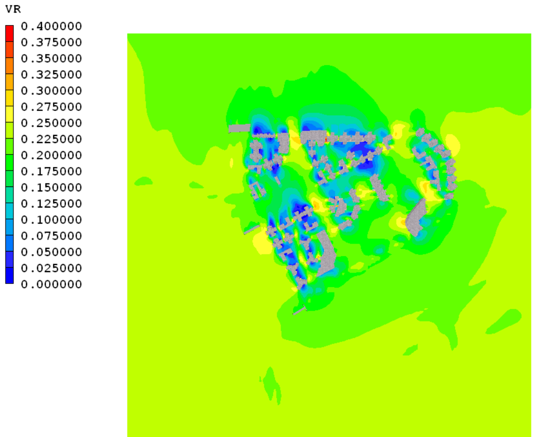
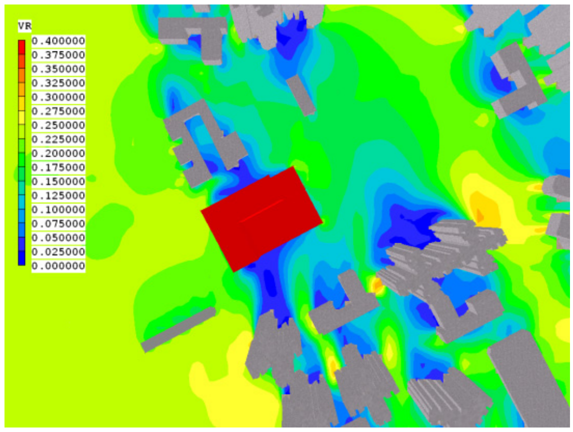
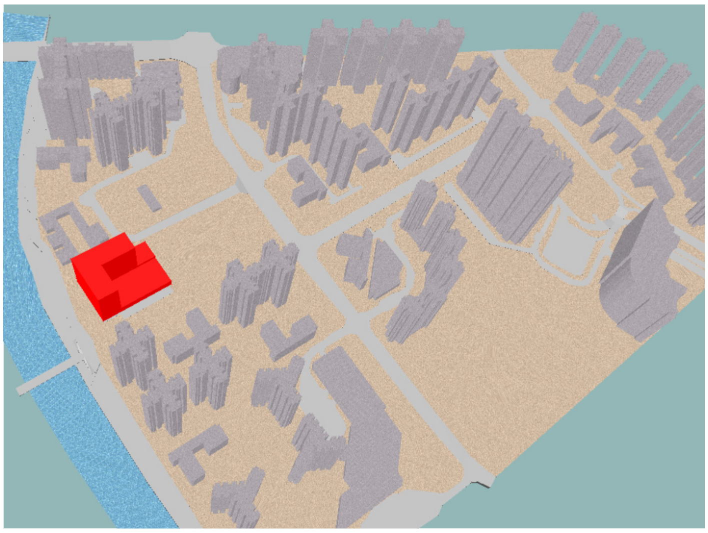




Architectural Services Department

Construction of Tin Shui Wai Hospital at TSW Area 32, at Tin Tan Street, Tin Shui Wai

Air Ventilation Assessment (AVA) Initial Study Report



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Construction of Tin Shui Wai Hospital at TSW Area 32, at Tin Tan Street, Tin Shui Wai

Air Ventilation Assessment (AVA) Initial Study Report

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Report No	EB000612/AVA/R002
Date	24 February 2010

This report has been prepared for Architectural Services Department in accordance with the terms and conditions of appointment for Initial Air Ventilation Assessment dated November 16, 2009. Hyder Consulting Limited (Company Number 126012) cannot accept any responsibility for any use of or reliance on the contents of this report by any third party.

CONTENTS

Tables

Figures

1 EXECUTIVE SUMMARY

In November 2009, Hyder Consulting Ltd (HCL) was commissioned by the Architectural Services Department (ArchSD) to undertake an Air Ventilation Assessment (AVA) Initial Study for the ***Tin Shui Wai Hospital at TSW Area 32, at Tin Tan Street, Tin Shui Wai***, to assess air ventilation performance of the building design and its impacts to the surrounding pedestrian accessible locations. Finding from the AVA Initial Study undertaken are documented in this report and summarised in the following section. Computational Fluid Dynamics (CFD) simulation was employed as the assessment tool for quantitative ventilation performance evaluation in the study.

Local AVA simulated results computed by analysing the group of overall test points and perimeter test points, and Site AVA results evaluated by considering perimeter test points only are summarised in the tables below and graphically illustrated overleaf.

Local Air Ventilation Assessment Results (LVR)			
Prevailing Wind Direction	**Prior to Construction of Tin Shui Wai Hospital**	**Subsequent to Construction of Tin Shui Wai Hospital**	**VR Change**
NNE (22.5º)	0.112	0.095	-0.017
NE (45º)	0.118	0.101	-0.017
ENE (67.5º)	0.099	0.089	-0.010
E (90º)	0.109	0.096	-0.013
ESE (112.5º)	0.102	0.093	-0.008
SE (135º)	0.095	0.086	-0.010
SSE (157.5º)	0.164	0.140	-0.024
Overall (weighted)	**0.111**	**0.098**	**-0.013**

Table 1-1 Summary of Local Velocity Ratios for Tin Shui Wai Hospital under Prevailing Wind Directions

Site Air Ventilation Assessment Results (SVR)			
Prevailing Wind Direction	**Prior to Construction of Tin Shui Wai Hospital**	**Subsequent to Construction of Tin Shui Wai Hospital**	**VR Change**
NNE (22.5º)	0.118	0.088	-0.029
NE (45º)	0.129	0.097	-0.032
ENE (67.5º)	0.109	0.088	-0.021
E (90º)	0.123	0.096	-0.027
ESE (112.5º)	0.111	0.094	-0.016
SE (135º)	0.100	0.079	-0.021
SSE (157.5º)	0.171	0.126	-0.045
Overall (weighted)	**0.121**	**0.094**	**-0.027**

Table 1-2 Summary of Site Velocity Ratios for Tin Shui Wai Hospital under Prevailing Wind Directions

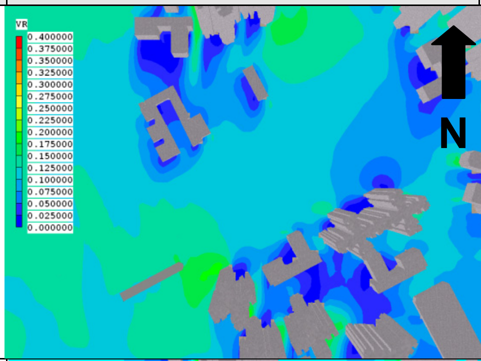
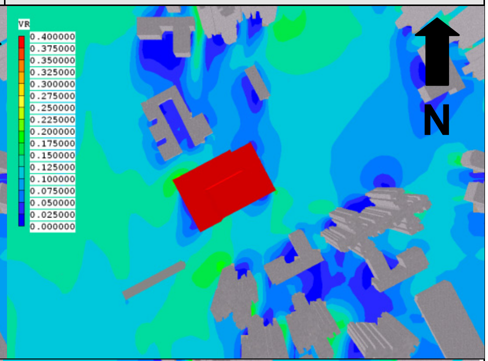
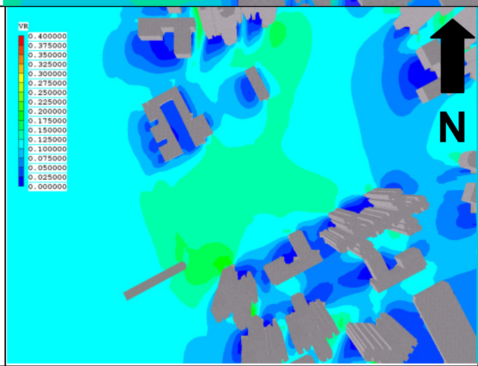
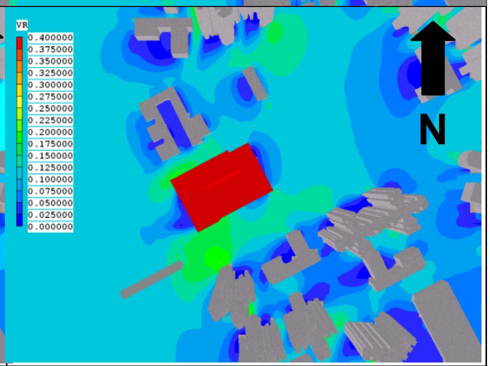
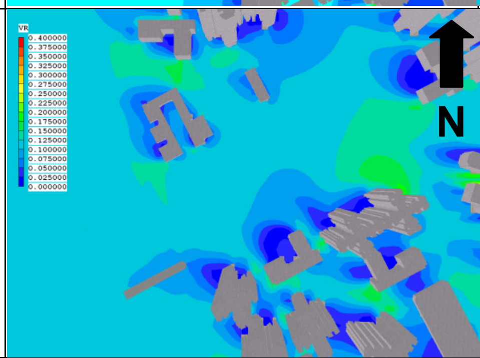
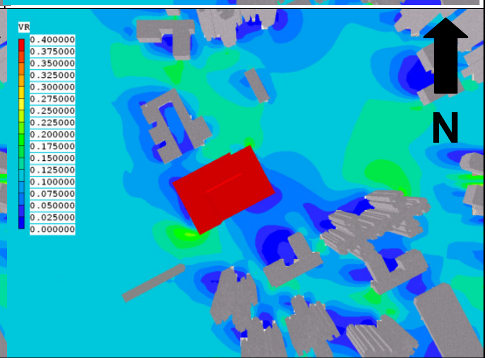
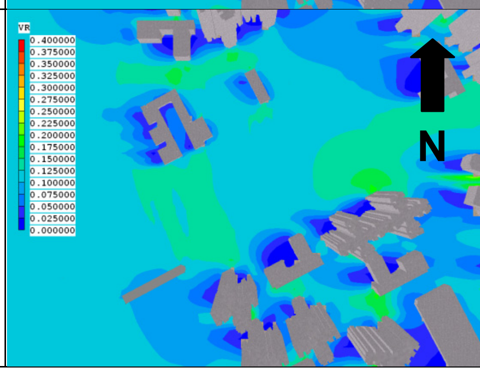
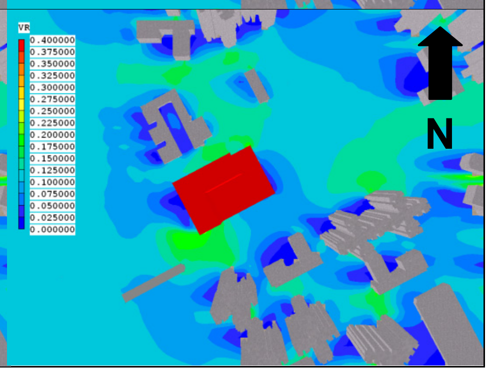
Prevailing Wind Direction	Prior to Construction of Tin Shui Wai Hospital	Subsequent to Construction of Tin Shui Wai Hospital
NNE (22.5º)		
NE (45°)		
ENE (67.5°)		
E (90º)		

Table 1-3 Velocity Ratio Plots for Tin Shui Wai Hospital under Prevailing Wind Directions

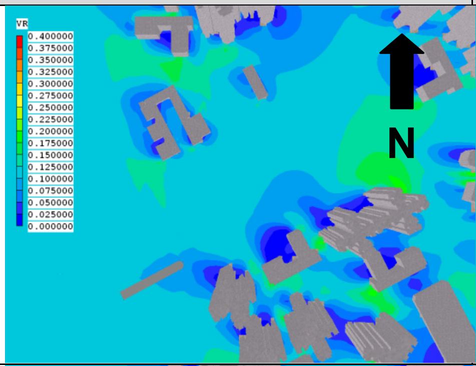
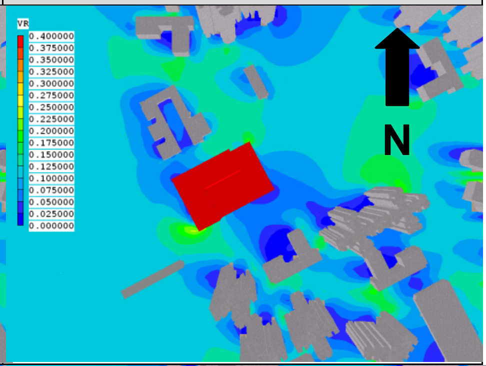
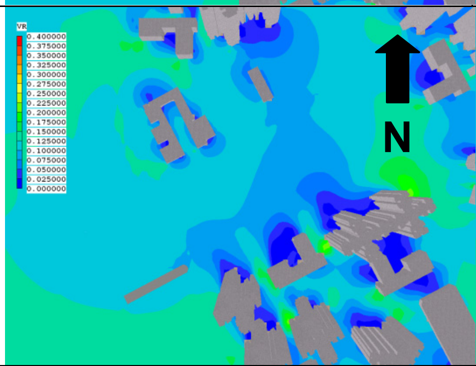
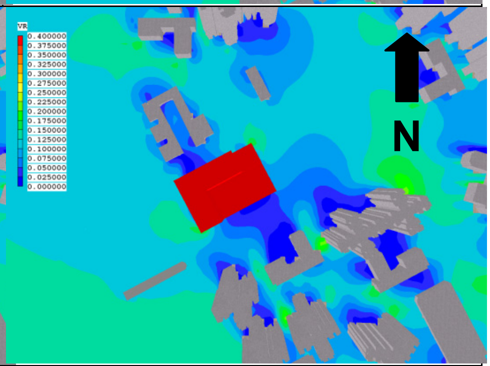
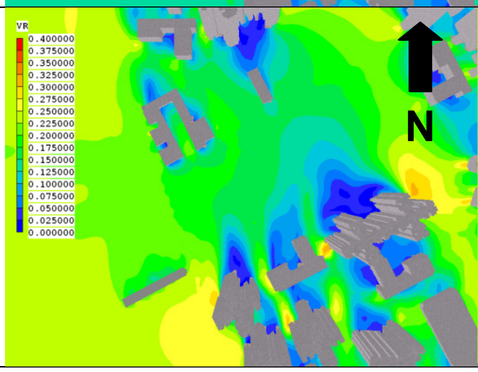
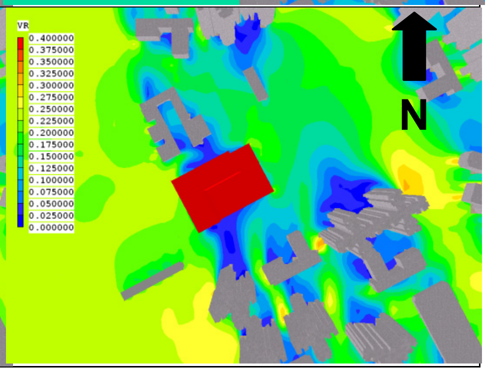
Prevailing Wind Direction	Prior to Construction of Tin Shui Wai Hospital	Subsequent to Construction of Tin Shui Wai Hospital
ESE (112.5º)		
SE (135°)		
SSE (157.5º)		

Table 1-4 Velocity Ratio Plots for Tin Shui Wai Hospital under Prevailing Wind Directions

CFD simulation results of the LVR from above reveal that ventilation performance of adjacent pedestrian access areas within the vicinity of the site will be predominately unaffected by the construction of Tin Shui Wai Hospital. The change in weighted LVR is 0.013 and this is equivalent to a speed reduction of less than 0.1 m/s at pedestrian level which should be deemed insignificant and acceptable.

As predicted from the qualitative ventilation performance evaluation in *Section 3.3*, high rise obstructive buildings are situated at northern and southern directions to the site which cause wind blockage and impact upon ventilation performance. As a result of this, even prior to construction of the Tin Shui Wai Hospital, wind availability of the project site and its surrounding community is inherently limited with a weighted LVR of 0.111 which is equivalent to wind speeds of less than 0.9 m/s at nearby pedestrian areas.

As explained in *Section 3.3,* surrounding topology of the site creates a wind corridor along Tin Wing Road from the eastern direction and wind is directed towards the site and surrounding communities. Coupled with this wind corridor, the erection of the hospital building induces wind paths at northern and southern directions to the site. Open spaces are present at the eastern and western direction of the development. Roads around the hospital building act as a linkage between these two open spaces in such a way to form air paths. Prevailing Wind from the major breezeway along Tin Wing Road could therefore penetrate pedestrian areas through these air paths as illustrated below. The general principle of this "air path" effect in urbanised areas is provided in Figure 1.2 overleaf for reference.

On the above basis, ventilation impacts from construction of the hospital building is not significantly reduced under eastern quadrant prevailing winds, resulting in LVR reductions ranging from 0.008 to 0.013 (equivalent to less than 0.1 m/s velocity reduction) under ENE, E, ESE and SE directions.

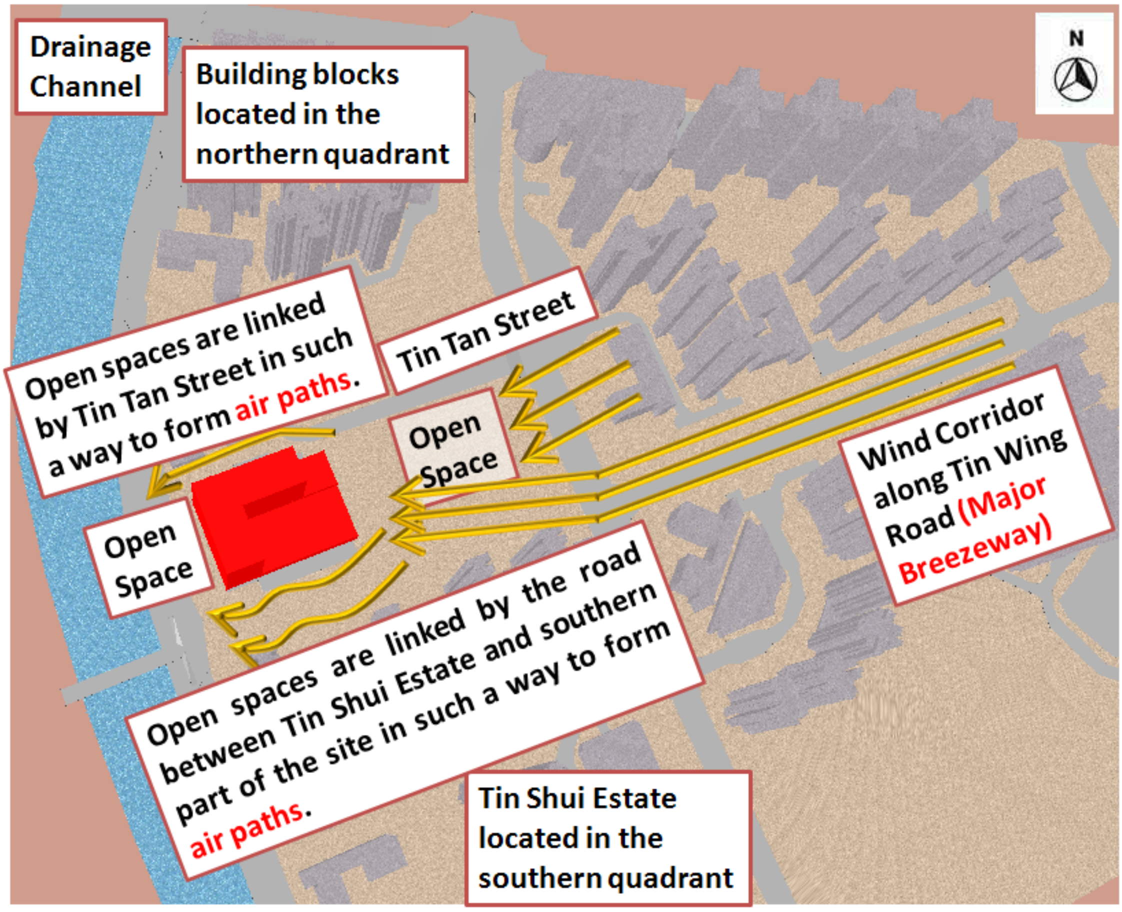


Figure 1-1 Wind Paths Created around the Hospital Building to Minimise Air Ventilation Impacts

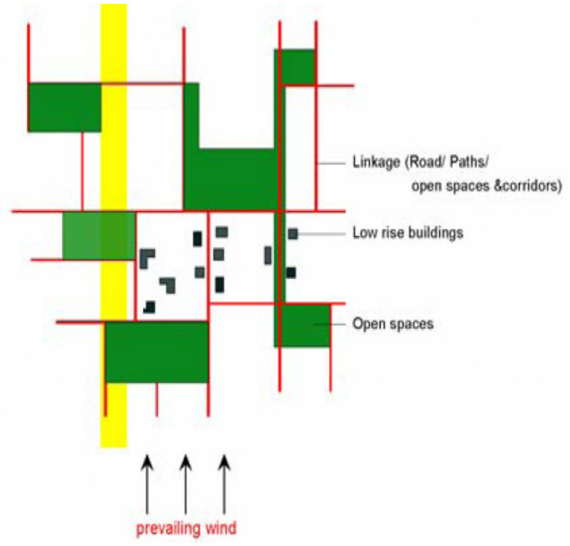


Figure 1-2 Open spaces (coloured in green) are linked by road such that air paths are created around buildings (prevailing wind directions are coloured in yellow)

Under northern and southern quadrants of prevailing wind directions, the construction of the hospital building induces a barrier effect with LVR reductions ranging from 0.017 and 0.024 for NNE, NE and SSE prevailing winds. Although ventilation impacts under these directions appear to be more sever but in absolute terms, the associated velocity reduction is less than 0.2 m/s.

In summary, the overall weighted VR change in the local Air Ventilation Assessment from the construction of Tin Shui Wai Hospital is not substantial (less than 0.013 which is equivalent to 0.1 m/s wind velocity reduction) and its impact upon ventilation performance of potential pedestrian areas is deemed insignificant. Therefore, it can be concluded that the design and erection of Tin Shui Wai Hospital is unlikely to have a significant adverse wind impact on pedestrian level ventilation performance.

The ventilation performance of the site perimeter as a result of the Tin Shui Wai Hospital construction is summarised in the table below (Site Perimeter Velocity Ratio for each prevailing wind direction is summarised in the SVR results in table 1-2). Using the same CFD simulation data, local and site velocity assessments findings are also summarised below:

	Before Development	After Development
LVR (Overall Test Points)	0.111	0.098
SVR (Perimeter Test Point)	0.121	0.094

Table 1-5 Summary of Local Velocity Ratio and Site Velocity Ratio for Tin Shui Wai Hospital under Prevailing Wind Directions

The construction of the Tin Shui Wai Hospital involves erection of vertical structures which would ultimately lead to reduced wind permeability at pedestrian levels within the project site area (originally entirely exposed). Therefore, as shown by the velocity ratios in the table above, the Tin Shui Wai Hospital development would generally have some impact upon the wind availability of these test points, as expected. However, a SVR reduction of 0.03 (0.2 m/s reduction in wind velocity) for the hospital building can be considered as relatively insignificant and acceptable.

The AVA study findings reveal that the construction of the Tin Shui Wai Hospital Development is unlikely to have an adverse ventilation performance impact upon pedestrian areas at nearby sensitive communities and within the site. The design and erection of the hospital building leads to ventilation performance results of LVR change = 0.013 (equivalent to less than 0.1 m/s wind speed reduction) and SVR change = 0.027 (equivalent to less than 0.2 m/s wind speed reduction), all of which are deemed to be insignificant and acceptable.

It should be noted, however, in the interest of continual improvement, an additional AVA study should be considered at later project stages to investigate and identify opportunities to further enhance pedestrian level ventilation performance around the Tin Shui Wai Hospital Development, as possible.

2 Introduction

2.1 Background

The Planning Department (PD) completed a Feasibility Study for Establishment of Air Ventilation Assessment System (AVAS) for Hong Kong in 2005. As a way forward from the study, the Housing, Planning and Lands Bureau (HPLB) and the Environment, Transport and Works Bureau (ETWB) jointly issued the Technical Circular No. 1/06 – Air Ventilation Assessments (AVA). This technical circular provides guidelines on undertaking AVA for developments in Hong Kong with the core objective of assessing impacts on pedestrian wind environment. Technical Circular No. 1/06 – AVA is provided in Appendix A for reference.

In November 2009, Hyder Consulting Ltd (HCL) was commissioned by the Architectural Services Department (ArchSD) to undertake an Air Ventilation Assessment (AVA) Initial Study for the ***Tin Shui Wai Hospital at TSW Area 32, at Tin Tan Street, Tin Shui Wai***, to assess air ventilation performance of the building design and its impacts to the surrounding pedestrian accessible locations.

2.2 Objective

Using methodology outlined in the *Technical Guide for AVA for Developments in Hong Kong (Technical Guide) annexed in HPLB and ETWB TC No. 1/06* as a basis, the impacts of the proposed Tin Shui Wai Hospital at TSW Area 32, at Tin Tan Street, Tin Shui Wai on pedestrian level wind environment were analysed and investigated. Computational Fluid Dynamics (CFD) simulation was employed as the assessment tool for quantitative ventilation performance evaluation in the study. In essence, the main purposes of this assignment, echoing the technical guide include:

- to assess characteristics of the wind availability (V_∞) of the site;
- to give a general pattern of the proposed design and a quantitative estimates of wind performance at pedestrian levels (at street level) reported using Wind Velocity Ratio (VR); and
- to identify ventilation performance of the proposed design and areas of concerns in the neighbourhood.

This report describes the AVA initial study undertaken for the proposed design of the Tin Shui Wai Hospital at Tin Tan Street and the remainder of the report is sectionalised as follows:

Section 3:	Site Wind Conditions and Expert Evaluation, Site Environs
Section 4:	Site Wind Availability
Section 5:	Assessment Methodology and Criteria
Section 6:	Results and Analysis

Detailed AVA study data and results are given in *Appendix C*.

3 Site Wind Conditions and Expert Evaluation

3.1 Site Environs

The project site is located in the western region of Tin Shui Wai district at Area 32, Tin Tan Street and has an area of approximately 13,400 m^2. The site is bounded by high rise Tin Wai Estate and Tin Tan Street to its north, high rise Tin Sui Estate to its south and a drainage channel to its west. There is an open space car park situated at the east of the site. The subject site and its surrounding topography are illustrated below.

Figure 3-1 Location of Tin Shui Wai Hospital and Surrounding Topography

The proposed design of the Tin Shui Wai Hospital at TSW Area 32, at Tin Tan Street (TSW Hospital) is a 14-storeyed hospital building with a one-storey basement carpark, a two-storey podium housing the entrance hall, emergency services, diagnostic departments and back-of-house support facilities, and 11 levels of clinical departments/in-patient wards/offices above the podium.

3.2 Project Area, Assessment Area Boundary and Surrounding Area Boundary

The project area is defined by project site boundaries including all open areas for which pedestrian are likely to access. For the purpose of this study, the project area is therefore equivalent to the project site area as illustrated (by the shaded area) below.

The assessment area (encoded by green boundary line) includes the site's surrounding environment up to a perpendicular distance of H (where H is the height of the tallest building within the project site) as shown below. For the project site, H is 66 metres.

The surrounding area should normally be up to a perpendicular distance of 2H from the project site boundary, which is 132 meters for this study. However, since there are bulky and obstructive developments immediate outside the assessment area regions, the surrounding area for this AVA study has been enlarged as shown below (encoded by black boundary line) for eastern and southern incoming winds and these are modelled in the CFD simulation described in *Section 5*. Project site area, assessment area and surrounding area boundaries are all shown below.

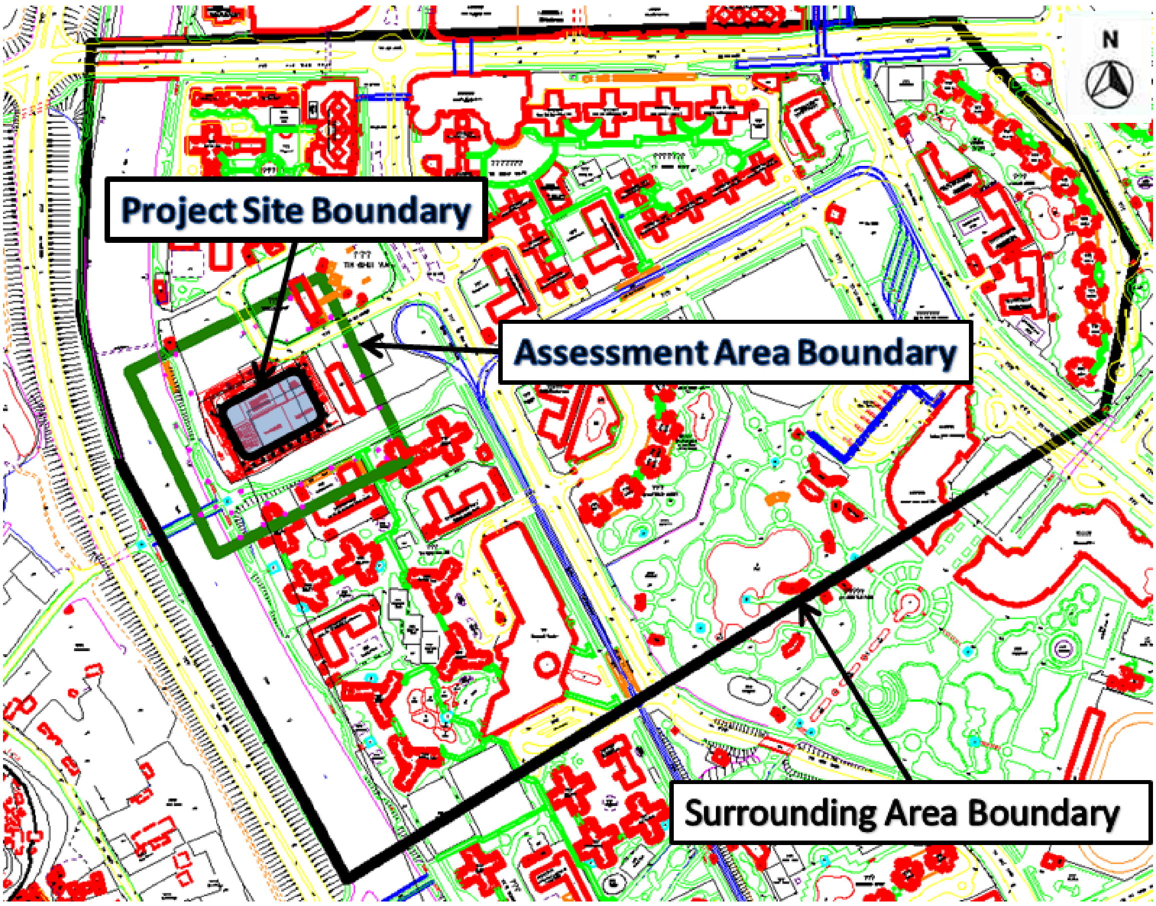


Figure 3-2 Project Site Boundary, Assessment Area Boundary and Surrounding Area Boundary

3.3 General Prevailing Wind Conditions and Expert Evaluation

Air ventilation assessments would generally be affected by wind availability under all wind directions and frequency of occurrence of individual wind directions, and in particular predominated by prevailing wind flows. With regards to the project site, based on the site wind availability data provided by the Planning Department for the immediate vicinity of the project site in Tin Shui Wai region (see *Section 4* for more details), north-north-easterly to south-south-easterly winds occurrence exceed 75% of the time throughout the year.

Potential wind barriers to the overall wind environment of the project site are high rise building blocks within close proximity. These include Tin Wai Public Housing Estate and Tin Chung Public Housing Estates located at north/northeast directions to the site, Tin Shui Public Housing Estate situated to the south and Chestwood Court Kingswood Villas erected on the east. A potential wind corridor is available along Tin Wing Road (shown by yellow arrows) under north-eastern directions as air circulation is directed towards the project site (see illustrated below). A large plot of scattered vacant lands and low-rise small villages are found at south eastern and south western directions to the site. The open nature of these non obstructive developments should encourage air circulation to the site. However, due to the relative low probability occurrence of these winds (less than 10% as deduced in *Section 4.2*), this wind enhancement effect is substantially diminished. As a result of congested and high rise nature of surrounding developments and topography, wind availability is likely to be limited and the inherent wind conditions on site should be relatively calm.

Figure 3-3 Wind Corridor Directing Air Circulation toward Project Site

The erection of a hospital building on the project site could potentially block northern, eastern and southern winds available to pedestrian areas within close vicinity. The extent of these impacts is unknown since wind availability at these areas is inherently limited. The ventilation impact of the hospital building to the surrounding community was investigated by CFD simulation and explained in *Section 6*. However, under ENE and ESE prevailing winds, the development could form corridors with surrounding buildings, along Tin Wing Road and thus potentially reducing wind availability impacts to nearby pedestrian areas.

Using CFD simulation as the assessment tool, quantitative ventilation performance evaluation of proposed design of Tin Shui Wai Hospital and its surrounding community was undertaken, with methodology adopted described in *Section 5* and results explained in *Section 6*.

3.4 Focus

Wind availability of individual areas within the site and close proximity are verified in the study as detailed below:

- Whether the building height and disposition design of the Tin Shui Wai Hospital has significant impact on surrounding areas; and
- Whether air ventilation performance will deteriorate after construction of the hospital development.

Specifically, the ventilation performance of pedestrian areas within close proximity to the project is the main focus of this AVA study.

4 Site Wind Availability

4.1 Simulated Site Wind Data

Site Wind Availability Data for Hong Kong obtained from the Planning Department website was used for the AVA study in this report. The simulated wind data were made available by Planning Department (PD) using simulation model - 5th Generation NCAR /Penn State Mesoscale Model (MM5).

One set of data from the site wind availability data representing the immediate vicinity of the project site (Tin Shui Wai District) was extracted for simulation as the black square shown below.

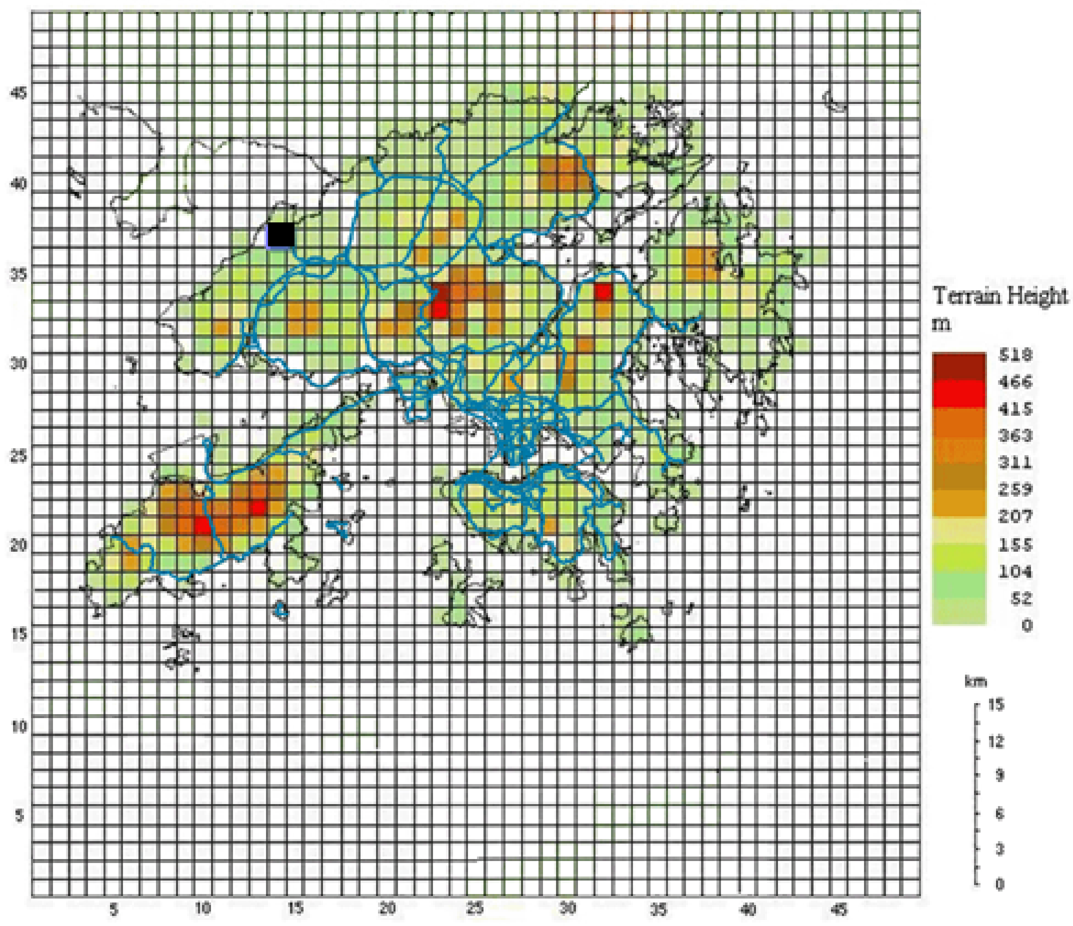


Figure 4-1 Location of Project Site

4.2 Wind Rose and Probability in 16 directions

Relevant wind rose and wind probability table were also obtained from the Planning Department (PD) website (http://www.pland.gov.hk/pland_en/misc/MM5/index.html). The wind rose result indicates dominance of each of the 16 wind directions and distribution of wind speed. The figure below shows relevant wind rose for the assessment area. The wind probability table showing simulated wind speed of the selected region at infinity (596m above the terrain) shown in *Appendix B*. Individual wind direction occurrence is directly extracted from the wind probability table. The 16-wind direction occurrences in percentage for the project site and assessment area are also shown in the table overleaf.

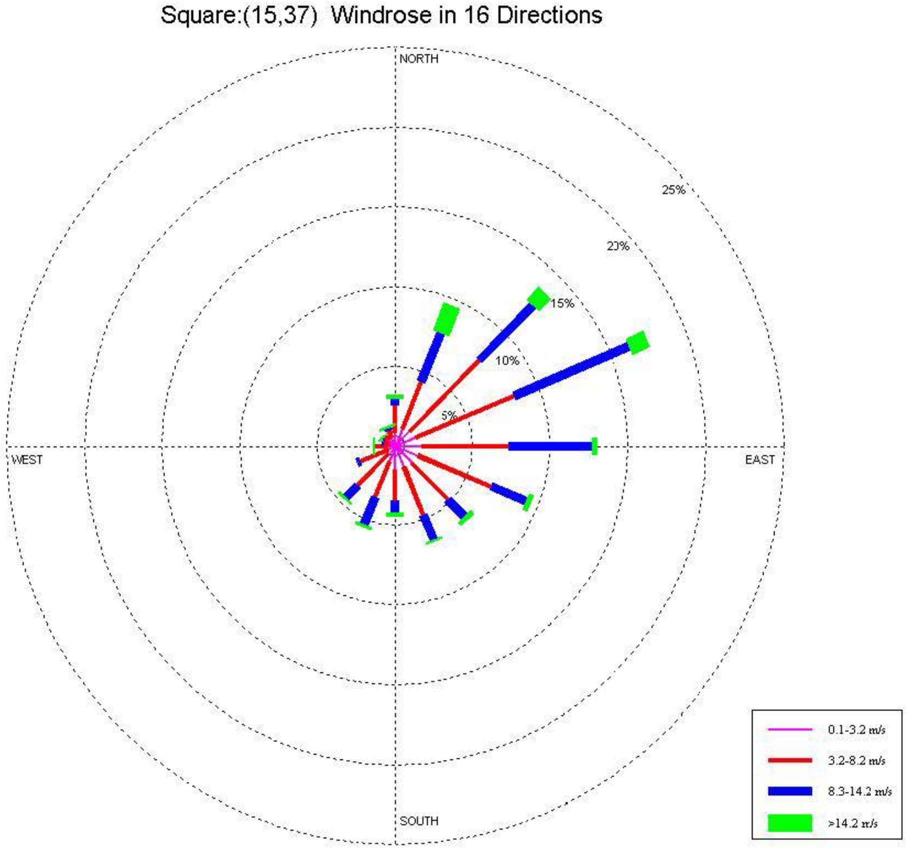


Figure 4-2 Relevant Wind Rose for Tin Shui Wai District

4.3 Simplification of Wind Data for the Study

According to the Technical Circular No. 1/06 – AVA, probability of wind coming from a reduced set of directions exceeding 75% of time would normally be considered adequate. The seven most frequent wind directions with accumulative occurrence percentage of approximately 75.2% are shown below. The table below shows the selected wind direction with corresponding average speed at infinity height, 596m (using raw data extracted from PD website: http://www.pland.gov.hk/pland_en/misc/MM5/index.html).

Angle (^{O})	Wind Direction	Wind Speed at infinity, 596 m (m/s)	Probability	
67.5	ENE	8.49	17.30%	75.20%
45.0	NE	7.87	13.40%	
90.0	E	7.43	12.90%	
22.5	NNE	8.63	9.40%	
112.5	ESE	6.23	9.30%	
135.0	SE	5.71	6.50%	
157.5	SSE	6.22	6.40%	
202.5	SSW	6.89	5.40%	
225.0	SW	5.90	4.60%	
180.0	S	4.89	4.40%	
0.0	N	5.30	3.20%	
247.5	WSW	4.75	2.60%	
270.0	W	3.21	1.40%	
337.5	NNW	3.15	1.30%	
315.0	NW	2.25	1.00%	
292.5	WNW	2.78	0.90%	

Table 4-1 Wind Data for Tin Shui Wai District

5 Assessment Methodology and Criteria

5.1 CFD Software

The numerical simulation undertaken for the study involved complex 3-dimensional turbulence flow for the assessment area. The CFD software employed for this assignment is the PHOENICS-2008 <CORE> module.

5.1.1 Assessment Methodology and Assumption

Wind environment within the assessment area prior to and subsequent to construction of the hospital development on the project site was simulated using PHOENICS-2008 <CORE> under the impact of the with seven selected wind directions (ie NNE, NE, ENE, E, ESE, SE, SSE). The methodology as stipulated in Technical Circular No. 1/06 – AVA was adopted, with the assessment and surrounding areas as previously described, and these were modelled and analysed using the PHOENICS-2008 <CORE> CFD simulation with computer specify with 64-bits quad-core of 2.93GHz Xeon CPU and 12.0GB of RAM.

3-Dimensional Modelling

In this study, 3-dimensional models within the surrounding and assessment area were built in order to conduct CFD simulation as shown below. The blockage ratio for 5H (where H is 66 meters) around the area of interest is 2%.

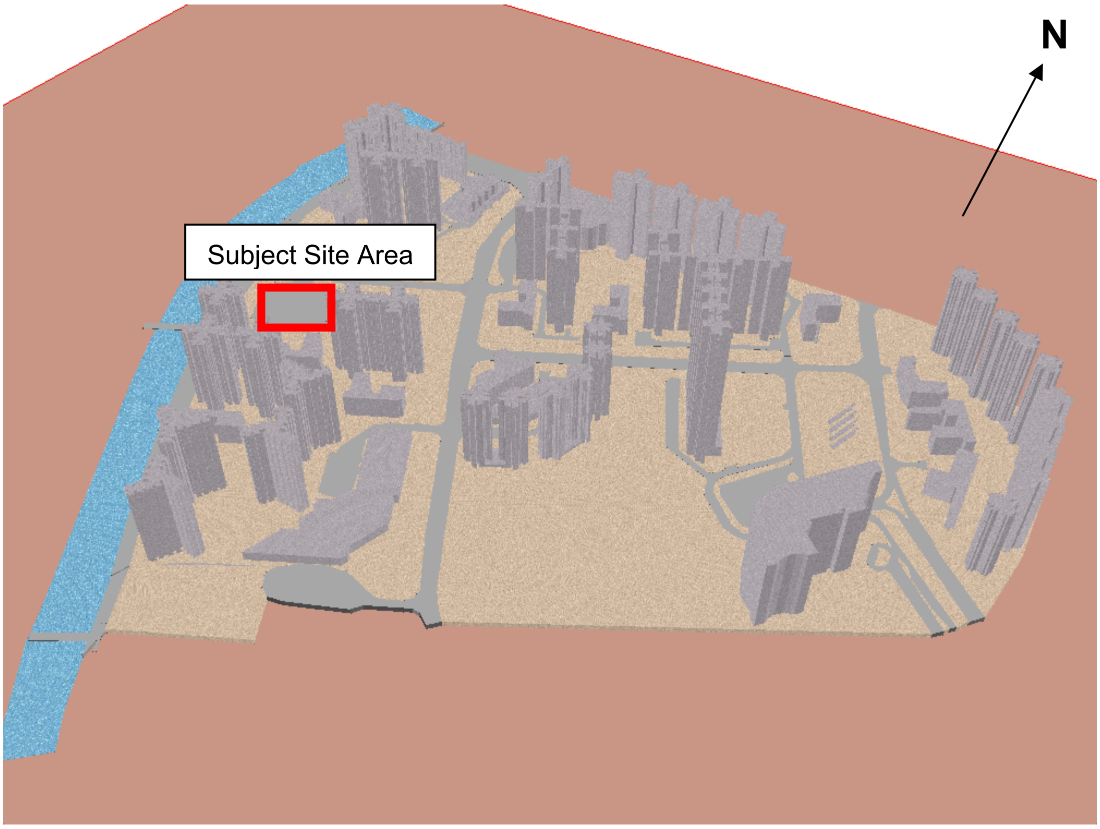


Figure 5-1 3 – Dimensional Virtual Model Prior to Construction of the Tin Shui Wai Hospital Development

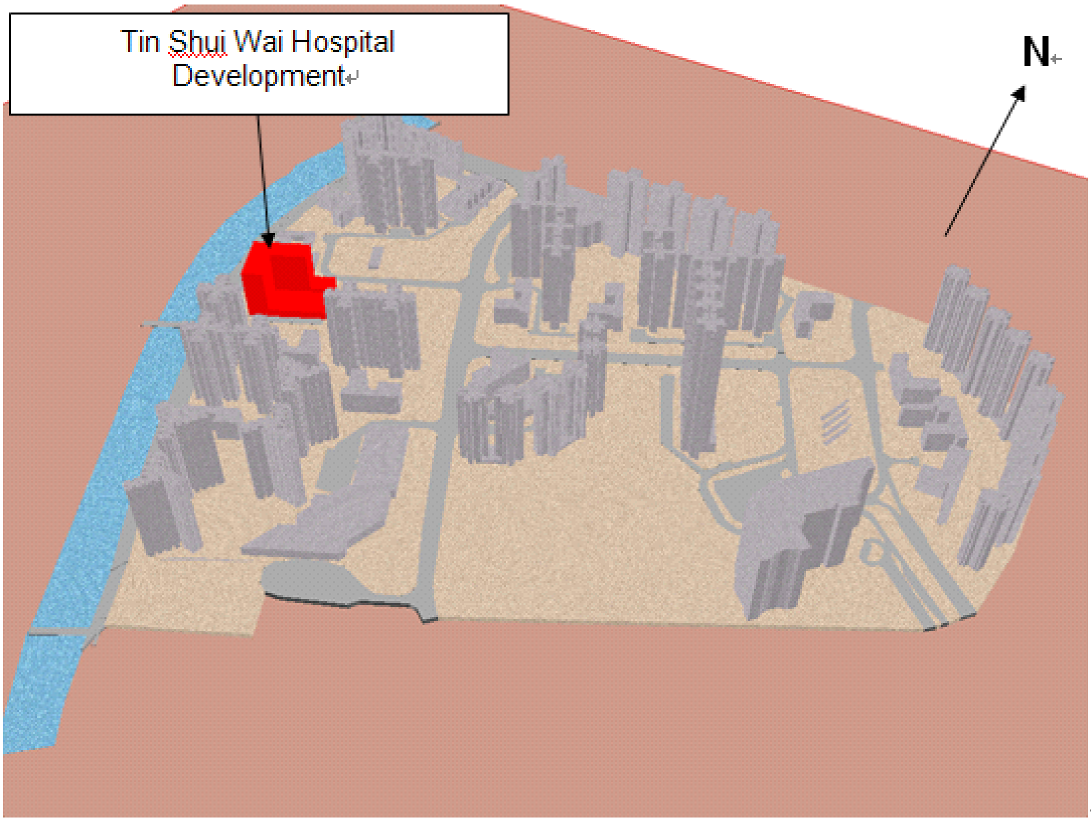


Figure 5-2 3 – Dimensional Virtual Model Subsequent to Construction of the Tin Shui Wai Hospital Development

Computational Fluid Dynamics (CFD) techniques employing Reynolds Averaged Navier-Stokes (RANS) method using turbulence models to solve ensemble-averaged Navier-Stokes equations.

Wind Profile

Although the site wind speed at infinity (terrain height = 596m) were provided, appropriate wind speed were input to the program for our CFD simulation. Vertical wind profile is determined using the Power Law:

$$\frac{\overline{V_Z}}{V_{ZG}} = \left(\frac{Z}{Z_G}\right)^{\alpha}$$

V_Z is the mean wind speed at height Z
V_{ZG} is the gradient wind speed at gradient height (boundary layer ht)
Z is the height of interest
Z_G is the gradient height (boundary layer ht)
α is a coefficient due to the roughness length of the terrain;

Where different power law exponents (α) are chosen for the estimation of wind profile of different prevailing direction based on the roughness length of the surrounding area of the subject site. A high value of α implies a high surface roughness of the area that the incoming wind flows through. Alpha Coefficient (α) in this study is set at 0.5 for all NNE, NE, ENE, E, ESE and SE prevailing wind directions analysed in this study as the terrain in these directions around the project site are of urban and city nature. Due to the suburban topology of scattered vacant lands and mid rise housing to south east of the project site, an Alpha Coefficient of 0.35 is set for SSE. Wind profile drawings for each CFD simulated prevailing wind direction is provided in *Appendix B*.

Terrain crossed by approaching wind	α	Z_G	Z_0
Sea and open space	≈ 0.15	≈ 300	≈ 0.1
Suburban or mid-rise	≈ 0.35	≈ 400	≈ 1
City center or high-rise	≈ 0.50	≈ 500	≈ 3

These coefficients are suggested as a guide only. Wind engineers could fine tune them for the task at hand. For more details, reference could be made to, for example, American Society of Civil Engineers Wind Tunnel Studies of Buildings and Structures 1999.

Table 5-1 Alpha Coefficient in different topography

Turbulence model

The Chen-Kim Turbulence Model (Chen K-Epsilon Model, Chen κ-ε Model) is adopted in the CFD simulation of this AVA study. This is one of the modifications of the standard κ-ε Model in the high Reynolds Number Form. The Standard κ-ε Model is a two-equation model of turbulent kinetic energy κ and dissipation rate ε as explained below.

For turbulent kinetic energy κ

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + P_k + P_b - \rho\epsilon - Y_M + S_k$$

For dissipation rate ε

$$\frac{\partial}{\partial t}(\rho\epsilon) + \frac{\partial}{\partial x_i}(\rho\epsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial \epsilon}{\partial x_j}\right] + C_{1\epsilon}\frac{\epsilon}{k}\left(P_k + C_{3\epsilon}P_b\right) - C_{2\epsilon}\rho\frac{\epsilon^2}{k} + S_\epsilon$$

where the dimensionless constant $C_{1\varepsilon}, C_{2\varepsilon}, C_\mu$ and the Prandtl Numbers $\sigma_\kappa, \sigma_\varepsilon$ are

$$C_{1\epsilon} = 1.44, \quad C_{2\epsilon} = 1.92, \quad C_\mu = 0.09, \quad \sigma_k = 1.0, \quad \sigma_\epsilon = 1.3$$

The original κ-ε Model allows large variation in ε when large eddies occur which will cause large degree of error in the CFD simulation.

The modified Chen κ-ε Model contains a new transport equation with a small coefficient multiplied to the turbulent dissipation rate,ε so that turbulence distortion ratio (P_κ / ε) can be varied and the production of turbulent kinetic energy increases. The Chen κ-ε Model differs from the standard high-Reynolds-Number Form of the κ-ε Model in that:

- The following model constants take different values: σ_κ =0.75; σ_ε =1.15; $C_{1\varepsilon}$ =1.15; $C_{2\varepsilon}$ =1.9 ; and
- An extra timescale κ / P_κ is included in the ε-equation via the following additional source term per unit volume: $S_\varepsilon = \rho * f_1 * C_{3\varepsilon} * P_\kappa^{\,2} / \kappa$

where $C_{3\varepsilon}$ =0.25, P_κ is the volumetric production rate of κ and f_1 is the Lam-Bremhorst [1981] damping function which tends to unity at high turbulence Reynolds numbers. The above modifications permit Chen-Kim Turbulence Model to be appropriate and adequately accurate for CFD simulation analysis in the AVA study.

Domain Size

Following is the domain dimensions employed and graphically illustrated below.

- x-direction = 2,000 m;
- y-direction = 2,000 m; and
- z-direction = 600 m,

H is height of tallest building within subject site which is 66 m.

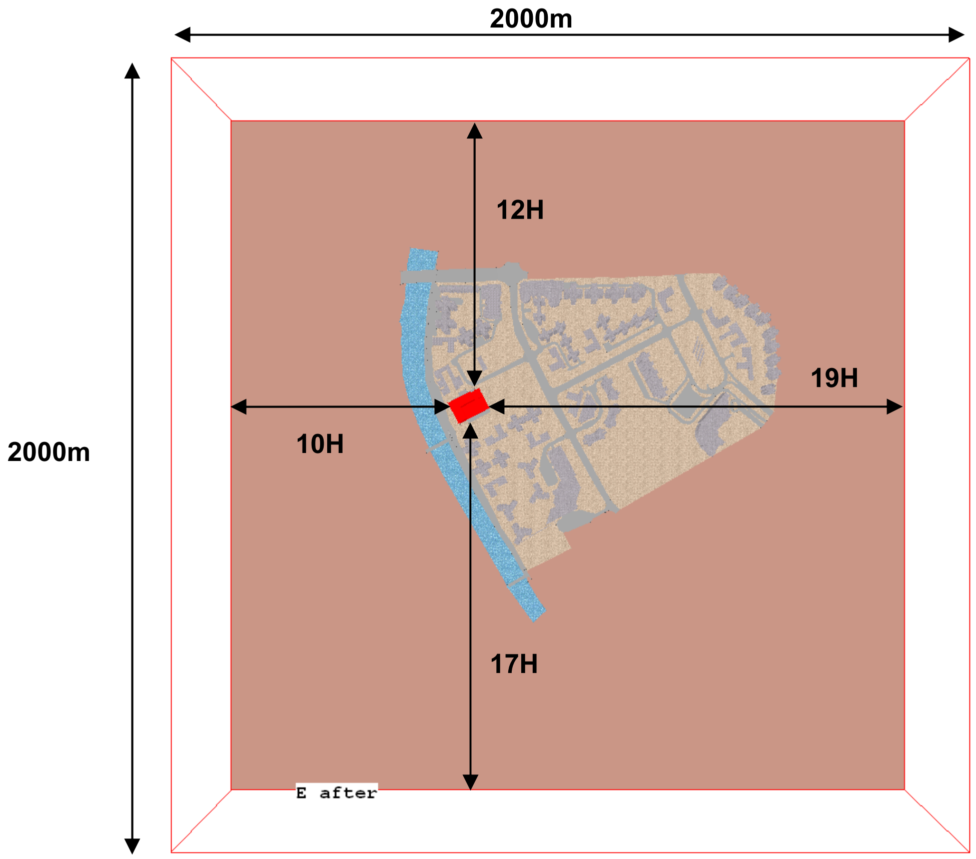


Figure 5-3 Birds View of Domain Dimension

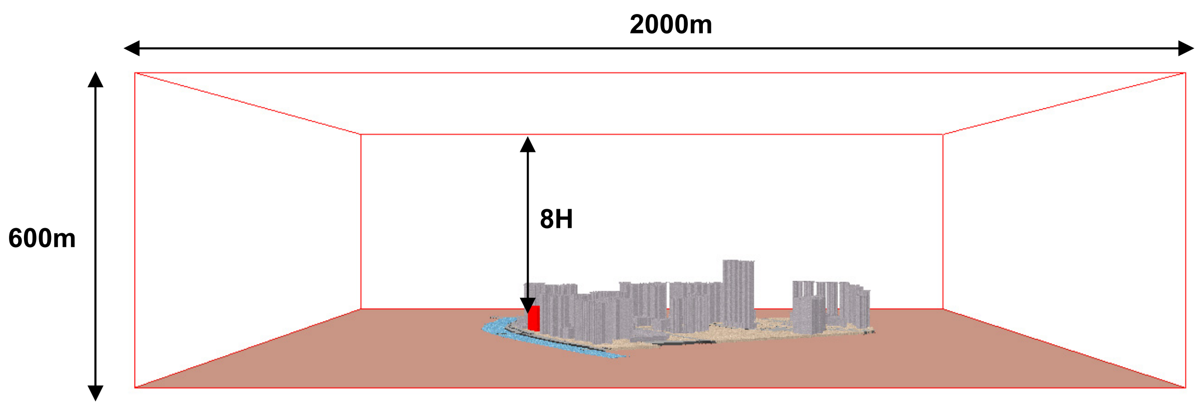


Figure 5-4 Side View of Domain Dimension

Simulation Meshing

Cell meshing is set an adequate resolution to ensure accurate simulation results:

Average size in: x-direction = 12m (largest one near boundary is 25m); y-direction = 13m (largest one near boundary is 42m); z-direction = 7m (largest one near boundary is 26m).

Areas of interest (test points) around and within subject site at ground level: x-direction = 4m; y-direction = 4m; z-direction = 0.5m, with expansion ratio of 1 from 0 to 5m above test points' level[1].

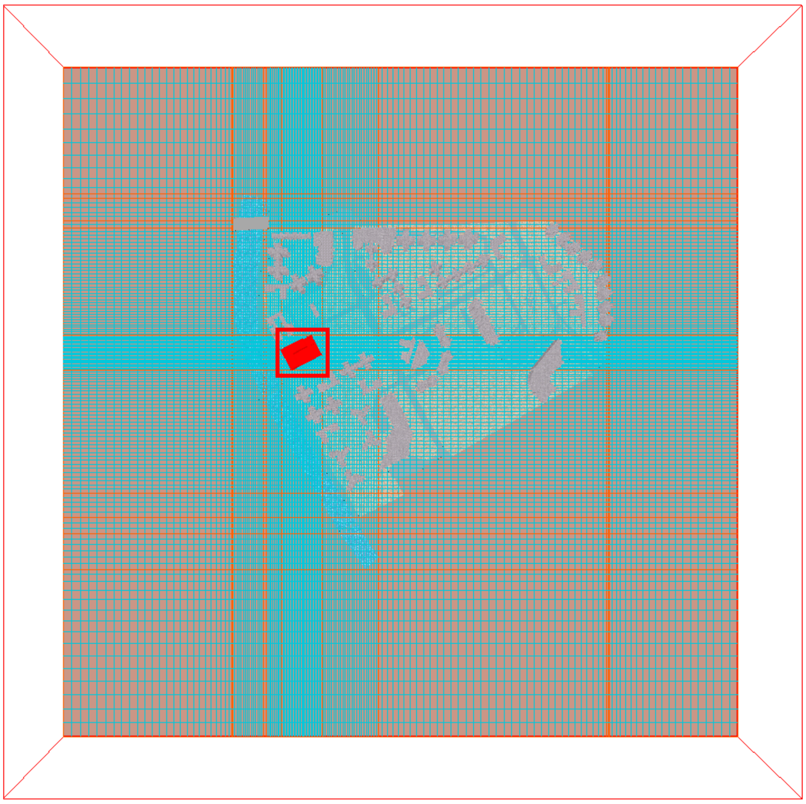


Figure 5-5 Birds View of Meshing Arrangement

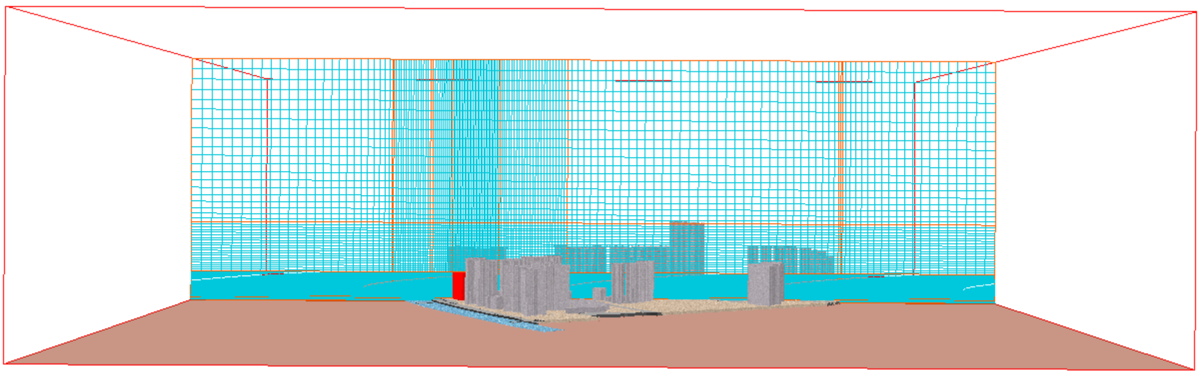


Figure 5-6 Side View of Meshing Arrangement

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[1] Reference to Cost C14

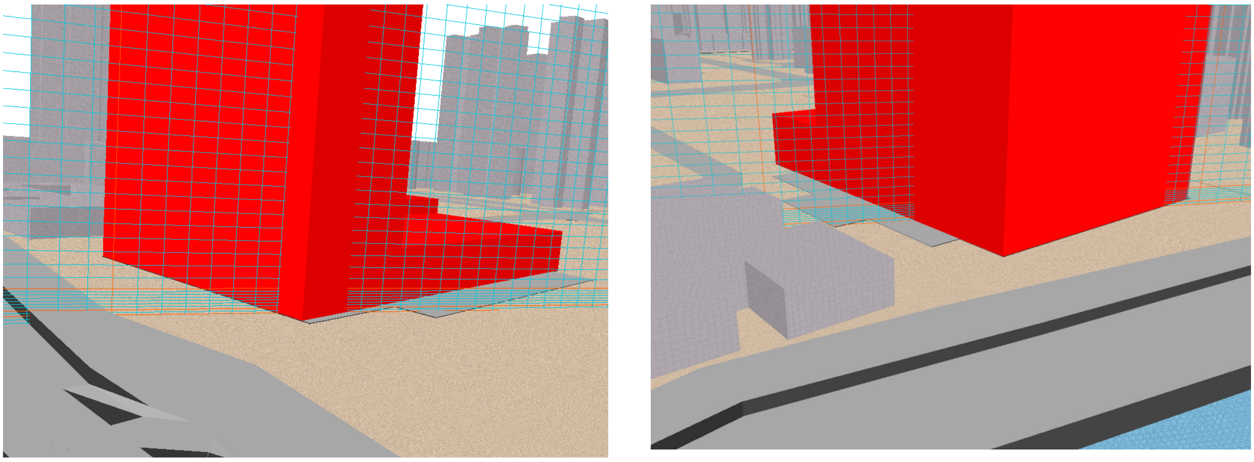


Figure 5-7 Side Views of Meshing Arrangements at Area of Interest (Near Ground Level)

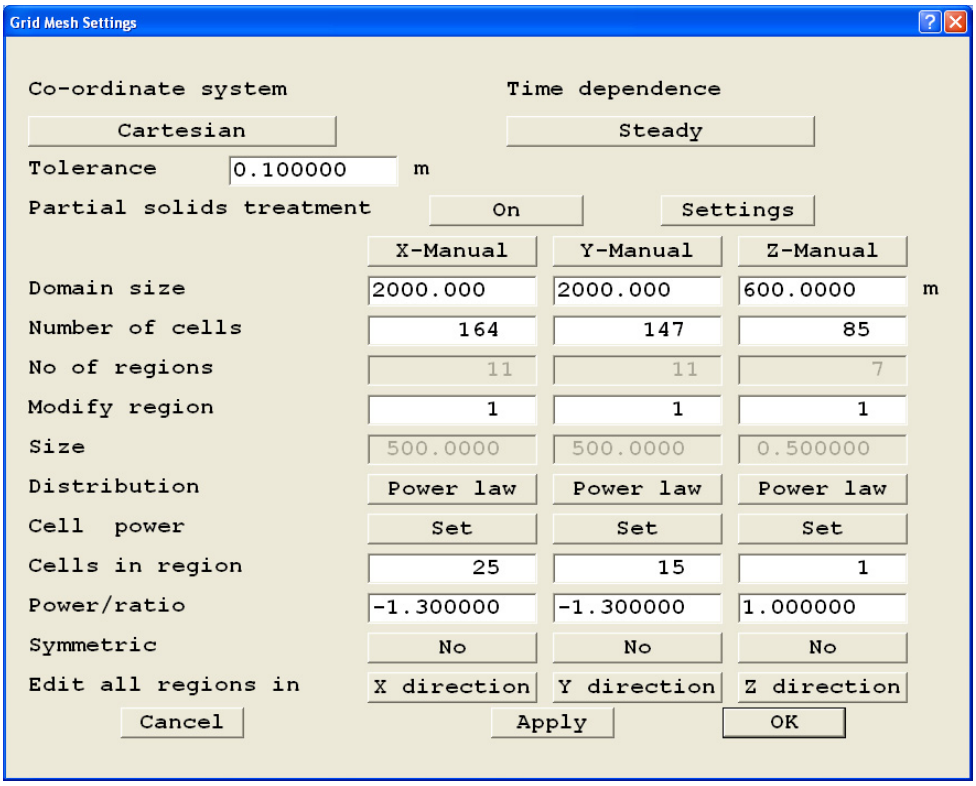


Figure 5-8 Mesh Setting

Other Variables

Fluid velocity, pressure, temperature, turbulence KE, turbulence KE dissipation and turbulence viscosity are variables to be adjusted in order to obtain converging results for the CFD simulation. All of these components were calculated throughout the software domain. The CFD code captures, simulates and determines the airflow inside the domain under study, based on viscous fluid turbulence model employed, and solutions are obtained by iterations. CFD simulations are set to be completed at coverage = 0.1%[2]. Variable settings applied for the CFD simulation are tabulated in overleaf.

[2] A converge solution is considered to be adequate and iteration for cells in each simulation stops when errors in all solved equations have fallen below this minimum threshold value.

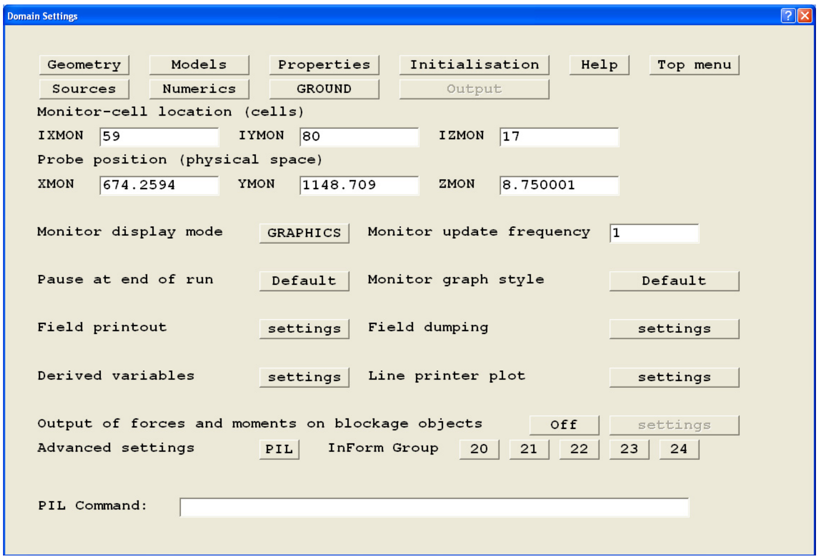


Figure 5-9 Variables Control Settings Employed in CFD Simulations

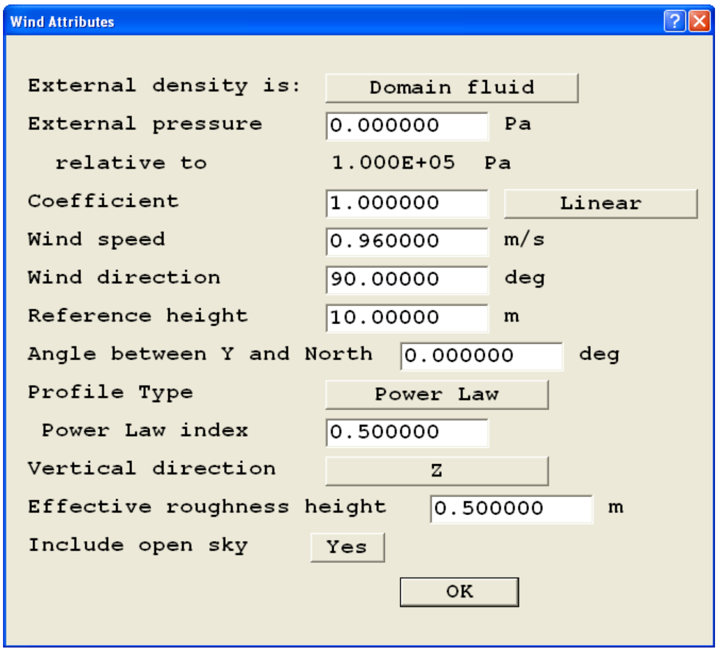


Figure 5-10 Wind Profile Attributes in CFD Simulations

Test Points

Test Points are the locations where Wind Velocity Ratio (VRs) is reported. Based on the VR of the Test Points, the resultant wind environment of the project can be assessed. Perimeter Test Points, special Test Points and local Test Points are distributed around the project site. In all instances, VR reported at test points are taken at 2 meters above ground level.

Perimeter Test Points are distributed to areas around perimeters of the project site boundary including open spaces. Test Points in this group are named with prefix 'P' for labelling purposes (i.e. P1, P2...) as illustrated below. The distribution is shown in the followings as described in paragraph 27 of the Technical Guide for Air Ventilation Assessment for Developments in *Appendix A*.

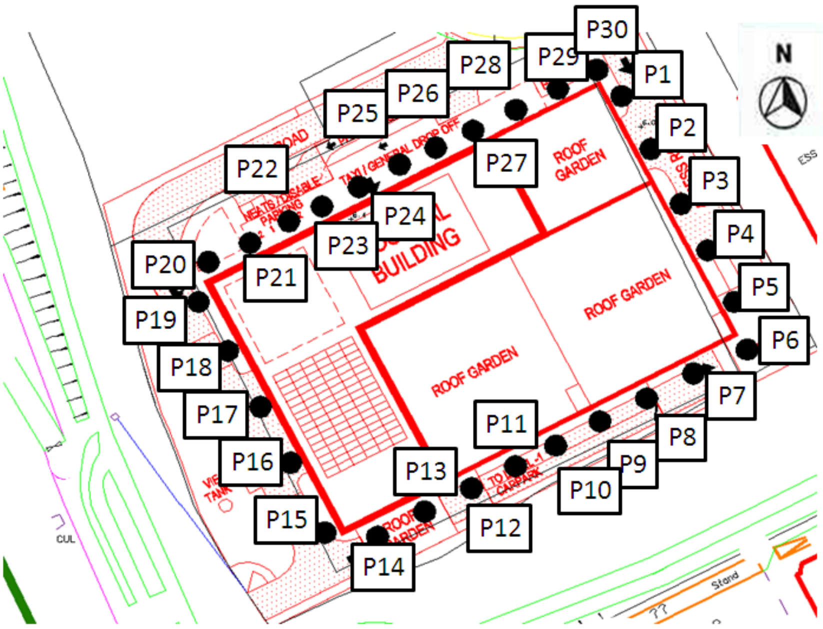


Figure 5-11 Perimeter Test Points

Local Test Points are distributed on those potentially pedestrian accessible areas within the assessment area boundary and project site boundary. The local Test Points are lying within the assessment area boundary (coloured in green) and project site boundary (named by "Site") as illustrated in the figures overleaf. Test Points in this group are named with prefix 'L' for labelling purposes (i.e. L1, L2…). The requirements of local Test Points are stipulated in paragraph 28 of the Technical Guide for Air Ventilation Assessment for Developments *Appendix A.*

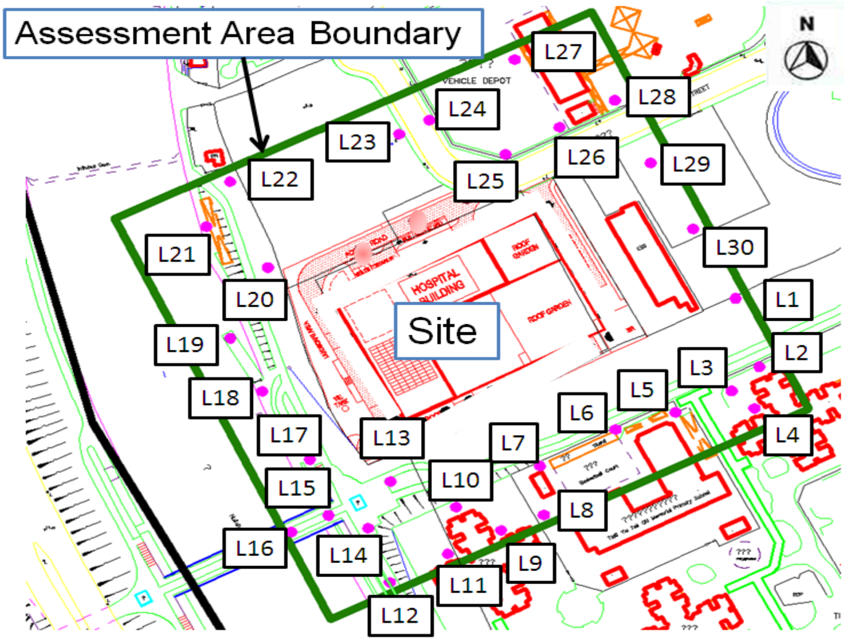


Figure 5-12 Local Test Points

Special Test Points are positioned at the ground floor entrance of the hospital building where these areas are likely to be frequent accessed by pedestrians as illustrated below. Test Points in this group are named with prefix ‘S’ for labelling purposes (i.e. S1, S2…). The distribution is shown in the followings as described in paragraph 29 of the Technical Guide for Air Ventilation Assessment for Developments in Appendix A.

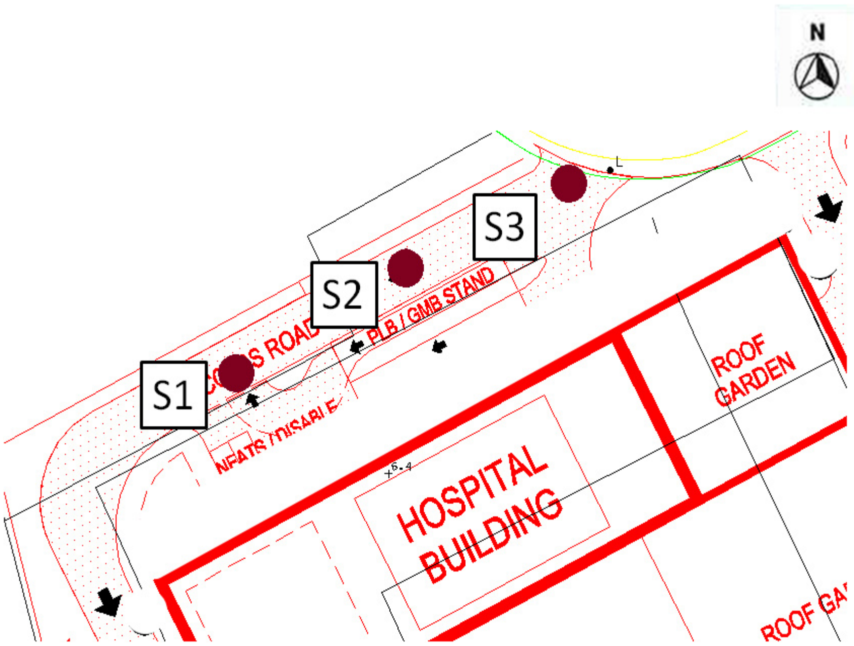


Figure 5-13 Special Test Points

5.2 Wind Velocity Ratio

Wind velocity ratio (VR) is defined as V_p/V_∞ (velocity at pedestrian level/velocity at infinity) and is adopted as the indicator of wind performance enjoyed by pedestrians at particular levels, taking into account of surrounding buildings, topography and the project site. In addition, VR can also be used for the purpose of objective comparison between ventilation performances of various building-massing scenarios. VR for all test points reported in this AVA are taken at 2 meters above ground level.

V_∞ captures the wind velocity at the top of the wind boundary layer and is taken as the wind availability of the site. MM5 Data from Planning Department website are used to determine velocity at infinity level for the project site. Vp captures the wind velocity at pedestrian level and is taken from CFD simulation results.

Adopting this ratio method for analysing CFD results will determine the extent to which the new proposed development impact upon the wind environment of its immediately vicinity and local areas. In general, a higher VR means the proposed building design provides a better ventilation performance to the site and its surrounding environments. The higher the value of VR is, the lesser the impact of the proposed design to the wind availability of the site and its macro wind environment. However in some instances, too high VRs and uneven VR distribution could be a cause of concern and our analysis will address these issues as necessary.

6 Results and Analysis

AVA study and CFD simulation results for the assignment are provided in *Appendix C*. Pedestrian level velocity ratios and plots for each test point described in *Section 5.2,* prior to and subsequent to construction of the Tin Shui Wai Hospital, for each of the seven prevailing wind direction are also tabulated in the *Appendix C*. Wind probability weighted VR for each test point is also provided in the same appendix. The following sections provide a summary and discussions upon study findings.

Local AVA results computed by analysing the group of overall test points and perimeter test points and Site AVA results evaluated by considering perimeter test points only are summarised in the tables below and graphically illustrated overleaf.

Local Air Ventilation Assessment Results (LVR)			
Prevailing Wind Direction	**Prior to Construction of Tin Shui Wai Hospital**	**Subsequent to Construction of Tin Shui Wai Hospital**	**VR Change**
NNE (22.5º)	0.112	0.095	-0.017
NE (45º)	0.118	0.101	-0.017
ENE (67.5º)	0.099	0.089	-0.010
E (90º)	0.109	0.096	-0.013
ESE (112.5º)	0.102	0.093	-0.008
SE (135º)	0.095	0.086	-0.010
SSE (157.5º)	0.164	0.140	-0.024
Overall (weighted)	**0.111**	**0.098**	**-0.013**

Table 6-1 Summary of Local Velocity Ratios for Tin Shui Wai Hospital under Prevailing Wind Directions

Site Air Ventilation Assessment Results (SVR)			
Prevailing Wind Direction	**Prior to Construction of Tin Shui Wai Hospital**	**Subsequent to Construction of Tin Shui Wai Hospital**	**VR Change**
NNE (22.5º)	0.118	0.088	-0.029
NE (45º)	0.129	0.097	-0.032
ENE (67.5º)	0.109	0.088	-0.021
E (90º)	0.123	0.096	-0.027
ESE (112.5º)	0.111	0.094	-0.016
SE (135º)	0.100	0.079	-0.021
SSE (157.5º)	0.171	0.126	-0.045
Overall (weighted)	**0.121**	**0.094**	**-0.027**

Table 6-2 Summary of Site Velocity Ratios for Tin Shui Wai Hospital under Prevailing Wind Directions

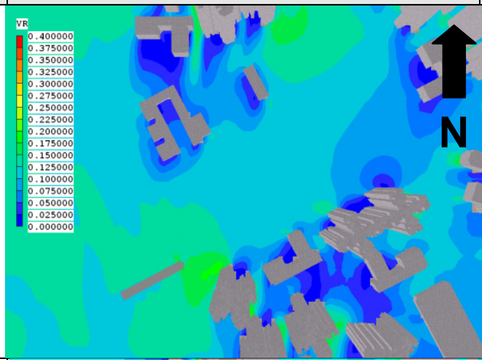
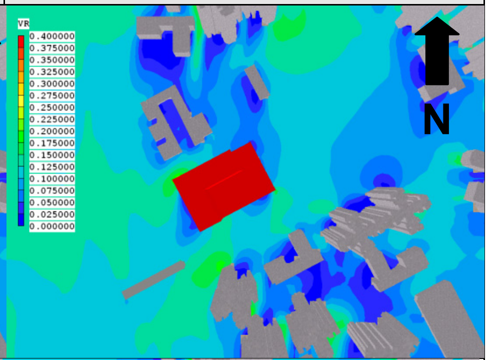
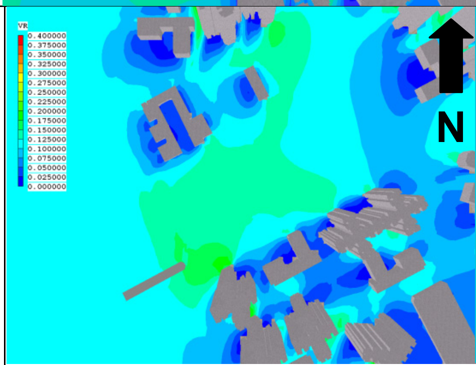
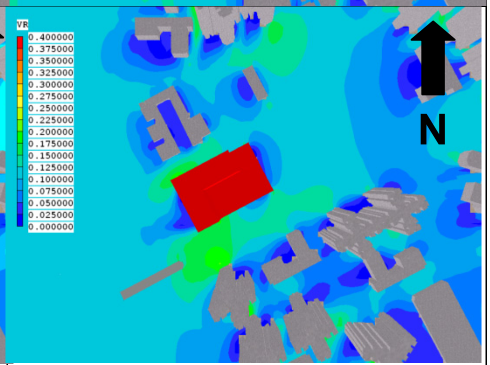
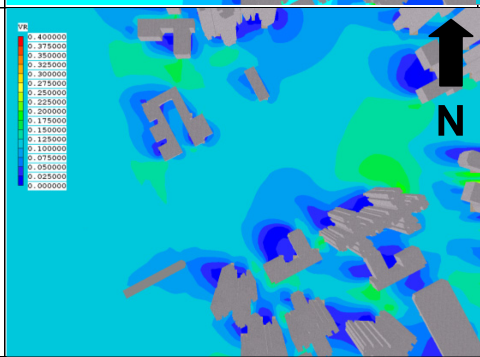
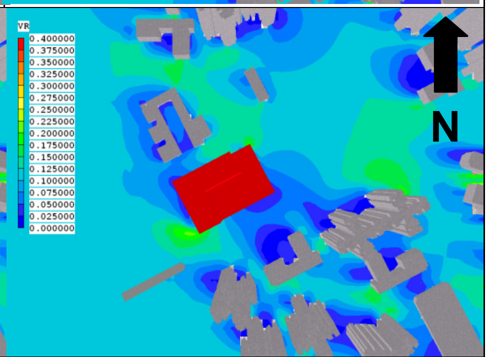
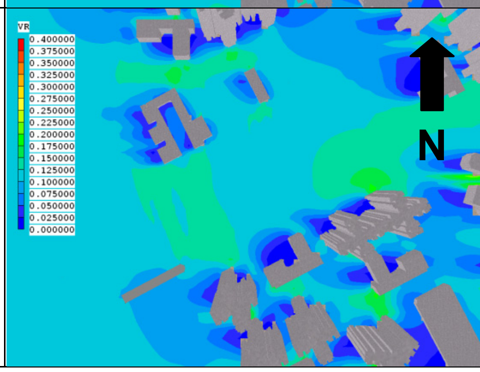
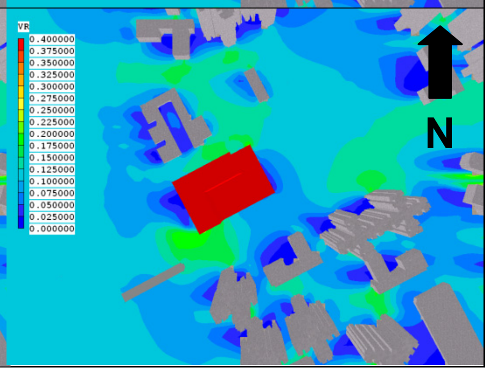
Prevailing Wind Direction	Prior to Construction of Tin Shui Wai Hospital	Subsequent to Construction of Tin Shui Wai Hospital
NNE (22.5º)		
NE (45°)		
ENE (67.5°)		
E (90º)		

Table 6-3 Velocity Ratio Plots for Tin Shui Wai Hospital under Prevailing Wind Directions

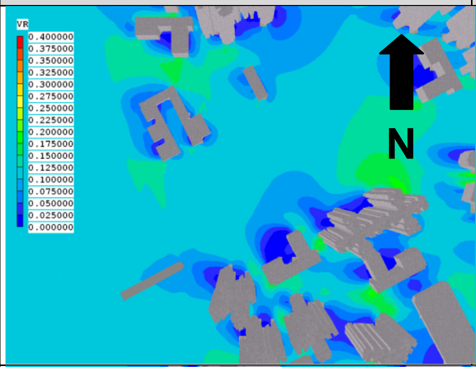
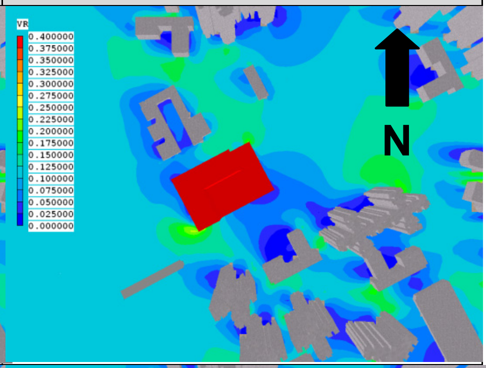
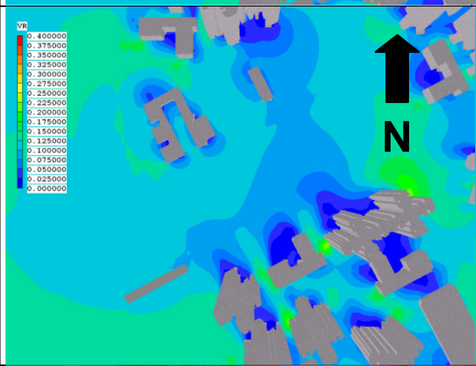
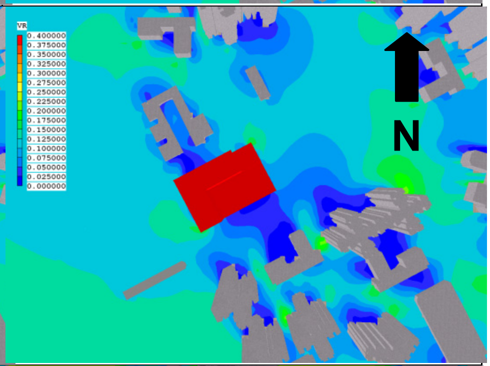
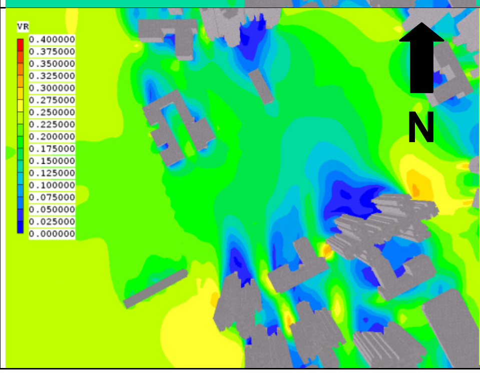
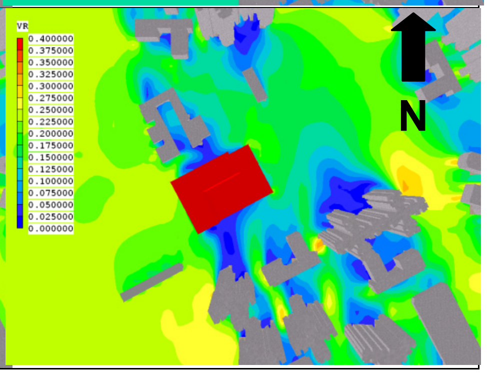
Prevailing Wind Direction	Prior to Construction of Tin Shui Wai Hospital	Subsequent to Construction of Tin Shui Wai Hospital
ESE (112.5º)		
SE (135°)		
SSE (157.5º)		

Table 6-4 Velocity Ratio Plots for Tin Shui Wai Hospital under Prevailing Wind Directions

6.1 Local Air Ventilation Assessment Findings

CFD simulation results of the LVR from above reveal that ventilation performance of adjacent pedestrian access areas within the vicinity of the site will be predominately unaffected by the construction of Tin Shui Wai Hospital. The change in weighted LVR is 0.013 and this is equivalent to a speed reduction of less than 0.1 m/s at pedestrian level which should be deemed insignificant and acceptable.

As predicted from the qualitative ventilation performance evaluation in *Section 3.3*, high rise obstructive buildings are situated at northern and southern directions to the site which cause wind blockage and impact upon ventilation performance as illustrated overleaf. As a result of this, even prior to construction of the Tin Shui Wai Hospital, wind availability of the project site and its surrounding community is inherently limited with a weighted LVR of 0.111 which is equivalent to wind speeds of less than 0.9 m/s at nearby pedestrian areas.

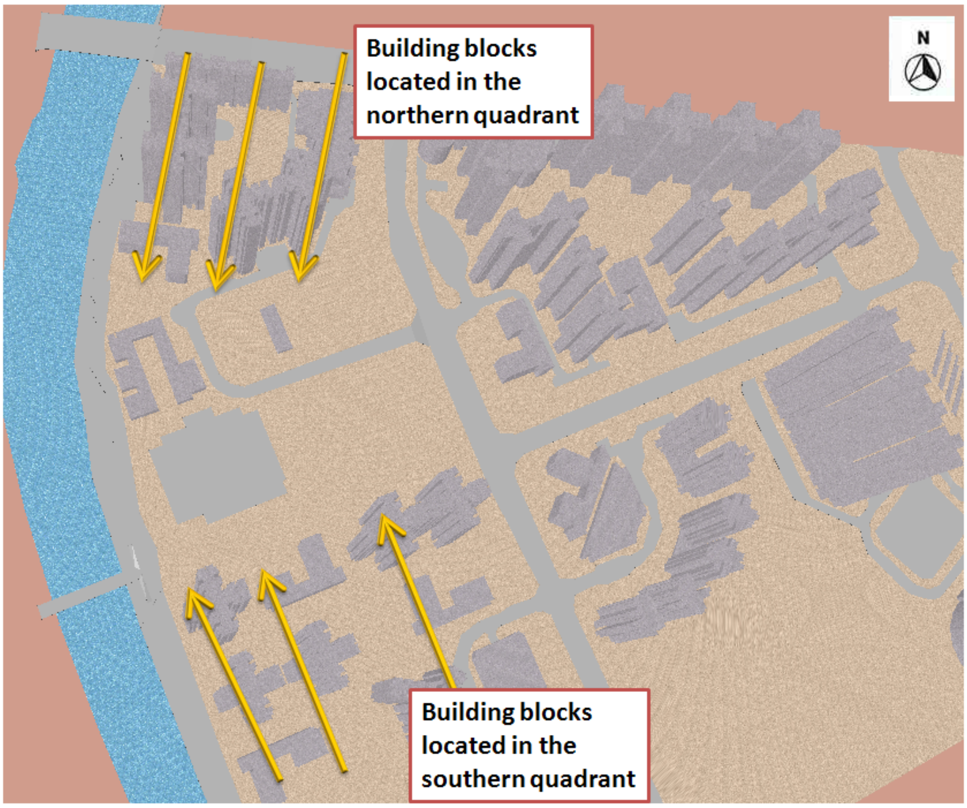


Figure 6-1 High Rise Obstructive Buildings Creates Wind Barriers to Subject Site and Surrounding Environment under Northern and Sothern Quadrant Winds

As explained in *Section 3.3,* surrounding topology of the site creates a wind corridor along Tin Wing Road from the eastern direction and wind is directed towards the site and surrounding communities. Coupled with this wind corridor, the erection of the hospital building induces wind paths at northern and southern directions to the site. Open spaces are present at the eastern and western direction of the development. Roads around the hospital building act as a linkage between these two open spaces in such a way to form air paths. Prevailing Wind from the major breezeway along Tin Wing Road could therefore penetrate pedestrian areas through these air paths as illustrated in Figure 6.2 overleaf. The general principle of this "air path" effect in urbanised areas is provided in Figure 6.3 overleaf for reference.

On the above basis, ventilation impacts from construction of the hospital building is not significantly reduced under eastern quadrant prevailing winds, resulting in LVR reductions ranging from 0.008 to 0.013 (equivalent to less than 0.1 m/s velocity reduction) under ENE, E, ESE and SE directions.

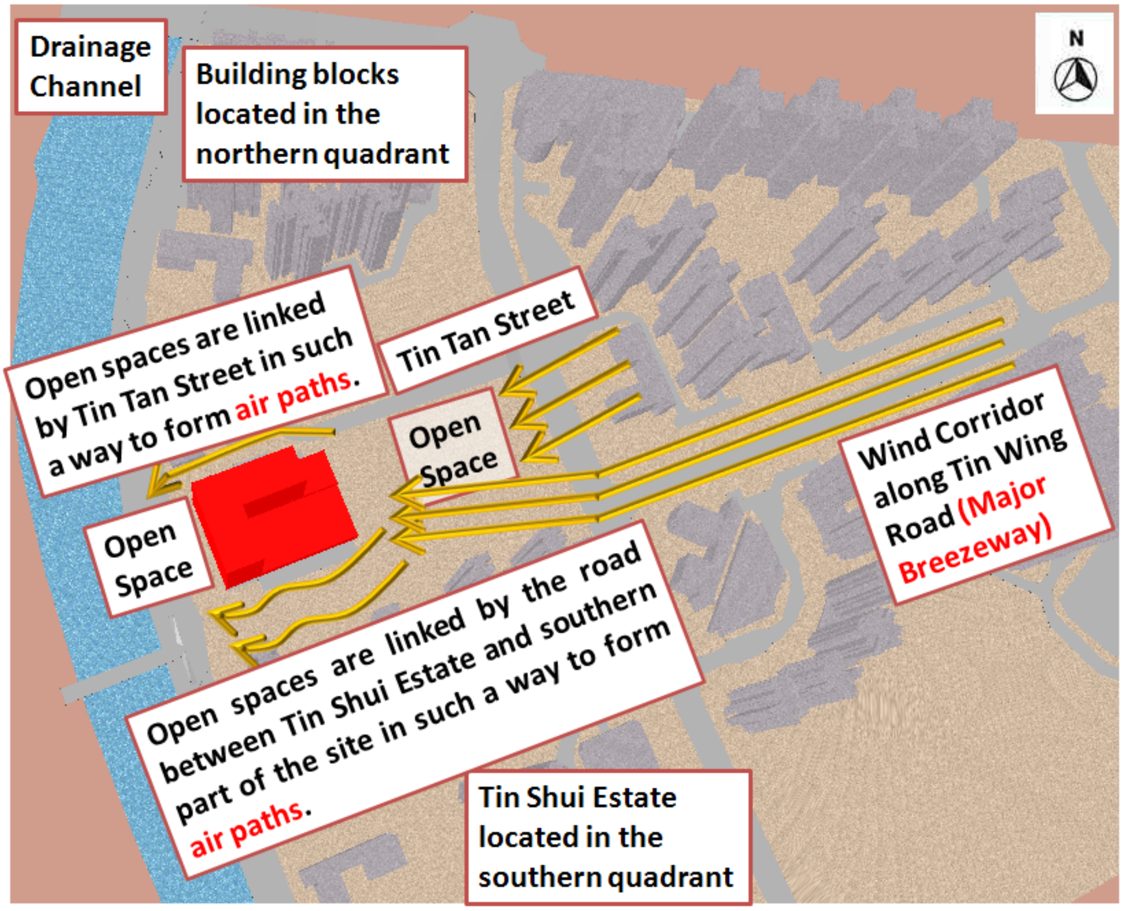


Figure 6-2 Wind Paths Created around the Hospital Building to Minimise Air Ventilation Impacts

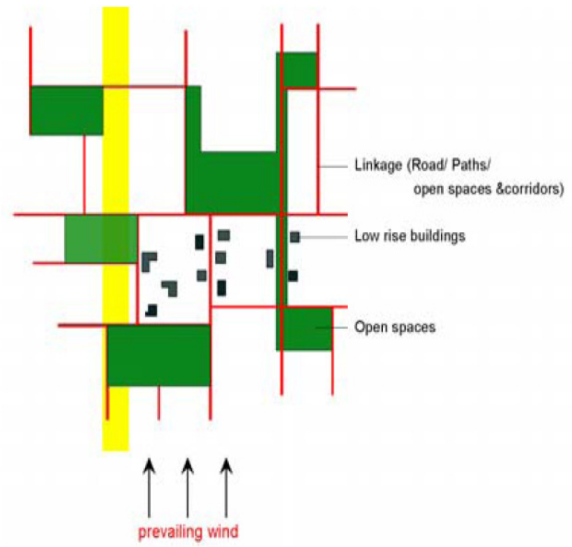


Figure 6-3 Open spaces (coloured in green) are linked by road such that air paths are created around buildings (prevailing wind directions are coloured in yellow)

Under northern and southern quadrants of prevailing wind directions, the construction of the hospital building induces a barrier effect with LVR reductions ranging from 0.017 and 0.024 for NNE, NE and ESE prevailing winds. Although ventilation impacts under these directions appear to be more sever but in absolute terms, the associated velocity reduction is less than 0.2 m/s.

In summary, the overall weighted VR change in the local Air Ventilation Assessment from the construction of Tin Shui Wai Hospital is not substantial (less than 0.013 which is equivalent to 0.1 m/s wind velocity reduction) and its impact upon ventilation performance of potential pedestrian areas is deemed insignificant. Therefore, it can be concluded that the design and erection of Tin Shui Wai Hospital is unlikely to have a significant adverse wind impact on pedestrian level ventilation performance.

6.2 Site Air Ventilation Assessment Findings

The ventilation performance of the site perimeter as a result of the Tin Shui Wai Hospital construction is summarised in the table below. Using the same CFD simulation data, local and site velocity assessments findings are also summarised below:

	Before Development	After Development
LVR (Overall Test Points)	0.111	0.098
SVR (Perimeter Test Point)	0.121	0.094

Table 6-4 Summary of Local Velocity Ratio and Site Velocity Ratio for Tin Shui Wai Hospital under Prevailing Wind Directions

The construction of the Tin Shui Wai Hospital involves erection of vertical structures which would ultimately lead to reduced wind permeability at pedestrian levels within the project site area (originally entirely exposed). Therefore, as shown by the velocity ratios in table 6-4, the Tin Shui Wai Hospital development would generally have some impact upon the wind availability of these test points, as expected. However, a SVR reduction of 0.03 (0.2 m/s reduction in wind velocity) for the hospital building can be considered as relatively insignificant and acceptable.

The Site Perimeter Velocity Ratio for each prevailing wind direction is summarised in the SVR results table 6-2. With reference to these simulated results, a similar ventilation performance trend to LVR is apparent. As a result of wind paths created to northern and southern directions to the site, the erection of the hospital building will have least ventilation impacts under NNE, NE and SSE directions with SVR reductions of less than 0.03 (equivalent to less than 0.2 m/s wind velocity change). Wind availability impacts under NNE, NE and SSE directions are more adverse with up to 0.045 SVR reduction which is equivalent to less than 0.3 m/s reduction in wind speed.

In essence, in terms of overall ventilation performance of site perimeter areas with respect to impact from construction of Tin Shui Wai Hospital, a SVR reduction of 0.027 (0.20m/s reduction in wind velocity) for the subject assessment can be considered as relatively insignificant and acceptable.

6.3 Air Ventilation Performance of Special Test Points

The ventilation performance of special test points within Tin Shui Wai Hospital as extracted from CFD simulation results are tabulated below.

Special Air Ventilation Assessment Results			
Prevailing Wind Direction	**Prior to Construction of Tin Shui Wai Hospital**	**Subsequent to Construction of Tin Shui Wai Hospital**	**VR Change**
NNE (22.5º)	0.113	0.103	-0.010
NE (45º)	0.129	0.140	0.011
ENE (67.5º)	0.110	0.134	0.023
E (90º)	0.123	0.157	0.033
ESE (112.5º)	0.112	0.130	0.018
SE (135º)	0.075	0.075	0.000
SSE (157.5º)	0.166	0.052	-0.114
Overall (weighted)	**0.120**	**0.122**	**0.002**

Table 6-5 Summary of Special Velocity Ratios under Prevailing Wind Directions

The construction of Tin Shui Wai Hospital involves erection of building with height of 66 meters which would ultimately lead to reduced wind permeability in these areas (originally entirely exposed). However, as the special test points are designated only along the Tin Tan Street wind corridor, wind is directly towards these areas under almost all prevailing wind directions as illustrated below.

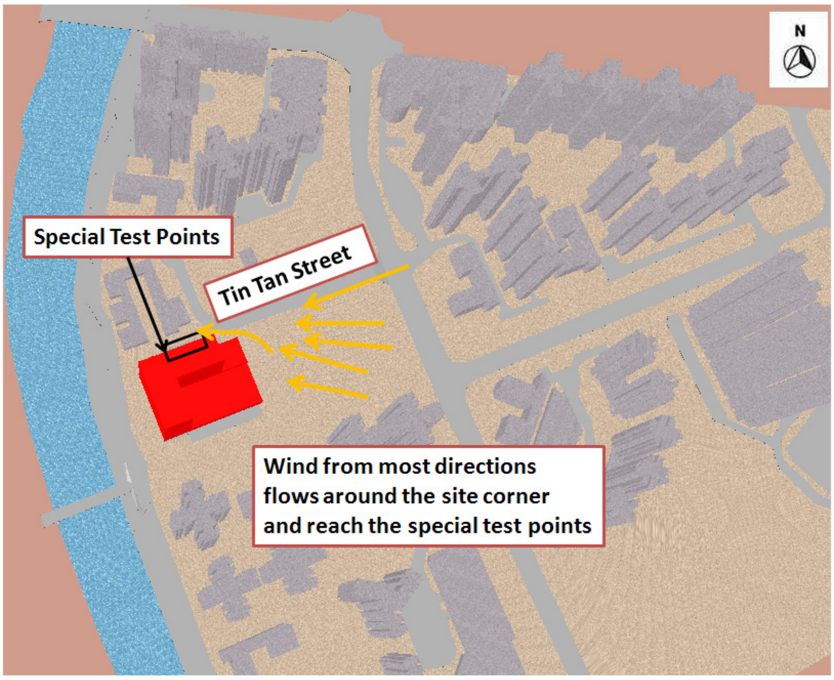


Figure 6-4 Air Path Effect causes Ventilation Improvements to Special Test Points

On this basis, under NE, ENE, E, ESE, SE prevailing winds, ventilation performance of special test points is enhanced with VR improvements ranging from 0.011 to 0.033 which is equivalent to wind speed escalation of up to 0.3 m/s. The wind barrier and obstructive nature of the site under extreme northern and southern wind directions leads to adverse ventilation impacts at NNE and SSE prevailing winds with reductions of up to 0.114 VR which is equivalent to wind speed change of 0.8 m/s. Taking into account of annual probability occurrence of prevailing winds, there is a weighted VR improvement of 0.002 (equivalent to wind speed escalation of 0.02 m/s). In terms of overall pedestrian level ventilation performance of special test points on site, this level of VR change is deemed to be insignificant and satisfactory.

6.4 Overall Conclusion

The AVA study findings reveal that the construction of the Tin Shui Wai Hospital Development is unlikely to have an adverse ventilation performance impact upon pedestrian areas at nearby sensitive communities and within the site. The design and erection of the hospital building leads to ventilation performance results of LVR change = 0.013 (equivalent to less than 0.1 m/s wind speed reduction) and SVR change = 0.027 (equivalent to less than 0.2 m/s wind speed reduction), all of which are deemed to be insignificant and acceptable.

It should be noted, however, in the interest of continual improvement, an additional AVA study should be considered at later project stages to investigate and identify opportunities to further enhance pedestrian level ventilation performance around the Tin Shui Wai Hospital Development, as possible,

Appendix A

Technical Guide for Air Ventilation Assessment for Developments in Hong Kong

19th July 2006

HOUSING, PLANNING AND LANDS BUREAU
TECHNICAL CIRCULAR NO. 1/06
ENVIRONMENT, TRANSPORT AND WORKS BUREAU
TECHNICAL CIRCULAR NO. 1/06

Air Ventilation Assessments

Purpose

This Technical Circular sets out the guidance for applying air ventilation assessments (AVA) to major government projects.

Effective Date

2. This Circular takes immediate effect.

Effect on Existing Circular

3. There is no effect on existing circulars.

Background

4. In the Team Clean report published in August 2003, Government undertook to examine the practicality of stipulating air ventilation assessment (AVA) as one of the considerations for all major development or redevelopment proposals and in future plan making. In the "First Sustainable Development Strategy for Hong Kong" promulgated by the Office of the Chief Secretary for Administration in May 2005, a strategic objective to promote sustainable urban planning and design practices has been set out amongst other objectives with special regard to issues such as buildings affecting view corridors or restricting air flow.

5. A framework for applying AVA is developed on the basis of the "Feasibility Study on Establishment of Air Ventilation Assessment" completed this year and endorsed by the Committee on Planning and Land Development on 7 June 2005. The Committee agreed that Government will take the lead to apply AVA to all major government projects which may have major impacts on the macro wind environment, including public housing projects, planning studies for new development areas and comprehensive redevelopment areas, preparation of new town plans and major revision to town plans. Quasi-government organizations and the private sector are also encouraged to apply AVA to their projects on voluntary and need basis.

Policy

6. Proponent departments / bureaux or authorities responsible for major government projects which may bring about potential impact on air ventilation in the macro wind environment are strongly advised to include AVA in the planning and design of projects. The main purpose of AVA is to promote the awareness of project proponents to ensure that air ventilation impacts are duly considered as one of the main criteria in the planning and design process. The framework developed at this stage does not provide an absolute benchmark standard against which the air ventilation impacts can be confirmed to be acceptable or unacceptable. The framework would however, enable comparison of design options in external air ventilation terms and identification of potential problem areas for design improvements. A further study to develop benchmark standards for AVA in Hong Kong will be commissioned in 2006. Upon completion of the study and gaining sufficient experience, the AVA system may be refined.

Application of AVA

Projects Requiring AVA

7. For the purpose of this Technical Circular, government projects refer generally to projects under the policy initiatives, support or programmes of government departments / bureaux / authorities e.g. public housing, government office buildings, footbridges etc.; regardless of their ownership. Proponent departments / bureaux or authorities should assess the need to apply

AVA to the following categories of major government projects during the planning stage as early as possible:

(a) Planning studies for new development areas;
(b) Comprehensive land use restructuring schemes, including schemes that involve agglomeration of sites together with closure and building over of existing streets;
(c) Area-wide plot ratio and height control reviews;
(d) Developments on sites of over 2 hectares and with an overall plot ratio of 5 or above;
(e) Development proposals with total Gross Floor Area exceeding 100,000square metres;
(f) Developments with podium coverage extending over one hectare;
(g) Developments above public transport terminus;
(h) Buildings with height exceeding 15 metres within a public open space or breezeway designated on layout plans / outline development plans / outline zoning plans or proposed by planning studies ;
(i) Developments on waterfront sites with lot frontage exceeding 100 metres in length; or
(j) Extensive elevated structures of at least 3.5 metres wide, which abut or partially cover a pedestrian corridor along the entire length of a street block that has / allows development at plot ratio 5 or above on both sides; or which covers 30% of a public open space.

8. The above list is not exhaustive and proponent departments / bureaux or authorities may exercise their discretion to include specific projects within their jurisdiction as appropriate.

9. In assessing the need for AVAs for individual projects, the proponent departments / bureaux or authorities should also take into account the following factors :

(a) Whether there are existing / planned outdoor sensitive receivers located in the vicinity of the project site falling within the assessment area. The sensitive receivers should include pedestrians or open space users;
(b) Whether there are known or reasonable assumptions of the development parameters available at the time to conduct the AVA;

(c) Whether alternative designs are feasible or alternative locations are available for the project if the AVA to be conducted would reveal major problem areas;
(d) Whether there are other overriding factors which would prevail over air ventilation considerations in the determination of the project design;
(e) Whether the desirable project design for better air ventilation may compromise other important objectives for the benefits of the public;
(f) Whether the public has raised concern on air ventilation in the neighbourhood area of the project; and /or
(g) Whether the project is already in advanced stage to incorporate the AVA.

10. An officer of D2 rank or above of the proponent departments /bureaux or authorities should be responsible for deciding whether AVA is necessary for the project. If it is decided that the AVA shall be waived, strong justifications should be provided and it is necessary to obtain agreement of the respective policy bureau. If the AVA is considered necessary but pre-mature, a recommended timing or stage of the project for carrying out the AVA should be indicated.

11. For projects waived from the AVA requirement, the proponent departments / bureaux or authorities should, as good practice, still incorporate appropriate qualitative design guidelines to minimize impacts on air ventilation. These qualitative design guidelines are available in the "Urban Design Guidelines", Chapter 11 of the Hong Kong Planning Standards and Guidelines, downloadable from Planning Department's (PlanD) homepage http://www.pland.gov.hk.

AVA Methodology

12. Proponent departments / bureaux or authorities should ensure that the AVAs are properly done by referring to the methodology as in the Technical Guide (*Annex A*).

AVA Register

13. For ease of reference and to facilitate any necessary review of the AVA process, PlanD will maintain an AVA register open for public inspection (format of the AVA register for major government projects is attached in *Annex B*). The register should document the following information with inputs from relevant proponent departments / bureaux or authorities:

(a) projects for which AVA may be needed according to the categories mentioned in para. 7, together with an outline of the project details;
(b) projects which have undergone an AVA;
(c) projects waived from AVA with full justifications, and any qualitative design guidelines which have been incorporated to improve the project designs; and
(d) copies of the AVA report (three hard copies and an electronic copy in Acrobat format).

14. Returns for updating of the AVA register would be requested by PlanD at quarterly intervals.

15. For on-going government projects, the proponent departments / bureaux or authorities should whenever possible still consider if there is scope to apply AVA to the projects. Similarly, results of these reviews should also be included in the AVA register.

16. For AVAs commissioned by the private sector or quasi-government organizations and which have been submitted to government as part of the development submissions, the concerned departments / bureaux should also include the AVAs in the register (format of the AVA register for private/quasi-government projects is attached in *Annex C*) and the submitted AVA report(s) should also be forwarded to PlanD. Consents from the private or quasi-government project proponents should be sought to release information contained in the AVA proforma and /or the AVA reports for public inspection. Three hard copies and an electronic copy in Acrobat format for each AVA report shall be attached upon return of the completed register.

17. For projects which cannot be disclosed due to confidentiality or consents from private / quasi-government project proponents have not been given, the information would be kept solely for government's internal reference.

18. While PlanD will maintain the AVA register, the concerned proponent departments / bureaux or authorities would be responsible for conducting, overseeing and self-appraisal of all AVAs. The AVA register would be uploaded to Planning Department's Homepage and shall be available for public inspection at the Planning Information Counter on 17th floor, North Point Government Offices, 333 Java Road, Hong Kong and on 14th floor, Sha Tin Government Offices, 1 Sheung Wo Che Road, Sha Tin.

<u>Annexes</u>

Annex A	Technical Guide for AVA for Developments in Hong Kong
Annex B	AVA Register for Government Projects
Annex C	AVA Register for Private/Quasi-Government Projects

(Michael M.Y. Suen)

Secretary for the Housing, Planning and Lands

(Dr. Sarah Liao)

Secretary for the Environment, Transport and Works

Annex A

Technical Guide for Air Ventilation Assessment for Developments in Hong Kong

1. This Technical Guide assists project proponent to undertake Air Ventilation Assessment (AVA) to assess the impacts of the proposal on the pedestrian wind environment. The assessment should follow this Technical Guide as far as possible and a report should be submitted to the proponent departments / bureaux or authorities on the assessment findings.

2. Every site is different. The assessor is strongly advised to approach the assessment intellectually and discretionally taking into account different site conditions. Working with experienced practising wind engineers throughout the assessment process is strongly recommended.

Indicator

3. Wind Velocity Ratio (VR) should be used as an indicator of wind performance for the AVA. It indicates how much of the wind availability of a location could be experienced and enjoyed by pedestrians on ground taking into account the surrounding buildings and topography and the proposed development. Given the general weak wind conditions in Hong Kong, the higher the wind velocity ratio, the less likely would be the impact of the proposed development on the wind availability.

4. Wind VR is defined as V_p/V_∞ (V pedestrian/V infinity). V_∞ captures the wind velocity at the top of the wind boundary layer (typically assumed to be around 400 m to 600 m above city centre, or at a height wind is unaffected by the urban roughness below). V_∞ is taken as the wind availability of the site. V_p captures the wind velocity at the pedestrian level (2 m above ground) after taking into account the effects of buildings and urban features.

Expert Evaluation / Initial Study / Detailed Study

5. It is always useful and cost effective for the assessor to conduct an early round of **Expert Evaluation.** This provides a qualitative assessment to the design and/or design options and facilitates the identification of

problems and issues. The Expert Evaluation is particularly useful for large sites and/or sites with specific and unique wind features, issues, concerns and problems. The following tasks may be achieved with Expert Evaluation:

(a) Identifies good design features.

(b) Identifies obvious problem areas and propose some mitigation measures.

(c) Defines "focuses" and methodologies of the Initial and/or Detailed studies.

(d) Determines if further study should be staged into Initial Study and Detailed Study, or Detailed Study alone.

6. In exercising expert knowledge and experience, the assessor should refer to the "Urban Design Guidelines", Chapter 11 of the Hong Kong Planning Standards and Guidelines downloadable from the Planning Department's (PlanD) website at http://www.pland.gov.hk.

7. The Expert Evaluation could lead to an Initial Study or directly to a Detailed Study depending on the nature of the development. The **Initial Study** will refine and substantiate the Expert Evaluation. The following tasks may be achieved with the Initial Study:

(a) Initially assesses the characteristics of the wind availability ($V\infty$) of the site.

(b) Gives a general pattern and a rough quantitative estimate of wind performance at the pedestrian level reported using Wind VR.

(c) Further refines the understanding (good design features and problem areas) of the Expert Evaluation.

(d) Further defines the "focuses", methodologies and scope of work of the Detailed Study.

8. It is sometimes necessary to reiterate the Initial Study so as to refine the design and/or design options.

9. With or without the Initial Study, the **Detailed Study** concludes the AVA. With the Detailed Study, the assessor could accurately and "quantitatively" compare designs so that a better one could be selected. Detailed Study is essential for more complex sites and developments, and where key air ventilation concerns have been reviewed and identified in the Expert Evaluation / Initial Study. The following tasks may be achieved with the Detailed Study:

(a) To assess the characteristics of the wind availability ($V\infty$) of the site in detail.

(b) To report all VR of test points. To report Site VR (SVR) and Local VR (LVR) when appropriate (as outlined in paras 27 to 30). To report, if any, wind gust problems.

(c) To provide a summary of how the identified problems, if any, have been resolved.

Site Wind Availability Data

10. It is necessary to account for the characteristics of the natural wind availability of the site. As far as possible, the design should utilize and optimize the natural wind.

11. For the Expert Evaluation, it is advisable to make reference to the Hong Kong Observatory Waglan Island wind data, as well as reasonable wind data of nearby weather stations. Expertly interpreted, it is possible to qualitatively estimate the prevailing wind directions and magnitudes of the site necessary for the evaluation.

12. For the Initial Study, it is necessary to be more precise. Either "simulated" site wind data, or "experimental" site wind data, as described in paras. 13 and 15 below, respectively, could be used.

13. Using appropriate mathematical models (e.g. MM5 and CALMET), it is possible to simulate and estimate the site wind availability data ($V\infty$). For the Expert Evaluation and Initial Study, project proponent may refer to the preliminary set of simulated "Site Wind Availability Data" ($V\infty$) available at PlanD's website.

14. For the Detailed Study, it is necessary to be even more precise. "Experimental" site wind data, as described in para 15 below, should be used.

15. Using large scale topographical model (typically 1:2000 to 1:4000) tested in a boundary layer wind tunnel, more precise wind availability and characteristics information in terms of wind rose, wind profile(s) and wind turbulence intensity profile(s) of the site could be obtained. Hong Kong Observatory Waglan Island wind data should be referenced to for the experimental study.

Tools

16. Wind tunnel is recommended for both the Initial and the Detailed Studies, and most particularly for the Detailed Study. The conduct of the wind tunnel test should comply, as far as practicable, with established international best practices, such as, but not be limited to:

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

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

17. Computational Fluid Dynamics (CFD) may be used with caution, it is more likely admissible for the Initial Studies. There is no internationally recognized guideline or standard for using CFD in outdoor urban scale studies. The onus is on the assessor to demonstrate that the tool used is "fit for the purpose".

18. Should the assessor wish to use other forms of tool for the assessment not described above, the onus is on the proponent to demonstrate that the tool to be employed is "fit for the purpose". The scientific suitability, as well as the practical merits of the tool to be used must be demonstrated.

Simplification of Wind Data for the Initial Study

19. In general, the characteristics of the site wind availability data should be reported in 16 directions. This is necessary to work out the Wind Velocity Ratio.

20. For the Initial Study, if using CFD, it may be appropriate and cost effective, to reduce the number of directions in the study. This is reasonable especially for sites with only a few incoming prevailing wind directions. The assessor must demonstrate that the probability of wind coming from the reduced set of directions should exceed 75% of the time in a typical reference year. Wind profile(s) for the site could also be appropriated from the V_∞ data developed from simulation models (e.g. MM5 and CALMET) and with reference to the Power Law or Log Law using coefficients appropriate to the site conditions.

21. For the Detailed Study, no simplification is allowed. Wind from all 16 directions and their probability of occurrences must be accounted for, and wind profiles(s) obtained from wind tunnel experiments should be used to conduct the study, and when calculating the Wind Velocity Ratio.

Project, Assessment and Surrounding Areas

22. The testing model for the Initial and the Detailed Studies should cover the Project, the Assessment and the Surrounding Areas.

23. The Project Area is defined by the project site boundaries and includes all open areas within the project that pedestrians are likely to access.

24. A key aim of AVA is to assess a design's impact and effects on its surroundings. The Assessment Area of the project should include the project's surrounding up to a perpendicular distance H from the project boundary, H being the height of the tallest building on site. Occasionally, it may be necessary to include an assessment area larger than that defined above so that special surrounding features and open spaces are not omitted.

25. For the model, it is necessary to include areas surrounding the site. The Surrounding Area is important as it gives a reasonable and representative context to the Assessment Area. It "conditions" the approaching wind profiles appropriately. If the Surrounding Area is not

correctly included and modeled, the wind performance of the Assessment Area will likely to be wrongly estimated. The Surrounding Area of up to a perpendicular distance of 2H from the project boundary must be included. Sometimes it may be necessary to enlarge the Surrounding Area if there are prominent features (e.g. tall buildings or large and bulky obstructions) immediately outside the 2H zone. Other than the method recommended, wind engineers can advise alternative extent of the surroundings to be included on a case-by-case basis, especially when there are nearby prominent topographical features.

Test Points

26. Test points are the locations where Wind VRs are reported. Based on the VR of the test points, the resultant wind environment of the project can be assessed. As each site is unique, it is impossible to be specific about the number and distribution of the required test points; but they must be carefully and strategically located. Three types of test points may be specified for assessment: Perimeter, Overall and Special.

27. Perimeter test points are positioned on the project site boundary. They are useful to assess the "immediate" effect of the project to the Assessment Area. Test points at around 10 m to 50 m center to center (or more if larger test site is evaluated) may be located around the perimeters of the project site boundary. Test points are normally not necessary at perimeter(s) where there is no major air ventilation issues e.g. waterfront area with ample sea breeze, inaccessible land such as green belt. Tests points must be located at the junctions of all roads leading to the project site, at main entrances to the project, and at corners of the project site. This group of perimeter test points will provide data for the **Site Air Ventilation Assessment**. Typically about 30 to 50 perimeter test points well spaced out and located will suffice.

28. Overall test points are evenly distributed and positioned in the open spaces, on the streets and places of the project and Assessment Areas where pedestrians frequently access. This group of overall test points, together with the perimeter test points, will provide data for the **Local Air Ventilation Assessment**. For practical reasons, around 50 to 80 test points may be adequate for typical development sites.

29. Special test points may be positioned in areas that special localized

problems are likely to appear (e.g. wind gust problem for exposed sites). These special test points should not be included in the Site and Local Air Ventilation Assessments, as they may distort the average VRs. They independently may provide additional information to assessors.

Reporting

30. For the purpose of the AVA, Wind Velocity Ratios of all test points should be individually reported. They help to identify problem areas. Two ratios may also be reported, they give a simple quantity to summarise the overall impact on the wind environment for easy comparison:

(a) For the **Site Air Ventilation Assessment**, the Site spatial average Velocity Ratio (SVR) of all perimeter test points (para 27 refers) may be reported. This gives a hint of how the development proposal impacts the wind environment of its immediate vicinity.

(b) For the **Local Air Ventilation Assessment**, the Local spatial average velocity ratio (LVR) of all perimeter and overall test points (paras 27 and 28, respectively refer) may be reported. This gives a hint of how the development proposal impacts the wind environment of the local area.

The local air ventilation considerations should always take precedence over the site specific air ventilation considerations. For exposed sites, concerns of wind gust should be reported.

31. The AVA report should contain the following key sections. The technical merit, as well as the results of the AVA of the project must be demonstrated:

(a) An introductory section of the details of **the project**.

(b) A section on results of the **Expert Evaluation**. Concerns and potential problems should be identified. Focuses and methodologies of further studies should be defined.

(c) A section on the characteristics of the **Site Wind Availability** to be used for Initial Studies and Detail Studies. Methodologies used to obtain the information must be explained in detail.

(d) A section on the **Methodology of the Initial Study**. The tool used for the studies must be explained in detail. It is important for the assessor to demonstrate and to justify that the tool and work process used is technically "fit for the purpose".

(e) A section on results and **key findings of the Initial Study**.

(f) A section on **Methodology of the Detailed Study**. The tool used for the studies must be explained in detail. It is important for the assessor to demonstrate and to justify that the tool and work process used is technically "fit for the purpose".

(g) A section on results and **key findings of the Detailed Study**.

(h) A section on Evaluation and **Assessment**. Summarise findings, highlight problems and outline mitigation measures, if any.

32. Based on the reported VR, the assessor would compare the merits and demerits of different design options. The following considerations on the reporting of SVR and LVR may be useful to note:

(a) In the general weak wind conditions in Hong Kong, for the AVA, the higher the values of the spatial average VR, the better the design. Comparing performances of design options using the spatial average VR (both SVR and LVR) is recommended (para 30 refers).

(b) The **Site Air Ventilation Assessment** (SVR) gives an idea of how the lower portion of the buildings on the project site may affect the immediate surroundings. When problems are detected, it is likely that design changes may be needed for the lower portion of the development (e.g. the coverage of the podium) (para 30(a) refers).

(c) The **Local Air Ventilation Assessment** (LVR) gives an idea of how the upper portion of the buildings on the project site may affect the surroundings. When problems are detected, it is likely that design changes may be needed for the upper portion of the development (e.g. re-orientation of blocks and adjustment to the extent of the towers) (para 30(b) refers).

(d) For very large sites, or for sites with elongated or odd geometry, it may be necessary to work out the SVR and LVR to suit the size or geometry. For example, say for an elongated site, it might be useful to sub-divide the site into smaller sub-sections to work out the spatial averages. It is possible that the development may have a high VR at one end and a low VR at the other end.

(e) It is necessary to examine VR of the individual test points of SVR and/or LVR to ensure that none is way below the spatial average. When this happens, it indicates possible stagnant zones to be avoided.

(f) On the other hand, no individual VR should be obviously above the spatial average SVR and/or LVR. When this happens, it indicates wind amplification, and the possibility of wind gust and pedestrian safety concerns. Further assessments and mitigation measures may be required.

(g) Where large differentials in individual VRs are reported, the spatial average SVR and/or LVR should be interpreted more carefully to avoid overlooking problem areas due to averaging of the individual VRs.

(h) In addition to SVR and LVR, and beyond the key focus of AVA in this Technical Guide, VR of special test points, if positioned, may be analysed. The results from these additional test points will identify potential wind problems in areas of special concerns.

Appendix B

MM5 Wind Speed/ Probability Data and Wind Profile Drawings

RawMM5WindDataEmployedforAVAStudy

Square (15,37)	Wind direction	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
V infinity (m/s)	Sum	0.032	0.094	0.134	0.173	0.129	0.093	0.065	0.064	0.044	0.054	0.046	0.026	0.014	0.009	0.01	0.013
0_to_1	0.02	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.001	0.001
1_to_2	0.052	0.002	0.003	0.004	0.005	0.004	0.004	0.005	0.006	0.006	0.004	0.002	0.001	0.002	0.001	0.002	0.002
2_to_3	0.075	0.005	0.005	0.006	0.006	0.008	0.008	0.005	0.005	0.006	0.005	0.004	0.002	0.002	0.001	0.003	0.003
3_to_4	0.085	0.004	0.009	0.01	0.009	0.01	0.009	0.007	0.004	0.004	0.004	0.003	0.003	0.001	0.001	0.002	0.003
4_to_5	0.099	0.006	0.008	0.015	0.013	0.01	0.01	0.005	0.006	0.004	0.005	0.005	0.005	0.003	0.001	0.001	0.002
5_to_6	0.098	0.004	0.008	0.011	0.015	0.01	0.012	0.007	0.007	0.004	0.004	0.007	0.005	0.001	0.001	0	0
6_to_7	0.098	0.002	0.004	0.014	0.017	0.013	0.01	0.008	0.007	0.005	0.004	0.006	0.005	0.001	0.001	0	0
7_to_8	0.083	0.001	0.003	0.012	0.013	0.013	0.008	0.007	0.008	0.003	0.005	0.006	0.002	0.001	0	0	0
8_to_9	0.081	0.001	0.006	0.011	0.012	0.014	0.01	0.005	0.006	0.002	0.007	0.006	0.001	0	0	0	0
9_to_10	0.076	0.002	0.007	0.008	0.019	0.011	0.007	0.005	0.006	0.002	0.005	0.003	0	0	0	0	0
10_to_11	0.06	0.001	0.007	0.011	0.016	0.009	0.004	0.002	0.002	0.002	0.003	0.001	0	0	0	0	0.001
11_to_12	0.052	0	0.005	0.009	0.016	0.011	0.003	0.002	0.002	0.001	0.002	0	0	0	0	0	0
12_to_13	0.037	0	0.003	0.006	0.011	0.007	0.002	0.001	0.002	0.001	0.002	0.001	0	0	0	0	0
13_to_14	0.026	0	0.005	0.005	0.007	0.004	0.001	0.001	0.001	0	0.001	0	0	0	0	0	0
14_to_15	0.017	0	0.006	0.004	0.003	0.002	0	0	0	0	0.001	0	0	0	0	0	0
15_to_16	0.012	0.001	0.006	0.002	0.002	0	0	0	0	0	0	0	0	0	0	0	0
16_to_17	0.012	0.001	0.005	0.002	0.002	0	0	0	0	0	0.001	0	0	0	0	0	0
17_to_18	0.006	0	0.001	0.001	0.002	0	0	0	0	0	0	0	0	0	0	0	0
18_to_19	0.005	0	0	0.001	0.002	0	0.001	0	0	0	0	0	0	0	0	0	0
19_to_20	0.003	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0
20_to_21	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21_to_22	0.002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22_to_23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23_to_24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24_to_25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25_to_26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Wind Probability and Wind Profiles

Using Tin Shui Wai region raw MM5 data for the subject site, wind speed and probability under prevailing direction are computed as follows:

Angle (^{O})	Wind Direction	Wind Speed at infinity (m/s)	Probability	
67.5	ENE	8.49	17.30%	75.20%
45.0	NE	7.87	13.40%	
90.0	E	7.43	12.90%	
22.5	NNE	8.63	9.40%	
112.5	ESE	6.23	9.30%	
135.0	SE	5.71	6.50%	
157.5	SSE	6.22	6.40%	
202.5	SSW	6.89	5.40%	
225.0	SW	5.90	4.60%	
180.0	S	4.89	4.40%	
0.0	N	5.30	3.20%	
247.5	WSW	4.75	2.60%	
270.0	W	3.21	1.40%	
337.5	NNW	3.15	1.30%	
315.0	NW	2.25	1.00%	
292.5	WNW	2.78	0.90%	

Using infinity wind speed (terrain height = 596m) from above, vertical wind profiles were evaluated at each prevailing direction through adoption of the Power Law:

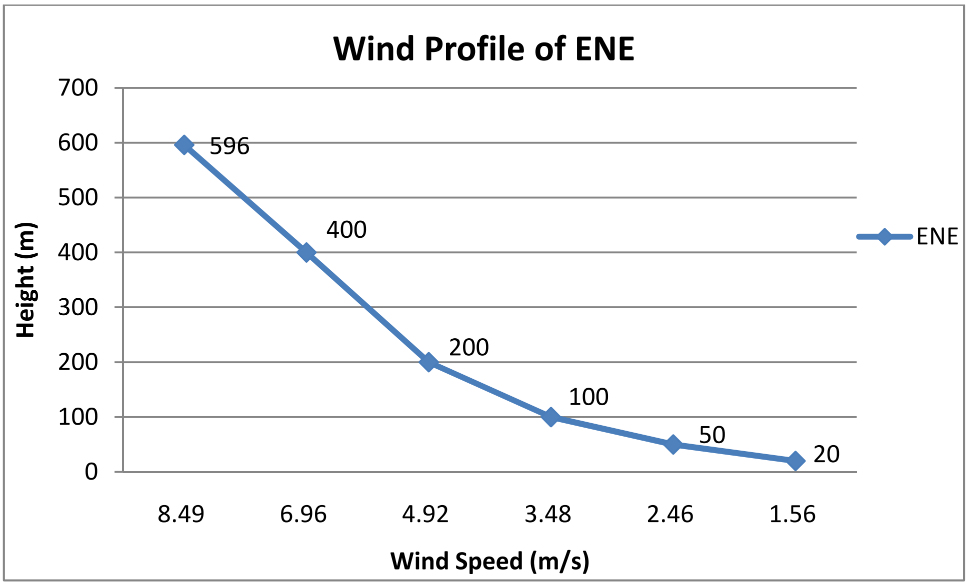
$$\frac{\overline{V}_Z}{V_{ZG}} = \left(\frac{Z}{Z_G}\right)^{\alpha}$$

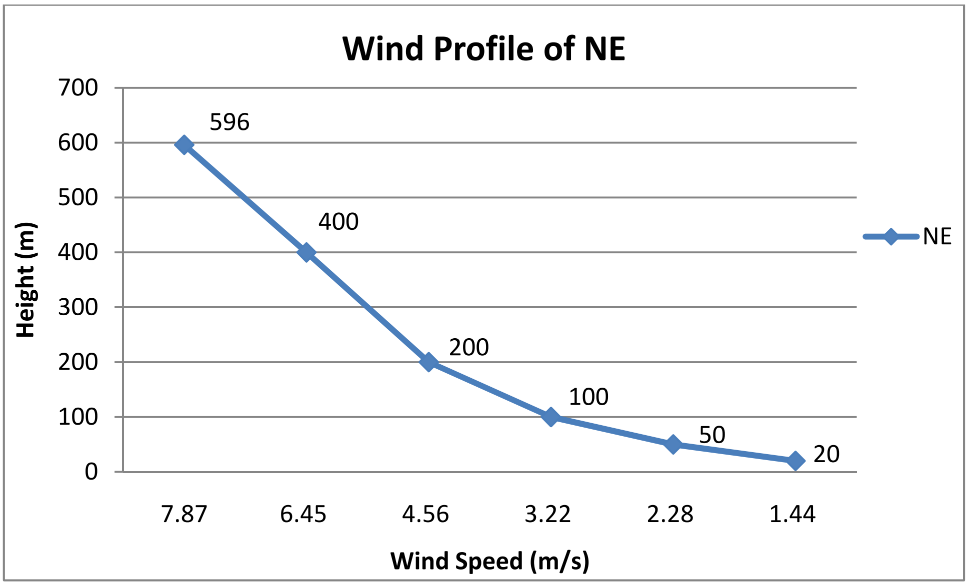
V_Z is the mean wind speed at height Z
V_{ZG} is the gradient wind speed at gradient height (boundary layer ht)
Z is the height of interest
Z_G is the gradient height (boundary layer ht)
α is a coefficient due to the roughness length of the terrain;

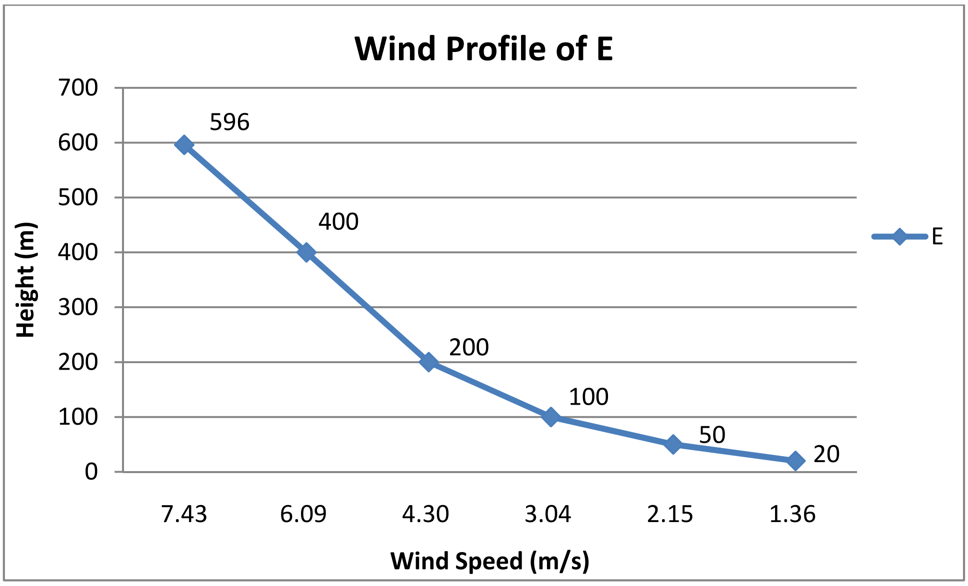
Terrain crossed by approaching wind	α	Z_G	Z_0
Sea and open space	≈ 0.15	≈ 300	≈ 0.1
Suburban or mid-rise	≈ 0.35	≈ 400	≈ 1
City center or high-rise	≈ 0.50	≈ 500	≈ 3

These coefficients are suggested as a guide only. Wind engineers could fine tune them for the task at hand. For more details, reference could be made to, for example, American Society of Civil Engineers Wind Tunnel Studies of Buildings and Structures 1999.

Where different power law exponents (α) are chosen for the estimation of wind profile of different prevailing direction based on the roughness length of the surrounding area of the subject site. A high value of α implies a high surface roughness of the area that the incoming wind flows through. **Alpha Coefficient** (α) in this study is set at 0.5 for all NNE, NE, ENE, E, ESE and SE prevailing wind directions analysed in this study as the terrain in these directions around the project site are of urban and city nature. Due to the suburban topology of scattered vacant lands and mid rise housing to south east of the project site, an Alpha Coefficient of 0.35 is set for SSE.




Wind Profile of NE
Height (m)
700
600
500
400
300
200
100
0
596
400
200
100
50
20
7.87
6.45
4.56
3.22
2.28
1.44
Wind Speed (m/s)
NE


Wind Profile of E
700
600
500
400
300
200
100
0
Height (m)
596
400
200
100
50
20
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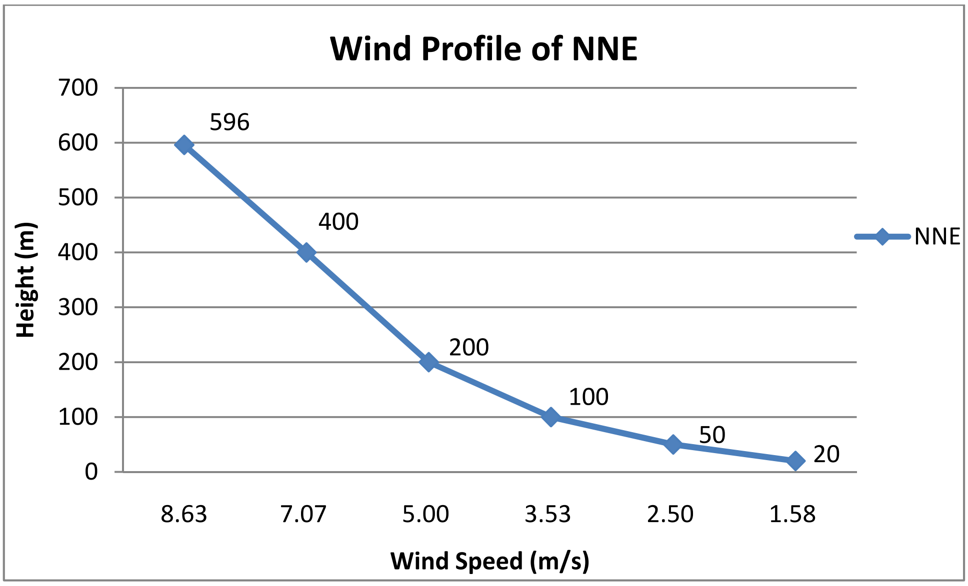
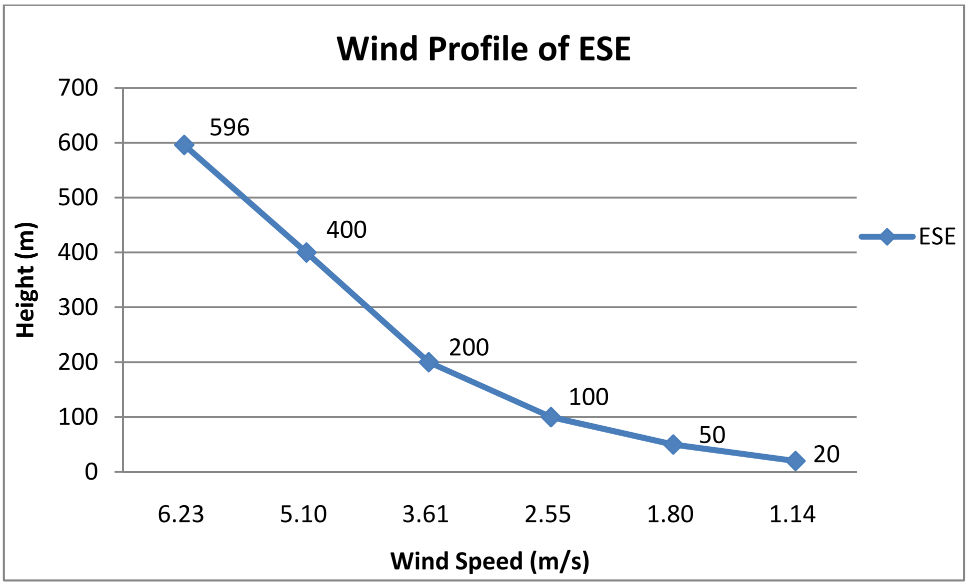
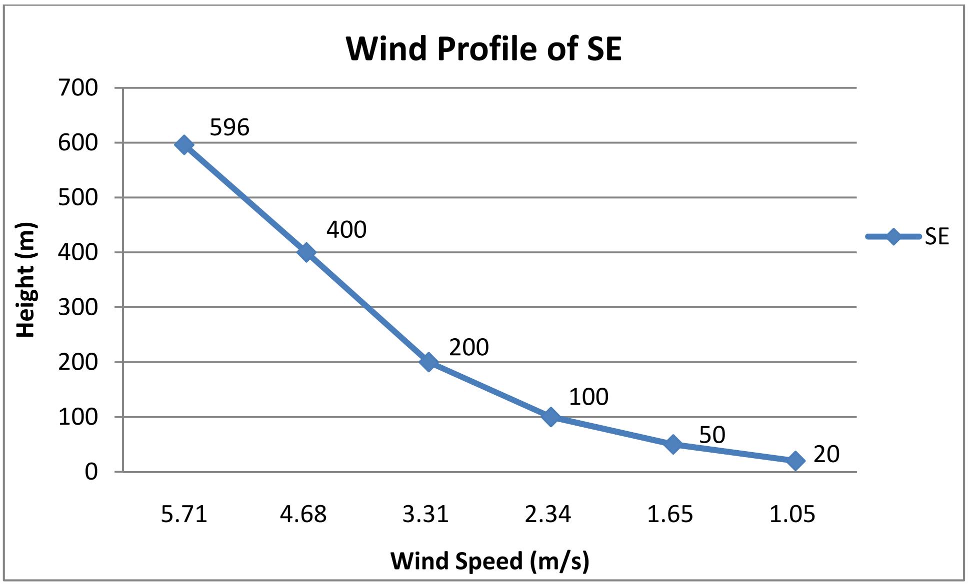
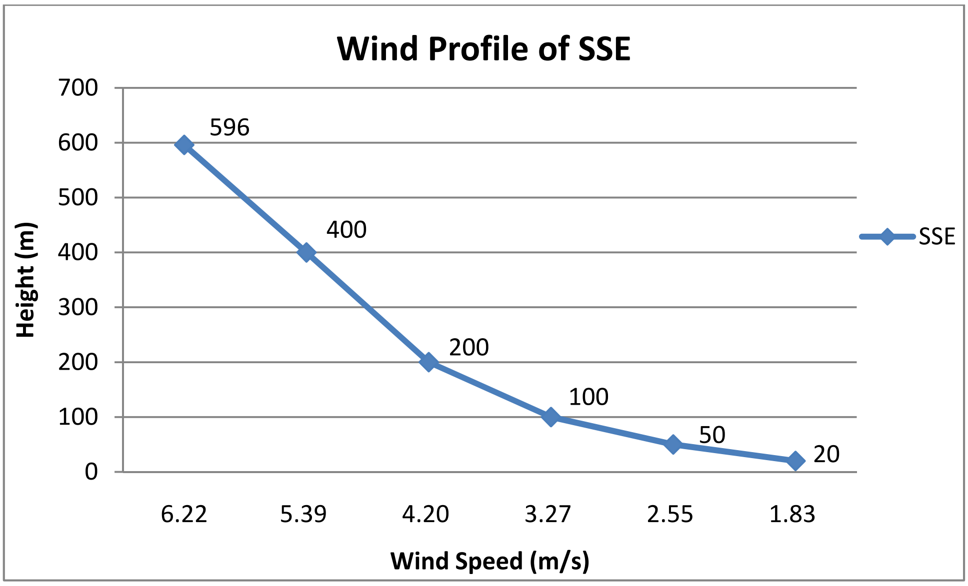
6.09
4.30
3.04
2.15
1.36
Wind Speed (m/s)
E


Wind Profile of NNE
700
600
500
400
300
200
100
0
Height (m)
596
400
200
100
50
20
8.63
7.07
5.00
3.53
2.50
1.58
Wind Speed (m/s)
NNE


Wind Profile of ESE
700
600
500
400
300
200
100
0
Height (m)
596
400
200
100
50
20
6.23
5.10
3.61
2.55
1.80
1.14
Wind Speed (m/s)
ESE

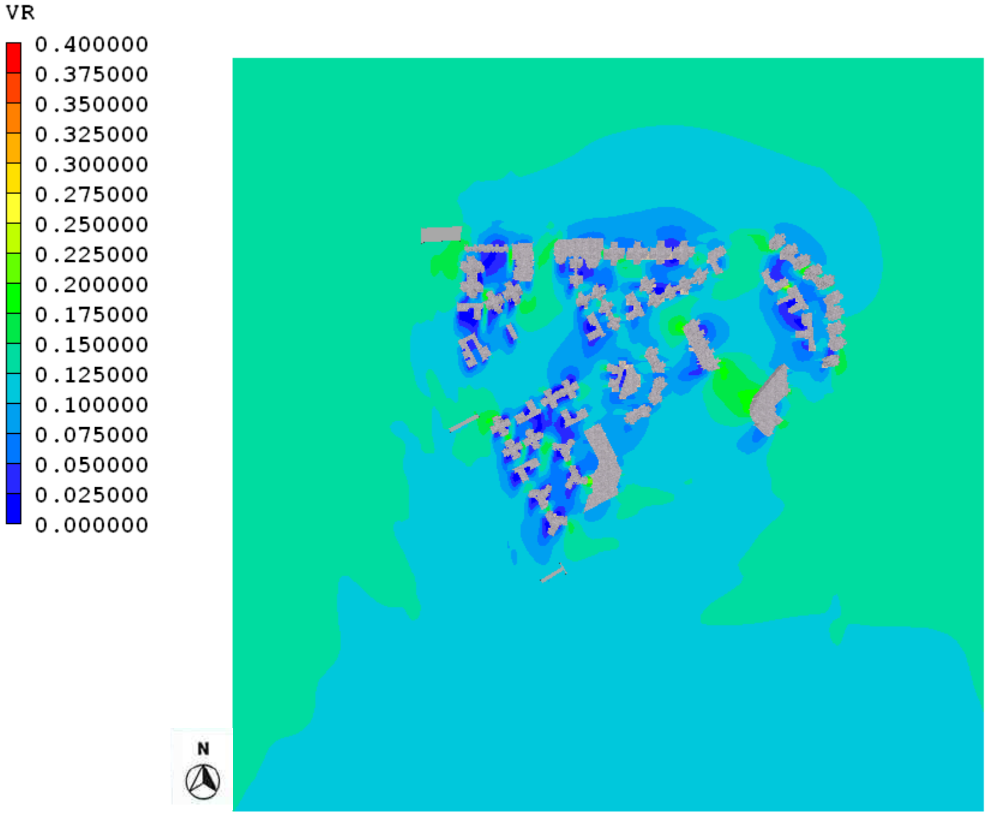

Wind Profile of SE
Height (m)
700
600
500
400
300
200
100
0
596
400
200
100
50
20
5.71
4.68
3.31
2.34
1.65
1.05
Wind Speed (m/s)
SE

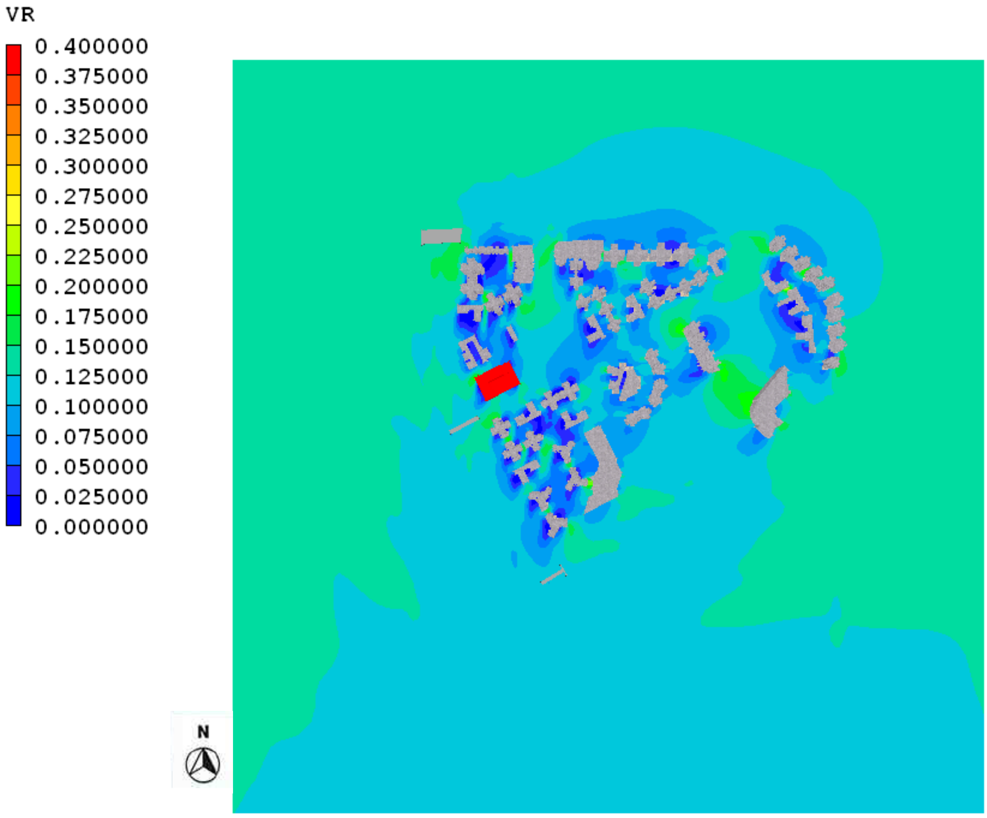

Wind Profile of SSE
Height (m)
700
600
500
400
300
200
100
0
596
400
200
100
50
20
6.22
5.39
4.20
3.27
2.55
1.83
Wind Speed (m/s)
SSE

Appendix C

Wind Velocity Ratio Simulation Results

Before and After Construction of Tin Shui Wai Hospital

<table>
<tr><th>Wind Direction</th><th>NNE (22.5˚)</th></tr>
<tr><td>Prior to Construction of Tin Shui Wai Hospital Development</td><td>


</td></tr>
<tr><td>Subsequent to Construction of Tin Shui Wai Hospital Development</td><td>


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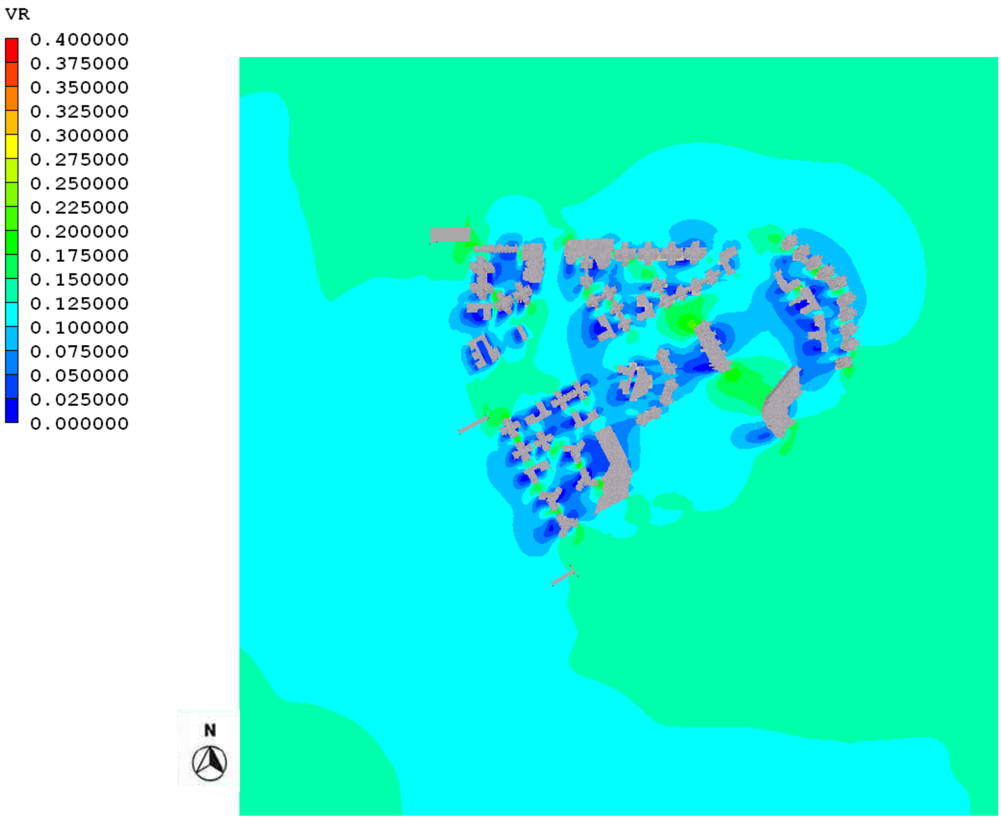
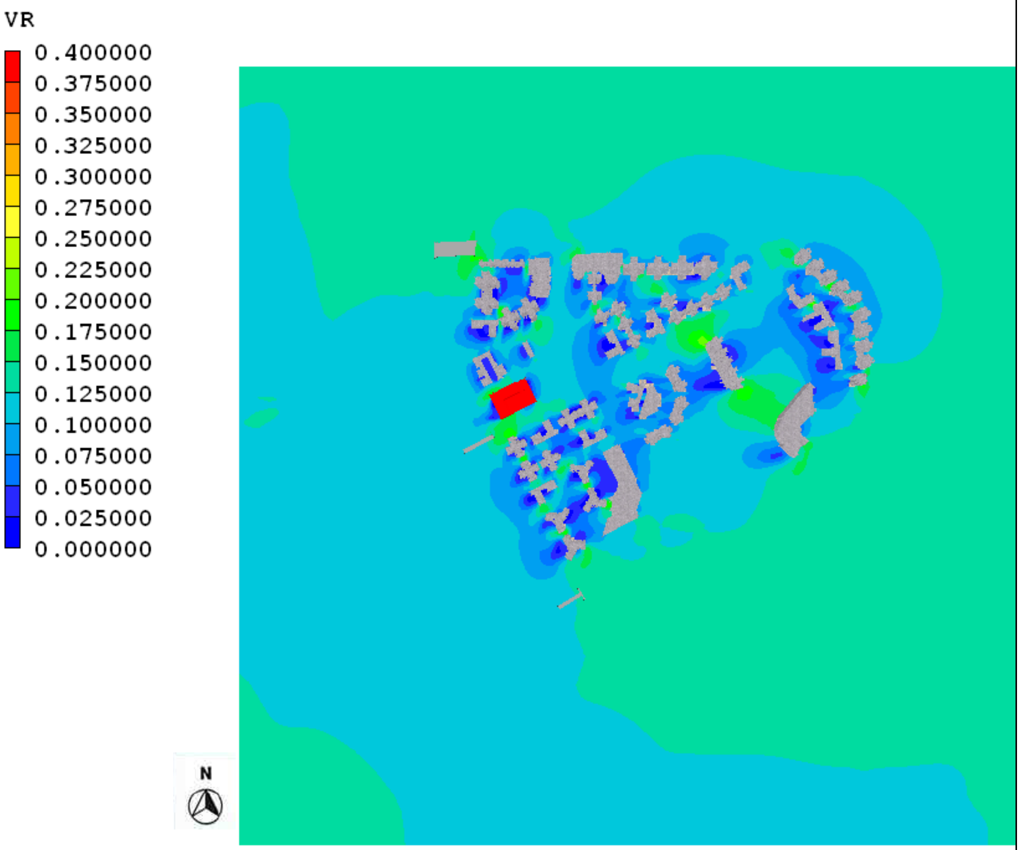
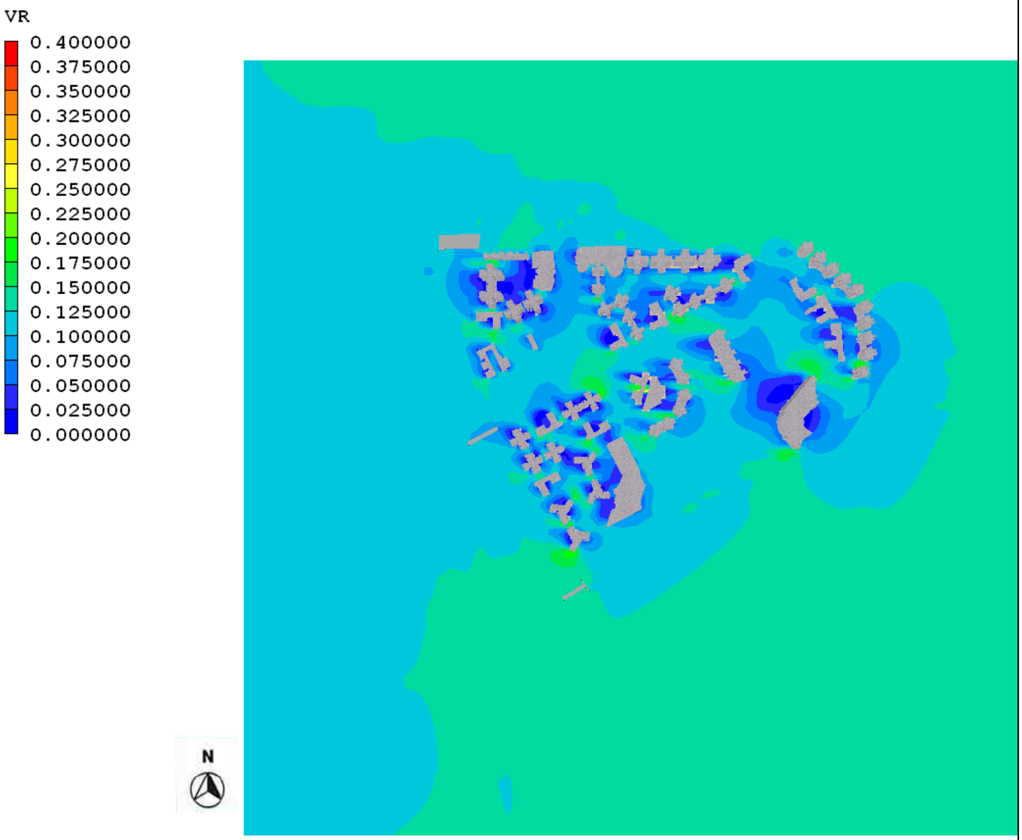
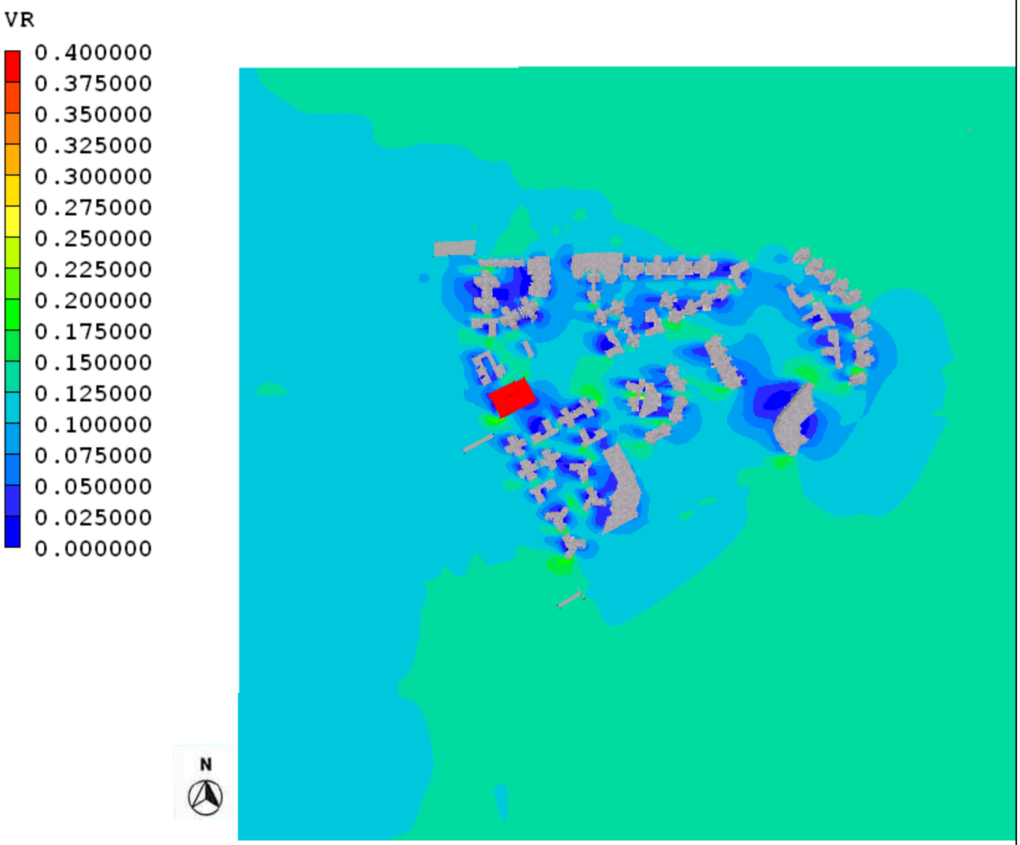
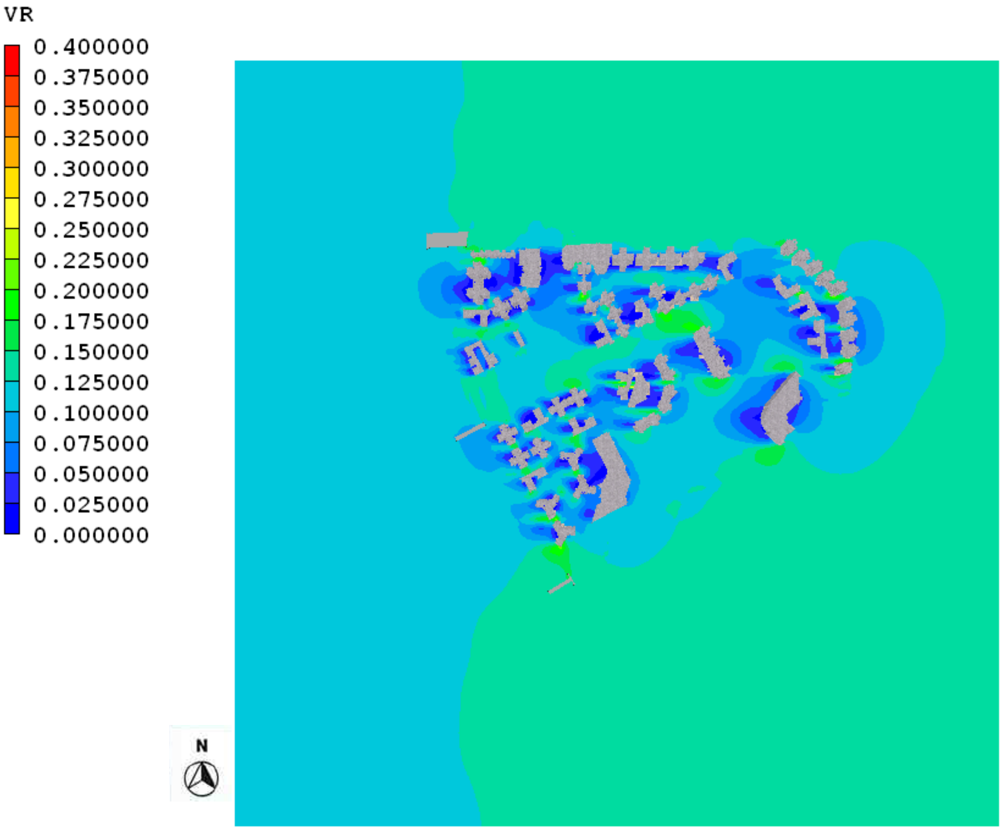
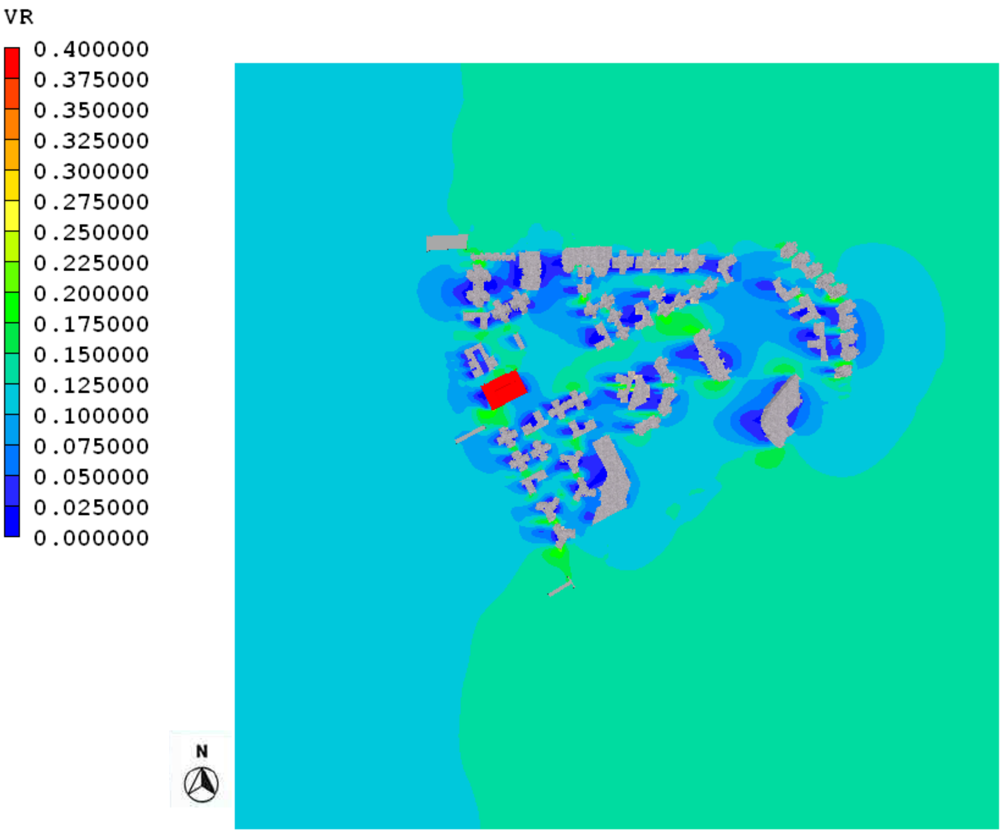
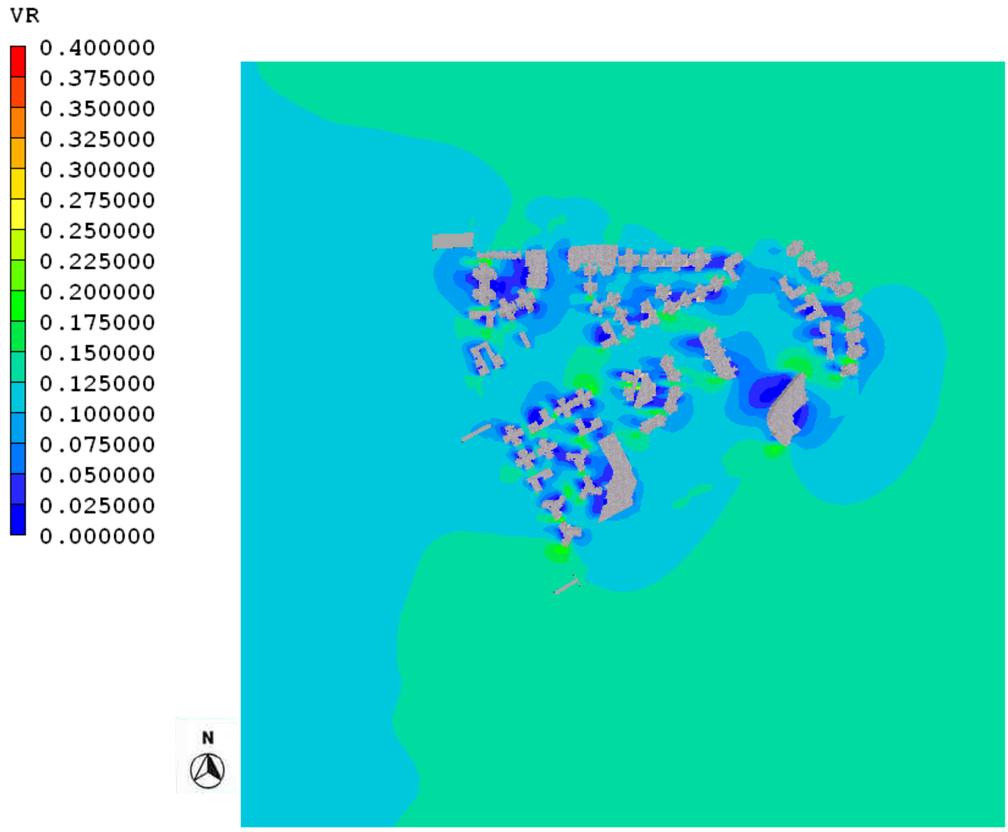
Wind Direction	NE (45˚)
Prior to Construction of Tin Shui Wai Hospital Development	
Subsequent to Construction of Tin Shui Wai Hospital Development	

Wind Direction	ENE (67.5˚)
Prior to Construction of Tin Shui Wai Hospital Development	
Subsequent to Construction of Tin Shui Wai Hospital Development	

Wind Direction	E (90˚)
Prior to Construction of Tin Shui Wai Hospital Development	
Subsequent to Construction of Tin Shui Wai Hospital Development	

<table>
<tr><th>Wind Direction</th><th>ESE (112.5˚)</th></tr>
<tr><td>Prior to Construction of Tin Shui Wai Hospital Development</td><td>


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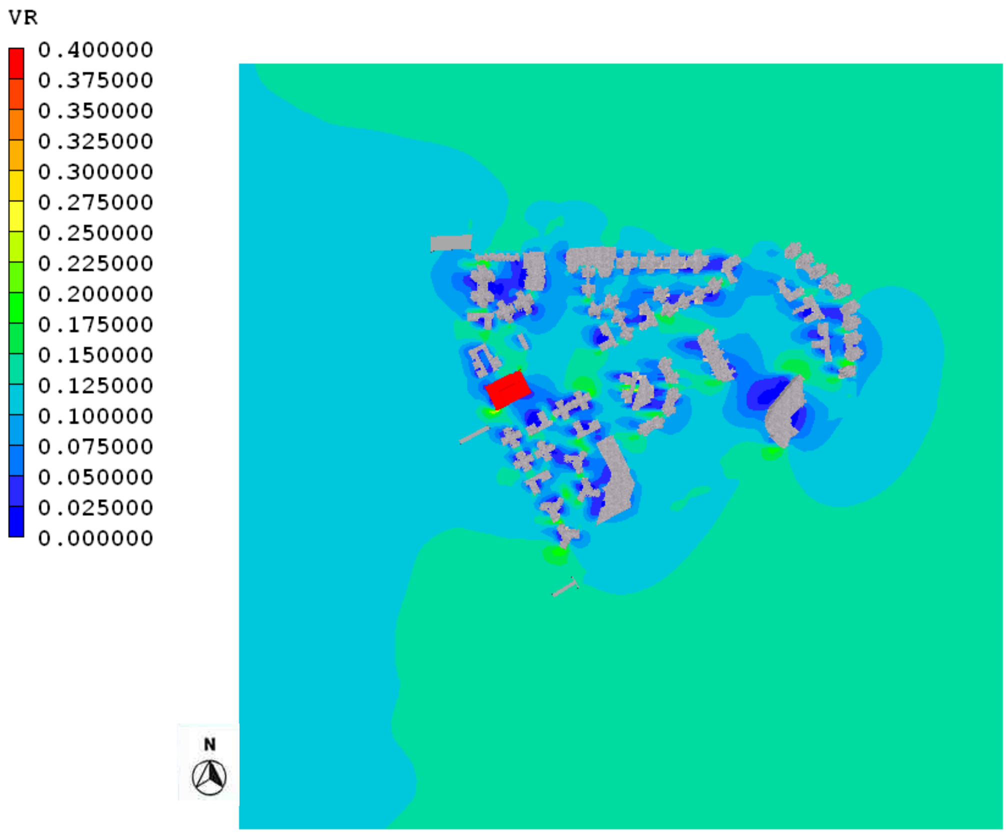
<tr><td>Subsequent to Construction of Tin Shui Wai Hospital Development</td><td>


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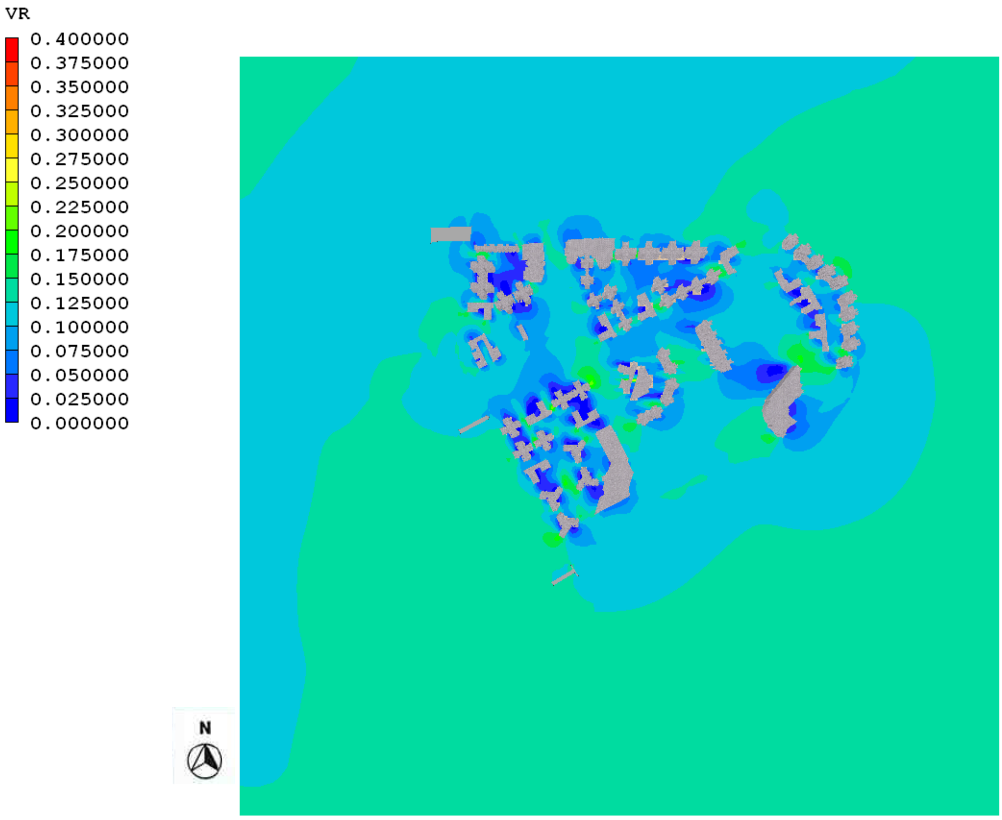
<table>
<tr><th>Wind Direction</th><th>SE (135˚)</th></tr>
<tr><td>Prior to Construction of Tin Shui Wai Hospital Development</td><td>
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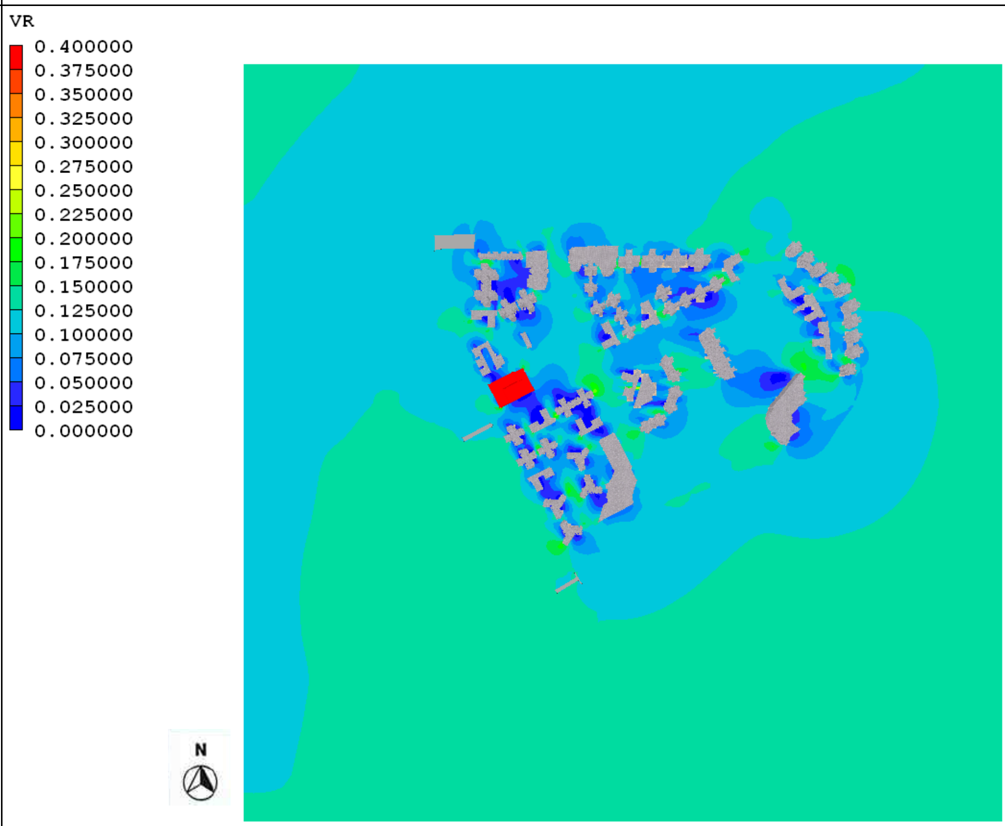
<tr><td>Subsequent to Construction of Tin Shui Wai Hospital Development</td><td>
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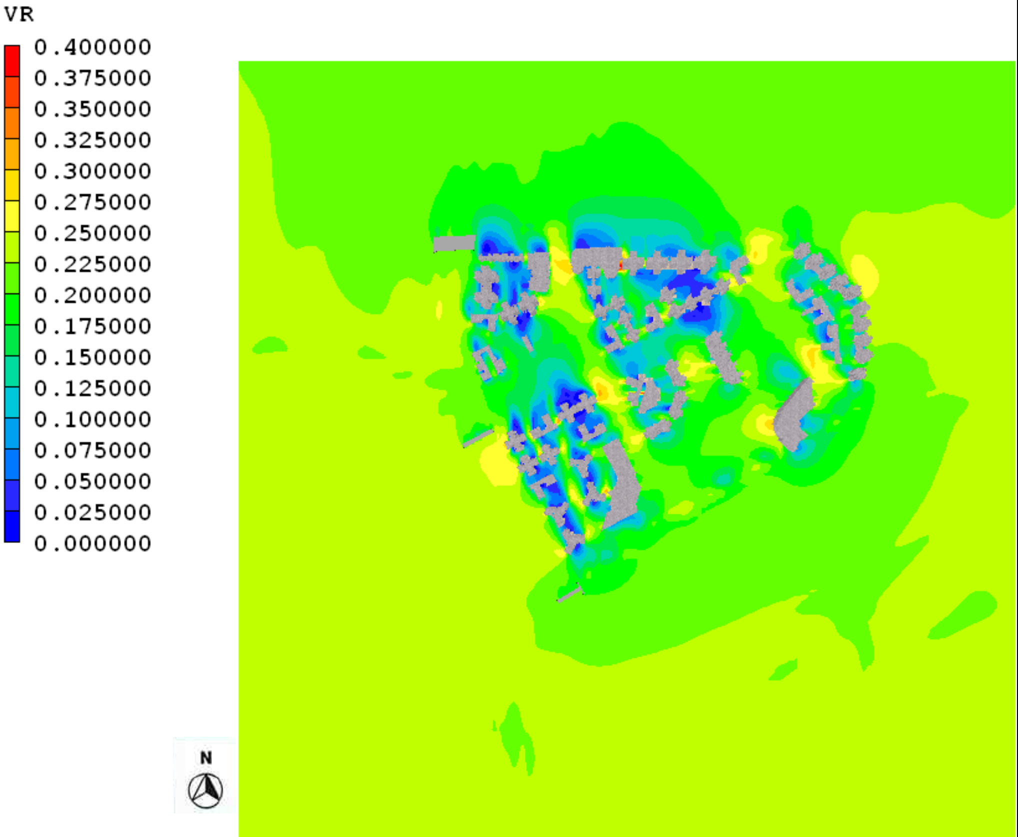
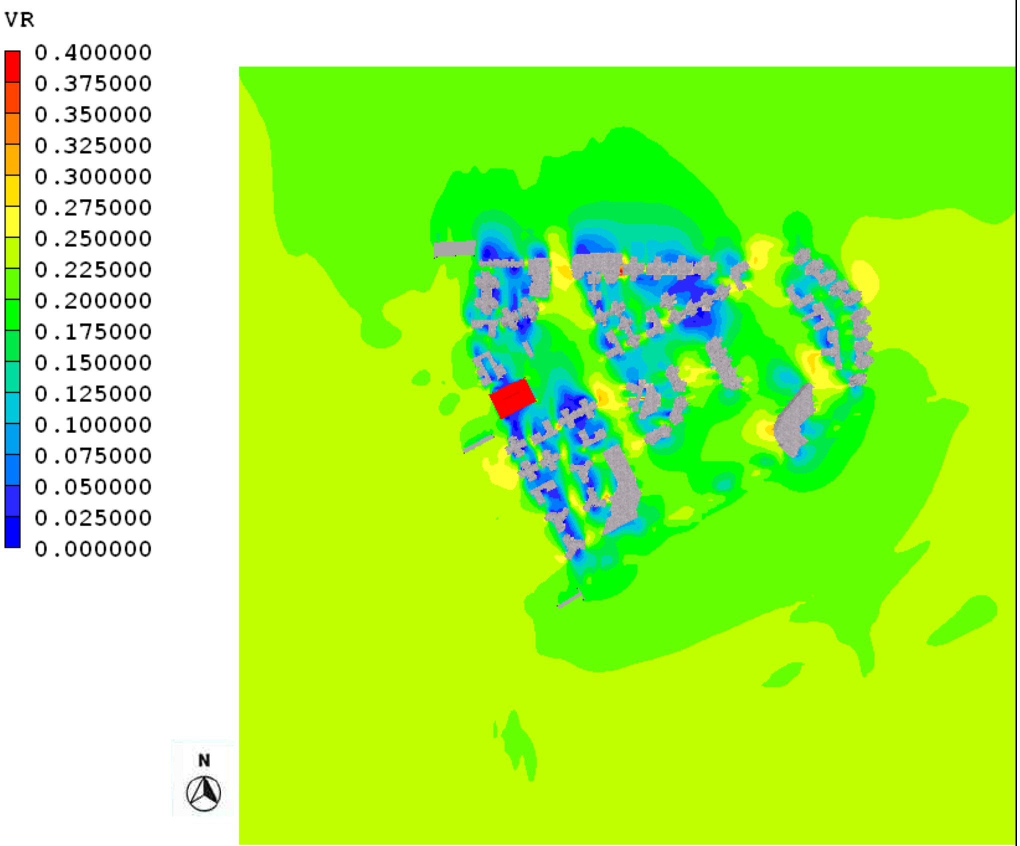
Wind Direction	SSE (157.5˚)
Prior to Construction of Tin Shui Wai Hospital Development	
Subsequent to Construction of Tin Shui Wai Hospital Development	

Wind Velocity Ratio of Perimeter Test Points in NNE direction

NNE Perimeter Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
P1	0.113	P1	0.037	-0.08
P2	0.116	P2	0.056	-0.06
P3	0.116	P3	0.076	-0.04
P4	0.117	P4	0.069	-0.05
P5	0.116	P5	0.087	-0.03
P6	0.116	P6	0.099	-0.02
P7	0.116	P7	0.129	0.01
P8	0.117	P8	0.068	-0.05
P9	0.117	P9	0.048	-0.07
P10	0.118	P10	0.082	-0.04
P11	0.119	P11	0.103	-0.02
P12	0.122	P12	0.136	0.01
P13	0.126	P13	0.133	0.01
P14	0.132	P14	0.111	-0.02
P15	0.131	P15	0.048	-0.08
P16	0.129	P16	0.038	-0.09
P17	0.128	P17	0.038	-0.09
P18	0.126	P18	0.031	-0.10
P19	0.122	P19	0.017	-0.10
P20	0.118	P20	0.068	-0.05
P21	0.109	P21	0.176	0.07
P22	0.101	P22	0.197	0.10
P23	0.101	P23	0.150	0.05
P24	0.112	P24	0.126	0.01
P25	0.111	P25	0.114	0.00
P26	0.118	P26	0.105	-0.01
P27	0.119	P27	0.095	-0.02
P28	0.117	P28	0.080	-0.04
P29	0.114	P29	0.073	-0.04
P30	0.109	P30	0.057	-0.01
Average	**0.118**	**Average**	**0.088**	**-0.03**
Max	0.132		0.197	
Min	0.101		0.017	

Wind Velocity Ratio of Special Test Points in NNE direction

NNE Special Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
S1	0.103	S1	0.110	0.01
S2	0.116	S2	0.104	-0.01
S3	0.120	S3	0.094	-0.03
Average	**0.113**	**Average**	**0.103**	**-0.01**
Max	0.120		0.110	
Min	0.103		0.094	

Wind Velocity Ratio of Local Test Points in NNE direction

NNE Local Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
L1	0.122	L1	0.123	0.00
L2	0.128	L2	0.130	0.00
L3	0.115	L3	0.119	0.00
L4	0.006	L4	0.007	0.00
L5	0.052	L5	0.053	0.00
L6	0.148	L6	0.155	0.01
L7	0.100	L7	0.106	0.01
L8	0.108	L8	0.102	-0.01
L9	0.006	L9	0.007	0.00
L10	0.167	L10	0.172	0.00
L11	0.103	L11	0.092	-0.01
L12	0.153	L12	0.142	-0.01
L13	0.137	L13	0.116	-0.02
L14	0.146	L14	0.122	-0.02
L15	0.151	L15	0.127	-0.02
L16	0.090	L16	0.082	-0.01
L17	0.139	L17	0.107	-0.03
L18	0.130	L18	0.134	0.00
L19	0.121	L19	0.130	0.01
L20	0.102	L20	0.150	0.05
L21	0.118	L21	0.127	0.01
L22	0.085	L22	0.088	0.00
L23	0.079	L23	0.075	0.00
L24	0.093	L24	0.079	-0.01
L25	0.104	L25	0.079	-0.02
L26	0.081	L26	0.066	-0.02
L27	0.032	L27	0.025	-0.01
L28	0.124	L28	0.115	-0.01
L29	0.117	L29	0.104	-0.01
L30	0.112	L30	0.108	0.00
Average	**0.106**	**Average**	**0.101**	**0.00**
Max	0.167		0.172	
Min	0.006		0.007	

Wind Velocity Ratio of Perimeter Test Points in NE direction

NE Perimeter Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
P1	0.126	P1	0.028	-0.10
P2	0.126	P2	0.014	-0.11
P3	0.126	P3	0.037	-0.09
P4	0.126	P4	0.040	-0.09
P5	0.126	P5	0.056	-0.07
P6	0.126	P6	0.070	-0.06
P7	0.127	P7	0.122	0.00
P8	0.127	P8	0.081	-0.05
P9	0.127	P9	0.074	-0.05
P10	0.127	P10	0.095	-0.03
P11	0.129	P11	0.119	-0.01
P12	0.133	P12	0.167	0.03
P13	0.137	P13	0.172	0.04
P14	0.141	P14	0.158	0.02
P15	0.138	P15	0.031	-0.11
P16	0.138	P16	0.052	-0.09
P17	0.136	P17	0.044	-0.09
P18	0.135	P18	0.038	-0.10
P19	0.130	P19	0.011	-0.12
P20	0.129	P20	0.036	-0.09
P21	0.125	P21	0.158	0.03
P22	0.124	P22	0.198	0.07
P23	0.126	P23	0.169	0.04
P24	0.130	P24	0.151	0.02
P25	0.129	P25	0.146	0.02
P26	0.130	P26	0.142	0.01
P27	0.130	P27	0.135	0.01
P28	0.127	P28	0.124	0.00
P29	0.125	P29	0.117	-0.01
P30	0.124	P30	0.132	0.01
Average	**0.129**	**Average**	**0.097**	**-0.03**
Max	0.141		0.198	
Min	0.124		0.011	

Wind Velocity Ratio of Special Test Points in NE direction

NE Special Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
S1	0.127	S1	0.145	0.02
S2	0.131	S2	0.141	0.01
S3	0.129	S3	0.133	0.00
Average	**0.129**	**Average**	**0.140**	**0.01**
Max	0.131		0.145	
Min	0.127		0.133	

Wind Velocity Ratio of Local Test Points in NE direction

NE Local Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
L1	0.139	L1	0.136	0.00
L2	0.128	L2	0.128	0.00
L3	0.109	L3	0.111	0.00
L4	0.024	L4	0.021	0.00
L5	0.040	L5	0.042	0.00
L6	0.135	L6	0.142	0.01
L7	0.105	L7	0.114	0.01
L8	0.049	L8	0.051	0.00
L9	0.007	L9	0.007	0.00
L10	0.185	L10	0.199	0.01
L11	0.075	L11	0.066	-0.01
L12	0.139	L12	0.134	0.00
L13	0.147	L13	0.163	0.02
L14	0.147	L14	0.146	0.00
L15	0.150	L15	0.143	-0.01
L16	0.087	L16	0.080	-0.01
L17	0.142	L17	0.112	-0.03
L18	0.135	L18	0.122	-0.01
L19	0.127	L19	0.121	-0.01
L20	0.130	L20	0.155	0.02
L21	0.111	L21	0.114	0.00
L22	0.054	L22	0.060	0.01
L23	0.103	L23	0.103	0.00
L24	0.099	L24	0.099	0.00
L25	0.113	L25	0.109	0.00
L26	0.112	L26	0.104	-0.01
L27	0.031	L27	0.039	0.01
L28	0.134	L28	0.125	-0.01
L29	0.126	L29	0.111	-0.02
L30	0.124	L30	0.115	-0.01
Average	**0.107**	**Average**	**0.106**	**0.00**
Max	0.185		0.199	
Min	0.007		0.007	

Wind Velocity Ratio of Perimeter Test Points in ENE direction

ENE Perimeter Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
P1	0.110	P1	0.130	0.02
P2	0.108	P2	0.090	-0.02
P3	0.106	P3	0.073	-0.03
P4	0.104	P4	0.065	-0.04
P5	0.099	P5	0.061	-0.04
P6	0.096	P6	0.053	-0.04
P7	0.089	P7	0.051	-0.04
P8	0.093	P8	0.032	-0.06
P9	0.096	P9	0.044	-0.05
P10	0.100	P10	0.048	-0.05
P11	0.104	P11	0.057	-0.05
P12	0.112	P12	0.095	-0.02
P13	0.114	P13	0.126	0.01
P14	0.113	P14	0.168	0.06
P15	0.111	P15	0.153	0.04
P16	0.113	P16	0.127	0.01
P17	0.114	P17	0.114	0.00
P18	0.115	P18	0.049	-0.07
P19	0.116	P19	0.026	-0.09
P20	0.118	P20	0.039	-0.08
P21	0.118	P21	0.045	-0.07
P22	0.117	P22	0.043	-0.07
P23	0.118	P23	0.071	-0.05
P24	0.117	P24	0.078	-0.04
P25	0.116	P25	0.096	-0.02
P26	0.113	P26	0.113	0.00
P27	0.110	P27	0.142	0.03
P28	0.111	P28	0.144	0.03
P29	0.112	P29	0.123	0.01
P30	0.113	P30	0.194	0.14
Average	**0.109**	**Average**	**0.088**	**-0.02**
Max	0.118		0.194	
Min	0.089		0.026	

Wind Velocity Ratio of Special Test Points in ENE direction

ENE Special Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
S1	0.115	S1	0.116	0.00
S2	0.110	S2	0.136	0.03
S3	0.106	S3	0.149	0.04
Average	**0.110**	**Average**	**0.134**	**0.02**
Max	0.115		0.149	
Min	0.106		0.116	

Wind Velocity Ratio of Local Test Points in ENE direction

ENE Local Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
L1	0.084	L1	0.071	-0.01
L2	0.057	L2	0.048	-0.01
L3	0.047	L3	0.049	0.00
L4	0.018	L4	0.018	0.00
L5	0.148	L5	0.135	-0.01
L6	0.015	L6	0.015	0.00
L7	0.072	L7	0.058	-0.01
L8	0.140	L8	0.126	-0.01
L9	0.022	L9	0.024	0.00
L10	0.074	L10	0.095	0.02
L11	0.014	L11	0.016	0.00
L12	0.088	L12	0.088	0.00
L13	0.109	L13	0.148	0.04
L14	0.076	L14	0.105	0.03
L15	0.086	L15	0.098	0.01
L16	0.080	L16	0.085	0.00
L17	0.105	L17	0.143	0.04
L18	0.120	L18	0.107	-0.01
L19	0.124	L19	0.096	-0.03
L20	0.129	L20	0.065	-0.06
L21	0.127	L21	0.097	-0.03
L22	0.063	L22	0.061	0.00
L23	0.122	L23	0.127	0.01
L24	0.116	L24	0.131	0.01
L25	0.115	L25	0.140	0.03
L26	0.117	L26	0.128	0.01
L27	0.071	L27	0.075	0.00
L28	0.105	L28	0.110	0.00
L29	0.110	L29	0.113	0.00
L30	0.105	L30	0.094	-0.01
Average	**0.089**	**Average**	**0.089**	**0.00**
Max	0.148		0.148	
Min	0.014		0.015	

Wind Velocity Ratio of Perimeter Test Points in E direction

E Perimeter Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
P1	0.122	P1	0.114	-0.01
P2	0.121	P2	0.074	-0.05
P3	0.121	P3	0.051	-0.07
P4	0.120	P4	0.043	-0.08
P5	0.118	P5	0.040	-0.08
P6	0.116	P6	0.035	-0.08
P7	0.113	P7	0.074	-0.04
P8	0.114	P8	0.077	-0.04
P9	0.115	P9	0.083	-0.03
P10	0.116	P10	0.085	-0.03
P11	0.120	P11	0.096	-0.02
P12	0.126	P12	0.141	0.01
P13	0.130	P13	0.165	0.04
P14	0.131	P14	0.184	0.05
P15	0.127	P15	0.088	-0.04
P16	0.129	P16	0.107	-0.02
P17	0.128	P17	0.090	-0.04
P18	0.127	P18	0.043	-0.08
P19	0.125	P19	0.011	-0.11
P20	0.127	P20	0.016	-0.11
P21	0.125	P21	0.066	-0.06
P22	0.127	P22	0.120	-0.01
P23	0.128	P23	0.128	0.00
P24	0.127	P24	0.127	0.00
P25	0.127	P25	0.138	0.01
P26	0.125	P26	0.149	0.02
P27	0.123	P27	0.161	0.04
P28	0.122	P28	0.158	0.04
P29	0.122	P29	0.140	0.02
P30	0.123	P30	0.208	0.09
Average	**0.123**	**Average**	**0.100**	**-0.02**
Max	0.131		0.208	
Min	0.113		0.011	

Wind Velocity Ratio of Special Test Points in E direction

E Special Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
S1	0.127	S1	0.150	0.02
S2	0.124	S2	0.160	0.04
S3	0.119	S3	0.161	0.04
Average	**0.123**	**Average**	**0.157**	**0.03**
Max	0.127		0.161	
Min	0.119		0.150	

Wind Velocity Ratio of Local Test Points in E direction

E Local Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
L1	0.122	L1	0.112	-0.01
L2	0.085	L2	0.080	-0.01
L3	0.032	L3	0.030	0.00
L4	0.004	L4	0.011	0.01
L5	0.141	L5	0.128	-0.01
L6	0.041	L6	0.053	0.01
L7	0.079	L7	0.081	0.00
L8	0.098	L8	0.083	-0.01
L9	0.013	L9	0.014	0.00
L10	0.130	L10	0.157	0.03
L11	0.020	L11	0.021	0.00
L12	0.059	L12	0.067	0.01
L13	0.133	L13	0.178	0.05
L14	0.113	L14	0.138	0.03
L15	0.106	L15	0.121	0.02
L16	0.074	L16	0.077	0.00
L17	0.124	L17	0.159	0.04
L18	0.128	L18	0.083	-0.04
L19	0.128	L19	0.086	-0.04
L20	0.139	L20	0.096	-0.04
L21	0.130	L21	0.105	-0.02
L22	0.050	L22	0.044	-0.01
L23	0.121	L23	0.127	0.01
L24	0.117	L24	0.132	0.01
L25	0.123	L25	0.146	0.02
L26	0.129	L26	0.133	0.00
L27	0.058	L27	0.063	0.01
L28	0.119	L28	0.118	0.00
L29	0.123	L29	0.117	-0.01
L30	0.123	L30	0.109	-0.01
Average	**0.095**	**Average**	**0.096**	**0.00**
Max	0.141		0.178	
Min	0.004		0.011	

Wind Velocity Ratio of Perimeter Test Points in ESE direction

ESE Perimeter Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
P1	0.113	P1	0.135	0.02
P2	0.111	P2	0.093	-0.02
P3	0.109	P3	0.075	-0.03
P4	0.107	P4	0.068	-0.04
P5	0.103	P5	0.064	-0.04
P6	0.100	P6	0.057	-0.04
P7	0.093	P7	0.054	-0.04
P8	0.097	P8	0.035	-0.06
P9	0.100	P9	0.048	-0.05
P10	0.104	P10	0.053	-0.05
P11	0.108	P11	0.063	-0.04
P12	0.114	P12	0.101	-0.01
P13	0.115	P13	0.136	0.02
P14	0.113	P14	0.189	0.08
P15	0.111	P15	0.190	0.08
P16	0.114	P16	0.160	0.05
P17	0.115	P17	0.100	-0.01
P18	0.116	P18	0.018	-0.10
P19	0.117	P19	0.055	-0.06
P20	0.120	P20	0.055	-0.06
P21	0.119	P21	0.053	-0.07
P22	0.119	P22	0.043	-0.08
P23	0.119	P23	0.074	-0.05
P24	0.118	P24	0.084	-0.03
P25	0.117	P25	0.099	-0.02
P26	0.115	P26	0.114	0.00
P27	0.112	P27	0.139	0.03
P28	0.113	P28	0.146	0.03
P29	0.114	P29	0.129	0.02
P30	0.115	P30	0.202	0.11
Average	**0.111**	**Average**	**0.094**	**-0.02**
Max	0.120		0.202	
Min	0.093		0.018	

Wind Velocity Ratio of Special Test Points in ESE direction

ESE Special Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
S1	0.116	S1	0.113	0.00
S2	0.112	S2	0.131	0.02
S3	0.107	S3	0.145	0.04
Average	**0.112**	**Average**	**0.130**	**0.01**
Max	0.116		0.145	
Min	0.107		0.113	

Wind Velocity Ratio of Local Test Points in ESE direction

ESE Local Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
L1	0.081	L1	0.068	-0.01
L2	0.055	L2	0.046	-0.01
L3	0.068	L3	0.066	0.00
L4	0.021	L4	0.020	0.00
L5	0.167	L5	0.154	-0.01
L6	0.011	L6	0.013	0.00
L7	0.087	L7	0.071	-0.02
L8	0.145	L8	0.130	-0.01
L9	0.022	L9	0.023	0.00
L10	0.087	L10	0.108	0.02
L11	0.014	L11	0.016	0.00
L12	0.092	L12	0.094	0.00
L13	0.110	L13	0.151	0.04
L14	0.083	L14	0.108	0.02
L15	0.093	L15	0.106	0.01
L16	0.082	L16	0.086	0.00
L17	0.107	L17	0.139	0.03
L18	0.122	L18	0.107	-0.02
L19	0.125	L19	0.098	-0.03
L20	0.131	L20	0.071	-0.06
L21	0.129	L21	0.101	-0.03
L22	0.070	L22	0.066	0.00
L23	0.125	L23	0.130	0.01
L24	0.119	L24	0.132	0.01
L25	0.116	L25	0.144	0.03
L26	0.119	L26	0.130	0.01
L27	0.072	L27	0.076	0.00
L28	0.107	L28	0.112	0.00
L29	0.112	L29	0.115	0.00
L30	0.105	L30	0.094	-0.01
Average	**0.092**	**Average**	**0.093**	**0.00**
Max	0.167		0.154	
Min	0.011		0.013	

Wind Velocity Ratio of Perimeter Test Points in SE direction

SE Perimeter Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
P1	0.102	P1	0.136	0.03
P2	0.100	P2	0.099	0.00
P3	0.099	P3	0.089	-0.01
P4	0.096	P4	0.085	-0.01
P5	0.091	P5	0.085	-0.01
P6	0.089	P6	0.085	0.00
P7	0.082	P7	0.073	-0.01
P8	0.087	P8	0.027	-0.06
P9	0.090	P9	0.013	-0.08
P10	0.094	P10	0.016	-0.08
P11	0.097	P11	0.023	-0.07
P12	0.100	P12	0.048	-0.05
P13	0.097	P13	0.081	-0.02
P14	0.092	P14	0.151	0.06
P15	0.099	P15	0.156	0.06
P16	0.099	P16	0.047	-0.05
P17	0.102	P17	0.033	-0.07
P18	0.106	P18	0.077	-0.03
P19	0.110	P19	0.110	0.00
P20	0.112	P20	0.119	0.01
P21	0.112	P21	0.120	0.01
P22	0.109	P22	0.076	-0.03
P23	0.109	P23	0.019	-0.09
P24	0.108	P24	0.034	-0.07
P25	0.106	P25	0.047	-0.06
P26	0.104	P26	0.061	-0.04
P27	0.101	P27	0.085	-0.02
P28	0.104	P28	0.108	0.00
P29	0.105	P29	0.106	0.00
P30	0.104	P30	0.169	0.06
Average	**0.100**	**Average**	**0.079**	**-0.02**
Max	0.112		0.169	
Min	0.082		0.013	

Wind Velocity Ratio of Special Test Points in SE direction

SE Special Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
S1	0.103	S1	0.056	-0.05
S2	0.099	S2	0.072	-0.03
S3	0.097	S3	0.096	0.00
Average	**0.099**	**Average**	**0.075**	**-0.02**
Max	0.103		0.096	
Min	0.097		0.056	

Wind Velocity Ratio of Local Test Points in SE direction

SE Local Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
L1	0.028	L1	0.023	0.00
L2	0.020	L2	0.016	0.00
L3	0.090	L3	0.092	0.00
L4	0.027	L4	0.027	0.00
L5	0.159	L5	0.144	-0.01
L6	0.013	L6	0.016	0.00
L7	0.113	L7	0.095	-0.02
L8	0.169	L8	0.156	-0.01
L9	0.026	L9	0.026	0.00
L10	0.040	L10	0.056	0.02
L11	0.008	L11	0.006	0.00
L12	0.125	L12	0.124	0.00
L13	0.086	L13	0.114	0.03
L14	0.100	L14	0.106	0.01
L15	0.112	L15	0.116	0.00
L16	0.097	L16	0.099	0.00
L17	0.106	L17	0.124	0.02
L18	0.119	L18	0.124	0.01
L19	0.121	L19	0.119	0.00
L20	0.120	L20	0.114	-0.01
L21	0.125	L21	0.115	-0.01
L22	0.103	L22	0.098	0.00
L23	0.116	L23	0.115	0.00
L24	0.116	L24	0.114	0.00
L25	0.107	L25	0.123	0.02
L26	0.104	L26	0.118	0.01
L27	0.082	L27	0.083	0.00
L28	0.094	L28	0.102	0.01
L29	0.098	L29	0.109	0.01
L30	0.081	L30	0.080	0.00
Average	**0.090**	**Average**	**0.092**	**0.00**
Max	0.169		0.156	
Min	0.008		0.006	

Wind Velocity Ratio of Perimeter Test Points in SSE direction

SSE Perimeter Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
P1	0.168	P1	0.192	0.02
P2	0.165	P2	0.152	-0.01
P3	0.163	P3	0.151	-0.01
P4	0.162	P4	0.146	-0.02
P5	0.153	P5	0.134	-0.02
P6	0.146	P6	0.141	-0.01
P7	0.123	P7	0.170	0.05
P8	0.140	P8	0.139	0.00
P9	0.153	P9	0.102	-0.05
P10	0.169	P10	0.073	-0.10
P11	0.162	P11	0.054	-0.11
P12	0.130	P12	0.034	-0.10
P13	0.170	P13	0.026	-0.14
P14	0.193	P14	0.077	-0.12
P15	0.199	P15	0.209	0.01
P16	0.192	P16	0.169	-0.02
P17	0.190	P17	0.172	-0.02
P18	0.192	P18	0.190	0.00
P19	0.193	P19	0.214	0.02
P20	0.193	P20	0.234	0.04
P21	0.193	P21	0.247	0.05
P22	0.183	P22	0.155	-0.03
P23	0.180	P23	0.076	-0.10
P24	0.179	P24	0.047	-0.13
P25	0.175	P25	0.038	-0.14
P26	0.172	P26	0.030	-0.14
P27	0.171	P27	0.046	-0.13
P28	0.176	P28	0.068	-0.11
P29	0.177	P29	0.097	-0.08
P30	0.172	P30	0.202	0.03
Average	**0.171**	**Average**	**0.126**	**-0.05**
Max	0.199		0.247	
Min	0.123		0.026	

Wind Velocity Ratio of Special Test Points in SSE direction

SSE Special Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
S1	0.166	S1	0.057	-0.11
S2	0.164	S2	0.038	-0.13
S3	0.167	S3	0.060	-0.11
Average	**0.166**	**Average**	**0.052**	**-0.06**
Max	0.167		0.060	
Min	0.164		0.038	

Wind Velocity Ratio of Local Test Points in SSE direction

SSE Local Test Point				
Before Development		After Development		VR difference
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
L1	0.045	L1	0.063	0.02
L2	0.050	L2	0.037	-0.01
L3	0.136	L3	0.154	0.02
L4	0.049	L4	0.051	0.00
L5	0.156	L5	0.126	-0.03
L6	0.077	L6	0.082	0.01
L7	0.191	L7	0.173	-0.02
L8	0.230	L8	0.211	-0.02
L9	0.031	L9	0.032	0.00
L10	0.101	L10	0.073	-0.03
L11	0.017	L11	0.012	0.00
L12	0.253	L12	0.245	-0.01
L13	0.210	L13	0.167	-0.04
L14	0.219	L14	0.212	-0.01
L15	0.243	L15	0.236	-0.01
L16	0.176	L16	0.183	0.01
L17	0.205	L17	0.211	0.01
L18	0.215	L18	0.233	0.02
L19	0.213	L19	0.232	0.02
L20	0.200	L20	0.242	0.04
L21	0.215	L21	0.227	0.01
L22	0.207	L22	0.212	0.01
L23	0.175	L23	0.151	-0.02
L24	0.190	L24	0.136	-0.05
L25	0.174	L25	0.152	-0.02
L26	0.159	L26	0.176	0.02
L27	0.148	L27	0.145	0.00
L28	0.154	L28	0.164	0.01
L29	0.149	L29	0.169	0.02
L30	0.116	L30	0.135	0.02
Average	**0.157**	**Average**	**0.155**	**0.00**
Max	0.253		0.245	
Min	0.017		0.012	

Weighted Velocity of Perimeter Test Point for all 7 Prevailing Wind Directions (NNE, NE, ENE, E, ESE, SE, SSE)

	Before Development	After Development	VR difference
	Velocity Ratio	Velocity Ratio	
P1	0.120	0.104	-0.02
P2	0.119	0.076	-0.04
P3	0.118	0.071	-0.05
P4	0.117	0.066	-0.05
P5	0.113	0.068	-0.05
P6	0.111	0.069	-0.04
P7	0.106	0.090	-0.02
P8	0.110	0.062	-0.05
P9	0.112	0.059	-0.05
P10	0.116	0.067	-0.05
P11	0.118	0.078	-0.04
P12	0.120	0.112	-0.01
P13	0.126	0.131	0.00
P14	0.128	0.155	0.03
P15	0.127	0.116	-0.01
P16	0.128	0.100	-0.03
P17	0.128	0.084	-0.04
P18	0.128	0.054	-0.07
P19	0.127	0.047	-0.08
P20	0.127	0.064	-0.06
P21	0.125	0.110	-0.02
P22	0.123	0.116	-0.01
P23	0.123	0.104	-0.02
P24	0.125	0.100	-0.03
P25	0.124	0.106	-0.02
P26	0.123	0.112	-0.01
P27	0.121	0.125	0.00
P28	0.122	0.126	0.00
P29	0.122	0.116	-0.01
P30	0.121	0.168	0.05
Weighted average	**0.121**	**0.095**	**-0.026**

Weighted Velocity Ratio of Local Test Points for all 7 Prevailing Wind Directions (NNE, NE, ENE, E, ESE, SE, SSE)

	Before Development	After Development	VR difference
	Velocity Ratio	Velocity Ratio	
L1	0.096	0.091	-0.01
L2	0.079	0.074	-0.01
L3	0.078	0.080	0.00
L4	0.019	0.020	0.00
L5	0.119	0.109	-0.01
L6	0.062	0.067	0.01
L7	0.098	0.092	-0.01
L8	0.123	0.113	-0.01
L9	0.017	0.018	0.00
L10	0.116	0.130	0.01
L11	0.037	0.034	0.00
L12	0.118	0.117	0.00
L13	0.130	0.151	0.02
L14	0.119	0.129	0.01
L15	0.125	0.128	0.00
L16	0.091	0.092	0.00
L17	0.128	0.139	0.01
L18	0.134	0.121	-0.01
L19	0.132	0.117	-0.02
L20	0.133	0.117	-0.02
L21	0.131	0.118	-0.01
L22	0.079	0.078	0.00
L23	0.117	0.118	0.00
L24	0.117	0.118	0.00
L25	0.119	0.128	0.01
L26	0.116	0.120	0.00
L27	0.064	0.067	0.00
L28	0.119	0.119	0.00
L29	0.119	0.117	0.00
L30	0.111	0.104	-0.01
Weighted average	**0.102**	**0.101**	**0.00**

Weighted Velocity Ratio of Special Test Points for all 7 Prevailing Wind Directions (NNE, NE, ENE, E, ESE, SE, SSE)

	Before Development	After Development	VR difference
	Velocity Ratio	Velocity Ratio	
S1	0.121	0.116	-0.01
S2	0.121	0.122	0.00
S3	0.119	0.129	0.01
Weighted average	**0.120**	**0.122**	**0.00**