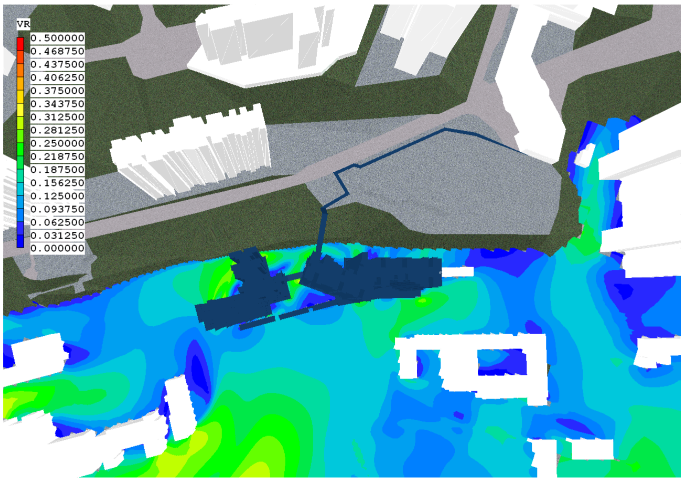
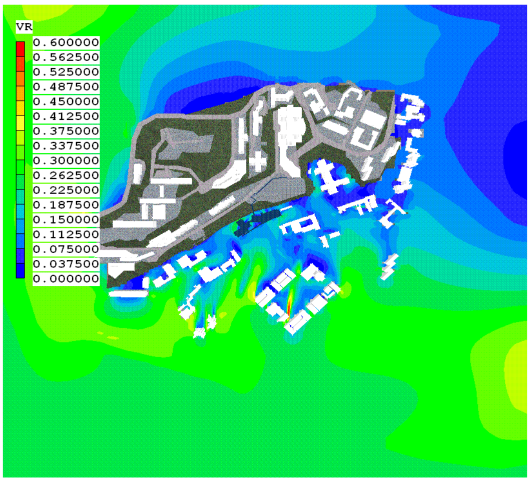
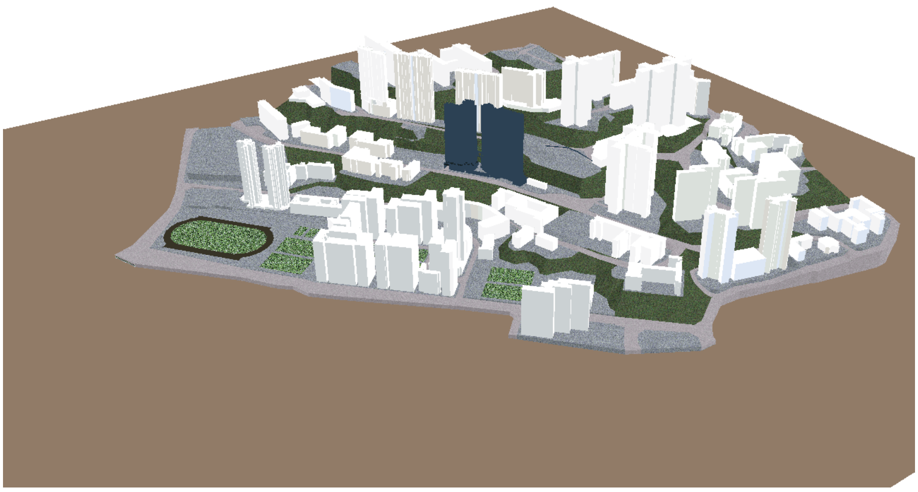




Hong Kong Housing Authority

Kwai Shing Circuit Public Housing Development, Kwai Chung (Agreement No CB20090005)

Air Ventilation Assessment (AVA) Study Report



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Kwai Shing Circuit Public Housing Development, Kwai Chung (Agreement No CB20090005)

Air Ventilation Assessment (AVA) Study Report

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Report No	EB000532\KSC\AVA\R02
Date	Monday, 28 Feb 2011

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1 EXECUTIVE SUMMARY

In April 2009, Hyder Consulting Ltd (HCL) was commissioned by the Hong Kong Housing Authority to undertake an Air Ventilation Assessment (AVA) Initial Study for the ***Kwai Shing Circuit (KSC) Public Housing Development***, 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 Kwai Shing Circuit Public Housing Development**	**Subsequent to Construction of Kwai Shing Circuit Public Housing Development**	**VR Change**
NNE	0.193	0.161	-0.031
NE	0.188	0.162	-0.026
ENE	0.193	0.179	-0.014
E	0.199	0.206	0.006
ESE	0.188	0.197	0.009
SE	0.145	0.161	0.016
SSW	0.135	0.140	0.005
Overall (weighted)	0.184	0.177	-0.007

Table 1-1 Summary of Local Velocity Ratios for Kwai Shing Circuit Public Housing Development under Prevailing Wind Directions

Site Air Ventilation Assessment Results (SVR)			
Prevailing Wind Direction	**Prior to Construction of Kwai Shing Circuit Public Housing Development**	**Subsequent to Construction of Kwai Shing Circuit Public Housing Development**	**VR Change**
NNE	0.211	0.149	-0.062
NE	0.208	0.158	-0.051
ENE	0.211	0.181	-0.030
E	0.220	0.205	-0.015
ESE	0.204	0.192	-0.012
SE	0.147	0.162	0.015
SSW	0.129	0.149	0.019
Overall (weighted)	0.200	0.176	-0.024

Table 1-2 Summary of Site Velocity Ratios for Kwai Shing Circuit Public Housing Development under Prevailing Wind Directions

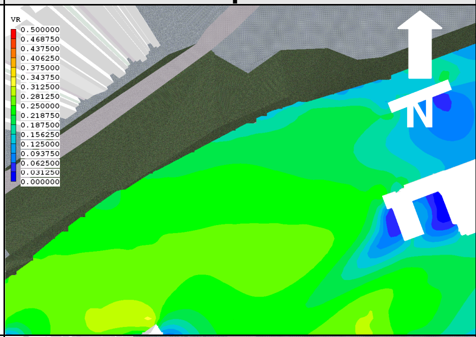
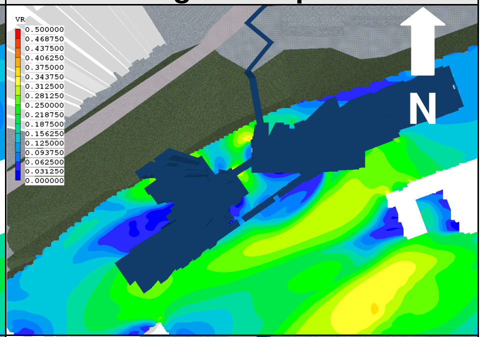
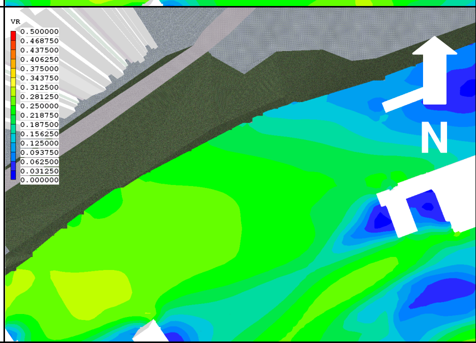
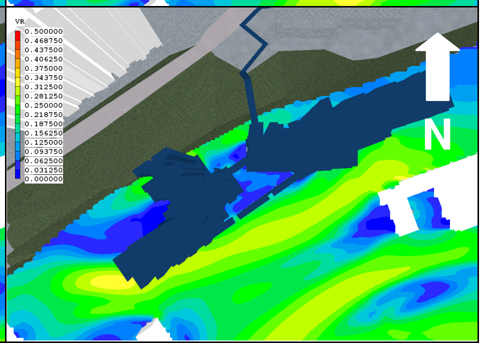
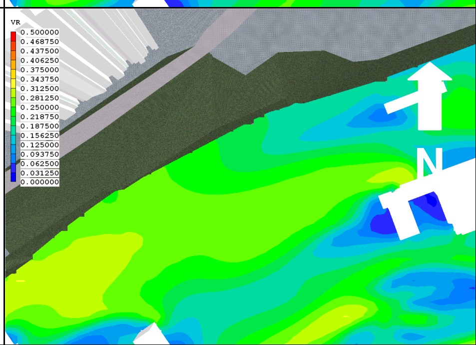
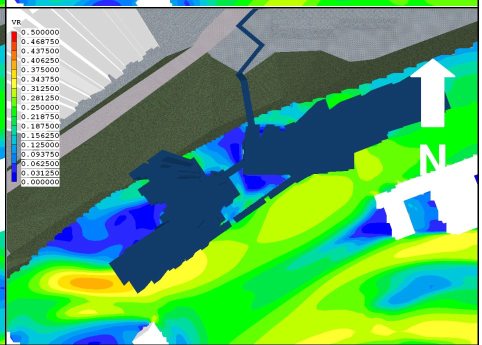
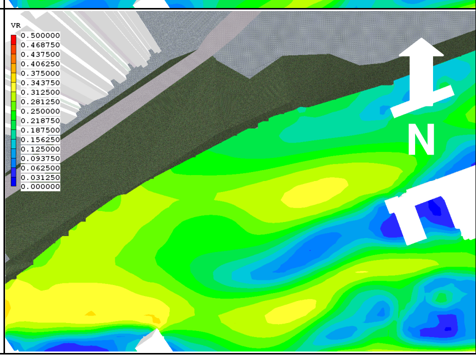
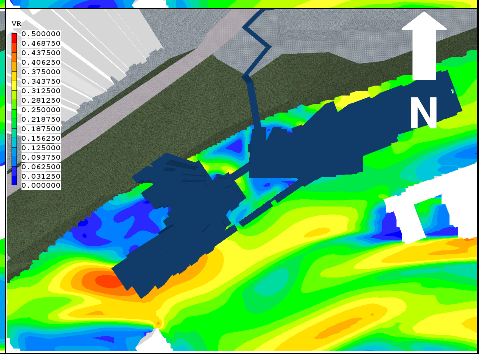
Prevailing Wind Direction	Prior to Construction of Kwai Shing Circuit Public Housing Development	Subsequent to Construction of Kwai Shing Circuit Public Housing Development
NNE at Ground level		
NE at Ground level		
ENE at Ground level		
E at Ground level		

Table 1-3 Velocity Ratio Plots for Kwai Shing Circuit Public Housing Development under Prevailing Wind Directions

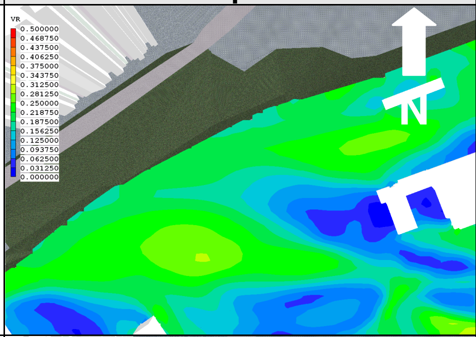
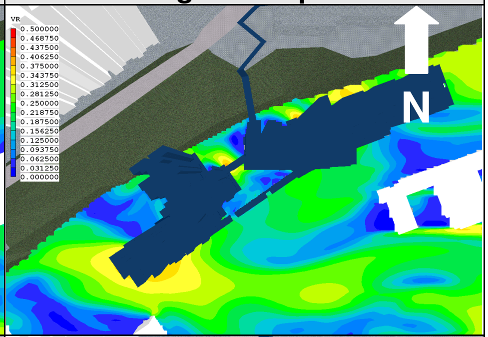
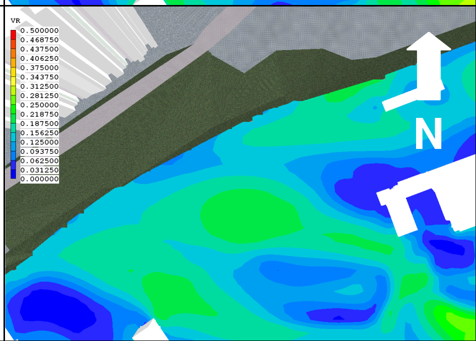
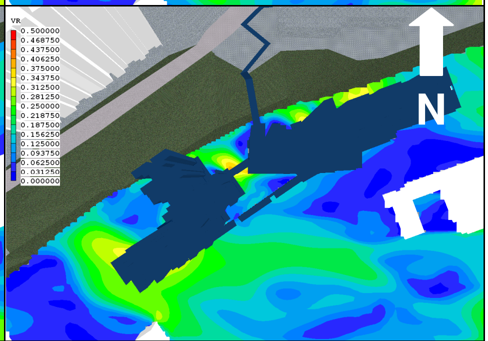
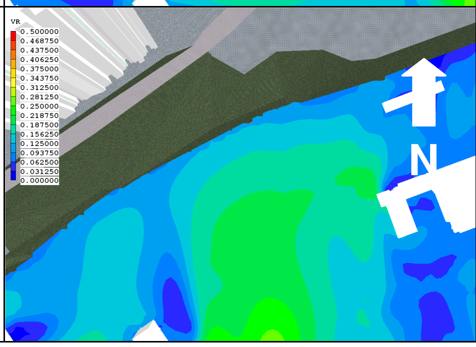
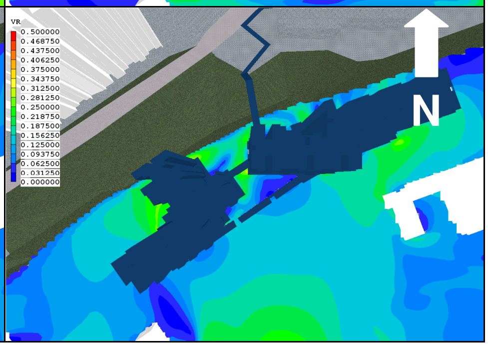
Prevailing Wind Direction	Prior to Construction of Kwai Shing Circuit Public Housing Development	Subsequent to Construction of Kwai Shing Circuit Public Housing Development
ESE at Ground level		
SE at Ground level		
SSW at Ground level		

Table 1-4 Velocity Ratio Plots for Kwai Shing Circuit Public Housing Development 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 Kwai Shing Circuit Public Housing Development. The change in weighted LVR is 0.007 (4%) and this is equivalent to a speed reduction of less than 0.07 m/s at pedestrian level which is deemed to be insignificant and acceptable.

As predicted from the qualitative ventilation performance evaluation in *Section 3.3*, mid-rise obstructive buildings are situated downhill at east-southeast to western directions to the site which allows air circulation from these wind directions. As a result of this, even prior to construction of the Kwai Shing Circuit Public Housing Development, wind availability of the project site and its surrounding community is inherently good with a weighted LVR of 0.184 which is equivalent to wind speeds of around 2 m/s at nearby pedestrian areas.

As explained in *Section 3.3,* the erection of the KSC development and its surrounding topology creates a wind corridor along Kwai Shing Circuit from the eastern to western direction and wind is directed towards the site and surrounding communities. Coupled with this wind corridor, the erection of the KSC development induces wind paths at eastern directions to the site as illustrated below. On this basis, there is a ventilation performance improvement of 0.006 (3%) and in absolute terms, the associated velocity increase is around 0.05 m/s.

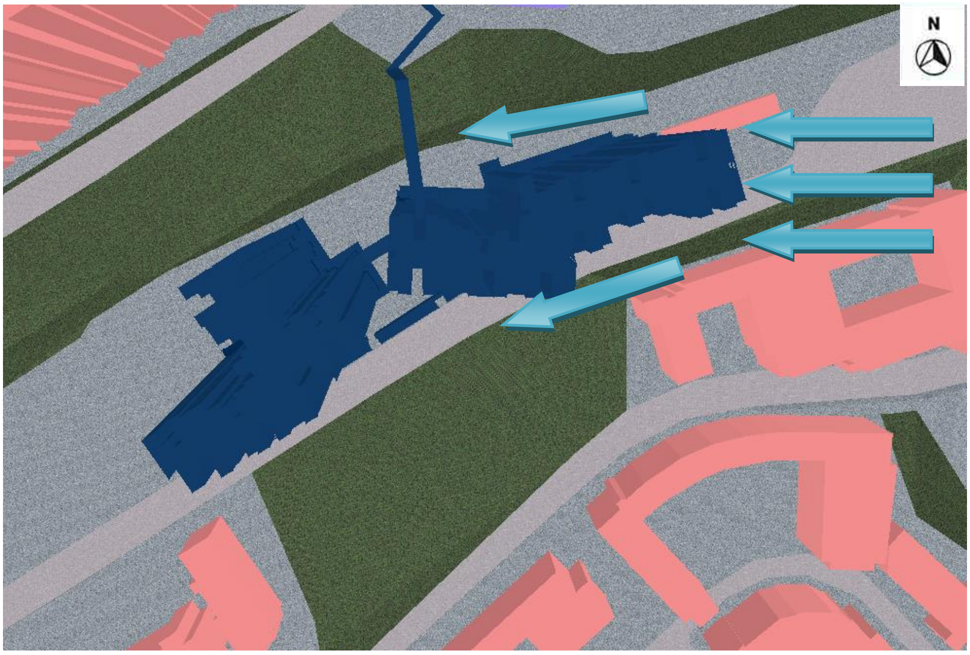


Figure 1-1 Wind path between KSC development and surrounding topography

Under southern quadrant of prevailing wind directions, the subject site is exposed to plenty of wind availability as most developments is lower than the ground level of the subject site as shown overleaf. Open spaces such as Hing Fong Road Playground and Jockey Club Hing Shing Road Playground are located further downhill at the southeast and southwest directions, respectively to the site. Wind corridors are present in these two directions from downhill to Kwai Shing East Estate as mentioned in *Section 3.3*. A separation distance of around 12 meters between Block 1 and Block 2 of the subject site induces enhanced air circulation from the two wind corridors to the surrounding pedestrian levels upon the construction of KSC development. These resulted in an increase LVR ranging from 0.005 (4%) and 0.016 (11%) for ESE, SE and SSW prevailing winds.

Figure 1-2 Most of the developments downhill are lower than site pedestrian level (for enhanced air circulation)

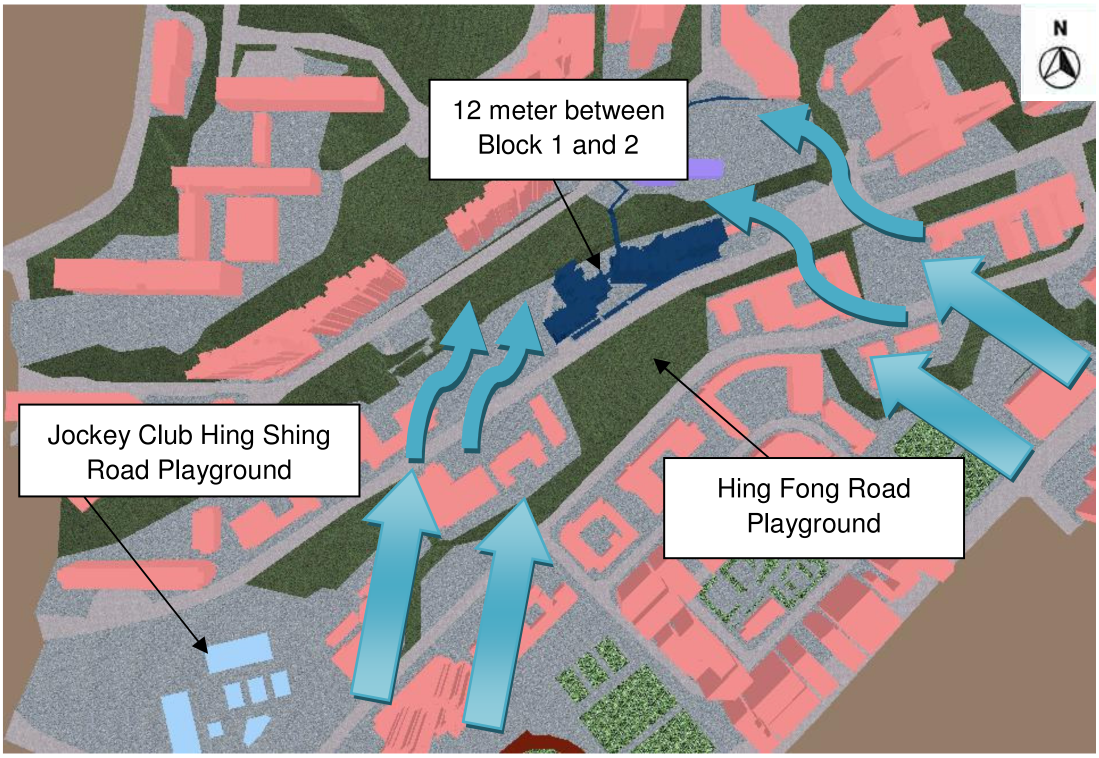


Figure 1-3 SE and SSW wind corridors

The reduction in VR should be predominately found in the northern quadrant of prevailing wind directions (NNE, NE, ENE) as obstructive buildings (described in Section 3.3) are erected at the northern part of the site and there is no obvious wind corridor in this direction. The construction of the KSC development induces a barrier effect with LVR reductions ranging from 0.014 (7%) and 0.031 (16%) for NNE, NE and ENE prevailing winds, but in absolute terms, the associated velocity reduction is less than 0.3m/s.

In summary, the overall weighted VR change in the local Air Ventilation Assessment from the construction of Kwai Shing Circuit Public Housing Development is not substantial (less than 0.007 which equivalent to 0.07 m/s wind velocity reduction) and its impact upon ventilation performance of potential pedestrian areas is deemed to be insignificant. Therefore, it can be concluded that the design and erection of Kwai Shing Circuit Public Housing Development is unlikely to have a significant adverse wind impact on pedestrian level ventilation performance of the surrounding community

The ventilation performance of the site perimeter as a result of the Kwai Shing Circuit Public Housing Development 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)	0.184	0.177
SVR (Perimeter Test Point)	0.200	0.176

Table 1-5 Summary of Local Velocity Ratio and Site Velocity Ratio for Kwai Shing Circuit Public Housing Development under Prevailing Wind Directions

The Site Perimeter Velocity Ratio for each prevailing wind direction is summarized in the SVR results table on page 1. The construction of the Kwai Shing Circuit Public Housing Development involves erection of vertical structures which would ultimately lead to reduced wind permeability at pedestrian levels within the project site area (originally almost entirely exposed). Therefore, as shown by velocity ratios in the table above, the KSC Public Housing Development would generally have some impact upon the wind availability of these test points, as expected. For the same ventilation pattern and reasons as LVR study findings previously mentioned, there are site VR improvements ranging from 0.015 (11%) to 0.019 (15%) which is both equivalent to 0.1m/s in absolute terms for SE and SSW prevailing wind directions. For NNE, NE, ENE, E and ESE prevailing wind directions, there are site VR reductions ranging from 0.012 (6%) to 0.062 (30%) which is equivalent to less than 0.5m/s pedestrian level velocity reduction. In summary, the construction of the KSC Public Housing Development will lead to an overall weighted SVR reduction of 0.02 (equivalent to 0.2 m/s reduction in pedestrian level velocity) which is less than 13% deterioration and thus can be considered as relatively insignificant and acceptable.

The AVA study findings reveal that the construction of the Kwai Shing Circuit Public Housing 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 public housing development leads to ventilation performance results of LVR change = 0.007 (equivalent to less than 0.06 m/s wind speed reduction) and SVR change = 0.024 (equivalent to 0.2 m/s wind speed reduction), all of which are deemed to be insignificant and acceptable.

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 April 2009, Hyder Consulting Ltd (HCL) was commissioned by the Hong Kong Housing Authority to undertake an Air Ventilation Assessment (AVA) Initial Study for the ***Kwai Shing Circuit Public (KSC) Public Housing Development, Kwai Chung, HK*** 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 Kwai Shing Circuit (KSC) Public Housing Development 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 KSC Public Housing Development 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 subject site for the proposed KSC public housing development is located at the southern region of the Kwai Chung, as shown below. The site is bounded at the south by the Hing Shing Road Playground and Kwai Shing Playground to the west. To the immediate north of the subject site, another public housing development will be erect at a stepping slope on Kwai Luen Road, upon completion of the KSC development.

This is a two-level site with flat surfaces formed at 31.4 and 55.1 mPD. The E.L.C.H.K. Kwai Shing Luthern Primary School is located at the north east and upper level of the site, adjacent to an existing rental housing block which will be demolished as part of the KSC development. At the lower level (31.4 mPD) of the subject site, it is currently an open space car-park, bounded by Kwai Shing Wai Substation to the east and Kwai Shing Playground to the west. Two housing towers (Block 1 on the west and Bock 2 to the east) will be constructed on this open car park area for the KSC development project.

Currently, the site has a surrounding urban and hilly terrain, with several large-scale high rise private and public housing estates, schools, recreational areas and some commercial low-rise buildings in close proximity.

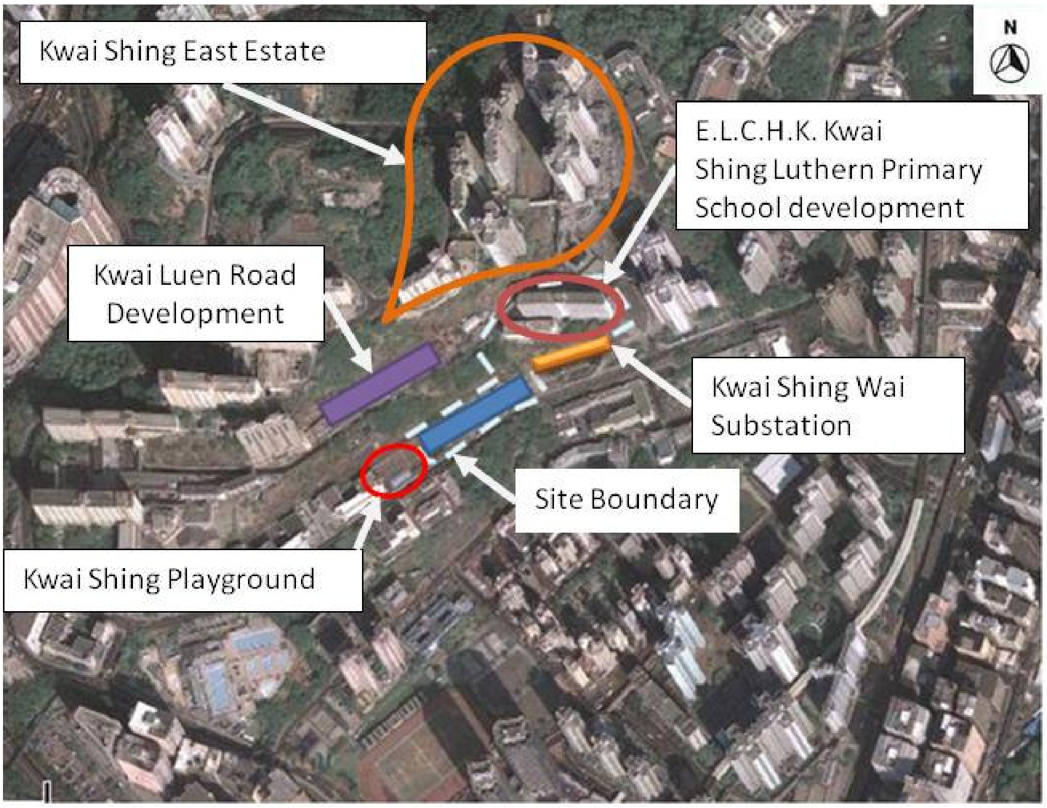


Figure 3-1 Location of the Subject Site and Surrounding Topography

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 (encoded by green boundary line) below.

The assessment area (encoded by blue 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 113 metres.

The surrounding area should normally be up to a perpendicular distance of 2H from the project site boundary, which is 226 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 red boundary line) 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.

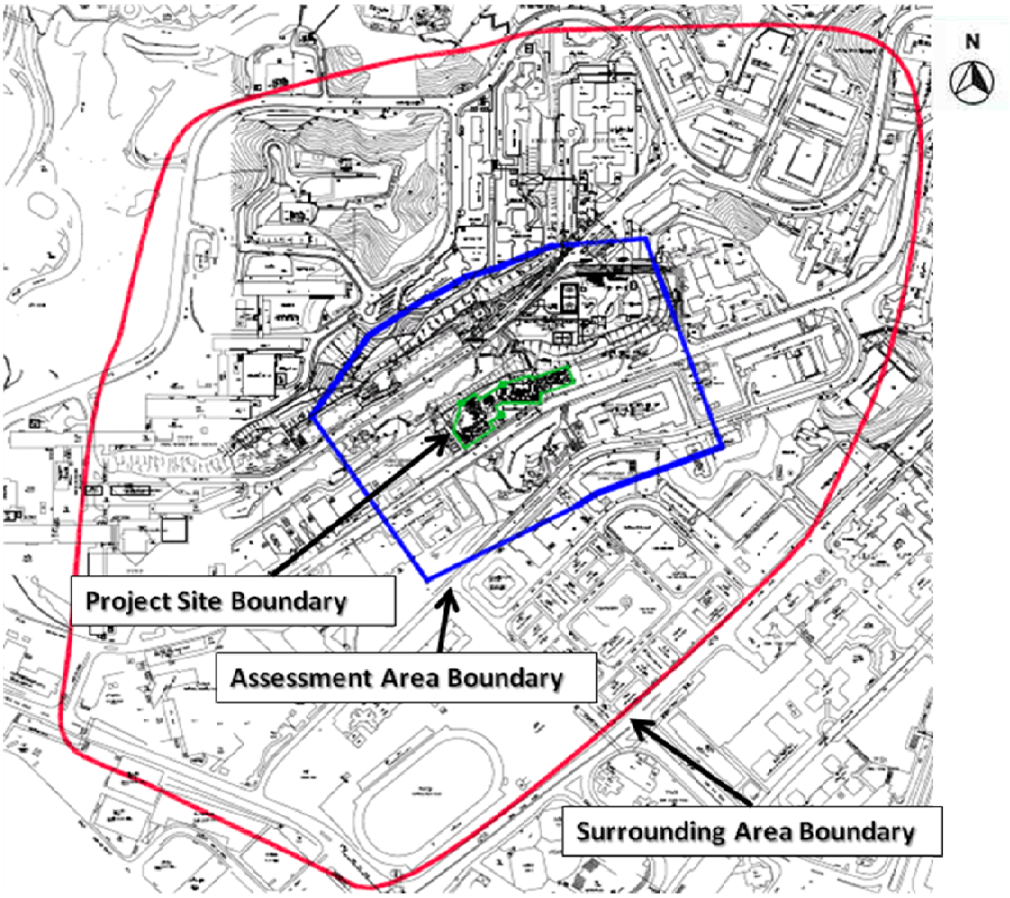


Figure 3-2 Project Site Boundary, Assessment Area Boundary and Surrounding Area Boundary

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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 Kwai Chung region (see *Section 4* for more details), north-north-easterly to south-south-westerly 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 uphill at north/northeast directions to the site. These include Kwai Shing East Estate located at north/northeast/east-northeast directions and the newly built Kwai Luen Road public housing development erected on the northwest of the site. A potential wind corridor is available along Kwai Shing Circuit (shown by yellow arrows below) under eastern direction and along southeast direction from downhill side up to Kwai Shing East Estate (see illustrated below). A large plot of downhill mid-rise developments is found at southern direction to the site. Due to the low-rise topography for east-southeast to western winds (around 38% annual probability occurrence as evaluated in *Section 4.2*), there is unlikely to be significant ventilation impacts under these prevailing directions. Finally, as a result of the open nature of Kwai Shing Wai Substation to the east and Kwai Shing Playground to the west in close proximity, the inherent overall wind performance at these areas should be acceptable.

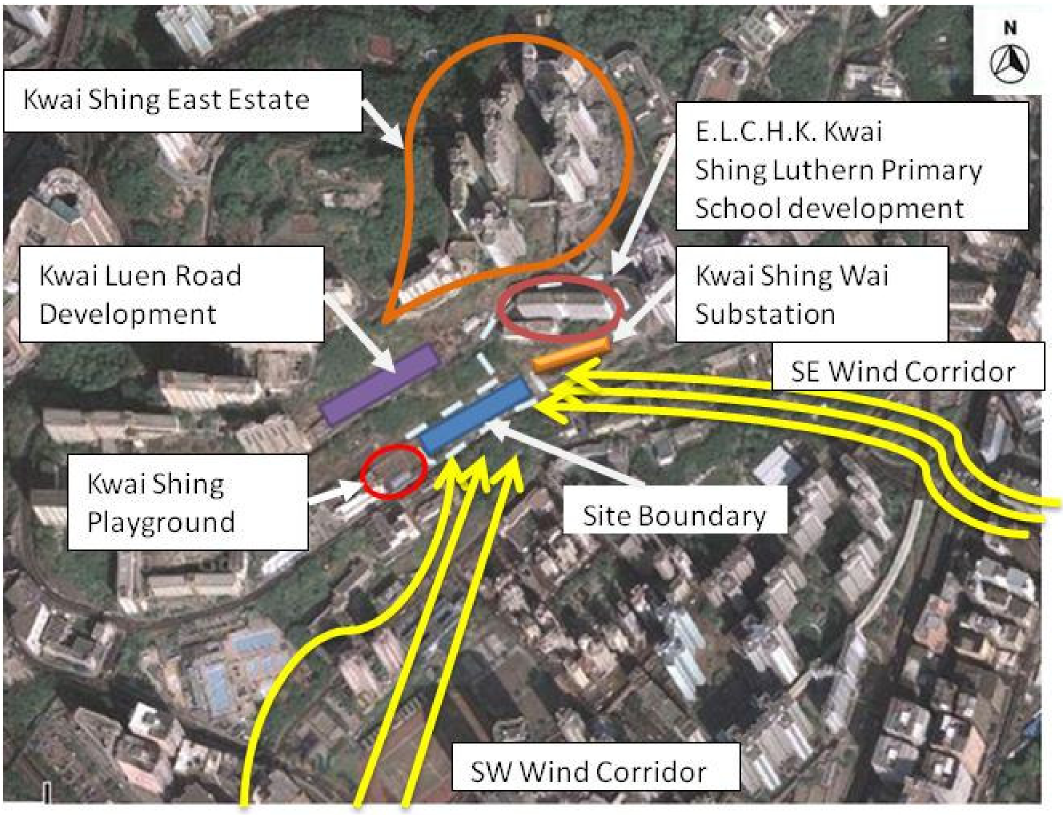

Figure 3-3 Wind Corridor Directing Air Circulation toward Project Site

The erection of the proposed KSC public housing development on the project site could potentially block all prevailing wind directions except eastern winds available to pedestrian areas within close vicinity. The extent of these impacts is unknown since the development is permeable at the ground floor lobby of Block 1 and 2 of the proposed development and there is also a width of 12 meters spacing between Block 1 and 2. The ventilation impact of the proposed KSC public housing development to the surrounding community was investigated by CFD simulation and explained in *Section 6*. Under eastern prevailing wind, the development could form corridors with surrounding topography and thus potentially increasing wind availability impacts to nearby pedestrian areas. On this basis, erection of the proposed KSC public housing development on the project site should not have a significant adversely impact upon air ventilation performance.

Using CFD simulation as the assessment tool, quantitative ventilation performance evaluation of proposed design of KSC public housing development 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 Kwai Shing Circuit Public Housing Development 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 wind data representing the immediate vicinity of the project site (Kwai Chung District) was extracted for CFD simulation as the black square shown below.

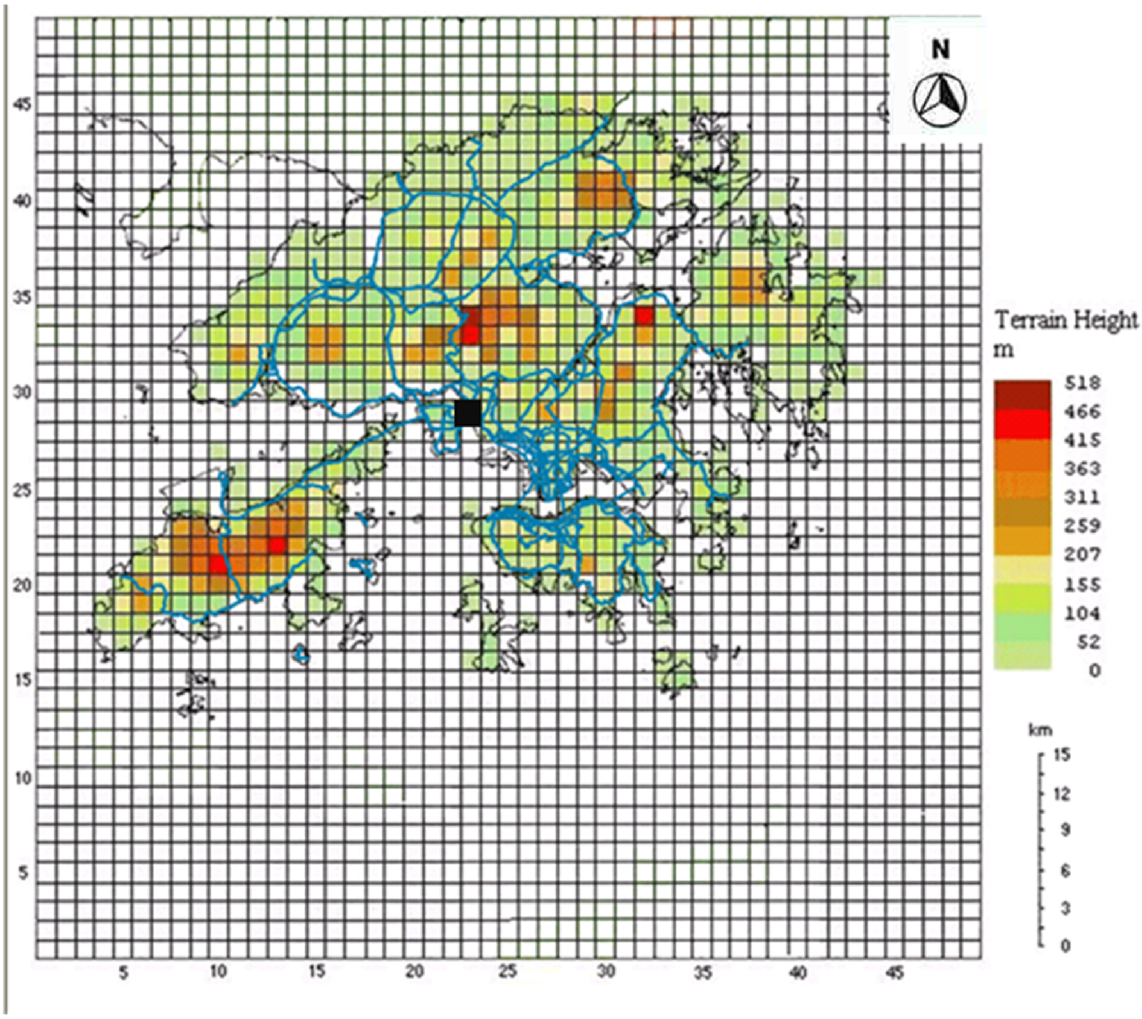

Figure 4-1 Location of Project Site

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/MM5/2329.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.

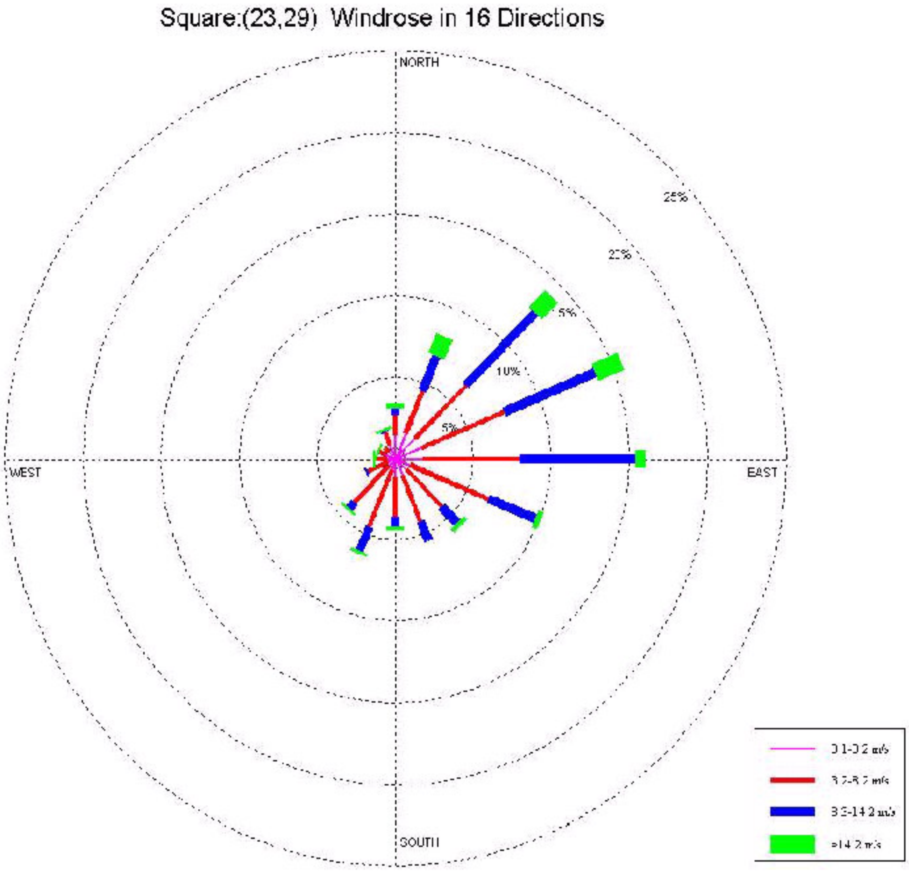

Figure 4-2 Relevant Wind Rose for Kwai Chung District

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 75.0% are shown overleaf. The table overleaf shows the selected wind direction with corresponding average speed at infinity height, 596m

(Using raw data extracted from Planning Department website: http://www.pland.gov.hk/pland_en/misc/MM5/2329.html).

Wind Direction	Wind speed at infinity, 596m (m/s)	Probability	
E	7.91	15.8%	75.0%
ENE	8.80	15.4%	
NE	8.78	13.9%	
ESE	7.07	9.9%	
NNE	8.07	8.0%	
SSW	6.55	6.2%	
SE	6.82	5.8%	
SSE	5.81	5.4%	
S	5.00	4.3%	
SW	5.27	4.3%	
N	4.84	3.4%	
WSW	4.29	2.1%	
NNW	2.98	2.0%	
W	4.07	1.4%	
WNW	2.71	1.2%	
NW	2.70	1.0%	

Table 4-1 Wind Data for Kwai Chung 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 (i.e. NNE, NE, ENE, E, ESE, SE, SSW). 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 specification of 64-bits quad-core, 2.93GHz Xeon CPU and 12.0GB of RAM.

3-Dimensional Modelling

In this study, 3-dimensional models[1] 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 113 meters) around the area of interest is 2%.

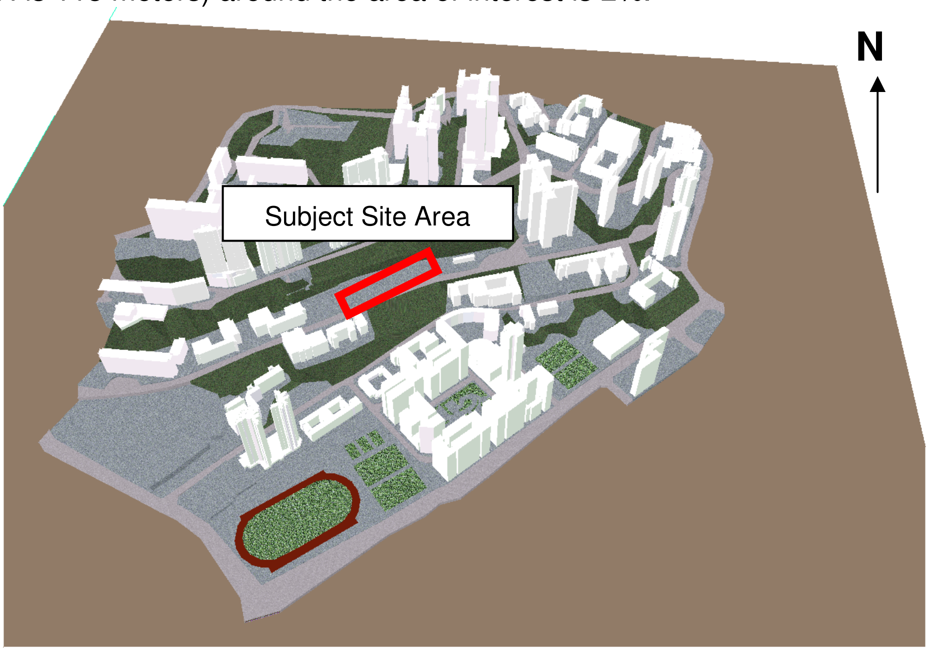

Figure 5-1 3 – Dimensional Virtual Model Prior to Construction of the Kwai Shing Circuit Public Housing Development

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[1] In order to fulfil EPD's noise compliance of domestic units within the KSC public housing development, a 7.5m high continuous noise barrier is proposed to be erected along Kwai Shing Circuit at the southern portion of the site to further mitigate traffic noise. The proposed noise barrier consists of a canopy extended over and 500mm beyond the Kwai Shing Circuit footpath. With the incorporation of the said noise barrier, the Environmental Assessment Study was finally accepted by the EPD. The virtual 3-Dimensional Model constructed for this AVA study has incorporated this proposed noise barrier to comprehensively investigate ventilation impacts resulting from the construction of the KSC development.

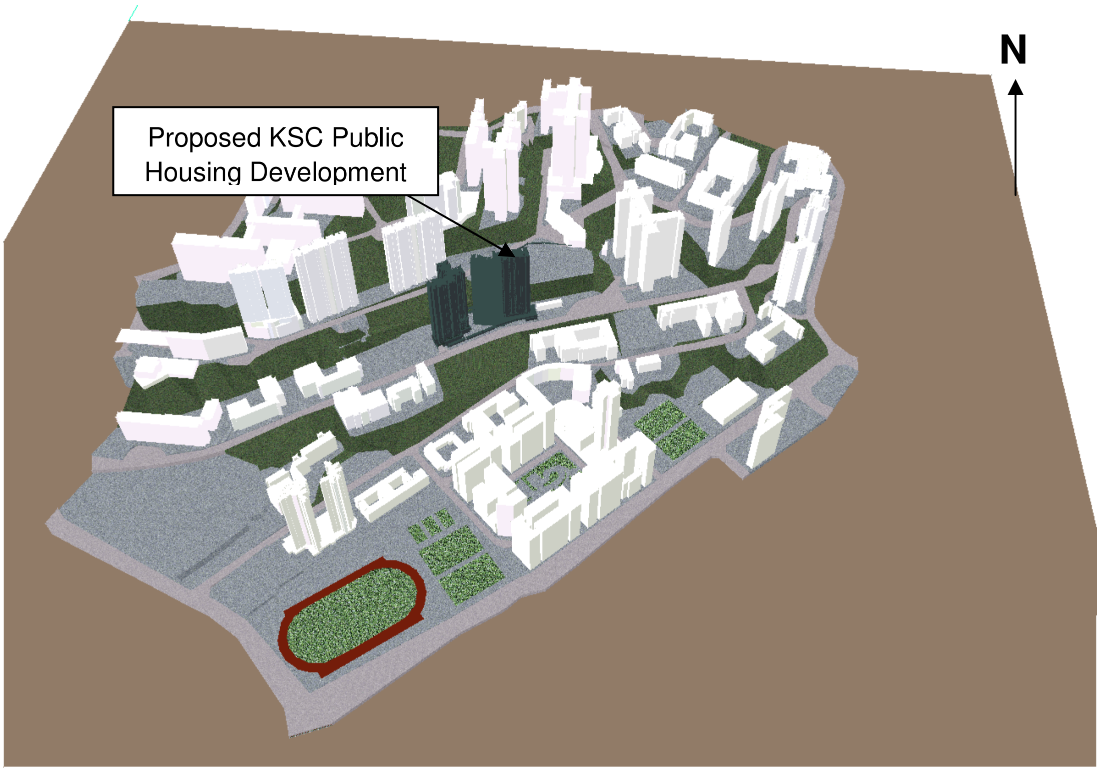


Figure 5-2 3 – Dimensional Virtual Model Subsequent to Construction of the Kwai Shing Circuit Public Housing Development

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, SE and SSW prevailing wind directions analysed in this study as the terrain in these directions around the project site are of urban and city nature. 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

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

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 = 1,500 m;
- y-direction = 1,500 m; and
- z-direction = 600 m,

H is height of tallest building within subject site which is 113 m.

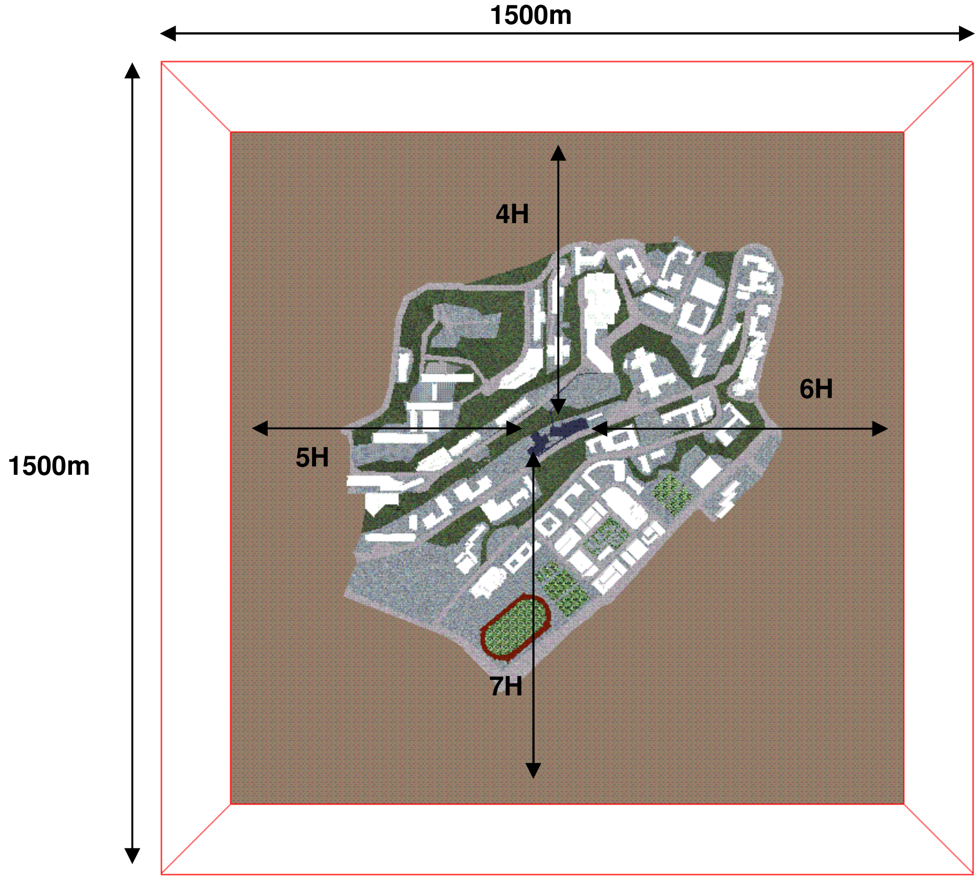


Figure 5-3 Birds View of Domain Dimension

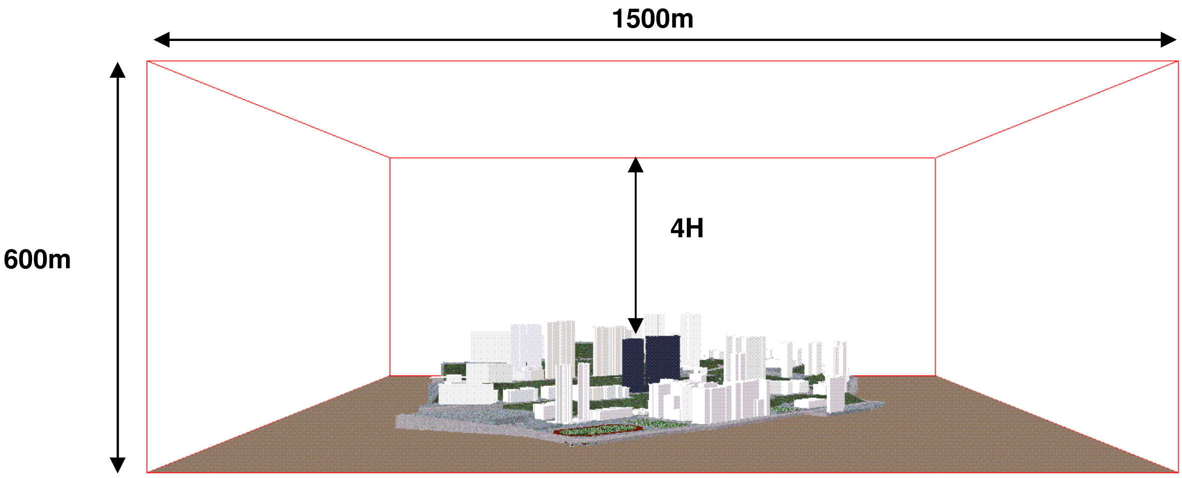


Figure 5-4 Side View of Domain Dimension

Simulation Meshing

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

Average size in: x-direction = 9m (largest one near boundary is 32m); y-direction = 12m (largest one near boundary is 50m); z-direction = 8m (largest one near boundary is 83m).

Areas of interest (test points) around and within subject site at ground level: x-direction = 3m; y-direction = 4m; z-direction = 0.5m, with expansion ratio of 1.05 from 0 to 10m above test points' level[2].

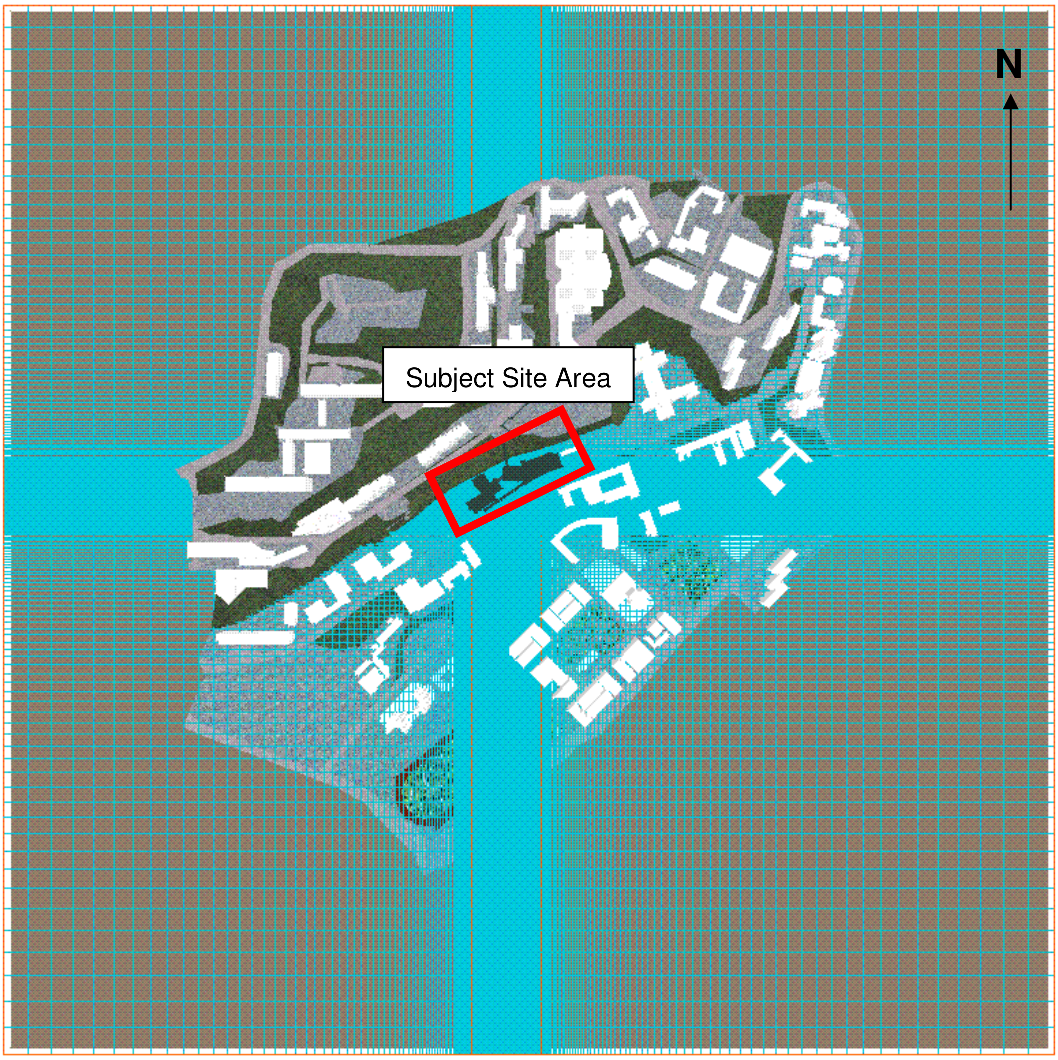


Figure 5-5 Birds View of Meshing Arrangement

[2] Reference to Cost C14

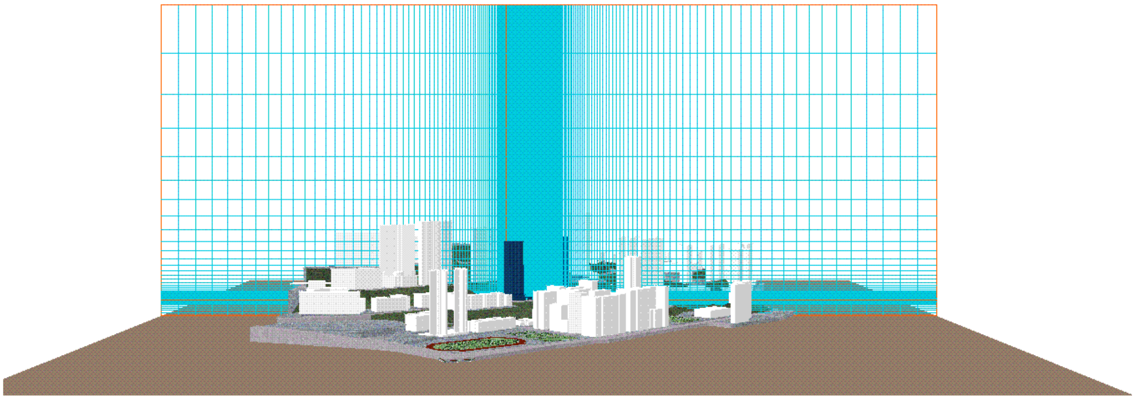


Figure 5-6 Side View of Meshing Arrangement

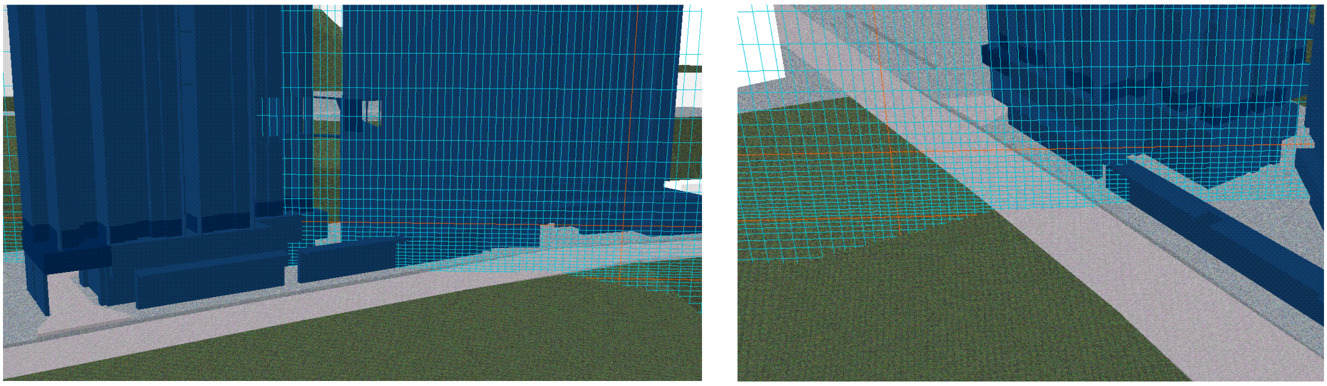


Figure 5-7 Side Views of Meshing Arrangements at Area of Interest (Near Ground Level)

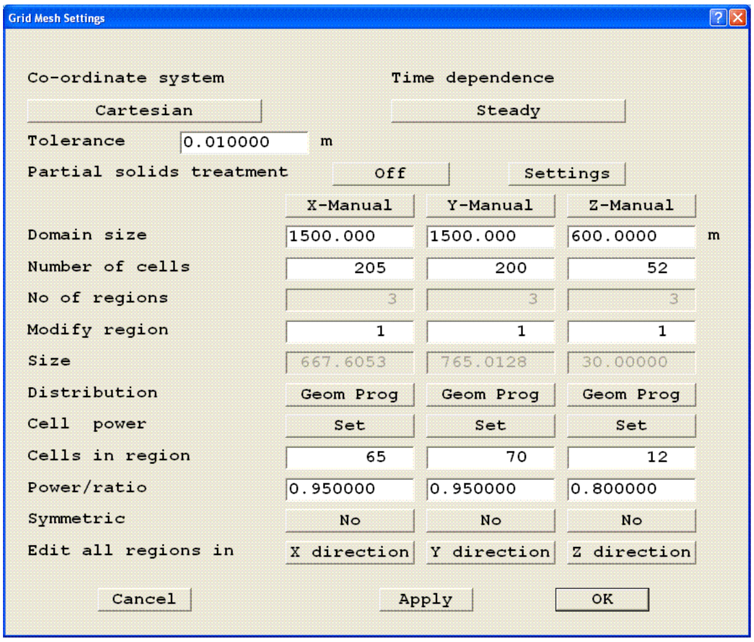


Figure 5-8 Mesh Setting

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%[3]. Variable settings applied for the CFD simulation are tabulated in overleaf.

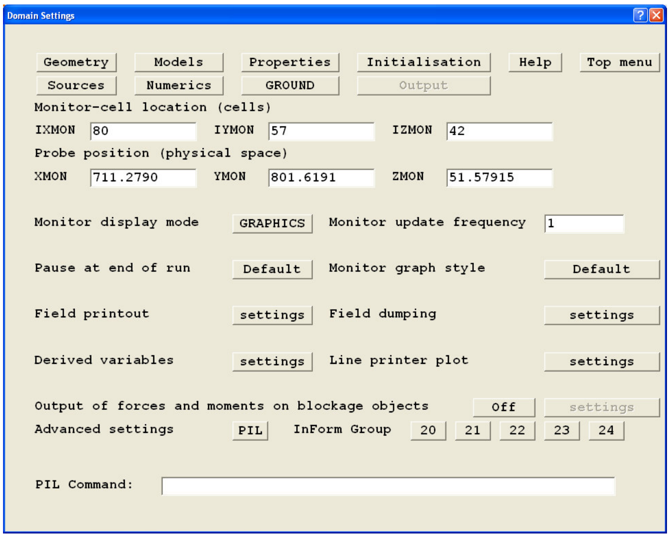


Figure 5-9 Variables Control Settings Employed in CFD Simulations

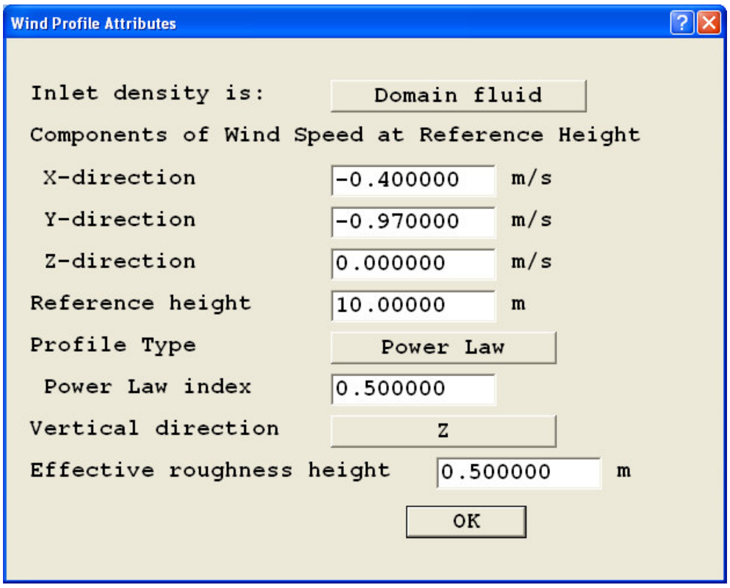


Figure 5-10 Wind Profile Attributes in CFD Simulations

[3] 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.

Test Points

Test Points are 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*.

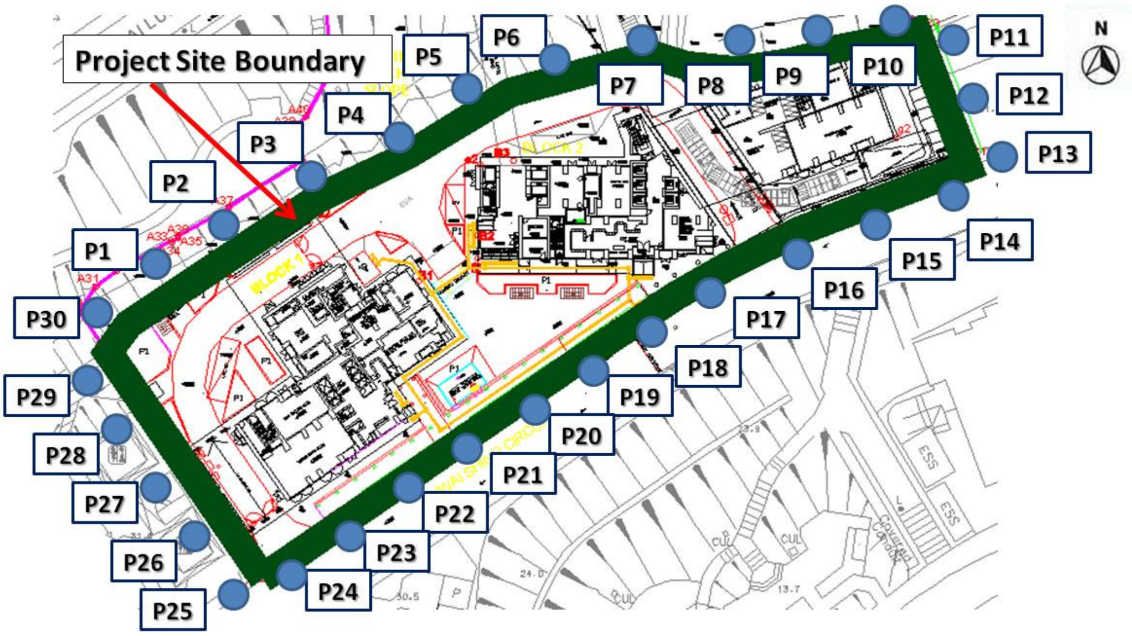


Figure 5-11 Perimeter Test Points

Local Test Points are distributed on those potentially pedestrian accessible areas within the assessment area boundary and project site boundary. Local Test Points are lying within the assessment area boundary (coloured in blue) and outside project site boundary (coloured in green) 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.*

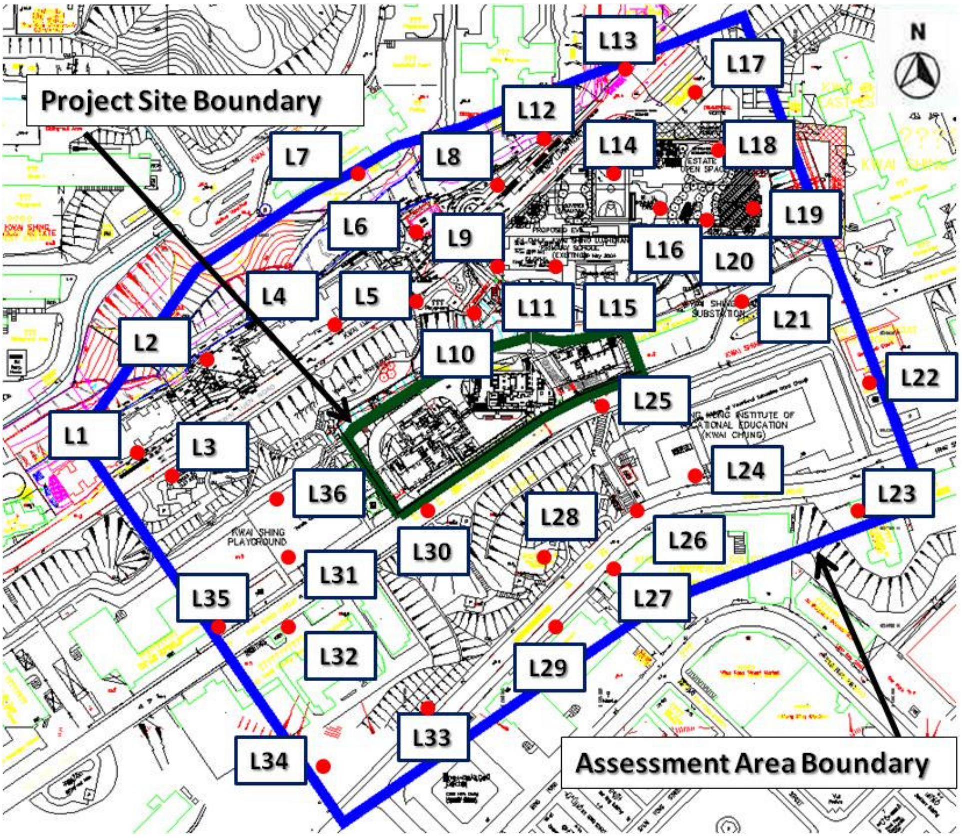


Figure 5-12 Local Test Points

Special Test Points are positioned at the pedestrian areas between the building block entrance and the noise barriers 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.

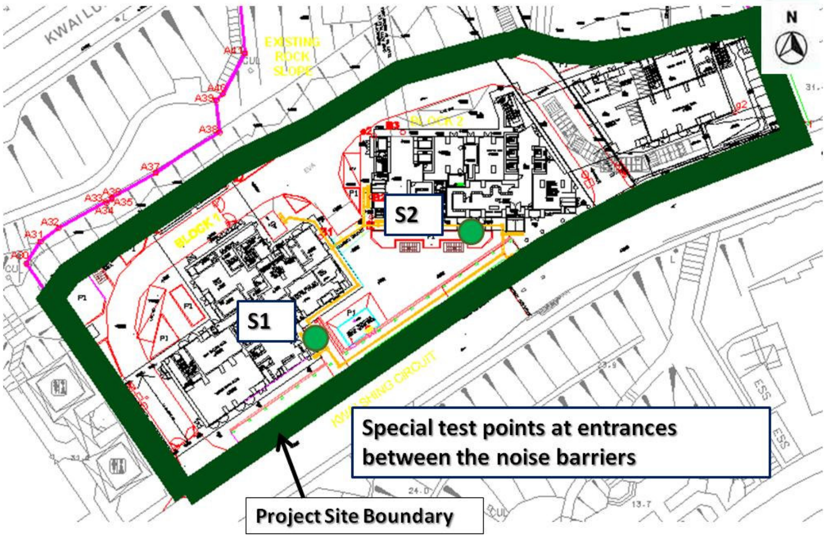


Figure 5-13 Special Test Points

5.2 Wind Velocity Ratio

Wind velocity ratio (VR) is defined as Vp/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 Kwai Shing Circuit Public Housing Development, for each of the seven prevailing wind directions 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 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 Kwai Shing Circuit Public Housing Development**	**Subsequent to Construction of Kwai Shing Circuit Public Housing Development**	**VR Change**
NNE (22.5º)	0.193	0.161	-0.031
NE (45º)	0.188	0.162	-0.026
ENE (67.5º)	0.193	0.179	-0.014
E (90º)	0.199	0.206	0.006
ESE (112.5º)	0.188	0.197	0.009
SE (135º)	0.145	0.161	0.016
SSW (202.5º)	0.135	0.140	0.005
Overall (weighted)	0.184	0.177	-0.007

Table 6-1 Summary of Local Velocity Ratios for Kwai Shing Circuit Public Housing Development under Prevailing Wind Directions

Site Air Ventilation Assessment Results (SVR)			
Prevailing Wind Direction	**Prior to Construction of Kwai Shing Circuit Public Housing Development**	**Subsequent to Construction of Kwai Shing Circuit Public Housing Development**	**VR Change**
NNE (22.5º)	0.211	0.149	-0.062
NE (45º)	0.208	0.158	-0.051
ENE (67.5º)	0.211	0.181	-0.030
E (90º)	0.220	0.205	-0.015
ESE (112.5º)	0.204	0.192	-0.012
SE (135º)	0.147	0.162	0.015
SSW (202.5º)	0.129	0.149	0.019
Overall (weighted)	0.200	0.176	-0.024

Table 6-2 Summary of Site Velocity Ratios for Kwai Shing Circuit Public Housing Development under Prevailing Wind Directions

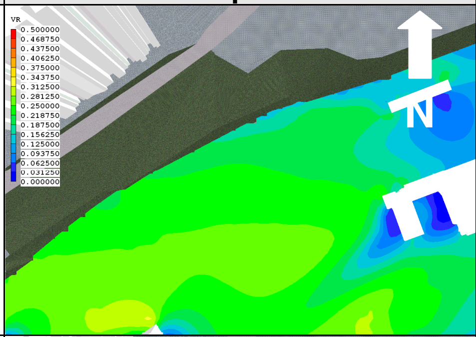
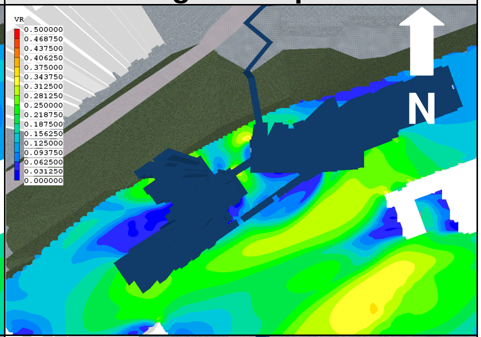
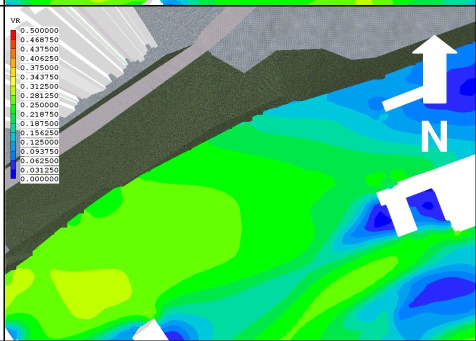
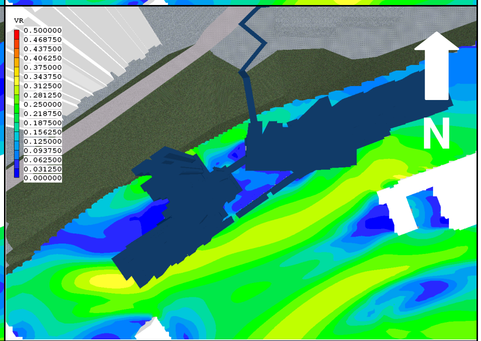
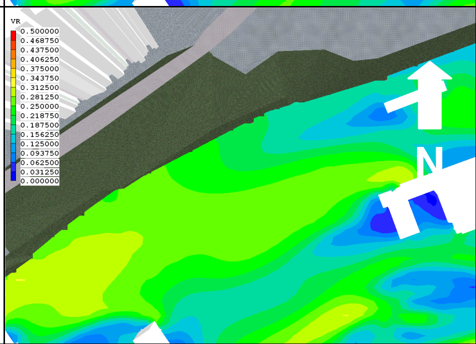
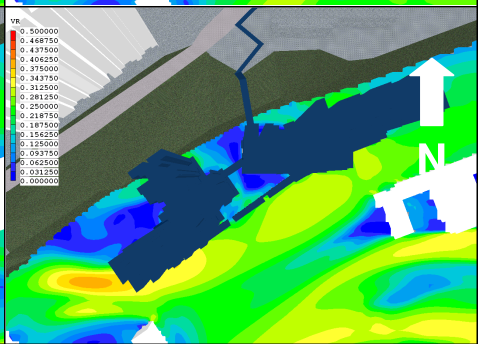
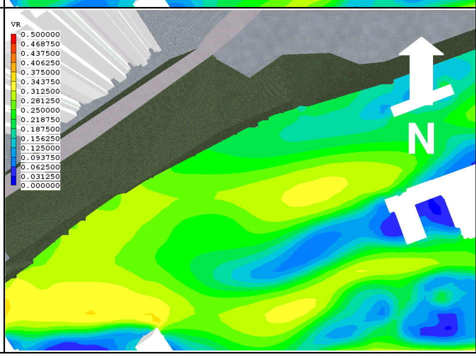
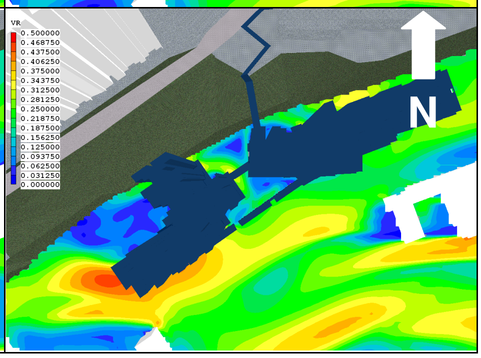
Prevailing Wind Direction	Prior to Construction of Kwai Shing Circuit Public Housing Development	Subsequent to Construction of Kwai Shing Circuit Public Housing Development
NNE at Ground level		
NE at Ground level		
ENE at Ground level		
E at Ground level		

Table 6-3 Velocity Ratio Plots for Kwai Shing Circuit Public Housing Development under Prevailing Wind Directions

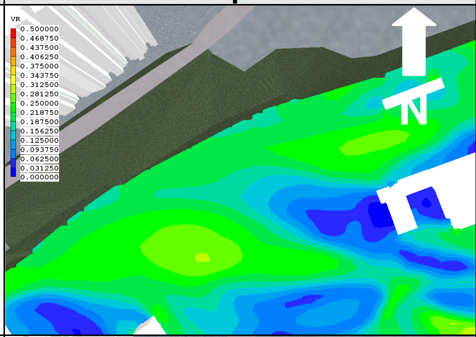
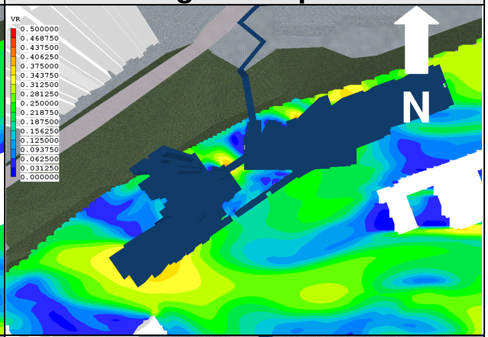
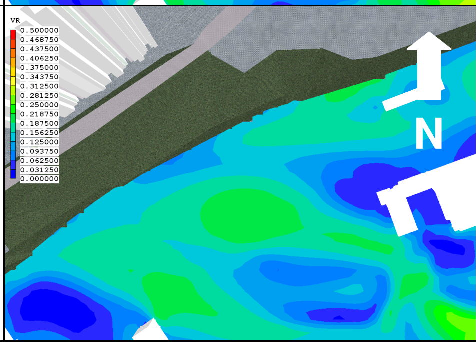
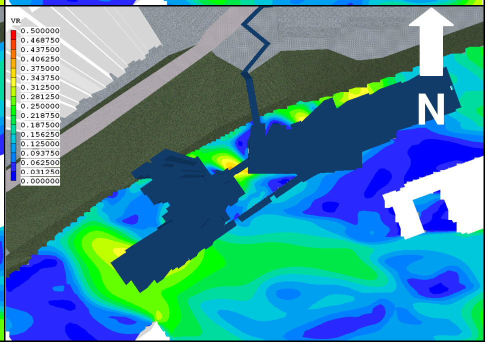
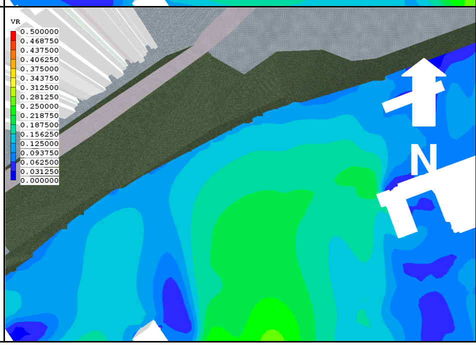
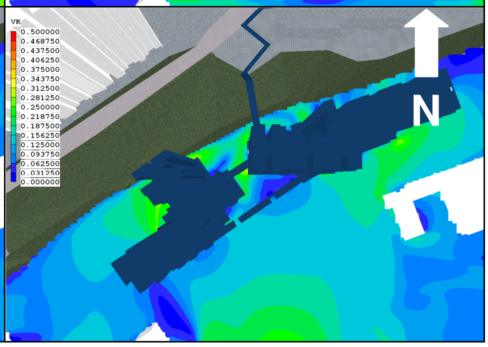
Prevailing Wind Direction	Prior to Construction of Kwai Shing Circuit Public Housing Development	Subsequent to Construction of Kwai Shing Circuit Public Housing Development
ESE at Ground level		
SE at Ground level		
SSW at Ground level		

Table 6-4 Velocity Ratio Plots for Kwai Shing Circuit Public Housing Development 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 Kwai Shing Circuit Public Housing Development. The change in weighted LVR is 0.007 (4%) and this is equivalent to a speed reduction of less than 0.07 m/s at pedestrian level which is deemed to be insignificant and acceptable.

As predicted from the qualitative ventilation performance evaluation in *Section 3.3*, mid-rise obstructive buildings are situated downhill at east-southeast to western directions to the site which allows air circulation from these wind directions. As a result of this, even prior to construction of the Kwai Shing Circuit Public Housing Development, wind availability of the project site and its surrounding community is inherently good with a weighted LVR of 0.184 which is equivalent to wind speeds of around 2 m/s at nearby pedestrian areas.

As explained in *Section 3.3,* the erection of the KSC development and its surrounding topology creates a wind corridor along Kwai Shing Circuit from the eastern to western direction and wind is directed towards the site and surrounding communities. Coupled with this wind corridor, the erection of the KSC development induces wind paths at eastern directions to the site as illustrated overleaf. On this basis, there is a ventilation performance improvement of 0.006 (3%) and in absolute terms, the associated velocity increase is around 0.05 m/s.

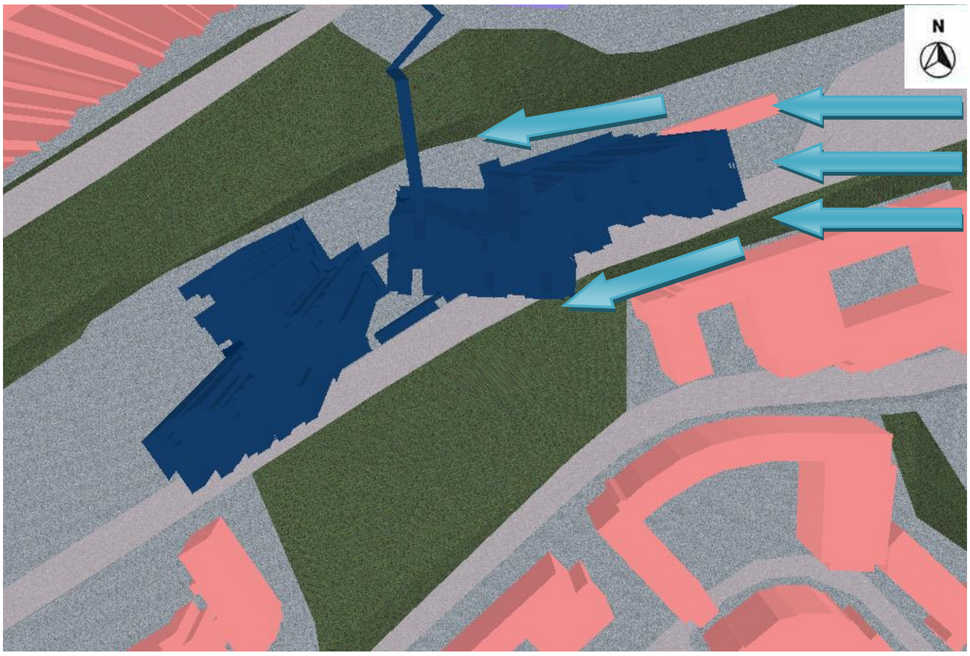


Figure 6-1 Wind path between KSC development and surrounding topography

Under southern quadrant of prevailing wind directions, the subject site is exposed to plenty of wind availability as most developments is lower than the ground level of the subject site as shown overleaf. Open spaces such as Hing Fong Road Playground and Jockey Club Hing Shing Road Playground are located further downhill at the southeast and southwest directions respectively to the site. Wind corridors are present in these two directions from downhill to Kwai Shing East Estate as mentioned in *Section 3.3*. A separation distance of around 12 meters between Block 1 and Block 2 of the subject site induces enhanced air circulation from the two wind corridors to the surrounding pedestrian levels upon the construction of KSC development. These result in an increase LVR ranging from 0.005 (4%) and 0.016 (11%) for ESE, SE and SSW prevailing winds.

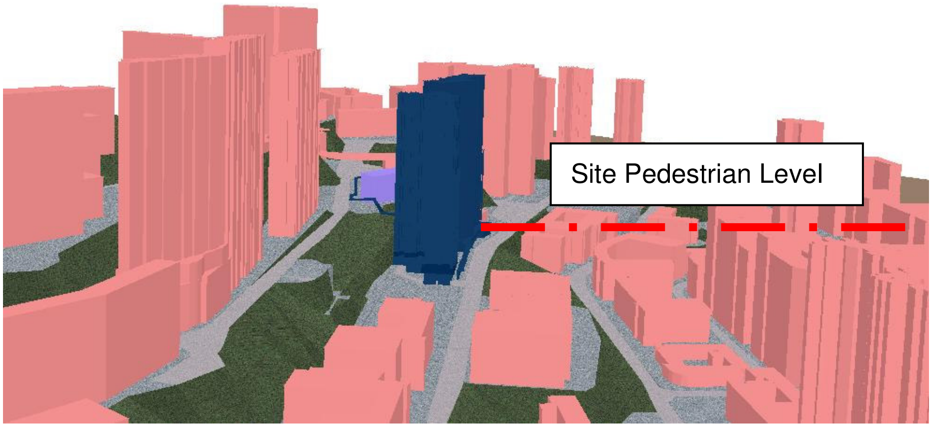


Figure 6-2 Most of the developments downhill are lower than site pedestrian level (for enhanced air circulation)

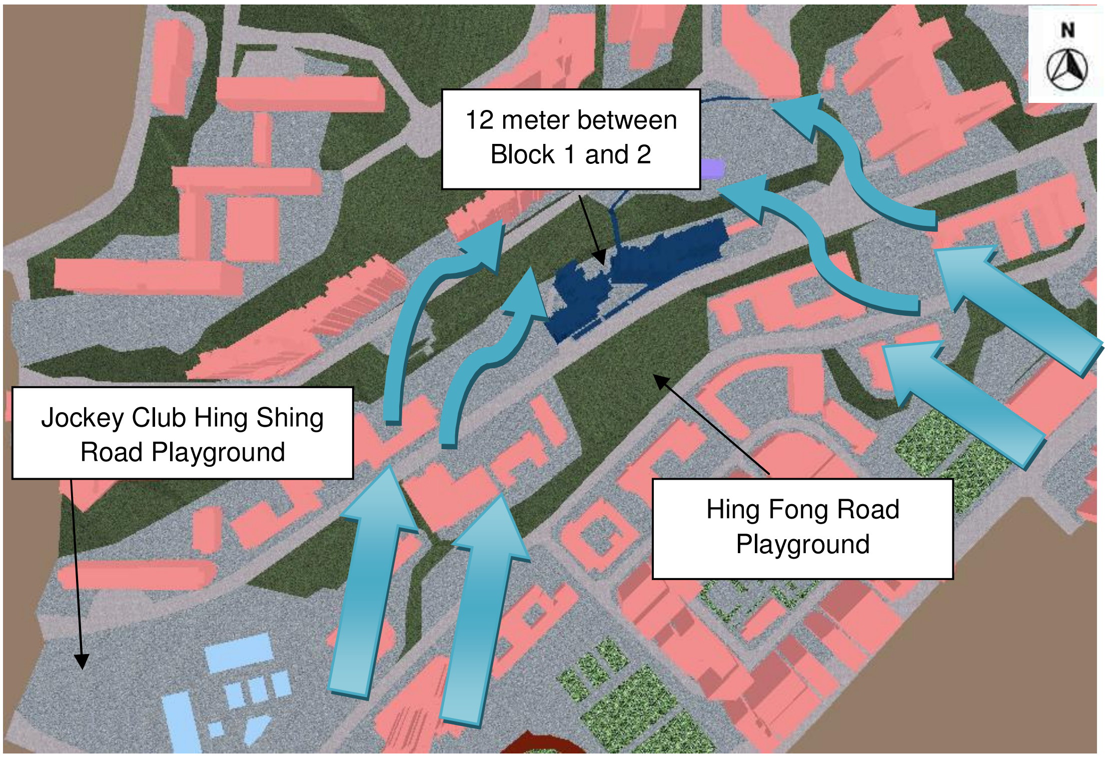


Figure 6-3 SE and SSW wind corridors

The reduction in VR should be predominately found in the northern quadrant of prevailing wind directions (NNE, NE, ENE) as obstructive buildings (described in Section 3.3) are erected at the northern part of the site and there is no obvious wind corridor in this direction. The construction of the KSC development induces a barrier effect with LVR reductions ranging from 0.014 (7%) and 0.031 (16%) for NNE, NE and

ENE prevailing winds, but in absolute terms, the associated velocity reduction is less than 0.3m/s.

In summary, the overall weighted VR change in the local Air Ventilation Assessment from the construction of Kwai Shing Circuit Public Housing Development is not substantial (less than 0.007 which is equivalent to 0.07 m/s wind velocity reduction) and its impact upon ventilation performance of potential pedestrian areas is deemed to be insignificant. Therefore, it can be concluded that the design and erection of Kwai Shing Circuit Public Housing Development is unlikely to have a significant adverse wind impact on pedestrian level ventilation performance of the surrounding community

6.2 Site Air Ventilation Assessment Findings

The ventilation performance of the site perimeter as a result of the Kwai Shing Circuit Public Housing Development construction is summarised in the table overleaf (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)	0.184	0.177
SVR (Perimeter Test Point)	0.200	0.176

Table 6-5 Summary of Local Velocity Ratio and Site Velocity Ratio for Kwai Shing Circuit Public Housing Development under Prevailing Wind Directions

The Site Perimeter Velocity Ratio for each prevailing wind direction is summarized in the SVR results table on page 26. The construction of the Kwai Shing Circuit Public Housing Development 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 KSC Public Housing Development would generally have some impact upon the wind availability of these test points, as expected. For the same ventilation pattern and reasons as LVR study findings mentioned in *Section 6.1*, there are site VR improvements ranging from 0.015 (11%) to 0.019 (15%) which is both equivalent to 0.1m/s in absolute terms for SE and SSW prevailing wind directions. For NNE, NE, ENE, E and ESE prevailing wind directions, there are site VR reductions ranging from 0.012 (6%) to 0.062 (30%) which is equivalent to less than 0.5m/s pedestrian level velocity reduction. In summary, the construction of the KSC Public Housing Development will lead to an overall weighted SVR reduction of 0.02 (equivalent to 0.2 m/s reduction in pedestrian level velocity) which is less than 13% deterioration and thus 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 Kwai Shing Circuit Public Housing Development as extracted from CFD simulation results are tabulated below.

Special Air Ventilation Assessment Results			
Prevailing Wind Direction	**Prior to Construction of Kwai Shing Circuit Public Housing Development**	**Subsequent to Construction of Kwai Shing Circuit Public Housing Development**	**VR Change**
NNE	0.237	0.071	-0.166
NE	0.237	0.074	-0.163
ENE	0.237	0.073	-0.164
E	0.251	0.087	-0.164
ESE	0.179	0.059	-0.119
SE	0.167	0.058	-0.109
SSW	0.177	0.046	-0.131
Overall (weighted)	0.222	0.071	-0.151

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

The construction of Kwai Shing Circuit Public Housing Development involves erection of buildings with height of 113 meters which would ultimately lead to reduced wind permeability in these areas (originally entirely exposed). For the same ventilation performance pattern and reasons as mentioned in LVR and study findings mentioned in *Section 6.1*, there is a slighter reduction in special VR for ESE, SE and SSW prevailing wind directions ranging from 0.109 to 0.131 and there are site VR reductions ranging from 0.163 to 0.166 for NNE, NE, ENE and E prevailing wind directions. Taking into account of annual probability occurrence of prevailing winds, there is a weighted VR reduction of 0.151, but in absolute terms, the resulted velocity subsequent to construction of Kwai Shing Circuit Public Housing Development is approaching 1m/s, which is deemed as acceptable.

6.4 Overall Conclusion

The AVA study findings reveal that the construction of the Kwai Shing Circuit Public Housing 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 public housing development leads to ventilation performance results of LVR change = 0.007 (equivalent to less than 0.06 m/s wind speed reduction) and SVR change = 0.024 (equivalent to 0.2 m/s wind speed reduction), all of which are deemed to be insignificant and acceptable.

Appendix 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 / bureau 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 practicing 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. Vp 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_∞) 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 ($V\infty$). Typically the site wind rose of $V\infty$ could be obtained[1].

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".

[1] Project proponents may write to PlanD to obtain the MM5 data translated into site wind availability data ($V\infty$) of the Territory for Expert Evaluation and Initial Study.

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 $V\infty$ 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 summaries 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**. Summarize 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 analyzed. 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

Raw MM5 Wind Data Employed for AVA Study

Square (23,29)	Wind direction	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
V infinity (m/s)	Sum	0.034	0.08	0.139	0.154	0.158	0.099	0.058	0.054	0.043	0.062	0.043	0.021	0.014	0.012	0.01	0.02
0_to_1	0.022	0.001	0.002	0.001	0.002	0.002	0.001	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.002
1_to_2	0.055	0.006	0.006	0.005	0.004	0.005	0.003	0.003	0.004	0.003	0.002	0.001	0.002	0.002	0.003	0.002	0.004
2_to_3	0.078	0.007	0.008	0.009	0.009	0.008	0.005	0.004	0.004	0.005	0.003	0.003	0.002	0.002	0.003	0.002	0.004
3_to_4	0.088	0.004	0.007	0.008	0.01	0.01	0.007	0.007	0.006	0.007	0.006	0.006	0.002	0.002	0.001	0.002	0.003
4_to_5	0.09	0.006	0.006	0.008	0.01	0.01	0.007	0.005	0.007	0.004	0.008	0.006	0.005	0.002	0.001	0.001	0.003
5_to_6	0.092	0.002	0.006	0.012	0.011	0.011	0.011	0.004	0.006	0.007	0.008	0.006	0.003	0.002	0.001	0	0.002
6_to_7	0.095	0.001	0.006	0.009	0.011	0.014	0.014	0.008	0.007	0.005	0.009	0.007	0.003	0.001	0.001	0.001	0
7_to_8	0.087	0	0.004	0.008	0.013	0.015	0.014	0.008	0.005	0.003	0.007	0.006	0.001	0.002	0	0	0.001
8_to_9	0.072	0	0.004	0.007	0.012	0.016	0.01	0.004	0.005	0.002	0.007	0.003	0.001	0	0	0	0
9_to_10	0.065	0.001	0.004	0.012	0.01	0.016	0.009	0.004	0.002	0.002	0.003	0.001	0	0	0	0	0
10_to_11	0.066	0.001	0.007	0.013	0.011	0.015	0.006	0.004	0.003	0.001	0.003	0.001	0	0	0	0	0
11_to_12	0.056	0.001	0.005	0.014	0.012	0.013	0.005	0.002	0.002	0	0.002	0	0	0	0	0	0
12_to_13	0.039	0	0.001	0.012	0.01	0.01	0.003	0.001	0.001	0	0.001	0	0	0	0	0	0
13_to_14	0.028	0	0.002	0.006	0.009	0.006	0.002	0.001	0	0	0.001	0	0	0	0	0	0
14_to_15	0.019	0.001	0.002	0.006	0.006	0.002	0.001	0	0	0.001	0.001	0	0	0	0	0	0
15_to_16	0.012	0.001	0.001	0.003	0.004	0.002	0	0.001	0	0	0	0	0	0	0	0	0
16_to_17	0.01	0	0.004	0.002	0.003	0.001	0	0	0	0	0	0	0	0	0	0	0
17_to_18	0.007	0.001	0.003	0.002	0.001	0	0	0	0	0	0	0	0	0	0	0	0
18_to_19	0.005	0	0.002	0.001	0.001	0	0	0	0	0	0	0	0	0	0	0	0
19_to_20	0.005	0	0.001	0.001	0.001	0	0	0	0	0	0	0	0	0	0	0	0
20_to_21	0.004	0	0	0	0.001	0	0	0.001	0	0	0	0	0	0	0	0	0
21_to_22	0.003	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0
22_to_23	0.001	0	0	0	0.001	0	0	0	0	0	0	0	0	0	0	0	0
23_to_24	0.001	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	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26_to_27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Wind Probability and Wind Profiles

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

Angle (°)	Wind Direction	Wind speed at infinity(m/s)	Probability	
90.0	E	7.91	15.8%	
67.5	ENE	8.80	15.4%	
45.0	NE	8.78	13.9%	
112.5	ESE	7.07	9.9%	75.0%
22.5	NNE	8.07	8.0%	
202.5	SSW	6.55	6.2%	
135.0	SE	6.82	5.8%	
157.5	SSE	5.81	5.4%	
180.0	S	5.00	4.3%	
225.0	SW	5.27	4.3%	
0.0	N	4.84	3.4%	
247.5	WSW	4.29	2.1%	
337.5	NNW	2.98	2.0%	
270.0	W	4.07	1.4%	
292.5	WNW	2.71	1.2%	
315.0	NW	2.70	1.0%	

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

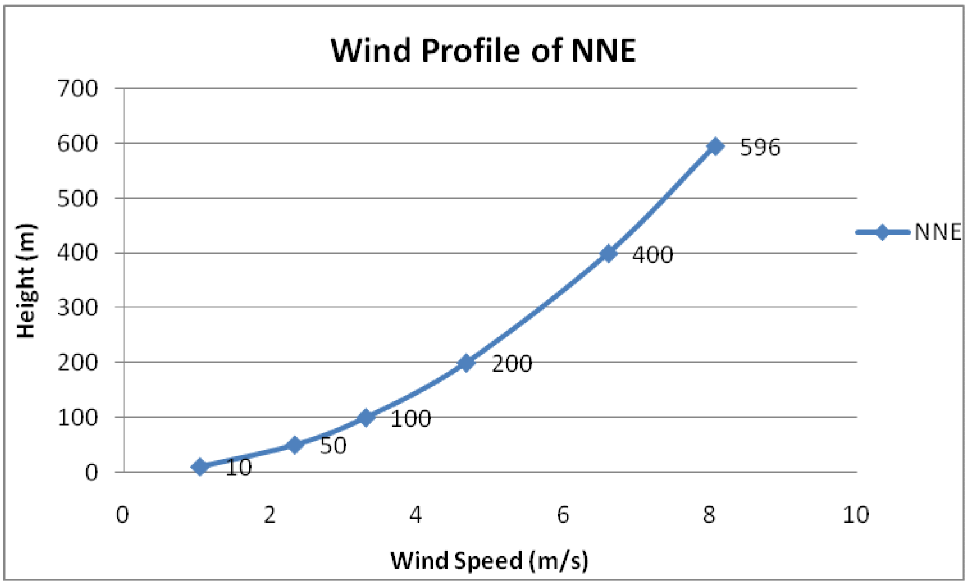
$$\frac{\overline{V_Z}}{V_{ZG}} = \left(\frac{Z}{Z_G}\right)^{\alpha}$$

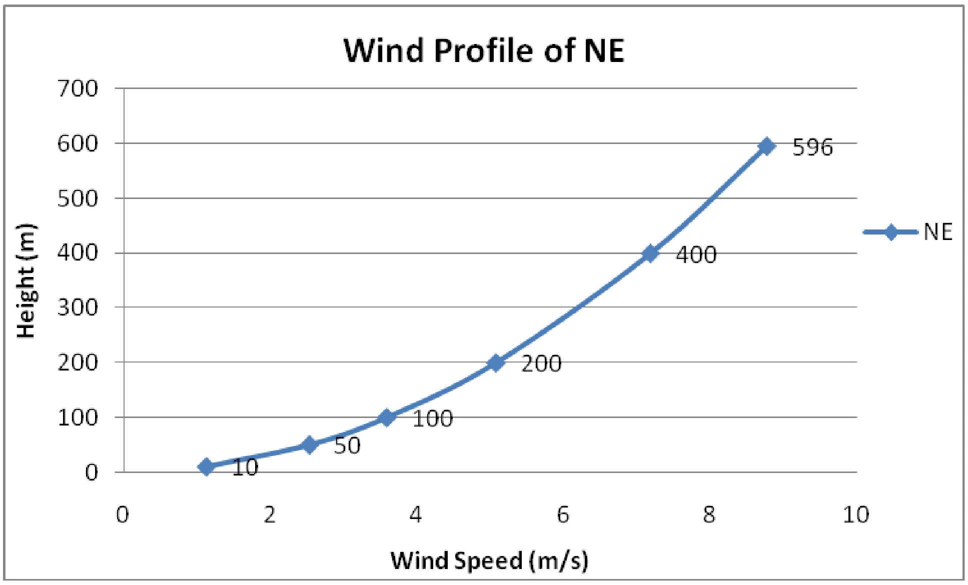
V_Z is the mean wind speed at height Z
V_{ZG} is the gradient wind speed at gradient height (boundary layer ht)
Z is the height of interest
Z_G is the gradient height (boundary layer ht)
α is a coefficient due to the roughness length of the terrain;

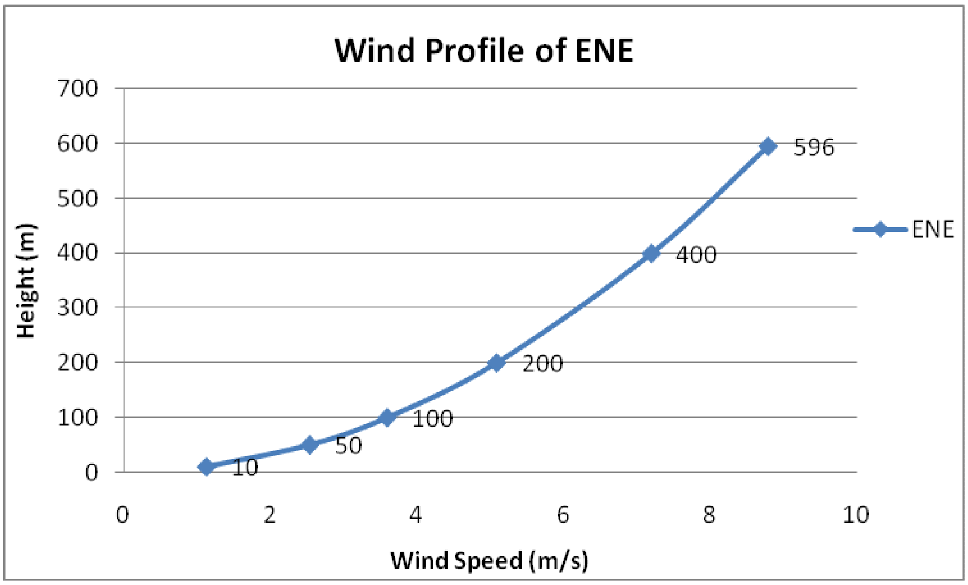
Terrain crossed by approaching wind	α	Z_G	Z_0
Sea and open space	≈ 0.15	≈ 300	≈ 0.1
Suburban or mid-rise	≈ 0.35	≈ 400	≈ 1
City center or high-rise	≈ 0.50	≈ 500	≈ 3

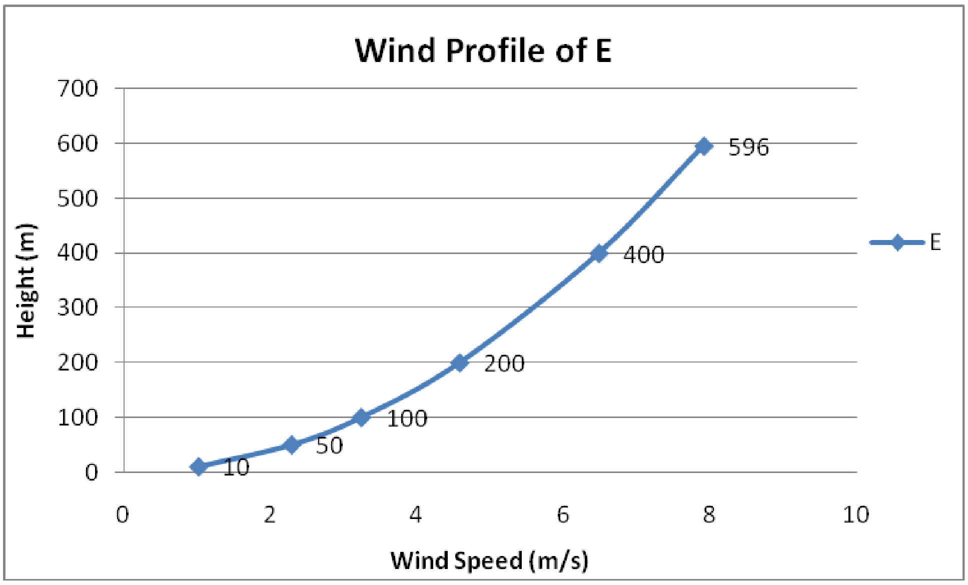
These coefficients are suggested as a guide only. Wind engineers could fine tune them for the task at hand. For more details, reference could be made to, for example, American Society of Civil Engineers Wind Tunnel Studies of Buildings and Structures 1999.

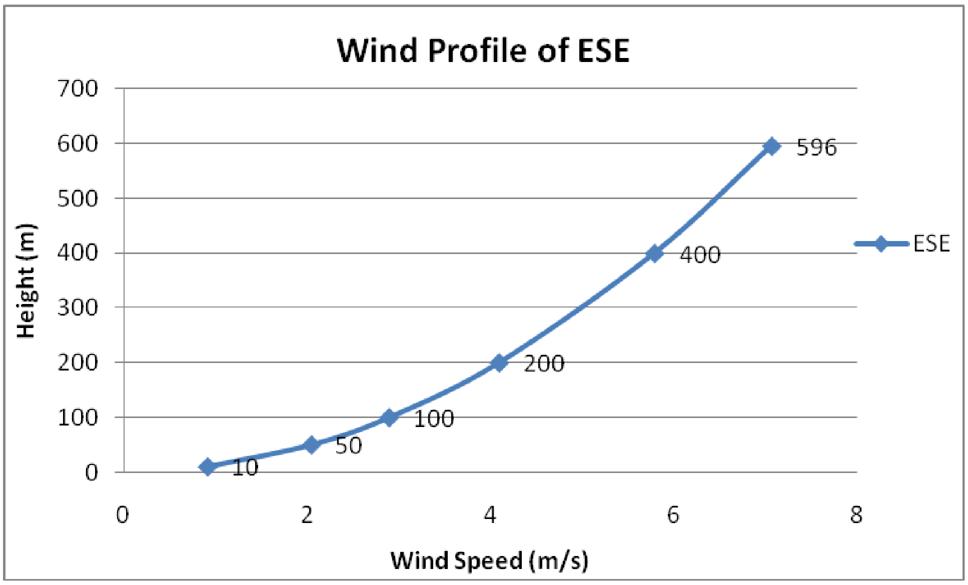
Where different power law exponents (α) are chosen for the estimation of wind profile of different prevailing direction based on the roughness length of the surrounding area of the subject site. A high value of α implies a high surface roughness of the area that the incoming wind flows through. **Alpha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

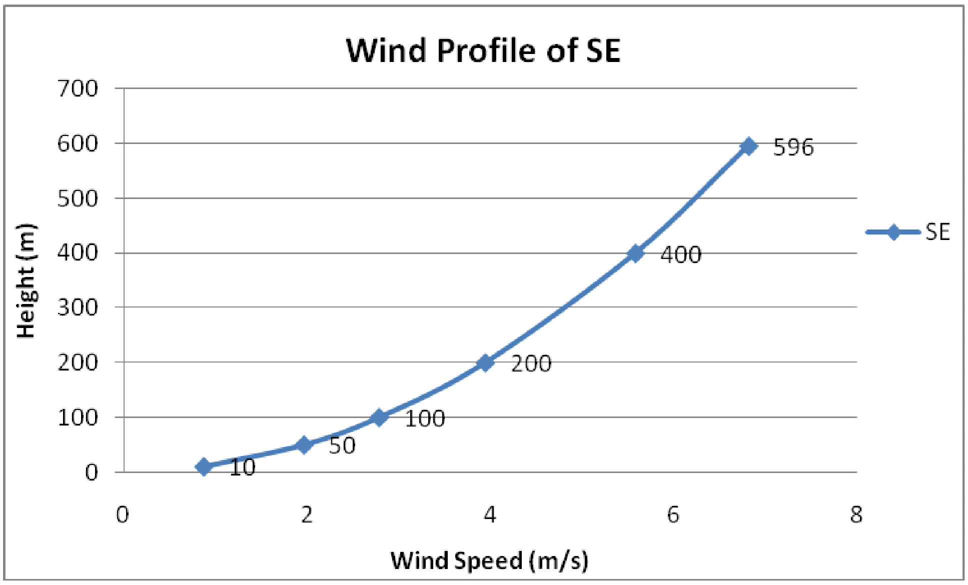


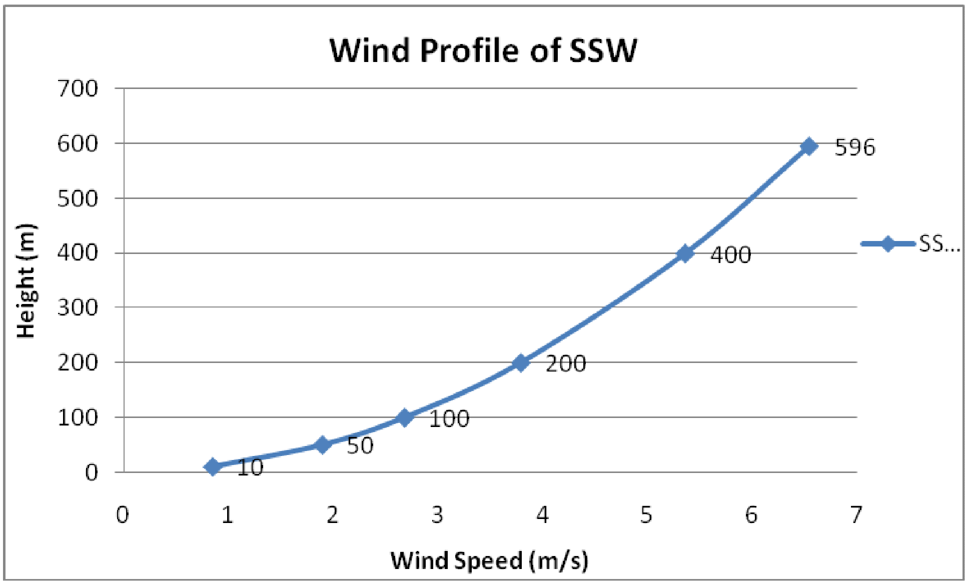

Wind Profile of NE
700
600
500
400
300
200
100
0
Height (m)
596
400
200
100
50
10
0
2
4
6
8
10
Wind Speed (m/s)
NE


Wind Profile of ENE
700
600
500
400
300
200
100
0
Height (m)
596
400
200
100
50
10
0
2
4
6
8
10
Wind Speed (m/s)
ENE


Wind Profile of E
Height (m)
Wind Speed (m/s)
E
596
400
200
100
50
10


Wind Profile of ESE
Height (m)
Wind Speed (m/s)
ESE
596
400
200
100
50
10

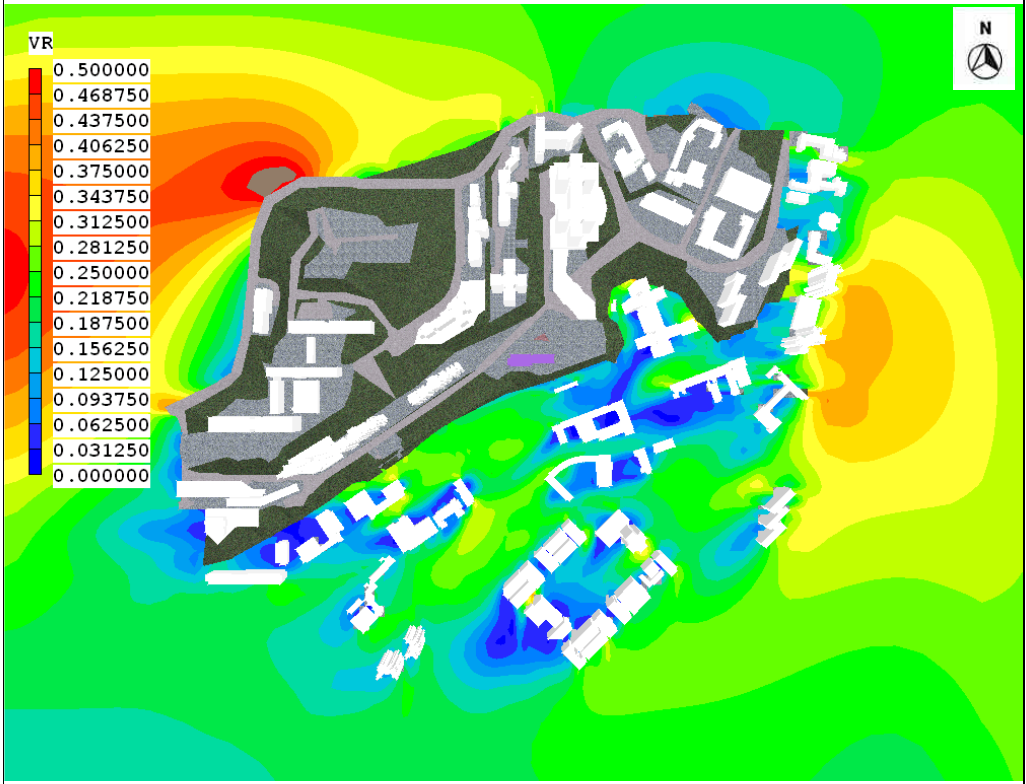
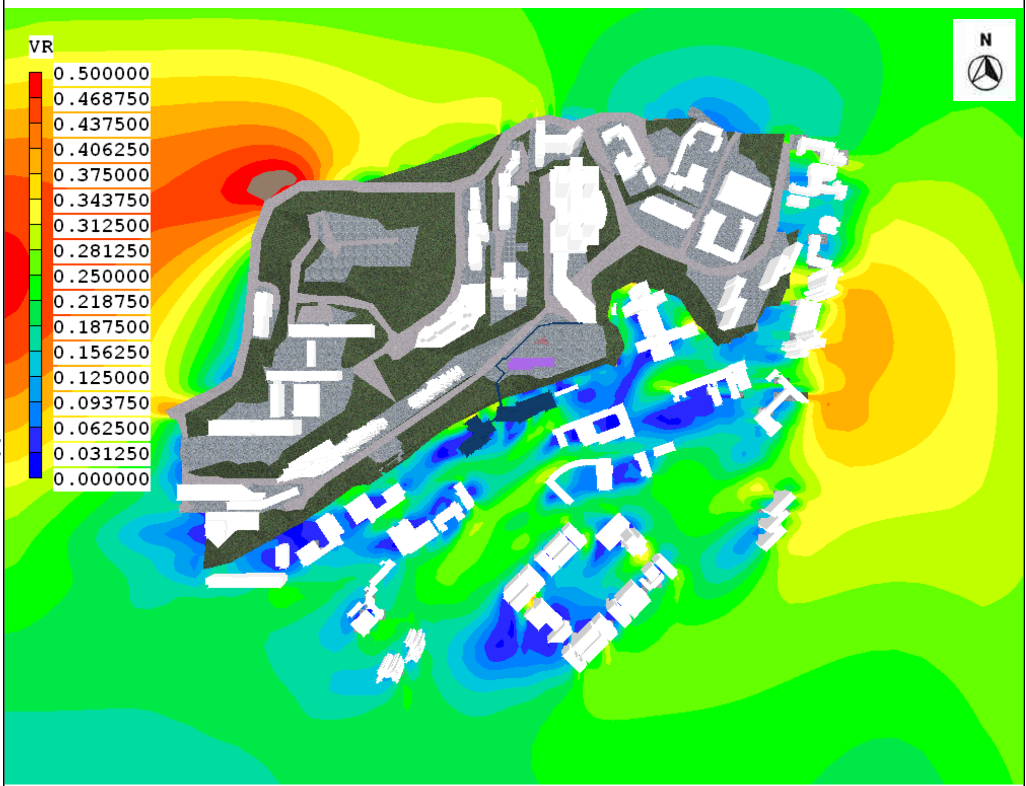

Wind Profile of SE
700
600
500
400
300
200
100
0
Height (m)
596
400
200
100
50
10
SE
0
2
4
6
8
Wind Speed (m/s)

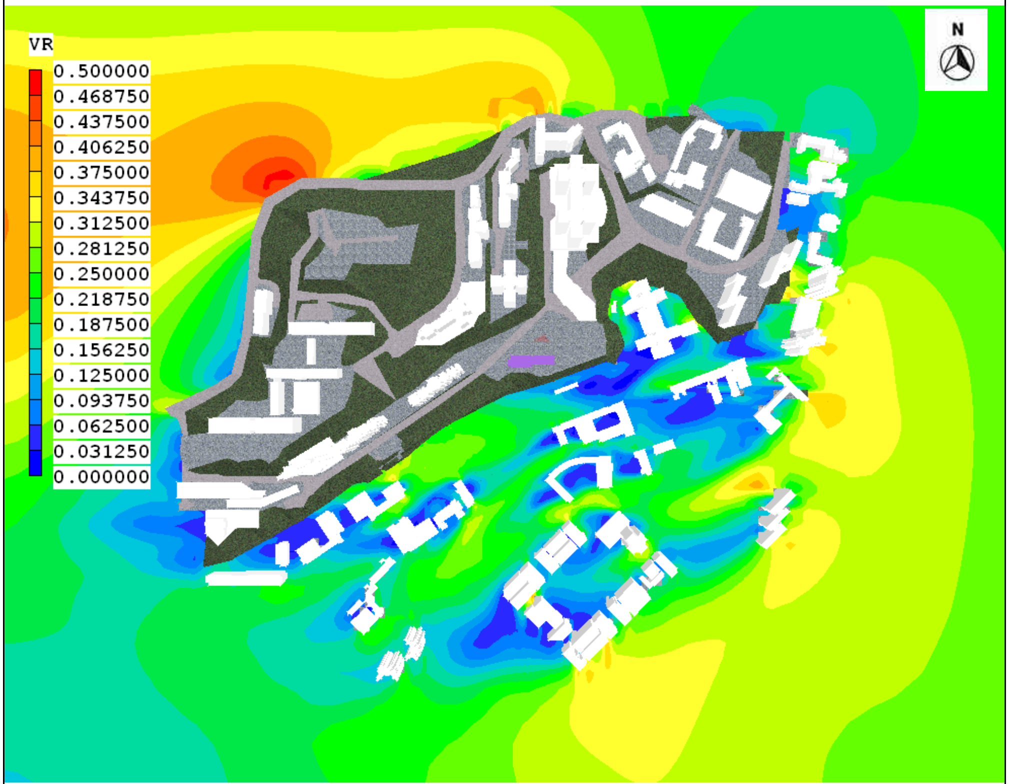
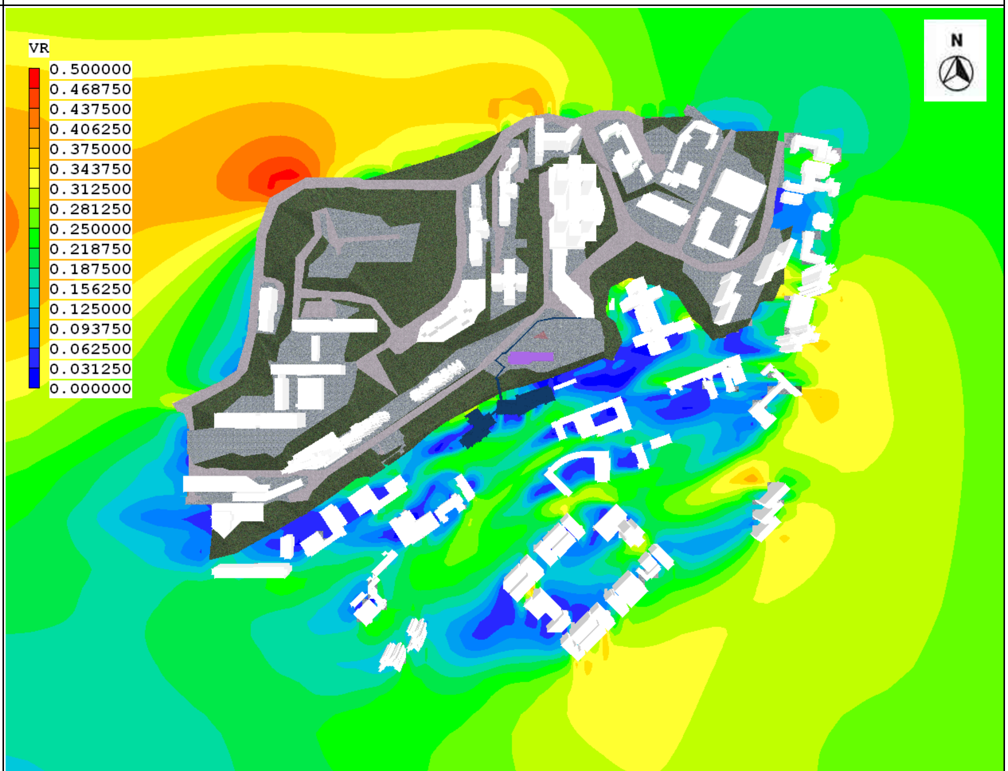

Wind Profile of SSW
700
600
500
400
300
200
100
0
Height (m)
596
400
200
100
50
10
SS...
0
1
2
3
4
5
6
7
Wind Speed (m/s)

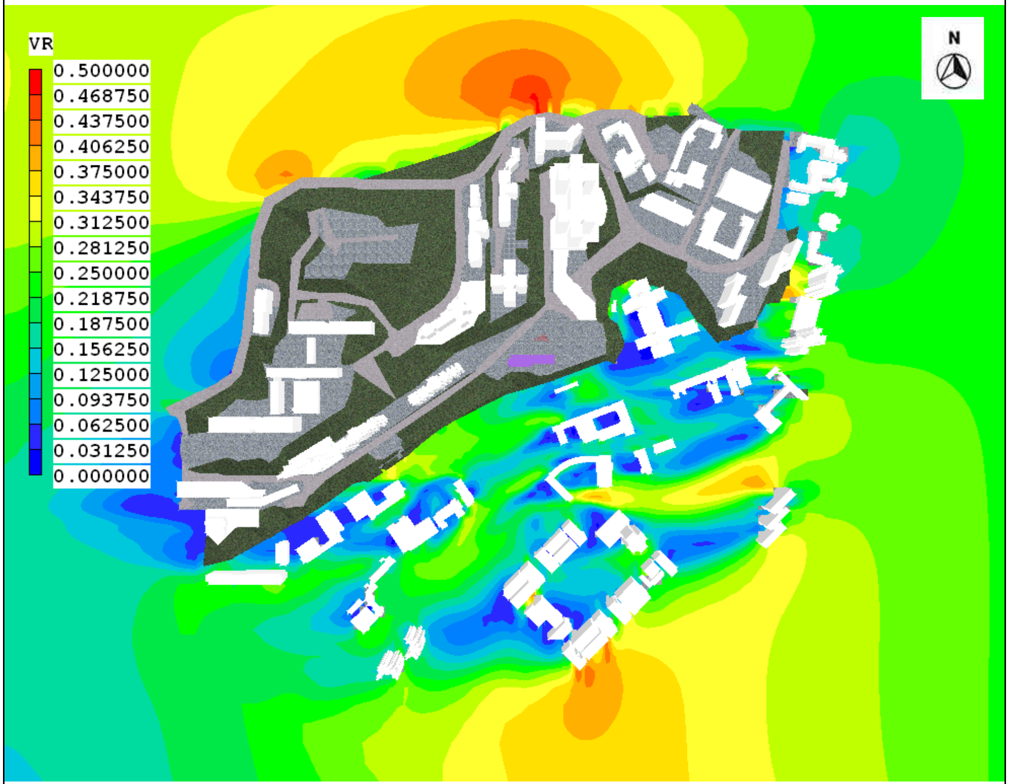
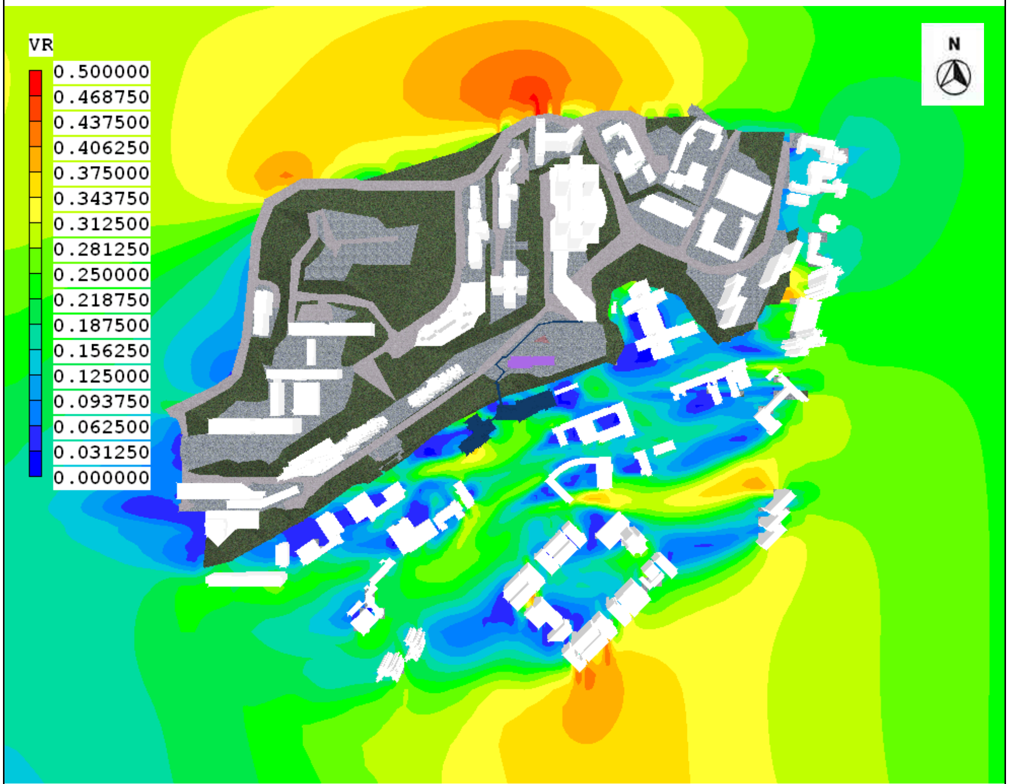
Appendix C

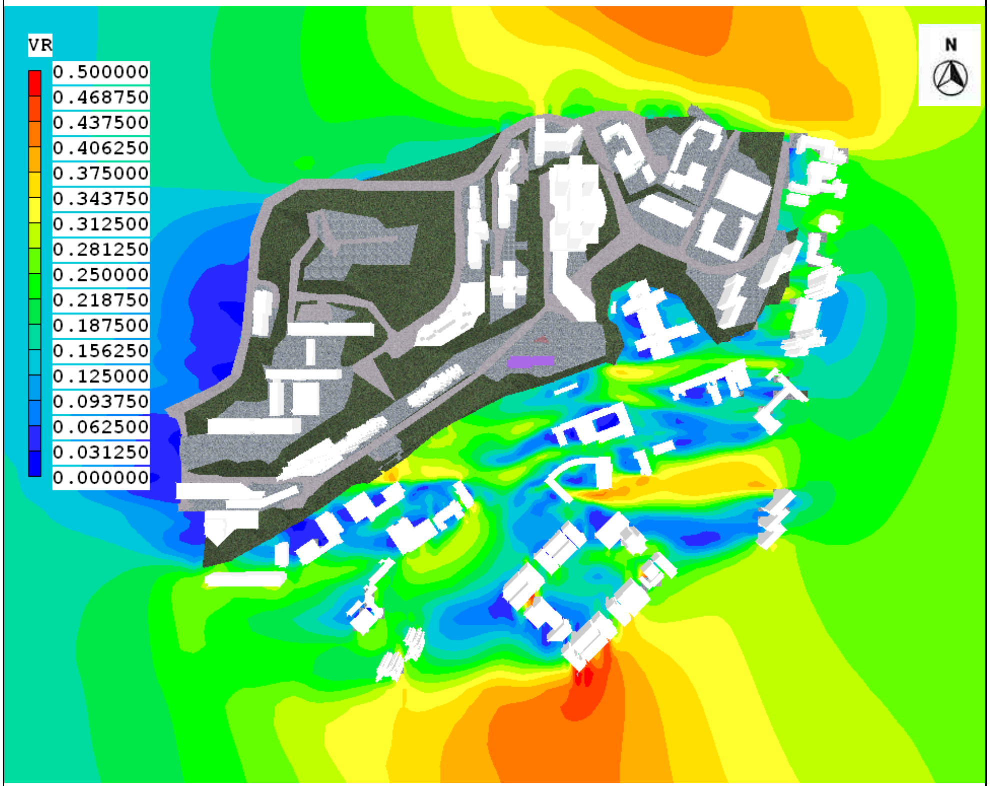
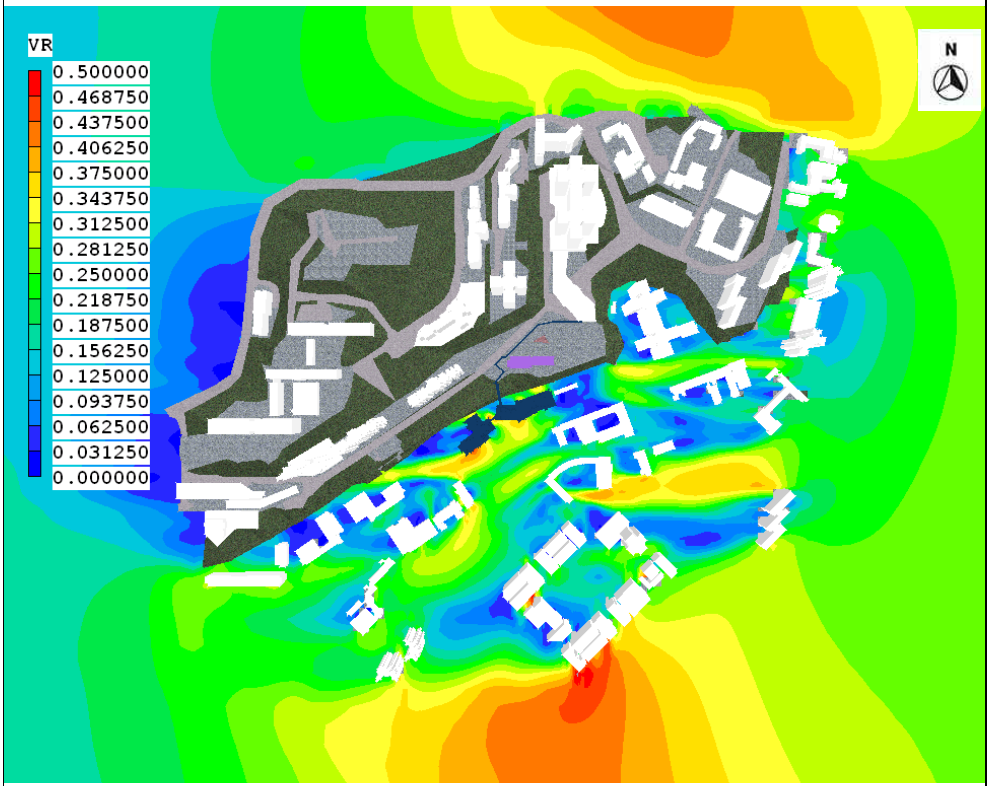
Wind Velocity Ratio Simulation Results

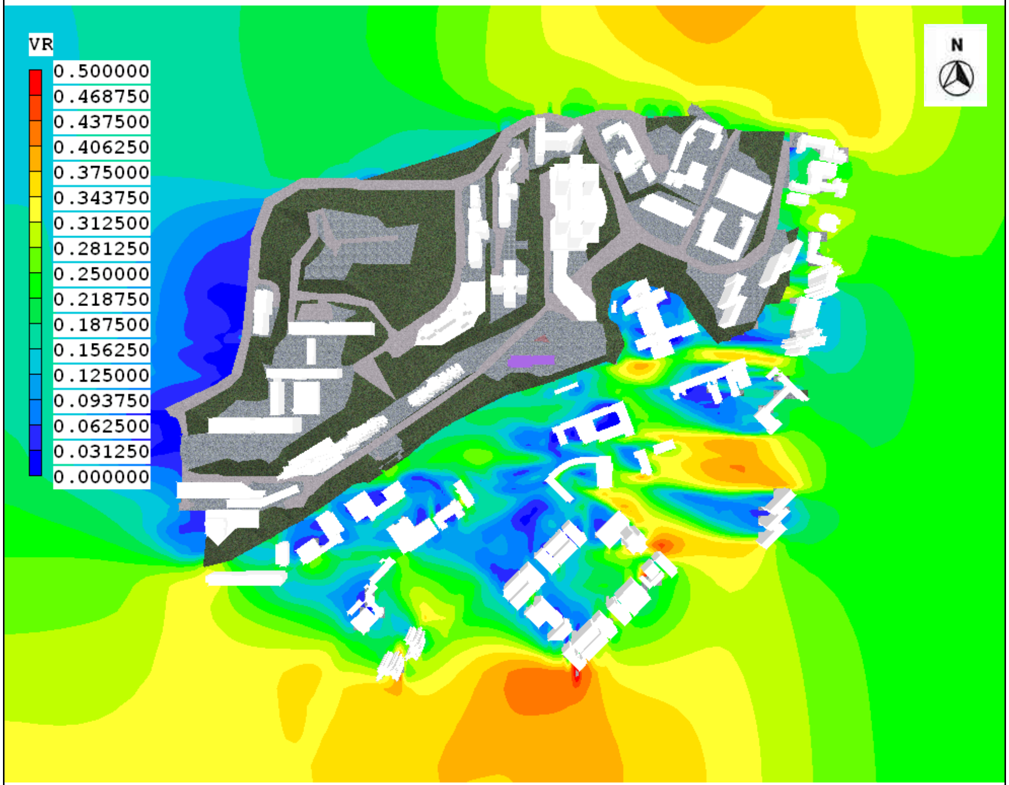
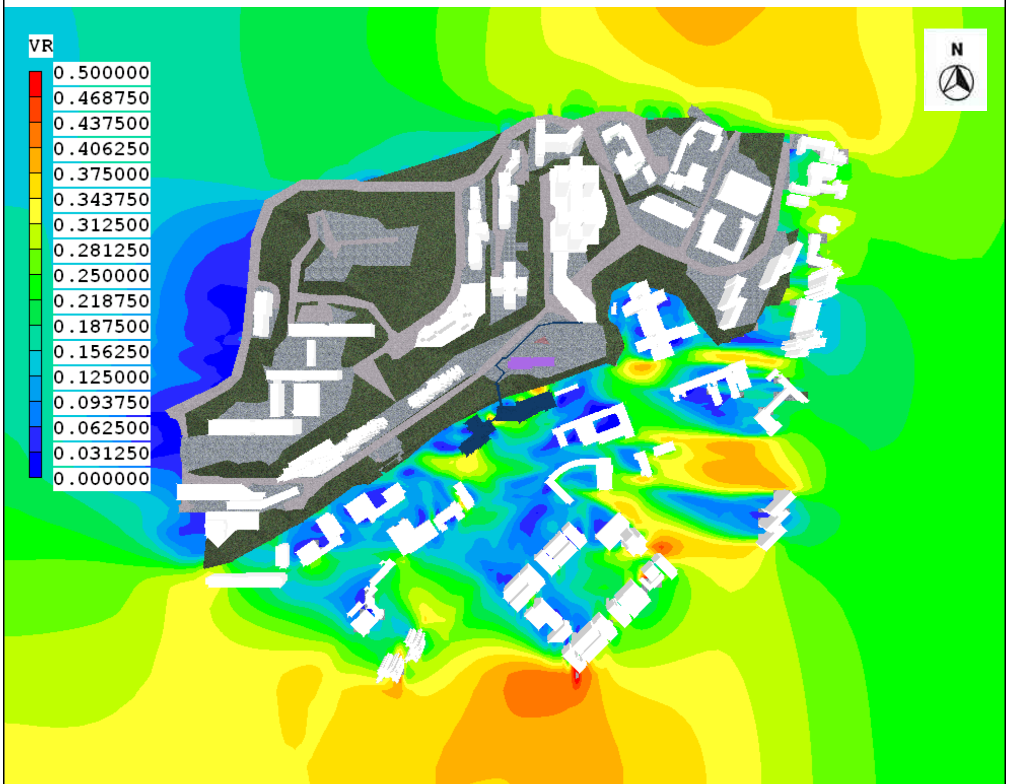
Before and After Construction of Kwai Shing Circuit

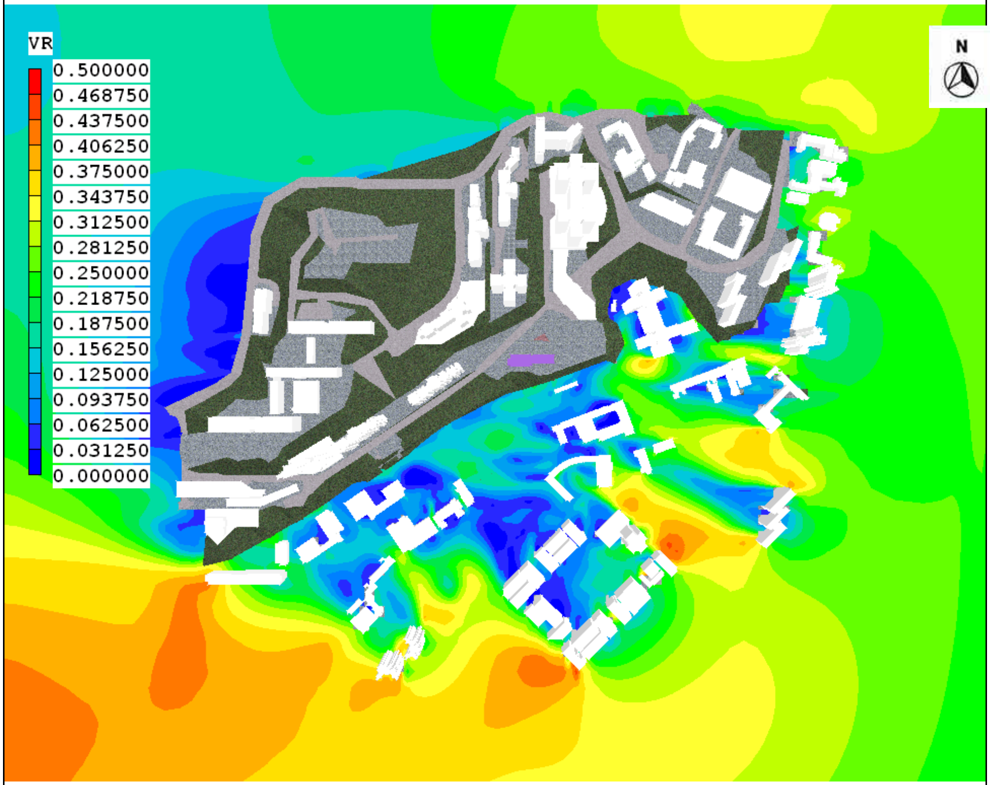
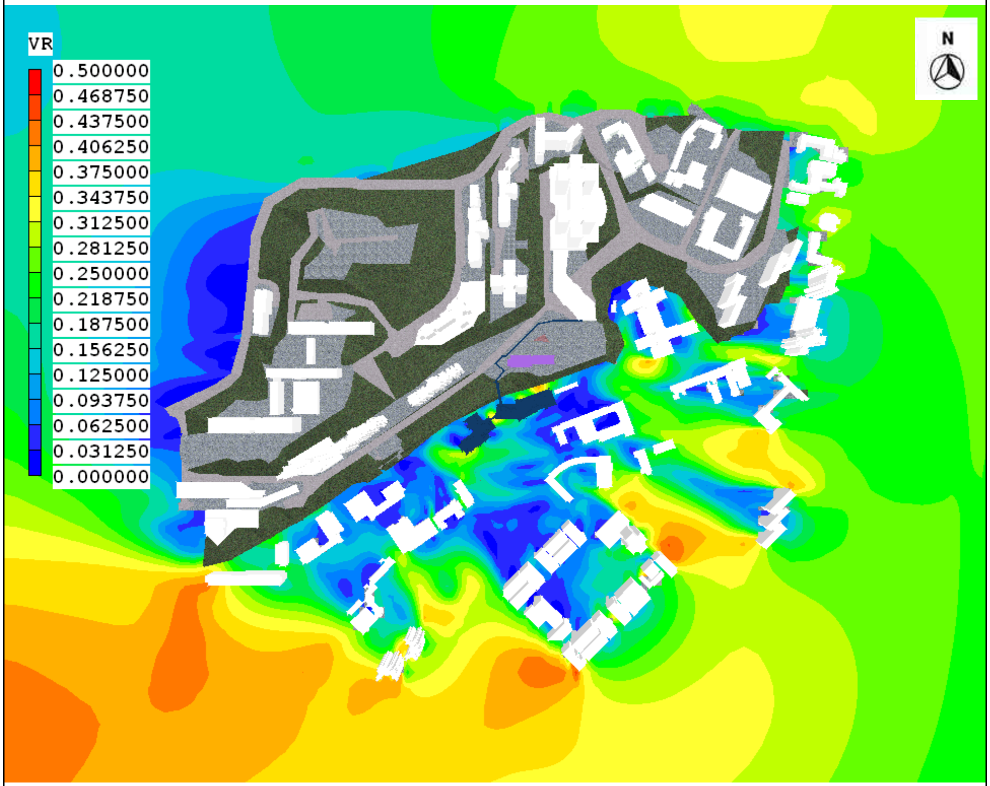
Wind Direction	NNE
Prior to Construction of Kwai Shing Circuit	
Subsequent to Construction of Kwai Shing Circuit	

Wind Direction	NE
Prior to Construction of Kwai Shing Circuit	
Subsequent to Construction of Kwai Shing Circuit	

Wind Direction	ENE
Prior to Construction of Kwai Shing Circuit	
Subsequent to Construction of Kwai Shing Circuit	

Wind Direction	E
Prior to Construction of Kwai Shing Circuit	
Subsequent to Construction of Kwai Shing Circuit	

Wind Direction	ESE
Prior to Construction of Kwai Shing Circuit	
Subsequent to Construction of Kwai Shing Circuit	

Wind Direction	SE
Prior to Construction of Kwai Shing Circuit	
Subsequent to Construction of Kwai Shing Circuit	

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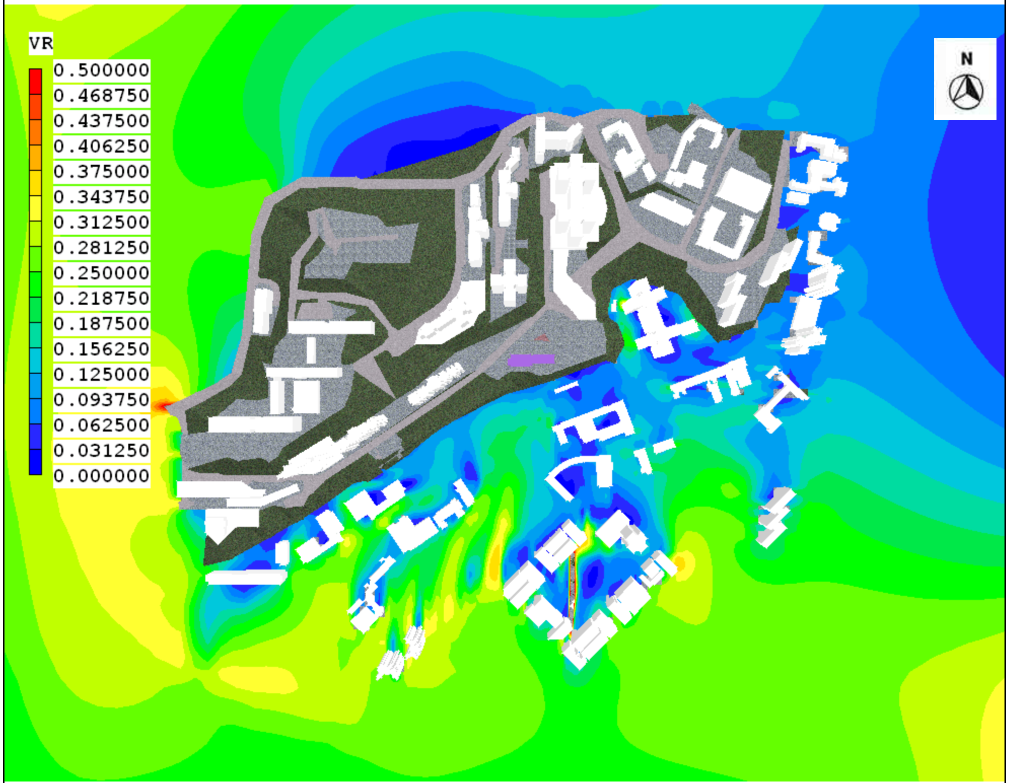
<tr><td>Prior to Construction of Kwai Shing Circuit</td><td>
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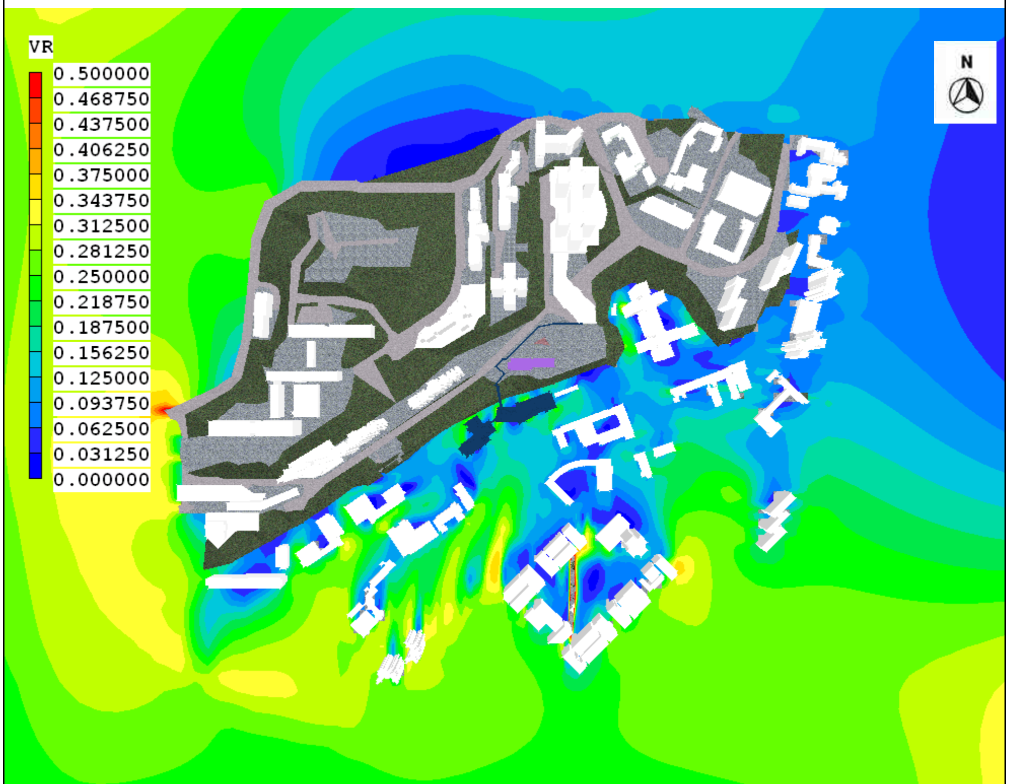
<tr><td>Subsequent to Construction of Kwai Shing Circuit</td><td>
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Wind Velocity Ratio of Perimeter Test Points in NNE direction

NNE Perimeter Test Points				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
P1	0.26	P1	0.24	-0.01
P2	0.20	P2	0.30	0.10
P3	0.20	P3	0.15	-0.05
P4	0.20	P4	0.28	0.08
P5	0.19	P5	0.24	0.05
P6	0.18	P6	0.17	-0.01
P7	0.21	P7	0.11	-0.10
P8	0.21	P8	0.09	-0.12
P9	0.19	P9	0.05	-0.14
P10	0.14	P10	0.05	-0.10
P11	0.19	P11	0.10	-0.09
P12	0.17	P12	0.12	-0.05
P13	0.15	P13	0.18	0.03
P14	0.15	P14	0.24	0.09
P15	0.17	P15	0.26	0.09
P16	0.18	P16	0.23	0.05
P17	0.20	P17	0.12	-0.07
P18	0.22	P18	0.04	-0.19
P19	0.24	P19	0.08	-0.16
P20	0.24	P20	0.05	-0.20
P21	0.25	P21	0.07	-0.18
P22	0.25	P22	0.16	-0.09
P23	0.25	P23	0.21	-0.05
P24	0.25	P24	0.22	-0.03
P25	0.25	P25	0.21	-0.05
P26	0.25	P26	0.06	-0.19
P27	0.25	P27	0.04	-0.21
P28	0.23	P28	0.02	-0.21
P29	0.22	P29	0.17	-0.05
P30	0.22	P30	0.23	0.01
Average	**0.21**	**Average**	**0.15**	**-0.06**
Max	0.26		0.30	
Min	0.14		0.02	

Wind Velocity Ratio of Special Test Points in NNE direction

NNE Special Test Points				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
S1	0.25	S1	0.04	-0.21
S2	0.23	S2	0.10	-0.13
Average	**0.24**	**Average**	**0.07**	**-0.17**
Max	0.25		0.10	
Min	0.23		0.04	

Wind Velocity Ratio of Local Test Points in NNE direction

NNE Local Test Points				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
L1	0.15	L1	0.16	0.01
L2	0.14	L2	0.10	-0.04
L3	0.26	L3	0.26	0.00
L4	0.10	L4	0.19	0.09
L5	0.12	L5	0.13	0.01
L6	0.22	L6	0.18	-0.05
L7	0.14	L7	0.09	-0.05
L8	0.25	L8	0.19	-0.05
L9	0.18	L9	0.17	-0.01
L10	0.15	L10	0.25	0.09
L11	0.18	L11	0.13	-0.06
L12	0.24	L12	0.18	-0.06
L13	0.29	L13	0.30	0.02
L14	0.26	L14	0.21	-0.05
L15	0.13	L15	0.12	-0.01
L16	0.20	L16	0.11	-0.09
L17	0.23	L17	0.27	0.04
L18	0.28	L18	0.23	-0.05
L19	0.25	L19	0.20	-0.05
L20	0.25	L20	0.22	-0.03
L21	0.13	L21	0.11	-0.02
L22	0.05	L22	0.07	0.02
L23	0.09	L23	0.19	0.10
L24	0.04	L24	0.15	0.11
L25	0.19	L25	0.27	0.08
L26	0.10	L26	0.21	0.11
L27	0.05	L27	0.07	0.02
L28	0.17	L28	0.13	-0.04
L29	0.12	L29	0.16	0.04
L30	0.25	L30	0.18	-0.07
L31	0.27	L31	0.22	-0.06
L32	0.12	L32	0.13	0.01
L33	0.11	L33	0.16	0.05
L34	0.12	L34	0.13	0.01
L35	0.30	L35	0.25	-0.04
L36	0.24	L36	0.06	-0.18
Average	**0.18**	**Average**	**0.17**	**-0.01**
Max	0.30		0.30	
Min	0.04		0.06	

Wind Velocity Ratio of Perimeter Test Points in NE direction

NE Perimeter Test Points				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
P1	0.29	P1	0.22	-0.07
P2	0.23	P2	0.27	0.05
P3	0.22	P3	0.18	-0.05
P4	0.21	P4	0.24	0.02
P5	0.19	P5	0.19	0.00
P6	0.15	P6	0.17	0.01
P7	0.15	P7	0.12	-0.04
P8	0.13	P8	0.13	-0.01
P9	0.11	P9	0.11	0.00
P10	0.12	P10	0.07	-0.04
P11	0.12	P11	0.07	-0.06
P12	0.14	P12	0.12	-0.02
P13	0.17	P13	0.21	0.04
P14	0.18	P14	0.23	0.05
P15	0.19	P15	0.21	0.03
P16	0.19	P16	0.12	-0.07
P17	0.20	P17	0.11	-0.08
P18	0.22	P18	0.09	-0.12
P19	0.23	P19	0.12	-0.12
P20	0.24	P20	0.07	-0.17
P21	0.25	P21	0.14	-0.11
P22	0.26	P22	0.23	-0.03
P23	0.26	P23	0.26	0.00
P24	0.26	P24	0.27	0.01
P25	0.27	P25	0.25	-0.01
P26	0.27	P26	0.05	-0.22
P27	0.27	P27	0.04	-0.23
P28	0.25	P28	0.04	-0.21
P29	0.24	P29	0.18	-0.05
P30	0.25	P30	0.21	-0.04
Average	**0.21**	**Average**	**0.16**	**-0.05**
Max	0.29		0.27	
Min	0.11		0.04	

Wind Velocity Ratio of Special Test Points in NE direction

NE Special Test Points				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
S1	0.25	S1	0.07	-0.18
S2	0.22	S2	0.08	-0.15
Average	**0.24**	**Average**	**0.07**	**-0.17**
Max	0.25		0.08	
Min	0.22		0.07	

Wind Velocity Ratio of Local Test Points in NE direction

NE Local Test Points				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
L1	0.19	L1	0.18	-0.01
L2	0.10	L2	0.02	-0.07
L3	0.28	L3	0.28	0.00
L4	0.13	L4	0.22	0.09
L5	0.12	L5	0.10	-0.01
L6	0.21	L6	0.19	-0.02
L7	0.10	L7	0.05	-0.06
L8	0.21	L8	0.20	0.00
L9	0.22	L9	0.19	-0.03
L10	0.20	L10	0.25	0.05
L11	0.18	L11	0.13	-0.05
L12	0.22	L12	0.20	-0.01
L13	0.30	L13	0.29	-0.01
L14	0.19	L14	0.18	-0.01
L15	0.11	L15	0.07	-0.04
L16	0.13	L16	0.05	-0.08
L17	0.28	L17	0.26	-0.02
L18	0.24	L18	0.19	-0.05
L19	0.19	L19	0.15	-0.04
L20	0.21	L20	0.13	-0.07
L21	0.03	L21	0.10	0.07
L22	0.12	L22	0.17	0.05
L23	0.10	L23	0.24	0.13
L24	0.08	L24	0.14	0.06
L25	0.20	L25	0.21	0.01
L26	0.09	L26	0.21	0.13
L27	0.04	L27	0.05	0.01
L28	0.17	L28	0.15	-0.02
L29	0.11	L29	0.15	0.03
L30	0.26	L30	0.24	-0.02
L31	0.27	L31	0.25	-0.02
L32	0.11	L32	0.12	0.01
L33	0.10	L33	0.16	0.06
L34	0.11	L34	0.12	0.01
L35	0.28	L35	0.24	-0.04
L36	0.26	L36	0.06	-0.20
Average	**0.17**	**Average**	**0.17**	**0.00**
Max	0.30		0.29	
Min	0.03		0.02	

Wind Velocity Ratio of Perimeter Test Points in ENE direction

ENE Perimeter Test Points				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
P1	0.30	P1	0.19	-0.11
P2	0.23	P2	0.24	0.02
P3	0.22	P3	0.14	-0.08
P4	0.22	P4	0.05	-0.16
P5	0.19	P5	0.02	-0.18
P6	0.18	P6	0.16	-0.01
P7	0.16	P7	0.16	0.00
P8	0.16	P8	0.08	-0.08
P9	0.15	P9	0.21	0.06
P10	0.13	P10	0.20	0.08
P11	0.09	P11	0.14	0.05
P12	0.10	P12	0.07	-0.03
P13	0.14	P13	0.17	0.04
P14	0.17	P14	0.24	0.08
P15	0.18	P15	0.28	0.10
P16	0.21	P16	0.27	0.07
P17	0.23	P17	0.25	0.02
P18	0.24	P18	0.25	0.01
P19	0.25	P19	0.23	-0.02
P20	0.25	P20	0.11	-0.14
P21	0.25	P21	0.16	-0.09
P22	0.25	P22	0.28	0.03
P23	0.24	P23	0.32	0.08
P24	0.23	P24	0.33	0.09
P25	0.25	P25	0.33	0.08
P26	0.27	P26	0.08	-0.19
P27	0.27	P27	0.07	-0.20
P28	0.27	P28	0.04	-0.23
P29	0.25	P29	0.15	-0.10
P30	0.26	P30	0.19	-0.07
Average	**0.21**	**Average**	**0.18**	**-0.03**
Max	0.30		0.33	
Min	0.09		0.02	

Wind Velocity Ratio of Special Test Points in ENE direction

ENE Special Test Points				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
S1	0.25	S1	0.09	-0.16
S2	0.22	S2	0.06	-0.17
Average	**0.24**	**Average**	**0.07**	**-0.17**
Max	0.25		0.09	
Min	0.22		0.06	

Wind Velocity Ratio of Local Test Points in ENE direction

ENE Local Test Points				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
L1	0.29	L1	0.22	-0.07
L2	0.22	L2	0.03	-0.19
L3	0.30	L3	0.28	-0.02
L4	0.25	L4	0.28	0.03
L5	0.23	L5	0.17	-0.06
L6	0.19	L6	0.24	0.05
L7	0.25	L7	0.22	-0.03
L8	0.15	L8	0.23	0.08
L9	0.19	L9	0.19	0.00
L10	0.25	L10	0.30	0.05
L11	0.12	L11	0.17	0.04
L12	0.18	L12	0.21	0.04
L13	0.18	L13	0.24	0.06
L14	0.05	L14	0.15	0.09
L15	0.10	L15	0.15	0.05
L16	0.12	L16	0.02	-0.10
L17	0.19	L17	0.21	0.02
L18	0.22	L18	0.15	-0.08
L19	0.17	L19	0.06	-0.11
L20	0.15	L20	0.05	-0.11
L21	0.09	L21	0.15	0.06
L22	0.19	L22	0.20	0.01
L23	0.15	L23	0.30	0.15
L24	0.15	L24	0.11	-0.04
L25	0.25	L25	0.27	0.01
L26	0.11	L26	0.25	0.15
L27	0.15	L27	0.04	-0.11
L28	0.14	L28	0.16	0.02
L29	0.18	L29	0.14	-0.04
L30	0.17	L30	0.28	0.11
L31	0.25	L31	0.26	0.01
L32	0.12	L32	0.13	0.01
L33	0.12	L33	0.16	0.04
L34	0.13	L34	0.13	-0.01
L35	0.19	L35	0.23	0.04
L36	0.23	L36	0.04	-0.19
Average	**0.18**	**Average**	**0.18**	**0.00**
Max	0.30		0.30	
Min	0.05		0.02	

Wind Velocity Ratio of Perimeter Test Points in E direction

E Perimeter Test Points				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
P1	0.28	P1	0.12	-0.16
P2	0.24	P2	0.31	0.07
P3	0.22	P3	0.25	0.03
P4	0.20	P4	0.12	-0.08
P5	0.20	P5	0.04	-0.16
P6	0.18	P6	0.14	-0.04
P7	0.17	P7	0.26	0.09
P8	0.17	P8	0.09	-0.09
P9	0.17	P9	0.26	0.09
P10	0.14	P10	0.29	0.15
P11	0.12	P11	0.18	0.06
P12	0.16	P12	0.12	-0.04
P13	0.19	P13	0.20	0.01
P14	0.21	P14	0.19	-0.01
P15	0.21	P15	0.21	0.00
P16	0.23	P16	0.21	-0.02
P17	0.25	P17	0.19	-0.06
P18	0.28	P18	0.18	-0.10
P19	0.29	P19	0.21	-0.08
P20	0.25	P20	0.19	-0.06
P21	0.22	P21	0.22	0.00
P22	0.21	P22	0.34	0.13
P23	0.21	P23	0.40	0.18
P24	0.22	P24	0.40	0.18
P25	0.24	P25	0.40	0.16
P26	0.25	P26	0.14	-0.11
P27	0.25	P27	0.12	-0.14
P28	0.29	P28	0.07	-0.22
P29	0.29	P29	0.11	-0.19
P30	0.28	P30	0.21	-0.06
Average	**0.22**	**Average**	**0.21**	**-0.01**
Max	0.29		0.40	
Min	0.12		0.04	

Wind Velocity Ratio of Special Test Points in E direction

E Special Test Points				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
S1	0.24	S1	0.10	-0.14
S2	0.26	S2	0.08	-0.18
Average	**0.25**	**Average**	**0.09**	**-0.16**
Max	0.26		0.10	
Min	0.24		0.08	

Wind Velocity Ratio of Local Test Points in E direction

E Local Test Points				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
L1	0.35	L1	0.12	-0.24
L2	0.34	L2	0.31	-0.03
L3	0.29	L3	0.25	-0.04
L4	0.24	L4	0.12	-0.12
L5	0.20	L5	0.04	-0.16
L6	0.20	L6	0.14	-0.06
L7	0.40	L7	0.26	-0.14
L8	0.14	L8	0.09	-0.06
L9	0.17	L9	0.26	0.09
L10	0.30	L10	0.29	-0.01
L11	0.25	L11	0.18	-0.06
L12	0.22	L12	0.12	-0.10
L13	0.08	L13	0.20	0.13
L14	0.13	L14	0.19	0.06
L15	0.16	L15	0.21	0.04
L16	0.06	L16	0.21	0.15
L17	0.06	L17	0.19	0.13
L18	0.04	L18	0.18	0.14
L19	0.08	L19	0.21	0.13
L20	0.09	L20	0.19	0.11
L21	0.12	L21	0.22	0.10
L22	0.16	L22	0.34	0.18
L23	0.17	L23	0.40	0.23
L24	0.15	L24	0.40	0.25
L25	0.27	L25	0.40	0.14
L26	0.20	L26	0.14	-0.05
L27	0.13	L27	0.12	-0.01
L28	0.10	L28	0.07	-0.03
L29	0.14	L29	0.11	-0.03
L30	0.21	L30	0.21	0.00
L31	0.32	L31	0.18	-0.14
L32	0.09	L32	0.20	0.11
L33	0.13	L33	0.19	0.07
L34	0.17	L34	0.27	0.11
L35	0.12	L35	0.15	0.04
L36	0.29	L36	0.25	-0.04
Average	**0.18**	**Average**	**0.21**	**0.03**
Max	0.40		0.40	
Min	0.04		0.04	

Wind Velocity Ratio of Perimeter Test Points in ESE direction

ESE Perimeter Test Points				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
P1	0.22	P1	0.14	-0.08
P2	0.19	P2	0.23	0.04
P3	0.20	P3	0.24	0.04
P4	0.19	P4	0.17	-0.02
P5	0.18	P5	0.04	-0.14
P6	0.17	P6	0.15	-0.02
P7	0.19	P7	0.36	0.18
P8	0.20	P8	0.10	-0.10
P9	0.19	P9	0.28	0.08
P10	0.17	P10	0.31	0.15
P11	0.14	P11	0.24	0.10
P12	0.18	P12	0.10	-0.08
P13	0.22	P13	0.08	-0.14
P14	0.22	P14	0.10	-0.12
P15	0.22	P15	0.17	-0.05
P16	0.22	P16	0.21	0.00
P17	0.21	P17	0.22	0.01
P18	0.17	P18	0.21	0.04
P19	0.14	P19	0.18	0.03
P20	0.17	P20	0.09	-0.08
P21	0.22	P21	0.14	-0.07
P22	0.25	P22	0.25	0.01
P23	0.28	P23	0.33	0.05
P24	0.27	P24	0.33	0.06
P25	0.26	P25	0.35	0.09
P26	0.25	P26	0.16	-0.09
P27	0.24	P27	0.14	-0.11
P28	0.19	P28	0.09	-0.10
P29	0.18	P29	0.16	-0.02
P30	0.19	P30	0.21	0.02
Average	**0.20**	**Average**	**0.19**	**-0.01**
Max	0.28		0.36	
Min	0.14		0.04	

Wind Velocity Ratio of Special Test Points in ESE direction

ESE Special Test Points				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
S1	0.19	S1	0.06	-0.13
S2	0.17	S2	0.06	-0.11
Average	**0.18**	**Average**	**0.06**	**-0.12**
Max	0.19		0.06	
Min	0.17		0.06	

Wind Velocity Ratio of Local Test Points in ESE direction

ESE Local Test Point				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
L1	0.10	L1	0.06	-0.04
L2	0.34	L2	0.21	-0.13
L3	0.18	L3	0.06	-0.12
L4	0.13	L4	0.19	0.06
L5	0.23	L5	0.13	-0.10
L6	0.17	L6	0.22	0.05
L7	0.35	L7	0.34	-0.01
L8	0.14	L8	0.22	0.09
L9	0.23	L9	0.16	-0.07
L10	0.28	L10	0.30	0.02
L11	0.21	L11	0.26	0.05
L12	0.21	L12	0.25	0.04
L13	0.12	L13	0.13	0.01
L14	0.15	L14	0.24	0.09
L15	0.15	L15	0.28	0.13
L16	0.13	L16	0.33	0.20
L17	0.15	L17	0.12	-0.03
L18	0.13	L18	0.22	0.09
L19	0.24	L19	0.33	0.10
L20	0.27	L20	0.35	0.08
L21	0.14	L21	0.24	0.10
L22	0.24	L22	0.28	0.04
L23	0.16	L23	0.24	0.07
L24	0.13	L24	0.11	-0.02
L25	0.21	L25	0.16	-0.05
L26	0.14	L26	0.24	0.10
L27	0.02	L27	0.05	0.02
L28	0.20	L28	0.17	-0.03
L29	0.03	L29	0.06	0.03
L30	0.25	L30	0.25	0.00
L31	0.20	L31	0.28	0.08
L32	0.16	L32	0.17	0.01
L33	0.04	L33	0.04	0.01
L34	0.16	L34	0.17	0.01
L35	0.14	L35	0.15	0.01
L36	0.21	L36	0.25	0.04
Average	**0.17**	**Average**	**0.20**	**0.03**
Max	0.35		0.35	
Min	0.02		0.04	

Wind Velocity Ratio of Perimeter Test Points in SE direction

SE Perimeter Test Point				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
P1	0.14	P1	0.13	-0.01
P2	0.09	P2	0.19	0.10
P3	0.10	P3	0.22	0.11
P4	0.14	P4	0.19	0.05
P5	0.15	P5	0.02	-0.13
P6	0.14	P6	0.08	-0.06
P7	0.16	P7	0.35	0.19
P8	0.17	P8	0.09	-0.07
P9	0.17	P9	0.26	0.09
P10	0.16	P10	0.32	0.16
P11	0.12	P11	0.22	0.10
P12	0.14	P12	0.09	-0.05
P13	0.14	P13	0.06	-0.09
P14	0.13	P14	0.07	-0.06
P15	0.14	P15	0.08	-0.06
P16	0.13	P16	0.10	-0.03
P17	0.11	P17	0.16	0.05
P18	0.12	P18	0.11	-0.01
P19	0.19	P19	0.14	-0.05
P20	0.21	P20	0.04	-0.17
P21	0.21	P21	0.10	-0.11
P22	0.19	P22	0.20	0.02
P23	0.15	P23	0.29	0.14
P24	0.15	P24	0.29	0.13
P25	0.17	P25	0.31	0.14
P26	0.16	P26	0.22	0.07
P27	0.15	P27	0.15	-0.01
P28	0.14	P28	0.10	-0.04
P29	0.13	P29	0.12	0.00
P30	0.12	P30	0.17	0.06
Average	**0.15**	**Average**	**0.16**	**0.01**
Max	0.21		0.35	
Min	0.09		0.02	

Wind Velocity Ratio of Special Test Points in SE direction

SE Special Test Point				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
S1	0.20	S1	0.07	-0.13
S2	0.14	S2	0.05	-0.09
Average	**0.17**	**Average**	**0.06**	**-0.11**
Max	0.20		0.07	
Min	0.14		0.05	

Wind Velocity Ratio of Local Test Points in SE direction

SE Local Test Point				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
L1	0.05	L1	0.07	0.02
L2	0.28	L2	0.17	-0.11
L3	0.14	L3	0.04	-0.10
L4	0.09	L4	0.12	0.03
L5	0.27	L5	0.07	-0.20
L6	0.13	L6	0.17	0.03
L7	0.30	L7	0.27	-0.02
L8	0.07	L8	0.17	0.10
L9	0.21	L9	0.15	-0.06
L10	0.24	L10	0.20	-0.04
L11	0.18	L11	0.26	0.07
L12	0.17	L12	0.20	0.03
L13	0.12	L13	0.13	0.01
L14	0.12	L14	0.20	0.08
L15	0.14	L15	0.21	0.07
L16	0.11	L16	0.26	0.15
L17	0.18	L17	0.16	-0.02
L18	0.13	L18	0.20	0.07
L19	0.17	L19	0.27	0.10
L20	0.19	L20	0.26	0.07
L21	0.09	L21	0.14	0.05
L22	0.23	L22	0.25	0.02
L23	0.12	L23	0.15	0.03
L24	0.10	L24	0.10	0.00
L25	0.09	L25	0.04	-0.05
L26	0.08	L26	0.21	0.12
L27	0.04	L27	0.04	0.00
L28	0.11	L28	0.08	-0.03
L29	0.04	L29	0.05	0.02
L30	0.18	L30	0.21	0.03
L31	0.15	L31	0.25	0.11
L32	0.19	L32	0.12	-0.07
L33	0.02	L33	0.03	0.01
L34	0.19	L34	0.12	-0.07
L35	0.14	L35	0.14	0.00
L36	0.15	L36	0.28	0.14
Average	**0.14**	**Average**	**0.16**	**0.02**
Max	0.30		0.28	
Min	0.02		0.03	

Wind Velocity Ratio of Perimeter Test Points in SSW direction

SSW Perimeter Test Point				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
P1	0.13	P1	0.21	0.08
P2	0.11	P2	0.30	0.19
P3	0.13	P3	0.24	0.11
P4	0.14	P4	0.16	0.02
P5	0.13	P5	0.18	0.05
P6	0.11	P6	0.14	0.03
P7	0.11	P7	0.22	0.11
P8	0.10	P8	0.03	-0.08
P9	0.10	P9	0.06	-0.04
P10	0.10	P10	0.15	0.06
P11	0.09	P11	0.12	0.03
P12	0.10	P12	0.10	-0.01
P13	0.12	P13	0.22	0.10
P14	0.13	P14	0.20	0.06
P15	0.14	P15	0.20	0.07
P16	0.17	P16	0.11	-0.06
P17	0.17	P17	0.19	0.02
P18	0.18	P18	0.10	-0.08
P19	0.19	P19	0.09	-0.10
P20	0.19	P20	0.05	-0.14
P21	0.19	P21	0.10	-0.09
P22	0.18	P22	0.09	-0.09
P23	0.13	P23	0.09	-0.05
P24	0.11	P24	0.11	0.00
P25	0.08	P25	0.12	0.04
P26	0.10	P26	0.17	0.06
P27	0.11	P27	0.20	0.09
P28	0.12	P28	0.20	0.07
P29	0.11	P29	0.17	0.06
P30	0.10	P30	0.17	0.07
Average	**0.13**	**Average**	**0.15**	**0.02**
Max	0.19		0.30	
Min	0.08		0.03	

Wind Velocity Ratio of Special Test Points in SSW direction

SSW Special Test Point				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
S1	0.18	S1	0.04	-0.14
S2	0.17	S2	0.05	-0.12
Average	**0.18**	**Average**	**0.05**	**-0.13**
Max	0.18		0.05	
Min	0.17		0.04	

Wind Velocity Ratio of Local Test Points in SSW direction

SSW Local Test Point				VR difference
Before Development		After Development		
Test Point	Velocity Ratio	Test Point	Velocity Ratio	
L1	0.05	L1	0.08	0.04
L2	0.26	L2	0.26	0.00
L3	0.17	L3	0.17	0.00
L4	0.10	L4	0.19	0.10
L5	0.34	L5	0.33	-0.01
L6	0.20	L6	0.16	-0.04
L7	0.22	L7	0.10	-0.12
L8	0.19	L8	0.14	-0.05
L9	0.25	L9	0.17	-0.08
L10	0.22	L10	0.20	-0.02
L11	0.09	L11	0.07	-0.02
L12	0.16	L12	0.12	-0.04
L13	0.12	L13	0.09	-0.03
L14	0.03	L14	0.06	0.03
L15	0.10	L15	0.10	0.00
L16	0.11	L16	0.12	0.01
L17	0.18	L17	0.17	-0.01
L18	0.10	L18	0.12	0.02
L19	0.14	L19	0.15	0.01
L20	0.16	L20	0.18	0.03
L21	0.08	L21	0.09	0.01
L22	0.12	L22	0.10	-0.02
L23	0.04	L23	0.11	0.08
L24	0.03	L24	0.08	0.05
L25	0.18	L25	0.15	-0.03
L26	0.10	L26	0.15	0.05
L27	0.06	L27	0.11	0.04
L28	0.14	L28	0.09	-0.05
L29	0.06	L29	0.06	0.00
L30	0.18	L30	0.08	-0.09
L31	0.14	L31	0.10	-0.03
L32	0.18	L32	0.11	-0.07
L33	0.08	L33	0.14	0.06
L34	0.18	L34	0.11	-0.07
L35	0.17	L35	0.21	0.04
L36	0.13	L36	0.14	0.02
Average	**0.14**	**Average**	**0.13**	**-0.01**
Max	0.34		0.33	
Min	0.03		0.06	

Weighted Velocity of Perimeter Test Point for all 7 Prevailing Wind Directions

(NNE, NE, ENE, E, ESE, SE and SSW)

Test Points	Before Development	After Development	VR difference
	Velocity Ratio	Velocity Ratio	
P1	0.25	0.18	-0.08
P2	0.20	0.27	0.07
P3	0.20	0.20	0.00
P4	0.19	0.16	-0.03
P5	0.18	0.09	-0.09
P6	0.16	0.15	-0.01
P7	0.17	0.21	0.05
P8	0.16	0.09	-0.07
P9	0.15	0.18	0.03
P10	0.13	0.20	0.07
P11	0.12	0.15	0.03
P12	0.14	0.10	-0.04
P13	0.16	0.17	0.00
P14	0.18	0.19	0.02
P15	0.19	0.21	0.03
P16	0.20	0.19	0.00
P17	0.21	0.18	-0.02
P18	0.22	0.15	-0.06
P19	0.23	0.16	-0.07
P20	0.23	0.10	-0.13
P21	0.23	0.15	-0.08
P22	0.23	0.24	0.01
P23	0.23	0.29	0.06
P24	0.22	0.30	0.08
P25	0.23	0.30	0.07
P26	0.24	0.11	-0.12
P27	0.24	0.10	-0.14
P28	0.23	0.07	-0.17
P29	0.22	0.15	-0.07
P30	0.22	0.20	-0.02
Weighted average	**0.20**	**0.18**	**-0.02**

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

Test Points	Before Development	After Development	VR difference
	Velocity Ratio	Velocity Ratio	
S1	0.23	0.07	-0.16
S2	0.21	0.07	-0.14
Weighted average	**0.22**	**0.07**	**-0.15**

Weighted Velocity Ratio of Local Test Points for all 7 Prevailing Wind Directions

(NNE, NE, ENE, E, ESE, SE and SSW)

Test Points	Before Development	After Development	VR difference
	Velocity Ratio	Velocity Ratio	
L1	0.21	0.14	-0.07
L2	0.24	0.15	-0.09
L3	0.25	0.21	-0.04
L4	0.17	0.19	0.03
L5	0.20	0.12	-0.08
L6	0.19	0.19	-0.01
L7	0.26	0.19	-0.06
L8	0.17	0.18	0.01
L9	0.20	0.19	-0.01
L10	0.24	0.27	0.03
L11	0.18	0.17	-0.01
L12	0.20	0.18	-0.02
L13	0.17	0.21	0.04
L14	0.13	0.18	0.05
L15	0.13	0.16	0.03
L16	0.12	0.14	0.03
L17	0.18	0.20	0.03
L18	0.17	0.18	0.02
L19	0.17	0.18	0.01
L20	0.18	0.18	0.00
L21	0.10	0.16	0.06
L22	0.16	0.21	0.06
L23	0.13	0.26	0.13
L24	0.11	0.18	0.07
L25	0.21	0.24	0.03
L26	0.12	0.20	0.08
L27	0.08	0.07	-0.01
L28	0.14	0.12	-0.02
L29	0.11	0.11	0.00
L30	0.22	0.22	0.01
L31	0.25	0.23	-0.02
L32	0.13	0.15	0.02
L33	0.09	0.14	0.05
L34	0.15	0.16	0.01
L35	0.19	0.20	0.01
L36	0.23	0.14	-0.09
Weighted average	**0.17**	**0.18**	**0.01**