11   Wind and Microclimate

11.1   Introduction

This chapter has been prepared by B-Fluid Limited.

B-Fluid Limited has been commissioned by 'Lafferty Project Managers' to carry out a Wind and Micro-climate Modelling Study for development at lands at 'The Grange', Brewery Road, Stillorgan, Blackrock, Co. Dublin.

Wind and Micro-climate study identify the possible wind patterns around the area proposed, under mean and peaks wind conditions typically occurring in Dublin.

The assessment is performed through Computational Fluid Dynamic (CFD) which is a numerical method to simulate the wind conditions and impact on the development and to identify areas of concern in terms of downwash/funneling/downdraft/critical flow accelerations that may likely occur.

These results will be utilized by 'Lafferty Project Managers' team to configure the optimal layout for Grange Development for the aim of achieving a high-quality environment for the scope of use intended of each areas/building (i.e. comfortable and pleasant for potential pedestrian) and not to introduce any critical wind impact on the surrounding areas and on the existing buildings.

Figure 11.1 - View of Proposed Grange Development Level 01 Plan

The following paragraphs describe the wind modelling study performed, it's methodology and assumptions which B-Fluid Ltd. has adopted for this study.

Objective of the Wind Modelling

The CFD wind model is adopted to identify areas of concern in terms of critical flows and areas where the pedestrian safety and comfort could be compromised. Pedestrian Wind Comfort and Safety Studies are conducted to predict, assess and, where necessary, mitigate the impact of the

development on pedestrian level wind conditions. The objective is to maintain comfortable and safe pedestrian level wind conditions that are appropriate for the season and the intended use of pedestrian areas. Pedestrian areas include side-walks and street frontages, pathways, building entrance areas, open spaces, amenity areas, outdoor sitting areas, and accessible roof top areas among others.

DUBLIN WIND SCENARIOS AND DIRECTIONS

Velocity (m=s)	Direction (deg)	Frequency
5.601	225	11.233
4.626	135	6.849
5.847	236.25	6.792
6.049	258.75	6.747
6.034	247.5	6.689
5.888	270	5.662
4.994	315	4.338
5.503	281.25	3.904
4.974	292.5	3.436
5.357	213.75	3.288
4.736	123.75	3.105
4.406	146.25	2.751
5.101	303.75	2.648
5.246	112.5	2.500
4.121	157.5	2.386
4.581	101.25	2.340
4.169	45	2.180
3.558	90	2.135

Table 11.1 - Summary of the 18 scenarios modelled for the Grange Development

For this purpose, 18 different wind scenarios and directions have been modelled as shown in Table 11.1 in order to take into consideration all the different relevant wind directions. In particular, a total of 18 compass directions on the wind rose are selected. For each direction, the reference wind speed is set to the 5% exceedance wind speed for that direction, i.e. the wind speed that is exceeded for only 5% of the time whenever that wind direction occurs.

This study focuses on reporting 9 worst case and most relevant wind speeds with cardinal directions, which are the speeds and directions showing the most critical wind speeds relevant to the development. The 9 modelled scenarios reported in this study are presented in Table 11.2.

DOMINANT WIND SCENARIOS AND DIRECTIONS IN DUBLIN		
Velocity (m=s)	Direction (deg)	Frequency
5.601	225	11.233
4.626	135	6.849
5.847	236.25	6.792
6.049	258.75	6.747
6.034	247.5	6.689
5.888	270	5.662
4.994	315	4.338
5.503	281.25	3.904
4.169	45	2.180

Table 11.2 - Summary of the dominant wind directions in Dublin

Figure 11.2 - Summary of the dominant wind directions in Dublin

Chapter 11 - Wind and Microclimate
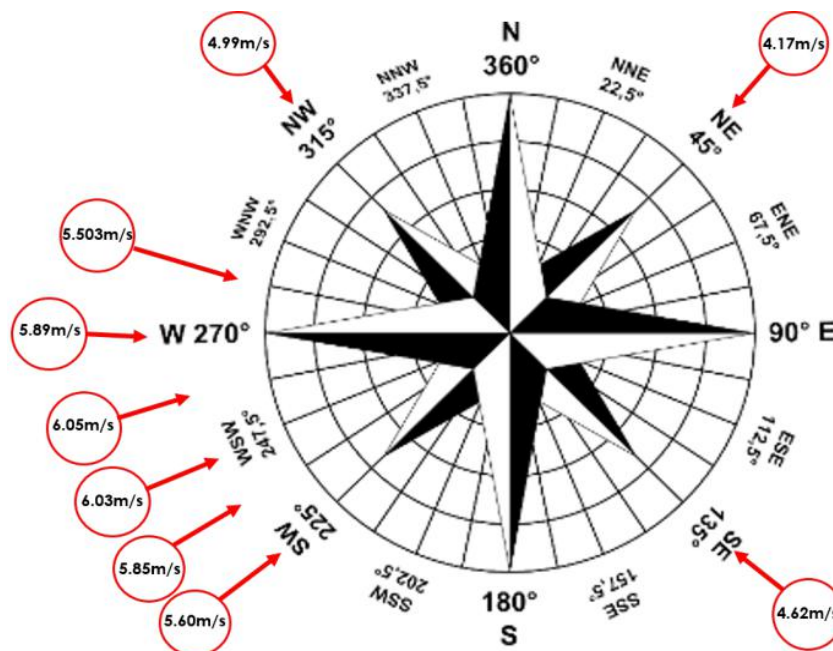
11.2   Study Methodology

<u>**Acceptance Criteria**</u>

<u>Pedestrian Comfort</u>

Pedestrian Wind Comfort is measured in function of the frequency of wind speed threshold exceeded based on the pedestrian activity. The assessment of pedestrian level wind conditions requires a standard against which measured or expected wind velocities can be compared.

Only gust winds are considered in the safety criterion. These are usually rare events, but deserve special attention in city planning and building design due to their potential impact on pedestrian safety. Gusts cause the majority of cases of annoyance and distress and are assessed in addition to average wind speeds. Gust speeds should be divided by 1.85 and these "gust equivalent mean" (GEM) speeds are compared to the same criteria as for the mean hourly wind speeds. This avoids the need for different criteria for mean and gust wind speeds.

The following criteria are widely accepted by municipal authorities as well as the international building design and city planning community:

Discomfort Criteria:

Relates to the activity of the individual. Onset of discomfort:

- Depends on the activity in which the individual is engaged and is defined in terms of a mean hourly wind speed (or GEM) which is exceeded for 5% of the time.

Distress Criteria:

Relates to the physical well-being of the individual. Onset of distress:

- *'Frail Person or Cyclist'*: equivalent to an hourly mean speed of 15 m/s and a gust speed of 28 m/s (62 mph) to be exceeded less often than once a year. This is intended to identify wind conditions which less able individuals or cyclists may find physically difficult. Conditions in excess of this limit may be acceptable for optional routes and routes which less physically able individuals are unlikely to use.
- *'General Public'*: A mean speed of 20 m/s and a gust speed of 37 m/s (83 mph) to be exceeded less often than once a year. Beyond this gust speed, aerodynamic forces approach body weight and it rapidly becomes impossible for anyone to remain standing. Where wind speeds exceed these values, pedestrian access should be discouraged.

The above criteria set out six pedestrian activities and notes that calm activity requires calm wind conditions, which are summarised by the Lawson scale, shown in Figure 11.3. The Lawson scale assesses pedestrian wind comfort in absolute terms and defines the reaction of an average person to the wind. Each wind type is associated to a number, corresponding to the Beaufort scale, which is represented in Figure 11.4. The Beaufort scale is an empirical measure that relates wind speed to observed conditions at sea or on land. A 20% exceedance is used in these criteria to determine the comfort category, which suggests that wind speeds would be comfortable for the corresponding activity at least 80% of the time or four out of five days.

Figure 11.3 - Lawson Scale

Beaufort Scale	Wind Type	Mean Hourly Wind Speed (m/s)		Acceptance Level Based on Activity–Lawson Criteria			
				Sitting	Standing/ Entrances	Leisure Walking	Business Walking
0-1	Light Air	0 – 1.55	COMFORT				
2	Light Breeze	1.55 - 3.35					
3	Gentle Breeze	3.35 - 5.45					
4	Moderate	5.45 - 7.95					
5	Fresh Breeze	7.95 - 10.75					
6	Strong Breeze	10.75 - 13.85					
7	Near Gale	13.85 - 17.15					
8	Gale	17.15 - 20.75	DISTRESS				
9	Strong Gale	20.75 - 24.45					
Legend	Acceptable / Tolerable / Not acceptable / Dangerous						

THE BEAUFORT SCALE

WIND	SYMBOL	SPEED	FORCE	EFFECT	WIND	SYMBOL	SPEED	FORCE	EFFECT
CALM		>1 MPH	0	SMOKE RISES VERTICALLY	MODERATE GALE		32-38 MPH	7	WHOLE TREES IN MOTION
LIGHT AIR		1-3 MPH	1	SMOKE DRIFTS SLIGHTLY	FRESH GALE		39-46 MPH	8	TWIGS BROKEN OFF TREES: DIFFICULT TO DRIVE A CAR
LIGHT BREEZE		4-7 MPH	2	LEAVES RUSTLE: WIND VANE MOVES	STRONG GALE		47-54 MPH	9	SLIGHT STRUCTURAL DAMAGE OCCURES
GENTLE BREEZE		8-12 MPH	3	LEAVES IN CONSTANT MOTION: LIGHT FLAG EXTENDED	WHOLE GALE		55-63 MPH	10	TREES UPROOTED: SEVERE STRUCTURAL DAMAGE
MODERATE BREEZE		13-18 MPH	4	RAISES DUST AND PAPERS: SMALL BRANCHES STIR	STORM		64-73 MPH	11	WIDESPREAD DAMAGE
FRESH BREEZE		19-24 MPH	5	SMALL TREES SWAY	HURRICANE		ABOVE 75 MPH	12	DEVASTATION
STRONG BREEZE		25-31 MPH	6	LARGE BRANCHES MOVE: USE OF UMBRELLA DIFFICULT	THE BEAUFORT SCALE HAS UNOFFICIALLY BEEN EXTENDED TO FORCE 17 TO DESCRIBE TROPICAL STORMS EXCEEDING 126 MILES PER HOUR.				

Figure 11.4 - The Beaufort Scale

These criteria for wind forces represent average wind tolerances. They are subjective and variable depending on thermal conditions, age, health, clothing, etc. which can all affect a person's perception of a local microclimate. Moreover, pedestrian activity alters between winter and summer months. The criteria assume that people will be suitably dressed for the time of year and individual activity. It is reasonable to assume, for instance, that areas designated for outdoor seating will not be used on the windiest days of the year.

Weather data measured are used to calculate how often a given wind speed will occur each year over a specified area. Pedestrian comfort criteria are assessed at 1.5m above ground level. Unless in extremely unusual circumstances, velocities at pedestrian level increase as you go higher from ground level.

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A breach of the distress criteria requires a consideration of:

- whether the location is on a major route through the complex,

  - whether there are suitable alternate routes which are not distressful.

If the predicted wind conditions exceed the threshold, then conditions are unacceptable for the type of pedestrian activity and mitigation measure should be implemented into the design.

CFD Modelling Method

Computational Fluid Dynamics (CFD) is a numerical technique used to simulate fluid flow, heat and mass transfer, chemical reaction and combustion, multiphase flow, and other phenomena related to fluid flows. CFD modelling includes three main stage: pre-processing, simulation and post-processing as described in Figure 11.5. The Navier-Stokes equations, used within CFD analysis, are based entirely on the application of fundamental laws of physics and therefore produce extremely accurate results provided that the scenario modelled is a good representation of reality.
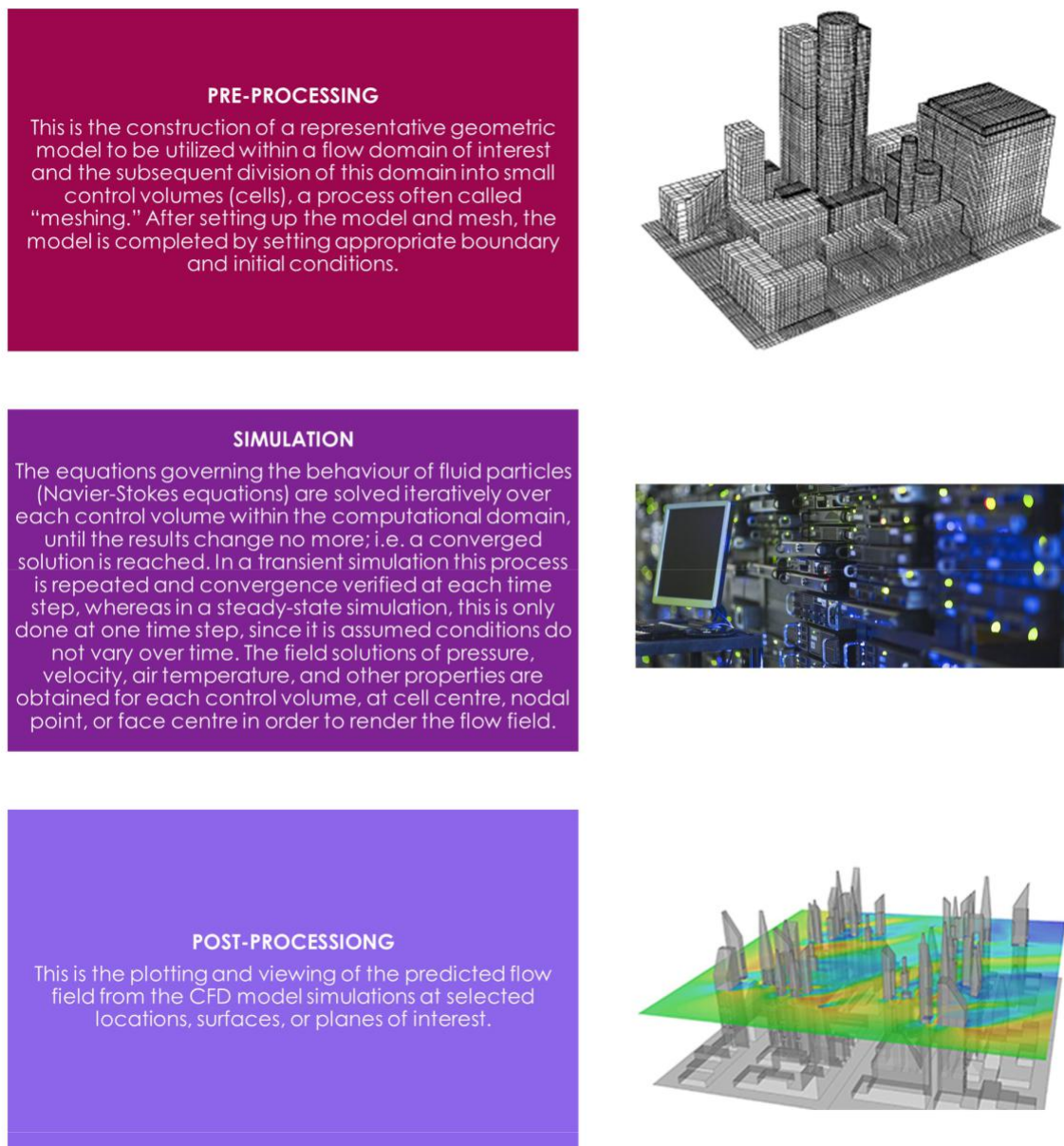

PRE-PROCESSING
This is the construction of a representative geometric model to be utilized within a flow domain of interest and the subsequent division of this domain into small control volumes (cells), a process often called "meshing." After setting up the model and mesh, the model is completed by setting appropriate boundary and initial conditions.

SIMULATION
The equations governing the behaviour of fluid particles (Navier-Stokes equations) are solved iteratively over each control volume within the computational domain, until the results change no more; i.e. a converged solution is reached. In a transient simulation this process is repeated and convergence verified at each time step, whereas in a steady-state simulation, this is only done at one time step, since it is assumed conditions do not vary over time. The field solutions of pressure, velocity, air temperature, and other properties are obtained for each control volume, at cell centre, nodal point, or face centre in order to render the flow field.

POST-PROCESSIONG
This is the plotting and viewing of the predicted flow field from the CFD model simulations at selected locations, surfaces, or planes of interest.

Figure 11.5 - CFD Modelling Process Explanation

Openfoam numerical solver details

This study employs OpenFoam Code, which is based on a volume averaging method of discretization and uses the post-processing visualisation toolkit Paraview version 5.5. OpenFoam is a CFD software code released and developed primarily by OpenCFD Ltd, since 2004. It has a large user base across most areas of engineering and science, from both commercial and academic organisations.

OpenFOAM CFD code has capabilities of utilizing a Reynolds Averaged Navier-Stokes (RANS) approach, Unsteady Reynolds Averaged Navier-Stokes (URANS) approach, Detached Eddy Simulation (DES) approach, Large Eddy Simulation (LES) approach or the Direct Numerical Simulation (DNS) approach, which are all used to solve anything from complex fluid flows involving chemical reactions, turbulence and heat transfer, to acoustics, solid mechanics and electromagnetics. Quality assurance is based on rigorous testing. The process of code evaluation, verification and validation includes several hundred daily unit tests, a medium-sized test battery run on a weekly basis, and large industry-based test battery run prior to new version releases. Tests are designed to assess regression behaviour, memory usage, code performance and scalability.

The OpenFOAM solver algorithm directly solves the mass and momentum equations for the large eddies that comprise most of the fluid's energy. By solving the large eddies directly no error is introduced into the calculation.

To reduce computational time and associated costs the small eddies within the flow have been solved using the widely used and recognised Smagorinsky Sub-Grid Scale (SGS) model. The small eddies only comprise a small proportion of the fluids energy therefore the errors introduced through the modelling of this component are minimal.

The error introduced by modelling the small eddies can be considered of an acceptable level. Computational time will be reduced by modelling the small eddies (compared to directly solving).

11.3 The Existing Receiving Environment (Baseline)

Existing Receiving Environment Assessment

In this study, wind impact has been assessed on the existing receiving environment considered as the existing buildings and the topography of the site prior to construction of the proposed development. A statistical analysis of 30 years historical weather wind data has been carried out to assess the most critical wind speeds, directions and frequency of occurrence of the same, furthermore, B-Fluid's weather station has recorded locally 1 month of wind data on the existing site for comparison with the historical data. The aim of this assessment has been to identify the wind microclimate of the area that may cause critical conditions for pedestrians comfort criteria.

Site Location and Surrounding Area

The Grange Development will be situated in Dublin, on the corner of Stillorgan Road and Brewery Road, in Blackrock, Co. Dublin. The site location is shown in Figure 11.6 and Figure 11.7. The modelled area for the wind modelling study comprises a 2km² area around the "The Grange Development", as represented in Figure 11.8.

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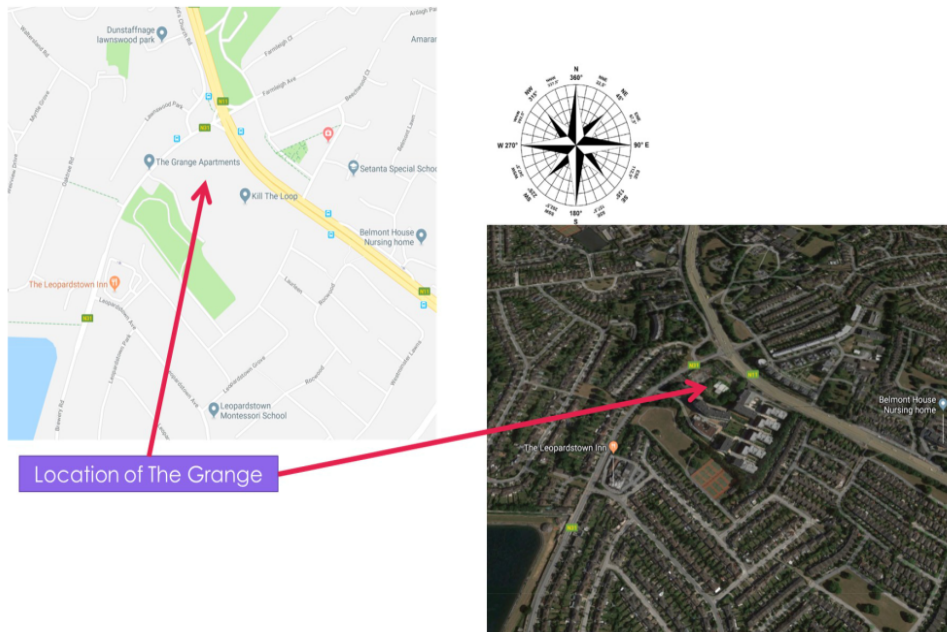*Figure 11.6 - View of The Grange Development Site*

Figure 11.7 - The Grange Development Site Location

Figure 11.8 - Extents of Analysed Area around The Grange Development

Topography and built in Environment

Figure 11.9 shows an aerial photograph of the terrain surrounding the construction site at The Grange Development.

The Grange is ideally located just a short drive from Dublin City Centre, off the N11 route. The area is serviced by numerous bus routes, including the 84, 75 and 46A-46E routes and benefits in terms of travel time from the Quality Bus Corridor (QBC). The Sandyford Luas stop is within walking distance. The Grange benefits from the Stillorgan Road and Brewery Road Cycle Way, which passes alongside the development. Within easy reach of Foxrock, Blackrock Village, Dundrum, Donnybrook, Stillorgan, Ballsbridge, Ranelagh and the city centre. The M50 Motorway (Sandyford/Junction13) is located approx 1.7km southwest of The Grange and offer convenient access to Dublin Airport and nationwide network of roads which feeds off the M50.

The area surrounding the site can be characterised as urban environment. Some shelter effect can be expected for wind approaching from directions within this sector. All for the study considered main wind directions of west to southwest and Southeast are in this connection "urban winds" and no distinction will be made between them.
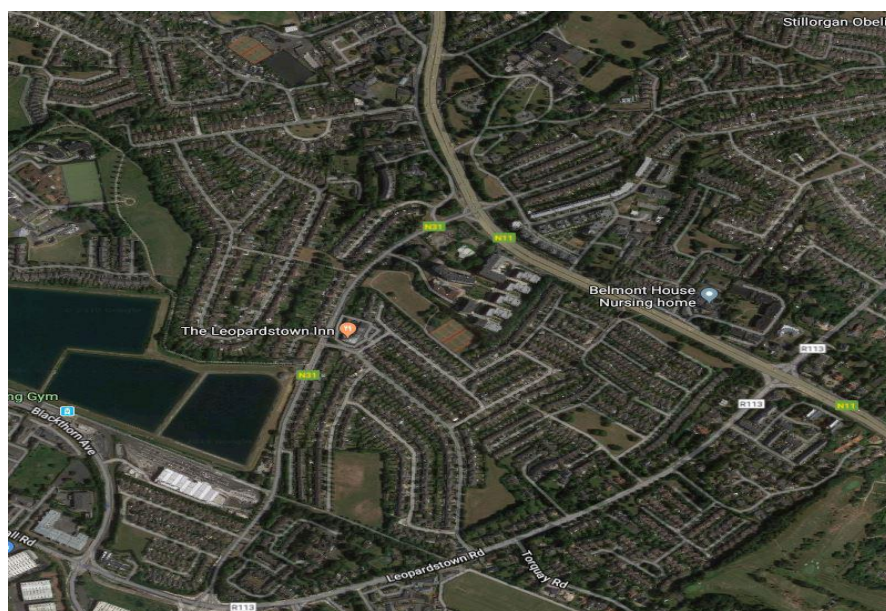

Figure 11.9 - Built-in Environment around Construction Site at The Grange

10

Wind and Microclimate Conditions

The simulations consider the whole development being exposed to the typical wind condition of the site, in order to assess the wind impact on the pedestrian areas. The building is oriented as shown in the previous sections. The wind is applied in the CFD model as a velocity boundary condition with a prescribed profile, which specifies the wind magnitude variation with the height and the wind direction. The wind profile is built using the annual average of meteorology data collected at Dublin Airport Weather Station. Figure 11.10 shows on the map the position of The Grange Development and the position of Dublin Airport.
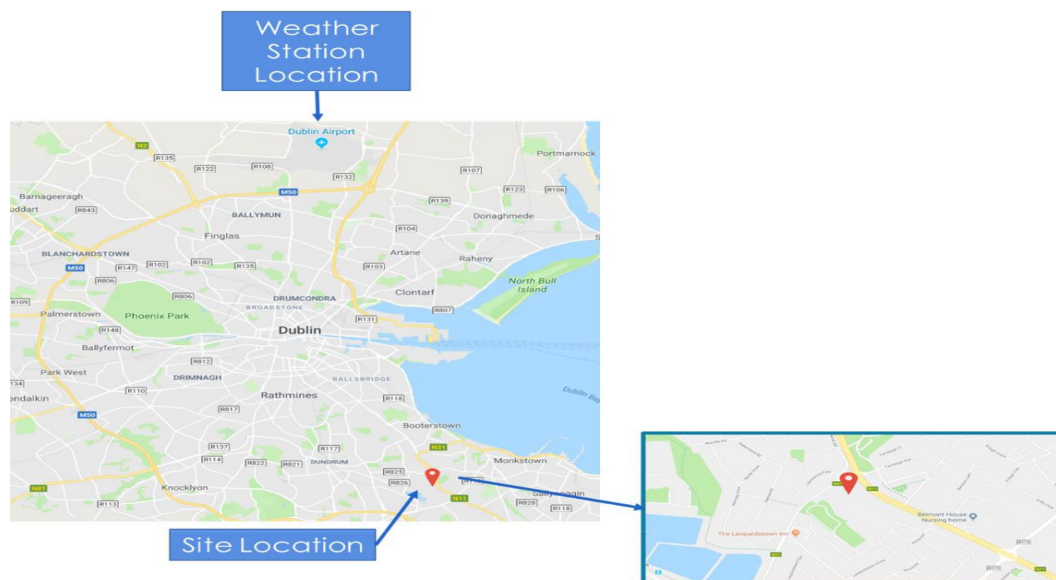

Figure 11.10 - Map showing the position of The Grange Development and Dublin Airport

Regarding the transferability of the available wind climate data following considerations have been made:

- **Terrain:** The meteorological station is located in the flat open terrain of the airport, whereas the development site is located in urban area with dense built-in structure with buildings of at least 15m height in average.

- **Mean Wind Speeds:** Due to the different terrain environment, the ground-near wind speeds (at pedestrian level) will be lower at the construction site compared to the meteorological station at the airport.

- **Wind Directions:** The landscape around the development site can in principle be characterized as flat terrain. Isolated elevations in the near area of the development should have no influence on the wind speed and wind directions. With respect to the general wind climate no significant influence is expected.

Based on the above considerations it can be concluded that the data from the meteorological station at Dublin Airport are applicable for the desktop assessment of the wind comfort at the development site.

Local, Maximum and Mean Wind Conditions

Local Wind Conditions

The assessment of the wind comfort conditions at the new development will be based on the dominating wind directions throughout a year (annual wind statistic).

As stated above, the local wind climate is determined from historical meteorological data recorded at Dublin Airport. Two different data sets are analysed for this assessment as follows:

- The meteorological data associated with the maximum daily wind speeds recorded over a 30 year period between 1985 and 2015 and,

- The mean hourly wind speeds recorded over a 10 year period between 2005 and 2015. The data is recorded at a weather station at the airport, which is located 10m above ground or 71mOD.
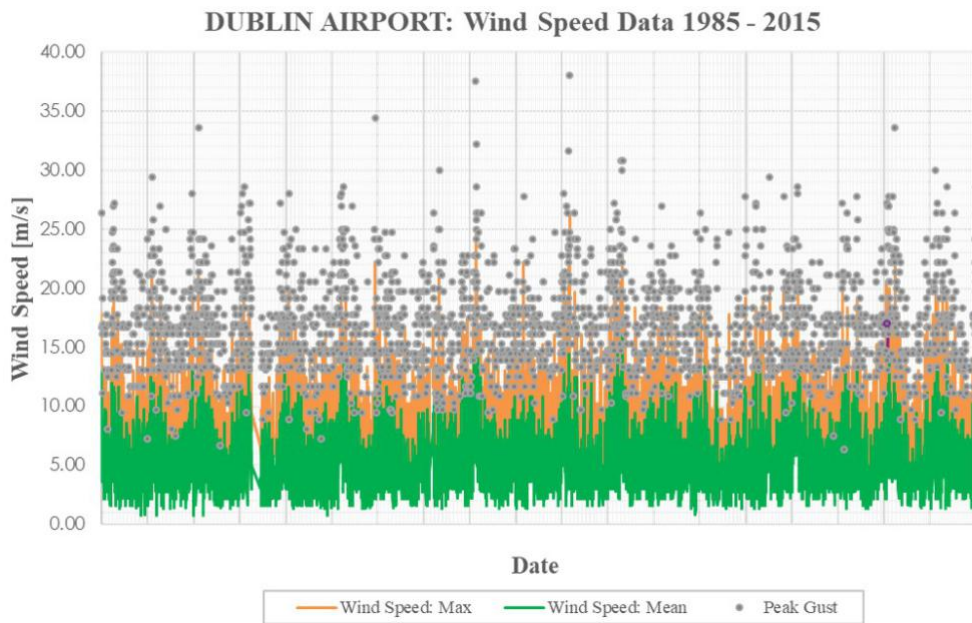

Figure 11.11 - Local Wind Conditions

Figure 12 presenting the wind speed diagram for Dublin, shows the days per month, during which the wind reaches a certain speed. In Figure 11.13, the wind rose for Dublin shows how many hours per year the wind blows from the indicated direction, confirming how the predominant directions are WSW, W, and SW.
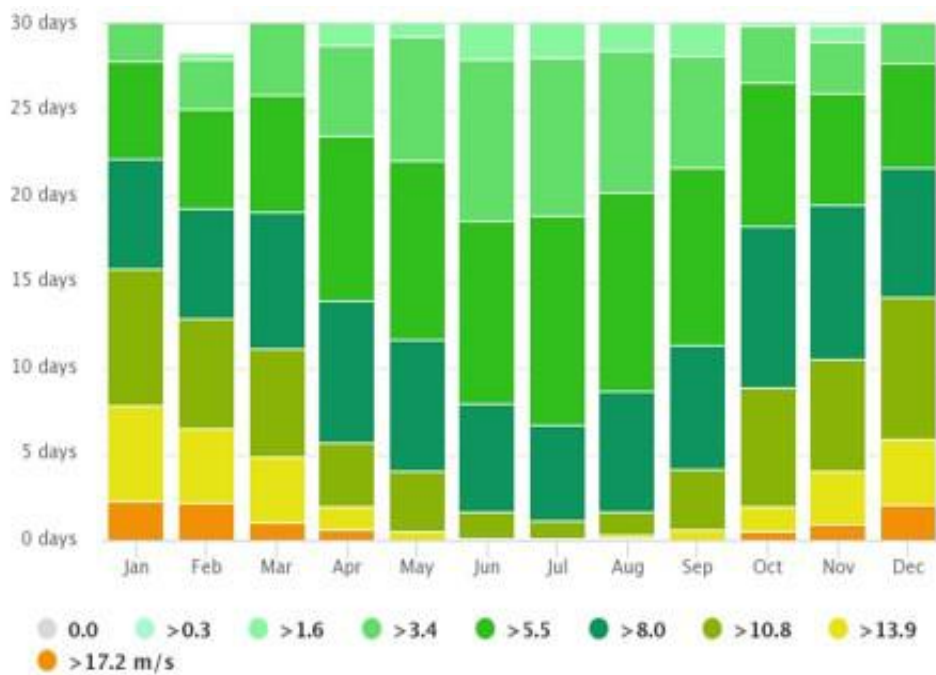

Figure 11.12 - Dublin Wind Speed Diagram
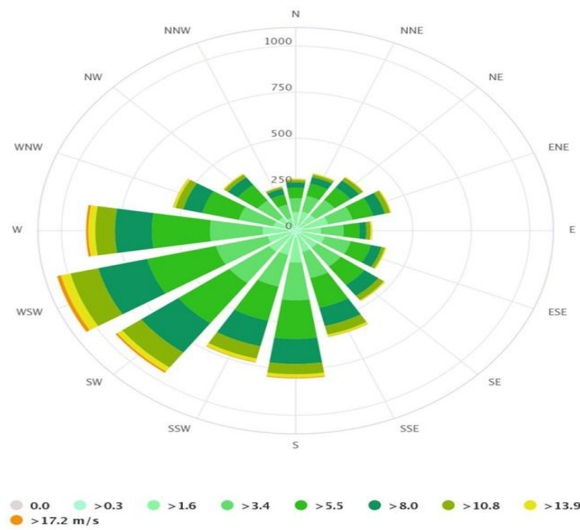
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Figure 11.13 - Dublin Wind Rose

Mean and maximum wind conditions

Examination of the daily wind data reveals that the wind predominantly blows from West and Southwest directions, however, there is a secondary wind from the Southeast. It is apparent that winds from other directions are rare. Maximum daily wind speeds of nearly 30 m/s were recorded in the past 30 years, however, the maximum daily winds are commonly found between 6 m/s and 15 m/s. the strongest winds arise from the West and Southwest.
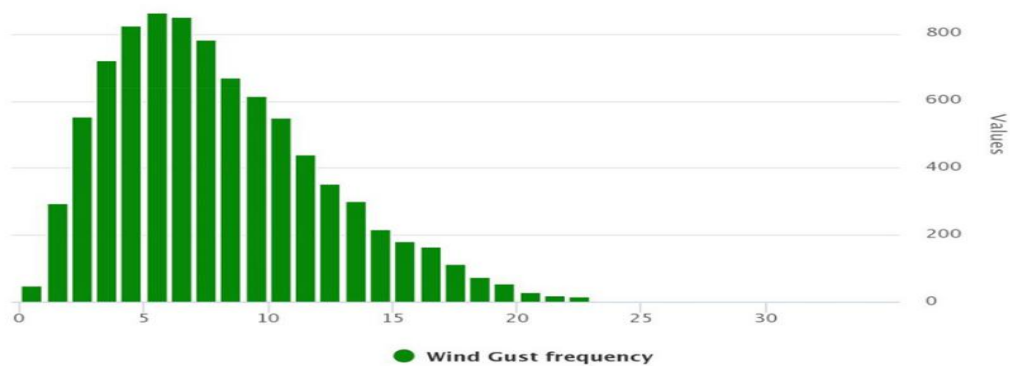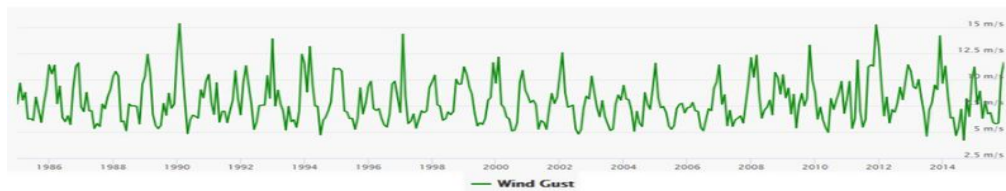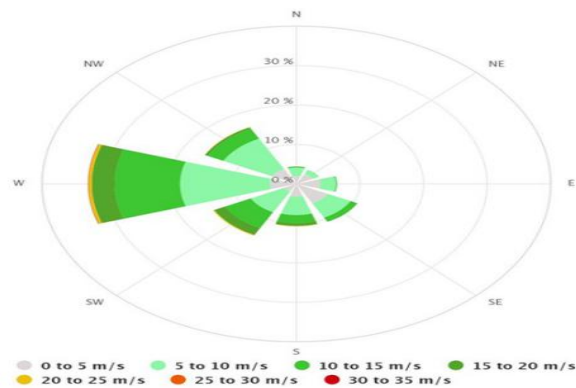

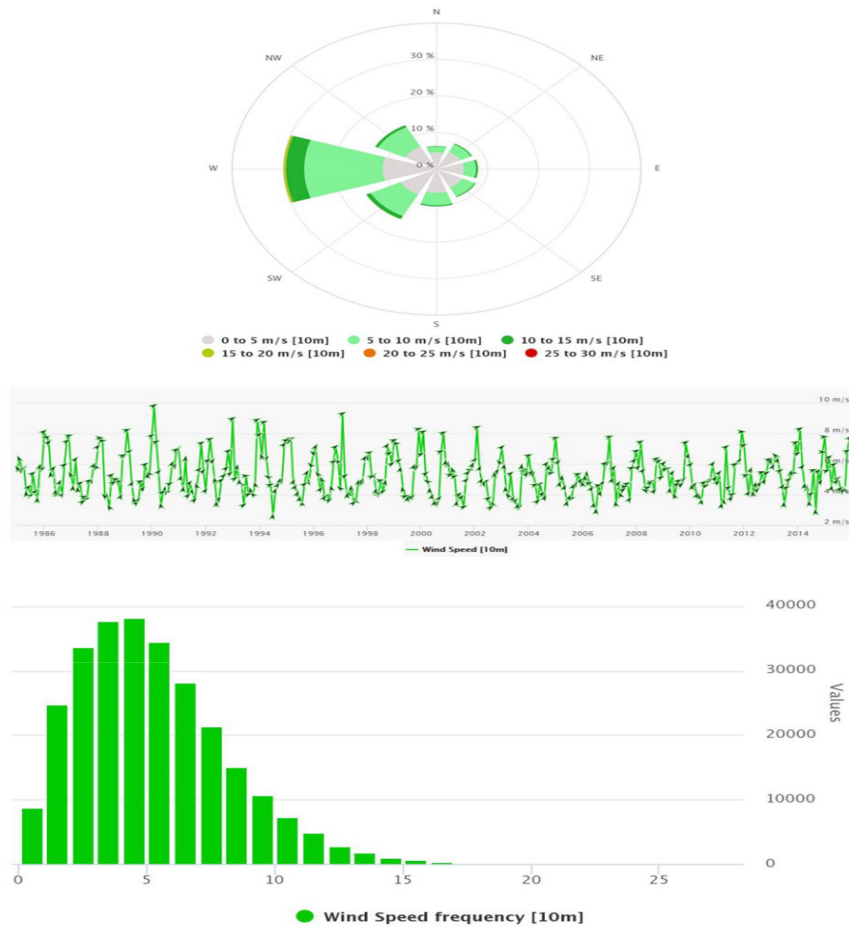*Figure 11.14 - Maximum Wind Conditions*

Figure 11.15 - Mean Wind Conditions

Based on the criterion of occurrence frequency, the main wind directions to be considered in pedestrian wind comfort assessment are presented in Figure 16. For each direction, the reference wind speed is set to the 5% exceedance wind speed for that direction, i.e. the wind speed that is exceeded for only 5% of the time whenever that wind direction occurs. A total of at least 8 compass directions will be selected from these directions, starting from the top of the table. Between all, the most frequent velocities are:

1. South-West with most frequent wind speeds around 6m/s (all year).

2. South-East

3. West-South-West.

The desktop study will mainly focus on the large sector of prevailing wind directions of winds from above. Other wind directions will be discussed if deemed necessary for the study.

Velocity (m/s)	Direction (°)	Frequency
5.601	225	11.233
4.626	135	6.849
5.847	236.25	6.792
6.049	258.75	6.747
6.034	247.5	6.689
5.888	270	5.662
4.994	315	4.338
5.503	281.25	3.904
4.974	292.5	3.436
5.357	213.75	3.288
4.736	123.75	3.105
4.406	146.25	2.751
5.101	303.75	2.648
5.246	112.5	2.500
4.121	157.5	2.386
4.581	101.25	2.340
4.169	45	2.180
3.558	90	2.135
4.801	202.5	2.021
3.689	78.75	1.963
3.627	168.75	1.495
4.285	67.5	1.370
4.863	56.25	1.279
4.042	191.25	1.199
4.630	326.25	1.164
3.844	11.25	1.142
4.418	337.5	1.062
4.787	348.75	0.982
4.006	22.5	0.959
3.555	180	0.879
4.059	33.75	0.845
0.700	0	0.011
Selected Conditions : 32	Total Coverage : 95.35 %	

Figure 11.16 - Main Wind Directions Occurrence Frequency

Comparison with on - site weather station

The wind profile built using the data from Dublin Airport, is also compared with the one obtained using the data collected on-site in the period 22nd February - 4th April. Figure 11.17 shows B-Fluid weather station and its characteristics.

Figure 11.17 - B-Fluid On-site Weather Station

For clarity, Figures 11.18 and 11.19 respectively show the last two weeks of the wind speed and direction and wind gust recorded by the on-site weather station. The green, blue and black data represent the wind speed/gust daily mean, max and min respectively.

Figure 11.18 - Wind speed and Direction recorded by B-Fluid On-site Weather Station

Figure 11.19 - Wind gust recorded by B-Fluid On-site Weather Station

As it is possible to assess the comparison between on-site and airport measurements, as presented in Figure 11.20 and 11.21, it can be concluded that the wind speed daily mean and the wind gust daily mean recorded on site follow the same pattern as the one recorded at Dublin Airport. However, the trends of the wind speed levels and the gust wind speed levels registered on-site are slightly lower. This is due to the fact that the site is located in the urban environment thus much more shielded if compared with Dublin Airport. This confirms that using wind data from Dublin Airport ensures a conservative analysis of the wind impact around Grange Development.
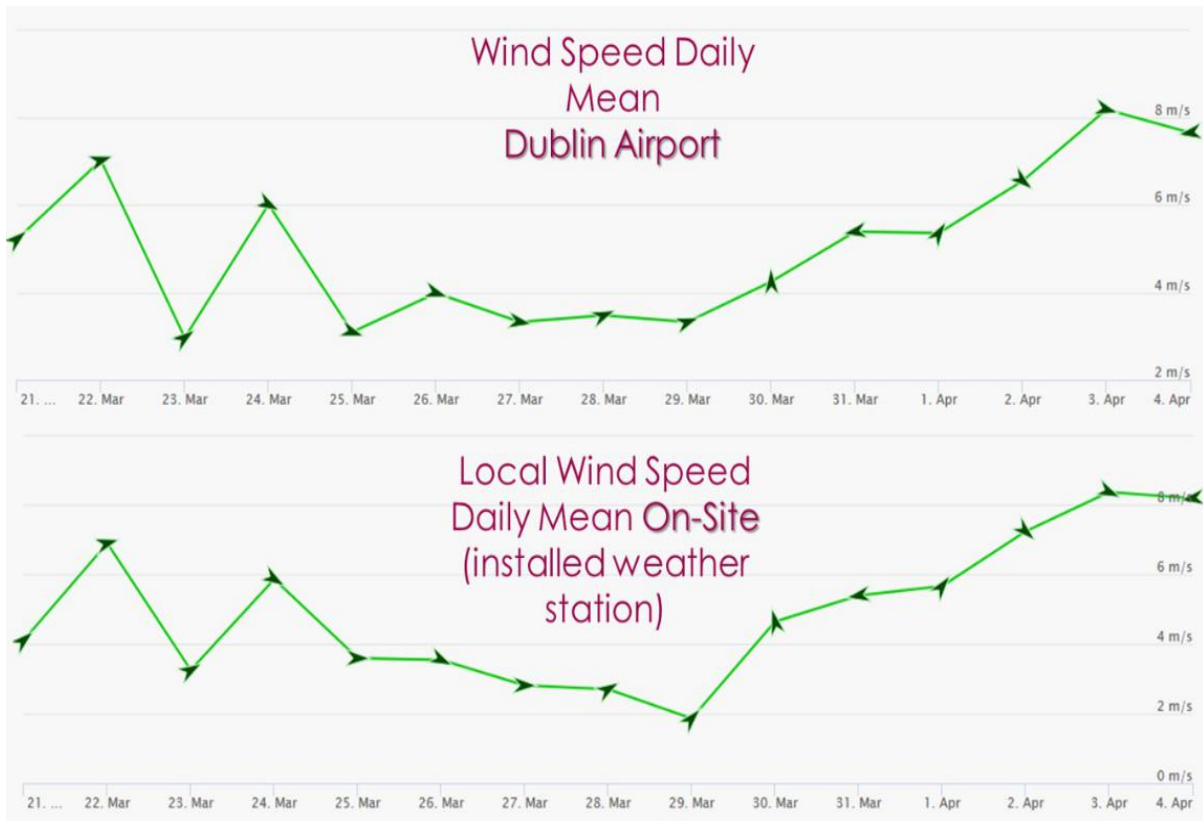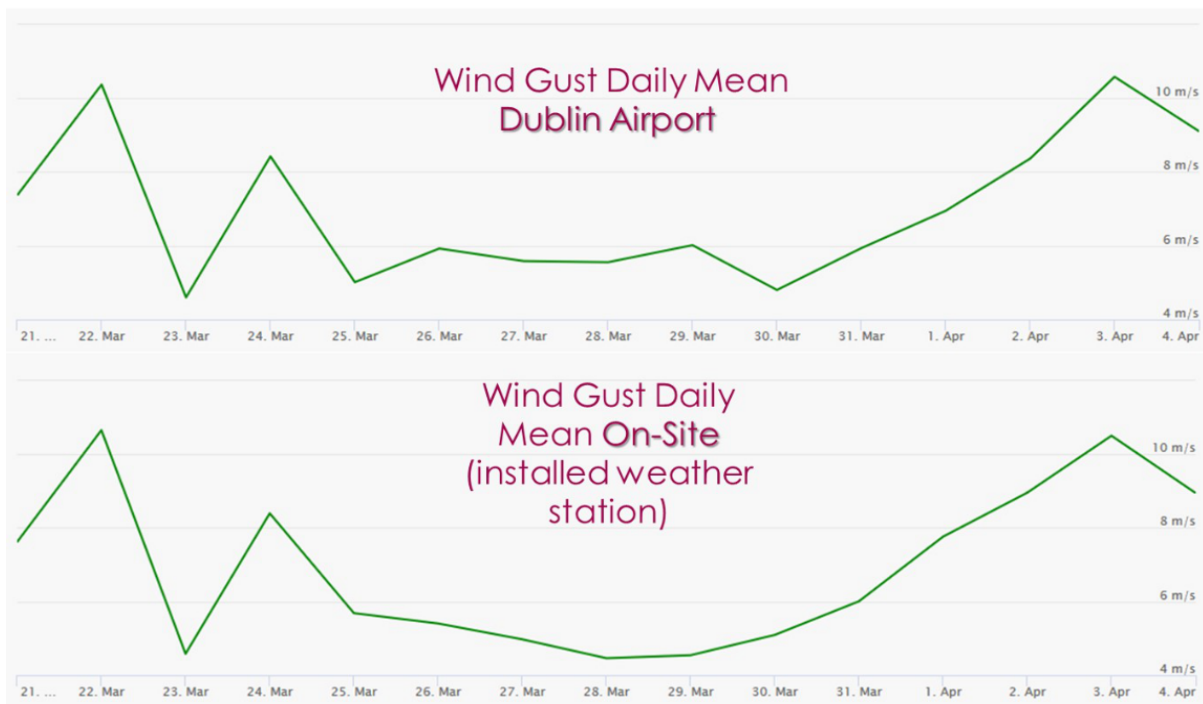
Figure 11.20 - Wind Speed Daily Mean Comparison

Figure 21 - Wind Gust Daily Mean Comparison

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<u>Open Area Functions</u>

The assessment of pedestrian wind comfort in urban areas focuses on activities people are likely to perform in the open space between buildings, which are in turn related to a specific function. For example, the activity sitting a longer period of time is typically associated with the location of a street café or similar. Such combinations of activity and area can be grouped in four main categories:

A	Sitting for a long period of time; laying steady position; pedestrian sitting; *Terrace; street café or restaurant; open field theatre; pool*
B	Pedestrian standing; standing/sitting over a short period of time; short steady positions; *Public park; playing field; shopping street; mall*
C	Pedestrian walking; leisurely walking; normal walking; ramble; stroll *Walkway; building entrance; shopping street; mall*
D	Objective business walking; brisk or fast walking *Car park; avenue; sidewalk; belvedere*

Figure 11.22 - Main Categories for Pedestrian Activities

11.4 Characteristics of the Proposed Development

In summary, the project provides for the demolition (total c.1,398 sq m GFA) of:

- The Grange Select Marketing Suite' (1 storey)
- 'Oaktree Business Centre' (2 storeys)
- 'The Lodge' (2 storeys)

and the construction of a new 'Build to Rent' residential scheme of 287 residential apartment units; residential tenant amenity space of 961.5 sq m; a crèche facility of 658 sq m; and a substation of 96.5 sq m in the form of 6 new blocks (Blocks H, J, M, N, P and Q) ranging in height from 1 - 11 storeys. The residential element of the scheme provides for the following development mix:

- 19 x Studio Units (6.6%)
- 125 x 1 Bedroom Units (43.6%)
- 143 x 2 Bedroom Units (49.8%)

A total of 100 no. car parking spaces, 596 no. cycle spaces and 5 no. motorcycle spaces are also proposed together with all associated site development works.

Figures 23 to 27 shows elevations of Blocks H, J, M, N and P of the development.
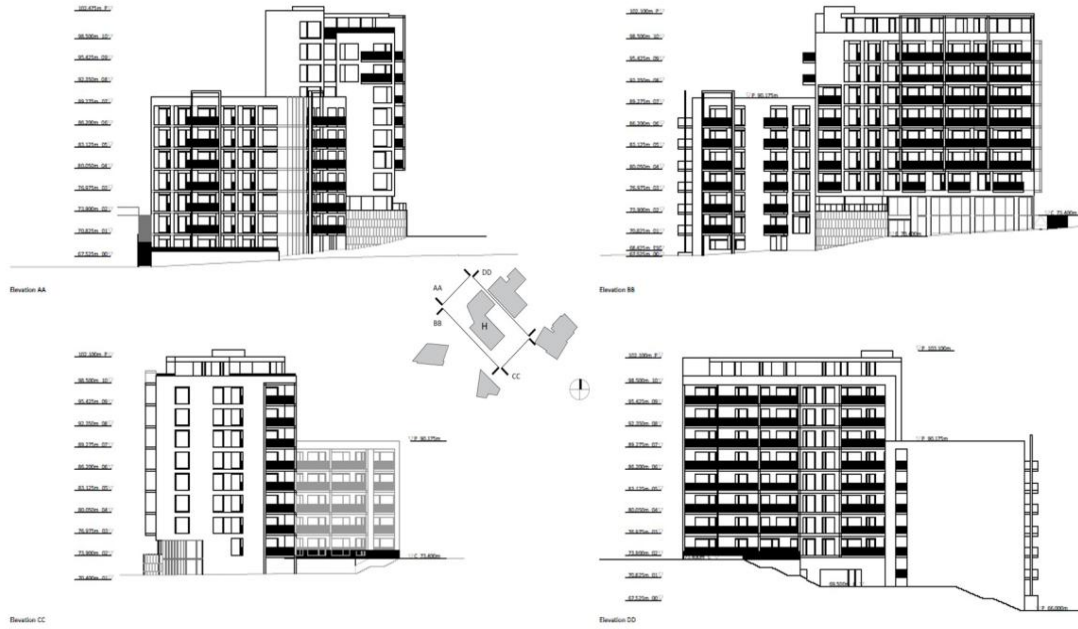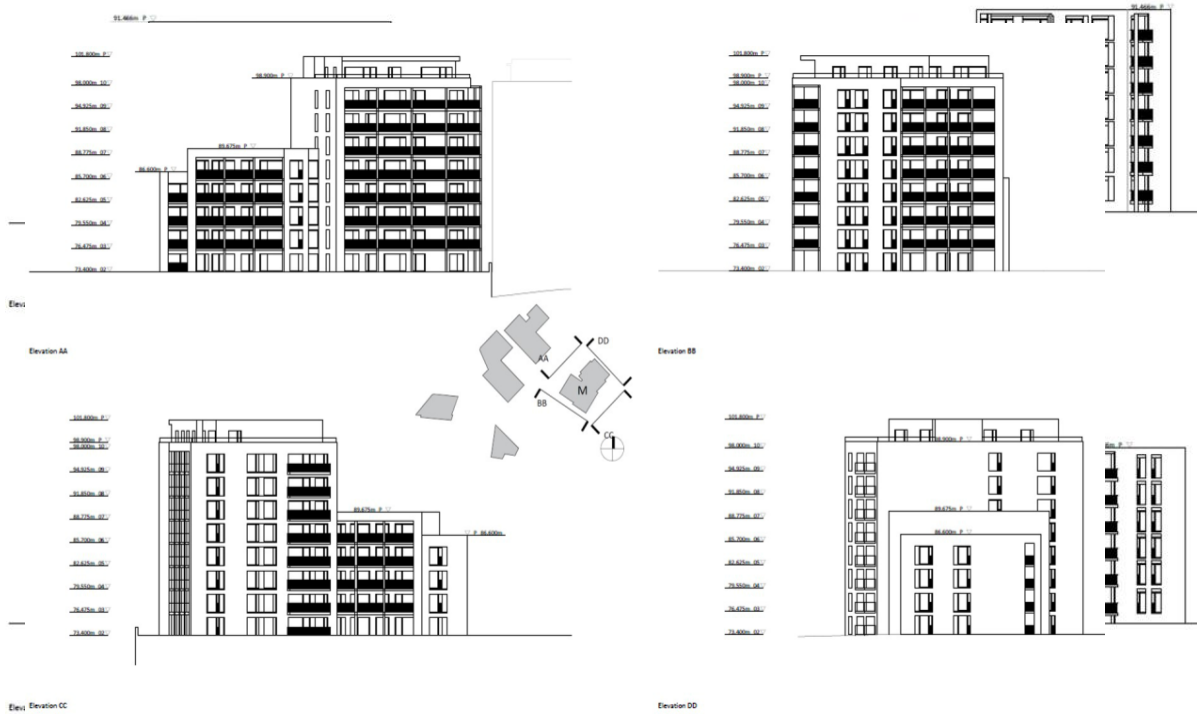

Figure 11.23 - Block H Elevation

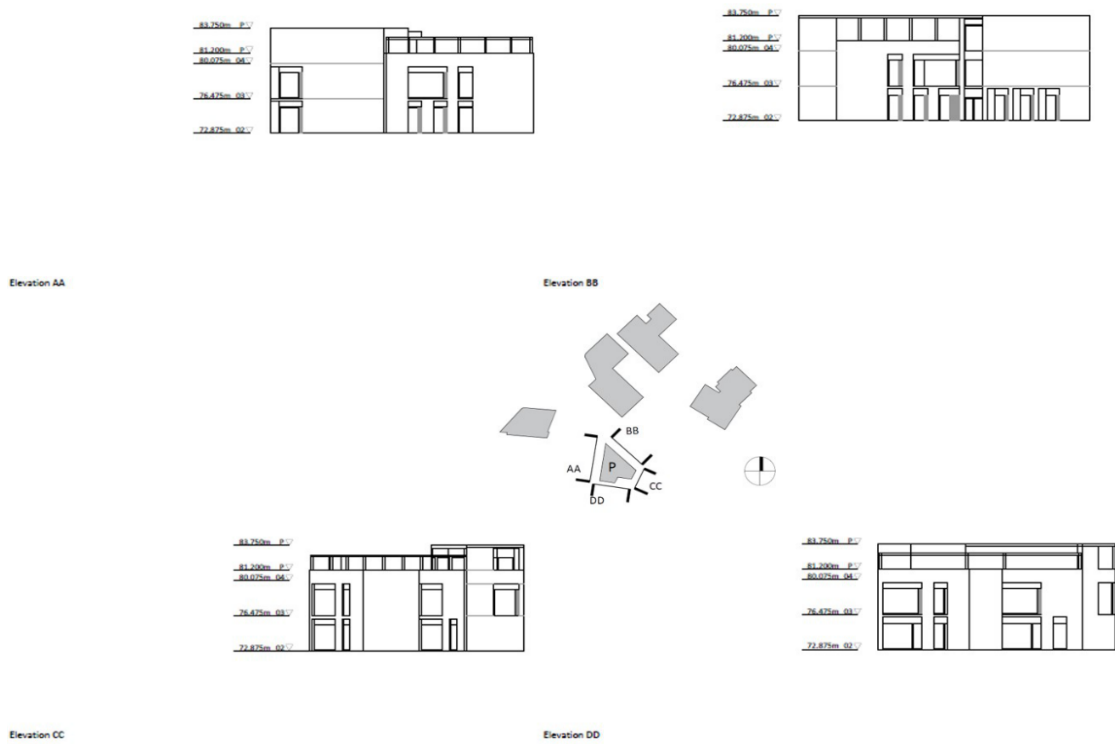*Figure 11.24 - Block M Elevation*

Figure 11.25 - Block J Elevation

Figure 11.26 - Block P Elevation

Figure 11.27 - Block N Elevations

11.5   Potential Impact of the Proposed Development

Construction Phase

The effects on wind microclimate at the Site during the construction phase have been assessed using professional judgement.

As construction of the Proposed Development progresses the wind conditions at the Site would gradually adjust to those of the completed development, and mitigation measures would need to be implemented before completion and operation.

Operational Phase

The construction of the development can potentially calm the existing wind condition in the area by providing further "urban context" to the existing topography, however, some areas can become more critical from a wind acceleration and re-circulation point of view and phenomena such as downwash, funnelling and downdraft can be experienced as well.

The development, in principle, offer more drag to the incoming wind profile as detailed in the session that follow (see "Planetary boundary layer and terrain roughness"). Consequently, the wind at lower level can reduce and modify its flow path directions. However, zones of re-circulations caused by the re-direction of the wind can also been expected, especially in the West South West direction where some funnelling can potentially occur.

The potential impact of the development on the local wind microclimate have been quantify through the modelling of different wind scenarios and where areas of criticism have been detected, appropriate mitigation has been implemented and modelled to verify the reduction of the criticism and the suitability of the specific area to the designated pedestrian activity.

Planetary boundary layer and terrain roughness

Due to aerodynamic drag, there is a wind gradient in the wind flow just a few hundred meters above the Earth's surface – "the surface layer of the planetary boundary layer".

Wind speed increases with increasing height above the ground, starting from zero, due to the no-slip condition. In particular, the wind velocity profile is parabolic. Flow near the surface encounters obstacles that reduce the wind speed and introduce random vertical and horizontal velocity components. This turbulence causes vertical mixing between the air moving horizontally at one level, and the air at those levels immediately above and below it. For this reason, the velocity profile is given by a fluctuating velocity along a mean velocity value. Figure 11.28 shows the wind velocity profile, as described above.
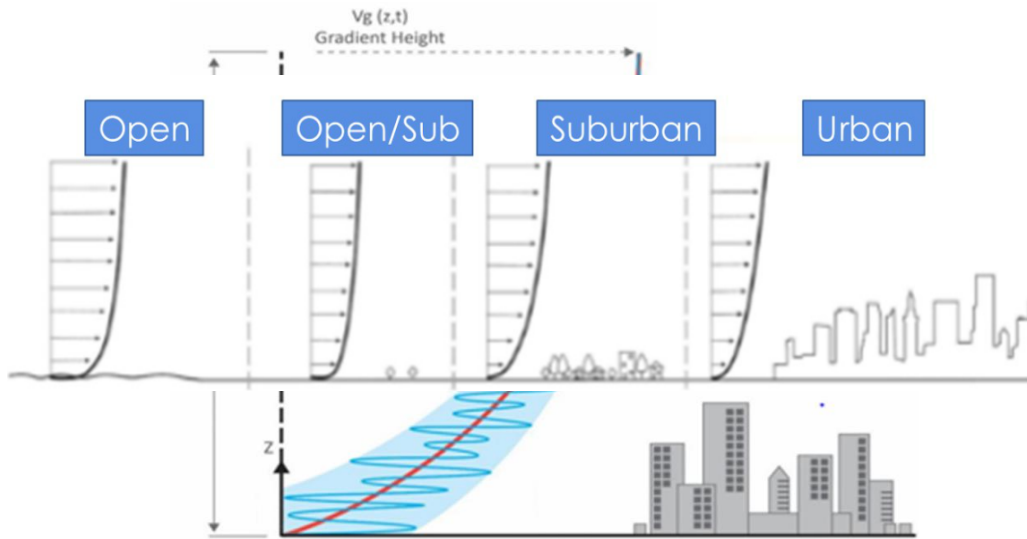

Figure 11.28 - Wind Velocity Profile

Two effects influence the shape of the wind speed profile:

- Contours of the terrain: a rising terrain such as an escarpment will produce a fuller profile at the top of the slope compared with the profile of the wind approaching the slope.

- Aerodynamic 'roughness' of the upstream terrain: natural roughness in the form of woods or man-made roughness in the form of buildings. Obstructions near the ground create turbulence and friction, lowering the average wind speed. The higher the obstructions, the greater the turbulence and the lower the windspeed. As a general rule, windspeed increases with height.
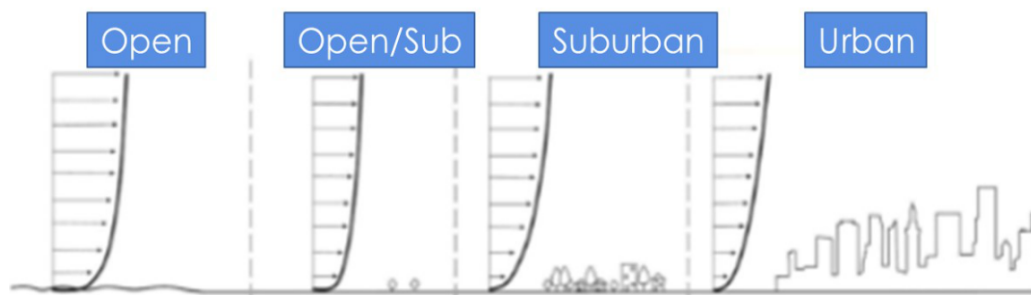

Figure 11.29 - Wind Velocity Profile for different terrains

In order to assess the wind conditions in a particular area, it is important to know (Figure 11.30):

- Weather conditions in the area,

- Location and orientation of the site,

- Buildings distribution in the area,
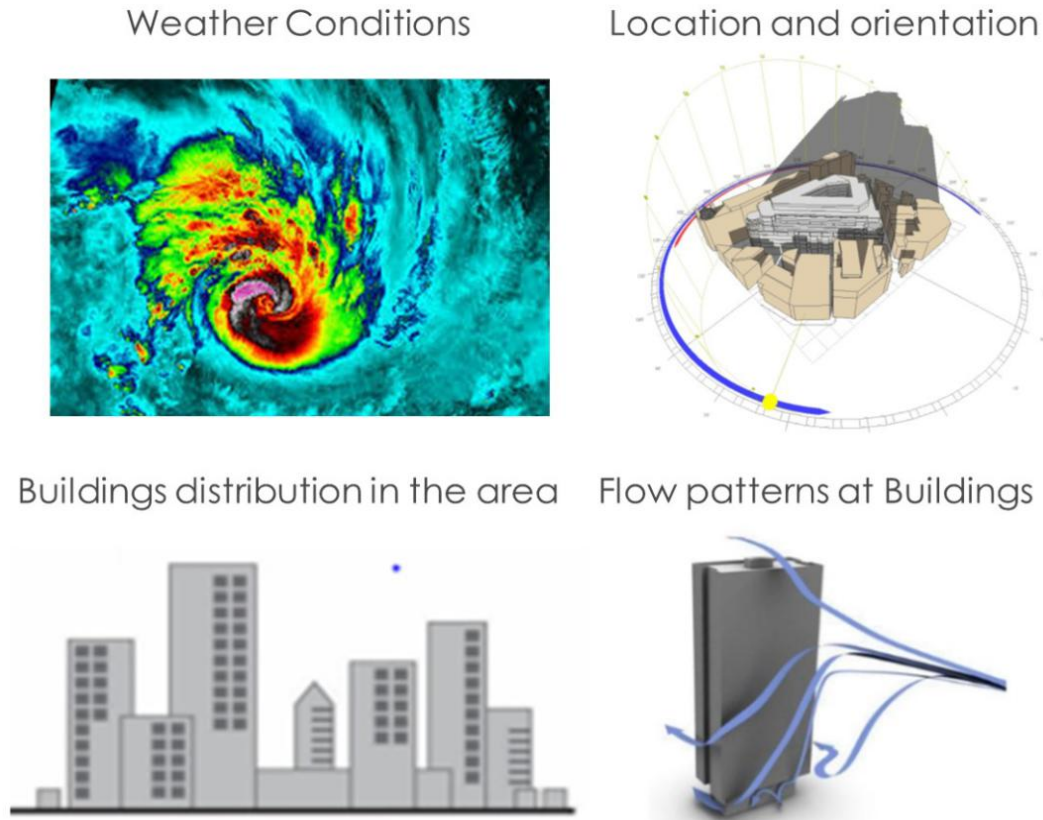
- Flow patterns at the building.

Figure 11.30 - Parameters to know for Wind Conditions Assessment

Moreover, it is important to understand key flow features (Figure 11.31):

- Broad Building Face creates "DOWNWASH",

- Low Building Upwind Increases Wind Effects,

- Gaps Between Buildings Increases Wind Velocity,

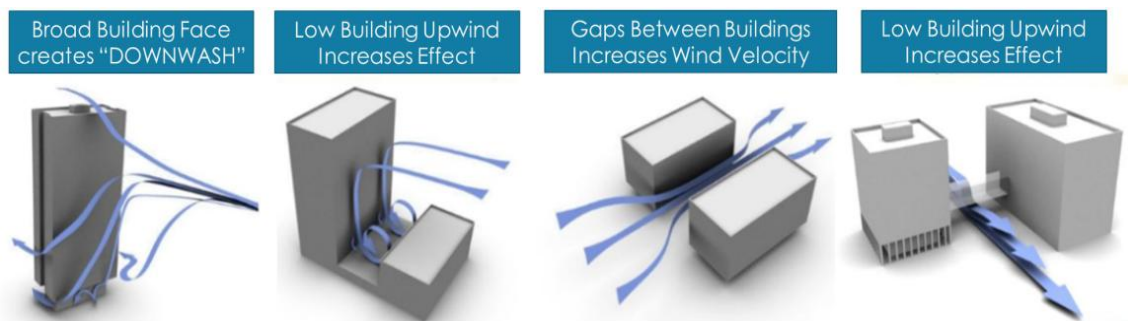- Low Building Upwind Increases Wind Effects.

Figure 11.31 - Parameters to know for Wind Conditions Assessment

11.6   Potential Cumulative Impacts

As stated in the previous section, if the predicted wind conditions exceed the threshold, then conditions are unacceptable for the type of pedestrian activity and mitigation measure should be accounted for.
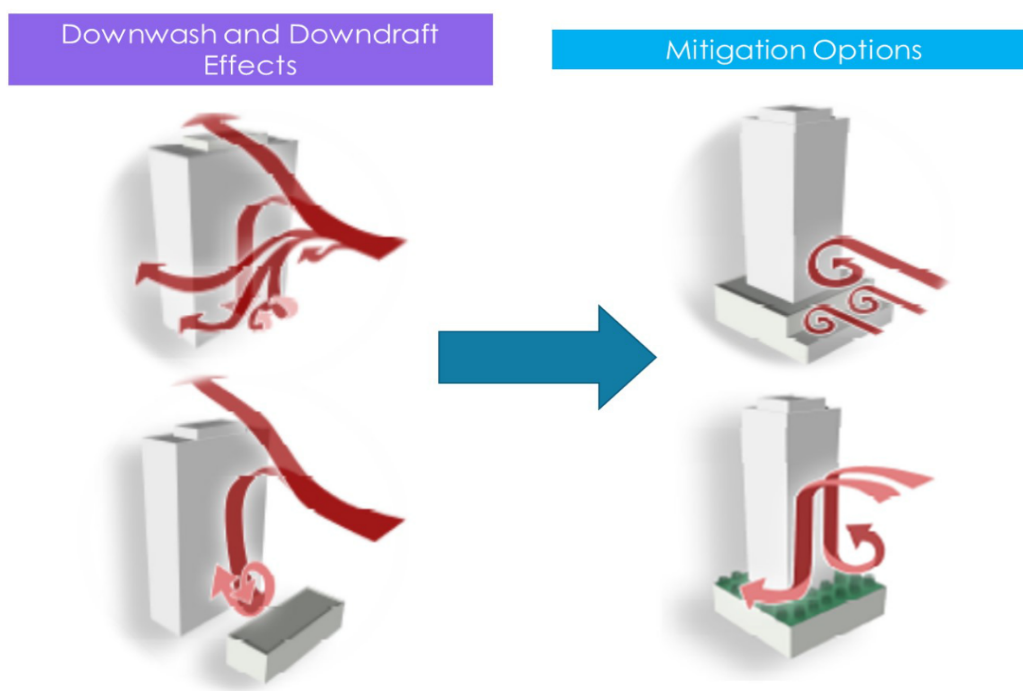
Figure 11.32 - *Mitigation Measures for Downwash and Downdraft Effects*

Mitigation measures include:

- **Landscaping:** the use vegetation to protect buildings from wind,

- **Sculptural screening** (solid or porous): to either deflect the wind or bleed the wind by removing its energy,

- **Canopies and Wind gutters:** horizontal canopies are used to deflect the wind and redirect the wind around the building and above the canopy.

In particular, it is possible to summarise the different flow features and the corresponding mitigation option as follows (Figures 11.32 and 11.33):

- **Downwash Effects:** when wind hits the windward face of a tall building, the building tends to deflect the wind downwards, causing accelerated wind speeds at pedestrian level and around the windward corners of the building. This can occur when Tall and wide building facades face the prevailing winds.

- **Downdraft Effects:** When the leeward face of a low building faces the windward face of a tall building, it causes an increase in the downward flow of wind on the windward face of the tall building. This results in accelerated winds at pedestrian level in the space between the two buildings and around the windward corners of the tall building.

An Example of Typical Mitigation Options:

- To mitigate unwanted wind effects, it is recommended to introduce a base building or podium with a step back, and setting back a tower relative to the base building, the downward wind flow can be deflected, resulting in reduced wind speed at pedestrian level.

- Landscaping the base building roof and tower step back, wind speeds at grade can be further reduced, and wind conditions on the base building roof can improve.
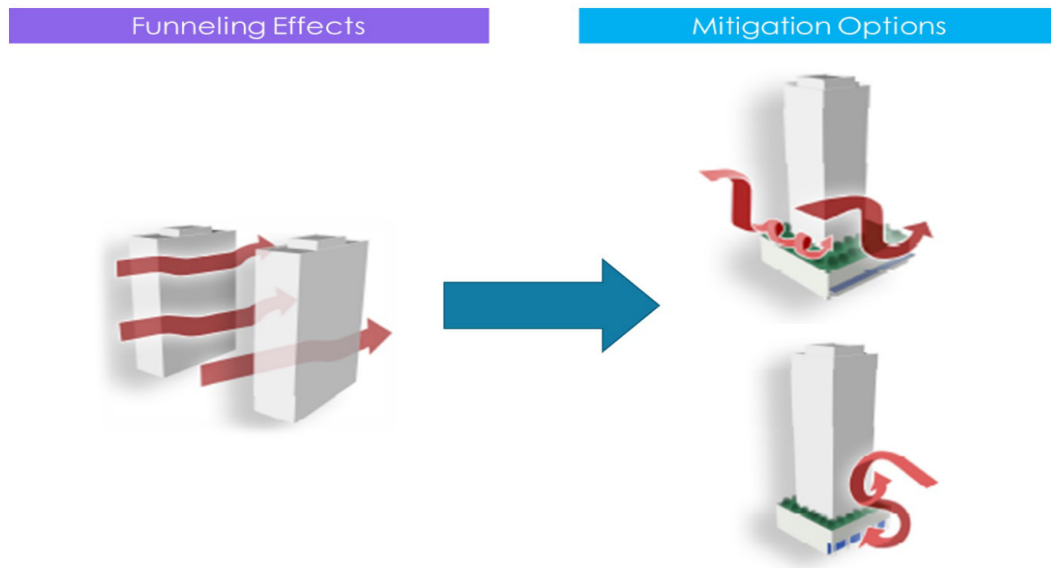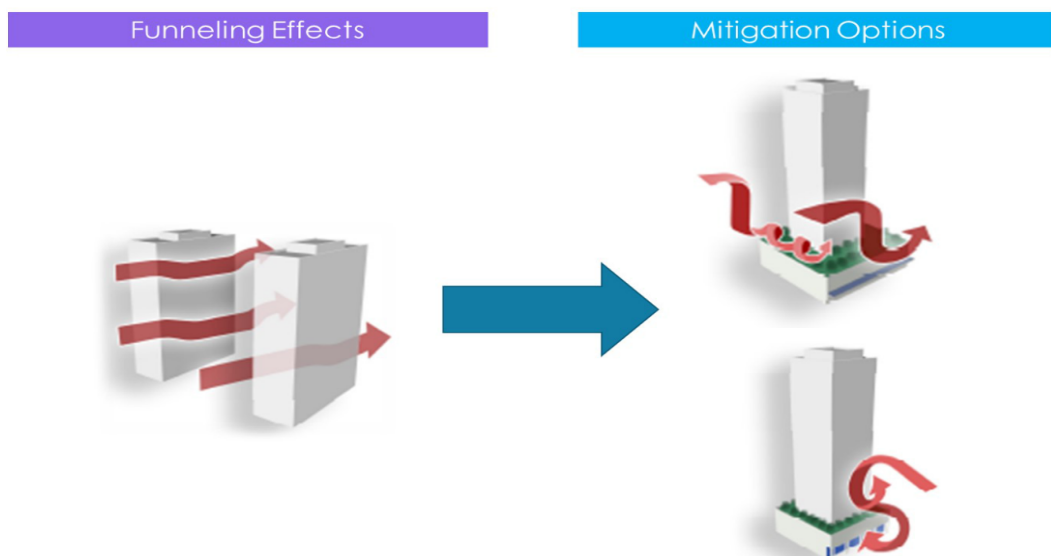
Figure 11.32 - Mitigation Measures for Downwash and Downdraft Effects

- **Funneling Effects:** Wind speed is accelerated when wind is funneled between two buildings. This is referred to as the "wind canyon effect". The intensity of the acceleration is influenced by the building heights, size of the facades, building separation distance and building orientation. Similar effect can be noticed when a bridge is connecting two buildings, the wind passing below the bridge is accelerated, therefore pedestrians can experience high uncomfortable velocities of wind.

An Example of Typical Mitigation Options:

- A horizontal canopy on the windward face of a base building can improve pedestrian level wind conditions. Parapet walls around a canopy can make the canopy more effective.

- Sloped canopies only provide partial deflection of downward wind flow.

- A colonnade on the windward face of the base building provides the pedestrian with a calm area

where to walk while being protected or a breeze walking space outside the colonnade zone.

Figure 11.33 - Mitigation Measures for Funelling Effects

Existing Grange Development

The existing urban context of the Grange Development receives a prevailing wind from West South West and funnelling effect can be noticed. As discussed in the previous session and demonstrated with this assessment through CFD modelling, any adverse wind impact has been considered and mitigated to make it suitable to its intended use.

The existing site is considered as "urban context" and its cumulative assessment has accounted for the modelling and simulation of all the topography and existing developments in the surrounding as the presence of adjacent buildings dictates how the wind will approach the proposed development.

Future Phase 2 Development

Evidently, the applicant does not control the entirety of remaining lands to provide consolidated development to the N11 frontage. This current application therefore relates to a Phase 1 development on lands that can deliver critically required residential units. OMP Architects have developed a phased Masterplan approach to provide an indicative future context for consideration by An Bord Pleanala, which is enclosed herewith. There has been a carefully considered design approach to development to ensure that the subject application can be delivered without compromising existing amenity or the future potential for development addressing the N11.

The Masterplan successfully integrates this new phase of development with the existing built fabric of The Grange. The approach has been to set the blocks around a central garden, which complements the existing scheme and delivers significant enhancements to the public realm.

Overall, it is estimated that there is potential for a further c. 250 units as part of a Phase 2 development.

11.7   Do Nothing Scenario

In case no mitigation measures are implemented in areas where wind shows behaviour as detailed above, the criteria of comfort and distress may be not satisfied with the consequence of creating unpleasant conditions within and in the surroundings of the development and with the risk of adverse human impact.

The mitigation of wind is fundamental to design areas that could be effectively used for their intended scope.

11.8   Mitigation Measures

Construction Phase

The effects on wind microclimate at the Site during the construction phase have been assessed using professional judgement.

As construction of the Proposed Development progresses the wind conditions at the Site would gradually adjust to those of the completed development, and mitigation measures would need to be implemented before completion and operation.

Operational Phase

The mitigation measures utilized used for this development project is landscaping using trees, which creating a reduced vorticity, makes it possible to reduce the velocities, thus the wind impact on the building. Small particles randomly distributed within an area are normally used in numerical modelling to model trees, as shown in Figure 11.34. These introduce a pressure drop in the model and

therefore causes the wind to reduce its speed when passing through the trees, as expected in reality. The CFD plot shown in Figure 11.35 demonstrate this effect.

Figure 11.36 shows the implementation of mitigation measures on the ground floor. Here tree planting is implemented.
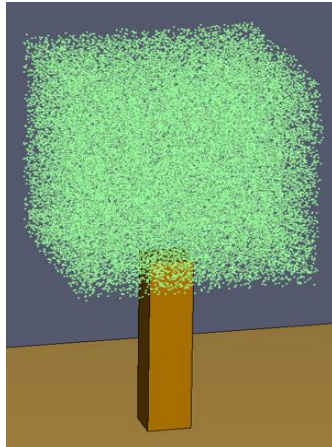

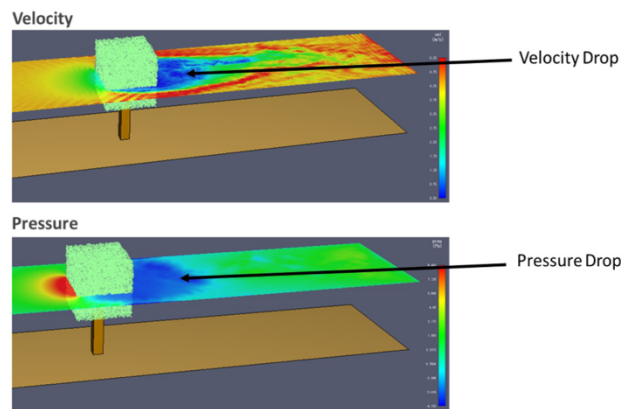*Figure 11.34 - CFD Modelling of a Tree*

Figure 11.35 - Generic Result of Wind Impacting a Tree

Figure 11.36 - Mitigation Measures modelled at ground floor of Grange Development

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11.9 Predicted Impacts of the Proposed Development

CFD Model Details of the Proposed Development

This section describes all features included in the geometrical and physical representation of the CFD model. Any object which may have significant impact on wind movement and circulation are represented within the model.

To be accurate, the structural layout of the building being modelled should include only the obstacles, blockages, openings and closures which can impact the wind around the building.

It is important to remember that a CFD simulation approximates reality, so providing more details of the geometry within the model will not necessarily increase the understanding of the bulk flows in the real environment.

Modelled Geometry

The Grange Development Model consists of building blocks H, J, M, N and P as shown in Figure 11.37.

The modelled layout and dimensions of the surrounding environment are outlined in the table below (Table 3).

In order to represent reality and consider the actual wind impacting on the site, the modelled area for the wind modelling study comprises a wider urban area of 2km² around the Grange Development, as represented in Figure 11.38.

Grange Development and its surrounding environment are utilized, highlighting the presence of surrounding buildings. The surrounding buildings have been modelled also. This is highly beneficial at pedestrian level of Grange development, as it shields it from some prevailing wind directions.

	MODELLED CFD ENVIRONMENT DIMENSIONS		
	Width	Length	Height
CFD Mesh Domain	900m approx	900m approx	120m approx

Table 11.3 - Modelled Environment Dimensions

Figure 11.37 - Grange Development Model Showing Block H, J, M, N and P: Top View

Figure 11.38 - Extents of Modelled Area around Grange Development

Boundary Conditions

A rectangular computational domain was used for the analysis. The wind directions were altered without changing the computational mesh. For each simulation scenario, an initial wind velocity was set according to the statistical weather data collected in order to consider the worst case scenario (see session 11.3). Building surfaces within the model are specified as 'no slip' boundary conditions. This condition ensures that flow moving parallel to a surface is brought to rest at the point where it meets the surface. Air flow inlet boundaries possess the 'Inlet' wind profile velocity patch boundary condition with its appropriate inflow turbulence intensity and dissipation rates. Air exits the domain at the 'pressure outlet' boundary condition.

The wind velocity data provided by the historical data collection and by the local data measuring are used in the formula below for the logarithmic wind profile to specify the wind velocity profile (wind velocity at different heights) to be applied within the CFD model:

$$v_2 = v_1 \cdot \frac{ln\frac{h_2}{z_0}}{ln\frac{h_1}{z_0}}$$

- v_1 = wind speed measured at the reference height h_1.
- h_1 = reference height to measure v_1.
- h_2 = height of the wind speed v_2 calculated for the wind profile.
- z_0 = 0.4 [m] roughness length selected (see table in Figure 11.39 below).

Roughness Classes and Lengths

Roughness class	Roughness length z_0	Land cover types
0	0.0002 m	Water surfaces: seas and Lakes
0.5	0.0024 m	Open terrain with smooth surface, e.g. concrete, airport runways, mown grass etc.
1	0.03 m	Open agricultural land without fences and hedges; maybe some far apart buildings and very gentle hills
1.5	0.055 m	Agricultural land with a few buildings and 8 m high hedges seperated by more than 1 km
2	0.1 m	Agricultural land with a few buildings and 8 m high hedges seperated by approx. 500 m
2.5	0.2 m	Agricultural land with many trees, bushes and plants, or 8 m high hedges seperated by approx. 250 m
3	0.4 m	Towns, villages, agricultural land with many or high hedges, forests and very rough and uneven terrain
3.5	0.6 m	Large towns with high buildings
4	1.6 m	Large cities with high buildings and skyscrapers

Figure 11.39 - Roughness length and class to be used for the logarithmic wind profile

The wind profile used in the model has been calculated using the formula above and is represented in Figure 11.40.
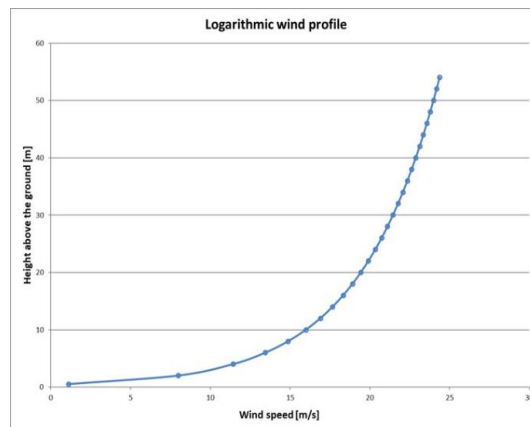
Figure 11.40 - Wind profile used in the model

Computational Mesh

The level of accuracy of the CFD results are determined by the level of refinement of the computational mesh. A mesh independent analysis is carried out prior to detailed simulation for final results. Details of parameters utilized for air and the computational mesh are presented in Table 11.4, while an example of the utilized computational mesh grid is as shown in Figure 11.41 to 11.43.

The grid follows the principles of the 'Finite Volume Method', which implies that the solution of the model equations is calculated at discrete points (nodes) on a three-dimensional grid, which includes all the flow volume of interest. The mathematical solution for the flow is calculated at the centre of each of these cells and then an interpolation function is used by the software to provide the results in the entire domain.

AIR AND COMPUTATIONAL MESH PARAMETERS

Air Density r	$1:2 kg{=}m^3$
Ambient Temperature (T)	288K(approx:15C)
Min mesh cell size	0.2 m At Development Building 0.5m In The Refined Volume Surroundings 1.5m At Other Environment Buildings 2m Elsewhere
Min cell size ratio	1:1:1 (dx:dy:dz)
Total mesh size	Approx. cells number = 26 million

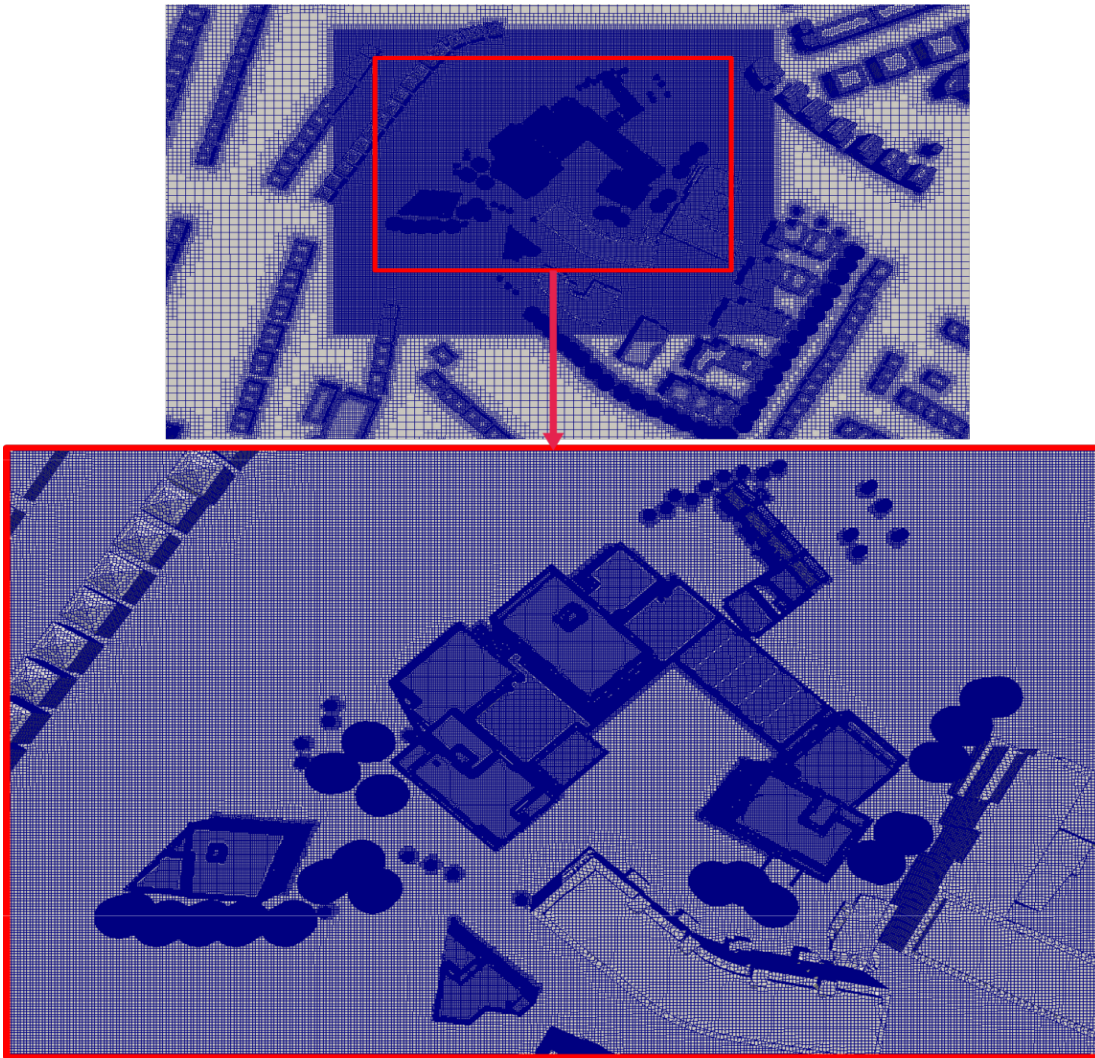*Table 11.4 - Air and Computational Mesh Parameters*

Figure 11.41 - Grange Development Computational Mesh Utilized: Top View
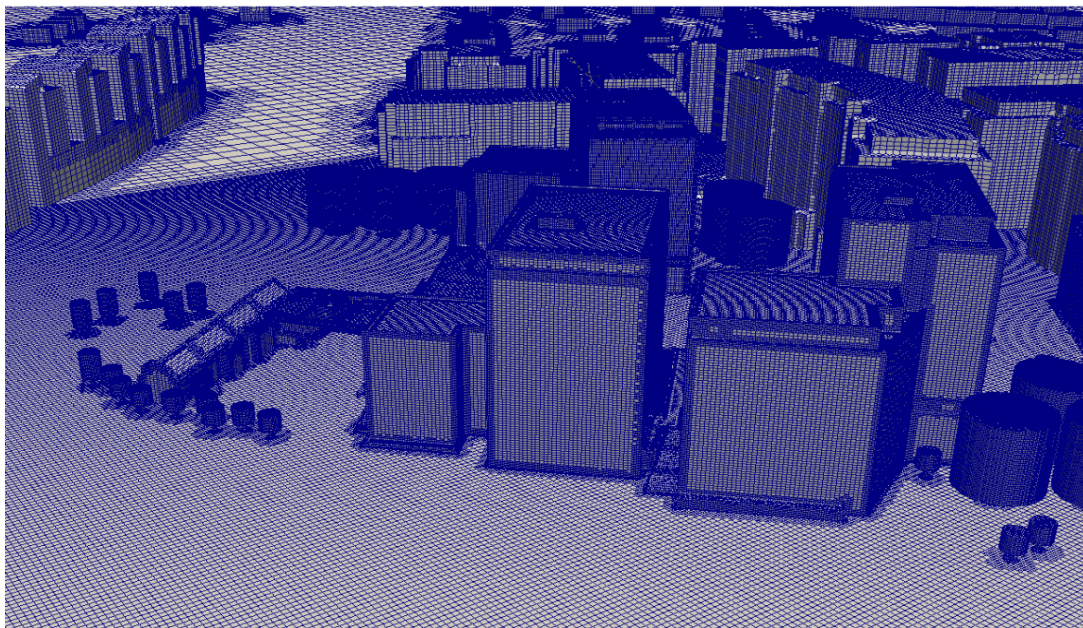

Figure 11.42: Grange Development Computational Mesh Utilized: North West Isometric View
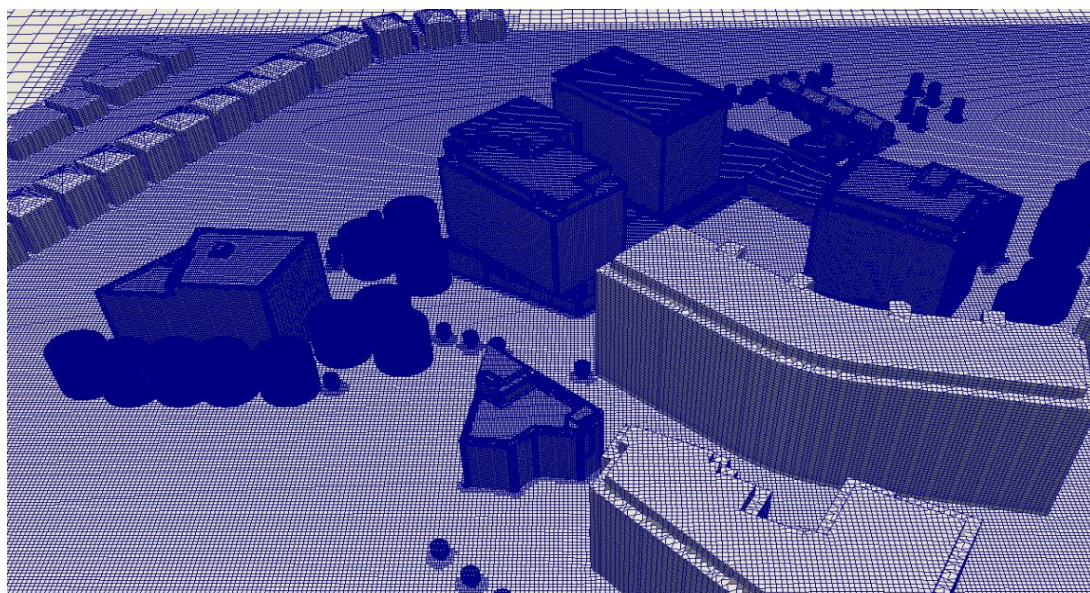
Figure 11. 43 - Grange Development Computational Mesh Utilized: South East Isometric View

Construction Phase

The possible effects on wind micro-climate at the site during the construction phase of Grange Development has not been directly assessed but was evaluated based on professional judgment. The wind data obtained from the on-site wind measurements have been used to carry out this analysis based on the fact that the dominant wind direction is from South-West.

As the finalization of the development proceeds, the wind setting at the site would progressively conform to those of the completed development. It is possible that in the final stages of construction, implementation of the mitigation measures would be needed in areas that are expected to be windier than others should in case some areas of the site are expected to be functional before the construction is finalized.

Due to the fact that windier conditions are acceptable within a construction area (not accessible to the public), and the proposed development would not be the reason for critical wind conditions on-Site (and are slightly calmer when the development is in situ), the impacts evaluated on-Site are considered to be insignificant. Thus, the predicted impacts during construction phase are identified as negligible.

In summary, as construction of the Grange Development progresses, the wind conditions at the site would gradually adjust to those of the completed development, and mitigation measures would need to be implemented before completion and operation. During the construction phase the predicted impacts are classified as negligible.

Operational Phase

This section shows CFD results of wind assessment carried out considering the "Operational Phase". In this case the assessment has considered the impact of wind on the existing area including the proposed Grange Development. For this scenario, the Grange Development has been simulated inclusive of its mitigation measures impact in the locations identified as critical. Wind simulations have been carried out on all the various directions for which the development could show critical areas in terms of pedestrian comfort and safety. For this, the Lawson and Distress Maps have been presented to identify the suitability of each areas to its prescribed level of usage and activity. The results present parameters outlined within the acceptance criteria previously described.

A summary of CFD model input data used in this project is given in the table shown in Figure 11.44.

Parameter	GRANGE DEVELOPMENT CFD MODEL DATA
Environment Conditions	
Ambient pressure	101325 Pa
Wind profile	Logarithmic atmospheric profile
Ambient temperature	15°C
Analysis type	Steady state
Computational Details	
Total cells used	> 26,000,000
Development Mesh size	0.2 m
Turbulence treatment	K-epsilon turbulence model
Convergence Criteria	$< 10^{-6}$
Boundary Conditions	
CFD Domain Inlet	Statistical Wind Profile
CFD Domain Outlet	Pressure Outlet condition (zero pressure gradient)
All Buildings	Zero velocity gradient (No-slip condition)

Figure 11.44 - Summary of CFD Model Input Data

It is also of interest at this point to underline once more the objectives of simulations performed. In particular:

- Pedestrian Wind Comfort and Safety Studies are conducted to predict, assess and, where necessary, mitigate the impact of the development on pedestrian level wind conditions.

- To assess comfortable and safe pedestrian level wind conditions that are appropriate for the intended use of pedestrian areas. Pedestrian areas include sidewalks and street frontages, pathways, building entrance areas, open spaces, amenity areas and outdoor sitting areas.

Results of the simulations carried out are detailed in the following sections. The results present parameters as outlined in the acceptance criteria section described previously for Grange development. Results of wind flow speeds are collected throughout the simulation and analysed based on the Lawson Discomfort Criteria.

Figure 45 shows an example of wind speed results collected at 1.5m height above ground floor.
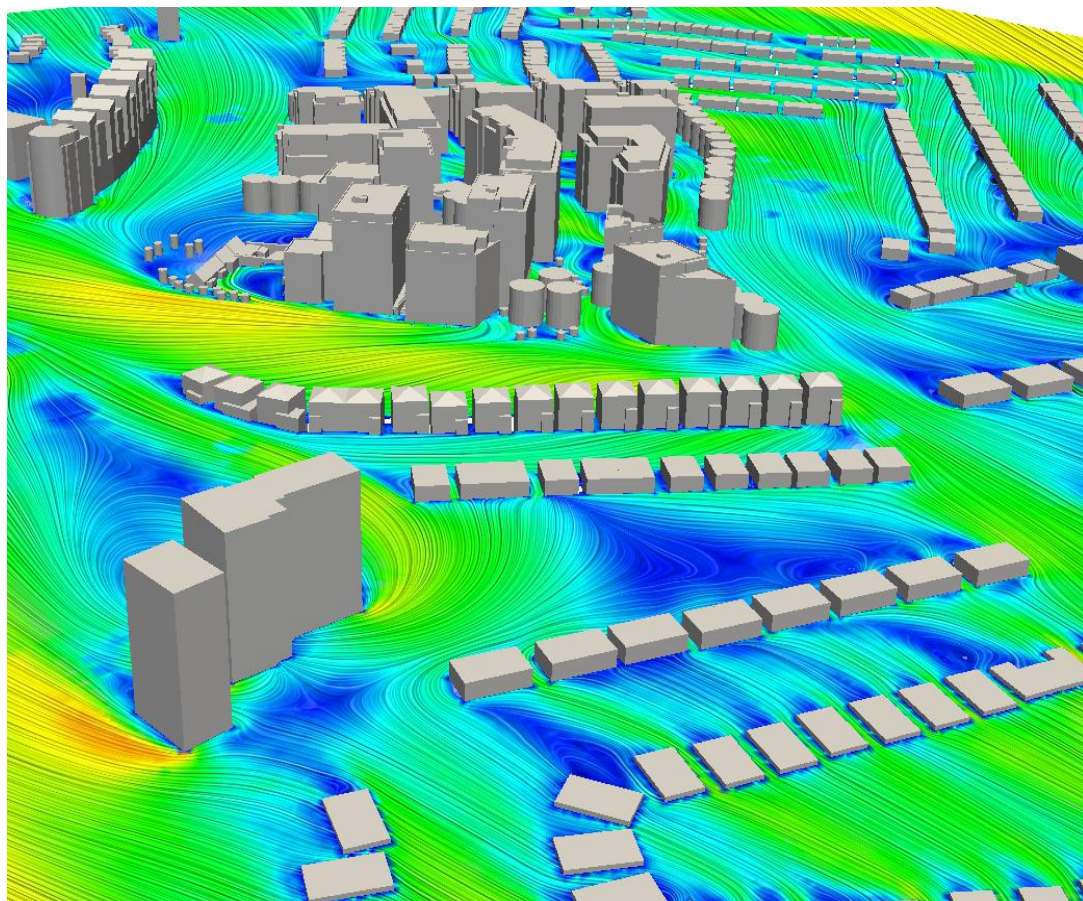
Figure 11.45 - Example of Wind Flow Results Collected At 1.5m Height Above Ground Floor

Therefore, this section aims to predict the wind patterns around the proposed Grange Development under mean and peak wind conditions typically occurring in the area, in order to assess the impact of the proposed mitigation measures. A view of the Grange model is presented again in Figure 11.46.
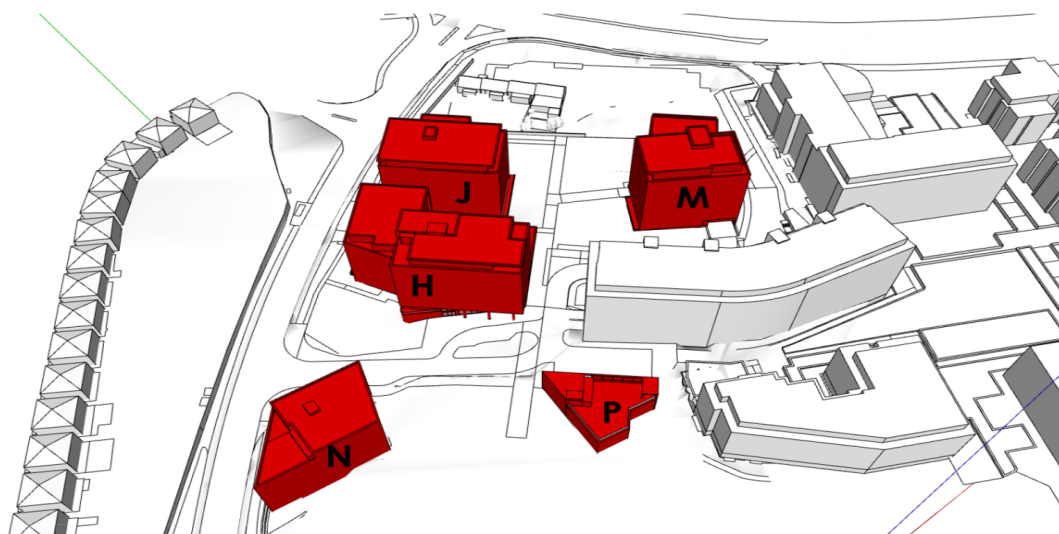

Figure 11.46 - Grange Development Model: Block H, J, M, N and P: North West Isometric View

The results present the parameters outlined within the acceptance criteria section described previously. The images within the following subsections show the flow velocity results obtained and maps to assess the pedestrian comfort in the area.

From the simulation results the following observations are pointed out:

- The proposed Grange Development will produce a quality environment that, once the landscaping is implemented, is attractive and comfortable for pedestrians both on the terraces (Block P) and at ground floor. The landscaping plans have been adapted and designed to provide further protection from the wind. Different sizes of trees have been specified, as well as all around the buildings to help disperse the approaching wind and protect the roof terrace (Block P), footpaths and cycling paths.

- At Ground Floor, the mitigation implemented achieves good shielding on all critical roads. High velocity areas are limited to the part of the roads where the cars pass. Footpaths and cycling paths are clearly successfully shielded by vegetation.

- The pedestrian comfort assessment, performed at Ground Floor level accordingly to the Lawson criteria, identified the areas that are suitable for the different pedestrian activities in order to guarantee pedestrian comfort. Moreover, in terms of distress, some critical conditions were found for "Frail persons or cyclists" in the surrounding of the development only in the west direction. However, the frequency at which these conditions happen are below the critical threshold for distress.

Flow Velocity Results - Ground Floor Level

Results of wind speeds and their circulations at pedestrian level of 1.5m above the development ground are presented in Figures 11.47 to 11.51 for Cardinal and Ordinal Directions respectively in order to assess wind flows at ground floor level of Grange Development. Wind flow speeds are shown to be always below critical levels.

Figure 11.52 to 11.56 equally presents isometric views of wind flow speeds and circulations through the development for the dominant wind gust directions in Dublin and shows how that flow speeds at ground level are always below critical values.

Therefore, it can be concluded that the mitigations implemented at ground floor level achieves good shielding around the development to enable comfortable wind speeds that do not attain critical levels. Footpaths and cycling paths are clearly successfully shielded.
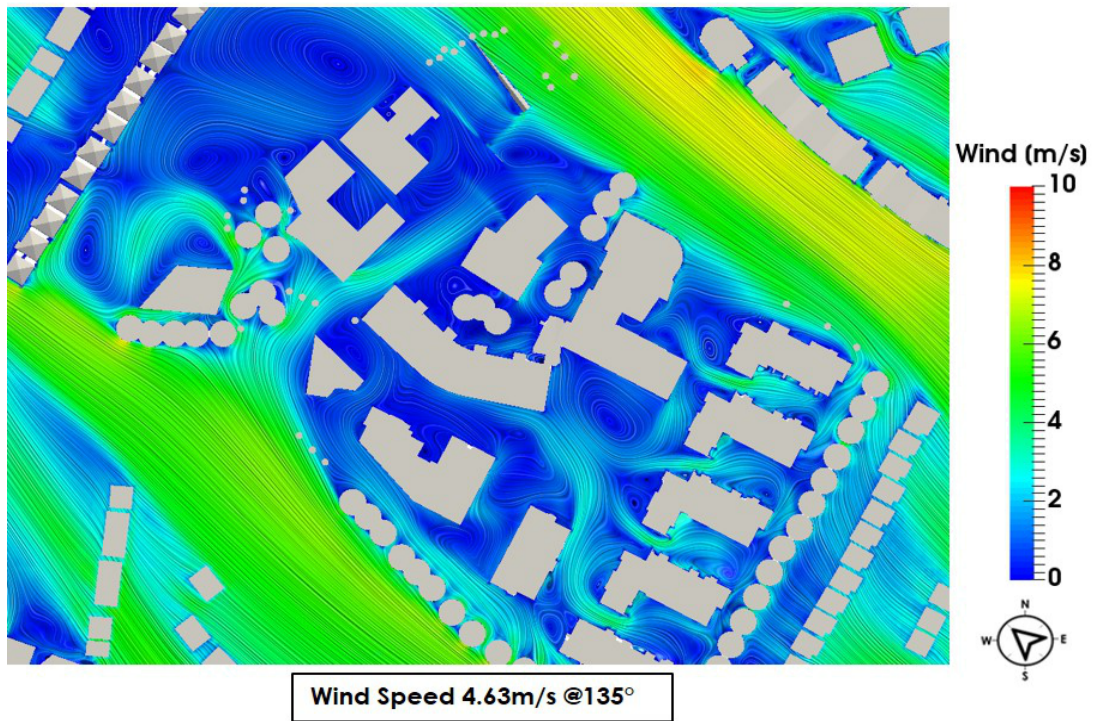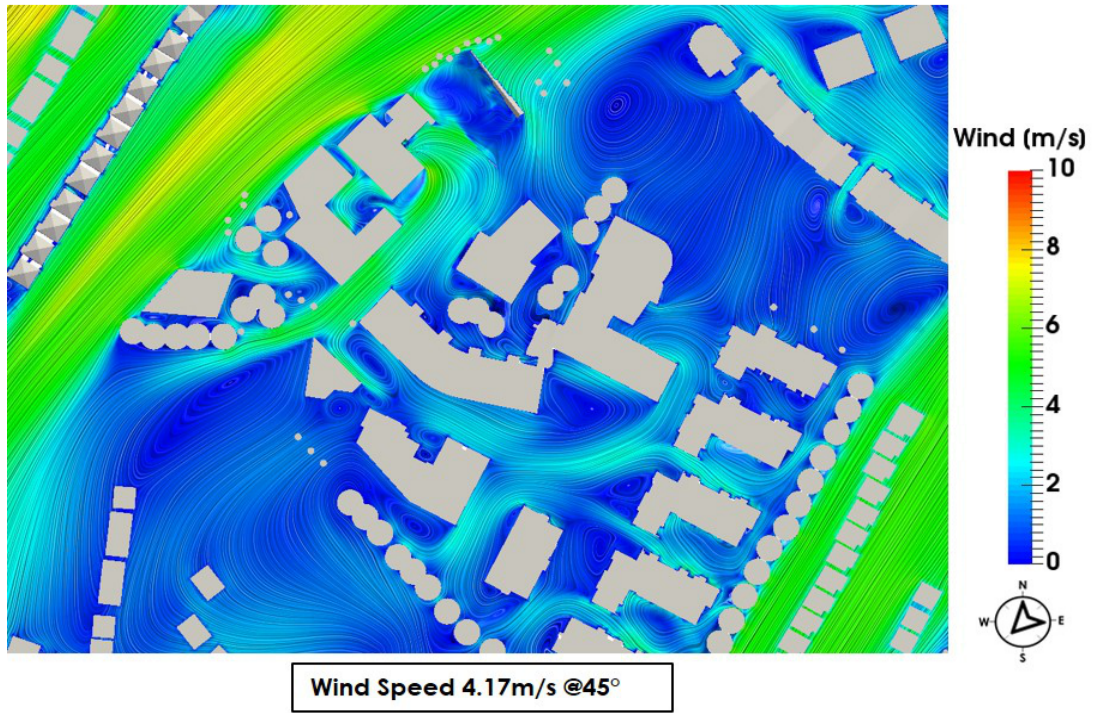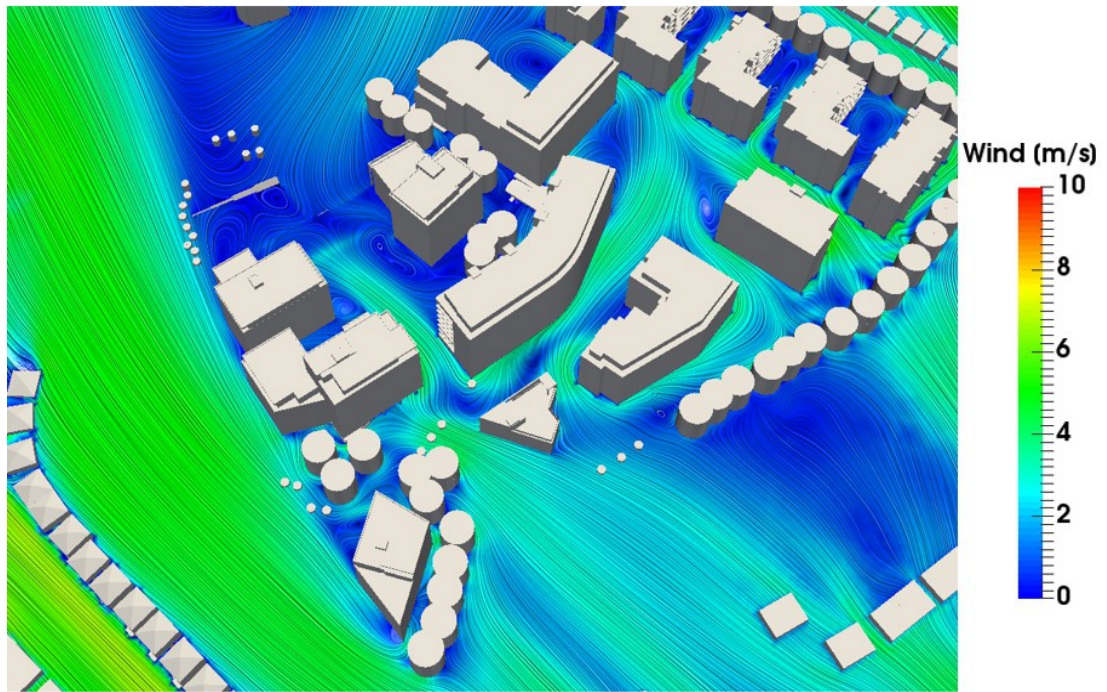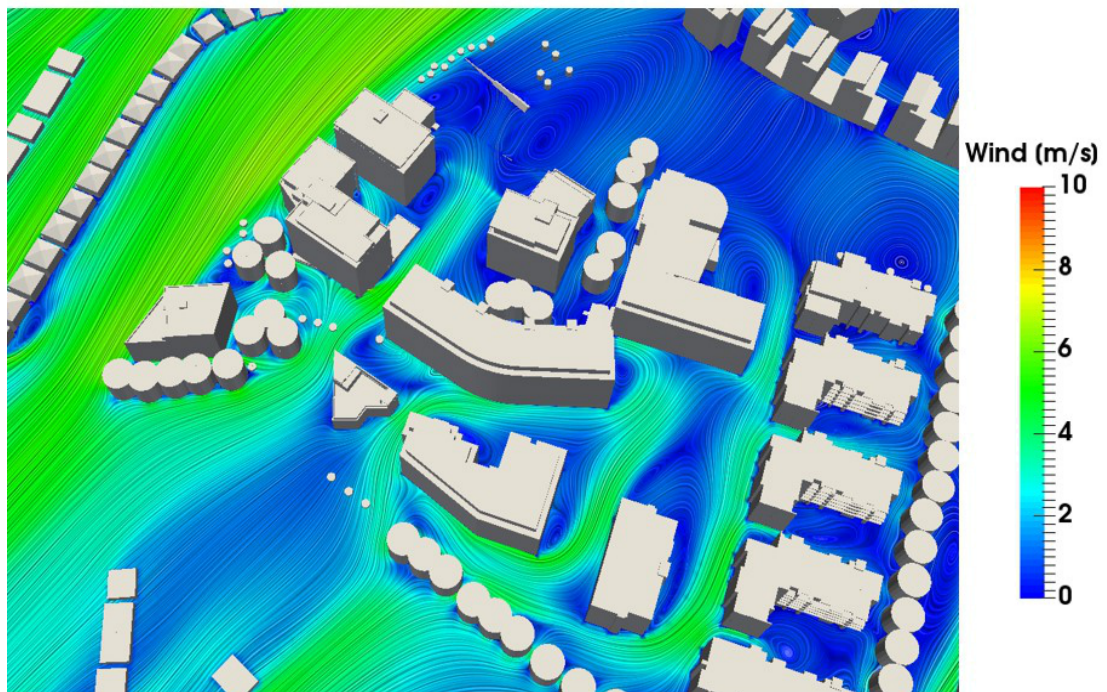
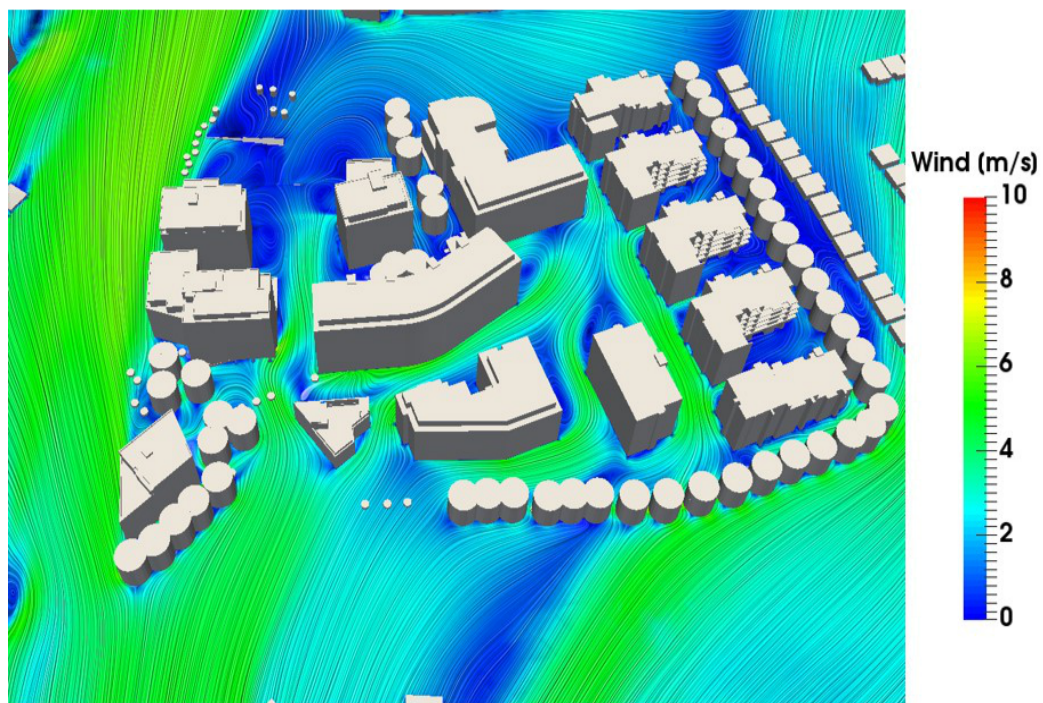*Figure 11.47 - Wind Speed Results at 1.5m Above Ground-Top View: 45°, 135°*

Wind Speed 5.60m/s @225° SW ISO View
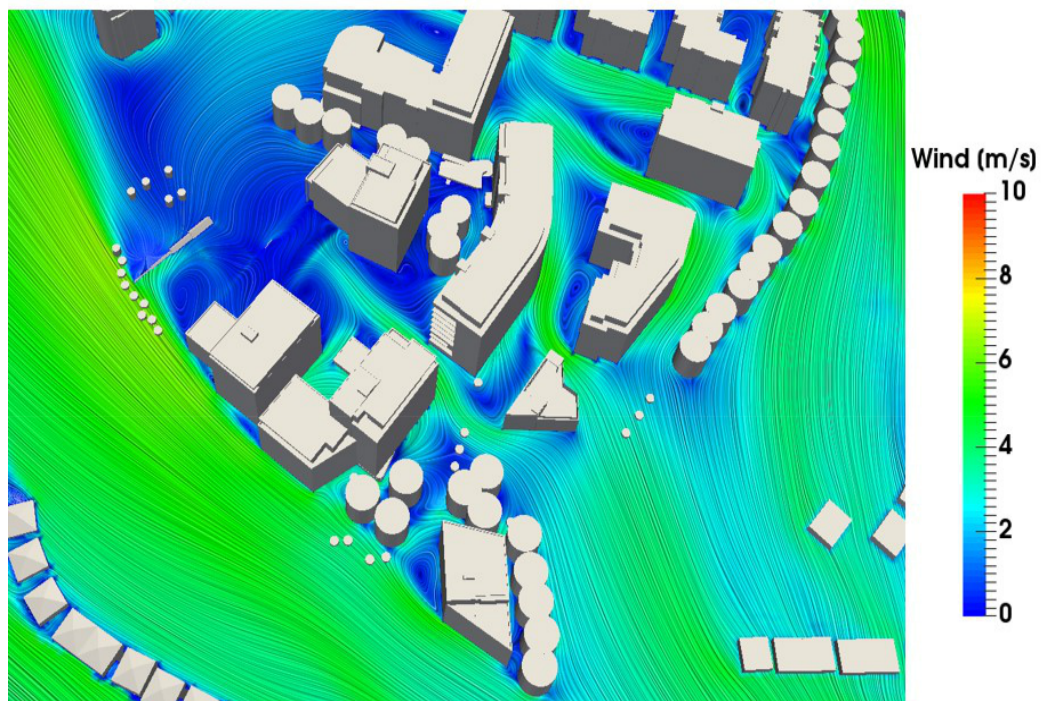

Wind Speed 5.85m/s @236.25° S ISO View

Figure 11.48 - Wind Speed Results at 1.5m Above Development Ground-Top View: 225°, 236.25°

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Wind Speed 6.03m/s @247.5° SW ISO View

Wind Speed 6.05m/s @258.75° W ISO View

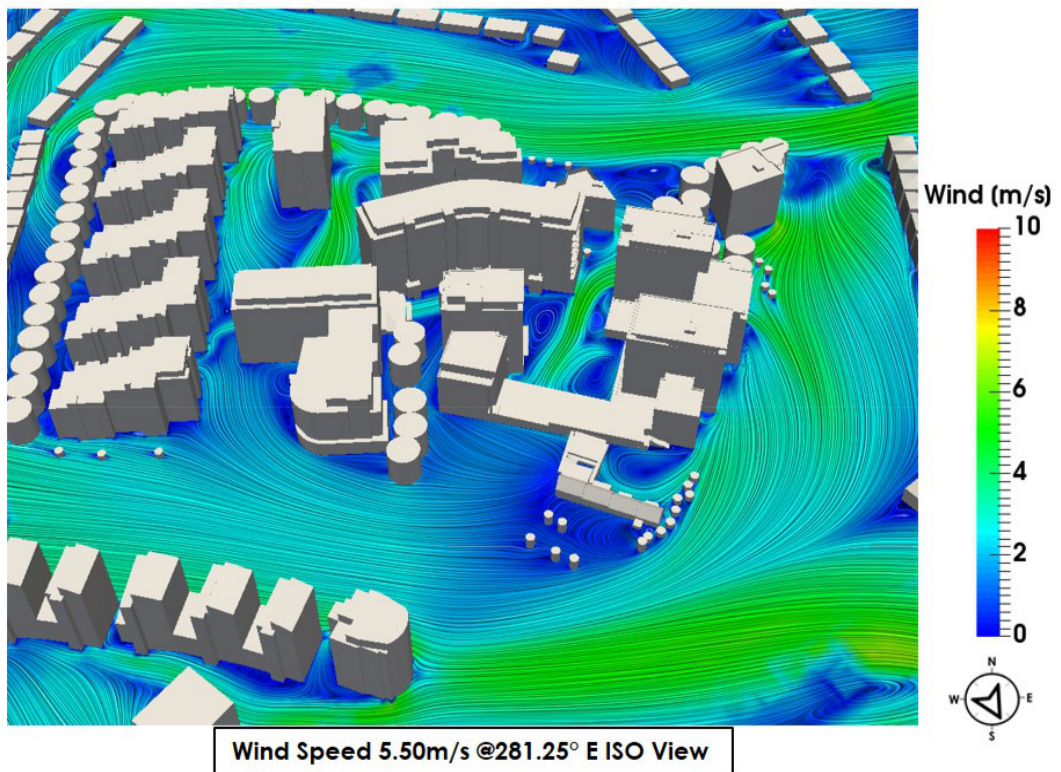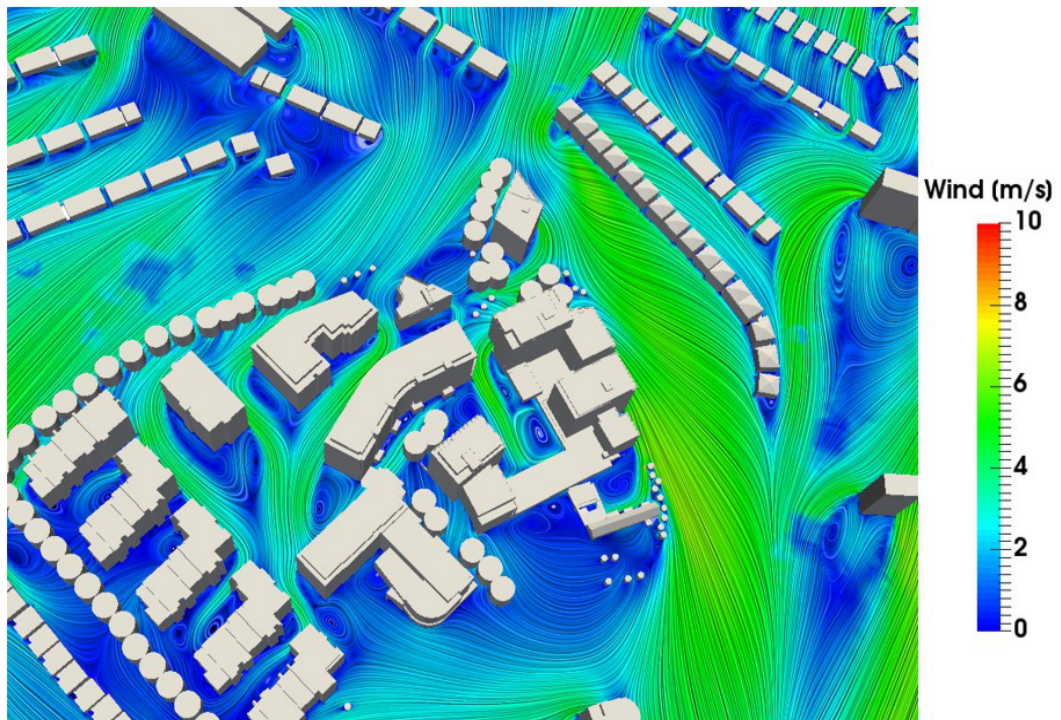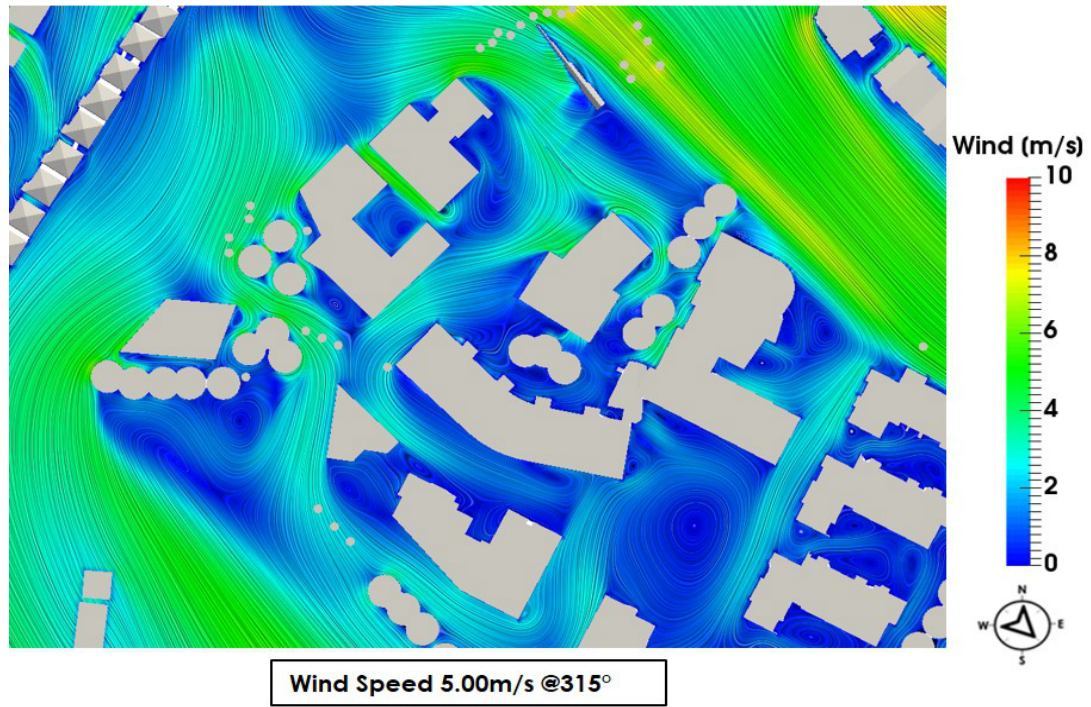*Figure 11.49 - Wind Speed Results at 1.5m Above Development Ground-Top View: 247.5°,258.75°*

Wind Speed 5.89m/s @270° NE ISO View

Wind Speed 5.50m/s @281.25° E ISO View

Figure 11.50 - Wind Speed Results at 1.5m Above Development Ground-Top View: 270°,281.25

Figure 11.51 - Wind Speed Results at 1.5m Above Development Ground-Top View: 315
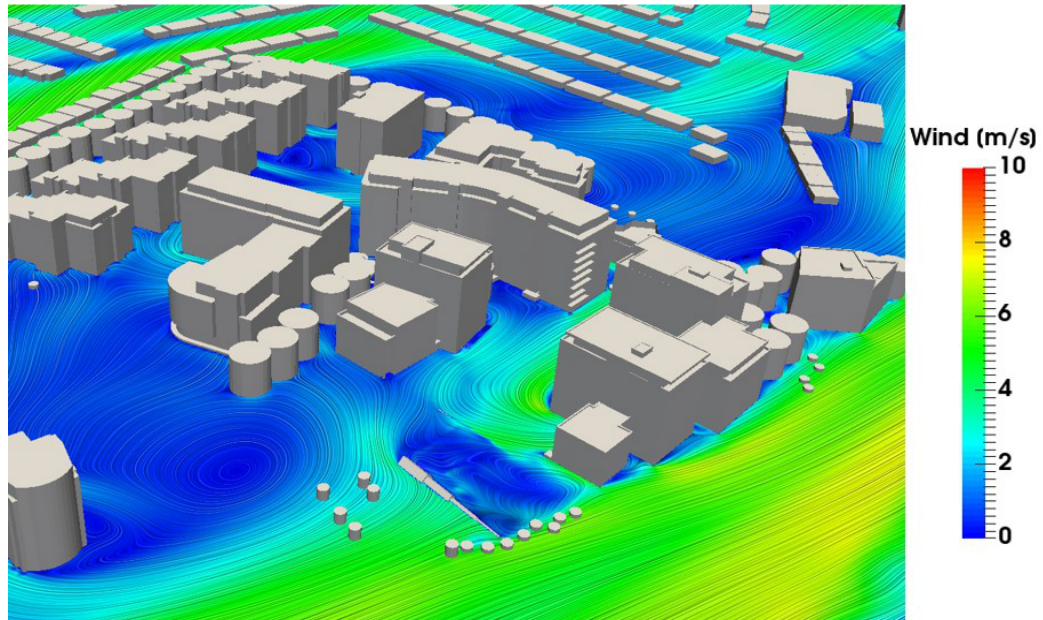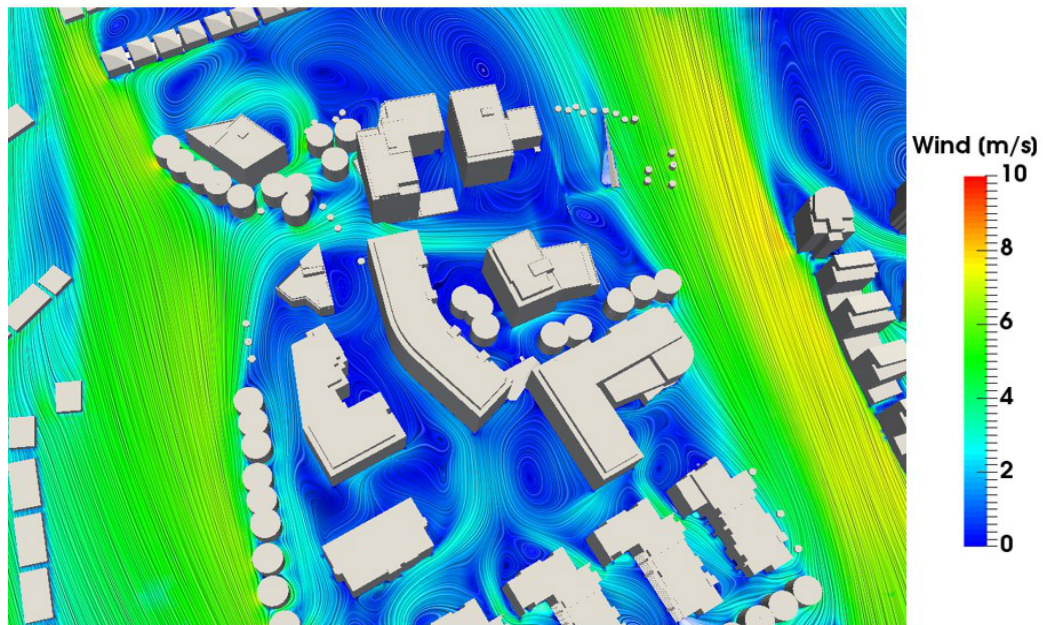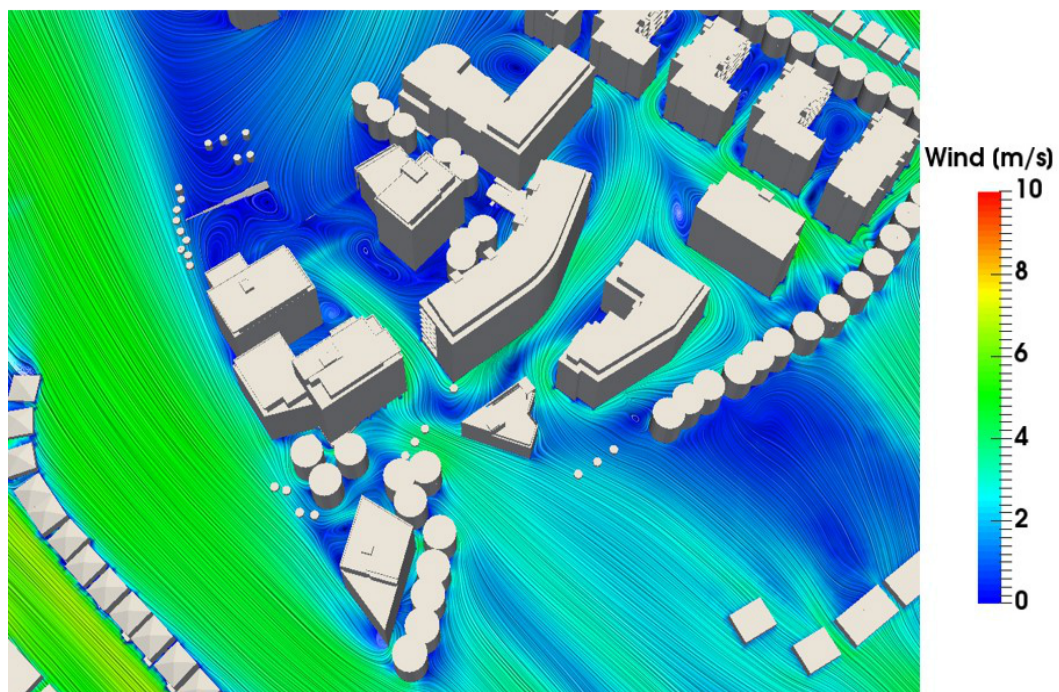
Figure 11.52 - Wind Speed Results at 1.5m Above Development Ground-Isometric View: 45°, 135

Wind Speed 5.60m/s @225° SW ISO View
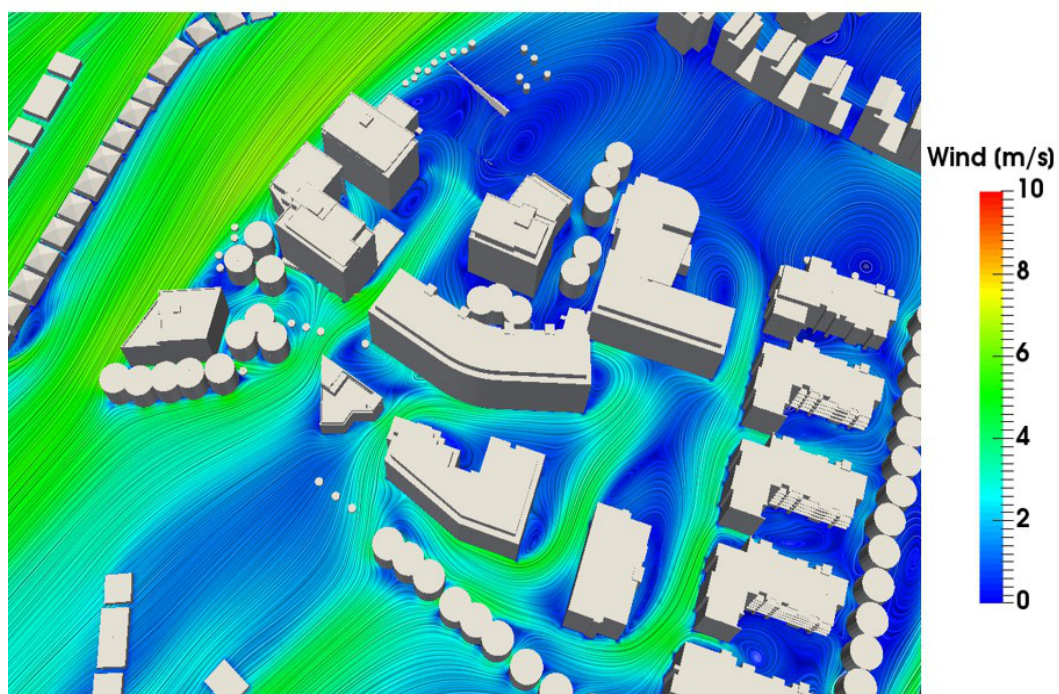
Wind Speed 5.85m/s @236.25° S ISO View

Figure 11.53 - Wind Speed Results at 1.5m Above Development Ground-Isometric View: 225°, 236.25°

Wind Speed 6.03m/s @247.5°
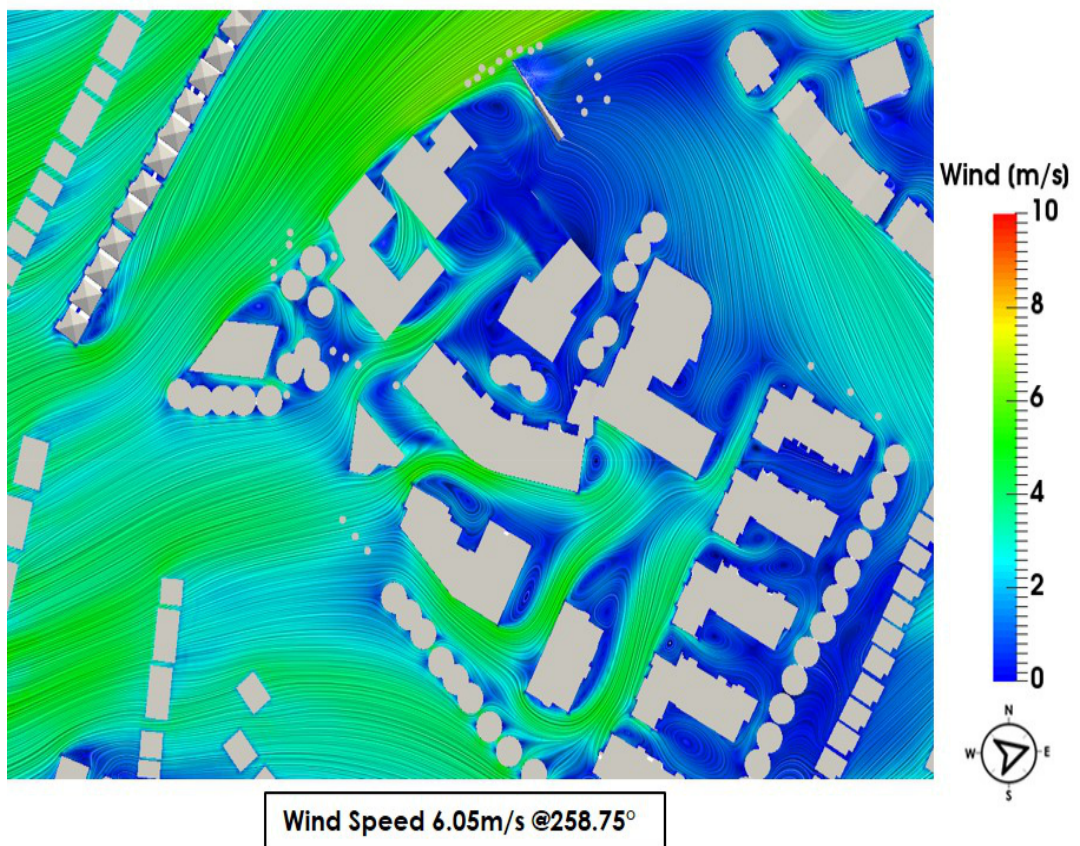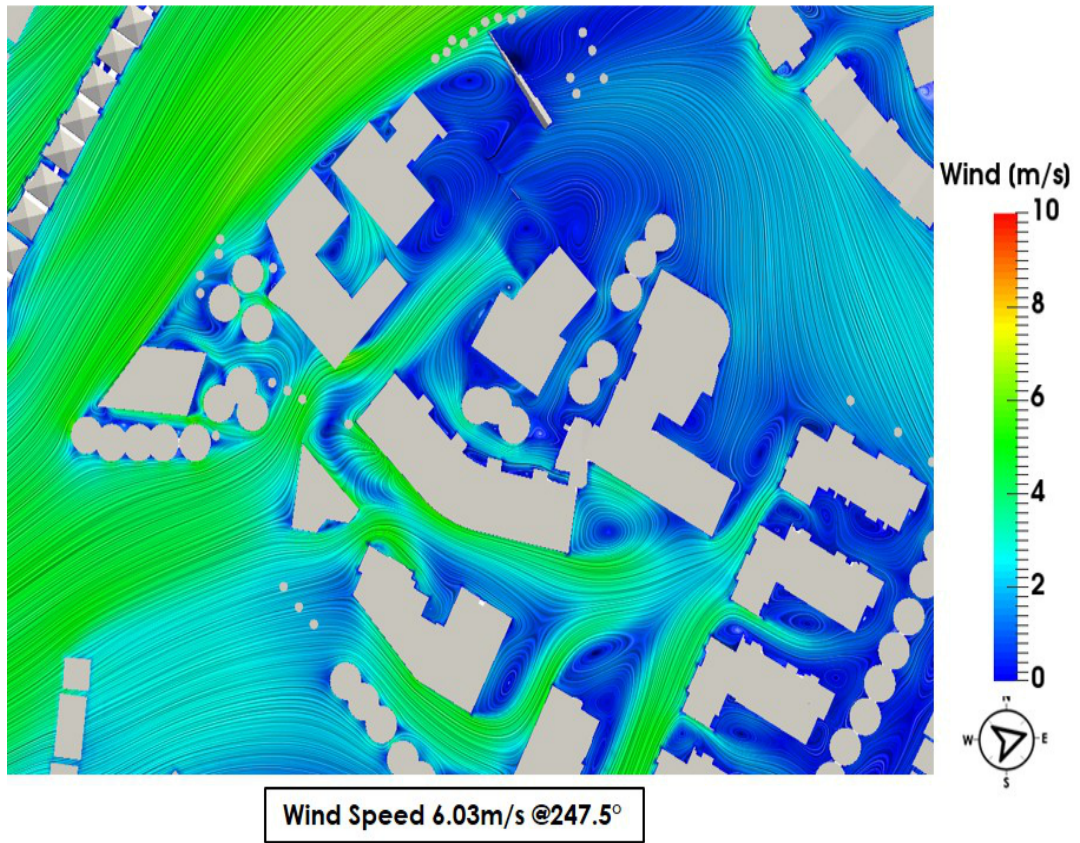

Wind Speed 6.05m/s @258.75°

Figure 11.54 - Wind Speed Results at 1.5m Above Development Ground-Isometric View: 247.5°,258.75°

Wind Speed 5.89m/s @270° NE ISO View

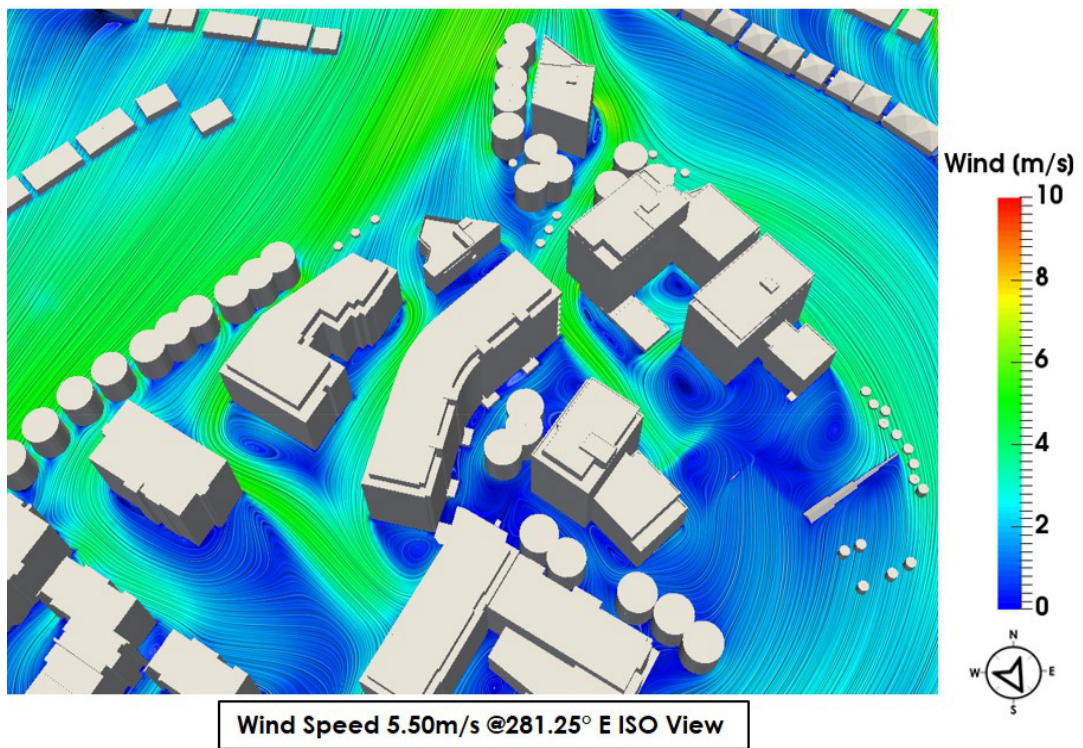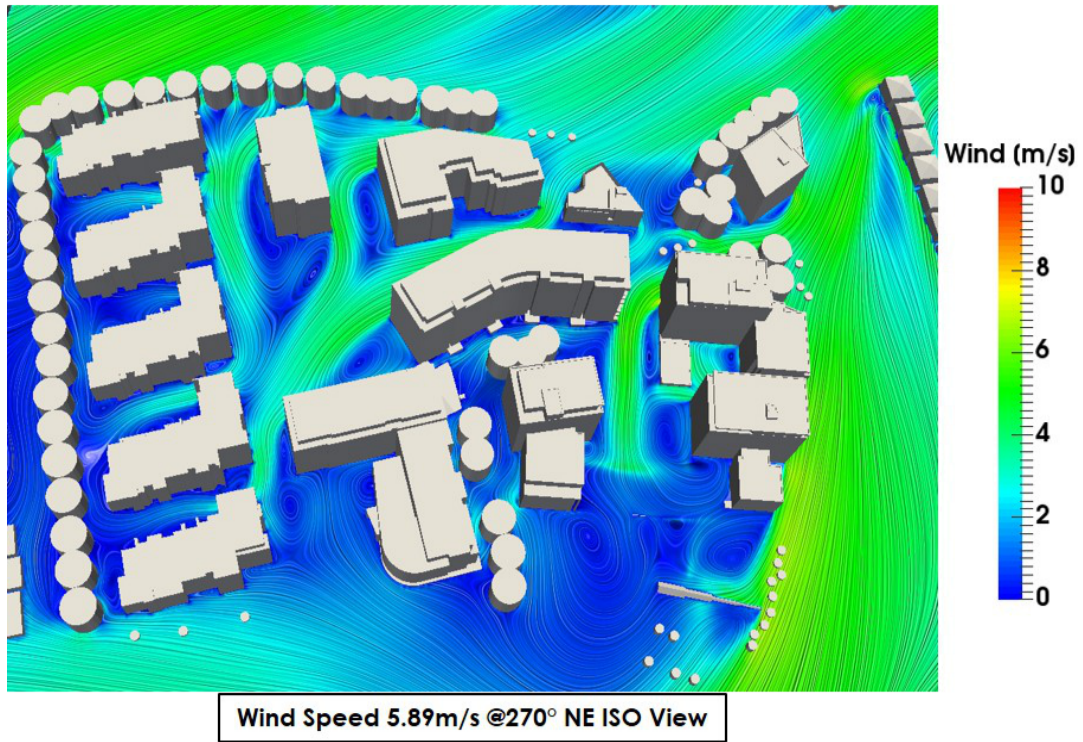Wind Speed 5.50m/s @281.25° E ISO View

Figure 11.55 - Wind Speed Results at 1.5m Above Development Ground-Isometric View: 270°,281.25°
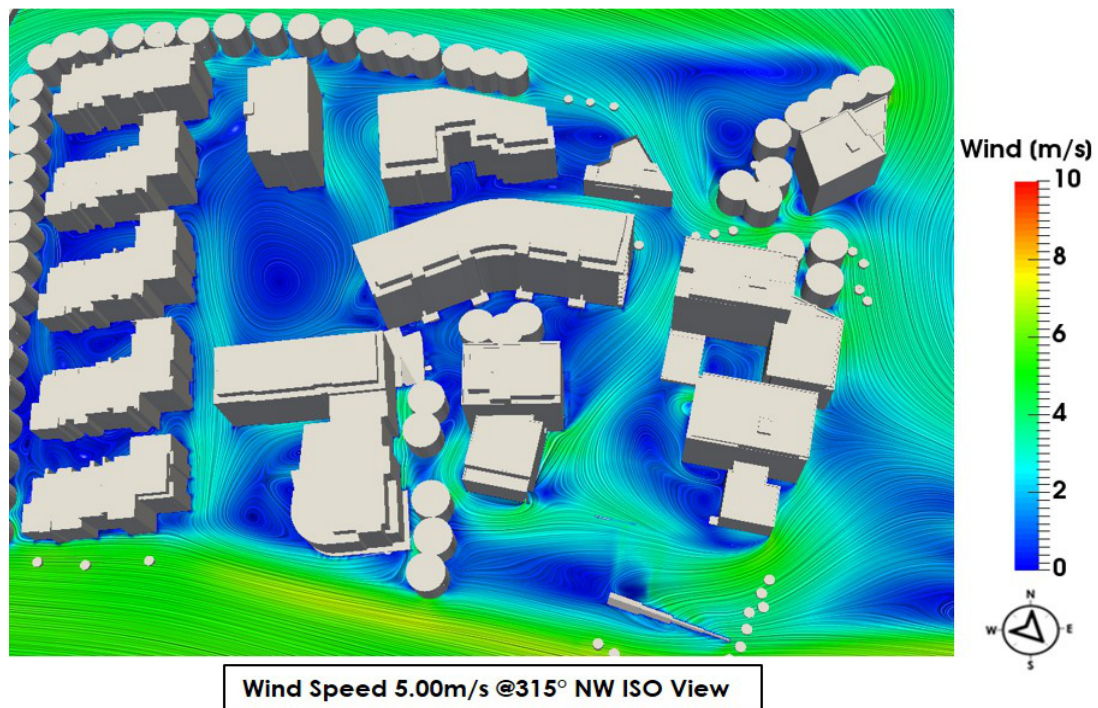
Figure 11.56 - Wind Speed Results at 1.5m Above Development Ground-Isometric View: 315°

11.10 Risk to Human Health-Pedestrian Comfort Assessment

This section aims to identify areas of Grange Development where the pedestrian safety and comfort could be compromised (in accordance with the Lawson Acceptance Criteria previously described). Pedestrian comfort criteria are assessed at 1.5m above ground level.

Discomfort Criteria

Figures 11.58 to 11.62 shows the Lawson comfort categories over the ground floor area around Grange Development, respectively for the cardinal and the ordinal directions. In all cases, the scale used is set out in Figure 11.57.

Thus, depending on the wind direction, the suitability of the different areas can be assessed using these maps. It can be seen that the wind conditions range from "suitable for long term sitting" to "suitable for walking and strolling" and really rarely are only suitable for "business walking" or "unacceptable for pedestrian comfort".
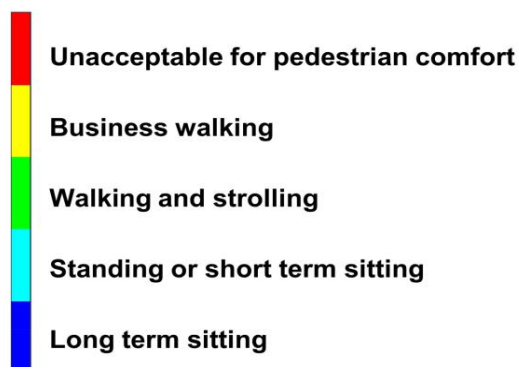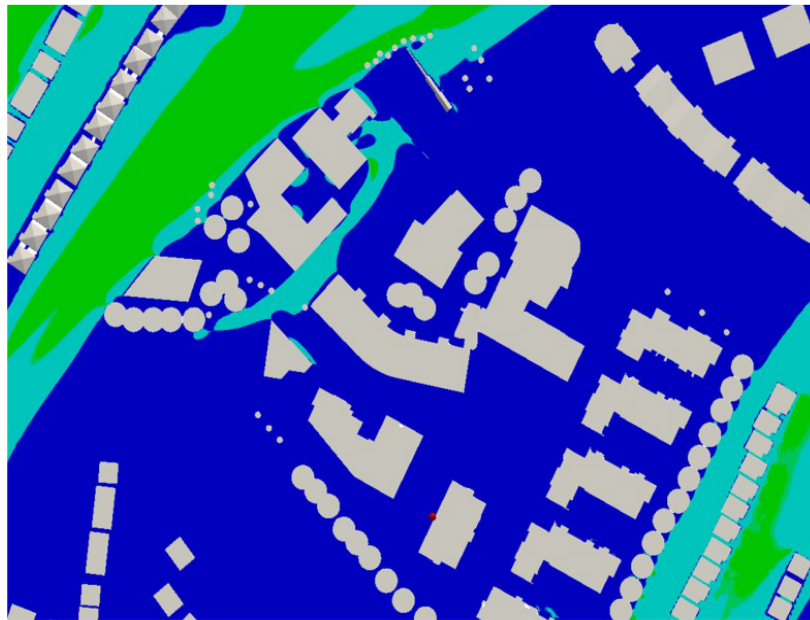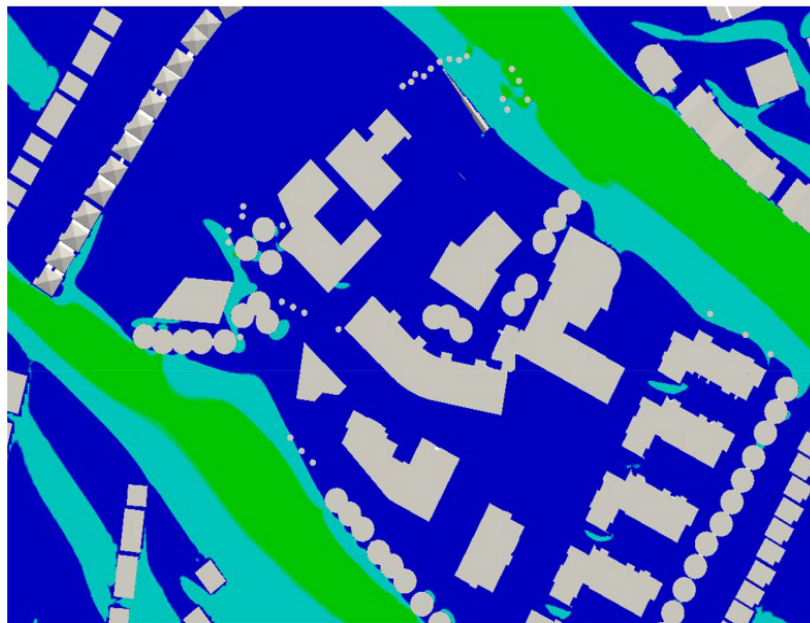

Figure 11.57 - Lawson Comfort Categories

Lawson Discomfort Map For 4.17m/s @45°

Lawson Discomfort Map for 4.63m/s @135°

Plot Colour:

Unacceptable for pedestrian comfort

Business walking

Walking and strolling

Standing or short term sitting

Long term sitting

Figure 11.58 - Ground Floor - Lawson Discomfort Map - Cardinal Directions

Lawson Discomfort Map For 5.60m/s @225°

Lawson Discomfort Map For 5.85m/s @236.25°

Plot Colour:

- Unacceptable for pedestrian comfort
- Business walking
- Walking and strolling
- Standing or short term sitting
- Long term sitting

Figure 11.59 - Ground Floor - Lawson Discomfort Map - Cardinal Directions

Lawson Discomfort Map For 6.03m/s @247.5°

Lawson Discomfort Map For 6.05m/s @258.75°

Plot Colour:

- Unacceptable for pedestrian comfort
- Business walking
- Walking and strolling
- Standing or short term sitting
- Long term sitting

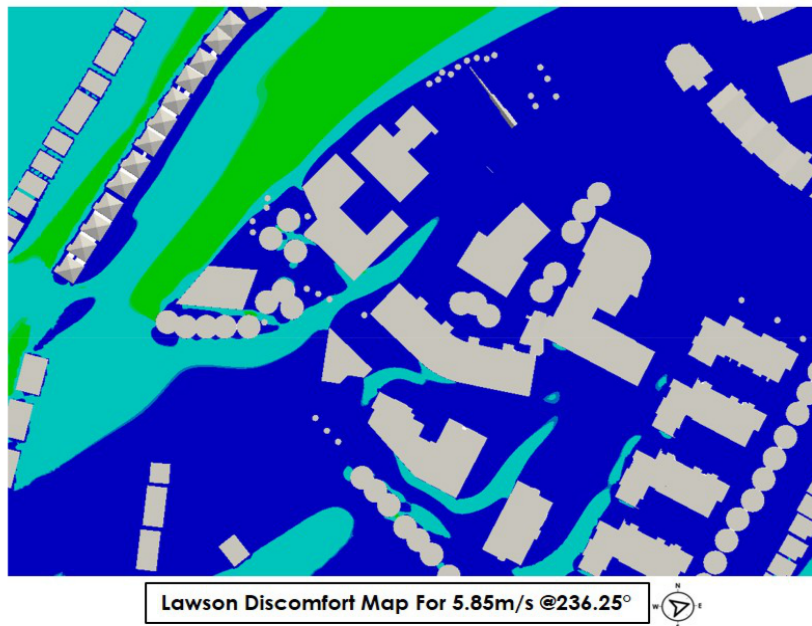*Figure 11.60 - Ground Floor - Lawson Discomfort Map - Cardinal Directions*

Lawson Discomfort Map For 5.89m/s @270°
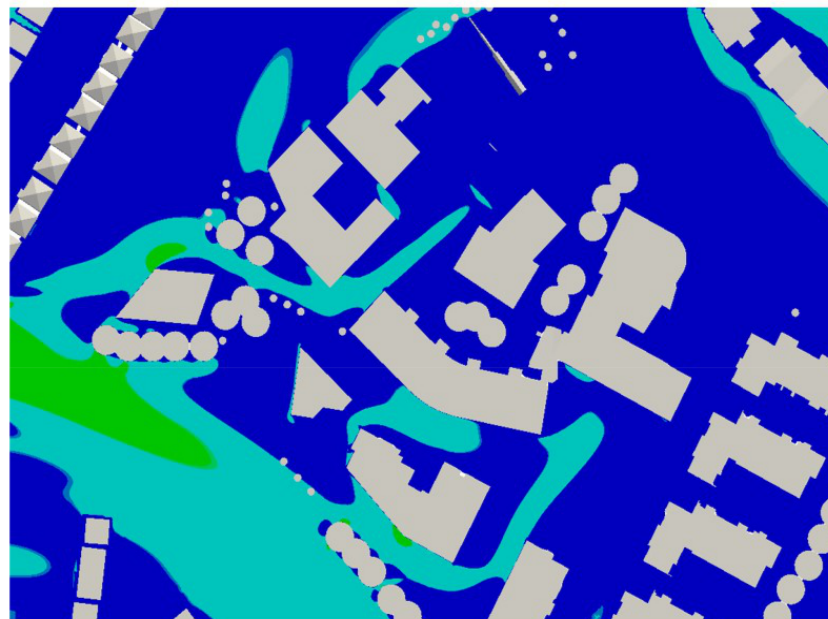
Lawson Discomfort Map For 5.50m/s @281.25°

Plot Colour:

Unacceptable for pedestrian comfort

Business walking

Walking and strolling

Standing or short term sitting

Long term sitting

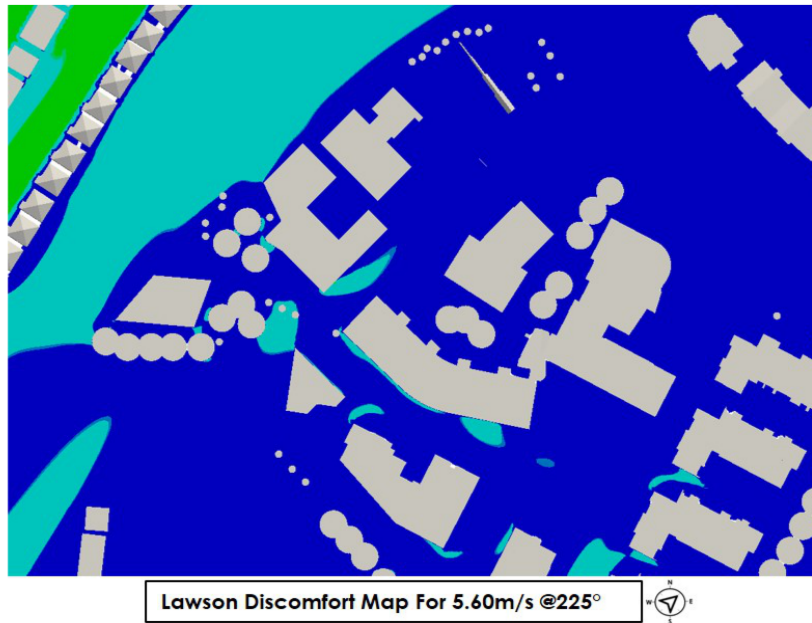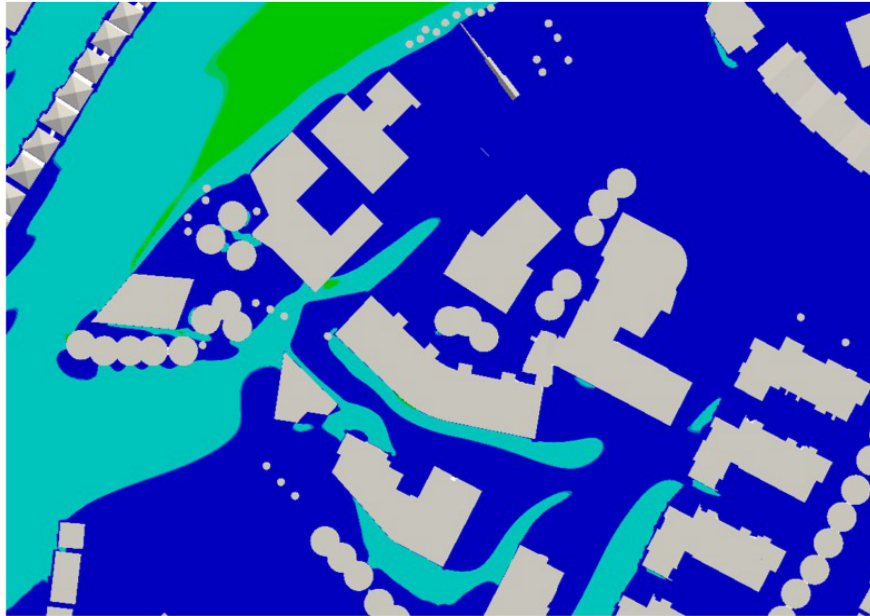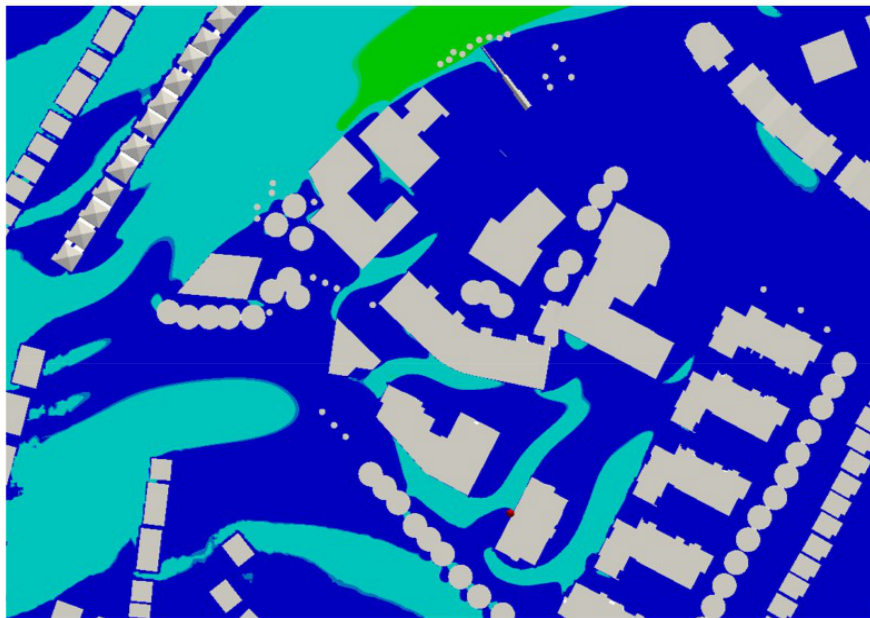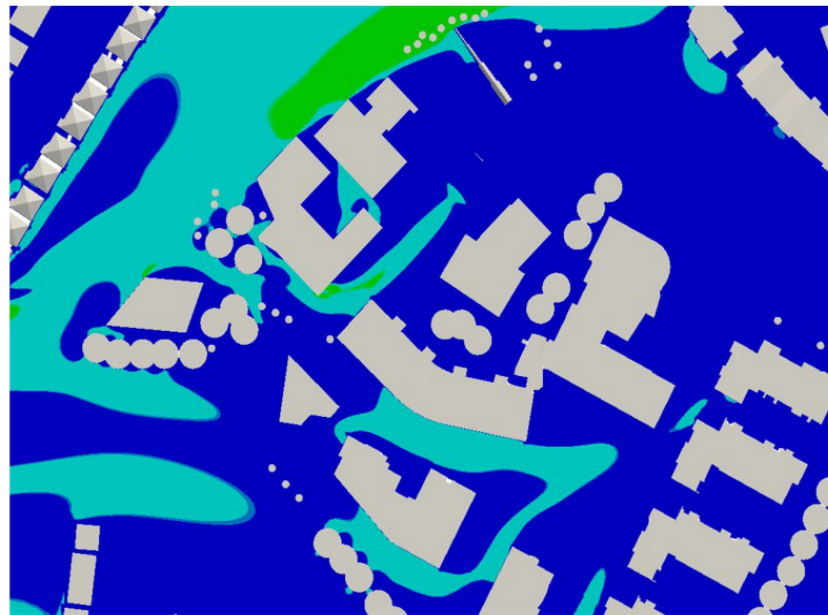*Figure 11.61 - Ground Floor - Lawson Discomfort Map - Cardinal Directions*
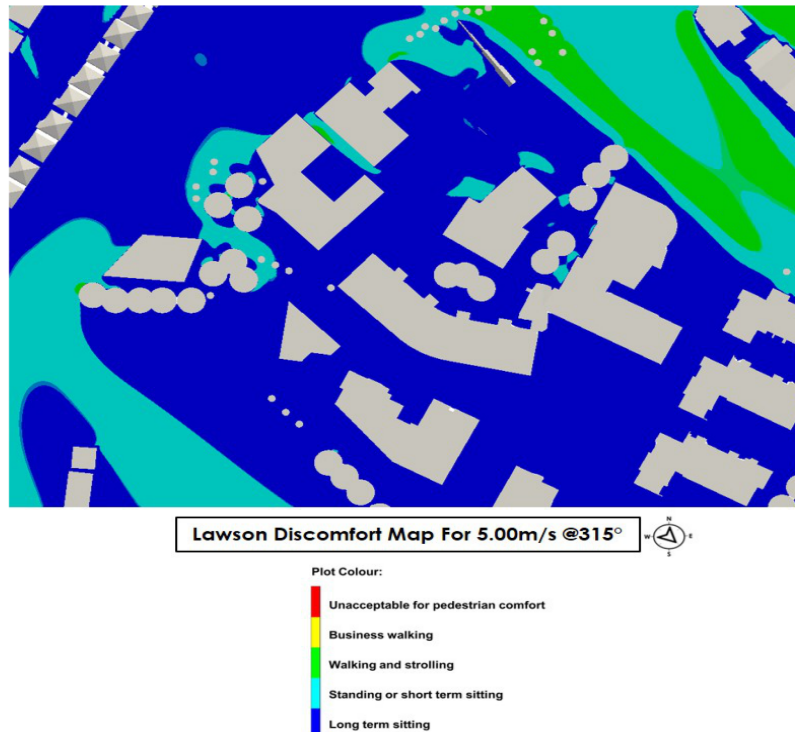
Figure 11.62 - Ground Floor - Lawson Discomfort Map - Ordinal Directions

For the Lawson discomfort criteria, the onset of discomfort depends on the activity in which the individual is engaged and it is defined in terms of a mean hourly wind speed (or GEM) which is exceeded for 5% of the time. However, the results shown in these maps show that there are no critical area which are unacceptable for pedestrian comfort. Thus, the discomfort criteria is satisfied for all the different cases and in all directions.

Distress Criteria

In addition to the criteria for "discomfort" the Lawson method presents criteria for "distress". The discomfort criteria focus on wind conditions which may be encountered for hundreds of hours per year. The distress criteria require higher wind speeds to be met, but focus on two hours per year. These are rare wind conditions but with the potential for injury rather than inconvenience.

Figure 11.63 shows the hourly wind gust rose for Dublin, from 1985 to 2015. This will be necessary to assess how many hours per year on average the velocity exceed the threshold values.

Figure 11.63 - Hourly Dublin Wind Gust Rose

The criteria for distress for a frail person or cyclist is 15m/s wind occurring for more than two hours per year. Limiting the results from the above wind rose to the only values above 15m/s (as reported in Figure 64), it is possible to see how a gust velocity of 15m/s is exceed at pedestrian level only in the West direction, for a total of 5 hours over 30 years.
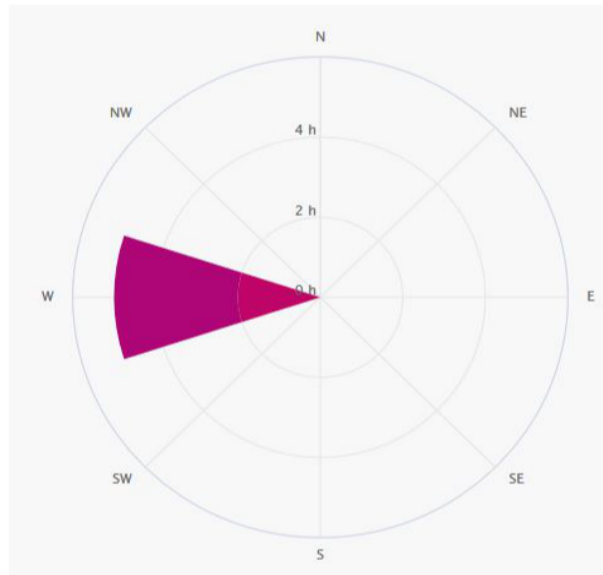
Figure 11.64 - Hourly Dublin Wind Gust Rose - Cumulative hours when the velocity is above 15m/s

Figures 11.66 below shows the areas where the measured wind speeds are potentially above 15 m/s in all directions. Figure 11.65 shows the scale used in this case. In all these cases, there is no or little risk of attaining critical wind levels in terms of distress.
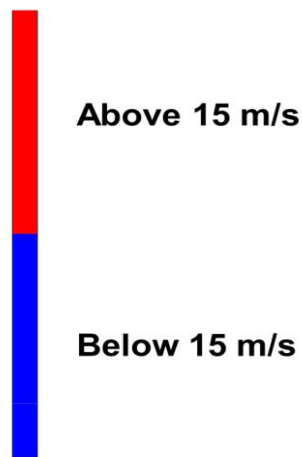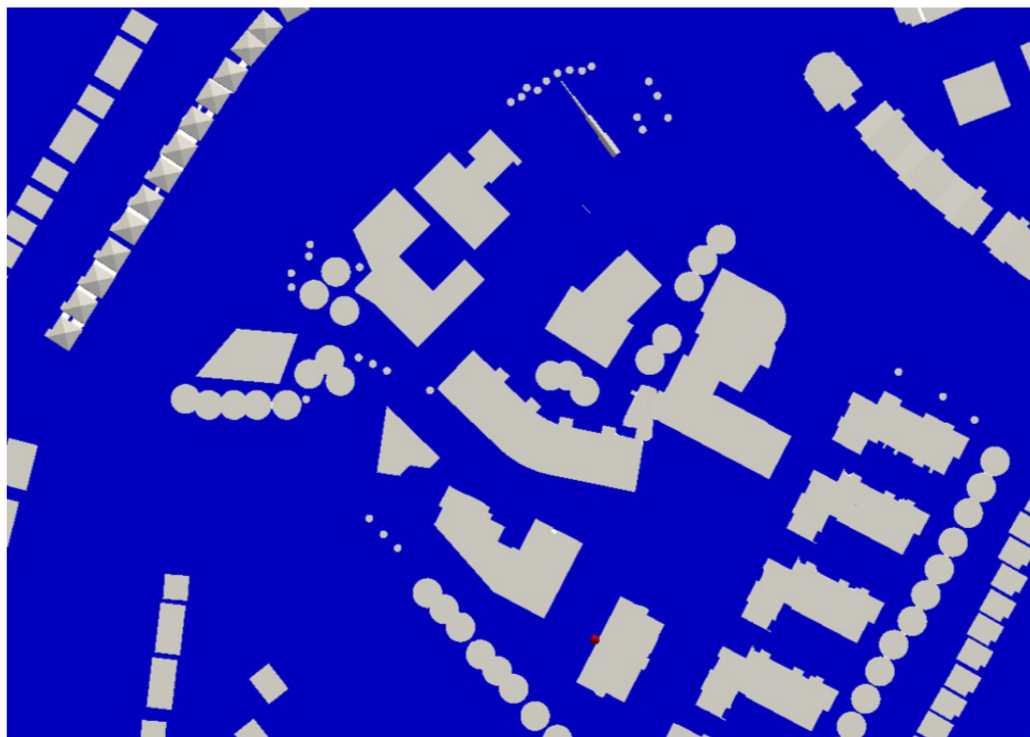

Figure 11.65 - Lawson Distress Categories - Frail Person or Cyclist

Figure 11.66 - Ground Floor Level - Lawson Distress Map - Frail Person or Cyclist - All Directions

The criteria for distress for a member of the general population is 20m/s wind occurring for more than two hours per year. In this case, a gust velocity of 20m/s is never exceed neither at pedestrian ground floor level nor at terraces level for more than 2 hours per year. Therefore there are not distress conditions for the general public for the mitigated proposed development.

11.11   Monitoring

There is not particular requirement to monitor the wind impact during construction phase as the designated amenity areas will not be in use during this phase of the project.

The development has been designed to conform with the Lawson Criteria for Comfort and Distress in accordance with the Wind Beaufort Scale.

11.12   Reinstatement

Not applicable.

11.13 Interactions

The interactions between the proposed development and landscaping is fundamental to mitigate the unwanted impact of wind. As discussed in the previous sessions, the landscaping has reduced and re-directed the flow velocity of the incoming wind in the areas that were found to be critical.

The interaction with the existing and surrounding developments has also been evaluated. In particular, the presence of urban environment has a beneficial effect in mitigating the impact of incoming south-west wind, however some funnelling effects are expected. The prevailing wind directions for the site are identified in the West, West South-West and South with magnitude of approximately 6m/s. In all these directions the development area the mitigated conditions have been obtained with the use of tree landscaping.

11.14 Difficulties Encountered

No difficulties have been encountered for the assessment of the wind and microclimate impact.

11.15 Conclusions

This study presents the CFD modelling assumptions and results of Wind and Microclimate Modelling of Grange Development.

Results of this are utilized by Lafferty Project Managers team to configure the optimal layout for Grange Development for the aim of achieving a high-quality environment for the scope of use intended for each areas/building (i.e. comfortable and pleasant for potential pedestrian) and not to introduce any critical wind impact on the surrounding areas and on the existing buildings (in accordance with the Lawson Acceptance Criteria).

Existing Receiving Environment Summary

The wind desktop study of the development environment showed that:

- The wind profile was built using the annual average of meteorology data collected at Dublin Airport Weather Station. In particular, the local wind climate was determined from historical meteorological data recorded 10 m above ground level at Dublin Airport.

- 18 different scenarios were selected in order to take into consideration all the different relevant wind directions. In particular, a total of 18 compass directions on the wind rose are selected. For each direction, the reference wind speed is set to the 5% exceedance wind speed for that direction, i.e. the wind speed that is exceeded for over 5% of the time whenever that wind direction occurs.

- The presence of urban environment has a beneficial effect in mitigating the impact of incoming south-west wind, however some funnelling effects are expected. The prevailing wind directions for the site are identified in the West, West South-West and South with magnitude of approximately 6m/s. In all these directions the development area can be mitigated with the use of tree landscaping. The trees are beneficial in calming incoming winds and possibly deviating it.

- Areas where velocities can be higher and some funnelling and recirculation effects experienced have been highlighted. However, these are mitigated by tree landscaping, with particular attention to the corners of the buildings.

Potential and Cumulative Impact of the Proposed Development Summary

Micro-climate Model Assessment (Mitigated Layout) of Grange Development and it's environment was performed utilizing a CFD (Computational Fluid Dynamics) methodology. 9 worst case wind

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scenarios are selected for presentation in this study, as these scenarios and directions showed to be the most relevant wind speeds and cardinal directions.

CFD modelled results of the mitigated scheme showed that:

- The proposed Grange Development will produce a high quality environment that is attractive and comfortable for pedestrians of all categories.

- The Surrounding environment, development and mitigation tress properly shields all paths/walkways around and within the development. Pedestrian footpaths are always successfully shielded and comfortable.

- The development Courtyard is generally suitable for long term sitting, short term sitting, standing, walking and strolling activities.

- Shielding conditions in the South-West, South-East, North-East and North-West areas are always acceptable.

- Balconies within the development are comfortable for pedestrian sitting, standing, walking and strolling.

- The proposed development does not impact or give rise to negative or critical wind speed profiles at the nearby adjacent roads, or nearby buildings.

- Pedestrian comfort assessment, performed according to the Lawson criteria, identified the areas that are suitable for different pedestrian activities in order to guarantee pedestrian comfort. In terms of distress, no critical conditions were found for "Frail persons or cyclists" in the surrounding of the development. No critical conditions have been found for members of the "General Public".

- During Grange Development construction phase the predicted impacts are classified as negligible.

- Cumulative assessment has been performed by accounting for all topography of the existing environment, Grange Proposed development, landscaping mitigations, wind statistical data and microclimate modelling of the site.

- From the Cumulative assessment, The Proposed Grange Development will introduce negligible negative wind and microclimate impact on the existing environment, adjacent buildings or future phased developments within its vicinity. A wind and microclimate modelling of future phase will need to be performed for all future phases.

Therefore, the CFD study carried out has shown that under the assumed wind conditions typically occurring within Dublin for the past 30 years:

- **The development is designed to be a high-quality environment for the scope of use intended of each areas/building (i.e. comfortable and pleasant for potential pedestrian), and,**

- **The development does not introduce any critical impact on the sur-rounding buildings, or nearby adjacent roads.**

11.16 References

- Lawson, T.V., 2001, 'Building Aerodynamics', Imperial College Press, London

- Simiu, E., 2011, 'Design of buildings for wind: a guide for ASCE 7-10 Standard users and designers of special structures', 2nd Edition, John Wiley and Sons, Inc., Hoboken, New Jersey, U.S.A.

- Building Aerodynamics, Tom Lawson FREng. Imperial College Press, 2001

- Blocken, B., 2015. Computational Fluid Dynamics for Urban Physics: Importance, scales, possibilities, limitations and ten tips and tricks towards accurate and reliable simulations. Building and Environment.

- Blocken, B., Janssen, W.D. and van Hooff, T., 2012. CFD simulation for pedestrian wind comfort and wind safety in urban areas: General decision framework and case study for the Eindhoven University campus. Environmental Modelling and Software, 30, pp.15–34.

- Franke, J., Hellsten, A., Schlunzen, H., Carissimo, B, Ed. (2007); Best Practice Guidelines for the CFD Simulation of Flows in the Urban Environment, University of Hamburg