Highways Department
Major Works Project Management Office

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主要工程管理處

# Agreement No. CE 43/2010 (HY)
# Central Kowloon Route
# - Design and Construction

## Air Ventilation Assessment -
## Volume 1: Kai Tak Administration and Ventilation Building

## (Ref: REP-285-02)

September 2016

Arup-Mott MacDonald Joint Venture

Highways Department

# Agreement No. CE 43/2010 (HY) Central Kowloon Route – Design and Construction

## Air Ventilation Assessment - Volume 1: Kai Tak Administration and Ventilation Building

CKR-REP-285-02

Revised Final | September 2016

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Job number 217722

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# Document Verification

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| | | | |
|---|---|---|---|
| **Job title** | Agreement No. CE 43/2010 (HY)<br>Central Kowloon Route – Design and Construction | **Job number** | 217722 |
| **Document title** | Air Ventilation Assessment - Volume 1: Kai Tak Administration and Ventilation Building | **File reference** | 4.3 |
| **Document ref** | CKR-REP-285-02 | | |

| **Revision** | **Date** | **Filename** | CKR-REP-285-00 | | |
|---|---|---|---|---|---|
| Draft 1 | 20/4/16 | **Description** | First draft | | |
| | | | Prepared by | Checked by | Approved by |
| | | Name | Various | Lin-Fat Mak | Eric Chan |
| | | Signature | | | |
| Final | 11/7/16 | **Filename** | CKR-REP-285-01 | | |
| | | **Description** | Final | | |
| | | | Prepared by | Checked by | Approved by |
| | | Name | Various | K S Li | H T Cheng |
| | | Signature | | | |
| Revised Final | 22/9/16 | **Filename** | CKR-REP-285-02 | | |
| | | **Description** | Revised Final | | |
| | | | Prepared by | Checked by | Approved by |
| | | Name | Various | Ken Chan | Eric Chan |
| | | Signature | | [signature] | E Chan |
| | | **Filename** | | | |
| | | **Description** | | | |
| | | | Prepared by | Checked by | Approved by |
| | | Name | | | |
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**Issue Document Verification with Document** ✓

# Contents

# 1 Introduction

This report is in relation to the Detailed Study for the Air Ventilation Assessment Study of the development known as the Central Kowloon Route (CKR) Project, Kowloon, Hong Kong.

A detailed study of air ventilation characteristics for the proposed administration and ventilation buildings located at Kai Tak was carried out. The study was undertaken in accordance with the current best international practice requirements stipulated in “Manuals and Reports on Engineering Practice No. 67 : Wind Tunnel Studies of Buildings and Structures, Virginia 1999 issued by American Society of Civil Engineers”, “Wind Engineering Studies of Buildings, Quality Assurance Manual on Environment Wind Studies AWES-QAM-1-2001 issued by Australasian Wind Engineering Society” and “Hong Kong Environment Transport and Works Bureau, 2006, Technical Circular No. 1/06 for Air Ventilation Assessments”.

The location of the proposed site for this study is provided in Figure 1. The site is located in Kai Tak, at the site of the old Kai Tak Airport to the north of Kowloon Bay. The area is currently undeveloped and quite exposed to winds from all directions, particularly for winds approaching from the South across Kowloon Bay. However, the surrounding areas are subject to redevelopment as a sporting precinct, including a large stadium to the west of the subject development site.

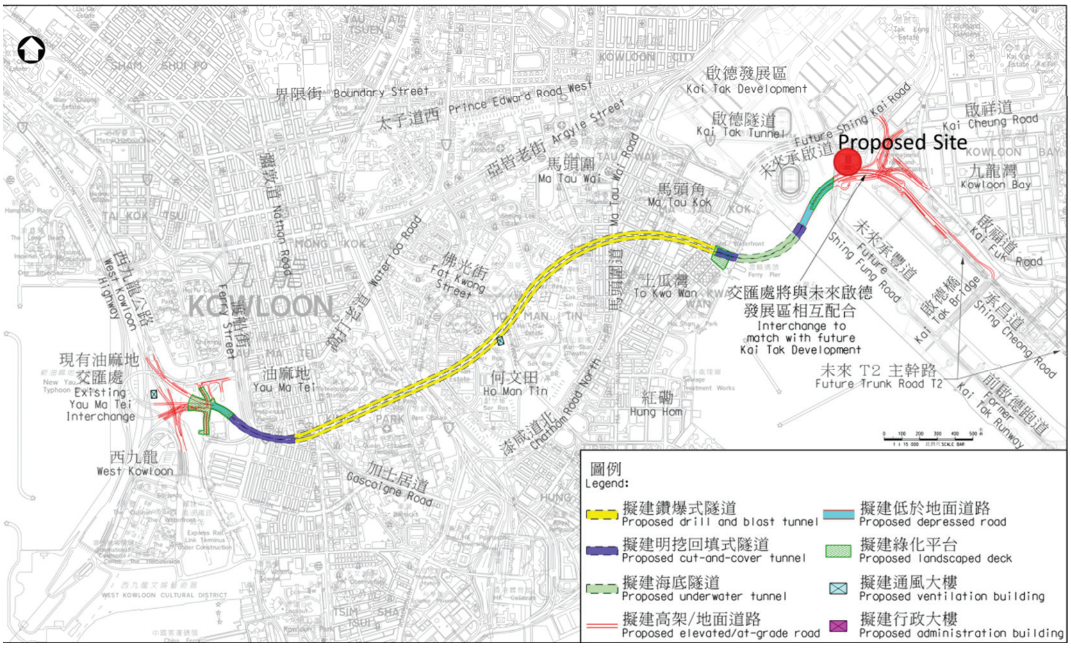


**Figure 1: Proposed Site for the Study**

# 2 The Wind Tunnel Model

Wind tunnel testing was undertaken to obtain accurate wind velocity ratio measurements using a 1:300 scale model. The study model incorporates all necessary features on the development to ensure an accurate wind flow is achieved around the model. A proximity model was also constructed and represents the surrounding buildings and significant topographical effects within a radius of 375m. Testing was performed for two configurations as follows:

- Existing site configuration: Photographs of the wind tunnel model are shown in Figures 2a to 2e.

- Proposed site configuration: With the inclusion of the proposed CKR administration and ventilation buildings. Photographs of the wind tunnel model are shown in Figures 2f to 2k.

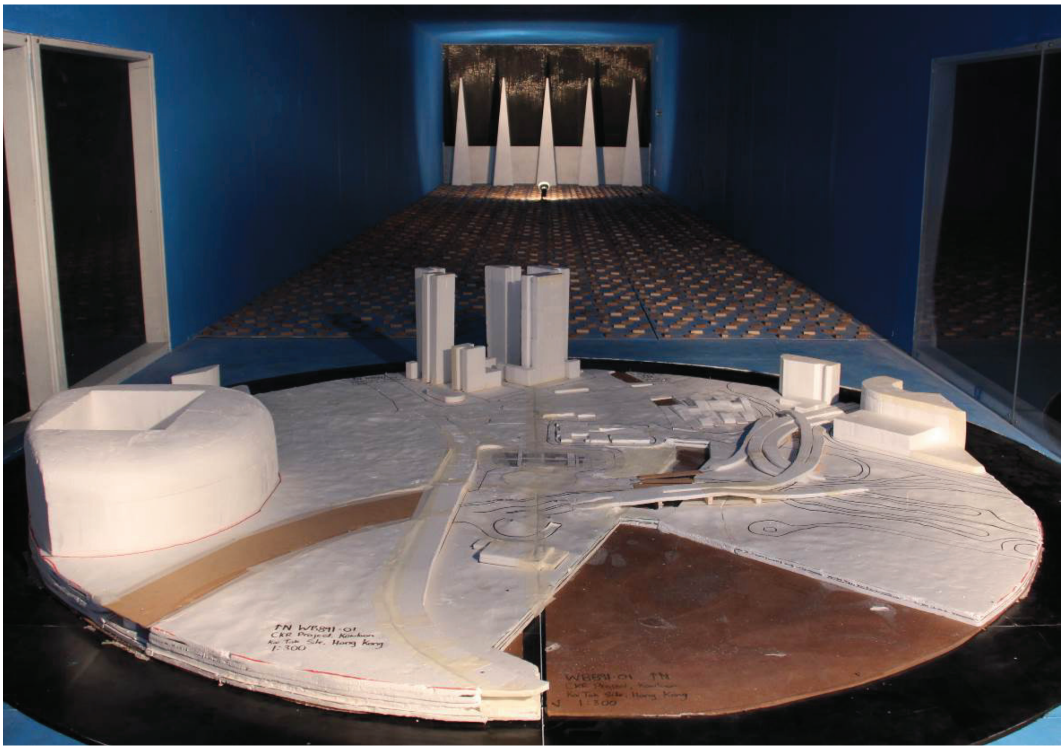

**Figure 2a: Photograph of the Wind Tunnel Model Existing Site Conditions (view from the south)**

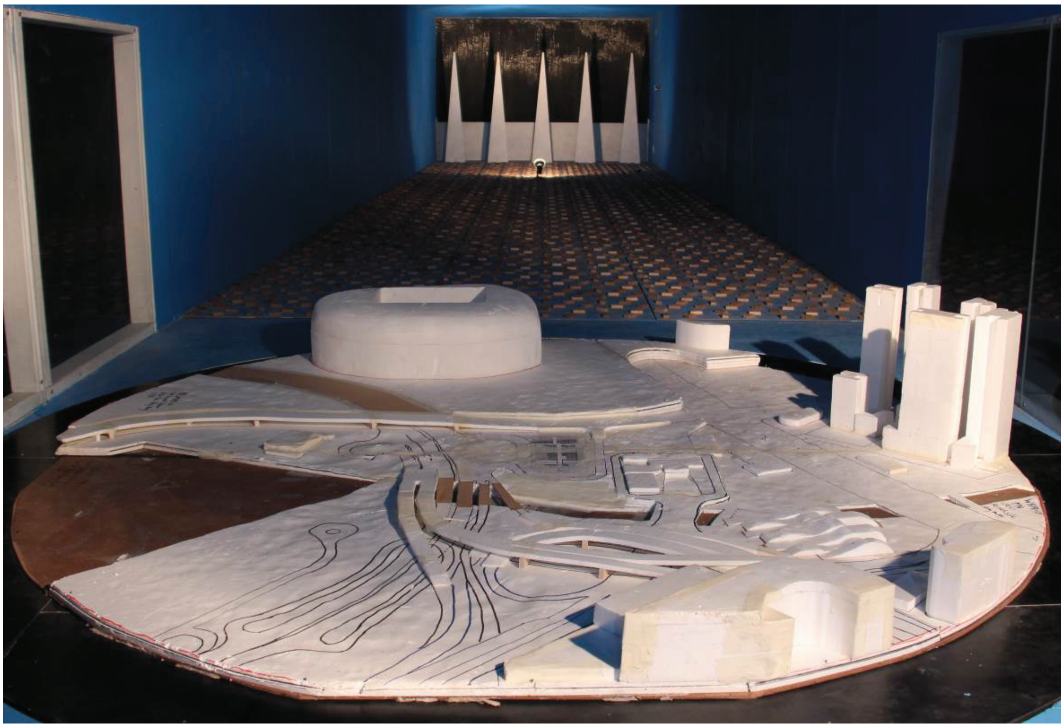

**Figure 2b: Photograph of the Wind Tunnel Model Existing Site Conditions (view from the east)**

**Figure 2c: Photograph of the Wind Tunnel Model Existing Site Conditions (view from the north)**

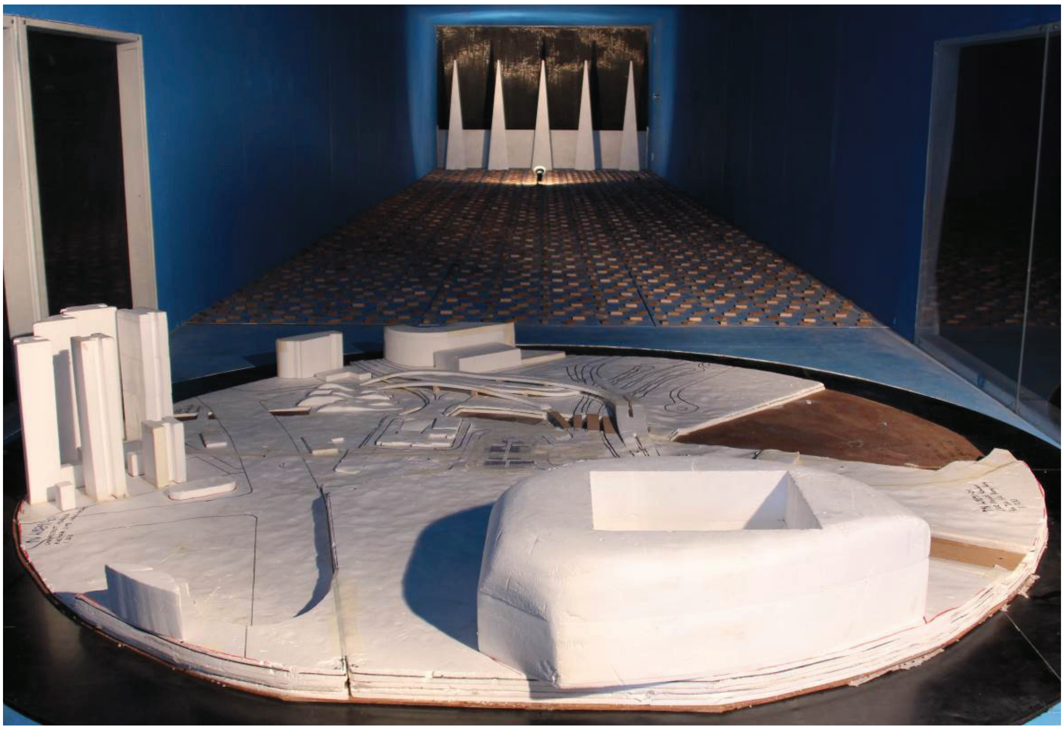

**Figure 2d: Photograph of the Wind Tunnel Model Existing Site Conditions (view from the west)**

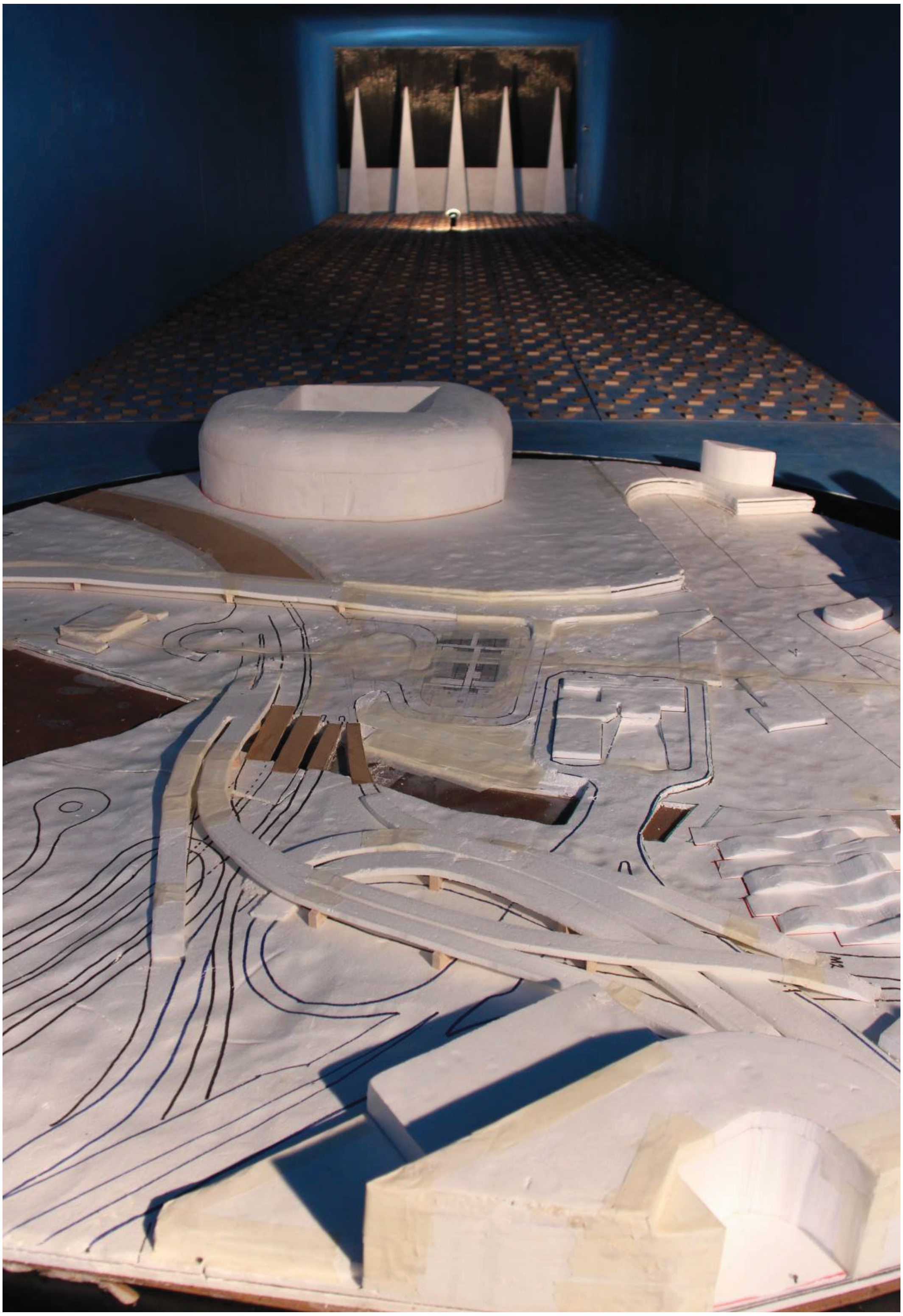

**Figure 2e: Photograph of the Wind Tunnel Model Existing Site Conditions (view from the east)**

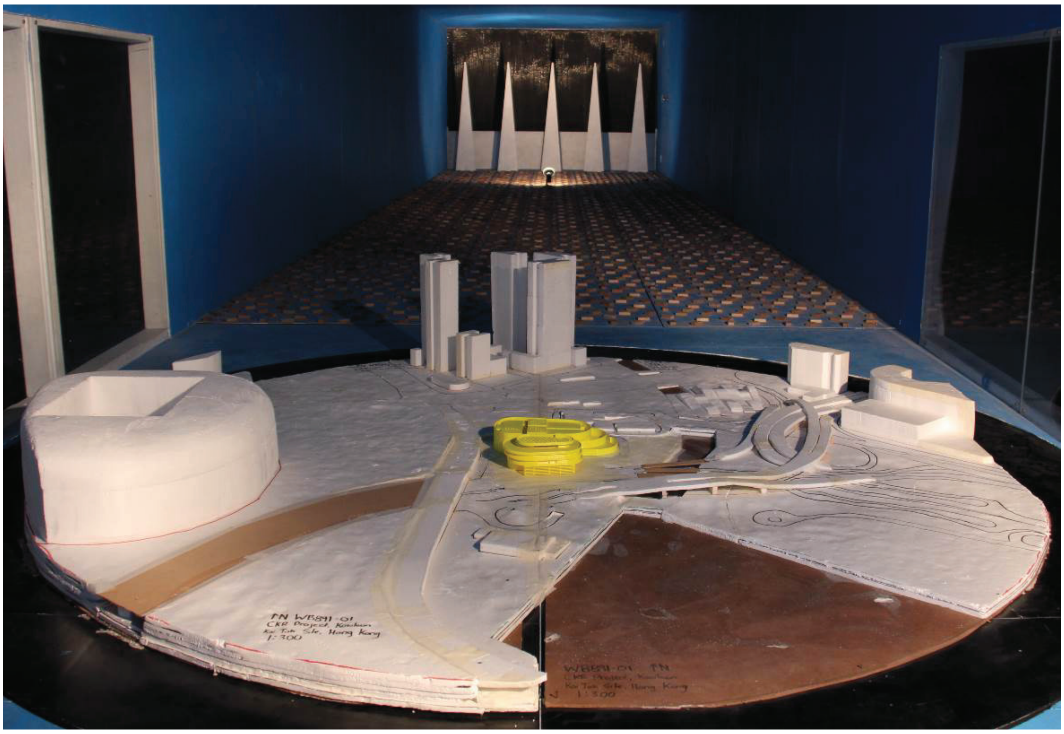

**Figure 2f: Photograph of the Wind Tunnel Model Proposed Development (view from the south)**

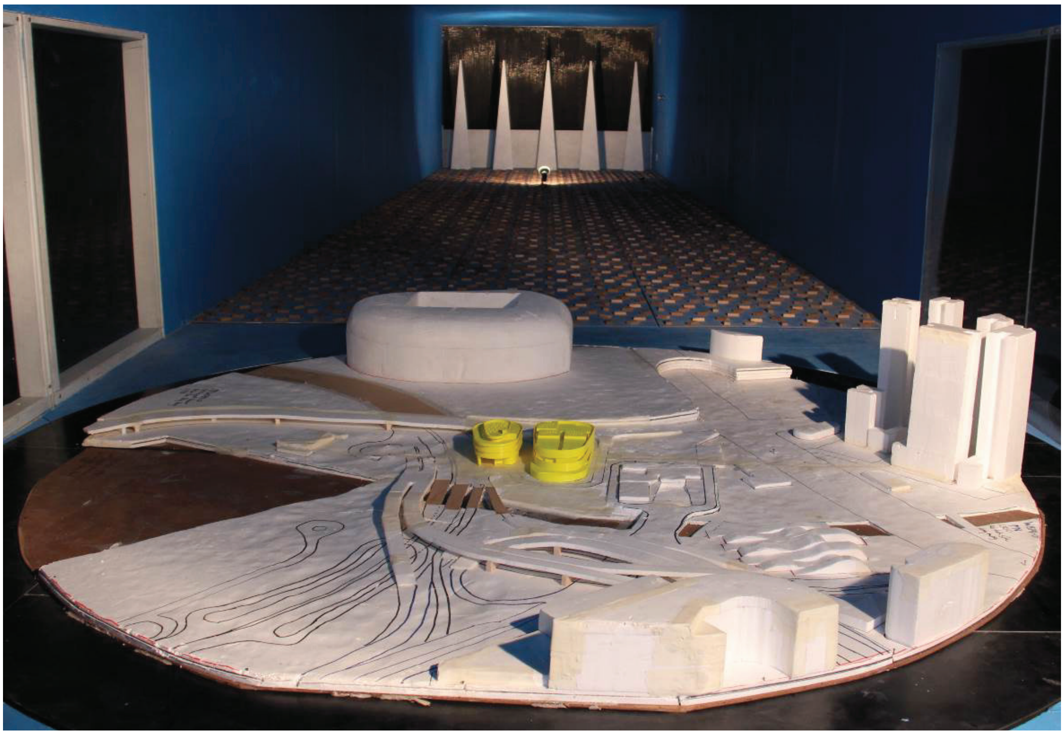

**Figure 2g: Photograph of the Wind Tunnel Model Proposed Development (view from the east)**

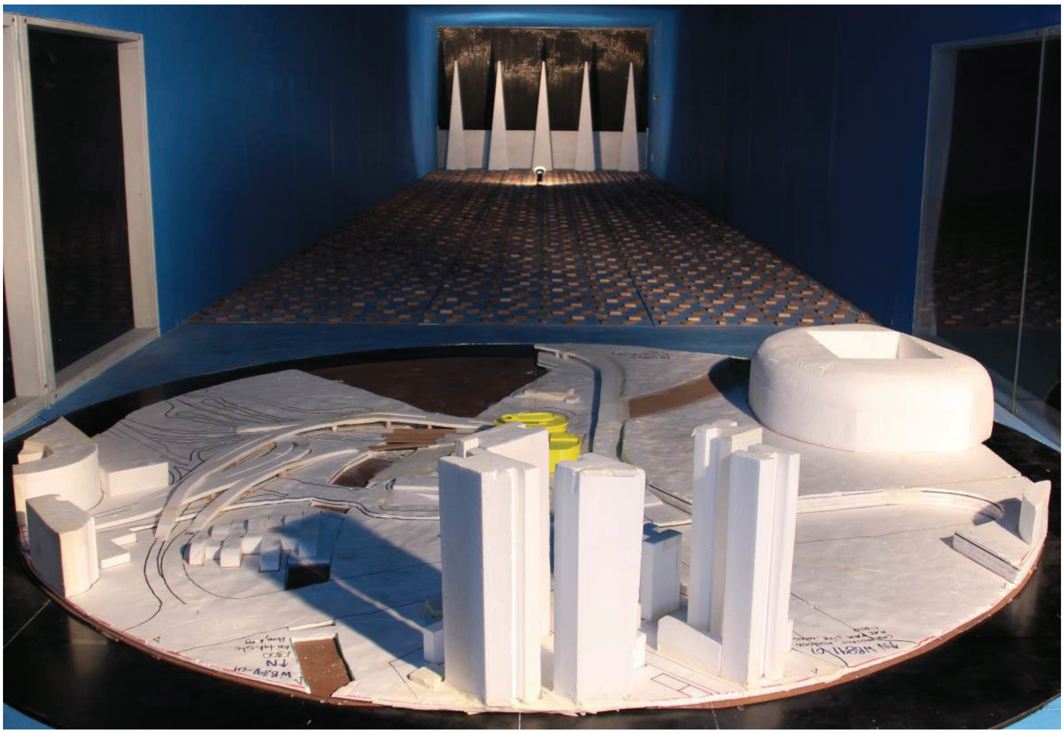

**Figure 2h: Photograph of the Wind Tunnel Model Proposed Development (view from the north)**

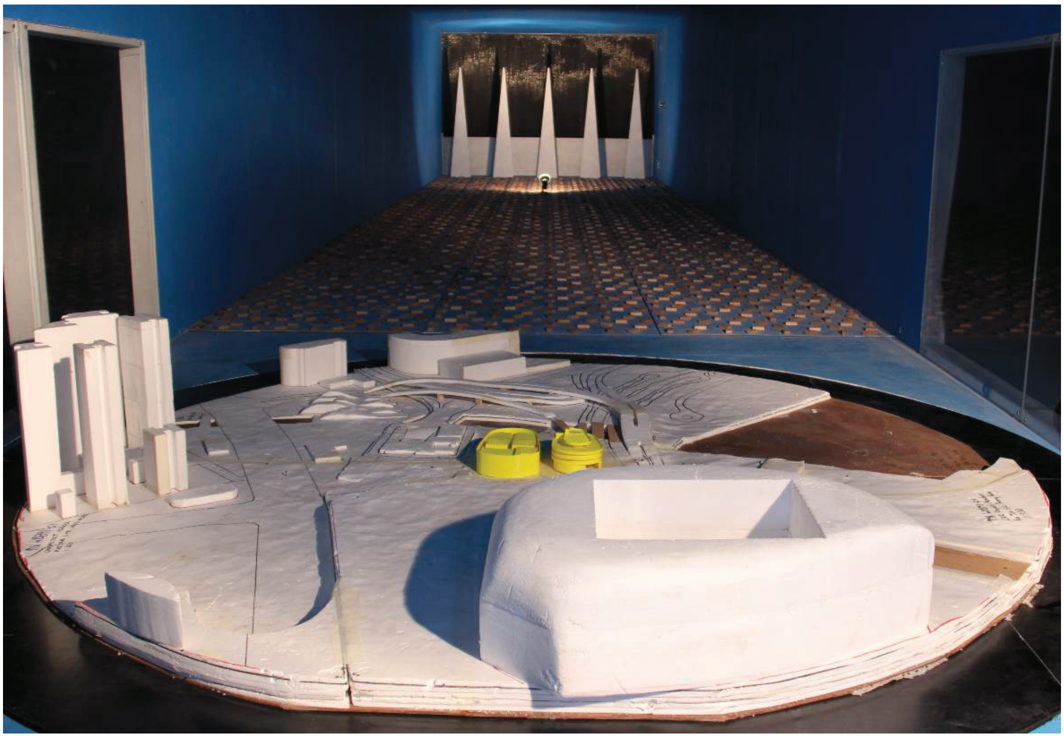

**Figure 2i: Photograph of the Wind Tunnel Model Proposed Development (view from the west)**

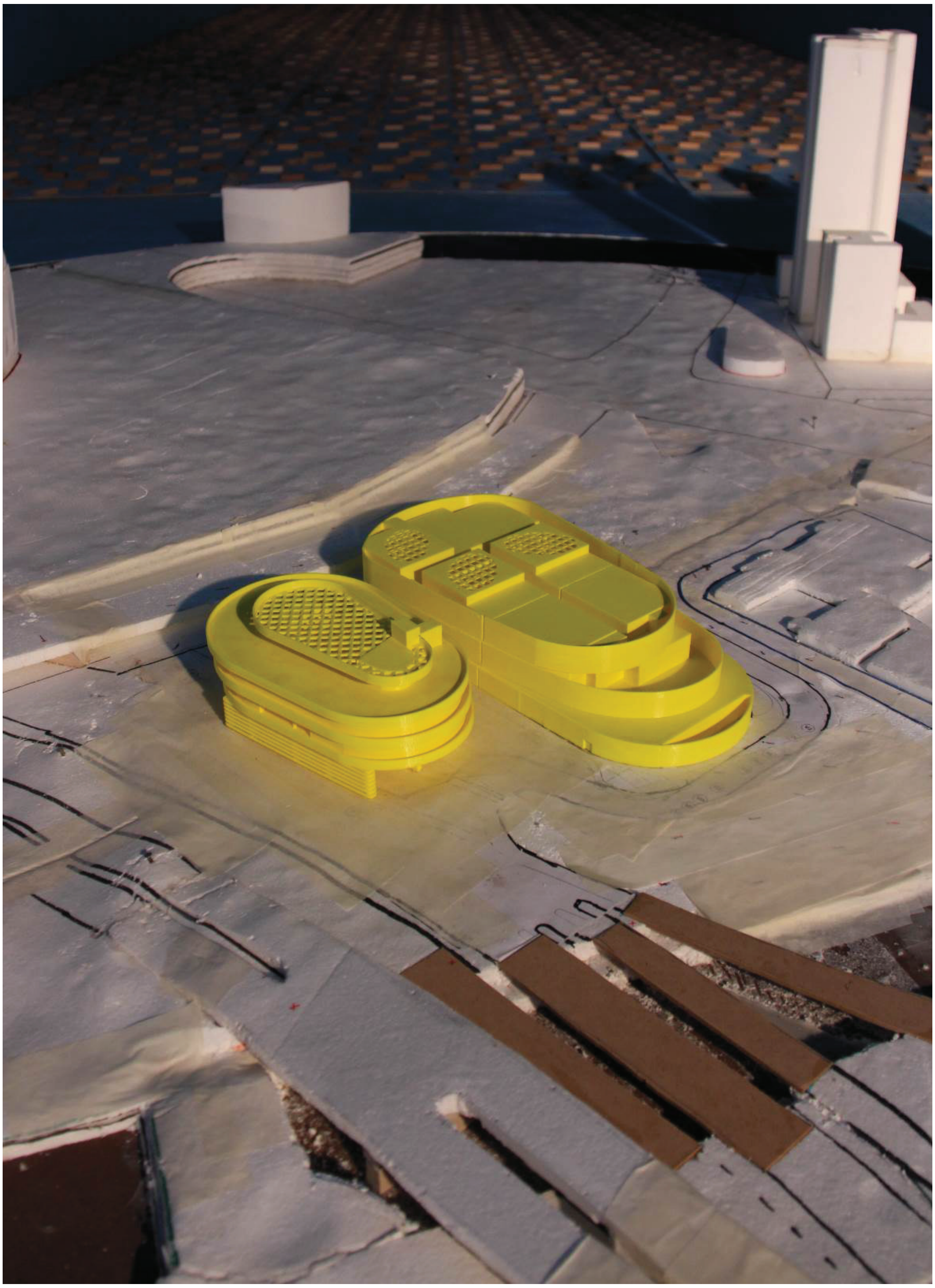

**Figure 2j: Photograph of the Wind Tunnel Model Proposed Development (view from the south-east)**

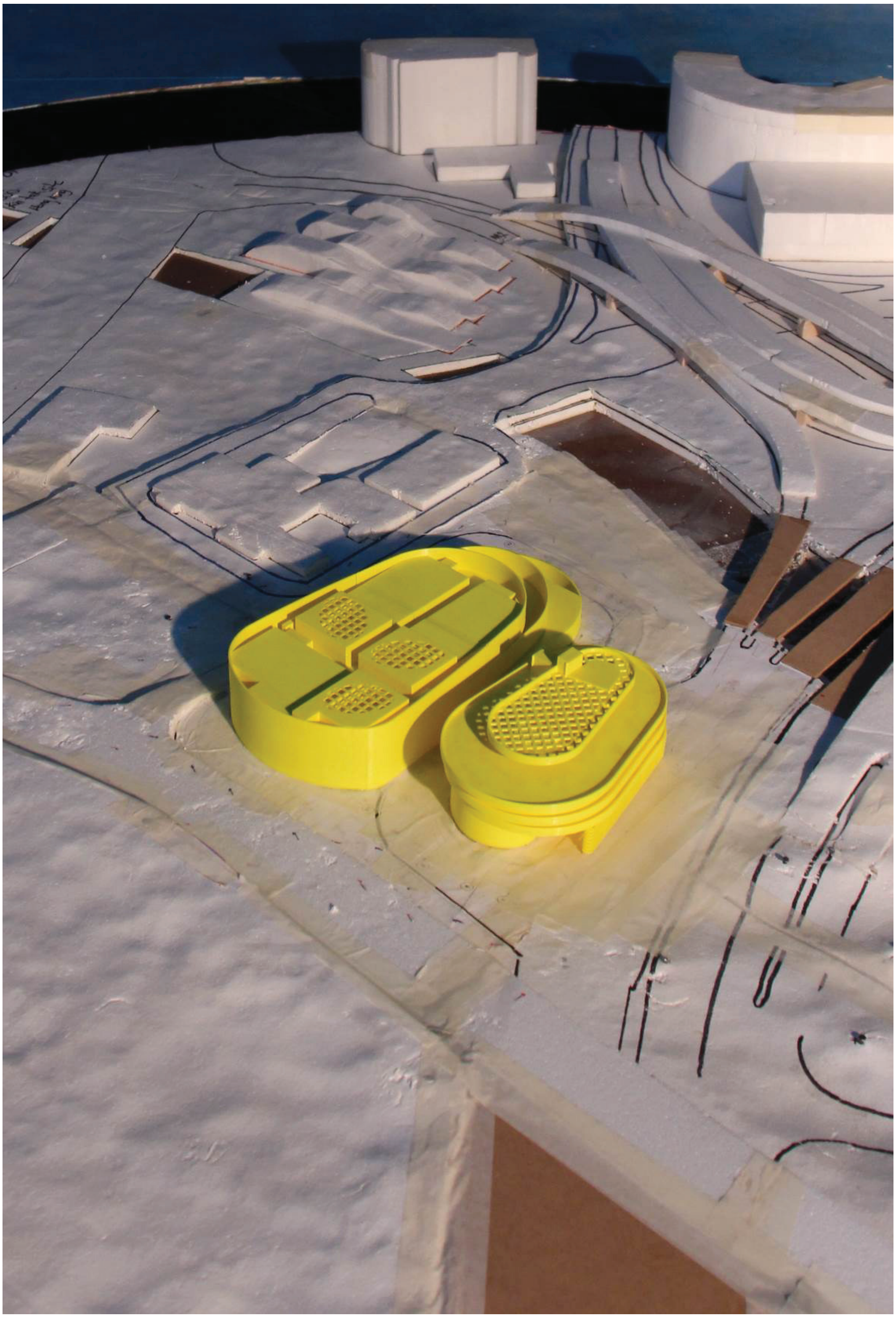

**Figure 2k: Photograph of the Wind Tunnel Model Proposed Development (view from the south-west)**

# 3 The Wind Model

Testing was performed using blockage-tolerant boundary layer wind tunnel facility, which has a 3.0m wide working section with a fetch length of 14m. No correction is required for blockage effects. The facility is set up to model atmospheric boundary layer flows at length scales ranging from 1:4000 to 1:50. The wind flow regime can be modified through the use of different surface roughness, spires and fences to model different scale atmospheric boundary layer flows and for different terrains.

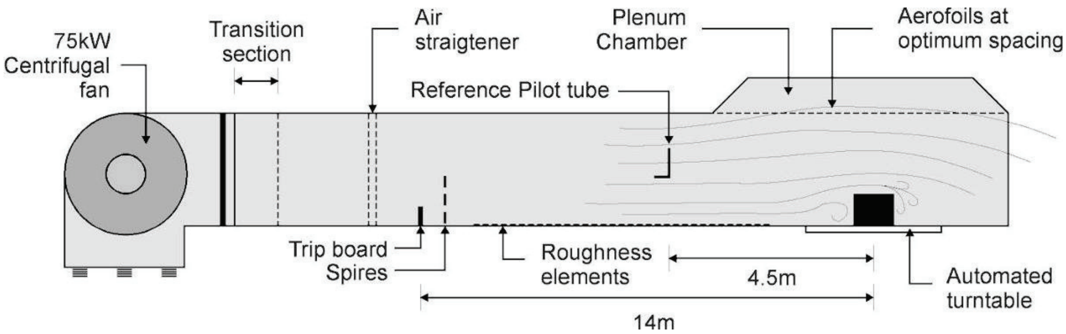


Figure 3: Boundary Layer Wind Tunnel Facility

The model of the subject development was setup in the wind tunnel, and mean wind speeds were measured in the form of velocity coefficients. Wind speed measurements are made in the wind tunnel for 16 wind directions, at 22.5 degree increments for the full 360 degree azimuth.

The free-stream wind speeds at the reference height, measured upstream of the test model and the local wind speeds at the test locations were monitored using a set of Dantec hot-wire anemometers. In addition, care was taken in the alignment of the probe wire and in avoiding wall-heating effects. This procedure provides comprehensive information about the wind environment to be expected at each of the study locations for the various wind directions.

The output from the hot-wire probes is obtained using a National Instruments 12-bit data acquisition card. The signal was low pass filtered at 32 Hz to simulate a 3-second gust in full-scale time. A sample rate of 1000 samples per second was used, which is more than adequate for the given frequency band.

Profiles for velocity and turbulence intensity were obtained for each of the 16 wind directions as part of the Site Wind Availability Study carried out at the 1:4000 scale. These profiles were classified into 5 test configurations and recreated at the 1:300 scale using an appropriate combination of roughness elements and fences in the wind tunnel fetch. Figures 4a to 4e show plots of the velocity and turbulence intensity profiles used for each test configuration, along with the angles tested for each configuration.

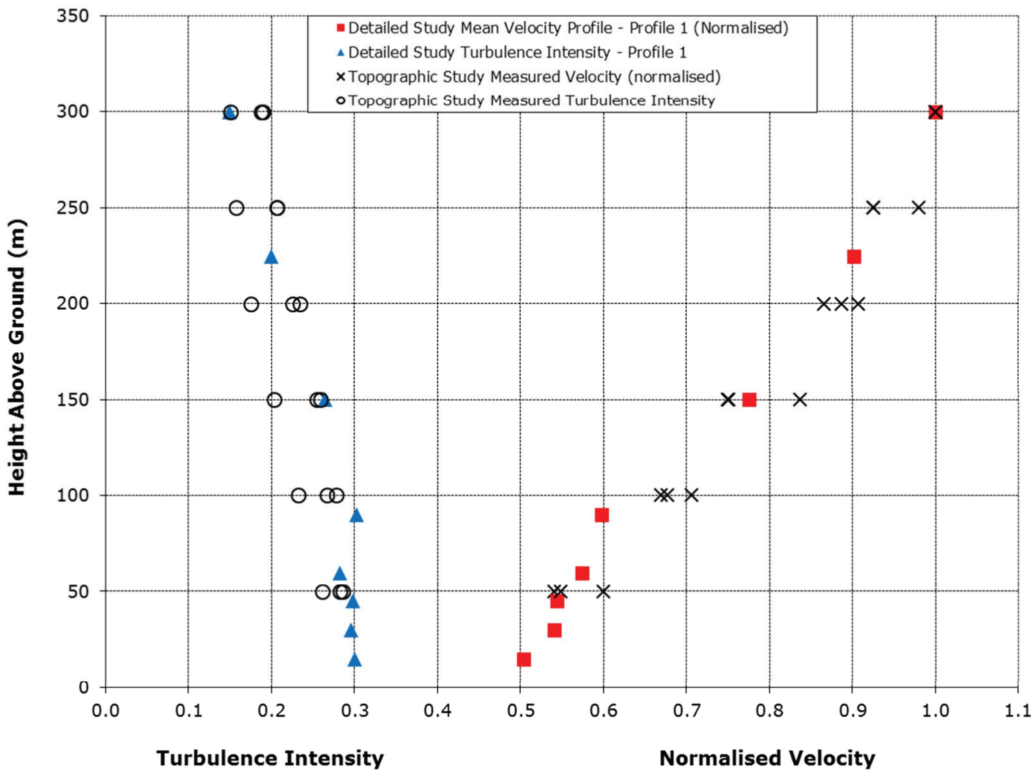


**Figure 4a: Wind Profile 1 (Angles 0°, 45° and 270°)**

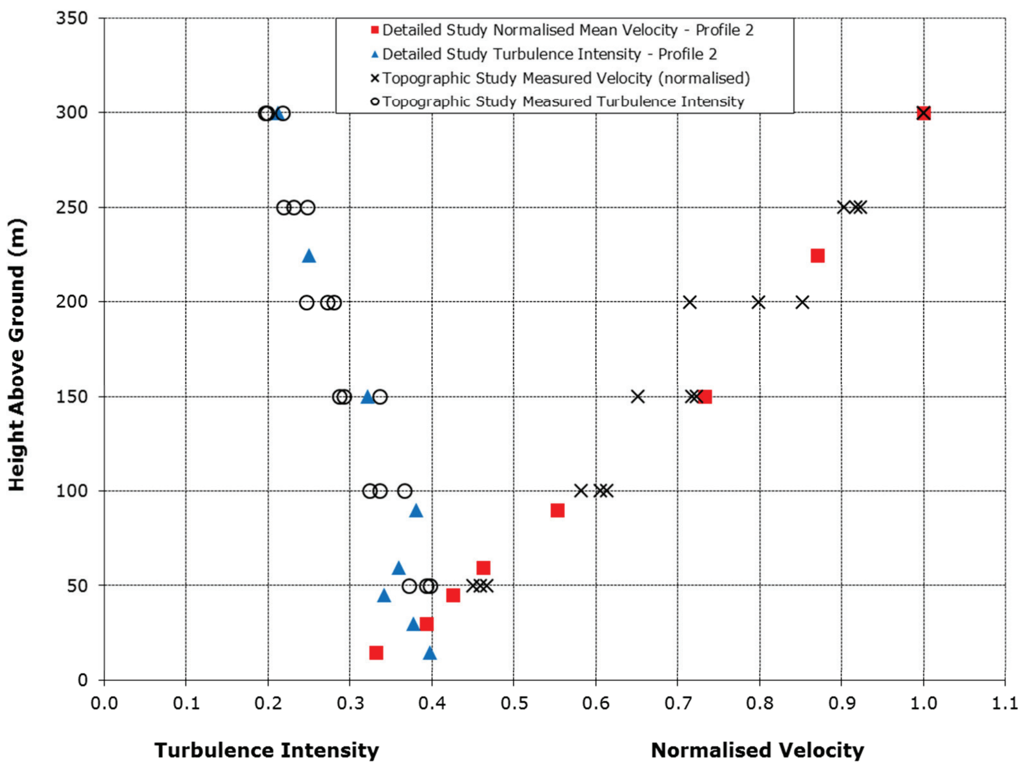


**Figure 4b: Wind Profile 2 (Angles 67.5°, 90° and 112.5°)**

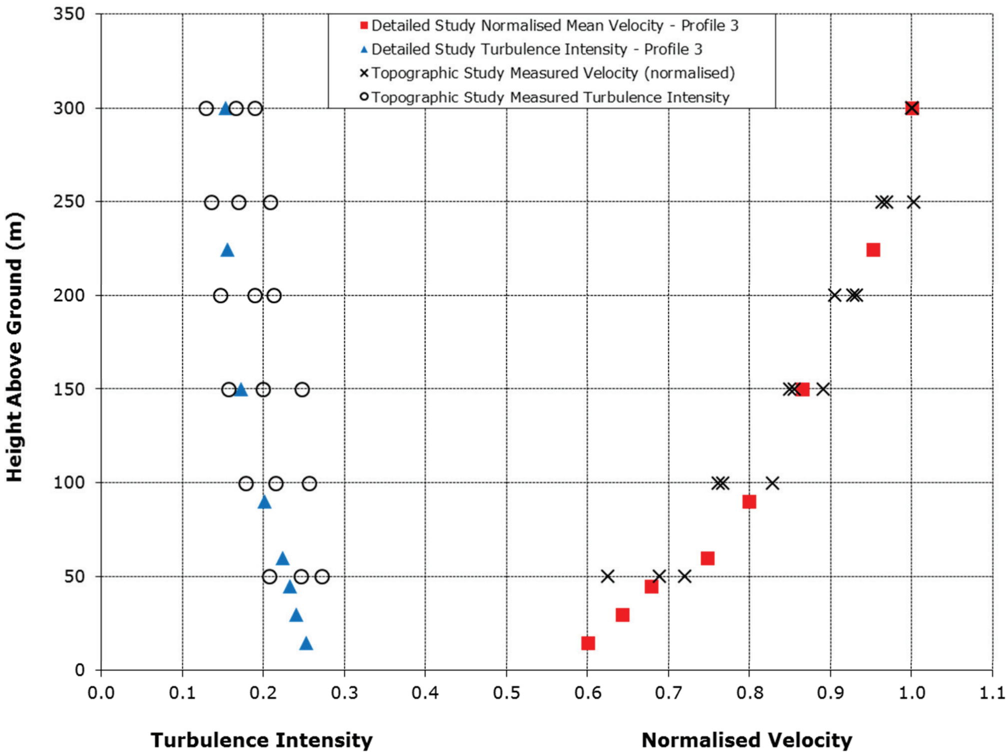


**Figure 4c: Wind Profile 3 (Angles 135°, 247.5° and 315°)**

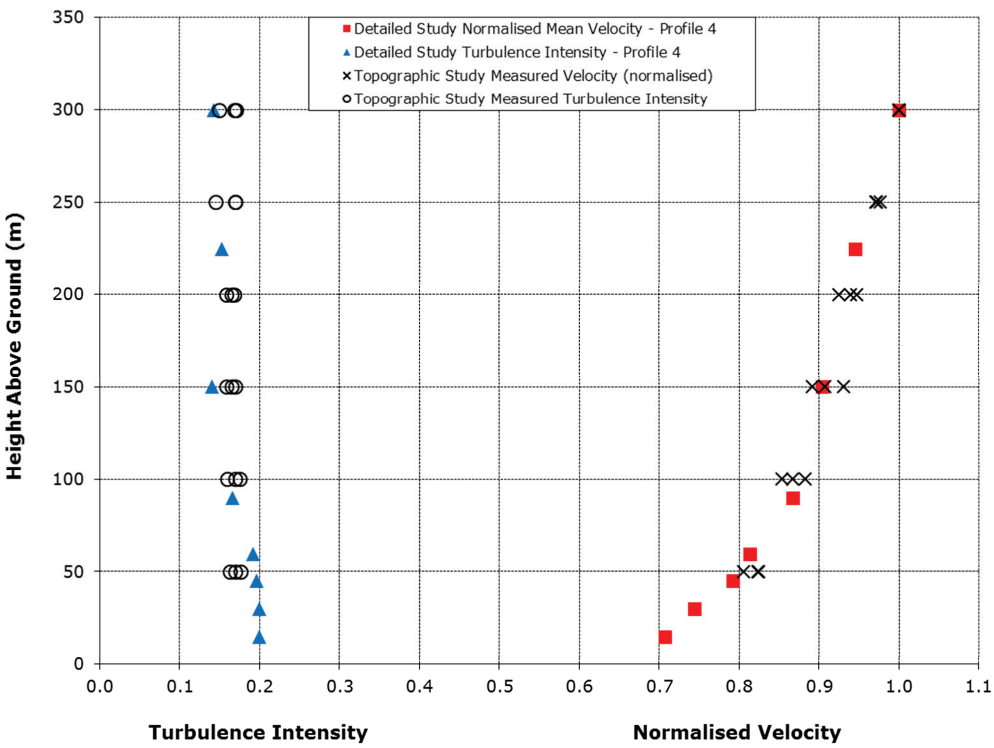


**Figure 4d: Wind Profile 4 (Angles 157.5°, 180° and 202.5°)**

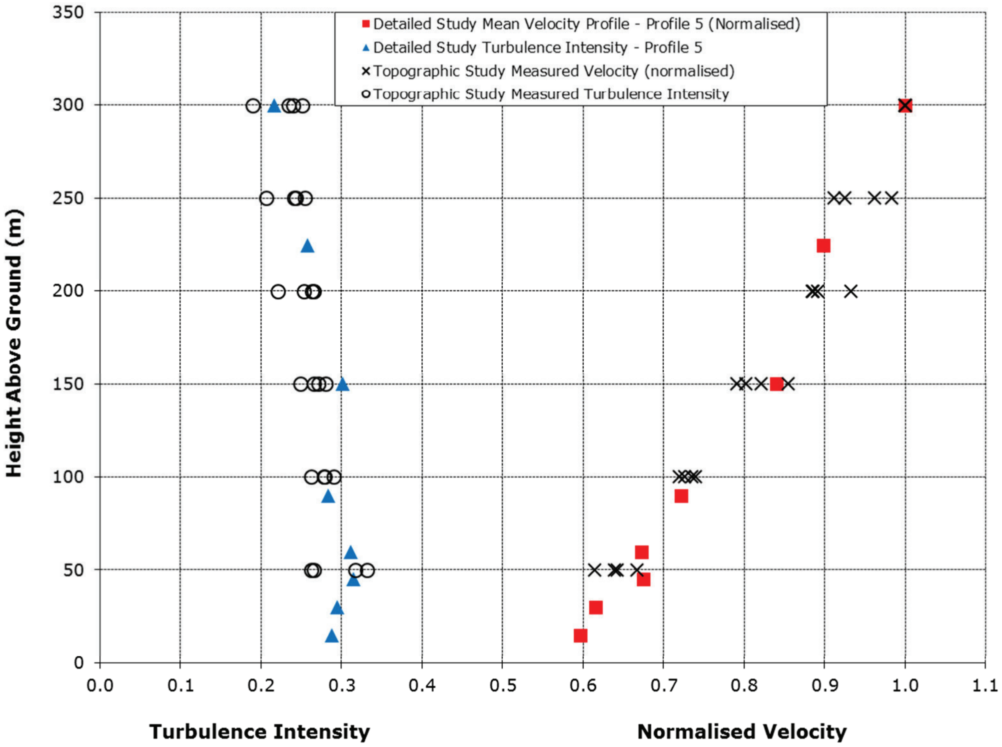


**Figure 4e: Wind Profile 5 (Angles 22.5°, 225°, 292.5° and 337.5°)**

The assessment area which houses the test points for the detailed study extend to a distance H from the perimeter of the proposed buildings, where H is the height of the tallest proposed structure, as defined in the Hong Kong Environment Transport and Works Bureau, Technical Circular No. 1/06 for Air Ventilation Assessments (2006). Test points were evenly spaced within the assessment area for each of the sites selected for analysis. The test points were placed both outside of and within the project site boundary.

The test point layout was devised to adequately track the flow of air towards and around the development site. A total of 53 study points were located and grouped as follows:

- 20 Perimeter test points: Positioned at a distance of H/2 from the perimeter of the base of the proposed structure. These "Perimeter" study points are to indicate the localised impacts on wind conditions for the immediate surrounding areas.
- 30 Overall Test Points: Evenly distributed throughout the open spaces, roads and pedestrian trafficable areas located within a distance of H from the perimeter of the base of the proposed structure. These points indicate the impact of the subject development on wind conditions in the overall surrounding area.
- 3 Special Test Points: At the request of the client, these study points were positioned along the pedestrian walkway underneath the CKR bridge sections to the south-east of the subject development site.

The layout of study points for the detailed study is presented in Figures 5a and 5b.

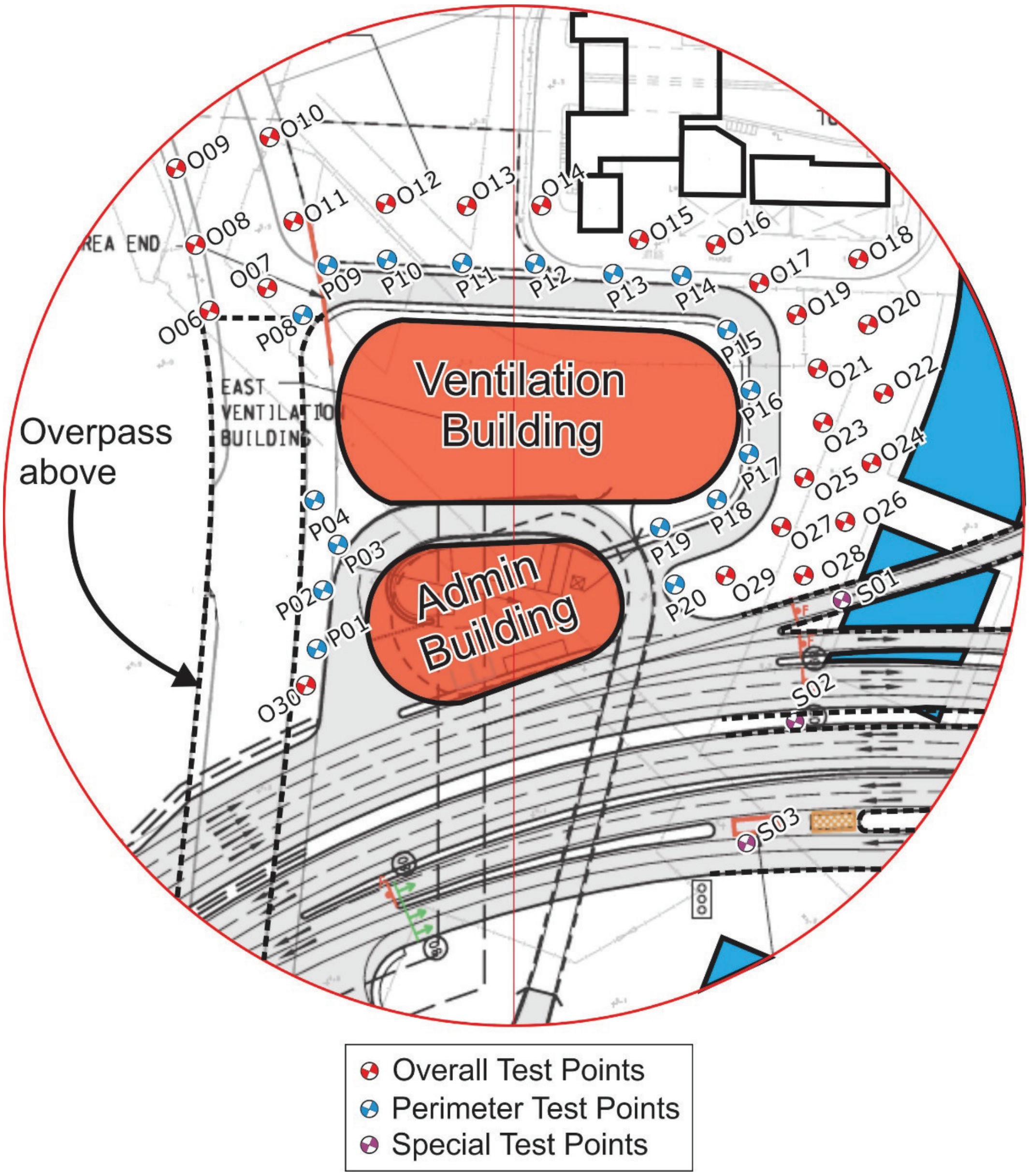


**Figure 5a: Layout of Study Points, Ground Level**

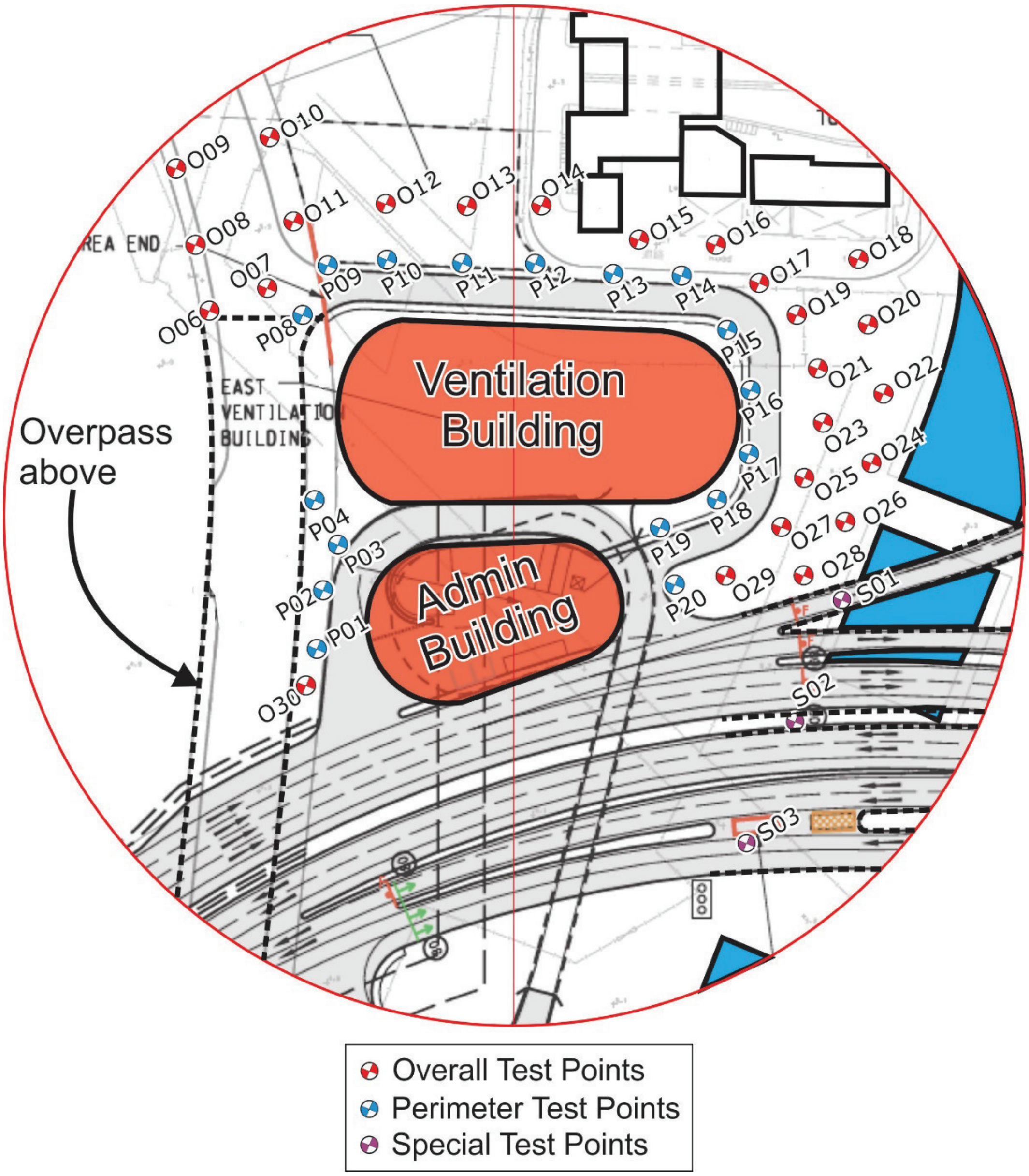


**Figure 5b: Layout of Study Points, Overpass Level**

# 4 Results

The local mean velocity ratios referenced to the mean upstream wind speed measured at 500m height were obtained for each of the 16 wind directions for both the existing site conditions and with the inclusion of the proposed development. The directional results were weighted based on the frequency of occurrence of wind from each direction under the annual and summer climate models, presented in the Site Wind Availability Report (**Appendix B**). The site velocity ratio (SVR) is the average of all perimeter test points, while the local velocity ratio (LVR) is the average of all perimeter and overall test points together. The velocity ratios for each point are given in Figures 6a, 6b and 6c for the annual wind conditions and Figures 7a, 7b and 7c for the summer wind conditions. Tables 1 and 2 show the average SVR and LVR for the entire development for the annual and summer wind climates respectively.

The results of this study indicate that the inclusion of the proposed development will result in acceptable air ventilation performance in the immediate vicinity and the surrounding local area of the subject development site for both the annual and summer wind conditions.

**Table 1: Summary of the Site and Local Average Annual Velocity Ratios**

| Test Configuration | SVR | LVR |
|---|---|---|
| Existing Site Conditions | 0.425 | 0.381 |
| With the Inclusion of the proposed administration and ventilation buildings | 0.370 | 0.359 |

**Table 2: Summary of the Site and Local Average Summer Velocity Ratios**

| Test Configuration | SVR | LVR |
|---|---|---|
| Existing Site Conditions | 0.430 | 0.399 |
| With the Inclusion of the proposed administration and ventilation buildings | 0.372 | 0.368 |

For the annual wind conditions, the SVR and LVR decrease for certain areas with the inclusion of the proposed development. This result is expected, since the existing site is undeveloped and very exposed to the prevailing winds. The proposed administration and ventilation buildings provide some shielding to the prevailing winds, but the velocity ratios are still high due to the site's exposure and a lack of densely packed high-rise buildings in the surrounding area. Similarly for the summer wind conditions, the SVR and LVR decrease with the inclusion of the proposed development, due to localised shielding effects. However due to the exposure of the site, the velocity ratios are still high and indicate that acceptable air ventilation will be achieved in the immediate vicinity and the local area of the subject development site.

As shown in figures 6a to 6c and 7a to 7c, the minimum velocity ratios with the inclusion of the proposed development are comparable to the minimum for the existing site conditions. This suggests that the minimum air ventilation performance across the immediate vicinity and surrounding local area are very similar between the existing case and with the inclusion of the proposed development.

Figures 6c and 7c show the velocity ratios of the special study points located on the pedestrian walkway underneath the CKR bridges to the south-east of the subject development site. The inclusion of the proposed administration and ventilation buildings have a negligible effect on air ventilation performance in these areas, and the magnitude of the velocity ratios suggest that acceptable air ventilation performance is expected.

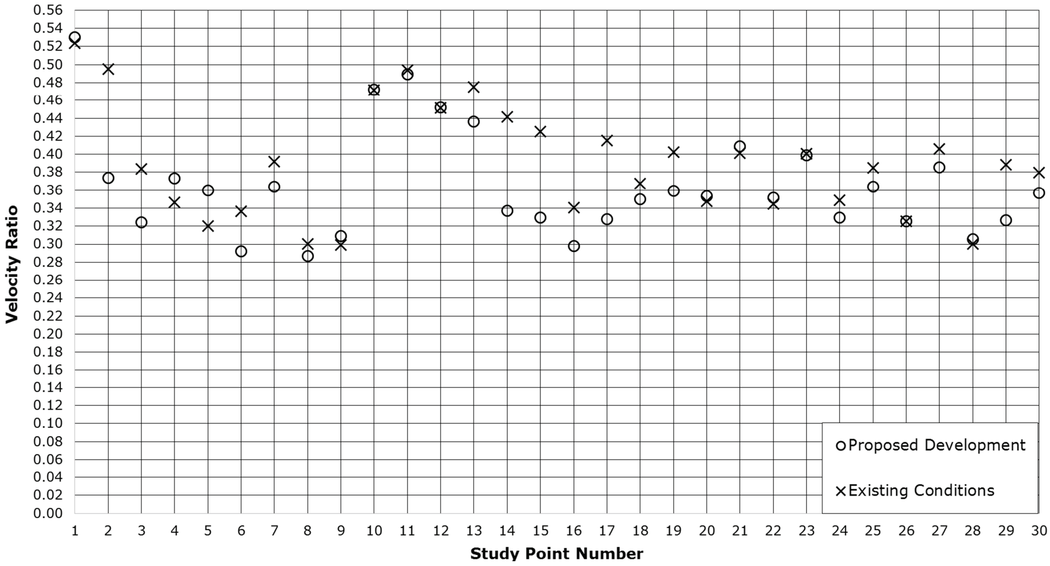


**Figure 6a: Velocity Ratios for Overall Study Points: Annual Winds**

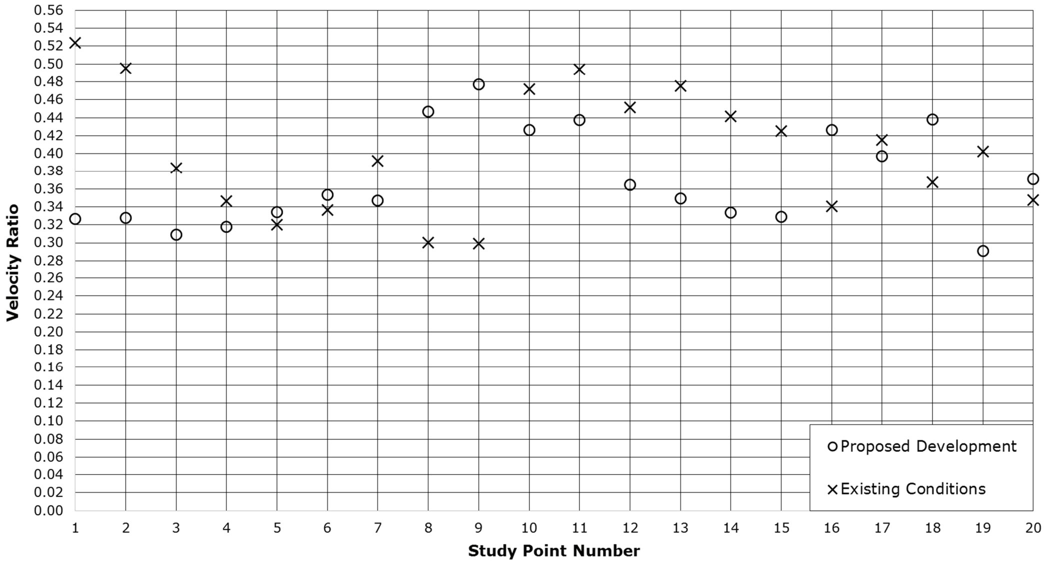


**Figure 6b: Velocity Ratios for Perimeter Study Points: Annual Winds**

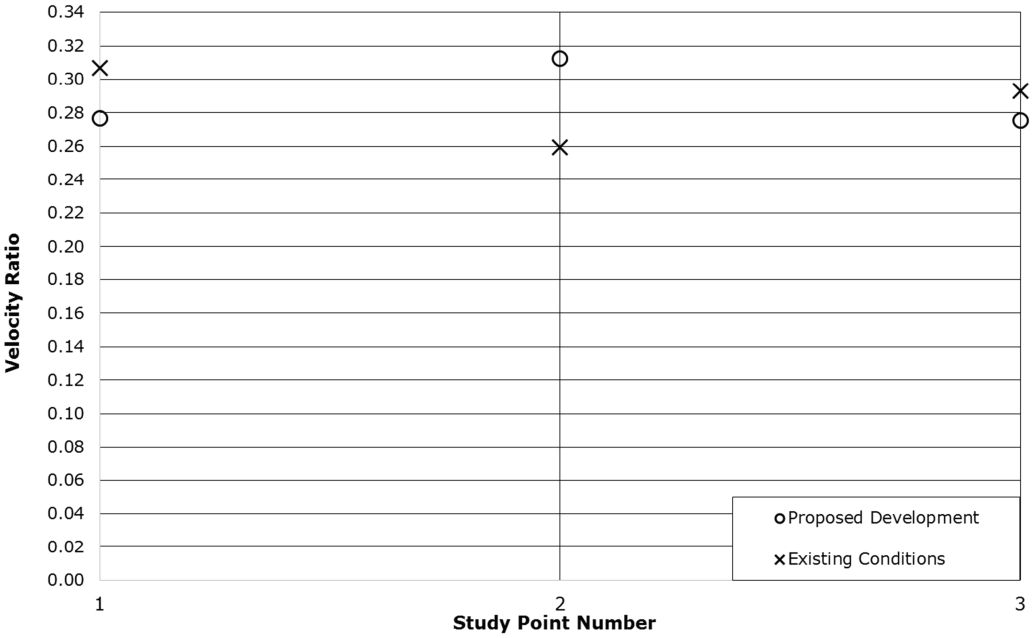


**Figure 6c: Velocity Ratios for Special Study Points: Annual Winds**

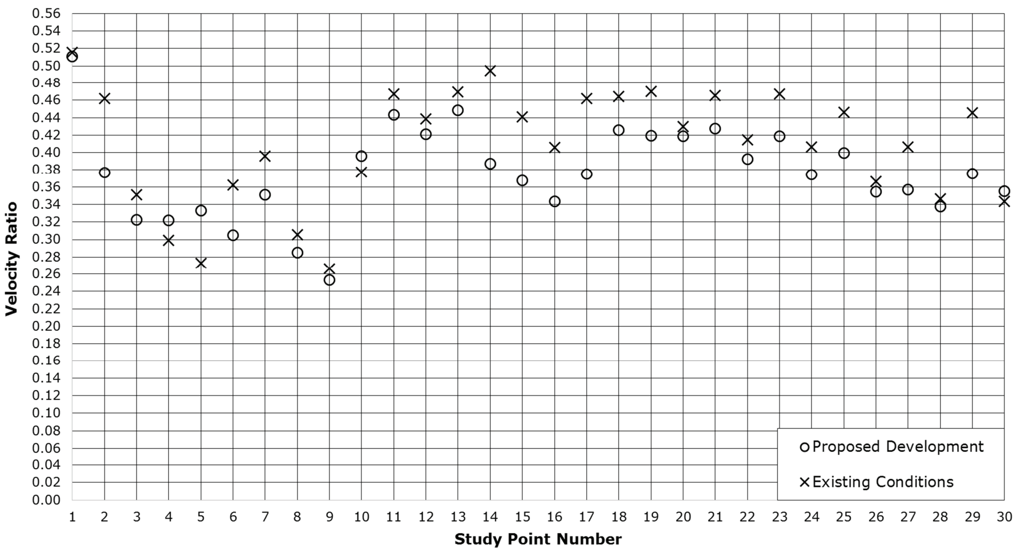


**Figure 7a: Velocity Ratios for Overall Study Points: Summer Winds**

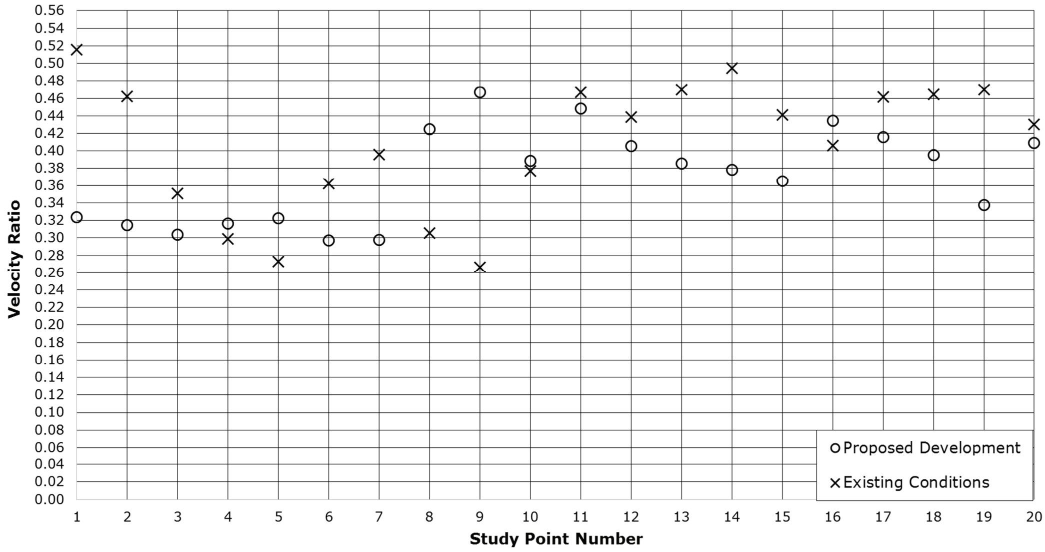


**Figure 7b: Velocity Ratios for Perimeter Study Points: Summer Winds**

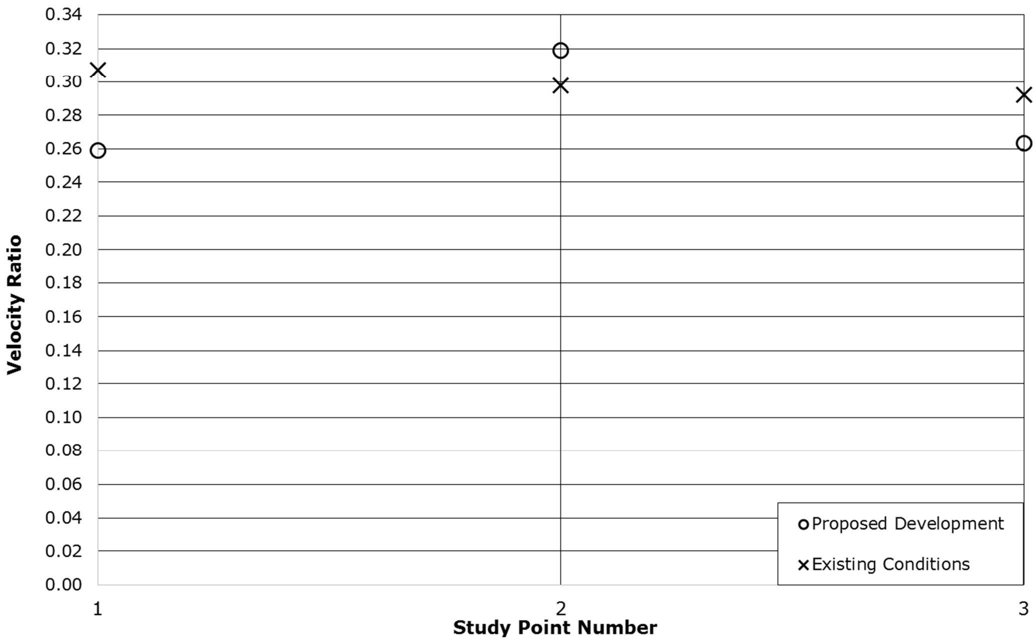


**Figure 7c: Velocity Ratios for Special Study Points: Summer Winds**

# 5 Conclusion

A Detailed Study was carried out as part of the Air Ventilation Assessment (AVA) for the CKR Project. This report relates to the Administration and Ventilation Buildings located in Kai Tak at the eastern end of the CKR Project. Wind tunnel testing was performed using the boundary layer wind tunnel, which has a 3.0m wide working section and has a fetch length of 14m. The study was undertaken in accordance with the current best international practice requirements stipulated in “Manuals and Reports on Engineering Practice No. 67 : Wind Tunnel Studies of Buildings and Structures, Virginia 1999 issued by American Society of Civil Engineers”, “Wind Engineering Studies of Buildings, Quality Assurance Manual on Environment Wind Studies AWES-QAM-1-2001 issued by Australasian Wind Engineering Society” and “Hong Kong Environment Transport and Works Bureau, 2006, Technical Circular No. 1/06 for Air Ventilation Assessments”.

Measurements for the Detailed Study were carried out using a 1:300 scale model of the development. The effects of nearby buildings and land topography were accounted for through the use of a proximity model, which represents an area with a radius of 375m. The wind velocity and turbulence measurements obtained from the Site Wind Availability Study were categorised into five wind profiles and replicated at a scale of 1:300 for use in the this study. Velocity ratios referenced to a height of 500m were measured for the 16 compass wind directions and combined with the annual and summer wind directional frequencies presented in the Site Wind Availability Study. The SVR and LVR for the site were determined. Testing was performed for two scenarios; one with the existing site conditions, the other with the inclusion of the proposed development.

The results of this study indicate that the inclusion of the proposed development will result in acceptable air ventilation performance in the immediate vicinity and the surrounding local area of the subject development site for both the annual and summer wind conditions. The site has good exposure to the prevailing winds due to a lack of densely packed high-rise buildings in the surrounding area.

For the annual and summer wind conditions, velocity ratios generally decreased with the inclusion of the subject development. However, the minimum velocity ratios with the inclusion of the proposed development are comparable to the minimum for the existing site conditions. This suggests that the minimum air ventilation performance across the immediate vicinity and surrounding local area are very similar between the existing case and with the inclusion of the proposed development.

Air ventilation performance for the proposed walkway beneath the CKR bridges over the Kai Tak River is acceptable, and is not significantly impacted by the inclusion of the proposed administration and ventilation buildings.

# 6 References

"Manuals and Reports on Engineering Practice No. 67 : Wind Tunnel Studies of Buildings and Structures, Virginia 1999 issued by American Society of Civil Engineers"

"Wind Engineering Studies of Buildings, Quality Assurance Manual on Environment Wind Studies AWES-QAM-1-2001 issued by Australasian Wind Engineering Society"

"Hong Kong Environment Transport and Works Bureau, 2006, Technical Circular No. 1/06 for Air Ventilation Assessments"

# Appendix A

## Directional Velocity Ratios for Individual Study Points

# A1 Existing Site Conditions

| | 0° | 22.5° | 45° | 67.5° | 90° | 112.5° | 135° | 157.5° | 180° | 202.5° | 225° | 247.5° | 270° | 292.5° | 315° | 337.5° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Probability of Occurrence: Annual** | 0.121 | 0.083 | 0.088 | 0.151 | 0.234 | 0.049 | 0.031 | 0.030 | 0.043 | 0.031 | 0.049 | 0.032 | 0.025 | 0.010 | 0.006 | 0.015 |
| **Probability of Occurrence: Summer** | 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 | 0.020 | 0.011 | 0.012 |
| **O01** | 0.51 | 0.55 | 0.55 | 0.52 | 0.51 | 0.64 | 0.60 | 0.52 | 0.61 | 0.63 | 0.43 | 0.36 | 0.43 | 0.38 | 0.47 | 0.53 |
| **O02** | 0.45 | 0.44 | 0.44 | 0.48 | 0.65 | 0.55 | 0.44 | 0.46 | 0.35 | 0.31 | 0.40 | 0.41 | 0.58 | 0.45 | 0.43 | 0.50 |
| **O03** | 0.45 | 0.45 | 0.42 | 0.41 | 0.35 | 0.40 | 0.40 | 0.29 | 0.22 | 0.18 | 0.40 | 0.37 | 0.41 | 0.36 | 0.40 | 0.50 |
| **O04** | 0.37 | 0.35 | 0.43 | 0.43 | 0.34 | 0.31 | 0.25 | 0.26 | 0.31 | 0.32 | 0.32 | 0.18 | 0.16 | 0.22 | 0.42 | 0.43 |
| **O05** | 0.37 | 0.33 | 0.43 | 0.38 | 0.29 | 0.30 | 0.29 | 0.27 | 0.31 | 0.24 | 0.20 | 0.20 | 0.16 | 0.32 | 0.43 | 0.42 |
| **O06** | 0.24 | 0.25 | 0.29 | 0.35 | 0.36 | 0.46 | 0.46 | 0.50 | 0.48 | 0.41 | 0.34 | 0.22 | 0.20 | 0.28 | 0.28 | 0.29 |
| **O07** | 0.28 | 0.29 | 0.38 | 0.44 | 0.45 | 0.50 | 0.43 | 0.52 | 0.50 | 0.42 | 0.35 | 0.25 | 0.23 | 0.30 | 0.27 | 0.31 |
| **O08** | 0.20 | 0.24 | 0.29 | 0.33 | 0.34 | 0.34 | 0.39 | 0.47 | 0.41 | 0.30 | 0.27 | 0.16 | 0.18 | 0.23 | 0.21 | 0.24 |
| **O09** | 0.29 | 0.22 | 0.31 | 0.40 | 0.33 | 0.31 | 0.27 | 0.26 | 0.23 | 0.18 | 0.21 | 0.23 | 0.28 | 0.34 | 0.36 | 0.34 |
| **O10** | 0.41 | 0.25 | 0.48 | 0.66 | 0.66 | 0.58 | 0.52 | 0.23 | 0.19 | 0.21 | 0.23 | 0.24 | 0.34 | 0.39 | 0.50 | 0.42 |
| **O11** | 0.29 | 0.36 | 0.52 | 0.66 | 0.61 | 0.51 | 0.42 | 0.47 | 0.51 | 0.52 | 0.45 | 0.36 | 0.27 | 0.29 | 0.28 | 0.32 |
| **O12** | 0.27 | 0.55 | 0.46 | 0.52 | 0.51 | 0.47 | 0.52 | 0.47 | 0.39 | 0.32 | 0.46 | 0.43 | 0.37 | 0.36 | 0.34 | 0.29 |
| **O13** | 0.27 | 0.62 | 0.50 | 0.57 | 0.50 | 0.43 | 0.51 | 0.47 | 0.47 | 0.41 | 0.51 | 0.52 | 0.35 | 0.33 | 0.37 | 0.31 |
| **O14** | 0.30 | 0.44 | 0.43 | 0.47 | 0.42 | 0.38 | 0.49 | 0.62 | 0.62 | 0.57 | 0.56 | 0.53 | 0.44 | 0.35 | 0.35 | 0.29 |
| **O15** | 0.34 | 0.50 | 0.41 | 0.41 | 0.42 | 0.45 | 0.52 | 0.61 | 0.63 | 0.53 | 0.37 | 0.32 | 0.28 | 0.38 | 0.33 | 0.31 |
| **O16** | 0.20 | 0.25 | 0.27 | 0.30 | 0.37 | 0.47 | 0.43 | 0.53 | 0.55 | 0.53 | 0.41 | 0.31 | 0.30 | 0.38 | 0.38 | 0.23 |
| **O17** | 0.29 | 0.41 | 0.38 | 0.38 | 0.43 | 0.47 | 0.48 | 0.59 | 0.54 | 0.58 | 0.48 | 0.41 | 0.32 | 0.52 | 0.41 | 0.31 |
| **O18** | 0.25 | 0.26 | 0.31 | 0.28 | 0.37 | 0.47 | 0.47 | 0.47 | 0.46 | 0.56 | 0.55 | 0.60 | 0.54 | 0.48 | 0.32 | 0.26 |
| **O19** | 0.38 | 0.45 | 0.37 | 0.33 | 0.33 | 0.36 | 0.50 | 0.54 | 0.52 | 0.56 | 0.51 | 0.56 | 0.52 | 0.62 | 0.56 | 0.41 |
| **O20** | 0.30 | 0.34 | 0.29 | 0.27 | 0.30 | 0.32 | 0.48 | 0.43 | 0.41 | 0.50 | 0.52 | 0.58 | 0.53 | 0.59 | 0.49 | 0.34 |
| **O21** | 0.42 | 0.50 | 0.37 | 0.30 | 0.31 | 0.31 | 0.50 | 0.51 | 0.47 | 0.54 | 0.53 | 0.64 | 0.50 | 0.58 | 0.62 | 0.40 |
| **O22** | 0.34 | 0.32 | 0.32 | 0.28 | 0.28 | 0.35 | 0.44 | 0.41 | 0.36 | 0.49 | 0.46 | 0.58 | 0.55 | 0.56 | 0.52 | 0.36 |
| **O23** | 0.42 | 0.45 | 0.38 | 0.30 | 0.32 | 0.38 | 0.47 | 0.55 | 0.46 | 0.58 | 0.52 | 0.58 | 0.54 | 0.53 | 0.58 | 0.38 |
| **O24** | 0.37 | 0.37 | 0.30 | 0.28 | 0.28 | 0.35 | 0.37 | 0.40 | 0.34 | 0.46 | 0.50 | 0.55 | 0.52 | 0.49 | 0.49 | 0.33 |
| **O25** | 0.37 | 0.44 | 0.32 | 0.30 | 0.33 | 0.34 | 0.45 | 0.51 | 0.46 | 0.55 | 0.52 | 0.52 | 0.50 | 0.54 | 0.51 | 0.37 |
| **O26** | 0.33 | 0.38 | 0.33 | 0.28 | 0.27 | 0.24 | 0.28 | 0.30 | 0.28 | 0.44 | 0.45 | 0.51 | 0.56 | 0.48 | 0.41 | 0.32 |
| **O27** | 0.41 | 0.53 | 0.50 | 0.37 | 0.35 | 0.33 | 0.43 | 0.43 | 0.39 | 0.36 | 0.36 | 0.47 | 0.59 | 0.53 | 0.51 | 0.41 |
| **O28** | 0.28 | 0.36 | 0.31 | 0.26 | 0.24 | 0.25 | 0.21 | 0.21 | 0.27 | 0.42 | 0.47 | 0.48 | 0.55 | 0.47 | 0.44 | 0.34 |
| **O29** | 0.42 | 0.47 | 0.41 | 0.28 | 0.29 | 0.31 | 0.42 | 0.50 | 0.52 | 0.59 | 0.51 | 0.48 | 0.54 | 0.51 | 0.50 | 0.43 |
| **O30** | 0.41 | 0.37 | 0.44 | 0.38 | 0.39 | 0.45 | 0.38 | 0.43 | 0.36 | 0.23 | 0.26 | 0.23 | 0.32 | 0.34 | 0.45 | 0.51 |
| **P01** | 0.37 | 0.39 | 0.42 | 0.63 | 0.32 | 0.40 | 0.29 | 0.42 | 0.35 | 0.31 | 0.25 | 0.28 | 0.29 | 0.34 | 0.47 | 0.51 |
| **P02** | 0.40 | 0.34 | 0.42 | 0.38 | 0.34 | 0.35 | 0.25 | 0.33 | 0.32 | 0.35 | 0.25 | 0.25 | 0.30 | 0.33 | 0.43 | 0.48 |
| **P03** | 0.35 | 0.39 | 0.42 | 0.43 | 0.33 | 0.30 | 0.25 | 0.31 | 0.33 | 0.40 | 0.28 | 0.22 | 0.26 | 0.31 | 0.38 | 0.47 |
| **P04** | 0.34 | 0.35 | 0.39 | 0.39 | 0.33 | 0.34 | 0.23 | 0.32 | 0.29 | 0.32 | 0.22 | 0.22 | 0.28 | 0.31 | 0.37 | 0.43 |
| **P05** | 0.45 | 0.38 | 0.50 | 0.41 | 0.42 | 0.38 | 0.45 | 0.35 | 0.26 | 0.23 | 0.38 | 0.22 | 0.25 | 0.35 | 0.49 | 0.51 |
| **P06** | 0.43 | 0.39 | 0.50 | 0.52 | 0.54 | 0.48 | 0.44 | 0.37 | 0.26 | 0.22 | 0.28 | 0.26 | 0.28 | 0.40 | 0.56 | 0.47 |
| **P07** | 0.37 | 0.33 | 0.41 | 0.41 | 0.42 | 0.42 | 0.47 | 0.36 | 0.25 | 0.20 | 0.26 | 0.32 | 0.27 | 0.40 | 0.51 | 0.45 |
| **P08** | 0.30 | 0.35 | 0.48 | 0.55 | 0.54 | 0.51 | 0.55 | 0.60 | 0.49 | 0.50 | 0.45 | 0.37 | 0.31 | 0.34 | 0.32 | 0.34 |

| | 0° | 22.5° | 45° | 67.5° | 90° | 112.5° | 135° | 157.5° | 180° | 202.5° | 225° | 247.5° | 270° | 292.5° | 315° | 337.5° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Probability of Occurrence: Annual** | 0.121 | 0.083 | 0.088 | 0.151 | 0.234 | 0.049 | 0.031 | 0.030 | 0.043 | 0.031 | 0.049 | 0.032 | 0.025 | 0.010 | 0.006 | 0.015 |
| **Probability of Occurrence: Summer** | 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 | 0.020 | 0.011 | 0.012 |
| **P09** | 0.30 | 0.41 | 0.56 | 0.61 | 0.55 | 0.45 | 0.50 | 0.43 | 0.51 | 0.51 | 0.48 | 0.46 | 0.32 | 0.33 | 0.35 | 0.39 |
| **P10** | 0.46 | 0.46 | 0.55 | 0.57 | 0.56 | 0.54 | 0.67 | 0.66 | 0.52 | 0.42 | 0.39 | 0.30 | 0.32 | 0.55 | 0.57 | 0.58 |
| **P11** | 0.26 | 0.43 | 0.50 | 0.47 | 0.59 | 0.44 | 0.53 | 0.46 | 0.47 | 0.43 | 0.51 | 0.55 | 0.34 | 0.34 | 0.34 | 0.32 |
| **P12** | 0.33 | 0.50 | 0.50 | 0.46 | 0.41 | 0.48 | 0.52 | 0.48 | 0.49 | 0.46 | 0.48 | 0.50 | 0.40 | 0.36 | 0.42 | 0.34 |
| **P13** | 0.32 | 0.48 | 0.45 | 0.47 | 0.41 | 0.50 | 0.49 | 0.57 | 0.63 | 0.59 | 0.62 | 0.56 | 0.38 | 0.32 | 0.30 | 0.29 |
| **P14** | 0.35 | 0.44 | 0.38 | 0.38 | 0.39 | 0.44 | 0.48 | 0.60 | 0.62 | 0.60 | 0.49 | 0.43 | 0.37 | 0.52 | 0.43 | 0.37 |
| **P15** | 0.38 | 0.49 | 0.52 | 0.45 | 0.47 | 0.42 | 0.47 | 0.52 | 0.59 | 0.64 | 0.53 | 0.56 | 0.47 | 0.36 | 0.39 | 0.32 |
| **P16** | 0.37 | 0.49 | 0.32 | 0.31 | 0.31 | 0.35 | 0.51 | 0.60 | 0.54 | 0.55 | 0.52 | 0.62 | 0.56 | 0.60 | 0.58 | 0.42 |
| **P17** | 0.46 | 0.47 | 0.40 | 0.32 | 0.33 | 0.36 | 0.51 | 0.58 | 0.55 | 0.59 | 0.53 | 0.56 | 0.63 | 0.58 | 0.55 | 0.45 |
| **P18** | 0.41 | 0.53 | 0.52 | 0.40 | 0.40 | 0.69 | 0.44 | 0.51 | 0.37 | 0.32 | 0.49 | 0.56 | 0.64 | 0.58 | 0.50 | 0.40 |
| **P19** | 0.42 | 0.52 | 0.49 | 0.31 | 0.33 | 0.33 | 0.51 | 0.55 | 0.61 | 0.58 | 0.49 | 0.54 | 0.54 | 0.52 | 0.56 | 0.42 |
| **P20** | 0.44 | 0.56 | 0.49 | 0.30 | 0.33 | 0.34 | 0.52 | 0.58 | 0.61 | 0.61 | 0.53 | 0.53 | 0.54 | 0.48 | 0.58 | 0.45 |
| **S01** | 0.37 | 0.37 | 0.36 | 0.26 | 0.25 | 0.25 | 0.27 | 0.37 | 0.37 | 0.32 | 0.23 | 0.23 | 0.53 | 0.42 | 0.48 | 0.35 |
| **S02** | 0.17 | 0.28 | 0.33 | 0.21 | 0.22 | 0.28 | 0.37 | 0.50 | 0.45 | 0.42 | 0.28 | 0.20 | 0.19 | 0.17 | 0.16 | 0.15 |
| **S03** | 0.37 | 0.44 | 0.40 | 0.22 | 0.22 | 0.20 | 0.26 | 0.32 | 0.32 | 0.36 | 0.35 | 0.33 | 0.20 | 0.21 | 0.32 | 0.31 |
| | | | | | | | | | | | | | | | | |

# A2 With Proposed Development

| | 0° | 22.5° | 45° | 67.5° | 90° | 112.5° | 135° | 157.5° | 180° | 202.5° | 225° | 247.5° | 270° | 292.5° | 315° | 337.5° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Probability of Occurrence: Annual** | 0.121 | 0.083 | 0.088 | 0.151 | 0.234 | 0.049 | 0.031 | 0.030 | 0.043 | 0.031 | 0.049 | 0.032 | 0.025 | 0.010 | 0.006 | 0.015 |
| **Probability of Occurrence: Summer** | 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 | 0.020 | 0.011 | 0.012 |
| **O01** | 0.48 | 0.46 | 0.35 | 0.69 | 0.58 | 0.66 | 0.44 | 0.56 | 0.57 | 0.60 | 0.54 | 0.25 | 0.35 | 0.39 | 0.42 | 0.54 |
| **O02** | 0.42 | 0.44 | 0.30 | 0.32 | 0.35 | 0.49 | 0.31 | 0.53 | 0.41 | 0.36 | 0.33 | 0.30 | 0.39 | 0.44 | 0.41 | 0.51 |
| **O03** | 0.39 | 0.40 | 0.32 | 0.31 | 0.25 | 0.38 | 0.28 | 0.41 | 0.35 | 0.32 | 0.29 | 0.32 | 0.29 | 0.36 | 0.47 | 0.47 |
| **O04** | 0.43 | 0.41 | 0.39 | 0.62 | 0.25 | 0.28 | 0.23 | 0.38 | 0.41 | 0.40 | 0.26 | 0.23 | 0.20 | 0.53 | 0.45 | 0.42 |
| **O05** | 0.37 | 0.37 | 0.40 | 0.42 | 0.34 | 0.30 | 0.23 | 0.39 | 0.40 | 0.37 | 0.28 | 0.28 | 0.25 | 0.41 | 0.44 | 0.47 |
| **O06** | 0.25 | 0.10 | 0.34 | 0.34 | 0.31 | 0.35 | 0.29 | 0.43 | 0.45 | 0.42 | 0.15 | 0.29 | 0.27 | 0.09 | 0.26 | 0.08 |
| **O07** | 0.27 | 0.12 | 0.47 | 0.43 | 0.46 | 0.44 | 0.25 | 0.38 | 0.52 | 0.53 | 0.15 | 0.28 | 0.31 | 0.05 | 0.25 | 0.05 |
| **O08** | 0.22 | 0.24 | 0.27 | 0.33 | 0.33 | 0.32 | 0.21 | 0.34 | 0.39 | 0.31 | 0.32 | 0.14 | 0.18 | 0.19 | 0.21 | 0.22 |
| **O09** | 0.44 | 0.23 | 0.26 | 0.39 | 0.35 | 0.29 | 0.24 | 0.22 | 0.24 | 0.20 | 0.21 | 0.15 | 0.17 | 0.31 | 0.33 | 0.35 |
| **O10** | 0.34 | 0.36 | 0.44 | 0.66 | 0.65 | 0.53 | 0.45 | 0.21 | 0.23 | 0.26 | 0.35 | 0.21 | 0.44 | 0.44 | 0.46 | 0.41 |
| **O11** | 0.27 | 0.43 | 0.54 | 0.66 | 0.63 | 0.52 | 0.25 | 0.26 | 0.44 | 0.49 | 0.50 | 0.34 | 0.29 | 0.26 | 0.26 | 0.30 |
| **O12** | 0.29 | 0.50 | 0.49 | 0.59 | 0.51 | 0.44 | 0.50 | 0.29 | 0.25 | 0.34 | 0.45 | 0.49 | 0.40 | 0.31 | 0.27 | 0.26 |
| **O13** | 0.24 | 0.42 | 0.44 | 0.57 | 0.45 | 0.50 | 0.48 | 0.44 | 0.25 | 0.44 | 0.51 | 0.59 | 0.42 | 0.37 | 0.33 | 0.24 |
| **O14** | 0.20 | 0.32 | 0.24 | 0.36 | 0.36 | 0.39 | 0.38 | 0.43 | 0.29 | 0.45 | 0.47 | 0.52 | 0.34 | 0.31 | 0.28 | 0.24 |
| **O15** | 0.18 | 0.32 | 0.21 | 0.34 | 0.37 | 0.46 | 0.53 | 0.57 | 0.42 | 0.27 | 0.38 | 0.33 | 0.20 | 0.29 | 0.25 | 0.22 |
| **O16** | 0.19 | 0.25 | 0.20 | 0.26 | 0.34 | 0.44 | 0.43 | 0.51 | 0.44 | 0.23 | 0.32 | 0.36 | 0.25 | 0.29 | 0.41 | 0.22 |
| **O17** | 0.20 | 0.40 | 0.20 | 0.31 | 0.31 | 0.38 | 0.51 | 0.58 | 0.56 | 0.27 | 0.39 | 0.28 | 0.21 | 0.60 | 0.40 | 0.44 |
| **O18** | 0.22 | 0.29 | 0.24 | 0.29 | 0.37 | 0.46 | 0.47 | 0.45 | 0.43 | 0.39 | 0.39 | 0.62 | 0.55 | 0.53 | 0.31 | 0.33 |
| **O19** | 0.30 | 0.45 | 0.23 | 0.31 | 0.30 | 0.36 | 0.59 | 0.68 | 0.60 | 0.35 | 0.28 | 0.56 | 0.35 | 0.53 | 0.60 | 0.44 |
| **O20** | 0.34 | 0.33 | 0.28 | 0.26 | 0.33 | 0.37 | 0.48 | 0.54 | 0.45 | 0.48 | 0.37 | 0.58 | 0.45 | 0.47 | 0.50 | 0.36 |
| **O21** | 0.45 | 0.46 | 0.49 | 0.31 | 0.34 | 0.39 | 0.56 | 0.64 | 0.61 | 0.39 | 0.30 | 0.39 | 0.36 | 0.61 | 0.58 | 0.49 |
| **O22** | 0.38 | 0.35 | 0.33 | 0.30 | 0.28 | 0.38 | 0.40 | 0.49 | 0.44 | 0.52 | 0.38 | 0.37 | 0.41 | 0.53 | 0.49 | 0.39 |
| **O23** | 0.48 | 0.42 | 0.38 | 0.37 | 0.31 | 0.35 | 0.47 | 0.61 | 0.60 | 0.54 | 0.34 | 0.32 | 0.33 | 0.64 | 0.56 | 0.43 |
| **O24** | 0.34 | 0.32 | 0.33 | 0.26 | 0.27 | 0.34 | 0.36 | 0.46 | 0.46 | 0.55 | 0.36 | 0.35 | 0.35 | 0.54 | 0.47 | 0.34 |
| **O25** | 0.32 | 0.44 | 0.32 | 0.34 | 0.31 | 0.32 | 0.44 | 0.54 | 0.60 | 0.57 | 0.35 | 0.29 | 0.35 | 0.36 | 0.43 | 0.40 |
| **O26** | 0.30 | 0.37 | 0.30 | 0.31 | 0.30 | 0.29 | 0.28 | 0.35 | 0.39 | 0.54 | 0.39 | 0.36 | 0.35 | 0.28 | 0.40 | 0.34 |
| **O27** | 0.39 | 0.52 | 0.47 | 0.38 | 0.35 | 0.34 | 0.36 | 0.44 | 0.44 | 0.41 | 0.31 | 0.28 | 0.26 | 0.25 | 0.27 | 0.36 |
| **O28** | 0.26 | 0.34 | 0.37 | 0.28 | 0.26 | 0.27 | 0.19 | 0.29 | 0.38 | 0.50 | 0.46 | 0.33 | 0.35 | 0.27 | 0.23 | 0.29 |
| **O29** | 0.32 | 0.38 | 0.33 | 0.27 | 0.25 | 0.30 | 0.35 | 0.47 | 0.61 | 0.59 | 0.42 | 0.27 | 0.30 | 0.27 | 0.27 | 0.27 |
| **O30** | 0.40 | 0.33 | 0.29 | 0.32 | 0.37 | 0.48 | 0.40 | 0.44 | 0.39 | 0.27 | 0.26 | 0.31 | 0.34 | 0.44 | 0.53 | 0.52 |
| **P01** | 0.39 | 0.31 | 0.31 | 0.30 | 0.31 | 0.37 | 0.33 | 0.34 | 0.31 | 0.28 | 0.24 | 0.40 | 0.33 | 0.44 | 0.51 | 0.50 |
| **P02** | 0.36 | 0.32 | 0.29 | 0.32 | 0.35 | 0.36 | 0.29 | 0.36 | 0.33 | 0.31 | 0.24 | 0.26 | 0.31 | 0.41 | 0.45 | 0.43 |
| **P03** | 0.30 | 0.37 | 0.32 | 0.30 | 0.30 | 0.31 | 0.23 | 0.32 | 0.35 | 0.31 | 0.27 | 0.29 | 0.31 | 0.38 | 0.35 | 0.40 |
| **P04** | 0.30 | 0.35 | 0.32 | 0.31 | 0.31 | 0.36 | 0.28 | 0.38 | 0.35 | 0.27 | 0.24 | 0.34 | 0.34 | 0.43 | 0.38 | 0.41 |
| **P05** | 0.45 | 0.35 | 0.39 | 0.33 | 0.25 | 0.35 | 0.27 | 0.38 | 0.39 | 0.39 | 0.24 | 0.31 | 0.30 | 0.38 | 0.48 | 0.43 |
| **P06** | 0.43 | 0.39 | 0.45 | 0.47 | 0.30 | 0.23 | 0.19 | 0.27 | 0.28 | 0.31 | 0.28 | 0.26 | 0.30 | 0.35 | 0.43 | 0.44 |
| **P07** | 0.34 | 0.37 | 0.40 | 0.43 | 0.37 | 0.27 | 0.15 | 0.23 | 0.25 | 0.33 | 0.30 | 0.25 | 0.24 | 0.35 | 0.35 | 0.45 |
| **P08** | 0.31 | 0.30 | 0.58 | 0.58 | 0.49 | 0.70 | 0.17 | 0.33 | 0.45 | 0.65 | 0.33 | 0.36 | 0.34 | 0.12 | 0.26 | 0.16 |

| | 0° | 22.5° | 45° | 67.5° | 90° | 112.5° | 135° | 157.5° | 180° | 202.5° | 225° | 247.5° | 270° | 292.5° | 315° | 337.5° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Probability of Occurrence: Annual** | 0.121 | 0.083 | 0.088 | 0.151 | 0.234 | 0.049 | 0.031 | 0.030 | 0.043 | 0.031 | 0.049 | 0.032 | 0.025 | 0.010 | 0.006 | 0.015 |
| **Probability of Occurrence: Summer** | 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 | 0.020 | 0.011 | 0.012 |
| **P09** | 0.27 | 0.42 | 0.55 | 0.63 | 0.55 | 0.47 | 0.28 | 0.24 | 0.44 | 0.56 | 0.58 | 0.50 | 0.38 | 0.29 | 0.26 | 0.32 |
| **P10** | 0.30 | 0.42 | 0.55 | 0.54 | 0.45 | 0.56 | 0.40 | 0.19 | 0.30 | 0.33 | 0.34 | 0.46 | 0.33 | 0.31 | 0.30 | 0.31 |
| **P11** | 0.27 | 0.39 | 0.46 | 0.47 | 0.50 | 0.63 | 0.57 | 0.29 | 0.20 | 0.46 | 0.46 | 0.56 | 0.44 | 0.43 | 0.35 | 0.33 |
| **P12** | 0.26 | 0.31 | 0.35 | 0.32 | 0.39 | 0.48 | 0.58 | 0.53 | 0.25 | 0.33 | 0.38 | 0.54 | 0.42 | 0.42 | 0.43 | 0.33 |
| **P13** | 0.20 | 0.28 | 0.27 | 0.34 | 0.41 | 0.57 | 0.52 | 0.57 | 0.39 | 0.28 | 0.33 | 0.34 | 0.36 | 0.32 | 0.25 | 0.24 |
| **P14** | 0.19 | 0.27 | 0.22 | 0.30 | 0.40 | 0.52 | 0.51 | 0.60 | 0.44 | 0.24 | 0.40 | 0.30 | 0.23 | 0.33 | 0.26 | 0.25 |
| **P15** | 0.22 | 0.35 | 0.21 | 0.29 | 0.35 | 0.42 | 0.56 | 0.68 | 0.59 | 0.22 | 0.23 | 0.32 | 0.23 | 0.36 | 0.32 | 0.34 |
| **P16** | 0.47 | 0.56 | 0.41 | 0.42 | 0.31 | 0.33 | 0.63 | 0.77 | 0.75 | 0.33 | 0.26 | 0.35 | 0.30 | 0.68 | 0.62 | 0.46 |
| **P17** | 0.36 | 0.57 | 0.41 | 0.35 | 0.33 | 0.33 | 0.41 | 0.65 | 0.71 | 0.53 | 0.34 | 0.28 | 0.33 | 0.30 | 0.38 | 0.41 |
| **P18** | 0.31 | 0.57 | 0.51 | 0.41 | 0.57 | 0.34 | 0.23 | 0.31 | 0.41 | 0.42 | 0.36 | 0.32 | 0.40 | 0.53 | 0.29 | 0.30 |
| **P19** | 0.30 | 0.25 | 0.27 | 0.21 | 0.25 | 0.29 | 0.27 | 0.50 | 0.47 | 0.29 | 0.29 | 0.35 | 0.54 | 0.37 | 0.44 | 0.51 |
| **P20** | 0.30 | 0.46 | 0.43 | 0.28 | 0.31 | 0.49 | 0.41 | 0.64 | 0.67 | 0.51 | 0.37 | 0.22 | 0.31 | 0.28 | 0.21 | 0.28 |
| **S01** | 0.32 | 0.40 | 0.34 | 0.25 | 0.23 | 0.21 | 0.21 | 0.35 | 0.37 | 0.35 | 0.21 | 0.18 | 0.20 | 0.19 | 0.21 | 0.31 |
| **S02** | 0.18 | 0.28 | 0.31 | 0.21 | 0.46 | 0.36 | 0.33 | 0.48 | 0.43 | 0.43 | 0.23 | 0.15 | 0.19 | 0.18 | 0.13 | 0.14 |
| **S03** | 0.33 | 0.42 | 0.39 | 0.24 | 0.20 | 0.21 | 0.17 | 0.29 | 0.34 | 0.43 | 0.29 | 0.19 | 0.18 | 0.17 | 0.13 | 0.25 |
| | | | | | | | | | | | | | | | | |

# Appendix B

Site Wind Availability Study for the Central Kowloon Route (CKR) Project

**Highways Department**
**Major Works Project Management Office**

路 政 署
主要工程管理處

# Agreement No. CE 43/2010 (HY)
# Central Kowloon Route
# - Design and Construction

## Air Ventilation Assessment – Site Wind Availability Study

## (Ref: REP-190-00)

**October 2014**

**Arup-Mott MacDonald Joint Venture**

Highways Department

**Agreement No. CE 43/2010 (HY)**
**Central Kowloon Route –**
**Design and Construction**

Air Ventilation Assessment –
Site Wind Availability Study

217722-REP-190-00

Draft 1 | October 2014


**Arup-Mott MacDonald Joint Venture**
Level 5 Festival Walk
80 Tat Chee Avenue
Kowloon Tong
Kowloon
Hong Kong
www.arup.com




Job number 217722

**Arup-Mott MacDonald Joint Venture**

# Document Verification

**Arup-Mott MacDonald Joint Venture**

| | | | | |
|---|---|---|---|---|
| **Job title** | Agreement No. CE 43/2010 (HY) Central Kowloon Route – Design and Construction | | **Job number** | 217722 |
| **Document title** | Air Ventilation Assessment – Site Wind Availability Study | | **File reference** | |
| **Document ref** | 217722-REP-190-00 | | | |

| **Revision** | **Date** | **Filename** | REP-190-00, AVA Site Wind Availability Study.doc | | |
|---|---|---|---|---|---|
| Draft 1 | 14/10/14 | **Description** | First draft | | |
| | | | Prepared by | Checked by | Approved by |
| | | Name | Alastair Harmshaw | Alan Low | Jeff Sarsby |
| | | Signature | | | |
| | | **Filename** | | | |
| | | **Description** | | | |
| | | | Prepared by | Checked by | Approved by |
| | | Name | | | |
| | | Signature | | | |
| | | **Filename** | | | |
| | | **Description** | | | |
| | | | Prepared by | Checked by | Approved by |
| | | Name | | | |
| | | Signature | | | |
| | | **Filename** | | | |
| | | **Description** | | | |
| | | | Prepared by | Checked by | Approved by |
| | | Name | | | |
| | | Signature | | | |

**Issue Document Verification with Document** ✓





# Contents

# 1 Introduction

## 1.1 Description of Project

1.1.1 On 30 June 2011, Highways Department (HyD) of the Government of the Hong Kong Special Administrative Region appointed the Arup – Mott MacDonald Joint Venture (AMMJV) under Agreement No. CE43/2010(HY) to provide consultancy services in respect of Central Kowloon Route – Design and Construction (the Assignment).

## 1.2 Project Scope

1.2.1 The Project comprises the Central Kowloon Route (CKR) and the related works. The scope of the Project includes:

(a) A dual 3-lane east-west trunk road about 4.7km long with about 3.9km in tunnel connecting West Kowloon with the proposed KTD;

(b) Connection with Yau Ma Tei Interchange of the West Kowloon Highway and associated road network in West Kowloon;

(c) Connection to future Trunk Road T2 and associated road network in Kowloon Bay and KTD;

(d) A landscape deck at the west portal and the structure of landscape decks above the depressed road at east end;

(e) Demolition and/or re-provisioning of Government and other facilities affected by CKR;

(f) Re-provisioning of the section of Gascoigne Road Flyover affected by CKR;

(g) Conservation of the Yau Ma Tei Police Station;

(h) Enhancement works at Yau Ma Tei and Ma Tau Kok;

(i) Tunnel ventilation system and air purification system, and associated ventilation buildings, adits and shafts;

(j) Administration buildings, tunnel management system and operator facilities for the management and operation of the tunnel;

(k) TCSS for CKR, and associated interface with TCSS for other Route 6 projects and CBL, and control centres;





(l) Associated environmental, geotechnical, marine, landscape, utility, drainage, traffic engineering, fire services, electrical and mechanical works, and road works and modification works; and

(m) All other works associated with the construction or future operation of CKR.

## 1.3 Objective of this Study

1.3.1 The objective of this Site Wind Availability Study (SWAS) report is to present the effects of local topography and the surrounding urban environment on mean wind speed and turbulence intensity profiles. A 1:4000 scale topographical model was used in the study. These wind speed profiles will be used to accurately simulate the mean wind speed and turbulence intensity profiles for the approaching wind for the detailed Air Ventilation Assessment study, which will be conducted at a future date with a larger scale proximity model.

# 2 Methodology

2.1 The SWAS was undertaken in accordance with the current best international practice requirements stipulated in the Australasian Wind Engineering Society Quality Assurance Manual, AWES-QAM-1-2001 (2001), the American Society of Civil Engineers Manual, Report on Engineering Practice No. 67 for Wind Tunnel Studies of Buildings and Structures (1999), and the Hong Kong Environment Transport and Works Bureau, Technical Circular No. 1/06 for Air Ventilation Assessments (2006).

2.2 Details of the land topography and urban form were modelled for an area representing an approximate 15km radius from the subject site, excluding the buildings that would form part of the detailed study. The SWAS effectively defines the boundary conditions for modelling of the approach beyond the extent of the model for the detailed study. The approximate extent of the topographic model is shown in Figure 1.

2.3 The aim of the SWAS is to determine the correct local wind rose taking into account the effect of the local landforms. Due to the large area that the Central Kowloon Route covers, three sites have been selected for analysis and are labelled as follows:

- Site 1

  Represents the area surrounding the noise enclosures associated with the reconstructed Gascoigne Road Flyover (GRF) located in Yau Ma Tei.

- Site 2

  Represents the area surrounding the proposed ventilation building located in Ho Man Tin.

- Site 3

  Represents the area surrounding the proposed ventilation and administration buildings located in Kai Tak.

These site locations are also indicated in Figures 1 and 2.



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2.4 The landform in the model was fabricated at 40 m contour intervals. Photographs of the study model in the wind tunnel are provided in Figures 3a to 3d. Low-rise buildings are not included in the model for the 1:4000 scale SWAS study as their effect is negligible.

2.5 A hot-wire probe was used to take measurements of mean and standard deviation of wind speed at 22.5º increments for the full 360º azimuth, i.e. for 16 wind directions, and at eight (8) heights for each of the two study locations. Measurements were also made of the mean shift in yaw angle for each of the 16 wind directions. The shift in yaw angle was measured at 10-degree increments to provide a better resolution when determining the effect on the 16 directional sectors.

2.6 The topographical study results were combined with a statistical model of the Hong Kong wind climate, based on data from Hong Kong Observatory at Waglan Island during the period of 1953 2006 from HKUST, to arrive at the local wind rose and wind speed frequency table corresponding to annual mean wind speeds at the measurement position.


Figure 1: Approximate Extent of the Topographic Model and site locations

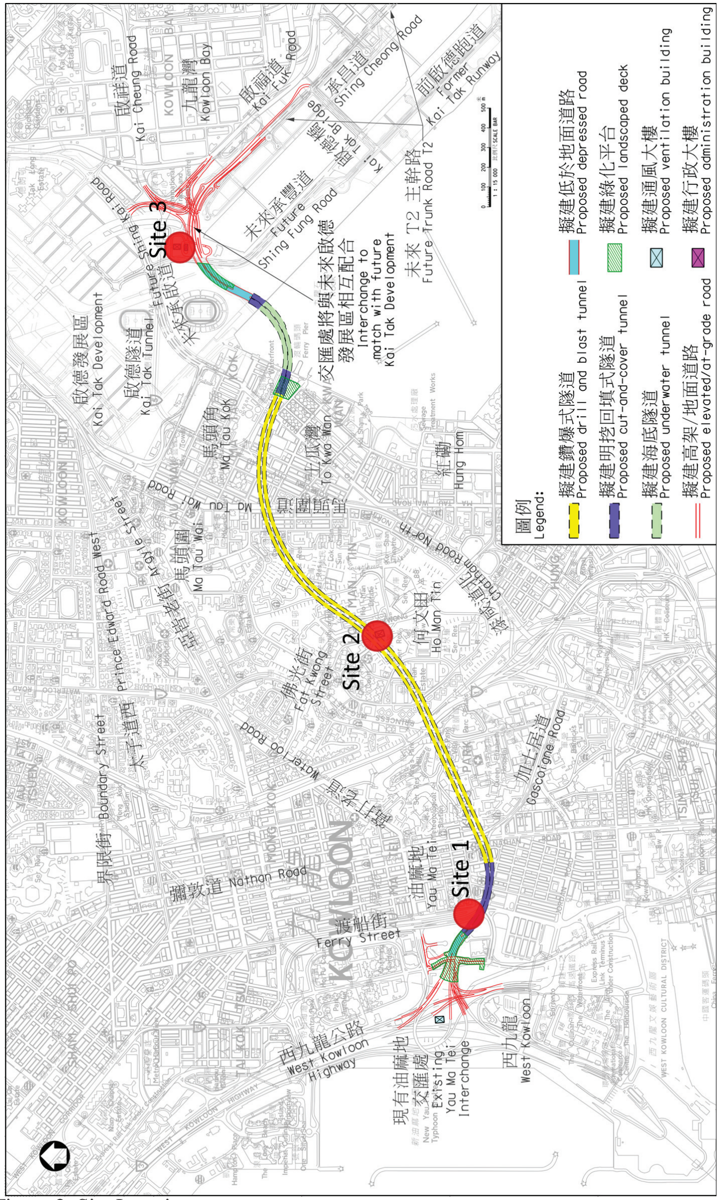


Figure 2: Site Locations



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Figure 3a: Photograph of the topographic model in the wind tunnel (view from the north north east)

Figure 3b: Photograph of the topographic model in the wind tunnel (view from the east north east)

Figure 3c: Photograph of the topographic model in the wind tunnel (view from the west south west)

Figure 3d: Photograph of the topographic model in the wind tunnel (view from the north west)





# 3 The Wind Model

**3.1** Waglan Island, located approximately 5km southeast of Hong Kong Island, has been used by Hong Kong Observatory, formerly The Royal Observatory, Hong Kong, for the collection of long-term wind data since December 1952 and that data is considered to be of the highest quality available for wind engineering purposes for Hong Kong. Due to its location, relative lack of development over the 50 years to 2001 and its generally uninterrupted exposure to winds, data collected at Waglan Island is considered to be representative of winds approaching the Hong Kong region. A study by the Hong Kong University of Science and Technology indicates that the amount and variety of nearby development that has taken place at other HKO measurement and monitoring sites, such as at Tsim Sha Tsui and the Central and Kowloon Star Ferry Piers, during their operational life makes them unsuitable for use for wind engineering applications.

**3.2** Hong Kong University of Science and Technology have applied correction factors for height and local terrain to the Waglan Island data to determine a wind rose corresponding to annual and summer mean wind speeds at a height equivalent to 500m above Waglan Island (refer to Appendix A). The annual wind rose for Waglan Island based on frequency data, is presented in Appendix A, indicates that prevailing and strong winds approaching Hong Kong occur mainly from the north-east quadrant and, to a lesser extent, the south-west. The summer wind rose is also presented.

**3.3** The key parameters for modelling the wind behaviour within the atmospheric boundary layer over a particular terrain are the variation in the mean wind speed with height and the variation of the turbulence intensity with height. 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.

**3.4** The boundary layer wind tunnel test facility used is shown in Figure 4. The test section has a 3m wide × 2m high working section and a maximum mean free stream wind speed of approximately 15m/s. This facility is set up to model atmospheric boundary layer flows at length scales ranging from 1:4000 to 1:50. The wind flow regime can be modified through the use of devices such as spires and fences to model different scale atmospheric boundary layer flows. For the current study, the wind speed profile in the wind tunnel facility was set up to simulate a 1:4000 scale open terrain by means of a 200mm high trip board upstream of the turntable to fine tune the mean wind speed and turbulence profile to match the target profile.

**3.5** Appropriate combinations of roughness elements and fences were used to simulate the characteristics of winds approaching Hong Kong through mean wind speed and turbulence intensity profiles corresponding to wind flowing over open water. The mean wind speed profile of the wind flow approaching the study area is in general agreement 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) as well as the corresponding profile defined in Hong Kong Code of Practice on Wind Effects (2004). This can be seen in Figure 5, below. The mean velocity profile stipulated by the Planning Department (2005) is based on a 0.15 power law exponent, as defined in equation (1), below, and closely resembles the Deaves and Harris (1978) profile for boundary layer flow over open terrain;

$$\frac{\bar{u}(z)}{\bar{u}_{ref}} = \left(\frac{z}{z_{ref}}\right)^{\alpha} \qquad (1)$$

where:

$\bar{u}(z)$ = mean wind speed at a height z (m/s);

$\bar{u}_{ref}$ = mean wind speed at a suitable reference height (m/s);

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

$z_{ref}$ = a suitable reference height (m);

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





**3.6** The turbulence intensity profile of the approaching wind flow was simulated in accordance with both the Hong Kong Code of Practice on Wind Effects (2004) and Terrain category 2 (Open) Terrain profile stipulated in Australian/New Zealand Standard AS/NZS 1170.2:2002. The simulated mean wind speed and turbulence intensity profiles are generally within ±10% of the target profiles defined in Equation (1), as well as in the Hong Kong Code of Practice on Wind Effects (2004) and AS/NZS 1170.2:2002 category 2 terrain and are presented in Figure 5. The spectrum of longitudinal turbulence of the approach flow measured at a height equivalent to 200m in prototype scale is presented in Figure 6 and satisfies the maximum ratio of 3 for modelling of the scaling of the length scale parameter, xLu as specified in the Engineering Science Data Unit 74031 (1974).

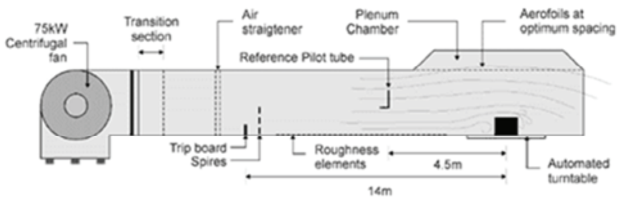


Figure 4: Boundary layer wind tunnel facility used for the study

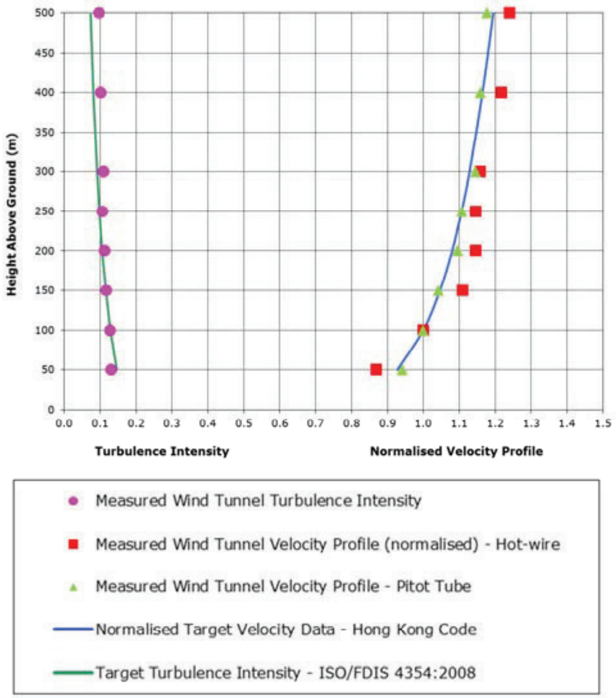


Figure 5: Comparison of Standard Turbulence Intensity and Wind Speed Profiles against the 1:4000 scale wind tunnel velocity profile for Hong Kong upstream winds beyond the radius of the topography model.





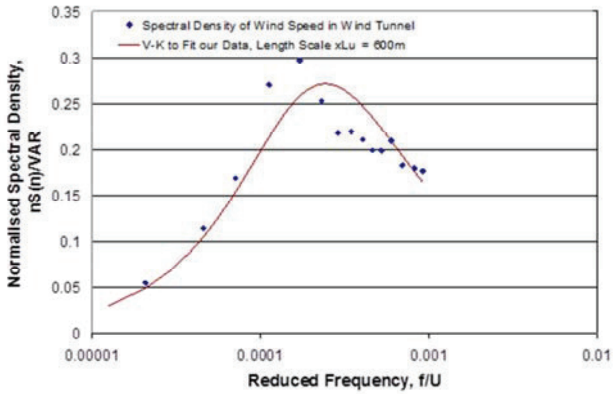


Figure 6: The Spectrum of Longitudinal Turbulence Intensity at 200m for 1:4000 scale open terrain against the Von Karman Spectrum for an integral length scale of 600m in open terrain.

# 4 Analysis and Results

**4.1** The location of the three study points, where the velocity profile is measured is indicated in Figure 2. 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 wind speed and turbulence intensity above the three measurement positions.

**4.2** Wind tunnel measurements were taken at 22.5° intervals for the full 360° azimuth (i.e. 16 wind directions), where a wind direction of 0° or 360° corresponds to an incident wind approaching the study area directly from the north, 90° corresponds to an incident wind approaching the study area directly from the east, etc.

**4.3** For each wind direction tested, mean wind speeds and turbulence intensities were determined at 8 heights, equivalent to 50, 100, 150, 200, 250, 300, 400 and 500m in prototype scale, above the respective measurement positions within the study area. While measurements were taken, all existing and proposed buildings within the 500m radius of the larger scale detailed study model were excluded from the 1:4000 scale wind tunnel model. Buildings within the 500m radius will be included in proximity models for the more detailed and larger scale study.





**4.4** The ratio of the wind speed at each of the above heights relative to the upstream reference wind speed at a 500m height is obtained. For each of these heights and wind directions, the turbulence intensity is also obtained from the local mean and standard deviation wind speeds. These two quantities are defined below by equations 1 and 2;

$$\text{normalised wind velocity} = \frac{\overline{V}_z(\theta)}{\overline{V}_{500,\text{approach}}(\theta)} \quad (1)$$

$$\text{turbulence intensity} = \frac{\sigma_{V,z}(\theta)}{\overline{V}_z(\theta)} \quad (2)$$

In Equations (1) and (2):

$\overline{V}_z(\theta)$ = mean wind speed at a height z (z = 50, 100, 150, 200, 250, 300, 400 or 500m in prototype scale) for an approaching wind direction θ (θ = 22.5°, 45°, 67.5°, 90°, 112.5°, 135°, 157.5°, 180°, 202.5°, 225°, 247.5°, 270°, 292.5°, 315°, 337.5° or 360°);

$\overline{V}_{500,\text{approach}}(\theta)$ = mean wind speed of the approaching wind at a height equivalent to 500 m in prototype scale for an approaching wind direction θ;

$\sigma_{V,z}(\theta)$ = the standard deviation of the fluctuating wind speed $V_z$ for an approaching wind direction θ.

**4.5** The results for each of the wind directions are presented in graphical as well as tabular form (Tables B1 to B16 inclusive) in Appendix B.

**4.6** The directional factors were then applied to the Hong Kong non-typhoon wind climate model, derived from HKO's Waglan Island wind data to determine the site-specific wind rose pertaining to annual hourly mean wind speeds at a height of 500m above the measurement positions. The site wind roses as well as the frequency table for heights of 50m and 500m are presented in Appendix C of this report.

# 5 Conclusions

**5.1** The analysis indicates that the three site locations chosen for analysis experienced varied topographical effects on the wind conditions due to their respective locations throughout Kowloon. Generally the three sites are most significantly affected by the mountains to the North and North-West and the local urban terrain. A number of the most significant impacts for each of the sites are summarised below:

- Site 1

  Benefits from its open aspect to the westerly directions yet experiences partial shielding from the mountains and urban landscape to the North and West of the site, particularly at the lower altitudes.

- Site 2

  Experiences partial shielding from the mountains to the North and North-west at the lower heights. The mountain ranges to the North and North-West also tend to cause a speed up of the winds at the higher heights.

- Site 3

  Benefits from its open aspect to the south easterly directions and the large fetch length of open water between the mountains to the south and the site. The mountain ranges to the north and north-west also tend to cause a speed up of winds at the higher heights.

**5.2** The proximity of three site locations to the north and north-westerly mountains results in significantly distorted upstream wind speed profiles for the approaching winds from the north-west to north directions. These profiles need to be matched when conducting the detailed larger scale study for Air Ventilation.



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# References

Australasian Wind Engineering Society (2001), Wind Engineering Studies of Buildings, AWES-QAM-1-2001.

Buildings Department (HKSAR) (2004), Code of Practice on Wind Effects in Hong Kong.

CLP Power Wind/Wave Tunnel Facility, The Hong Kong University of Science and Technology, Investigation Report WWTF007-2006, July 2006.

Deaves, D.M. and Harris, R.I. (1978), “A mathematical model of the structure of strong winds”, Construction Industry Research and Information Association (CIRIA) Report 76, London

Engineering Science Data Unit, Data Sheet 74031, “Characteristics of Atmospheric Turbulence Near the Ground. Part II: Single Point Data for Strong Winds (Neutral Atmosphere).

Manual of practice for wind tunnel studies of buildings and structures (1999), Editor Nicholas Isyumov, Task Committee on Wind Tunnel Testing of Buildings and Structures, Aerodynamics Committee, Aerospace Division, American Society of Civil Engineers.

Planning Department, The Government of the Hong Kong Special Administrative Region (2005), Technical Guide for Air Ventilation Assessment for Developments in Hong Kong.

Planning Department, The Government of the Hong Kong Special Administrative Region (2005), Feasibility Study for Establishment of Air Ventilation Assessment – Final Report, Department of Architecture, The Chinese University of Hong Kong.

# Appendix A

## Wind Rose for Waglan Island at 500m, from HKUST (1953-2006)

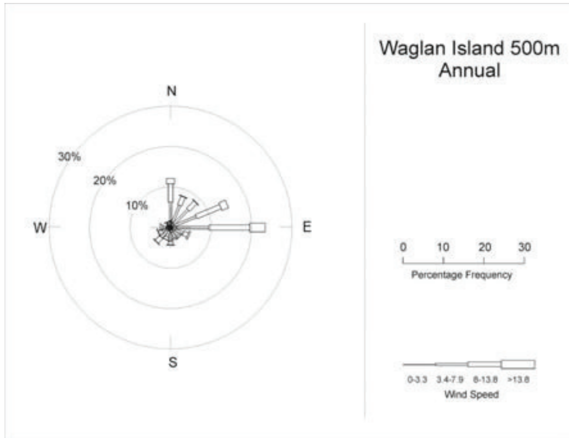



Figure A1: Annual Wind Rose for Waglan Island corrected for height and Terrain to 500m based on data collected between 1953 and 2006.

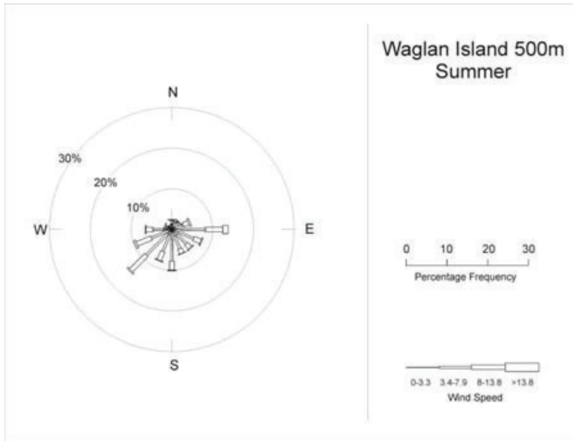



Figure A2: Summer Wind Rose for Waglan Island corrected for height and Terrain to 500m based on data collected between 1953 and 2006.





# Appendix B

## Plots and Tabulated Results of the Site Wind Speed and Turbulence Intensity Profiles

Note: Wind speeds are normalized with respect to the corrected Waglan Island wind speed at 500m

Table B1: Wind Characteristics at 0 $^o$ (North)

| Prototype scale height (m) | Point 1 Normalised mean wind speed | Point 2 Normalised mean wind speed | Point 3 Normalised mean wind speed | Point 1 Turbulence Intensity | Point 2 Turbulence Intensity | Point 3 Turbulence Intensity |
|---|---|---|---|---|---|---|
| 500 | 1.000 | 1.000 | 1.000 | 0.187 | 0.194 | 0.121 |
| 400 | 0.970 | 0.974 | 0.938 | 0.206 | 0.208 | 0.161 |
| 300 | 0.929 | 0.872 | 0.865 | 0.213 | 0.238 | 0.187 |
| 250 | 0.879 | 0.835 | 0.800 | 0.233 | 0.243 | 0.206 |
| 200 | 0.825 | 0.785 | 0.749 | 0.241 | 0.259 | 0.226 |
| 150 | 0.764 | 0.712 | 0.649 | 0.271 | 0.264 | 0.255 |
| 100 | 0.591 | 0.601 | 0.586 | 0.345 | 0.286 | 0.278 |
| 50 | 0.367 | 0.527 | 0.468 | 0.448 | 0.296 | 0.285 |

Table B2: Wind Characteristics at 22.5 $^o$ (North North East)

| Prototype scale height (m) | Point 1 Normalised mean wind speed | Point 2 Normalised mean wind speed | Point 3 Normalised mean wind speed | Point 1 Turbulence Intensity | Point 2 Turbulence Intensity | Point 3 Turbulence Intensity |
|---|---|---|---|---|---|---|
| 500 | 1.000 | 1.000 | 1.000 | 0.164 | 0.158 | 0.209 |
| 400 | 0.934 | 0.807 | 0.969 | 0.180 | 0.165 | 0.213 |
| 300 | 0.862 | 0.767 | 0.880 | 0.195 | 0.176 | 0.240 |
| 250 | 0.819 | 0.734 | 0.865 | 0.217 | 0.193 | 0.241 |
| 200 | 0.803 | 0.689 | 0.821 | 0.219 | 0.201 | 0.263 |
| 150 | 0.728 | 0.644 | 0.752 | 0.252 | 0.217 | 0.265 |
| 100 | 0.585 | 0.613 | 0.650 | 0.323 | 0.270 | 0.279 |
| 50 | 0.333 | 0.459 | 0.541 | 0.442 | 0.274 | 0.331 |

Table B3: Wind Characteristics at 45 ° (North East)

| Prototype scale height (m) | Point 1 Normalised mean wind speed | Point 2 Normalised mean wind speed | Point 3 Normalised mean wind speed | Point 1 Turbulence Intensity | Point 2 Turbulence Intensity | Point 3 Turbulence Intensity |
|---|---|---|---|---|---|---|
| 500 | 1.000 | 1.000 | 1.000 | 0.173 | 0.154 | 0.124 |
| 400 | 0.966 | 0.994 | 0.929 | 0.186 | 0.154 | 0.132 |
| 300 | 0.873 | 0.942 | 0.885 | 0.207 | 0.165 | 0.151 |
| 250 | 0.834 | 0.911 | 0.867 | 0.227 | 0.169 | 0.157 |
| 200 | 0.769 | 0.893 | 0.802 | 0.241 | 0.180 | 0.175 |
| 150 | 0.701 | 0.851 | 0.740 | 0.270 | 0.201 | 0.203 |
| 100 | 0.569 | 0.755 | 0.624 | 0.333 | 0.238 | 0.232 |
| 50 | 0.349 | 0.600 | 0.485 | 0.450 | 0.259 | 0.261 |

Table B4: Wind Characteristics at 67.5 ° (East North East)

| Prototype scale height (m) | Point 1 Normalised mean wind speed | Point 2 Normalised mean wind speed | Point 3 Normalised mean wind speed | Point 1 Turbulence Intensity | Point 2 Turbulence Intensity | Point 3 Turbulence Intensity |
|---|---|---|---|---|---|---|
| 500 | 1.000 | 1.000 | 1.000 | 0.132 | 0.138 | 0.137 |
| 400 | 0.946 | 0.951 | 0.935 | 0.140 | 0.152 | 0.164 |
| 300 | 0.900 | 0.909 | 0.809 | 0.165 | 0.154 | 0.217 |
| 250 | 0.855 | 0.855 | 0.742 | 0.186 | 0.168 | 0.248 |
| 200 | 0.768 | 0.809 | 0.646 | 0.214 | 0.186 | 0.280 |
| 150 | 0.679 | 0.679 | 0.527 | 0.235 | 0.231 | 0.335 |
| 100 | 0.611 | 0.563 | 0.471 | 0.240 | 0.253 | 0.366 |
| 50 | 0.477 | 0.416 | 0.364 | 0.302 | 0.300 | 0.397 |

Table B5: Wind Characteristics at 90 ° (East)

| Prototype scale height (m) | Point 1 Normalised mean wind speed | Point 2 Normalised mean wind speed | Point 3 Normalised mean wind speed | Point 1 Turbulence Intensity | Point 2 Turbulence Intensity | Point 3 Turbulence Intensity |
|---|---|---|---|---|---|---|
| 500 | 1.000 | 1.000 | 1.000 | 0.143 | 0.135 | 0.125 |
| 400 | 0.943 | 0.970 | 0.953 | 0.154 | 0.141 | 0.145 |
| 300 | 0.897 | 0.928 | 0.842 | 0.186 | 0.152 | 0.198 |
| 250 | 0.859 | 0.891 | 0.759 | 0.206 | 0.158 | 0.230 |
| 200 | 0.780 | 0.850 | 0.717 | 0.222 | 0.172 | 0.246 |
| 150 | 0.679 | 0.775 | 0.604 | 0.247 | 0.209 | 0.292 |
| 100 | 0.571 | 0.647 | 0.516 | 0.279 | 0.272 | 0.324 |
| 50 | 0.472 | 0.451 | 0.392 | 0.308 | 0.342 | 0.371 |





Table B6: Wind Characteristics at 112.5 ° (East South East)

| Prototype scale height (m) | Point 1 Normalised mean wind speed | Point 2 Normalised mean wind speed | Point 3 Normalised mean wind speed | Point 1 Turbulence Intensity | Point 2 Turbulence Intensity | Point 3 Turbulence Intensity |
|---|---|---|---|---|---|---|
| 500 | 1.000 | 1.000 | 1.000 | 0.123 | 0.123 | 0.155 |
| 400 | 1.003 | 0.963 | 0.944 | 0.135 | 0.130 | 0.175 |
| 300 | 0.947 | 0.910 | 0.885 | 0.156 | 0.143 | 0.196 |
| 250 | 0.904 | 0.882 | 0.817 | 0.169 | 0.149 | 0.219 |
| 200 | 0.871 | 0.833 | 0.633 | 0.191 | 0.158 | 0.272 |
| 150 | 0.809 | 0.776 | 0.640 | 0.201 | 0.174 | 0.287 |
| 100 | 0.686 | 0.687 | 0.535 | 0.213 | 0.203 | 0.336 |
| 50 | 0.564 | 0.531 | 0.406 | 0.234 | 0.292 | 0.392 |

Table B7: Wind Characteristics at 135 ° (South East)

| Prototype scale height (m) | Point 1 Normalised mean wind speed | Point 2 Normalised mean wind speed | Point 3 Normalised mean wind speed | Point 1 Turbulence Intensity | Point 2 Turbulence Intensity | Point 3 Turbulence Intensity |
|---|---|---|---|---|---|---|
| 500 | 1.000 | 1.000 | 1.000 | 0.148 | 0.133 | 0.105 |
| 400 | 0.985 | 0.850 | 0.967 | 0.170 | 0.172 | 0.114 |
| 300 | 0.900 | 0.756 | 0.920 | 0.202 | 0.206 | 0.128 |
| 250 | 0.839 | 0.723 | 0.891 | 0.223 | 0.225 | 0.136 |
| 200 | 0.769 | 0.682 | 0.834 | 0.259 | 0.234 | 0.147 |
| 150 | 0.695 | 0.628 | 0.782 | 0.288 | 0.269 | 0.157 |
| 100 | 0.602 | 0.540 | 0.706 | 0.304 | 0.309 | 0.178 |
| 50 | 0.523 | 0.434 | 0.575 | 0.302 | 0.363 | 0.207 |

Table B8: Wind Characteristics at 157.5 ° (South South East)

| Prototype scale height (m) | Point 1 Normalised mean wind speed | Point 2 Normalised mean wind speed | Point 3 Normalised mean wind speed | Point 1 Turbulence Intensity | Point 2 Turbulence Intensity | Point 3 Turbulence Intensity |
|---|---|---|---|---|---|---|
| 500 | 1.000 | 1.000 | 1.000 | 0.131 | 0.187 | 0.123 |
| 400 | 0.945 | 0.991 | 0.954 | 0.147 | 0.208 | 0.131 |
| 300 | 0.876 | 0.886 | 0.894 | 0.171 | 0.233 | 0.149 |
| 250 | 0.834 | 0.801 | 0.872 | 0.182 | 0.239 | 0.145 |
| 200 | 0.769 | 0.780 | 0.826 | 0.194 | 0.260 | 0.158 |
| 150 | 0.712 | 0.754 | 0.796 | 0.199 | 0.259 | 0.158 |
| 100 | 0.635 | 0.652 | 0.762 | 0.213 | 0.288 | 0.159 |
| 50 | 0.573 | 0.493 | 0.719 | 0.228 | 0.325 | 0.163 |

Table B9: Wind Characteristics at 180 ° (South)

| Prototype scale height (m) | Point 1 Normalised mean wind speed | Point 2 Normalised mean wind speed | Point 3 Normalised mean wind speed | Point 1 Turbulence Intensity | Point 2 Turbulence Intensity | Point 3 Turbulence Intensity |
|---|---|---|---|---|---|---|
| 500 | 1.000 | 1.000 | 1.000 | 0.167 | 0.122 | 0.152 |
| 400 | 0.929 | 1.029 | 0.954 | 0.183 | 0.137 | 0.162 |
| 300 | 0.868 | 0.987 | 0.898 | 0.209 | 0.154 | 0.170 |
| 250 | 0.829 | 0.941 | 0.871 | 0.222 | 0.167 | 0.169 |
| 200 | 0.767 | 0.901 | 0.850 | 0.257 | 0.186 | 0.165 |
| 150 | 0.647 | 0.758 | 0.815 | 0.310 | 0.193 | 0.170 |
| 100 | 0.553 | 0.675 | 0.778 | 0.360 | 0.243 | 0.169 |
| 50 | 0.423 | 0.532 | 0.739 | 0.429 | 0.305 | 0.169 |

Table B10: Wind Characteristics at 202.5 ° (South South West)

| Prototype scale height (m) | Point 1 Normalised mean wind speed | Point 2 Normalised mean wind speed | Point 3 Normalised mean wind speed | Point 1 Turbulence Intensity | Point 2 Turbulence Intensity | Point 3 Turbulence Intensity |
|---|---|---|---|---|---|---|
| 500 | 1.000 | 1.000 | 1.000 | 0.188 | 0.156 | 0.153 |
| 400 | 0.941 | 0.961 | 0.935 | 0.240 | 0.164 | 0.163 |
| 300 | 0.825 | 0.881 | 0.883 | 0.289 | 0.199 | 0.168 |
| 250 | 0.740 | 0.841 | 0.858 | 0.329 | 0.203 | 0.169 |
| 200 | 0.581 | 0.789 | 0.830 | 0.389 | 0.216 | 0.168 |
| 150 | 0.503 | 0.722 | 0.822 | 0.432 | 0.227 | 0.164 |
| 100 | 0.415 | 0.626 | 0.779 | 0.498 | 0.254 | 0.175 |
| 50 | 0.375 | 0.505 | 0.728 | 0.600 | 0.291 | 0.176 |

Table B11: Wind Characteristics at 225 ° (South West)

| Prototype scale height (m) | Point 1 Normalised mean wind speed | Point 2 Normalised mean wind speed | Point 3 Normalised mean wind speed | Point 1 Turbulence Intensity | Point 2 Turbulence Intensity | Point 3 Turbulence Intensity |
|---|---|---|---|---|---|---|
| 500 | 1.000 | 1.000 | 1.000 | 0.194 | 0.159 | 0.177 |
| 400 | 0.968 | 0.939 | 0.918 | 0.205 | 0.175 | 0.213 |
| 300 | 0.961 | 0.902 | 0.832 | 0.219 | 0.192 | 0.234 |
| 250 | 0.936 | 0.858 | 0.799 | 0.233 | 0.212 | 0.243 |
| 200 | 0.922 | 0.822 | 0.741 | 0.245 | 0.227 | 0.254 |
| 150 | 0.924 | 0.759 | 0.667 | 0.209 | 0.254 | 0.271 |
| 100 | 0.892 | 0.662 | 0.612 | 0.225 | 0.301 | 0.278 |
| 50 | 0.836 | 0.552 | 0.554 | 0.220 | 0.359 | 0.262 |





Table B12: Wind Characteristics at 247.5 ° (West South West)

| Prototype scale height (m) | Point 1 Normalised mean wind speed | Point 2 Normalised mean wind speed | Point 3 Normalised mean wind speed | Point 1 Turbulence Intensity | Point 2 Turbulence Intensity | Point 3 Turbulence Intensity |
|---|---|---|---|---|---|---|
| 500 | 1.000 | 1.000 | 1.000 | 0.110 | 0.119 | 0.144 |
| 400 | 0.971 | 0.985 | 0.911 | 0.115 | 0.128 | 0.165 |
| 300 | 0.945 | 0.883 | 0.833 | 0.120 | 0.172 | 0.190 |
| 250 | 0.949 | 0.817 | 0.803 | 0.122 | 0.202 | 0.208 |
| 200 | 0.899 | 0.744 | 0.773 | 0.128 | 0.207 | 0.213 |
| 150 | 0.899 | 0.687 | 0.712 | 0.139 | 0.233 | 0.247 |
| 100 | 0.842 | 0.627 | 0.634 | 0.144 | 0.235 | 0.256 |
| 50 | 0.803 | 0.546 | 0.574 | 0.146 | 0.272 | 0.272 |

Table B13: Wind Characteristics at 270 ° (West)

| Prototype scale height (m) | Point 1 Normalised mean wind speed | Point 2 Normalised mean wind speed | Point 3 Normalised mean wind speed | Point 1 Turbulence Intensity | Point 2 Turbulence Intensity | Point 3 Turbulence Intensity |
|---|---|---|---|---|---|---|
| 500 | 1.000 | 1.000 | 1.000 | 0.111 | 0.113 | 0.128 |
| 400 | 0.968 | 0.940 | 0.948 | 0.114 | 0.113 | 0.149 |
| 300 | 0.940 | 0.884 | 0.855 | 0.120 | 0.149 | 0.189 |
| 250 | 0.938 | 0.853 | 0.791 | 0.120 | 0.166 | 0.207 |
| 200 | 0.897 | 0.788 | 0.758 | 0.130 | 0.200 | 0.234 |
| 150 | 0.858 | 0.712 | 0.641 | 0.145 | 0.229 | 0.259 |
| 100 | 0.805 | 0.620 | 0.573 | 0.147 | 0.264 | 0.266 |
| 50 | 0.756 | 0.560 | 0.512 | 0.149 | 0.275 | 0.282 |

Table B14: Wind Characteristics at 292.5 ° (West North West)

| Prototype scale height (m) | Point 1 Normalised mean wind speed | Point 2 Normalised mean wind speed | Point 3 Normalised mean wind speed | Point 1 Turbulence Intensity | Point 2 Turbulence Intensity | Point 3 Turbulence Intensity |
|---|---|---|---|---|---|---|
| 500 | 1.000 | 1.000 | 1.000 | 0.121 | 0.114 | 0.145 |
| 400 | 0.966 | 0.732 | 0.900 | 0.123 | 0.155 | 0.164 |
| 300 | 0.942 | 0.730 | 0.920 | 0.134 | 0.173 | 0.190 |
| 250 | 0.930 | 0.685 | 0.851 | 0.137 | 0.186 | 0.206 |
| 200 | 0.893 | 0.625 | 0.814 | 0.157 | 0.218 | 0.221 |
| 150 | 0.858 | 0.559 | 0.727 | 0.163 | 0.262 | 0.249 |
| 100 | 0.794 | 0.486 | 0.661 | 0.179 | 0.315 | 0.262 |
| 50 | 0.710 | 0.351 | 0.588 | 0.175 | 0.377 | 0.265 |

Table B15: Wind Characteristics at 315 ° (North West)

| Prototype scale height (m) | Point 1 Normalised mean wind speed | Point 2 Normalised mean wind speed | Point 3 Normalised mean wind speed | Point 1 Turbulence Intensity | Point 2 Turbulence Intensity | Point 3 Turbulence Intensity |
|---|---|---|---|---|---|---|
| 500 | 1.000 | 1.000 | 1.000 | 0.130 | 0.142 | 0.144 |
| 400 | 0.935 | 0.945 | 0.945 | 0.147 | 0.149 | 0.159 |
| 300 | 0.869 | 0.896 | 0.906 | 0.164 | 0.155 | 0.166 |
| 250 | 0.815 | 0.872 | 0.907 | 0.181 | 0.170 | 0.169 |
| 200 | 0.737 | 0.793 | 0.843 | 0.198 | 0.186 | 0.190 |
| 150 | 0.680 | 0.714 | 0.807 | 0.219 | 0.243 | 0.199 |
| 100 | 0.577 | 0.628 | 0.750 | 0.239 | 0.280 | 0.215 |
| 50 | 0.432 | 0.474 | 0.652 | 0.264 | 0.291 | 0.246 |

Table B16: Wind Characteristics at 337.5 ° (North North West)

| Prototype scale height (m) | Point 1 Normalised mean wind speed | Point 2 Normalised mean wind speed | Point 3 Normalised mean wind speed | Point 1 Turbulence Intensity | Point 2 Turbulence Intensity | Point 3 Turbulence Intensity |
|---|---|---|---|---|---|---|
| 500 | 1.000 | 1.000 | 1.000 | 0.120 | 0.135 | 0.200 |
| 400 | 0.958 | 0.941 | 0.871 | 0.142 | 0.152 | 0.223 |
| 300 | 0.895 | 0.912 | 0.819 | 0.160 | 0.171 | 0.251 |
| 250 | 0.851 | 0.880 | 0.746 | 0.171 | 0.177 | 0.254 |
| 200 | 0.801 | 0.845 | 0.725 | 0.198 | 0.191 | 0.266 |
| 150 | 0.725 | 0.794 | 0.672 | 0.220 | 0.203 | 0.280 |
| 100 | 0.593 | 0.660 | 0.595 | 0.257 | 0.224 | 0.290 |
| 50 | 0.442 | 0.477 | 0.526 | 0.283 | 0.271 | 0.316 |





# Appendix C

## Wind Speed Frequency Tables and Wind Roses

Table C1: Percentage occurrence of directional winds at 50m for Point 1 - Annual

| Wind Angle (°) | Percentage Occurrence (%) for wind speed ranges: | | | | |
|---|---|---|---|---|---|
| | 0-3.3 m/s | 3.4–7.9 m/s | 8.0–13.8 m/s | >13.8 m/s | Total |
| 0 | 7.4 | 4.7 | 0.0 | 0.0 | 12.1 |
| 22.5 | 7.2 | 1.0 | 0.0 | 0.0 | 8.3 |
| 45 | 7.7 | 1.2 | 0.0 | 0.0 | 8.8 |
| 67.5 | 4.2 | 9.7 | 1.2 | 0.0 | 15.1 |
| 90 | 8.0 | 14.4 | 1.0 | 0.0 | 23.4 |
| 112.5 | 4.8 | 2.9 | 0.3 | 0.0 | 8.0 |
| 135 | 0.5 | 0.2 | 0.0 | 0.0 | 0.7 |
| 157.5 | 1.6 | 0.6 | 0.0 | 0.0 | 2.2 |
| 180 | 3.4 | 0.9 | 0.0 | 0.0 | 4.3 |
| 202.5 | 2.7 | 0.4 | 0.0 | 0.0 | 3.1 |
| 225 | 1.1 | 3.1 | 0.7 | 0.0 | 4.9 |
| 247.5 | 0.7 | 1.9 | 0.6 | 0.0 | 3.2 |
| 270 | 0.8 | 1.5 | 0.3 | 0.0 | 2.5 |
| 292.5 | 0.6 | 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 |

Corresponding wind rose below

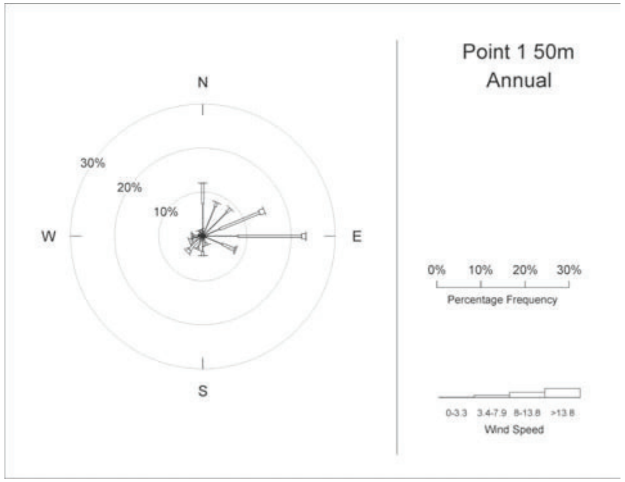


Table C2: Percentage occurrence of directional winds at 500m for Point 1 - Annual

| Wind Angle (º) | Percentage Occurrence (%) for wind speed ranges: | | | | |
|---|---|---|---|---|---|
| | 0-3.3 m/s | 3.4–7.9 m/s | 8.0–13.8 m/s | >13.8 m/s | Total |
| 0 | 1.4 | 4.9 | 4.5 | 1.3 | 12.1 |
| 22.5 | 1.4 | 4.6 | 2.2 | 0.1 | 8.3 |
| 45 | 1.3 | 5.3 | 2.2 | 0.1 | 8.8 |
| 67.5 | 0.8 | 4.7 | 6.6 | 3.0 | 15.1 |
| 90 | 1.7 | 8.5 | 10.0 | 3.2 | 23.4 |
| 112.5 | 1.3 | 2.1 | 1.2 | 0.3 | 4.9 |
| 135 | 1.2 | 1.4 | 0.5 | 0.0 | 3.1 |
| 157.5 | 1.2 | 1.4 | 0.3 | 0.0 | 3.0 |
| 180 | 1.4 | 2.1 | 0.7 | 0.1 | 4.3 |
| 202.5 | 0.9 | 1.6 | 0.5 | 0.0 | 3.1 |
| 225 | 0.7 | 2.8 | 1.3 | 0.1 | 4.9 |
| 247.5 | 0.5 | 1.6 | 1.0 | 0.1 | 3.2 |
| 270 | 0.5 | 1.3 | 0.7 | 0.1 | 2.5 |
| 292.5 | 0.4 | 0.4 | 0.2 | 0.1 | 1.0 |
| 315 | 0.4 | 0.1 | 0.1 | 0.1 | 0.6 |
| 337.5 | 0.4 | 0.6 | 0.4 | 0.2 | 1.5 |

Corresponding wind rose below

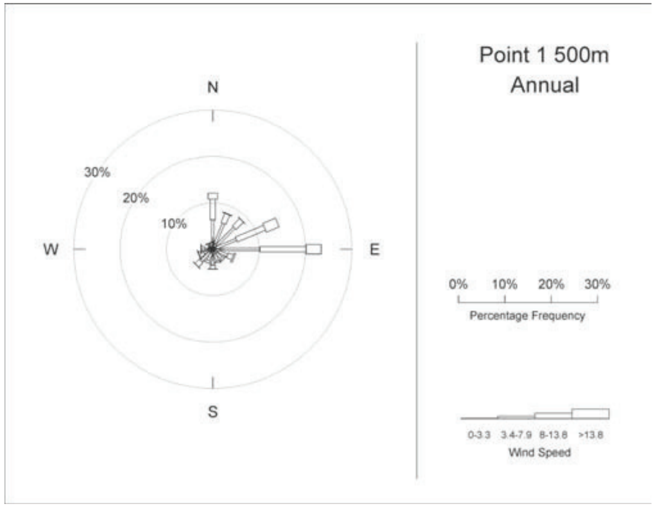







Table C3: Percentage occurrence of directional winds at 50m for Point 2 - Annual

| Wind Angle (º) | Percentage Occurrence (%) for wind speed ranges: | | | | |
|---|---|---|---|---|---|
| | 0-3.3 m/s | 3.4–7.9 m/s | 8.0–13.8 m/s | >13.8 m/s | Total |
| 0 | 4.6 | 6.8 | 0.7 | 0.0 | 12.1 |
| 22.5 | 4.9 | 3.3 | 0.0 | 0.0 | 8.3 |
| 45 | 3.5 | 5.2 | 0.1 | 0.0 | 8.8 |
| 67.5 | 5.8 | 9.0 | 0.3 | 0.0 | 15.1 |
| 90 | 6.5 | 14.9 | 2.0 | 0.0 | 23.4 |
| 112.5 | 2.4 | 2.1 | 0.4 | 0.0 | 4.9 |
| 135 | 2.5 | 0.6 | 0.0 | 0.0 | 3.1 |
| 157.5 | 2.7 | 0.3 | 0.0 | 0.0 | 3.0 |
| 180 | 2.9 | 1.4 | 0.0 | 0.0 | 4.3 |
| 202.5 | 1.7 | 1.3 | 0.1 | 0.0 | 3.1 |
| 225 | 2.6 | 2.3 | 0.0 | 0.0 | 4.9 |
| 247.5 | 1.3 | 1.8 | 0.1 | 0.0 | 3.2 |
| 270 | 1.3 | 1.2 | 0.1 | 0.0 | 2.5 |
| 292.5 | 0.9 | 0.2 | 0.0 | 0.0 | 1.0 |
| 315 | 0.5 | 0.1 | 0.0 | 0.0 | 0.6 |
| 337.5 | 0.9 | 0.5 | 0.1 | 0.0 | 1.5 |

Corresponding wind rose below

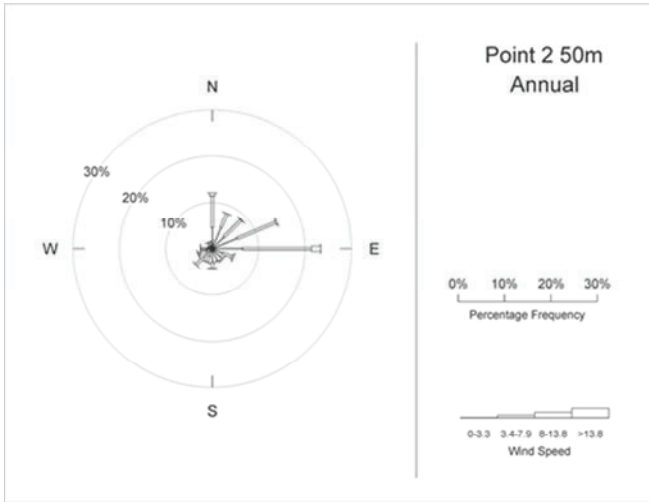


Table C4: Percentage occurrence of directional winds at 500m for Point 2 - Annual

| Wind Angle (°) | Percentage Occurrence (%) for wind speed ranges: | | | | |
|---|---|---|---|---|---|
| | 0-3.3 m/s | 3.4–7.9 m/s | 8.0–13.8 m/s | >13.8 m/s | Total |
| 0 | 1.5 | 5.1 | 4.4 | 1.1 | 12.1 |
| 22.5 | 1.2 | 4.4 | 2.4 | 0.2 | 8.3 |
| 45 | 1.2 | 5.1 | 2.4 | 0.1 | 8.8 |
| 67.5 | 1.6 | 7.3 | 5.6 | 0.6 | 15.1 |
| 90 | 1.2 | 6.5 | 9.9 | 5.8 | 23.4 |
| 112.5 | 1.1 | 1.9 | 1.3 | 0.5 | 4.9 |
| 135 | 1.2 | 1.4 | 0.5 | 0.0 | 3.1 |
| 157.5 | 1.6 | 1.3 | 0.1 | 0.0 | 3.0 |
| 180 | 1.4 | 2.1 | 0.7 | 0.1 | 4.3 |
| 202.5 | 0.7 | 1.5 | 0.8 | 0.1 | 3.1 |
| 225 | 0.9 | 3.0 | 1.1 | 0.0 | 4.9 |
| 247.5 | 0.5 | 1.5 | 1.1 | 0.2 | 3.2 |
| 270 | 0.5 | 1.3 | 0.7 | 0.1 | 2.5 |
| 292.5 | 0.5 | 0.4 | 0.2 | 0.1 | 1.0 |
| 315 | 0.4 | 0.1 | 0.1 | 0.1 | 0.6 |
| 337.5 | 0.5 | 0.6 | 0.3 | 0.2 | 1.5 |

Corresponding wind rose below

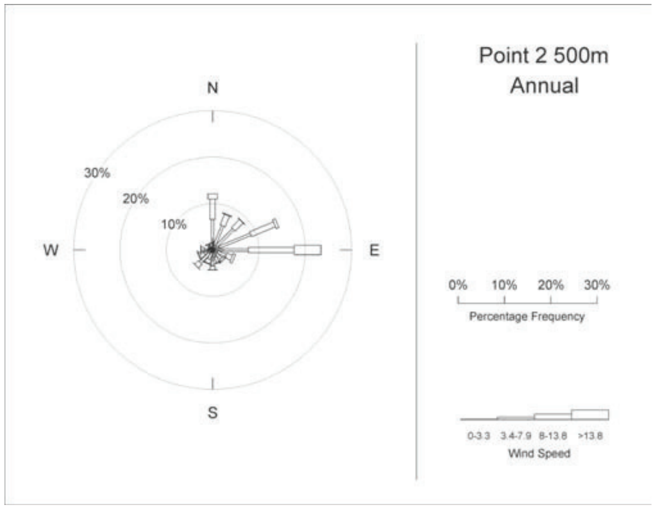







Table C5: Percentage occurrence of directional winds at 50m for Point 3 - Annual

| Wind Angle (°) | Percentage Occurrence (%) for wind speed ranges: | | | | |
|---|---|---|---|---|---|
| | 0-3.3 m/s | 3.4–7.9 m/s | 8.0–13.8 m/s | >13.8 m/s | Total |
| 0 | 6.1 | 5.8 | 0.2 | 0.0 | 12.1 |
| 22.5 | 4.8 | 3.5 | 0.0 | 0.0 | 8.3 |
| 45 | 4.2 | 4.6 | 0.0 | 0.0 | 8.8 |
| 67.5 | 5.5 | 5.8 | 0.1 | 0.0 | 11.3 |
| 90 | 1.8 | 1.9 | 0.0 | 0.0 | 3.8 |
| 112.5 | 12.8 | 14.6 | 0.8 | 0.0 | 28.3 |
| 135 | 1.9 | 1.1 | 0.1 | 0.0 | 3.1 |
| 157.5 | 1.6 | 1.2 | 0.1 | 0.0 | 3.0 |
| 180 | 1.9 | 2.0 | 0.3 | 0.0 | 4.3 |
| 202.5 | 3.9 | 4.0 | 0.2 | 0.0 | 8.0 |
| 225 | 0.4 | 0.4 | 0.0 | 0.0 | 0.8 |
| 247.5 | 1.1 | 1.3 | 0.0 | 0.0 | 2.4 |
| 270 | 1.5 | 1.1 | 0.0 | 0.0 | 2.5 |
| 292.5 | 0.6 | 0.3 | 0.1 | 0.0 | 1.0 |
| 315 | 0.4 | 0.1 | 0.0 | 0.0 | 0.6 |
| | 1.0 | 0.5 | 0.1 | 0.0 | 1.5 |

Corresponding wind rose below

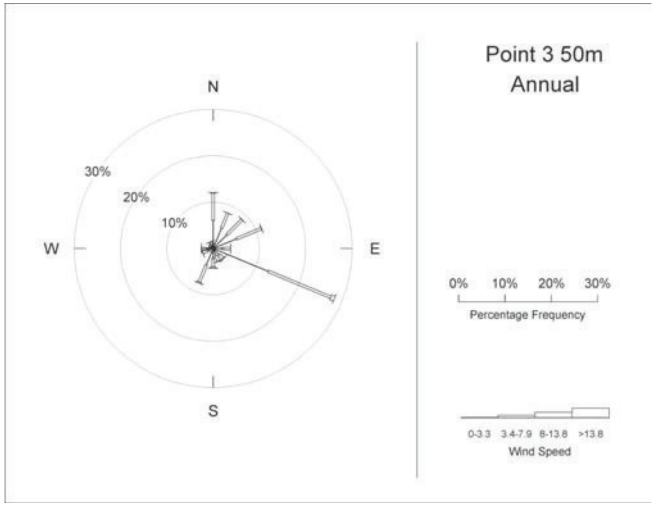


Table C6: Percentage occurrence of directional winds at 500m for Point 3 - Annual

| Wind Angle (°) | Percentage Occurrence (%) for wind speed ranges: | | | | |
|---|---|---|---|---|---|
| | 0-3.3 m/s | 3.4–7.9 m/s | 8.0–13.8 m/s | >13.8 m/s | Total |
| 0 | 1.7 | 5.5 | 4.1 | 0.8 | 12.1 |
| 22.5 | 1.6 | 4.9 | 1.7 | 0.0 | 8.3 |
| 45 | 0.9 | 4.5 | 3.2 | 0.2 | 8.8 |
| 67.5 | 0.9 | 5.0 | 6.6 | 2.6 | 15.1 |
| 90 | 1.3 | 6.8 | 9.9 | 5.3 | 23.4 |
| 112.5 | 1.3 | 2.1 | 1.2 | 0.4 | 4.9 |
| 135 | 1.0 | 1.4 | 0.6 | 0.1 | 3.1 |
| 157.5 | 1.1 | 1.4 | 0.4 | 0.0 | 3.0 |
| 180 | 1.3 | 2.1 | 0.8 | 0.1 | 4.3 |
| 202.5 | 1.0 | 1.7 | 0.4 | 0.0 | 3.1 |
| 225 | 0.7 | 2.8 | 1.4 | 0.1 | 4.9 |
| 247.5 | 0.6 | 1.7 | 0.9 | 0.1 | 3.2 |
| 270 | 0.5 | 1.3 | 0.6 | 0.1 | 2.5 |
| 292.5 | 0.4 | 0.4 | 0.2 | 0.1 | 1.0 |
| 315 | 0.4 | 0.1 | 0.1 | 0.1 | 0.6 |
| 337.5 | 0.6 | 0.6 | 0.3 | 0.1 | 1.5 |

Corresponding wind rose below

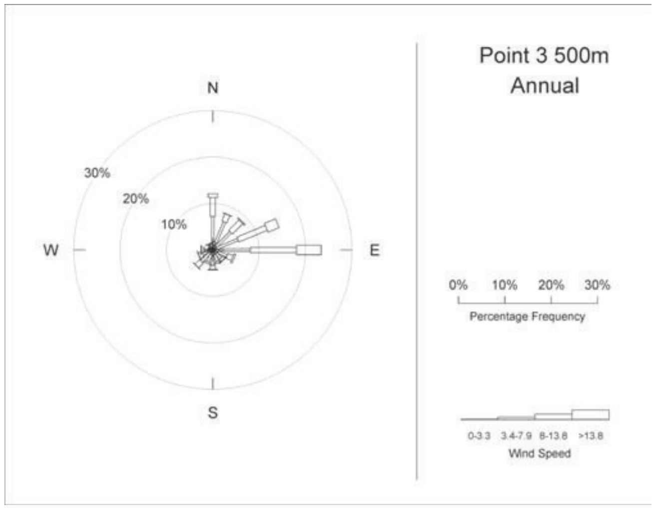







Table C7: Percentage occurrence of directional winds at 50m for Point 1 - Summer

| Wind Angle (°) | Percentage Occurrence (%) for wind speed ranges: | | | | |
|---|---|---|---|---|---|
| | 0-3.3 m/s | 3.4–7.9 m/s | 8.0–13.8 m/s | >13.8 m/s | Total |
| 0 | 2.3 | 0.2 | 0.0 | 0.0 | 2.5 |
| 22.5 | 2.1 | 0.1 | 0.0 | 0.0 | 2.2 |
| 45 | 2.2 | 0.3 | 0.0 | 0.0 | 2.5 |
| 67.5 | 2.2 | 2.3 | 0.3 | 0.0 | 4.8 |
| 90 | 7.4 | 6.0 | 0.4 | 0.0 | 13.8 |
| 112.5 | 8.3 | 5.9 | 0.2 | 0.0 | 14.4 |
| 135 | 0.9 | 0.6 | 0.0 | 0.0 | 1.6 |
| 157.5 | 2.8 | 1.9 | 0.0 | 0.0 | 4.8 |
| 180 | 7.9 | 2.2 | 0.0 | 0.0 | 10.1 |
| 202.5 | 7.0 | 1.3 | 0.0 | 0.0 | 8.3 |
| 225 | 2.5 | 9.5 | 2.4 | 0.0 | 14.5 |
| 247.5 | 1.5 | 5.7 | 2.5 | 0.1 | 9.7 |
| 270 | 1.9 | 3.6 | 1.0 | 0.0 | 6.5 |
| 292.5 | 1.1 | 0.8 | 0.1 | 0.0 | 2.0 |
| 315 | 0.9 | 0.2 | 0.0 | 0.0 | 1.1 |
| 337.5 | 1.1 | 0.0 | 0.0 | 0.0 | 1.2 |

Corresponding wind rose below

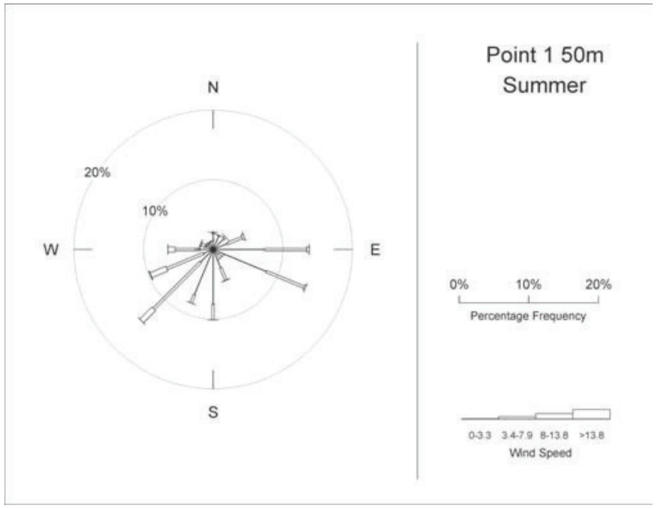


Table C8: Percentage occurrence of directional winds at 500m for Point 1 - Summer

| Wind Angle (°) | Percentage Occurrence (%) for wind speed ranges: | | | | |
|---|---|---|---|---|---|
| | 0-3.3 m/s | 3.4–7.9 m/s | 8.0–13.8 m/s | >13.8 m/s | Total |
| 0 | 1.4 | 0.8 | 0.2 | 0.0 | 2.5 |
| 22.5 | 1.0 | 0.9 | 0.2 | 0.0 | 2.2 |
| 45 | 0.8 | 1.2 | 0.5 | 0.1 | 2.5 |
| 67.5 | 0.8 | 1.8 | 1.5 | 0.7 | 4.8 |
| 90 | 2.6 | 6.0 | 4.1 | 1.1 | 13.8 |
| 112.5 | 1.9 | 3.9 | 1.8 | 0.2 | 7.9 |
| 135 | 1.8 | 3.2 | 1.3 | 0.1 | 6.5 |
| 157.5 | 1.7 | 3.4 | 1.2 | 0.1 | 6.4 |
| 180 | 2.6 | 5.5 | 2.0 | 0.1 | 10.1 |
| 202.5 | 1.8 | 4.7 | 1.7 | 0.1 | 8.3 |
| 225 | 1.7 | 8.2 | 4.5 | 0.2 | 14.5 |
| 247.5 | 0.9 | 4.5 | 3.8 | 0.5 | 9.7 |
| 270 | 1.2 | 3.1 | 1.9 | 0.3 | 6.5 |
| 292.5 | 0.8 | 0.8 | 0.3 | 0.1 | 2.0 |
| 315 | 0.6 | 0.3 | 0.1 | 0.1 | 1.1 |
| 337.5 | 0.6 | 0.5 | 0.0 | 0.0 | 1.2 |

Corresponding wind rose below

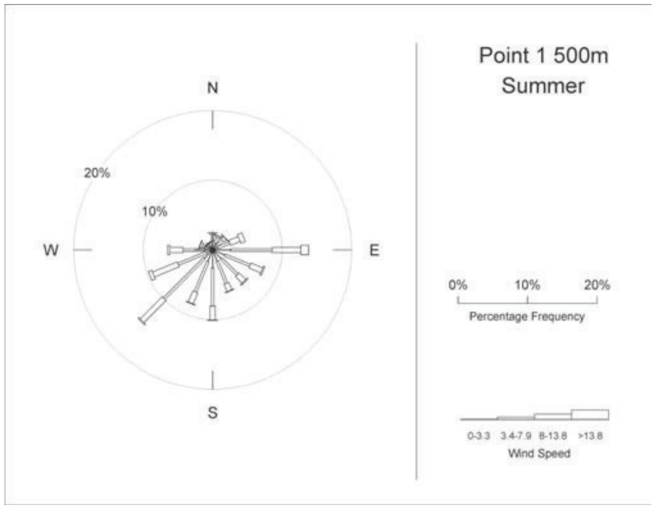







Table C9: Percentage occurrence of directional winds at 50m for Point 2 - Summer

| Wind Angle (°) | Percentage Occurrence (%) for wind speed ranges: | | | | |
|---|---|---|---|---|---|
| | 0-3.3 m/s | 3.4–7.9 m/s | 8.0–13.8 m/s | >13.8 m/s | Total |
| 0 | 2.0 | 0.4 | 0.0 | 0.0 | 2.5 |
| 22.5 | 1.8 | 0.4 | 0.0 | 0.0 | 2.2 |
| 45 | 1.4 | 1.0 | 0.1 | 0.0 | 2.5 |
| 67.5 | 2.7 | 2.0 | 0.1 | 0.0 | 4.8 |
| 90 | 6.5 | 6.6 | 0.7 | 0.0 | 13.8 |
| 112.5 | 3.9 | 3.7 | 0.3 | 0.0 | 7.9 |
| 135 | 4.8 | 1.7 | 0.0 | 0.0 | 6.5 |
| 157.5 | 5.4 | 1.0 | 0.0 | 0.0 | 6.4 |
| 180 | 6.3 | 3.8 | 0.1 | 0.0 | 10.1 |
| 202.5 | 3.9 | 4.3 | 0.1 | 0.0 | 8.3 |
| 225 | 6.9 | 7.6 | 0.0 | 0.0 | 14.5 |
| 247.5 | 3.0 | 6.2 | 0.5 | 0.0 | 9.7 |
| 270 | 3.1 | 3.2 | 0.2 | 0.0 | 6.5 |
| 292.5 | 1.7 | 0.2 | 0.0 | 0.0 | 2.0 |
| 315 | 1.0 | 0.1 | 0.0 | 0.0 | 1.1 |
| 337.5 | 1.1 | 0.1 | 0.0 | 0.0 | 1.2 |

Corresponding wind rose below

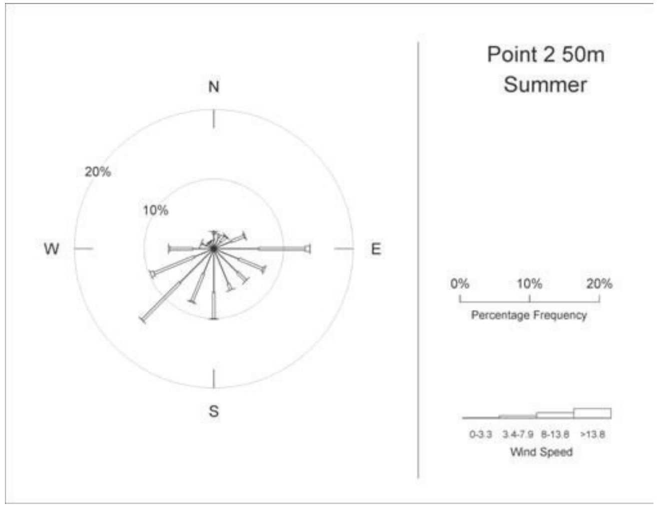
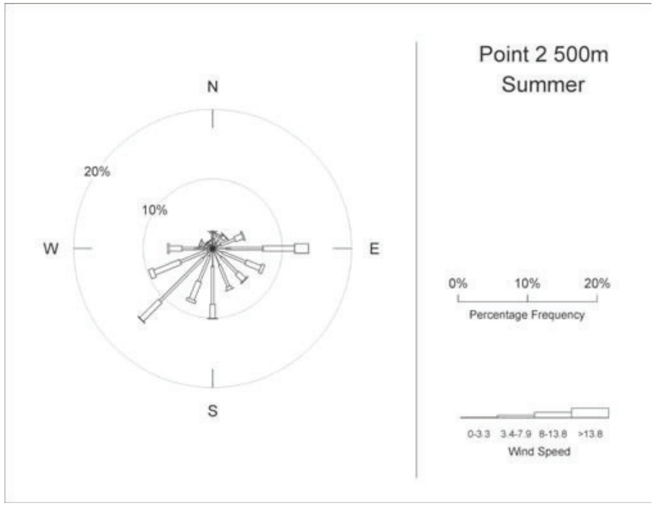


Table C10: Percentage occurrence of directional winds at 500m for Point 2 - Summer

| Wind Angle (°) | Percentage Occurrence (%) for wind speed ranges: | | | | |
|---|---|---|---|---|---|
| | 0-3.3 m/s | 3.4–7.9 m/s | 8.0–13.8 m/s | >13.8 m/s | Total |
| 0 | 1.4 | 0.8 | 0.2 | 0.0 | 2.5 |
| 22.5 | 1.0 | 0.9 | 0.3 | 0.0 | 2.2 |
| 45 | 0.8 | 1.2 | 0.5 | 0.1 | 2.5 |
| 67.5 | 1.2 | 2.2 | 1.1 | 0.2 | 4.8 |
| 90 | 2.0 | 5.2 | 4.6 | 2.0 | 13.8 |
| 112.5 | 1.5 | 3.6 | 2.2 | 0.4 | 7.9 |
| 135 | 1.8 | 3.2 | 1.4 | 0.2 | 6.5 |
| 157.5 | 2.6 | 3.4 | 0.5 | 0.0 | 6.4 |
| 180 | 2.5 | 5.5 | 2.0 | 0.1 | 10.1 |
| 202.5 | 1.2 | 4.0 | 2.8 | 0.4 | 8.3 |
| 225 | 2.0 | 8.7 | 3.8 | 0.1 | 14.5 |
| 247.5 | 0.8 | 4.2 | 4.0 | 0.7 | 9.7 |
| 270 | 1.2 | 3.2 | 1.8 | 0.3 | 6.5 |
| 292.5 | 0.8 | 0.8 | 0.3 | 0.0 | 2.0 |
| 315 | 0.7 | 0.3 | 0.1 | 0.0 | 1.1 |
| 337.5 | 0.6 | 0.5 | 0.0 | 0.0 | 1.2 |

Corresponding wind rose below



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Report Title

Table C11: Percentage occurrence of directional winds at 50m for Point 3 - Summer

| Wind Angle (°) | Percentage Occurrence (%) for wind speed ranges: | | | | |
|---|---|---|---|---|---|
| | 0-3.3 m/s | 3.4–7.9 m/s | 8.0–13.8 m/s | >13.8 m/s | Total |
| 0 | 2.2 | 0.3 | 0.0 | 0.0 | 2.5 |
| 22.5 | 1.8 | 0.4 | 0.0 | 0.0 | 2.2 |
| 45 | 1.5 | 0.9 | 0.1 | 0.0 | 2.5 |
| 67.5 | 2.3 | 1.2 | 0.0 | 0.0 | 3.6 |
| 90 | 0.8 | 0.4 | 0.0 | 0.0 | 1.2 |
| 112.5 | 13.4 | 7.9 | 0.3 | 0.0 | 21.7 |
| 135 | 3.2 | 3.0 | 0.3 | 0.0 | 6.5 |
| 157.5 | 2.6 | 3.3 | 0.4 | 0.0 | 6.4 |
| 180 | 3.8 | 5.5 | 0.8 | 0.0 | 10.1 |
| 202.5 | 9.2 | 13.0 | 0.6 | 0.0 | 22.8 |
| 225 | 0.9 | 1.5 | 0.1 | 0.0 | 2.4 |
| 247.5 | 2.7 | 4.4 | 0.2 | 0.0 | 7.3 |
| 270 | 3.6 | 2.8 | 0.1 | 0.0 | 6.5 |
| 292.5 | 1.2 | 0.7 | 0.1 | 0.0 | 2.0 |
| 315 | 0.8 | 0.2 | 0.1 | 0.0 | 1.1 |
| 337.5 | 1.1 | 0.0 | 0.0 | 0.0 | 1.2 |

Corresponding wind rose below

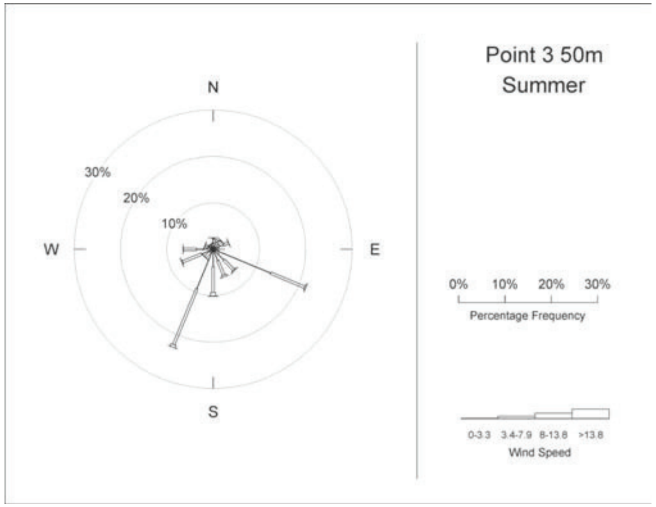

Table C12: Percentage occurrence of directional winds at 500m for Point 3 - Summer

| Wind Angle (º) | Percentage Occurrence (%) for wind speed ranges: | | | | |
|---|---|---|---|---|---|
| | 0-3.3 m/s | 3.4–7.9 m/s | 8.0–13.8 m/s | >13.8 m/s | Total |
| 0 | 1.5 | 0.8 | 0.2 | 0.0 | 2.5 |
| 22.5 | 1.1 | 0.9 | 0.2 | 0.0 | 2.2 |
| 45 | 0.6 | 1.1 | 0.6 | 0.1 | 2.5 |
| 67.5 | 0.9 | 1.9 | 1.5 | 0.6 | 4.8 |
| 90 | 2.1 | 5.4 | 4.5 | 1.8 | 13.8 |
| 112.5 | 1.8 | 3.9 | 1.9 | 0.3 | 7.9 |
| 135 | 1.5 | 3.1 | 1.6 | 0.3 | 6.5 |
| 157.5 | 1.6 | 3.4 | 1.3 | 0.1 | 6.4 |
| 180 | 2.4 | 5.4 | 2.2 | 0.2 | 10.1 |
| 202.5 | 2.0 | 4.9 | 1.4 | 0.0 | 8.3 |
| 225 | 1.6 | 8.0 | 4.7 | 0.2 | 14.5 |
| 247.5 | 1.1 | 5.0 | 3.3 | 0.3 | 9.7 |
| 270 | 1.3 | 3.3 | 1.7 | 0.2 | 6.5 |
| 292.5 | 0.7 | 0.8 | 0.3 | 0.1 | 2.0 |
| 315 | 0.7 | 0.3 | 0.1 | 0.1 | 1.1 |
| 337.5 | 0.8 | 0.4 | 0.0 | 0.0 | 1.2 |

Corresponding wind rose below