AECOM

Hong Kong Housing Authority

Public Rental Housing Development at Anderson Road Sites A and B

Air Ventilation Assessment

May 2013

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Executive Summary

Hong Kong Housing Authority (HKHA) proposes to develop a public housing development at a site adjoining Anderson Road (the Subject Site) between the existing Anderson Road Quarry and Sau Mau Ping Road in Kwun Tong District. AECOM Asia Co. Ltd was commissioned by a contractor of HKHA (Yau Lee Construction Co. Ltd.) in 2013 to undertake the air ventilation assessment of public housing development at Anderson Road Sites A and B.

To conclude, the proposed Subject Site has incorporated a number of ventilation improvement measures during the scheme design and the modelling results show that it maintains a comparatively good wind performance at the pedestrian level of the area around the Subject Site. No ventilation problem is generally found for the Subject Site. With the value greater than 0.15, the SVRW and LVRW of the Subject Site are found to be generally higher than other territories of Hong Kong and the air ventilation performance is satisfactory. The higher VRW of overall test points also proves that the mitigation measures incorporated in the Current Scheme are effective.

From the findings of this AVA Study, the SVRw for the Subject Site is 0.182 under the 16 winds directions which amount to about 80% of time in a year. Whereas the LVRw is 0.2 under the same 16 wind directions. These VRw reflect relatively good wind performance in the vicinity of the proposed development.

In summary, the proposed development has incorporated certain ventilation improvement measures in the scheme design and the modellling results show that it maintains a comparatively good wind performance at the pedestrian level of the area around the Subject Site. Several wind corridors reserved in design between building blocks have been maintained as shown in VR contour plots.

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1 INTRODUCTION

1.1 Background

1.1.1 AECOM Asia Company Ltd. has been commissioned by the Hong Kong Housing Authority (HKHA) to undertake an Air Ventilation Assessment (AVA) Study for the Public Rental Housing Development at Anderson Road Site A and B to examine the air ventilation performance of its building design and to formulate effective and practicable measures to enhance the air ventilation as part of the continuous design improvement process.

1.2 Objectives

1.2.1 The AVA Study for the Public Rental Housing Development at Anderson Road Sites A and B (i.e. the Subject Sites) has been conducted in accordance with the methodology outlined in the Technical Guide for AVA for Developments in Hong Kong (the Technical Guide) annexed in HPLB and ETWB TC No. 1/06. The main purposes of this AVA Study, echoing the Technical Guide, are:

- To assess the characteristics of the wind availability (V_∞) of the site;
- To give a general pattern and a rough quantitative estimate of wind performance at the pedestrian level reported using Wind Velocity Ratio (VR); and
- To quantitatively assess the air ventilation performance in the neighbourhood of the proposed development.

1.3 Content of this Report

1.3.1 Section 1 is this Introduction section. The remainder of the report is organized as follow:

- Section 2 on expert evaluation;
- Section 3 on assessment methodology;
- Section 4 on key findings of AVA study; and
- Section 5 with a summary and conclusion.

2 EXPERT EVALUATION

2.1 Site Environs

2.1.1 The Subject Sites, Public Rental Housing Development at Anderson Road Sites A and B, is located in the south-eastern part of Kowloon Peninsula. The proposed development consists of 2 separated sites, namely Site A and Site B, and is part of the Public Rental Housing Development (PRH) at Anderson Road at Kwun Tong. It presently consists of some residential building blocks suited north-west of the Shun Chi Court, Shun Lee Estate and Shun On Estate and the west-south of the Shun Tin Estate.

2.1.2 The Subject Site is bounded by Road L1 and Anderson Road to the east, Sau Mau Ping Road and Shun On Road to the south, as well as Lee On Road to the west. In general, it is located at a platform with dropping terrain from the east to west.

2.1.3 As shown in **Figure 2.1**, there are group of medium-rise to high-rise residential developments namely Shun Tin Estate, Shun On Estate, Shun Lee Estate and Shun Chi Court which are located at the downhill of the Subject Site from southerly west to northerly west position. The ground levels of those mid-rise to high-rise residential developments to the Subject Site have at least 30m in difference.

2.1.4 A planned primary school is located next to Site A and Site B at the east. Further to the east of the Subject Site are the new local road Road L1 and Anderson Road Quarry whose formation works would be finished in 2016, and would provide about 40ha of land for future development. As this development is under feasibility study stage, the layout for this future development has not been fixed, thus future development of Anderson Road Quarry would not be covered in this AVA study.

2.1.5 To the immediately south of Site B are Site C1 and Site C2 of Anderson Road Development, which will be developed in another phases. Two residential blocks with about 26 storeys are planned at Site C1 while some social facilities such as clinic, welfare facilities block and schools are planned at Site C2. Further away to the south are also planned Anderson Road Residential Development at Site D and Site E.

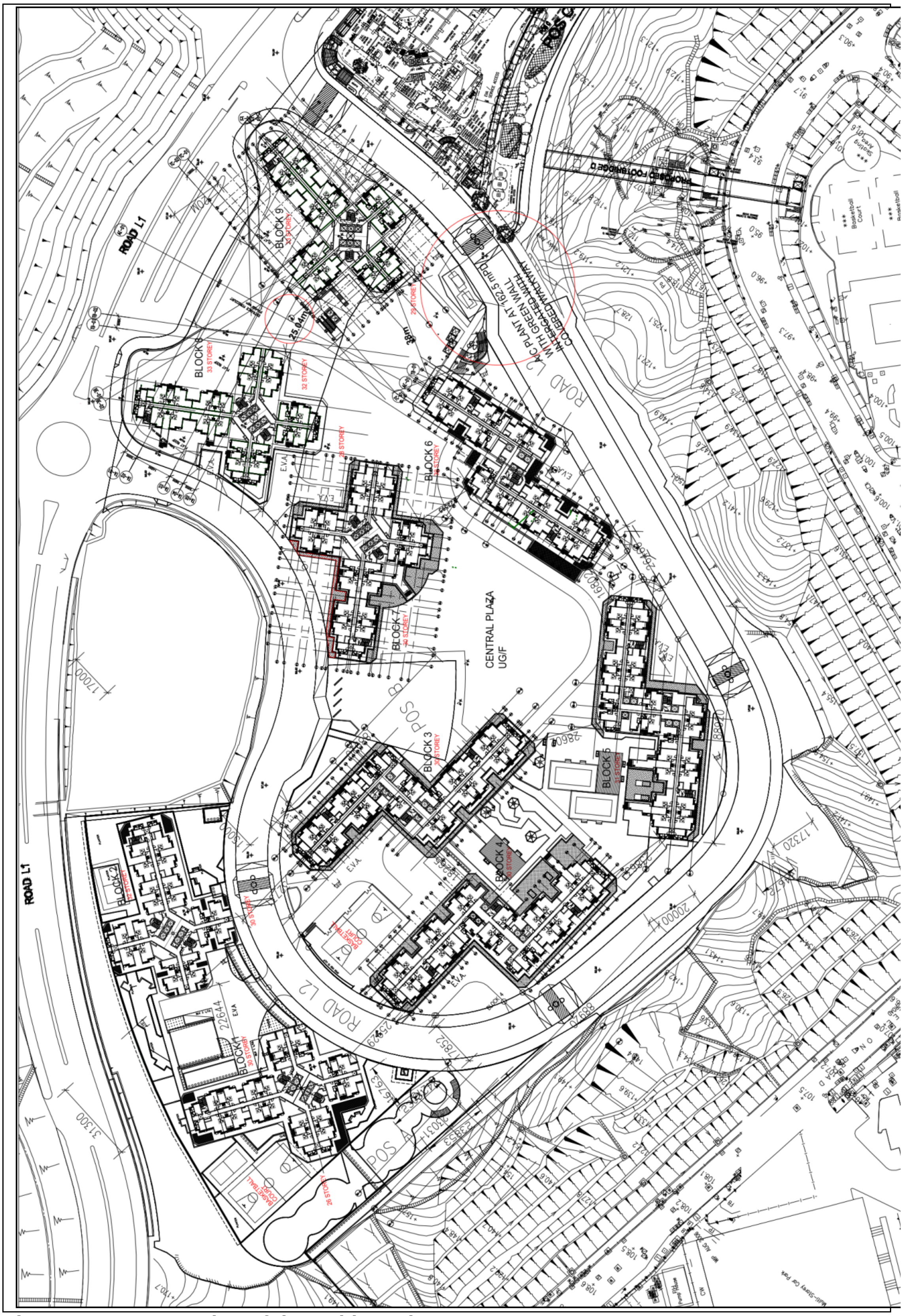


Figure 2.1 Location of the Subject Site

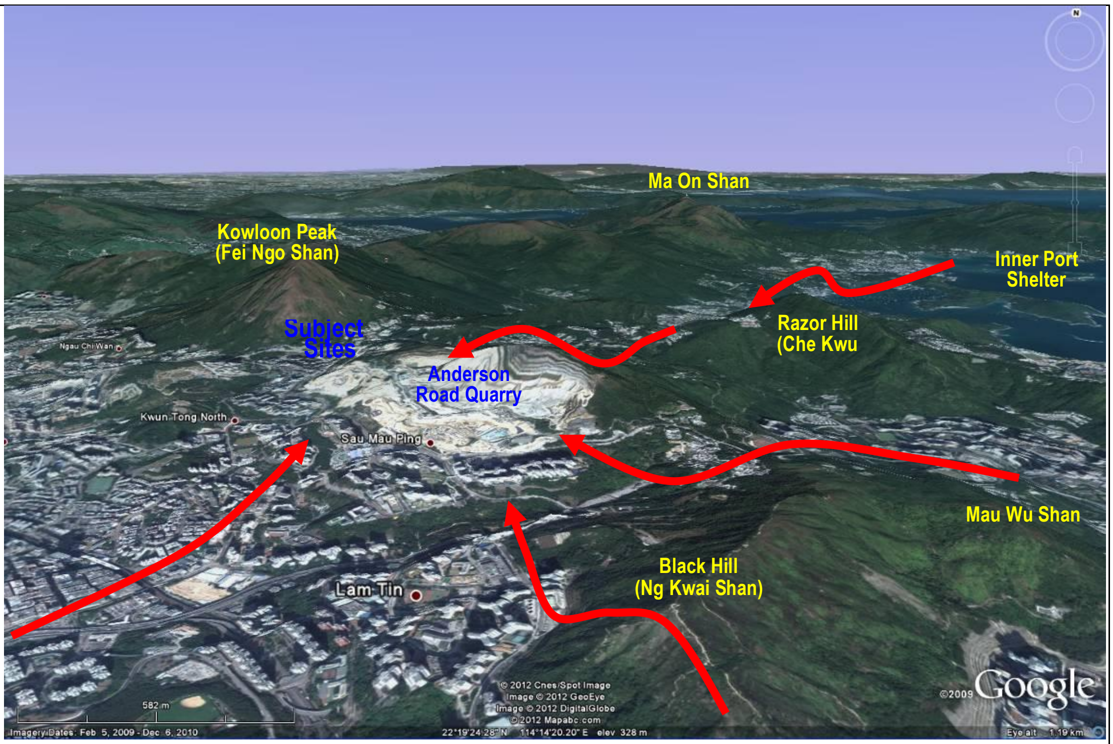
2.2 Prevailing Wind Condition

2.2.1 The Subject Site is located in the south-eastern part of Kowloon Peninsula. As shown in the aerial photo (**Figure 2.2** refers), the terrain surrounding the Subject Site is flat at west and bounded by hilly area from north to south. Influence of local topography to the wind flow pattern at the Subject Site should be significant. For example, if wind comes from north-east, wind will accelerate over the hilly terrain and across the Subject Site to Shun On Chun Area.

2.2.2 With regards to the location of the Public Rental Housing Development area, the Hong Kong Observatory (HKO) Automatic Weather Station next to the Subject Site is either Tseung Kwan O (TKO) Station or Kai Tak Station. As the Kai Tak Station is close to water front and will largely be affected by the sea breeze from the southeast, wind condition may not represent the wind condition of the Subject Site. Hence, it is proposed to use Tseung Kwan O Station instead of Kai Tai Station for lower level (at 14m above ground level) wind data to obtain the local wind conditions at the Subject Site.

2.2.3 It should be noted that the data recorded by the TKO Weather Station represents the lower level wind conditions which are subjected to the influence of its topography and built environment. In other words, the lower level wind data recorded at this weather station also reflect the possible blockage of winds by the surrounding medium- to high-rise buildings. For upper level wind, the MM5 wind data (Fifth-Generation NCR/ Penn State mesoscale Model) simulate the wind conditions at the top of the wind boundary layer at 596m above terrain which are not affected by local terrain.

2.2.4 In accordance with the recent five years (2006 to 2010) annual wind rose from TKO Automatic Weather Station (Figure 2.3 refers), the annual prevailing winds for these years at the lower level of the area are predominantly northeastly wind together with some northerly, easterly and southwesterly winds. The percentage occurrence of southeasterly and northwesterly winds is relatively low.



Source: Google Earth

Figure 2.2 Topographical Features in Kowloon Area

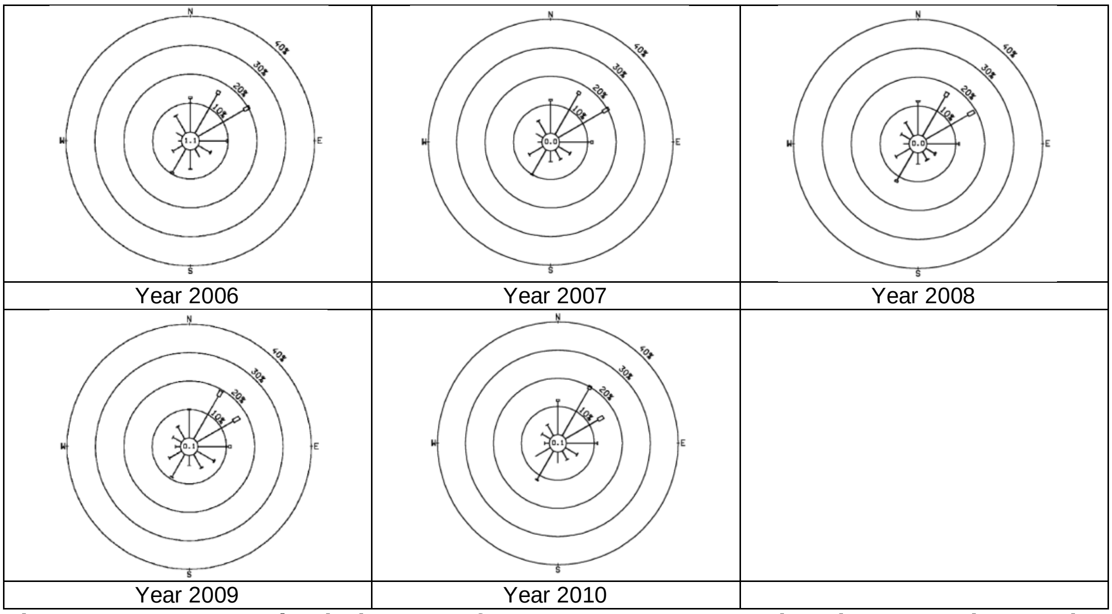


Figure 2.3 Annual Wind Roses from Tseung Kwan O (TKO) Automatic Weather Station for Year 2006 to 2010

2.3 Site Wind Availability

2.3.1 With reference to the "*Experimental Site Wind Availability Study for Development at Anderson Road (Sites A & B) – Investigation Report WWTF009-2013*", the wind availability data determined using large scale topographical model (1:2000) tested in a boundary layer wind tunnel under the this project were adopted for this AVA detailed study. The coverage of Study Site and the relevant wind availability data are extracted and shown in **Appendix A**.

2.3.2 The wind tunnel testing techniques used for the site wind availability study satisfied the quality assurance requirements stipulated in the Australasian Wind Engineering Society Quality Assurance Manual, AWES-QAM-1-2001 (2001) and the American Society of Civil Engineers Manual and Report on Engineering Practice No. 67 for Wind Tunnel Studies of Buildings and Structures (1999). The site wind availability study was also conducted in accordance with the recommendations of Planning Department's Feasibility Study for Establishment of Air Ventilation Assessment System – Final Report (2005) and Technical Guide for Air Ventilation Assessment for Developments in Hong Kong (2006).

2.3.3 The wind tunnel testing results were subsequently combined with a statistical model of the Subject Site non-typhoon wind climate to determine directional wind characteristics and availability for the Development at Anderson Sites A & B Area.

2.3.4 Photographs of the 1:2000 scale topographical model of the Public Rental Housing Development at Anderson Road at Sites A & B under north, east, south and west directions are shown in **Figure 2.4** to **Figure 2.7**.

2.3.5 Based on the findings of the site wind availability study (**Appendix A**), the annual prevailing non-typhoon winds at the Subject Site are mainly coming from the east quadrant while from east and south-west quadrants during summer months (June to August). The site wind availability study also pointed out that significant reductions in the magnitudes of wind speed were measured at elevations below 500 mPD for N, NNE, NE and ENE wind directions caused by the sea to the north and north-east of the Subject Site. Those were caused by the Razor Hill to the east of the Subject Site.

2.3.6 The annual and summer wind roses at 500 mPD (level not affected by local topography) based on the results of the experimental site wind availability study are shown in **Figure 2.8**. The wind roses indicate the dominance of each of the 16 wind directions and distribution of the wind speed at 500 mPD. The percentage of annual and summer season occurrence of a particular wind direction at level 500 mPD is presented in **Table 2.1**.

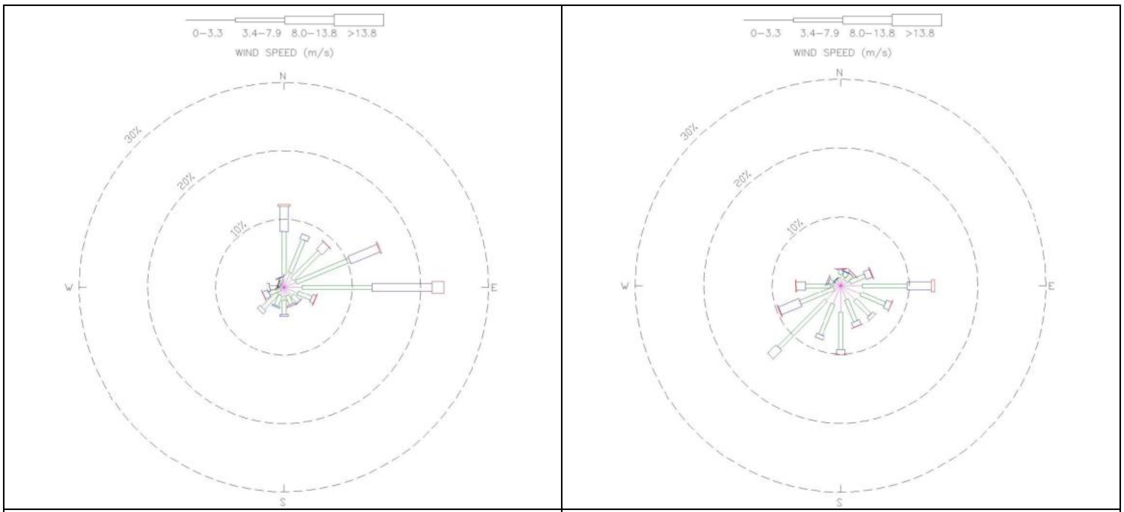
2.3.7 As shown in **Table 2.1**, E wind is the most predominant wind at upper level and contributes 23.4% of in a year. Other predominant winds at upper level include ENE, N and NE winds.

Figure 2.4 1:2000 scale topographical model of the Development at Anderson Road in the low speed test section (North wind direction, 360^0)

Figure 2.5 1:2000 scale topographical model of the Development at Anderson Road in the low speed test section (East wind direction, 90^0)

Figure 2.6 1:2000 scale topographical model of the Development at Anderson Road in the low speed test section (South wind direction, 180^0)

Figure 2.7 1:2000 scale topographical model of the Development at Anderson Road in the low speed test section (West wind direction, 270^0)



(a) Annual | (b) Summer

Figure 2.8 Wind Roses for Annual and Summer, non-typhoon winds for Development at Anderson Road, corrected to 500mPD

Table 2.1 Frequency of Annual and Summer Season Occurrence of individual Wind Directions at 500mPD

Wind Direction	% of Annual Occurrence	% of Summer Season Occurrence
0º (N)	12.1 %	2.5 %
22.5º (NNE)	8.3 %	2.2 %
45º (NE)	8.8 %	2.5 %
67.5º (ENE)	15.1 %	4.8 %
90º (E)	23.4 %	13.8 %
112.5º (ESE)	4.9 %	7.9 %
135º (SE)	3.1 %	6.5 %
157.5º (SSE)	3.0 %	6.4 %
180º (S)	4.3 %	10.1 %
202.5º (SSW)	3.1 %	8.3 %
225º (SW)	4.9 %	14.5 %
247.5º (WSW)	3.2 %	9.7 %
270º (W)	2.5 %	6.5 %
292.5º (WNW)	1.0 %	2.1 %
315º (NW)	0.6 %	1.1 %
337.5º (NNW)	1.5 %	1.2 %

3 ASSESSMENT METHODOLOGY

3.1 General

3.1.1 This AVA study was carried out in accordance with the guidelines stipulated in the Technical Guide for AVA for Developments in Hong Kong with regards to Computational Fluid Dynamics (CFD) modelling. Reference was also made to the "Recommendations on the use of CFD in Predicting Pedestrian Wind Environment" issued by a working group of the COST action C14 "Impact of Wind and Storms on City Life and Built Environment" (COST stands for the European Cooperation in the field of Scientific and Technical Research). COST action C14 is developed by European Laboratories/Institutes dealing with wind and/or structural engineering, whose cumulative skills, expertise and facilities have an internationally leading position. Thus, it is considered that the COST action C14 is a valid and good reference for CFD modelling in AVA study.

3.2 Modelling Tool and Model Setup

3.2.1 Assessment was conducted by means of 3-dimensional CFD model. The well-recognised commercial CFD package FLUENT was used in this exercise. FLUENT model had been widely applied for various AVA research and studies worldwide. The accuracy level of the FLUENT model was very much accepted by the industry for AVA application.

3.2.2 Wind Directions: In the CFD model, all 16 wind directions together with their respective % of occurrence determined for the Subject Site were adopted for simulation of air ventilation performance (**Table 2.1** refers).

3.2.3 Vertical Wind Profile: Wind environment under different wind directions was defined in the CFD environment. The wind profiles for the 16 wind directions will follow those determined from the experimental site wind availability study as extracted in **Appendix A**.

3.2.4 Turbulence Model: As recommended in COST action C14, realizable K-epsilon turbulence model was adopted in the CFD model to simulate the real life problem. Common computational fluid dynamics equations were adopted in the analysis.

3.2.5 Variables including fluid velocities and fluid static pressure were calculated throughout the domain. The CFD code captures, simulates and determines the air flow inside the domain under study based on viscous fluid turbulence model. Solutions were obtained by iterations.

3.2.6 Computational Domain: A 3-dimensional CFD model was constructed to capture all major components such as topographical features and buildings within and in the vicinity of the Project Area that would likely affect the wind flow. The methodology described in the Technical Guide was adopted for this assessment. According to the Technical Guide, the surrounding area up to a perpendicular distance of 2 times of the maximum building height within the Subject Site (2H) is included in the CFD model. The maximum height of building block for Development at Anderson Road is about 100m about site platform.

3.2.7 The size of the domain of the CFD model for this Study is approximately 7870m (L) x 5370m (W) x 1500m (H) and contains about 6,000,000 cells. Given the large computational domain adopted in this assessment and the physical limitation on the computational resources of the CFD model, the horizontal grid size employed in the CFD model in the vicinity of the Project Area was taken as a global general minimum size of about 2m (smaller grid size was also employed for specific fine details including elevated road, proposed car park, etc) and increased for the grid cells further away from the Project Area. Besides, prism cells (each layer of not more than 0.5m thick) were employed above the terrain so that the pedestrian level test points (located at 2m above ground level) were located at least the third cell away from the terrain to ensure a better resolution of flow close to the ground as per the recommendation of COST action C14.

3.2.8 The advection terms of the momentum and viscous terms are resolved with the second order numerical schemes. The scaled residuals are converged to an order of magnitude of at least 1×10^{-4} as recommended in COST action C14.

3.2.9 **Figure 3.1** shows the boundaries of the Project Area, Assessment Area and Surrounding Area that were examined in this AVA. **Figure 3.2** shows respectively the extent of the computational domain that was adopted in the CFD model. Images of the general model setup and grid cell setup in the CFD model are shown in **Figure 3.3** and **Figure 3.4** respectively.

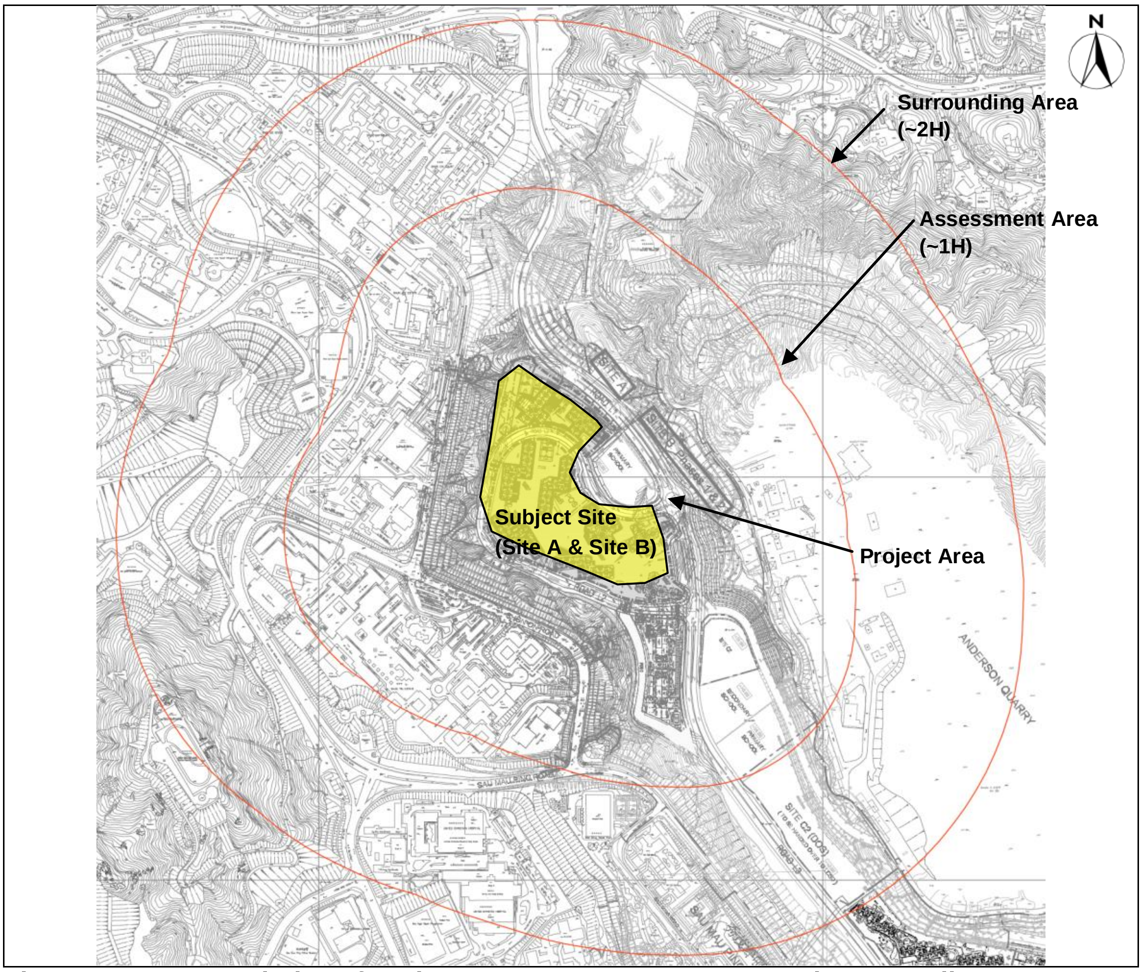


Figure 3.1 Boundaries of Project Area, Assessment Area and Surrounding Area

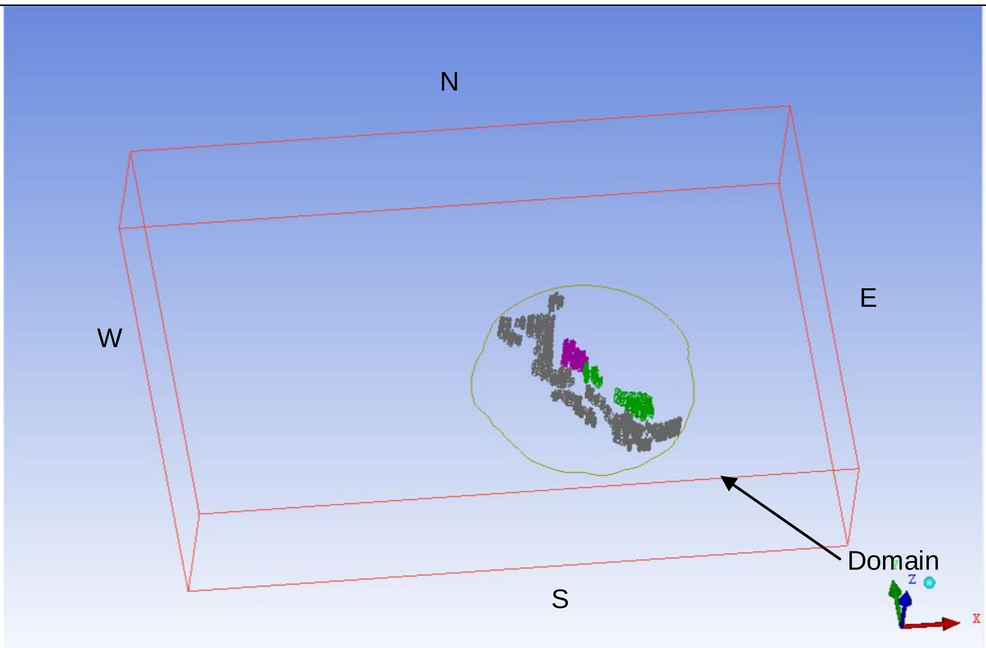


Figure 3.2 Extent of Computational Domain for CFD Model

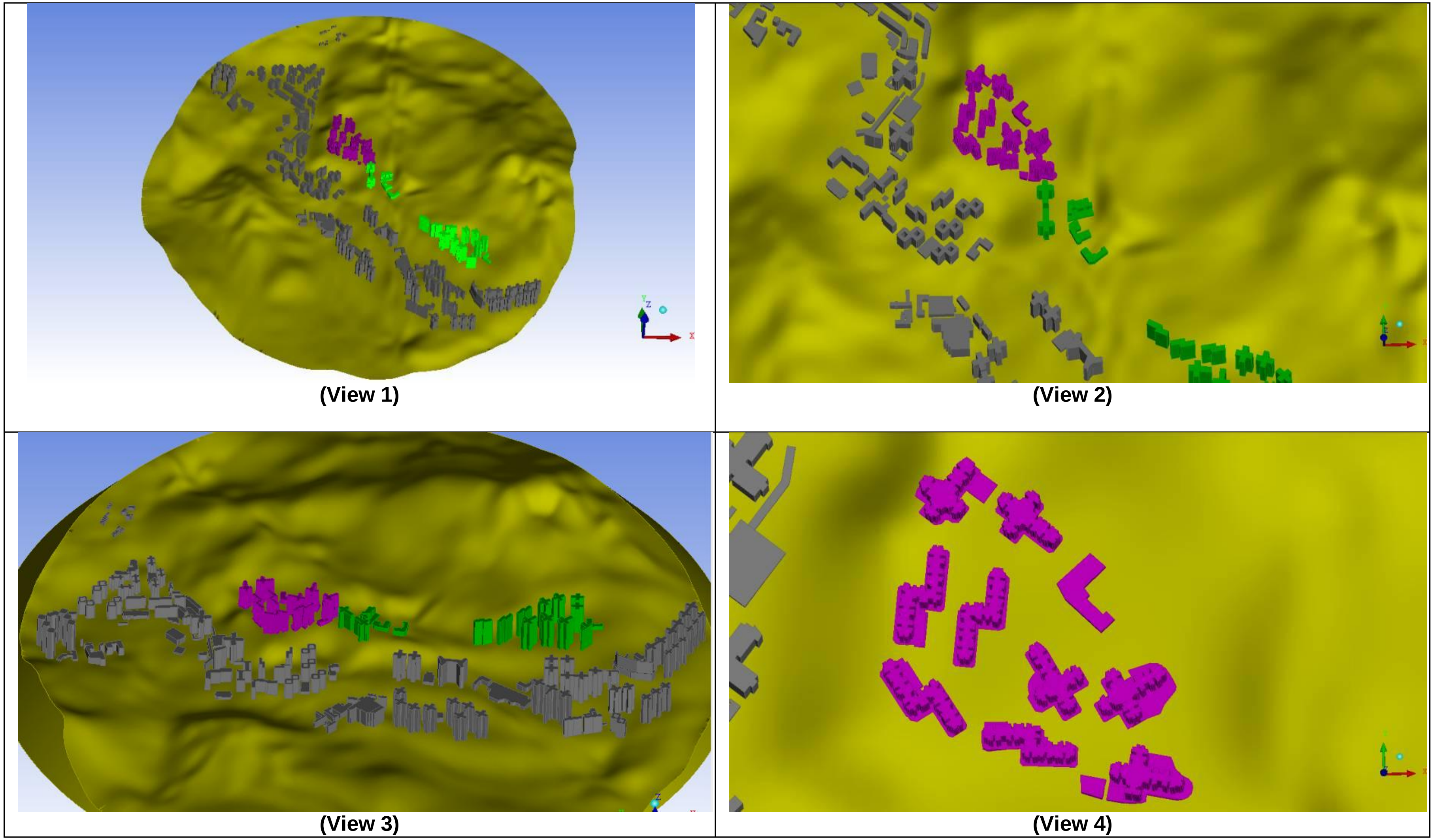


Figure 3.3 Images of General Setup in the CFD Model

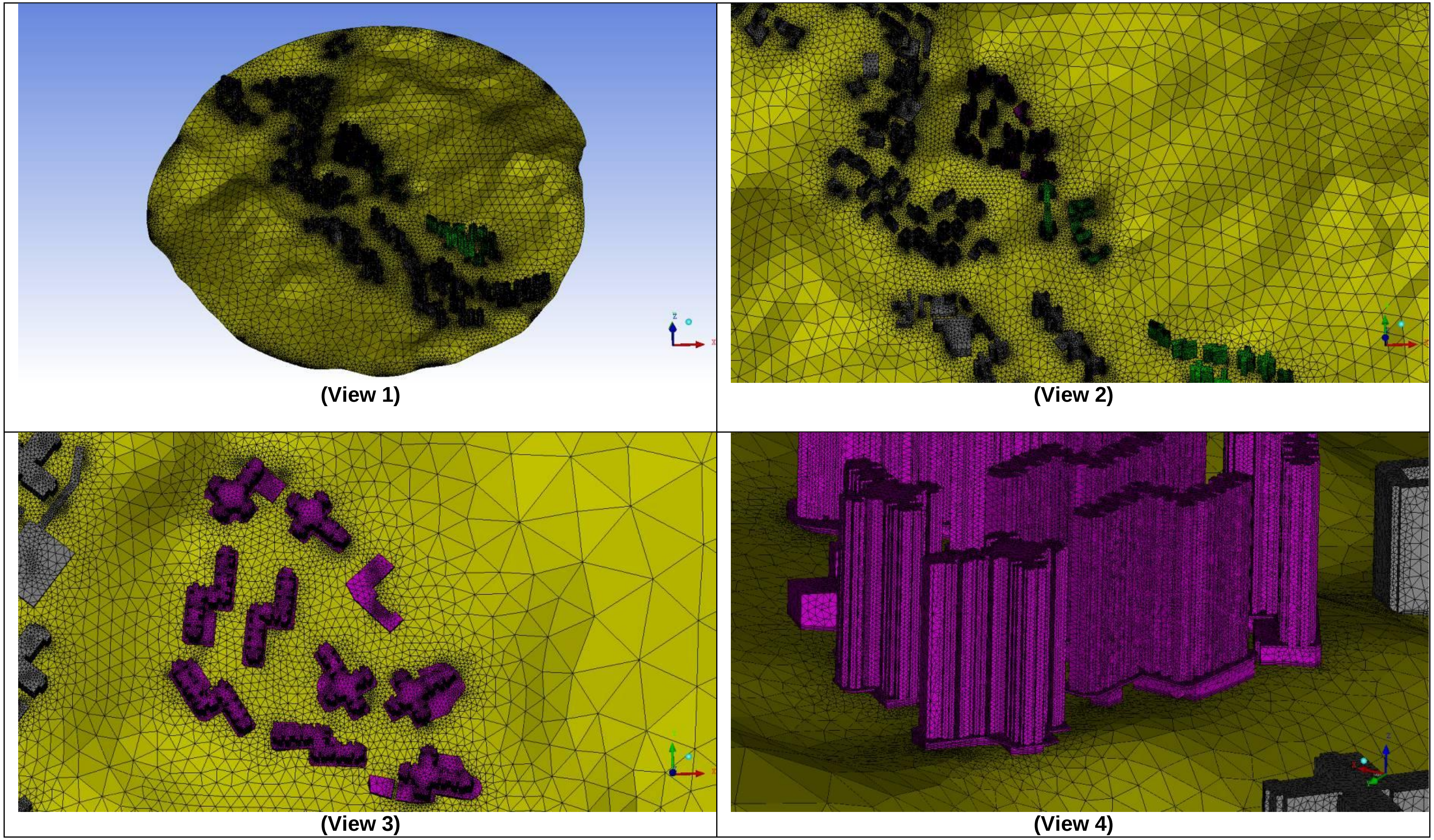


Figure 3.4 Images of Grid Cell Setup in the CFD Model

3.2.10 Test Points: Both perimeter test points and overall test points were selected within the Assessment Area in order to assess the impact on the immediate surroundings and local areas respectively. Perimeter test points were selected along the boundary of the Project Area with centre to centre separation distance of about 130m. Overall test points were evenly distributed over surrounding open spaces, streets and other parts of the Assessment Area where pedestrian can or will mostly access. All test points are elevated at 2m above ground.

3.2.11 The selected overall test points were grouped based on the land use / sensitive receivers as shown in **Figure 3.5 & Figure 3.6** and summarized in **Table 3.1** for ease of discussion. There are 49 perimeter test points (with prefix “P”) and 71 overall test points (with prefix “T”) selected for the purpose of this AVA study. For test points along the roads, they are located along the footpath on either side of the road. In the CFD model, the pedestrian level test points were all located at the third or fourth cell away from the terrain to ensure a better resolution of flow close to the ground as per the recommendation of COST action C14.

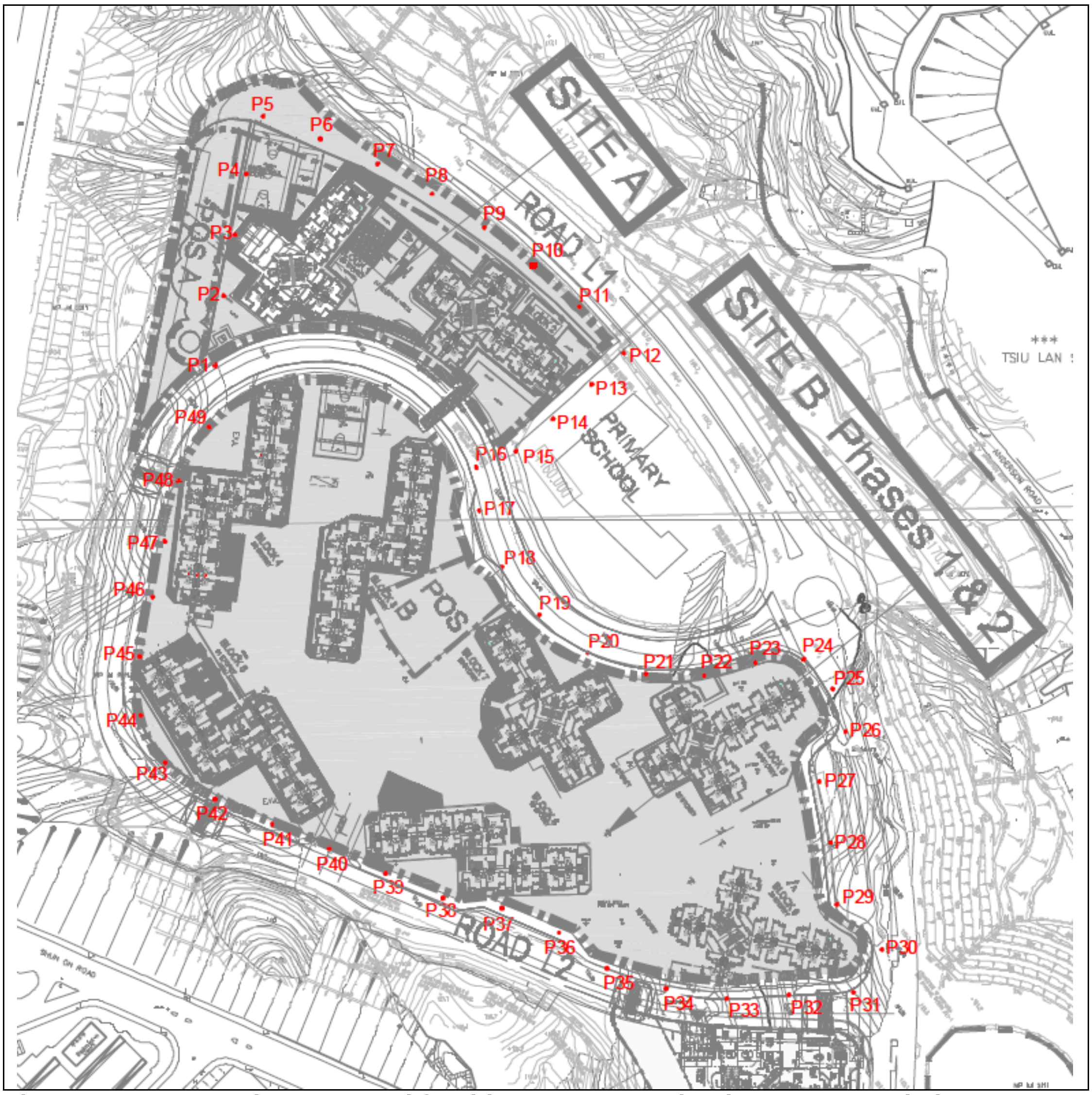


Figure 3.5 Test Points Selected for this Assessment (Perimeter Test Point)

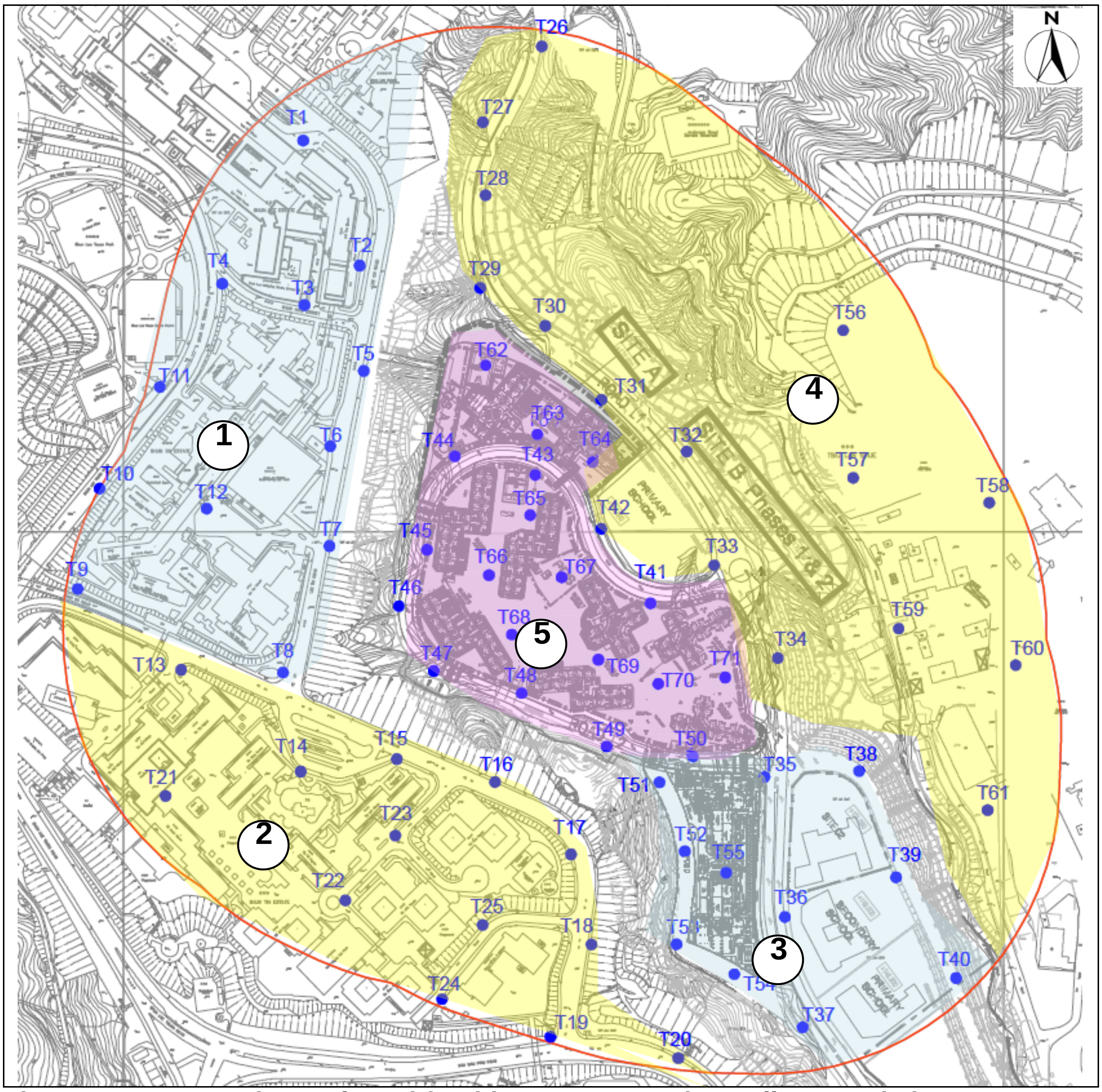


Figure 3.6 Test Points Selected for this Assessment (Overall Test Point)

Table 3.1 Grouping of the Overall Test Points

Group	Description	Test Points
1	West of Subject Sites including Shun Lee Estate and Shun On Estate etc	T1 to T12
2	Southwest of Subject Sites, i.e. Sau Tin Estate	T13 to T25
3	Immediately south and southeast of Subject Site B including Site C1 and Site C2	T35 to T40 and T51 to T55
4	East of Subject Sites including planned Anderson Road Quarry Development Area and new Road L1	T26 to T34, T42 and T56 to T61
5	Open Space/Open area within Project Area and also the new Road L2	T33, T41 to T50, and T62 to T71

3.3 Wind Velocity Ratio

3.3.1 Wind velocity ratio (VRw) indicates how much of the wind availability is experienced by pedestrians on the ground which is a relatively simple indicator to reflect the wind environment of the study site. VR is defined as VR = V_P / V_{INF} where V_{INF} is the wind velocity at the top of the wind boundary layer and it would not be affected by the ground roughness and local site features and V_P is the wind velocity at the 2m pedestrian level.

3.3.2 VR_W is the frequency weighted wind velocity ratio calculated based on the frequency of occurrence of all the 16 wind directions for the purpose of comparison.

3.3.3 For Site Air Ventilation Assessment, the Site Spatial Average Wind Velocity Ratio (SVR_W) and individual VR_W of all perimeter test points are reported. SVR_W is the average of VR_W of all perimeter test points.

3.3.4 For Local Air Ventilation Assessment, the Local Spatial Average Wind Velocity Ratio (LVR_W) of all overall test points and perimeter test points, and individual VR_W of the overall test points are reported. LVR_W is the average of all overall test points and perimeter test points.

3.3.5 The SVR_W and LVR_W are worked out so as to understand the overall impact of air ventilation on the immediate and further surroundings of the Project Area due to the proposed development.

3.3.6 The local situation including the site environs, site wind environment, and site wind availability of the Subject Site are described in **Section 2** above.

4 KEY FINDINGS OF AVA STUDY

4.1 Air Ventilation Issues

4.1.1 In accordance with the wind availability data, the prevailing wind for Development at Anderson Road Sites A & B area is mainly on easterly and east-northern east winds. Therefore, any potential blockage to these prevailing winds due to the project would affect wind availability to the site.

4.1.2 As discussed in **Section 2** above, the terrain surrounding the Subject Site is flat at west and bounded by hilly area from north to south. Influence of local topography to the wind flow pattern at the Subject Sites should be significant. When the prevailing wind comes from north-east, wind will accelerate over the hilly terrain and across the Subject Site to Shun On Chun Area.

4.1.3 The design in this AVA Study has incorporated many openings/"empty bays"at ground floor and upper ground floor of each domestic blocks to enhance/maintain air performance at pedestrian level around Project Sites and Assessment Area. **Figure 4.1** shows the location of those openings/ empty bays in this AVA Study.

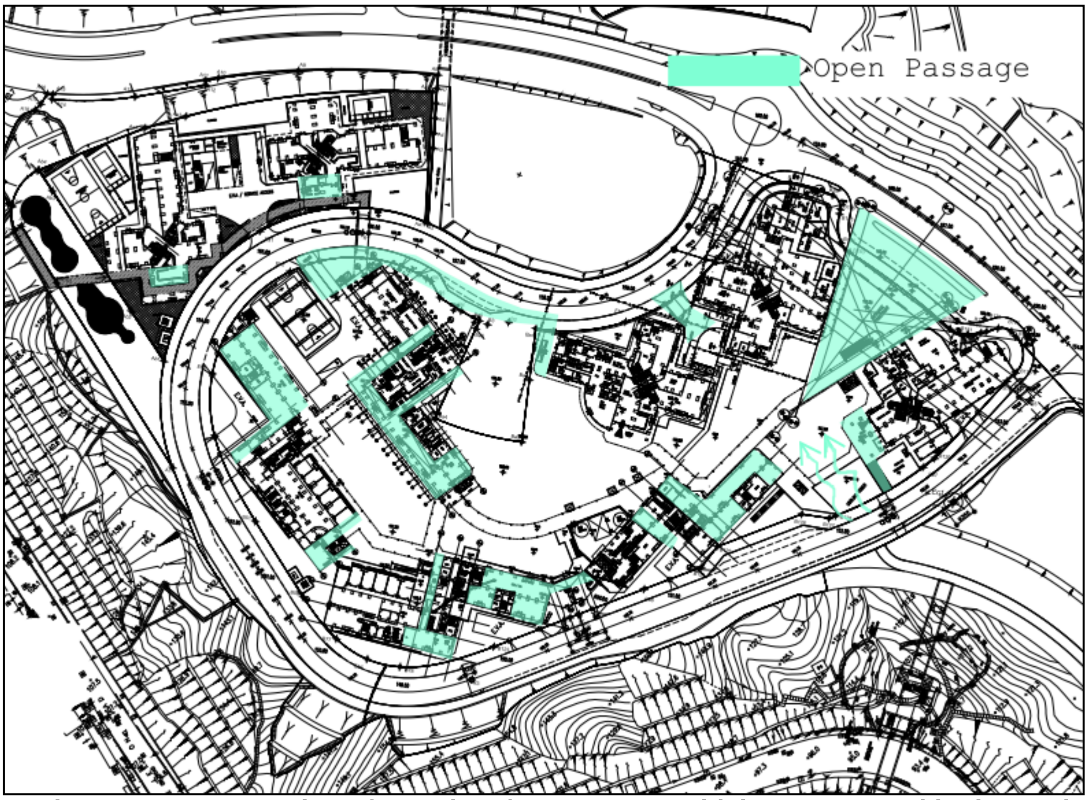


Figure 4.1 Location of Openings/ Empty Bays which Incorporated in the Design for Air Ventilation Improvement

4.2 Wind Velocity Ratio Results

4.2.1 A summary of the predicted wind velocity ratios for the Perimeter Test Points and the Overall Test Points as well as the SVR_W and LVR_W are presented in **Table 4.1** below. Details of the predicted wind velocity ratios are presented in **Appendix B**.

Table 4.1 Summary of Wind Velocity Ratios for Subject Site

	Wind Velocity Ratios
Perimeter Test Point VR_W	0.067 - 0.395
Overall Test Point VR_W	0.066 - 0.470
SVR_W	0.182
LVR_W	0.200

4.2.2 The results of VR_W for different groups of test points are summarized in **Table 4.2** while result of wind velocity ratios for each group under 16-assessed wind directions is summarized in **Table 4.3.**

Table 4.2 Summary of Wind Velocity Ratio for Different Test Point Groups

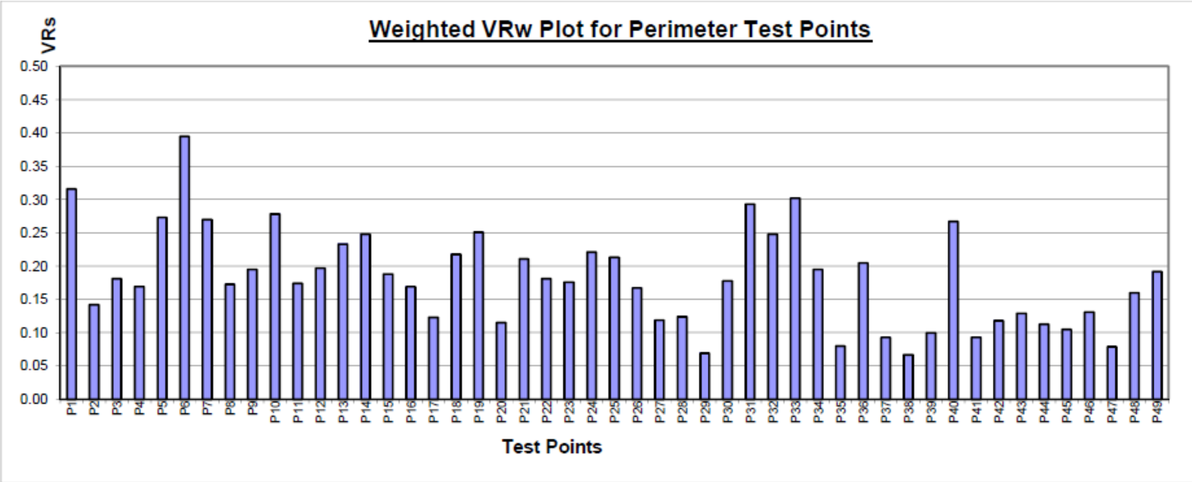
Group	Description	Test Points	Test Points Level	Average VR_w
1	West of Subject Sites including Shun Lee Estate and Shun On Estate etc	T1 to T12	Pedestrian Level	0.179
2	Southwest of Subject Sites, i.e. Sau Tin Estate	T13 to T25	Pedestrian Level	0.126
3	Immediately south and southeast of Subject Site B including Site C1 and Site C2	T35 to T40 and T51 to T55	Pedestrian Level	0.210
4	East of Subject Sites including planned Anderson Road Quarry Development Area and new Road L1	T26 to T34, T42 and T56 to T61	Pedestrian Level	0.343
5	Open Space/Open area within Project Area and also the new Road L2	T33, T41 to T50, and T62 to T71	Pedestrian Level	0.184

Table 4.3 Summary of Wind Velocity Ratio for Different Test Point Groups under 16-assessed Wind Directions

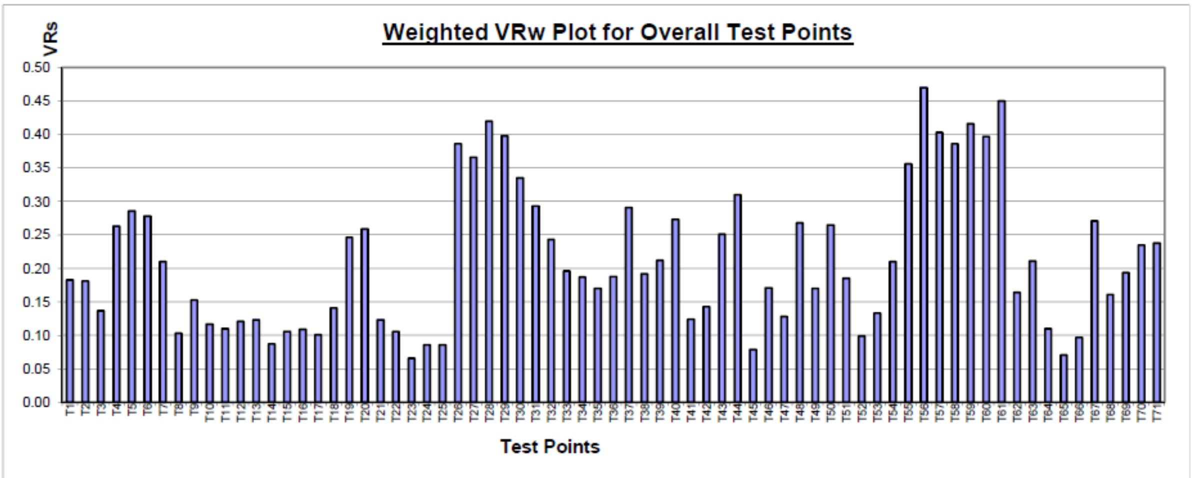
Group	Wind Velocity Ratios (VRs)								
	N	NNE	NE	ENE	E	ESE	SE	SSE	
1	0.139	0.182	0.210	0.281	0.181	0.103	0.101	0.119	
2	0.129	0.134	0.118	0.157	0.117	0.116	0.094	0.133	
3	0.145	0.203	0.242	0.338	0.214	0.232	0.102	0.113	
4	0.317	0.294	0.362	0.540	0.390	0.402	0.357	0.171	
5	0.156	0.138	0.214	0.308	0.175	0.140	0.111	0.132	
Group	Wind Velocity Ratios (VRs)								Average VRw
	S	SSW	SW	WSW	W	WNW	NW	NNW	
1	0.171	0.098	0.102	0.202	0.203	0.122	0.132	0.157	0.179
2	0.130	0.087	0.109	0.133	0.122	0.117	0.115	0.137	0.126
3	0.158	0.096	0.154	0.246	0.201	0.154	0.118	0.141	0.210
4	0.236	0.134	0.131	0.167	0.173	0.125	0.320	0.370	0.343
5	0.170	0.135	0.133	0.158	0.183	0.136	0.157	0.171	0.184

4.2.3 The averaged VR_W result for individual test points and test point groups are also presented in the form of bar chart as shown in **Figure 4.2**. The averaged VR_W result for individual test points and test points groups in the form of bar chart under the 16 wind directions are shown in **Appendix C**.

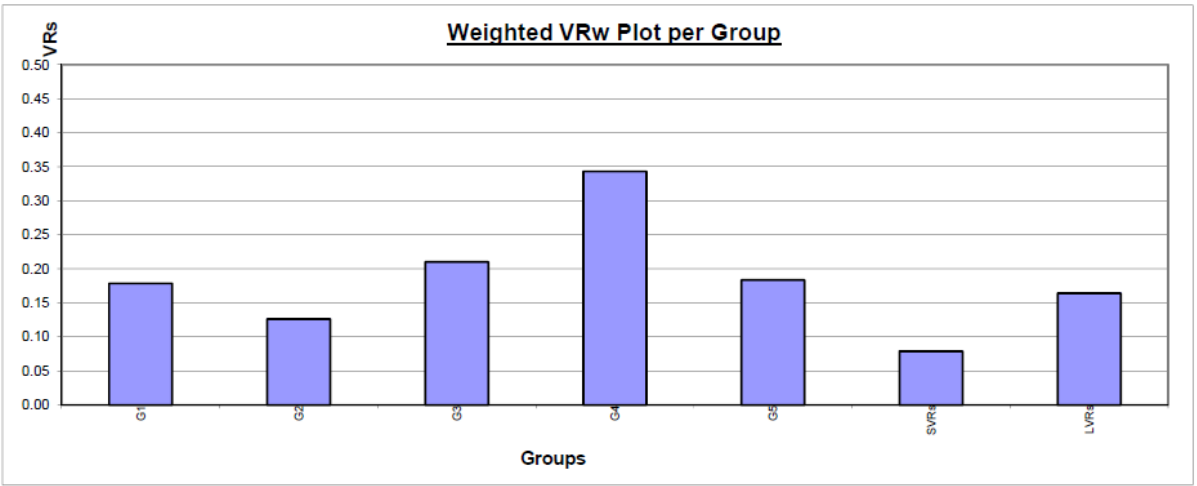
4.2.4 Contour plots of wind velocity ratio and wind vector plots at 2m above the pedestrian level of assessment area under the 16 wind directions are shown in **Appendix D** and **Appendix E** respectively. The contour plot of the frequency weighted wind velocity ratio at 2m above ground is shown in **Figure 4.2** below.



(a) Perimeter Test Points



(b) Overall Test Points



(c) Test Point Groups

Figure 4.2 Averaged VR_W Result

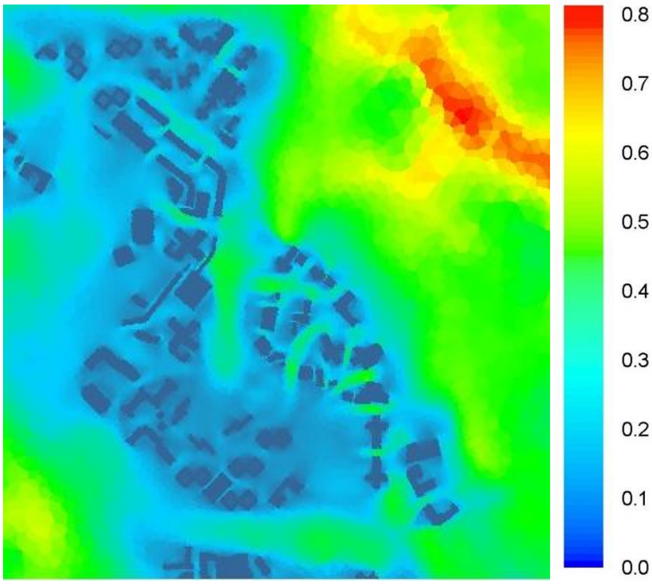


Figure 4.3 Frequency Weighted Wind Velocity Ratio Contour Plot at 2m above Ground Level

4.3 Site Ventilation Assessment

4.3.1 The predicated SVRw is 0.182 under the 16 selected wind directions (N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, and NNW) which occur for about 80% of these in a year. As shown in **Figure 4.2,** the predicted wind velocity ratio of all perimeter test points exceeds 0.05.

4.3.2 The SVRw indicates how the lower portion of the buildings within the Subject Site might affect the wind environment of its immediate vicinity. As discussed above, many openings/empty bays are incorporated in this Study Design to enhance movement at the pedestrian level. This is indicated by the relatively higher VRw predicted at the northeastern boundary of Site A (test point P5 to P15) and eastern boundary of Site B (P25 to P34) as shown in **Figure 4.2** and **Figure 4.3.**

4.3.3 The higher VRw along northeastern and eastern of Site A and Site B might be due to channelling of prevailing winds northeasterly and southwesterly winds along Road L1, Road L2, Sau Mau Ping Road and Lee On Road.

4.3.4 Relatively lower VRw are predicted along western part of Site B (P44 to 49) and discrete along the site boundary namely test points P27 to P38 and P4. It might be due to the shielding effect from their close proximity to the adjacent building structure under the downwind position of dominated prevailing northerly-east winds with weak incoming wind directions from southerly-west.

4.4 Local Air Ventilation Assessment

4.4.1 The averaged LVRw is 0.20 under the 16 selected wind directions namely N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, and NNW which occur for about 80% of time in a year

4.4.2 The LVRw indicates how the upper portion of the buildings within Subject Site might affect the wind environment of its immediate vicinity. In the current design, a number of ventilation improvement measures as described in above sections have been incorporated into the development to improve the air ventilation.

4.4.3 The averaged VRw of Group 1 to 5 test points is shown in **Table 4.3** and **Figure 4.2** above. By comparing the averaged VRw of different test point groups, it is noted that relatively lower VRw of 0.126 is predicted at Group 2. The main reason of this might be due to partially blockage of incoming winds by the cluster of existing building structures within Group 2.

4.4.4 Furthermore, for Group 4, which is located near the topography to the northeast of the proposed development, the predicted averaged VRw at ENE is 0.54 which is the dominant wind during the winter season. Also shown in the contours in **Figure 4.2** and **Appendix C**, relatively larger wind can be observed near the mountain areas located to the north east of the proposed development site. During the summer season, a VRw value of 0.134 can be observed under SSW, indicating that the proposed development would allow incoming winds to blow across the development to provide necessary ventilation at its downstream locations.

4.4.5 Apart from that, average VRw value of 0.184 is obtained for Group 5 which is located above the podium of the proposed development, implying that the development is capable of providing necessary ventilation at the pedestrian level.

4.4.6 Overall, the block disposition of the proposed development has allowed incoming winds to blow across the development to provide the necessary ventilation at pedestrian level, and at the same time minimized the blockage of wind flow to the downwind locations.

5 SUMMARY AND CONCLUSIONS

5.1.1 This AVA Study Report aims at assessing the characteristics of the wind availability of the site, providing a general pattern and a quantitative estimate of wind performance at the pedestrian level under different wind directions and investigating the effectiveness of ventilation improvement measures of the Current Scheme.

5.1.2 To conclude, the proposed Subject Site has incorporated a number of ventilation improvement measures during the scheme design and the modelling results show that it maintains a comparatively good wind performance at the pedestrian level of the area around the Subject Site. No ventilation problem is generally found for the Subject Site. With the value greater than 0.15, the SVR_W and LVR_W of the Subject Site are found to be generally higher than other territories of Hong Kong and the air ventilation performance is satisfactory. The higher VR_W of overall test points also proves that the mitigation measures incorporated in the Current Scheme are effective.

5.1.3 From the findings of this AVA Study, the SVRw for the Subject Site is 0.182 under the 16 winds directions which amount to about 80% of time in a year. Whereas the LVRw is 0.2 under the same 16 wind directions. These VRw reflect relatively good wind performance in the vicinity of the proposed development.

5.1.4 In summary, the proposed development has incorporated certain ventilation improvement measures in the scheme design and the modellling results show that it maintains a comparatively good wind performance at the pedestrian level of the area around the Subject Site. Several wind corridors reserved in design between building blocks have been maintained as shown in VR contour plots.

APPENDICES

--Appendix A Information extracted from "*Experimental Site Wind Availability Study for Development at Anderson Road (Sites A & B)*"

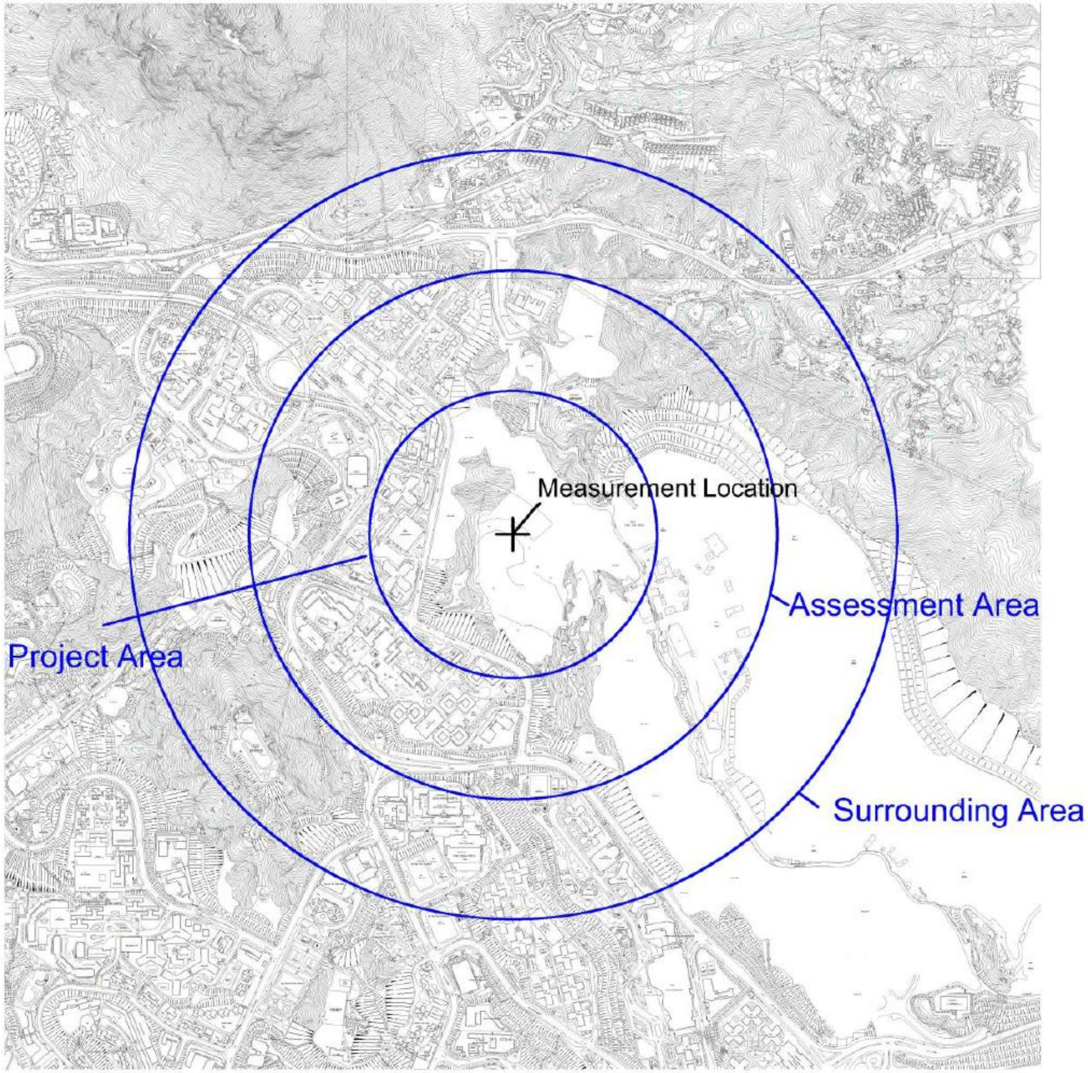


Table A 1: Site wind characteristics of Development at Anderson Road at 0°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.37	32.8%	-6.7	13.8
25	0.41	31.1%	-8.3	14.7
50	0.45	30.1%	-11.2	13.5
75	0.49	28.9%	-12.5	11.1
100	0.51	27.9%	-13.6	8.3
150	0.57	25.9%	-13.2	2.7
200	0.61	23.4%	-12.4	-1.7
250	0.63	21.9%	-10.3	-3.7
300	0.67	19.2%	-8.6	-5.0
400	0.73	16.0%	-5.6	-5.4
500	0.78	14.6%	-4.4	-4.8
600	0.81	13.7%	-3.3	-4.4

Table A 2: Site wind characteristics of Development at Anderson Road at 22.5°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.20	35.1%	0.7	-5.0
25	0.21	36.7%	-0.2	-3.9
50	0.22	37.5%	-0.8	-3.6
75	0.23	39.3%	-1.8	-2.1
100	0.25	40.7%	-2.5	-1.4
150	0.30	42.0%	-4.9	-0.4
200	0.37	39.2%	-5.9	-0.9
250	0.46	34.4%	-5.8	-0.7
300	0.57	28.2%	-4.5	-0.9
400	0.71	18.6%	-2.5	-0.2
500	0.77	14.6%	-1.6	0.0
600	0.81	13.8%	-1.6	0.3

Table A 3: Site wind characteristics of Development at Anderson Road at 45°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.34	31.3%	-3.2	6.6
25	0.37	30.8%	-5.0	7.1
50	0.41	30.1%	-7.9	5.5
75	0.45	28.4%	-9.6	4.9
100	0.50	26.4%	-10.1	2.5
150	0.57	22.8%	-9.7	1.2
200	0.61	19.5%	-8.3	1.8
250	0.66	17.2%	-7.1	2.6
300	0.70	15.4%	-6.1	3.0
400	0.76	13.0%	-4.2	2.7
500	0.83	10.8%	-3.1	1.8
600	0.86	10.0%	-2.1	1.2

Table A 4: Site wind characteristics of Development at Anderson Road at 67.5°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.42	30.6%	-2.5	8.5
25	0.47	29.0%	-5.1	9.4
50	0.54	27.1%	-8.3	8.4
75	0.58	25.7%	-10.4	6.5
100	0.62	24.3%	-12.2	4.5
150	0.67	22.8%	-13.3	0.8
200	0.71	22.1%	-13.4	-0.2
250	0.72	21.6%	-12.4	0.2
300	0.72	21.2%	-11.3	1.7
400	0.71	20.4%	-7.3	5.0
500	0.72	19.0%	-4.4	7.0
600	0.77	17.7%	-2.2	6.3

Table A 5: Site wind characteristics of Development at Anderson Road at 90°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.20	37.1%	2.5	-5.6
25	0.22	40.1%	1.6	-3.6
50	0.24	40.3%	1.4	-4.4
75	0.26	41.2%	0.3	-2.7
100	0.29	42.4%	-0.5	1.2
150	0.36	39.8%	-3.2	7.3
200	0.44	35.8%	-5.6	9.5
250	0.52	30.0%	-6.0	9.3
300	0.60	25.8%	-5.7	7.1
400	0.73	17.6%	-4.1	5.7
500	0.81	12.8%	-2.6	5.3
600	0.87	10.4%	-1.6	4.6

Table A 6: Site wind characteristics of Development at Anderson Road at 112.5°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.24	33.4%	-0.5	-11.5
25	0.27	33.8%	-3.0	-12.0
50	0.29	34.1%	-4.5	-10.9
75	0.32	34.0%	-6.9	-9.9
100	0.34	33.9%	-7.5	-8.2
150	0.37	33.2%	-6.6	-5.9
200	0.39	33.0%	-5.5	-2.9
250	0.40	33.1%	-5.1	0.8
300	0.45	31.5%	-5.0	3.4
400	0.59	24.5%	-3.7	5.5
500	0.70	17.8%	-1.8	5.3
600	0.78	13.7%	-0.8	4.4

Table A 7: Site wind characteristics of Development at Anderson Road at 135°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.17	32.3%	0.6	-2.4
25	0.18	34.4%	-1.8	-2.5
50	0.21	37.2%	-4.8	-2.8
75	0.23	38.4%	-6.7	-2.2
100	0.26	38.4%	-8.4	-2.3
150	0.32	36.7%	-8.6	-2.2
200	0.40	31.6%	-7.2	0.3
250	0.45	28.8%	-4.3	1.1
300	0.51	25.1%	-2.3	2.5
400	0.61	20.3%	-0.4	2.0
500	0.70	16.5%	-0.1	1.4
600	0.81	12.7%	0.4	1.3

Table A 8: Site wind characteristics of Development at Anderson Road at 157.5°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.22	30.0%	1.1	-1.8
25	0.24	31.6%	-0.5	-2.3
50	0.26	32.5%	-1.6	-2.4
75	0.29	32.6%	-3.1	-2.5
100	0.33	32.6%	-3.3	-2.4
150	0.38	31.1%	-3.1	-2.0
200	0.46	27.8%	-2.4	-0.4
250	0.53	24.2%	-1.9	0.0
300	0.61	20.8%	-1.5	0.0
400	0.75	14.3%	-0.7	0.4
500	0.84	10.3%	0.0	0.7
600	0.88	8.2%	0.5	0.9

Table A 9: Site wind characteristics of Development at Anderson Road at 180°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.29	29.2%	1.2	-16.1
25	0.31	30.1%	0.1	-14.7
50	0.34	29.4%	-1.6	-13.0
75	0.37	29.4%	-2.1	-10.4
100	0.39	28.8%	-2.6	-8.1
150	0.45	26.8%	-2.0	-6.0
200	0.52	23.9%	-1.6	-4.0
250	0.55	22.7%	-0.4	-1.9
300	0.60	20.1%	-0.5	-1.3
400	0.66	17.6%	0.1	0.2
500	0.71	16.2%	0.7	1.7
600	0.78	14.5%	0.8	1.9

Table A 10: Site wind characteristics of Development at Anderson Road at 202.5°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.25	23.8%	3.0	-0.5
25	0.27	24.8%	2.0	-2.0
50	0.29	26.4%	2.1	-2.6
75	0.31	27.4%	1.2	-2.4
100	0.33	26.9%	0.8	-1.7
150	0.37	26.7%	1.1	-1.2
200	0.43	25.4%	1.7	-0.2
250	0.48	23.5%	2.8	-0.5
300	0.54	21.3%	3.4	-0.7
400	0.61	17.8%	4.0	-0.7
500	0.67	16.4%	4.5	-1.3
600	0.73	15.4%	4.2	-1.3

Table A 11: Site wind characteristics of Development at Anderson Road at 225°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.27	29.9%	-2.0	-8.8
25	0.31	29.8%	-1.5	-8.8
50	0.32	30.8%	-0.8	-8.6
75	0.35	30.3%	-1.0	-8.5
100	0.37	30.2%	-1.2	-7.5
150	0.41	29.0%	0.7	-5.7
200	0.47	27.3%	1.4	-4.9
250	0.51	25.4%	2.3	-3.7
300	0.57	23.0%	3.0	-3.4
400	0.65	19.6%	3.9	-2.7
500	0.72	17.3%	3.5	-2.7
600	0.76	16.2%	3.6	-2.3

Table A 12: Site wind characteristics of Development at Anderson Road at 247.5°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.31	27.5%	-1.5	12.5
25	0.35	26.5%	-1.4	12.0
50	0.37	27.0%	-1.2	9.6
75	0.40	26.9%	-1.5	7.8
100	0.43	26.5%	-1.3	6.3
150	0.51	24.5%	-0.7	4.1
200	0.57	21.2%	-0.1	2.6
250	0.66	17.9%	-0.1	2.2
300	0.71	15.4%	0.3	1.5
400	0.80	12.5%	0.3	0.7
500	0.87	10.6%	0.6	0.0
600	0.93	8.7%	0.8	-0.3

Table A 13: Site wind characteristics of Development at Anderson Road at 270°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.28	31.1%	-0.5	7.0
25	0.32	30.4%	-1.6	7.5
50	0.36	30.2%	-2.3	8.9
75	0.39	29.8%	-2.7	9.1
100	0.43	28.6%	-2.6	9.3
150	0.51	25.2%	-2.5	8.2
200	0.60	21.2%	-2.0	6.3
250	0.67	17.8%	-1.3	4.9
300	0.73	14.9%	-1.0	3.9
400	0.81	11.6%	-0.2	2.7
500	0.89	9.3%	0.3	2.0
600	0.93	7.3%	0.6	1.7

Table A 14: Site wind characteristics of Development at Anderson Road at 292.5°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.38	28.5%	-1.2	19.8
25	0.43	27.3%	-3.0	21.6
50	0.48	26.3%	-4.9	20.4
75	0.52	25.0%	-5.7	19.1
100	0.56	24.1%	-6.4	16.9
150	0.63	20.8%	-6.4	13.0
200	0.70	17.3%	-5.8	10.6
250	0.74	15.1%	-5.0	9.0
300	0.78	12.8%	-4.5	7.8
400	0.80	12.5%	-3.5	6.0
500	0.83	12.4%	-2.7	4.1
600	0.85	12.3%	-2.5	2.8

Table A 15: Site wind characteristics of Development at Anderson Road at 315°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.23	30.4%	4.9	-3.0
25	0.24	31.7%	3.5	-4.7
50	0.25	33.0%	1.4	-5.1
75	0.28	34.6%	-0.6	-4.9
100	0.32	35.0%	-2.5	-2.1
150	0.38	32.9%	-4.4	1.5
200	0.44	30.5%	-3.5	3.9
250	0.49	27.4%	-2.5	5.3
300	0.55	24.2%	-1.9	5.4
400	0.62	19.7%	-0.8	4.8
500	0.67	17.9%	-0.4	3.7
600	0.71	16.5%	-0.2	2.7

Table A 16: Site wind characteristics of Development at Anderson Road at 337.5°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.25	30.0%	1.6	-9.0
25	0.26	30.3%	-0.2	-10.9
50	0.28	30.7%	-2.7	-7.9
75	0.28	31.6%	-3.9	-7.1
100	0.31	31.4%	-4.7	-6.3
150	0.33	31.8%	-5.3	-4.2
200	0.34	31.7%	-4.1	-2.8
250	0.37	31.3%	-2.6	-0.3
300	0.39	31.2%	-1.8	1.0
400	0.44	30.7%	0.0	3.5
500	0.51	29.2%	-0.2	3.2
600	0.62	25.3%	-0.8	2.6

Table B 6: Percentage occurrence for annual, non-typhoon directional winds at 500 mPD above the Study Site

Wind Angle	Percentage occurrence for wind speed ranges:				
	0 < u ≤ 3.3 m/s	3.3 < u ≤ 7.9 m/s	7.9 < u ≤ 13.8 m/s	u > 13.8 m/s	Total
0°	1.9%	6.3%	3.7%	0.3%	12.1%
22.5°	2.3%	5.1%	0.8%	0.0%	8.3%
45°	1.7%	5.6%	1.5%	0.0%	8.8%
67.5°	1.9%	8.5%	4.6%	0.2%	15.1%
90°	2.7%	10.2%	8.9%	1.7%	23.4%
112.5°	2.2%	2.1%	0.5%	0.0%	4.9%
135°	1.8%	1.2%	0.2%	0.0%	3.1%
157.5°	1.3%	1.4%	0.2%	0.0%	3.0%
180°	2.0%	2.0%	0.3%	0.0%	4.3%
202.5°	1.3%	1.6%	0.2%	0.0%	3.1%
225°	1.3%	3.1%	0.5%	0.0%	4.9%
247.5°	0.5%	1.8%	0.9%	0.0%	3.2%
270°	0.8%	1.3%	0.4%	0.0%	2.5%
292.5°	0.5%	0.3%	0.1%	0.0%	1.0%
315°	0.5%	0.1%	0.0%	0.0%	0.6%
337.5°	1.0%	0.5%	0.1%	0.0%	1.5%

Table B 10: Percentage occurrence for summer, non-typhoon directional winds at 500 mPD above the Study Site

Wind Angle	Percentage occurrence for wind speed ranges:				
	0 < u ≤ 3.3 m/s	3.3 < u ≤ 7.9 m/s	7.9 < u ≤ 13.8 m/s	u > 13.8 m/s	Total
0°	1.7%	0.7%	0.1%	0.0%	2.5%
22.5°	1.4%	0.7%	0.0%	0.0%	2.2%
45°	1.1%	1.2%	0.3%	0.0%	2.5%
67.5°	1.5%	2.4%	0.9%	0.1%	4.8%
90°	3.1%	6.5%	3.6%	0.5%	13.8%
112.5°	3.1%	3.9%	0.8%	0.0%	7.9%
135°	3.0%	3.0%	0.5%	0.0%	6.5%
157.5°	2.2%	3.4%	0.7%	0.0%	6.4%
180°	3.9%	5.4%	0.8%	0.0%	10.1%
202.5°	2.9%	4.8%	0.6%	0.0%	8.3%
225°	3.0%	9.7%	1.8%	0.0%	14.5%
247.5°	1.1%	5.4%	3.2%	0.1%	9.7%
270°	1.5%	3.6%	1.4%	0.1%	6.5%
292.5°	1.0%	0.8%	0.2%	0.0%	2.0%
315°	0.8%	0.2%	0.0%	0.0%	1.1%
337.5°	1.1%	0.1%	0.0%	0.0%	1.2%

Appendix B Details of Predicted Wind Velocity Ratios (VR_W)

"Annual Wind"

Test Point	Wind Velocity Ratio - Annual																VR_W for Total 16 Wind Directions
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	
Wind probability	0.121	0.083	0.088	0.151	0.234	0.049	0.031	0.03	0.043	0.031	0.049	0.032	0.025	0.01	0.006	0.015	1
P1	0.096	0.183	0.410	0.642	0.389	0.336	0.131	0.098	0.111	0.199	0.215	0.263	0.231	0.177	0.148	0.162	0.316
P2	0.196	0.159	0.109	0.183	0.108	0.088	0.108	0.114	0.100	0.140	0.159	0.174	0.131	0.081	0.260	0.267	0.142
P3	0.337	0.247	0.033	0.167	0.124	0.106	0.116	0.113	0.076	0.230	0.263	0.339	0.361	0.202	0.184	0.248	0.181
P4	0.296	0.206	0.084	0.161	0.096	0.087	0.137	0.143	0.186	0.188	0.209	0.318	0.352	0.188	0.118	0.208	0.169
P5	0.238	0.199	0.434	0.512	0.200	0.048	0.117	0.179	0.235	0.215	0.230	0.376	0.389	0.213	0.100	0.081	0.273
P6	0.117	0.177	0.544	0.834	0.497	0.255	0.028	0.081	0.165	0.233	0.255	0.423	0.474	0.262	0.275	0.186	0.395
P7	0.107	0.085	0.380	0.616	0.383	0.253	0.063	0.073	0.078	0.025	0.020	0.048	0.076	0.109	0.380	0.328	0.270
P8	0.084	0.080	0.209	0.383	0.248	0.136	0.038	0.053	0.088	0.023	0.034	0.042	0.038	0.040	0.137	0.158	0.173
P9	0.099	0.108	0.220	0.424	0.211	0.121	0.041	0.016	0.115	0.039	0.157	0.273	0.259	0.193	0.108	0.109	0.195
P10	0.211	0.045	0.196	0.554	0.440	0.380	0.187	0.007	0.130	0.037	0.046	0.058	0.084	0.051	0.234	0.316	0.278
P11	0.253	0.102	0.176	0.208	0.228	0.251	0.141	0.023	0.127	0.029	0.047	0.025	0.025	0.049	0.229	0.316	0.174
P12	0.280	0.170	0.225	0.228	0.237	0.257	0.163	0.054	0.092	0.032	0.102	0.069	0.072	0.043	0.118	0.271	0.197
P13	0.254	0.230	0.379	0.409	0.251	0.217	0.092	0.069	0.104	0.020	0.092	0.035	0.043	0.033	0.032	0.047	0.233
P14	0.096	0.163	0.279	0.476	0.335	0.309	0.113	0.094	0.014	0.052	0.081	0.222	0.281	0.200	0.259	0.159	0.248
P15	0.220	0.204	0.278	0.235	0.192	0.178	0.096	0.108	0.122	0.075	0.132	0.131	0.079	0.087	0.259	0.113	0.188
P16	0.208	0.206	0.211	0.369	0.122	0.063	0.085	0.139	0.058	0.084	0.098	0.035	0.028	0.016	0.092	0.066	0.169
P17	0.203	0.171	0.098	0.194	0.103	0.122	0.080	0.110	0.057	0.050	0.047	0.041	0.022	0.015	0.080	0.107	0.123
P18	0.285	0.269	0.288	0.387	0.100	0.206	0.092	0.132	0.169	0.173	0.165	0.187	0.186	0.119	0.151	0.201	0.218
P19	0.298	0.300	0.352	0.515	0.229	0.198	0.132	0.047	0.038	0.034	0.041	0.058	0.045	0.038	0.124	0.244	0.251
P20	0.132	0.137	0.153	0.184	0.113	0.115	0.043	0.037	0.030	0.039	0.057	0.021	0.078	0.068	0.107	0.183	0.115
P21	0.186	0.172	0.232	0.379	0.199	0.175	0.091	0.155	0.223	0.138	0.174	0.172	0.046	0.057	0.140	0.197	0.211
P22	0.240	0.217	0.250	0.427	0.112	0.112	0.053	0.052	0.059	0.027	0.030	0.023	0.068	0.009	0.160	0.254	0.181
P23	0.148	0.058	0.099	0.407	0.256	0.228	0.074	0.059	0.067	0.017	0.012	0.032	0.025	0.017	0.049	0.121	0.176
P24	0.257	0.159	0.068	0.433	0.330	0.268	0.146	0.023	0.063	0.022	0.022	0.022	0.030	0.019	0.077	0.189	0.221
P25	0.305	0.304	0.202	0.213	0.280	0.317	0.215	0.057	0.065	0.029	0.019	0.022	0.067	0.038	0.066	0.243	0.213
P26	0.290	0.334	0.294	0.119	0.122	0.223	0.179	0.105	0.040	0.043	0.040	0.063	0.059	0.027	0.038	0.224	0.167
P27	0.063	0.069	0.235	0.217	0.069	0.090	0.077	0.099	0.135	0.085	0.045	0.109	0.301	0.182	0.088	0.110	0.119
P28	0.077	0.116	0.145	0.169	0.075	0.079	0.069	0.084	0.203	0.168	0.202	0.281	0.241	0.117	0.056	0.040	0.124
P29	0.058	0.132	0.164	0.088	0.029	0.053	0.041	0.024	0.055	0.046	0.059	0.078	0.024	0.038	0.046	0.063	0.069
P30	0.022	0.347	0.411	0.373	0.094	0.136	0.121	0.113	0.174	0.043	0.063	0.090	0.061	0.043	0.033	0.031	0.178
P31	0.116	0.174	0.383	0.614	0.259	0.102	0.049	0.230	0.346	0.245	0.300	0.399	0.357	0.263	0.168	0.073	0.293
P32	0.126	0.127	0.267	0.428	0.271	0.274	0.121	0.120	0.221	0.197	0.253	0.336	0.293	0.211	0.161	0.029	0.248
P33	0.135	0.191	0.437	0.663	0.316	0.198	0.107	0.102	0.174	0.183	0.190	0.233	0.274	0.183	0.128	0.082	0.302
P34	0.103	0.148	0.364	0.483	0.114	0.108	0.021	0.116	0.153	0.115	0.101	0.185	0.189	0.128	0.100	0.081	0.195
P35	0.027	0.049	0.156	0.195	0.042	0.037	0.030	0.029	0.095	0.027	0.069	0.096	0.094	0.061	0.052	0.054	0.080
P36	0.038	0.176	0.291	0.421	0.224	0.169	0.044	0.103	0.166	0.111	0.112	0.160	0.254	0.150	0.076	0.111	0.205
P37	0.043	0.093	0.112	0.134	0.058	0.047	0.059	0.091	0.105	0.125	0.087	0.201	0.264	0.140	0.091	0.118	0.093
P38	0.058	0.045	0.053	0.080	0.041	0.050	0.080	0.068	0.115	0.073	0.087	0.123	0.213	0.123	0.057	0.047	0.067
P39	0.065	0.066	0.128	0.104	0.054	0.037	0.149	0.208	0.263	0.149	0.162	0.106	0.212	0.102	0.059	0.049	0.100
P40	0.203	0.244	0.331	0.478	0.282	0.193	0.137	0.197	0.214	0.110	0.092	0.203	0.259	0.097	0.075	0.206	0.267
P41	0.104	0.105	0.102	0.110	0.029	0.044	0.130	0.146	0.096	0.092	0.135	0.176	0.254	0.092	0.126	0.071	0.093
P42	0.061	0.088	0.127	0.133	0.054	0.040	0.249	0.331	0.326	0.198	0.113	0.089	0.241	0.250	0.076	0.107	0.118
P43	0.070	0.095	0.134	0.167	0.055	0.024	0.267	0.372	0.387	0.215	0.131	0.113	0.144	0.304	0.191	0.088	0.129
P44	0.059	0.043	0.039	0.145	0.072	0.022	0.109	0.217	0.356	0.242	0.207	0.188	0.053	0.282	0.311	0.243	0.113
P45	0.215	0.120	0.026	0.099	0.055	0.033	0.033	0.030	0.075	0.112	0.188	0.227	0.086	0.196	0.375	0.388	0.105
P46	0.093	0.113	0.134	0.212	0.129	0.044	0.030	0.069	0.083	0.129	0.128	0.128	0.160	0.206	0.331	0.321	0.131
P47	0.041	0.050	0.045	0.086	0.088	0.052	0.022	0.019	0.050	0.138	0.145	0.129	0.116	0.113	0.306	0.302	0.079
P48	0.192	0.149	0.198	0.255	0.101	0.053	0.020	0.121	0.120	0.171	0.211	0.246	0.054	0.062	0.325	0.326	0.160
P49	0.188	0.145	0.265	0.294	0.153	0.134	0.120	0.096	0.158	0.189	0.231	0.267	0.120	0.116	0.148	0.140	0.192
Average SVR	**0.155**	**0.154**	**0.219**	**0.318**	**0.175**	**0.144**	**0.099**	**0.105**	**0.136**	**0.109**	**0.124**	**0.156**	**0.159**	**0.119**	**0.149**	**0.165**	**0.182**
P_{Min}	0.022	0.043	0.026	0.080	0.029	0.022	0.020	0.007	0.014	0.017	0.012	0.021	0.022	0.009	0.032	0.029	0.067
P_{Max}	0.337	0.347	0.544	0.834	0.497	0.380	0.267	0.372	0.387	0.245	0.300	0.423	0.474	0.304	0.380	0.388	0.395

Test Point	Wind Velocity Ratio - Annual																VR_W for Total 16 Wind Directions
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	
Wind probability	0.121	0.083	0.088	0.151	0.234	0.049	0.031	0.03	0.043	0.031	0.049	0.032	0.025	0.01	0.006	0.015	1
T1	0.134	0.134	0.233	0.302	0.260	0.153	0.135	0.125	0.078	0.026	0.031	0.061	0.101	0.118	0.094	0.077	0.183
T2	0.056	0.171	0.243	0.282	0.271	0.288	0.027	0.030	0.134	0.088	0.052	0.069	0.060	0.053	0.030	0.037	0.181
T3	0.068	0.200	0.125	0.185	0.101	0.075	0.014	0.082	0.070	0.026	0.181	0.410	0.351	0.147	0.240	0.358	0.137
T4	0.219	0.357	0.363	0.555	0.208	0.104	0.120	0.115	0.161	0.108	0.053	0.222	0.223	0.165	0.121	0.146	0.263
T5	0.195	0.221	0.324	0.505	0.372	0.130	0.101	0.177	0.222	0.134	0.129	0.257	0.193	0.092	0.140	0.115	0.286
T6	0.243	0.261	0.378	0.574	0.313	0.031	0.062	0.124	0.192	0.107	0.055	0.117	0.168	0.079	0.171	0.155	0.278
T7	0.294	0.222	0.271	0.359	0.094	0.053	0.212	0.285	0.333	0.196	0.134	0.105	0.051	0.124	0.227	0.274	0.210
T8	0.109	0.069	0.092	0.112	0.105	0.093	0.078	0.082	0.144	0.081	0.043	0.164	0.245	0.142	0.103	0.072	0.103
T9	0.083	0.080	0.162	0.112	0.179	0.052	0.157	0.214	0.307	0.188	0.128	0.267	0.346	0.191	0.128	0.226	0.153
T10	0.088	0.187	0.095	0.071	0.097	0.095	0.100	0.055	0.145	0.031	0.167	0.357	0.319	0.126	0.110	0.200	0.117
T11	0.071	0.143	0.064	0.167	0.096	0.102	0.052	0.060	0.141	0.073	0.112	0.181	0.171	0.112	0.168	0.106	0.110
T12	0.104	0.143	0.169	0.149	0.077	0.066	0.151	0.080	0.126	0.114	0.139	0.210	0.204	0.111	0.053	0.115	0.121
T13	0.125	0.177	0.042	0.150	0.104	0.065	0.147	0.171	0.168	0.068	0.089	0.157	0.178	0.142	0.111	0.235	0.123
T14	0.173	0.060	0.064	0.036	0.093	0.181	0.126	0.073	0.037	0.073	0.082	0.075	0.033	0.038	0.070	0.123	0.087
T15	0.138	0.142	0.063	0.119	0.074	0.111	0.083	0.147	0.191	0.115	0.095	0.065	0.090	0.038	0.062	0.154	0.106
T16	0.072	0.084	0.113	0.132	0.113	0.133	0.068	0.175	0.163	0.113	0.103	0.035	0.040	0.074	0.236	0.226	0.109
T17	0.094	0.107	0.128	0.171	0.075	0.094	0.072	0.070	0.078	0.043	0.091	0.086	0.089	0.089	0.070	0.073	0.101
T18	0.188	0.156	0.109	0.226	0.088	0.024	0.071	0.219	0.290	0.058	0.102	0.155	0.099	0.181	0.078	0.100	0.141
T19	0.141	0.231	0.312	0.320	0.320	0.194	0.059	0.244	0.056	0.138	0.205	0.342	0.285	0.301	0.135	0.069	0.246
T20	0.233	0.273	0.307	0.354	0.305	0.207	0.056	0.118	0.151	0.086	0.195	0.311	0.283	0.268	0.122	0.110	0.259
T21	0.130	0.088	0.114	0.144	0.109	0.153	0.165	0.090	0.070	0.085	0.129	0.189	0.205	0.176	0.133	0.071	0.123
T22	0.193	0.139	0.028	0.105	0.050	0.074	0.188	0.183	0.123	0.123	0.124	0.114	0.090	0.072	0.163	0.227	0.106
T23	0.026	0.033	0.046	0.094	0.049	0.093	0.090	0.073	0.103	0.074	0.102	0.089	0.075	0.047	0.155	0.197	0.066
T24	0.099	0.127	0.139	0.075	0.065	0.074	0.057	0.059	0.117	0.059	0.054	0.078	0.069	0.060	0.097	0.157	0.086
T25	0.060	0.129	0.072	0.119	0.081	0.098	0.041	0.101	0.140	0.095	0.049	0.039	0.046	0.040	0.065	0.032	0.086
T26	0.293	0.321	0.454	0.569	0.462	0.455	0.524	0.142	0.213	0.184	0.216	0.235	0.248	0.209	0.254	0.259	0.386
T27	0.310	0.361	0.458	0.525	0.437	0.377	0.341	0.056	0.255	0.179	0.200	0.253	0.184	0.133	0.185	0.241	0.366
T28	0.371	0.385	0.482	0.626	0.487	0.474	0.333	0.117	0.268	0.245	0.206	0.323	0.260	0.152	0.346	0.347	0.420
T29	0.269	0.265	0.409	0.671	0.527	0.426	0.124	0.171	0.236	0.214	0.205	0.340	0.296	0.172	0.318	0.258	0.398
T30	0.121	0.086	0.333	0.606	0.493	0.436	0.252	0.077	0.103	0.161	0.169	0.310	0.380	0.241	0.354	0.244	0.335
T31	0.199	0.056	0.231	0.569	0.473	0.436	0.237	0.018	0.102	0.019	0.043	0.065	0.060	0.028	0.298	0.336	0.293
T32	0.293	0.140	0.149	0.308	0.338	0.435	0.352	0.126	0.017	0.026	0.081	0.120	0.114	0.081	0.314	0.390	0.243
T33	0.097	0.074	0.140	0.388	0.307	0.306	0.121	0.053	0.076	0.058	0.083	0.051	0.051	0.017	0.148	0.105	0.196
T34	0.336	0.350	0.271	0.192	0.087	0.115	0.128	0.149	0.197	0.105	0.041	0.089	0.284	0.141	0.048	0.294	0.187
T35	0.073	0.219	0.269	0.347	0.105	0.193	0.093	0.252	0.253	0.054	0.061	0.081	0.066	0.057	0.044	0.083	0.170
T36	0.084	0.244	0.242	0.397	0.162	0.127	0.069	0.140	0.080	0.091	0.116	0.149	0.176	0.113	0.104	0.154	0.188
T37	0.116	0.240	0.336	0.450	0.360	0.310	0.082	0.107	0.070	0.132	0.263	0.502	0.467	0.390	0.199	0.057	0.291
T38	0.333	0.260	0.233	0.274	0.108	0.212	0.073	0.157	0.181	0.033	0.081	0.111	0.123	0.057	0.047	0.310	0.192
T39	0.387	0.357	0.343	0.273	0.097	0.207	0.076	0.057	0.126	0.079	0.101	0.153	0.123	0.075	0.074	0.338	0.212
T40	0.347	0.287	0.257	0.339	0.326	0.416	0.072	0.094	0.169	0.098	0.071	0.211	0.196	0.118	0.018	0.287	0.273
T41	0.079	0.081	0.125	0.231	0.162	0.159	0.022	0.028	0.042	0.032	0.041	0.098	0.096	0.097	0.154	0.149	0.124
T42	0.228	0.203	0.150	0.213	0.081	0.168	0.102	0.084	0.160	0.048	0.073	0.047	0.097	0.054	0.090	0.175	0.143
T43	0.161	0.137	0.279	0.477	0.350	0.280	0.069	0.104	0.121	0.136	0.043	0.081	0.102	0.071	0.326	0.188	0.251
T44	0.106	0.153	0.378	0.632	0.392	0.339	0.114	0.097	0.105	0.199	0.209	0.253	0.233	0.169	0.176	0.192	0.310
T45	0.049	0.040	0.034	0.064	0.099	0.061	0.027	0.012	0.033	0.140	0.151	0.119	0.151	0.151	0.348	0.341	0.079
T46	0.248	0.155	0.083	0.059	0.171	0.047	0.151	0.251	0.388	0.289	0.231	0.195	0.083	0.241	0.437	0.476	0.171
T47	0.028	0.041	0.075	0.088	0.134	0.083	0.280	0.364	0.353	0.226	0.141	0.100	0.240	0.316	0.323	0.172	0.128
T48	0.240	0.241	0.356	0.458	0.275	0.096	0.154	0.228	0.267	0.143	0.128	0.141	0.222	0.108	0.056	0.218	0.268
T49	0.077	0.113	0.262	0.357	0.165	0.096	0.052	0.084	0.146	0.084	0.070	0.096	0.260	0.190	0.096	0.160	0.170
T50	0.123	0.178	0.417	0.630	0.256	0.084	0.042	0.100	0.149	0.165	0.155	0.186	0.252	0.165	0.114	0.077	0.265
T51	0.090	0.081	0.111	0.355	0.256	0.119	0.103	0.114	0.195	0.109	0.147	0.196	0.095	0.137	0.149	0.066	0.185
T52	0.026	0.059	0.112	0.156	0.106	0.099	0.068	0.072	0.136	0.059	0.122	0.174	0.087	0.065	0.046	0.097	0.099
T53	0.023	0.121	0.181	0.236	0.129	0.081	0.119	0.105	0.150	0.043	0.133	0.211	0.134	0.104	0.228	0.021	0.133
T54	0.022	0.069	0.081	0.148	0.362	0.424	0.167	0.079	0.154	0.151	0.306	0.517	0.414	0.341	0.194	0.082	0.210
T55	0.088	0.295	0.495	0.748	0.347	0.363	0.195	0.070	0.223	0.204	0.298	0.404	0.327	0.235	0.199	0.054	0.356
T56	0.419	0.373	0.437	0.693	0.562	0.530	0.655	0.367	0.398	0.052	0.119	0.224	0.368	0.349	0.563	0.524	0.470
T57	0.378	0.349	0.411	0.658	0.482	0.450	0.531	0.264	0.318	0.030	0.054	0.095	0.056	0.104	0.486	0.458	0.403
T58	0.339	0.365	0.422	0.603	0.432	0.398	0.515	0.302	0.347	0.200	0.062	0.055	0.115	0.136	0.473	0.498	0.386
T59	0.485	0.429	0.477	0.681	0.382	0.461	0.495	0.246	0.341	0.191	0.069	0.073	0.142	0.048	0.391	0.553	0.416
T60	0.433	0.448	0.437	0.624	0.325	0.435	0.568	0.309	0.379	0.216	0.202	0.092	0.028	0.073	0.513	0.616	0.397

Test Point	Wind Velocity Ratio - Annual																VR_W for Total 16 Wind Directions
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	
Wind probability	**0.121**	**0.083**	**0.088**	**0.151**	**0.234**	**0.049**	**0.031**	**0.03**	**0.043**	**0.031**	**0.049**	**0.032**	**0.025**	**0.01**	**0.006**	**0.015**	**1**
T61	0.501	0.502	0.530	0.711	0.369	0.531	0.428	0.248	0.363	0.217	0.280	0.299	0.079	0.067	0.334	0.619	0.450
T62	0.239	0.211	0.212	0.121	0.063	0.068	0.123	0.112	0.172	0.222	0.250	0.408	0.439	0.210	0.090	0.151	0.164
T63	0.302	0.226	0.344	0.316	0.079	0.191	0.037	0.127	0.153	0.040	0.202	0.357	0.358	0.266	0.116	0.196	0.211
T64	0.183	0.092	0.179	0.162	0.075	0.075	0.140	0.126	0.023	0.054	0.072	0.045	0.040	0.033	0.055	0.071	0.110
T65	0.050	0.051	0.039	0.141	0.054	0.057	0.044	0.031	0.029	0.095	0.029	0.073	0.216	0.192	0.177	0.116	0.071
T66	0.193	0.038	0.066	0.154	0.065	0.029	0.112	0.045	0.052	0.040	0.066	0.191	0.145	0.116	0.166	0.053	0.097
T67	0.166	0.224	0.373	0.529	0.283	0.194	0.140	0.179	0.266	0.186	0.164	0.077	0.141	0.057	0.063	0.102	0.271
T68	0.187	0.143	0.205	0.318	0.142	0.075	0.100	0.140	0.118	0.078	0.061	0.041	0.045	0.024	0.051	0.178	0.161
T69	0.097	0.138	0.229	0.363	0.135	0.137	0.196	0.235	0.330	0.206	0.191	0.201	0.145	0.069	0.155	0.188	0.194
T70	0.269	0.178	0.269	0.371	0.173	0.177	0.130	0.205	0.320	0.209	0.227	0.262	0.166	0.131	0.064	0.169	0.235
T71	0.161	0.181	0.276	0.393	0.208	0.223	0.168	0.160	0.266	0.187	0.208	0.297	0.350	0.185	0.084	0.121	0.238
Average LVR	**0.171**	**0.176**	**0.229**	**0.327**	**0.201**	**0.177**	**0.135**	**0.124**	**0.161**	**0.113**	**0.126**	**0.170**	**0.171**	**0.127**	**0.165**	**0.188**	**0.200**
T_{Min}	0.022	0.033	0.028	0.036	0.049	0.024	0.014	0.012	0.017	0.019	0.029	0.035	0.028	0.017	0.018	0.021	0.066
T_{Max}	0.501	0.502	0.530	0.748	0.562	0.531	0.655	0.367	0.398	0.289	0.306	0.517	0.467	0.390	0.563	0.619	0.470

Appendix B Details of Predicted Wind Velocity Ratios (VR_W)

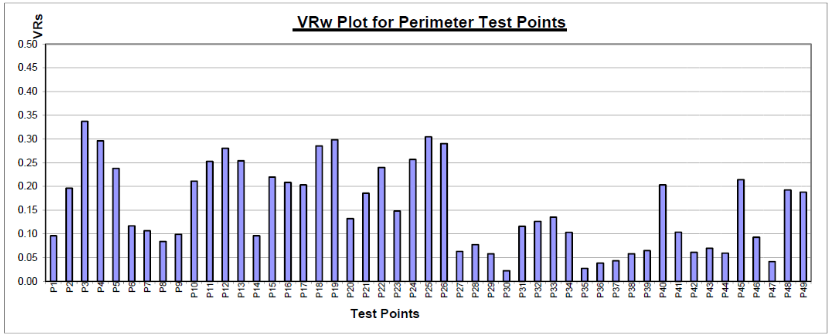
"Summer Wind"

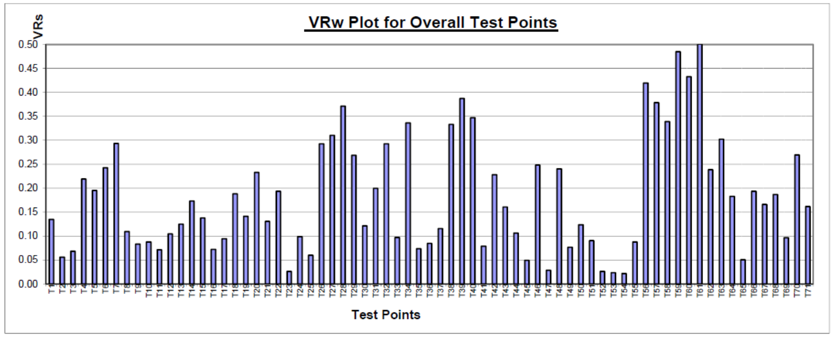
Test Point	Wind Velocity Ratio - Summer Season																VR_W for Total 16 Wind Directions
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	
Wind probability	0.025	0.022	0.025	0.048	0.138	0.079	0.065	0.064	0.101	0.083	0.145	0.097	0.065	0.002	0.011	0.012	0.982
P1	0.096	0.183	0.410	0.642	0.389	0.336	0.131	0.098	0.111	0.199	0.215	0.263	0.231	0.177	0.148	0.162	0.250
P2	0.196	0.159	0.109	0.183	0.108	0.088	0.108	0.114	0.100	0.140	0.159	0.174	0.131	0.081	0.260	0.267	0.135
P3	0.337	0.247	0.033	0.167	0.124	0.106	0.116	0.113	0.076	0.230	0.263	0.339	0.361	0.202	0.184	0.248	0.193
P4	0.296	0.206	0.084	0.161	0.096	0.087	0.137	0.143	0.186	0.188	0.209	0.318	0.352	0.188	0.118	0.208	0.186
P5	0.238	0.199	0.434	0.512	0.200	0.048	0.117	0.179	0.235	0.215	0.230	0.376	0.389	0.213	0.100	0.081	0.240
P6	0.117	0.177	0.544	0.834	0.497	0.255	0.028	0.081	0.165	0.233	0.255	0.423	0.474	0.262	0.275	0.186	0.312
P7	0.107	0.085	0.380	0.616	0.383	0.253	0.063	0.073	0.078	0.025	0.020	0.048	0.076	0.109	0.380	0.328	0.159
P8	0.084	0.080	0.209	0.383	0.248	0.136	0.038	0.053	0.088	0.023	0.034	0.042	0.038	0.040	0.137	0.158	0.106
P9	0.099	0.108	0.220	0.424	0.211	0.121	0.041	0.016	0.115	0.039	0.157	0.273	0.259	0.193	0.108	0.109	0.160
P10	0.211	0.045	0.196	0.554	0.440	0.380	0.187	0.007	0.130	0.037	0.046	0.058	0.084	0.051	0.234	0.316	0.185
P11	0.253	0.102	0.176	0.208	0.228	0.251	0.141	0.023	0.127	0.029	0.047	0.025	0.025	0.049	0.229	0.316	0.120
P12	0.280	0.170	0.225	0.228	0.237	0.257	0.163	0.054	0.092	0.032	0.102	0.069	0.072	0.043	0.118	0.271	0.140
P13	0.254	0.230	0.379	0.409	0.251	0.217	0.092	0.069	0.104	0.020	0.092	0.035	0.043	0.033	0.032	0.047	0.138
P14	0.096	0.163	0.279	0.476	0.335	0.309	0.113	0.094	0.014	0.052	0.081	0.222	0.281	0.200	0.259	0.159	0.186
P15	0.220	0.204	0.278	0.235	0.192	0.178	0.096	0.108	0.122	0.075	0.132	0.131	0.079	0.087	0.259	0.113	0.144
P16	0.208	0.206	0.211	0.369	0.122	0.063	0.085	0.139	0.058	0.084	0.098	0.035	0.028	0.016	0.092	0.066	0.105
P17	0.203	0.171	0.098	0.194	0.103	0.122	0.080	0.110	0.057	0.050	0.047	0.041	0.022	0.015	0.080	0.107	0.082
P18	0.285	0.269	0.288	0.387	0.100	0.206	0.092	0.132	0.169	0.173	0.165	0.187	0.186	0.119	0.151	0.201	0.176
P19	0.298	0.300	0.352	0.515	0.229	0.198	0.132	0.047	0.038	0.034	0.041	0.058	0.045	0.038	0.124	0.244	0.134
P20	0.132	0.137	0.153	0.184	0.113	0.115	0.043	0.037	0.030	0.039	0.057	0.021	0.078	0.068	0.107	0.183	0.075
P21	0.186	0.172	0.232	0.379	0.199	0.175	0.091	0.155	0.223	0.138	0.174	0.172	0.046	0.057	0.140	0.197	0.176
P22	0.240	0.217	0.250	0.427	0.112	0.112	0.053	0.052	0.059	0.027	0.030	0.023	0.068	0.009	0.160	0.254	0.094
P23	0.148	0.058	0.099	0.407	0.256	0.228	0.074	0.059	0.067	0.017	0.012	0.032	0.025	0.017	0.049	0.121	0.108
P24	0.257	0.159	0.068	0.433	0.330	0.268	0.146	0.023	0.063	0.022	0.022	0.022	0.030	0.019	0.077	0.189	0.131
P25	0.305	0.304	0.202	0.213	0.280	0.317	0.215	0.057	0.065	0.029	0.019	0.022	0.067	0.038	0.066	0.243	0.135
P26	0.290	0.334	0.294	0.119	0.122	0.223	0.179	0.105	0.040	0.043	0.040	0.063	0.059	0.027	0.038	0.224	0.109
P27	0.063	0.069	0.235	0.217	0.069	0.090	0.077	0.099	0.135	0.085	0.045	0.109	0.301	0.182	0.088	0.110	0.109
P28	0.077	0.116	0.145	0.169	0.075	0.079	0.069	0.084	0.203	0.168	0.202	0.281	0.241	0.117	0.056	0.040	0.153
P29	0.058	0.132	0.164	0.088	0.029	0.053	0.041	0.024	0.055	0.046	0.059	0.078	0.024	0.038	0.046	0.063	0.055
P30	0.022	0.347	0.411	0.373	0.094	0.136	0.121	0.113	0.174	0.043	0.063	0.090	0.061	0.043	0.033	0.031	0.121
P31	0.116	0.174	0.383	0.614	0.259	0.102	0.049	0.230	0.346	0.245	0.300	0.399	0.357	0.263	0.168	0.073	0.276
P32	0.126	0.127	0.267	0.428	0.271	0.274	0.121	0.120	0.221	0.197	0.253	0.336	0.293	0.211	0.161	0.029	0.242
P33	0.135	0.191	0.437	0.663	0.316	0.198	0.107	0.102	0.174	0.183	0.190	0.233	0.274	0.183	0.128	0.082	0.231
P34	0.103	0.148	0.364	0.483	0.114	0.108	0.021	0.116	0.153	0.115	0.101	0.185	0.189	0.128	0.100	0.081	0.146
P35	0.027	0.049	0.156	0.195	0.042	0.037	0.030	0.029	0.095	0.027	0.069	0.096	0.094	0.061	0.052	0.054	0.067
P36	0.038	0.176	0.291	0.421	0.224	0.169	0.044	0.103	0.166	0.111	0.112	0.160	0.254	0.150	0.076	0.111	0.166
P37	0.043	0.093	0.112	0.134	0.058	0.047	0.059	0.091	0.105	0.125	0.087	0.201	0.264	0.140	0.091	0.118	0.108
P38	0.058	0.045	0.053	0.080	0.041	0.050	0.080	0.068	0.115	0.073	0.087	0.123	0.213	0.123	0.057	0.047	0.086
P39	0.065	0.066	0.128	0.104	0.054	0.037	0.149	0.208	0.263	0.149	0.162	0.106	0.212	0.102	0.059	0.049	0.135
P40	0.203	0.244	0.331	0.478	0.282	0.193	0.137	0.197	0.214	0.110	0.092	0.203	0.259	0.097	0.075	0.206	0.205
P41	0.104	0.105	0.102	0.110	0.029	0.044	0.130	0.146	0.096	0.092	0.135	0.176	0.254	0.092	0.126	0.071	0.113
P42	0.061	0.088	0.127	0.133	0.054	0.040	0.249	0.331	0.326	0.198	0.113	0.089	0.241	0.250	0.076	0.107	0.156
P43	0.070	0.095	0.134	0.167	0.055	0.024	0.267	0.372	0.387	0.215	0.131	0.113	0.144	0.304	0.191	0.088	0.169
P44	0.059	0.043	0.039	0.145	0.072	0.022	0.109	0.217	0.356	0.242	0.207	0.188	0.053	0.282	0.311	0.243	0.160
P45	0.215	0.120	0.026	0.099	0.055	0.033	0.033	0.030	0.075	0.112	0.188	0.227	0.086	0.196	0.375	0.388	0.111
P46	0.093	0.113	0.134	0.212	0.129	0.044	0.030	0.069	0.083	0.129	0.128	0.128	0.160	0.206	0.331	0.321	0.116
P47	0.041	0.050	0.045	0.086	0.088	0.052	0.022	0.019	0.050	0.138	0.145	0.129	0.116	0.113	0.306	0.302	0.093
P48	0.192	0.149	0.198	0.255	0.101	0.053	0.020	0.121	0.120	0.171	0.211	0.246	0.054	0.062	0.325	0.326	0.147
P49	0.188	0.145	0.265	0.294	0.153	0.134	0.120	0.096	0.158	0.189	0.231	0.267	0.120	0.116	0.148	0.140	0.180
Average SVR	**0.155**	**0.154**	**0.219**	**0.318**	**0.175**	**0.144**	**0.099**	**0.105**	**0.136**	**0.109**	**0.124**	**0.156**	**0.159**	**0.119**	**0.149**	**0.165**	**0.149**
P_{Min}	0.022	0.043	0.026	0.080	0.029	0.022	0.020	0.007	0.014	0.017	0.012	0.021	0.022	0.009	0.032	0.029	0.055
P_{Max}	0.337	0.347	0.544	0.834	0.497	0.380	0.267	0.372	0.387	0.245	0.300	0.423	0.474	0.304	0.380	0.388	0.312

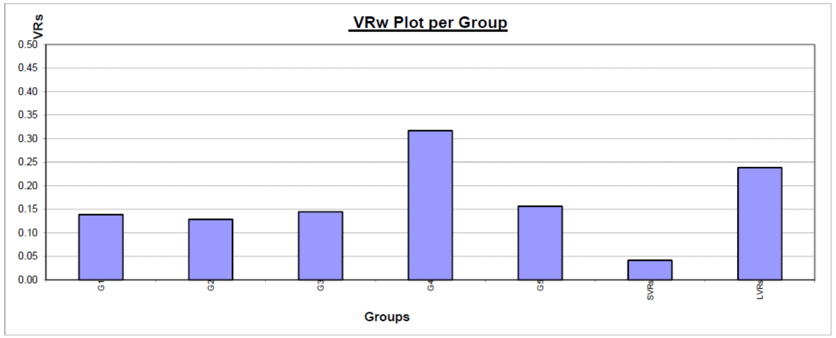
Test Point	Wind Velocity Ratio - Summer Season																VR_W for Total
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	16 Wind Directions
Wind probability	0.025	0.022	0.025	0.048	0.138	0.079	0.065	0.064	0.101	0.083	0.145	0.097	0.065	0.002	0.011	0.012	0.982
T1	0.134	0.134	0.233	0.302	0.260	0.153	0.135	0.125	0.078	0.026	0.031	0.061	0.101	0.118	0.094	0.077	0.123
T2	0.056	0.171	0.243	0.282	0.271	0.288	0.027	0.030	0.134	0.088	0.052	0.069	0.060	0.053	0.030	0.037	0.131
T3	0.068	0.200	0.125	0.185	0.101	0.075	0.014	0.082	0.070	0.026	0.181	0.410	0.351	0.147	0.240	0.358	0.152
T4	0.219	0.357	0.363	0.555	0.208	0.104	0.120	0.115	0.161	0.108	0.053	0.222	0.223	0.165	0.121	0.146	0.177
T5	0.195	0.221	0.324	0.505	0.372	0.130	0.101	0.177	0.222	0.134	0.129	0.257	0.193	0.092	0.140	0.115	0.218
T6	0.243	0.261	0.378	0.574	0.313	0.031	0.062	0.124	0.192	0.107	0.055	0.117	0.168	0.079	0.171	0.155	0.172
T7	0.294	0.222	0.271	0.359	0.094	0.053	0.212	0.285	0.333	0.196	0.134	0.105	0.051	0.124	0.227	0.274	0.177
T8	0.109	0.069	0.092	0.112	0.105	0.093	0.078	0.082	0.144	0.081	0.043	0.164	0.245	0.142	0.103	0.072	0.108
T9	0.083	0.080	0.162	0.112	0.179	0.052	0.157	0.214	0.307	0.188	0.128	0.267	0.346	0.191	0.128	0.226	0.187
T10	0.088	0.187	0.095	0.071	0.097	0.095	0.100	0.055	0.145	0.031	0.167	0.357	0.319	0.126	0.110	0.200	0.146
T11	0.071	0.143	0.064	0.167	0.096	0.102	0.052	0.060	0.141	0.073	0.112	0.181	0.171	0.112	0.168	0.106	0.114
T12	0.104	0.143	0.169	0.149	0.077	0.066	0.151	0.080	0.126	0.114	0.139	0.210	0.204	0.111	0.053	0.115	0.128
T13	0.125	0.177	0.042	0.150	0.104	0.065	0.147	0.171	0.168	0.068	0.089	0.157	0.178	0.142	0.111	0.235	0.124
T14	0.173	0.060	0.064	0.036	0.093	0.181	0.126	0.073	0.037	0.073	0.082	0.075	0.033	0.038	0.070	0.123	0.084
T15	0.138	0.142	0.063	0.119	0.074	0.111	0.083	0.147	0.191	0.115	0.095	0.065	0.090	0.038	0.062	0.154	0.107
T16	0.072	0.084	0.113	0.132	0.113	0.133	0.068	0.175	0.163	0.113	0.103	0.035	0.040	0.074	0.236	0.226	0.109
T17	0.094	0.107	0.128	0.171	0.075	0.094	0.072	0.070	0.078	0.043	0.091	0.086	0.089	0.089	0.070	0.073	0.085
T18	0.188	0.156	0.109	0.226	0.088	0.024	0.071	0.219	0.290	0.058	0.102	0.155	0.099	0.181	0.078	0.100	0.130
T19	0.141	0.231	0.312	0.320	0.320	0.194	0.059	0.244	0.056	0.138	0.205	0.342	0.285	0.301	0.135	0.069	0.216
T20	0.233	0.273	0.307	0.354	0.305	0.207	0.056	0.118	0.151	0.086	0.195	0.311	0.283	0.268	0.122	0.110	0.212
T21	0.130	0.088	0.114	0.144	0.109	0.153	0.165	0.090	0.070	0.085	0.129	0.189	0.205	0.176	0.133	0.071	0.128
T22	0.193	0.139	0.028	0.105	0.050	0.074	0.188	0.183	0.123	0.123	0.124	0.114	0.090	0.072	0.163	0.227	0.114
T23	0.026	0.033	0.046	0.094	0.049	0.093	0.090	0.073	0.103	0.074	0.102	0.089	0.075	0.047	0.155	0.197	0.082
T24	0.099	0.127	0.139	0.075	0.065	0.074	0.057	0.059	0.117	0.059	0.054	0.078	0.069	0.060	0.097	0.157	0.076
T25	0.060	0.129	0.072	0.119	0.081	0.098	0.041	0.101	0.140	0.095	0.049	0.039	0.046	0.040	0.065	0.032	0.078
T26	0.293	0.321	0.454	0.569	0.462	0.455	0.524	0.142	0.213	0.184	0.216	0.235	0.248	0.209	0.254	0.259	0.315
T27	0.310	0.361	0.458	0.525	0.437	0.377	0.341	0.056	0.255	0.179	0.200	0.253	0.184	0.133	0.185	0.241	0.285
T28	0.371	0.385	0.482	0.626	0.487	0.474	0.333	0.117	0.268	0.245	0.206	0.323	0.260	0.152	0.346	0.347	0.333
T29	0.269	0.265	0.409	0.671	0.527	0.426	0.124	0.171	0.236	0.214	0.205	0.340	0.296	0.172	0.318	0.258	0.317
T30	0.121	0.086	0.333	0.606	0.493	0.436	0.252	0.077	0.103	0.161	0.169	0.310	0.380	0.241	0.354	0.244	0.282
T31	0.199	0.056	0.231	0.569	0.473	0.436	0.237	0.018	0.102	0.019	0.043	0.065	0.060	0.028	0.298	0.336	0.195
T32	0.293	0.140	0.149	0.308	0.338	0.435	0.352	0.126	0.017	0.026	0.081	0.120	0.114	0.081	0.314	0.390	0.187
T33	0.097	0.074	0.140	0.388	0.307	0.306	0.121	0.053	0.076	0.058	0.083	0.051	0.051	0.017	0.148	0.105	0.142
T34	0.336	0.350	0.271	0.192	0.087	0.115	0.128	0.149	0.197	0.105	0.041	0.089	0.284	0.141	0.048	0.294	0.140
T35	0.073	0.219	0.269	0.347	0.105	0.193	0.093	0.252	0.253	0.054	0.061	0.081	0.066	0.057	0.044	0.083	0.137
T36	0.084	0.244	0.242	0.397	0.162	0.127	0.069	0.140	0.080	0.091	0.116	0.149	0.176	0.113	0.104	0.154	0.143
T37	0.116	0.240	0.336	0.450	0.360	0.310	0.082	0.107	0.070	0.132	0.263	0.502	0.467	0.390	0.199	0.057	0.268
T38	0.333	0.260	0.233	0.274	0.108	0.212	0.073	0.157	0.181	0.033	0.081	0.111	0.123	0.057	0.047	0.310	0.138
T39	0.387	0.357	0.343	0.273	0.097	0.207	0.076	0.057	0.126	0.079	0.101	0.153	0.123	0.075	0.074	0.338	0.142
T40	0.347	0.287	0.257	0.339	0.326	0.416	0.072	0.094	0.169	0.098	0.071	0.211	0.196	0.118	0.018	0.287	0.202
T41	0.079	0.081	0.125	0.231	0.162	0.159	0.022	0.028	0.042	0.032	0.041	0.098	0.096	0.097	0.154	0.149	0.090
T42	0.228	0.203	0.150	0.213	0.081	0.168	0.102	0.084	0.160	0.048	0.073	0.047	0.097	0.054	0.090	0.175	0.107
T43	0.161	0.137	0.279	0.477	0.350	0.280	0.069	0.104	0.121	0.136	0.043	0.081	0.102	0.071	0.326	0.188	0.172
T44	0.106	0.153	0.378	0.632	0.392	0.339	0.114	0.097	0.105	0.199	0.209	0.253	0.233	0.169	0.176	0.192	0.246
T45	0.049	0.040	0.034	0.064	0.099	0.061	0.027	0.012	0.033	0.140	0.151	0.119	0.151	0.151	0.348	0.341	0.095
T46	0.248	0.155	0.083	0.059	0.171	0.047	0.151	0.251	0.388	0.289	0.231	0.195	0.083	0.241	0.437	0.476	0.203
T47	0.028	0.041	0.075	0.088	0.134	0.083	0.280	0.364	0.353	0.226	0.141	0.100	0.240	0.316	0.323	0.172	0.184
T48	0.240	0.241	0.356	0.458	0.275	0.096	0.154	0.228	0.267	0.143	0.128	0.141	0.222	0.108	0.056	0.218	0.205
T49	0.077	0.113	0.262	0.357	0.165	0.096	0.052	0.084	0.146	0.084	0.070	0.096	0.260	0.190	0.096	0.160	0.131
T50	0.123	0.178	0.417	0.630	0.256	0.084	0.042	0.100	0.149	0.165	0.155	0.186	0.252	0.165	0.114	0.077	0.190
T51	0.090	0.081	0.111	0.355	0.256	0.119	0.103	0.114	0.195	0.109	0.147	0.196	0.095	0.137	0.149	0.066	0.164
T52	0.026	0.059	0.112	0.156	0.106	0.099	0.068	0.072	0.136	0.059	0.122	0.174	0.087	0.065	0.046	0.097	0.106
T53	0.023	0.121	0.181	0.236	0.129	0.081	0.119	0.105	0.150	0.043	0.133	0.211	0.134	0.104	0.228	0.021	0.130
T54	0.022	0.069	0.081	0.148	0.362	0.424	0.167	0.079	0.154	0.151	0.306	0.517	0.414	0.341	0.194	0.082	0.269
T55	0.088	0.295	0.495	0.748	0.347	0.363	0.195	0.070	0.223	0.204	0.298	0.404	0.327	0.235	0.199	0.054	0.303
T56	0.419	0.373	0.437	0.693	0.562	0.530	0.655	0.367	0.398	0.052	0.119	0.224	0.368	0.349	0.563	0.524	0.376
T57	0.378	0.349	0.411	0.658	0.482	0.450	0.531	0.264	0.318	0.030	0.054	0.095	0.056	0.104	0.486	0.458	0.284
T58	0.339	0.365	0.422	0.603	0.432	0.398	0.515	0.302	0.347	0.200	0.062	0.055	0.115	0.136	0.473	0.498	0.290
T59	0.485	0.429	0.477	0.681	0.382	0.461	0.495	0.246	0.341	0.191	0.069	0.073	0.142	0.048	0.391	0.553	0.296
T60	0.433	0.448	0.437	0.624	0.325	0.435	0.568	0.309	0.379	0.216	0.202	0.092	0.028	0.073	0.513	0.616	0.313

Test Point	Wind Velocity Ratio - Summer Season																VR_W for Total 16 Wind Directions
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	
Wind probability	**0.025**	**0.022**	**0.025**	**0.048**	**0.138**	**0.079**	**0.065**	**0.064**	**0.101**	**0.083**	**0.145**	**0.097**	**0.065**	**0.002**	**0.011**	**0.012**	**0.982**
T61	0.501	0.502	0.530	0.711	0.369	0.531	0.428	0.248	0.363	0.217	0.280	0.299	0.079	0.067	0.334	0.619	0.355
T62	0.239	0.211	0.212	0.121	0.063	0.068	0.123	0.112	0.172	0.222	0.250	0.408	0.439	0.210	0.090	0.151	0.198
T63	0.302	0.226	0.344	0.316	0.079	0.191	0.037	0.127	0.153	0.040	0.202	0.357	0.358	0.266	0.116	0.196	0.186
T64	0.183	0.092	0.179	0.162	0.075	0.075	0.140	0.126	0.023	0.054	0.072	0.045	0.040	0.033	0.055	0.071	0.079
T65	0.050	0.051	0.039	0.141	0.054	0.057	0.044	0.031	0.029	0.095	0.029	0.073	0.216	0.192	0.177	0.116	0.068
T66	0.193	0.038	0.066	0.154	0.065	0.029	0.112	0.045	0.052	0.040	0.066	0.191	0.145	0.116	0.166	0.053	0.086
T67	0.166	0.224	0.373	0.529	0.283	0.194	0.140	0.179	0.266	0.186	0.164	0.077	0.141	0.057	0.063	0.102	0.207
T68	0.187	0.143	0.205	0.318	0.142	0.075	0.100	0.140	0.118	0.078	0.061	0.041	0.045	0.024	0.051	0.178	0.108
T69	0.097	0.138	0.229	0.363	0.135	0.137	0.196	0.235	0.330	0.206	0.191	0.201	0.145	0.069	0.155	0.188	0.201
T70	0.269	0.178	0.269	0.371	0.173	0.177	0.130	0.205	0.320	0.209	0.227	0.262	0.166	0.131	0.064	0.169	0.220
T71	0.161	0.181	0.276	0.393	0.208	0.223	0.168	0.160	0.266	0.187	0.208	0.297	0.350	0.185	0.084	0.121	0.232
Average LVR	**0.171**	**0.176**	**0.229**	**0.327**	**0.201**	**0.177**	**0.135**	**0.124**	**0.161**	**0.113**	**0.126**	**0.170**	**0.171**	**0.127**	**0.165**	**0.188**	**0.167**
T_{Min}	0.022	0.033	0.028	0.036	0.049	0.024	0.014	0.012	0.017	0.019	0.029	0.035	0.028	0.017	0.018	0.021	0.068
T_{Max}	0.501	0.502	0.530	0.748	0.562	0.531	0.655	0.367	0.398	0.289	0.306	0.517	0.467	0.390	0.563	0.619	0.376

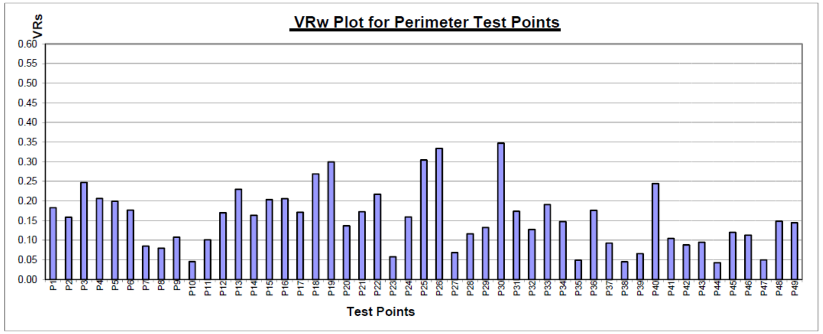
Appendix C Average VR_W Result for Individual Test Points and Different Test Points Groups under Different Wind Directions

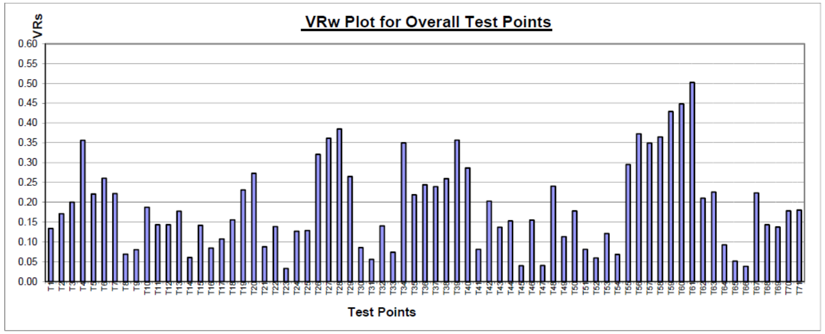


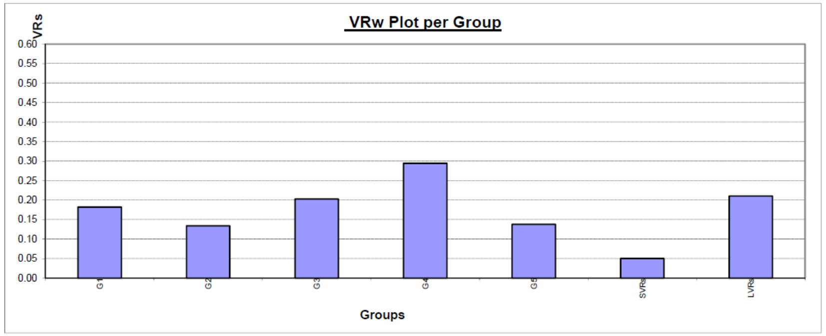




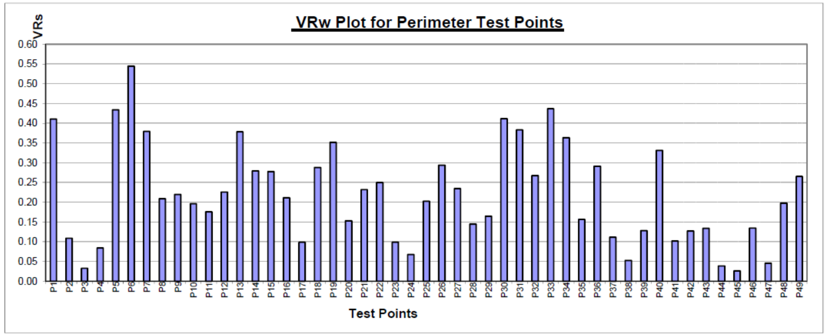
VR_W Result under N Wind Direction

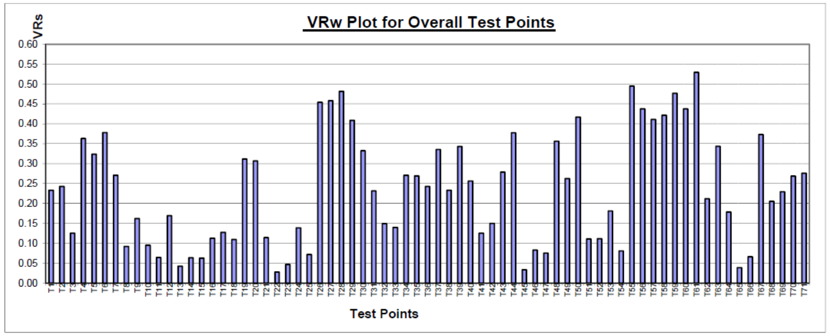


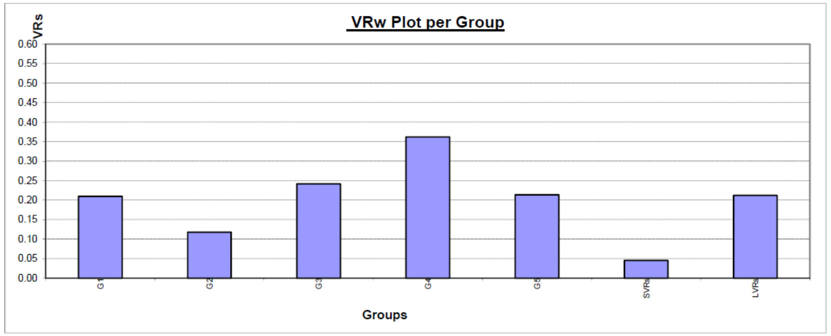




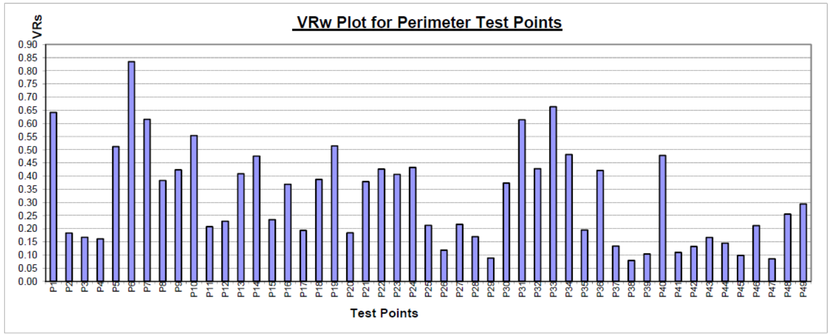
VR_W Result under NNE Wind Direction

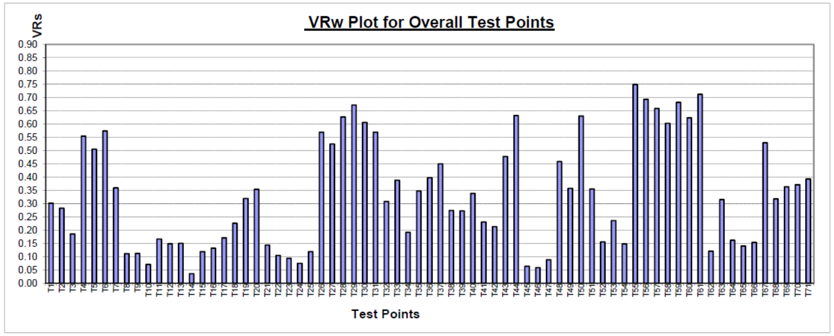


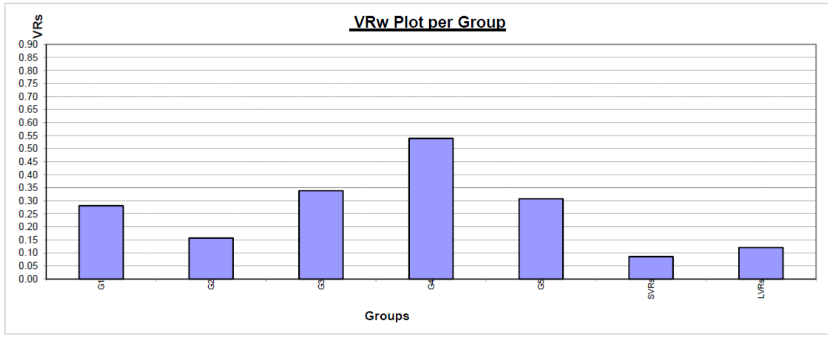




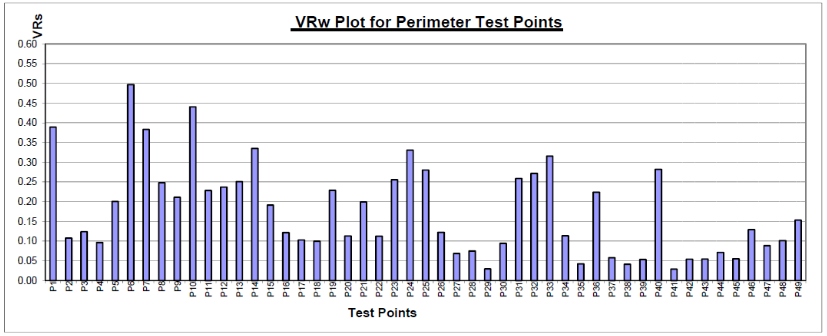
VR$_w$ Result under NE Wind Direction

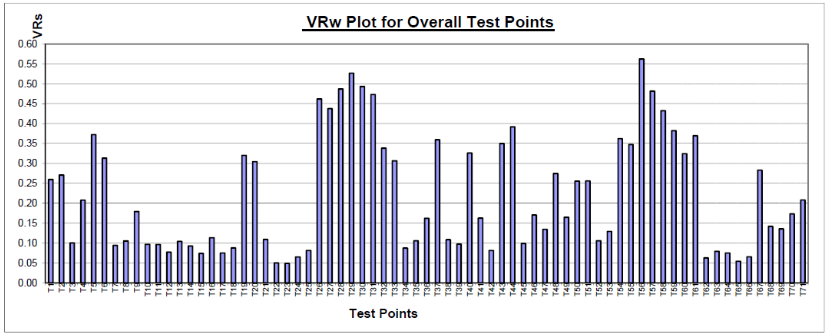


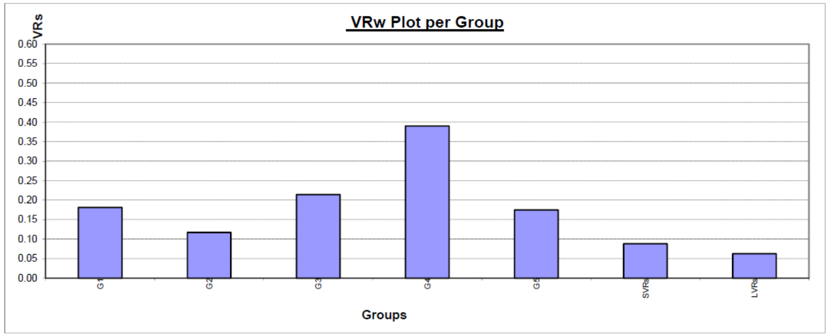




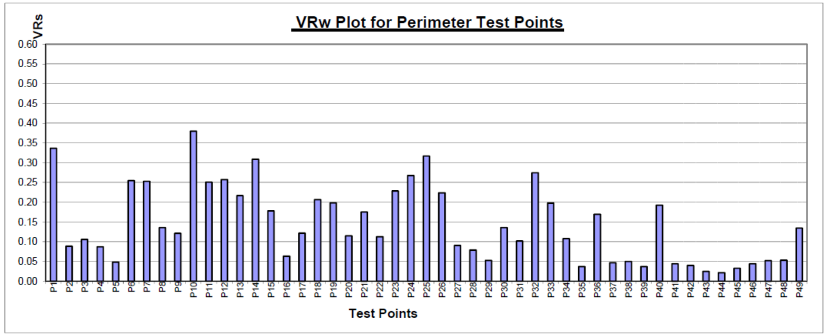
VR$_w$ Result under ENE Wind Direction

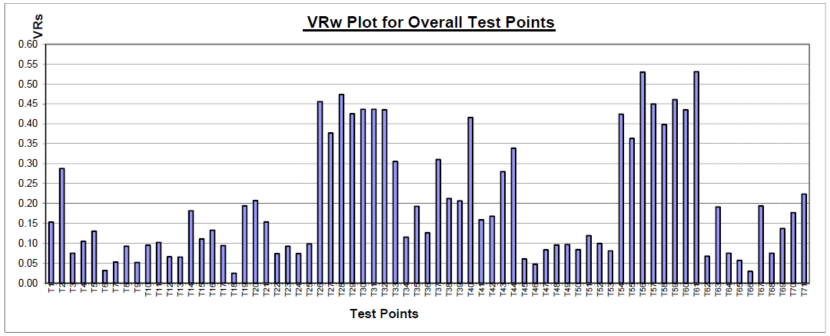


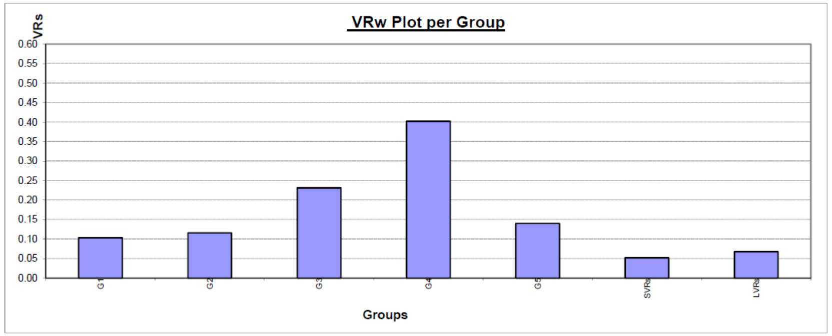




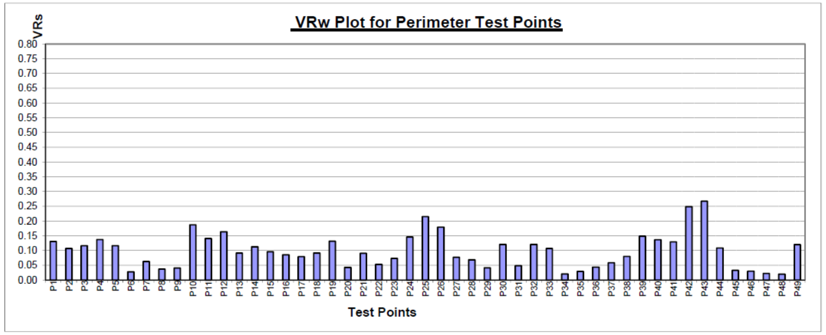
VR_w Result under E Wind Direction

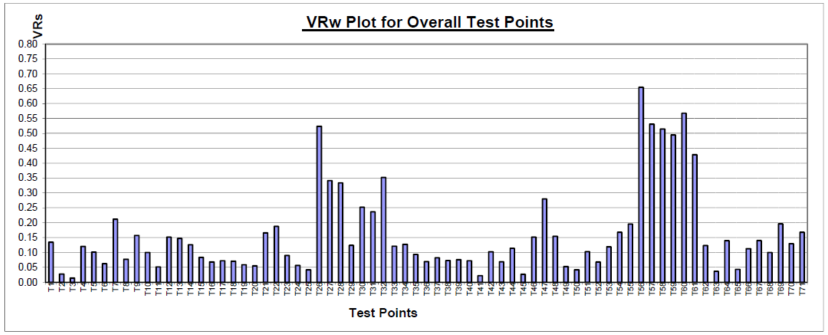


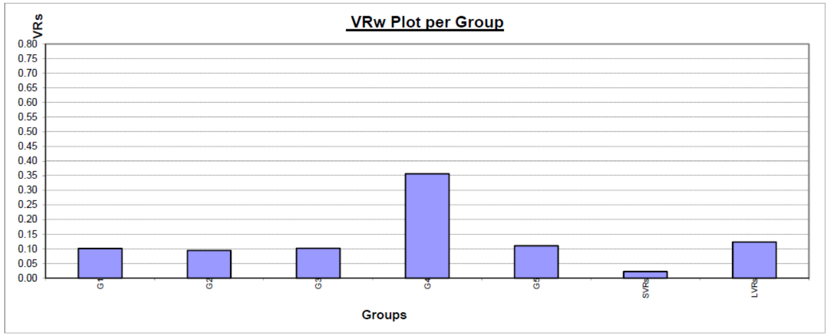




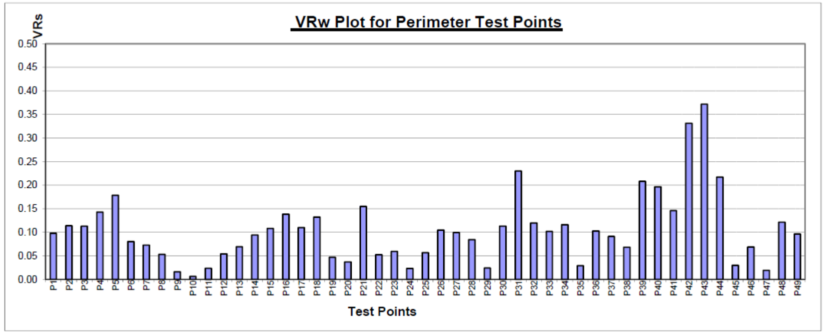
VR_w Result under ESE Wind Direction

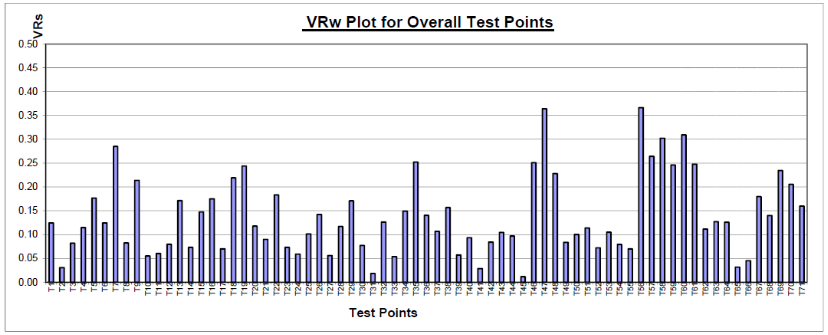


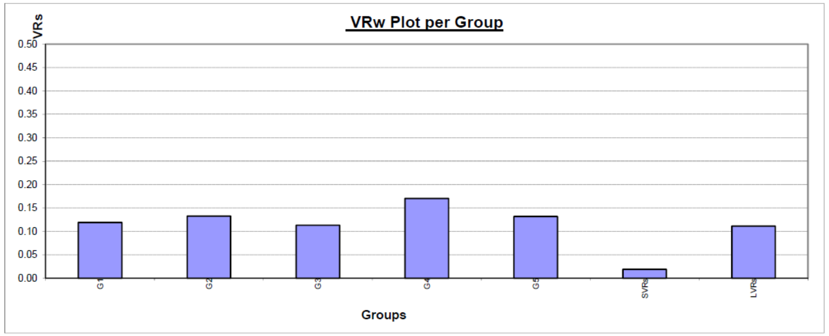




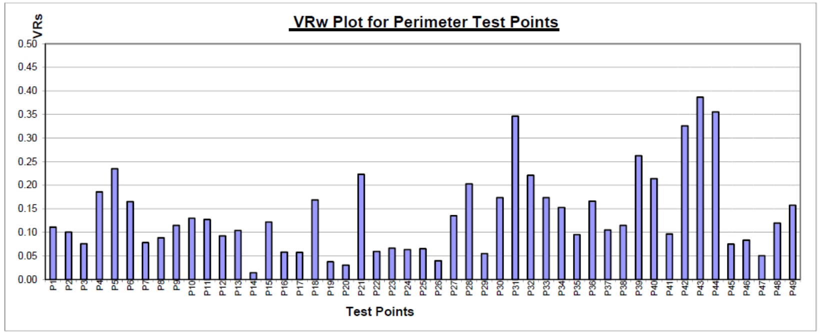
VR$_w$ Result under SE Wind Direction

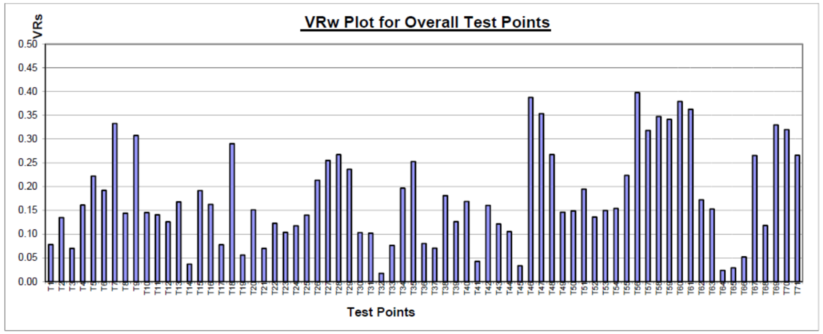


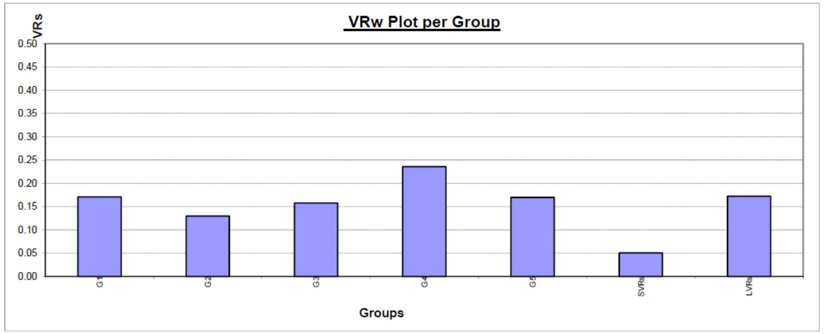




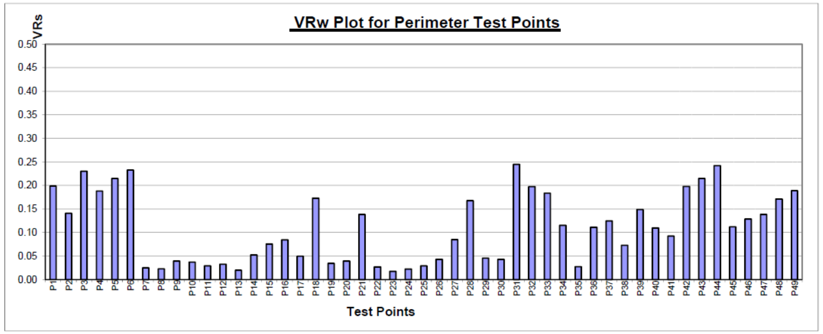
VR$_w$ Result under SSE Wind Direction

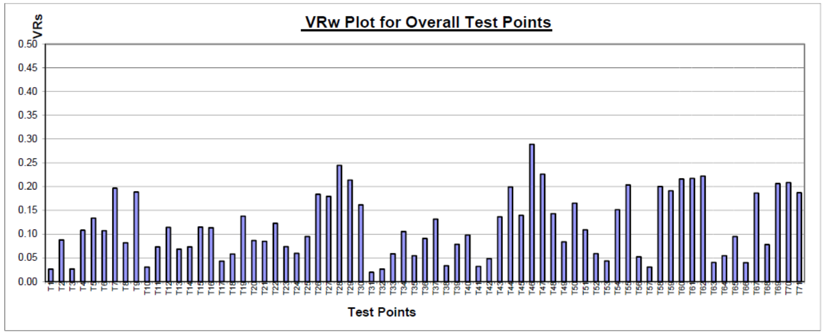


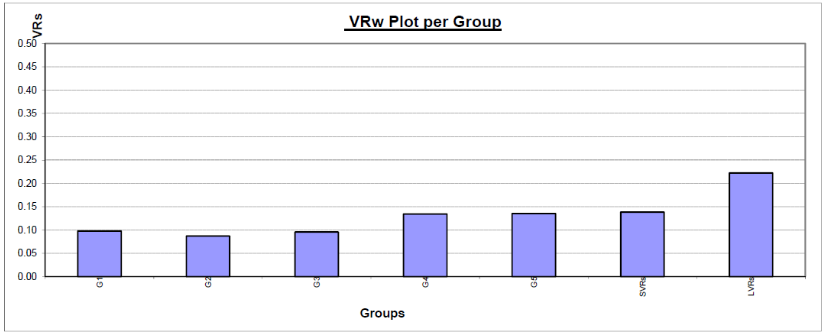




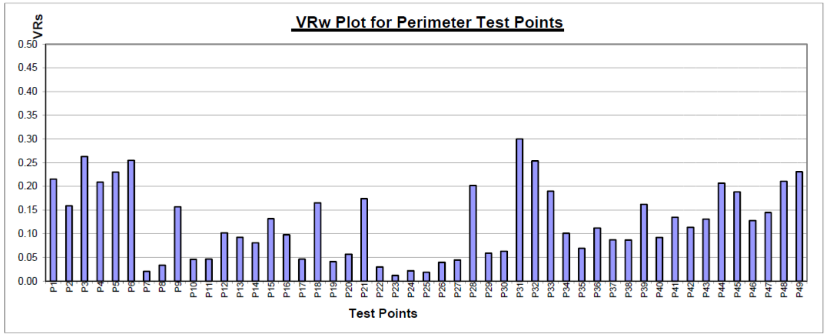
VR_w Result under S Wind Direction

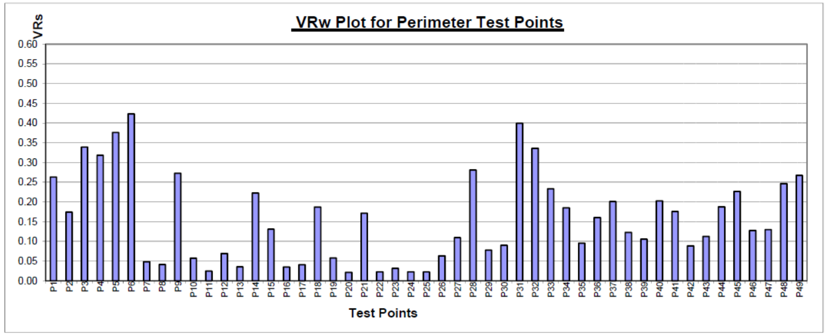


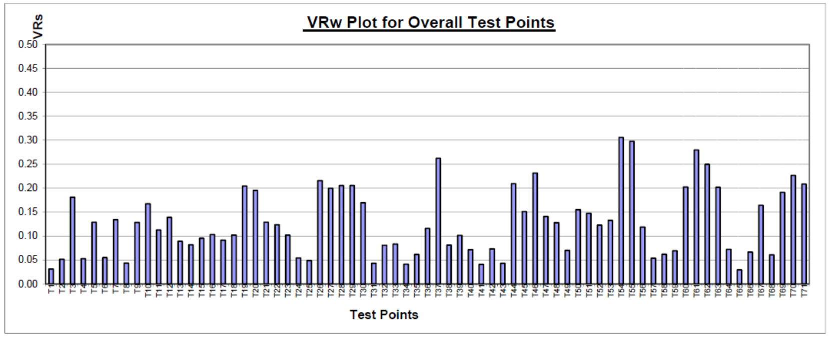


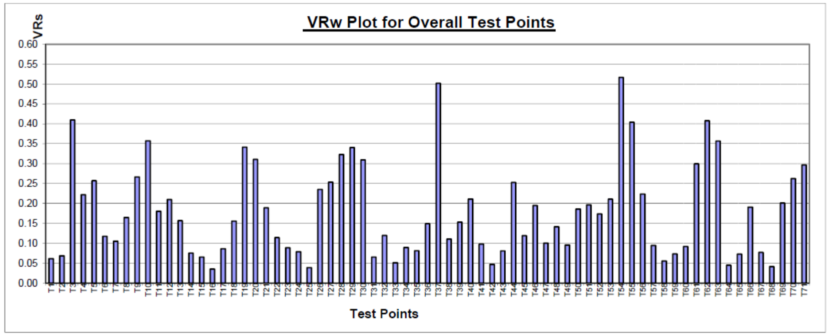


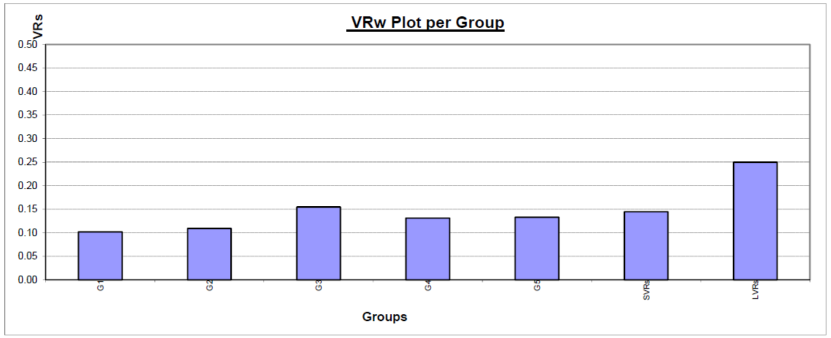
VR_w Result under SSW Wind Direction

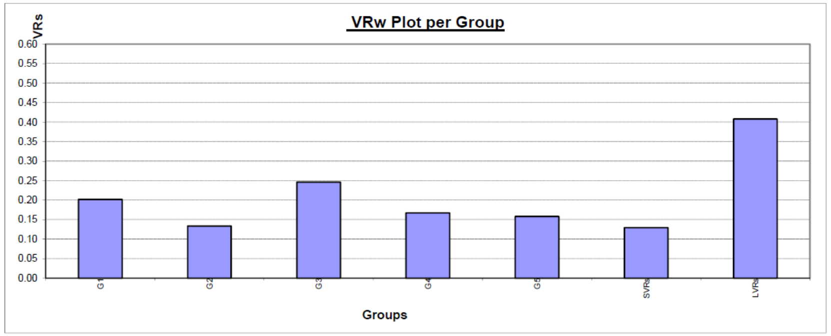






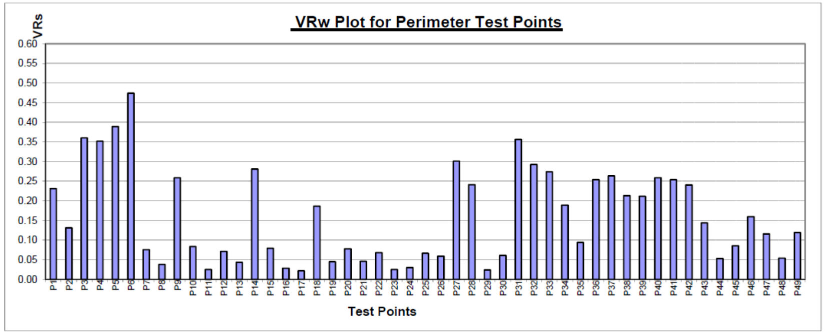


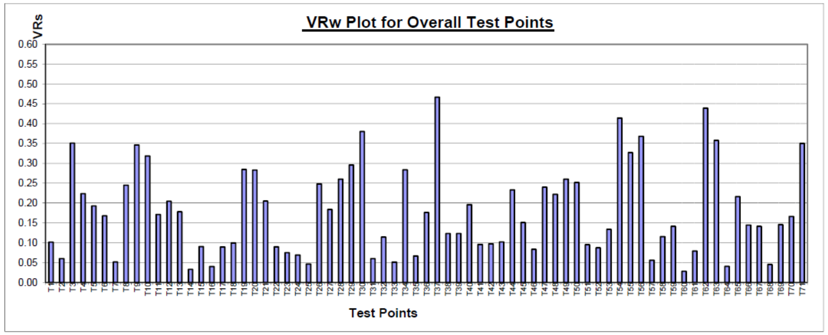


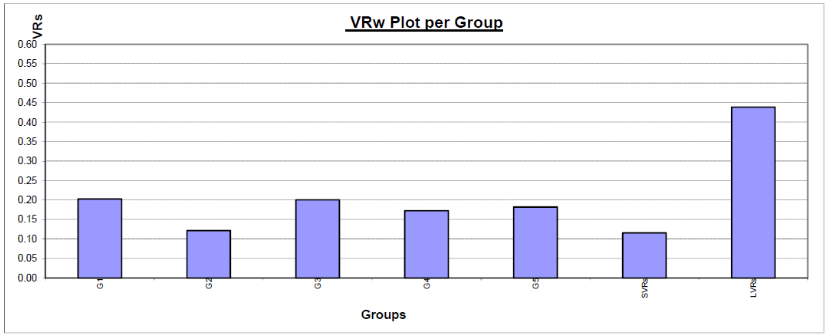


VR_w Result under SW Wind Direction

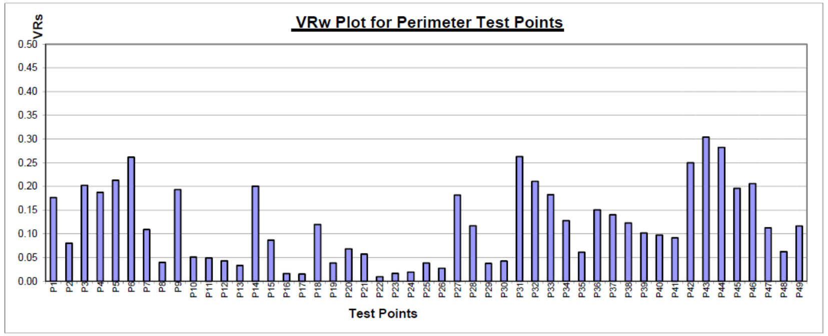
VR_w Result under WSW Wind Direction

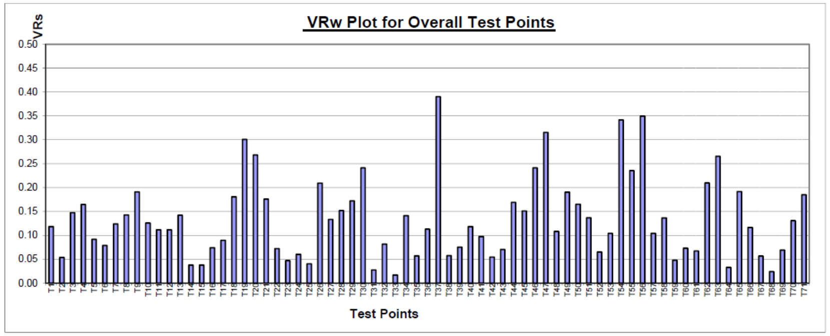


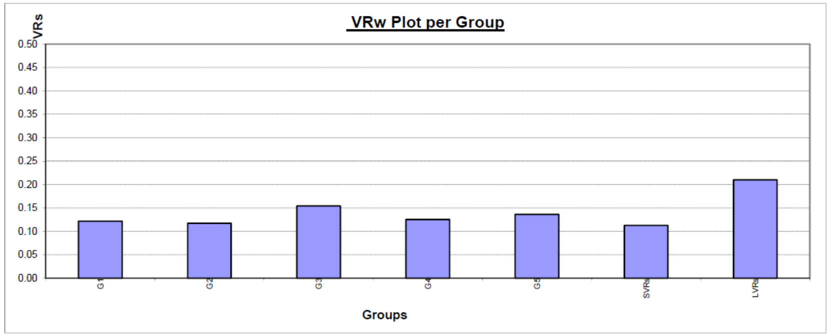




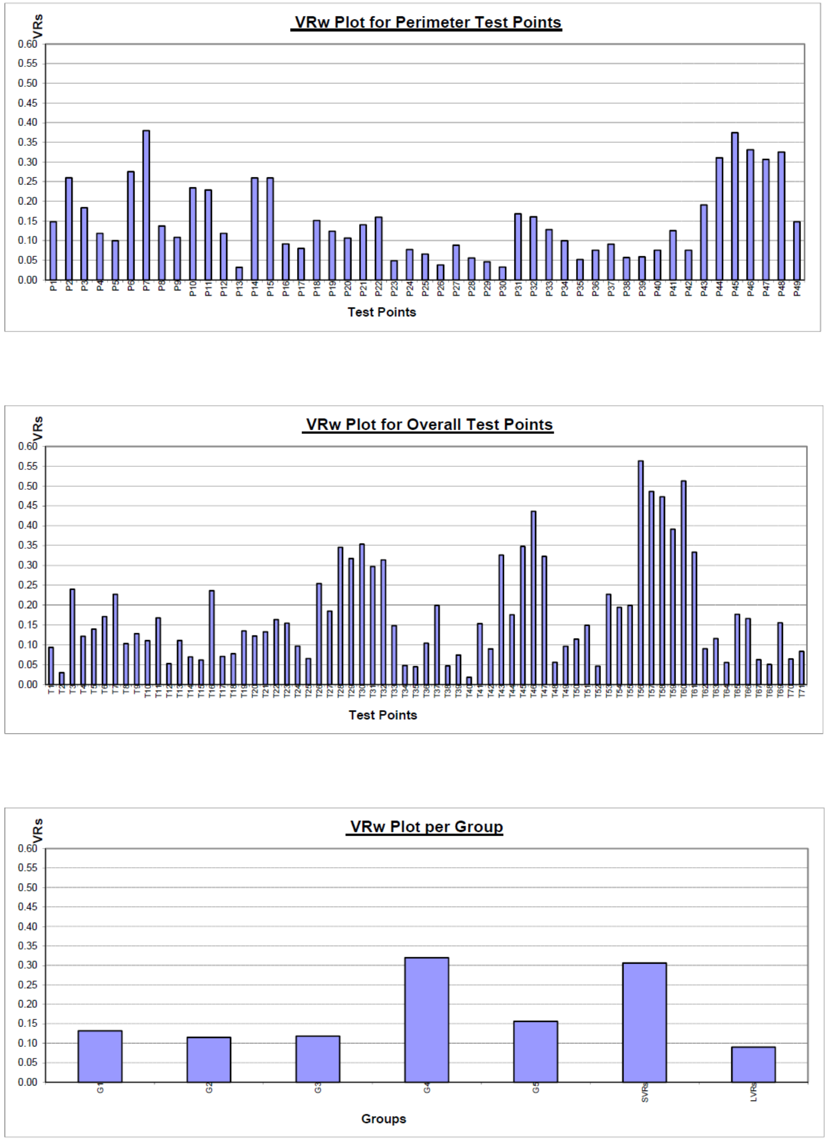
VR$_w$ Result under W Wind Direction



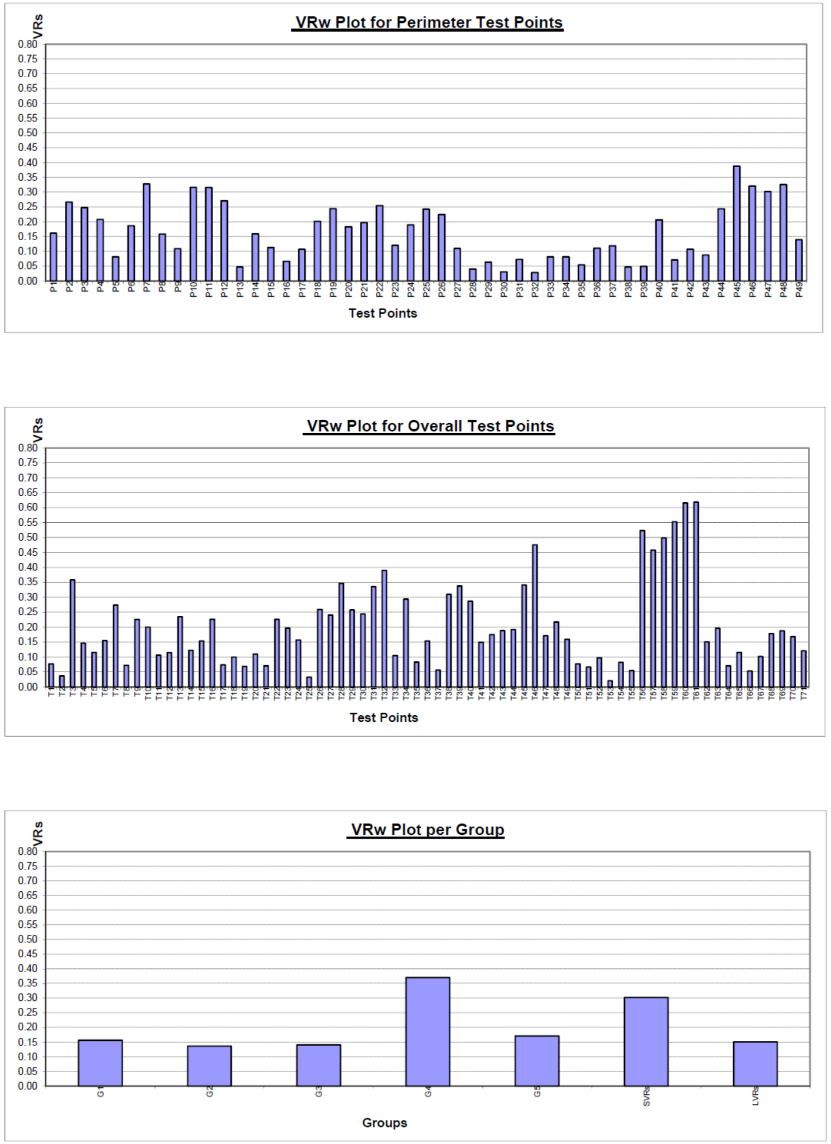




VR$_w$ Result under WNW Wind Direction



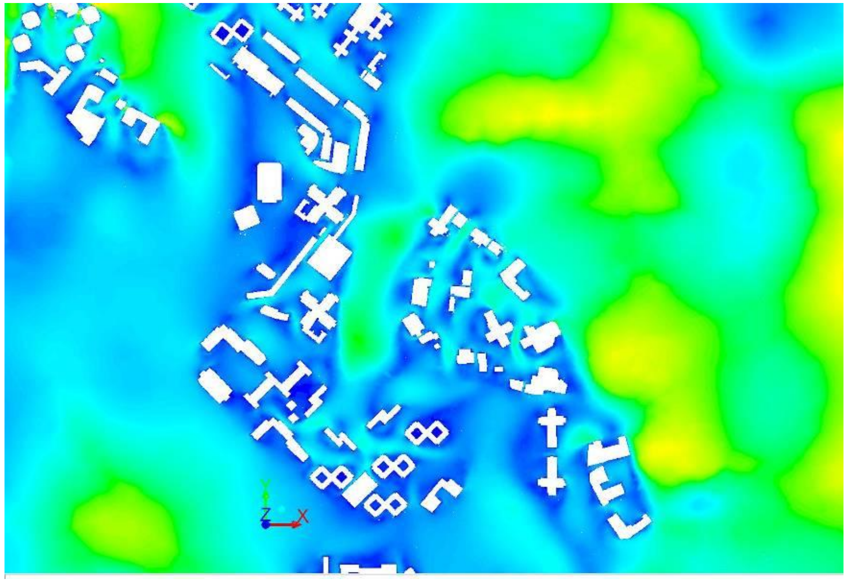
VR_w Result under NW Wind Direction

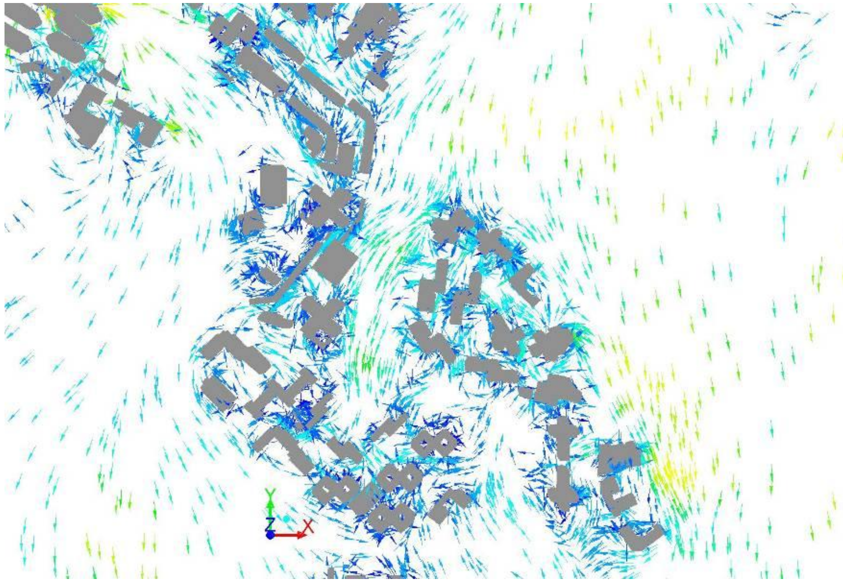


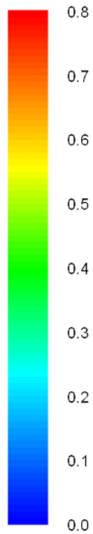
VR_w Result under NNW Wind Direction

Appendix D Wind Velocity Ratio Contour and Vector Plots at 2m above Ground under Different Wind Directions

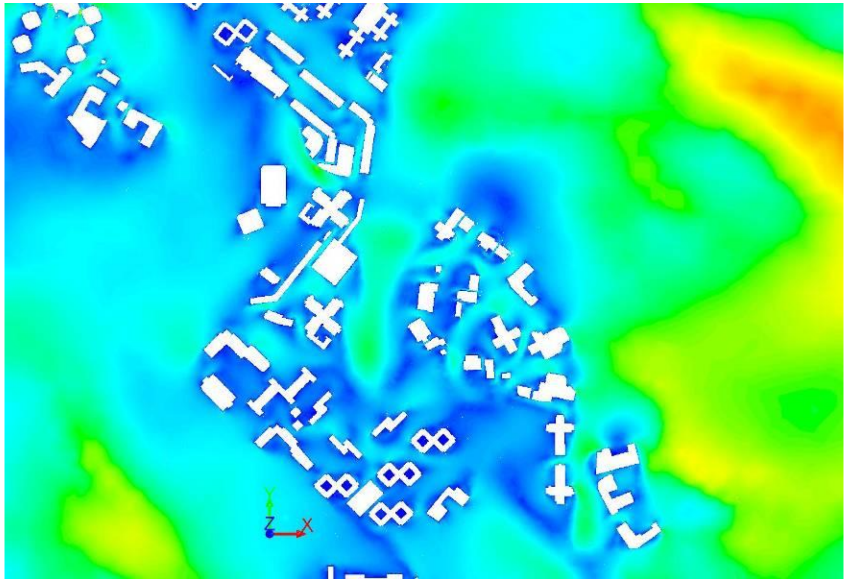
"N"

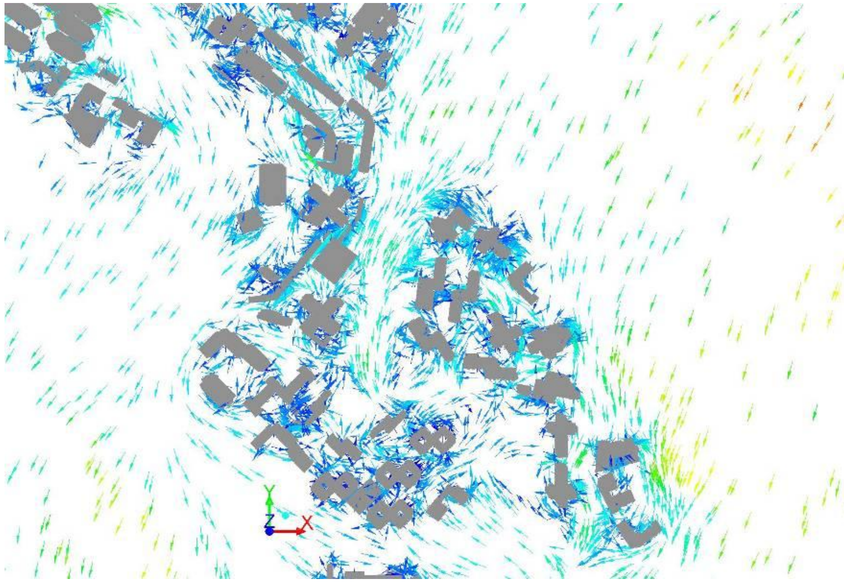






"NNE"

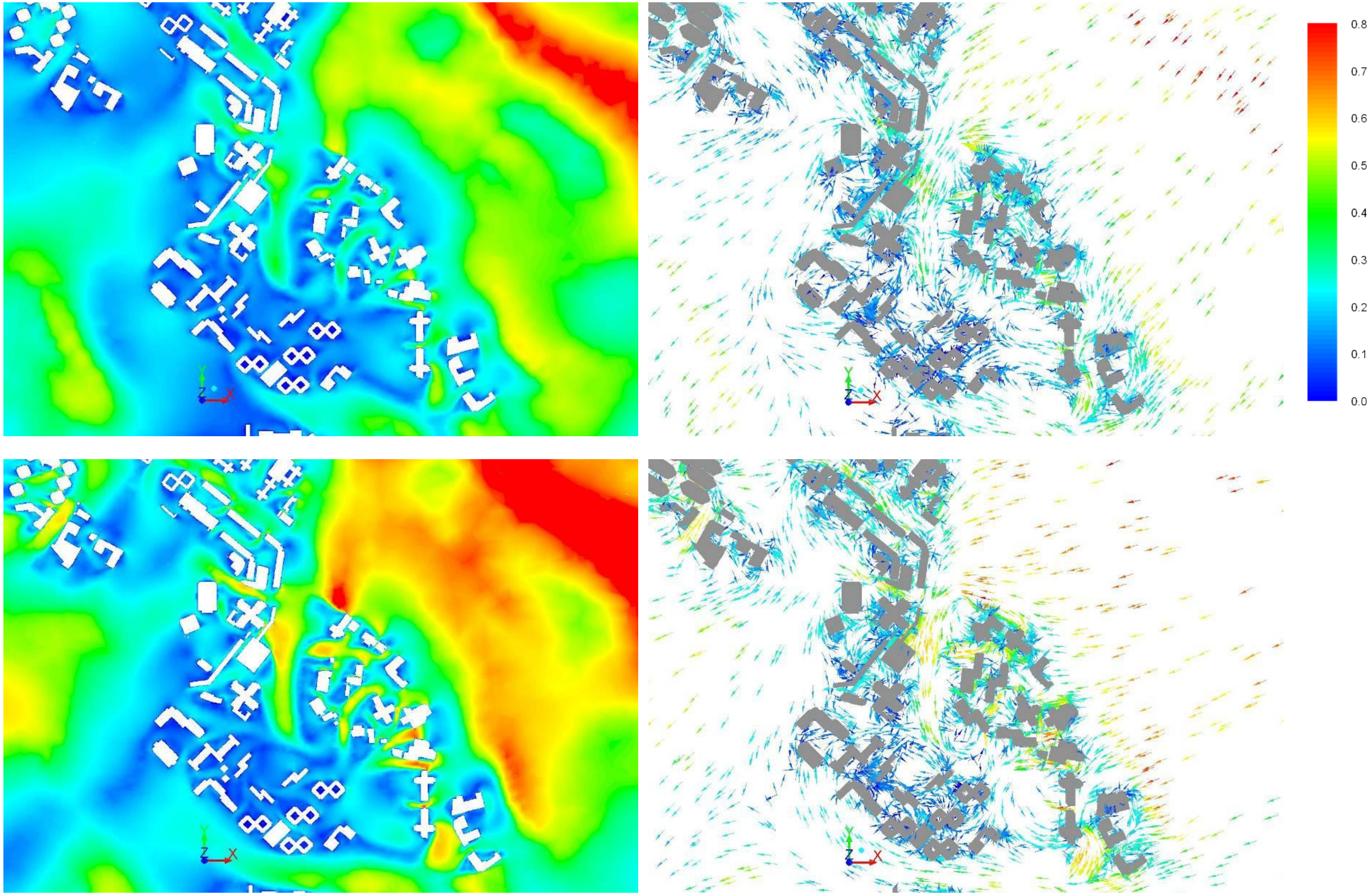




Wind Velocity Ratio Contour Plot at 2m above Ground **Wind Velocity Vector Plot at 2m above Ground**

"NE"

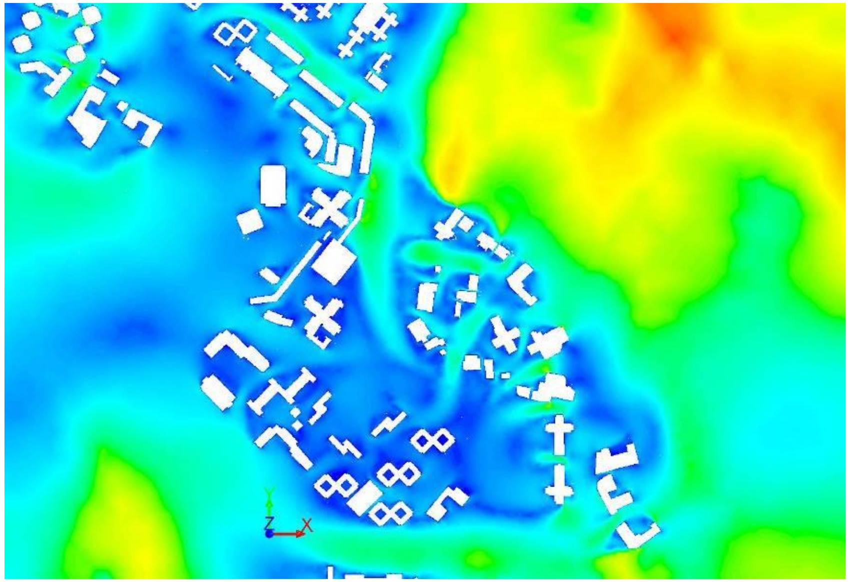
"ENE"

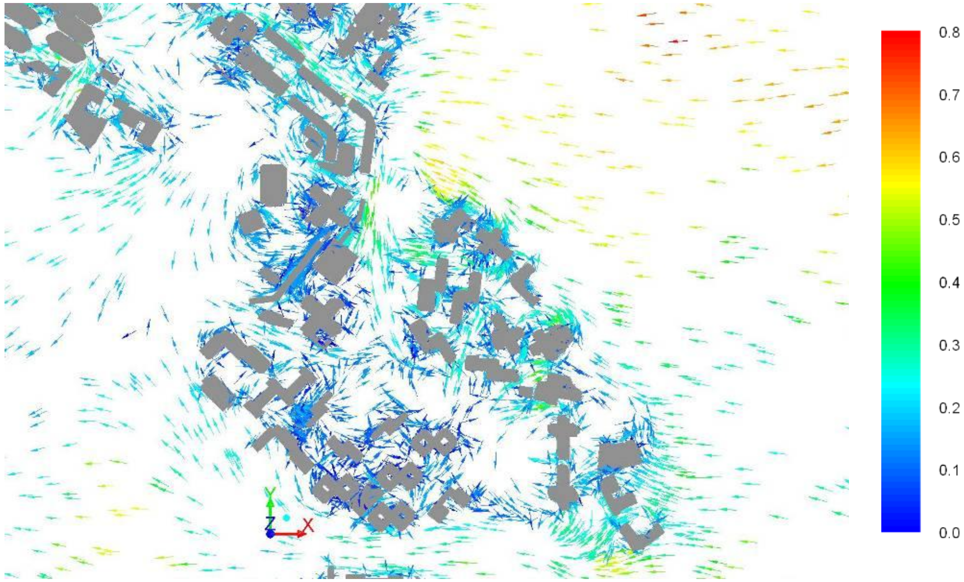


Wind Velocity Ratio Contour Plot at 2m above Ground

Wind Velocity Vector Plot at 2m above Ground

"E"





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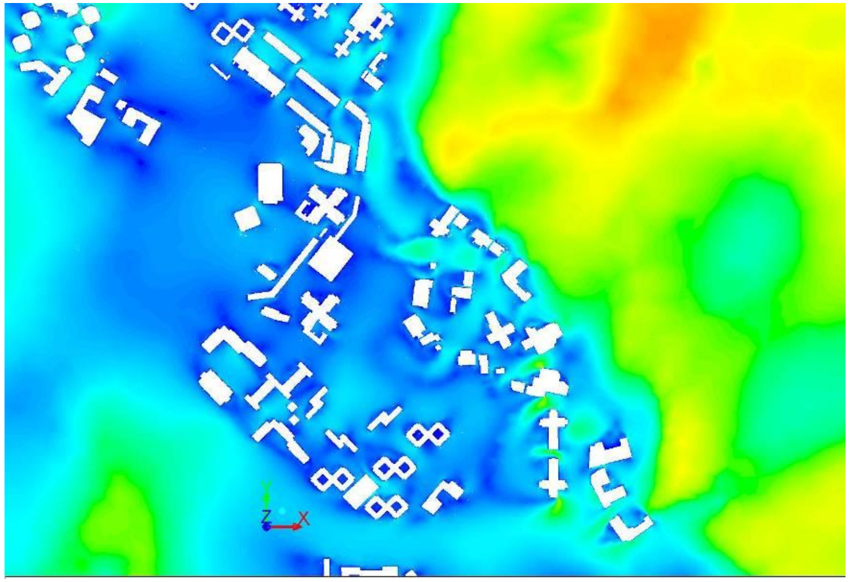

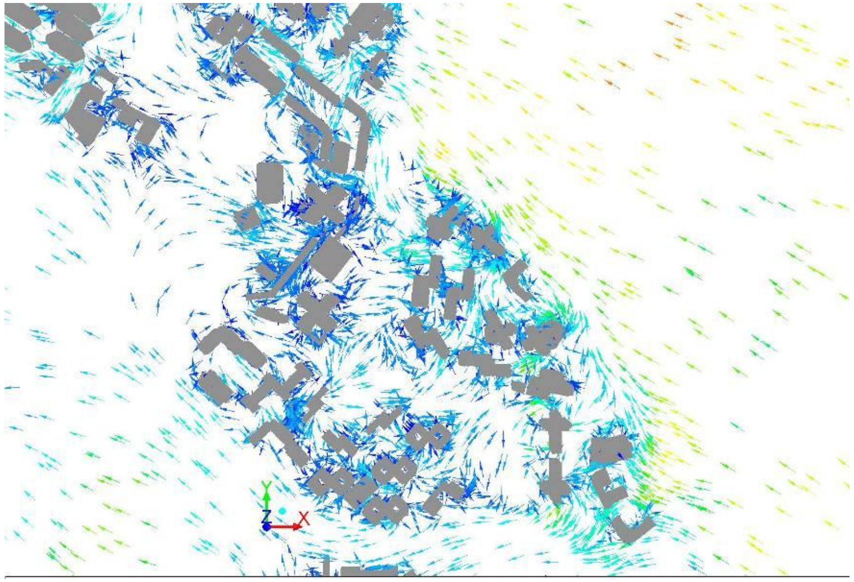

Wind Velocity Ratio Contour Plot at 2m above Ground

Wind Velocity Vector Plot at 2m above Ground

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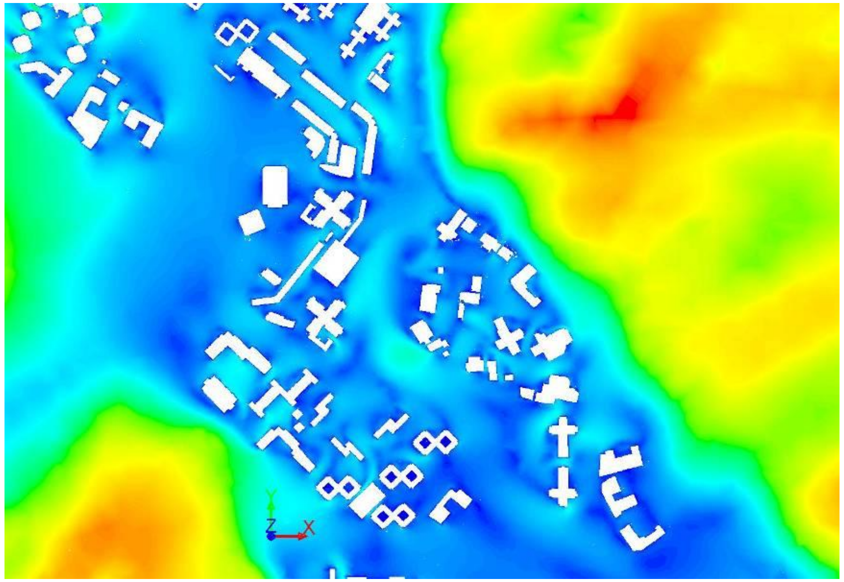

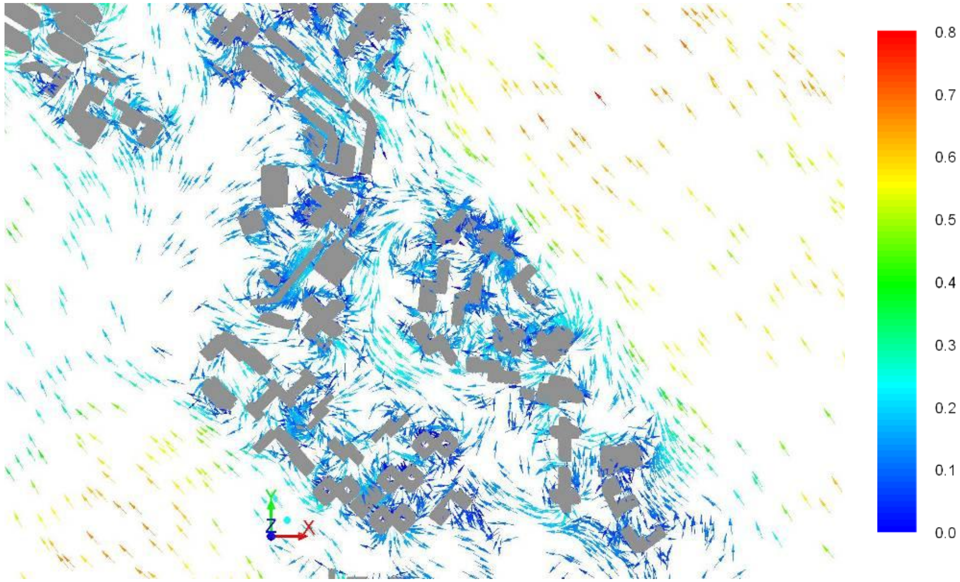

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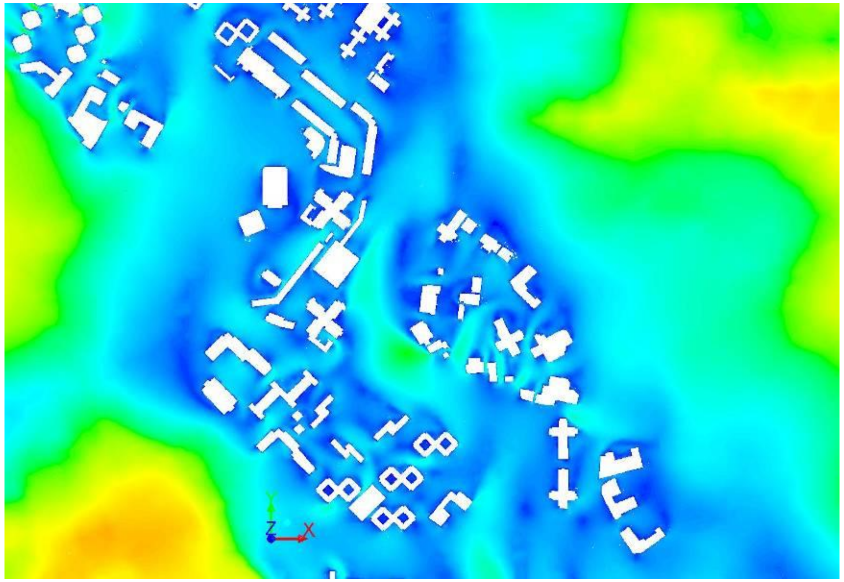

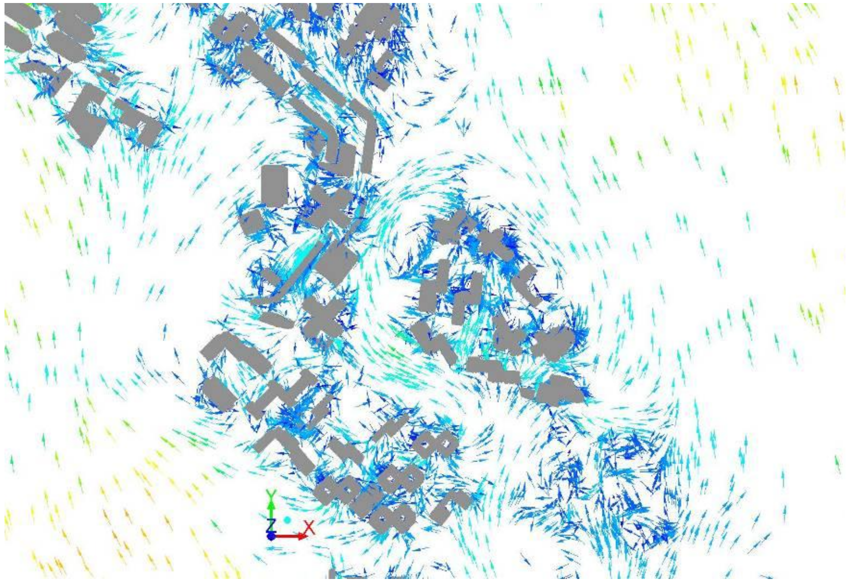

Wind Velocity Ratio Contour Plot at 2m above Ground

Wind Velocity Vector Plot at 2m above Ground

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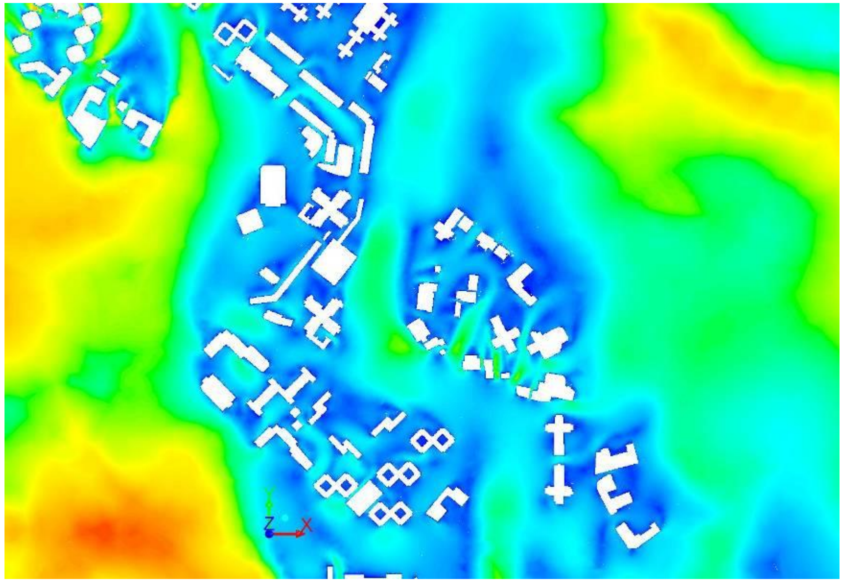

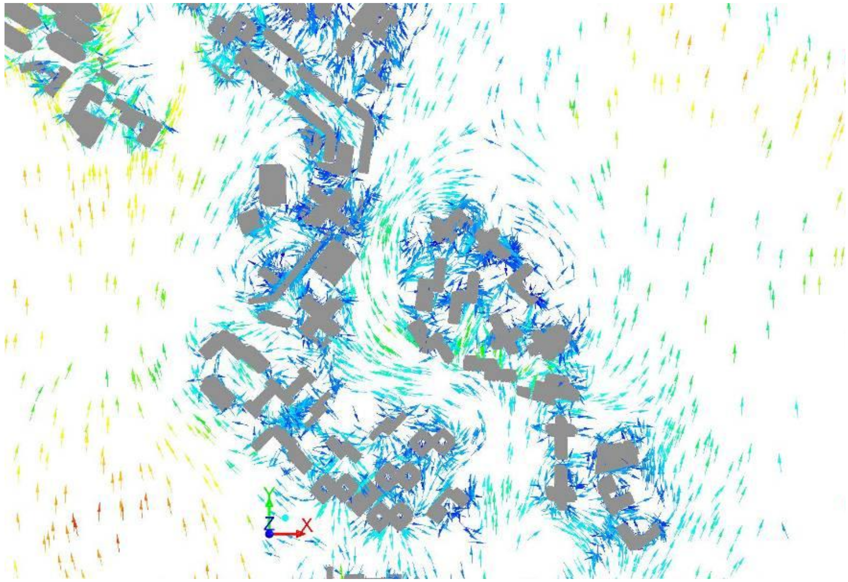

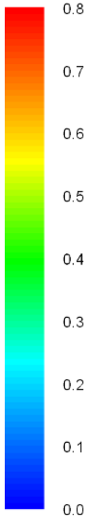

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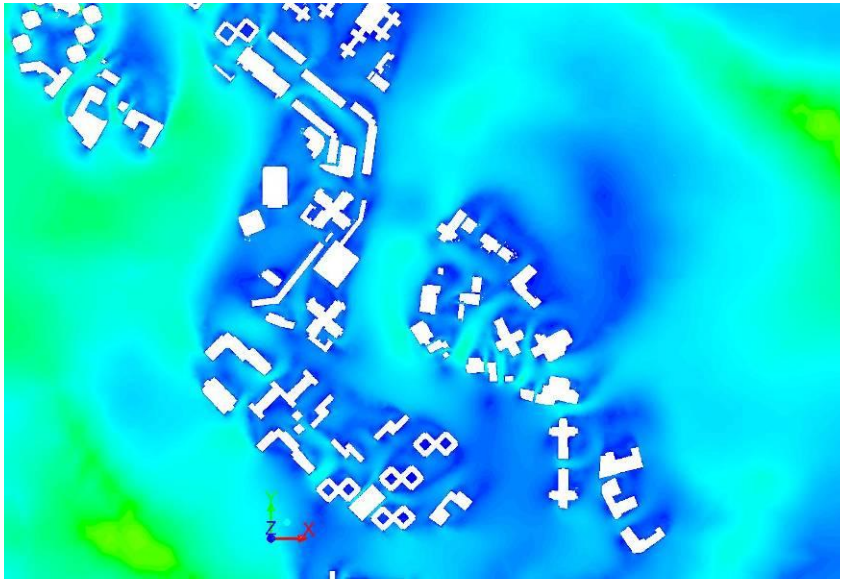

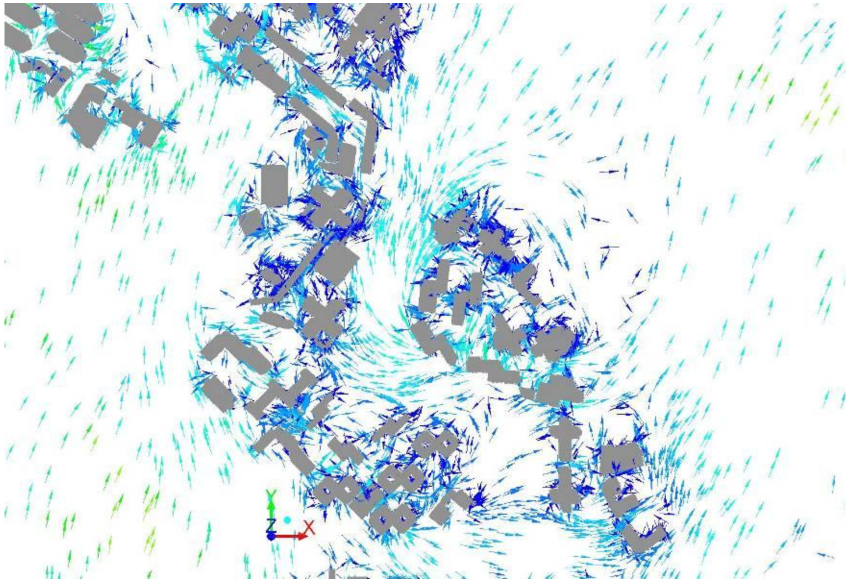

Wind Velocity Ratio Contour Plot at 2m above Ground

Wind Velocity Vector Plot at 2m above Ground

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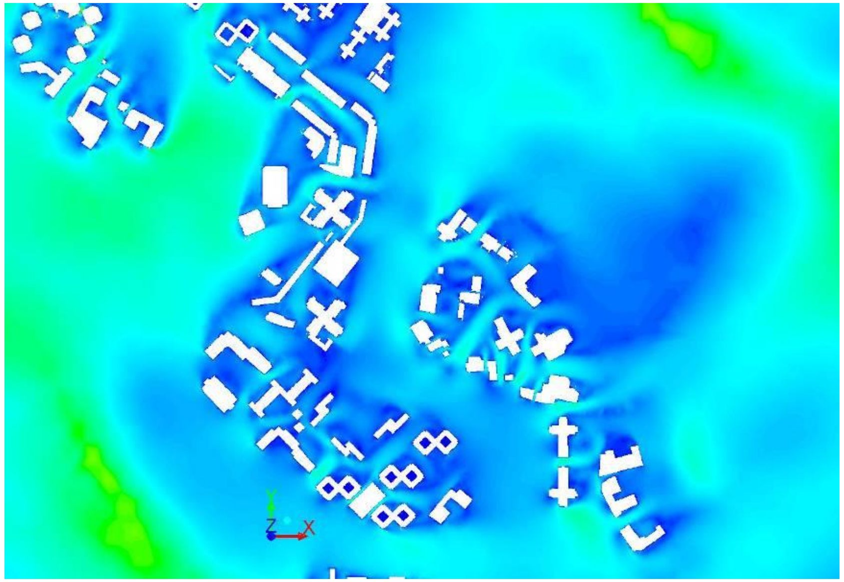

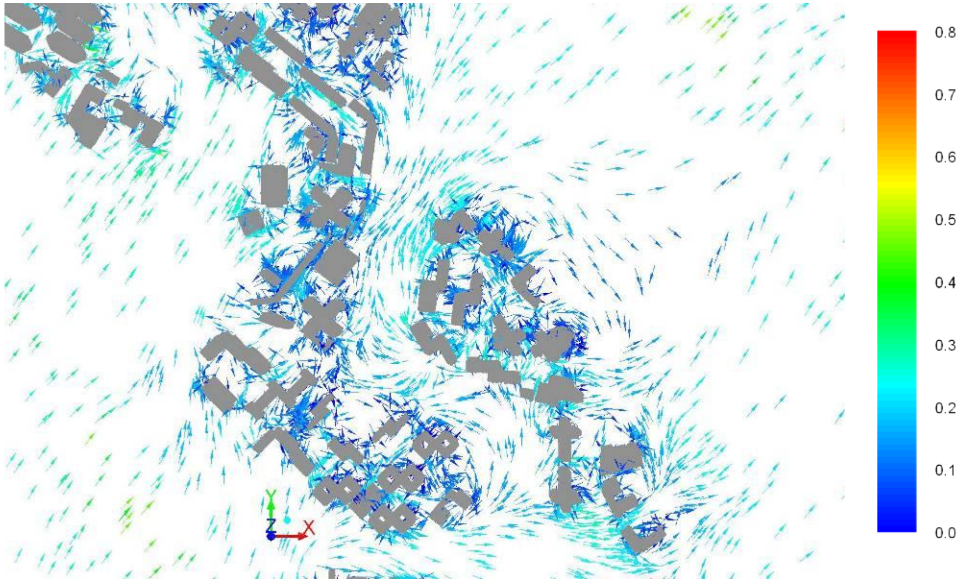

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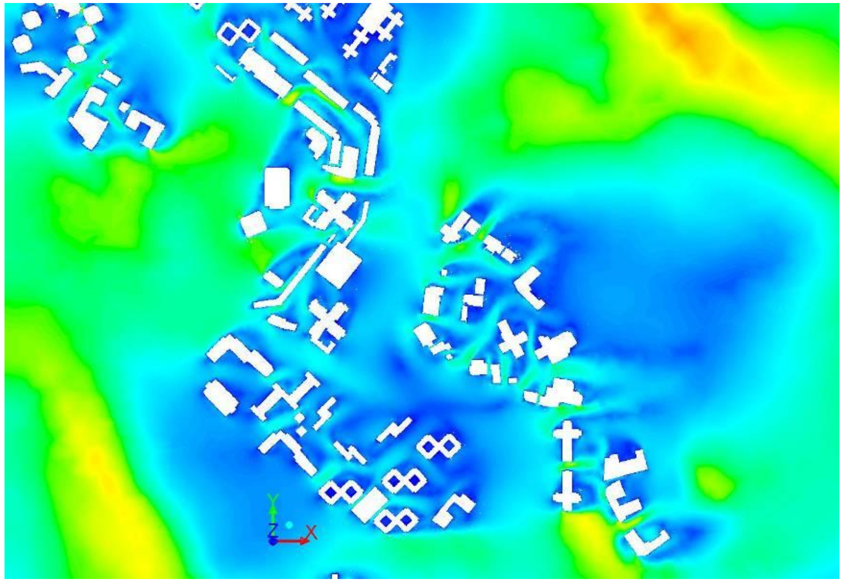

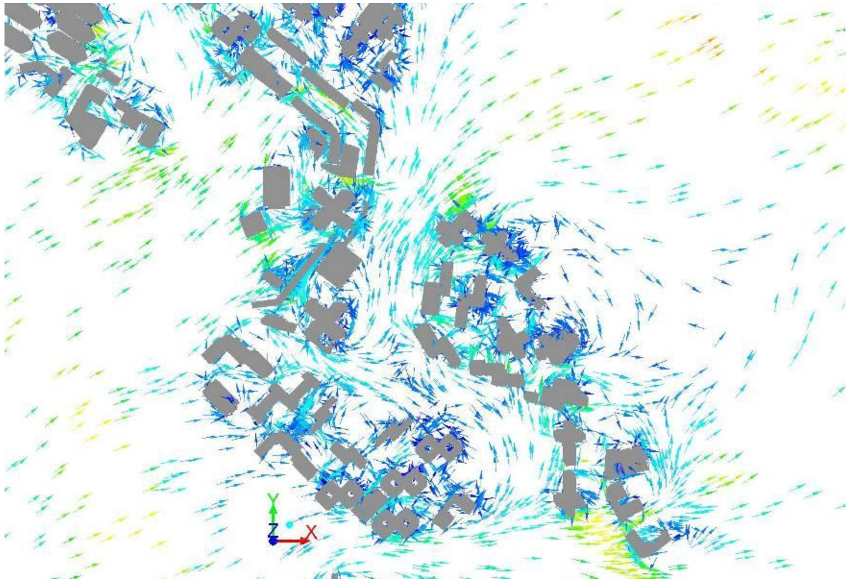

Wind Velocity Ratio Contour Plot at 2m above Ground

Wind Velocity Vector Plot at 2m above Ground

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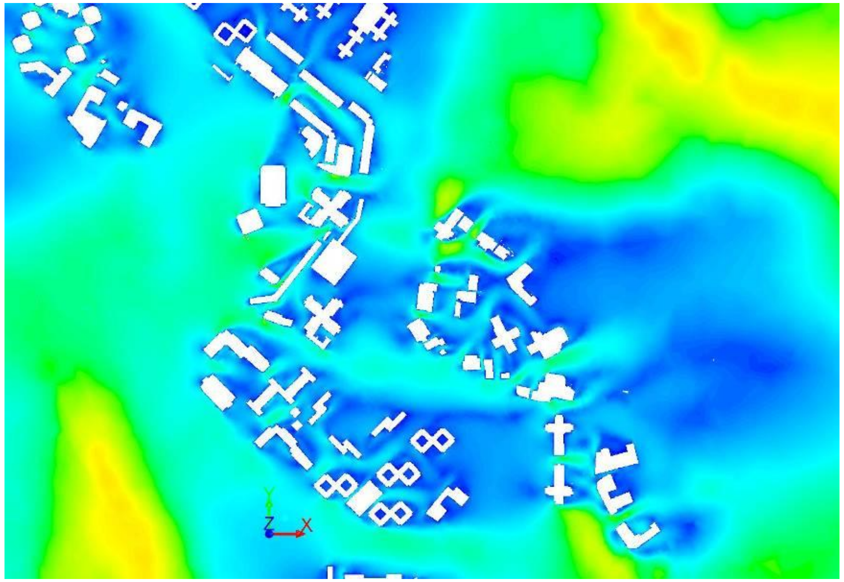

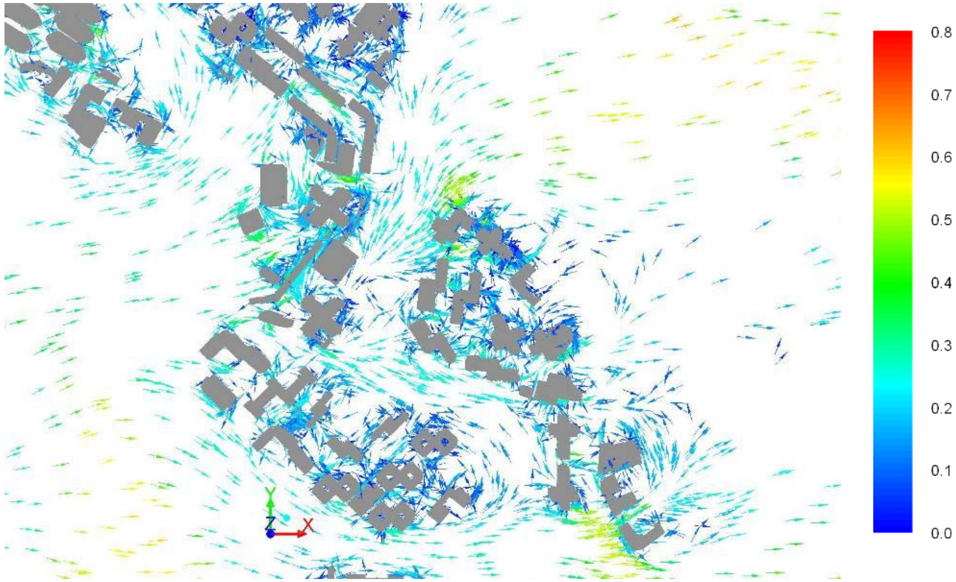

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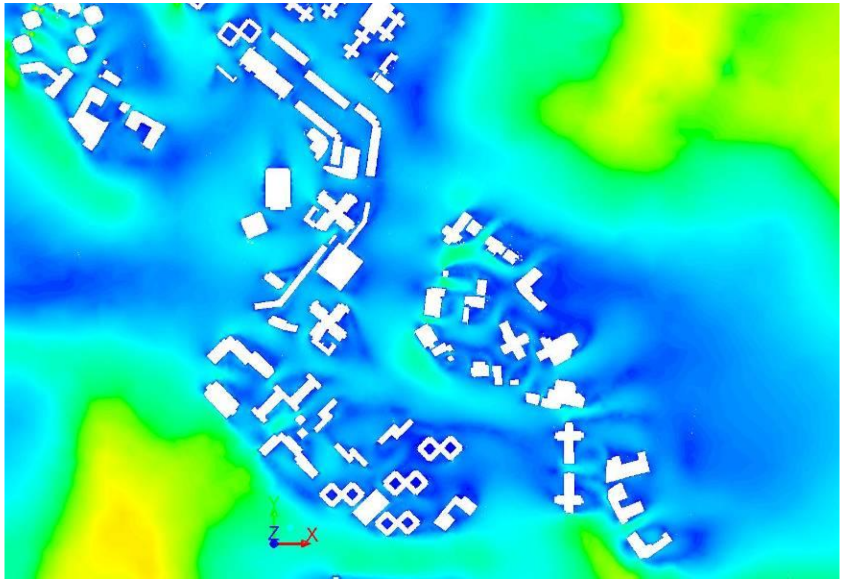

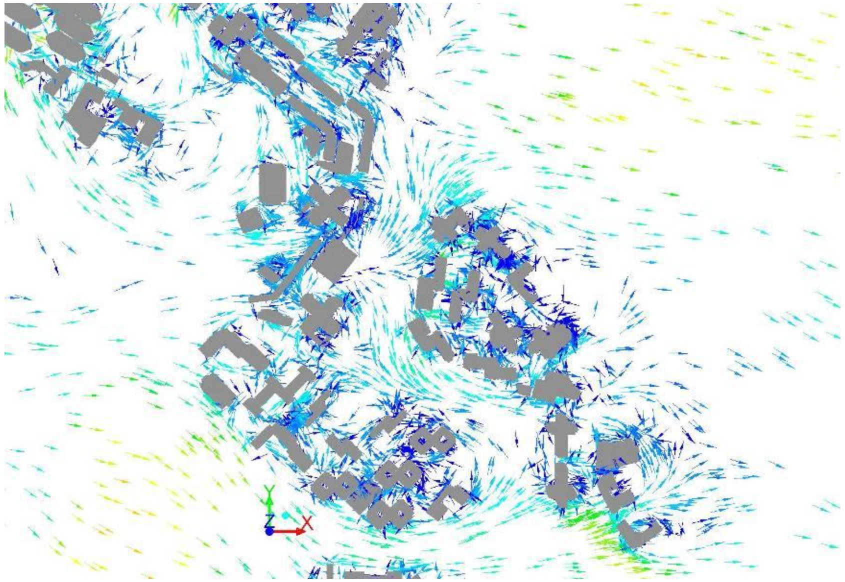

Wind Velocity Ratio Contour Plot at 2m above Ground

Wind Velocity Vector Plot at 2m above Ground

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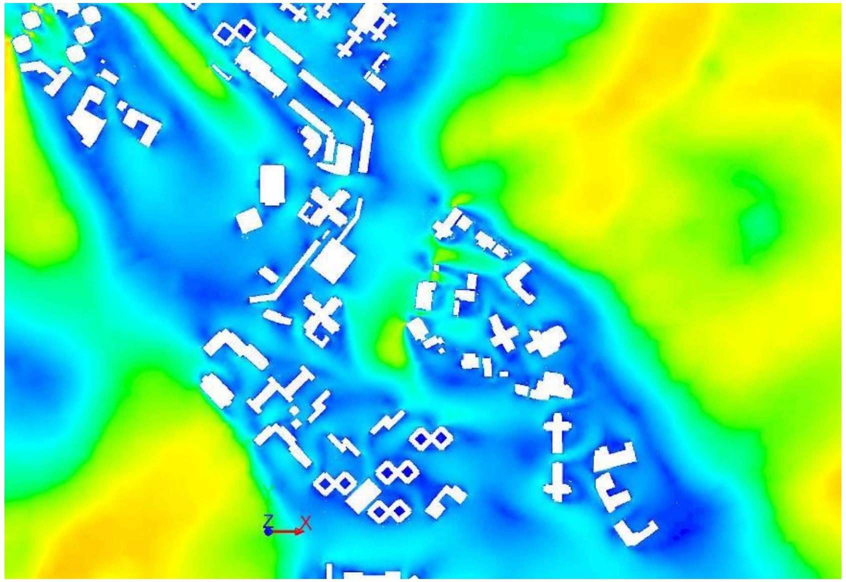

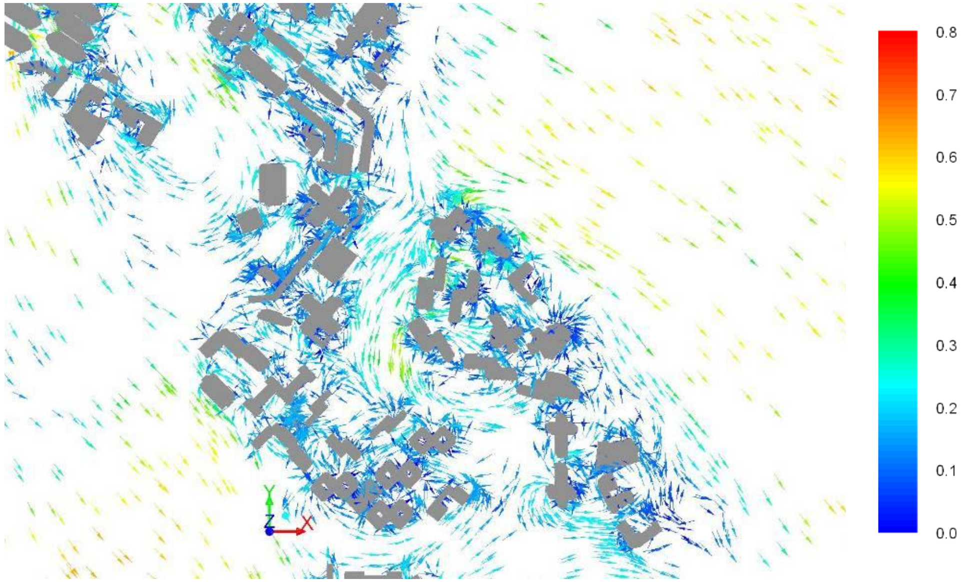

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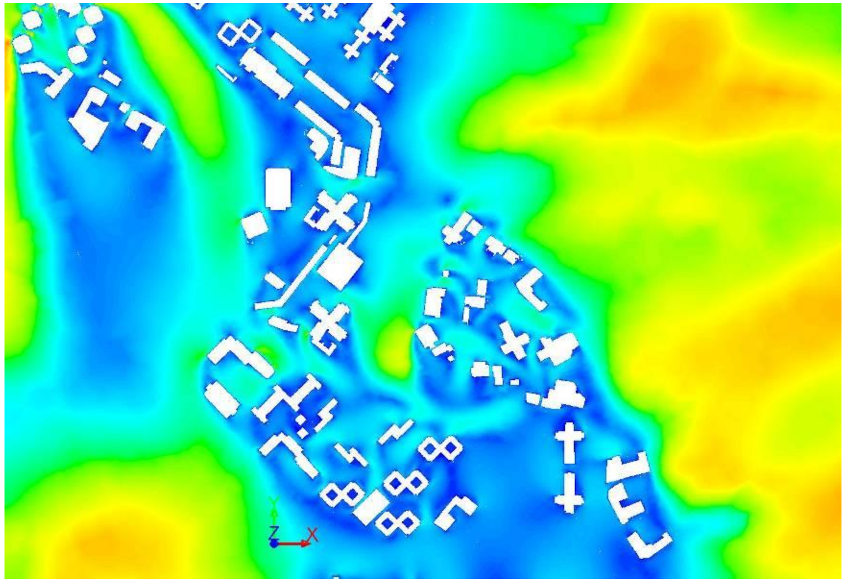

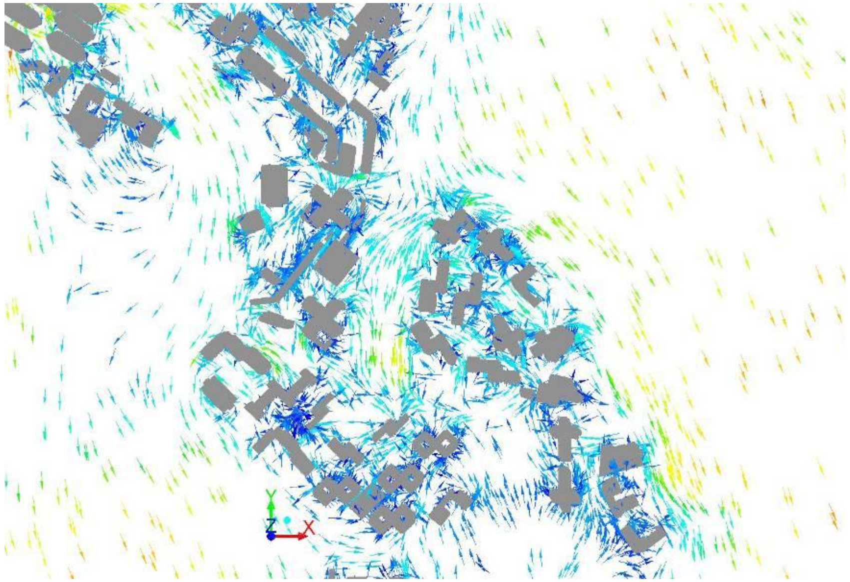

Wind Velocity Ratio Contour Plot at 2m above Ground

Wind Velocity Vector Plot at 2m above Ground

APPENDICES

EXPERIMENTAL SITE WIND AVAILABILITY STUDY FOR DEVELOPMENT AT ANDERSON ROAD (SITES A & B)

2013

中電風洞實驗所

CLP Power Wind/Wave Tunnel Facility

香港科技大學

THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Investigation Report WWTF009-2013

Submitted to:

AECOM Asia Company Limited

15 March 2013

EXECUTIVE SUMMARY

At the request of AECOM Asia Company Limited, a wind tunnel study was conducted by CLP Power Wind/Wave Tunnel Facility (WWTF) at the Hong Kong University of Science and Technology to determine the site wind availability for Development at Anderson Road (Sites A and B), Kowloon. The study was undertaken in accordance with the requirements stipulated in the Australasian Wind Engineering Society Quality Assurance Manual, AWES-QAM-1-2001 (2001) and the American Society of Civil Engineers Manual and Report on Engineering Practice No. 67 for Wind Tunnel Studies of Buildings and Structures (1999). The study was also conducted in accordance with the recommendations of Planning Department's Feasibility Study for Establishment of Air Ventilation Assessment System – Final Report (2005) and Technical Guide for Air Ventilation Assessment for Developments in Hong Kong (2006).

A 1:2000 scale topography study was undertaken to determine the effects of the surrounding topography and built environment on mean wind speeds, turbulence intensities and mean wind directions above the Study Site at Anderson Road.

A miniature dynamic pressure (Cobra) probe was used to take measurements of the longitudinal, lateral and vertical components of wind speed, at 22.5° increments for the full 360° azimuth, i.e. for sixteen (16) wind directions, and at eleven (11) elevations to determine profiles of mean wind speed and turbulence intensity above the Study Site. The topography study results were then combined with WWTF's statistical model of the Hong Kong non-typhoon wind climate, based on measurements of non-typhoon winds taken by Hong Kong Observatory at Waglan Island during the period of 1953 – 2006 inclusive, to determine wind roses corresponding to annual and summer (i.e. June, July and August) mean wind speeds at elevations of 50, 100, 200 and 500 mPD above the Study Site.

Winds approaching the Study Site from 0° to 135° inclusive and 292.5° to 337.5° inclusive are reduced by the mountainous topographies at Kowloon and the reduction in the mean wind speeds were most significant for winds from 337.5° due to the shielding effects from Kowloon Peak. The reductions in the mean wind speeds for winds from 157.5° to 292.5° inclusive are attributed to the built-up urban areas in Kwun Tong. Winds approaching the Study Site from 180° to 225° were also reduced by the mountains at Hong Kong Island.

In general, the annual and summer prevailing wind characteristics corresponding to non-typhoon winds at an elevation of 500 mPD above the Study Site were similar to the overall characteristics of non-typhoon winds approaching the Hong Kong region, although the magnitudes of the directional wind speeds were reduced. At lower elevations of 50, 100 and 200 mPD, the magnitudes of the mean wind speeds were further reduced. The directional distributions of annual and summer wind at an elevation of 50 mPD were deviated from those at an elevation of 500 mPD, as indicated by the significant yaw angle measured for 0°, 180° and 292.5° wind at an elevation of 50 mPD. The deviations of the directional distribution at lower elevation are attributed to the mountainous terrain surrounding the Study Site.

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1. INTRODUCTION

1.1. Project Background

At the request of AECOM Asia Company Limited, a wind tunnel study was conducted by CLP Power Wind/Wave Tunnel Facility (WWTF) at the Hong Kong University of Science and Technology to determine the site wind availability for Development at Anderson Road (Sites A and B), Kowloon.

The study was undertaken in accordance with the requirements stipulated in the Australasian Wind Engineering Society Quality Assurance Manual, AWES-QAM-1-2001 (2001) and the American Society of Civil Engineers Manual and Report on Engineering Practice No. 67 for Wind Tunnel Studies of Buildings and Structures (1999). The study was also conducted in accordance with the recommendations of Planning Department’s Feasibility Study for Establishment of Air Ventilation Assessment System – Final Report (2005) and Technical Guide for Air Ventilation Assessment for Developments in Hong Kong (2006).

The Study Site at Anderson Road is located to the north of Kwun Tong, as shown in Figure 1. Measurements were taken at the centre of the Study Site. The average ground elevation of the Study Site is approximately 155 mPD. The Study Site is surrounded by significant topographies, with Kowloon Peak located to the north of the Study Site and Anderson Road Quarry to the east of the study site. The 1:2000 scale topography study was undertaken to determine the effects of the surrounding topography and built environment on mean wind speeds and turbulence intensities at the study site. The topography study results were combined with WWTF’s statistical model of the Hong Kong non-typhoon wind climate, based on measurements of non-typhoon winds taken by Hong Kong Observatory at Waglan Island during the period of 1953 – 2006 inclusive, to determine site-specific annual and summer wind roses for hourly mean wind speeds.

2. ANALYSIS OF THE HONG KONG WIND CLIMATE

Waglan Island, located approximately 5 km south-east of Hong Kong Island, has been used by Hong Kong Observatory (HKO), formerly The Royal Observatory, Hong Kong, for the collection of long-term wind data since December 1952. Due to its location, relative lack of development over the past 50 years and its generally uninterrupted exposure to winds, the data collected at Waglan Island is considered to be of the highest quality available for wind engineering purposes in Hong Kong and, on a probabilistic basis, representative of winds approaching the Hong Kong region. Wind speed and direction measurements at Waglan Island are essentially free from the interference effects of nearby developments that may affect measurements taken at other stations, as discussed by Melbourne (1984).

Waglan Island wind records have been analysed previously in studies of the Hong Kong wind climate, most notably by Davenport et al. (1984), Melbourne (1984) and Hitchcock et al. (2003). In the study conducted by Hitchcock et al. (2003), wind tunnel tests were undertaken to correct wind records for position and topographical effects at the four anemometer locations used since 1952, with the exception of the location used during the period 1 January 1964 to 11 July 1966 inclusive. In that study, thermal (hotwire) anemometer measurements were taken at 22.5° intervals for the full 360° azimuth relating wind speeds at anemometer height to wind speeds at a height equivalent to 200 m in the free stream. The directional characteristics of the former anemometer sites were found to be similar to those discussed by Davenport et al. (1984) and Melbourne (1984), whereas the current anemometer site is much less affected than its predecessors, due mainly to its additional height.

Wind data measured by HKO at Waglan Island were corrected for position and height and subsequently applied to non-typhoon wind data collected at Waglan Island to determine a probability distribution of directional mean wind speeds for Hong Kong. The corresponding annual wind rose for mean wind speeds at an elevation equivalent to 500 mPD above open water is presented in Figure 2 and indicates that, on an annual basis, prevailing and strong non-typhoon winds approaching Hong Kong occur mainly from the north-east quadrant and to a lesser extent, from the south-west. The summer (i.e. June, July, and August) wind rose for mean wind speeds at an elevation equivalent to 500 mPD above open water is presented in Figure 3. In contrast to the corresponding annual wind rose, prevailing and strong non-typhoon winds approaching Hong Kong during summer months occur mainly from the south-east and south-west quadrants.

In Figure 2 and Figure 3, mean wind speeds are segregated into four categories (0 – 3.3 m/s, 3.4 – 7.9 m/s, 8.0 – 13.8 m/s and greater than 13.8 m/s) that are indicated by the thickness of the bars for the 16 cardinal wind directions. The length of the bars indicates the average percentage of occurrence per year. For example, Figure 2 illustrates that, on an annual basis, easterly winds occur approximately 23% of the time and hourly mean wind speeds exceed 13.8 m/s approximately 4% of the time at an elevation of 500 mPD.

3. WIND TUNNEL STUDY

The wind tunnel test techniques used in this investigation are in accordance with the procedures and recommendations of the Australasian Wind Engineering Society Quality Assurance Manual, AWES QAM-1-2001 (2001) and the American Society of Civil Engineers Manual and Report on Engineering Practice No. 67 for Wind Tunnel Studies of Buildings and Structures (1999). Those requirements cover the satisfactory modelling of the turbulent natural wind, the accuracy of the wind tunnel models, experimental and analysis procedures and quality assurance.

3.1. Modelling the Natural Wind

Air moving relative to the Earth's surface has frictional forces imparted on it, which effectively cause it to be slowed down. Those forces have a decreasing effect on airflow as the height above ground increases, generally resulting in mean wind speed increasing with height to a point where the effects of surface drag become negligible. In wind engineering, a convenient measure of the thickness of the atmospheric boundary layer is commonly referred to as the gradient height which will vary depending on the surrounding surface roughness over which the air will flow. Obstacles to air flow can vary from relatively large expanses of smooth, open water, to vegetation such as forests, built-up environments such as city centres and large rugged mountain ranges. The resulting gradient heights typically vary from several hundred metres to in excess of 1000 m.

Winds within the atmospheric boundary layer are also usually highly turbulent or gusty. Turbulence intensity is a measure of the gustiness of wind due to eddies and vortices generated by frictional effects at surface level, the roughness of the terrain over which air is flowing and convective effects due to opposing movements of air masses of different temperature. In typical atmospheric boundary layer flow, turbulence intensity generally decreases with height. Closer to the ground, at pedestrian level for example, the magnitude of the turbulence intensity can be very large due to the effects of wind flowing around buildings and other structures.

In conducting wind tunnel model studies of wind characteristics and wind effects on and around tall buildings and other structures on the surface of the Earth, it is necessary to adequately simulate the relevant characteristics of atmospheric boundary layer. WWTF's boundary layer wind tunnel test sections can be used to simulate atmospheric boundary layer flow over various types of terrain, ranging from open terrain, such as open water, to urban or mountainous terrain.

WWTF comprises two long fetch boundary layer wind tunnel test sections as shown in Figure 4. The 28 m long high speed test section has a 3 m wide by 2 m high working section and a maximum free stream wind speed of approximately 30 m/s. The 40 m long low speed test section has a 5 m wide by 4 m high working section and a maximum free stream wind speed of approximately 10 m/s. Various terrains can be modelled in either test section at length scales ranging from approximately 1:5000 to 1:50.

The characteristics of the wind flow in the low speed test section can be modified through the use of devices such as spires, grids and fences to model various atmospheric boundary layer flows. For the current study, wind speed and turbulence intensity characteristics corresponding to wind flow above open water were simulated in WWTF's low speed test section by using various roughness elements. The mean wind speed profile of the wind flow approaching the Study Site was simulated in accordance with the power law expression, defined in Equation (1), specified in Planning Department's Feasibility Study for Establishment of Air Ventilation Assessment System – Final Report (2005).

$$\frac{V_{z,\ open}}{V_{ref,\ open}} = \left(\frac{z}{z_{ref}}\right)^{\alpha} \qquad (1)$$

where

$V_{z,open}$ = mean wind speed at a height z above open water terrain (m/s);

$V_{ref,open}$ = mean wind speed at a height z_{ref} above open water terrain (m/s);

z = height above zero plane displacement height (m);

z_{ref} = a suitable reference height above open water terrain (m), taken as 500 mPD for this study;

α = a power law exponent, which is a constant commensurate with the terrain roughness, taken as 0.15 for this study.

The turbulence intensity profile of the approaching wind flow was simulated in accordance with Terrain category 2 stipulated in Australian/New Zealand Standard AS/NZS 1170.2:2002, i.e. corresponding to non-typhoon wind flow above rough open water surfaces.

The simulated mean wind speed and turbulence intensity profiles were calibrated to within ±10% of the target mean wind speed and turbulence intensity profiles. The simulated and target mean wind speed profiles normalised by the mean wind speed at a reference height of 500 mPD above open water terrain ($V_{ref,open}$), and the simulated and target turbulence intensity profiles are presented in Figure 5. The spectrum of longitudinal turbulence of the simulated wind flow measured at a height equivalent to 500 m in prototype scale is presented in Figure 6.

3.2. Physical Model of the Study Site

WWTF has a 1:2000 scale topographical model of the Outlying Islands, New Territories, Kowloon and Hong Kong Island fabricated at 20 m contour intervals from information acquired from the Survey and Mapping Office of Lands Department, HKSAR. The relevant sections of the topographical model were also updated for the current study. For all wind directions tested, the wind tunnel model included surrounding areas within a distance of up to approximately 10 km from the Study Site.

The topographical model was updated to include greater detail within a zone from 831 m up to approximately 1500 m from the measurement location. Beyond the 1500 m radius, the topographical model included roughness representative of the surrounding areas. Representative views of the 1:2000 scale topographical model used in the current study are shown in Figure 7 to Figure 10 inclusive.

3.3. Experimental and Analysis Procedures

The terrain surrounding the Study Site comprises a complex mixture of built environment and mountainous topography. Winds approaching the modelled region were scaled to simulate non-typhoon winds flowing over open water and the topographical model was used to determine the modifying effects of the surrounding complex terrain on the mean wind speeds, turbulence intensities and mean wind directions above the Study Site.

Wind tunnel measurements were taken using a Cobra probe, a miniature dynamic pressure probe manufactured by Turbulent Flow Instrumentation Pty Ltd, at 22.5° intervals for the full 360° azimuth (i.e. 16 wind directions). A wind direction of 0° corresponds to an incident wind approaching the Study Site directly from the north; 90° corresponds to an incident wind approaching the Study Site directly from the east, etc. For each wind direction tested, mean wind speeds, turbulence intensities and mean wind directions were measured at elevations equivalent to 10, 25, 50, 75, 100, 150, 200, 250, 300, 400, 500 and 600 mPD in prototype scale, above the centre of the Study Site. While measurements were taken at the Study Site, all topographical features, buildings and other structures within a diameter of approximately 1662 m from the centre of the Study Site were removed from the wind tunnel model for all measured wind directions. This was done so that only far-field effects were included in the measured wind characteristics.

4. EXPERIMENTAL RESULTS AND DISCUSSION

For each tested wind direction, the results of the 1:2000 scale topography study are presented in graphical format in Figure 11 to Figure 26 inclusive for the Study Site. A full listing of the results for the Study Site is also presented in tabular format in Appendix A.

The normalised wind characteristics, which include the measured resultant mean wind speed profiles and turbulence intensity profiles, are shown in Figure 11a to Figure 26a inclusive. Normalised mean wind speed profiles were determined by normalising the local mean wind speeds with respect to the mean wind speed of the approaching wind flow measured at an elevation equivalent to 500 mPD, as defined in Equation (2). Vertical profiles of turbulence intensity, defined in Equation (3), are also presented in Figure 11a to Figure 26a. Mean yaw and pitch angles, i.e. the lateral and vertical deviations respectively, of the local mean wind direction relative to the approaching mean wind direction are presented in Figure 11b to Figure 26b inclusive. The sign conventions used to define yaw angles and pitch angles are provided in Appendix C.

$$\text{normalised mean wind speed} = \frac{V_{z,\ site,i}}{V_{500,\ open,i}} \qquad (2)$$

$$\text{turbulence intensity} = \frac{\sigma_{z,\ site,i}}{V_{z,site,i}} \qquad (3)$$

In Equations (2) and (3), $V_{z,site,i}$ is the resultant mean wind speed above the centre of the Study Site measured at an elevation z, where z = 10, 25, 50, 75, 100, 150, 200, 250, 300, 400, 500 or 600 mPD in prototype scale for an approaching wind direction, i, where i = 0°, 22.5°, 45°, 67.5°, 90°, 112.5°, 135°, 157.5°, 180°, 202.5°, 225°, 247.5°, 270°, 292.5°, 315° or 337.5°; $V_{500,open,i}$ is the resultant mean wind speed of the approaching wind at an elevation equivalent to 500 mPD in prototype scale for an approaching wind direction, i; and $\sigma_{z,site,i}$ is the standard deviation of the fluctuating resultant wind speed above the Study Site for an approaching wind direction i.

The wind tunnel measurements were also used to determine directional factors for the 16 measured wind directions, relating the mean wind speeds at elevations equivalent to 50, 100, 200 and 500 mPD above the Study Site to the mean wind speed of the approach flow at a reference elevation of 500 mPD. Those directional factors were then applied to WWTF's Hong Kong non-typhoon wind climate model, derived from HKO's Waglan Island wind data as discussed in Section 2 of this report, to determine site specific wind roses pertaining to annual and summer hourly mean wind speeds at elevations of 50, 100, 200 and 500 mPD above the Study Site. The annual wind roses are presented in Figure 27 to Figure 30 inclusive and the summer wind roses are presented in Figure 31 to Figure 34 inclusive. Corresponding wind rose data are presented in tabular format in Appendix B.

4.1. Wind Characteristics for Development at Anderson Road (Sites A & B)

Winds approaching the Study Site from 0° to 135° inclusive and 292.5° to 337.5° inclusive are reduced by the mountainous topographies at Kowloon, including the mountains at Lion Rock Country Park and Ma On Shan Country Park, as indicated by the reductions in the upper level mean wind speed measured from these wind directions. The reductions in mean wind speeds were most significant for winds from 337.5° due to the shielding effects from Kowloon Peak that has a peak elevation of approximately 600mPD. Similar magnitude of reductions were also measured for winds from 315°. The turbulence intensities of the aforementioned wind directions were enhanced due to the effects of the mountainous topography.

Mean wind speeds were reduced significantly for winds approaching from 157.5° to 292.5° inclusive, highlighting the sheltering effects due to the urban area in Kwun Tong. Winds from 180° to 225° are also affected by the mountains at Hong Kong Island. The combined effects of the mountains at Hong Kong Island and the built-up areas at Kwun Tong have resulted in the reductions of mean wind speeds at all elevations for winds from 180° to 225°. Upper level winds approaching the Study Site from 157.5°, 247.5° and 270° were less affected due to the open exposure at the Victoria Harbour and absent of significant topographies in the corresponding wind directions.

A comparison of the annual and summer wind roses at 500 mPD above Waglan Island (Figure 2 and Figure 3 respectively) to those above the Study Site (Figure 30 and Figure 34 respectively) illustrates that there is no significant change to the overall directional distribution of the upper level wind speeds, although the overall magnitudes of mean wind speeds are reduced. The annual and summer wind roses corresponding to elevations of 50, 100 and 200 mPD above the Study Site (Figure 27 to Figure 29 and Figure 31 to Figure 33) demonstrate further reductions in the overall magnitudes of wind speeds.

The annual and summer wind roses also indicate that the directional distributions of mean wind speeds at an elevation of 50 mPD were deviated from those at an elevation of 500 mPD, as indicated by the significant yaw angle, i.e. exceeding ±11.25°, measured for 0°, 180° and 292.5° wind at an elevation of 50 mPD. The deviations of the directional distribution at lower elevation are attributed to the mountainous terrain surrounding the Study Site.

5. CONCLUSION

At the request of AECOM Asia Company Limited, a wind tunnel study was conducted by CLP Power Wind/Wave Tunnel Facility (WWTF) at the Hong Kong University of Science and Technology to determine the site wind availability for Development at Anderson Road (Sites A and B), Kowloon.

A 1:2000 scale topography study was undertaken to determine the effects of the local topography and the surrounding urban environment on mean wind speeds, turbulence intensities and mean wind directions above the Study Site.

A miniature dynamic pressure (Cobra) probe was used to take measurements of the longitudinal, lateral and vertical components of wind speed, at 22.5° increments for the full 360° azimuth, i.e. for sixteen (16) wind directions, and at eleven (11) elevations to determine profiles of mean wind speed and turbulence intensity above the Project Area. The topography study results were then combined with WWTF's statistical model of the Hong Kong non-typhoon wind climate, based on measurements of non-typhoon winds taken by Hong Kong Observatory at Waglan Island during the period of 1953 – 2006 inclusive, to determine wind roses corresponding to annual and summer (i.e. June, July and August) mean wind speeds at elevations of 50, 100, 200 and 500 mPD above the Study Site.

Winds approaching the Study Site from 0° to 135° inclusive and 292.5° to 337.5° inclusive are reduced by the mountainous topographies at Kowloon and the reduction in the mean wind speeds were most significant for winds from 337.5° due to the shielding effects from Kowloon Peak. The reductions in the mean wind speeds for winds from 157.5° to 292.5° inclusive are attributed to the built-up urban areas in Kwun Tong. Winds approaching the Study Site from 180° to 225° were also reduced by the mountains at Hong Kong Island.

In general, the annual and summer prevailing wind characteristics corresponding to non-typhoon winds at an elevation of 500 mPD above the Study Site were similar to the overall characteristics of non-typhoon winds approaching the Hong Kong region, although the magnitudes of the directional wind speeds were reduced. At lower elevations of 50, 100 and 200 mPD, the magnitudes of the mean wind speeds were further reduced. The directional distributions of annual and summer wind at an elevation of 50 mPD were deviated from those at an elevation of 500 mPD, as indicated by the significant yaw angle measured for 0°, 180° and 292.5° wind at an elevation of 50 mPD. The deviations of the directional distribution at lower elevation are attributed to the mountainous terrain surrounding the Study Site.

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7. FIGURES

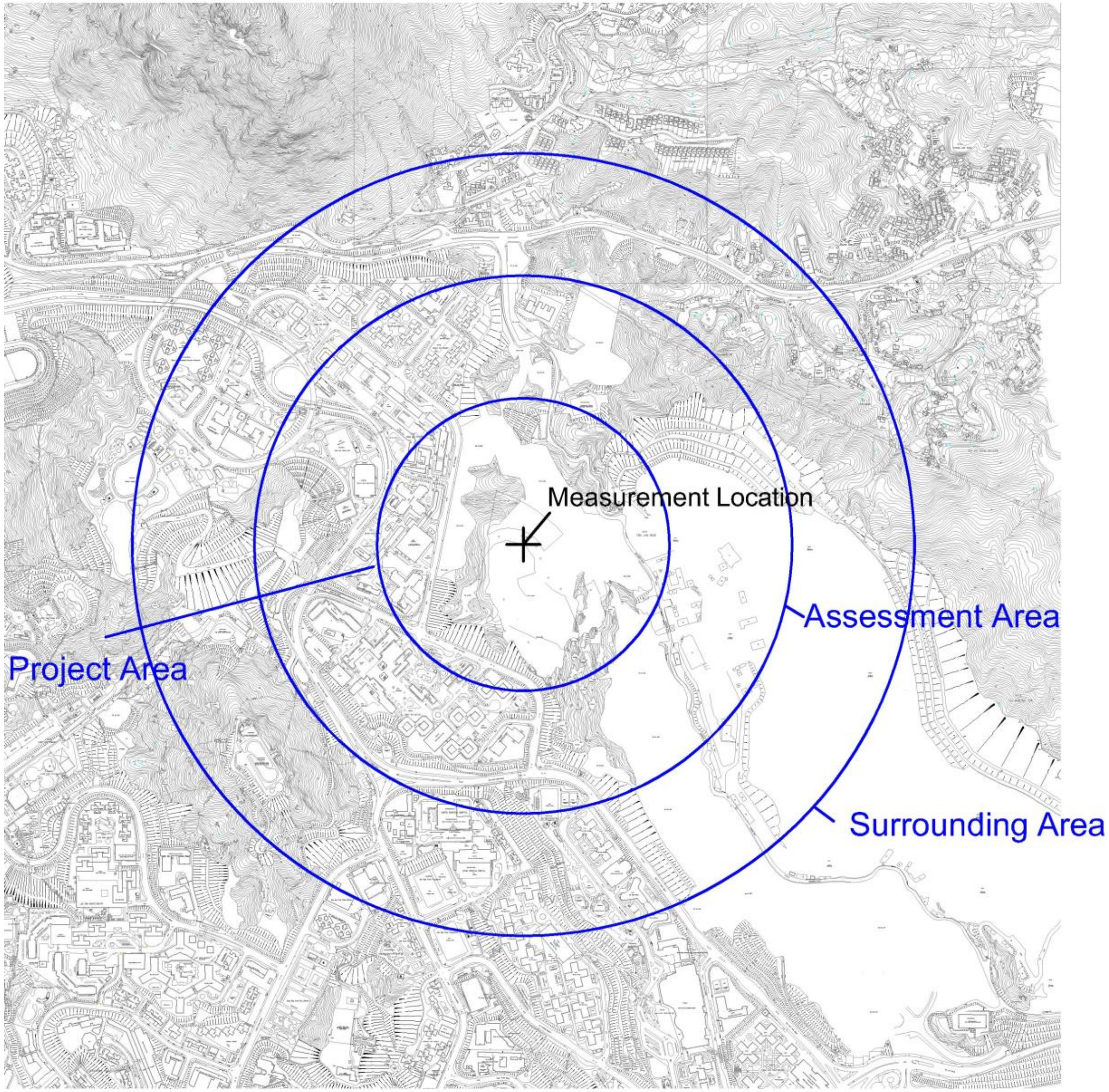


Figure 1: Location of the Development at Anderson Road, Kowloon

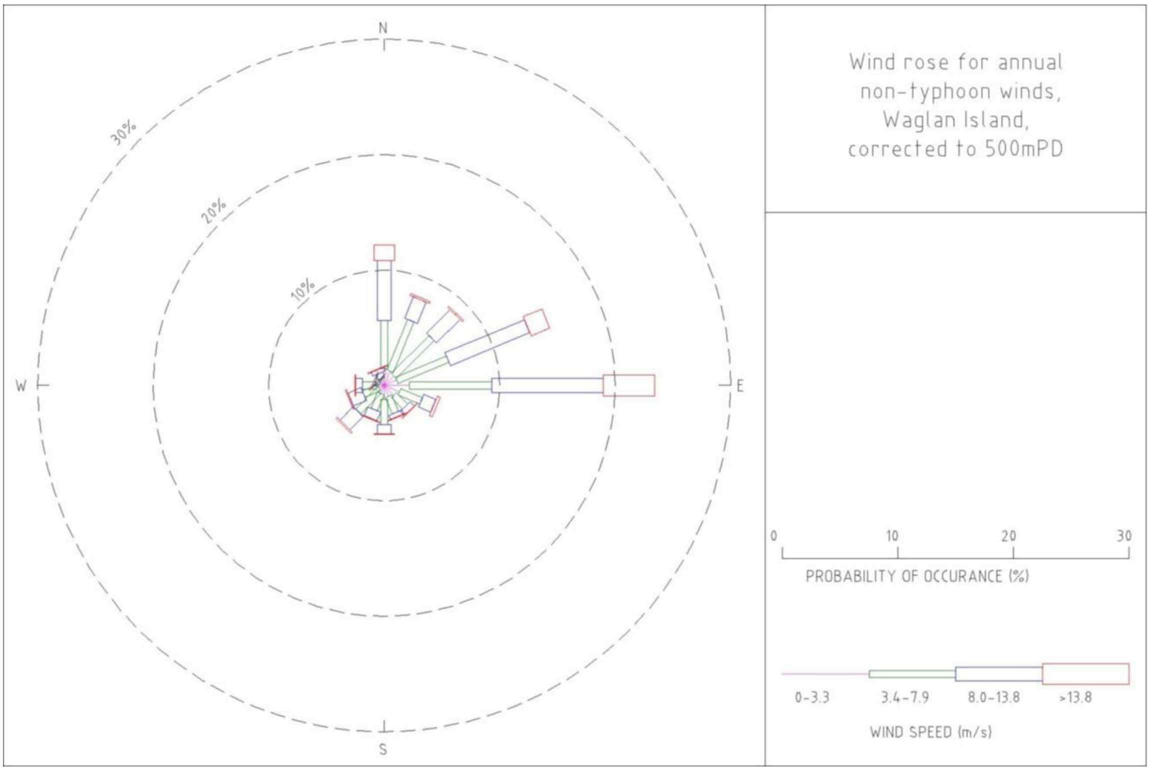


Figure 2: Wind rose for annual non-typhoon winds measured at Waglan Island, corrected to 500 mPD above open sea, 1953-2006

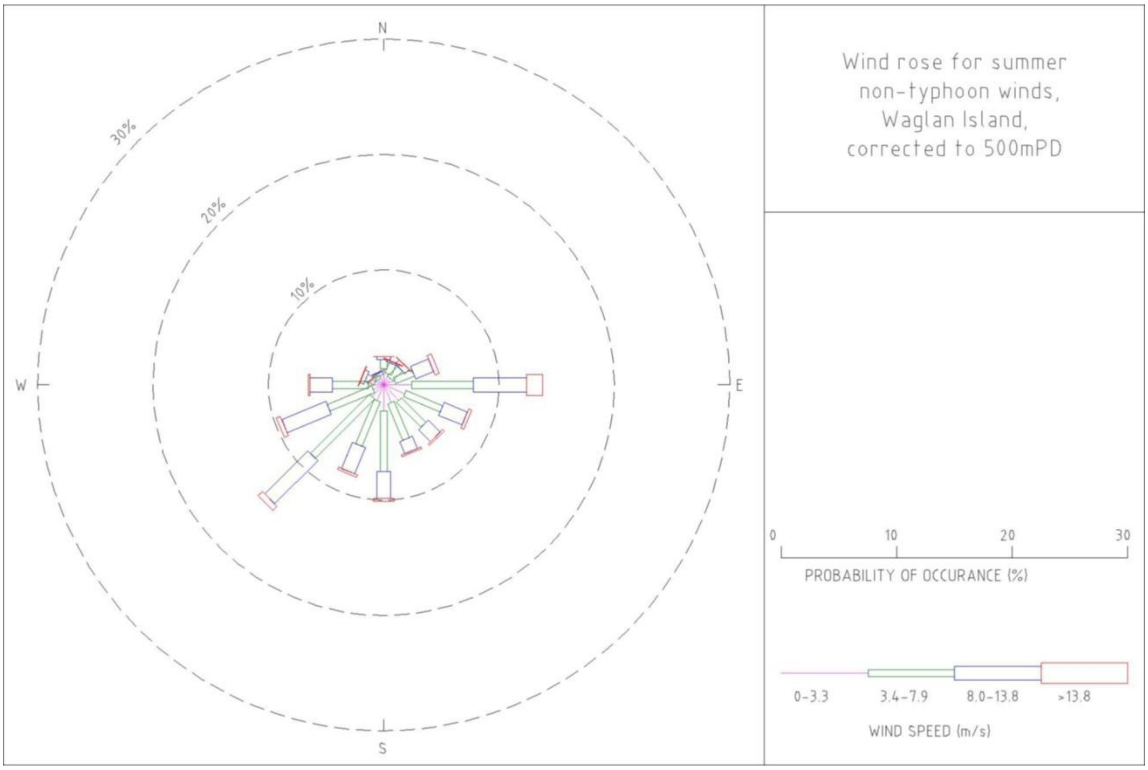


Figure 3: Wind rose for summer (June, July, August) non-typhoon winds measured at Waglan Island, corrected to 500 mPD above open sea, 1953-2006

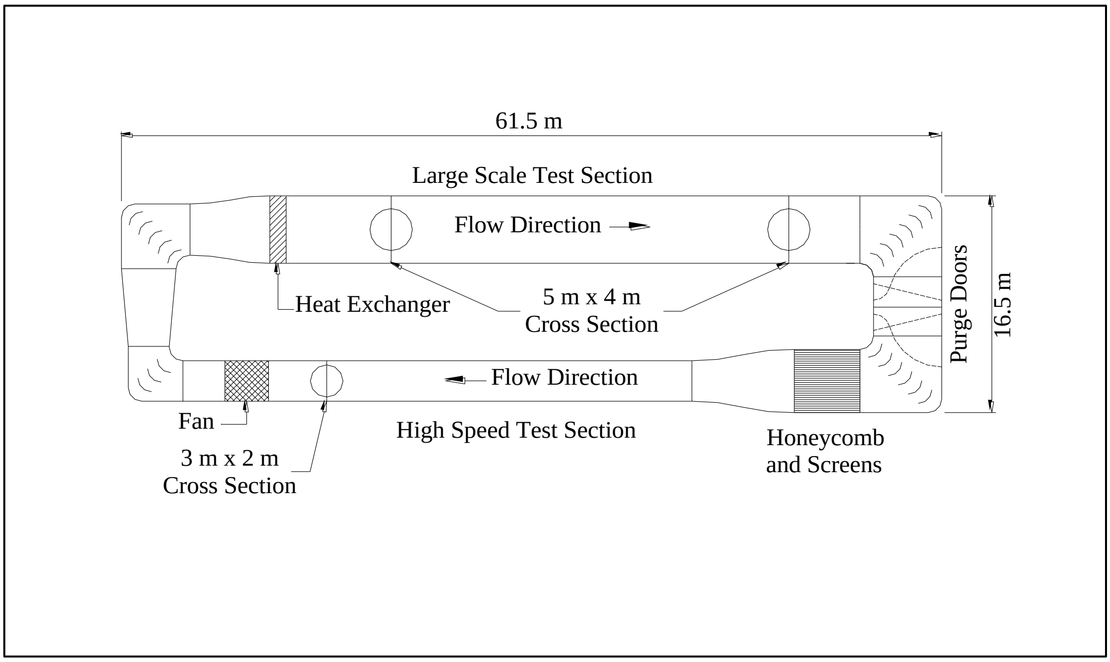


Figure 4: WWTF boundary layer wind tunnel sections

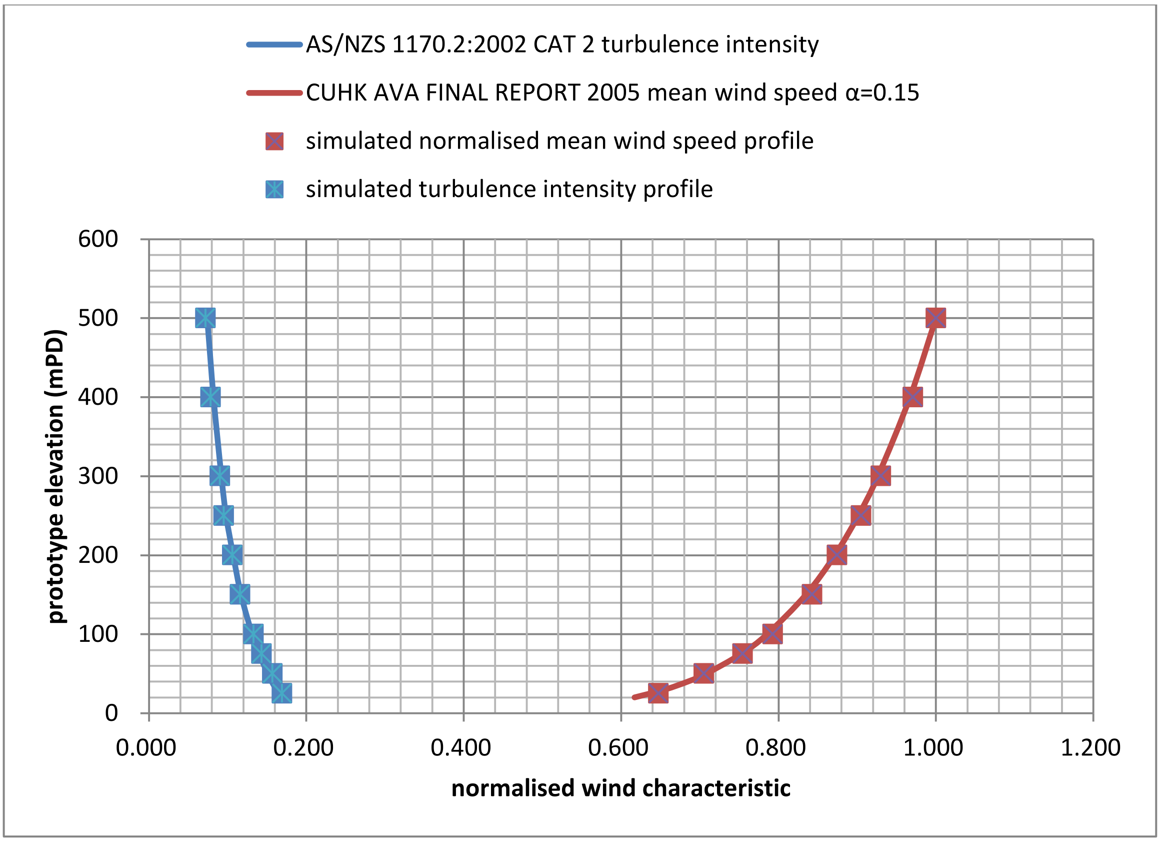


Figure 5: Simulated and target mean wind speed and turbulence intensity profiles of approach wind

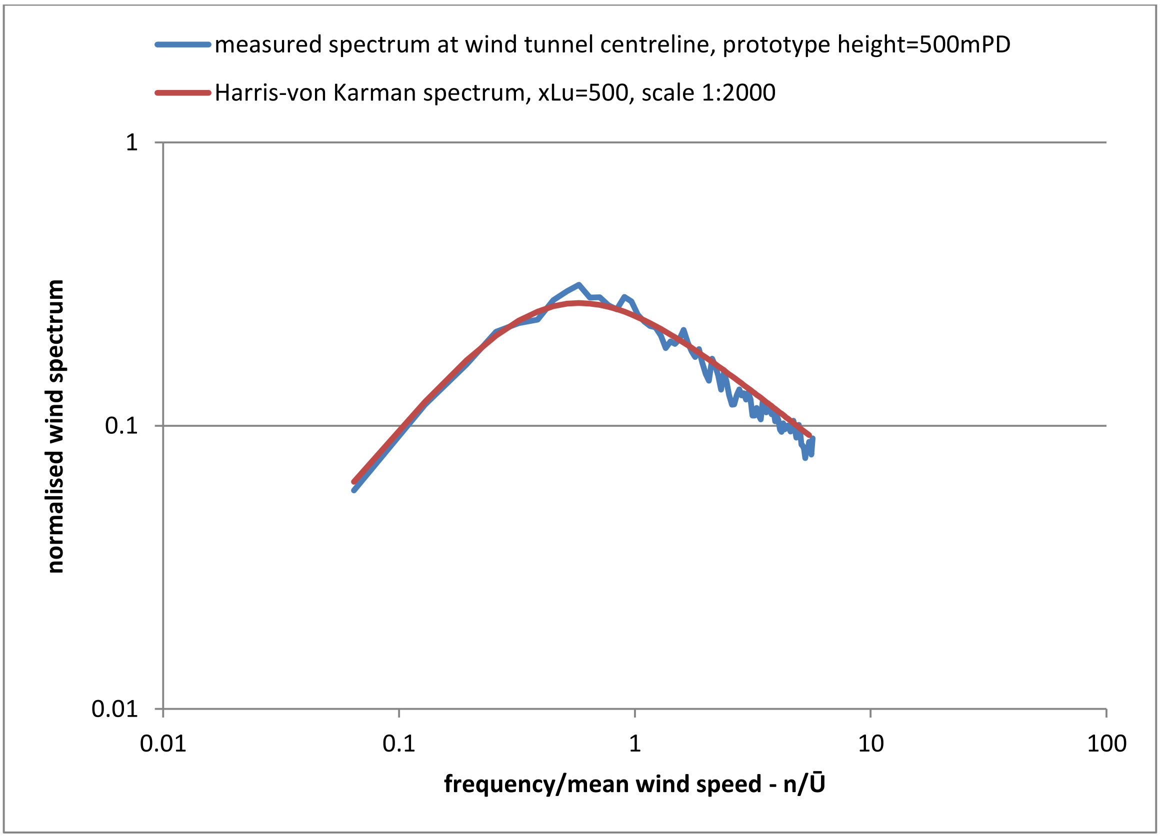


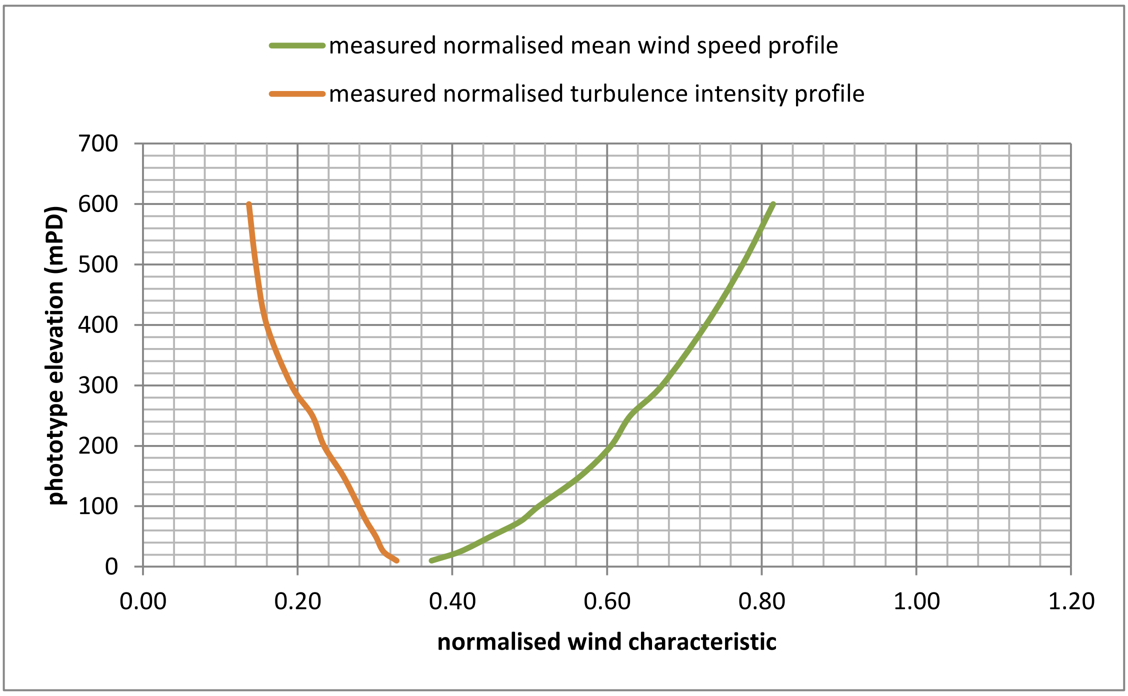
Figure 6: Spectrum of longitudinal turbulence of the simulated approach wind flow measured at 500 mPD

Figure 7: WWTF's 1:2000 topographical model of Hong Kong, 0° wind direction, downstream view.

Figure 8: WWTF's 1:2000 topographical model of Hong Kong, 90° wind direction, downstream view.

Figure 9: WWTF's 1:2000 topographical model of Hong Kong, 180° wind direction, downstream view.

Figure 10: WWTF's 1:2000 topographical model of Hong Kong, 270° wind direction, downstream view.



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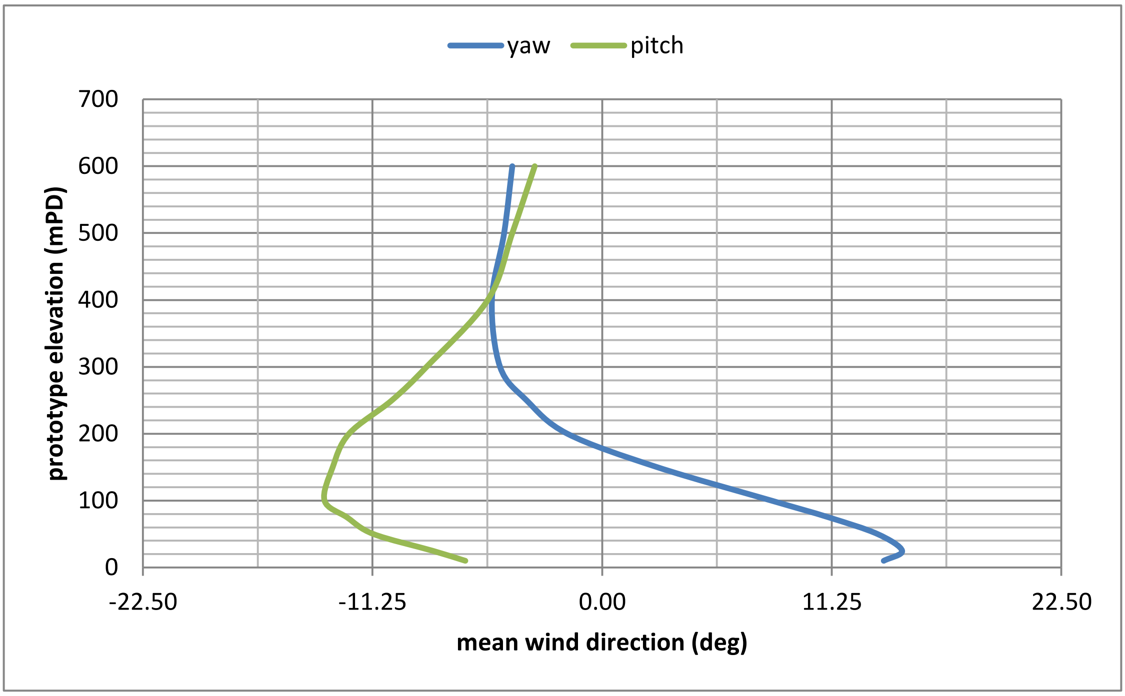

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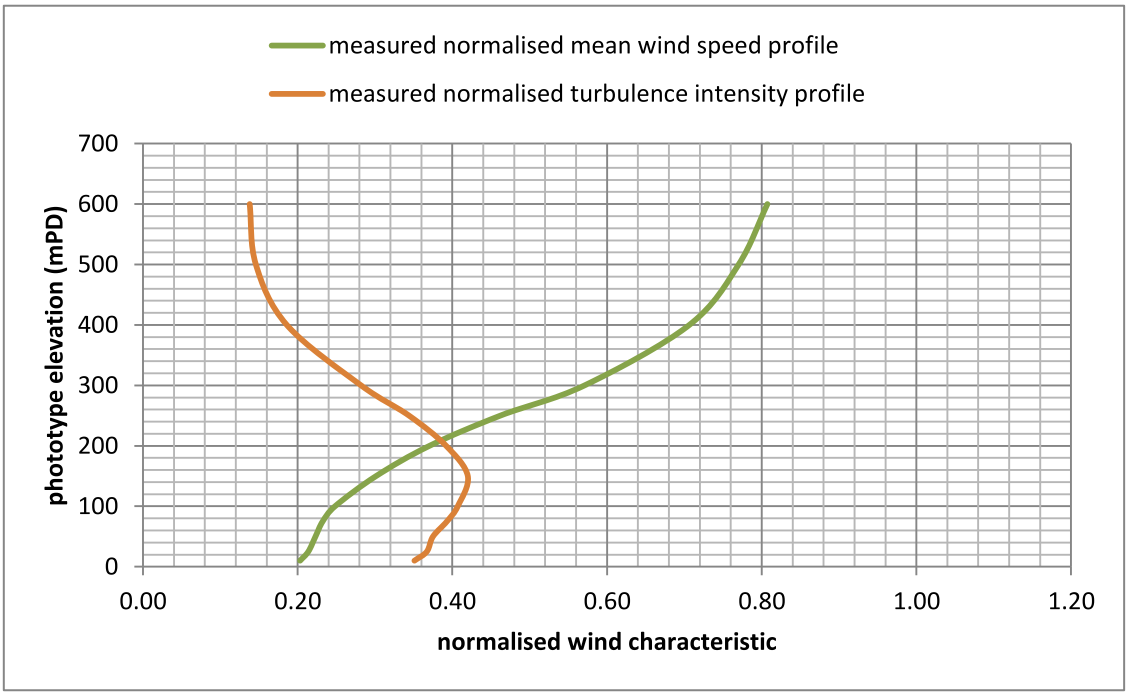
Figure 11: Measured wind characteristics at an approach wind direction of 0°



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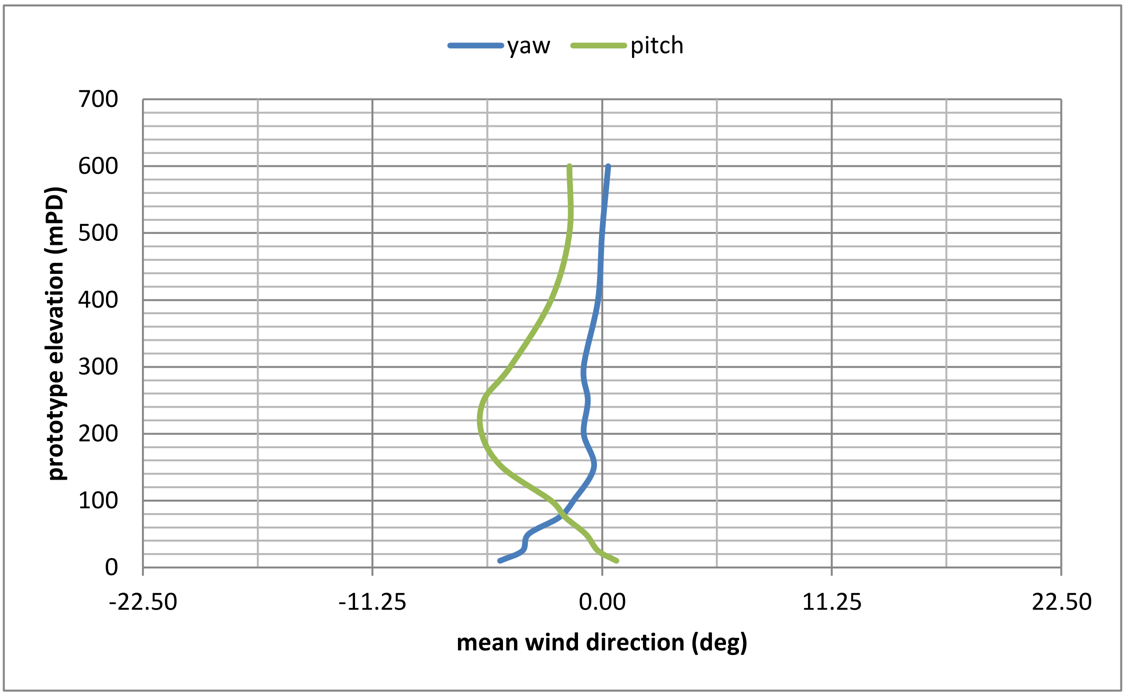

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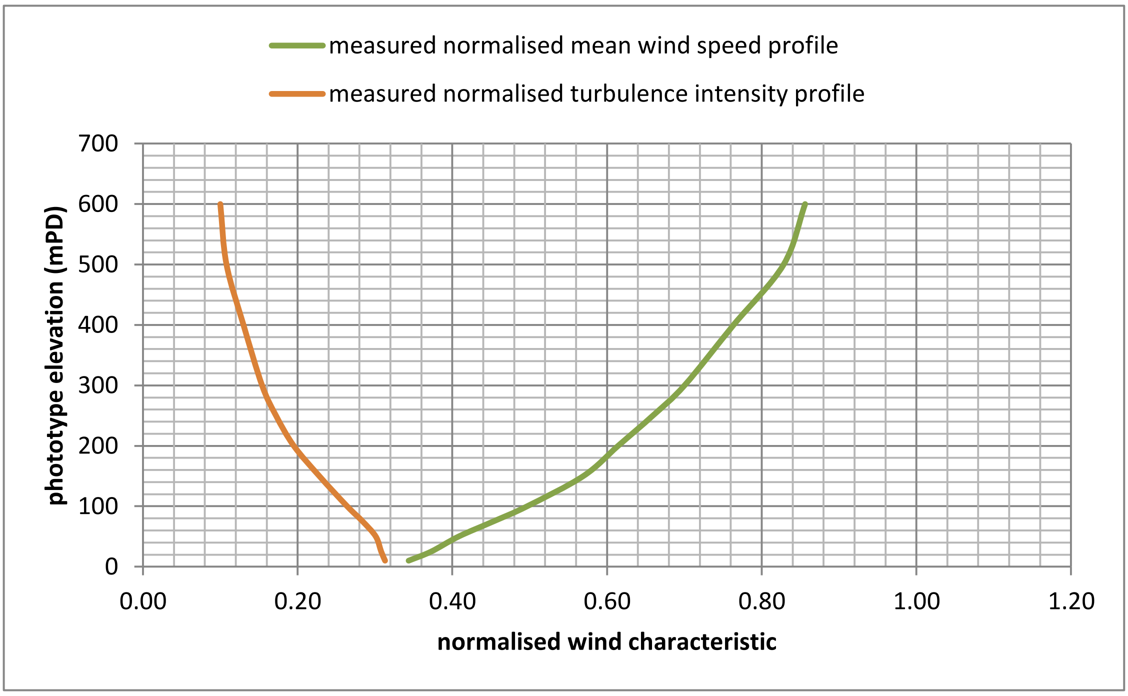
Figure 12: Measured wind characteristics at an approach wind direction of 22.5°



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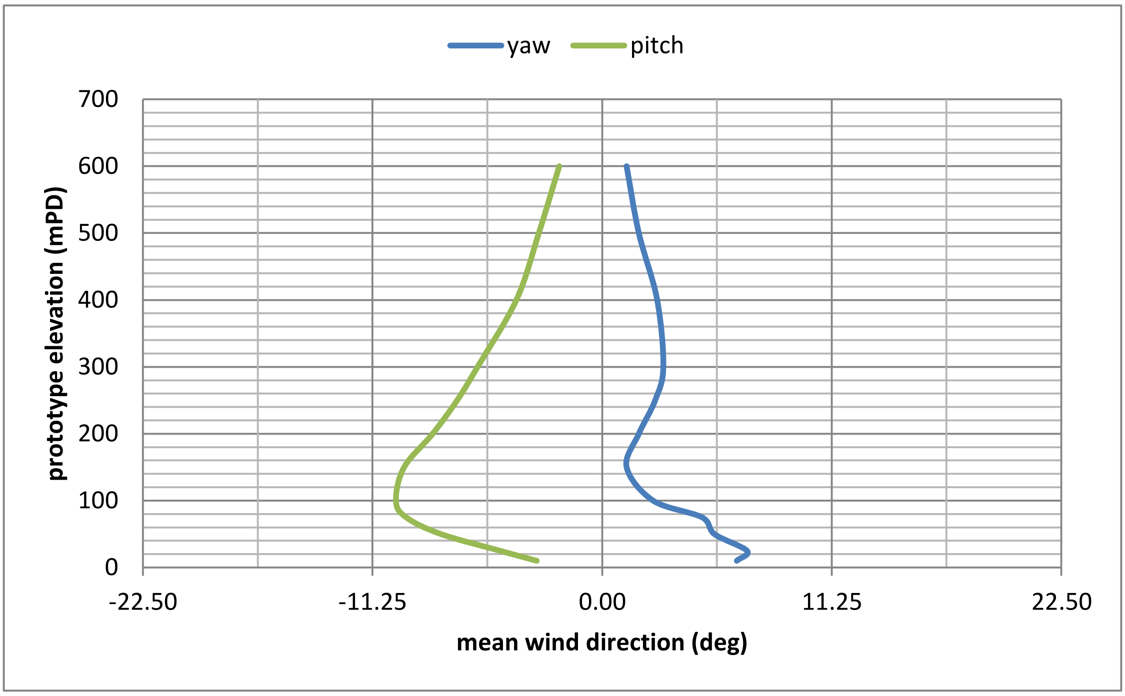

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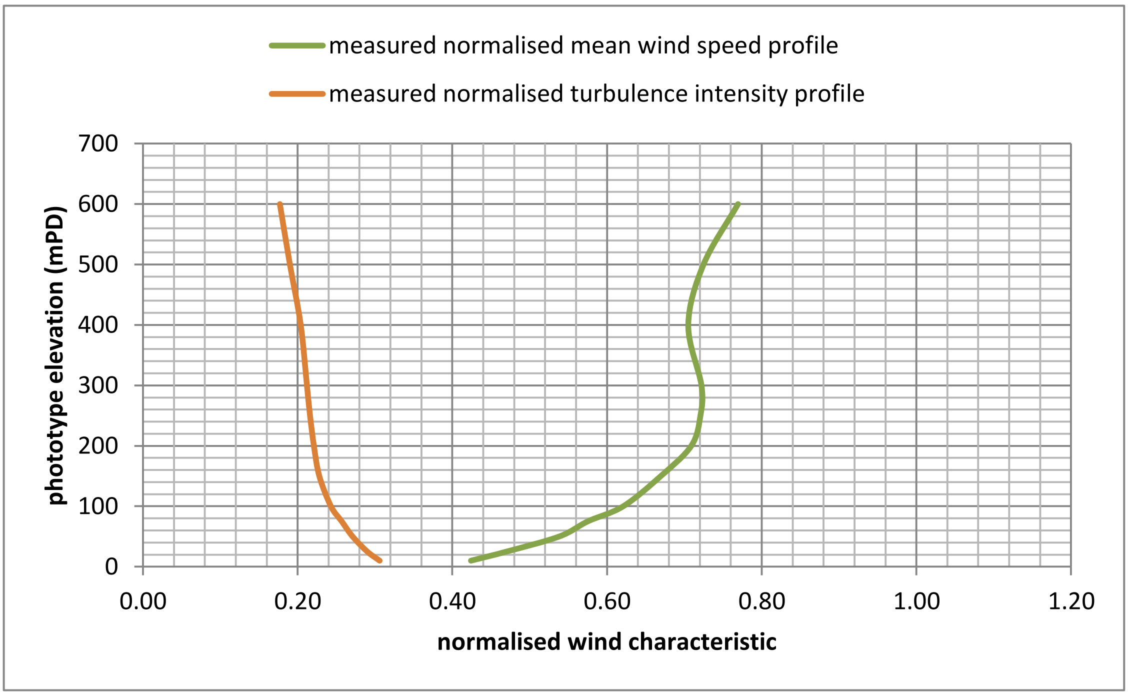
Figure 13: Measured wind characteristics at an approach wind direction of 45°



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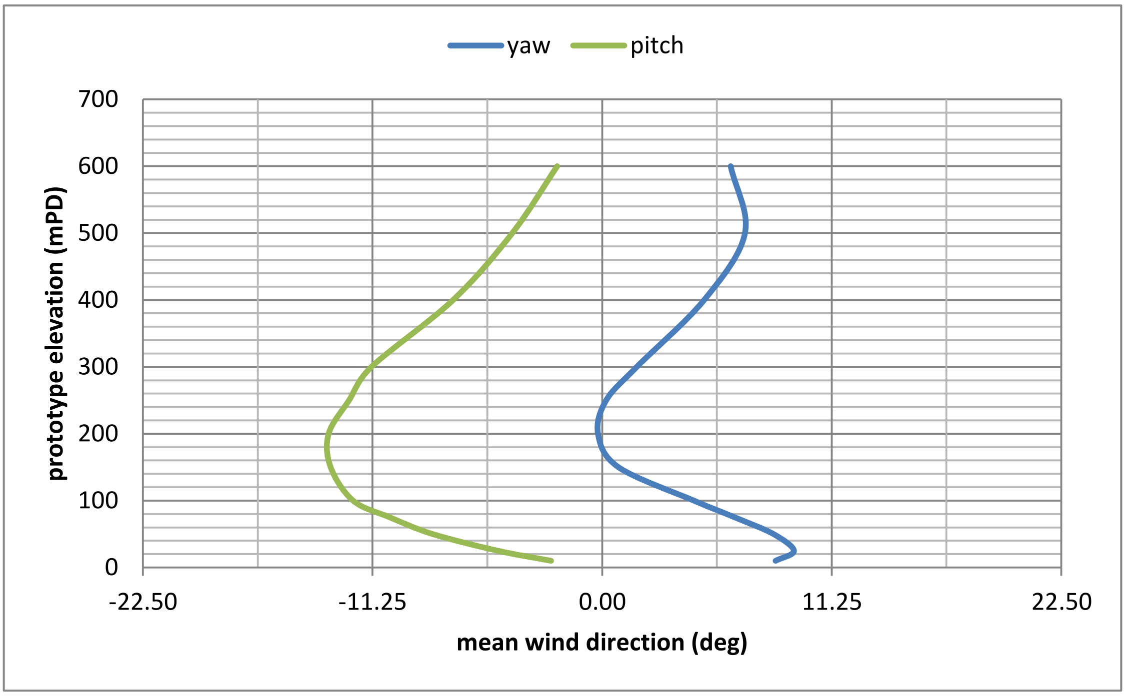

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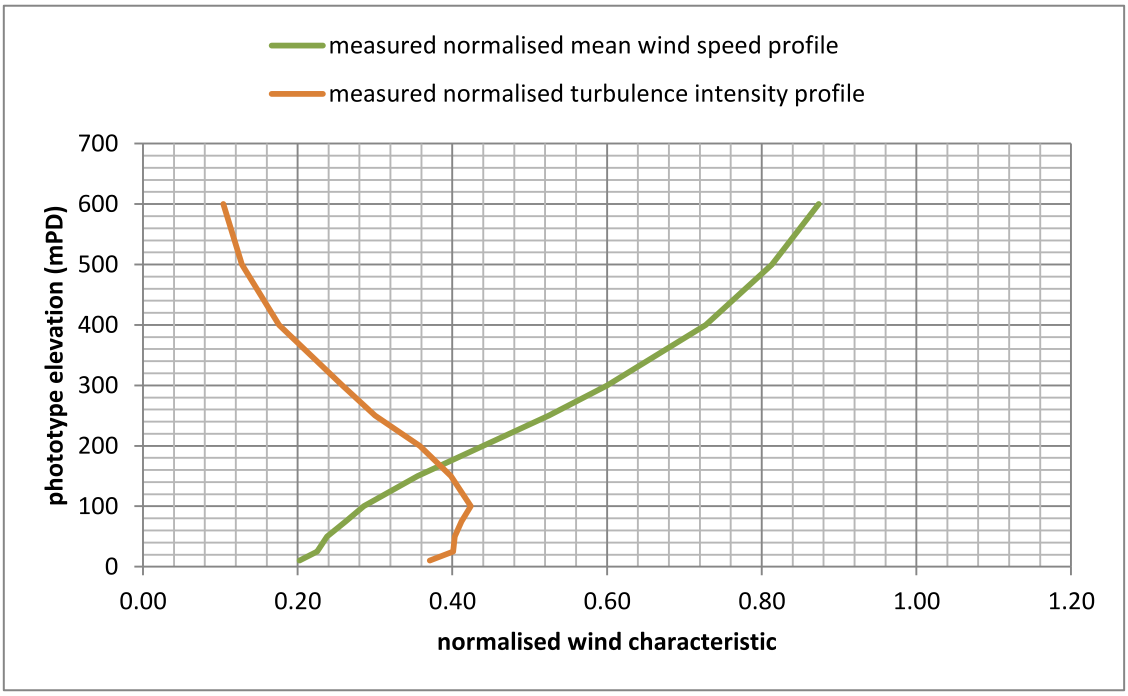
Figure 14: Measured wind characteristics at an approach wind direction of 67.5°



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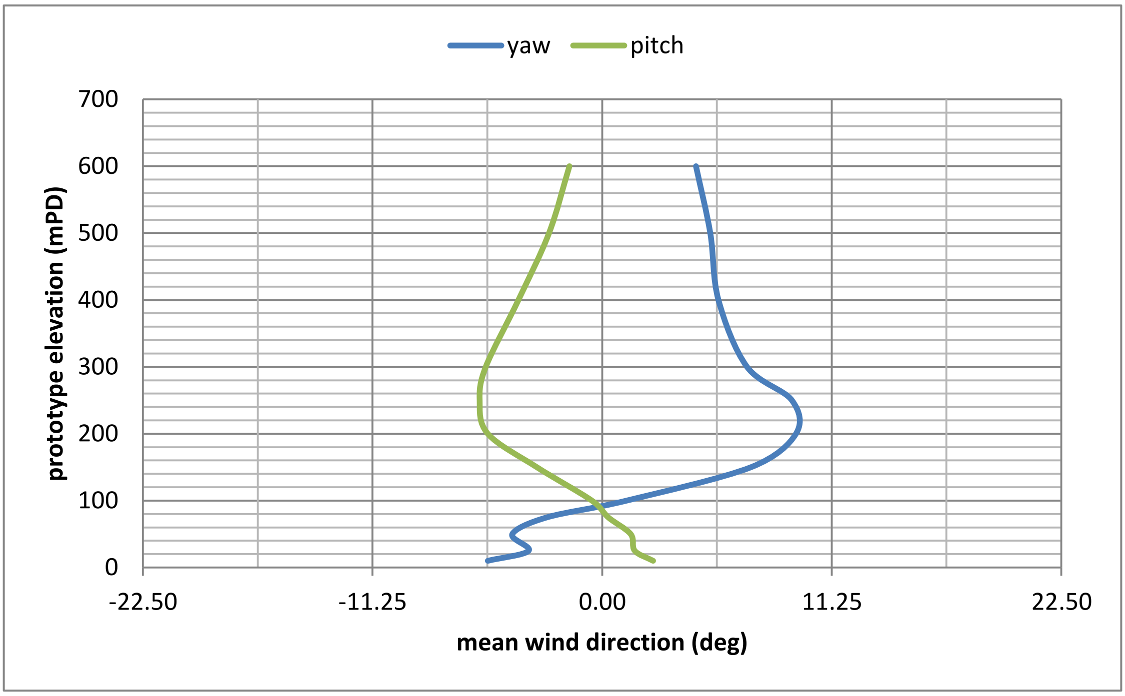

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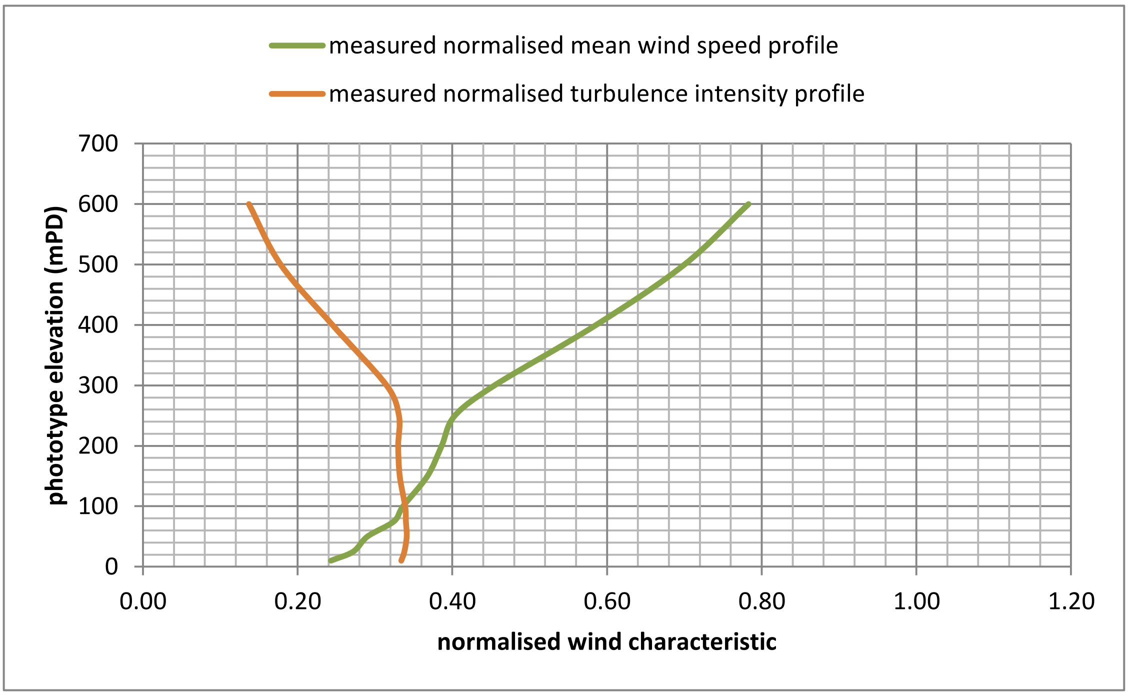
Figure 15: Measured wind characteristics at an approach wind direction of 90°



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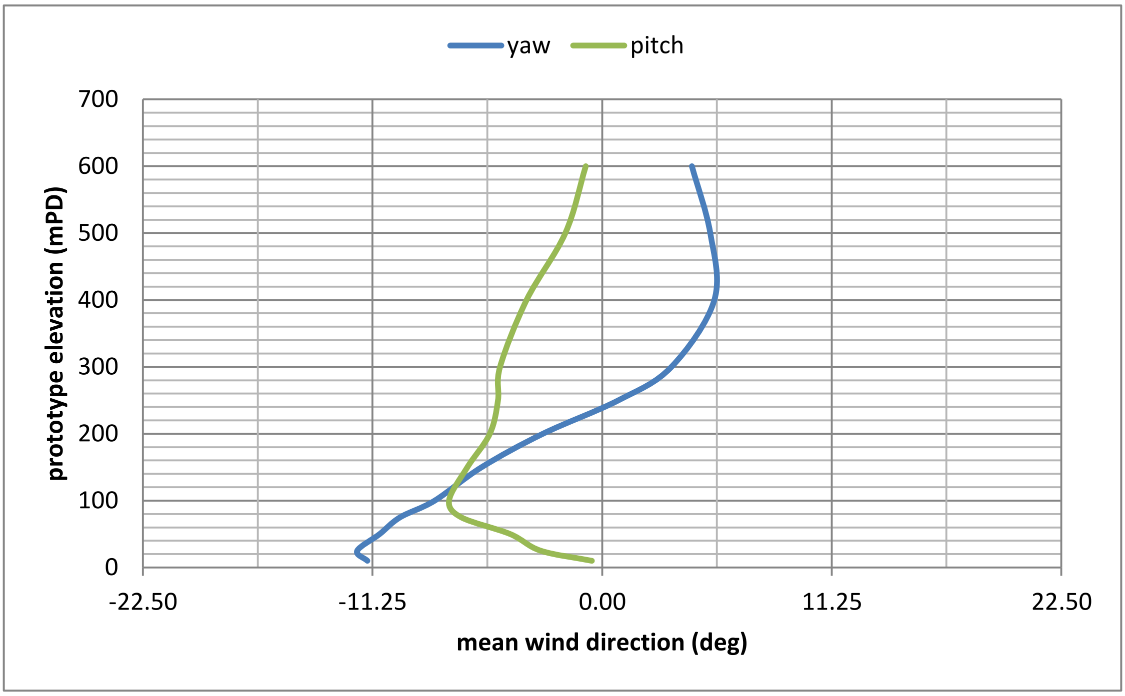

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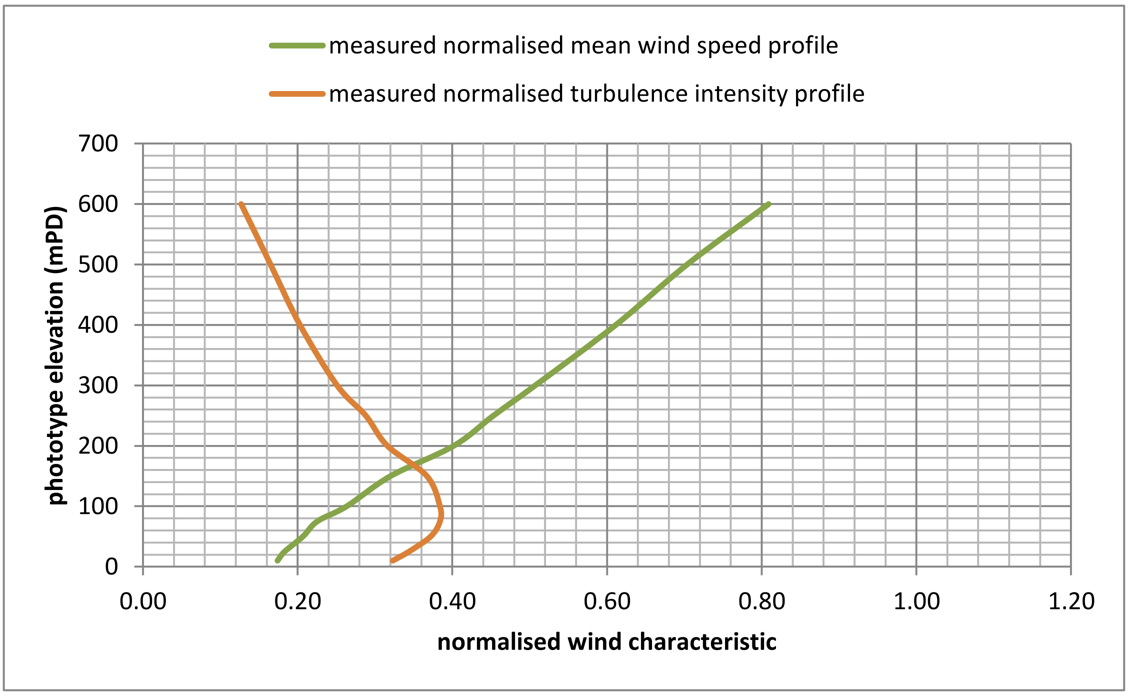
Figure 16: Measured wind characteristics at an approach wind direction of 112.5°



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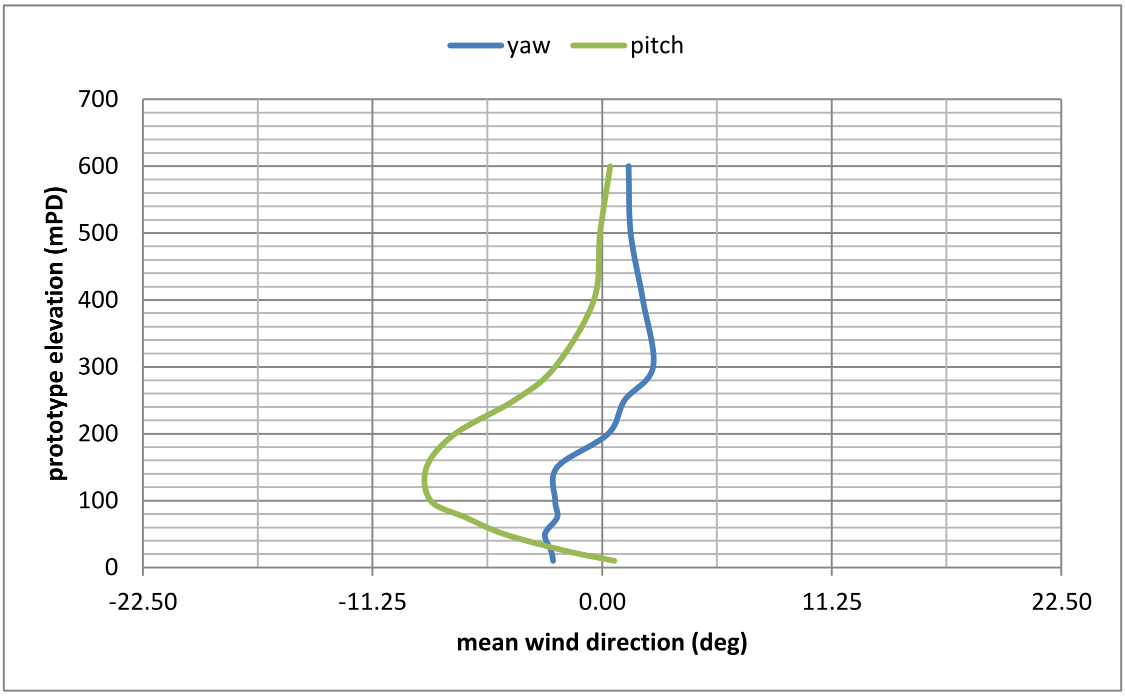

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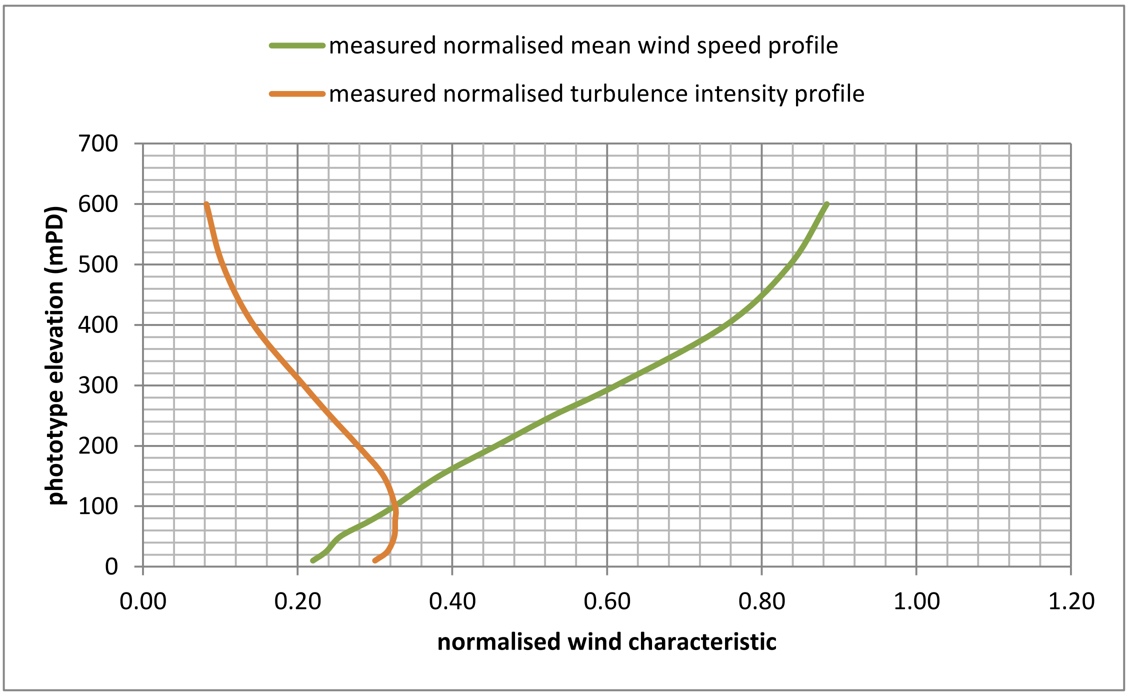
Figure 17: Measured wind characteristics at an approach wind direction of 135°



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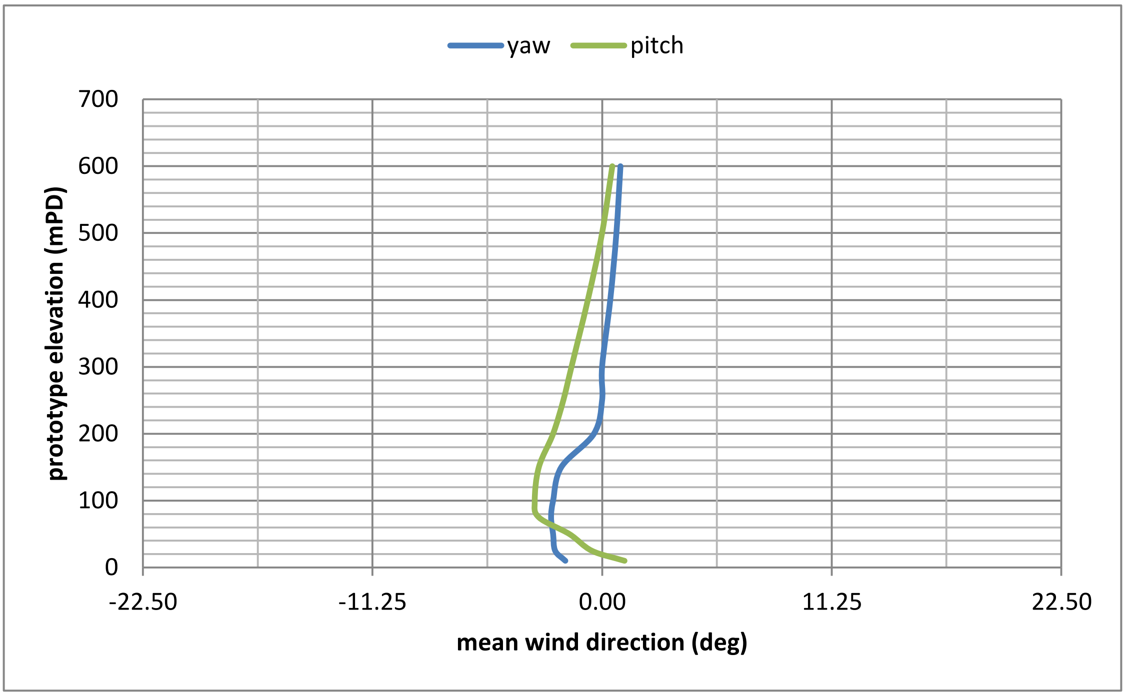

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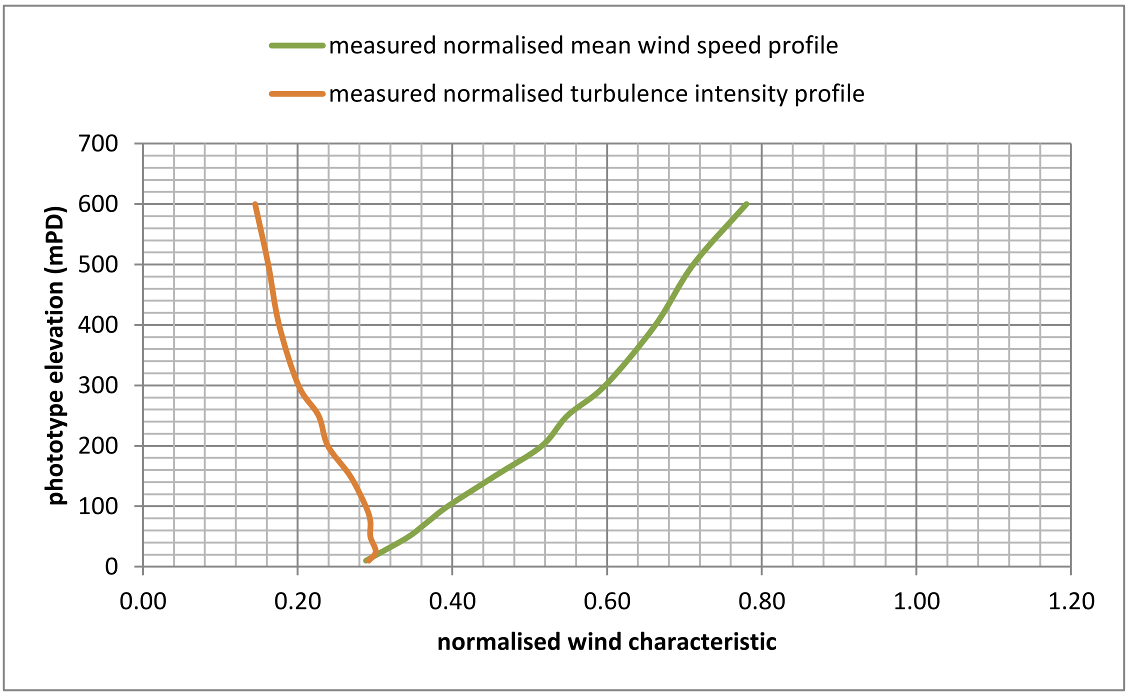
Figure 18: Measured wind characteristics at an approach wind direction of 157.5°



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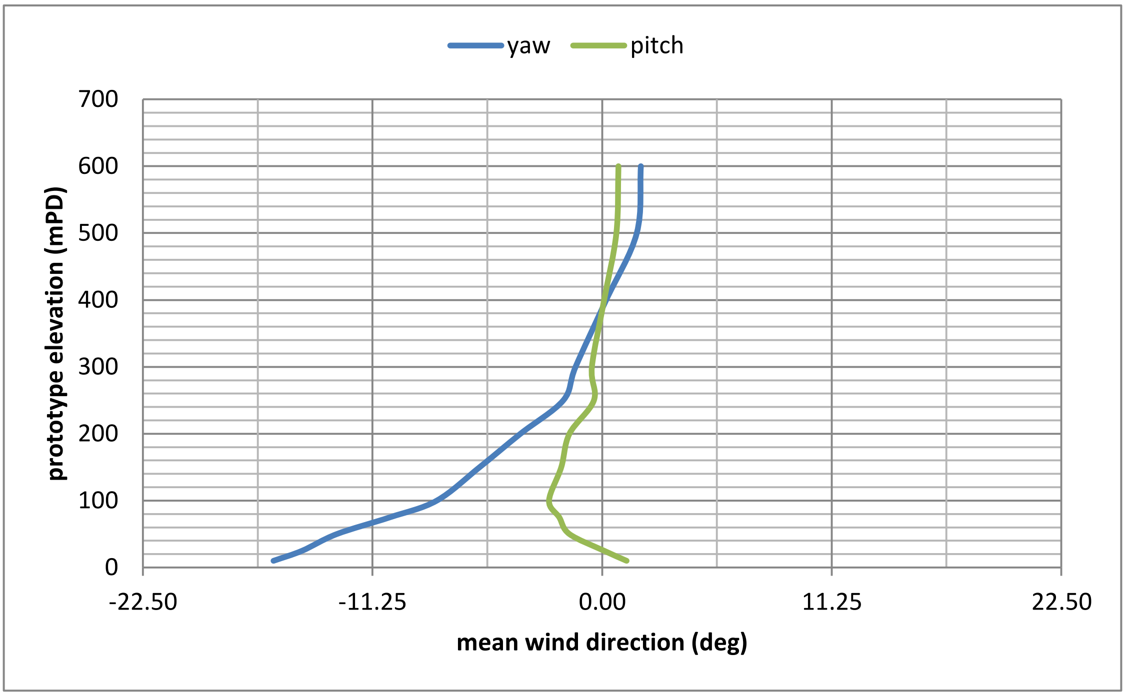

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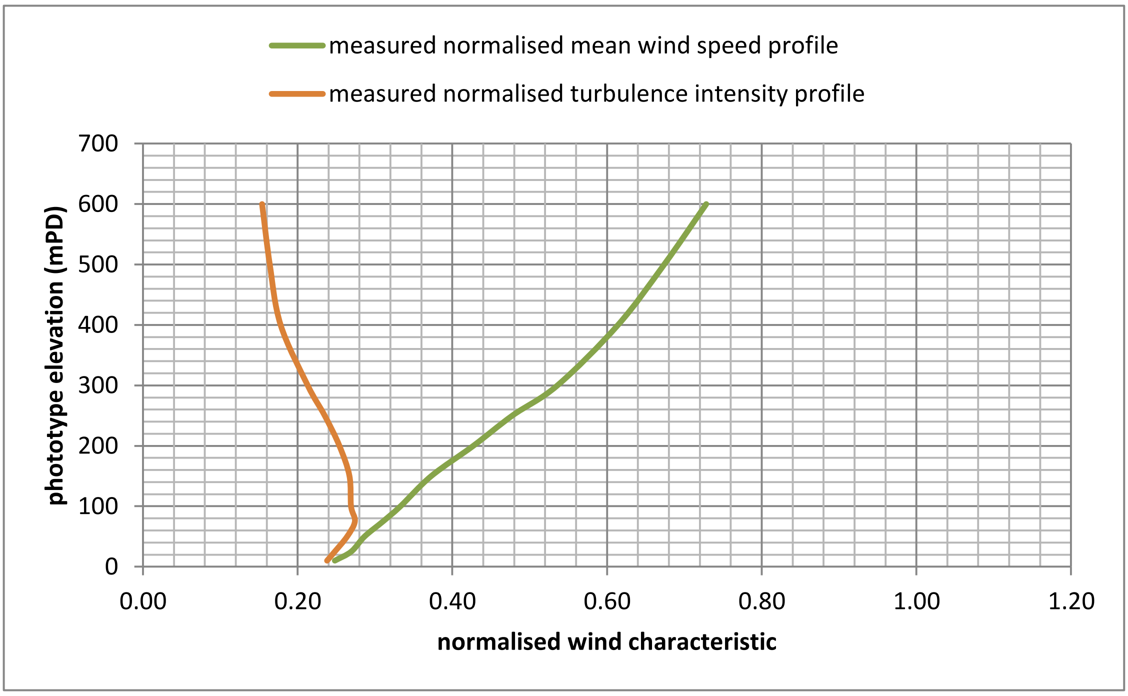
Figure 19: Measured wind characteristics at an approach wind direction of 180°



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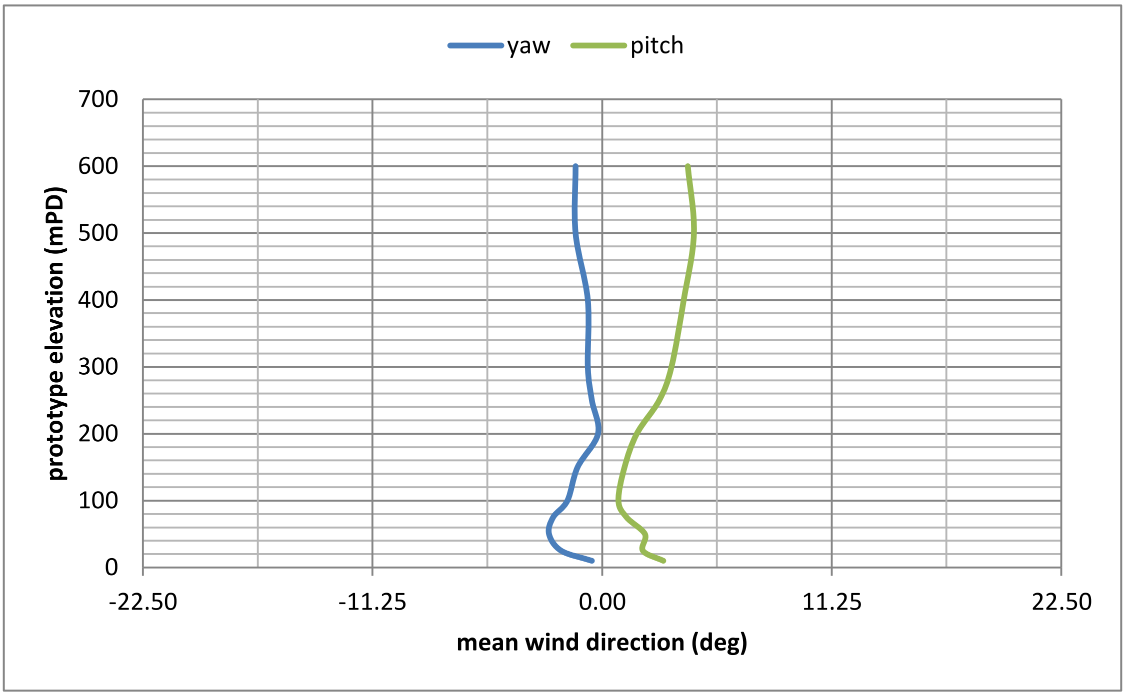

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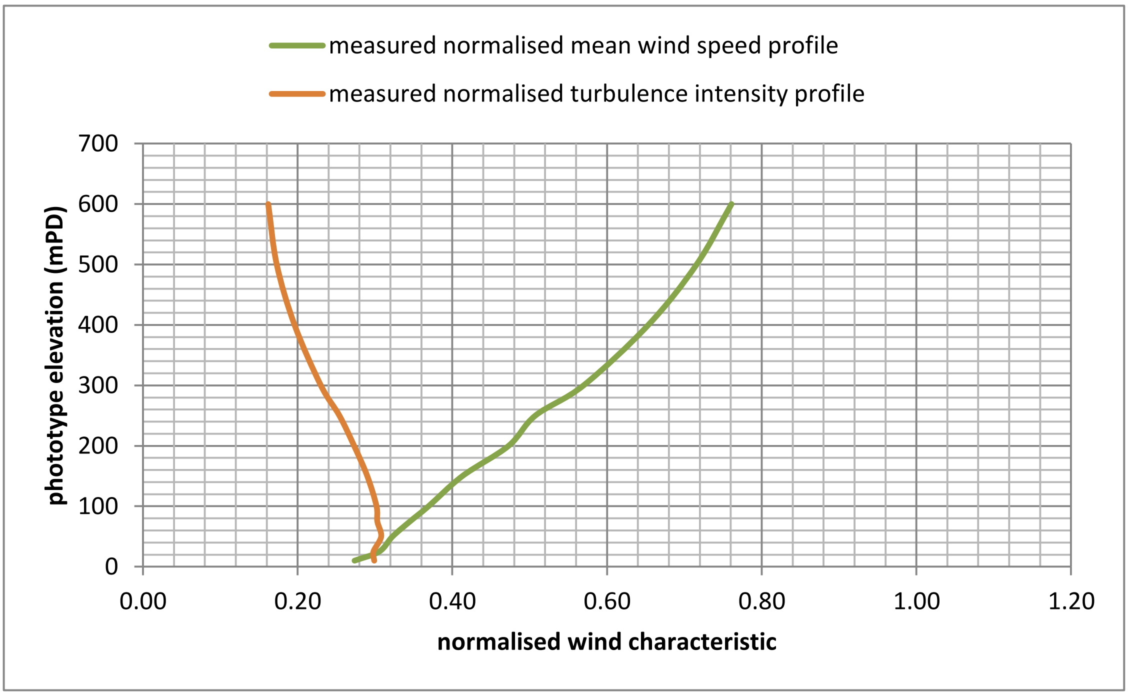
Figure 20: Measured wind characteristics at an approach wind direction of 202.5°



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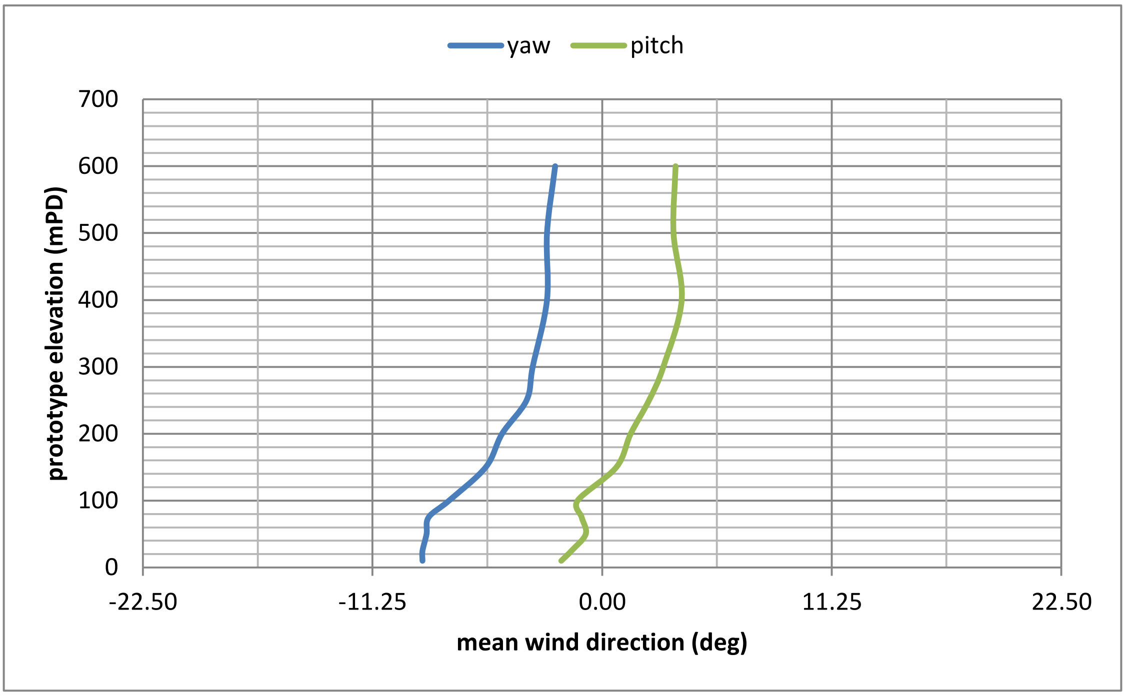

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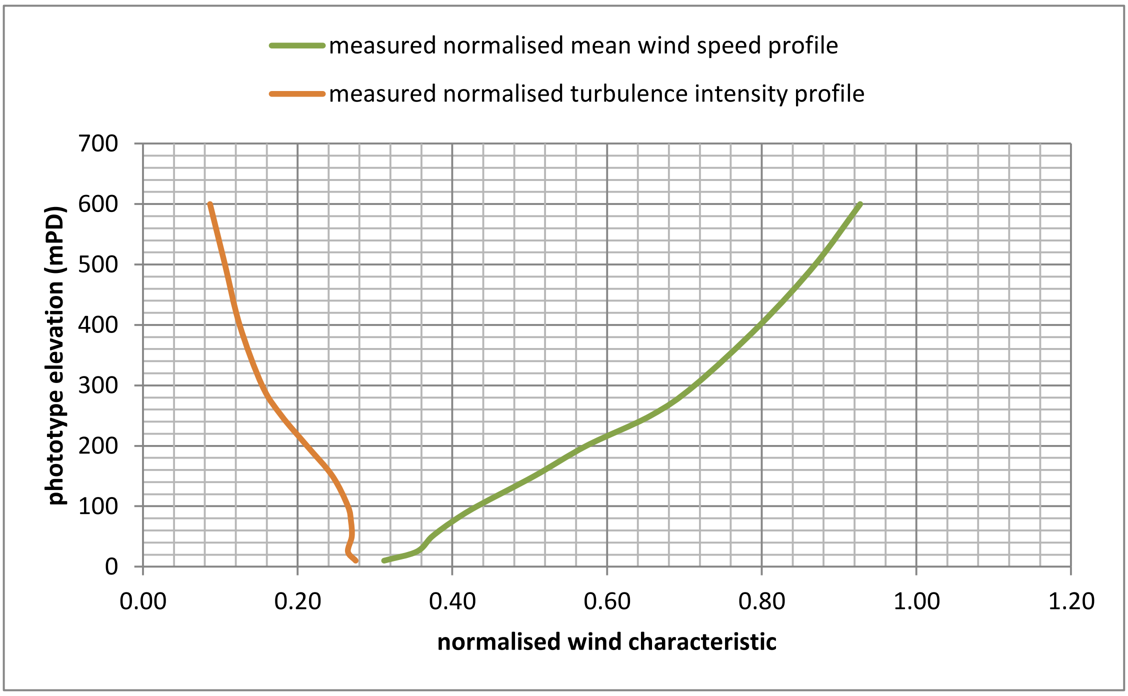
Figure 21: Measured wind characteristics at an approach wind direction of 225°



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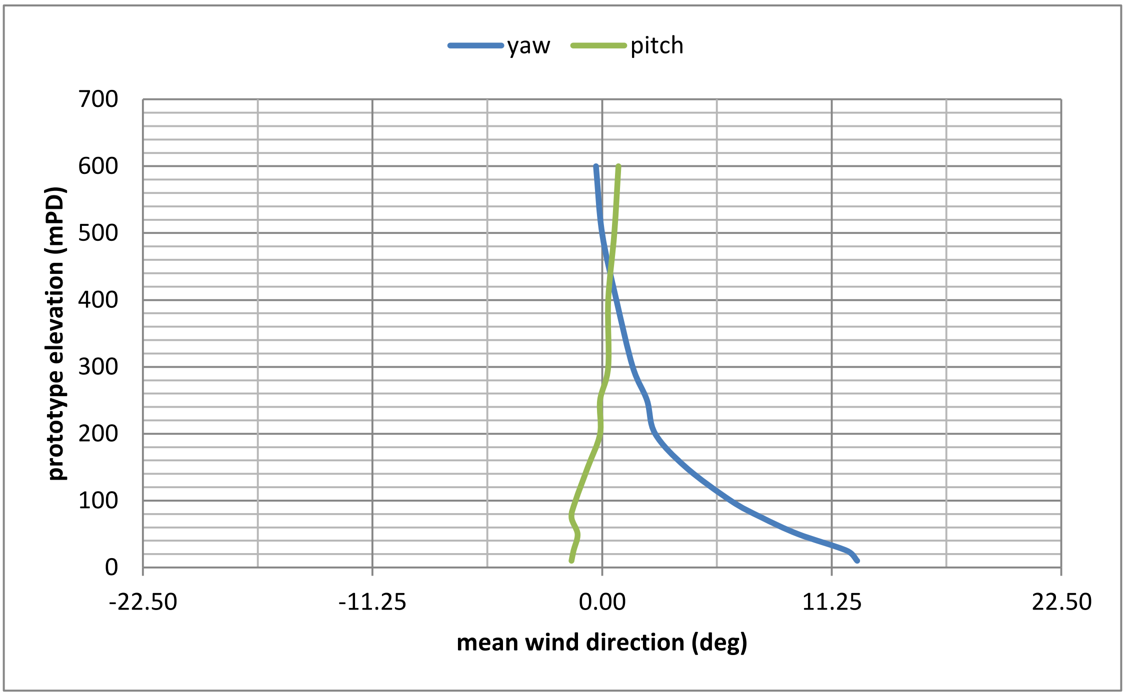

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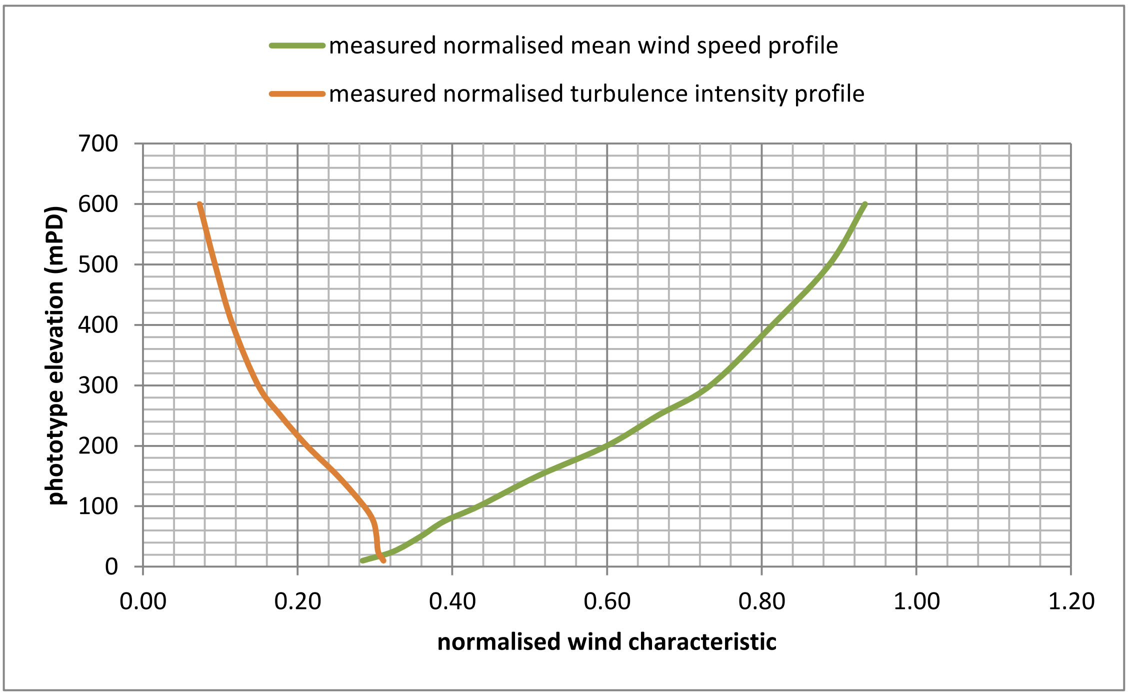
Figure 22: Measured wind characteristics at an approach wind direction of 247.5°



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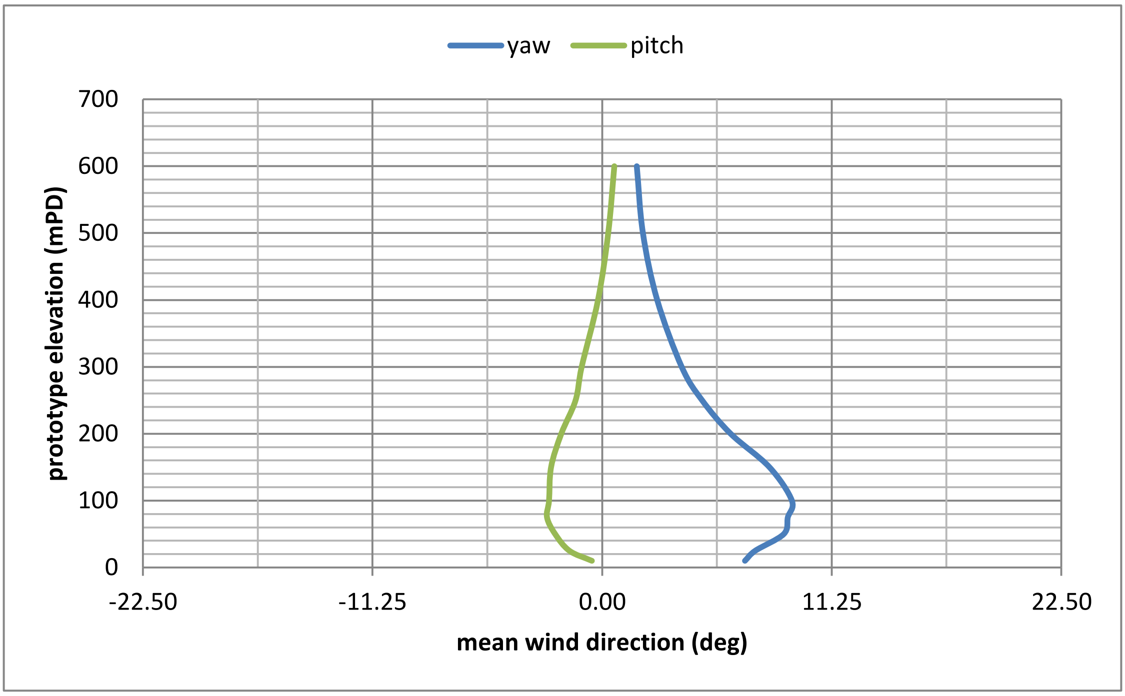

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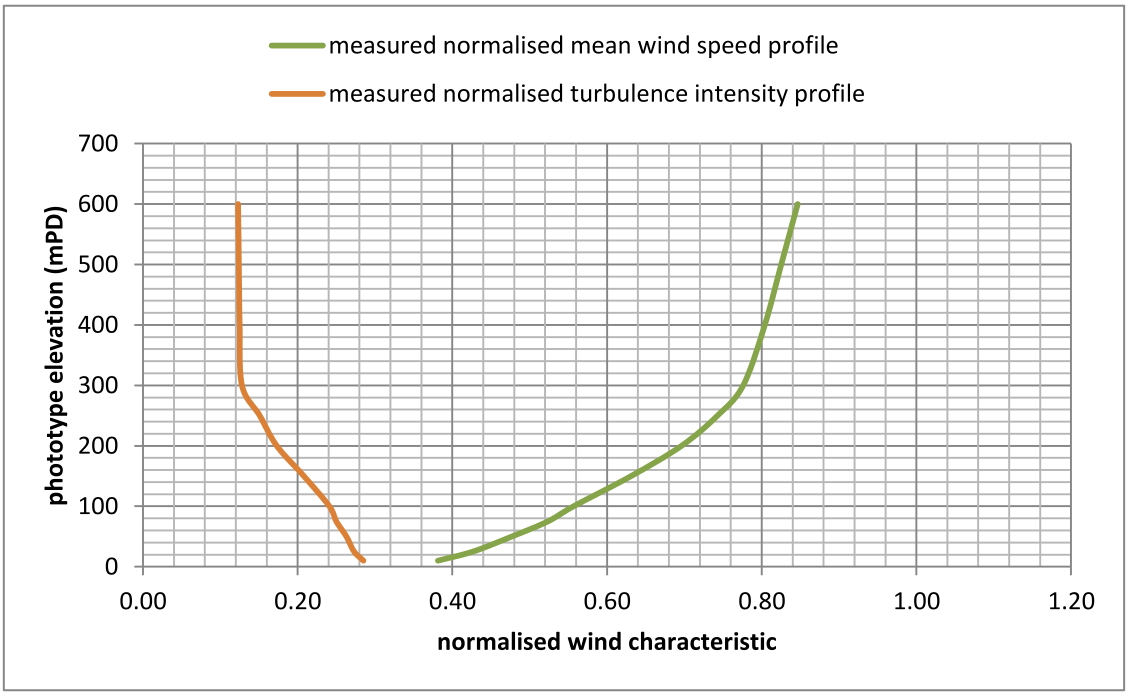
Figure 23: Measured wind characteristics at an approach wind direction of 270°



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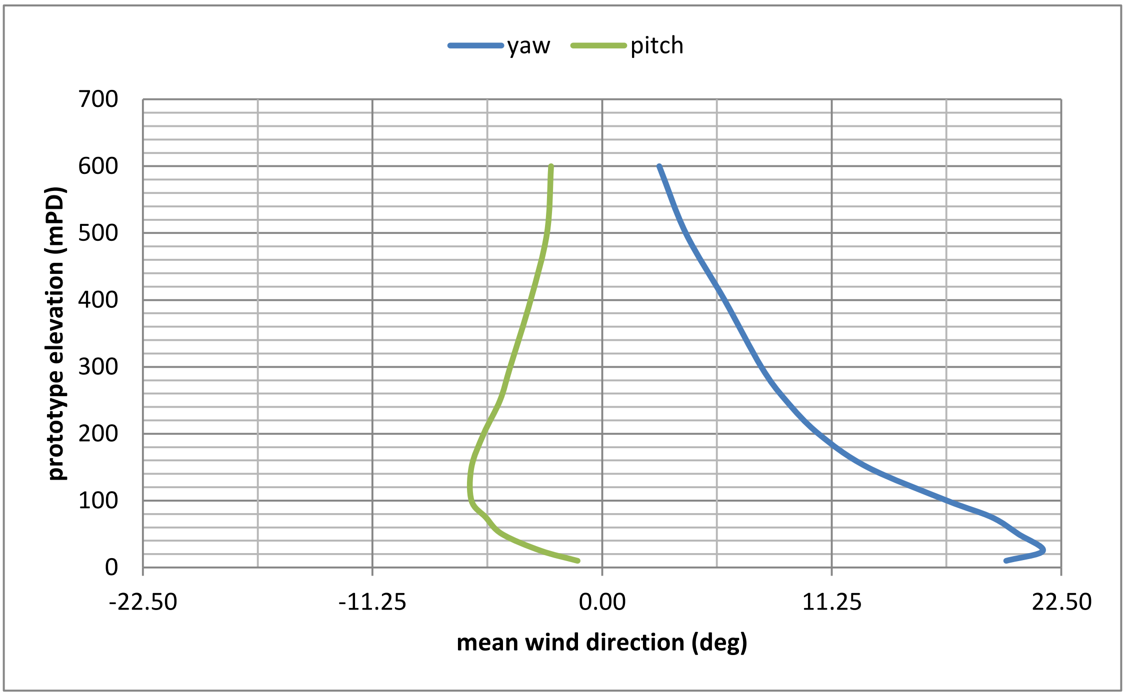

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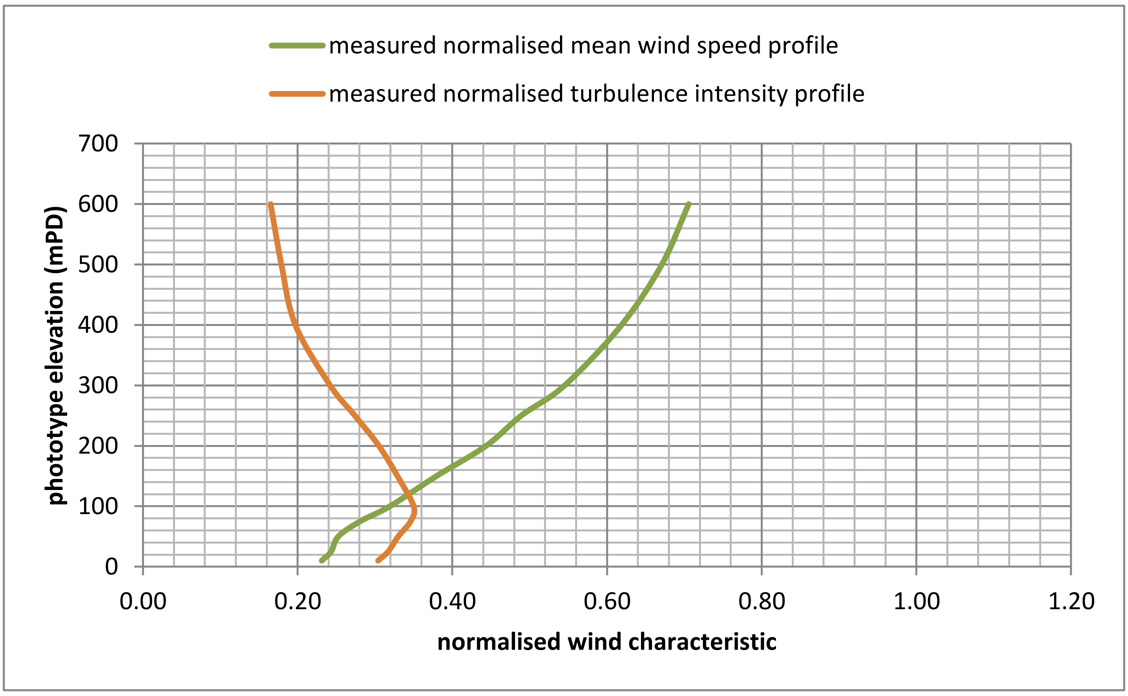
Figure 24: Measured wind characteristics at an approach wind direction of 292.5°



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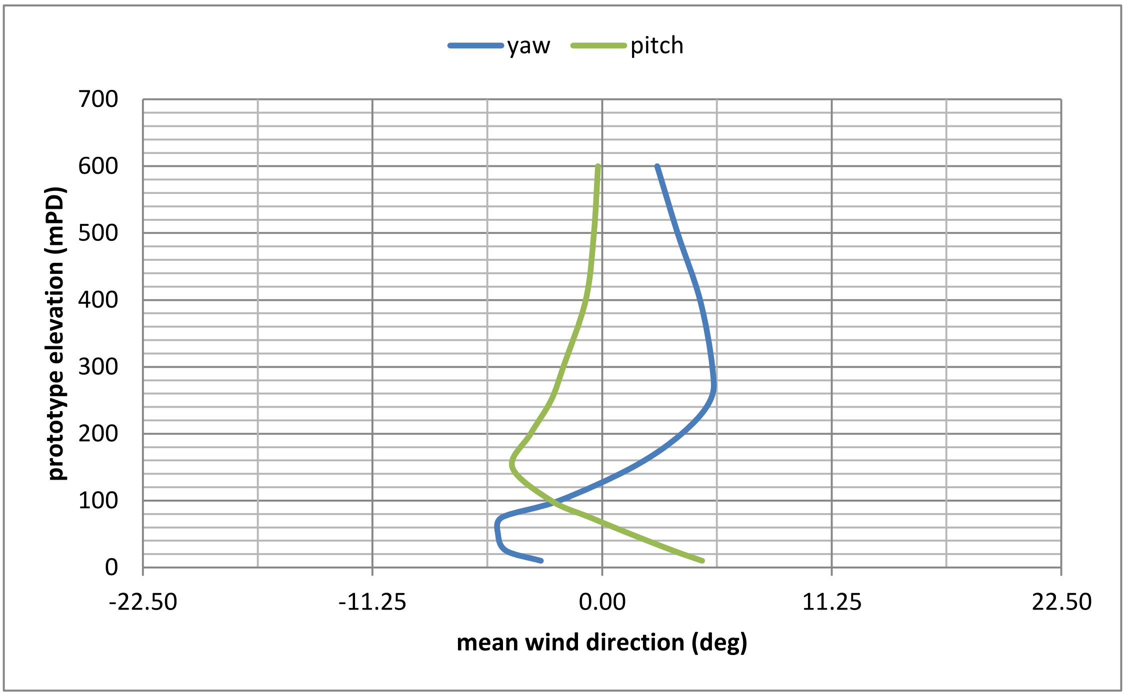

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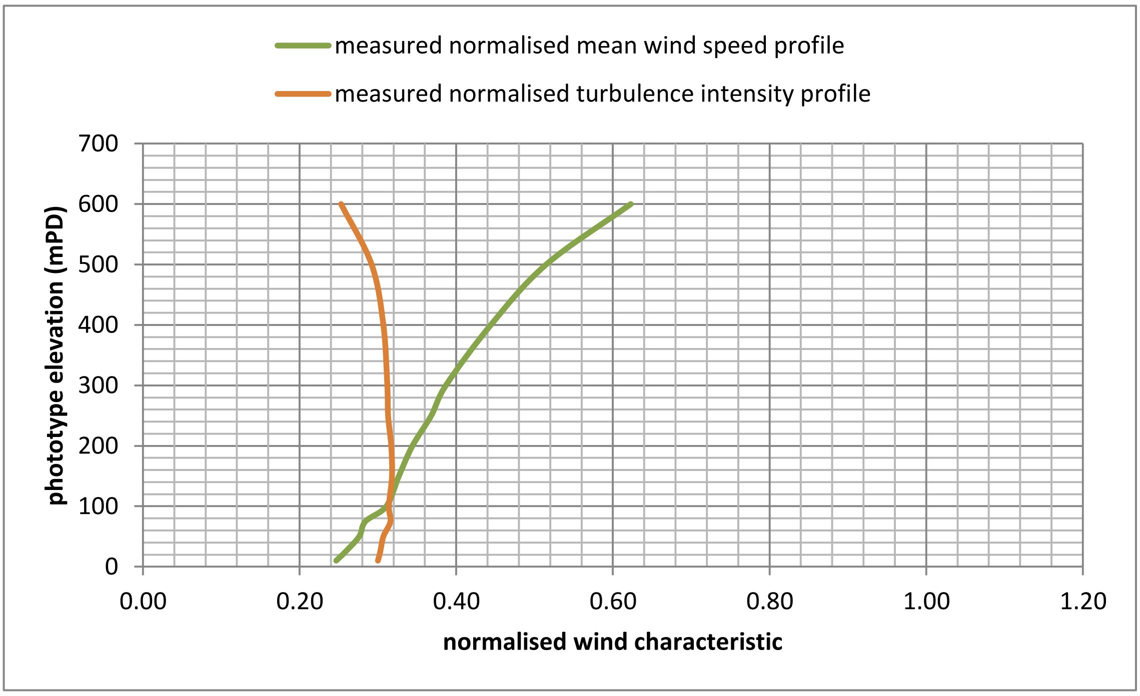
Figure 25: Measured wind characteristics at an approach wind direction of 315°



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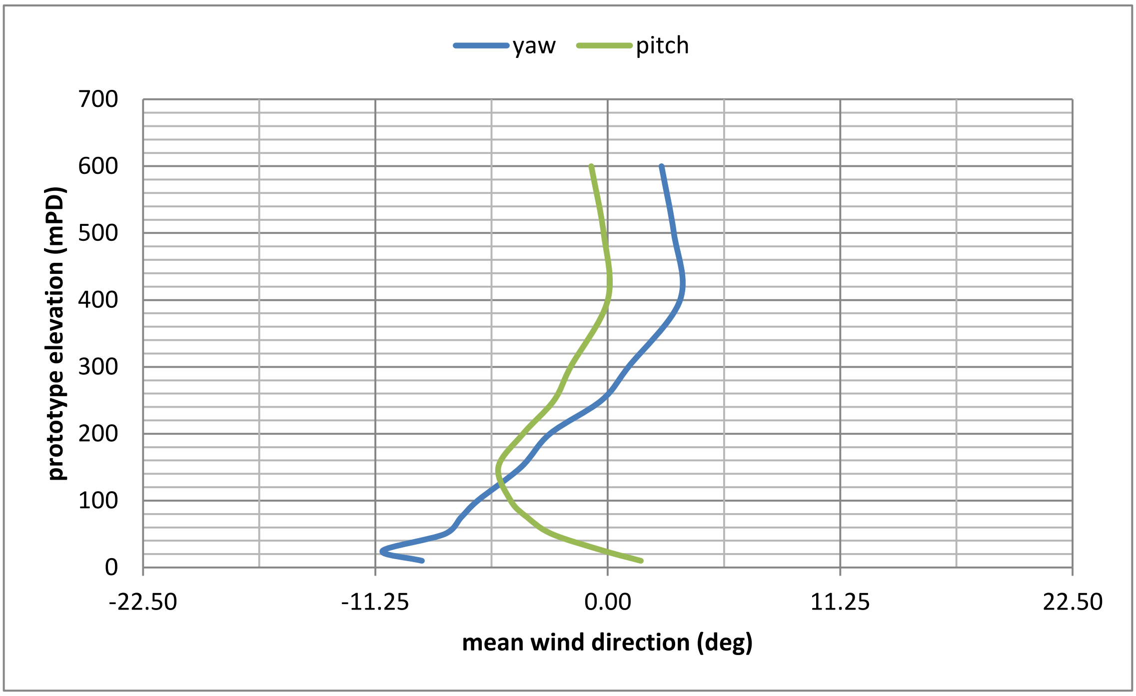

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Figure 26: Measured wind characteristics at an approach wind direction of 337.5°

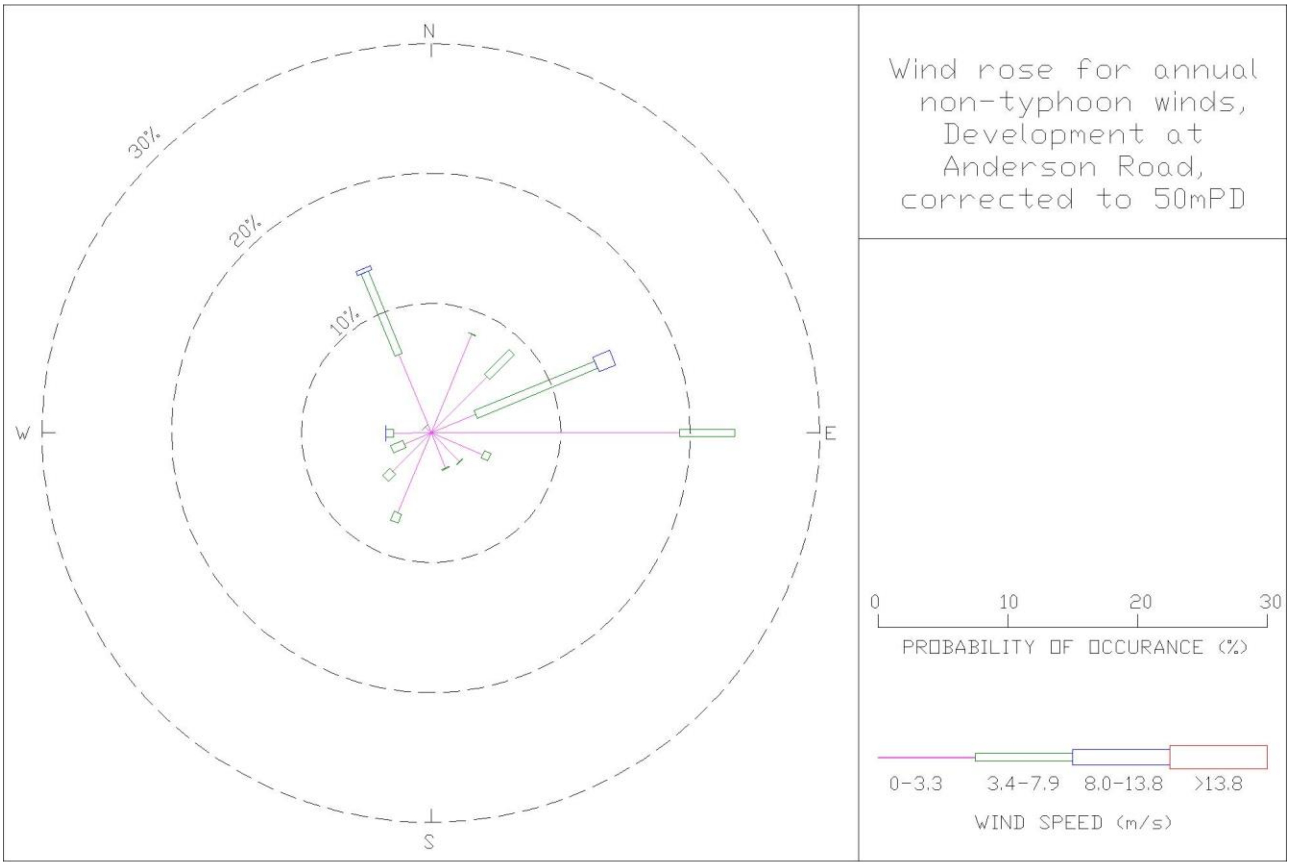

Figure 27: Windrose for annual, non-typhoon winds for Development at Anderson Road, corrected to 50 mPD

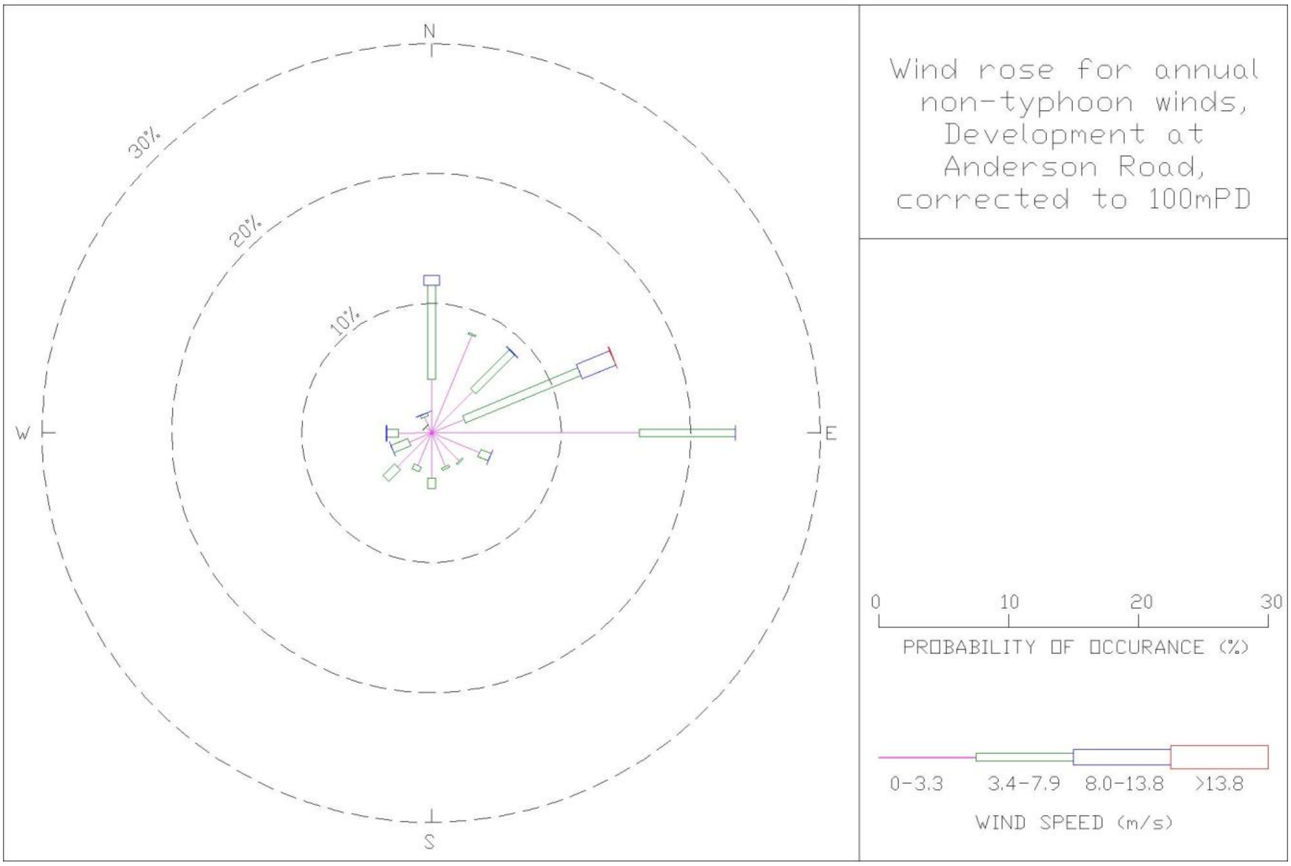

Figure 28: Windrose for annual, non-typhoon winds for Development at Anderson Road, corrected to 100 mPD

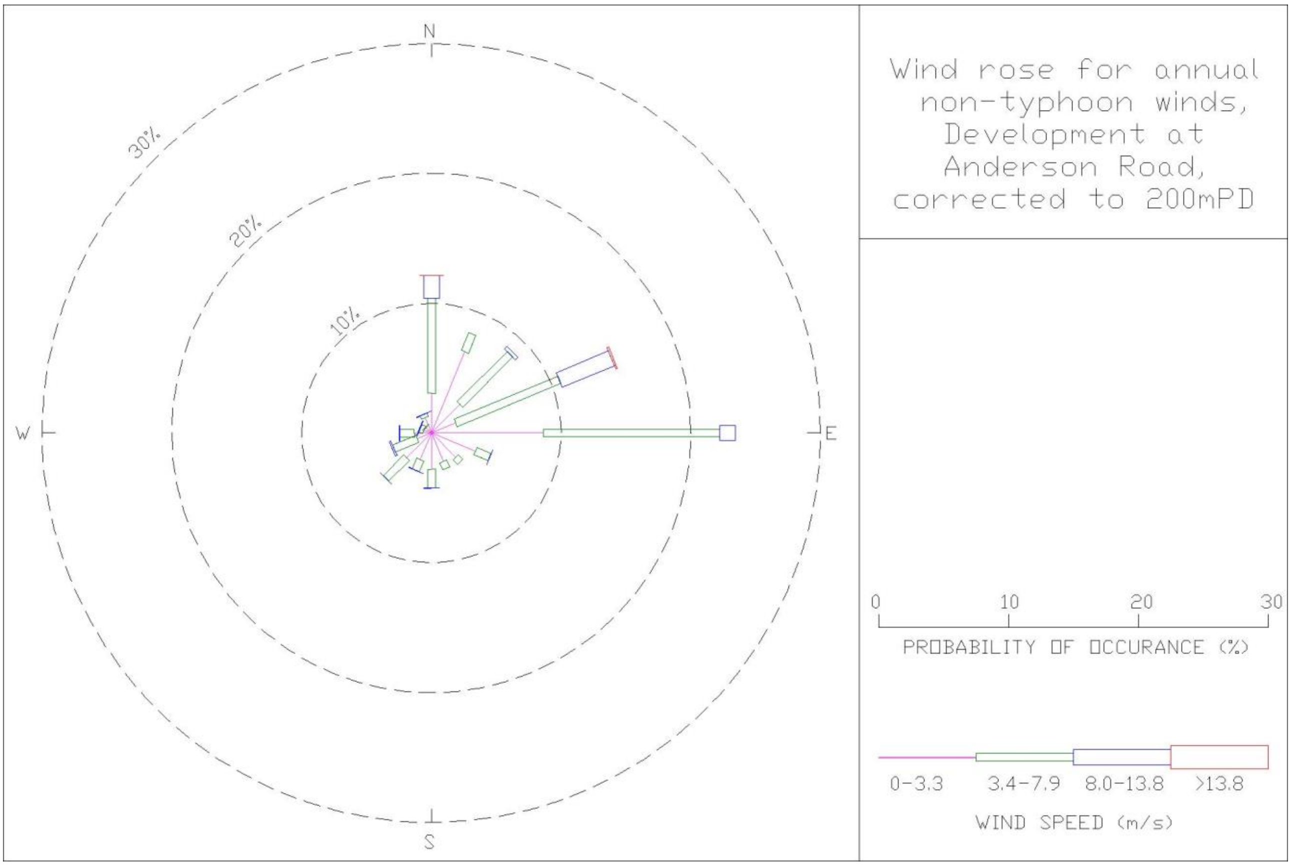

Figure 29: Windrose for annual, non-typhoon winds for Development at Anderson Road, corrected to 200 mPD

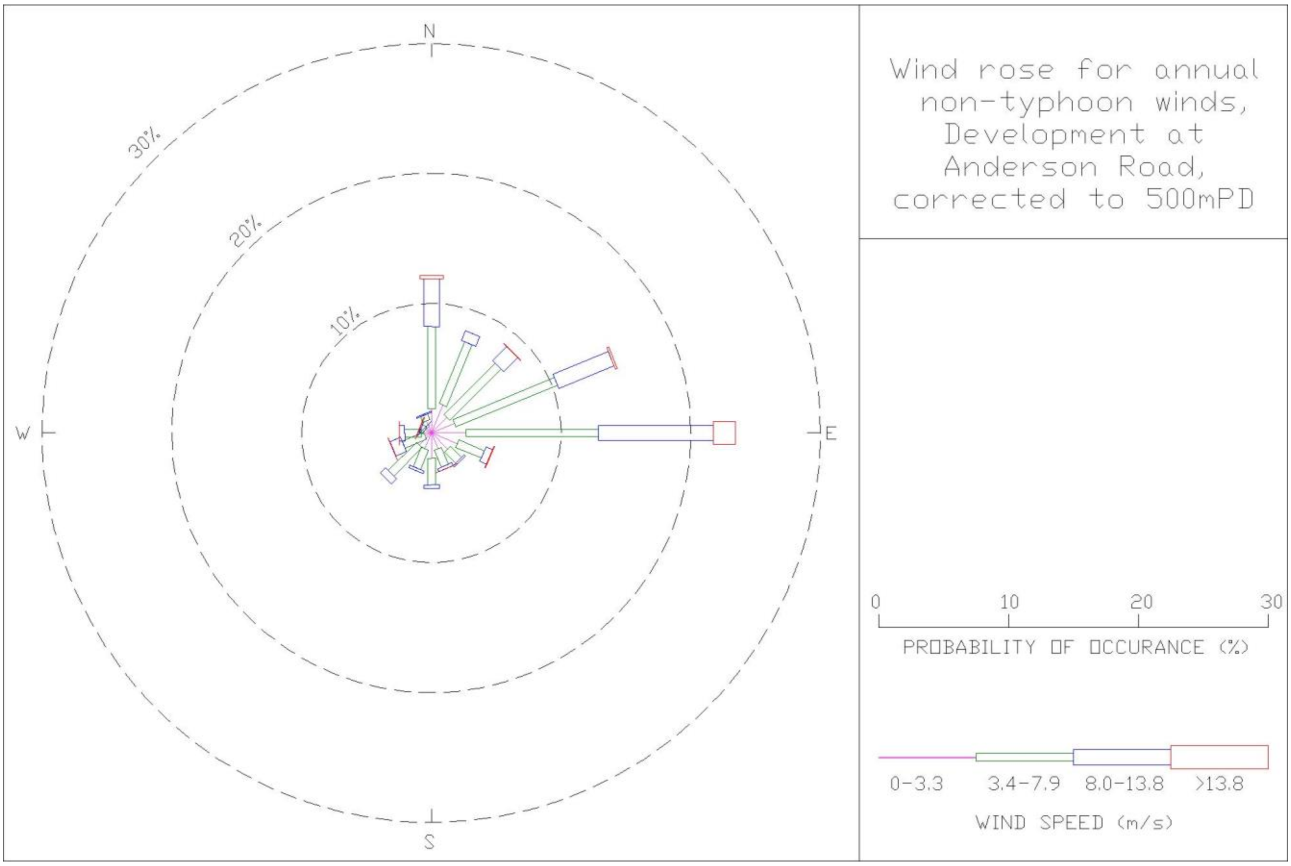

Figure 30: Windrose for annual, non-typhoon winds for Development at Anderson Road, corrected to 500 mPD

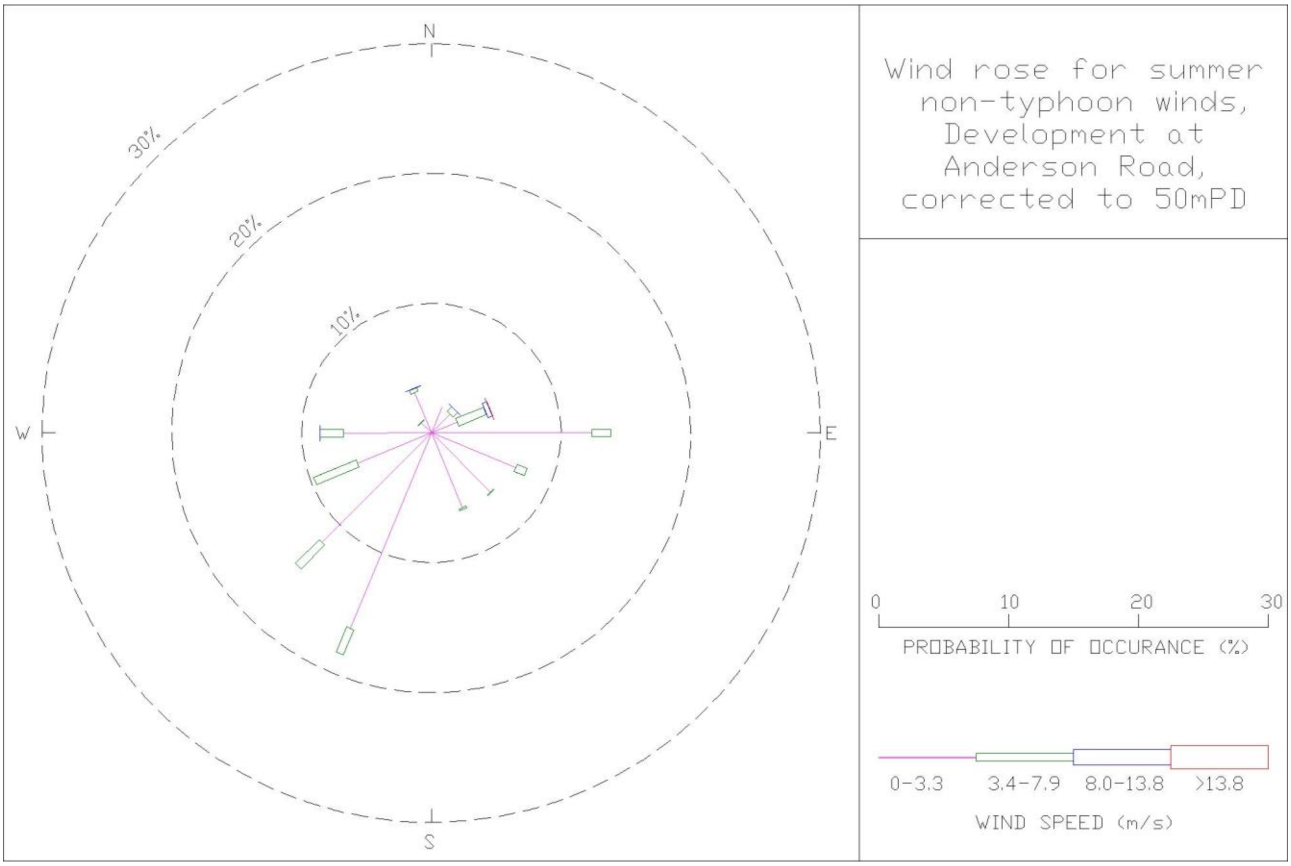

Figure 31: Windrose for summer, non-typhoon winds for Development at Anderson Road, corrected to 50 mPD

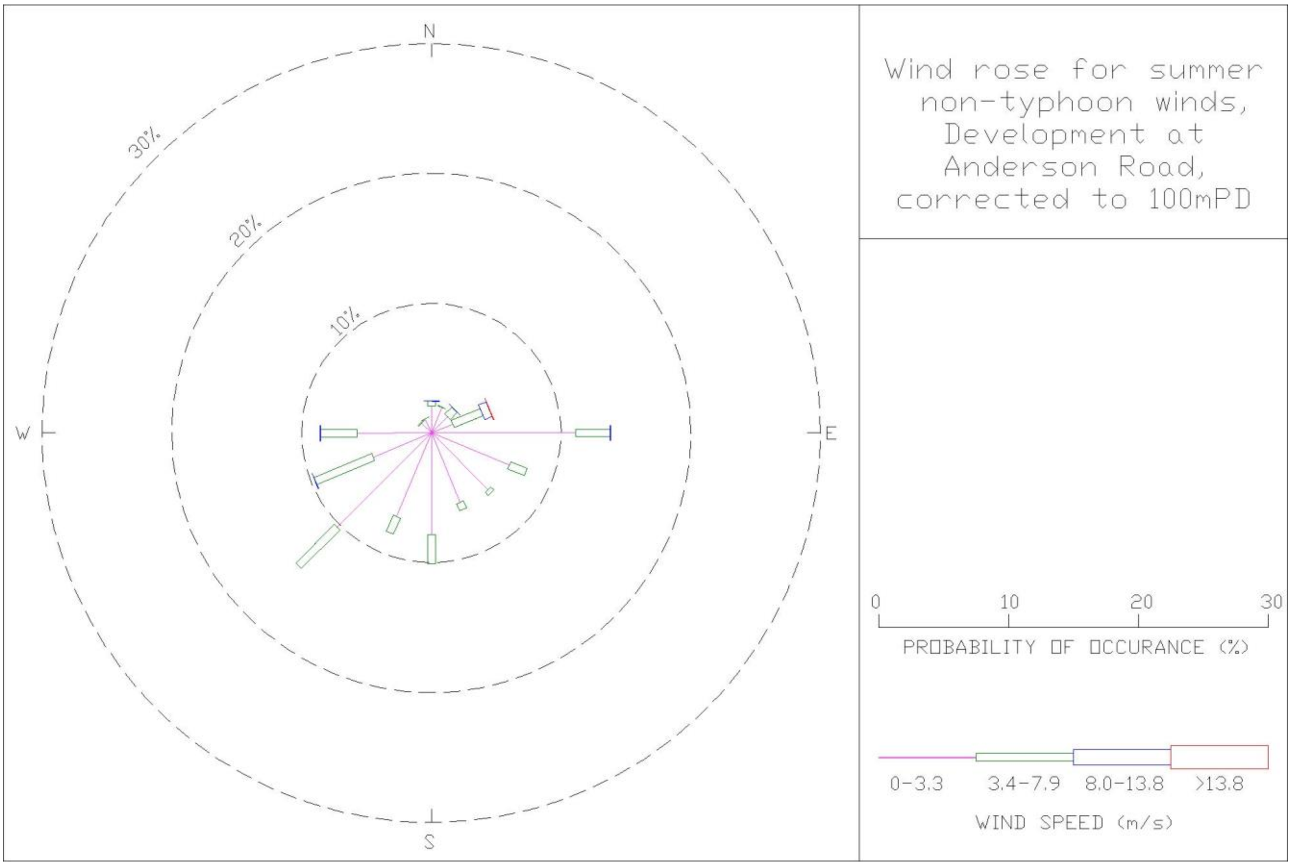

Figure 32: Windrose for summer, non-typhoon winds for Development at Anderson Road, corrected to 100 mPD

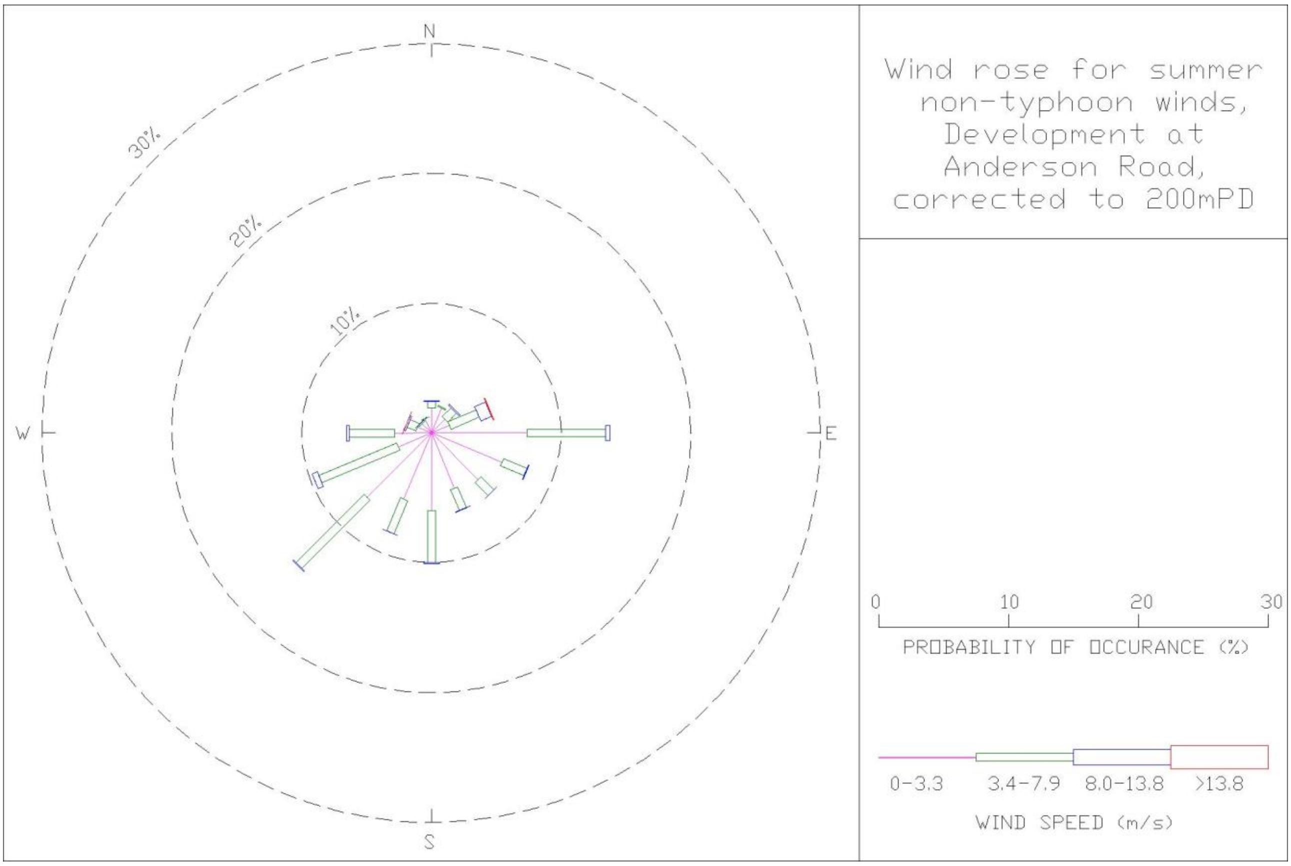

Figure 33: Windrose for summer, non-typhoon winds for Development at Anderson Road, corrected to 200 mPD

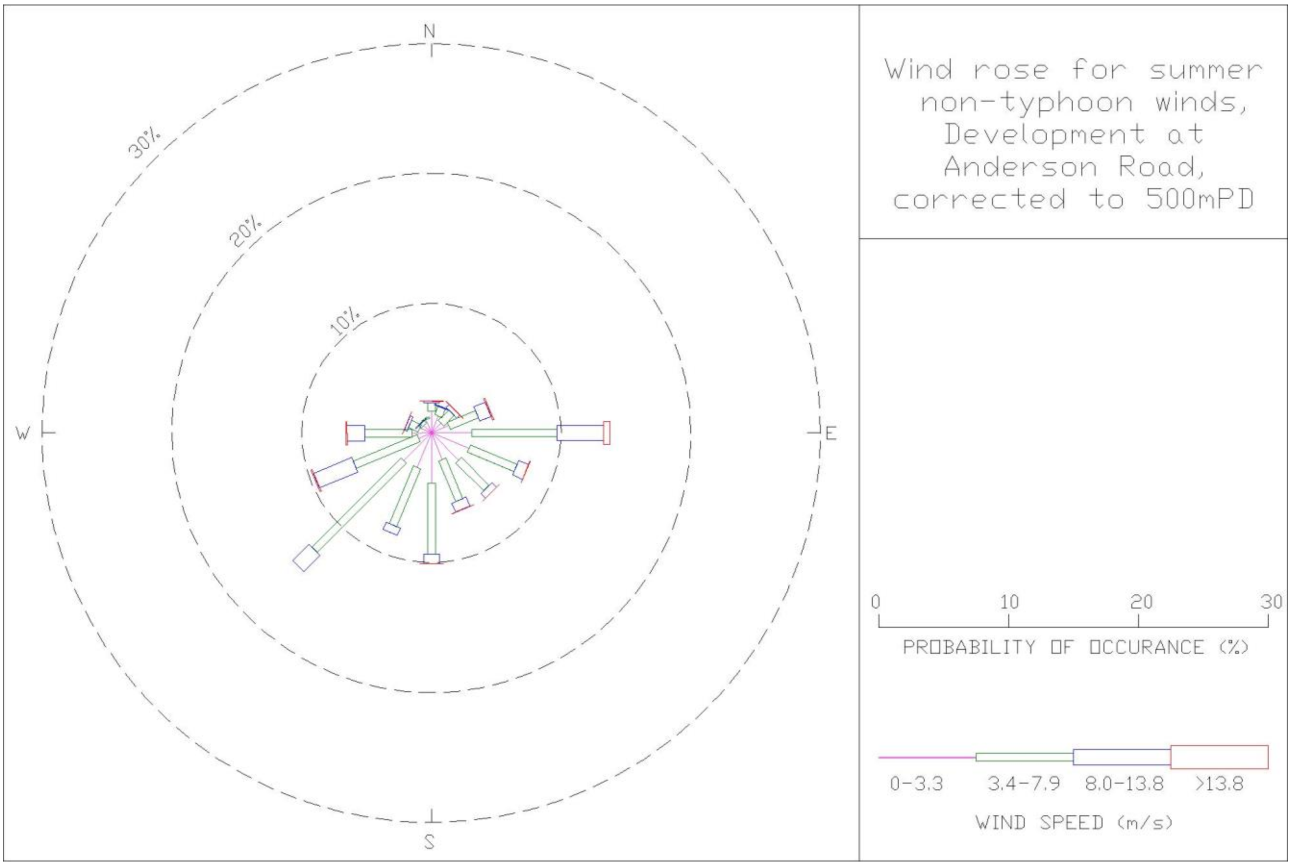

Figure 34: Windrose for summer, non-typhoon winds for Development at Anderson Road, corrected to 500 mPD

APPENDIX A – TABULATED RESULTS

Table A 1: Site wind characteristics of Development at Anderson Road at 0°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.37	32.8%	-6.7	13.8
25	0.41	31.1%	-8.3	14.7
50	0.45	30.1%	-11.2	13.5
75	0.49	28.9%	-12.5	11.1
100	0.51	27.9%	-13.6	8.3
150	0.57	25.9%	-13.2	2.7
200	0.61	23.4%	-12.4	-1.7
250	0.63	21.9%	-10.3	-3.7
300	0.67	19.2%	-8.6	-5.0
400	0.73	16.0%	-5.6	-5.4
500	0.78	14.6%	-4.4	-4.8
600	0.81	13.7%	-3.3	-4.4

Table A 2: Site wind characteristics of Development at Anderson Road at 22.5°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.20	35.1%	0.7	-5.0
25	0.21	36.7%	-0.2	-3.9
50	0.22	37.5%	-0.8	-3.6
75	0.23	39.3%	-1.8	-2.1
100	0.25	40.7%	-2.5	-1.4
150	0.30	42.0%	-4.9	-0.4
200	0.37	39.2%	-5.9	-0.9
250	0.46	34.4%	-5.8	-0.7
300	0.57	28.2%	-4.5	-0.9
400	0.71	18.6%	-2.5	-0.2
500	0.77	14.6%	-1.6	0.0
600	0.81	13.8%	-1.6	0.3

Table A 3: Site wind characteristics of Development at Anderson Road at 45°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.34	31.3%	-3.2	6.6
25	0.37	30.8%	-5.0	7.1
50	0.41	30.1%	-7.9	5.5
75	0.45	28.4%	-9.6	4.9
100	0.50	26.4%	-10.1	2.5
150	0.57	22.8%	-9.7	1.2
200	0.61	19.5%	-8.3	1.8
250	0.66	17.2%	-7.1	2.6
300	0.70	15.4%	-6.1	3.0
400	0.76	13.0%	-4.2	2.7
500	0.83	10.8%	-3.1	1.8
600	0.86	10.0%	-2.1	1.2

Table A 4: Site wind characteristics of Development at Anderson Road at 67.5°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.42	30.6%	-2.5	8.5
25	0.47	29.0%	-5.1	9.4
50	0.54	27.1%	-8.3	8.4
75	0.58	25.7%	-10.4	6.5
100	0.62	24.3%	-12.2	4.5
150	0.67	22.8%	-13.3	0.8
200	0.71	22.1%	-13.4	-0.2
250	0.72	21.6%	-12.4	0.2
300	0.72	21.2%	-11.3	1.7
400	0.71	20.4%	-7.3	5.0
500	0.72	19.0%	-4.4	7.0
600	0.77	17.7%	-2.2	6.3

Table A 5: Site wind characteristics of Development at Anderson Road at 90°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.20	37.1%	2.5	-5.6
25	0.22	40.1%	1.6	-3.6
50	0.24	40.3%	1.4	-4.4
75	0.26	41.2%	0.3	-2.7
100	0.29	42.4%	-0.5	1.2
150	0.36	39.8%	-3.2	7.3
200	0.44	35.8%	-5.6	9.5
250	0.52	30.0%	-6.0	9.3
300	0.60	25.8%	-5.7	7.1
400	0.73	17.6%	-4.1	5.7
500	0.81	12.8%	-2.6	5.3
600	0.87	10.4%	-1.6	4.6

Table A 6: Site wind characteristics of Development at Anderson Road at 112.5°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.24	33.4%	-0.5	-11.5
25	0.27	33.8%	-3.0	-12.0
50	0.29	34.1%	-4.5	-10.9
75	0.32	34.0%	-6.9	-9.9
100	0.34	33.9%	-7.5	-8.2
150	0.37	33.2%	-6.6	-5.9
200	0.39	33.0%	-5.5	-2.9
250	0.40	33.1%	-5.1	0.8
300	0.45	31.5%	-5.0	3.4
400	0.59	24.5%	-3.7	5.5
500	0.70	17.8%	-1.8	5.3
600	0.78	13.7%	-0.8	4.4

Table A 7: Site wind characteristics of Development at Anderson Road at 135°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.17	32.3%	0.6	-2.4
25	0.18	34.4%	-1.8	-2.5
50	0.21	37.2%	-4.8	-2.8
75	0.23	38.4%	-6.7	-2.2
100	0.26	38.4%	-8.4	-2.3
150	0.32	36.7%	-8.6	-2.2
200	0.40	31.6%	-7.2	0.3
250	0.45	28.8%	-4.3	1.1
300	0.51	25.1%	-2.3	2.5
400	0.61	20.3%	-0.4	2.0
500	0.70	16.5%	-0.1	1.4
600	0.81	12.7%	0.4	1.3

Table A 8: Site wind characteristics of Development at Anderson Road at 157.5°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.22	30.0%	1.1	-1.8
25	0.24	31.6%	-0.5	-2.3
50	0.26	32.5%	-1.6	-2.4
75	0.29	32.6%	-3.1	-2.5
100	0.33	32.6%	-3.3	-2.4
150	0.38	31.1%	-3.1	-2.0
200	0.46	27.8%	-2.4	-0.4
250	0.53	24.2%	-1.9	0.0
300	0.61	20.8%	-1.5	0.0
400	0.75	14.3%	-0.7	0.4
500	0.84	10.3%	0.0	0.7
600	0.88	8.2%	0.5	0.9

Table A 9: Site wind characteristics of Development at Anderson Road at 180°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.29	29.2%	1.2	-16.1
25	0.31	30.1%	0.1	-14.7
50	0.34	29.4%	-1.6	-13.0
75	0.37	29.4%	-2.1	-10.4
100	0.39	28.8%	-2.6	-8.1
150	0.45	26.8%	-2.0	-6.0
200	0.52	23.9%	-1.6	-4.0
250	0.55	22.7%	-0.4	-1.9
300	0.60	20.1%	-0.5	-1.3
400	0.66	17.6%	0.1	0.2
500	0.71	16.2%	0.7	1.7
600	0.78	14.5%	0.8	1.9

Table A 10: Site wind characteristics of Development at Anderson Road at 202.5°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.25	23.8%	3.0	-0.5
25	0.27	24.8%	2.0	-2.0
50	0.29	26.4%	2.1	-2.6
75	0.31	27.4%	1.2	-2.4
100	0.33	26.9%	0.8	-1.7
150	0.37	26.7%	1.1	-1.2
200	0.43	25.4%	1.7	-0.2
250	0.48	23.5%	2.8	-0.5
300	0.54	21.3%	3.4	-0.7
400	0.61	17.8%	4.0	-0.7
500	0.67	16.4%	4.5	-1.3
600	0.73	15.4%	4.2	-1.3

Table A 11: Site wind characteristics of Development at Anderson Road at 225°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.27	29.9%	-2.0	-8.8
25	0.31	29.8%	-1.5	-8.8
50	0.32	30.8%	-0.8	-8.6
75	0.35	30.3%	-1.0	-8.5
100	0.37	30.2%	-1.2	-7.5
150	0.41	29.0%	0.7	-5.7
200	0.47	27.3%	1.4	-4.9
250	0.51	25.4%	2.3	-3.7
300	0.57	23.0%	3.0	-3.4
400	0.65	19.6%	3.9	-2.7
500	0.72	17.3%	3.5	-2.7
600	0.76	16.2%	3.6	-2.3

Table A 12: Site wind characteristics of Development at Anderson Road at 247.5°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.31	27.5%	-1.5	12.5
25	0.35	26.5%	-1.4	12.0
50	0.37	27.0%	-1.2	9.6
75	0.40	26.9%	-1.5	7.8
100	0.43	26.5%	-1.3	6.3
150	0.51	24.5%	-0.7	4.1
200	0.57	21.2%	-0.1	2.6
250	0.66	17.9%	-0.1	2.2
300	0.71	15.4%	0.3	1.5
400	0.80	12.5%	0.3	0.7
500	0.87	10.6%	0.6	0.0
600	0.93	8.7%	0.8	-0.3

Table A 13: Site wind characteristics of Development at Anderson Road at 270°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.28	31.1%	-0.5	7.0
25	0.32	30.4%	-1.6	7.5
50	0.36	30.2%	-2.3	8.9
75	0.39	29.8%	-2.7	9.1
100	0.43	28.6%	-2.6	9.3
150	0.51	25.2%	-2.5	8.2
200	0.60	21.2%	-2.0	6.3
250	0.67	17.8%	-1.3	4.9
300	0.73	14.9%	-1.0	3.9
400	0.81	11.6%	-0.2	2.7
500	0.89	9.3%	0.3	2.0
600	0.93	7.3%	0.6	1.7

Table A 14: Site wind characteristics of Development at Anderson Road at 292.5°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.38	28.5%	-1.2	19.8
25	0.43	27.3%	-3.0	21.6
50	0.48	26.3%	-4.9	20.4
75	0.52	25.0%	-5.7	19.1
100	0.56	24.1%	-6.4	16.9
150	0.63	20.8%	-6.4	13.0
200	0.70	17.3%	-5.8	10.6
250	0.74	15.1%	-5.0	9.0
300	0.78	12.8%	-4.5	7.8
400	0.80	12.5%	-3.5	6.0
500	0.83	12.4%	-2.7	4.1
600	0.85	12.3%	-2.5	2.8

Table A 15: Site wind characteristics of Development at Anderson Road at 315°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.23	30.4%	4.9	-3.0
25	0.24	31.7%	3.5	-4.7
50	0.25	33.0%	1.4	-5.1
75	0.28	34.6%	-0.6	-4.9
100	0.32	35.0%	-2.5	-2.1
150	0.38	32.9%	-4.4	1.5
200	0.44	30.5%	-3.5	3.9
250	0.49	27.4%	-2.5	5.3
300	0.55	24.2%	-1.9	5.4
400	0.62	19.7%	-0.8	4.8
500	0.67	17.9%	-0.4	3.7
600	0.71	16.5%	-0.2	2.7

Table A 16: Site wind characteristics of Development at Anderson Road at 337.5°

Prototype scale height (m)	Normalise mean wind speed	Turbulence intensity (%)	Pitch angle (°)	Yaw angle (°)
10	0.25	30.0%	1.6	-9.0
25	0.26	30.3%	-0.2	-10.9
50	0.28	30.7%	-2.7	-7.9
75	0.28	31.6%	-3.9	-7.1
100	0.31	31.4%	-4.7	-6.3
150	0.33	31.8%	-5.3	-4.2
200	0.34	31.7%	-4.1	-2.8
250	0.37	31.3%	-2.6	-0.3
300	0.39	31.2%	-1.8	1.0
400	0.44	30.7%	0.0	3.5
500	0.51	29.2%	-0.2	3.2
600	0.62	25.3%	-0.8	2.6

APPENDIX B – TABULATED WINDROSE AND MEDIAN MEAN WIND SPEED DATA

Table B 1: Percentage occurrence for annual, non-typhoon directional winds at 500 mPD above Waglan Island

Wind Angle	Percentage occurrence for wind speed ranges:				
	0 < u ≤ 3.3 m/s	3.3 < u ≤ 7.9 m/s	7.9 < u ≤ 13.8 m/s	u > 13.8 m/s	Total
0°	1.5%	4.1%	5.2%	1.3%	12.1%
22.5°	1.3%	4.7%	2.0%	0.2%	8.3%
45°	1.2%	4.6%	2.9%	0.1%	8.8%
67.5°	1.2%	4.8%	7.4%	1.8%	15.2%
90°	2.2%	7.1%	9.7%	4.4%	23.4%
112.5°	1.4%	2.0%	1.2%	0.3%	4.9%
135°	1.2%	1.4%	0.5%	0.1%	3.1%
157.5°	1.0%	1.5%	0.4%	0.0%	3.0%
180°	1.2%	2.2%	0.8%	0.1%	4.3%
202.5°	0.8%	1.5%	0.8%	0.1%	3.1%
225°	0.7%	2.5%	1.6%	0.1%	4.9%
247.5°	0.5%	1.4%	1.2%	0.1%	3.3%
270°	0.7%	1.2%	0.6%	0.1%	2.5%
292.5°	0.5%	0.4%	0.1%	0.0%	1.0%
315°	0.4%	0.2%	0.1%	0.0%	0.6%
337.5°	0.6%	0.5%	0.4%	0.1%	1.6%

Table B 2: Percentage occurrence for summer, non-typhoon directional winds at 500 mPD above Waglan Island

Wind Angle	Percentage occurrence for wind speed ranges:				
	0 < u ≤ 3.3 m/s	3.3 < u ≤ 7.9 m/s	7.9 < u ≤ 13.8 m/s	u > 13.8 m/s	Total
0°	1.4%	0.8%	0.2%	0.0%	2.5%
22.5°	1.1%	0.9%	0.1%	0.0%	2.2%
45°	0.8%	1.2%	0.5%	0.1%	2.5%
67.5°	1.0%	1.8%	1.7%	0.4%	4.8%
90°	2.4%	5.4%	4.6%	1.4%	13.8%
112.5°	2.0%	3.4%	2.2%	0.3%	7.9%
135°	1.9%	3.0%	1.5%	0.2%	6.5%
157.5°	1.7%	3.4%	1.1%	0.1%	6.4%
180°	2.2%	5.3%	2.3%	0.2%	10.1%
202.5°	1.5%	4.2%	2.5%	0.2%	8.3%
225°	1.4%	7.2%	5.3%	0.5%	14.5%
247.5°	1.0%	4.2%	4.2%	0.4%	9.7%
270°	1.3%	3.1%	1.9%	0.2%	6.6%
292.5°	0.8%	0.8%	0.4%	0.1%	2.0%
315°	0.7%	0.3%	0.1%	0.0%	1.1%
337.5°	0.9%	0.3%	0.0%	0.0%	1.2%

Table B 3: Percentage occurrence for annual, non-typhoon directional winds at 50 mPD above the Study Site

Wind Angle	**Percentage occurrence for wind speed ranges:**				
	0 < u ≤ 3.3 m/s	3.3 < u ≤ 7.9 m/s	7.9 < u ≤ 13.8 m/s	u > 13.8 m/s	Total
0°	0.0%	0.0%	0.0%	0.0%	0.0%
22.5°	8.2%	0.0%	0.0%	0.0%	8.3%
45°	6.1%	2.7%	0.0%	0.0%	8.8%
67.5°	3.7%	10.0%	1.4%	0.0%	15.1%
90°	19.2%	4.3%	0.0%	0.0%	23.4%
112.5°	4.3%	0.6%	0.0%	0.0%	4.9%
135°	3.1%	0.0%	0.0%	0.0%	3.1%
157.5°	2.9%	0.0%	0.0%	0.0%	3.0%
180°	0.0%	0.0%	0.0%	0.0%	0.0%
202.5°	6.7%	0.7%	0.0%	0.0%	7.4%
225°	4.2%	0.8%	0.0%	0.0%	4.9%
247.5°	2.2%	1.0%	0.0%	0.0%	3.2%
270°	2.9%	0.6%	0.0%	0.0%	3.5%
292.5°	0.0%	0.0%	0.0%	0.0%	0.0%
315°	0.6%	0.0%	0.0%	0.0%	0.6%
337.5°	6.5%	6.8%	0.3%	0.0%	13.7%

Table B 4: Percentage occurrence for annual, non-typhoon directional winds at 100 mPD above the Study Site

Wind Angle	Percentage occurrence for wind speed ranges:				
	0 < u ≤ 3.3 m/s	3.3 < u ≤ 7.9 m/s	7.9 < u ≤ 13.8 m/s	u > 13.8 m/s	Total
0°	4.1%	7.2%	0.8%	0.0%	12.1%
22.5°	8.1%	0.1%	0.0%	0.0%	8.3%
45°	4.6%	4.2%	0.0%	0.0%	8.8%
67.5°	2.7%	9.6%	2.8%	0.0%	15.1%
90°	16.0%	7.4%	0.0%	0.0%	23.4%
112.5°	4.0%	0.8%	0.0%	0.0%	4.9%
135°	3.0%	0.1%	0.0%	0.0%	3.1%
157.5°	2.8%	0.2%	0.0%	0.0%	3.0%
180°	3.5%	0.8%	0.0%	0.0%	4.3%
202.5°	2.7%	0.4%	0.0%	0.0%	3.1%
225°	3.7%	1.3%	0.0%	0.0%	4.9%
247.5°	1.8%	1.4%	0.0%	0.0%	3.2%
270°	2.5%	0.9%	0.0%	0.0%	3.5%
292.5°	0.0%	0.0%	0.0%	0.0%	0.0%
315°	0.6%	0.0%	0.0%	0.0%	0.6%
337.5°	1.3%	0.2%	0.0%	0.0%	1.5%

Table B 5: Percentage occurrence for annual, non-typhoon directional winds at 200 mPD above the Study Site

Wind Angle	Percentage occurrence for wind speed ranges:				
	0 < u ≤ 3.3 m/s	3.3 < u ≤ 7.9 m/s	7.9 < u ≤ 13.8 m/s	u > 13.8 m/s	Total
0°	3.0%	7.3%	1.7%	0.0%	12.1%
22.5°	6.8%	1.5%	0.0%	0.0%	8.3%
45°	3.1%	5.5%	0.2%	0.0%	8.8%
67.5°	2.0%	8.7%	4.3%	0.1%	15.1%
90°	8.6%	13.6%	1.2%	0.0%	23.4%
112.5°	3.7%	1.2%	0.0%	0.0%	4.9%
135°	2.6%	0.5%	0.0%	0.0%	3.1%
157.5°	2.4%	0.6%	0.0%	0.0%	3.0%
180°	2.8%	1.4%	0.0%	0.0%	4.3%
202.5°	2.2%	0.9%	0.0%	0.0%	3.1%
225°	2.7%	2.2%	0.0%	0.0%	4.9%
247.5°	1.2%	1.9%	0.1%	0.0%	3.2%
270°	1.3%	1.1%	0.1%	0.0%	2.5%
292.5°	0.6%	0.3%	0.0%	0.0%	1.0%
315°	0.6%	0.1%	0.0%	0.0%	0.6%
337.5°	1.3%	0.3%	0.0%	0.0%	1.5%

Table B 6: Percentage occurrence for annual, non-typhoon directional winds at 500 mPD above the Study Site

Wind Angle	Percentage occurrence for wind speed ranges:				
	0 < u ≤ 3.3 m/s	3.3 < u ≤ 7.9 m/s	7.9 < u ≤ 13.8 m/s	u > 13.8 m/s	Total
0°	1.9%	6.3%	3.7%	0.3%	12.1%
22.5°	2.3%	5.1%	0.8%	0.0%	8.3%
45°	1.7%	5.6%	1.5%	0.0%	8.8%
67.5°	1.9%	8.5%	4.6%	0.2%	15.1%
90°	2.7%	10.2%	8.9%	1.7%	23.4%
112.5°	2.2%	2.1%	0.5%	0.0%	4.9%
135°	1.8%	1.2%	0.2%	0.0%	3.1%
157.5°	1.3%	1.4%	0.2%	0.0%	3.0%
180°	2.0%	2.0%	0.3%	0.0%	4.3%
202.5°	1.3%	1.6%	0.2%	0.0%	3.1%
225°	1.3%	3.1%	0.5%	0.0%	4.9%
247.5°	0.5%	1.8%	0.9%	0.0%	3.2%
270°	0.8%	1.3%	0.4%	0.0%	2.5%
292.5°	0.5%	0.3%	0.1%	0.0%	1.0%
315°	0.5%	0.1%	0.0%	0.0%	0.6%
337.5°	1.0%	0.5%	0.1%	0.0%	1.5%

Table B 7: Percentage occurrence for summer, non-typhoon directional winds at 50 mPD above the Study Site

Wind Angle	Percentage occurrence for wind speed ranges:				
	0 < u ≤ 3.3 m/s	3.3 < u ≤ 7.9 m/s	7.9 < u ≤ 13.8 m/s	u > 13.8 m/s	Total
0°	0.0%	0.0%	0.0%	0.0%	0.0%
22.5°	2.1%	0.0%	0.0%	0.0%	2.2%
45°	2.0%	0.5%	0.0%	0.0%	2.5%
67.5°	2.2%	2.3%	0.4%	0.0%	4.8%
90°	12.4%	1.4%	0.0%	0.0%	13.8%
112.5°	7.0%	0.8%	0.0%	0.0%	7.9%
135°	6.4%	0.1%	0.0%	0.0%	6.5%
157.5°	6.2%	0.1%	0.0%	0.0%	6.4%
180°	0.0%	0.0%	0.0%	0.0%	0.0%
202.5°	16.3%	2.1%	0.0%	0.0%	18.4%
225°	11.9%	2.6%	0.0%	0.0%	14.5%
247.5°	6.1%	3.5%	0.0%	0.0%	9.7%
270°	6.8%	1.8%	0.0%	0.0%	8.6%
292.5°	0.0%	0.0%	0.0%	0.0%	0.0%
315°	1.1%	0.0%	0.0%	0.0%	1.1%
337.5°	3.4%	0.3%	0.0%	0.0%	3.7%

Table B 8: Percentage occurrence for summer, non-typhoon directional winds at 100 mPD above the Study Site

Wind Angle	Percentage occurrence for wind speed ranges:				
	0 < u ≤ 3.3 m/s	3.3 < u ≤ 7.9 m/s	7.9 < u ≤ 13.8 m/s	u > 13.8 m/s	Total
0°	2.1%	0.4%	0.0%	0.0%	2.5%
22.5°	2.1%	0.0%	0.0%	0.0%	2.2%
45°	1.8%	0.7%	0.0%	0.0%	2.5%
67.5°	1.8%	2.4%	0.6%	0.0%	4.8%
90°	11.1%	2.7%	0.0%	0.0%	13.8%
112.5°	6.5%	1.4%	0.0%	0.0%	7.9%
135°	6.2%	0.3%	0.0%	0.0%	6.5%
157.5°	5.8%	0.6%	0.0%	0.0%	6.4%
180°	7.8%	2.2%	0.0%	0.0%	10.1%
202.5°	7.0%	1.3%	0.0%	0.0%	8.3%
225°	10.3%	4.2%	0.0%	0.0%	14.5%
247.5°	4.8%	4.8%	0.0%	0.0%	9.7%
270°	5.7%	2.8%	0.1%	0.0%	8.6%
292.5°	0.0%	0.0%	0.0%	0.0%	0.0%
315°	1.1%	0.1%	0.0%	0.0%	1.1%
337.5°	1.2%	0.0%	0.0%	0.0%	1.2%

Table B 9: Percentage occurrence for summer, non-typhoon directional winds at 200 mPD above the Study Site

Wind Angle	Percentage occurrence for wind speed ranges:				
	0 < u ≤ 3.3 m/s	3.3 < u ≤ 7.9 m/s	7.9 < u ≤ 13.8 m/s	u > 13.8 m/s	Total
0°	1.9%	0.5%	0.0%	0.0%	2.5%
22.5°	2.1%	0.1%	0.0%	0.0%	2.2%
45°	1.5%	1.0%	0.1%	0.0%	2.5%
67.5°	1.5%	2.4%	0.9%	0.1%	4.8%
90°	7.4%	6.0%	0.4%	0.0%	13.8%
112.5°	5.9%	1.9%	0.0%	0.0%	7.9%
135°	5.1%	1.4%	0.0%	0.0%	6.5%
157.5°	4.6%	1.7%	0.0%	0.0%	6.4%
180°	6.0%	4.0%	0.1%	0.0%	10.1%
202.5°	5.5%	2.8%	0.0%	0.0%	8.3%
225°	7.0%	7.4%	0.0%	0.0%	14.5%
247.5°	2.8%	6.5%	0.4%	0.0%	9.7%
270°	2.8%	3.5%	0.2%	0.0%	6.5%
292.5°	1.1%	0.8%	0.1%	0.0%	2.0%
315°	1.0%	0.1%	0.0%	0.0%	1.1%
337.5°	1.2%	0.0%	0.0%	0.0%	1.2%

Table B 10: Percentage occurrence for summer, non-typhoon directional winds at 500 mPD above the Study Site

Wind Angle	Percentage occurrence for wind speed ranges:				
	0 < u ≤ 3.3 m/s	3.3 < u ≤ 7.9 m/s	7.9 < u ≤ 13.8 m/s	u > 13.8 m/s	Total
0°	1.7%	0.7%	0.1%	0.0%	2.5%
22.5°	1.4%	0.7%	0.0%	0.0%	2.2%
45°	1.1%	1.2%	0.3%	0.0%	2.5%
67.5°	1.5%	2.4%	0.9%	0.1%	4.8%
90°	3.1%	6.5%	3.6%	0.5%	13.8%
112.5°	3.1%	3.9%	0.8%	0.0%	7.9%
135°	3.0%	3.0%	0.5%	0.0%	6.5%
157.5°	2.2%	3.4%	0.7%	0.0%	6.4%
180°	3.9%	5.4%	0.8%	0.0%	10.1%
202.5°	2.9%	4.8%	0.6%	0.0%	8.3%
225°	3.0%	9.7%	1.8%	0.0%	14.5%
247.5°	1.1%	5.4%	3.2%	0.1%	9.7%
270°	1.5%	3.6%	1.4%	0.1%	6.5%
292.5°	1.0%	0.8%	0.2%	0.0%	2.0%
315°	0.8%	0.2%	0.0%	0.0%	1.1%
337.5°	1.1%	0.1%	0.0%	0.0%	1.2%