Appendices 1 to 4.

1.1.2 The site is located to the north west of the Liverpool city centre close to Princes Dock. The site is bounded by Leeds Street to the north, Back Leeds Street to the west and is neighboured a car park on the eastern and southern sides. The surroundings are mainly characterized by mixed commercial buildings including hotels and warehouses along the River Mersey, while some residential developments are noticeable towards the inner east area.

1.1.3 The proposed development consists of the construction of a 27-storey residential tower to replace an existing parking area on Leeds Street. The development will include commercial areas at the ground level and various size apartments ranging from studios to 3 bedroom flats. Figure 1.1 illustrates the ground floor plan with building accesses.

Figure 1-1 122 Old Hall Street, Ground floor plan

1.1.4 The effect of the proposed development on the local microclimate has been assessed against best practice guidelines for pedestrian comfort and safety. These two aspects are associated with pedestrian use of public open spaces and it is important to ensure that the design follows national good practice design guidelines developed to minimise associated negative effects. Where appropriate the report also identifies proposed mitigation measures to prevent, minimise or control likely adverse effects arising from the proposed development.

1.1.5 Wind environment is defined as the wind flow experienced by people and the subsequent influence it has on their activities. It is concerned primarily with wind characteristics at pedestrian level. Other potential wind effects including wind loads, structural response and natural ventilation are not directly related to the wind environment at pedestrian level and therefore, have not been considered within this assessment.

2 GUIDANCE

2.1.1 The widely applied wind environment criteria for pedestrian comfort and safety developed by T.V. Lawson (Lawson, 2001) from Bristol University have been used in this study. This method is comparable with international guidance.

2.1.2 The Best Practice Guidelines for the Computational Fluid Dynamics Simulation of Flows in the Urban Environment (Franke et al, 2007) have also been used as a technical reference for the study.

3 URBAN WIND EFFECTS

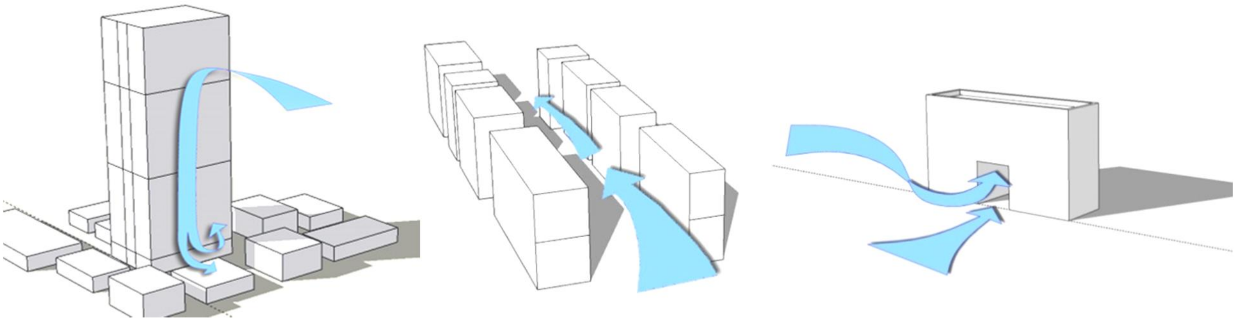
3.1.1 Buildings and terrain affect the speed and direction of wind flows. Over a ground surface of uniform roughness, the wind speed increases with height. Relative shelter near ground level is a result of friction over the ground. Wind speeds amongst buildings of uniform height are generally very low compared with upper-level wind speeds or those experienced at ground level in large open areas between buildings.

3.1.2 The anticipation of the likely wind conditions resulting from new developments are important considerations in the context of pedestrian comfort and the safe use of the public realm. While it is not always practical to design out all the risks associated with the wind environment, it is possible to provide local mitigation to minimise risk or discomfort where required.

3.1.3 Potential negative effects on pedestrian safety and comfort include:

- A significant increase in wind speeds that puts the safety of pedestrians at risk.
- Localised zones of acceleration that result in pedestrian discomfort. These effects will vary according to the intended use for each area. For example, an area designated primarily as a pedestrian circulation route should aim for a wind condition suitable for strolling or leisure walking. Similarly, wind conditions at building entrances should be within the comfort range for people standing. An area designed to function as an outdoor café should have a wind environment which is suitable for a more sedentary activity such as sitting.
- Adverse wind effects can result from large flanking facades facing the prevailing wind which can cause downwash effects; Buildings of high massing will also tend to create increased windiness around its corners extending to the opposite side from the wind direction, due to pressure differences.
- Narrow passageways at the ground level of a building can cause funnelling effect of wind which can be uncomfortable for users and passer-byes. Figure 3-1 shows examples of generic wind effects from buildings.

Figure 3-1 Wind Effects due to various building configurations



4 METHODOLOGY

4.1 ASSESSMENT METHODOLOGY

4.1.1 A quantified assessment of the existing wind environment at the site was used to establish the 'baseline scenario'. This was followed by an assessment of the site with the proposed development modelled surrounded by existing buildings in order to determine the effect of the 'Proposed Scenario'. A further scenario includes the consented developments to determine the cumulative effects.

4.1.2 The method for the study combines the use of Computational Fluid Dynamics (CFD) to predict wind velocities and air flow patterns, the use of wind data from the nearest suitable meteorological station and the recommended comfort and safety standards (Lawson Criteria). A full 3 dimensional model of the site and surrounding areas have been constructed for the assessment. The extent of the model comprises the site and a surrounding context within a radius of approximately 500 metres. The study took into account the following factors:

- The effect of the geometry, height and massing of the proposed development and existing surroundings on local wind speed and direction;
- The wind speed as a function of the local environment as topography, ground roughness and nearby obstructions (buildings, bridges, etc.);
- The effects of the built up urban site on the wind flow patterns;
- Orientation of the buildings relative to the prevailing wind direction; and
- The pedestrian activity to be expected (sitting, standing, strolling and fast walking). It should be noted that effects on pedestrian comfort and safety are only considered externally to the building. No assessment has been made of the potential effects of the wind environment inside buildings as microclimate studies are only intended to address external conditions.

4.1.3 The results of the assessment are presented in the form of wind velocity contours at a plane 1.5m above the ground level. This reference height is industry standard to assess comfort and safety at pedestrian level.

4.2 THE SITE AND STUDY AREA

4.2.1 The 3d model constructed for the study includes the built area within a radius of approximately 500 metres from the site to account for the influence of the surrounding context on the incoming winds as they reach the site. Buildings beyond this region are only represented in the model if their distance from the region of interest is less than 6 times their height, in line with best practice guidelines.

4.2.2 The existing and committed developments in the surroundings have been included in the cumulative scenario and quantitatively assessed as part of the study. Figure 4-1 illustrates the extent of the study area.

Figure 4-1 Extent of the wind study area

4.2.3 The model excludes both soft and hard landscaping (trees, street furniture etc.), which is a representation of the worst case scenario since landscaping will generally improve the wind environment.

4.3 CRITERIA FOR PEDESTRIAN SAFETY AND COMFORT

4.3.1 The Lawson Criteria (Bristol Method) have been applied to determine the acceptability of wind conditions for pedestrian safety and comfort. The Lawson Criteria stipulates that for the comfort and safety assessment of wind effects, it is not only the velocity of wind that is considered but also the frequency of occurrence of these velocities. The frequency of occurrences is used as an indicator of the likely duration of certain wind speeds. The criteria provide ranges of acceptability to maintain pedestrian comfort for different activities and relate frequency of occurrence to the hourly average wind speed ranges of the Beaufort scale, (Tables 4-1, 4-2 and 4-3).

Table 4-1 The Beaufort Scale

BEAUFORT FORCE	HOURLY AVERAGE WIND SPEED (M/S)	DESCRIPTION OF WIND
0	< 0.45	Calm
1	0.45-1.55	Light
2	1.55-3.35	Light
3	3.35-5.60	Light
4	5.60-8.25	Moderate
5	8.25-10.95	Fresh
6	10.95-14.10	Strong
7	14.10-17.20	Strong
8	17.20-20.80	Gale
9	20.80-24.35	Gale
10	24.35- 28.40	Strong Gale
11	28.40-32.40	Storm
12	>32.40	Hurricane

Table 4-2 Lawson's Comfort Assessment Criteria

PEDESTRIAN ACTIVITY	ACCEPTABILITY CRITERIA	EQUIVALENT ANNUAL NO. OF HOURS
Sitting	1% > B3 (3.35 - 5.60 m/s)	88
Pedestrian Standing	6% > B3 (3.35 - 5.60 m/s)	526
Pedestrian Leisure Walk	4% > B4 (5.60 - 8.25 m/s)	350
Business Walk	2% >B5 (8.25 - 10.95 m/s)	175

4.3.2 The Lawson method also identifies a safety criterion to identify those areas where someone could find walking difficult, or even stumble and fall. The Lawson criteria defines Beaufort Force 6 as the limit for pedestrian safety and locations where the wind speed have a 0.01% probability of being exceeded over the whole year have been identified in this assessment.

Table 4-3 Lawson's Comfort Assessment Criteria

PEDESTRIAN ACTIVITY	ACCEPTABILITY CRITERIA	EQUIVALENT ANNUAL NO. OF HOURS
All pedestrians including sensitive pedestrians	0.01% > B6 (10.95-14.10 m/s)	1

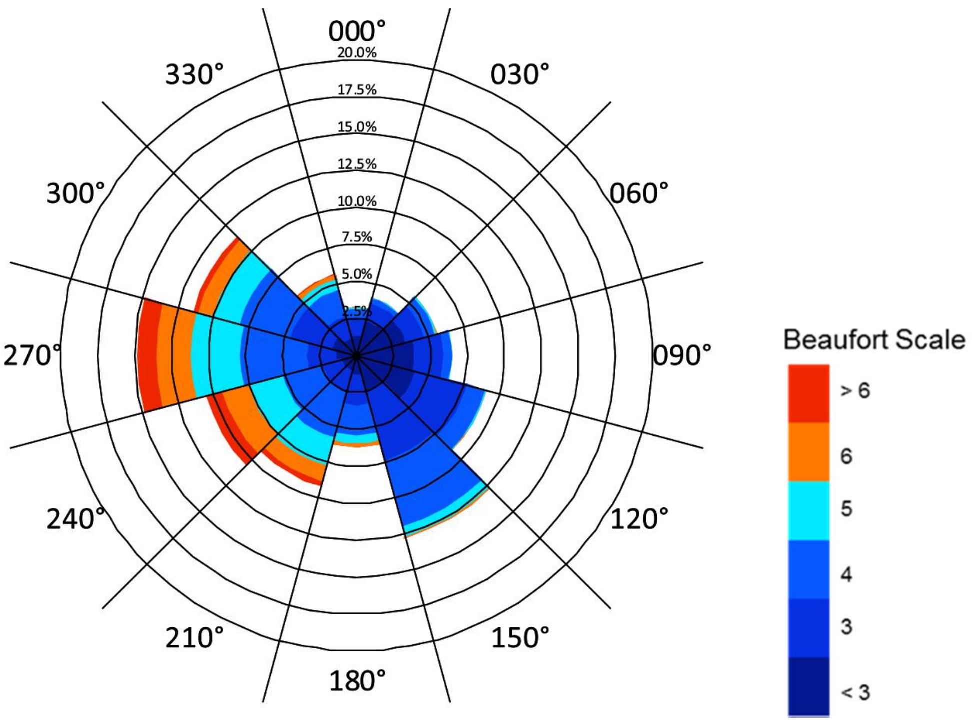
4.4 WIND CLIMATE ANALYSIS

4.4.1 Ten-year hourly wind data from the Liverpool Airport Weather Station was used to assess the local wind conditions surrounding the site. For this region, the most frequent wind direction is the West, followed by the Northwest, South/Southwest and South/Southeast quadrants blowing overall with the highest frequency at Beaufort Force 3 and 4 (i.e. between 3.35-8.25m/s).The wind speeds exceed Beaufort Force 6 for 3.3% of the time. The summary of the wind data at the station can be found in Table 4-4 and Figure 4-2.

Table 4-4 Directional Frequency of Wind Speed at the Met Station

BEAUFORT FORCE	PERCENTAGE OF WIND FREQUENCY BY DIRECTION (%)												
	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°	Total
Below 3	1.4	2.4	3.5	3.9	4.2	2.5	1.3	1.1	1.1	1.4	1.8	1.2	25.9
3	1.1	1.1	1.2	1.9	3.5	4.8	2.0	1.4	1.3	1.9	2.8	1.5	24.3
4	0.6	0.4	0.8	0.6	1.3	4.6	2.0	3.2	2.8	4.5	3.6	1.8	26.3
5	0.1	0.0	0.1	0.0	0.1	0.7	0.6	2.0	2.4	3.3	1.9	0.7	11.9
6	0.0	0.0	0.0	0.0	0.0	0.1	0.2	1.1	1.8	2.3	1.0	0.3	6.9
Above 6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.1	1.3	0.3	0.1	3.3
Calm	-	-	-	-	-	-	-	-	-	-	-	-	1.3
Total	3.2	4.0	5.6	6.4	9.1	12.7	6.2	9.2	10.5	14.8	11.4	5.7	100.0

Figure 4-2 Wind Rose for the Met Station



4.5 WIND DATA ADJUSTMENTS FOR SITE TERRAIN

4.5.1 In order to adapt the data from the weather station to the site and account for the difference in topography and terrain, a procedure to 'transpose' the wind data from the weather station onto the site was undertaken using the software BREVe 3.2 which provides roughness factors and other terrain characteristics for the specific site. The software provides design wind speeds for any national grid reference within the UK determining the input parameters from databases of ground roughness and maximum/minimum altitude. Based on this method, adjustment factors have been applied to the reference wind data to adapt the meteorological conditions from the weather station onto the site. Further details of this process and software output are given in Appendix 3.

4.5.2 CFD SIMULATION AND INTERPRETATION OF DATA

4.5.3 Since the Lawson Criteria are based on frequency of occurrence of wind speeds rather than absolute wind speeds alone, a procedure to combine all wind speeds and directions is required. This process involves the following key steps:

- A reference wind speed from the meteorological station, generally measured at 10 metre height is used to generate a wind velocity profile taking into account the roughness of the site and its surroundings.
- Using the generated velocity profile, twelve different wind directions are simulated, spaced at 30° intervals to represent all wind directions. The results are generated in the form of CFD contour plots at 1.5 m above the ground level and the magnitude of the wind velocity at each measurement point is extracted.
- A wind speed factor is derived from the simulated wind directions at each measurement point;
- The wind speed factor is scaled up by the hourly weather data measured at the meteorological station to derive the resulting wind speed experienced at each measurement point;
- A statistical frequency distribution of all hourly wind speeds throughout the 10-year period is performed for each measurement point and a classification made based on the Lawson pedestrian safety and comfort criteria; and
- The resulting combined wind speed frequencies for the 10-year period integrated into a single combined wind contour map and classified by pedestrian activity. The results of this analysis for pedestrian safety and comfort are presented in Appendix 1.

4.6 GENERAL TARGET WIND CONDITIONS

4.6.1 The wind assessment for each of these criteria has been tested taking into account the season and expected activity on the site based on the following general target wind conditions:

- Pedestrian thoroughfares: Leisure walking during windiest season
- Building entrances, bus stops, drop off areas: Standing throughout the year
- Outdoor amenity and seating areas: Sitting during the summer season

4.7 SENSITIVE RECEPTORS

4.7.1 Sensitive receptors for the wind assessment are all pedestrian circulation routes, building entrances and leisure open areas within the site and in neighbouring adjacent areas. Specifically the receptors identified for this assessment are showed in figure 4.3 and listed in table 4.5.

Figure 4-3 Plan showing Sensitive Receptors

Table 4-5 Receptors for Wind Assessment

RECEPTOR NUMBER	Location	Proposed Use	Sensitivity
1	122 Old Hall Street Residential Entrance	Standing	High
2-3	122 Old Hall Street Lounge Entrance	Standing	High
4	122 Old Hall Street Secondary Entrances	Standing	High
5	Back Leeds Street Car Park	Business Walking/Car Park	High
6	109 Old Hall Street Entrance	Standing	High
7	Old Hall Street Paving	Leisure Walking	High
8	Old Hall Street Amenity Area	Sitting	High

9	Ark Health Club Entrance	Standing	High
10	Radisson Blue Hotel Entrance	Standing	High
11	Lancaster House Entrance	Standing	High
12	Old Leeds Street Entrances	Sitting	High
13	The Plaza - Weightmans Entrance	Standing	High
14	The Plaza - Rigby Street Entrance	Standing	High
15	The Plaza - Saint Paul's Square	Standing	High
16-17	4 Saint Paul's Square – East Street Entrance	Standing	High
18	Saint Paul's Square	Sitting	High
19	NCP Pall Mall Car Park	Business Walking/Car Park	High
20	SEAT Showroom Entrance	Standing	High
21	Seat Showroom Car Park	Business Walking/Car Park	High
22-25	Leeds Street Paving	Leisure Walking	High
26-27	Mercedes-Benz Showroom Entrance	Standing	High
28	Mercedes-Benz Showroom Car Park	Business Walking/Car Park	High
29	Rigo Spa Warehouse Entrance	Standing	High
30	Rigo Spa Car Park	Business Walking/Car Park	High
31-32	BMW Showroom Car Park	Business Walking/Car Park	High
33	BMW Showroom Entrance	Standing	High
34-35	Great Howard Street Paving	Leisure Walking	High
36	The MMA Academy Entrance	Standing	High
37	The MMA Academy Car Park	Business Walking/Car Park	High
38-39	Paisley Street Paving	Leisure Walking	High
40-41	King Edward Street Paving	Leisure Walking	High
42-54	Entrances to warehouses - Gibraltar Row	Standing	High
55-64	Warehouse Carparks - Gibraltar Row	Business Walking/Car Park	High

65-67	Commercial Entrances	Standing	High
68	Waterloo Road Paving	Leisure Walking	High
69-72	Waterloo Apartments Entrances	Standing	High
73	William Jessop Way Paving	Leisure Walking	High
74	Car Park Waterloo Road	Business Walking/Car Park	High
75	William Jessop Way 1 Entrance	Standing	High
76	William Jessop Way 1 Carpark	Business Walking/Car Park	High

4.8 MODELLING ASSUMPTIONS AND LIMITATIONS

4.8.1 The wind speeds on the site and surroundings have been calculated through CFD. CFD is a widely recognised method for modelling airflows both, internal and external, and as computer power develops, it increasingly improves its applicability.

4.8.2 CFD as a tool for pedestrian wind modelling is fairly well validated against wind tunnel tests and real world data and is often considered advantageous due to the sophisticated visualization and domain wide measurements characteristics. It has limitations in the same way that any other tool will have limitations. For example, CFD uses time-averaged data for its analysis which does not capture the effect of short term gusts, and it models turbulence rather than calculating it explicitly. However, the mean hourly analysis adopted in CFD provides a detailed wind distribution across the flow domain, to determine the suitability of open spaces with regards to pedestrian comfort, and provides a good indication of the areas of high speeds and wind acceleration to help identify suitable mitigation measures. Also, CFD is performed at full scale with a mesh made out of several millions of cells where speeds are calculated at each cell point of the mesh, allowing for a much larger amount of data to be used for the comfort and safety analyses. Technical assumptions of the CFD modelling are presented in Appendix 4.

4.8.3 The wind environment assessment focuses on conditions at pedestrian level. Other potential wind effects such as wind loads, structural response and natural ventilation have not been considered within this assessment.

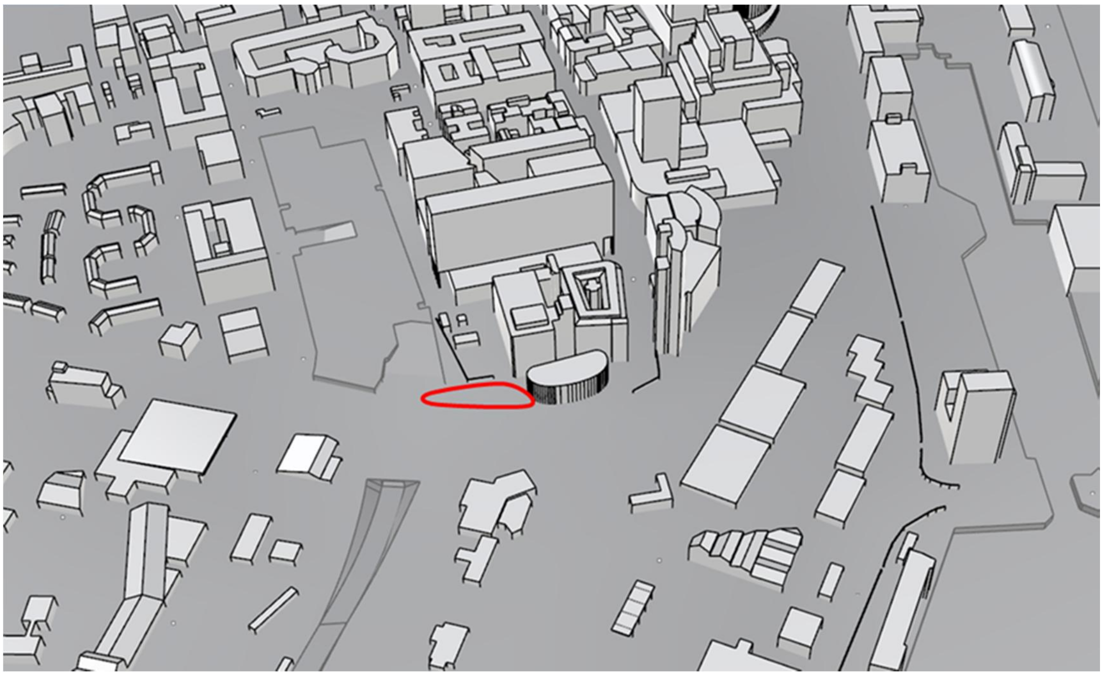
4.8.4 The Lawson criteria for pedestrian comfort focus on the effect of wind force on people's activities but do not factor in other environmental variables such as air temperature, solar radiation and relative humidity which also affect people's perception of comport. Overlaying all these climatic factors would be a complex process and Lawson's method presents the best available methodology for anticipating wind effects in the built environment.

5 BASELINE CONDITIONS

5.1 MODEL OF THE EXISTING SITE

5.1.1 A 'baseline scenario' has been modelled to represent the conditions on the site prior to the introduction of the proposed development, (Figure 5-1). The model of the existing buildings in the surroundings has been based on models provided by Hodder & Partners Architects and supplemented with information from the mapping database ArcGIS and available aerial photographic data for the area. The results of the wind environment assessment of the 'baseline scenario' are presented in the form of CFD contour plots in Appendices 1 and 2.

Figure 5-1 Model of the 'Baseline Scenario' showing the existing building on site.



5.2 PEDESTRIAN COMFORT ASSESSMENT - BASELINE CONDITION

5.2.1 The results of the baseline assessment indicate that the existing wind environment surrounding the site is rather windy due to its proximity to the exposed water front with a number of areas in the surroundings of the site showing exceedance of the comfort criteria. Other areas particularly away from the water side towards the east of the site show calmer wind conditions.

5.2.2 With regards to existing wind conditions and how they relate to pedestrian comfort criteria the following points can be highlighted. The sitting area between Leeds Street and Old Hall Street (receptor 8) and the pavement in front of 109 Old Hall Street (receptor 7) are notably windy and exceed the standing criteria. Various other areas show exceedance of the standing and leisure walking criteria to the extent that some areas are only suitable for carpark/roadway use. During the summer period wind conditions improve and all areas are suitable for sitting, standing and leisure walking.

5.2.3 The junction at Leeds Street, Great Howard Street and King Edward Street is generally an area of wind acceleration mainly due to winds blowing form the westerly and south-westerly quadrants. This is largely due to the downwash effect resulting from winds hitting the western façade of the Radisson Hotel Tower combined with the pressure difference across both sides of the building which increases wind acceleration at ground level. The adjacent areas to the Panoramic 34 Tower are also notably windy showing suitability to leisure walking and above, i.e. exceeding the pedestrian sitting and standing thresholds.

5.2.4 The site's surroundings are overall characterized by a windy environment that shows various areas within the thresholds of suitability for the intended use but also presents localized areas that exceed the recommended standards particularly during colder seasons. For further detail, the results of the wind conditions for the baseline and the pedestrian comfort wind plots in relation to each category according to the Lawson criteria are presented in Appendix 1.

5.3 PEDESTRIAN SAFETY ASSESSMENT - BASELINE CONDITION

5.3.1 In addition to the comfort assessment, an assessment of wind effects during strong wind events has also been carried out. These are short term and infrequent strong winds which represent a scenario where some pedestrians could find walking difficult posing a potential safety hazard particularly in areas close to roads, and it is referred to as the distress or the safety criteria. The safety criteria are defined in terms of a wind speed which is exceeded on average during one wind event per year. As a reference, one year has 8,760 hours and one strong winds event represents an occurrence of 0.01% of the time.

5.3.2 The results indicate that the wind environment within the site in the baseline condition presents various areas that exceed criteria for safety particularly in the areas closer to the water front to the west of the site, Princess Dock and in more noticeable at Old Hall Street as it turns into Leeds Street, due to the tall buildings in that area.

5.3.3 The junction between Leeds Street, King Edward Street and Great Howard Street (around receptors 8, 7, 35 and 32) also shows excessive wind acceleration in the existing condition. This area of exceedance mainly falls on the road however the junction presents various crossing points which would be a hazard for pedestrians in windy weather. Closer to the docks and seafront, the results also identifies the junction between Bath Street, Waterloo Road and William Jessop Way (receptors 74, 68, 69), and the car park on Waterloo Road (receptor 73) as exceeding the safety criteria. In all of the above cases, these effects are mainly due to the relatively unobstructed position of this area of the city and exposure to the stronger and more frequent westerly and south-westerly winds together with a combination of downwash effects and pressure differences by the buildings themselves especially the larger structures and facades such as the Radisson Hotel Tower, Panoramic 34 Tower, the William Jessop 1 Tower and the Waterloo Apartment development.

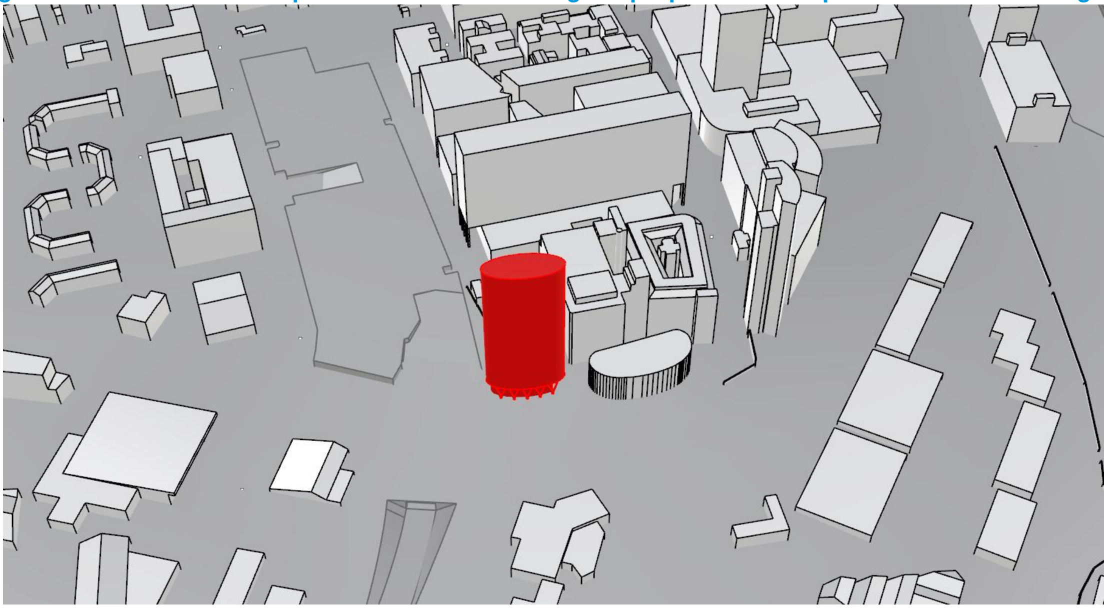
5.3.4 The wind maps of the pedestrian safety assessment (i.e. the wind environment under strong wind conditions) for the baseline and proposed cases are presented in Appendix 1.

6 PROPOSED CONDITIONS

6.1 THE PROPOSED SCENARIO

6.1.1 In order to assess the effect of the Proposed Development, it was inserted into the CFD model to represent the ‘Proposed Scenario’ (Figure 5.1). The geometry, position and massing of the Proposed Development has been based on 3d models and drawings provided by Hodder & Partners Architects. The ‘Proposed Scenario’ model was simulated under the same wind conditions as the ‘Baseline Scenario’ to enable a direct comparison. The wind assessment results, to assess the effect of the Proposed Development, are presented in Appendices 1 and 2.

Figure 6-1 Model of the 'Proposed Scenario' showing the proposed development and surroundings



6.1.2 The results of the wind assessment indicate that the local wind environment once the proposed development is complete would be subject to a relatively moderate increase in the general wind speeds of the adjacent areas compared to the baseline condition. Higher wind speeds due to the increased massing on the proposed site are typically expected as a result of new development. However the results indicate that this increase in windiness in the context of the area which is windy already is not excessive and does not represent a significant impact from the proposed building. Furthermore, the results also indicate that wind conditions in some adjacent areas are likely to improve by the proposed development especially on the northwest of the site.

6.1.3 The wind environment of the site has been assessed on the basis of frequency accounting for all directions based on the recommended criteria discussed in section 3.3. The results of the wind assessment and the impacts on pedestrian comfort and safety are discussed below with supporting wind maps of the results included in Appendix 1.

6.2 EFFECT OF PROPOSED DEVELOPMENT ON PEDESTRIAN COMFORT

6.2.1 The results indicate that most areas remain suitable for sitting, standing and leisure walking with some localised exceptions which are only suitable for business walking and car park such as the open area north of the Radisson Hotel (receptor 8), although this effect is also observed in the baseline condition therefore it is not an effect of the proposed development.

6.2.2 The additional massing introduced by the proposed development, compared to the existing car park creates some wind acceleration in some areas and improves others depending on the wind direction. During autumn and winter the junction opposite 109 Old Hall Street (receptors 7, 8, 35, 32) is suitable for leisure walking and the localized wind acceleration areas at the sitting area (receptor 8) are slightly improved.

6.2.3 The entrances to the proposed building (receptors 1-4) remain overall suitable for the intended use, however the main lounge entrance on Leeds Street (receptor 2) tends to be exposed to stronger winds that shift the suitability of the area towards leisure walking. This will require some local mitigation to maintain the suitability for standing.

6.2.4 The results show that the site is overall suitable for the intended use during all seasons with slightly higher wind speeds recorded during winter on the paving along Leeds Street. As shown in the wind maps in Appendix 2, westerly and south-westerly winds are the main sources of windiness of the site and its surroundings.

6.2.5 In summary, the impact of the proposed development is relatively moderate and does not significantly deteriorate the wind conditions from the baseline when measured against the pedestrian comfort criteria.

6.3 ASSESSMENT OF PROPOSED CONDITIONS FOR PEDESTRIAN SAFETY

6.3.1 The results of the assessment of the proposed development under strong wind conditions indicate that there is an increase in windiness in the area adjacent to the BMW car park opposite the site (receptor 32). This is mainly due to southerly and westerly winds deflected by the proposed building and generating wind pressure differences across the facades creating the wind acceleration in this location. Mitigation measures will be considered necessary to reduce wind speeds in the immediate surroundings of the site and reduce the areas exceeding the pedestrian safety threshold. Further away from the site the impacts of the proposed development against the safety criteria are not significant when compared to the existing condition with the areas of windiness remaining generally in the same locations. Further detail of these results are shown on the wind maps of the results included in Appendix 1.

7 WIND MITIGATION

7.1.1 The wind results discussed in this study are based on a model without the effect of trees or landscape features, either proposed or existing trees, which is a representation of the worst case. Both existing trees in the surrounding area and the proposed trees within the site will provide further improvement of the wind environment as they filter the incoming wind reducing the speeds locally, especially during periods when trees are in full foliage.

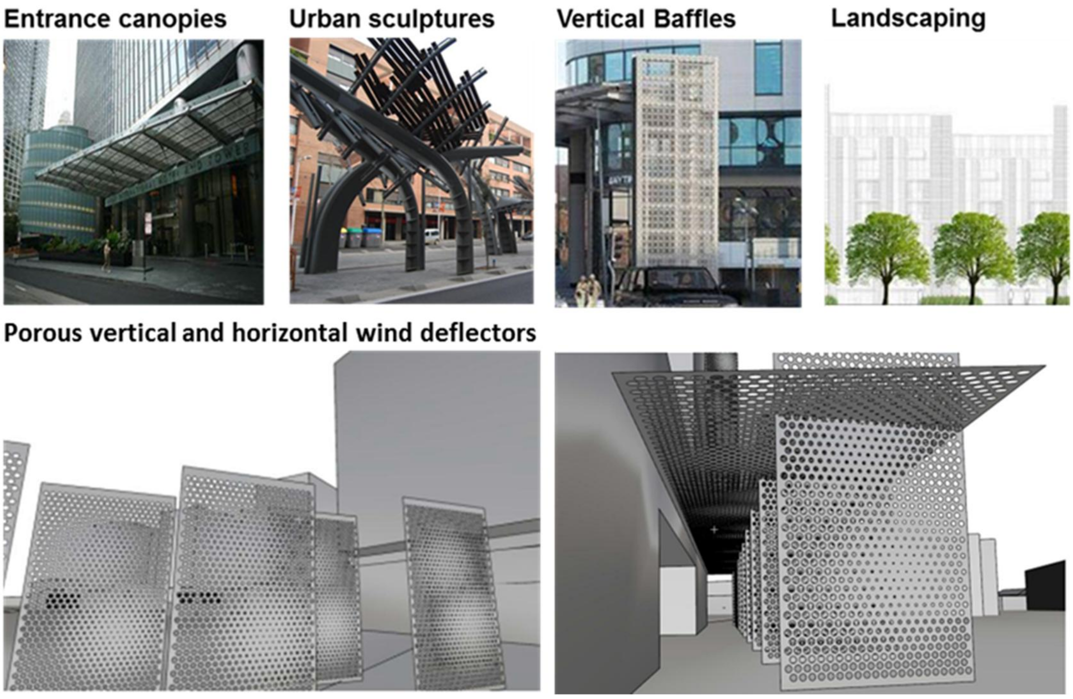
7.1.2 Given the results, mitigation measures are considered necessary to improve conditions at pedestrian level within the proposed development and in the immediate surroundings. These could include any of the measures indicated below or a combination of these however, in any case further testing would be recommended to select the most adequate mitigation scheme.

7.1.3 Mitigation measures to improve the wind environment (where found to be required) could include trees, landscape features, low level planting, wind screens, entrance canopies, perimeter balustrades, as described below:

- Building canopies: tend to provide shelter from wind being driven downwards if of adequate area, however they provide little shelter for horizontal ground level winds.
- Planting & landscaping: wind tolerant species of trees and shrubs may provide shelter from both downward driven winds and horizontal winds around corners and passage ways. The aerodynamic losses caused by the wind passing through the tree's foliage ameliorate the wind environment during winter. However, if too dense this may cause an increase in wind speed below the foliage.
- Physical barriers ameliorate wind environment by disconnecting the windward and leeward wind pressure areas that determine air flow.

- Porous barriers: Urban sculptures and baffles ameliorate horizontal wind speeds providing local shelter by dissipating the wind’s energy. The sheltered area depends on the barrier’s size.
- Solid barriers: Screens and solid barriers interrupt high speed winds locally but tend to displace the problem elsewhere. It is thus important to use caution when implementing this type of measures.

Figure 7-1 Example of mitigation strategies



8 SUMMARY AND CONCLUSIONS

8.1.1 This report summarises the results of the wind assessment at pedestrian level within the site and its surroundings.

8.1.2 The results of the wind assessment indicate that the local wind environment once the proposed development is complete would be subject to a relatively moderate increase in the general wind speeds of the adjacent areas compared to the baseline condition. Higher wind speeds due to the increased massing on the proposed site are typically expected as a result of new development. However the results indicate that this increase in windiness in the context of the area which is windy already is not excessive and does not represent a significant impact from the proposed building.

8.1.3 With regard to pedestrian comfort, the results indicate that most areas remain suitable for sitting, standing and leisure walking with some localised exceptions which are only suitable for business walking and car park such as the open area north of the Radisson Hotel, although this effect is also observed in the baseline condition therefore it is not an effect of the proposed development.

8.1.4 The entrances to the proposed building (receptors 1-4) remain overall suitable for the intended use, however the main lounge entrance on Leeds Street (receptor 2) tends to be exposed to stronger winds that shift the suitability of the area towards leisure walking. This will require some local mitigation to maintain the suitability for standing.

8.1.5 The results show that the site is overall suitable for the intended use during all seasons with slightly higher wind speeds recorded during winter on the paving along Leeds Street.

8.1.6 In terms of pedestrian safety, the results of the assessment indicate that there is a potential increase in windiness in the area adjacent to the BMW car park opposite the site (receptor 32). This is mainly due to southerly and westerly winds deflected by the proposed building, generating wind pressure differences across the facades and creating the wind acceleration in this location.

8.1.7 Mitigation measures will be considered necessary to reduce wind speeds in the immediate surroundings of the site and reduce the areas exceeding the pedestrian safety threshold.

8.1.8 Further away from the site the impacts of the proposed development against the safety criteria are not significant when compared to the existing condition with the areas of windiness remaining generally in the same locations.

8.1.9 In summary, it can be concluded that whilst the proposed development would generate an increased level of windiness due to its massing and scale, its impact is unlikely to be too significant given the general windiness of the area in both the baseline and proposed conditions. However due to the additional windiness identified in localised areas, wind mitigation measures to improve conditions at pedestrian level are recommended. Within the proposed development, these could include tree planting, baffles and canopies to respectively absorb and deflect the air flow. To this end, further testing is recommended to select the most suitable measures and assess their impact on the wind environment.

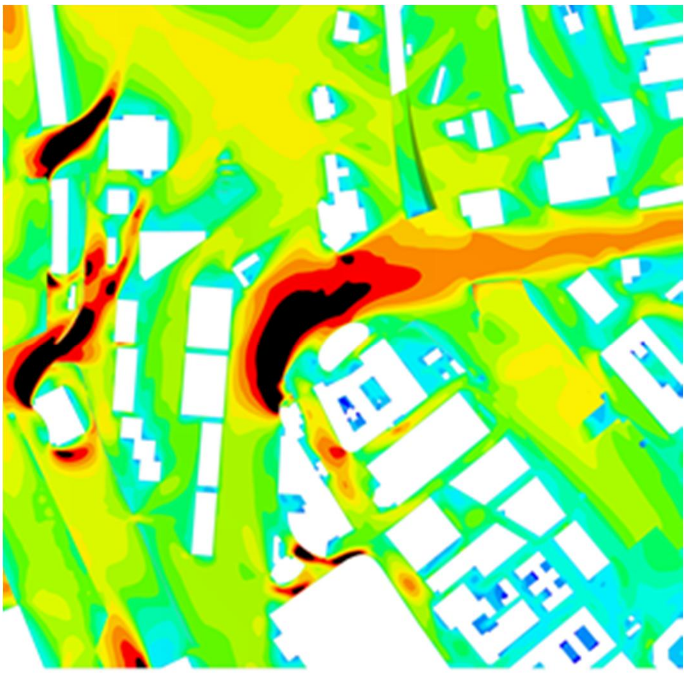
REFERENCES

- T.V. Lawson (2001) Building Aerodynamics, Imperial College Press.
- J. Franke, A.Hellsten, H. Schlunzen, B. Carrisimo (2007). Best Practice Guideline for the CFD Simulation of flows in the Urban Environment – Cost Action 73

Appendix 1 – Contour Wind Plots - Pedestrian Safety Assessment

(Wind Speeds likely to be exceeded for 0.01% of the year)

BASELINE



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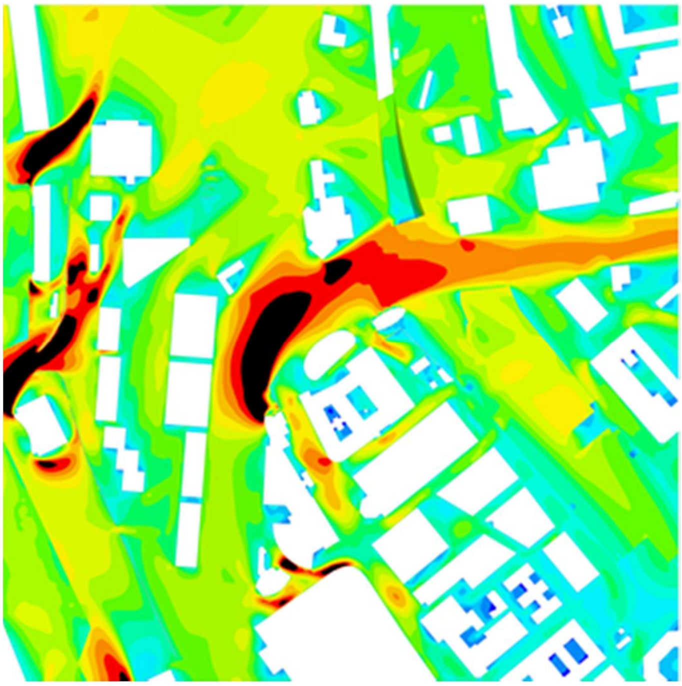
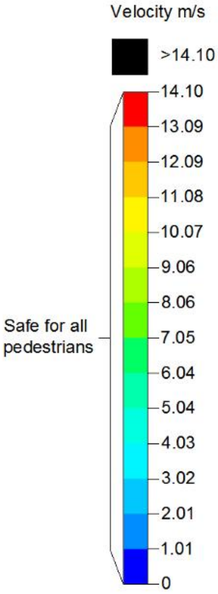
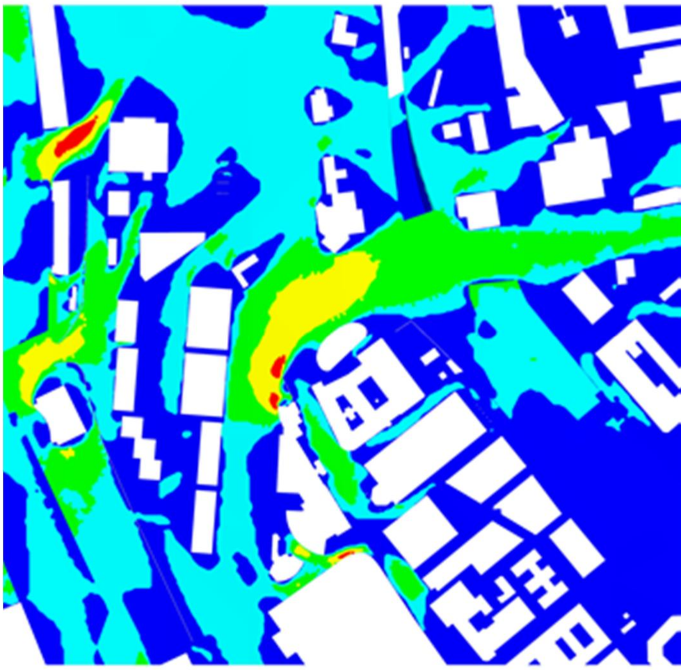




Contour Wind Plots - Seasonal Pedestrian Comfort Assessment

Winter

BASELINE



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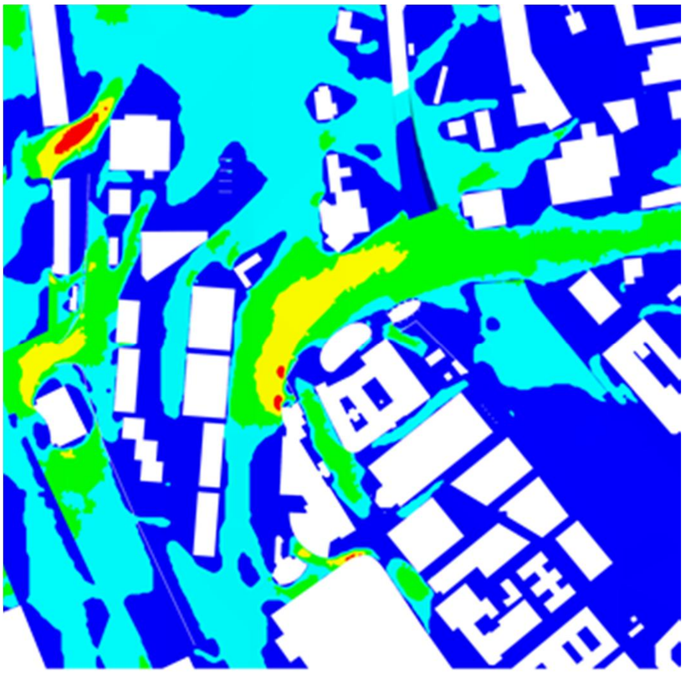
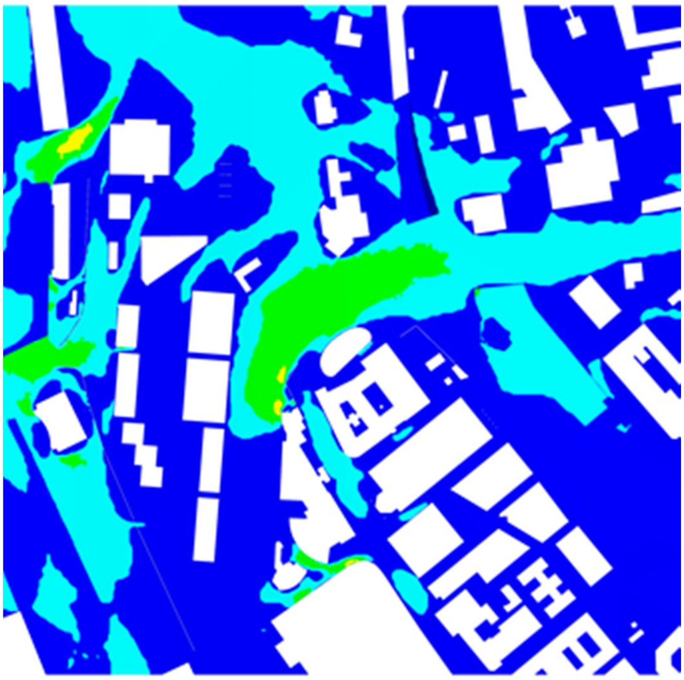


Spring

BASELINE



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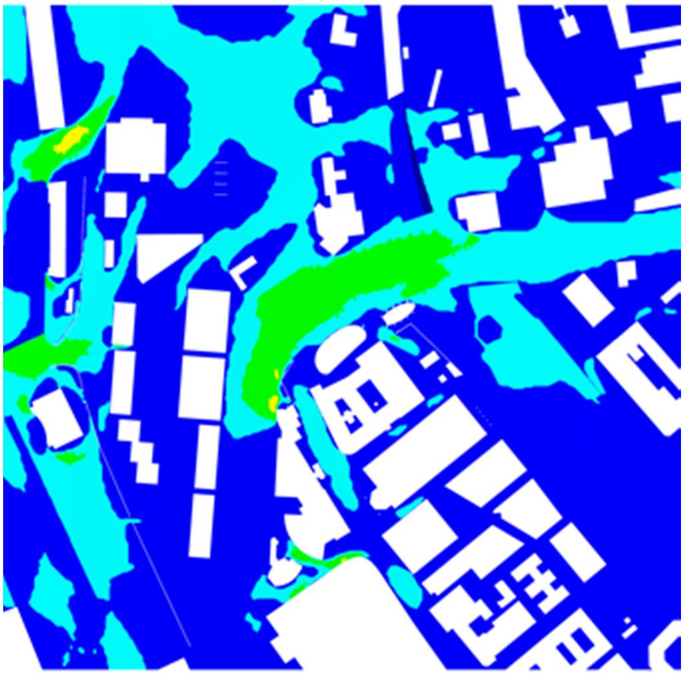
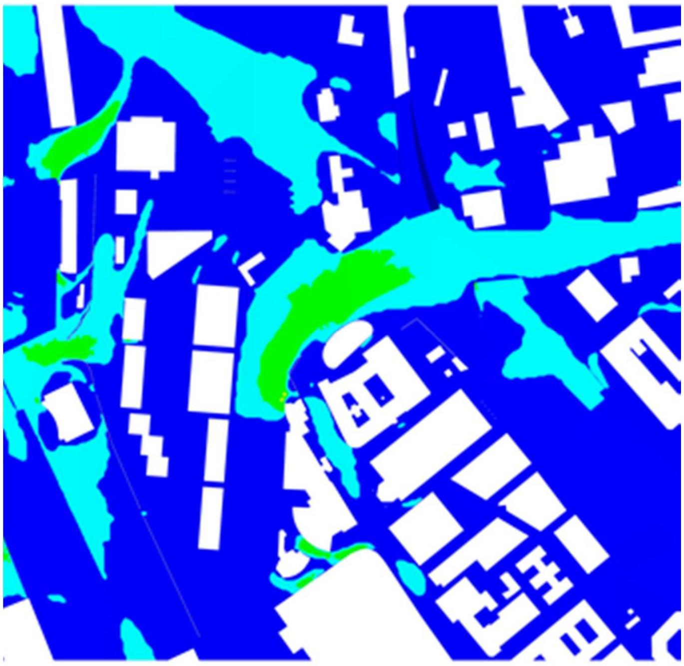


Summer

BASELINE



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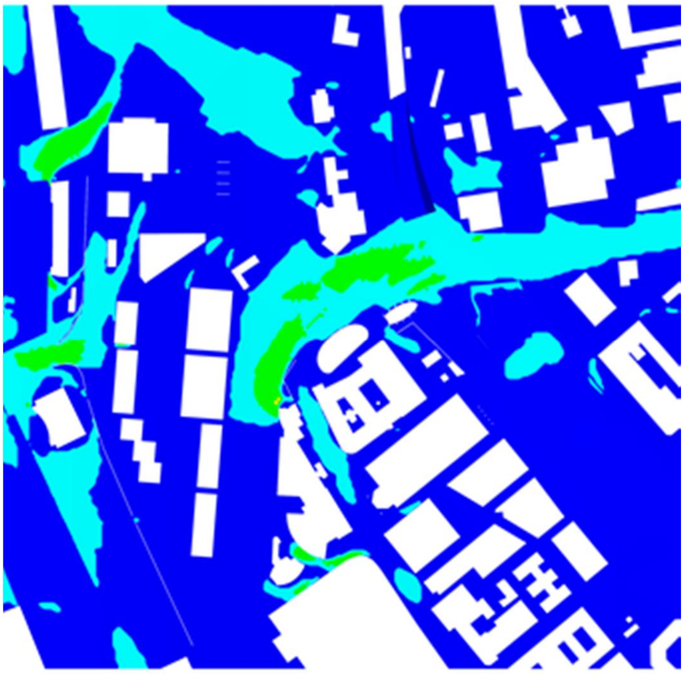
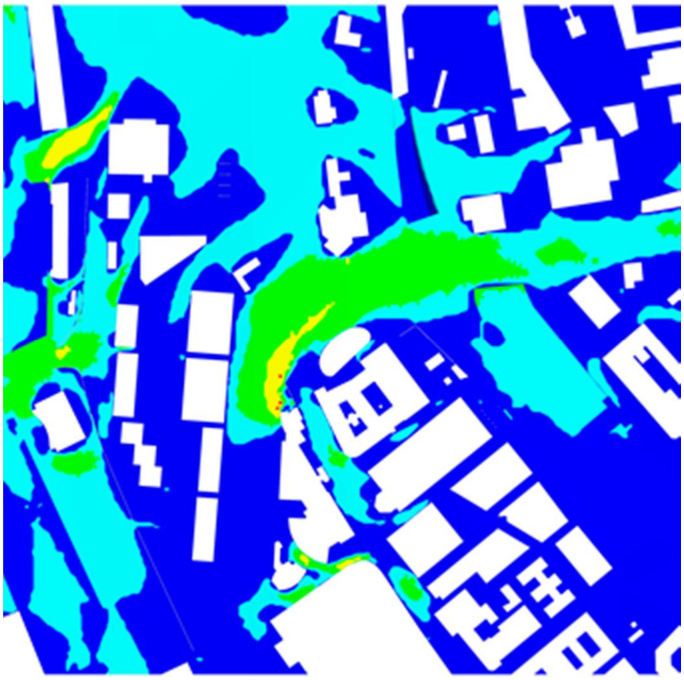


Autumn

BASELINE



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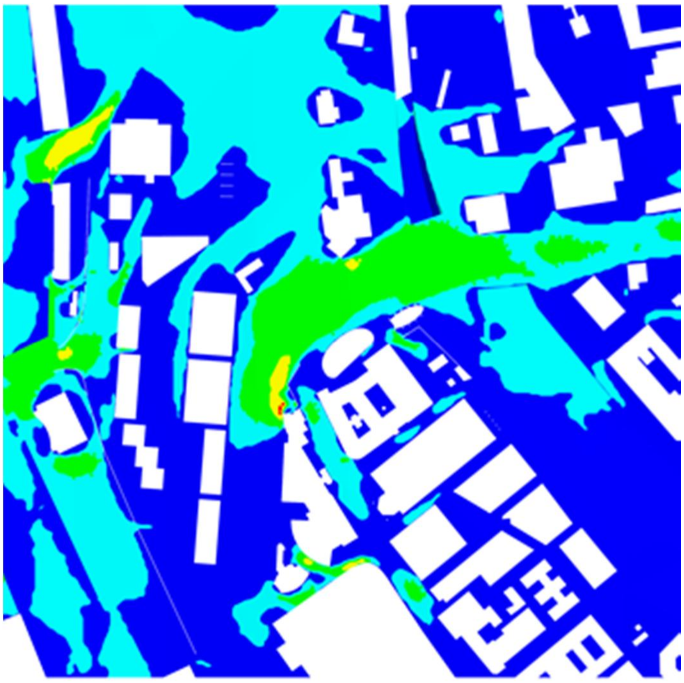
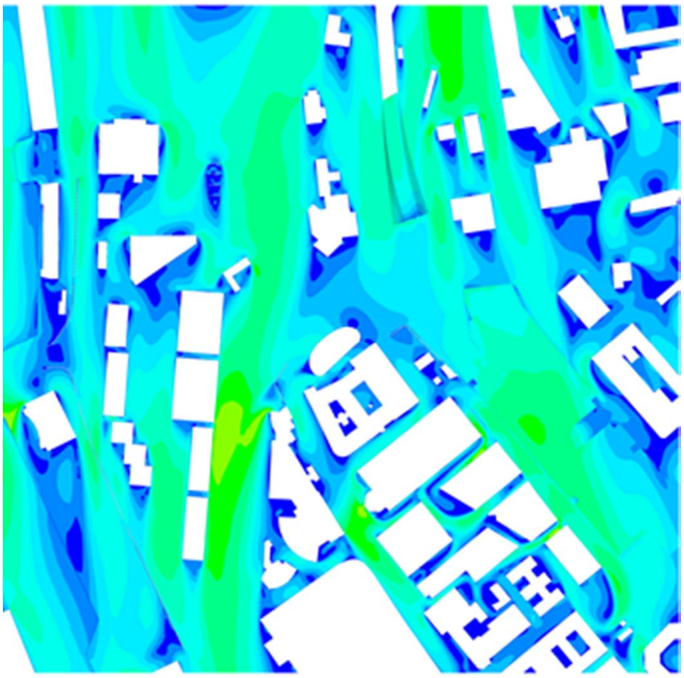
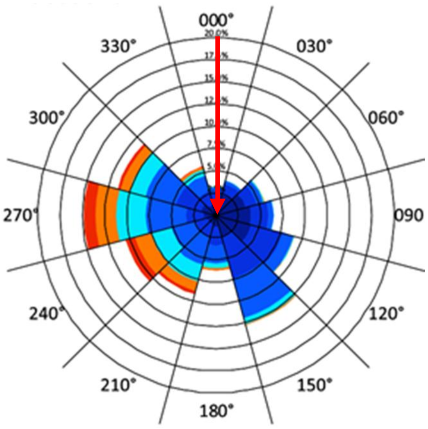


APPENDIX 2 CONTOUR PLOTS FOR INDIVIDUAL WIND DIRECTIONS

Condition 1: Northerly wind direction (0°)

BASELINE





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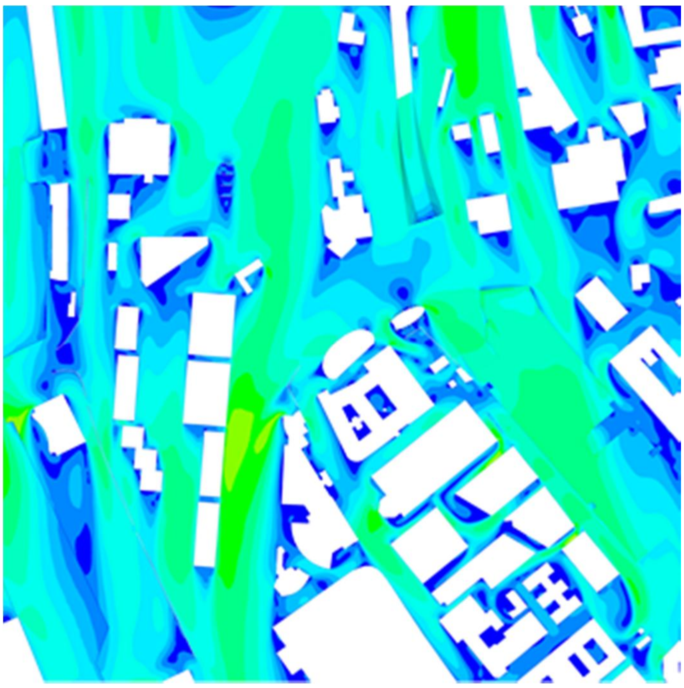
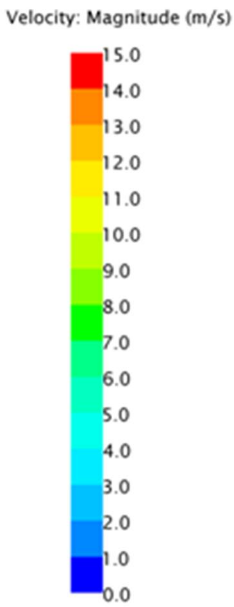
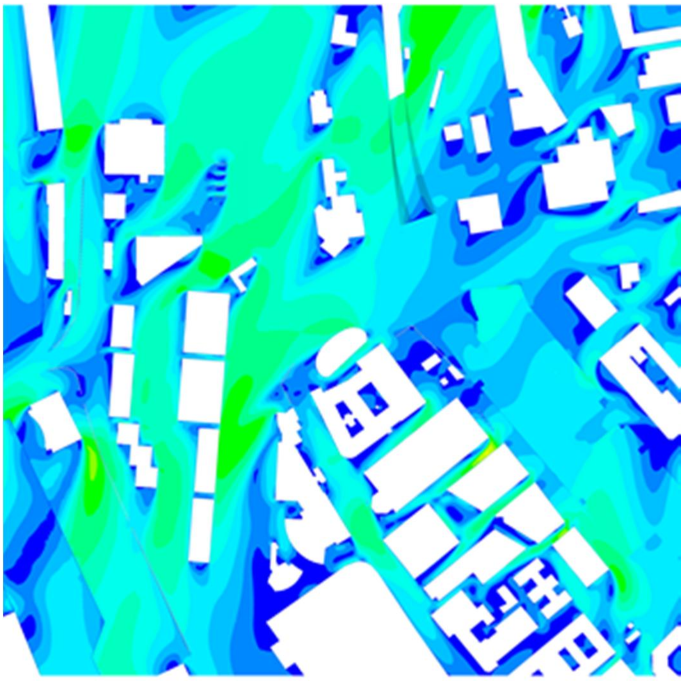
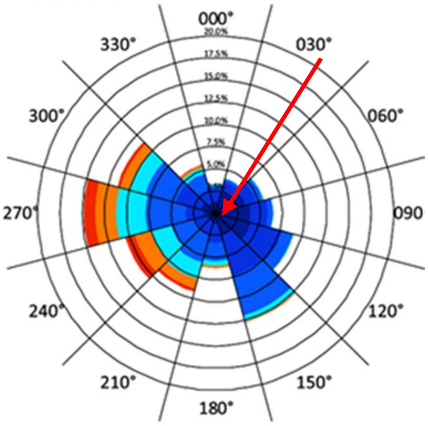




Condition 2: North North-east wind direction (30°)

BASELINE





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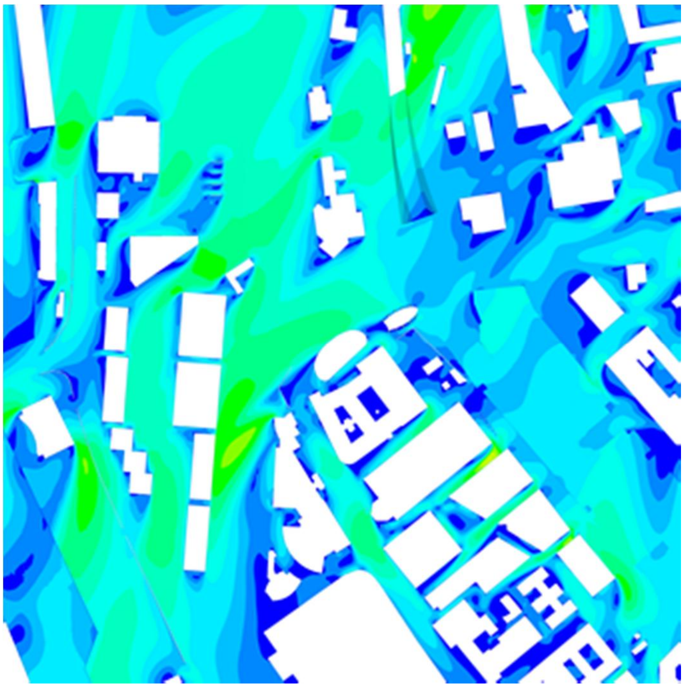
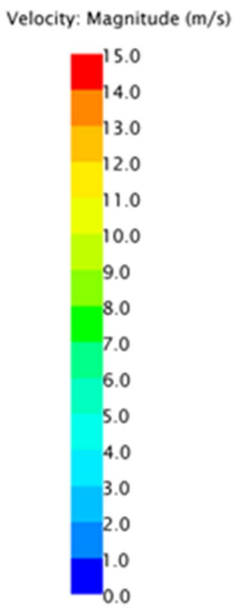
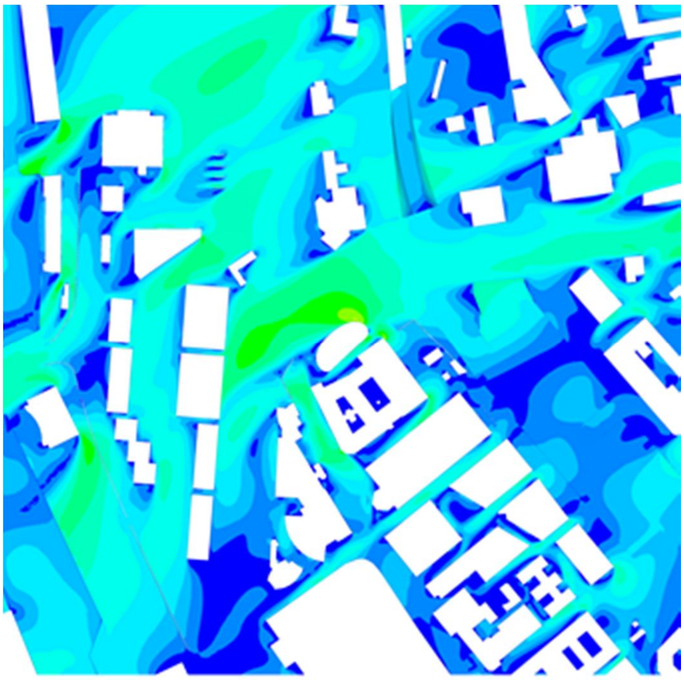
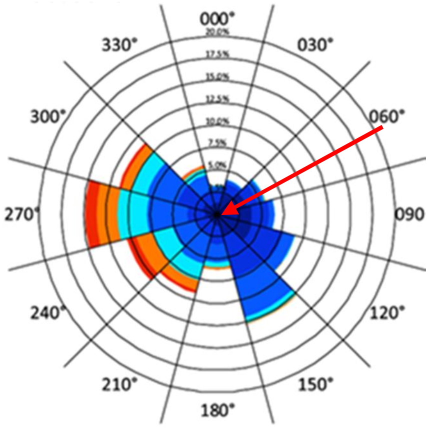




Condition 3: East North-east wind direction (60°)

BASELINE





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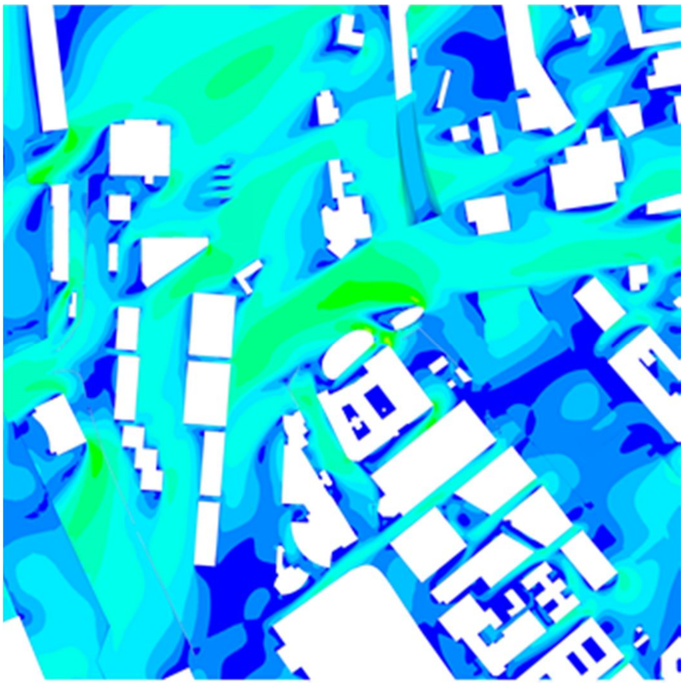
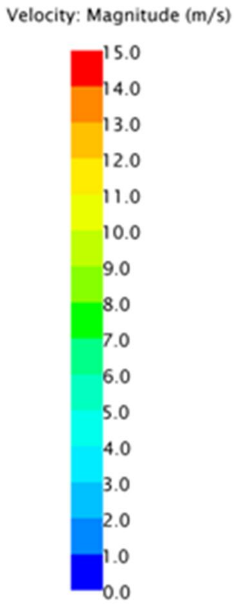
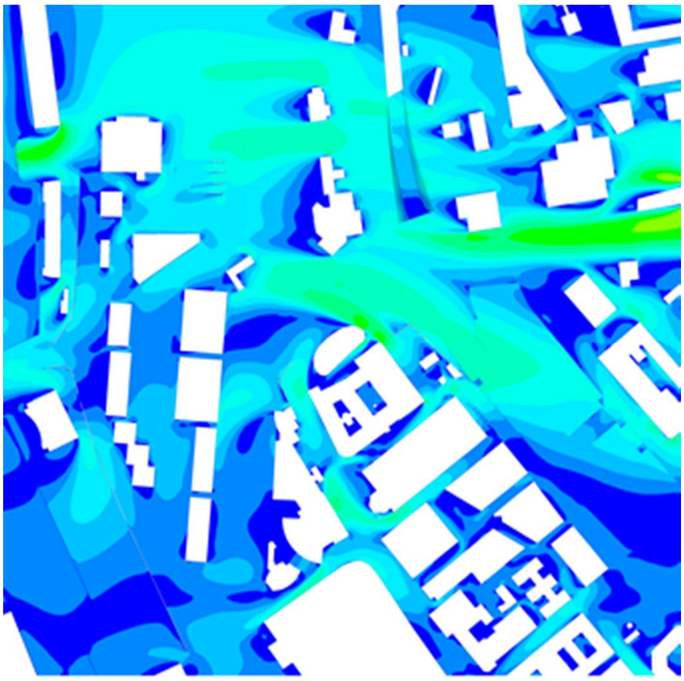
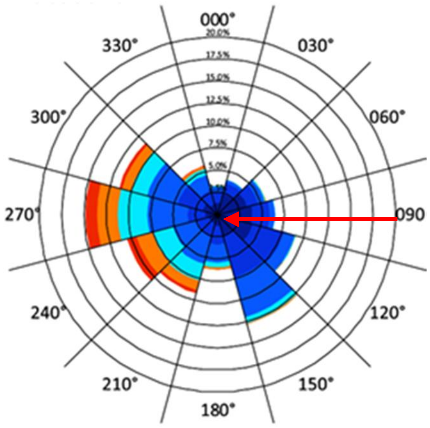




Condition 4: Easterly wind direction (90°)

BASELINE





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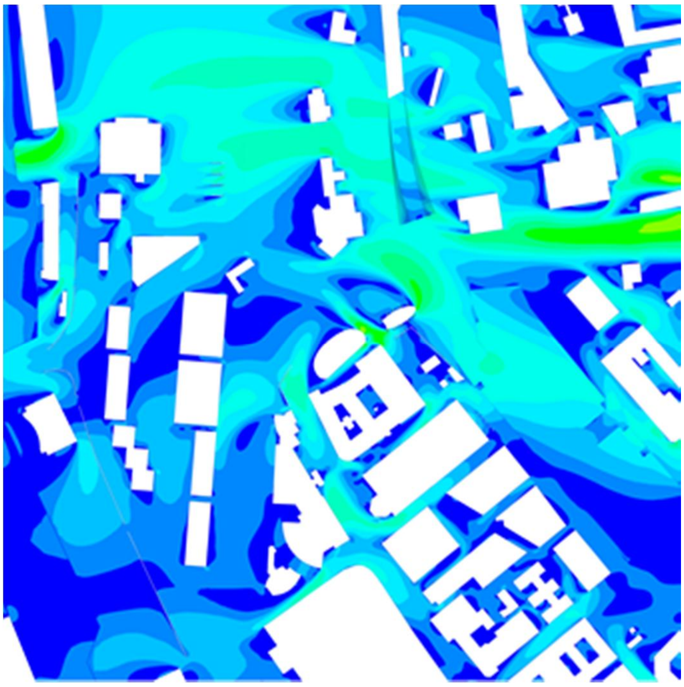
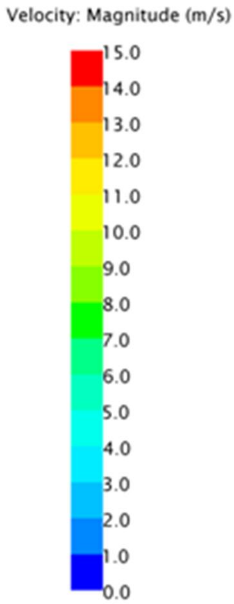
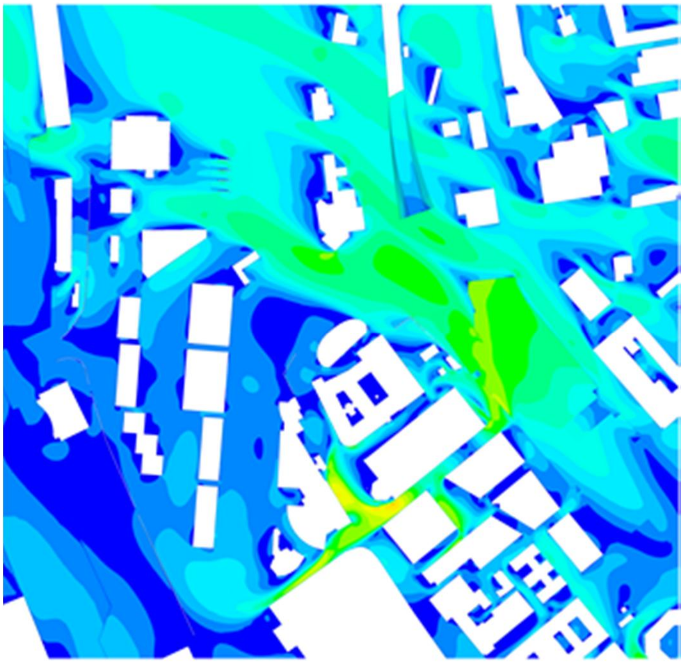
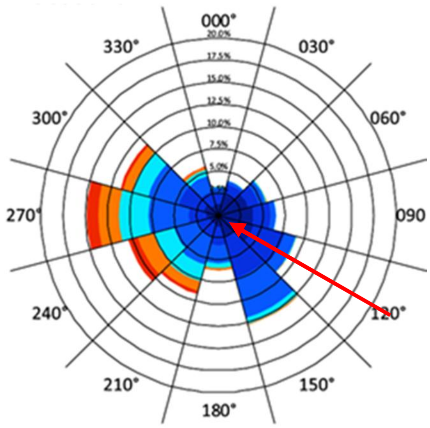




Condition 5: East South-east wind direction (120°)

BASELINE





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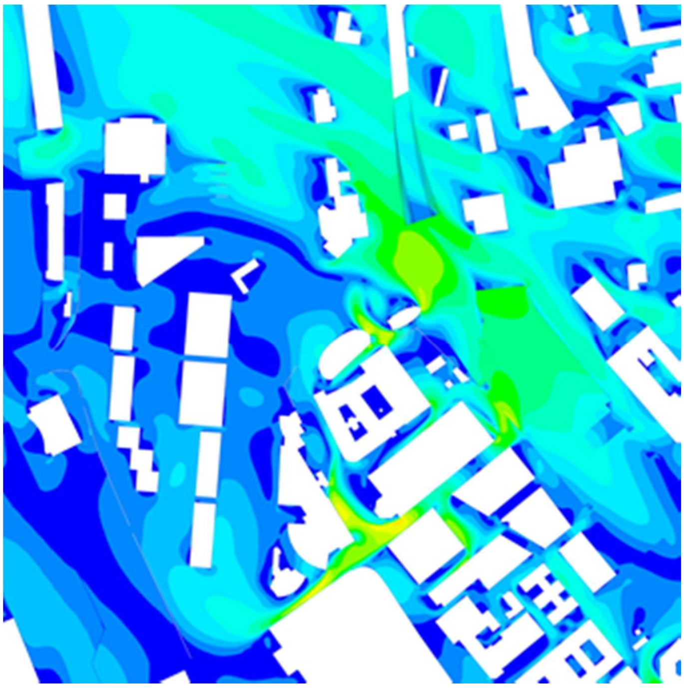
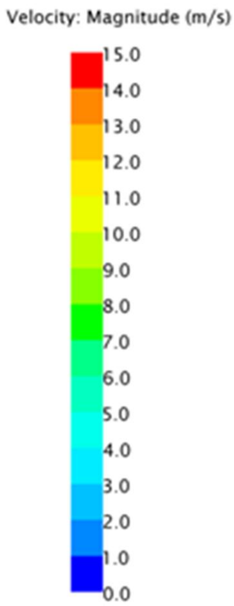
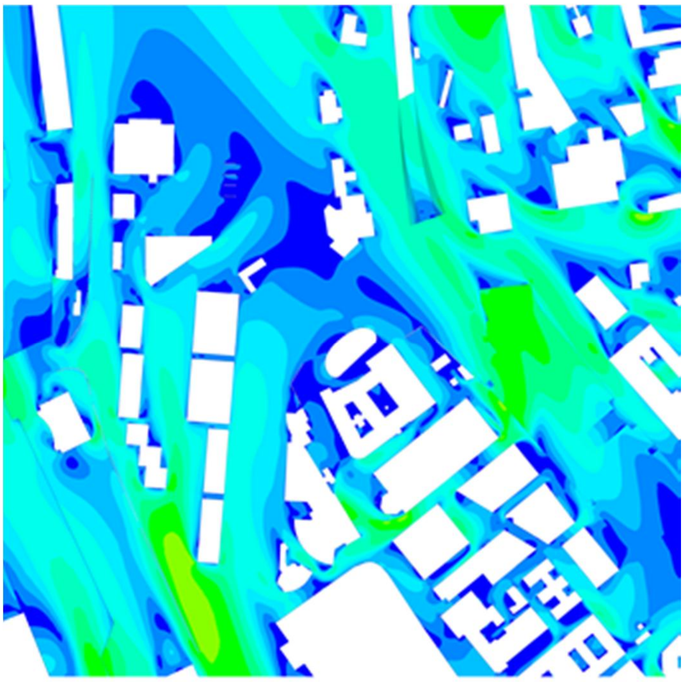
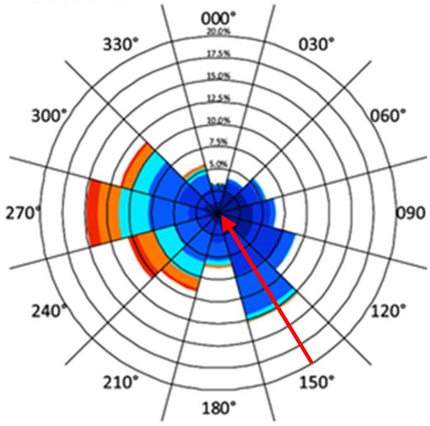




Condition 6: South South-east wind direction (150°)

BASELINE





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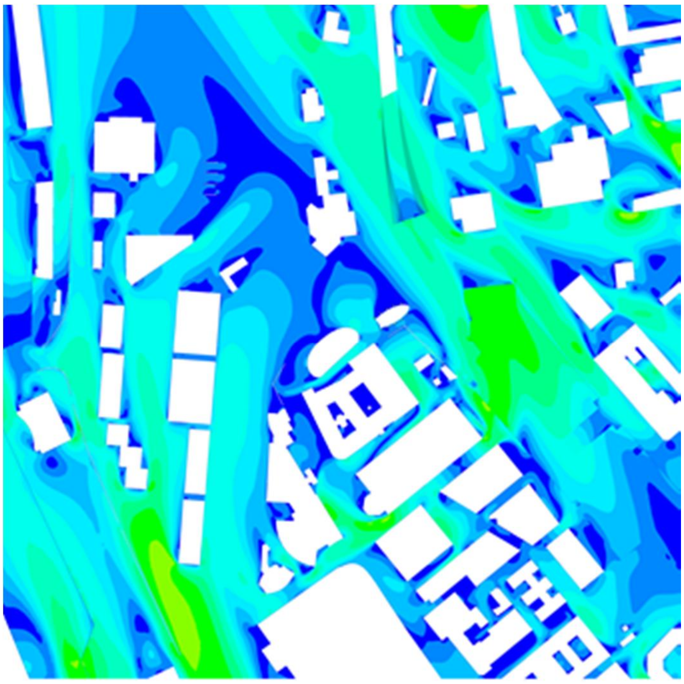
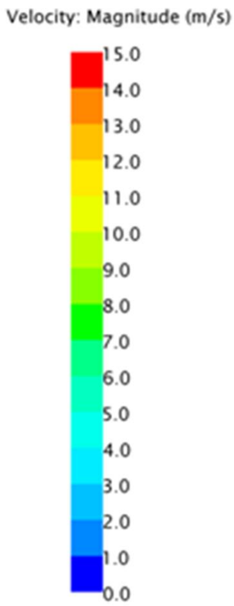
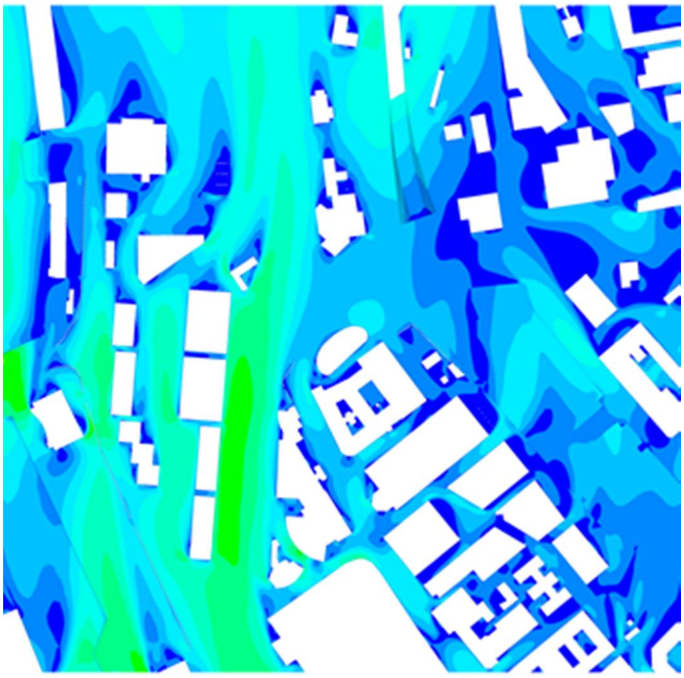
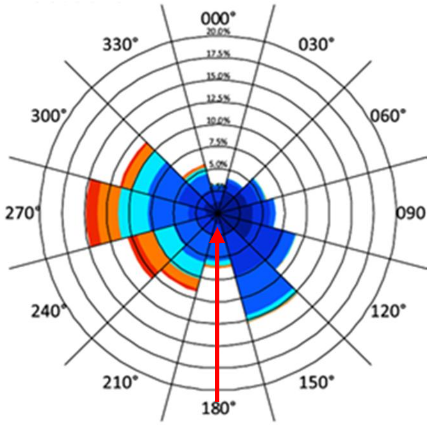




Condition 7: Southerly wind direction (180°)

BASELINE





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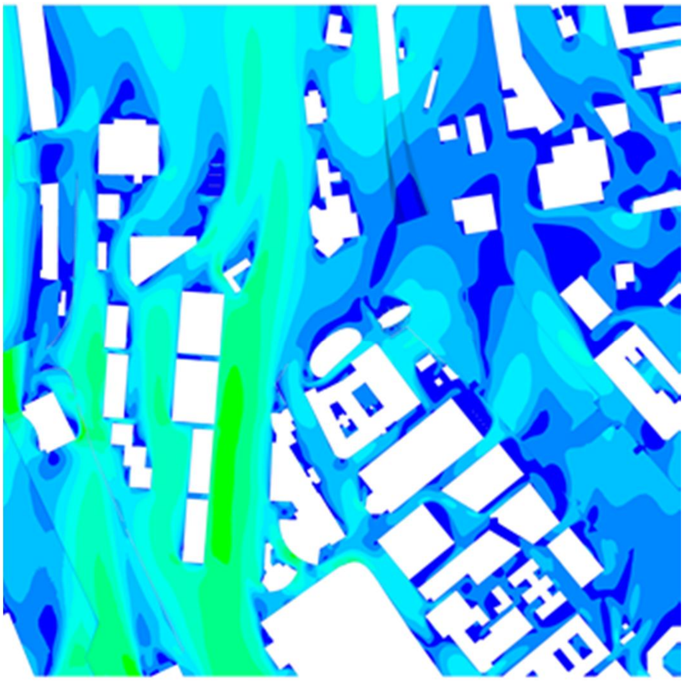
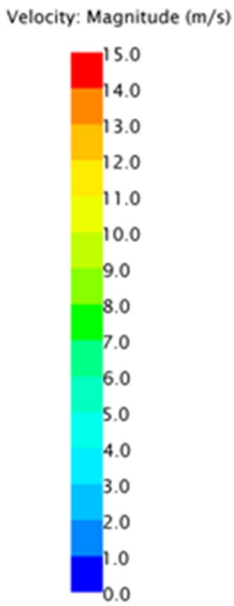
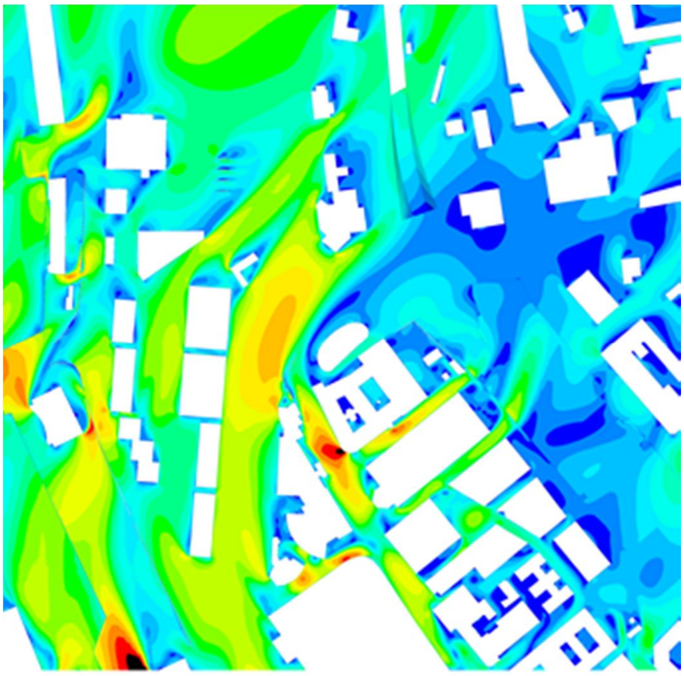
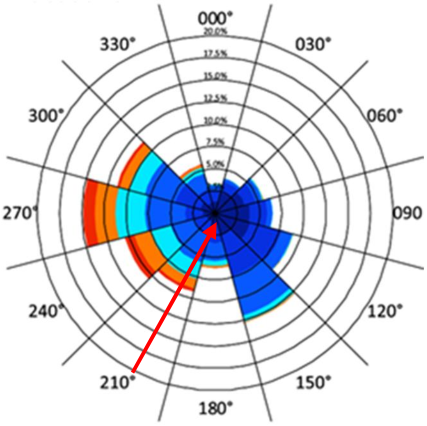




Condition 8: South South-west wind direction (210°)

BASELINE





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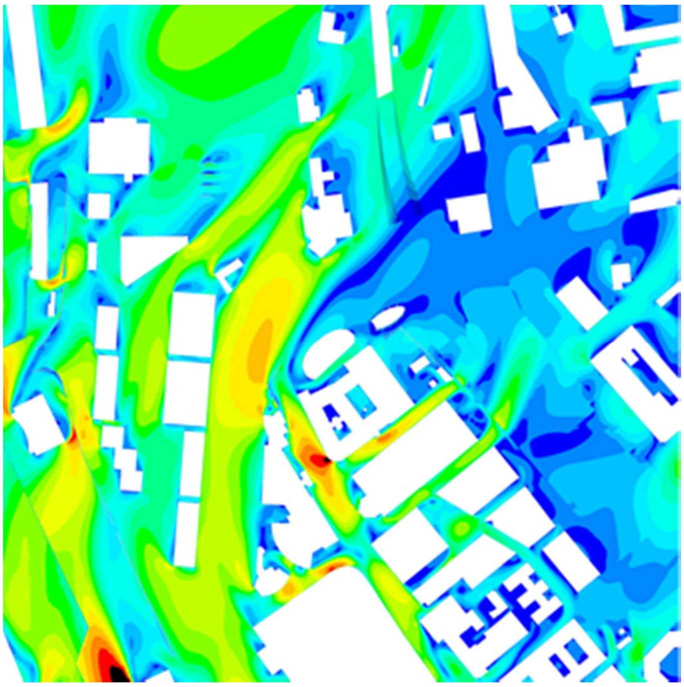
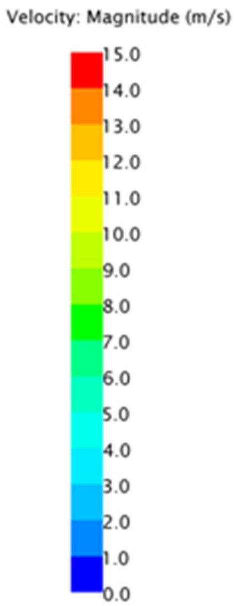
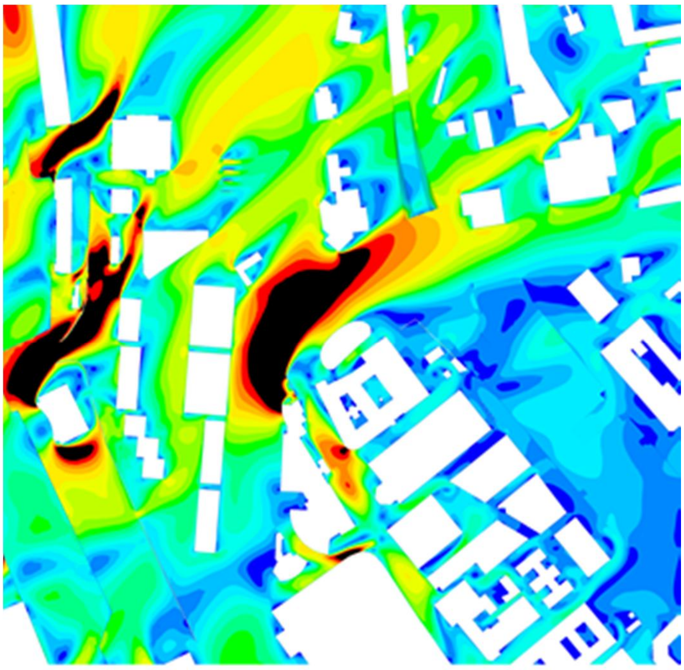
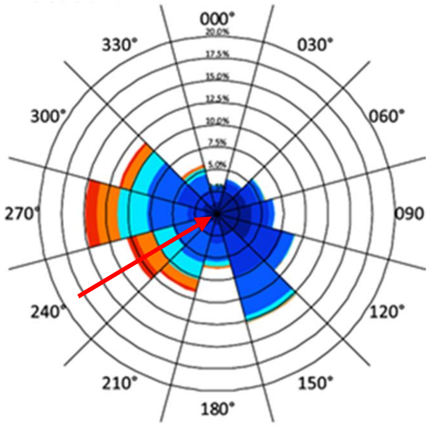




Condition 9: West South-west wind direction (240°)

BASELINE





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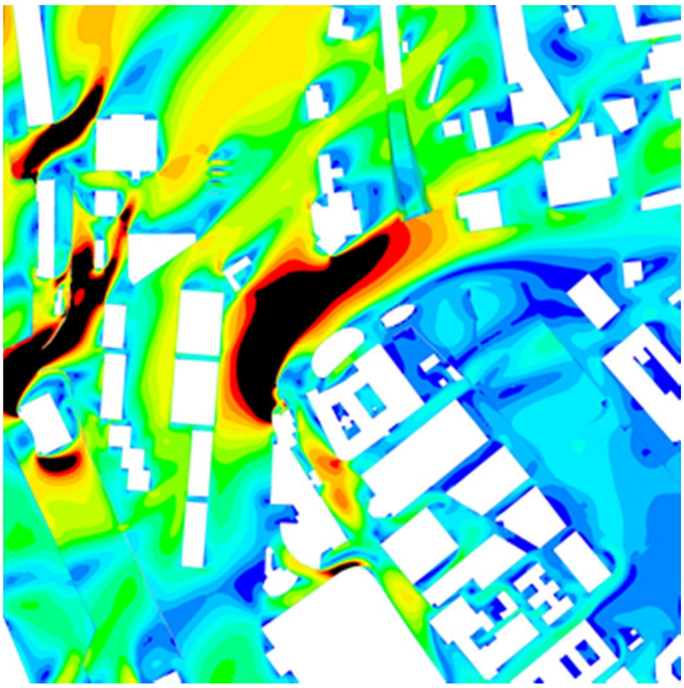
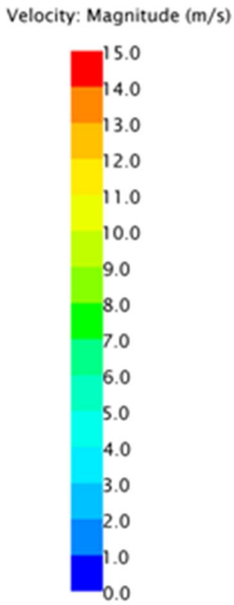
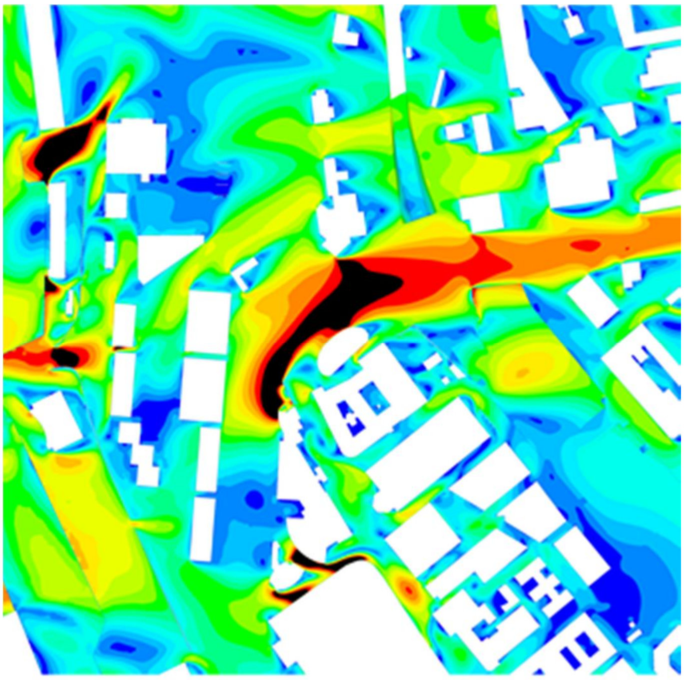
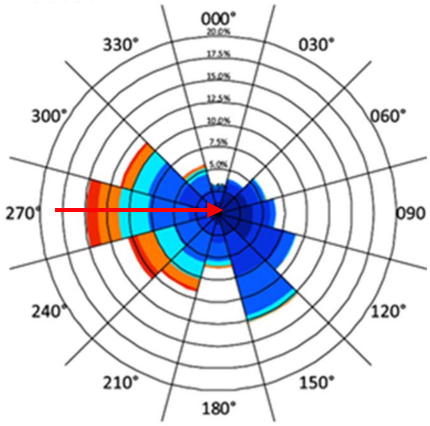




Condition 10: Westerly wind direction (270°)

BASELINE





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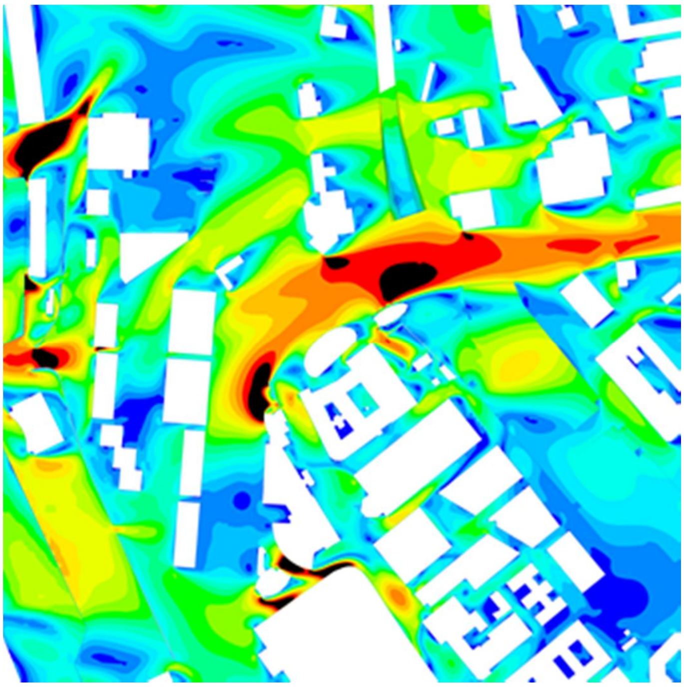
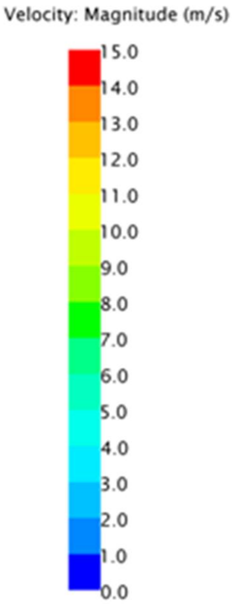
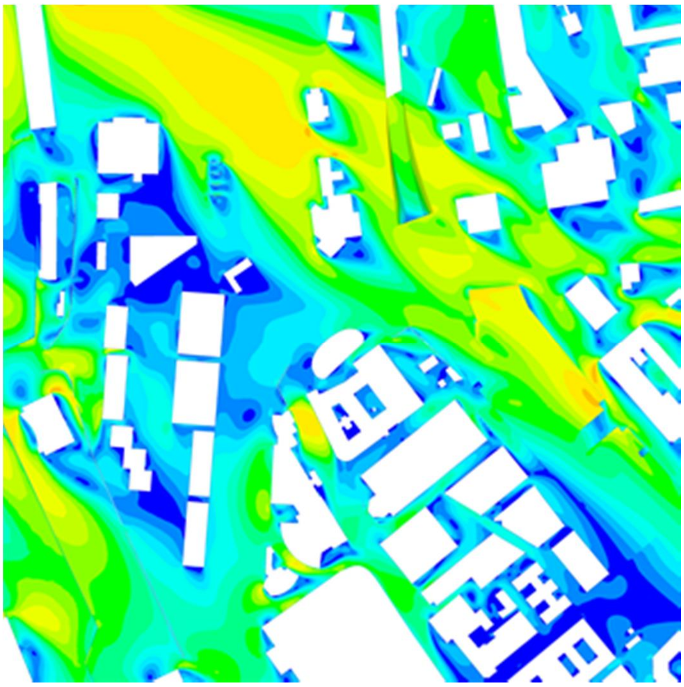
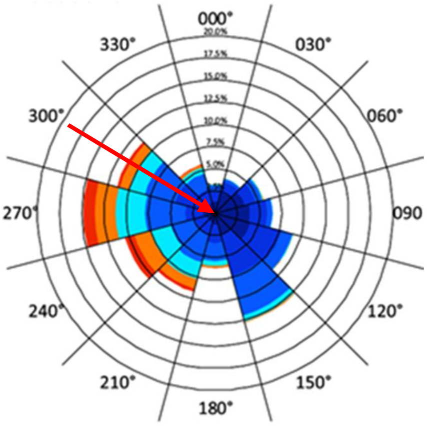




Condition 11: West North-west wind direction (300°)

BASELINE





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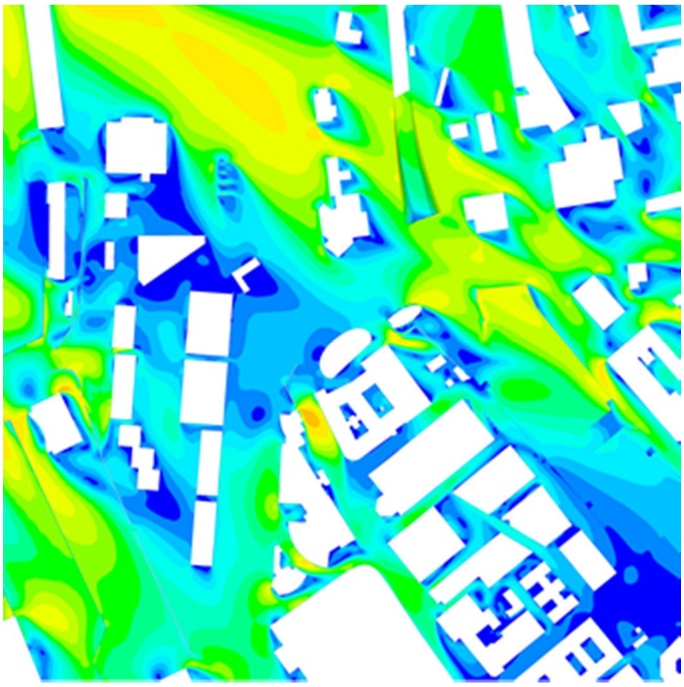
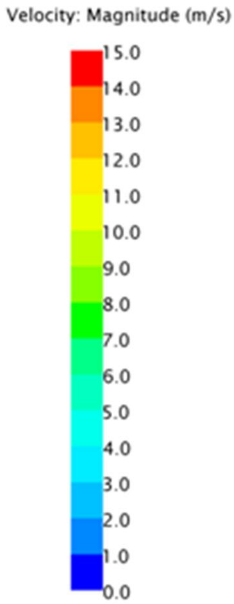
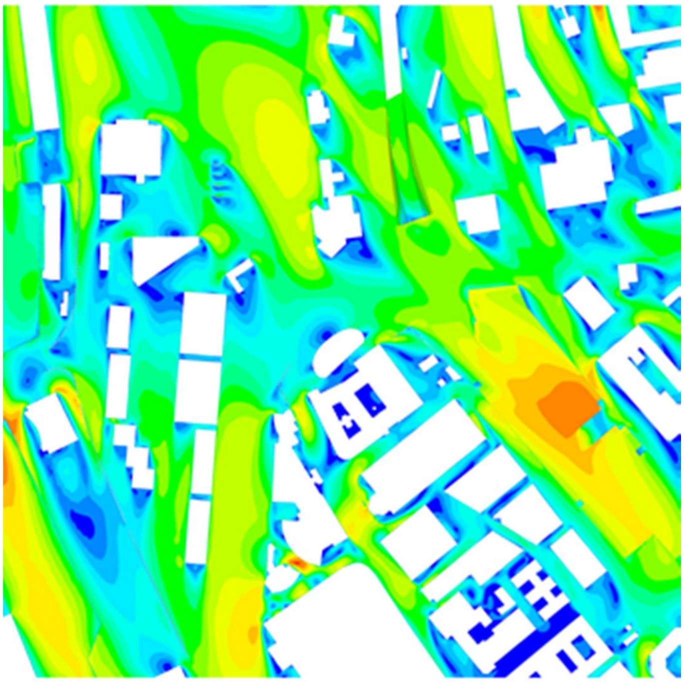
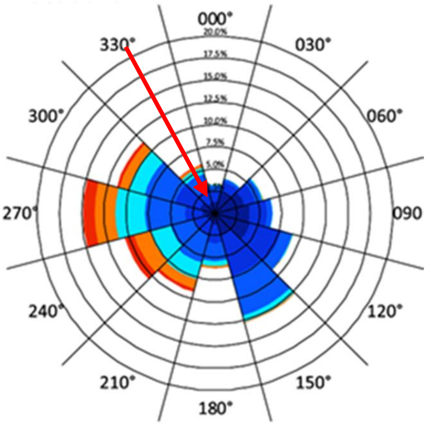




Condition 12: North North-west wind direction (330°)

BASELINE





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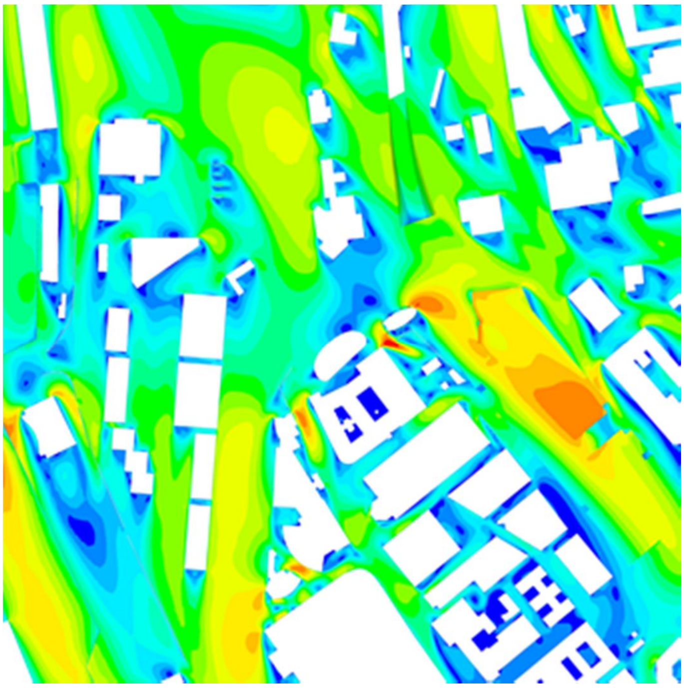

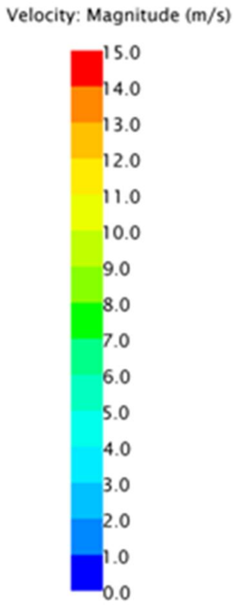

APPENDIX 3- Site Terrain Adjustment

Wind condition at weather station

BREVe32 : An aid to the use of BS6399-2 and EN1991-1-4

Design wind speeds in m/s

Provenance

Report generated by BREVe 3.2.1.5, 20/10/2016 16:51:53
SD299005 BREVe3 site data for SD299005
Design annual risk = 0.02000
Shelter effect from obstructions is **NOT** included.
Site altitude = 11.0m.
Topographic increment from internal parameters. Range = 500 m
Season length is all year.
Using UK / Irish direction factors.
Basic wind speeds :

BS*Vb* (1 hour) = 22.7 m/s.
EN*Vb*,map (10 min.) = 23.2 m/s.

BS6399-2 Directional Method - Mean and turbulence wind speeds

SD299005 BREVe3 site data for SD299005

Height above ground = 2.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	15.6	12.1	12.1	7.3	7.0	8.2	18.7	20.4	22.0	21.8	19.3	17.9
1s gust *V* (m/s) :	26.5	21.0	21.0	17.8	16.9	19.9	30.4	33.3	35.8	35.4	31.8	29.2
Turbulence *V* (m/s) :	3.16	2.60	2.60	3.03	2.89	3.39	3.41	3.73	4.01	3.97	3.65	3.29

Height above ground = 5.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	19.0	14.8	14.8	10.9	10.4	12.2	22.7	24.9	26.7	26.5	23.5	21.7
1s gust *V* (m/s) :	29.5	24.5	24.5	22.6	21.5	25.3	34.1	37.3	40.1	39.7	35.6	32.7
Turbulence *V* (m/s) :	3.05	2.82	2.82	3.39	3.23	3.79	3.30	3.61	3.88	3.84	3.53	3.18

Height above ground = 10.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	21.6	16.8	16.8	13.6	13.0	15.2	25.7	28.2	30.3	30.0	26.7	24.6
1s gust *V* (m/s) :	31.8	27.1	27.1	26.2	25.0	29.3	36.7	40.2	43.2	42.7	38.4	35.2
Turbulence *V* (m/s) :	2.95	2.98	2.98	3.66	3.49	4.09	3.19	3.49	3.75	3.71	3.41	3.08

Height above ground = 15.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	22.9	18.0	18.0	15.2	14.5	17.0	27.1	29.7	31.9	31.6	28.1	26.0
1s gust *V* (m/s) :	33.2	28.5	28.5	28.3	27.0	31.3	38.2	41.8	44.9	44.5	40.0	36.7
Turbulence *V* (m/s) :	2.99	3.06	3.06	3.81	3.63	4.14	3.23	3.53	3.79	3.76	3.45	3.11

Height above ground = 20.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	23.7	18.9	18.9	16.4	15.6	18.3	27.9	30.6	32.9	32.6	29.1	26.8
1s gust *V* (m/s) :	34.0	29.6	29.6	29.8	28.4	32.4	39.1	42.8	46.0	45.6	41.0	37.6
Turbulence *V* (m/s) :	3.00	3.11	3.11	3.92	3.73	4.10	3.24	3.55	3.82	3.78	3.47	3.13

Height above ground = 30.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	24.8	20.1	20.1	18.0	17.2	20.2	29.1	31.8	34.2	33.9	30.4	27.9
1s gust *V* (m/s) :	35.2	31.0	31.0	31.4	30.4	34.0	40.2	44.0	47.3	46.9	42.3	38.7
Turbulence *V* (m/s) :	3.00	3.16	3.16	3.90	3.86	4.01	3.24	3.55	3.82	3.78	3.47	3.13

Height above ground = 50.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	26.3	21.7	21.7	20.1	19.2	22.5	30.4	33.3	35.8	35.5	32.0	29.3
1s gust *V* (m/s) :	36.5	32.6	32.6	33.1	32.7	35.8	41.4	45.3	48.7	48.2	43.7	39.8
Turbulence *V* (m/s) :	2.94	3.18	3.18	3.78	3.92	3.85	3.18	3.48	3.74	3.70	3.40	3.07

Height above ground = 100.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	28.5	24.0	24.0	23.2	22.1	25.9	32.2	35.3	37.9	37.5	34.2	31.1
1s gust *V* (m/s) :	37.9	34.6	34.6	35.1	34.7	37.9	42.3	46.3	49.8	49.3	45.0	40.8
Turbulence *V* (m/s) :	2.72	3.09	3.09	3.48	3.66	3.49	2.94	3.22	3.46	3.42	3.15	2.84

Height above ground = 102.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	28.6	24.1	24.1	23.3	22.2	26.0	32.3	35.3	38.0	37.6	34.3	31.1
1s gust *V* (m/s) :	37.9	34.7	34.7	35.2	34.7	38.0	42.4	46.3	49.8	49.3	45.1	40.8
Turbulence *V* (m/s) :	2.71	3.08	3.08	3.47	3.65	3.48	2.93	3.21	3.45	3.41	3.14	2.83

Wind condition at the proposed site

BREVe32 : An aid to the use of BS6399-2 and EN1991-1-4

Design wind speeds in m/s

Provenance

Report generated by BREVe 3.2.1.5, 20/10/2016 16:52:10
SJ340910 BREVe3 site data for SJ340910
Design annual risk = 0.02000
Shelter effect from obstructions is **NOT** included.
Site altitude = 23.0m.
Topographic increment from internal parameters. Range = 500 m
Season length is all year.
Using UK / Irish direction factors.
Basic wind speeds :

BS*Vb* (1 hour) = 22.4 m/s.
EN*Vb*,map (10 min.) = 23.1 m/s.

BS6399-2 Directional Method - Mean and turbulence wind speeds

SJ340910 BREVe3 site data for SJ340910

Height above ground = 2.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	7.6	7.1	7.1	7.2	7.1	7.9	8.6	9.9	11.6	21.5	11.5	10.2
1s gust *V* (m/s) :	18.3	17.2	17.2	17.4	17.1	19.2	20.5	23.8	26.6	35.0	26.1	23.3
Turbulence *V* (m/s) :	3.12	2.93	2.94	2.97	2.92	3.27	3.47	4.03	4.33	3.92	4.26	3.81

Height above ground = 5.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	11.2	10.6	10.6	10.7	10.5	11.8	12.7	14.7	17.3	26.2	17.0	15.2
1s gust *V* (m/s) :	23.2	21.8	21.9	22.1	21.8	24.3	26.1	30.2	33.9	39.2	33.4	29.8
Turbulence *V* (m/s) :	3.49	3.28	3.29	3.32	3.27	3.66	3.88	4.50	4.84	3.79	4.77	4.26

Height above ground = 10.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	14.0	13.2	13.2	13.3	13.1	14.7	15.9	18.4	21.5	29.7	21.2	18.9
1s gust *V* (m/s) :	26.9	25.4	25.4	25.7	25.3	28.3	30.3	34.0	38.3	42.3	37.7	33.6
Turbulence *V* (m/s) :	3.76	3.54	3.55	3.58	3.53	3.95	4.19	4.53	4.87	3.66	4.80	4.29

Height above ground = 15.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	15.7	14.7	14.8	14.9	14.7	16.4	17.7	20.6	24.0	31.4	23.6	21.0
1s gust *V* (m/s) :	29.1	27.4	27.5	27.8	27.3	30.6	32.8	35.9	40.5	44.1	39.8	35.5
Turbulence *V* (m/s) :	3.92	3.69	3.69	3.73	3.67	4.11	4.37	4.45	4.78	3.71	4.71	4.21

Height above ground = 20.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	16.8	15.8	15.9	16.0	15.8	17.7	19.1	22.1	25.8	32.4	25.4	22.5
1s gust *V* (m/s) :	30.7	28.9	28.9	29.2	28.8	32.2	34.1	37.2	42.0	45.2	41.0	36.7
Turbulence *V* (m/s) :	4.03	3.79	3.80	3.84	3.77	4.22	4.36	4.38	4.71	3.73	4.55	4.14

Height above ground = 30.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	18.5	17.4	17.5	17.6	17.4	19.4	21.0	24.3	28.2	33.8	27.8	24.5
1s gust *V* (m/s) :	32.9	30.8	30.9	31.3	30.8	33.9	35.7	39.0	44.0	46.7	42.4	38.4
Turbulence *V* (m/s) :	4.17	3.90	3.91	3.97	3.91	4.21	4.28	4.25	4.58	3.73	4.25	4.03

Height above ground = 50.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	20.7	19.5	19.5	19.7	19.4	21.7	23.5	27.2	31.3	35.6	30.8	27.1
1s gust *V* (m/s) :	34.7	32.5	32.6	33.0	32.6	35.7	37.7	41.1	46.3	48.2	44.0	39.6
Turbulence *V* (m/s) :	4.06	3.79	3.79	3.86	3.83	4.07	4.13	4.04	4.34	3.65	3.82	3.64

Height above ground = 100.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	23.8	22.4	22.5	22.7	22.3	25.0	27.1	30.4	34.4	38.0	33.9	29.6
1s gust *V* (m/s) :	36.8	34.5	34.5	35.0	34.6	37.9	40.1	43.6	48.6	49.6	45.4	40.6
Turbulence *V* (m/s) :	3.76	3.50	3.51	3.58	3.55	3.75	3.77	3.84	4.13	3.38	3.34	3.21

Height above ground = 102.0 m

Direction (°N) :	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
Mean *V* (m/s) :	23.9	22.5	22.6	22.8	22.4	25.1	27.2	30.5	34.5	38.0	34.0	29.6
1s gust *V* (m/s) :	36.8	34.5	34.6	35.1	34.6	37.9	40.1	43.7	48.7	49.6	45.4	40.6
Turbulence *V* (m/s) :	3.75	3.49	3.50	3.57	3.54	3.74	3.76	3.83	4.12	3.37	3.33	3.20

APPENDIX 4-CFD TECHNICAL ASSUMPTIONS

CFD model
Computational Fluid Dynamics (CFD) solves the Navier Stokes equations governing fluid flow which is mapped out over a computational domain using the physics specific to the problem analysed; velocity, turbulence, pressure etc. The CFD code is solved via CD-adapco's STAR-CCM+ software, version 7.06. This program has been extensively used and widely validated and verified in many fluid driven applications, particularly in environmental wind cases involving atmospheric boundary layers such as this.
By using CFD to investigate the effects of a wind on a site enables a detailed understanding to be gained of the velocity distribution across the whole site. It also enables the local site microclimate to be compared with the annual weather data thus enabling assessments to be made of what activities could be comfortably undertaken at a particular location as a proportion of the year.

The fact that the flow is measured throughout the domain means that the cause of an elevated wind speed can be investigated and mitigation measures proposed that are suitable, for instance canopies or trees.

Boundary conditions
The CFD simulation has been set up in accordance with the COST Action 732 (2007)i detailing best practise guidelines for the CFD modelling of flows in the urban environment.

The CFD fluid domain has a minimum distance of 10 times the height of the tallest building from the extent of the modelled buildings to all inflow and outflow boundaries. The top of the CFD fluid domain has been modelled as a no slip wall boundary condition with a minimum distance of 6 times the height of the tallest building from the ground. The blockage ratio of the domain has been kept below 3% as detailed in Cost C14 (2004)ii.

Atmospheric Effects are accounted by the accurate modelling of the Atmospheric Boundary Layer profile as used in STAR-CCM+ by utilising the Zhang (2009)iii model of the expressions for turbulence and velocity.
Surface Roughness is accounted for in these equations by using the roughness parameter zo. This takes into account the effect of upstream buildings on velocity and turbulence formulation.

Meshing
A CFD model requires the fluid domain to be divided into discrete elements or "cells" that are linked together and communicate information between adjacent cells. The size, number and distribution of these cells define the level of accuracy that can be gained from the model.

In this model the domain has been meshed using hexahedral elements. The size of these hexahedral elements have been reduced around the buildings to ensure an adequate number of cells accurately resolve the geometry and flow field.
An inflation layer mesh has been used to increase the mesh density in areas of interest to ensure the flow field has been accurately resolved. This also ensures there is sufficient number of cells between the ground and the velocity slice plane.

Numerical Sub Models

Turbulence Modelling: Turbulent effects have been modelled using the Reynolds Averaged Navier Stokes (RANS) equations. The two equation k-ε RNG turbulence model was used as it is accepted to be accurate for swirling, turbulent flows such as the building immersed in an atmospheric boundary layer in this study.

Discretisation Scheme: Second order discretisation schemes have been used to spatially resolve flow and pressure distribution.

Convergence Criteria: Solutions to the Navier Stokes Equations are achieved using an iterative method to reduce the residual error within the solution, allowing closure of the governing equations for convective, diffusive and source terms. Solution convergence is a measure of the imbalance of the solution of each equation and relates to whether they have been sufficiently solved to an acceptable accuracy or not.

The residual error for this study is calculated using the RMS (root mean square) with a target of 0.0001 at selected locations around the buildings of interest.

The steady state CFD simulation will capture all major flow accelerations on the site that are likely to significantly impact pedestrian safety, it will not calculate velocity fluctuations expected in low speed turbulent wakes. Unsteady numerical modelling can account for this; however, it is computationally and time intensive to do so. Global site gusting is accounted for by running the simulation at higher range wind speeds at the site.

[i] COST Action 732, (2007) "*Best practice guideline for the CFD simulation of flows in the urban environment.*"

[ii] COST Action C14, (2004) *"Recommendations on the use of CFD in wind engineering."*

[iii] Xiaodong Zhang (2009) *"CFD simulation of neutral ABL flows"*