Final Report

For

Consultancy Study for Air Ventilation Assessment

For

S16 Planning Application

For

Hotel Development

In

CDA (1) Hung Hom

By

Parsons Brinckerhoff (Asia) Ltd.

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Revision 2

PARSONS BRINCKERHOFF

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Executive Summary

Detailed 3D CFD simulations have been conducted for three hotel design options, namely Urbis Scheme, Notional Scheme and Proposed Scheme. With the consideration of prevailing wind directions in Hung Hom, the pedestrian level wind environment around the hotel site are compared in details, based on the methodology outlined in "Technical Guide for Air Ventilation Assessment for Developments in Hong Kong" by Planning Department.

The long term annual non-typhoon prevailing wind directions of Hung Hom area are from north to east, i.e. North, North-north-east, North-east, East-north-east, and East. The cumulative frequency of these five wind directions is 77.9% and which is over the 75% requirement as stated in the Technical Guide. These wind directions have been adopted in the AVA CFD analysis.

Based on the 3D CFD simulation findings, it is noted that the pedestrian level ventilation in Whampoa Garden is low irrespective to the hotel scheme. This is due to the fact that the existing buildings in Whampoa Garden are all in a similar height and located in close proximity to each other. This unfavourable building layout results in a strong urban canopy effect which prevents a good air circulation even under windy weather. The hotel site is located downstream of the prevailing wind directions (north or east) and at approximately 100m away from Whampoa Garden. Therefore, the natural ventilation in Whampoa Garden is not that sensitive to the hotel building design.

On the buildings around the hotel site, based on the information obtained from various parties, there are all well spaced and ventilation corridors are provided. Based on the weighted velocity ratio contour plots for all three schemes, the Proposed Scheme will result in better natural ventilation on its north to north-western side than the other two schemes. The east and south sides of the hotel side is near the sea front, the proposed scheme shows significantly better ventilation than the others. And this is the recommended scheme for the hotel design.

For information purpose, additional runs had also been conducted to assess the pedestrian wind environment in typical summer prevailing wind directions. The results also indicate that the Proposed Scheme performs better than the others two.

The Site Wind Velocity Ratio (SVR) for each scheme for annual prevailing wind directions and summer prevailing wind directions are summarized as follows:

SVR	Urbis Scheme:	Notional Scheme	Proposed Scheme
Annual Prevailing Wind Directions	0.20	0.24	0.25 (Preferred)
Summer Prevailing Wind Direction (for information only)	0.19	0.22	0.24 (Preferred)

The Overall average LVR of each scheme based on annual prevailing wind directions are summarized as follows:

	Urbis Scheme	Notional Scheme	Proposed Scheme
Overall LVR	0.20	0.23	0.24 (Preferred)

1. Introduction

A hotel development will be constructed near the sea front of Hung Hom Bay. It is anticipated that the building form would have an effect on the wind environment to its surrounding area. As such, Air Ventilation Assessment (AVA) has been conducted to study the surrounding wind environment due to the hotel under the prevailing wind directions.

To ensure an optimum hotel design, three building schemes have been analyzed:

Urbis Scheme: This is the building form by the Government. It is used as the basis for the comparison.

Notional Scheme: A notional scheme, which is similar to the Proposed Scheme but with a revised building block above the podium for sightline consideration as well as other requirements.

Proposed Scheme: The building form taking into consideration the best practices on AVA and also hotel operations and consultation results.

Figure 1.1 illustrates the location of the hotel site in Hung Hom sea front.

Figure 1.1 – Site Locations in Hung Hom, Kowloon

The objective of this study is to complete the Air Ventilation Assessment (AVA) based on the occurrence of wind in different directions, which should not be less than 75% of the time in a typical reference year in Hung Hom, Kowloon. For information purpose, the summer prevailing wind directions had also been analyzed.

Three-dimensional Computational Fluid Dynamics (3D CFD) simulation techniques have been adopted in the AVA.

This Report consists of the following sections:

1. Site wind availability assessment in Hung Hom;
2. Details of the analytical approach used in the Air Ventilation Assessment, i.e. Three-dimensional Computational Fluid Dynamics (CFD) simulation, including the model setup, computer software, solution parameters, etc.;
3. Findings and discussions on CFD simulation for wind environment at pedestrian level for all three hotel design schemes, namely Urbis Scheme, Notional Scheme and Proposed Scheme; and
4. Conclusions

The requirements of the methodology for carrying out AVA stated in the “Technical Guide for Air Ventilation Assessment for Developments in Hong Kong” (the “Technical Guide” hereafter) are followed while taking due considerations on the current best practices on conduction this type of analysis. Please refer to Appendix A for the Technical Guide.

2. Site Wind Availability in Hung Hom

In the assessment of air ventilation at the pedestrian level inside an urban area, the long term characteristics of the approaching wind would need to be known in advance. For instance, the occurrence, i.e. the frequency, of a particular wind direction is the key parameter for the subsequent assessment. This is called Site Wind Availability.

To obtain the site wind availability in Hung Hom, several widely accepted methods would be adopted, namely mathematical models (MM5 or CALMET), reduced scale wind tunnel test and CFD simulations. In accordance with the "Technical Guide for Air Ventilation Assessment for Developments in Hong Kong", all these methods are considered acceptable. And the long term annual average non-typhoon prevailing wind directions should be adopted in the analysis.

Based on the information available, it is suggested to use public available information for the site wind availability. As such, a report published by Planning Department called "EXPERIMENTAL SITE WIND AVAILABILITY STUDY FOR TSIM SHA TSUI, HONG KONG" in 2007 / 2008 is adopted. This report outlines the methodology used to obtain the wind availability in Tsim Sha Tsui, Kowloon. Please refer to the following link for details.

http://www.pland.gov.hk/pland_en/info_serv/site_wind/wwtf003_2007_final.pdf

The approach wind data used in this wind tunnel study was based on measurements of non-typhoon winds taken by Hong Kong Observatory at Waglan Island during the period of 1953 – 2000. The measurement location is Granville Circuit in Tsim Sha Tsui, which is 1.4km from the hotel site. With the consideration of the practically flat terrain topology, and in meso-scale they are close to each other, it is considered that the wind tunnel measurement results are also applicable in Hung Hom. Please refer to Figures 2.1 and 2.2 for measurement location in wind tunnel and their relative positions respectively.

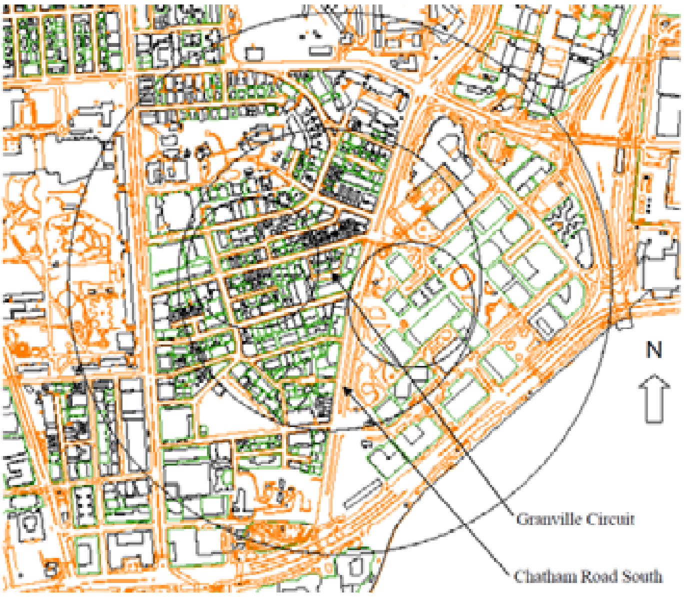


Figure 2.1 – Measurement Location (Granville Circuit) in Wind Tunnel

Figure 2.2 – Distance between Granville Circuit and Hotel Site in Hung Hom

Based on the Planning Department Report regarding the wind availability, the annual prevailing wind in Tsim Sha Tsui, and applicable in Hung Hom, are the five directions from north to east. Figure 2.3a is the wind rose for annual, non-typhoon winds for Tsim Sha Tsui, corrected to 500m, extracted from the Planning Department

Report. For information purpose, Figure 2.3b illustrates the summer, non-typhoon wind rose for Tsim Sha Tsui.

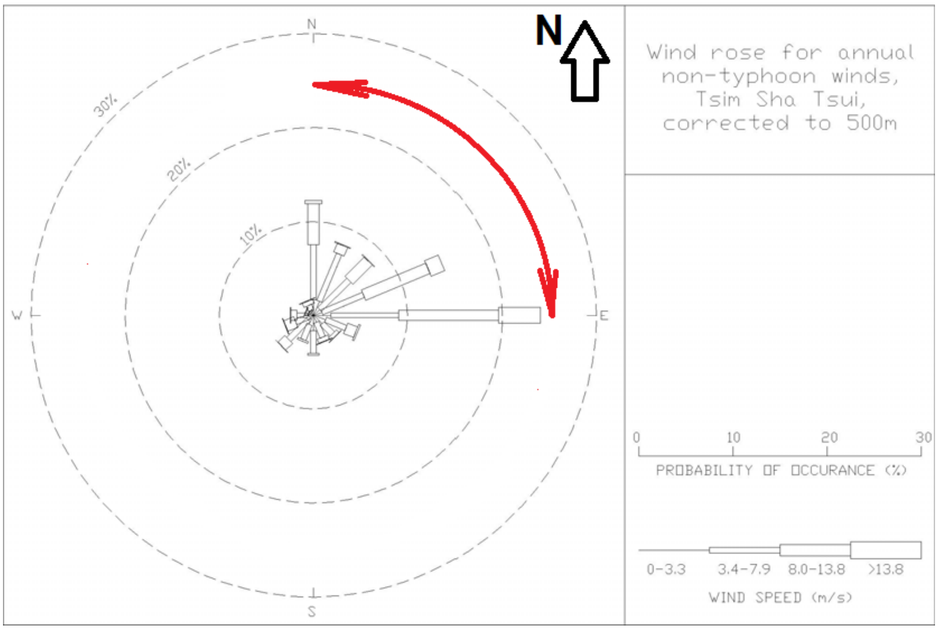


Figure 2.3a – Wind Rose for Annual, non-typhoon Winds for Tsim Sha Tsui, corrected to 500m

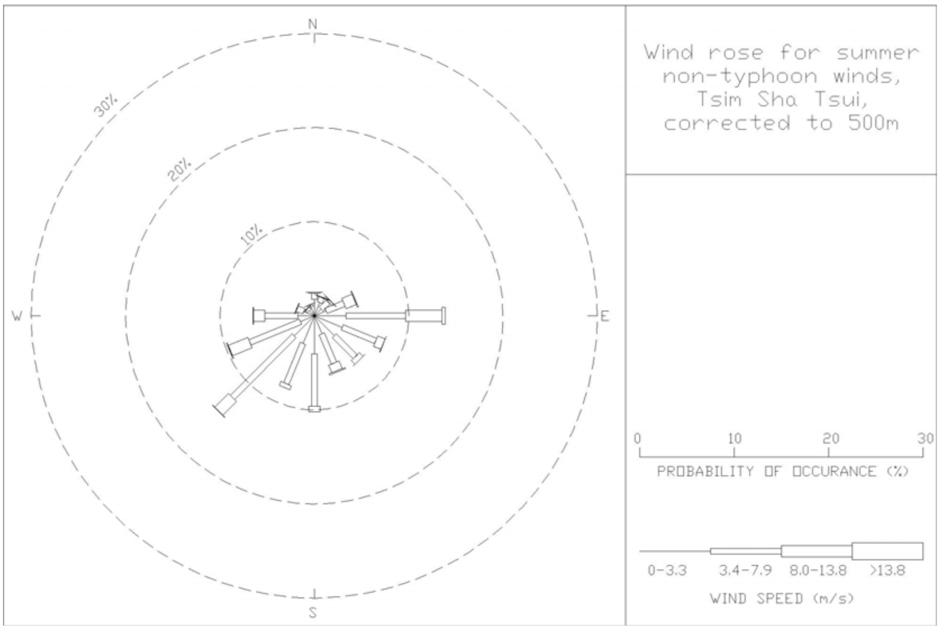


Figure 2.3b – Wind Rose for Summer, non-typhoon Winds for Tsim Sha Tsui, corrected to 500m

The hotel building form design should take into consideration of the annual prevailing wind directions, i.e. the building form should be so designed that wind could flow over the hotel with a consideration of pedestrian level natural ventilation.

In accordance with the requirements in the AVA Technical Guide, the reduced set of wind directions should exceed 75% of the time in a typical reference year. Table 2.1a summarizes the wind directions used in the 3D CFD analysis based on annual non-typhoon wind rose. Five wind directions from north (0^o / 360^o) to east (90^o) cover over 75% of the annual occurrence of non-typhoon weather already.

Table 2.1a: Wind Directions for 3D CFD Simulations based on Annual Non-Typhoon Wind Rose

Wind Direction (^{o})	0/360 (N)	22.5 (NNE)	45 (NE)	67.5 (ENE)	90 (E)
Occurrence (%)	14.2	9.3	9.6	17.0	27.8
Cumulative (%)	14.2	23.5	33.1	50.1	77.9

For information purpose, the summer pedestrian level wind environment has also been analyzed. Table 2.1b summarizes the wind directions used for the summer condition, which also cover over 75% of the occurrence.

Table 2.1b: Wind Directions for 3D CFD Simulations based on Summer Non-Typhoon Wind Rose

Wind Direction (^{o})	90.0 E	112.5 ESE	135.0 SE	180.0 S	202.5 SSW	225.0 SW	247.5 WSW	270.0 W
Occurrence (%)	13.4	7.5	6.3	9.6	7.7	18.3	9.2	6.3
Cumulative (%)	13.4	20.9	27.2	36.8	44.5	62.8	72.0	78.3

Under normal weather condition, wind speed varies from very low near the ground due the blockage, such as buildings, plants, etc., gradually increase with the height. This is called atmospheric boundary layer. With the consideration of the terrain in Hung Hom, Log-law profile is proposed for the approaching wind profile. The parameters used in the definition of the wind profile depend on site conditions, i.e. urban built-up areas.

The proposed Log-law profile is as follows:

$$V(z) = k_T \, Ln[z / z_0] \, V_{ref}$$

Where:

V(z) = mean wind velocity at height z (m/s)

V_{ref} = mean wind velocity at height z_{ref} (assume 3m/s at 10m above around)

k_T, z_0 = roughness parameters (z_0 = 1.5m, k_T to be calculated based on V_{ref} and z_{ref})

z = height (m)

The surface roughness length z_0, usually ranged from 0.3m for rough open sea to 2m for congested urban area covered with buildings. In this Project, z_0=1.5m has been adopted to represent the surface roughness of urban area for the calculation of the Log-law profile parameters. No adjustment is required as there is no wind coming from the sea in the analysis. Therefore, the resulting Log-law profile used in the CFD simulations is:

$$V(z) = 1.5813 \, Ln[z / 1.5]$$

While for the summer condition, part of the wind directions are from the sea, a roughness parameter of 0.3m has been adopted. And the wind profile from the sea is as follows:

$$V(z) = 0.8555 \, Ln[z / 0.3]$$

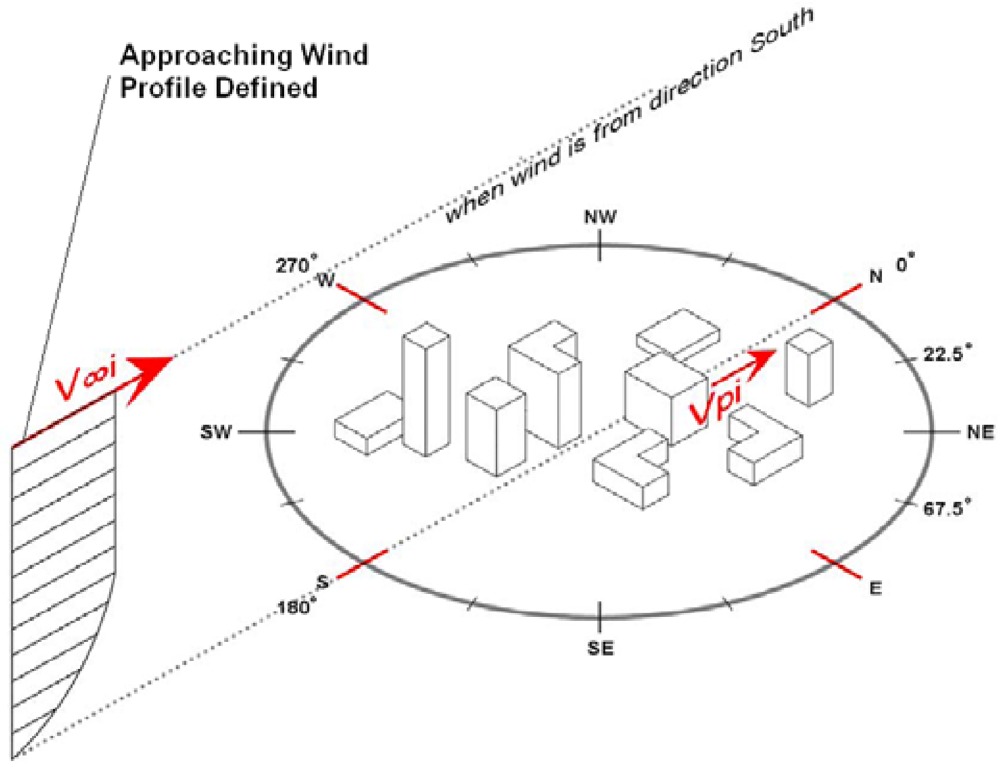
Table 2.2 summarizes the roughness parameter used for each direction.

Table 2.2: Roughness Parameters for Different Wind Directions

Wind Direction (°)	0/360	22.5	45.0	67.5	90.0	112.5	135.0	180.0	202.5	225.0	247.5	270.0
Roughness Length (m)	1.5	1.5	1.5	1.5	1.5	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Once the wind directional occurrence frequencies and approaching velocity profile have been established for a particular site, the pedestrian level wind environment can be assessed quantitatively. Based on the Technical Guide, the concept of Velocity Ratio (VR) has been adopted. Figure 2.4 is extracted from the "Feasibility Study for Establishment of Air Ventilation Assessment System, FINAL REPORT" by Chinese

University Hong Kong. It illustrates the concept of VR as well as the weighted VR, which considered the wind occurrence frequency of different directions.



$$VR_i = \frac{V_{pi}}{V_{\infty i}} \qquad VR_w = \sum_{i=1}^{16} F_i \times VR_i$$

Vpi is the pedestrian wind velocity of the location when wind comes from direction i.
V∞i is the available wind velocity of the site when wind comes from direction i.
VRi is the velocity ratio of the location when wind comes from direction i.
Fi is the frequency occurrence of wind from direction i. 16 directions are considered.
VRw is the wind velocity ratio

Figure 2.4 – Concept of VR and Weighted VR

3. Computational Fluid Dynamics (CFD) Approach for AVA

This Section summarizes the details on the CFD software used, meshing size, topology and quality, turbulence model, computational domain, boundary conditions as well as other miscellaneous settings. Apart from these details, the computer hardware to be used and the quality assurance approach adopted in the CFD analysis are also included.

3.1. General Review on CFD Package Suitable for AVA

Today, there are many commercial and research CFD codes in the commercial market and academia. Some of them are developed for a specific application, for instance, Airpak and FloVENT for HVAC system design, Fire Dynamics Simulator (FDS) for fire simulation. Some codes are intended for general CFD applications, such as ANSYS-FLUENT, ANSYS-CFX and StarCD. In particular for commercial packages, due to the user friendly interface and powerful post-processing features, it is true that misuse of any commercial CFD codes will still provide impressive, colourful figures, but with misleading results. As such, special attention on a proper selection of appropriate modeling approaches and solution parameter settings are vital when using any CFD code for AVA. The following sections outline the considerations on selecting suitable CFD code for AVA.

3.1.1. Computational Mesh

In this Project, due to the geometrical complexity of the buildings and terrains, the meshing method, i.e. the approach to discretize the computational domain for subsequent CFD simulations, must be capable to capture adequate details. Un-structured mesh is the best method for this purpose. Figure 3.1 is an illustration of structured mesh and unstructured mesh. It is clear from Figure 3.1 that unstructured mesh can be used to capture odd shape geometries and it is therefore suitable for the use in AVA, where the buildings and terrains are irregular in shape.

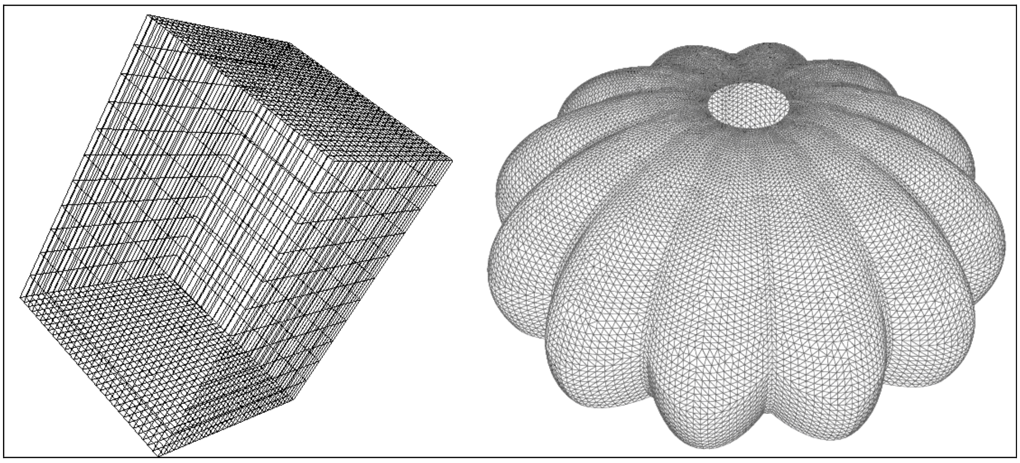


Figure 3.1 – Typical Surface Mesh Arrangement of Structured Mesh (Left) and Unstructured Mesh (Right)

Apart from the mesh topology, a good mesh quality will not just help the solution convergence and save CPU time. It is the key to an accurate CFD solution. The grid quality will be closely monitored during the CFD model meshing stage. A typical mesh skewness (a parameter to determine / measure the grid quality) of less than 0.7 and 0.9 will be used for hexagonal mesh and tetrahedral mesh respectively. Refer to Figure 3.2 for the illustration of mesh skewness for hexagonal mesh and tetrahedral mesh.

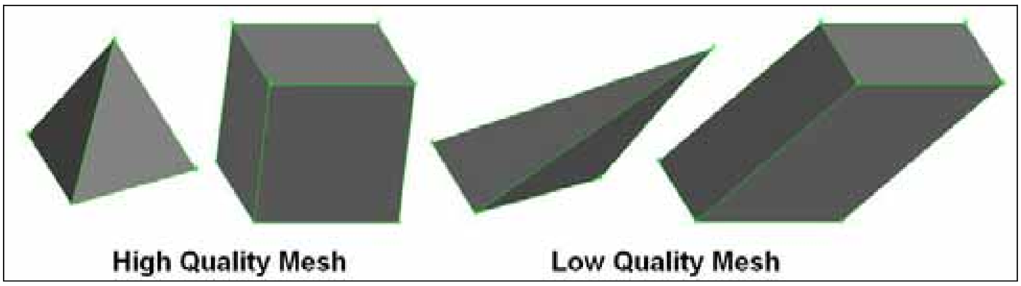


Figure 3.2 – Mesh Skewness for Hexagonal Mesh and Tetrahedral Mesh

For same length scale, tetrahedral mesh is considered less favourable than hexagonal or polyhedral mesh in numerical accuracy consideration. As such, tetrahedral mesh is only considered acceptable in location where other mesh topology would have difficulty for meshing.

Moreover, ground level grid will be in layer form and also be refined to ensure a good quality of the pedestrian level wind flow be resolved properly near ground.

3.1.2. Turbulence Model

The general use for the computation of turbulent flows for AVA should be the RANS approach. Apart from the standard k-ε model, two advanced k-ε models, namely Renormalization Group (RNG) k-ε model and Realizable k-ε model are commonly used in AVA today. In this project an improved RANS turbulence model, i.e. Realizable k-ε has been adopted.

3.1.3. Computational Domain

Due to the building height restriction, the Hotel height is around 75m above ground level. The tallest building around the site is Harbourfront Landmark, around 200m tall and which is located 400m in the north-eastern side from the site. With the consideration of site coverage, i.e. including assessment area and surrounding areas as defined in the Technical Guide, and Harbourfront Landmark (the tallest building nearby), the computation domain had been extended further to 1.3km diameter. This area coverage is considered necessary for this analysis as it includes also Ma Tau Chung Government Primary School (Hung Hom Bay), Whampoa Garden and Harbour Place, where the pedestrian level ventilation is of public interest.

In fact, on Paragraph 24 of the Technical Guide, it also suggested to use "an assessment area larger than that defined above so the special surrounding features and open spaces are not omitted."

The height used in the computational domain must be capable to represent the wind velocity at top of the atmospheric boundary layer, which is considered unaffected by the urban roughness, such as buildings and terrains. In this Project, 800m has been adopted, which is more than three times the height of the tallest building, i.e. Harbourfront Landmark, near the Hotel site.

Based on the above discussions, as well as the considerations of boundary condition settings, the computational domain is set as an 800m tall cylinder and with diameter of 1.3km. The domain blockage could be kept well below 5% for any wind direction, i.e. to reduce the influence of finite domain size. This cylindrical domain has specific inlet and outlet, and with a symmetry boundary condition at the top surface. As such, mass conservation is ensured. It is a well-posed CFD setup and should result in a mathematical correct numerical result.

As required on Paragraph 23 and 24 of the Technical Guide, the Project Area, Assessment Area and Surrounding Area are defined based on the tallest building on site, i.e. the hotel block, which is 75m above ground. As discussed above, the computation domain has been extended to cover Waterfront Landmark (~200m tall) so its influence on the wind pattern has also been simulated. In the case, the results outside the predefined Assessment Area could still be useful for the ventilation assessment.

Figure 3.3 illustrates the general arrangement of the CFD domain configuration, area definitions of Project Area, Assessment Area and Surrounding Area, and boundary conditions for the CFD simulations. The CFD model was developed based on the survey map in this area.

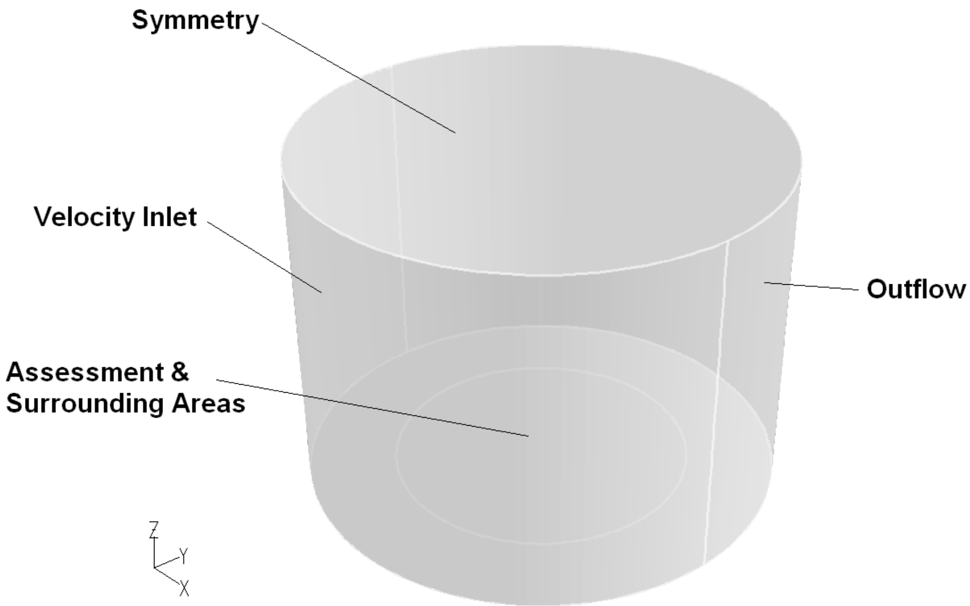


Figure 3.3 – Domain Configuration for CFD Simulations

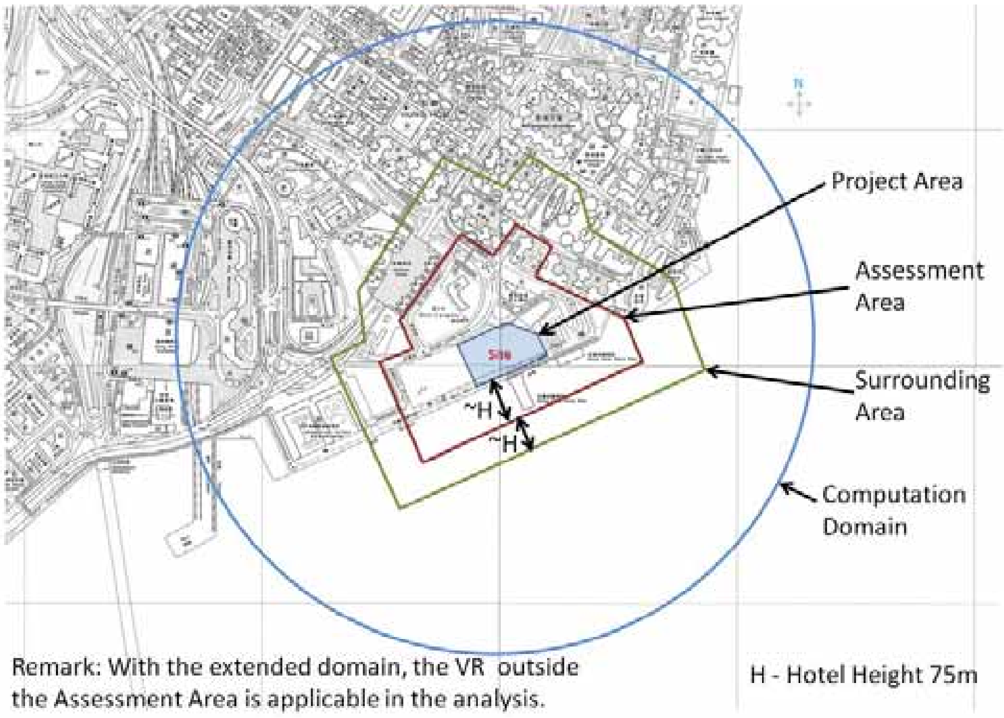


Figure 3.3 – Domain Configuration for CFD Simulations (Cont.)

3.1.4. Proposed CFD Package for AVA

Based on the above discussions as well as extensive project experiences of large scale CFD simulations, the following are the general requirements for the CFD code to be used for AVA:

1. Accept fully unstructured mesh, which is essential to capture the geometrical details and also for the generation of boundary layer near ground level
2. Has the required turbulence model, i.e. Realizable k-ε model in this Project
3. Has the parallel processing capability and also capable to simulate large CFD model (in term of number of cells)
4. Accept user specified incoming wind characteristics, i.e. profile and turbulent parameters
5. Widely accepted by the industries

The latest version of commercial CFD code ANSYS-FLUENT Version 14 has been adopted for the simulations in this Project as it satisfies all the above general requirements. A highly efficient meshing package HARPOON has been used to generate the computational mesh for the CFD analysis. The generated unstructured hexagonal mesh could reduce the total number of meshes and also provide a higher level of numerical accuracy than tetrahedral meshes. Layers of meshes have also been included on the ground surfaces to capture the detailed pedestrian level wind flow. The same approach had also been adopted by Environmental Protection Agency (EPA), USA for the assessment of urban scale environmental flow. Please refer to Appendix B for more details.

Figure 3.4 illustrates the general concept of hexagonal mesh and its applications in complicated geometries in a typical urban area. It clearly indicates that the geometrical details could still be maintained but the overall mesh quantity is reduced when comparing to tetrahedral mesh.

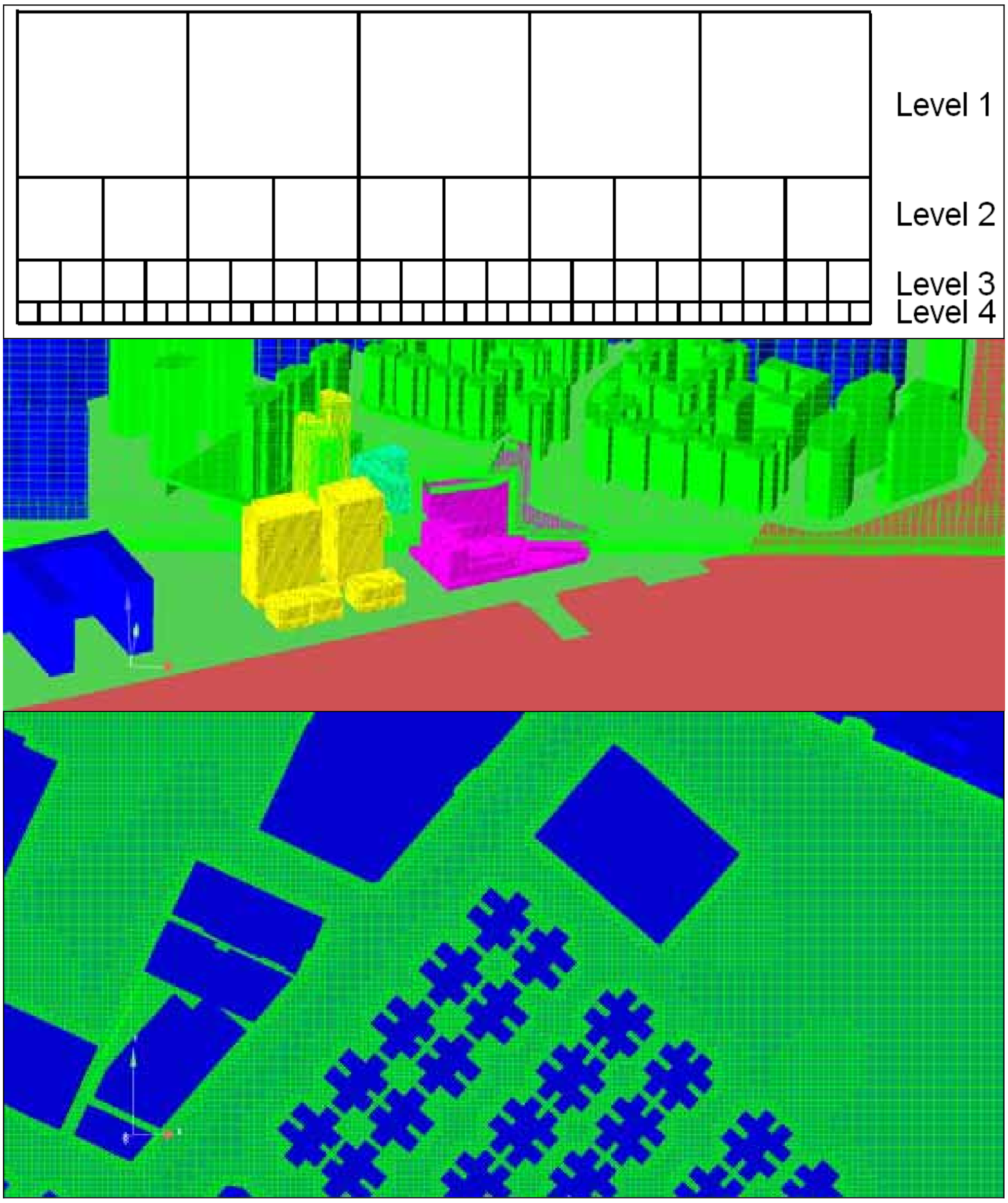


Figure 3.4 – Example of Hexagonal Mesh Concept and Arrangement in a Typical Urban Area

3.2. Boundary Condition Settings

For all successful CFD simulations, proper boundary condition settings are essential. For AVA, beside the geometrical model of the site, the most important boundary conditions are the approaching wind velocity and its turbulence parameters.

With the consideration of the terrain, log law is proposed for the approaching wind profile. The parameters used in the definition of the wind profile depend on site conditions, i.e. mainly urban built-up areas and from the sea. Please refer to Section 2 for the details regarding the wind profiles used.

Moreover, based on "Technical Guide", as discussed in Section 2, the wind directions used should cover over 75% of the site wind occurrences. And the probabilities as tabulated in Table 2.1a (Annual Non-Typhoon) and Table 2.1b (Summer Non-Typhoon) in Section 2 have been adopted. Apart from this, the Log-law wind profiles have also been adopted to characterize approaching wind. User Defined Function (UDF) (a method to specify the boundary condition settings in ANSYS-FLUENT) has been developed to specify all these parameters for the approach wind profiles.

For the boundary condition settings, "Velocity" boundary has been used for the incoming wind profile. The outflow boundary has been defined as "Outflow" and the top domain will be defined as "Symmetry". Please refer to Figure 3.3 for details.

For the buildings, ground and sea surfaces, a gird size of 0.5m were used. 6 layers of 0.5m thick cells were used from the ground and sea level to capture the pedestrian level wind flow details. A nominal expansion factor of around 1.2 was used and the maximum size of the grid is 12m. The total number of mesh is around 6 million for each case.

3.3. Convergence Criteria and Solution Monitoring Strategy

Ensure an adequately convergence of solution is in fact essential for CFD simulations. Usually, using residual monitoring only is not sufficient. In additional to the typical residual monitoring used in ANSYS-FLUENT, which the residuals of the variables (velocity, pressure and turbulence parameters) should be lower than 0.001, various monitoring points inside the computation domain have been used to monitoring the solution convergence progress. Therefore, in addition to the residuals report in ANSYS-FLUENT, the velocities in the monitoring points should also indicate a converged behaviour as well.

Apart from the solution convergence, an additional method has also been used to ensure the solution accuracy and consistency. Since the upstream flow pattern away from the site, which is different with different building form, should not be affected much due to the change in the hotel details. The flow patterns upstream from the site with the same wind direction should be compared against each other. No significant change should be observed for a correct simulation result. Otherwise, revisit the simulation model is necessary to eliminate such discrepancies. Figure 3.5 is a typical pedestrian level velocity ratio plots for 45º approaching wind with a different building form in the centre. The velocity ratios at the upper right side of these two plots appear to be identical, which also indicates the solution consistency.

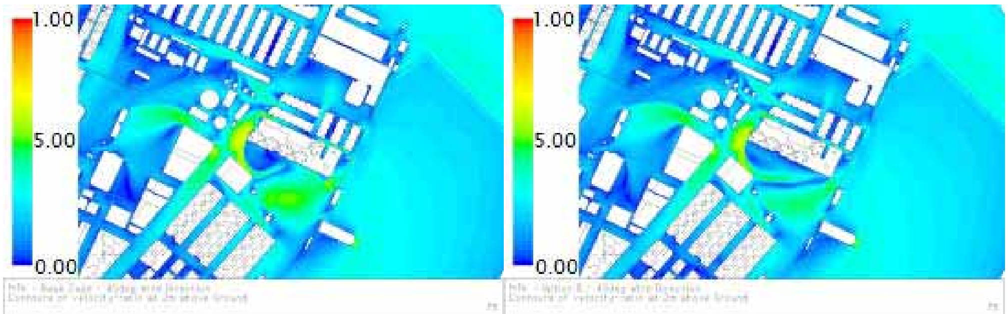


Figure 3.5 – Typical VR Contour Plots for Two Different Building Forms with Same Approaching Wind Direction at 45º

3.4. *Miscellaneous Settings*

The following sections summarize the miscellaneous settings which are necessary to ensure accuracy CFD simulations:

1. By using CFD simulation techniques, it is not necessary to define any measurement point within the computational domain. The required velocity ratios could be extracted from the simulation results directly.

2. The proper use of numerical method is essential but usually overlooked by some inexperienced CFD users. In fact a higher order scheme is a must for sufficient numerical accuracy of a CFD simulation. For a better convergence control, first order scheme has been used for the initial iterations and second order scheme has been used for all the variables, namely velocity, pressure and turbulent parameters.

3. A good contour plot could provide detailed information in relation to the resulting wind environment inside the computational domain. Therefore proper post-processing on the CFD simulation results for comparison of

different development options is vital. Suitable post-processing packages, including ANSYS-FLUENT and Tecplot, have been adopted in the Project.

4. AVA 3D CFD Models and Simulation Results

In this Project, three building forms have been analyzed in detailed, namely Urbis Scheme, Notional Scheme and Proposed Scheme. On the construction of 3D CFD model, the Hong Kong survey plans provided by the project team have been adopted. Figures 4.1 to 4.6 are the outline 3D views and plan views of these three 3D CFD models. For the domain coverage, please refer to Figure 3.3.

Urbis Scheme:

This is the building form by the Government for this area in 2008. It is used as the basis for the comparison. A cluster of hotel buildings of various heights from 40mPD to 75mPD atop a podium (not exceeding 15mPD). And a ventilation path is allowed between them.

Figure 4.1 and Figure 4.2 illustrate the 3D CFD model of the Urbis Scheme.

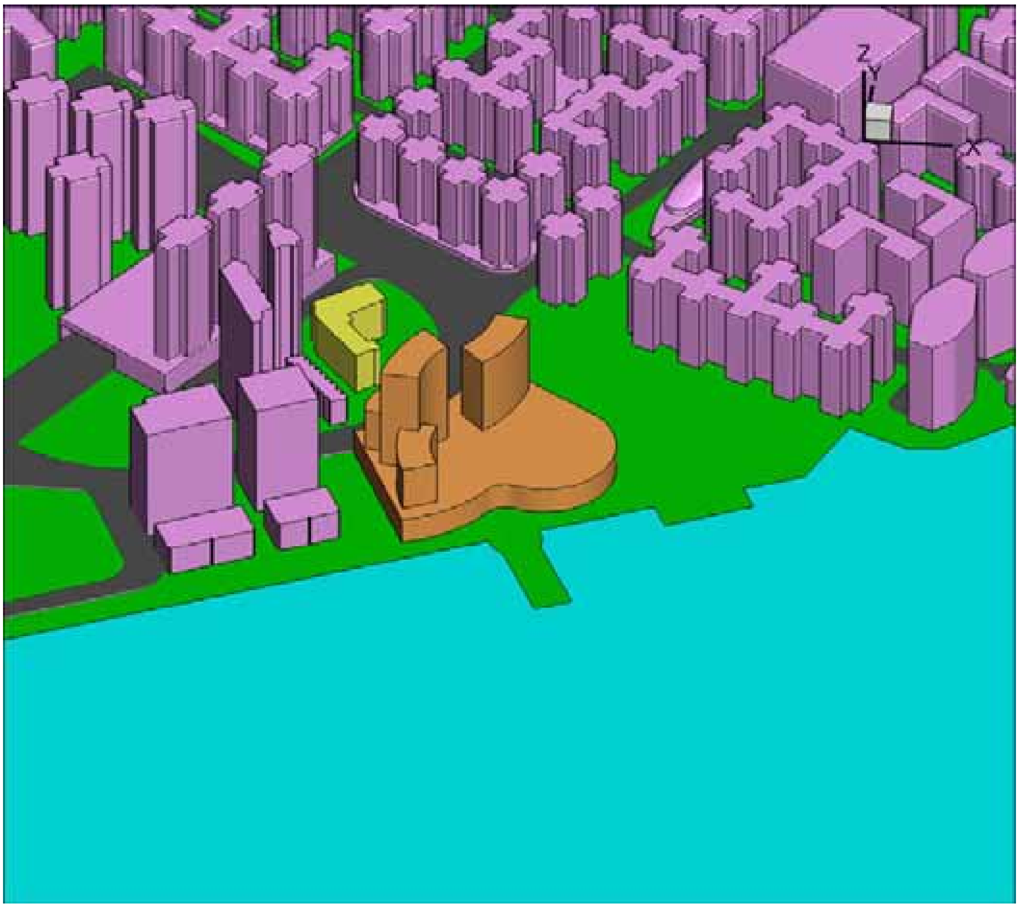


Figure 4.1 – 3D CFD Model for Urbis Scheme

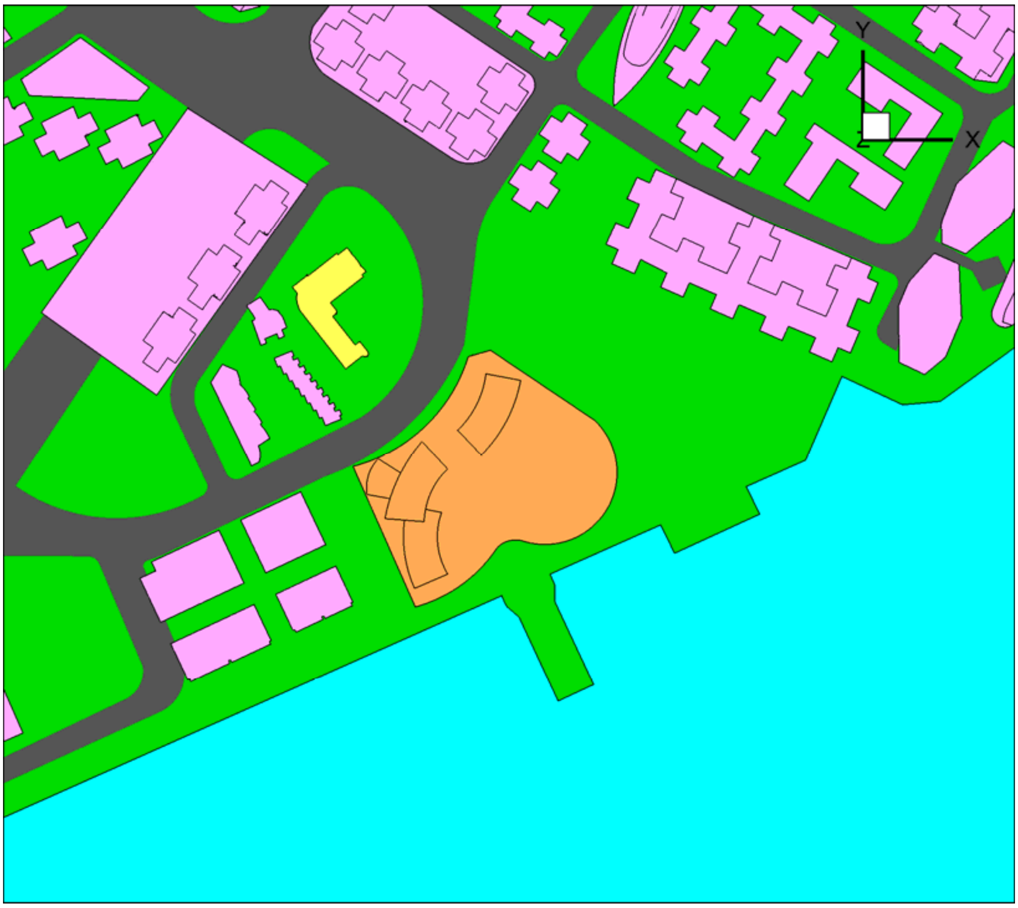


Figure 4.2 – Plan View for 3D CFD Model for Urbis Scheme

Notional Scheme:

A notional scheme, which is similar to the Proposed Scheme but with a revised building block above the podium for sightline consideration as well as other planning requirements. One of the purposes of this scheme to check the air ventilation performance when comparing to the Proposed Scheme. In general, the good features, such as smaller & stepped podium, hotel black alignment, have been retained.

Figure 4.3 and Figure 4.4 illustrate the 3D CFD model of the Notional Scheme.

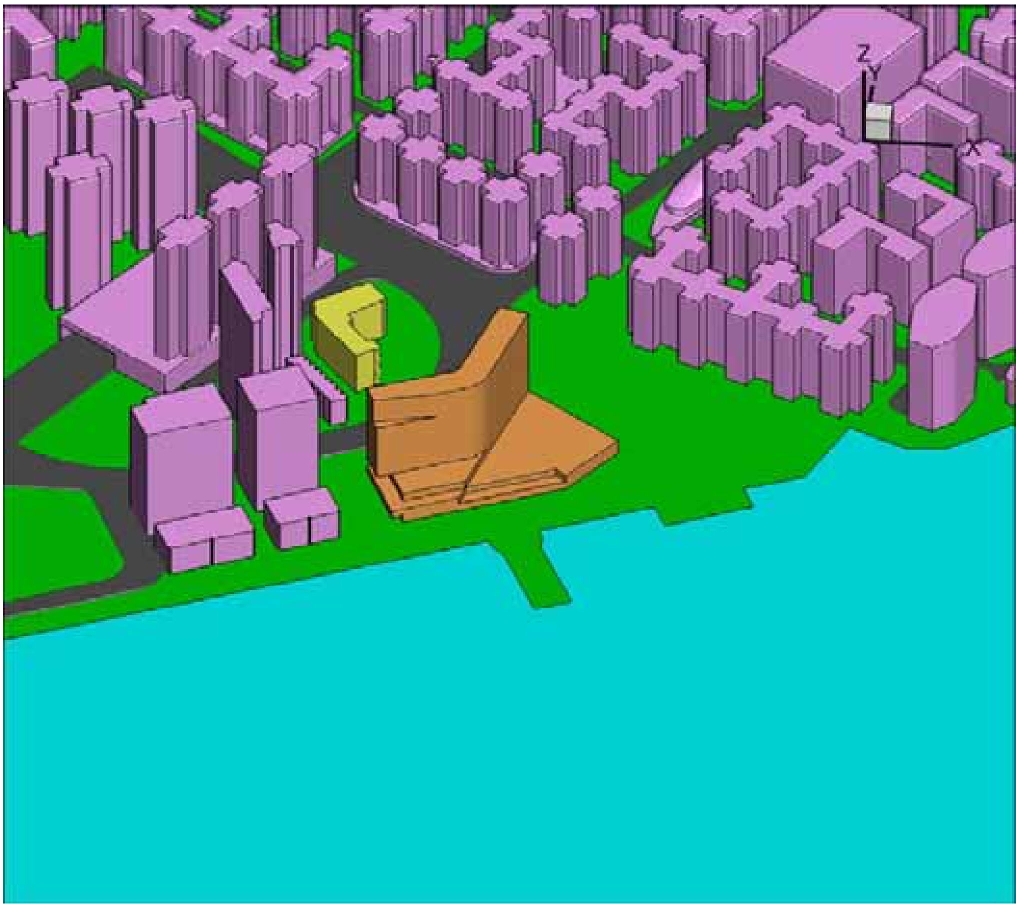


Figure 4.3 – 3D CFD Model for Notional Scheme

Figure 4.4 – Plan View for 3D CFD Model for Notional Scheme

Proposed Scheme: The building form taking into consideration of the best practices on AVA and also hotel operations and consultation results. The mass and footprint of the podium have been reduced to allow wider airflow paths, in particular near the seafront and also between the hotel site and the commercial development on its west, when comparing to the Urbis Scheme. The podium structure has also been arranged in step to facilitate wind passing it and also enhance the reattachment to pedestrian level afterward

The hotel block on top of the podium has been so arranged to allow the prevailing wind directions, i.e. north to east, passing through it easily. On the north-east side of the hotel block, the height has been reduced slightly as it might enhance the wind flow through the block.

Figure 4.5 and Figure 4.6 illustrate the 3D CFD model of the Proposed Scheme.

Figure 4.5 – 3D CFD Model for Proposed Scheme

Figure 4.6 – Plan View for 3D CFD Model for Proposed Scheme

3D CFD simulations have been conducted according to the methodology outlined in Section 3. The following sections summarize the 3D CFD simulation findings for the weighted pedestrian level wind velocity ratios.

4.1. Review of Site Wind Environment

Based on the site wind availability information as shown in Section 2, the long term annual non-typhoon prevailing wind directions of this site is from north to east. The Whampoa Garden is located to the north-eastern side of the proposed hotel site. This residential development is composed of many building blocks of similar height, located either at grade or on top of a podium, and placed in close proximity to each others. Figure 4.7 is the satellite view of Whampoa Garden and the proposed hotel site, and also the prevailing wind directions.

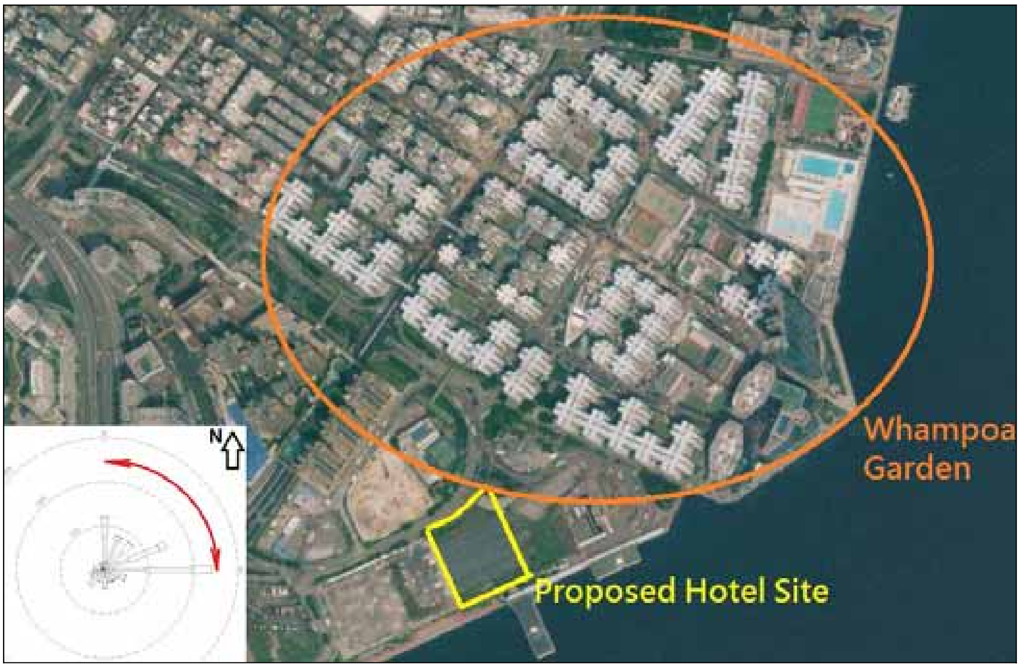


Figure 4.7 – Satellite View of Whampoa Garden and the Proposed Hotel Site

This type of building formation is highly undesirable for natural ventilation consideration. The resulting urban canopy effect will be significant and resulting in low pedestrian level ventilation. Without the consideration of building regulations, a good design should allow ventilation paths and also with irregular building height. Figure 4.8 illustrates a simple comparison of these two design concepts for building formation.

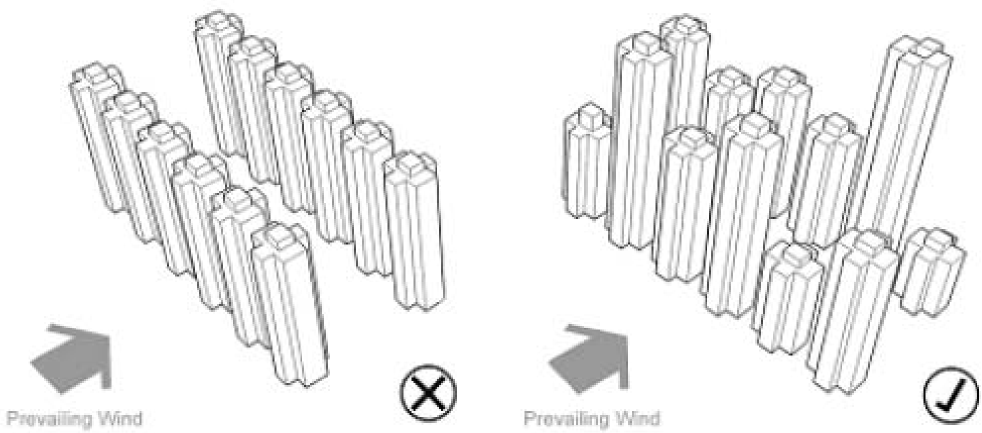


Figure 4.8 – Comparison of Good and Bad Building Formations

It is very likely that the pedestrian level ventilation within Whampoa Garden will be quite low. The proposed hotel site is separated from Whampoa Garden for around 120m and in between is an open area. Therefore, with the consideration of annual non-typhoon prevailing wind directions, the anticipated adverse wind environment within Whampoa Garden should not affect the proposed hotel site. Alternative, the proposed hotel building form should have no noticeable effect on Whampoa Garden as it is located in the downstream direction.

Around the proposed hotel site, the buildings (existing and proposed) are separated from each other and the pedestrian level ventilation will depend on the building design of the proposed hotel.

The following sections outline the findings of each scheme based on the CFD simulation results.

4.2. Urbis Scheme

Figures 4.9 and 4.10 are the weighted VR plot at 2m above ground level for the Urbis Scheme. It is clear that the pedestrian level natural ventilation in Whampoa Garden is rather low. This is due to the fact that the existing buildings in Whampoa Garden are all in a similar height and located in close proximity to each other. This results in a strong urban canopy effect which prevents a good air circulation even under windy weather. As a result, the pedestrian level ventilation will be low within Whampoa Garden.

On the buildings around the hotel site, based on the information obtained from various parties, there are all well spaced and ventilation corridors are provided. In general, the pedestrian level natural ventilation on north to north-western side of the hotel site is significantly better than that in Whampoa Garden.

On the south side of the proposed commercial development on the west of the proposed hotel, it is noted that the ventilation on the south, i.e. near the sea front is rather low. Some improvement work should be considered for this area with the Urbis Scheme.

Around the proposed hotel with Urbis Scheme, the VR appears to be low (0.1~0.15) on its north side, i.e. near the existing primary school. This is due to the large podium structure used. Some improvement on this area is anticipated.

The average weighted Site VR for the Urbis Scheme based on annual prevailing wind directions is 0.20. Detailed numerical of the each point of the Site VR please refer to Appendix G.

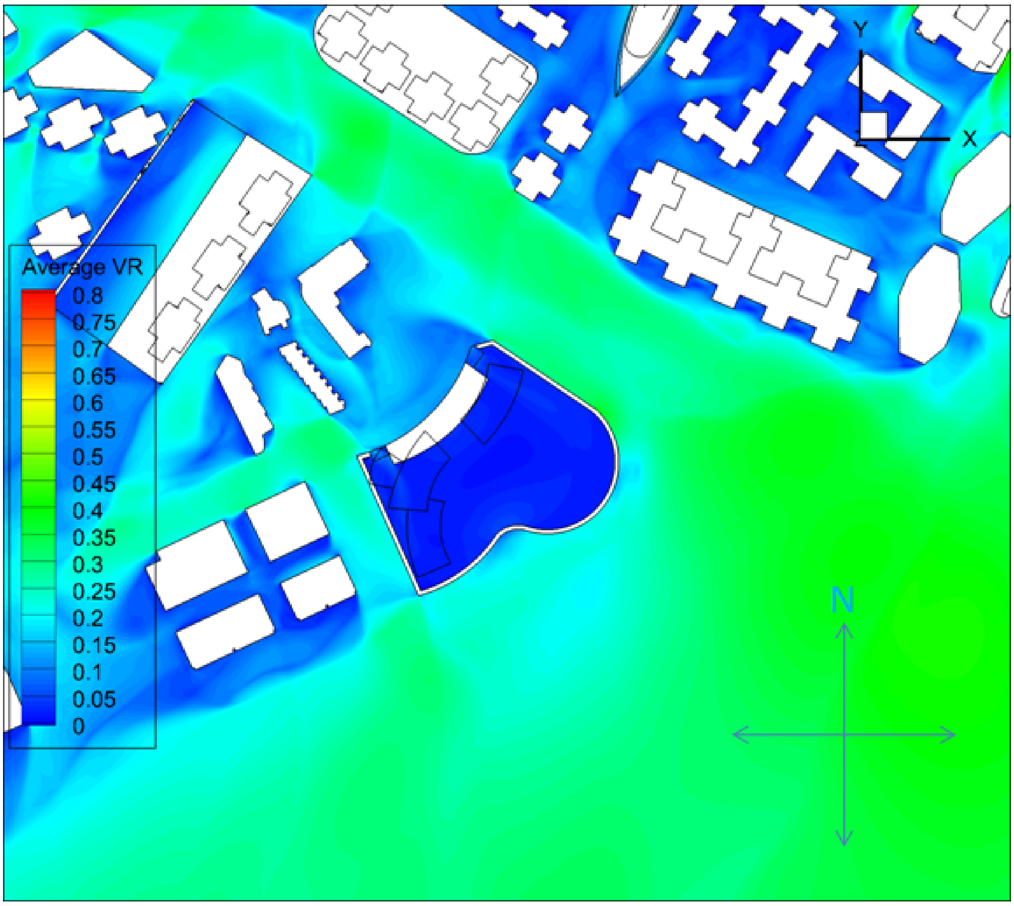


Figure 4.9 – Weighted VR Plot at 2m above Ground for Urbis Scheme (Plan View)

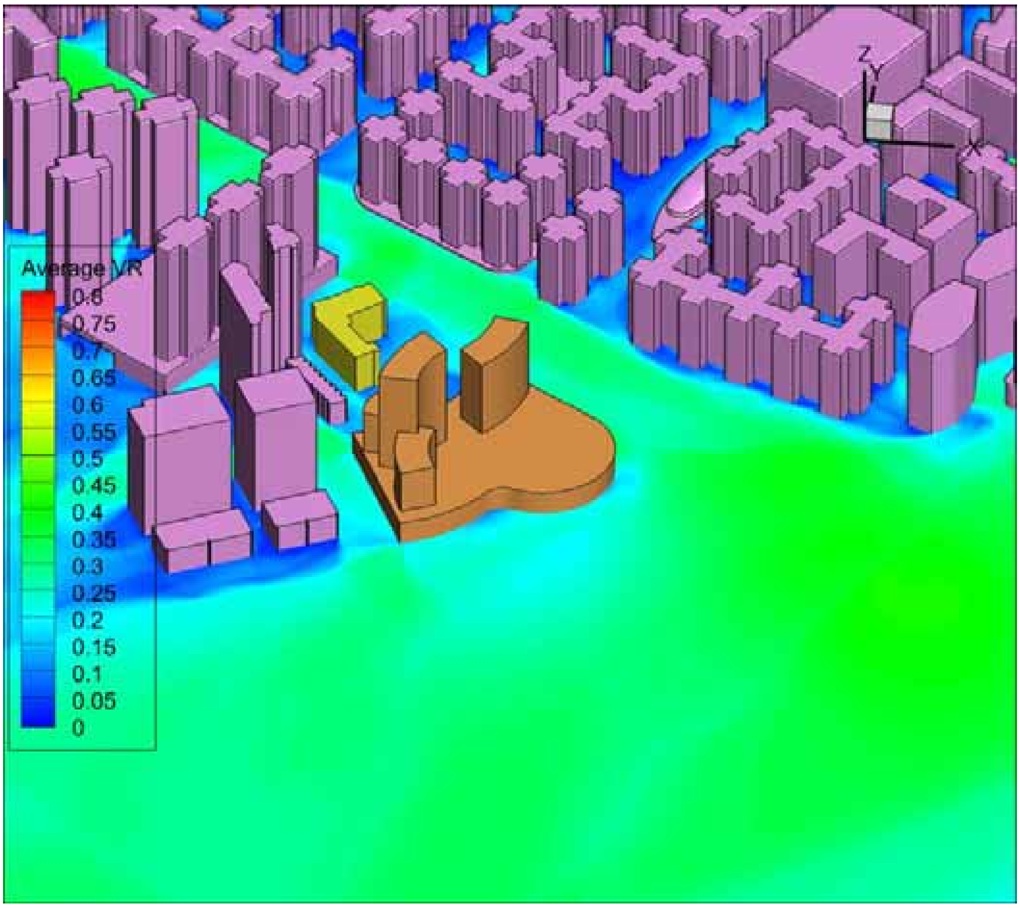


Figure 4.10 – Weighted VR Plot at 2m above Ground for Urbis Scheme (3D View)

Please refer to Appendix C for the individual pedestrian level VR plots and velocity vector plots for the Urbis Scheme.

For information purpose, the average weighted Site VR for the Urbis Scheme based on summer prevailing wind directions is 0.19.

4.3. Notional Scheme

Figures 4.11 and 4.12 are the weighted VR plot at 2m above ground level for the Notional Scheme. When comparing to the Urbis Scheme, the differences are the smaller podium design and one piece structure on top of it, which also take into consideration of the sightline requirement from Whampoa Garden.

From the CFD simulation results, same as the Urbis Scheme, the pedestrian level natural ventilation in Whampoa Garden is rather low and the buildings around the hotel site have significant better pedestrian level natural ventilation, primarily due to the small podium structure.

Same as the Urbis scheme, on the south side of the proposed commercial development on the west of the hotel, it is noted that the ventilation on the south, i.e. near the sea front is rather low. Some improvement work should be considered for this area.

Around the proposed hotel with Notional Scheme, the natural ventilation on the north has been improved and there is no area which indicates a stagnant zone. The average weighted Site VR for the Notional Scheme based on annual prevailing wind directions is 0.24. Detailed numerical of the each point of the Site VR please refer to Appendix G.

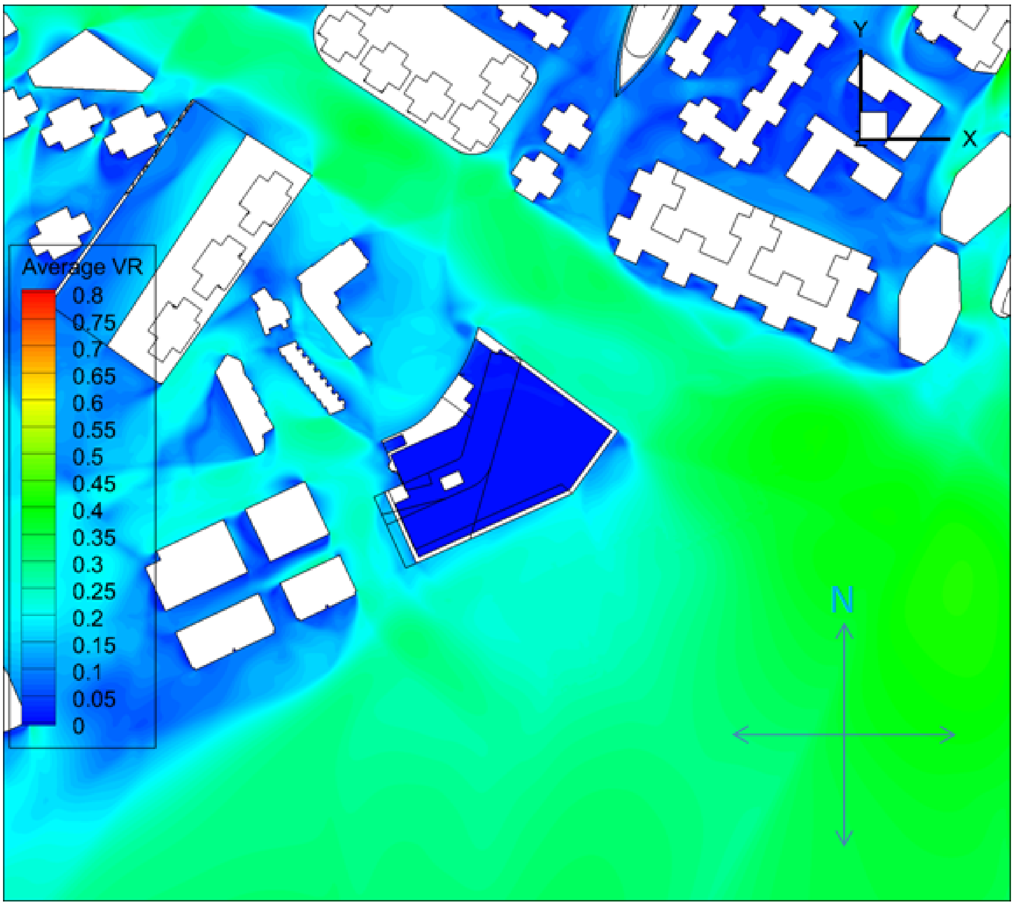
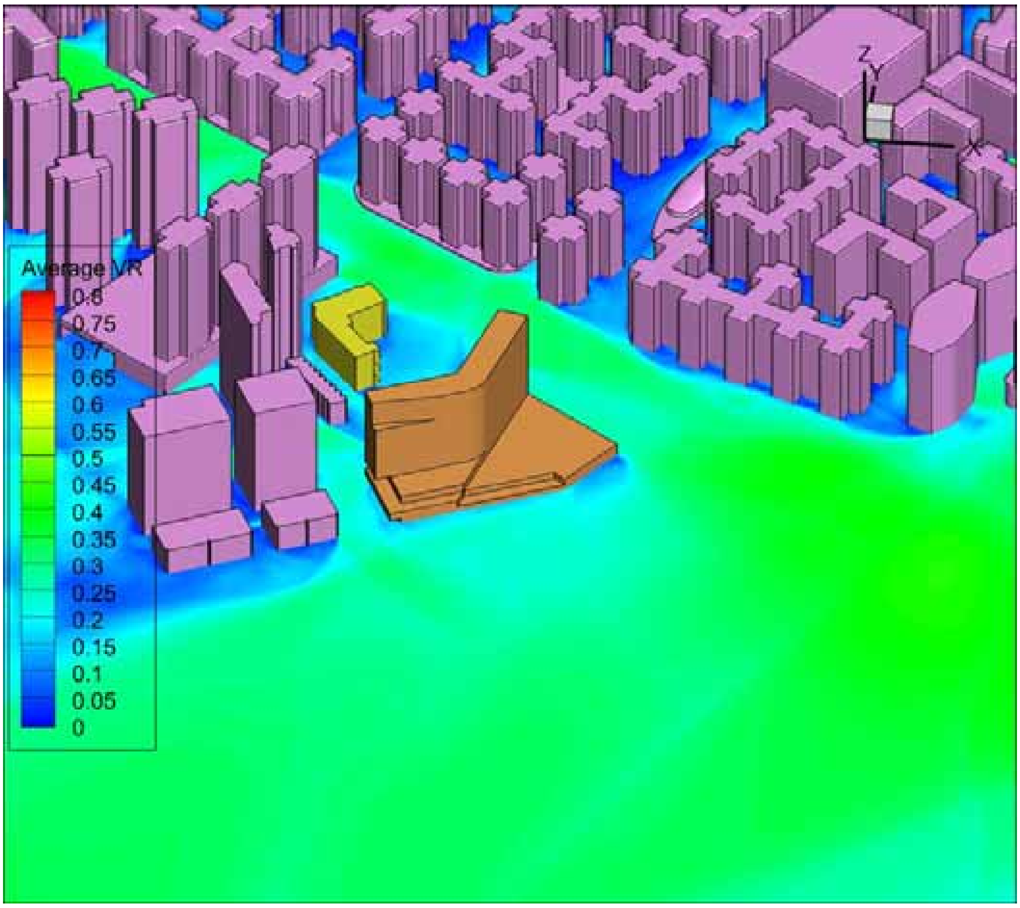


Figure 4.11 – Weighted VR Plot at 2m above Ground for Notional Scheme (Plan View)



<u>Figure 4.12 – Weighted VR Plot at 2m above Ground for Notional Scheme (3D View)</u>

Please refer to Appendix D for the individual pedestrian level VR plots and velocity vector plots for the Notional Scheme.

For information purpose, the average weighted Site VR for the Notional Scheme based on summer prevailing wind directions is 0.22.

4.4. Proposed Scheme

Figures 4.13 and 4.14 are the weighted VR plot at 2m above ground level for the Proposed Scheme. The Proposed Scheme design has taken into consideration of various Town Planning Board's comments and also hotel operation considerations.

From the CFD simulation results, there is no surprise that the pedestrian level natural ventilation in Whampoa Garden is rather low and the buildings around the hotel site have a significant better pedestrian level natural ventilation.

With the Proposed scheme, the ventilation on the south side (the sea front) of the proposed commercial development would result in a significant improvement than the Urbis Scheme and the Notional Scheme. On the north-eastern side and south-west side of the Proposed Scheme, the VR contour indicates an improvement on the natural ventilation. There is a slightly reduction on VR on its south side. As there will be no traffic between the hotel and the sea front, such small reduction on VR is considered acceptable as there is no pollutant source.

The average weighted Site VR for the Proposed Scheme based on annual prevailing wind directions is 0.25, which is the best among the other two schemes. Detailed numerical of the each point of the Site VR please refer to Appendix G.

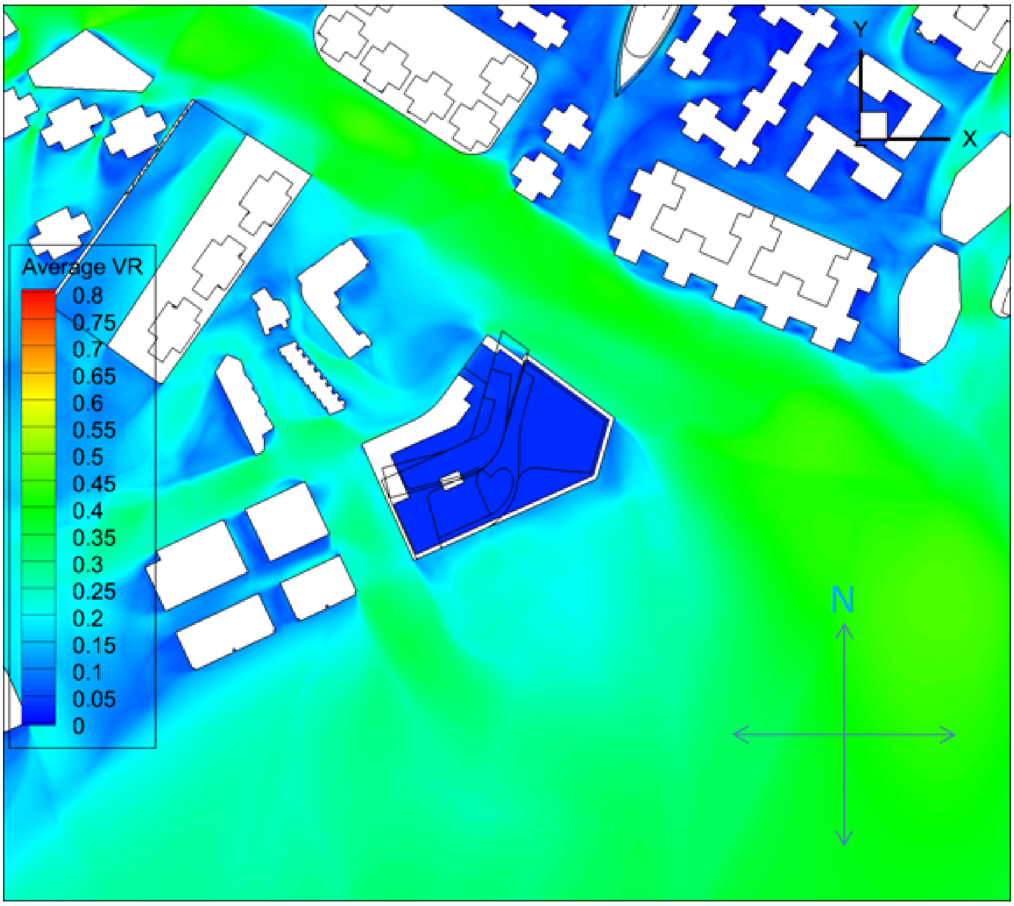


Figure 4.13 – Weighted VR Plot at 2m above Ground for Proposed Scheme (Plan View)

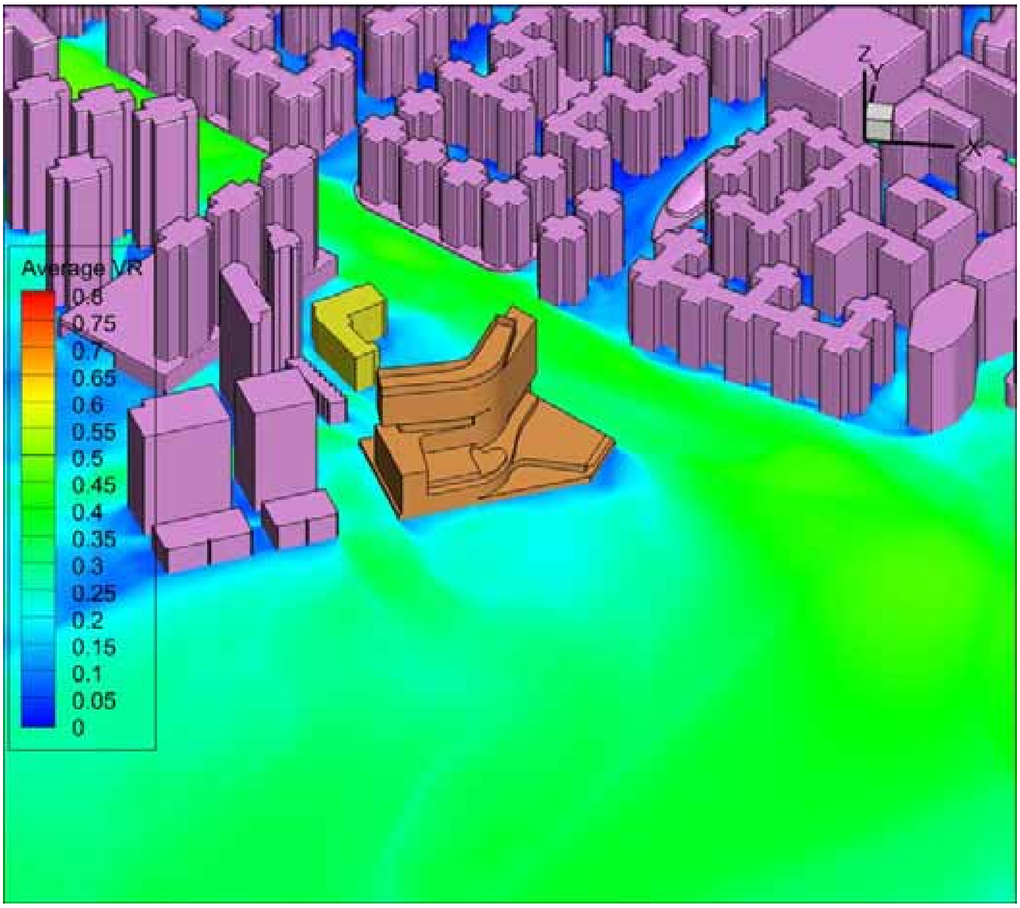


Figure 4.14 – Weighted VR Plot at 2m above Ground for Proposed Scheme (3D View)

Please refer to Appendix E for the individual pedestrian level VR plots and velocity vector plots for the Proposed Scheme.

For information purpose, the average weighted Site VR for the Proposed Scheme based on summer prevailing wind directions is 0.24.

4.5. Comparison of Different Building Schemes

For easy comparison, the weighted VR plots for all three schemes are combined as shown on Figure 4.15.

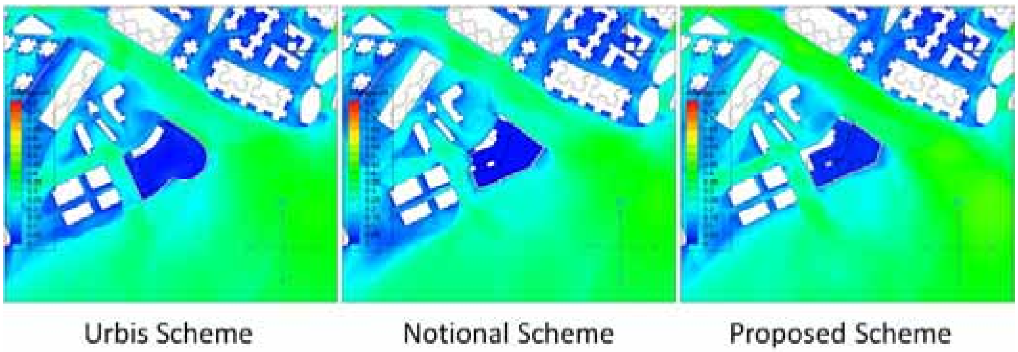


Figure 4.15 – Comparison of Weighted VR Plots for Three Building Schemes

The Site VR for each scheme based on annual prevailing wind directions is summarized as follows:

Urbis Scheme:	0.20
Notional Scheme:	0.24
Proposed Scheme:	0.25

The lower SVR for Urbis Scheme is due to the significantly lower ventilation on the north west side of its podium.

North to the Hung Hom South Road, i.e. the road from north-western to south-eastern on Figure 4.16, the VR in Whampoa Garden is generally insensitive to the hotel building form. It is because the annual prevailing wind direction is coming from north to east, i.e. Whampoa Garden is in the upstream direction and would not be affected by the hotel structure. As discussed in Section 4.1, it is anticipated that the pedestrian level ventilation in Whampoa Garden would not be favourable due to its building formation. Figure 4.16 to Figure 4.18 illustrate the typical low pedestrian level ventilation in Whampoa Garden with an eastern wind direction. And the wind environment of each scheme appears to be similar and also independent from the hotel design.

Figure 4.16 – Pedestrian Level VR Plot in Whampoa Garden with North-Eastern Wind - Urbis Scheme

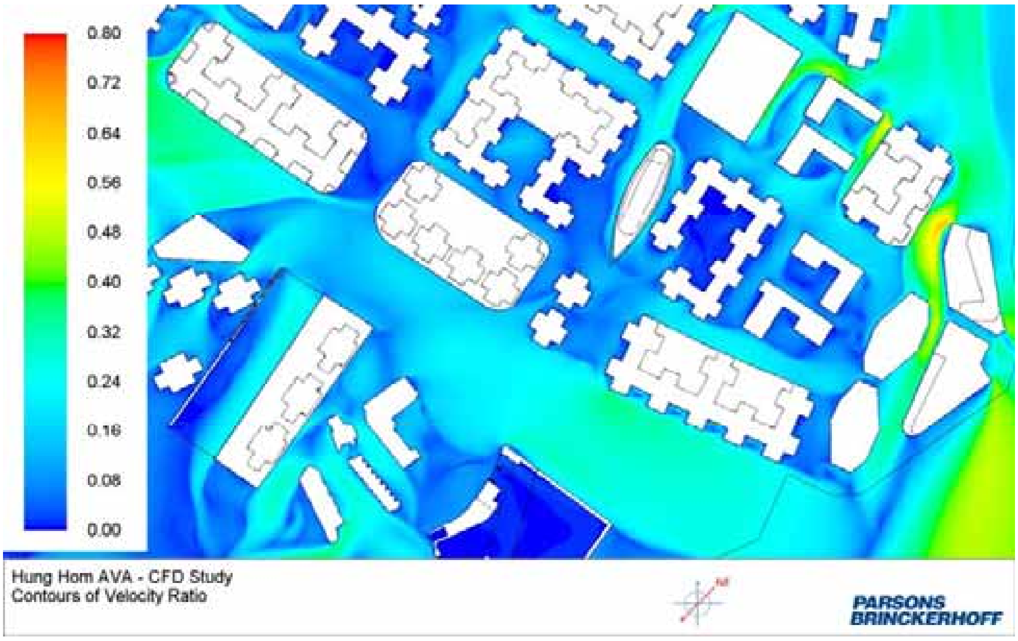


Figure 4.17 – Pedestrian Level VR Plot in Whampoa Garden with North-Eastern Wind - Notional Scheme

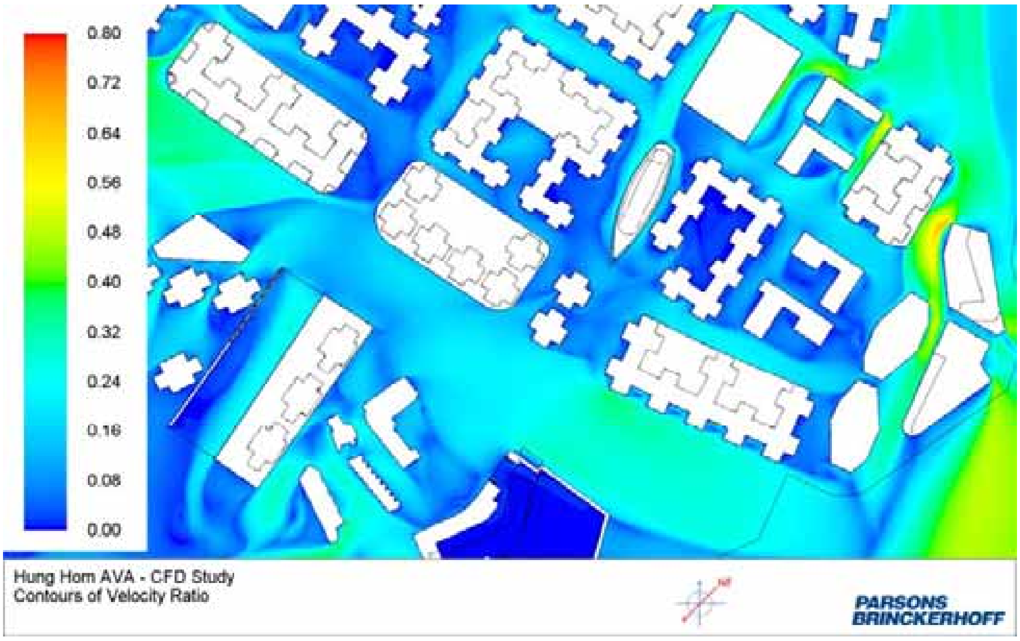


Figure 4.18 – Pedestrian Level VR Plot in Whampoa Garden with North-Eastern Wind - Proposed Scheme

To the south of Hung Hom South Road, the VR of individual scheme shows variation with the hotel building form. In general, the Urbis Scheme results in a lower site VR on this area. While the Notional Scheme and Proposed Scheme have a similar and yet better VR. It is because the podium mass is the smallest for the last two schemes, thus allow a better ventilation to the surrounding.

It is also observed that, with the use of the Proposed Scheme, the ventilation on the south side (the sea front) of the proposed commercial development on the western side of the hotel would result in a significant improvement than the Urbis Scheme and the Notional Scheme.

4.6. LVR and SVR of Different Building Schemes

According to the requirements for AVA Technical Guide, Local Velocity Ratio (LVR) on the open spaces, on the streets and places of the Project and Assessment Areas where pedestrians frequently access should be calculated and reported.

Based on the current site configuration, 15 key locations have been identified within the Assessment Area and 54 points (See Appendix A, Section 28 of AVA Technical Guide) have been distributed evenly among said locations. The nominal separation of the test points is around 30m. For the SVR, 50 points (See Appendix A, Section 27 of

AVA Technical Guide) were distributed evenly around the site perimeter with nominal separation of around 10m.

Figure 4.19 outlines these areas and the approximate test point locations.

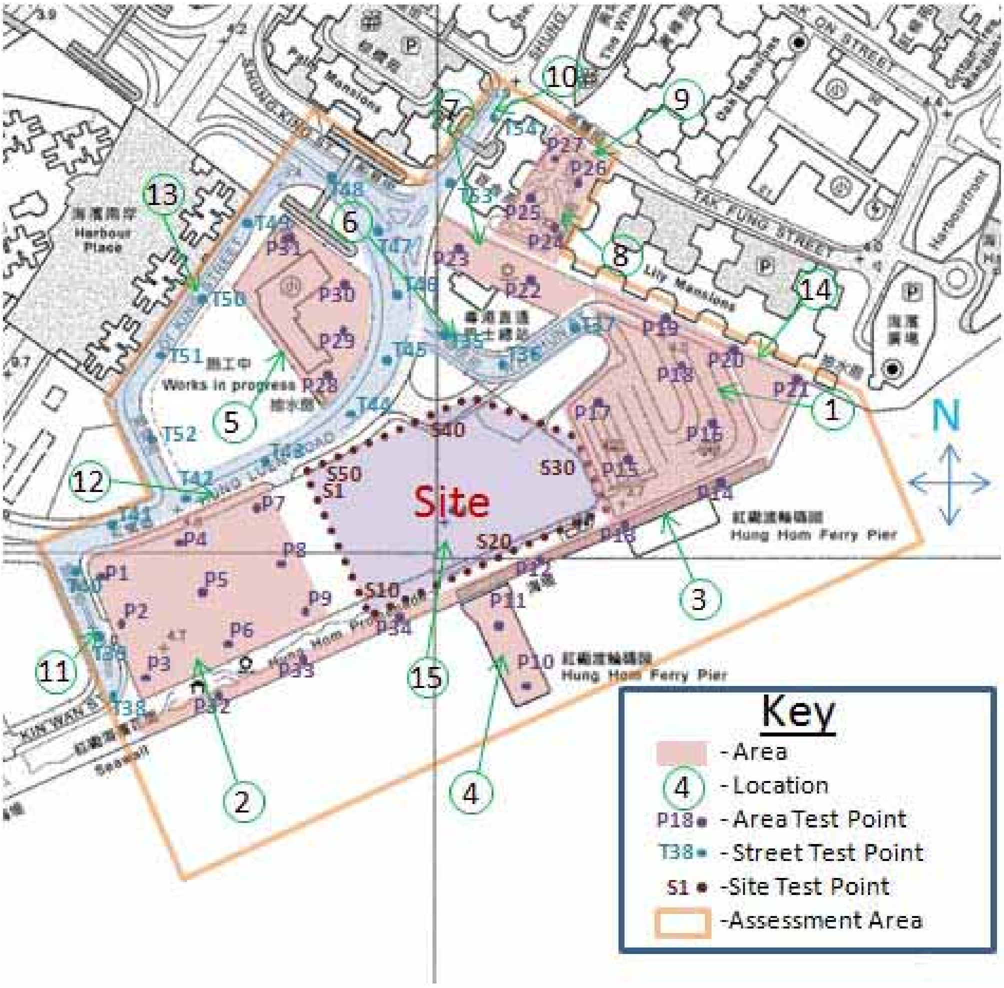


Figure 4.19 – Key Plan for Areas of Interested & Test Point Locations

Table 4.2 summarizes all these locations and the Spatial Averaged Velocity Ratio (SAVR) of them.

Table 4.2 – SAVR for Areas of Interest

Location Name	Relevant Test Points	Average VR Urbis	Average VR Notional	Average VR Proposed
1. Planned Comprehensive Development	P1-P9	0.20	0.22	0.21
2. Future Urban Park	P15-P18	0.34	0.35	0.38
3. Hung Hom Promenade	P12-P14 P32-34	0.27	0.30	0.32
4. Hung Hom Ferry Pier	P10-P11	0.30	0.32	0.31
5. Ma Tau Chung Gov. Primary 6. School (Hung Hom Bay)	P28-P31	0.18	0.18	0.19
6. Wa Shun Street	T35-T37	0.29	0.33	0.34
7. Amenity area to northeast of Wa Shun Street	P22-P23	0.35	0.33	0.33
8. Amenity area between Block 5 and 6 of Lily Mansions	P24-P25	0.18	0.18	0.19
9. Whampoa Garden Site 9	P26-P27	0.13	0.10	0.12
10. Shung King Street	T53-T54	0.14	0.14	0.15
11. Kin Wan Street	T38-T40	0.04	0.09	0.12
12. Hung Luen Road	T41-T48	0.13	0.13	0.15
13. Oi King Street	T49-T52	0.20	0.25	0.26
14. Garden Area of Lily Mansions	P19-P21	0.17	0.16	0.19
Average of All Area & Street Test Points	**P1-34, T35-T54**	**0.20**	**0.22**	**0.23**
15. Site Perimeter (SVR)	**S1-S50**	**0.20**	**0.24**	**0.25**

For numerical value of each point and the graphic presentation of the VR of these areas of interested, please refer to Appendix G.

Based on the numerical values of all test points of the SVR and SAVR above, the Overall LVR of each scheme are summarized in Table 4.3 for annual non-typhoon prevailing wind directions.

Table 4.3 – Overall LVR for Each Hotel Scheme

	Urbis	**Notional**	**Proposed**
Overall LVR	0.20	0.23	0.24

From the results of the SAVR for each interested area (Table 4.2), and also the Overall LVR (Table 4.3), the Proposed Scheme would result in a better air ventilation performance than the Urbis Scheme and Notional Scheme and therefore it is the recommended scheme.

5. Conclusions

Detailed 3D CFD simulations have been conducted for three hotel design options, namely Urbis Scheme, Notional Scheme and Proposed Scheme. With the consideration of annual non-typhoon prevailing wind directions in Hung Hom, i.e. from north to east, the pedestrian level wind environments are compared in details, based on the methodology outlined in "Technical Guide for Air Ventilation Assessment for Developments in Hong Kong" by Planning Department. For information purpose, the summer non-typhoon prevailing wind directions have also been analyzed.

The Site Wind Velocity Ratios (SVR) for each scheme based on annual prevailing wind direction and summer prevailing wind direction are summarized as follows:

SVR	**Urbis Scheme:**	**Notional Scheme**	**Proposed Scheme**
Annual Prevailing Wind Directions	0.20	0.24	0.25 (Preferred)
Summer Prevailing Wind Direction (for information only)	0.19	0.22	0.24 (Preferred)

Apart from the local effect as indicated by the SVR, the surrounding LVRs for each scheme are also compared in detailed for the annual non-typhoon prevailing wind directions. Based on the CFD VR contour plots and SAVR for the street segments and also the areas of interested, it is concluded that the VR to the north of Hung Hom South Road, i.e. Whampoa Garden, is rather low. Such a low value is due to the existing building form, which results in an unfavourable canopy effect and thus a low natural ventilation under the prevailing wind directions. And generally the VR is not sensitive to the choice of hotel design scheme since Whampoa Garden is located in the upstream direction.

While to the south of Hung Hom South Road, the VR of individual scheme shows variation with the hotel building form. The Urbis Scheme results in a lower VR on this area due to it large podium structure. The Notional Scheme and Proposed Scheme have a favourable feature that the hotel block on top of the podium has been so arranged to allow the prevailing wind directions, i.e. north to east, passing through it easily. And the podium structure is smaller than the Urbis Scheme and also arranged in steps. All these features would allow better ventilation to the surrounding.

The Overall average LVR of each scheme for annual non-typhoon prevailing wind directions are as follows:

	Urbis Scheme	**Notional Scheme**	**Proposed Scheme**
Overall LVR	0.20	0.23	0.24

Based on the findings of SVR, SAVR and Overall LVR, it is concluded that the Proposed Scheme would result in an overall better pedestrian level natural ventilation to itself as well as the surrounding areas and therefore is recommended.

Appendix A - Technical Guide for Air Ventilation Assessment for Developments in Hong Kong, by Hong Kong Planning Department

Technical Guide for Air Ventilation Assessment
for Developments in Hong Kong

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

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

Indicator

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

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

Page 1

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

(a) Identifies good design features.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Site Wind Availability Data

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

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

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

13. Using appropriate mathematical models (e.g. MM5 and CALMET), it is possible to simulate and estimate the site wind availability data ($V\infty$). 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 summarise the overall impact on the wind environment for easy comparison:

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

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

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

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

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

(b) A section on results of the **Expert Evaluation**. Concerns and

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potential problems should be identified. Focuses and methodologies of further studies should be defined.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Appendix B - The Use of FLUENT and HARPOON by US EPA

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Pollution Dispersion in Urban Landscapes

By Alan Huber, *National Oceanic and Atmospheric Administration, ASMD*, in partnership with *US Environmental Protection Agency, National Exposure Research Laboratory*, Research Triangle Park, North Carolina, USA; Matthew Freeman and Richard Spencer, *US EPA Environmental Modeling and Visualization Laboratory, Lockheed-Martin Operations Support*, Research Triangle Park, North Carolina, USA; Walter Schwarz, Brian Bell, and Karl Kuehlert, *Fluent Inc.*

Understanding the pathways of toxic air pollutants from their source through the air humans breathe in urban areas is of critical interest to governmental agencies that have a responsibility to protect the public health and welfare. Rapid assessments of risk, such as the migration of toxic gases related to major fires or chemical spills, are vital to first responders, local officials, federal officials, and the public. The scientific shortcomings are especially serious for incidents that occur in an urban center where the airflow around large buildings is very complex and poorly understood.

High-resolution, high-fidelity CFD simulations have long been used in the aerospace and automotive industries to evaluate the detailed airflow associated with the design and operation of airplanes and cars. CFD techniques also have the potential to be used to describe, for example, the flow of pollutants from accidental explosions, fires, or routine emissions from human activities such as driving motor vehicles; or the release of biological agents associated with an accident or terrorist event.

In recent years, CFD modeling has emerged as a promising technology for such assessments. Already in use by early-adopters, CFD has demonstrated the potential to yield accurate solutions because it is based on fundamental physics, on the effects of detailed three-dimensional geometry, and on local environmental conditions. However, today's CFD tools are not well evaluated for environmental modeling. Best-practice methodologies have not been established. Furthermore, today's CFD tools are not tailored to the specific needs and nomenclature of environmental scientists. All of these factors limit the ability of this group of researchers to benefit from CFD as a routine assessment technique.

Through a Cooperative Research and Development Agreement (CRADA), Fluent Inc. and the US Environmental Protection Agency (EPA) have worked towards the evaluation and demonstration of CFD for large-scale environmental applications. Efforts are being made to demonstrate best practices for using CFD as a tool for estimating potential human exposures to local sources of toxic air contaminants in geometrically complex environments.

In addition to this general goal,

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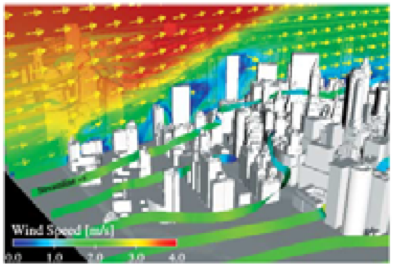
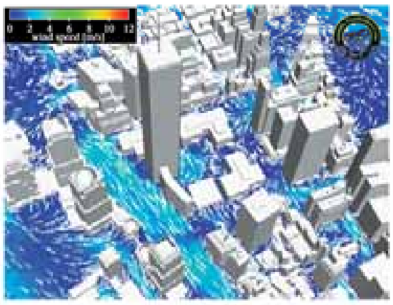
An example of the detailed building geometry for Manhattan, presented with a surface mesh on the ground; the mesh was created using Harpoon from CEI



A simulation of the complex wind patterns between the buildings of Manhattan, shown using vectors, pathlines, and contours of velocity on a vertical slice



Near surface winds from a CFD solution for lower Manhattan; while the solution has a 1-3m resolution near the ground only about 10% of the vectors are plotted; the winds are from the Northwest (upper left corner)

Fluent has been supporting the US EPA in developing simulations for large sections of Manhattan, which may be one of the most complex building environments worldwide. While it has been a challenging exercise to set up working CFD models that describe the detailed building environment for Manhattan, there have been many lessons learned that are making it easier to set up similarly complex urban environments for future studies. To date the project has focused on steady-state solutions using the widely used k-ε turbulence models. Ongoing developments are being extended to include unsteady solutions and higher order turbulence models as well.

Modeling large numbers of unique buildings typical of major urban areas presents special challenges in developing an applicable computational mesh. The digital geometries of many of the buildings in large cities have already been obtained and are being updated by government agencies and commercial vendors. While the typical building geometries from these sources easily support visual models, minor flaws that may not be visible lead to difficulties for CFD modeling. A great deal of development work has gone into improving and streamlining the clean-up procedures for flawed geometries of buildings and for other objects in general, such as manufactured equipment.

Once the geometry meets certain requirements, it is used for the creation of a surface mesh and subsequently, a volume mesh. For the steady-state simulations of urban areas performed to date, a mesh with computational cells one to two meters in size near the building surfaces has proven sufficient. This results in models with no more than 50 million cells overall, which can be handled by the computing resources available for the project. For future work the present methods are scalable to larger sized models.

One recent EPA study involved the dispersion of pollutants emanating from Ground Zero following the collapse of the World Trade Center (WTC), and this case has provided a unique opportunity to develop and demonstrate the capabilities of CFD for environmental analysis. Winds in urban micro-environments are very complex because of blockages

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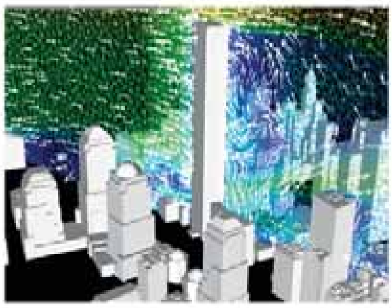
and aerodynamic influences from the built environment. Visualizations of the flow on vertical slices through city streets or horizontal slices near ground level illustrate the complexity in the wind patterns. Even if only 10 percent of the solution vectors are plotted in a typical display, the pattern of downward airflow on the windward side of a building and upward flow on the leeward side is clear.

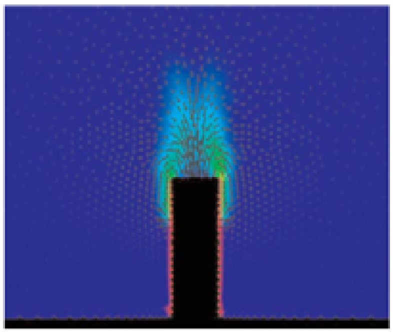
Before the collapse of the WTC, the buildings stored a great deal of potential energy, owing to their extreme height above the ground. During the collapse, this potential energy was converted to kinetic energy, and a large amount of momentum was generated. Each falling building entrained air into the volume previously occupied by the building, forming large circulation currents and strong local winds. In addition to the motion of the tower, the airflow in the vicinity of the WTC during the collapse was governed by the local built landscape and the air and smoke that squeezed out of the building and discharged into the surroundings as individual floors collapsed.

To simulate the fall of the tower, the dynamic mesh model in FLUENT was used. This capability allows the arbitrary motions of walls to be defined. By considering only the deformation of the outer shape of the building, the collapsing tower was essentially modeled as a piston approaching the ground surface. Approximately 90 to 95% of the volume of the WTC was assumed to be air and smoke; the remaining volume contained solid material.

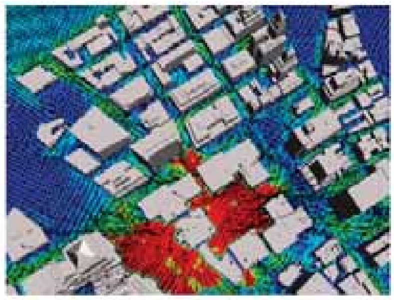
The collapse of the tower takes about 15 seconds. The CFD results indicate that the collapsing tower creates vortex structures in the surrounding air, which transport gaseous constituents and particulate matter radially outward from the base of the buildings. Particles of different size are injected into the airflow from each collapsed floor. The dispersion of the particles is directly controlled by the airflow and turbulence field. The smallest particles remain suspended within the displaced volume of the collapsing building, while the larger particles fall to the ground. The radial impulse created by the collapsed tower, with velocities of up to 30 to 40 m/s, is short-lived however, and soon the material is transported by the prevailing winds through lower



Winds from the northwest and the resulting airflow on a vertical plane in lower Manhattan



CFD simulation of a collapsing building showing air entrainment into the collapsed volume



Surface winds, 5m above the ground, immediately following the initiation of the building collapse

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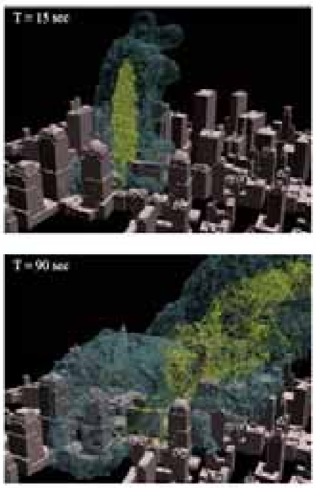


The outer boundaries of smoke (gray) and a particle cloud (yellow) 15 (top) and 90 (bottom) seconds after the start of the building collapse

Manhattan and into the surrounding metropolitan area.

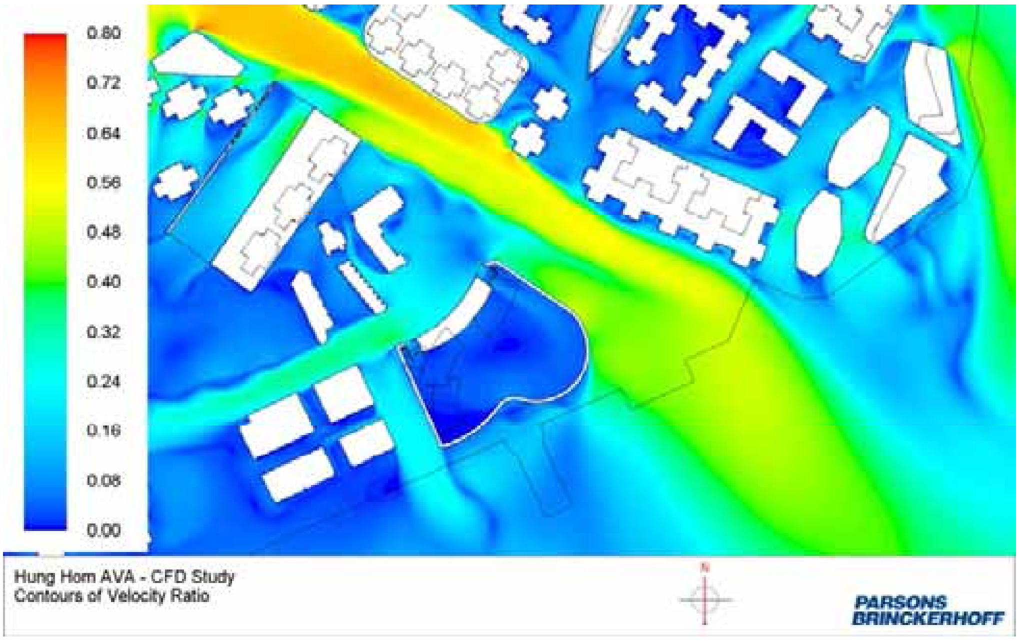
The CFD results are being compared to data recorded in an EPA wind tunnel model using post 9/11 conditions with westerly or south-westerly winds. Generally good comparison has been found at several measurement points, particularly in vertical profiles of wind speed. Other variables such as wind direction and turbulent kinetic energy have also been compared. Overall, these results support the CFD methodology.

The application of CFD simulations may evolve for routine environmental use following further demonstrated evaluations with wind tunnel models and field measurements. Measurements alone will rarely be sufficient for accurate planning or understanding what may have happened during an event. Ongoing developments and demonstrations of the reliability and accuracy of CFD simulations will lead to its broad future application for urban air quality and homeland security studies. As has happened for the aerospace and automotive industries, continued evaluation work will make CFD simulations increasingly trusted by environmental engineers for applications such as this. ■

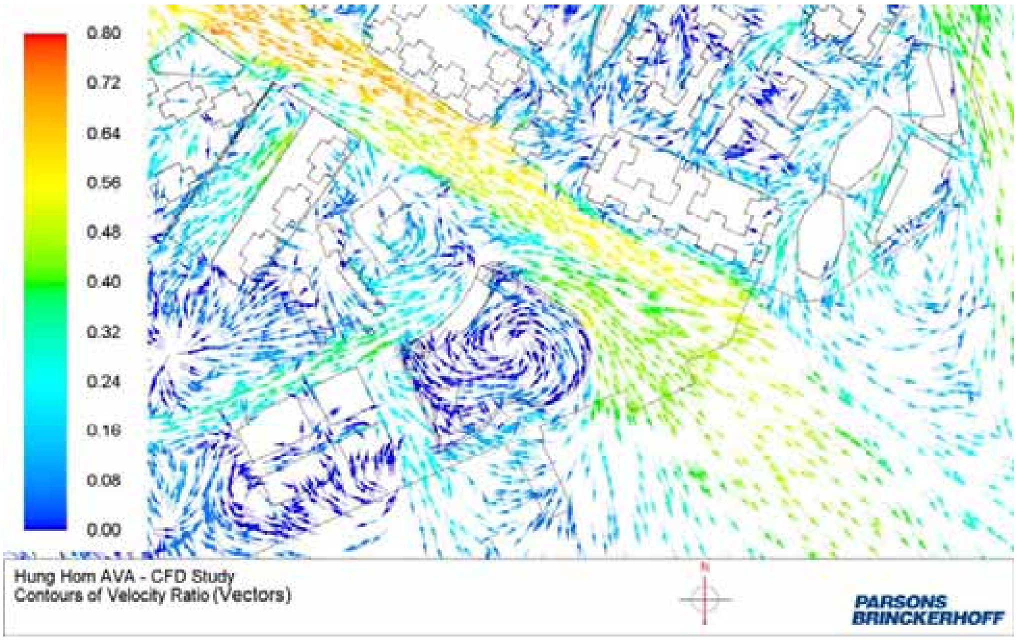
Disclaimer: Although this work has been reviewed by EPA and NOAA and approved for publication, it does not necessarily reflect their policies or views.

Acknowledgement: Scientific visualization and high performance computing were provided through support from the US EPA's National Environmental Computing Center.

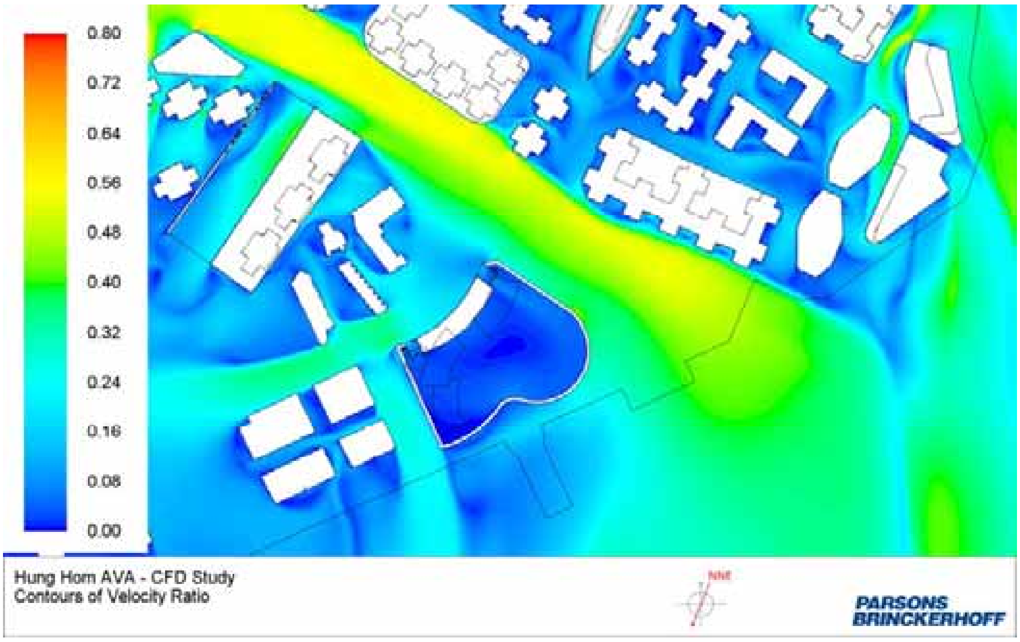
Appendix C - Summary of Velocity Ratio and Velocity Vector Plots for Urbis Scheme



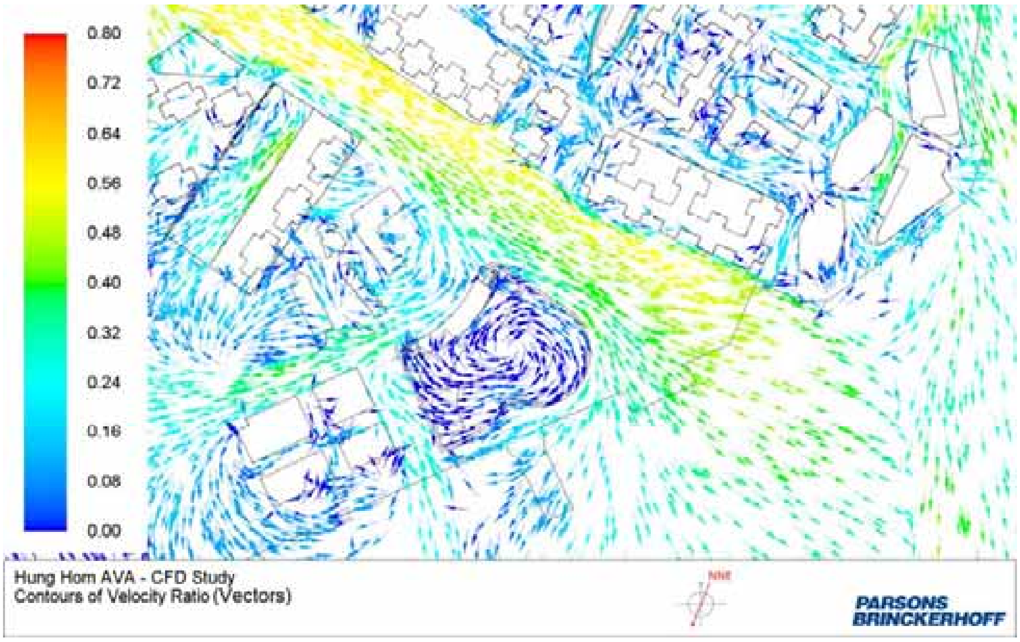
Velocity Ratio Plot at 2m above Ground for Northern Wind - Urbis Scheme



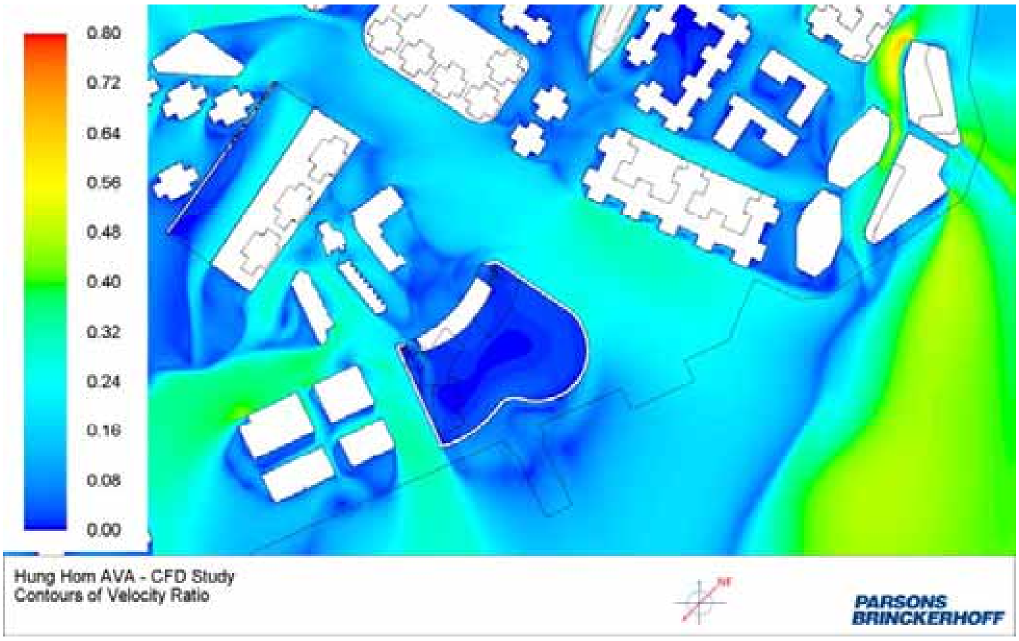
Velocity Vector Plot for Northern Wind - Urbis Scheme



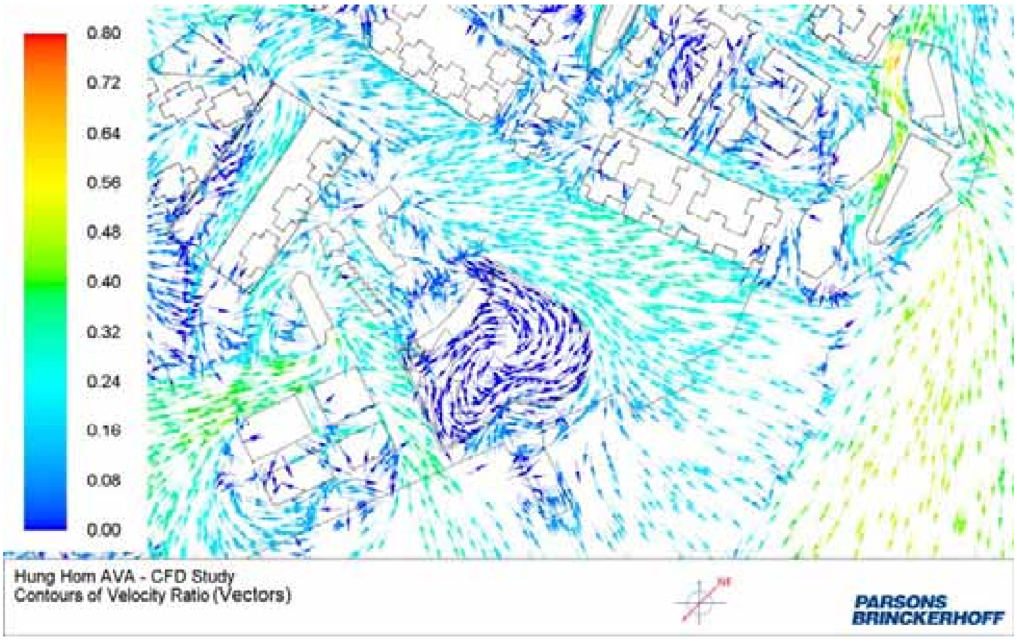
Velocity Ratio Plot at 2m above Ground for North-North-Eastern Wind - Urbis Scheme



Velocity Vector Plot for North-North-Eastern Wind - Urbis Scheme

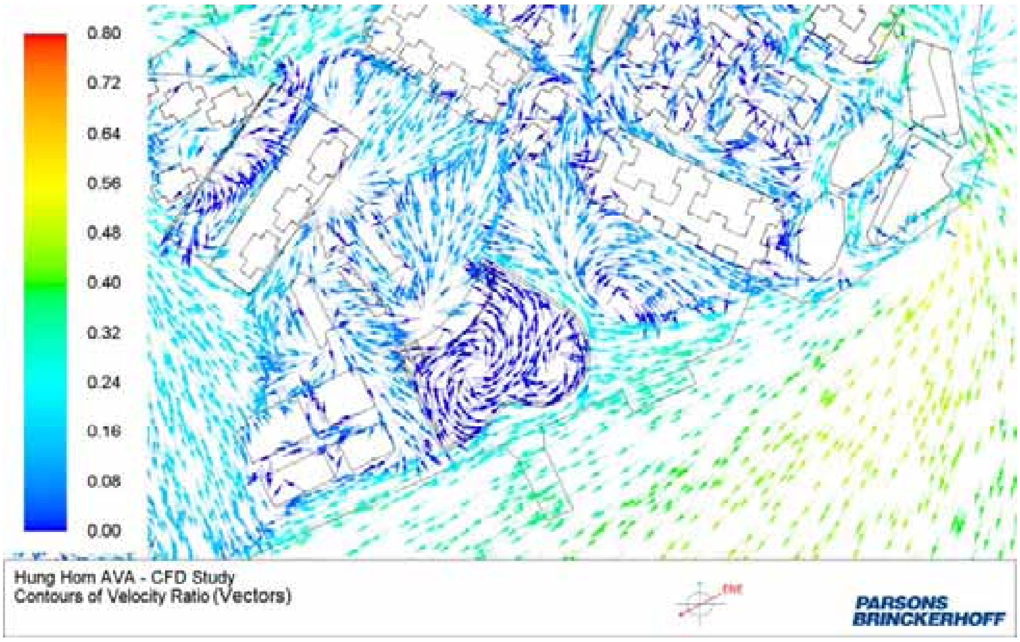


Velocity Ratio Plot at 2m above Ground for North-Eastern Wind - Urbis Scheme

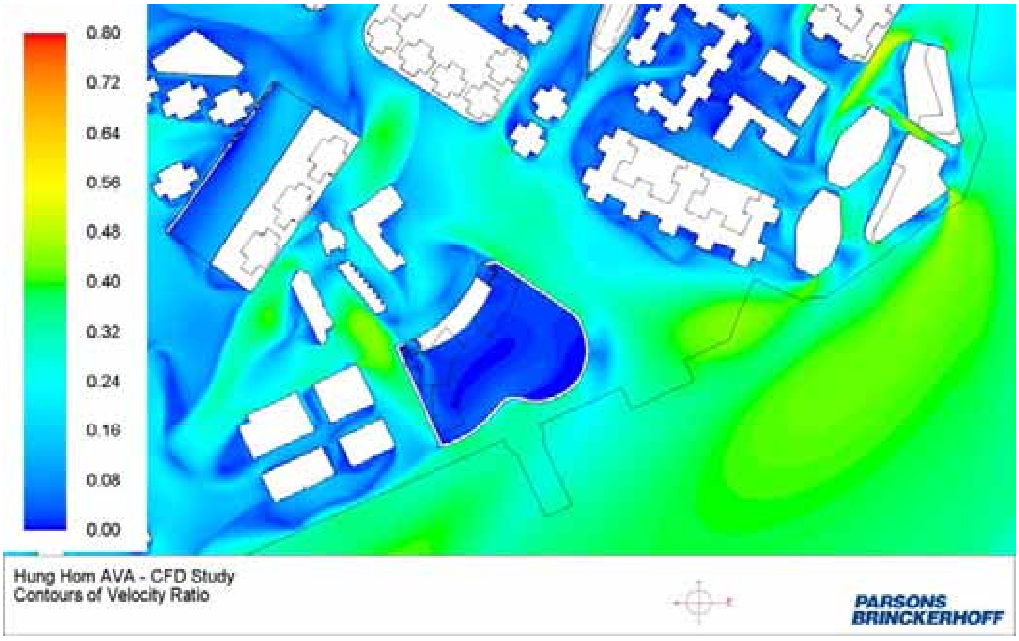


Velocity Vector Plot for North-Eastern Wind - Urbis Scheme

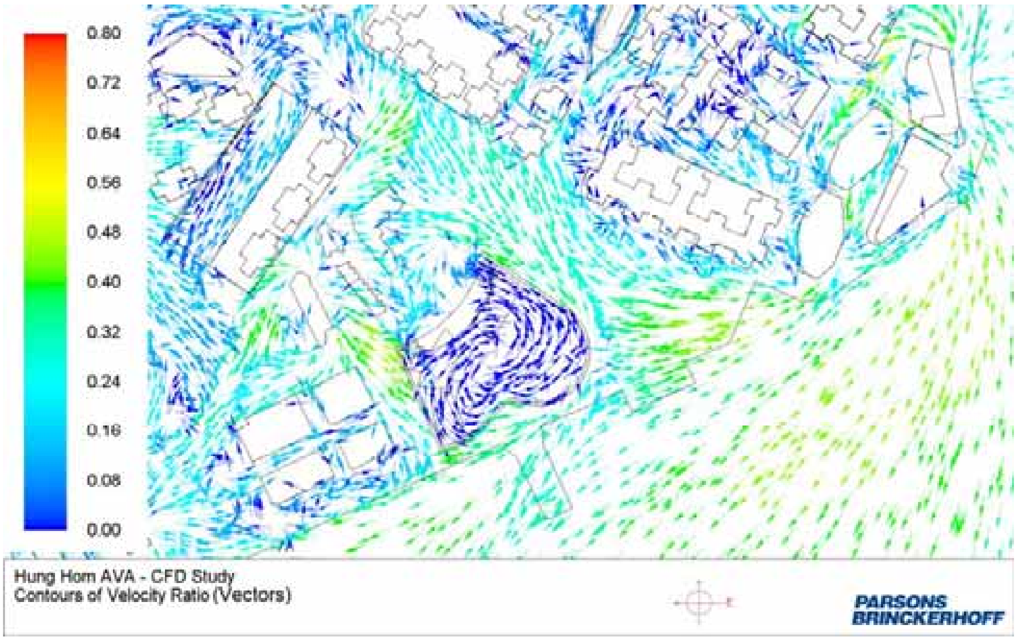
Velocity Ratio Plot at 2m above Ground for East-North-Eastern Wind - Urbis Scheme



Velocity Vector Plot for East-North-Eastern Wind - Urbis Scheme



Velocity Ratio Plot at 2m above Ground for Eastern Wind - Urbis Scheme



Velocity Vector Plot for Eastern Wind - Urbis Scheme

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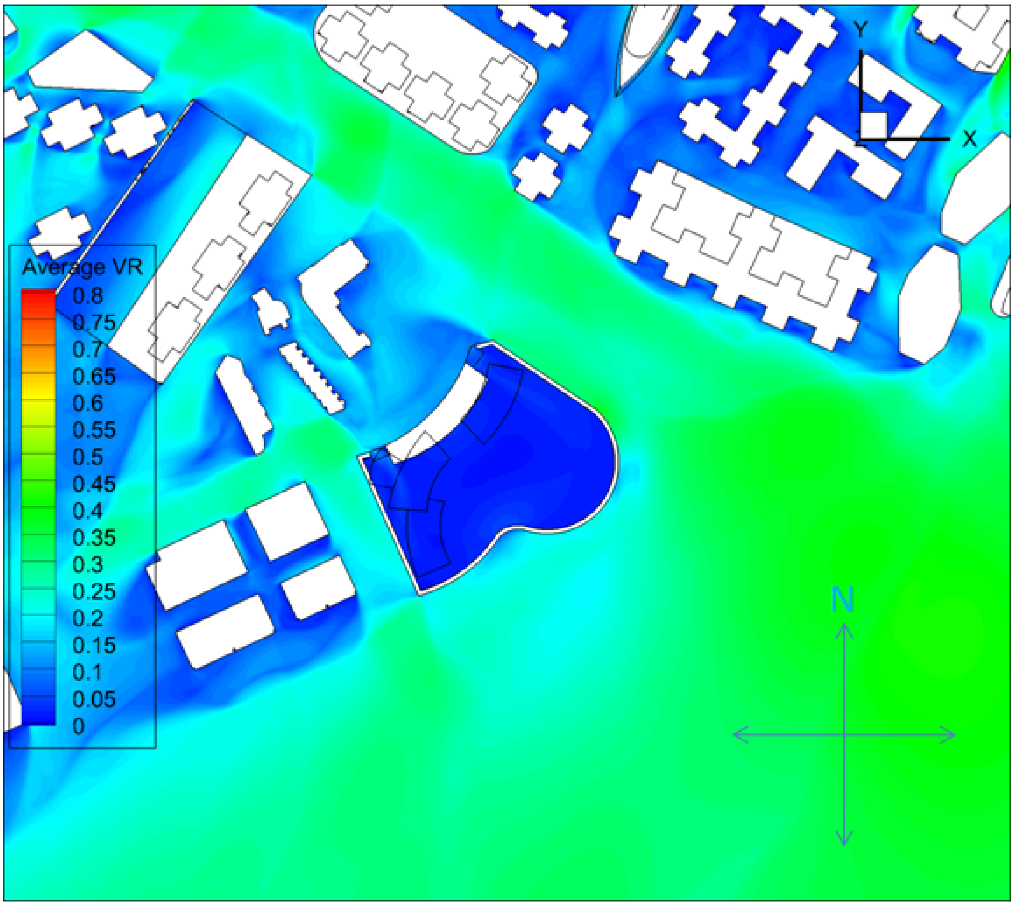
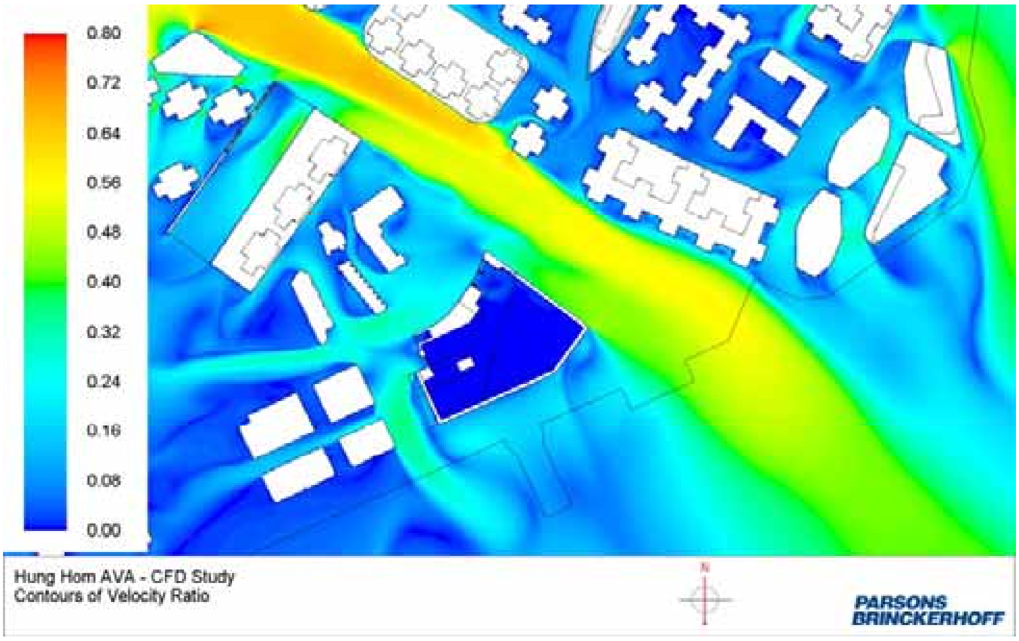
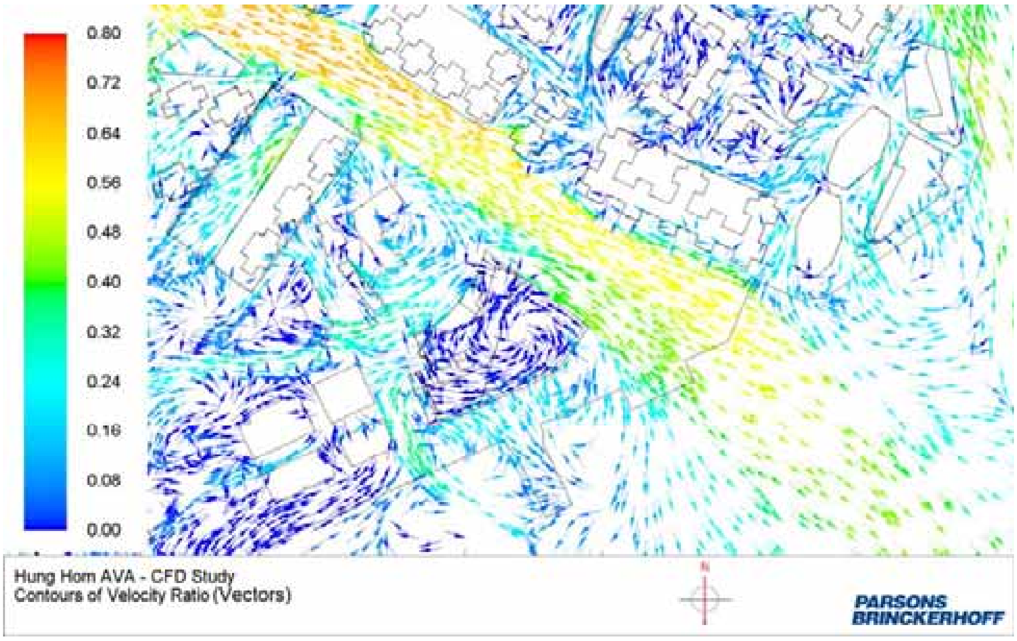


Average Velocity Ratio Plot at 2m above Ground - Urbis Scheme

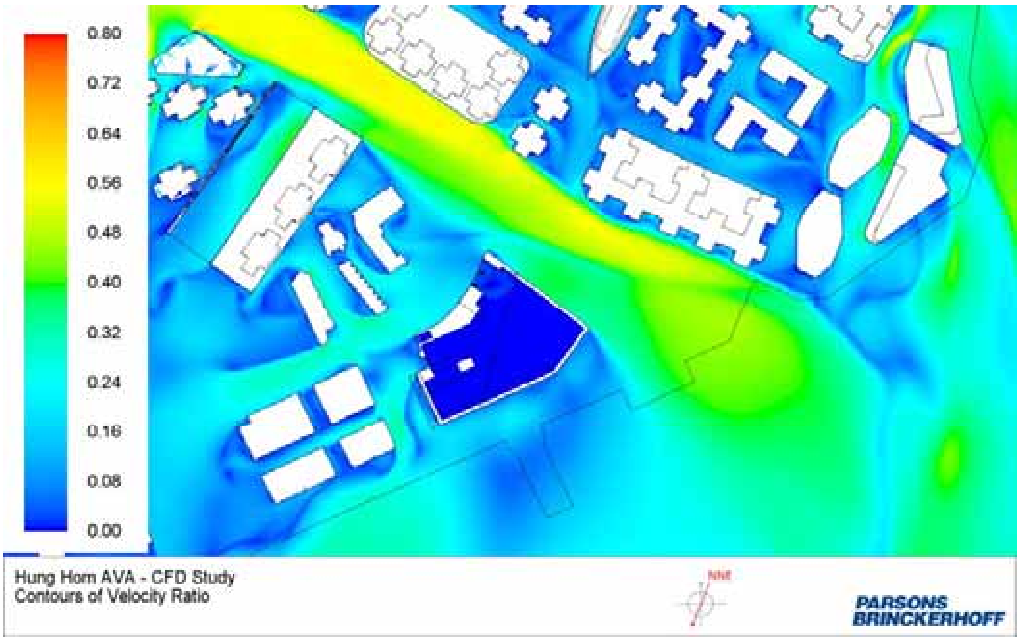
Appendix D - Summary of Velocity Ratio and Velocity Vector Plots for Notional Scheme



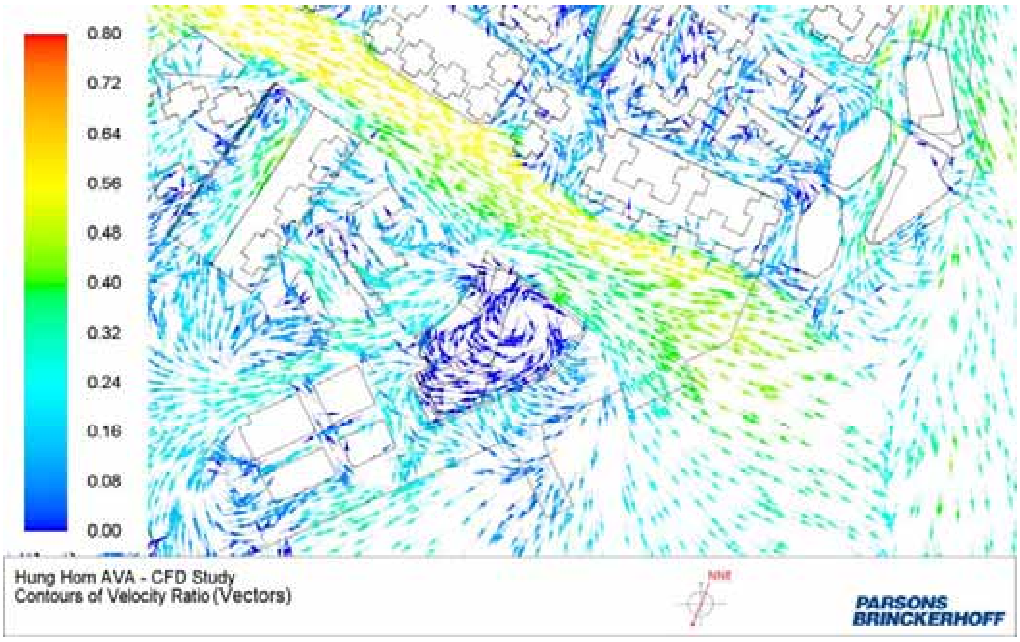
Velocity Ratio Plot at 2m above Ground for Northern Wind - Notional Scheme



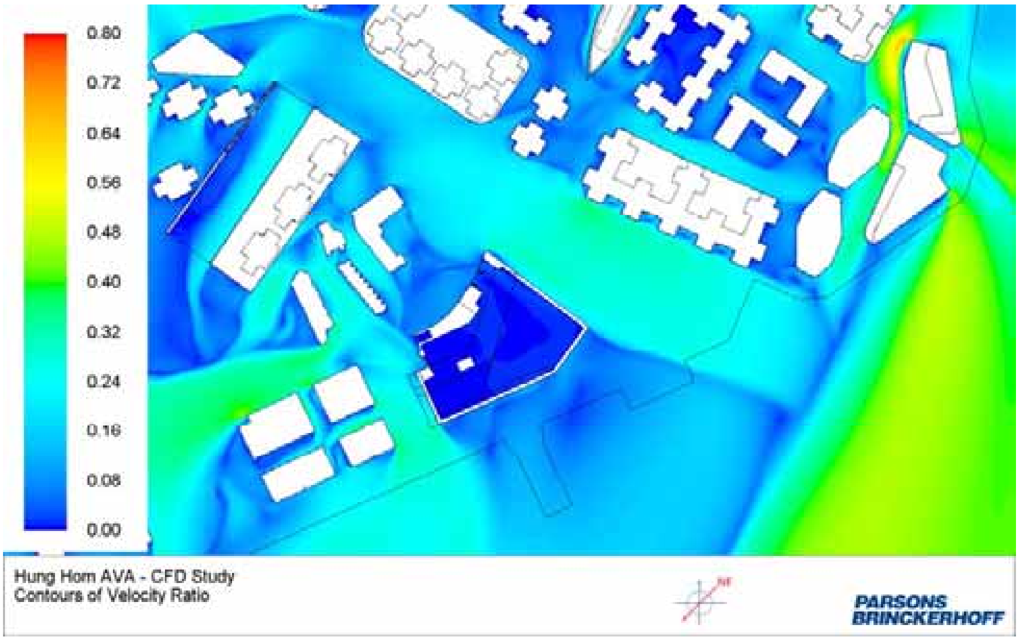
Velocity Vector Plot for Northern Wind - Notional Scheme



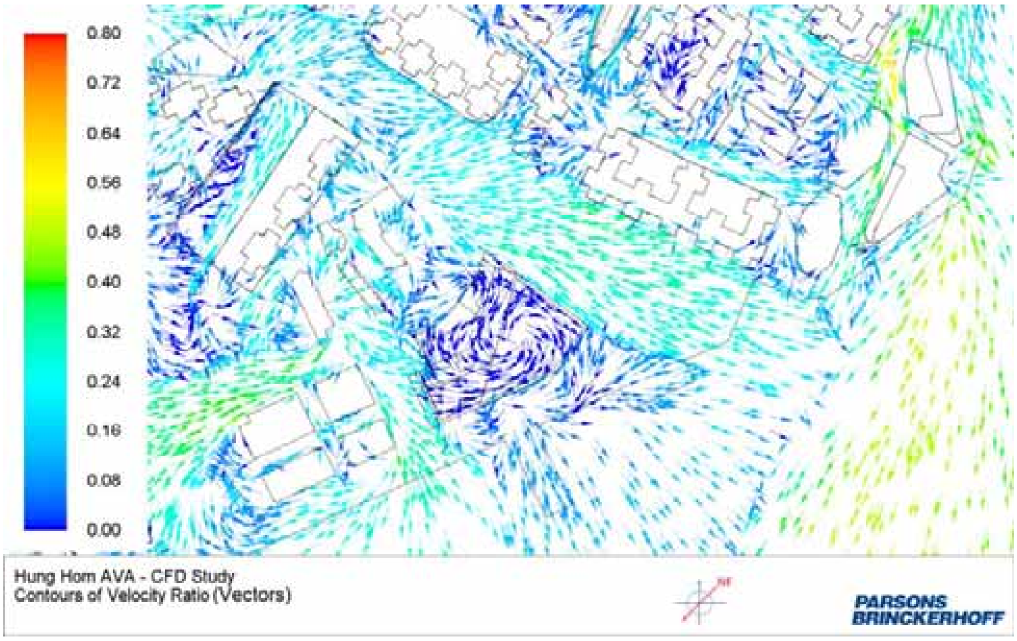
Velocity Ratio Plot at 2m above Ground for North-North-Eastern Wind - Notional Scheme



Velocity Vector Plot for North-North-Eastern Wind - Notional Scheme

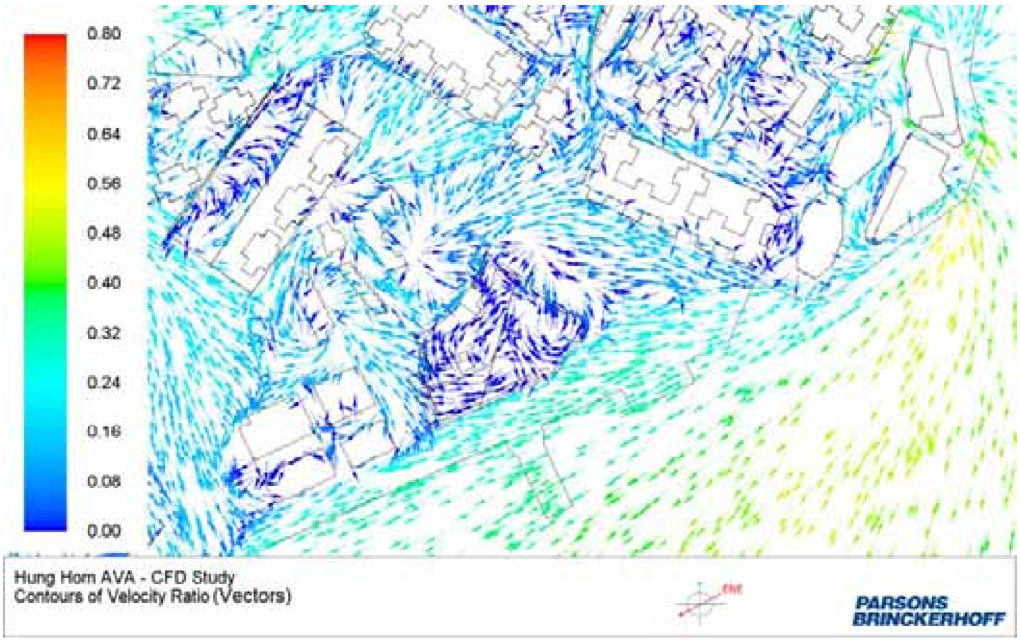


Velocity Ratio Plot at 2m above Ground for North-Eastern Wind - Notional Scheme

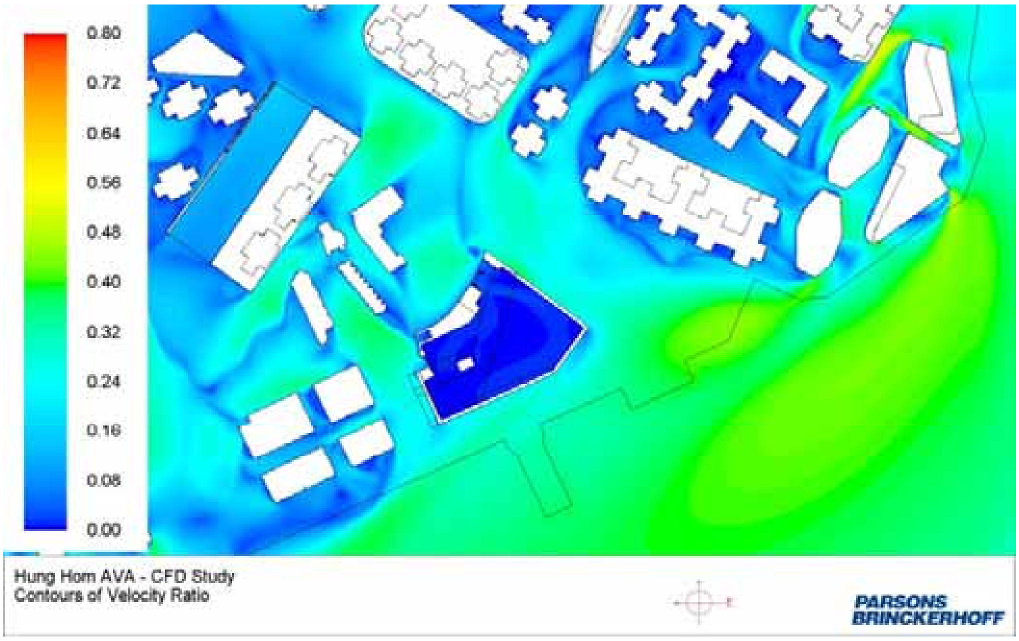


Velocity Vector Plot for North-Eastern Wind - Notional Scheme

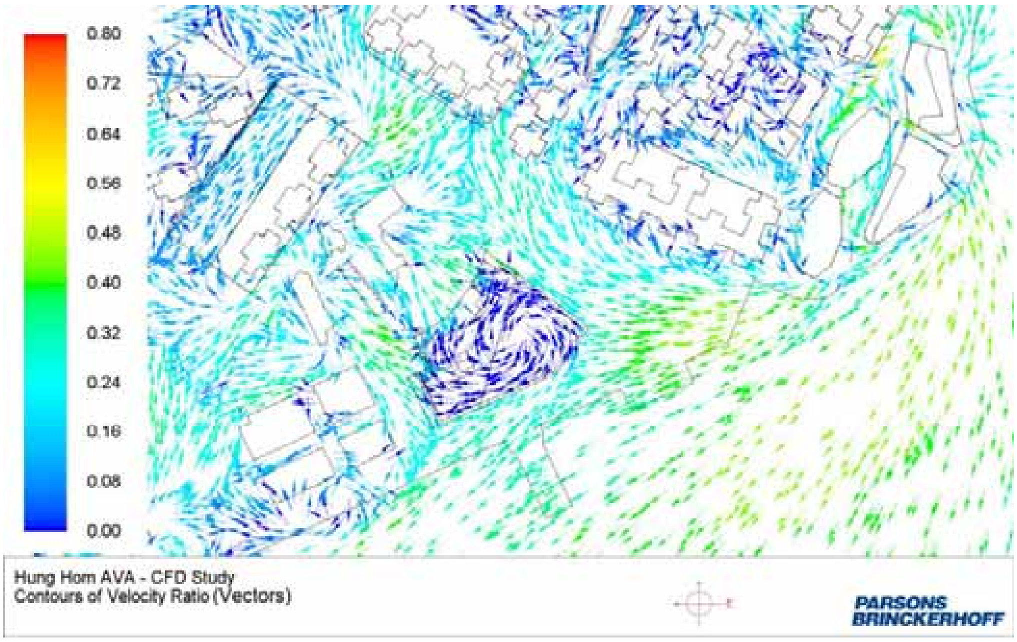
Velocity Ratio Plot at 2m above Ground for East-North-Eastern Wind - Notional Scheme



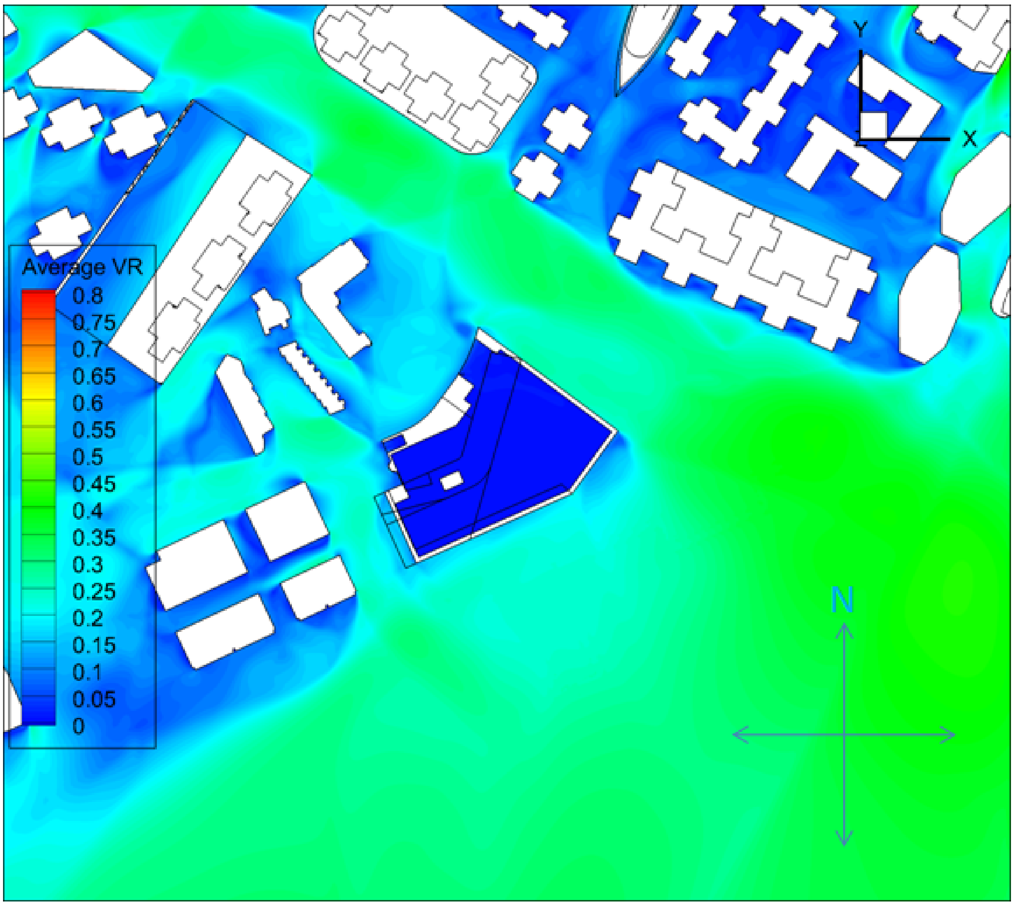
Velocity Vector Plot for East-North-Eastern Wind - Notional Scheme



Velocity Ratio Plot at 2m above Ground for Eastern Wind - Notional Scheme

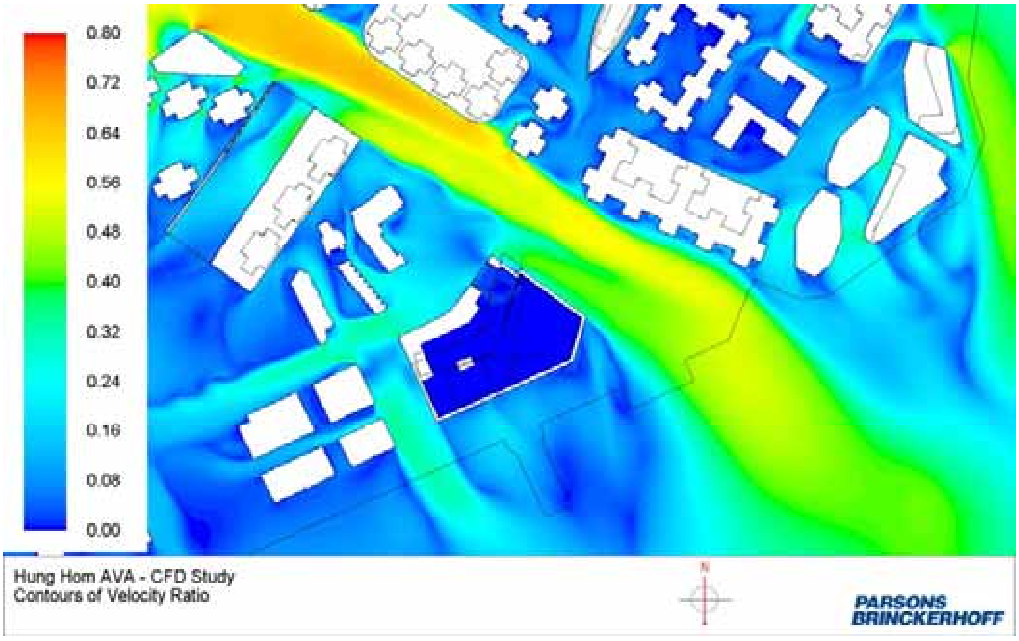


Velocity Vector Plot for Eastern Wind - Notional Scheme

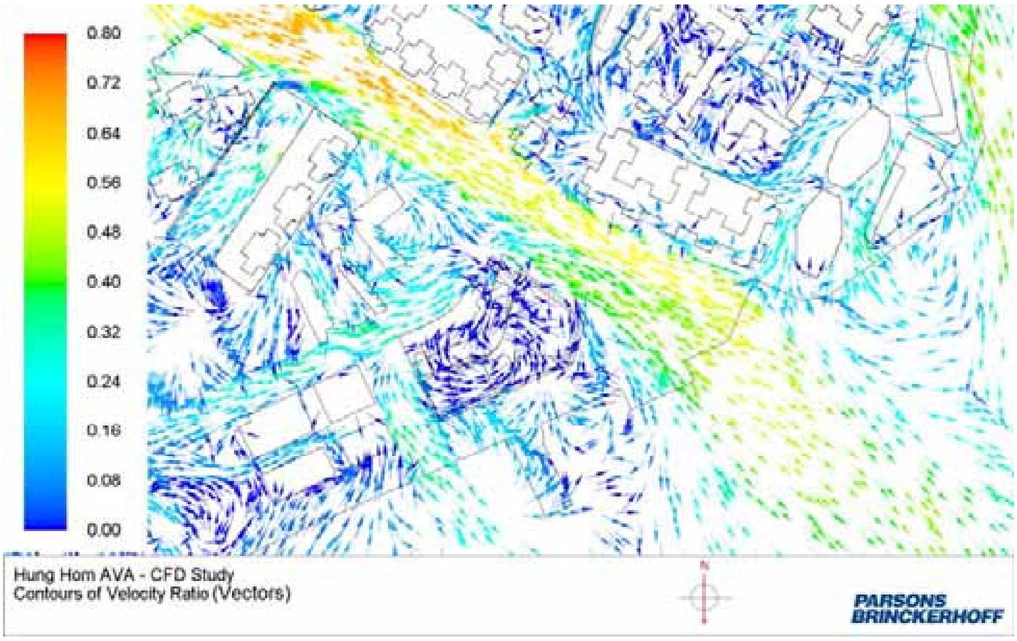


Average Velocity Ratio Plot at 2m above Ground - Notional Scheme

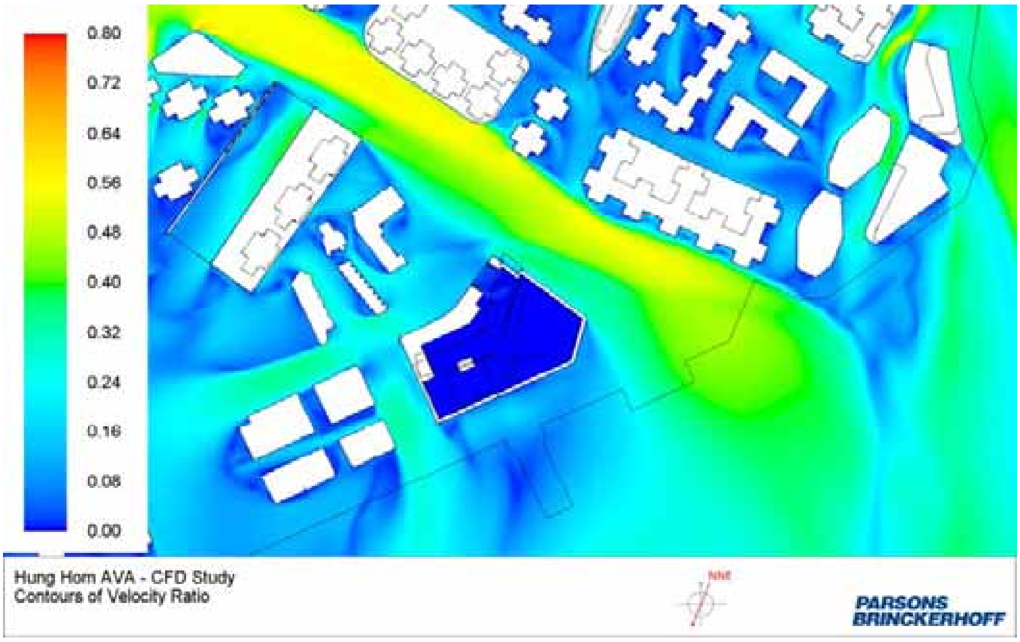
Appendix E - Summary of Velocity Ratio and Velocity Vector Plots for Proposed Scheme



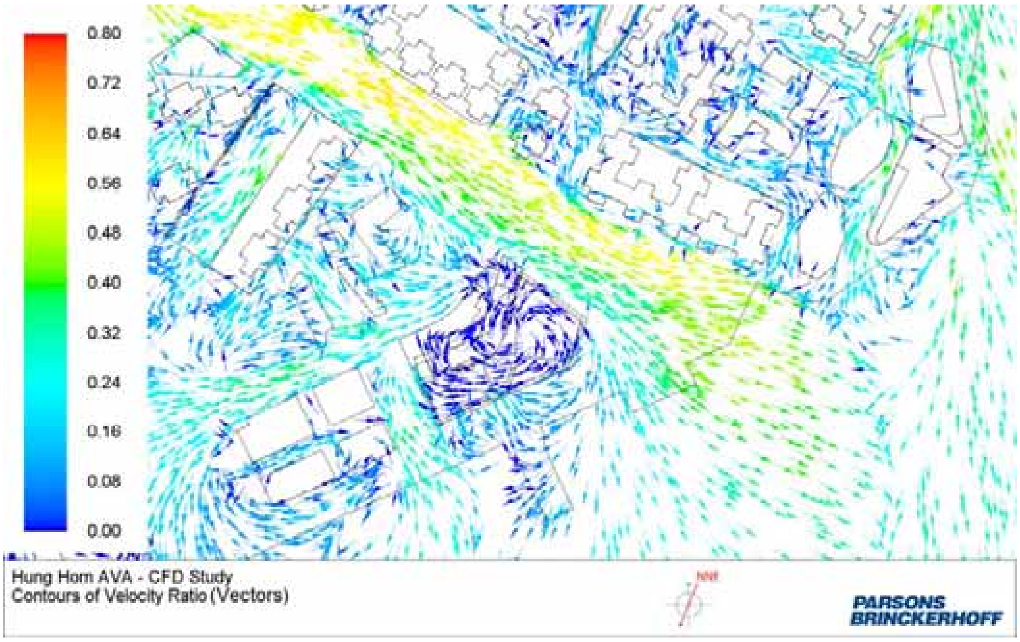
Velocity Ratio Plot at 2m above Ground for Northern Wind - Proposed Scheme



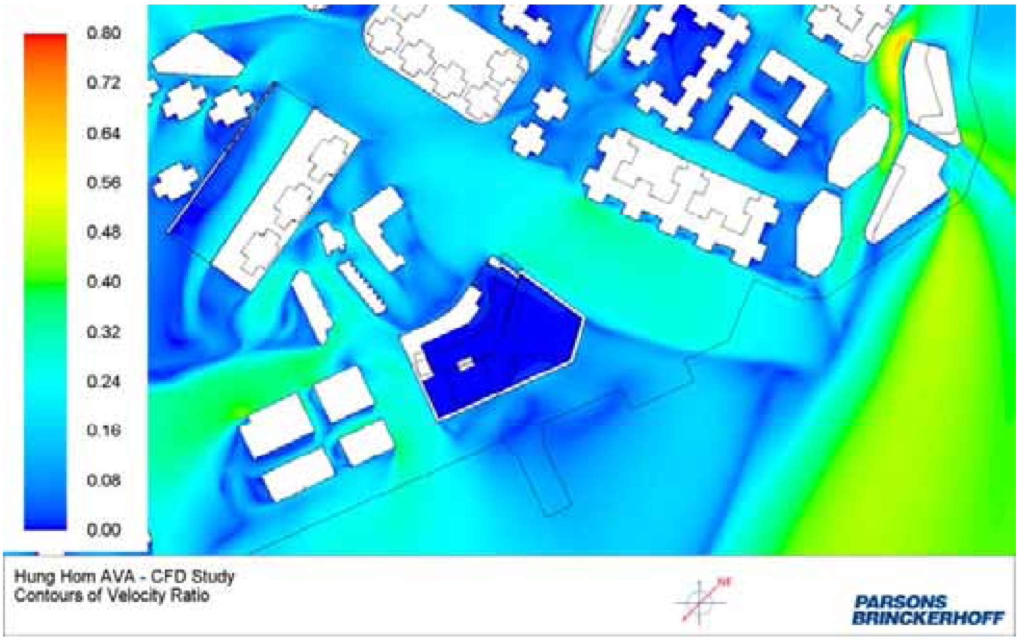
Velocity Vector Plot for Northern Wind - Proposed Scheme



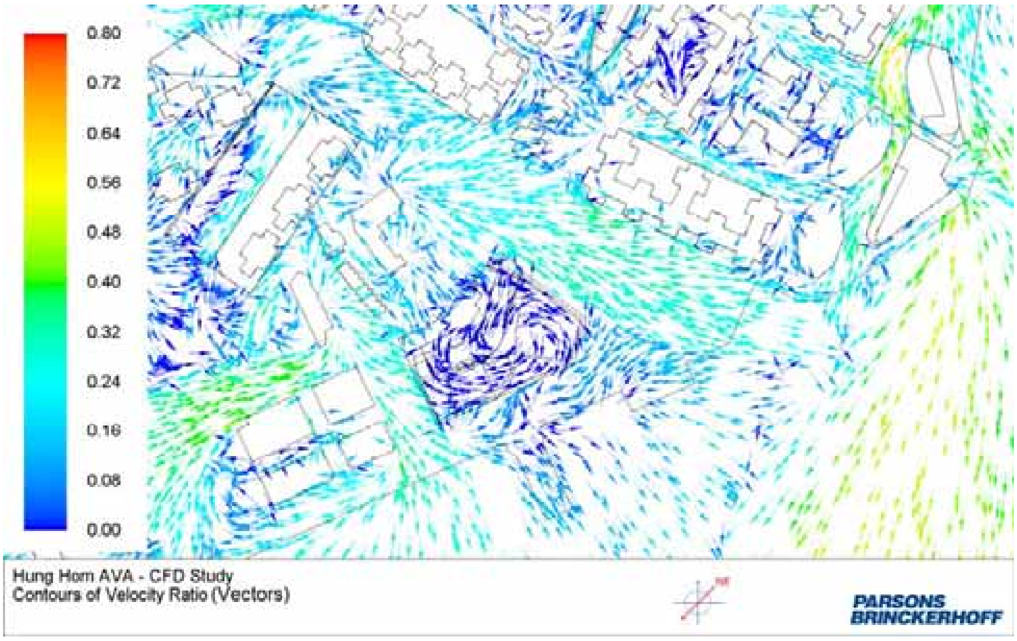
Velocity Ratio Plot at 2m above Ground for North-North-Eastern Wind - Proposed Scheme



Velocity Vector Plot for North-North-Eastern Wind - Proposed Scheme

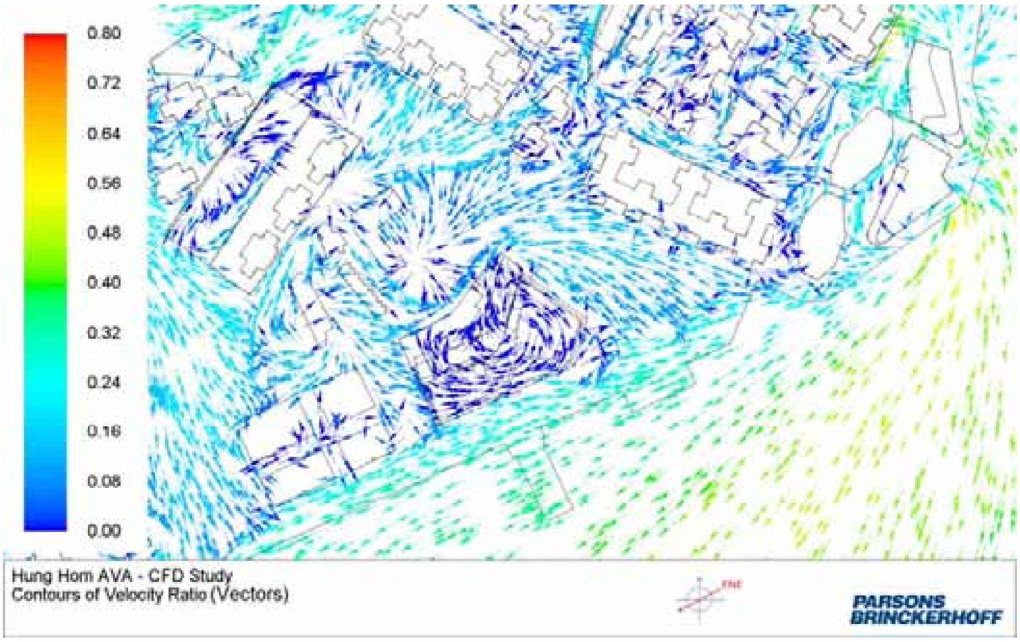


Velocity Ratio Plot at 2m above Ground for North-Eastern Wind - Proposed Scheme

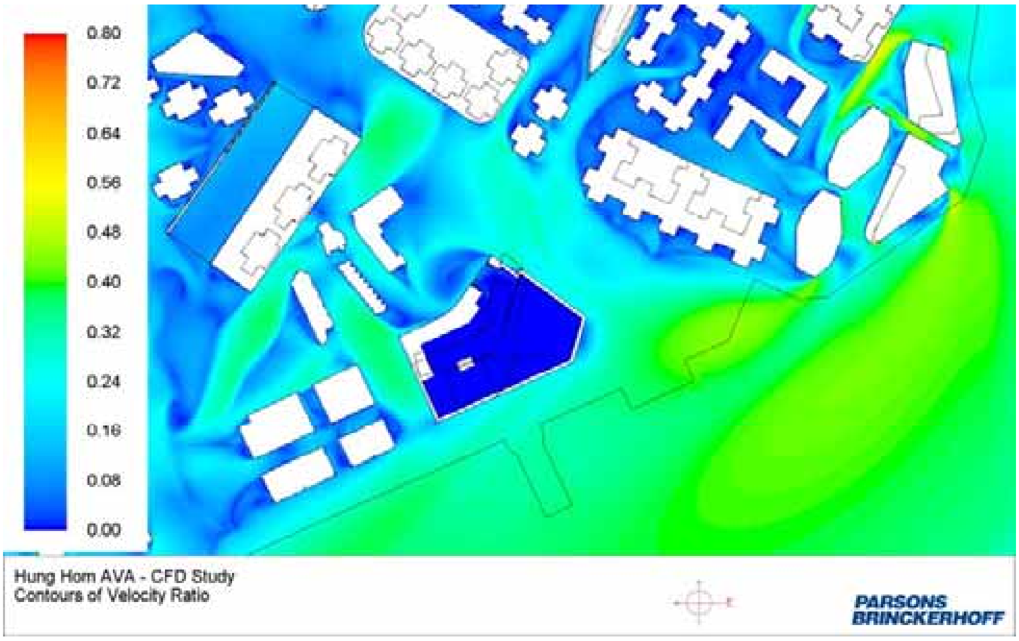


Velocity Vector Plot for North-Eastern Wind - Proposed Scheme

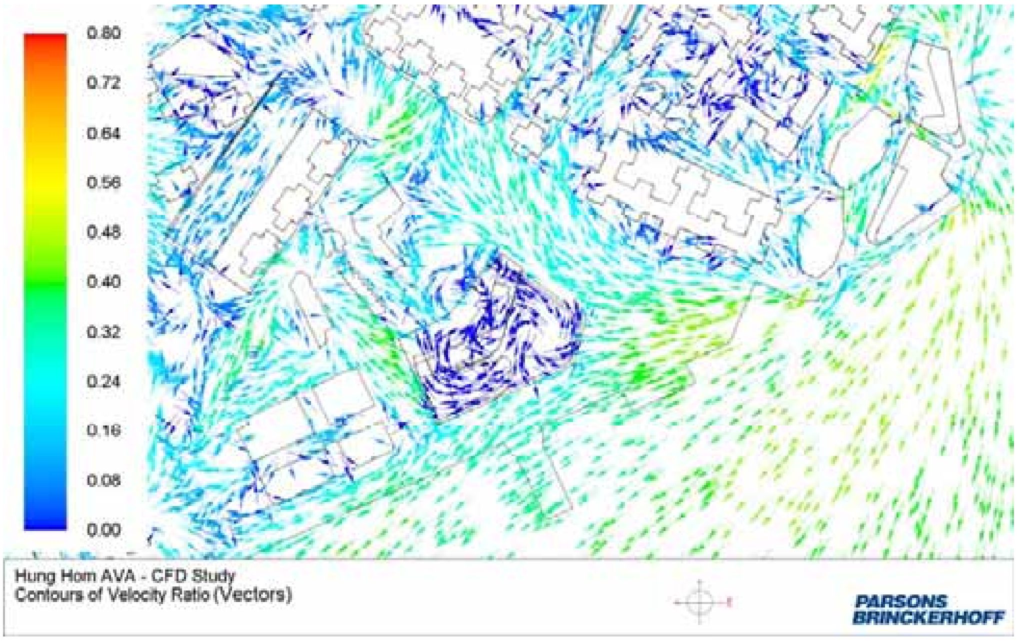
Velocity Ratio Plot at 2m above Ground for East-North-Eastern Wind - Proposed Scheme



Velocity Vector Plot for East-North-Eastern Wind - Proposed Scheme



Velocity Ratio Plot at 2m above Ground for Eastern Wind - Proposed Scheme



Velocity Vector Plot Eastern Wind - Proposed Scheme

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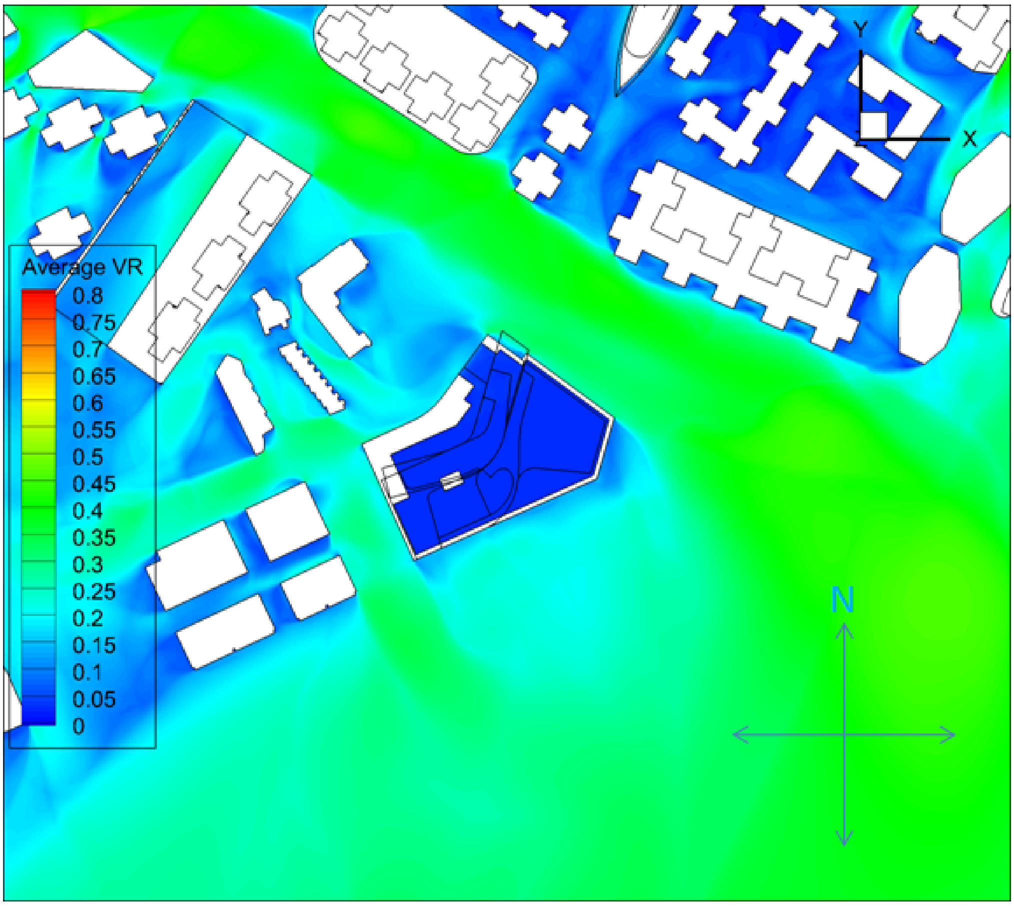
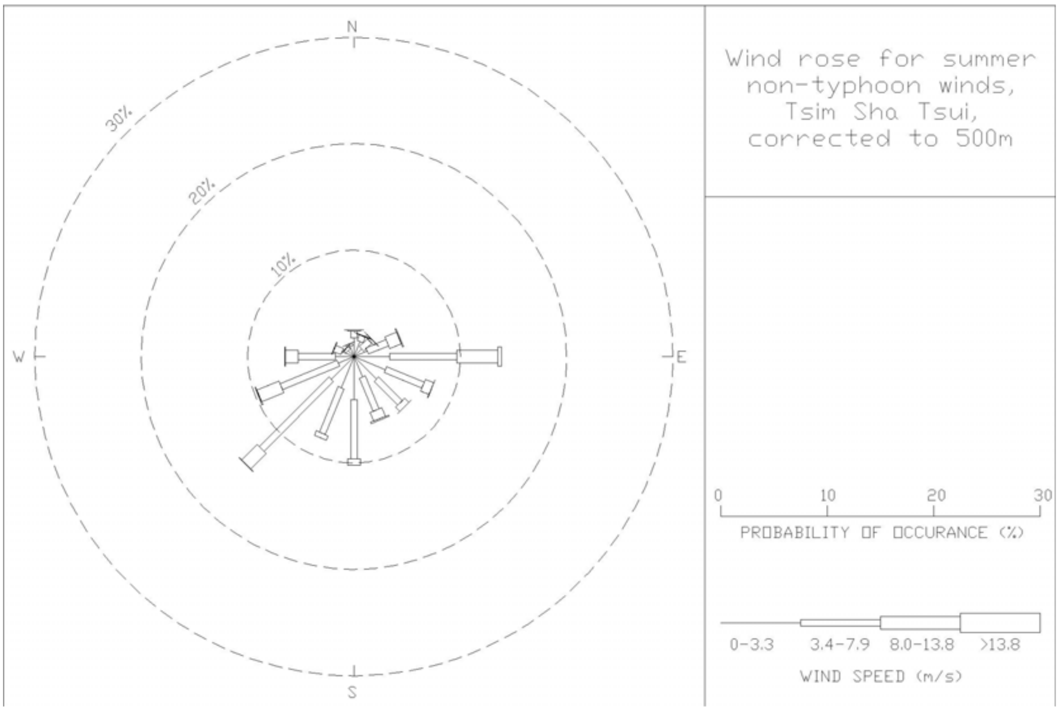


Average Velocity Ratio Plot at 2m above Ground - Proposed Scheme

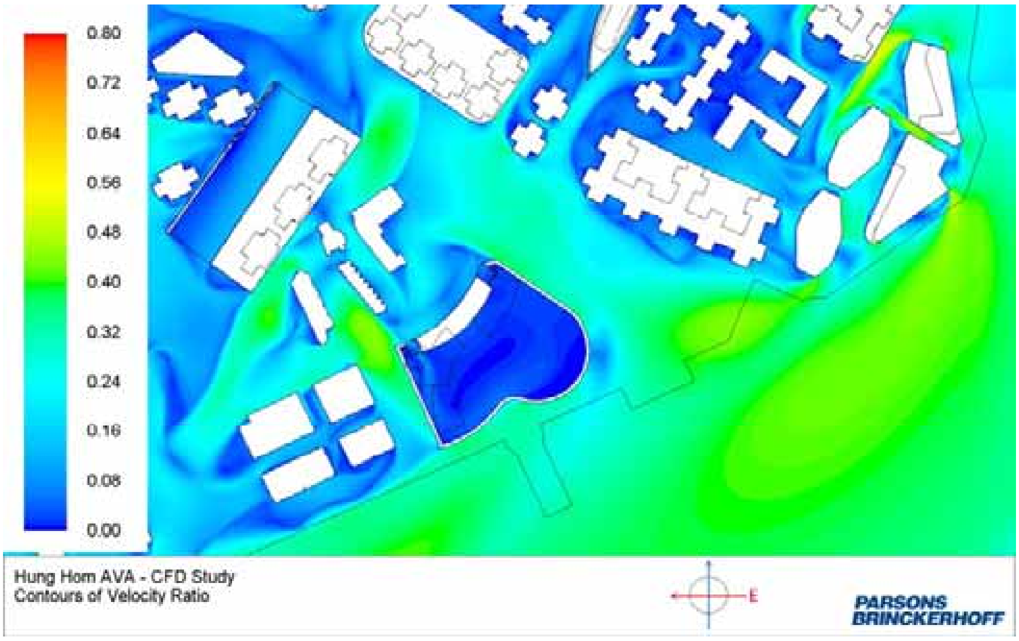
Appendix F – Summary of Velocity Ratio for Summer Prevailing Wind Directions for Urbis Scheme, Notional Scheme and Proposed Scheme

Summer Wind Rose Adopted

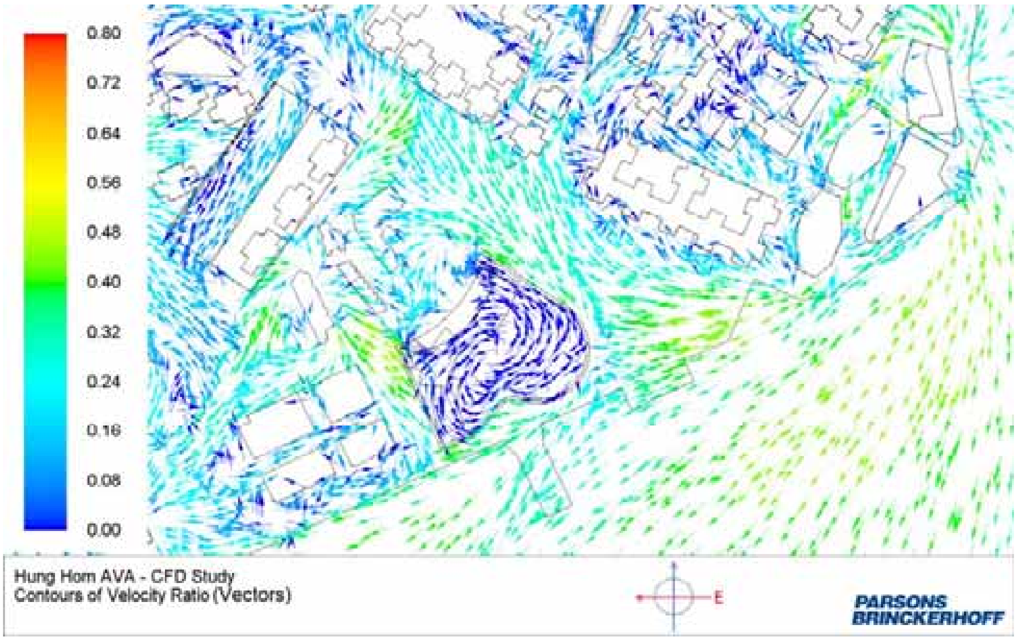


Wind Direction (°)	90.0 E	112.5 ESE	135.0 SE	180.0 S	202.5 SSW	225.0 SW	247.5 WSW	270.0 W
Occurrence (%)	13.4	7.5	6.3	9.6	7.7	18.3	9.2	6.3
Cumulative (%)	13.4	20.9	27.2	36.8	44.5	62.8	72.0	78.3

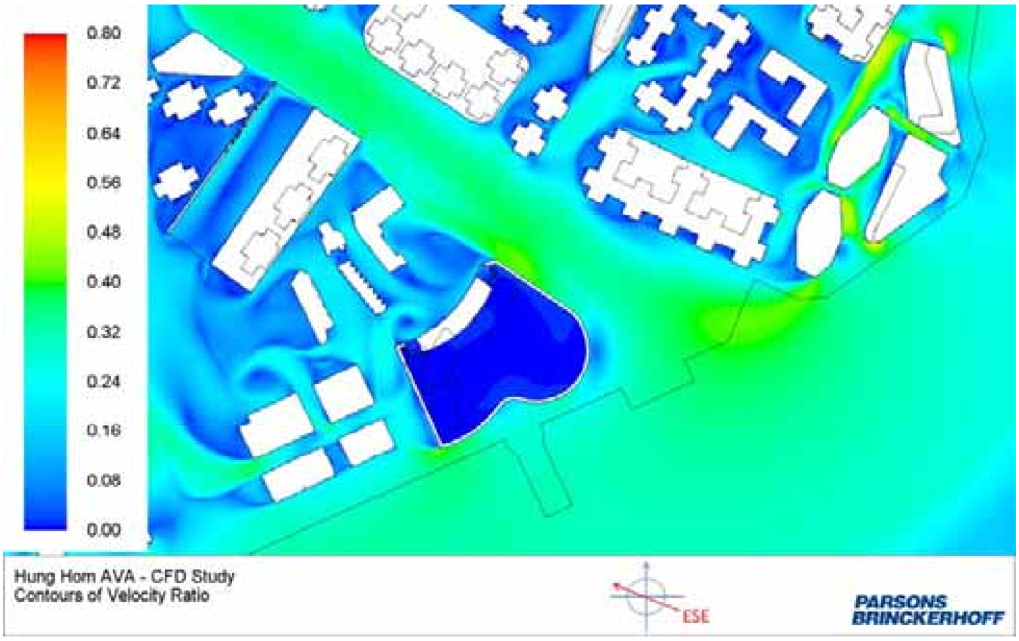
Summary of Velocity Ratio and Velocity Vector Plots for Urbis Scheme – Summer Non-Typhoon Prevailing Wind



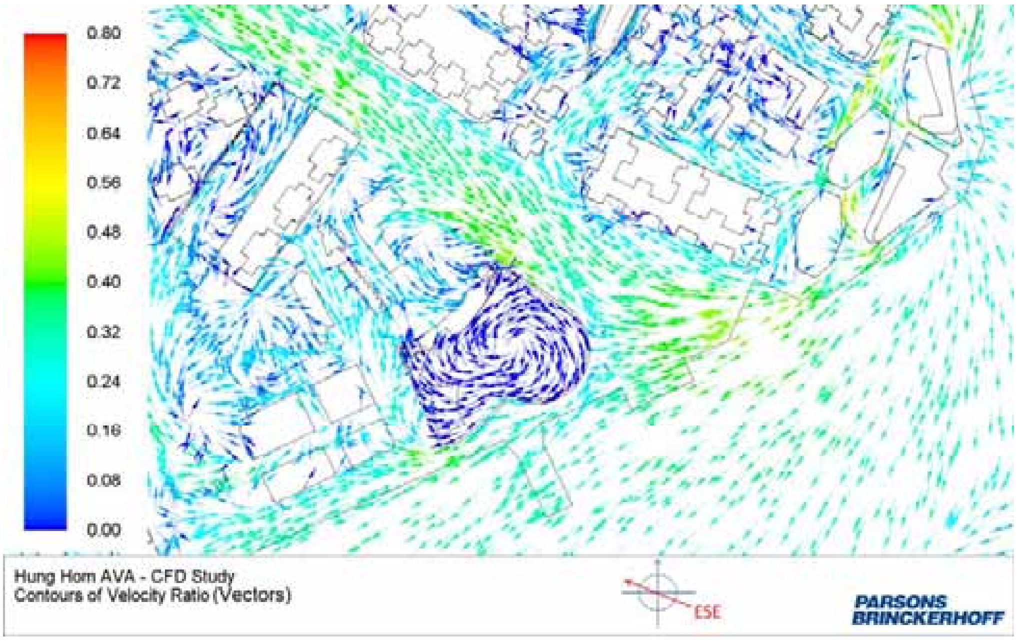
Velocity Ratio Plot at 2m above Ground for Eastern Wind - Urbis Scheme



Velocity Vector Plot Eastern Wind - Urbis Scheme



Velocity Ratio Plot at 2m above Ground for East-Southeastern Wind - Urbis Scheme



Velocity Vector Plot for East-Southeastern Wind - Urbis Scheme

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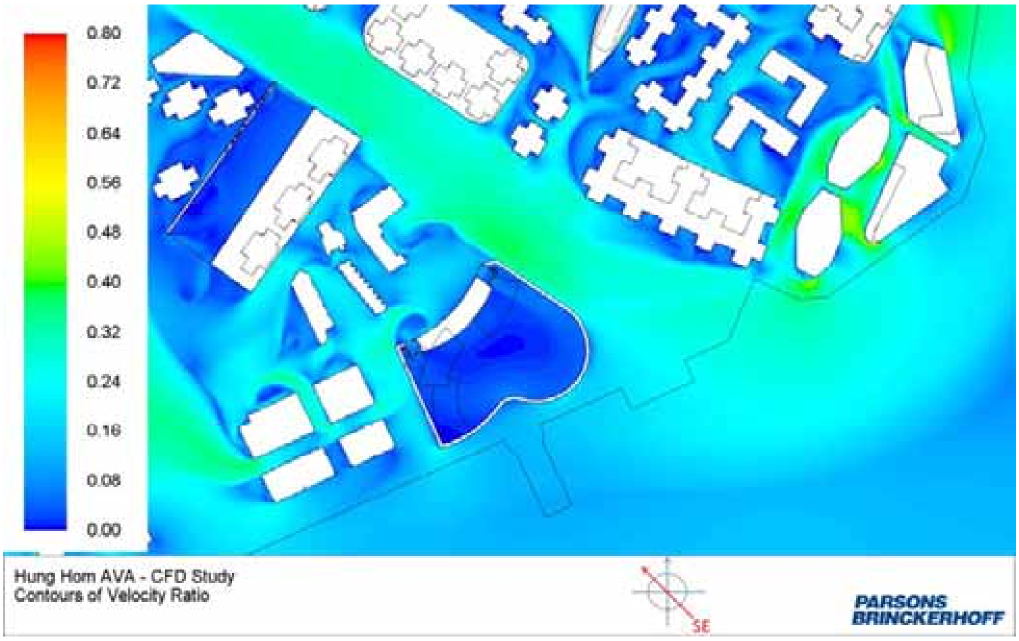
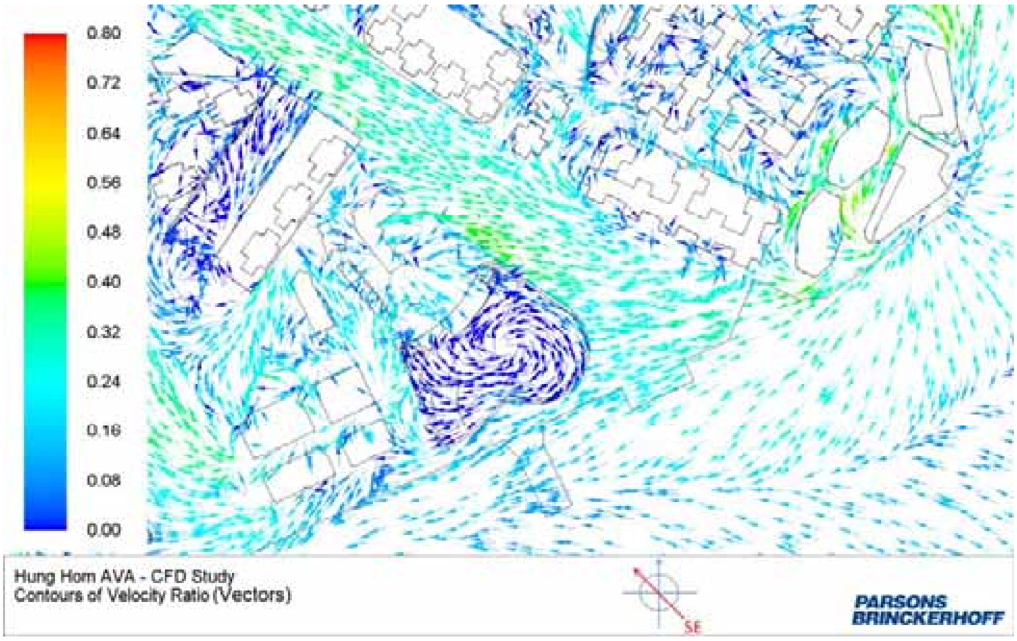
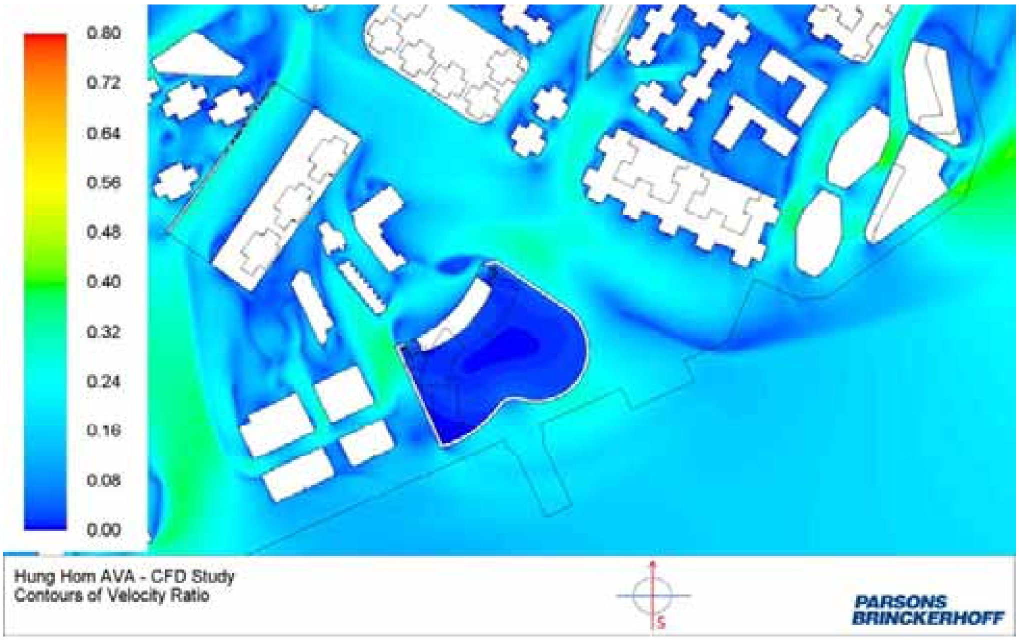


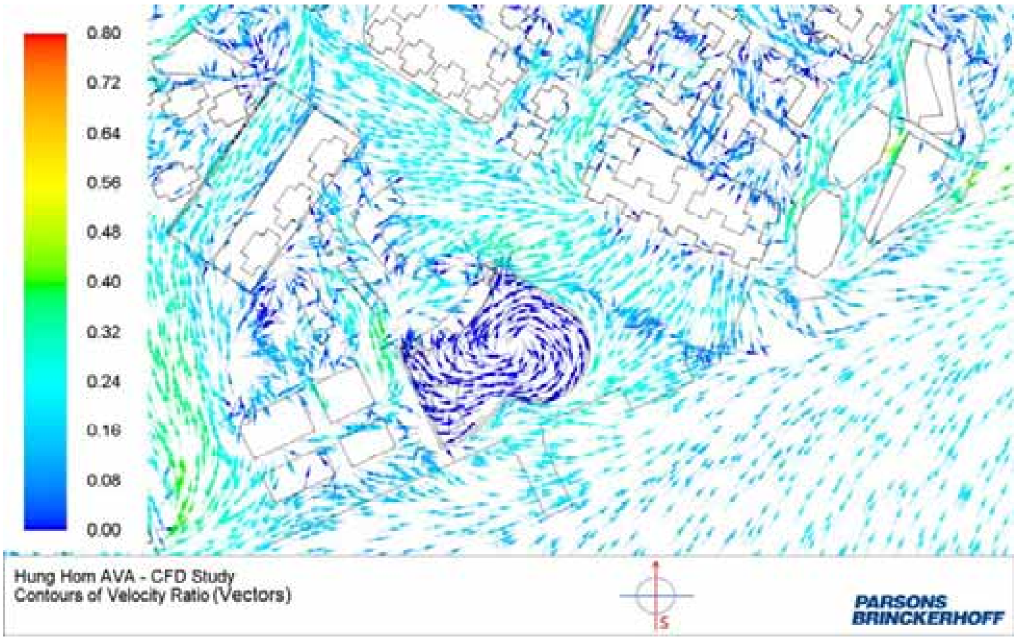
Velocity Ratio Plot at 2m above Ground for Southeastern Wind - Urbis Scheme



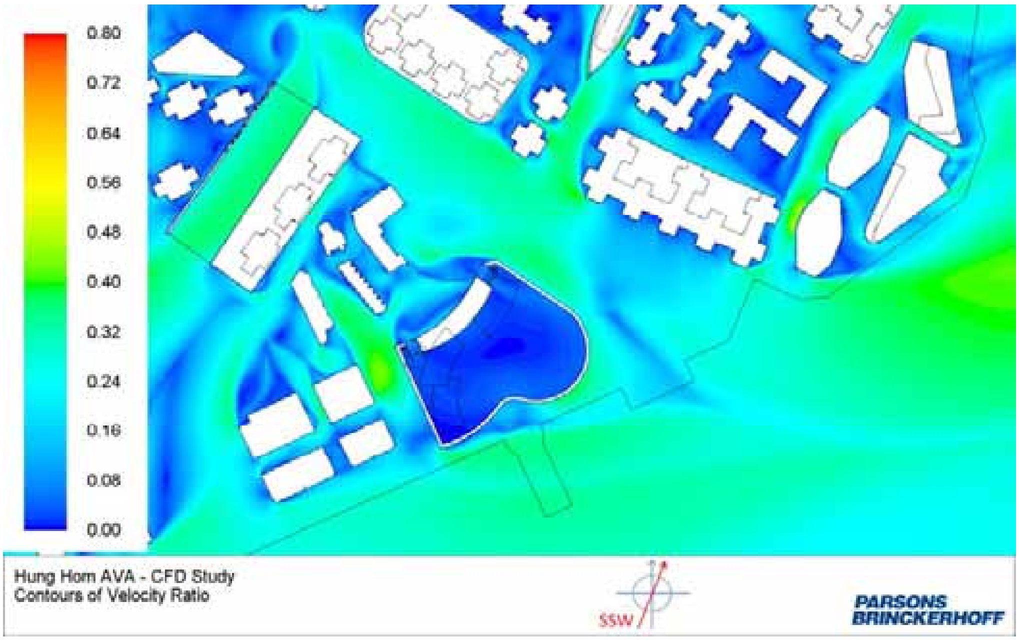
Velocity Vector Plot for Southeastern Wind - Urbis Scheme



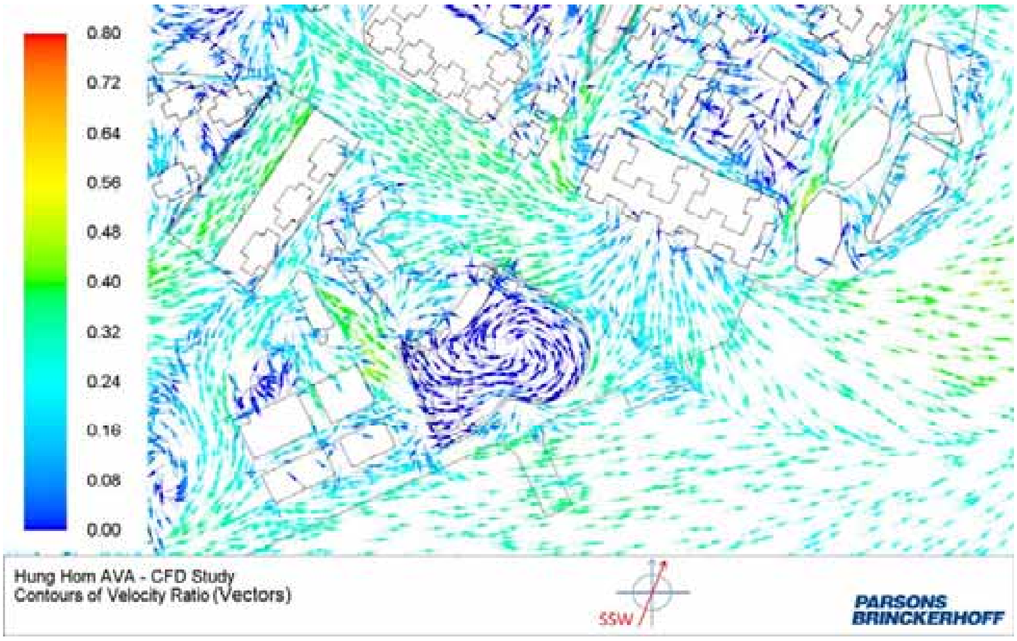
Velocity Ratio Plot at 2m above Ground for Southern Wind - Urbis Scheme



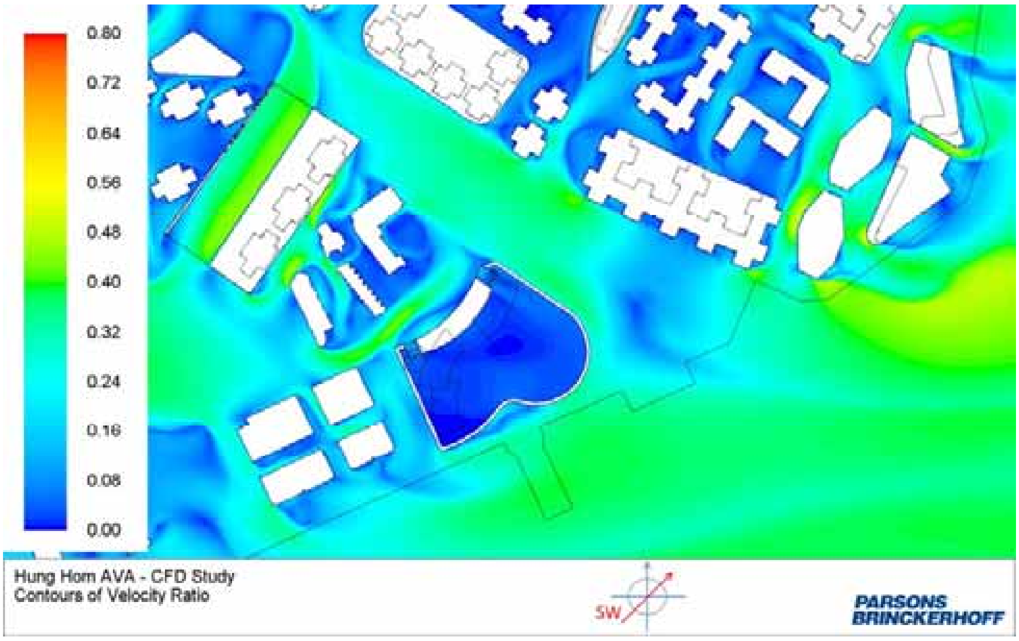
Velocity Vector Plot for Southern Wind - Urbis Scheme



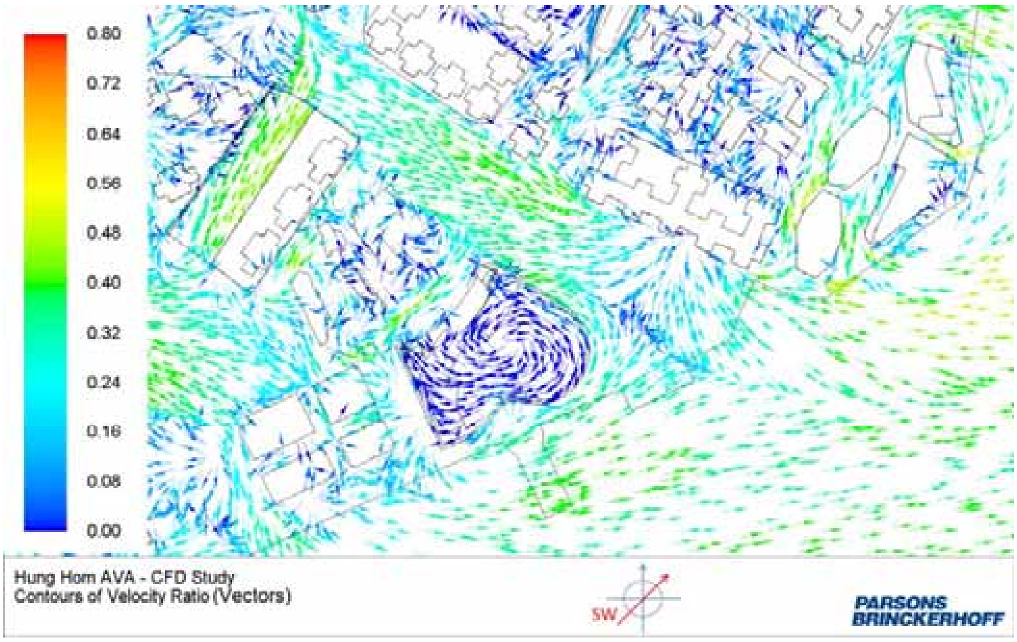
Velocity Ratio Plot at 2m above Ground for South-Southwestern Wind - Urbis Scheme



Velocity Vector Plot for South-Southwestern Wind - Urbis Scheme



Velocity Ratio Plot at 2m above Ground for Southwestern Wind - Urbis Scheme



Velocity Vector Plot for Southwestern Wind - Urbis Scheme

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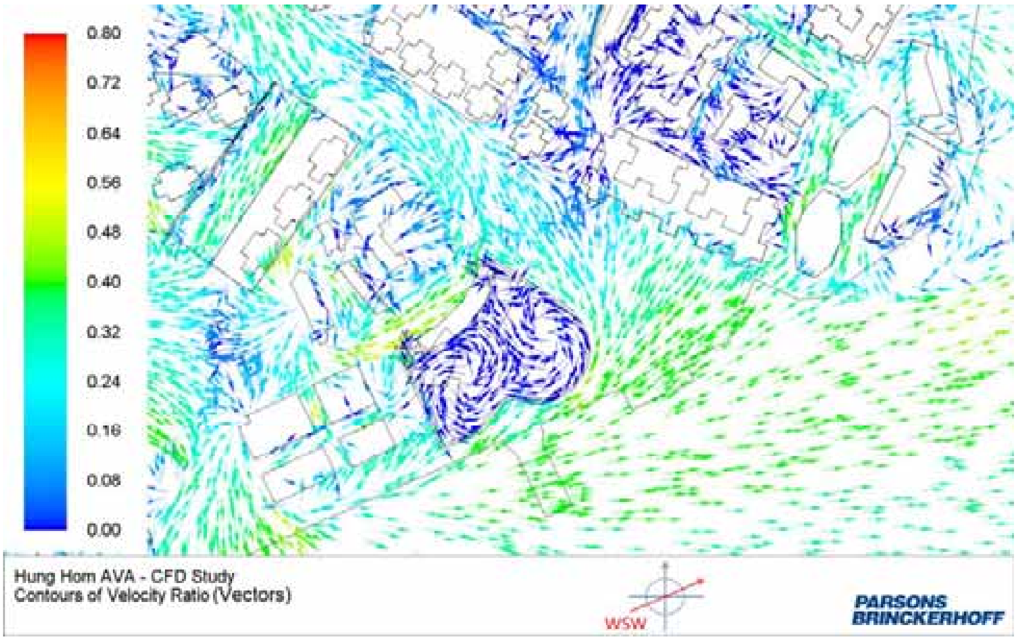
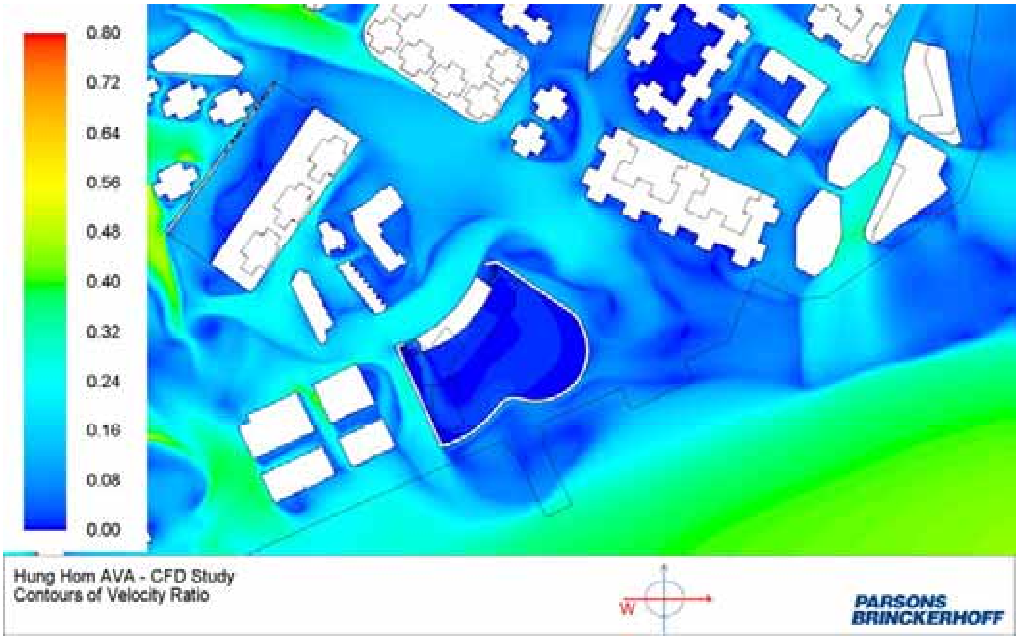
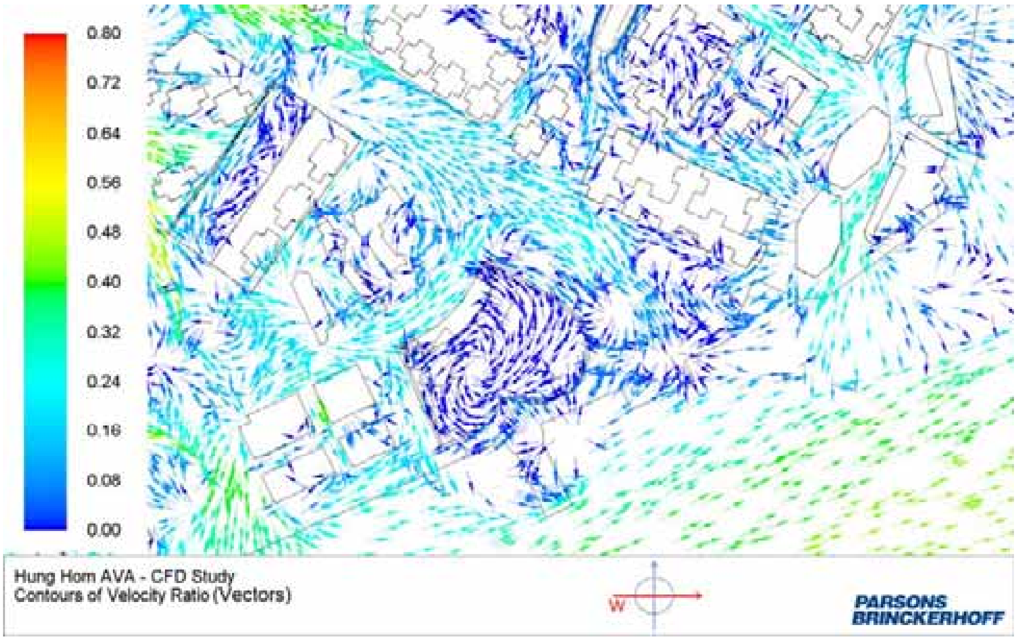
Velocity Ratio Plot at 2m above Ground for West-Southwestern Wind - Urbis Scheme



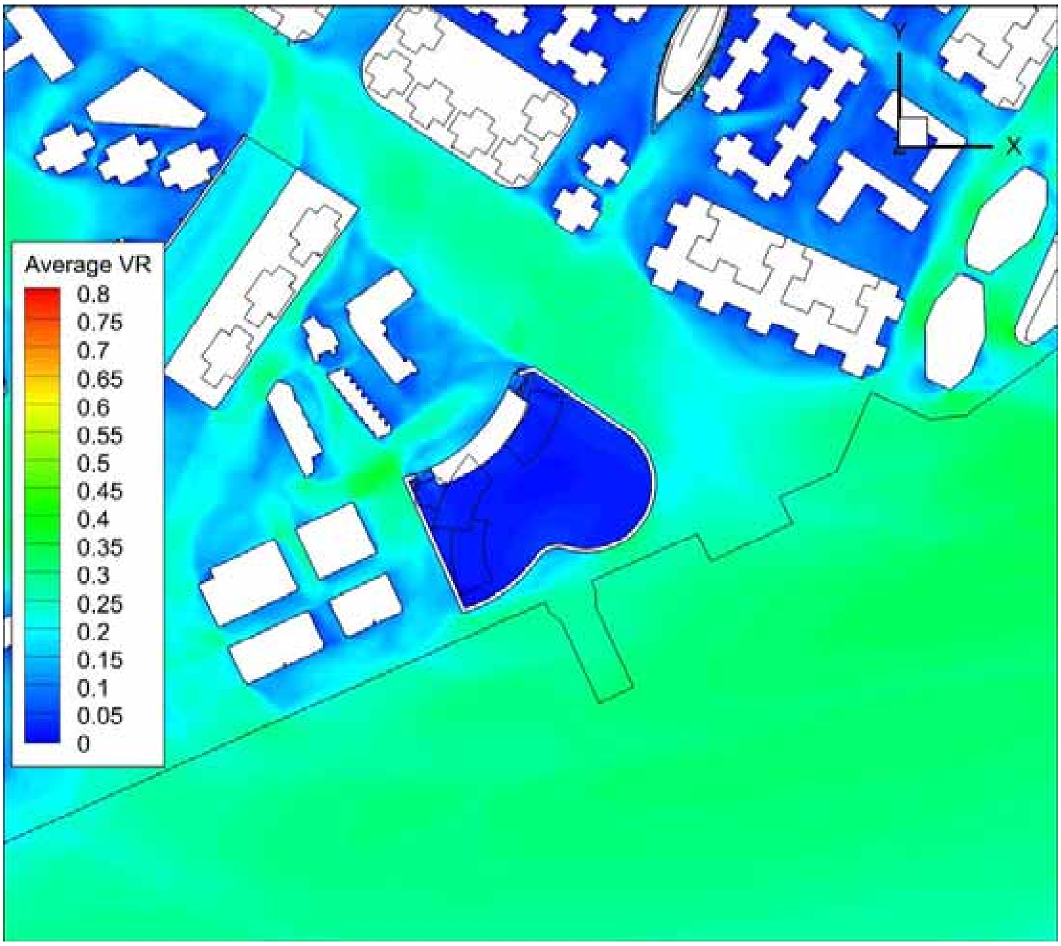
Velocity Vector Plot for West-Southwestern Wind - Urbis Scheme



Velocity Ratio Plot at 2m above Ground for Western Wind - Urbis Scheme

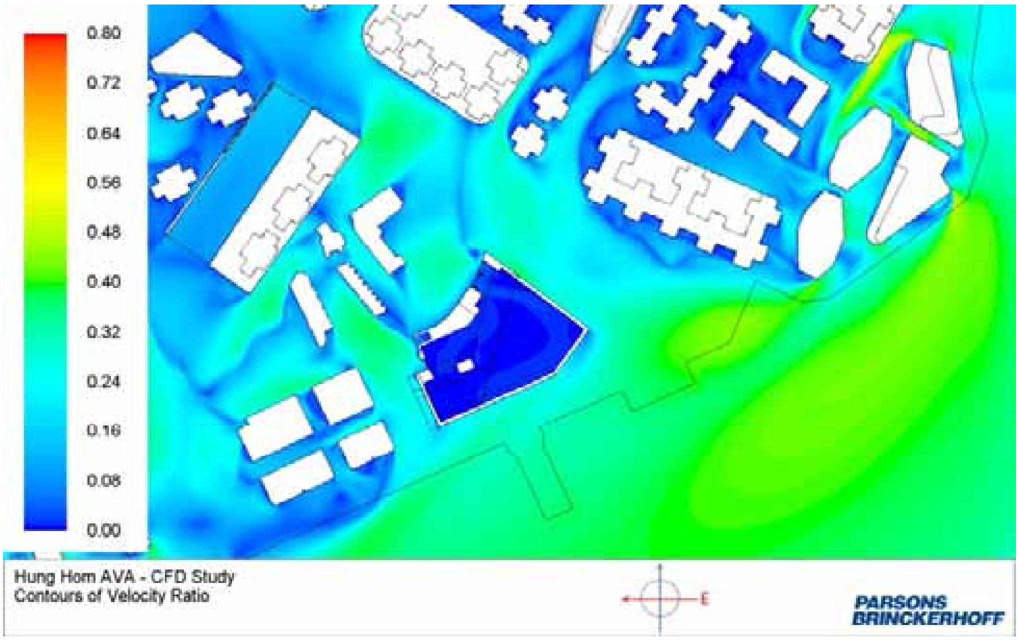


Velocity Vector Plot for Western Wind - Urbis Scheme

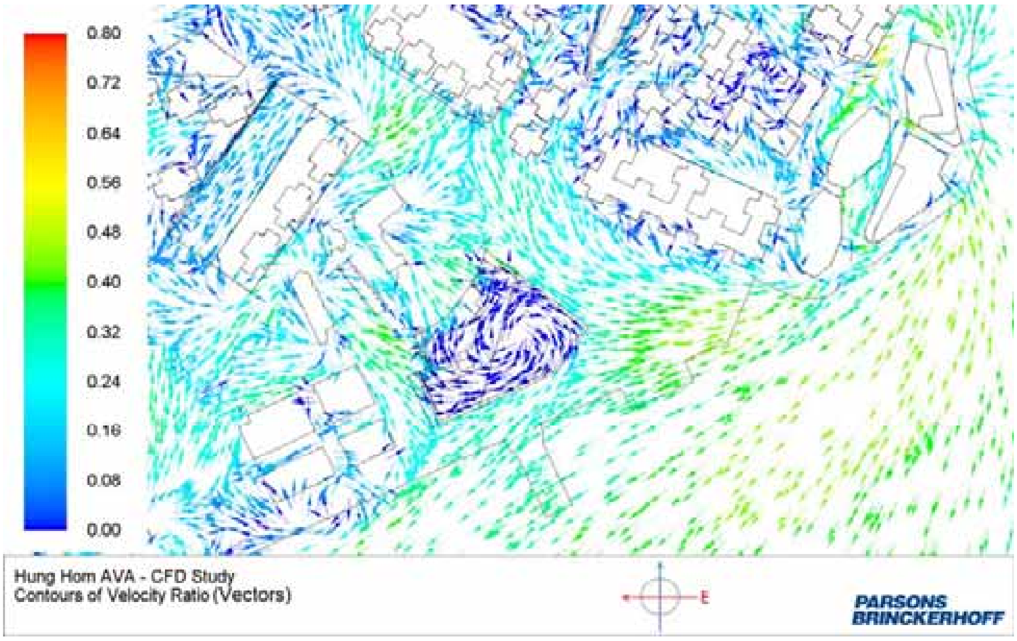


Urbis Scheme Pedestrian Level VR Summer Average

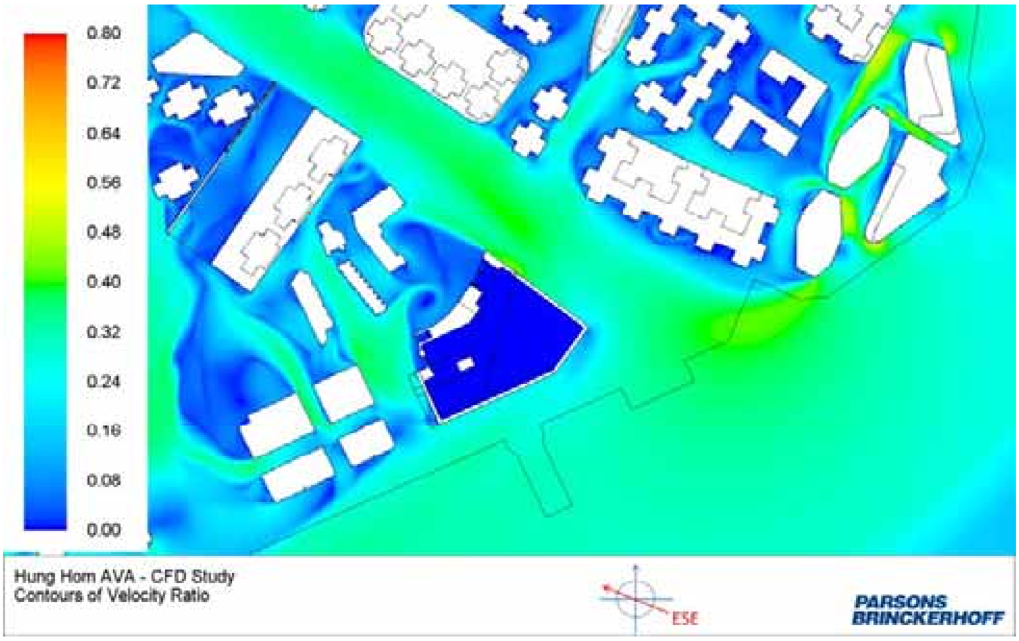
Summary of Velocity Ratio and Velocity Vector Plots for Notional Scheme – Summer Non-Typhoon Prevailing Wind



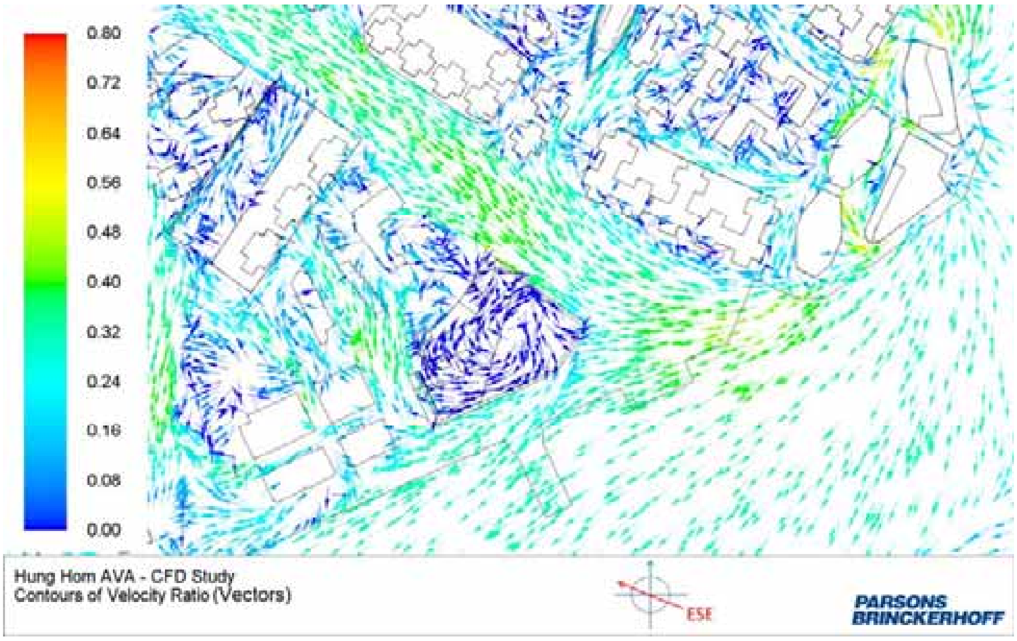
Velocity Ratio Plot at 2m above Ground for Eastern Wind - Notional Scheme



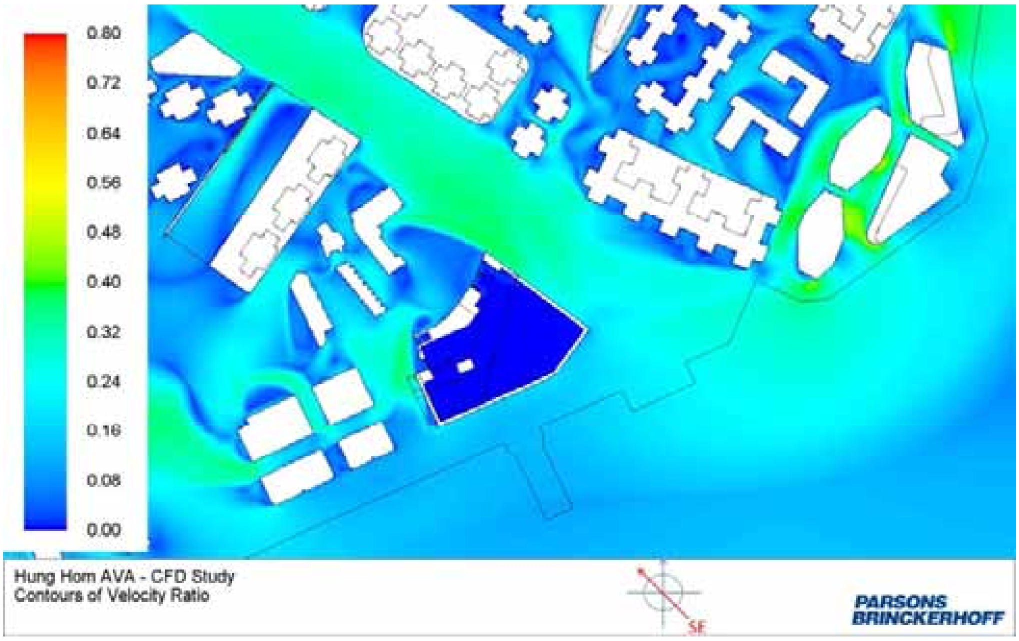
Velocity Vector Plot Eastern Wind - Notional Scheme



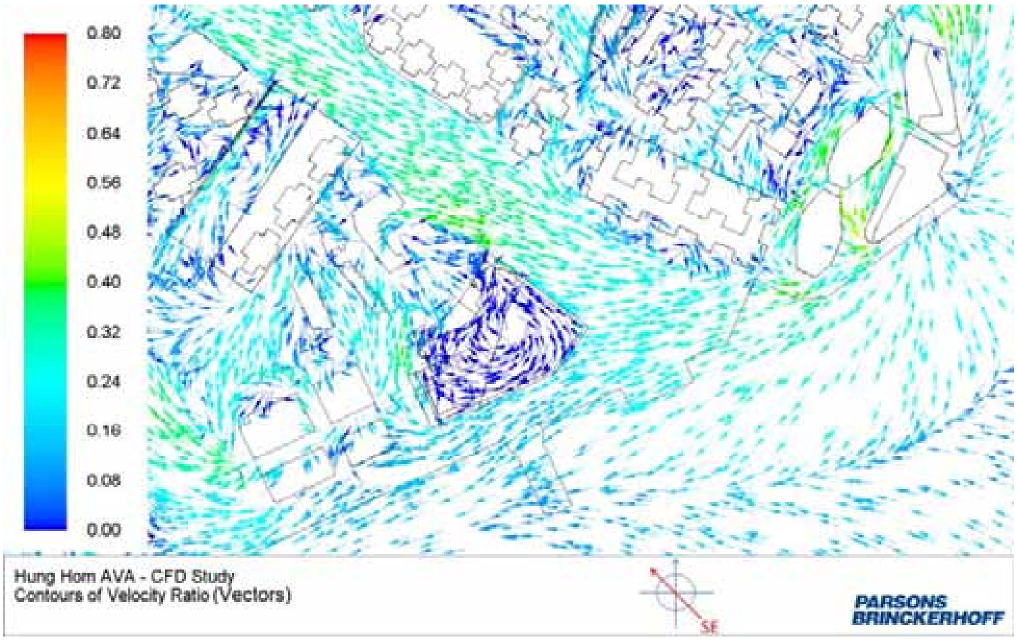
Velocity Ratio Plot at 2m above Ground for East-Southeastern Wind - Notional Scheme



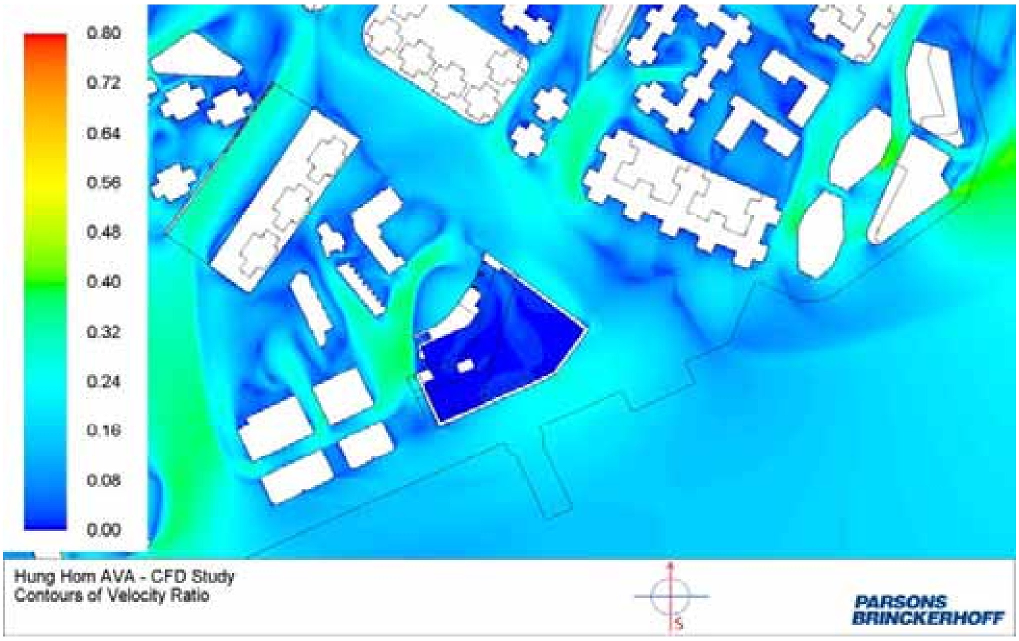
Velocity Vector Plot for East-Southeastern Wind - Notional Scheme



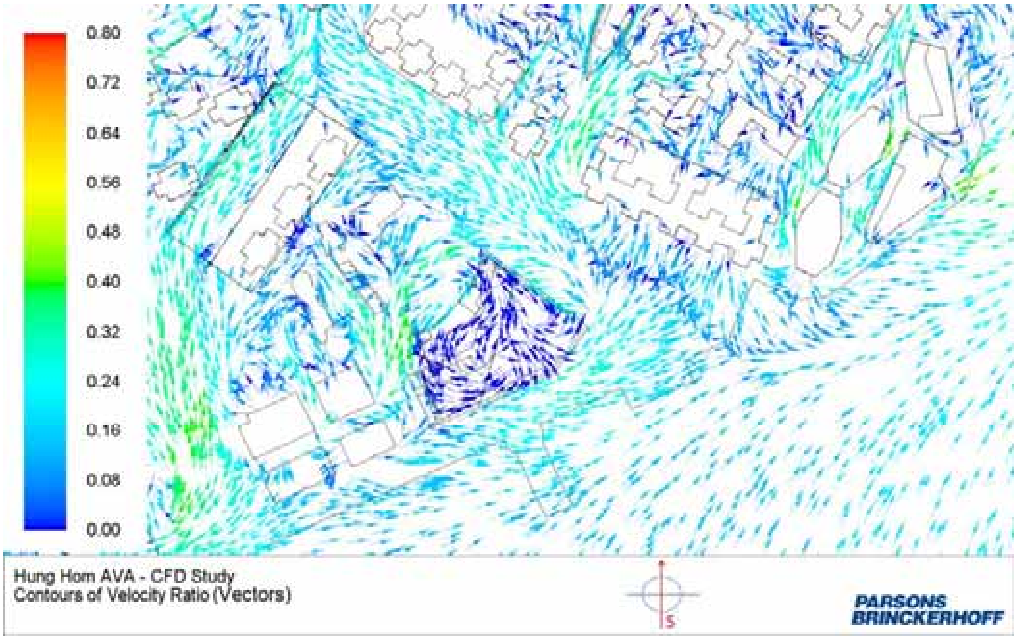
Velocity Ratio Plot at 2m above Ground for Southeastern Wind - Notional Scheme



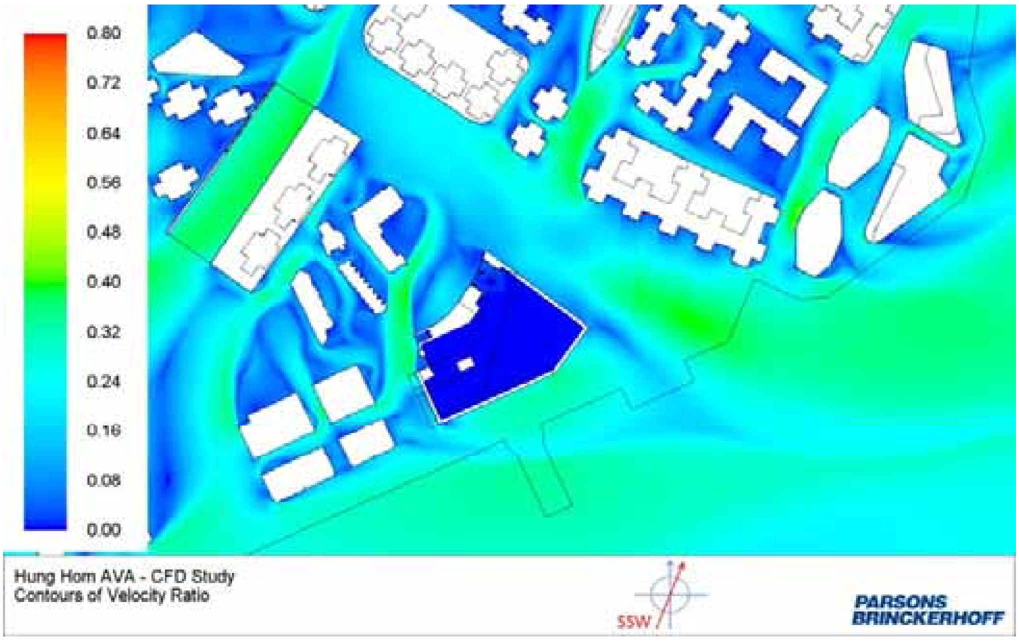
Velocity Vector Plot for Southeastern Wind - Notional Scheme



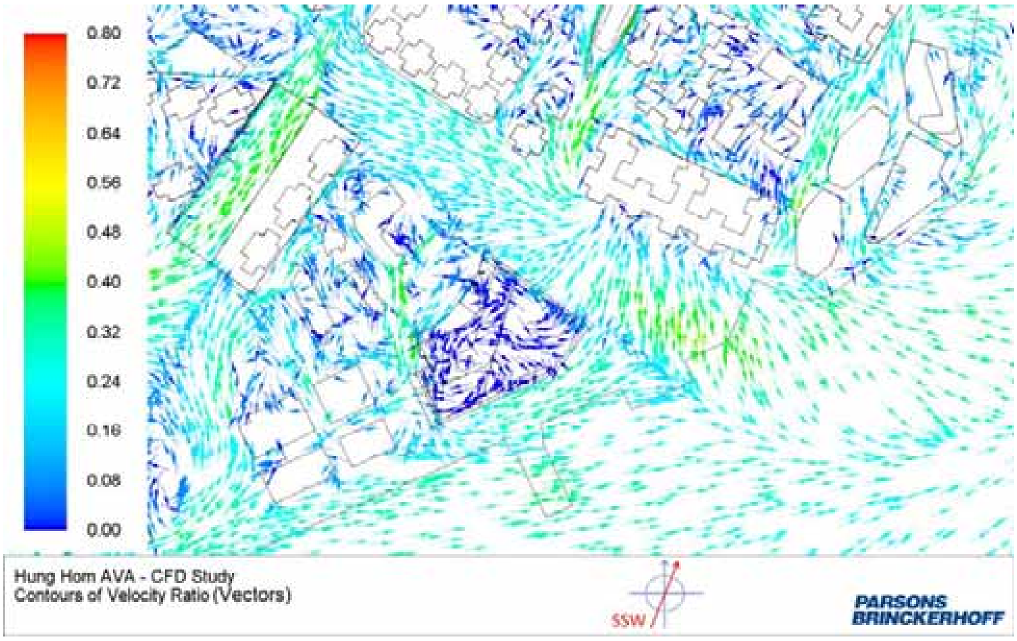
Velocity Ratio Plot at 2m above Ground for Southern Wind - Notional Scheme



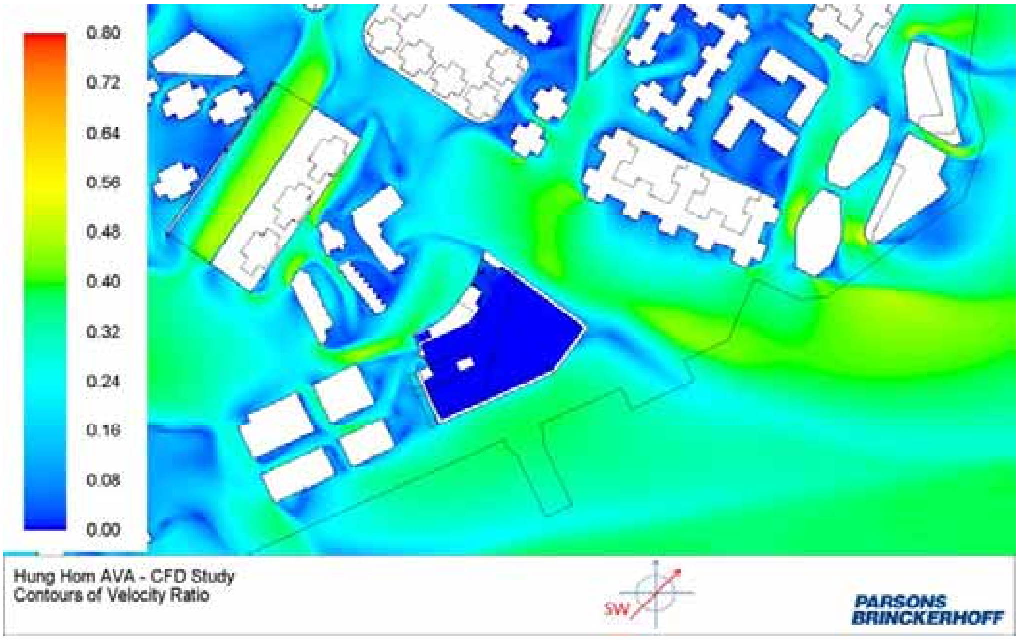
Velocity Vector Plot for Southern Wind - Notional Scheme



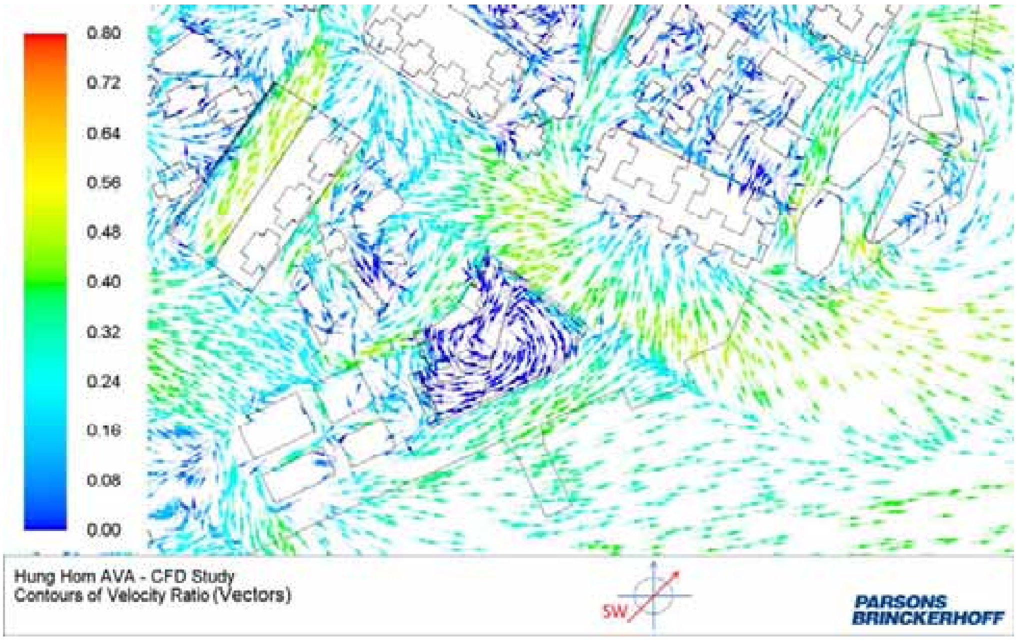
Velocity Ratio Plot at 2m above Ground for South-Southwestern Wind - Notional Scheme



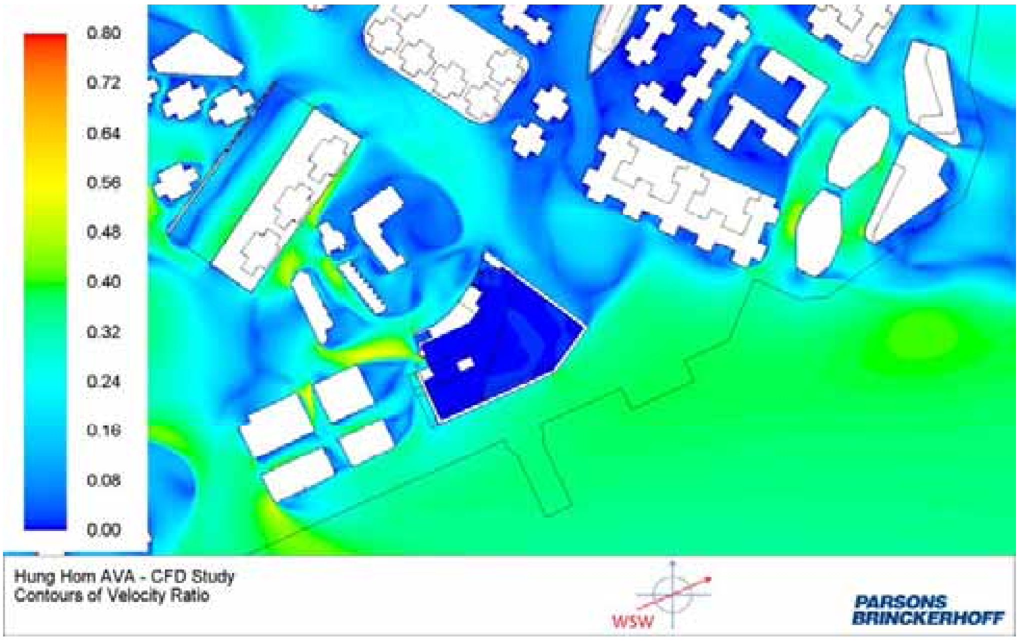
Velocity Vector Plot for South-Southwestern Wind - Notional Scheme



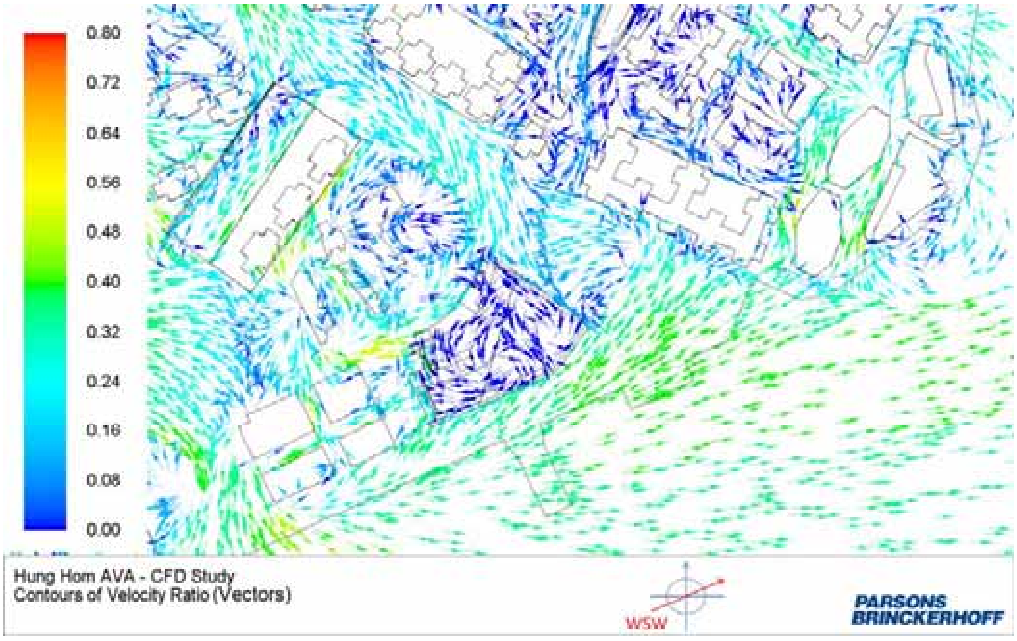
Velocity Ratio Plot at 2m above Ground for Southwestern Wind - Notional Scheme



Velocity Vector Plot for Southwestern Wind - Notional Scheme

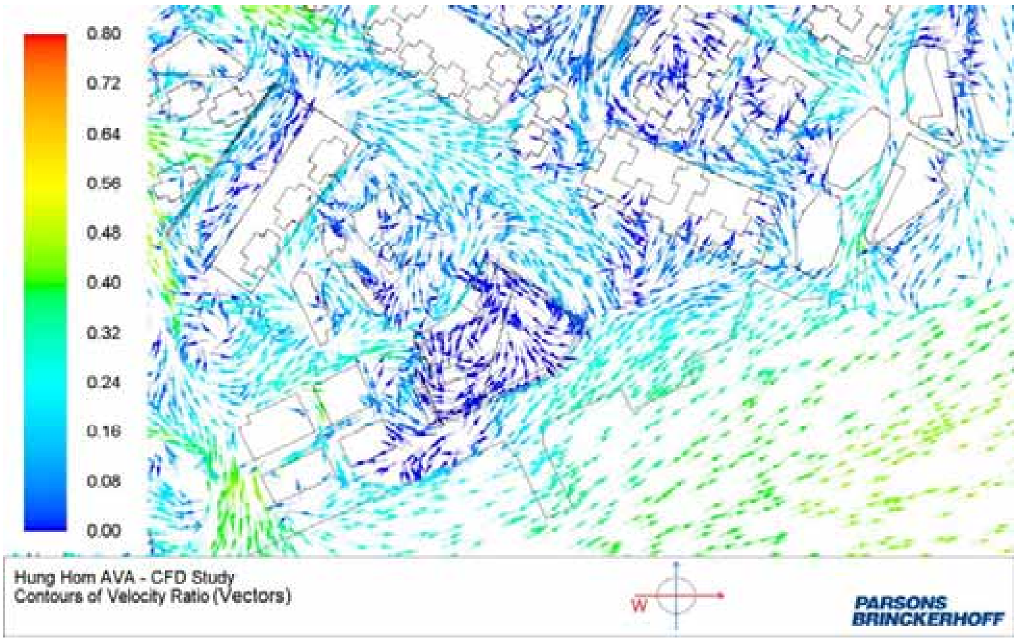


Velocity Ratio Plot at 2m above Ground for West-Southwestern Wind - Notional Scheme



Velocity Vector Plot for West-Southwestern Wind - Notional Scheme

Velocity Ratio Plot at 2m above Ground for Western Wind - Notional Scheme



Velocity Vector Plot for Western Wind - Notional Scheme

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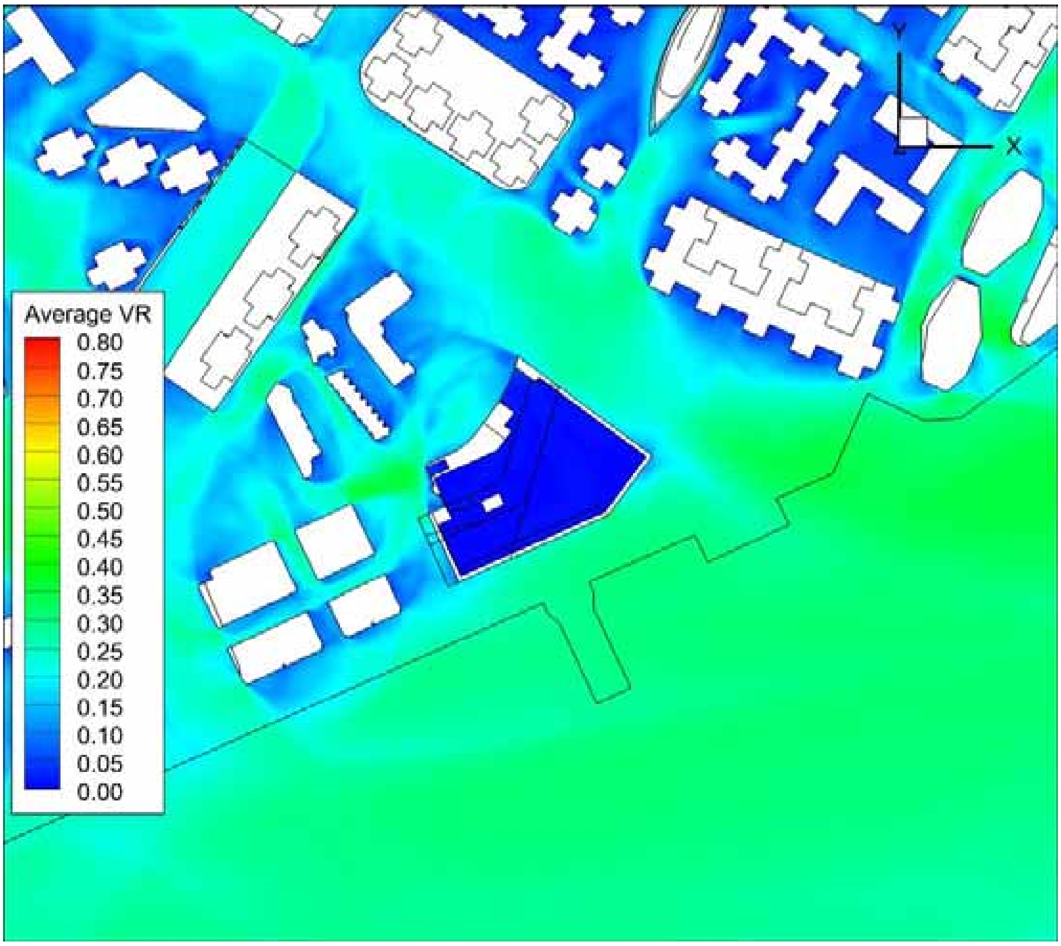
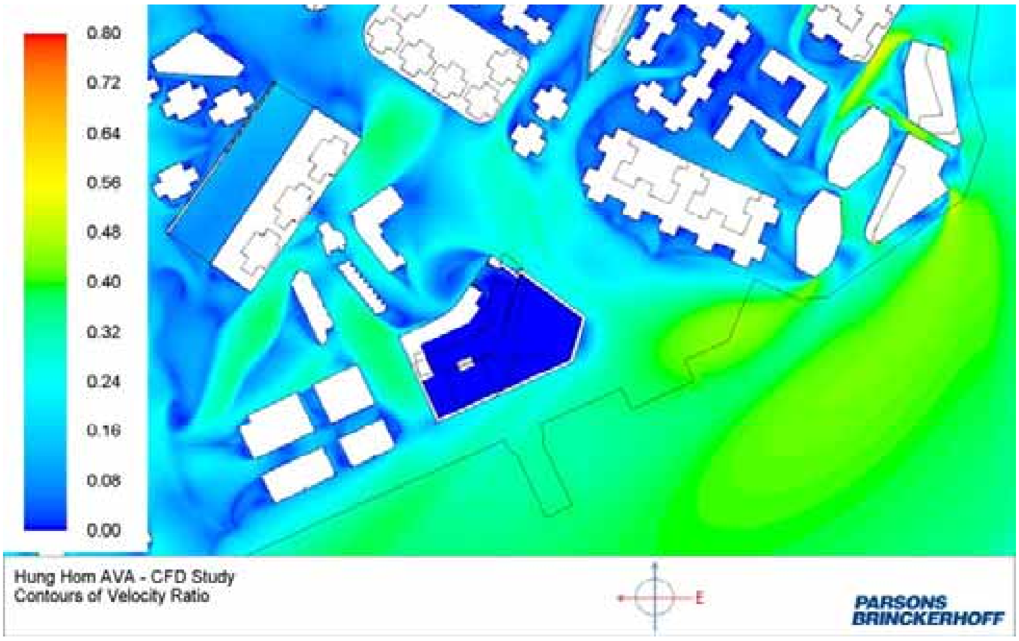
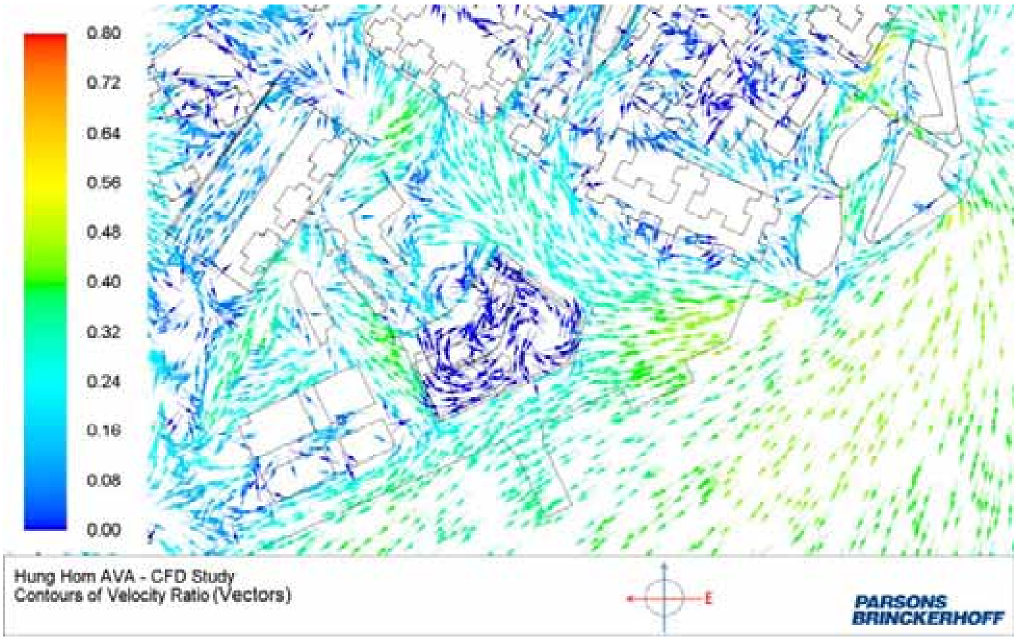


Notional Scheme Pedestrian Level Summer Average

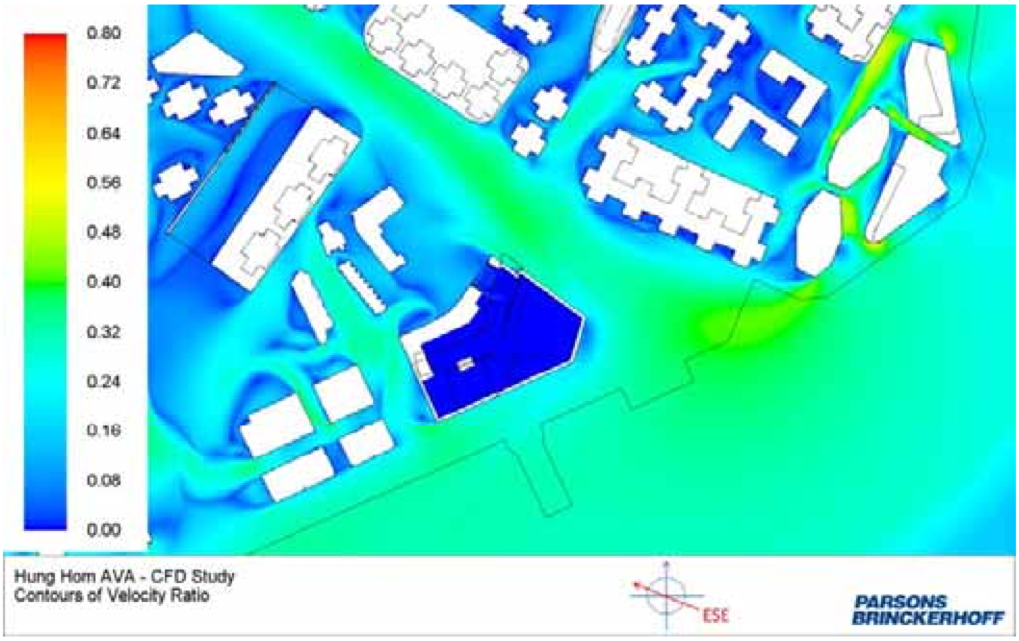
Summary of Velocity Ratio and Velocity Vector Plots for Proposed Scheme - Summer Non-Typhoon Prevailing Wind



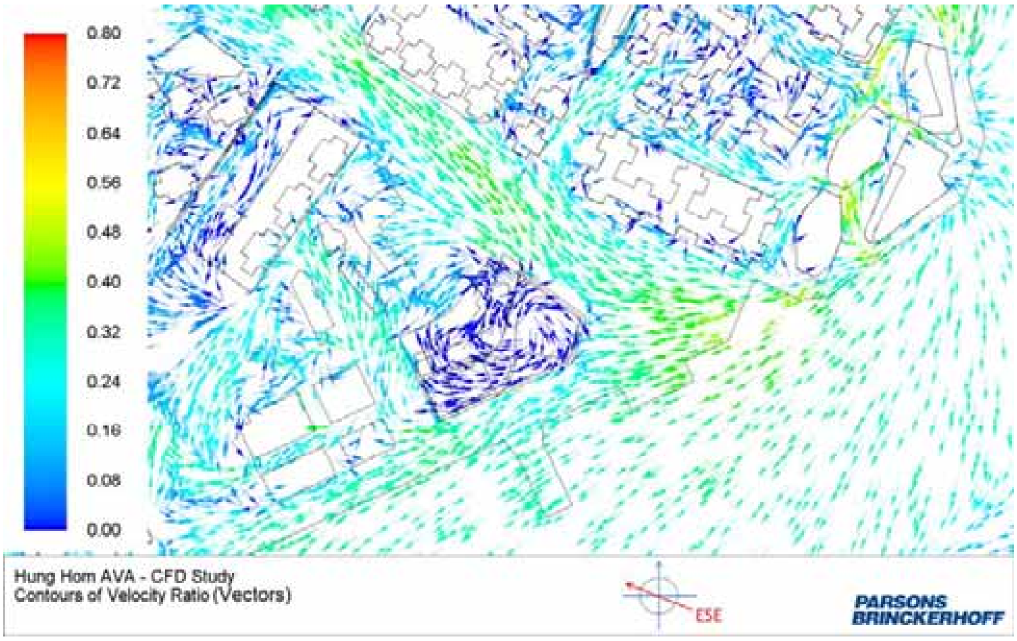
Velocity Ratio Plot at 2m above Ground for Eastern Wind - Proposed Scheme



Velocity Vector Plot Eastern Wind - Proposed Scheme



Velocity Ratio Plot at 2m above Ground for East-Southeastern Wind - Proposed Scheme



Velocity Vector Plot for East-Southeastern Wind - Proposed Scheme

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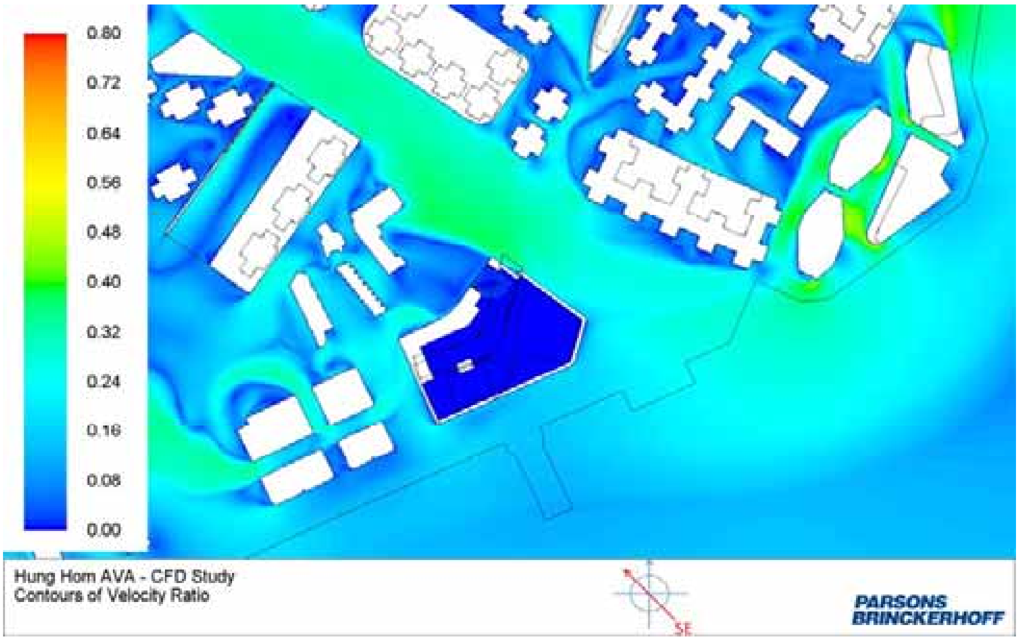
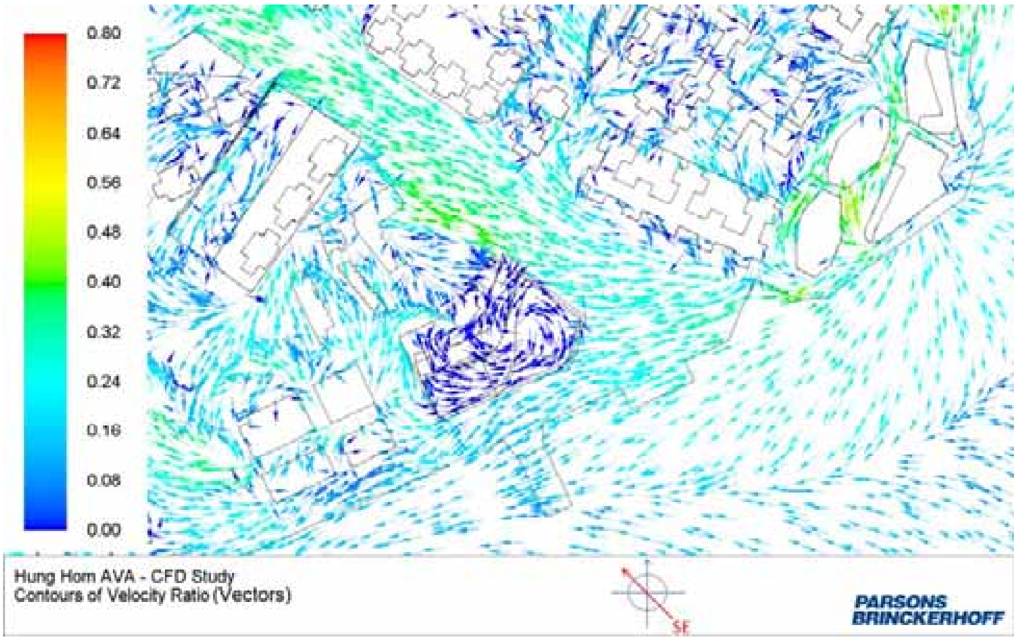
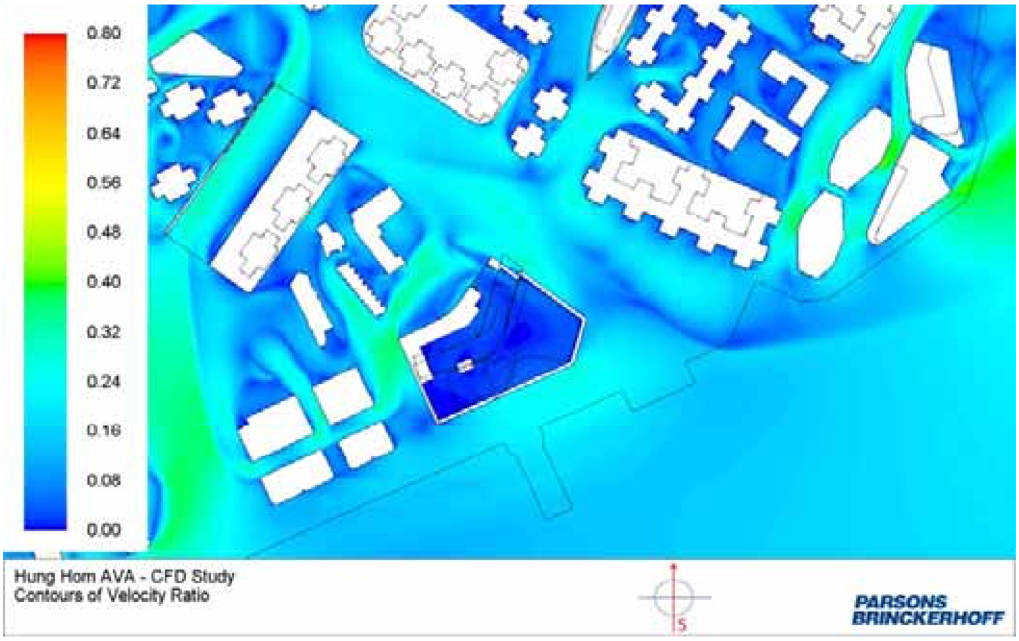


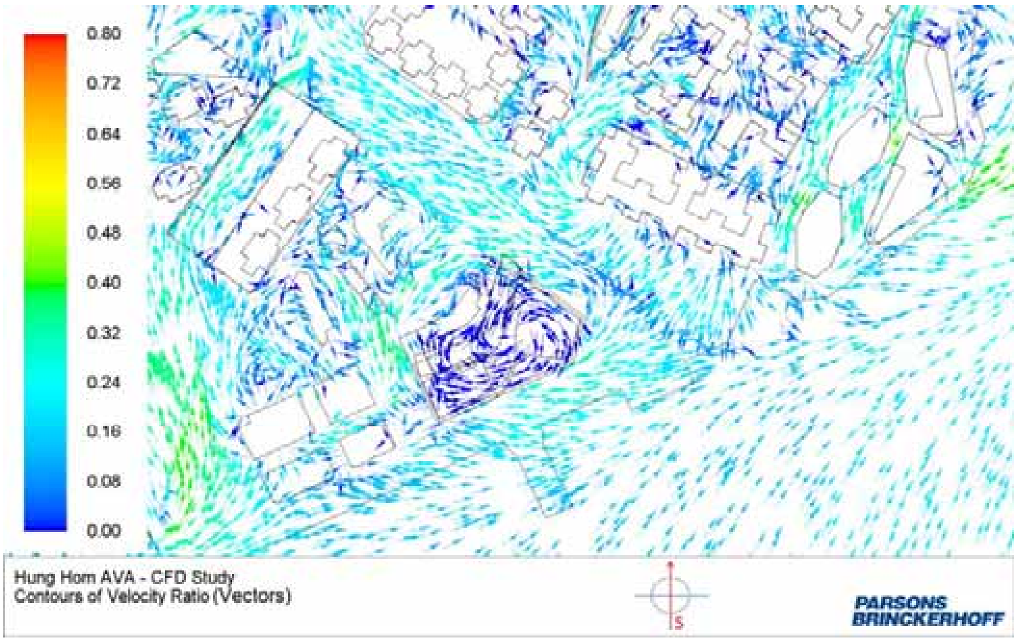
Velocity Ratio Plot at 2m above Ground for Southeastern Wind - Proposed Scheme



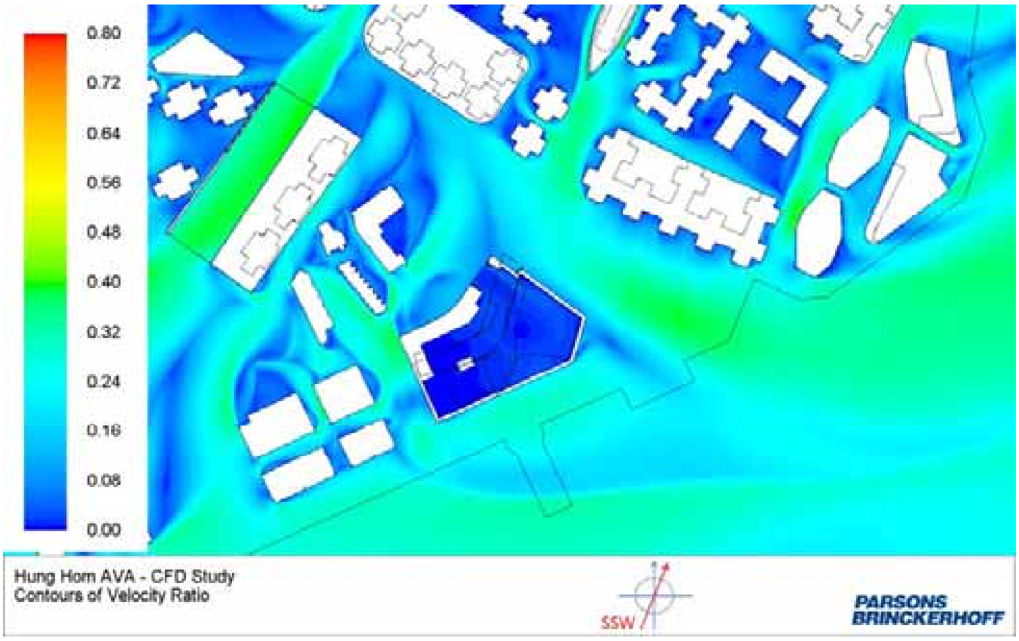
Velocity Vector Plot for Southeastern Wind - Proposed Scheme



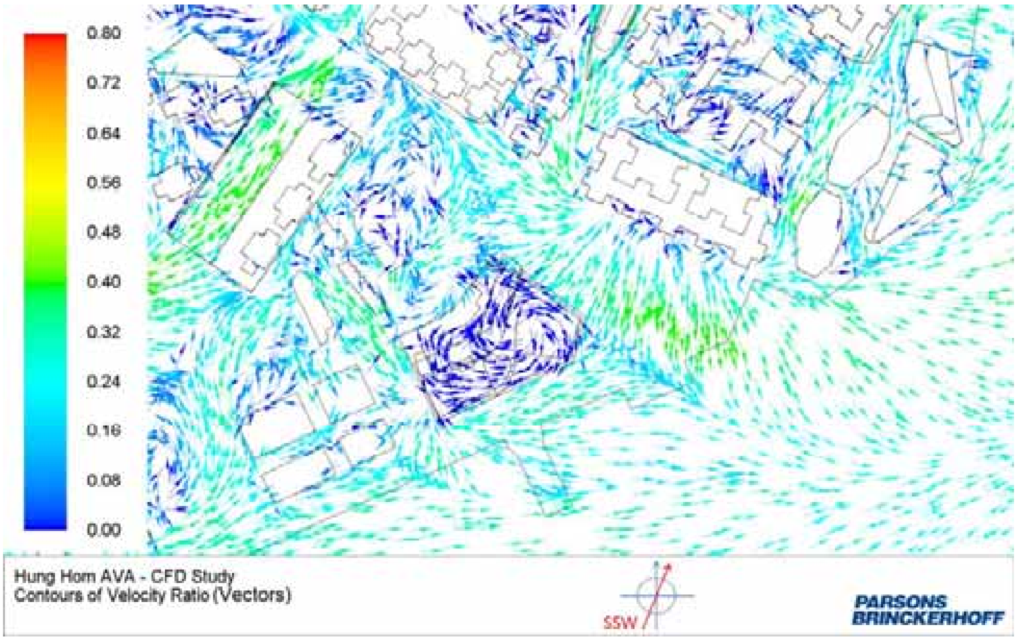
Velocity Ratio Plot at 2m above Ground for Southern Wind - Proposed Scheme



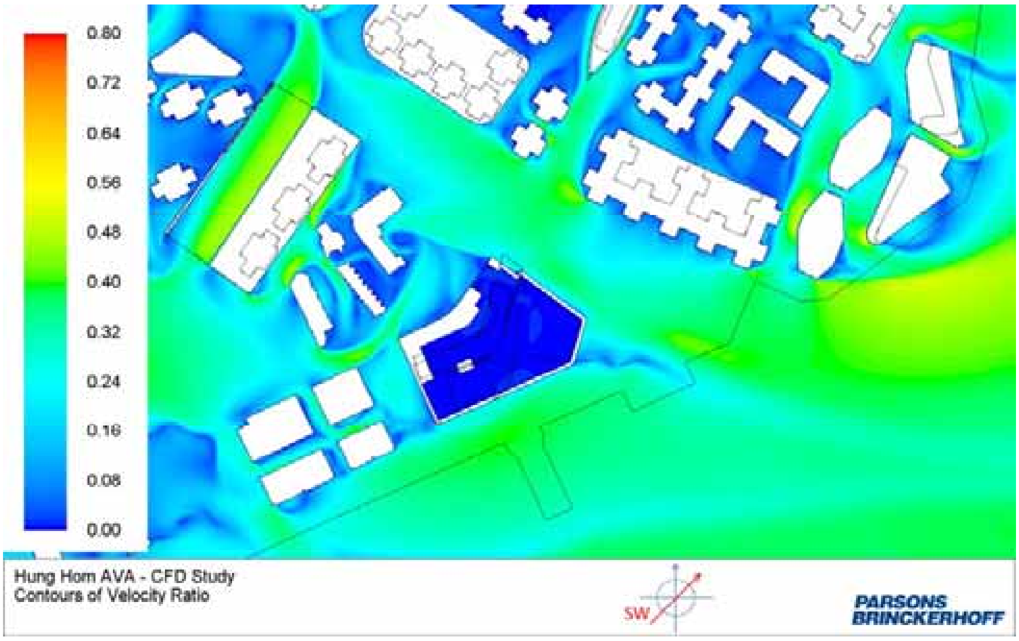
Velocity Vector Plot for Southern Wind - Proposed Scheme



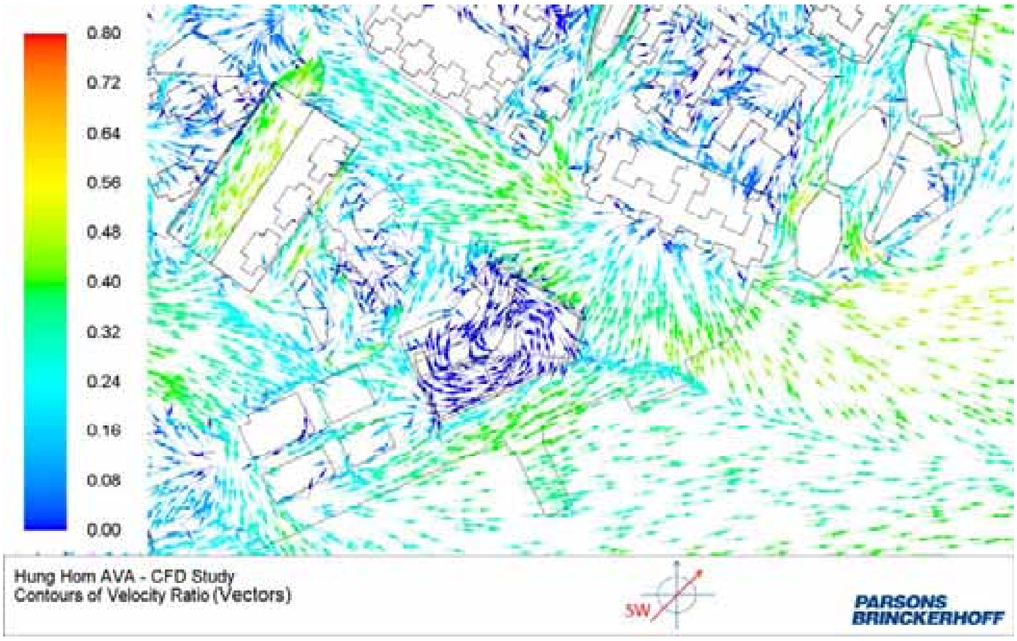
Velocity Ratio Plot at 2m above Ground for South-Southwestern Wind - Proposed Scheme



Velocity Vector Plot for South-Southwestern Wind - Proposed Scheme



Velocity Ratio Plot at 2m above Ground for Southwestern Wind - Proposed Scheme



Velocity Vector Plot for Southwestern Wind - Proposed Scheme

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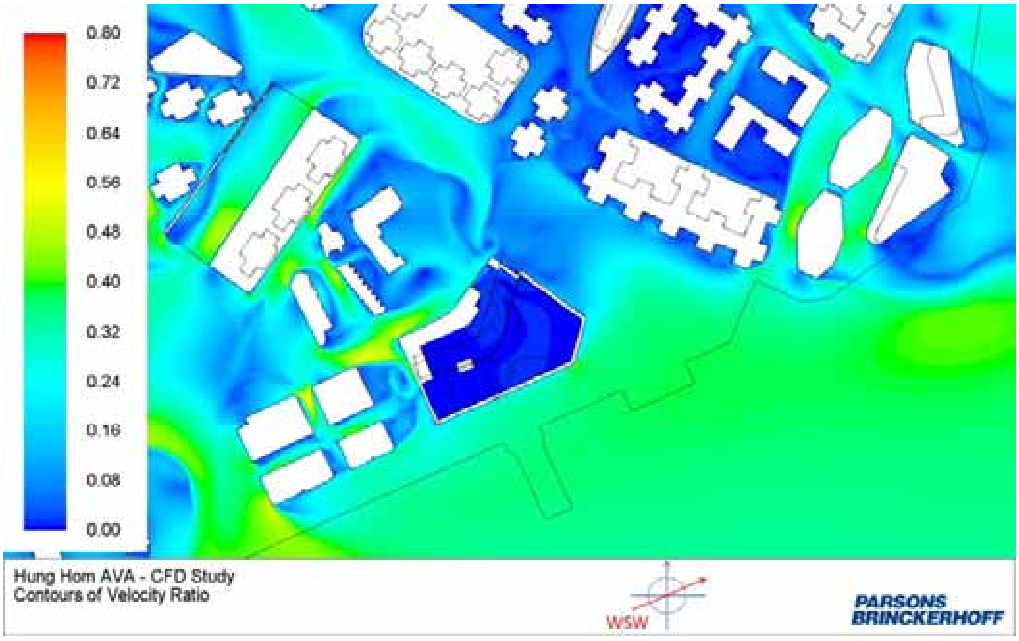
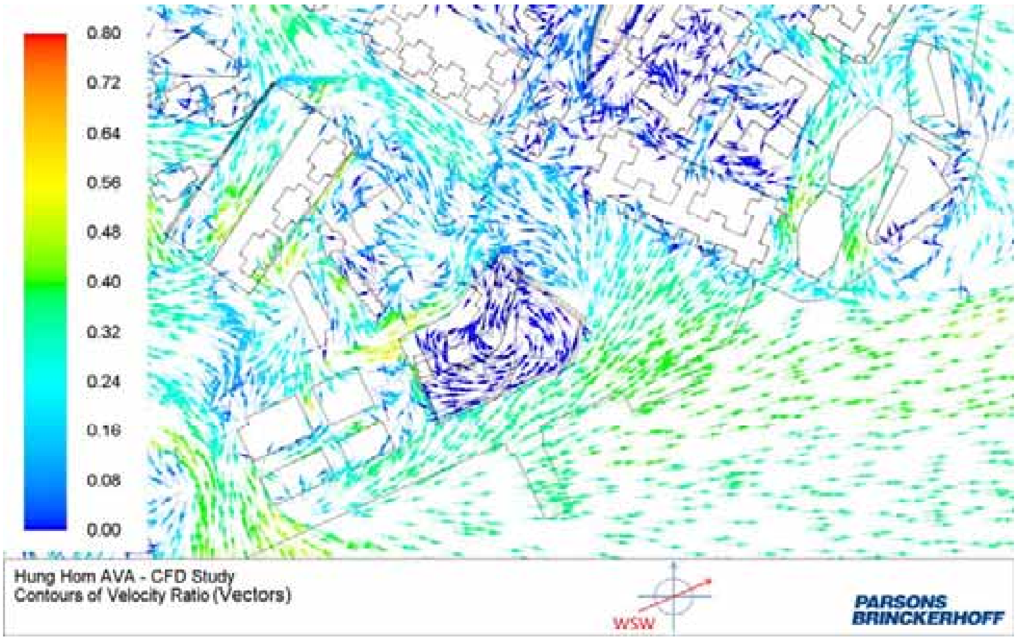
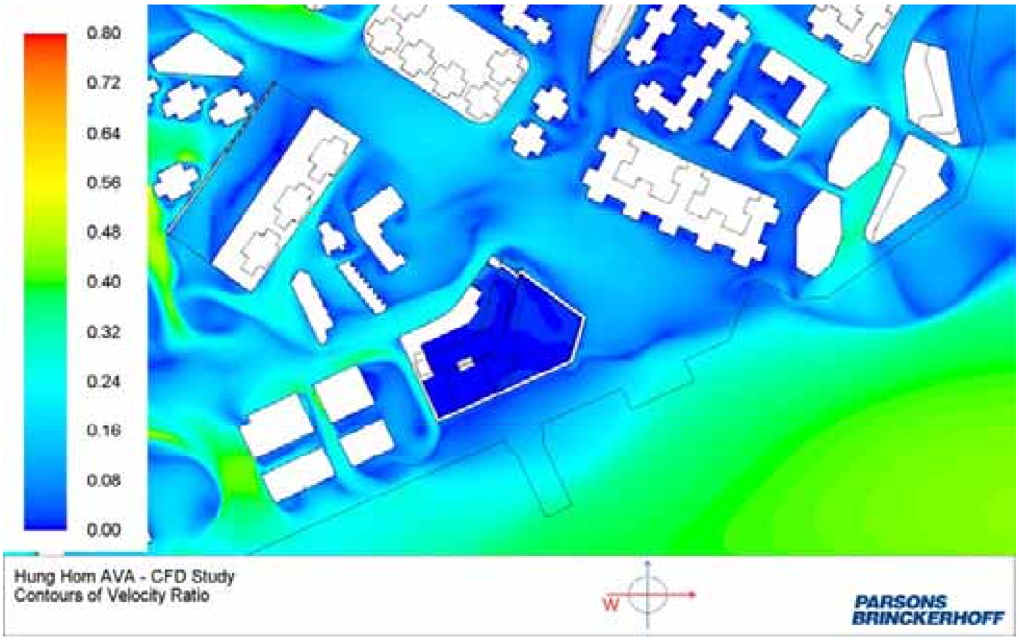


Velocity Ratio Plot at 2m above Ground for West-Southwestern Wind - Proposed Scheme

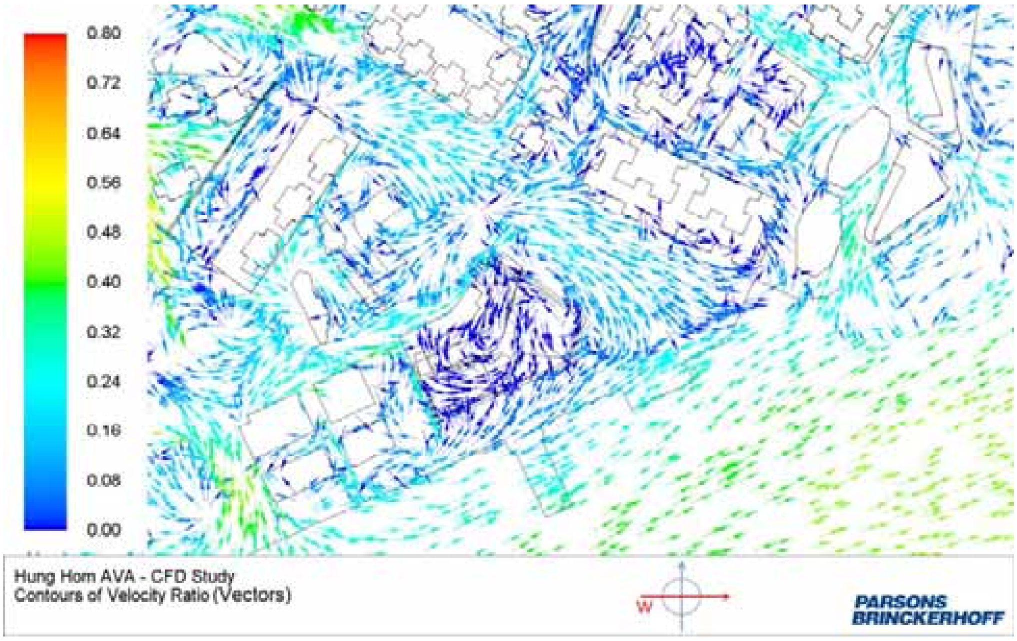


Velocity Vector Plot for West-Southwestern Wind - Proposed Scheme

PARSONS BRINCKERHOFF



Velocity Ratio Plot at 2m above Ground for Western Wind - Proposed Scheme



Velocity Vector Plot for Western Wind - Proposed Scheme

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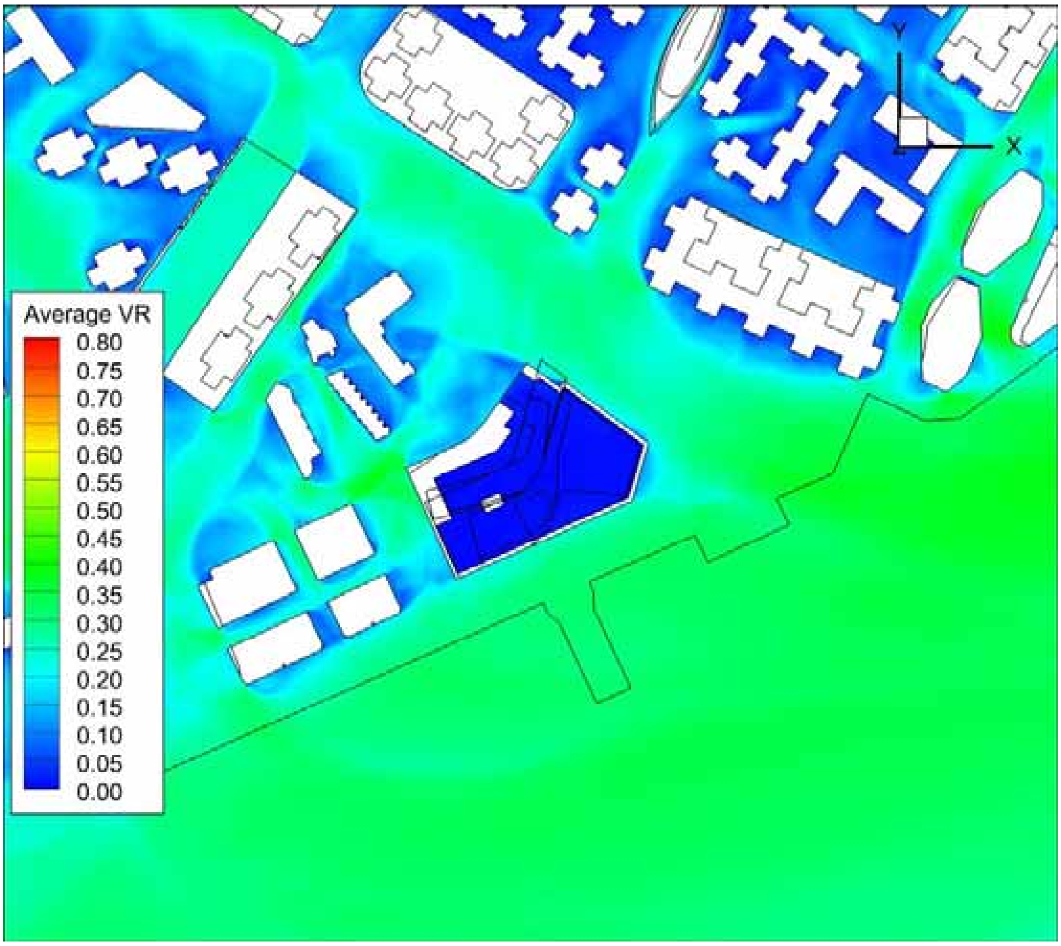
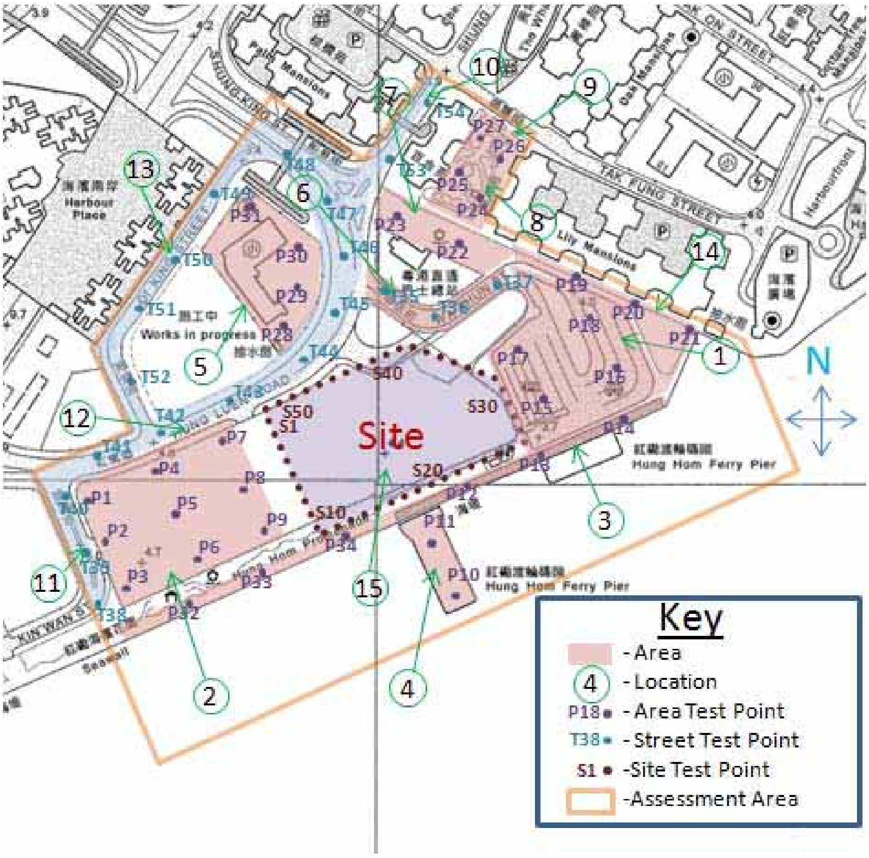


Proposed Scheme Pedestrian Level Summer Average

Appendix G – Numerical Value and Graphic Presentation of the VR for SVR and LVR

Key Plan



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Key Plan Guide and SAVR Values

		Average VR		
Location Name	**Relevant Test Points**	**Urbis**	**Notional**	**Proposed**
1. Planned Comprehensive Development	P1-P9	0.19	0.21	0.21
2. Future Urban Park	P15-P18	0.34	0.35	0.38
3. Hung Hom Promenade	P12-P14 P32-34	0.27	0.30	0.32
4. Hung Hom Ferry Pier	P10-P11	0.30	0.32	0.31
5. Ma Tau Chung Gov. Primary 6. School (Hung Hom Bay)	P28-P31	0.18	0.18	0.19
6. Wa Shun Street	T35-T37	0.29	0.33	0.34
7. Amenity area to northeast of Wa Shun Street	P22-P23	0.35	0.33	0.33
8. Amenity area between Block 5 and 6 of Lily Mansions	P24-P25	0.18	0.18	0.19
9. Whampoa Garden Site 9	P26-P27	0.13	0.10	0.12
10. Shung King Street	T53-T54	0.14	0.14	0.15
11. Kin Wan Street	T38-T40	0.04	0.09	0.12
12. Hung Luen Road	T41-T48	0.13	0.13	0.15
13. Oi King Street	T49-T52	0.20	0.25	0.26
14. Garden Area of Lily Mansions	P19-P21	0.17	0.16	0.19
15. Site Perimeter (SVR)	S1-S50	0.20	0.24	0.25

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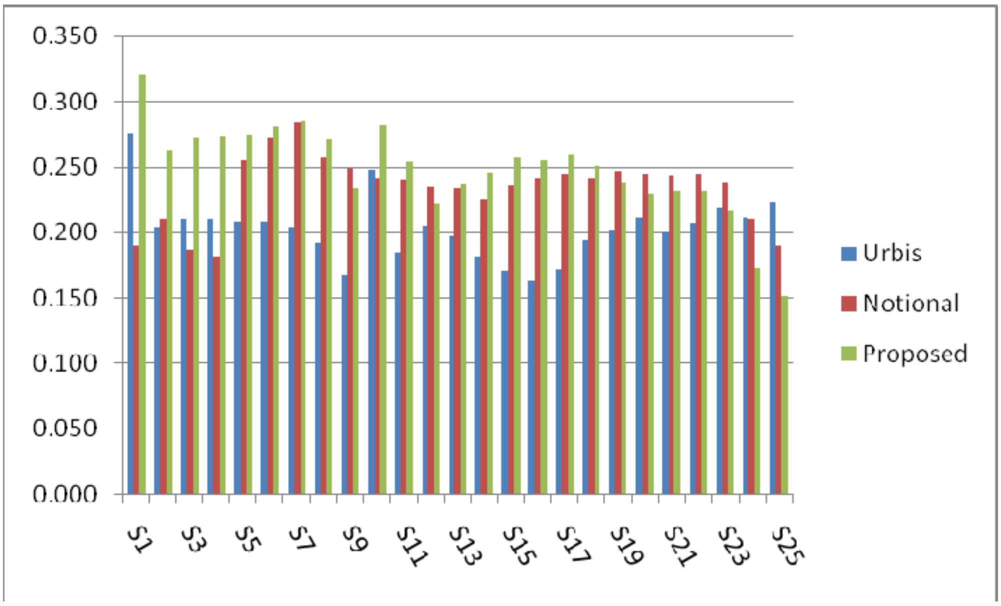
Table of Perimeter Test Point Values and SVR Values

	Urbis	Notional	Proposed
S1	0.276	0.190	0.320
S2	0.204	0.210	0.263
S3	0.210	0.187	0.272
S4	0.210	0.181	0.273
S5	0.208	0.254	0.274
S6	0.208	0.272	0.281
S7	0.203	0.284	0.286
S8	0.192	0.257	0.271
S9	0.168	0.249	0.233
S10	0.247	0.241	0.282
S11	0.185	0.241	0.254
S12	0.205	0.235	0.222
S13	0.197	0.234	0.236
S14	0.181	0.225	0.246
S15	0.170	0.235	0.258
S16	0.163	0.242	0.254
S17	0.171	0.245	0.260
S18	0.193	0.242	0.251
S19	0.201	0.247	0.237
S20	0.211	0.245	0.230
S21	0.201	0.243	0.231
S22	0.207	0.245	0.231
S23	0.218	0.239	0.216
S24	0.211	0.210	0.173
S25	0.223	0.190	0.151

	Urbis	Notional	Proposed
S26	0.205	0.187	0.156
S27	0.206	0.184	0.176
S28	0.239	0.229	0.310
S29	0.250	0.299	0.319
S30	0.269	0.289	0.314
S31	0.287	0.295	0.318
S32	0.280	0.299	0.318
S33	0.273	0.298	0.317
S34	0.273	0.296	0.318
S35	0.272	0.300	0.334
S36	0.269	0.302	0.337
S37	0.261	0.298	0.332
S38	0.252	0.280	0.298
S39	0.194	0.270	0.270
S40	0.076	0.255	0.250
S41	0.080	0.222	0.132
S42	0.081	0.161	0.174
S43	0.098	0.202	0.167
S44	0.112	0.219	0.171
S45	0.113	0.224	0.185
S46	0.125	0.225	0.222
S47	0.131	0.235	0.217
S48	0.152	0.223	0.185
S49	0.165	0.204	0.189
S50	0.271	0.163	0.285

	Urbis	Notional	Proposed
Average SVR	0.20	0.24	0.25

Graphical Comparison of VR of Each Perimeter Test Point



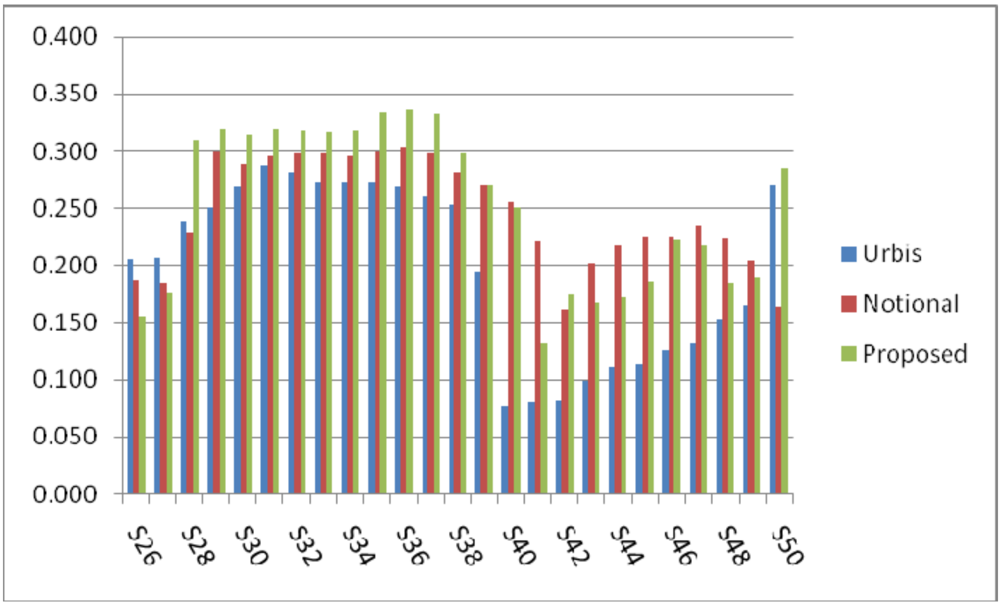


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Table of Overall Test Point Values and Overall LVR Values

	Urbis	Notional	Proposed
P1	0.256	0.274	0.288
P2	0.121	0.139	0.115
P3	0.143	0.177	0.157
P4	0.265	0.304	0.294
P5	0.122	0.152	0.159
P6	0.134	0.162	0.168
P7	0.324	0.319	0.323
P8	0.201	0.233	0.234
P9	0.211	0.205	0.185
P10	0.284	0.277	0.296
P11	0.315	0.359	0.330
P12	0.256	0.252	0.297
P13	0.312	0.371	0.399
P14	0.356	0.408	0.438
P15	0.333	0.316	0.375
P16	0.346	0.381	0.374
P17	0.329	0.369	0.416
P18	0.347	0.345	0.357
P19	0.163	0.135	0.189
P20	0.154	0.158	0.184
P21	0.186	0.174	0.189
P22	0.355	0.332	0.320
P23	0.344	0.334	0.347
P24	0.162	0.167	0.139
P25	0.195	0.197	0.237
P26	0.099	0.070	0.084
P27	0.158	0.135	0.154
P28	0.155	0.134	0.151
P29	0.167	0.183	0.163
P30	0.184	0.188	0.194
P31	0.220	0.200	0.258
P32	0.168	0.187	0.186
P33	0.186	0.200	0.196
P34	0.358	0.407	0.384

	Urbis	Notional	Proposed
T35	0.322	0.370	0.341
T36	0.284	0.310	0.327
T37	0.254	0.313	0.350
T38	0.059	0.106	0.106
T39	0.038	0.100	0.177
T40	0.033	0.066	0.084
T41	0.119	0.121	0.147
T42	0.123	0.123	0.147
T43	0.138	0.126	0.148
T44	0.130	0.128	0.148
T45	0.133	0.128	0.148
T46	0.137	0.150	0.185
T47	0.140	0.129	0.149
T48	0.142	0.131	0.150
T49	0.217	0.254	0.276
T50	0.200	0.249	0.265
T51	0.181	0.237	0.248
T52	0.164	0.218	0.227
T53	0.143	0.137	0.154
T54	0.144	0.138	0.144

	Urbis	Notional	Proposed
Average LVR	0.20	0.22	0.23

Graphical Comparison of VR of Each Overall Test Point