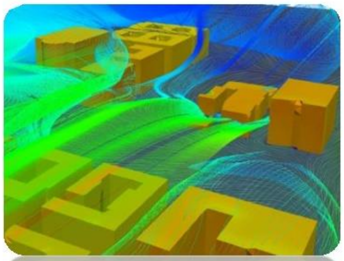 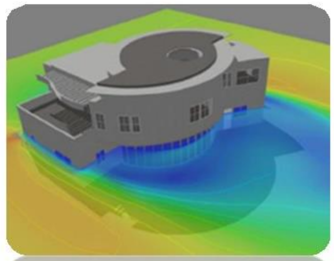 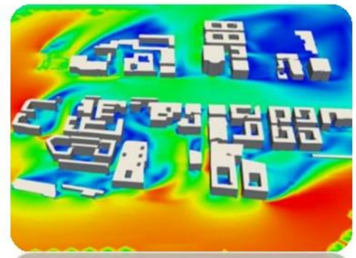

WIND MICROCLIMATE CFD ANALYSIS

Strategic Housing Development

Glenamuck Road North, Carrickmines, Dublin 18

Prepared by: B-Fluid Ltd.| Buildings Fluid Dynamics Consultants

For: Moran Park Homebuilders Ltd.

B-Fluid
Buildings Fluid Dynamics

<table>
<tr><th colspan="3">Document Reference</th></tr>
<tr><td>Project Name</td><td colspan="2">WIND MICROCLIMATE CFD ANALYSIS
Strategic Housing Development
Dublin 18</td></tr>
<tr><td>Project Ref.</td><td colspan="2">$W\_2109241$</td></tr>
<tr><td>Site location</td><td colspan="2">Glenamuck Road North, Carrickmines, Dublin 18</td></tr>
<tr><td>CFD Study by</td><td colspan="2">B-Fluid Ltd.</td></tr>
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Contents

1. EXECUTIVE SUMMARY

B-Fluid Limited has been commissioned by 'Moran Park Homebuilders Ltd.' to carry out a Wind Microclimate Analysis for Strategic Housing Development at Glenamuck Road North, Carrickmines, Dublin 18. The proposed development shall provide for the construction of (a) 118 no. residential apartment units in the form of 3 no. residential blocks of apartments ranging in height from 4 storey's and transitioning to 6-7 storeys overall. The site provides parking, open space, recreational services, communal areas located off the Glenamuck Road North, Carrickmines, Dublin 18.

This site is located on Glenamuck Road North within close proximity to the village of Foxrock to the North, and it is very close to M50, the LUAS Green Line stop at Carrickmines. The proposed development is being constructed on a site with no trees. Figure 1.1 shows the site location of the proposed development.

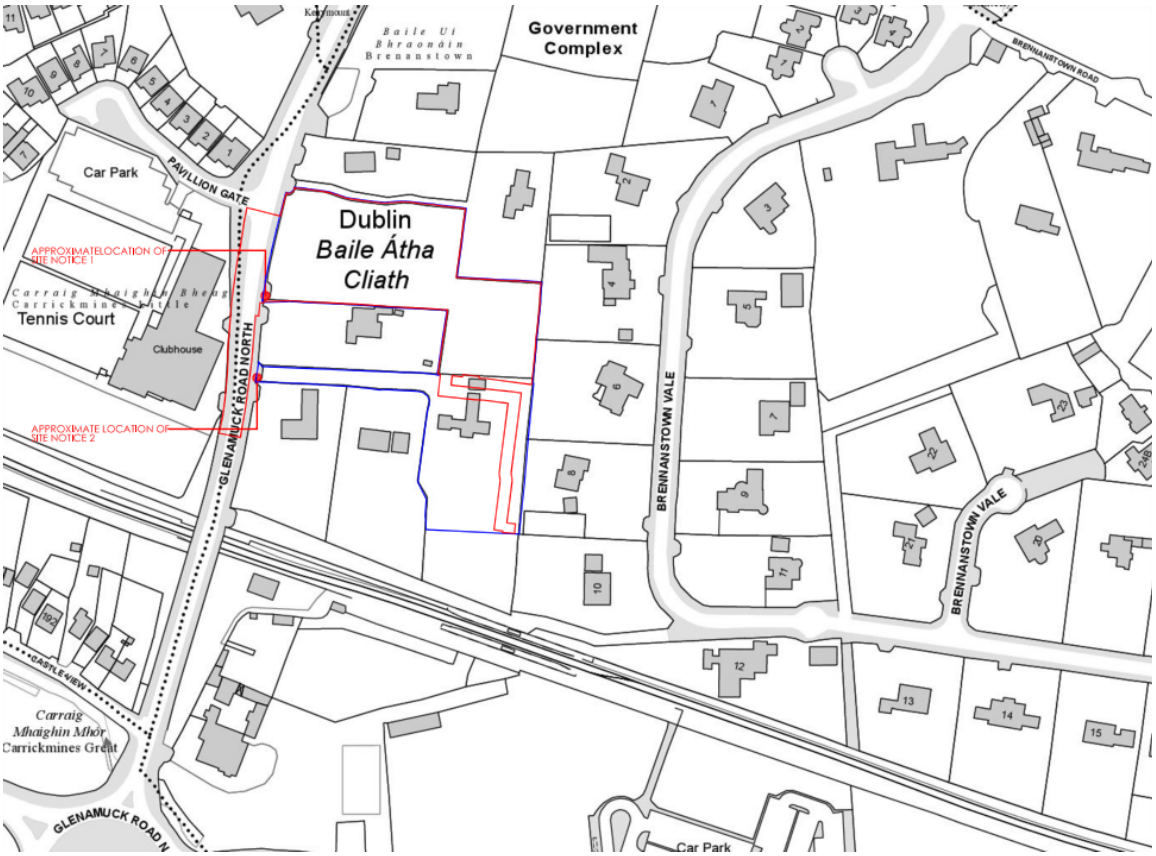


Figure 1.1: Proposed Site Location of Strategic Housing Development

A Wind Microclimate Study identifies the possible wind patterns around the existing environment and proposed development under mean and peak wind conditions typically occurring in Dublin. A wind microclimate assessment is performed through advanced Computational Fluid Dynamics (CFD) which is a numerical method used to simulate wind conditions and its impact on the development and to identify areas of concern in terms of downwash/funneling/downdraft/critical flow accelerations that may likely occur. The Advanced CFD numerical algorithms applied here are solved using high performance computing cluster.

Results of this study are utilized by the design team to configure an optimal layout for Strategic Housing Development, thereby achieving a quality environment that accounts for the appropriate use of each areas/building (i.e. comfortable and pleasant for potential pedestrian) and which does not introduce any critical wind impact on the surrounding areas and on existing buildings.

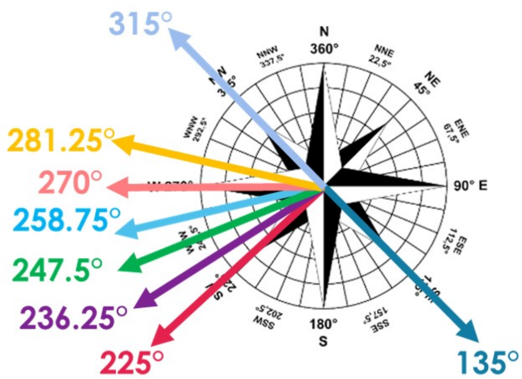
This technical report describes the wind desktop study performed and rationals of the methodology and assumptions that B-Fluid Ltd. adopted for this analysis.

For the purpose of performing an elaborate wind desktop study, 18 different wind scenarios and directions have been considered as shown in Table 1.1 in order to take into account all the relevant wind directions in Dublin. 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.

This technical report focuses on reporting the 8 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 modelled scenarios reported in this study are presented in Figure 1.2.

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 1.1: Summary of The 18 Wind Scenarios Modelled for Proposed Development



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

Figure 1.2: Summary of 8 Wind Scenarios Reported

A qualitative and quantitative summary of the wind microclimate modelling study performed for Strategic Housing Development shows that:

- The wind profile around the existing development environment was built using the annual average 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.
- The prevailing wind directions for the site are identified as West, South-East and West-South-West, with magnitude of approximately 6m/s.
- We consider that mitigation measures such as the use of landscaping on ground floor will be sufficient to ensure that the proposed Strategic Housing Development will be designed to produce a high-quality environment that is attractive and comfortable for pedestrians of all categories.
- South west corners of block A, B and C potentially experience high wind speeds. This wind speeds are not critical, and can be further mitigated by the use of landscaping trees.
- High speeds are observed in the spaces between block B and C. This high speeds are due to funnelling and recirculation effects, and can be mitigated with the use of landscaping in these areas.
- Given the position of the development blocks, and the recommended landscape, critical wind speeds are not expected on footpaths of the proposed development blocks.
- The proposed development does not impact or give rise to negative or critical wind speed profiles at the nearby adjacent roads, or nearby buildings.

2. PROJECT DESCRIPTION

2.1 INTRODUCTION

B-Fluid Limited has been commissioned by 'Moran Park Homebuilders Ltd.' to carry out a Wind Microclimate Desktop Study for Strategic Housing Development in Glenamuck Road North, Carrickmines, Dublin 18.

The following paragraphs detail all the project information used throughout the study, together with results of the assessment carried out.

2.2 DESCRIPTION OF DEVELOPMENT

Moran Park Homebuilders Limited intend to apply to An Bord Pleanála for planning permission for a strategic housing development on an overall site of c. 0.92 ha (c. 0.74 ha relates to the main development site and c. 0.18 ha relates to additional lands for drainage and access proposals) at Glenamuck Road North, Carrickmines, Dublin 18 (bounded by 'Tullybeg' to the north, 'Chigwell' to the northeast, 'Stafford Lodge' to the south and 'Carricáil' to the southeast).

The proposed development shall provide for the construction of (a) 118 no. residential apartment units in the form of 3 no. residential blocks of apartments ranging in height from 4 storey's and transitioning to 6-7 storeys overall.

- Block A (7 storeys) comprising 44 no. units (13 no. 1 bed units, 28 no. 2 bed. units and 3 no. 3 bed units);
- Block B (6-7 storeys overall) comprising 38 no. units (11 no. 1 bed units, 26 no. 2 bed units and 1 no. 3 bed units); and
- Block C (6 storeys overall) comprising 36 units (10 no. 1 bed units; 22 no. 2 bed units and 4 no. 3 bed units);

Each new residential unit has an associated area of private open space in the form of balcony / terrace area and set back upper floor levels. Open space (approx. 2071 sqm) is provided by one major centrally located public open space (1158.4 sqm) between blocks A and B which include a play area of 63.2 sqm, two further communal open space areas are provided adjoining Blocks B (471.8 sqm) and Block C (440.8 sqm). Communal Area located at the ground floor of Block B (approx. 161.3 sqm) comprising of a shared working space (35.6 sqm), meeting rooms (42.2 sqm.), a gym (36.6 sqm) and changing/tea stations (46.7 sqm) is also proposed.

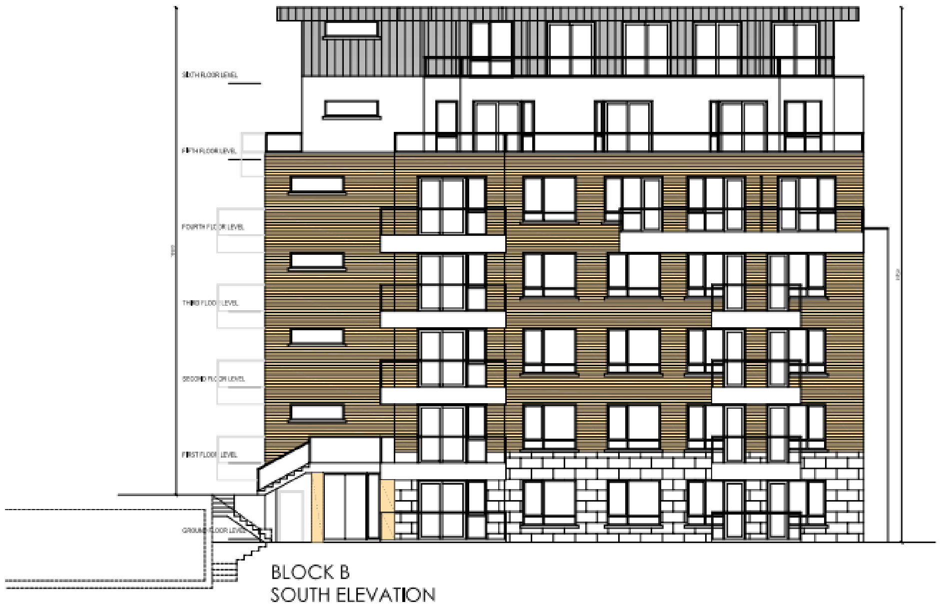
2 no. basement level areas (approx. 2340.9 sqm) are also proposed at lower ground / ground floor level of Blocks A, B (1470.0 sqm) and C (834.9 sqm) and include car parking, bicycle parking, refuse storage areas, plant areas and ESB Substation which is located between Block B and C. A total of 103 no. car parking spaces (67 no. at basement level and 36 no. at surface level to include 17 no. electric power points and 5 no. accessible parking spaces) are proposed.

In addition, 5 no. motorcycle parking spaces (3 no. at basement level A and B, and 2 no. at basement level C). A total of 280 no. bicycle parking spaces (254 no. at basement level and 26 no. at surface level) are also proposed.

Proposals for vehicular and pedestrian access comprise via Glenamuck Road North and all associated upgrade works; The access point to the south (via Carricáil) is for pedestrians and cyclists only. Associated site and infrastructural works including the provision for water services, foul and surface water drainage and connections; attenuation proposals; permeable paving; all landscaping works to include new tree and hedge planting; green roofs; boundary treatments; internal roads and footpaths; and electrical services.

Elevation view of the proposed development Blocks are presented in Figure 2.1 to 2.3. Figure 2.4 shows positions of the three Blocks on the development site.

Figure 2.1: Strategic Housing Development Block A Elevation Layout



BLOCK B
SOUTH ELEVATION

BLOCK B
WEST ELEVATION

Figure 2.2: Strategic Housing Development Block B Elevation Layout

BLOCK C
WEST ELEVATION

BLOCK C
SOUTH ELEVATION

Figure 2.3: Strategic Housing Development Block C Elevation Layout

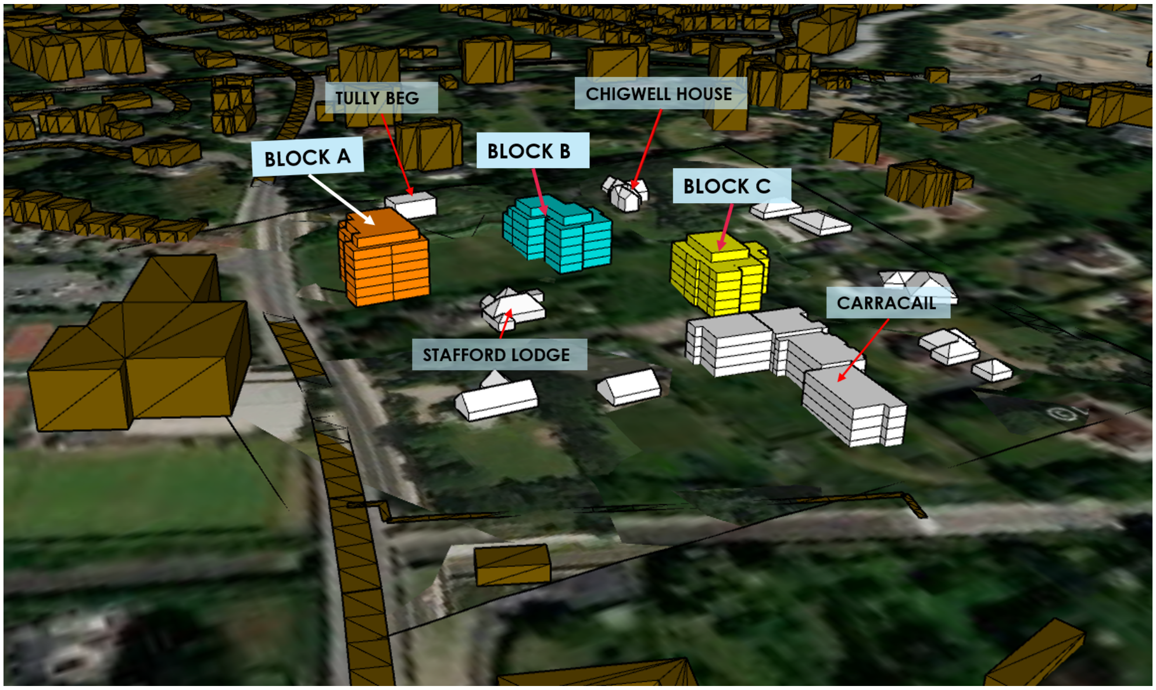


Figure 2.4: Strategic Housing Development 3D Model

2.3 EXTENTS OF ANALYSED AREA

Strategic Housing Development will be situated in Glenamuck Road North, Carrickmines, Dublin 18. The Existing Environment site is shown in Figure 2.5. The area considered for the existing environment and proposed development are represented in Figure 2.6.

Figure 2.5: Strategic Housing Development Site Location and Existing Environment.

Figure 2.6: Extents of Analysed Existing Environment Around Strategic Housing Development.

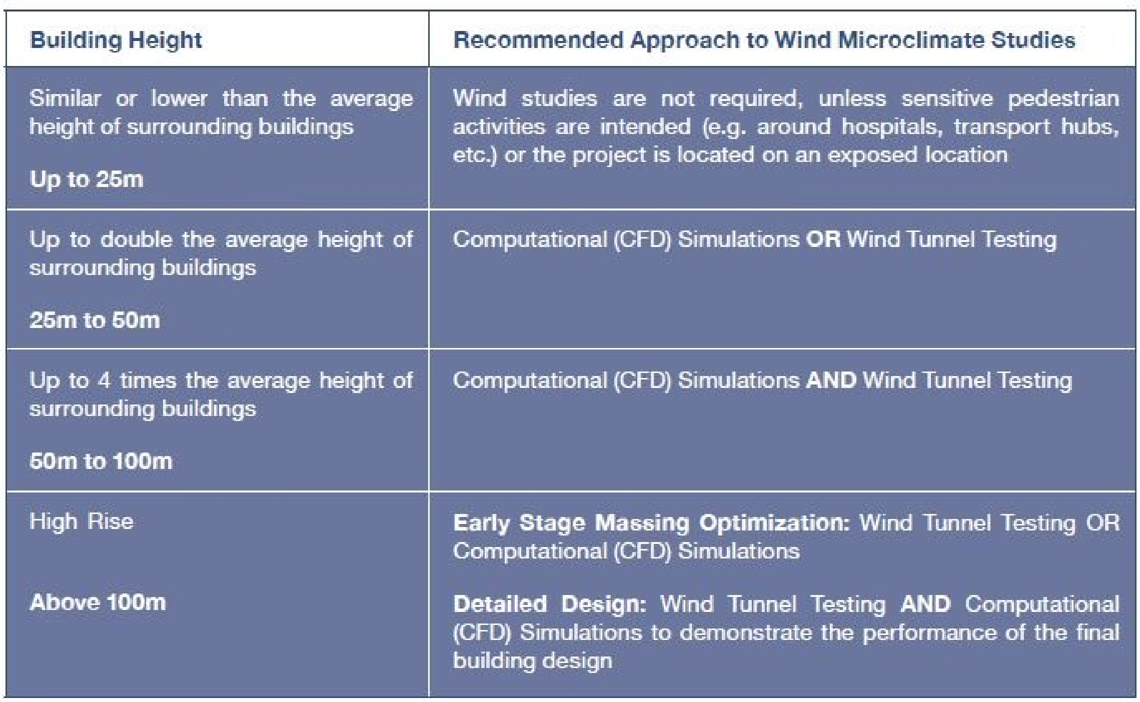
2.4 OBJECTIVE OF THE WIND MICROCLIMATE STUDY

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 sidewalks and street frontages, pathways, building entrance areas, open spaces, amenity areas, outdoor sitting areas, and accessible roof top areas among others.

2.4.1 National Policies

According to the 'Urban Development and Building Heights, Guidelines for Planning Authorities (Government of Ireland, December 2021)' document, specific impact assessment of the micro-climatic effects should be performed for 'buildings taller than prevailing building heights in urban areas'. (In the same guidance, standard buildings height is considered 6-8 storeys. Above this height, buildings are considered 'taller' for Dublin standards.)

Usually, the recommended approach to wind microclimate studies is based on the building height, as presented in Figure 2.7 and prescibed by the Wind Microclimate Guidelines for Developments in the City of London (August 2019).



Building Height	Recommended Approach to Wind Microclimate Studies
Similar or lower than the average height of surrounding buildings **Up to 25m**	Wind studies are not required, unless sensitive pedestrian activities are intended (e.g. around hospitals, transport hubs, etc.) or the project is located on an exposed location
Up to double the average height of surrounding buildings **25m to 50m**	Computational (CFD) Simulations **OR** Wind Tunnel Testing
Up to 4 times the average height of surrounding buildings **50m to 100m**	Computational (CFD) Simulations **AND** Wind Tunnel Testing
High Rise **Above 100m**	**Early Stage Massing Optimization:** Wind Tunnel Testing OR Computational (CFD) Simulations **Detailed Design:** Wind Tunnel Testing **AND** Computational (CFD) Simulations to demonstrate the performance of the final building design

Figure 2.7: Recommended Approach to Wind Microclimate Studies based on Building Height, as prescribed by the Wind Microclimate Guidelines for Developments in the City of London (August 2019)

Good wind microclimate conditions are necessary for creating outstanding public spaces.

Adverse wind effects can reduce the quality and usability of outdoor areas, and lead to safety concerns in extreme cases.

Computational fluid dynamics (CFD) tools can create high quality output that provide a good understanding of fundamental flow features. The CFD models must include a detailed three-dimensional representation of the proposed development.

Maximum cell sizes near critical locations (e.g. entrances, corners, etc.) must be 0.3m or smaller. Sufficient cells should be also used between buildings with a minimum of 10 across a street canyon. However, the cell size of buildings away from the target can be larger to allow for modelling efficiency. The CFD models should represent all surrounding buildings that are within 400m from the centre of the site. Other taller buildings outside of this zone that could have an influence on wind conditions within the project site should be included for wind directions where they are upwind of the project site. The models must contain at least 3 prism layers below 1.5m height, to capture near-ground effects.

CFD analysis also reports conditions in areas away from the site where cumulative effects of a cluster of tall buildings could lead to adverse wind conditions.

3. STUDY METHODOLOGY

3.1 STUDY METHODOLOGY

The methodology adopted for the wind microclimate analysis of the proposed development is outlined as follows;

The following sections give details on the methodology utilized.

- Perform a wind desktop study of the existing environment.
- Perform computational wind microclimate analysis of the proposed development within the existing environment.

3.2 WIND IMPACT ASSESSMENT ON BUILDINGS

3.2.1 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 3.1 shows the wind velocity profile, as described above.

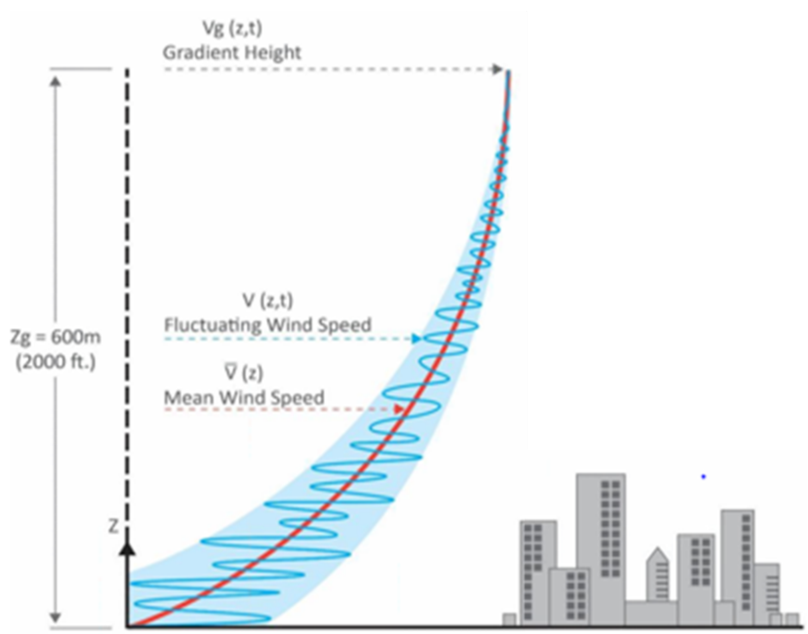


Figure 3.1: Wind Velocity Profile

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.

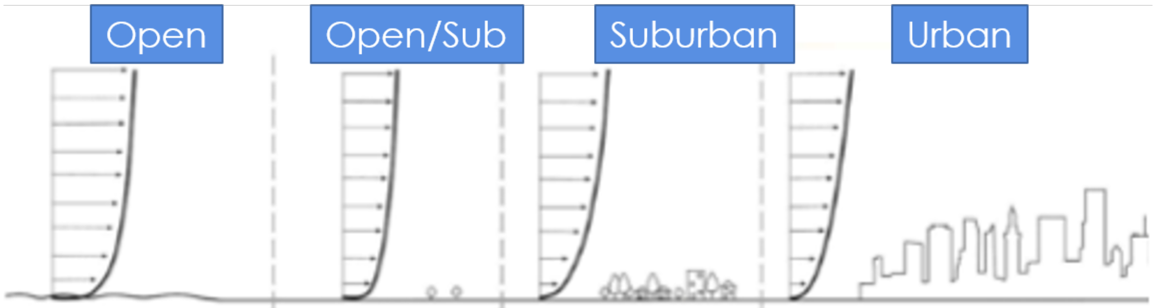


Figure 3.2: Wind Velocity Profile for different terrains

In order to assess the wind conditions in a particular area, it is important to know (Figure 3.3):

- Weather conditions in the area
- Location and orientation of the site
- Buildings distribution in the area
- Flow patterns at the building

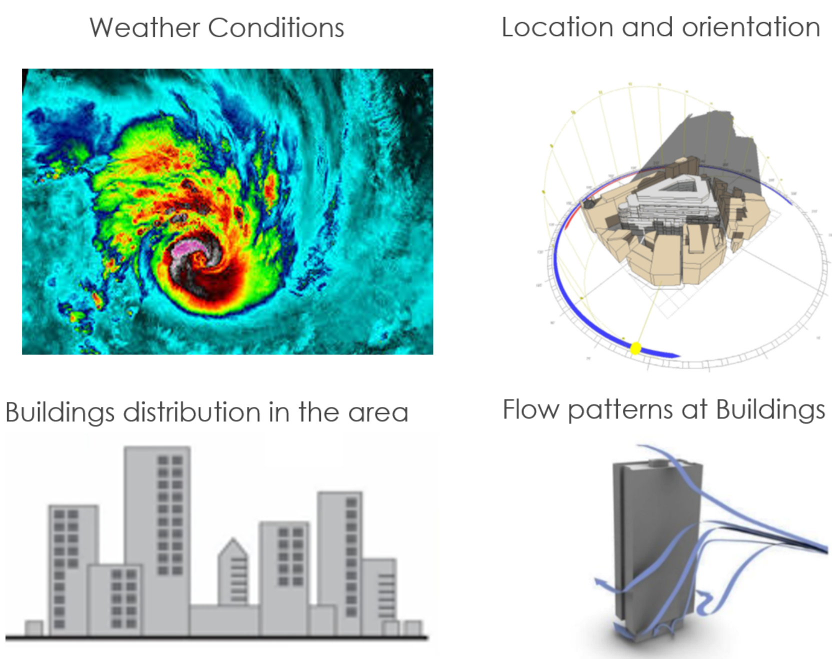


Figure 3.3: Parameters to know for Wind Conditions Assessment

Moreover, it is important to understand key flow features (Figure 3.3):

- Broad Building Face creates "DOWNWASH"
- Low Building Upwind Increases Wind Effects
- Gaps Between Buildings Increases Wind Velocity
- Low Building Upwind Increases Wind Effects

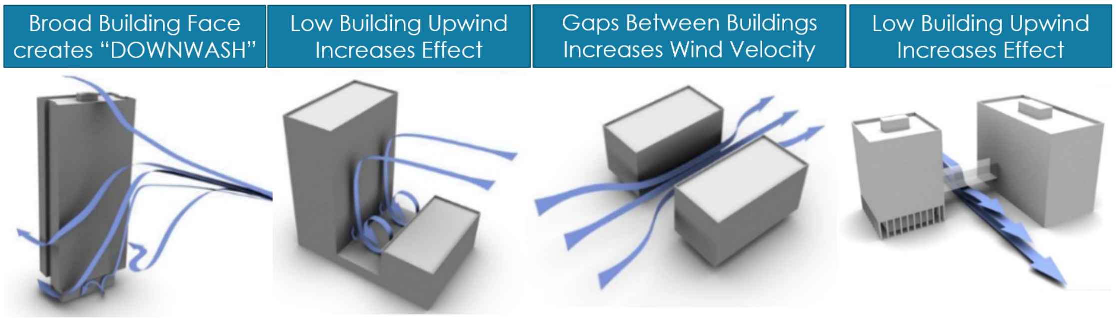


Figure 3.4: Parameters to know for Wind Conditions Assessment

3.3 ACCEPTANCE CRITERIA

3.3.1 PEDESTRIAN COMFORT AND LAWSON CRITERIA

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 reflect the fact that calm activity requires calm wind conditions, which are summarised by the Lawson scale, shown in Figure 3.5. 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 3.6. 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.

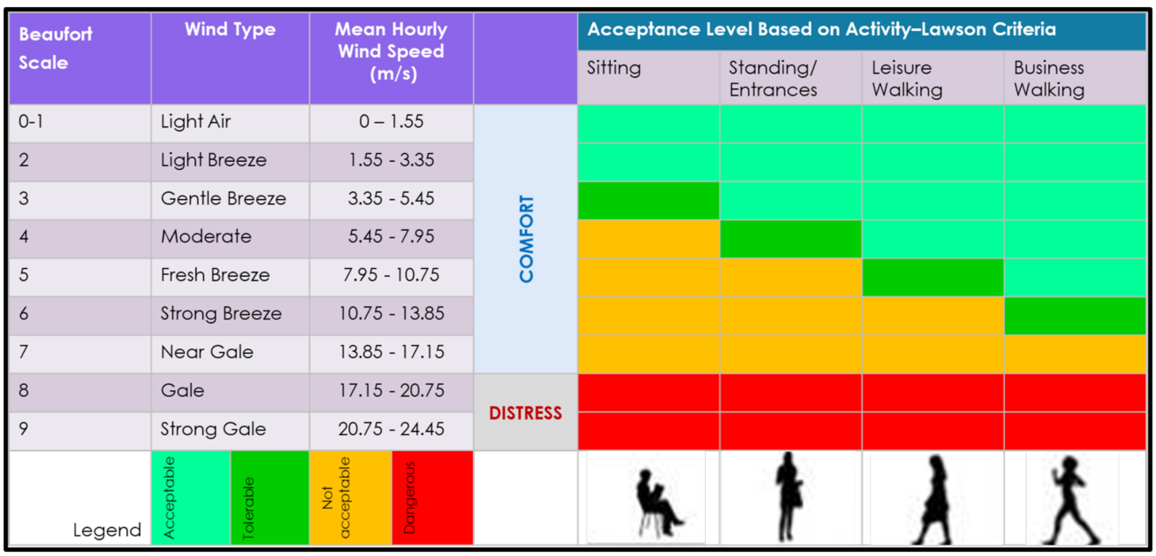


Figure 3.5: Lawson Scale

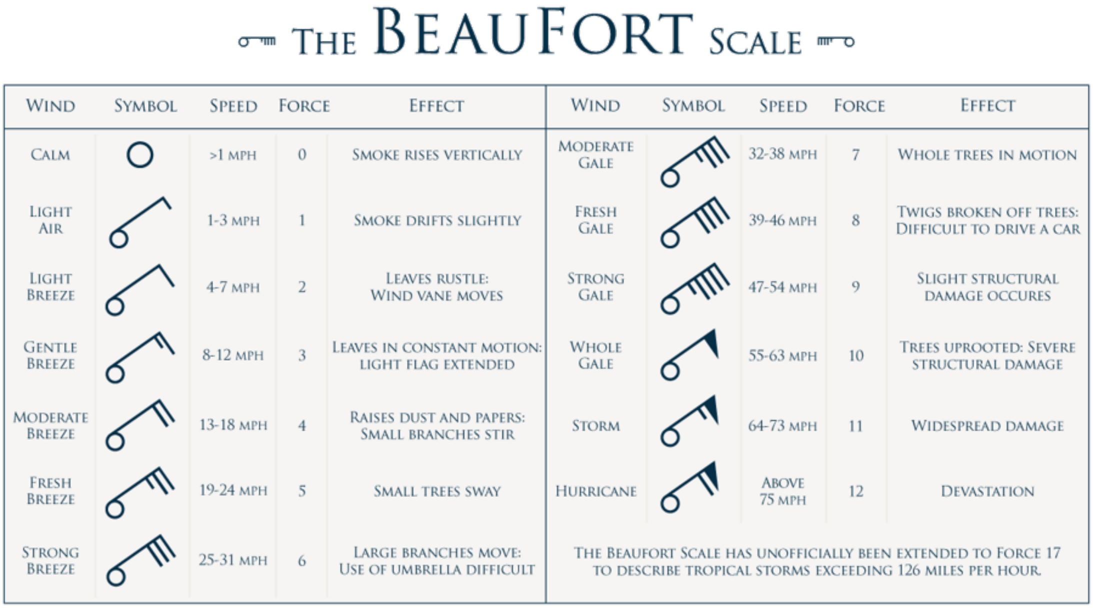


Figure 3.6: Beaufort Scale

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. Unless in extremely unusual circumstances, velocities at pedestrian level increase as you go higher from ground level.

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 condition are unacceptable for the type of pedestrian activity and mitigation measure should be implemented into the design.

For the scope of this report, a qualitative analysis is undertaken, therefore the flow pattern will be highlighted but it will not reflect the velocity magnitude developed.

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 3.7 shows the hourly wind gust rose for Dublin, from 1990 to 2020. This will be necessary to assess how many hours per year on average the velocity exceed the threshold values.

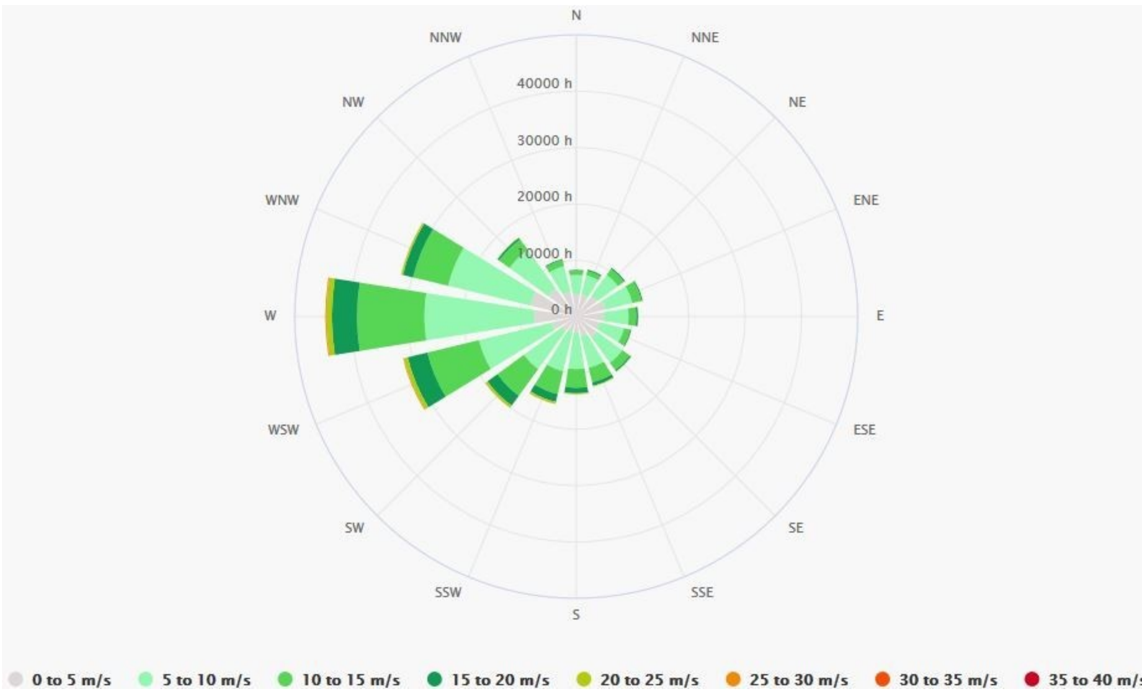


Figure 3.7: Hourly Dublin Wind Gust Rose

Distress for Frail Person or Cyclist
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 Figures 3.8 and 3.9 respectively as cumulative hours and cumulative percentage), it is possible to see how many hours in 30 years the gust velocity of 15m/s is exceed at pedestrian level in each direction.

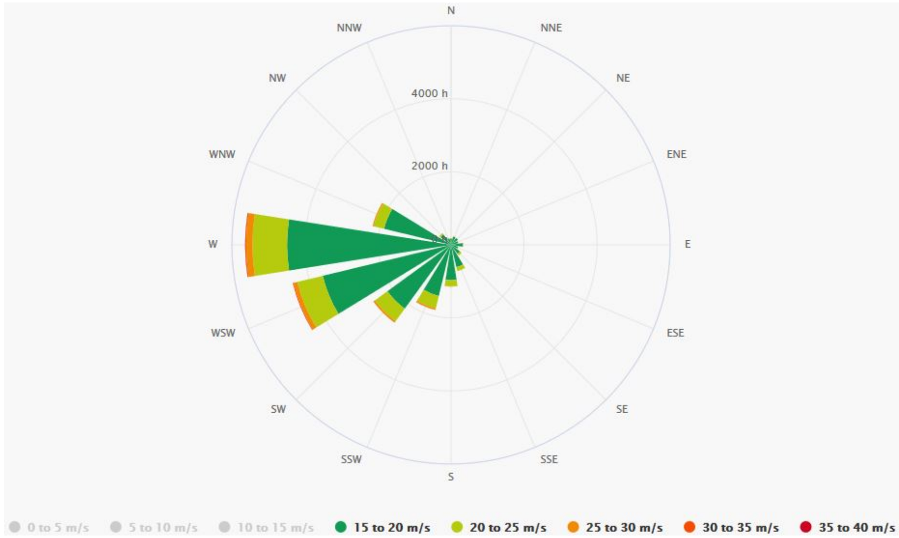


Figure 3.8: Hourly Dublin Wind Gust Rose - Cumulative hours when the velocity is above 15m/s

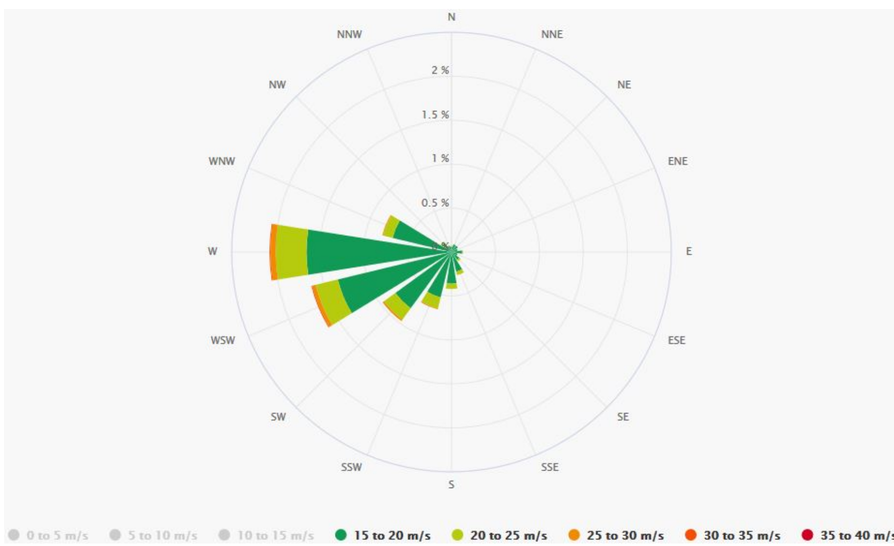


Figure 3.9: Hourly Dublin Wind Gust Rose - Cumulative percentage of time when the velocity is above 15m/s

A total of 2 hours per years corresponds to 0.02% in one year, which means 0.6% in 30 years. Looking at the wind roses above, it is possible to notice that a velocity of 15m/s was reached in Dublin only for the following directions (in increasing order of percentage) over the years 1990-2020:

1. West 270°
2. West-South-West 247.5°
3. South-West 225°

Distress for General Public

The criteria for distress for a member of the general population is 20m/s wind occurring for more than two hours per year. Limiting the results from the above wind rose to the only values above 20m/s (as reported in Figures 3.10 and 3.11 respectively as comulative hours and cumulative percentage), it is possible to see how many hours in 30 years the gust velocity of 20m/s is exceed at pedestrian level in each direction.

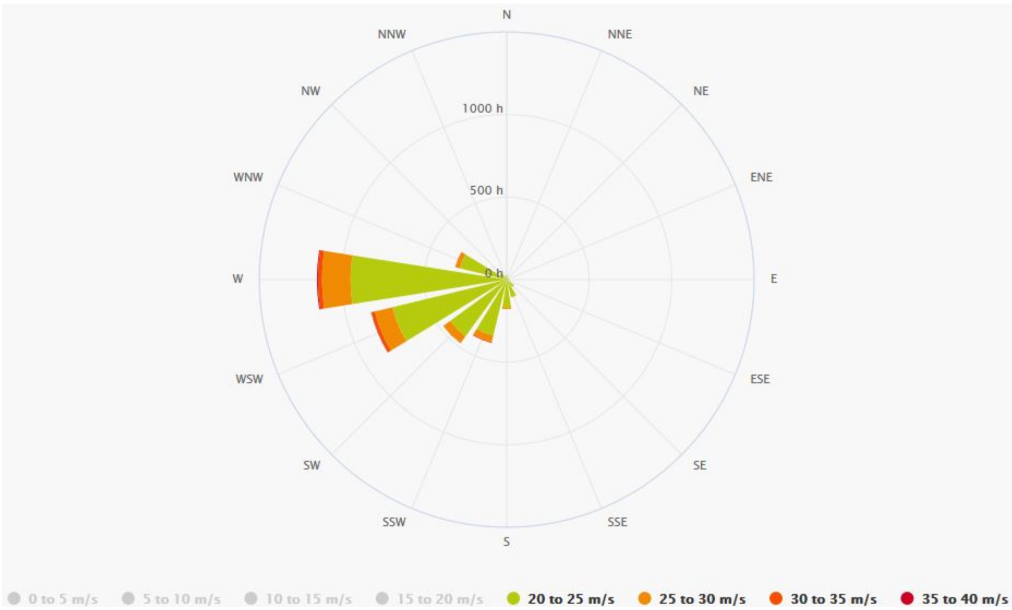


Figure 3.10: Hourly Dublin Wind Gust Rose - Cumulative hours when the velocity is above 20m/s

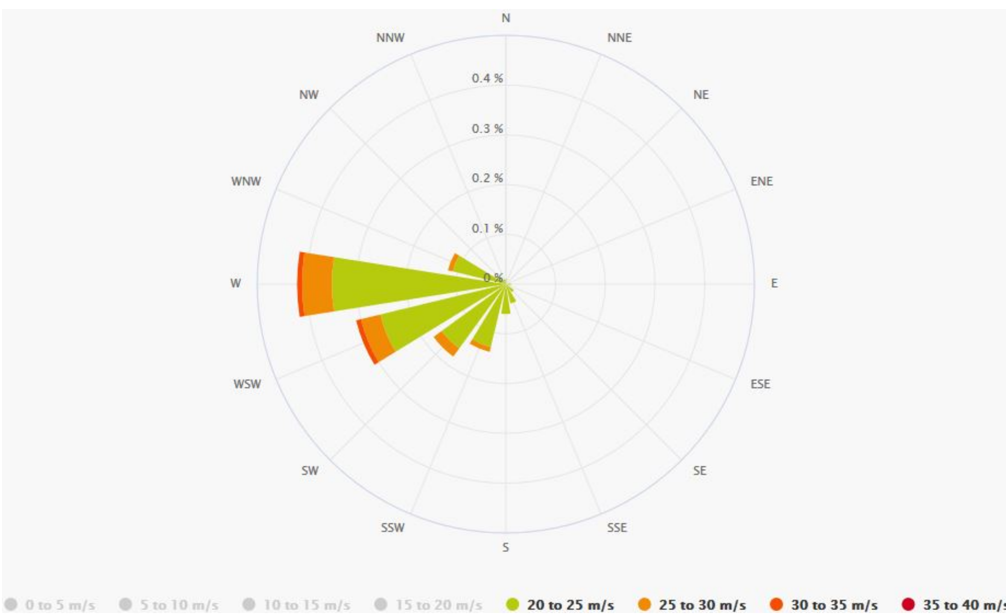


Figure 3.11: Hourly Dublin Wind Gust Rose - Cumulative percentage of time when the velocity is above 20m/s

A total of 2 hours per years corresponds to 0.02% in one year, which means 0.6% in 30 years. Looking at the wind roses above, it is possible to notice that a velocity of 20m/s was never reached in Dublin over the years 1990-2020.

3.4 MITIGATION MEASURES

As stated in the previous section, if the predicted wind conditions exceed the threshold, then condition are unacceptable for the type of pedestrian activity and mitigation measure should be accounted for.

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 3.12 and 3.13):

- **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.

  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.

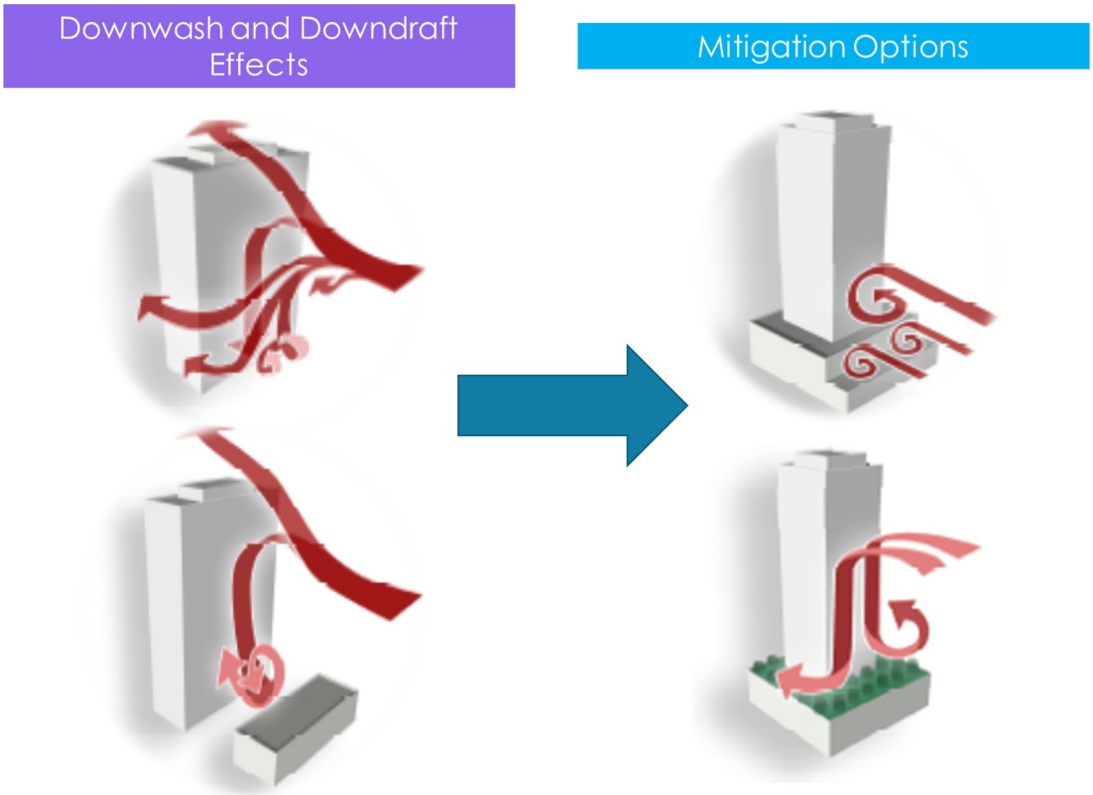


Figure 3.12: Mitigation Measures for Downwash and Downdraft Effects

- **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.

  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.

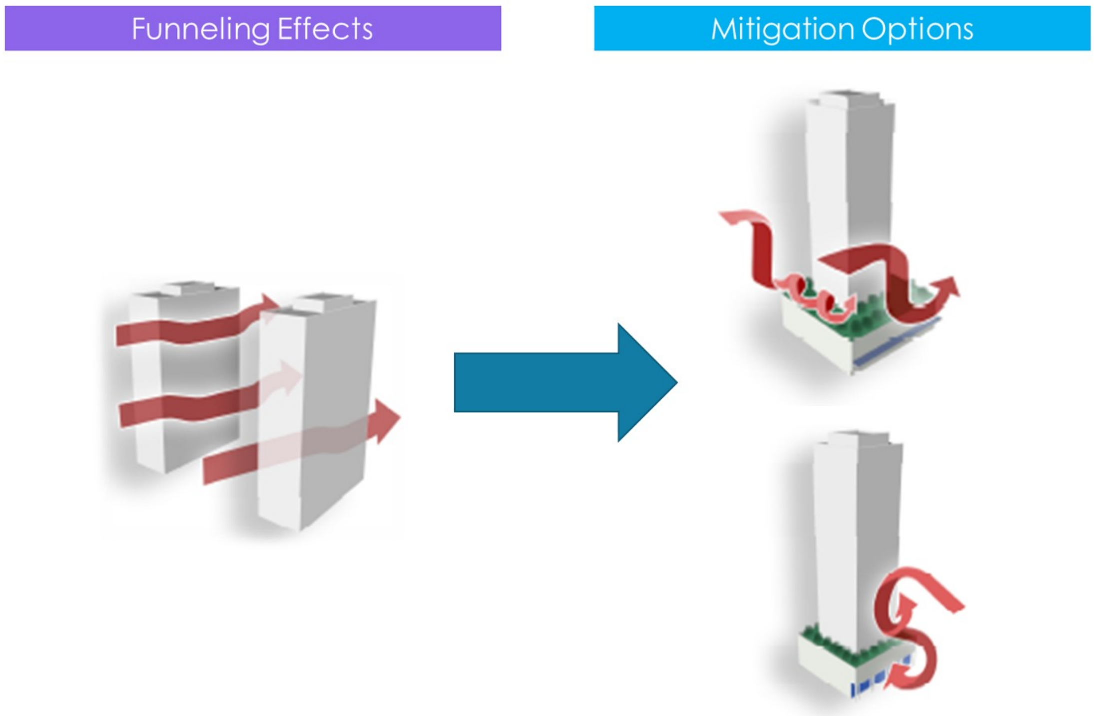


Figure 3.13: Mitigation Measures for Funnelling Effects

Landscape Trees Modelling (Using Porous Media)

Through CFD Modelling, it is possible to implement the effects of landscaping trees on the wind flowing through an urban environment. Urban landscape managers, local councils and architects can now observe and assess the effects of landscaping trees in their urban landscape models. The landscape trees are simulated as comprising effects of porous zones within the urban environments. This is an essential tool for accurately assessing the actual wind speed and pattern at a pedestrian level when landscape are available. Figure 3.14 show the plan view of the mitigation measures that will be implemented around the Strategic Housing Development at ground floor.

Figure 3.14: Plan View of the Mitigation Measures that will be implemented around the Strategic Housing Development

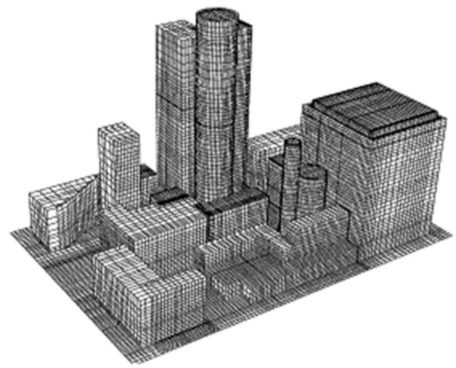
4. CFD MODELLING METHOD

4.1 CFD MODELLING METHOD

Computational Fluid Dynamics (CFD) is a numerical technique 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 4.1. 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 providing that the scenario modelled is a good representation of reality.

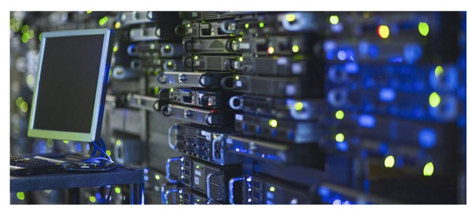
PRE-PROCESSING

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.

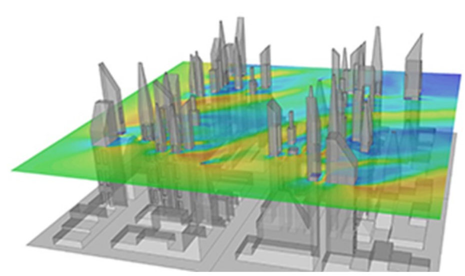


Figure 4.1: CFD Modelling Process Explanation

4.1.1 NUMERICAL SOLVER

This report 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).

4.2 COMPUTATIONAL MESH

The level of accuracy of the CFD results are determined by the level of refinement of the computational mesh. Details of parameters used to calculate the computational mesh are presented in Table 4.1. Figure 4.2 shows the mesh utilised in the simulations.

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 center of each of these cells and then an interpolation function is used by the software to provide the results in the entire domain.

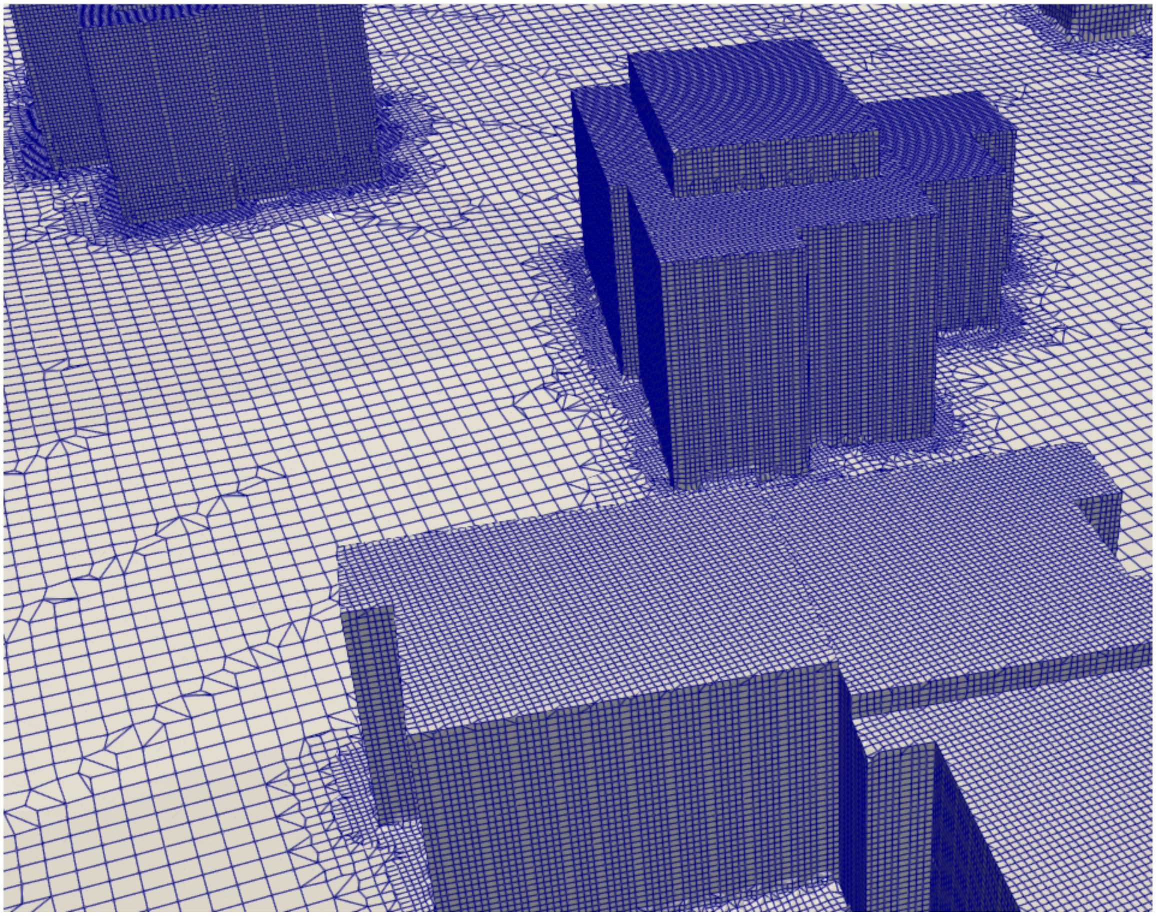


Figure 4.2: Strategic Housing Development Domain Computational Mesh Utilized

4.3 BOUNDARY CONDITIONS

A rectangular computational domain was used for the analysis. The wind direction were altered without changing the computational mesh. For each dimension, an initial wind velocity was set according to the weather data collected, in order to consider the worst case scenario (see Chapter 5). Surfaces within the model were specified as having 'no slip'. This condition ensures that flow moving parallel to a surface is brought to rest at the point where it meets the surface. all the other domain boundaries are set as "Open Boundaries".

PARAMETERS TO CALCULATE COMPUTATIONAL MESH	
Air Density ρ	$1.2kg/m^3$
Ambient Temperature (T)	$288K(approx.15C^{\circ})$
Gravity Acceleration (g)	$9.8m/s^2$
dx	0.5 m at the building 1m in the surroundings 2m elsewhere
Mesh cells size	0.1 m (ratio 1:1)
Total mesh size	Approx. cells number = 10 million

Table 4.1: Paramenters To Calculate Computational Mesh

5. WIND DESKTOP STUDY

5.1 WIND FLOW CONDITIONS

This analysis consider the whole development being exposed to the typical wind condition of the site. The building is oriented as shown in the previous sections. The wind profile is built using the annual average of meteorology data collected at Dublin Airport Weather Station. Figure 5.1 shows on the map the position of Strategic Housing Development and the position of Dublin Airport.

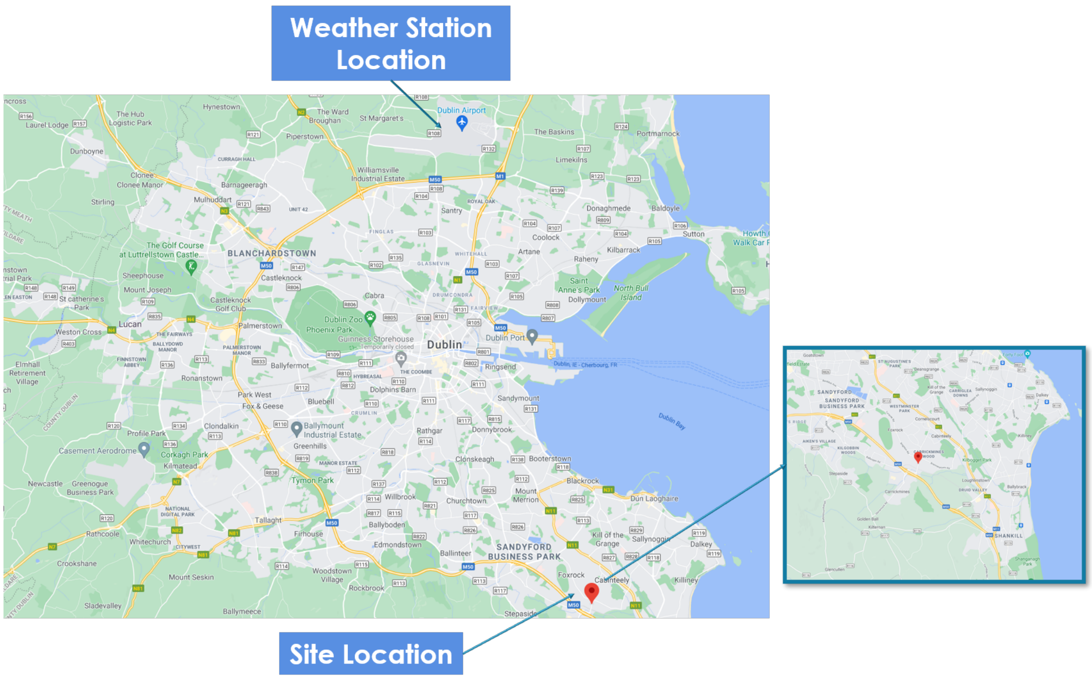


Figure 5.1: Map showing the position of Strategic Housing Development and Dublin Airport

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.

5.2 LOCAL, MAXIMUM AND MEAN WIND CONDITIONS

5.2.1 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 analyzed for this assessment as follows:

- The meteorological data associated with the maximum daily wind speeds recorded over a 30 year period between 1990 and 2020 and,
- The mean hourly wind speeds recorded over a 10 year period between 1990 and 2020. The data is recorded at a weather station at the airport, which is located 10m above ground or 71mOD.

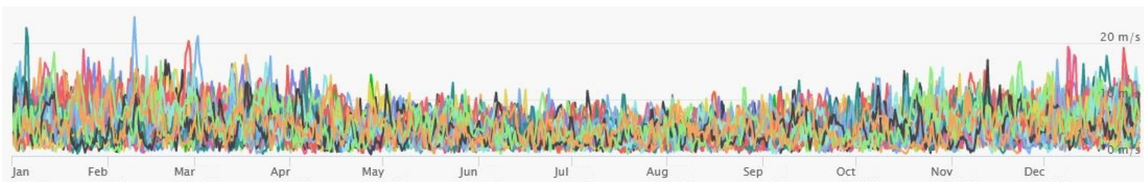


Figure 5.2: Local Wind Conditions - Wind Speed - 1990-2020

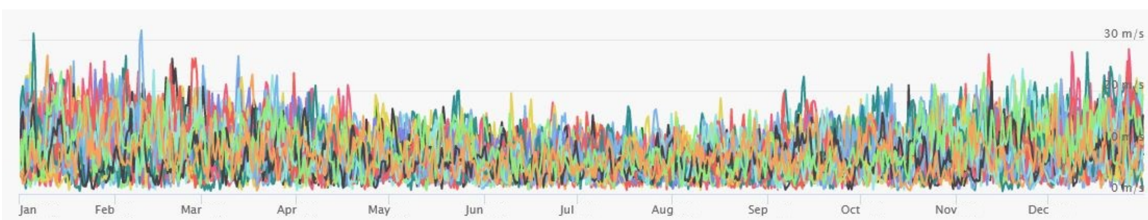


Figure 5.3: Local Wind Conditions - Wind Gust - 1990-2020

Figure 5.4, presenting the wind speed diagram for Dublin, shows the days per month, during which the wind reaches a certain speed. In Figure 5.5, 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.

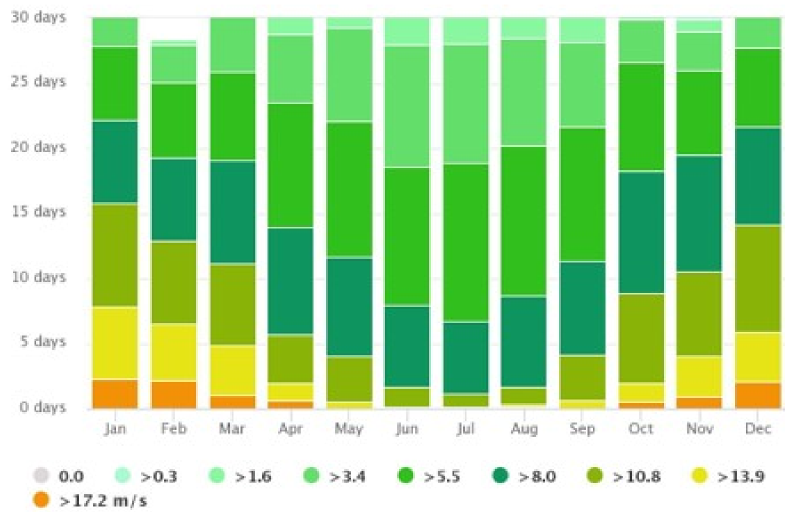


Figure 5.4: Dublin Wind Speed Diagram

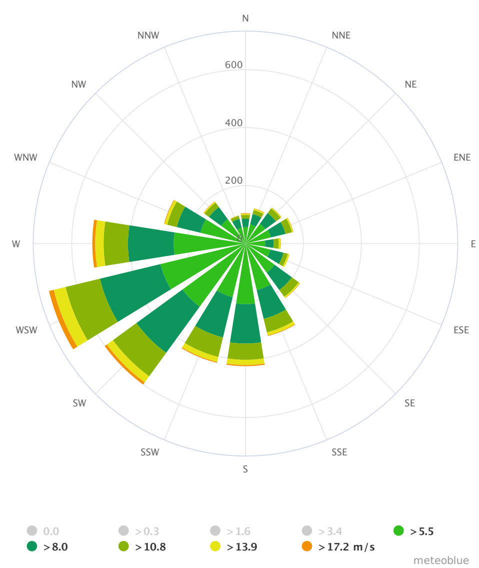


Figure 5.5: Dublin Wind Rose

Based on the criterion of occurrence frequency the main wind directions to be considered in pedestrian wind comfort assessment are presented in Figure 5.6 and listed below in descending order of dominance:

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 and will be further analysed during the final assessment.

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 5.6: Main Wind Directions Occurrence Frequency

5.2.2 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.

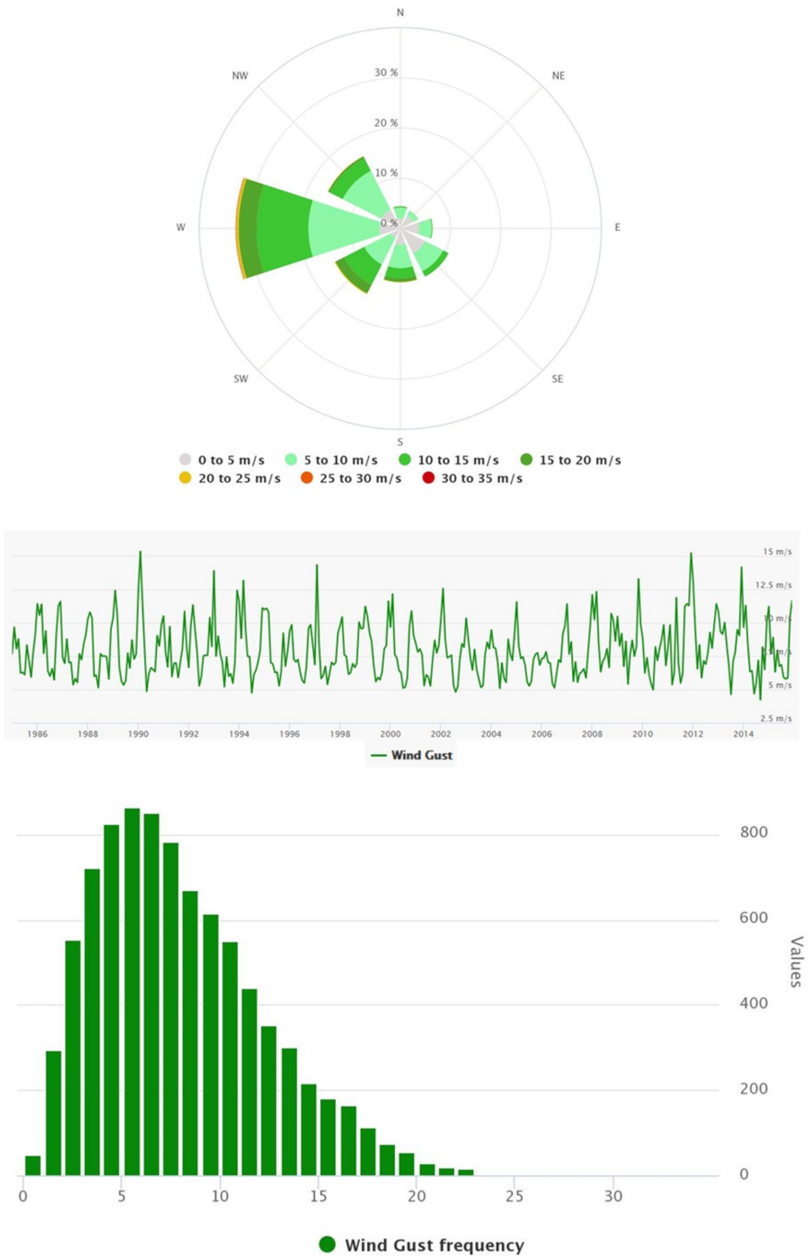


Figure 5.7: Maximum Wind Conditions

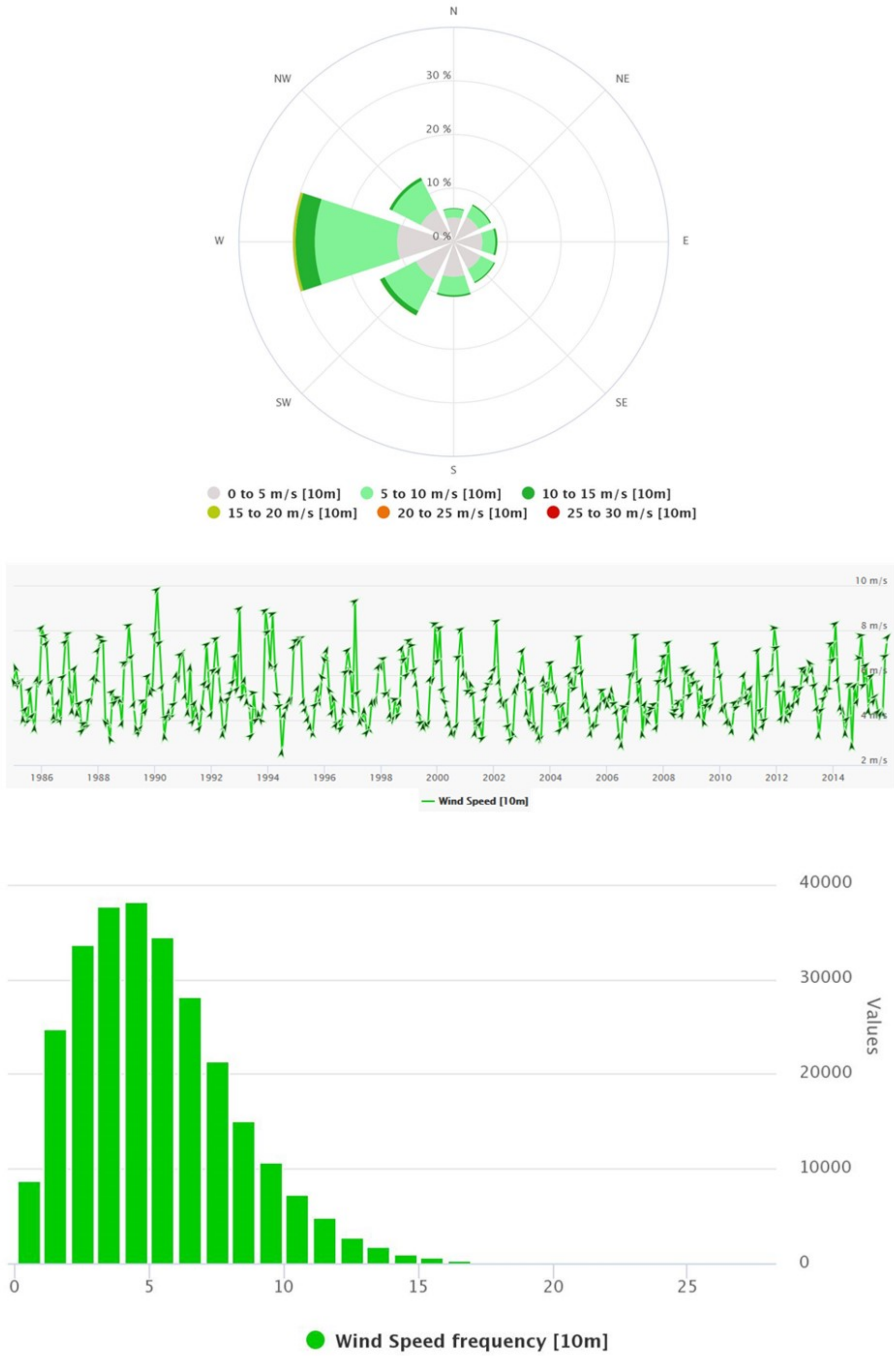


Figure 5.8: Mean Wind Conditions

5.2.3 TOPOGRAPHY and BUILT IN ENVIRONMENT

Figure 5.9 shows an aerial photograph of the terrain surrounding the construction site at Strategic Housing Development .

The Strategic Housing Development Site is located in Dublin 18. The Glenamuck Road North is located to the west of the site and forms the western boundary to the site. Carrickmines Croquet and Lawn Tennis Club are located further west of North Glenamuck Road, as detailed in the aerial view. There is also an existing access point serving the site from Glenamuck Road North.

The subject site is located within a distance of approximately 130m of the Green Luas Line with the Carrickmines stop located to the south of the site. The site is well serviced by the M50 motorway, which is located 400m to the Southwest and by cycle lanes on North Glenamuck Road. The established character of the surrounding area is mature and comprises large detached two storey family houses set on generous plots.

Residential densities are characterised as low within the immediate context. These dwellings and large plots reflect an area as it once was, i.e. suburban, with weak transport and retail links. These planning weaknesses have been eliminated by factors such as the LUAS stop (approx. 130m from the site), the M50 and its Junction (approx. 350m from the site) as well as the new retail centre at The Park (approx. 1.0km from the site) and Dundrum Town Centre (9 LUAS stops from the site). These services now enable the redevelopment of this area into more sustainable community.

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 the wind directions considered for this study are in this connection “urban winds” and no distinction will be made between them.

Figure 5.9: Built-in Environment Around Construction Site at Strategic Housing Development

5.2.4 OPEN AREA FUNCTIONS

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 cafe 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; shopping street; mall
D	Objective business walking; brisk or fast walking; Car park; avenue; sidewalk; belvedere

Table 5.1: Main Categories for Pedestrian Activities

5.2.5 WIND COMFORT ASSESSMENT

In order to conduct the wind comfort assessment, Figure 5.10 - Figure 5.11 shows different orientations of the Strategic Housing Development.

Figure 5.10: Orientation of Lands at Strategic Housing Development

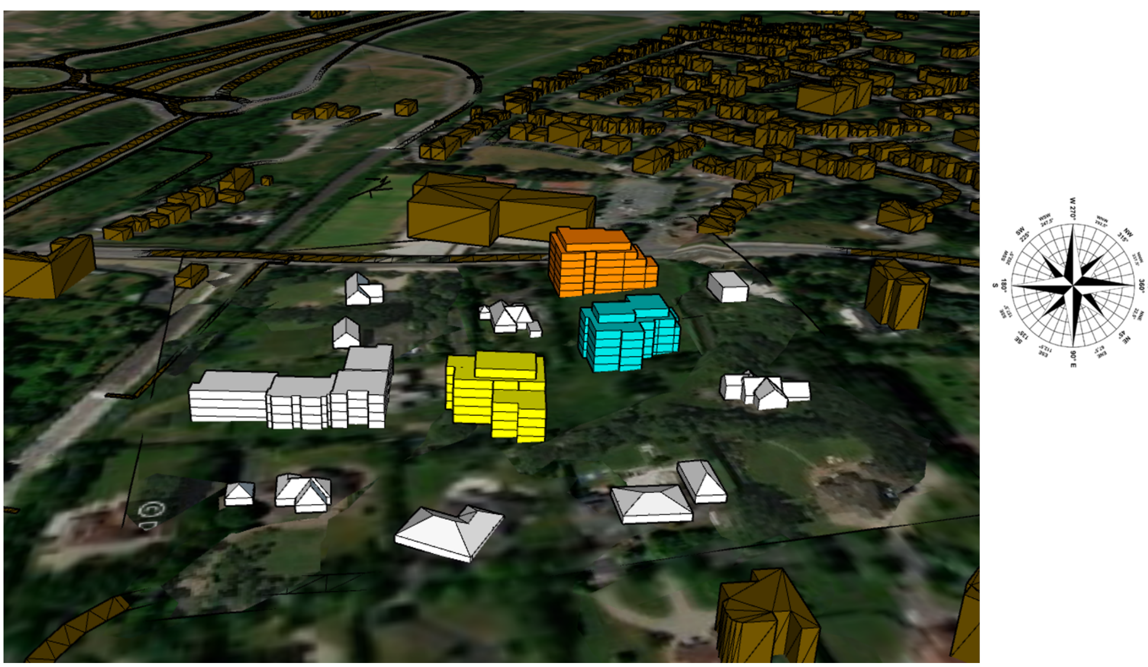


Figure 5.11: Orientation of Lands at Strategic Housing Development

WIND FROM WEST

The different flow features are indicated in Figure 5.12 by letters and discussed in the following text. It should be kept in mind that the presented flow pattern is only indicative and based on experience and fundamental fluid mechanical principles and does not reflect the real flow vector in magnitude and direction.

Potential funnelling effects could be experienced in area A and C. However, possible solutions for this could be horizontal canopies on the windward face of a base building, which improves 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.

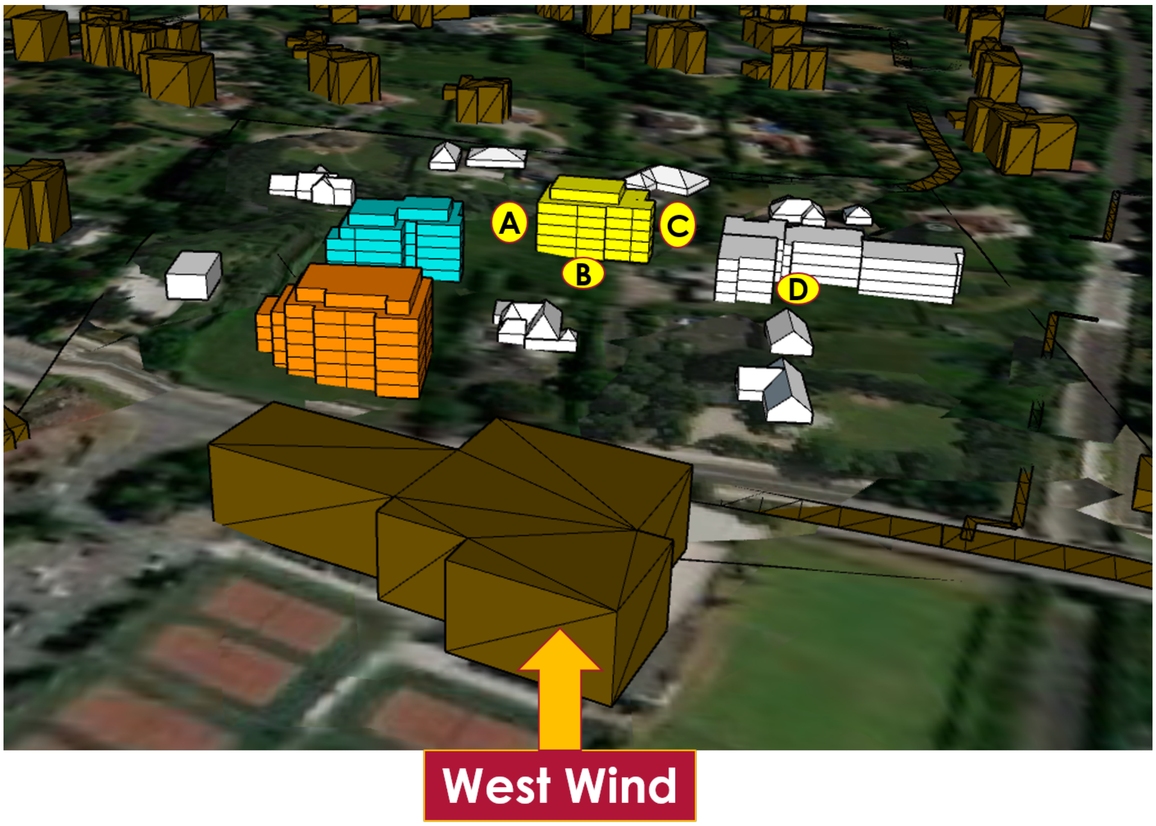


Figure 5.12: Flow around the Buildings at Strategic Housing Development for Wind from West

WIND FROM SOUTH

Wind from the south will flow through the south side of the buildings.

Funnelling effects could potentially be experienced in area E indicated in Figure 5.13. However, possible solutions for this could be horizontal canopies on the windward face of a base building, which 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.The use of rows of trees on either sides of the roads corresponding to these three areas have been implemented to contrast the above effects.

An air circulation zone is expected in F that can cause downwash effect. This can be mitigated by the presence of trees.

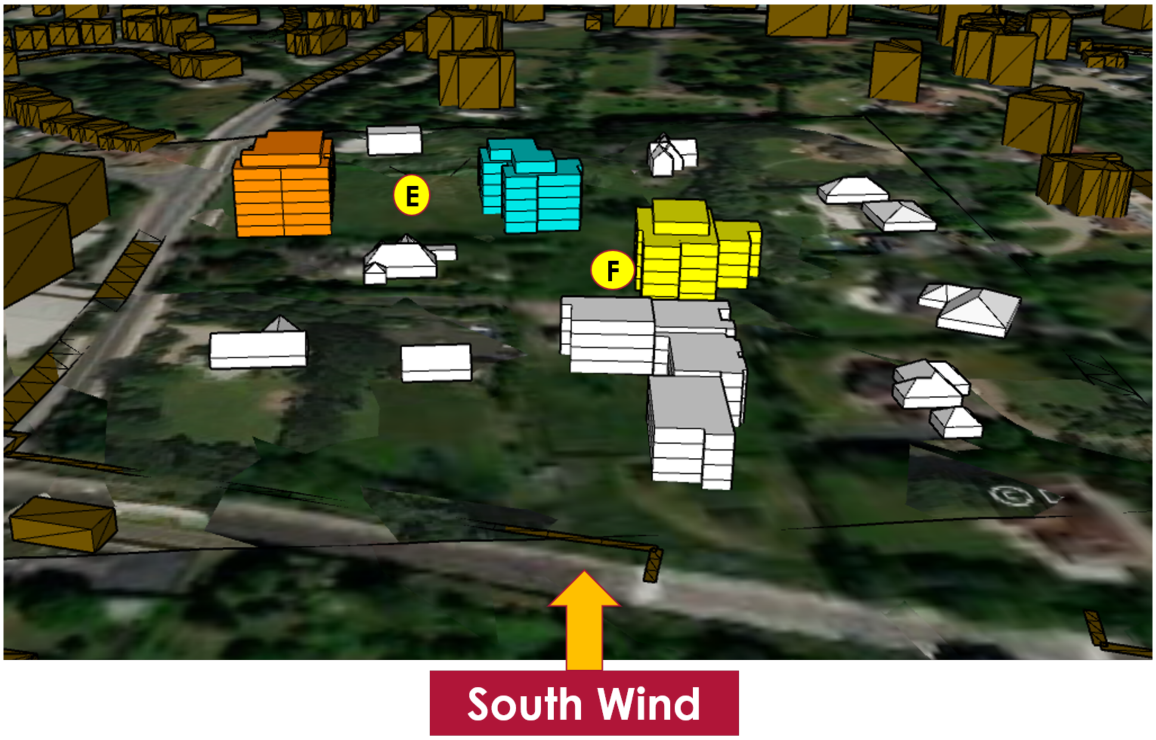


Figure 5.13: Flow around the Buildings at Strategic Housing Development for Wind from South

WIND FROM SOUTH-WEST

South-West wind will flow through the development. The surrounding buildings 5.14, in the South-West direction of the development will deflect airflow along towards the development at area G and H. This can be potentially mitigated by the presence of trees.

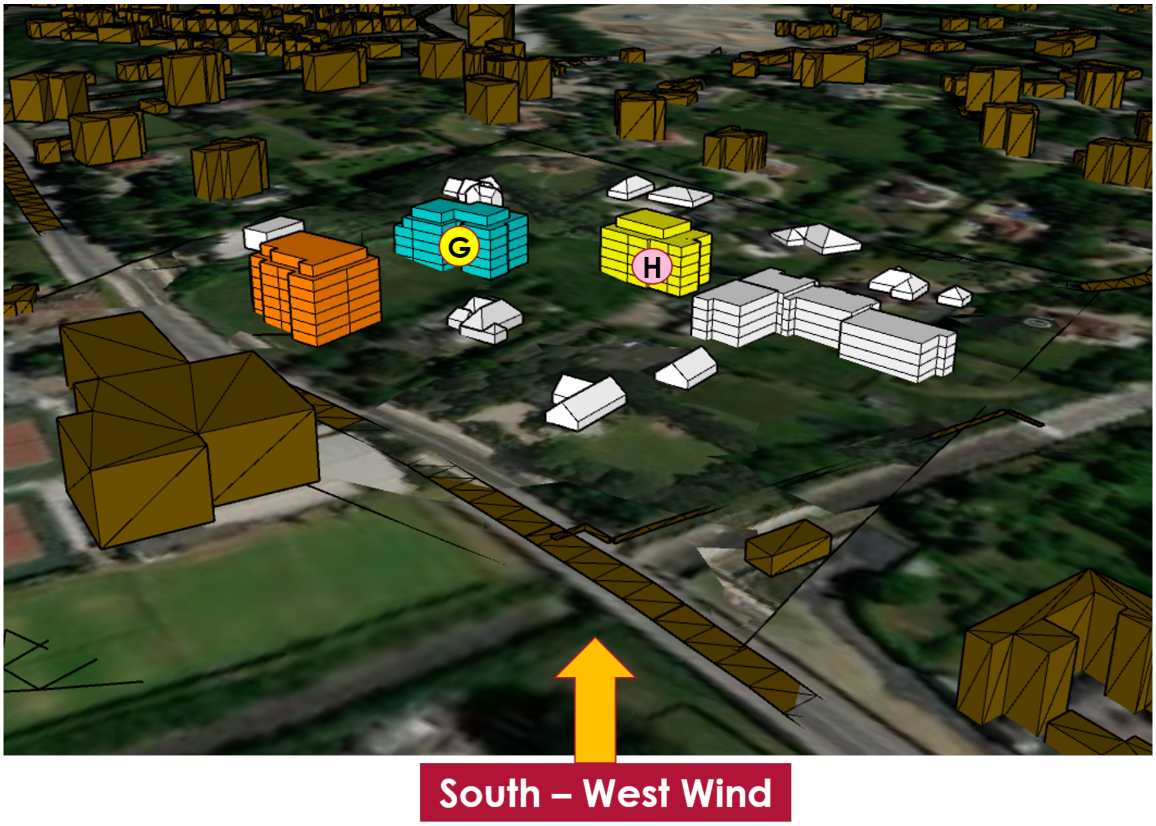


Figure 5.14: Flow around the Buildings at Strategic Housing Development for Wind from South-West

6. ANALYSIS OF CFD RESULTS

6.1 CFD RESULTS

It is of interest at this point to underline again the objectives of the CFD 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.

- 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 sidewalks and street frontages, pathways, building entrance areas, open spaces, amenity areas, outdoor sitting areas, and accessible roof top areas among others.

Results of the simulations carried out are detailed in the following Sections. The results present the parameters outlined in the acceptance criteria section described previously. Slices of the following parameters are collected throughout the simulation time and shown for steady state times:

- Flow Velocity
- Lawson Map

6.2 MICROCLIMATE ASSESSMENT OF PROPOSED DEVELOPMENT

This section aims to show wind patterns around the proposed development under mean and peaks wind conditions typically occurring in the area. A 3D view of the proposed development massing model in the domain is presented in Figure 6.1.

Figure 6.1: 3D View of the Proposed Strategic Housing Development Development and Adjacent Buildings - South Side 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 preliminary simulation results the following observations are pointed out:

- The wind profile around the existing development environment was built using the annual average 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.
- The prevailing wind directions for the site are identified as West, South-East and West-South-West, with magnitude of approximately 6m/s.
- We retain that mitigation measures such as the use of landscaping on ground floor will be sufficient to ensure that the proposed Strategic Housing Development will be designed to produce a high-quality environment that is attractive and comfortable for pedestrians of all categories.
- South west corners of block A, B and C potentially experience high wind speeds. This wind speeds are not critical, and can be further mitigated by the use of landscaping trees.
- High speeds are observed in the spaces between block B and C. This high speeds are due to funnelling and recirculation effects, and can be mitigated with the use of

landscaping in these areas.

- Given the position of the development blocks, and the recommended landscape, critical wind speeds are not expected on footpaths of the proposed development blocks.
- The proposed development does not impact or give rise to negative or critical wind speed profiles at the nearby adjacent roads, or nearby buildings.

6.2.1 Flow Velocity Results - Ground Floor

Results of wind speeds and their circulations at pedestrian level of 1.5m above the development ground are presented in Figures 6.4 to 6.19 in order to assess wind flows at ground floor level of Strategic Housing Development Development.

Wind flow speeds are shown to be within tenable conditions. Some higher velocity indicating minor funnelling effects are found near the North-West side of the development and the South-West corner of the Block A. However, as it can be seen, both areas were mitigated with landscaping and the flow velocities shown in the Lawson map indicate that the areas can be utilised for the intended use.

Therefore, it can be concluded that the wind speeds do not attain critical levels around the development.

Figure 6.3 shows an example of wind data mapped on surface, located at 1.5m above the ground. The scale used for all flow velocity results is set out in Figure 6.2. Red colors indicate critical values while blue colors indicate tenable conditions.

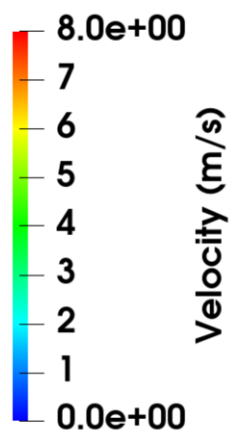


Figure 6.2: Velocity Colour Map

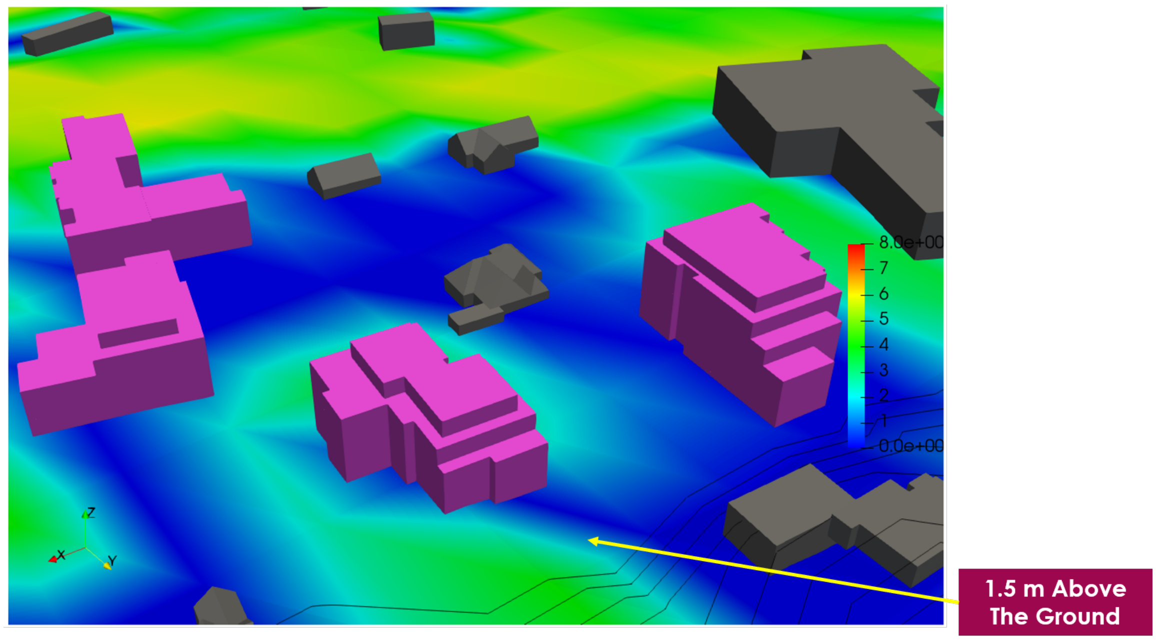


Figure 6.3: An example of wind data mapped on surface at 1.5m above the ground

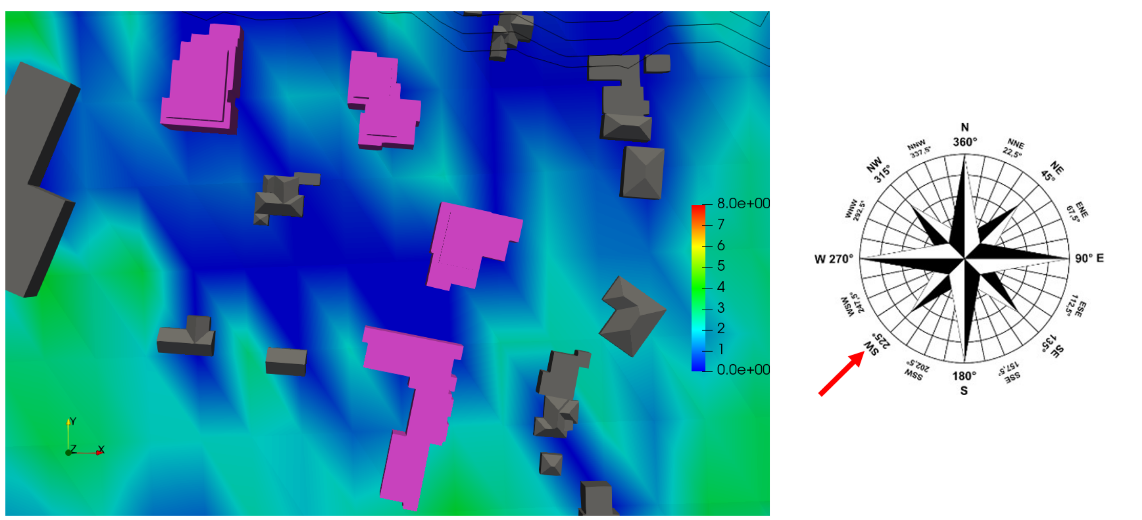


Figure 6.4: Ground Floor Level - Flow Velocity Results at Z=1.5m above the ground - Wind Direction: 225°

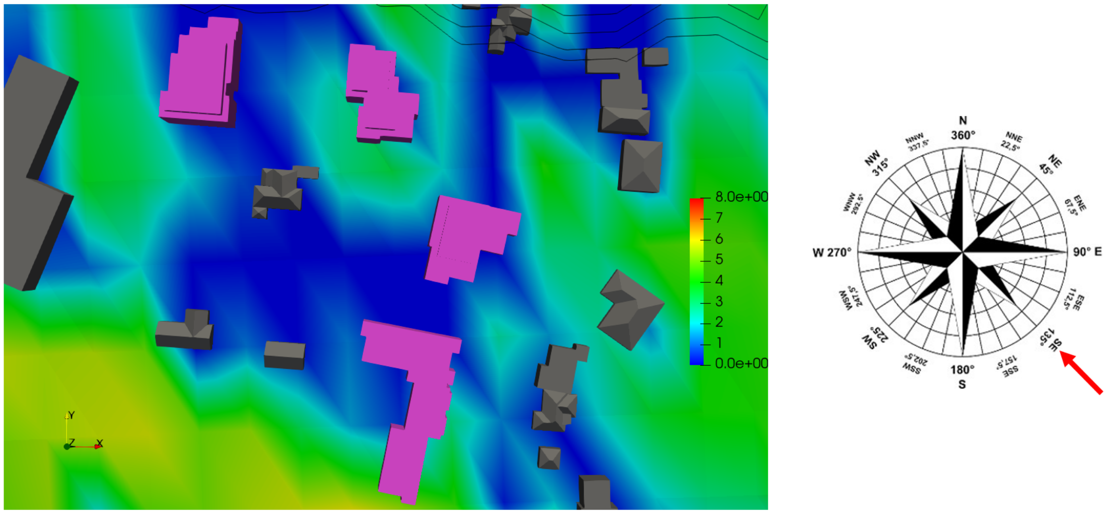


Figure 6.5: Ground Floor Level - Flow Velocity Results at Z=1.5m above the ground - Wind Direction: 135°

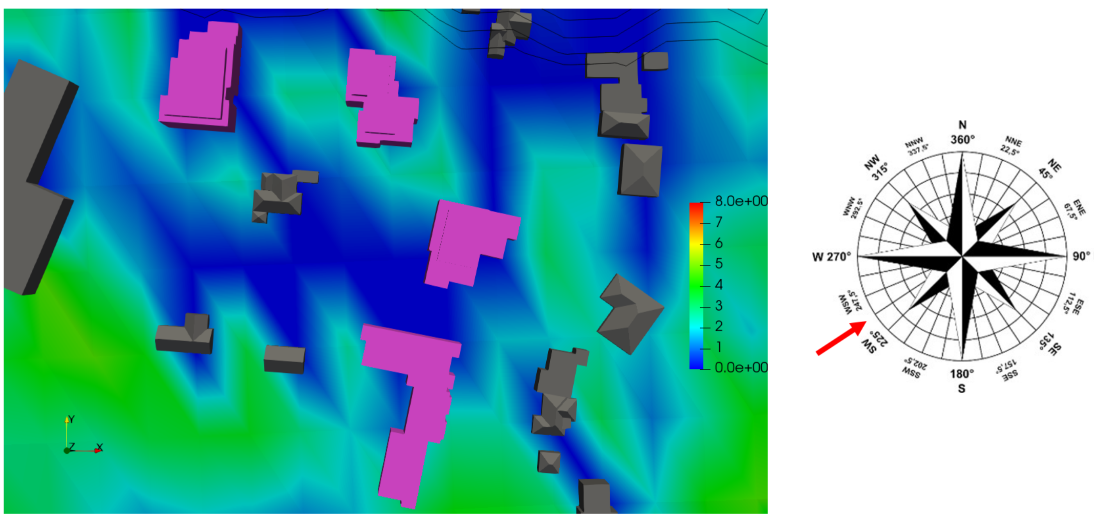


Figure 6.6: Ground Floor Level - Flow Velocity Results at Z=1.5m above the ground - Wind Direction: 236°

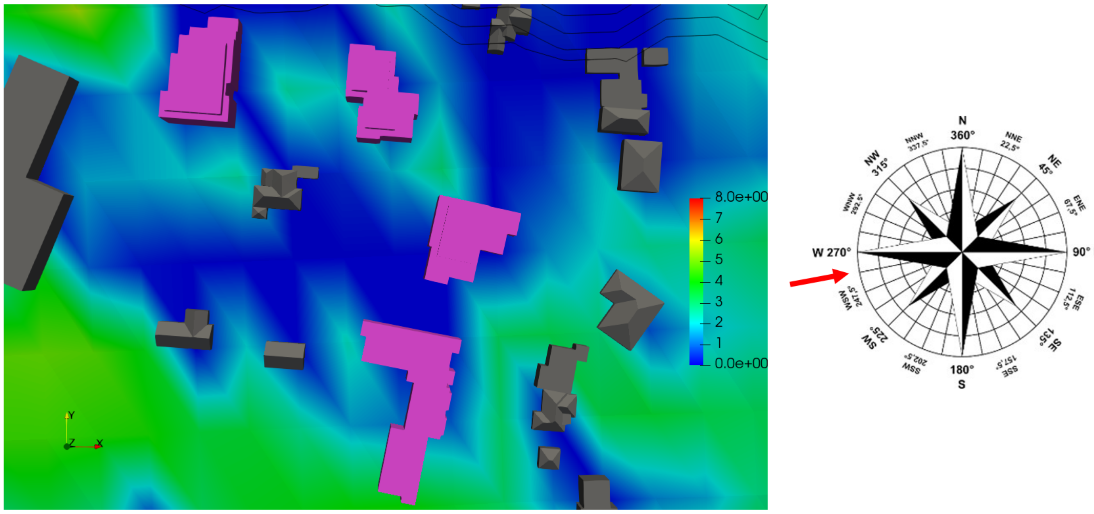


Figure 6.7: Ground Floor Level - Flow Velocity Results at Z=1.5m above the ground - Wind Direction: 258°

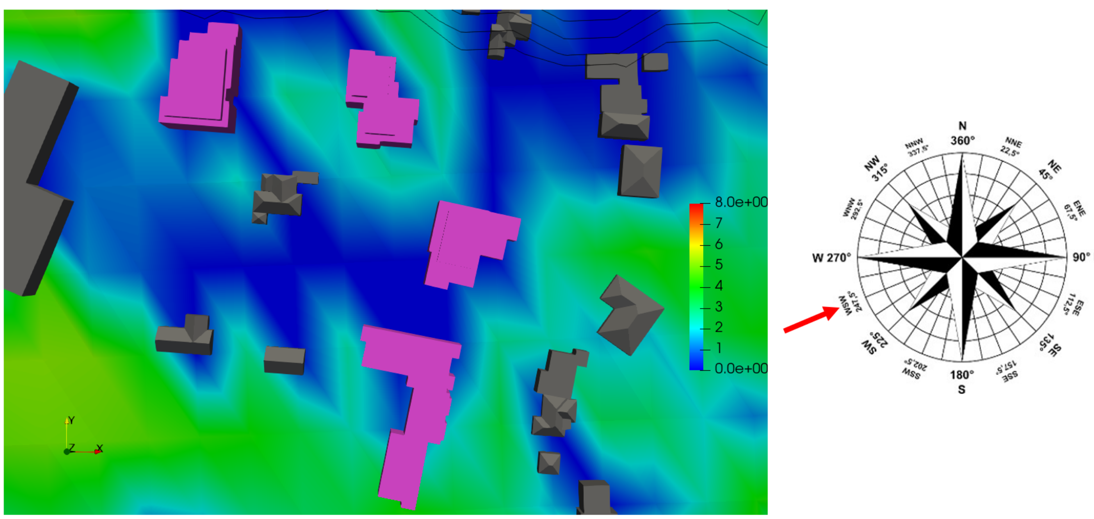


Figure 6.8: Ground Floor Level - Flow Velocity Results at Z=1.5m above the ground - Wind Direction: 247°

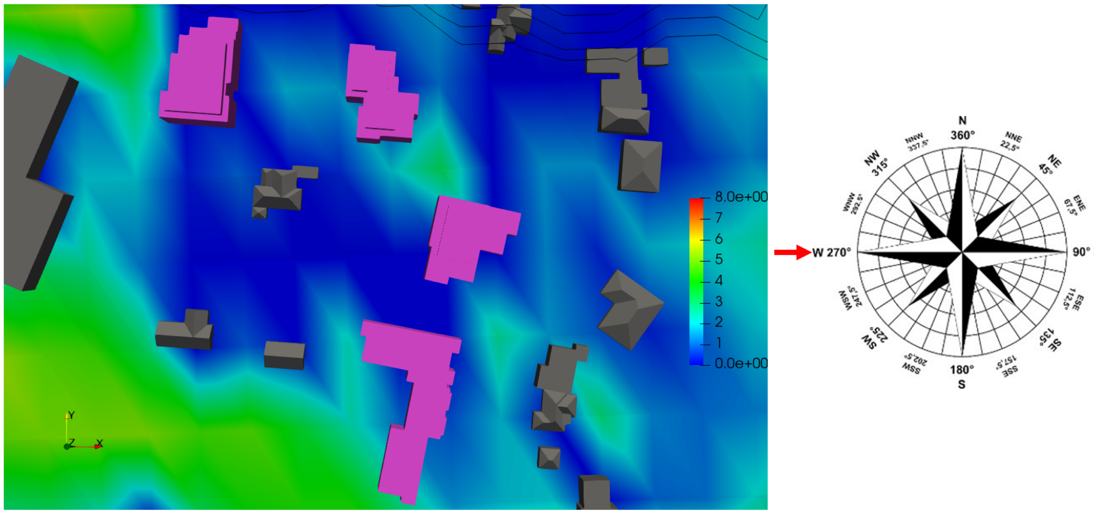


Figure 6.9: Ground Floor Level - Flow Velocity Results at Z=1.5m above the ground - Wind Direction: 270°

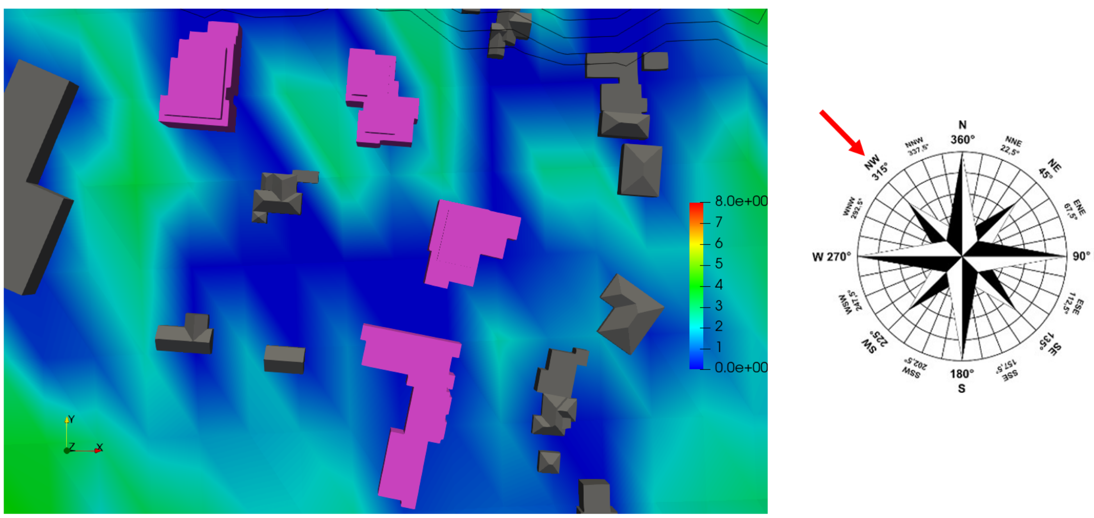


Figure 6.10: Ground Floor Level - Flow Velocity Results at Z=1.5m above the ground - Wind Direction: 315°

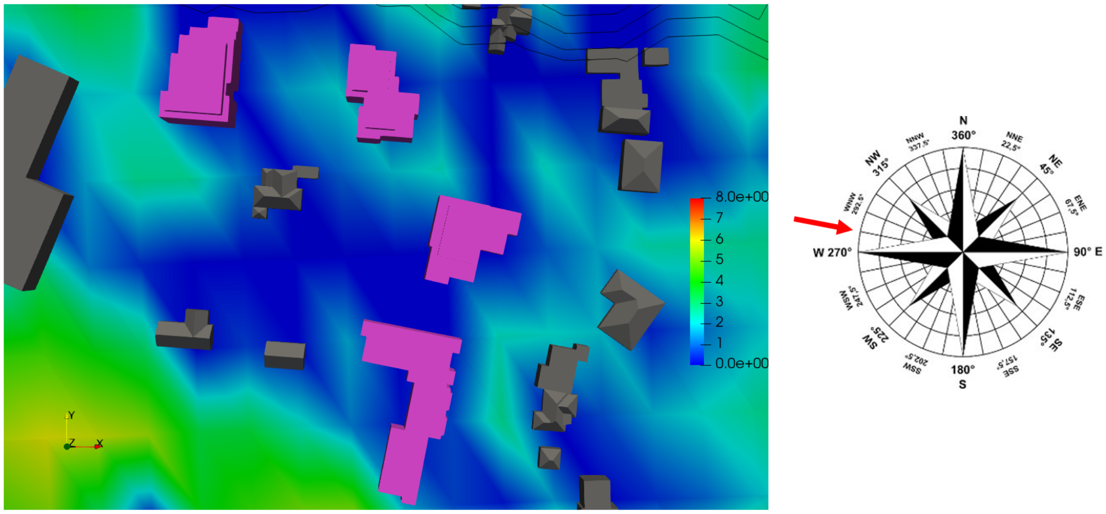


Figure 6.11: Ground Floor Level - Flow Velocity Results at Z=1.5m above the ground - Wind Direction: 281°

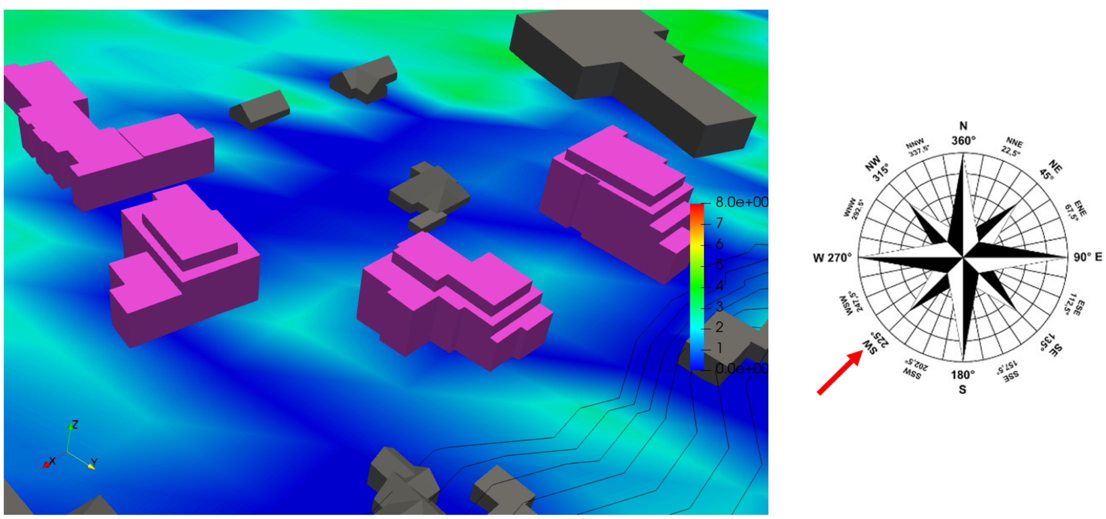


Figure 6.12: Wind Speed Results at 1.5m Above Development Ground Floor - 3D View - Wind Direction: 225°

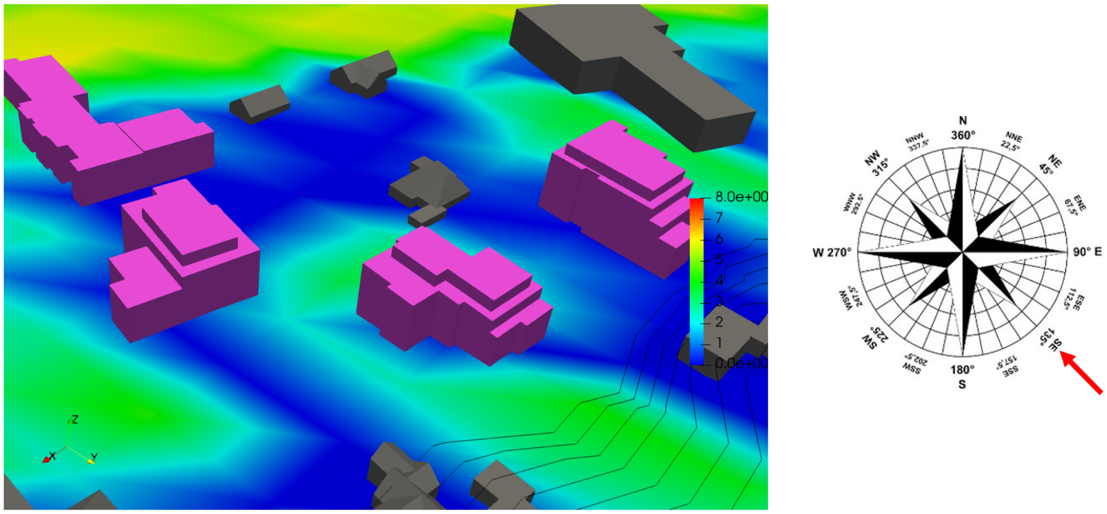


Figure 6.13: Wind Speed Results at 1.5m Above Development Ground Floor - 3D View - Wind Direction: 135°

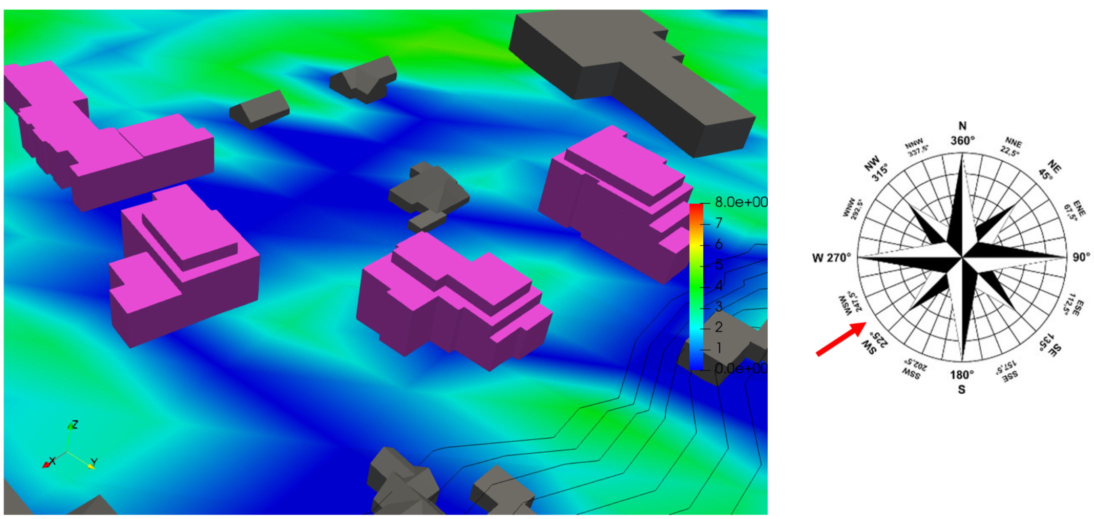


Figure 6.14: Wind Speed Results at 1.5m Above Development Ground Floor - 3D View - Wind Direction: 236°

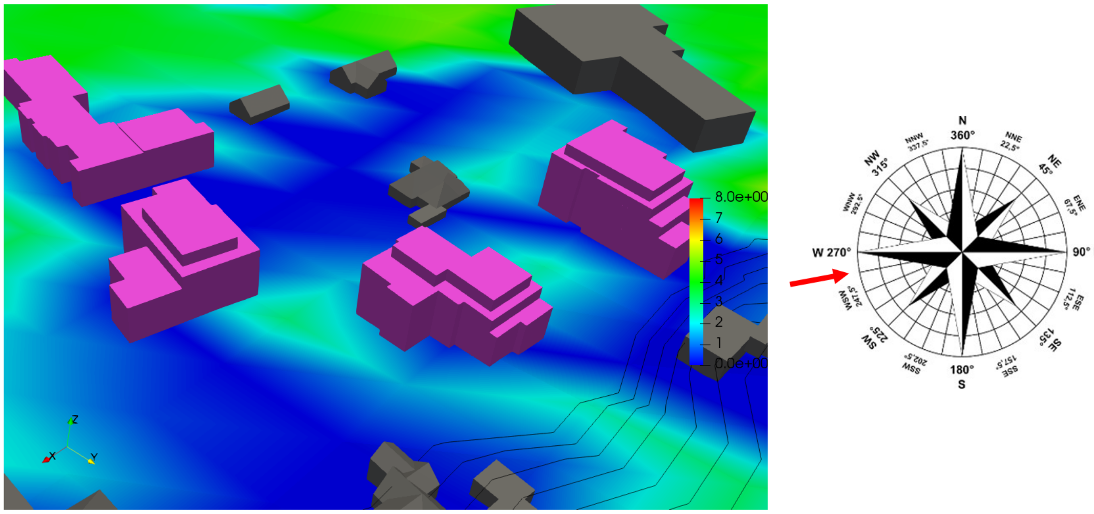


Figure 6.15: Wind Speed Results at 1.5m Above Development Ground Floor - 3D View - Wind Direction: 258°

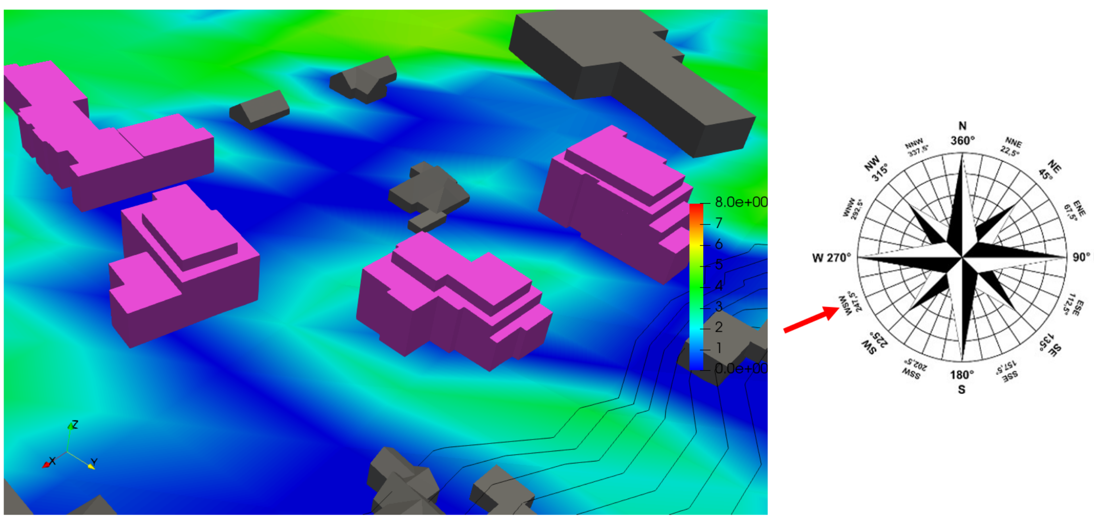


Figure 6.16: Wind Speed Results at 1.5m Above Development Ground Floor - 3D View - Wind Direction: 247°

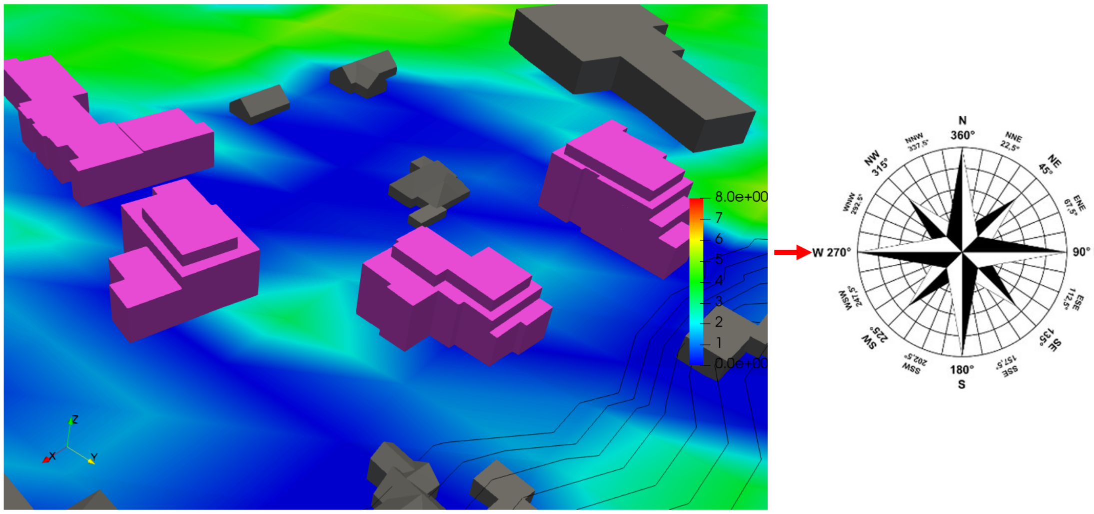


Figure 6.17: Wind Speed Results at 1.5m Above Development Ground Floor - 3D View - Wind Direction: 270°

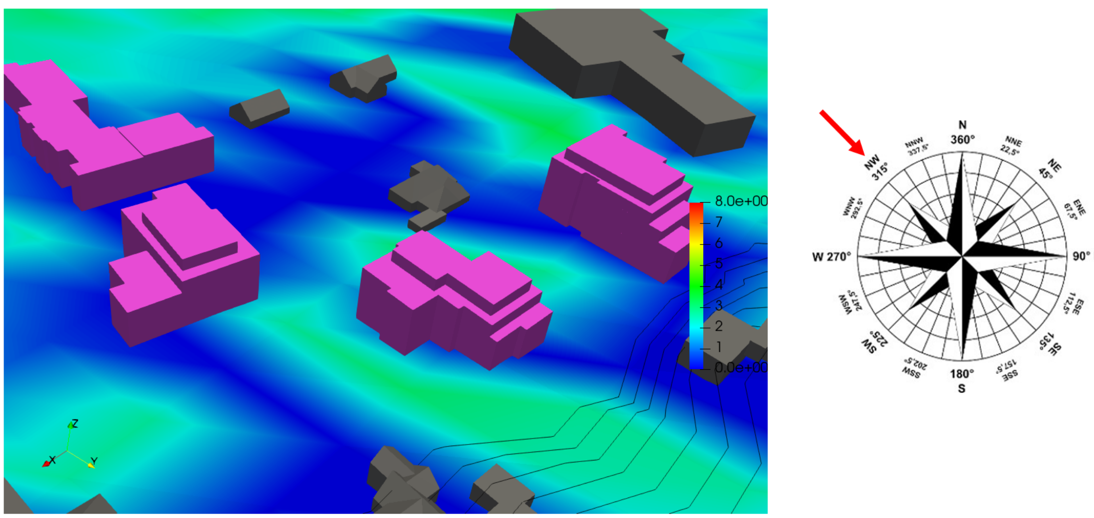


Figure 6.18: Wind Speed Results at 1.5m Above Development Ground Floor - 3D View - Wind Direction: 315°

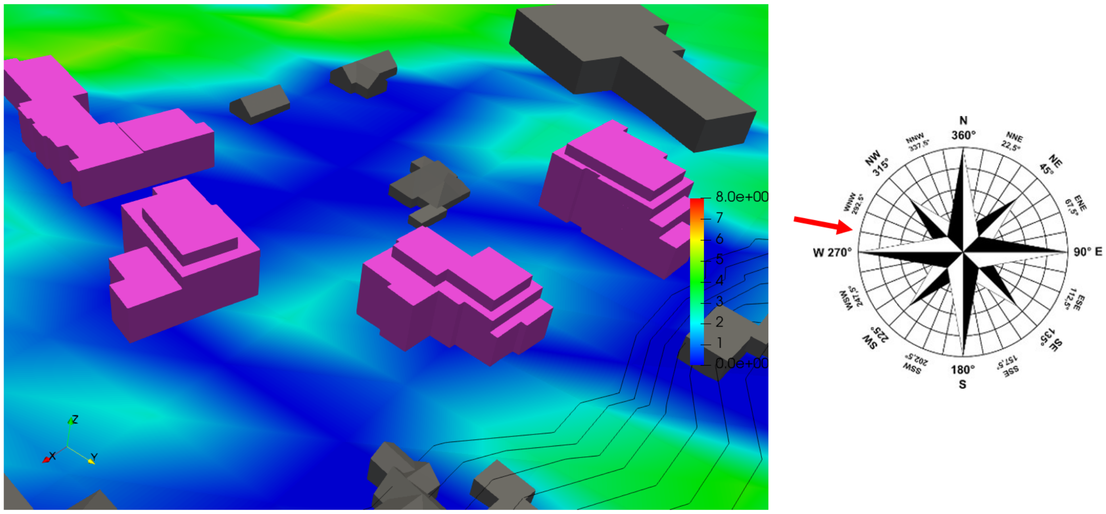


Figure 6.19: Wind Speed Results at 1.5m Above Development Ground Floor - 3D View - Wind Direction: 281°

7. CONCLUSIONS

7.1 CONCLUSIONS ON WIND DESKTOP AND PRELIMINARY CFD

This report presented the Wind Microclimate Modelling study performed for Strategic Housing Development at Glenamuck Road North, Carrickmines, Dublin 18. This study has been carried out to identify the possible wind patterns around the area proposed, under mean and peaks wind conditions typically occurring in Dublin, and also to assess impacts of the wind on pedestrian level comfort.

Results of this wind desktop study are utilized by Moran Park Homebuilders Ltd. to configure the optimal layout for Strategic Housing 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.

Preliminary qualitative and quantitative summary of the wind microclimate modelling study performed for Strategic Housing Development shows that:

- The wind profile around the existing development environment was built using the annual average 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.
- The prevailing wind directions for the site are identified as West, South-East and West-South-West, with magnitude of approximately 6m/s.
- We retain that mitigation measures such as the use of landscaping on ground floor will be sufficient to ensure that the proposed Strategic Housing Development will be designed to produce a high-quality environment that is attractive and comfortable for pedestrians of all categories.
- South west corners of block A, B and C potentially experience high wind speeds. This wind speeds are not critical, and can be further mitigated by the use of landscaping trees.
- High speeds are observed in the spaces between block B and C. This high speeds are due to funnelling and recirculation effects, and can be mitigated with the use of landscaping in these areas.
- Given the position of the development blocks, and the recommended landscape, critical wind speeds are not expected on footpaths of the proposed development blocks.
- The proposed development does not impact or give rise to negative or critical wind speed profiles at the nearby adjacent roads, or nearby buildings.

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