Hong Kong Housing Authority

Development of Hung Shui Kiu Area 13

Air Ventilation Assessment - Initial Study

025115-01

Issue | 29 August 2012

Job number 025115-01

Ove Arup & Partners Hong Kong Ltd
Level 5 Festival Walk
80 Tat Chee Avenue
Kowloon Tong
Kowloon
Hong Kong
www.arup.com

ARUP

Document Verification

ARUP

Job title	Development of Hung Shui Kiu Area 13	Job number 025115-01
Document title	Air Ventilation Assessment - Initial Study	File reference
Document ref	025115-01	

Revision	Date	Filename	20120828 HSK_AVA web version_rev.docx		
First Draft	28 Aug 2012	Description	First Draft of Web Version		
			Prepared by	Checked by	Approved by
		Name	Various	Sui Hang Yan	Vincent Cheng
		Signature			
Issue	29 Aug 2012	Filename	20120829 HSK_AVA for PlanD web_issue.docx		
		Description	Issue 1		
			Prepared by	Checked by	Approved by
		Name	Various	Sui Hang Yan	Vincent Cheng
		Signature		p.p. [signature]	[signature]
		Filename			
		Description			
			Prepared by	Checked by	Approved by
		Name			
		Signature			
		Filename			
		Description			
			Prepared by	Checked by	Approved by
		Name			
		Signature			

Issue Document Verification with Document ✓

Contents

Appendices

Appendix C

Velocity Ratio

Executive Summary

Introduction

Ove Arup & Partner Hong Kong Ltd (Arup) was commissioned by the Hong Kong Housing Authority (HKHA) to carry out an Air Ventilation Assessment (AVA) – Initial Study for the Development at Hung Shui Kiu Area 13 (The Development). This AVA study is to compare the wind performance of two schemes:

- Baseline Scheme – This is a reference scheme with Plot Ratio 3 of the former approved development of the Hong Kong Housing Society.
- Proposed Scheme – Newly proposed development scheme consists of 9 public housing blocks. Commercial and social welfare facilities are provided at street level. A three-storey carpark block and a public transport interchange are included in the development.

Methodology

The Technical Circular No. 1/06 – Air Ventilation Assessment (Technical Circular) was jointly issued by Housing, Planning and Land Bureau and Environment, Transport and works Bureau on 19 July 2006 to address the technical and implementation issues of AVA in Hong Kong. This Technical Circular is followed in this AVA study. Computational Fluid Dynamics (CFD) complying with SST k – ω turbulence modelling, is used for modeling the air ventilation under different prevailing wind directions.

Overall Wind Performance

The AVA study result shows the overall air ventilation performance of the area for the Proposed Scheme is similar to the Baseline Scheme. The Site Spatial Average Velocity Ratios (SVR) and Local Spatial Average Velocity Ratios (LVR) for the Baseline Scheme/ Proposed Scheme are 0.28/ 0.31 and 0.29/ 0.32 respectively.

Wind Enhancement Measures

There are some wind enhancement measures that help to provide a satisfactory ventilation performance of the Proposed Scheme. They are summarized as follows:

- Podium free design is introduced for better wind penetration.
- Dedicated wind corridors are provided along prevailing wind directions for minimal disturbance of wind flow to its surrounding areas.
- Large and sufficient building separations enhance permeability of wind flow through the site and improve the ventilation performance of the surrounding area.
- Ground floor empty bays improve air ventilation performance.

Wind Performance of Focus Areas

With adoption of the above enhancement measures, the Proposed Scheme has improved average velocity ratios in most of focus areas when compared to the Baseline Scheme.

1 Introduction

1.1 Project Background

Ove Arup & Partner Hong Kong Ltd (Arup) was commissioned by the Hong Kong Housing Authority (HKHA) to carry out an Air Ventilation Assessment (AVA) – Initial Study for the Development of Hung Shui Kiu Area 13 (The Development).

On Feb 2009, the HKHA revised the Proposed Scheme and requested for the incorporation of updated information for the CDA (Comprehensive Development Area) development at the southern side of the project site for consideration. With incorporation of the updated information, Arup has carried out the revised AVA Initial Study by remodelling both Baseline and Proposed Schemes to fulfil planning condition.

1.2 Objective of the Study

The purpose of this study is to assess the ventilation performance of the Proposed Development with reference to a baseline scheme using the methodology of Air Ventilation Assessment as stipulated in the "Housing, Planning and Lands Bureau – Technical Circular No. 1/06, Environment, Transport and Works Bureau - Technical Circular No. 1/06" issued on 19th July 2006 (Technical Circular) and Annex A of Technical Circular - "Technical Guide for Air Ventilation Assessment for Developments in Hong Kong" (Technical Guide).

1.3 Scope of the Study

This *Air Ventilation Assessment (AVA) Initial Study* was carried out for two scenarios:

1. **Baseline Scheme** – This is a reference scheme with Plot Ratio 3 of the former approved development of the Hong Kong Housing Society.
2. **Proposed Scheme** – Newly proposed development scheme involves the construction of 9 public housing blocks. Commercial and social welfare facilities are provided at street level. A three-storey carpark block and a public transport interchange are included in the development.

The deliverables of current study can be summarised as follows:

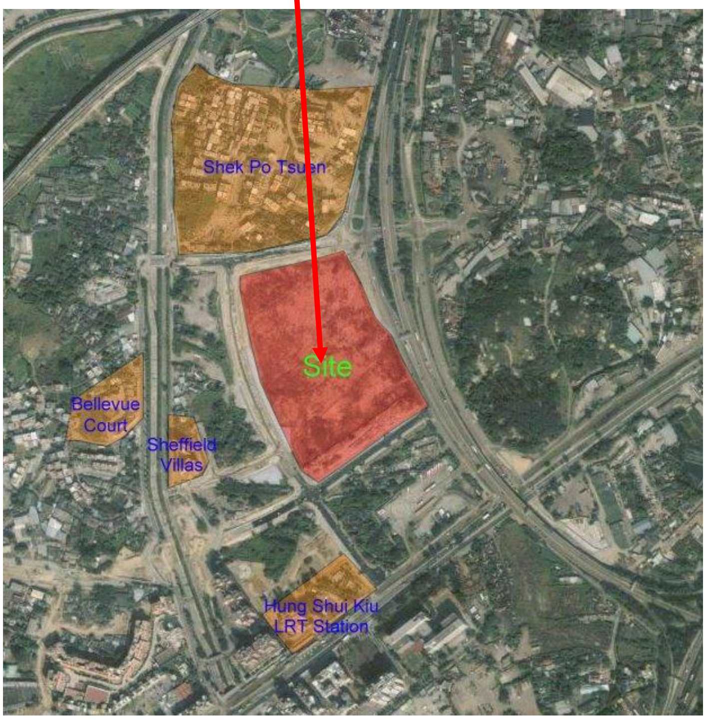
- Evaluation of the wind microclimate to determine the site wind characteristics
- Identification of air ventilation performance of the Development and surrounding area for different schemes.

2 Background

2.1 Site Characteristics

The Development has a gross site area of 6.4 ha. It is located in an area of comparatively low rise semi-rural developments to the north of Castle Peak Road, about 1½ miles west of Yuen Long. Hung Shui Kiu LRT Station is located to the South. Shek Po Tsuen, a low rise development is to the North of The Development. Bellevue Court and Sheffield Villas are on the West side of The Development. These locations would be deliberately considered during the wind performance analysis. Figure 1 below shows the locations of the Study Area and major surrounding developments.

(Source: Centamap)



(Source: GoogleEarth)

Figure 1 Locations of the Study Area and Major Surrounding Developments

2.2 Studied Scenarios

Totally two cases were investigated in the AVA study which includes:

Baseline Scheme

This is a reference scheme with Plot Ratio 3 of the former approved development of the Hong Kong Housing Society. It involves the construction of 24 blocks with building roof levels ranging from 51-61mPD (Figure 3). Table 2 shows the building roof levels in the Baseline Scheme.

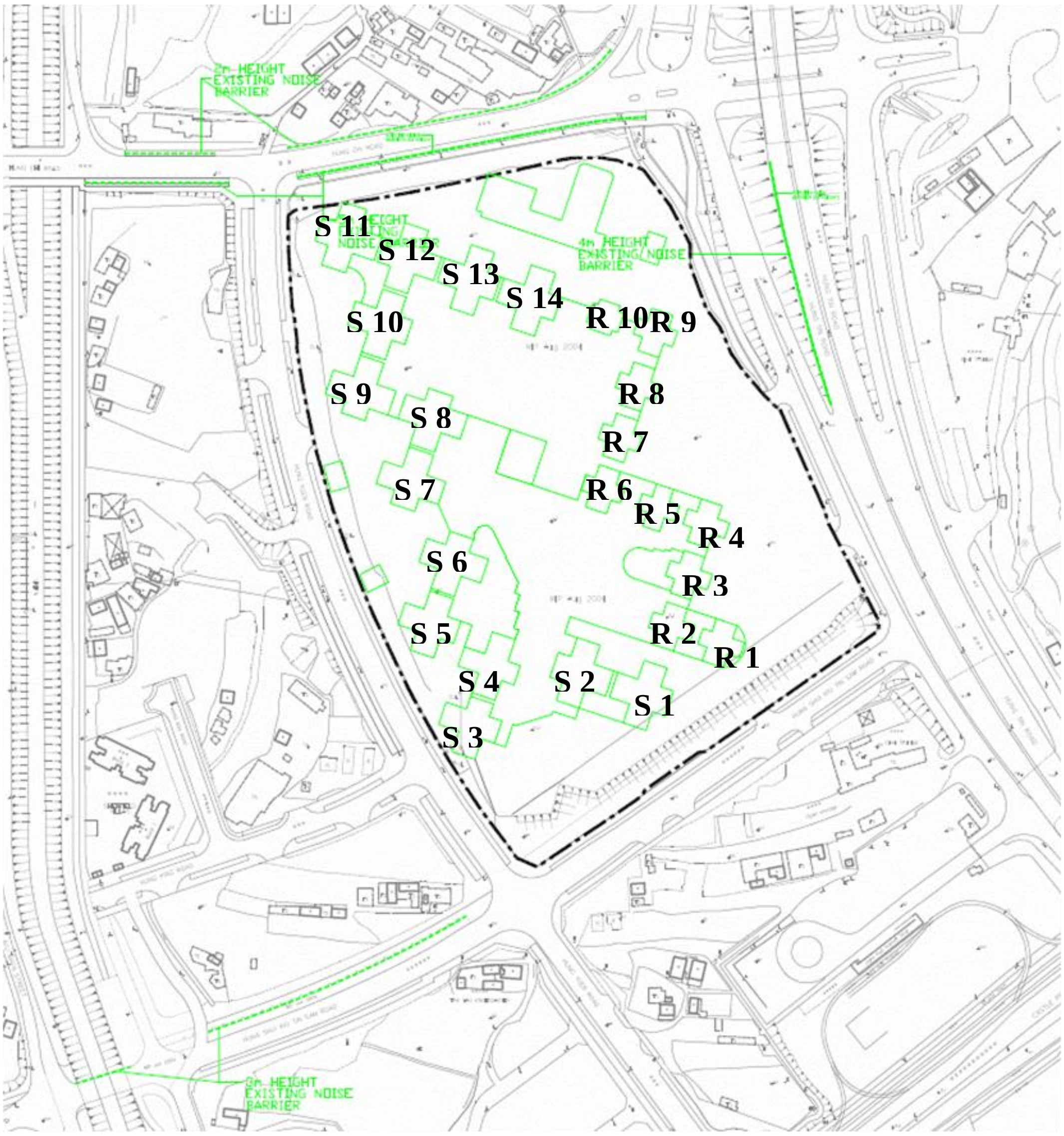


Figure 2 Master Layout Plan for the Baseline Scheme

Table 1 Building Roof Levels in the Baseline Scheme

Block	mPD	Block	mPD
S1	51	R1	51
S2	51	R2	51
S3	61	R3	51
S4	51	R4	51
S5	61	R5	51
S6	61	R6	51
S7	61	R7	51
S8	61	R8	51
S9	61	R9	51
S10	61	R10	51
S11	61		
S12	61		
S13	61		
S14	61		

Proposed Scheme

The Proposed Development is developed by HKHA, which involves the construction of:

- 9 nos. of non-standard domestic blocks with building heights ranging from 59-82mPD;
- Commercial centre at street level along Tin Sum Road and Hung Tin Road;
- A three-storey carpark block integrated with the ground-level wet market;
- A public transport interchange (PTI) with cover.

The details are shown in Figure 3 and Table 2.

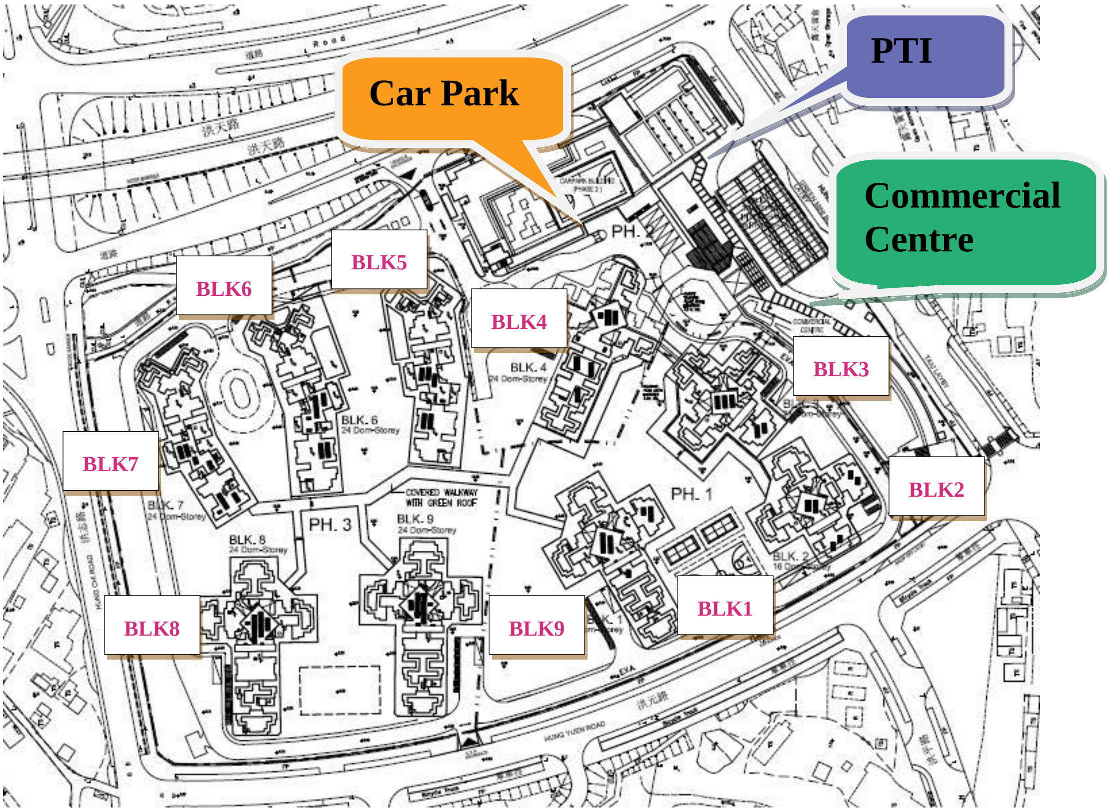


Figure 3 Master Layout Plan for the Proposed Scheme

Table 2 Building Roof Levels in the Proposed Scheme

Block	mPD	Block	mPD
BLK1	81	BLK5	81
BLK2	59	BLK6	81
BLK3	73	BLK7	81
BLK4	81	BLK8	82
		BLK9	82

3 Methodology of AVA Study

The Air Ventilation Assessment (AVA) methodology for Initial Study as stipulated in the Technical Circular and Technical Guide was employed for this study. The following sections describe the details of the study methodology.

3.1 Site Wind Availability

The site wind availability data was obtained from MM5 model available on the website of Planning Department. The data is calculated by mesoscale model (MM5) at the height of around 596 m above the ground. A wind rose showing the frequency of occurrence of different wind directions as well as a summary of the frequency for different wind directions are attached below.

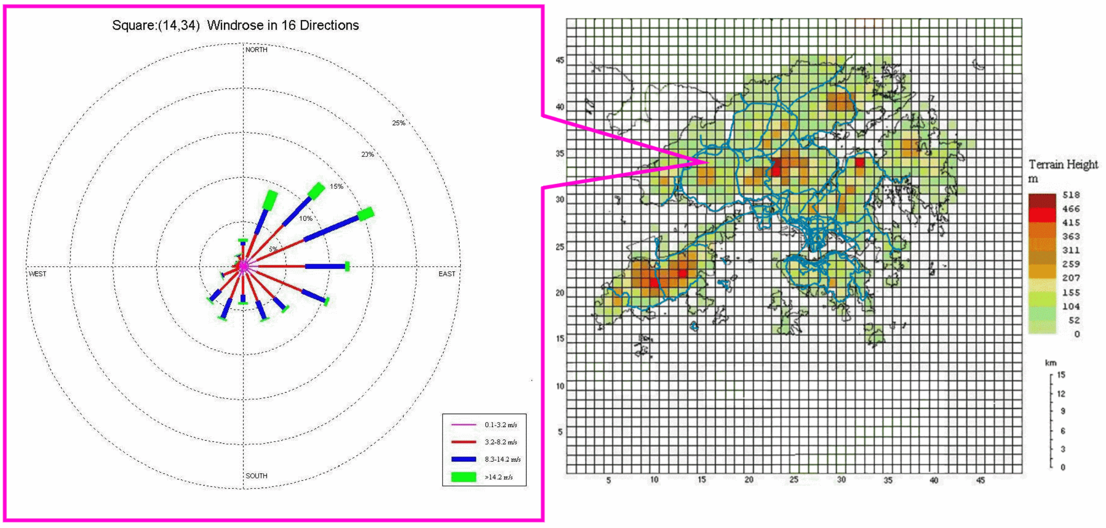


Figure 4 Wind Rose based on MM5 Simulation

Table 3 Wind Frequency

Wind Direction	Percentage of Occurrence (%)	Wind Direction	Percentage of Occurrence (%)	Wind Direction	Percentage of Occurrence (%)	Wind Direction	Percentage of Occurrence (%)
N	*3*	E	***12.1***	S	*4.2*	W	*1.3*
NNE	***9***	ESE	***10.5***	SSW	***6.4***	WNW	*1*
NE	***12.7***	SE	***6.9***	SW	*5.5*	NW	*0.9*
ENE	***16***	SSE	***6.5***	WSW	*2.7*	NNW	*1.4*

- *Numbers in green represent the selected prevailing wind directions for simulation*

Results show that the prevailing wind directions NNE, NE, ENE, E, ESE, SE, SSE and SSW are having corresponding frequency of occurrences of 9%, 12.7%, 16%, 12.1%, 10.5%, 6.9%, 6.5% and 6.4% respectively. Total wind frequency considered is 80.1% over a year, i.e. exceeding 75% of annual wind frequency as required by the Technical Circular of AVA.

3.2 Wind Profile

The wind profiles, including the mean wind speed and the turbulence intensity were taken as input parameters in the CFD models. As required by the Technical Circular, the wind profiles can be assumed by the power law for specific terrains as following equation:

$$\frac{U_z}{U_G} = \left(\frac{Z}{Z_G}\right)^n \text{, where}$$

U_G = reference velocity at height Z_G

U_z = velocity at height Z

Z_G = reference height

Z = height above ground

n = power law exponent

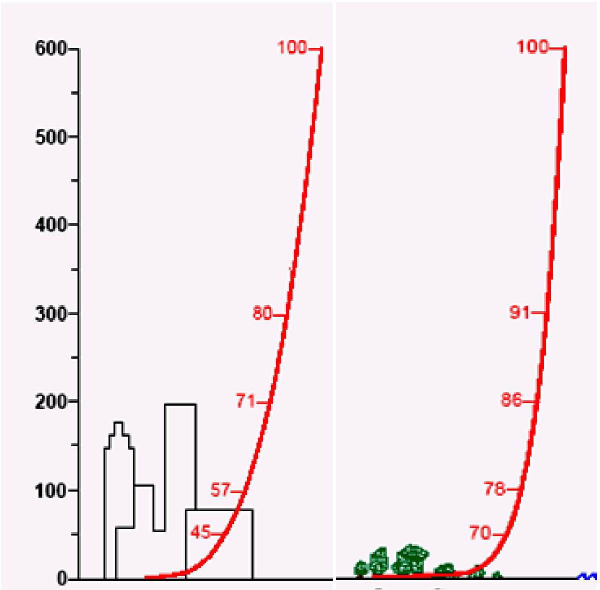


Figure 5 Wind Profile applied in the AVA Initial Study

The power n is related to the ground roughness, which is determined by terrain types. A larger value of the power n represents the higher roughness of the ground i.e. the dense city. Alternatively, smaller n represents the lower ground roughness i.e. the sea surface.

Terrain crossed by approaching wind	n-value
Sea and open space	~0.15
Suburban or mid-rise	~0.35
City center or high-rise	~0.50

As the study area is in a low rise semi rural area, n-value of the wind direction NNE, NE and SSW would be 0.35 while the others of the eight-most frequent wind directions would be 0.15. Based on this power law, the wind profile is shown in Figure 5, where the normalized wind characteristics of mean wind speed represented the mean wind speed at the different height above the site against wind speed at the height of 596m.

3.3 Project Assessment and Surrounding Areas

With reference to the Technical Guide, the area of evaluation and assessment includes all areas within the Development Site, as well as a belt up to 1H (H being the height of the tallest building within the Development which is equivalent to 80m) from the site boundary ***(Assessment Area)***. Further, the model area was built to include another 80m meters (2H) beyond the Assessment Area ***(Surrounding Area)***. Nearby prominent topographical features beyond the Surrounding Area were also included in the model to take into account the topographic effect.

Figure 6 Site Boundary (red), Assessment Area (green) and Surrounding Area (blue)

3.4 Assessment Parameter

The Velocity Ratio (VR) as proposed by the Technical Circular for AVA was employed to assess the impact of the proposed development and to the surroundings. High VR across the development implies less impact associated with the proposed development. The calculation of VR is given by the following formula:

$$VR = \frac{V_p}{V_\infty}$$

V_∞ = the wind velocity at the top of the wind boundary layer (typically assumed to be around 596m above the centre of the site of concern, or at a height where wind is unaffected by the urban roughness below).

V_p = the wind velocity at the pedestrian level (2m above ground) after taking into account the effect of buildings.

3.5 Test Points for Local and Site Ventilation Assessment

Monitoring test points are placed within the Development Site to determine the ventilation performance. There are three types of test points:

3.5.1 Perimeter Test Points

Perimeter test points are the points positioned on the project site boundary. According to the Technical Circular for AVA, 27 perimeter points *(red spots)* are positioned on the project site boundary and each point is around 10-50m in between as shown in Figure 7.

3.5.2 Overall Test Points

Overall test points are those points evenly positioned within the Assessment Area in the open space on the streets and places where pedestrian frequently access. According to the Technical Circular for AVA, 51 overall test points *(blue spots)* are selected and shown in Figure 7.

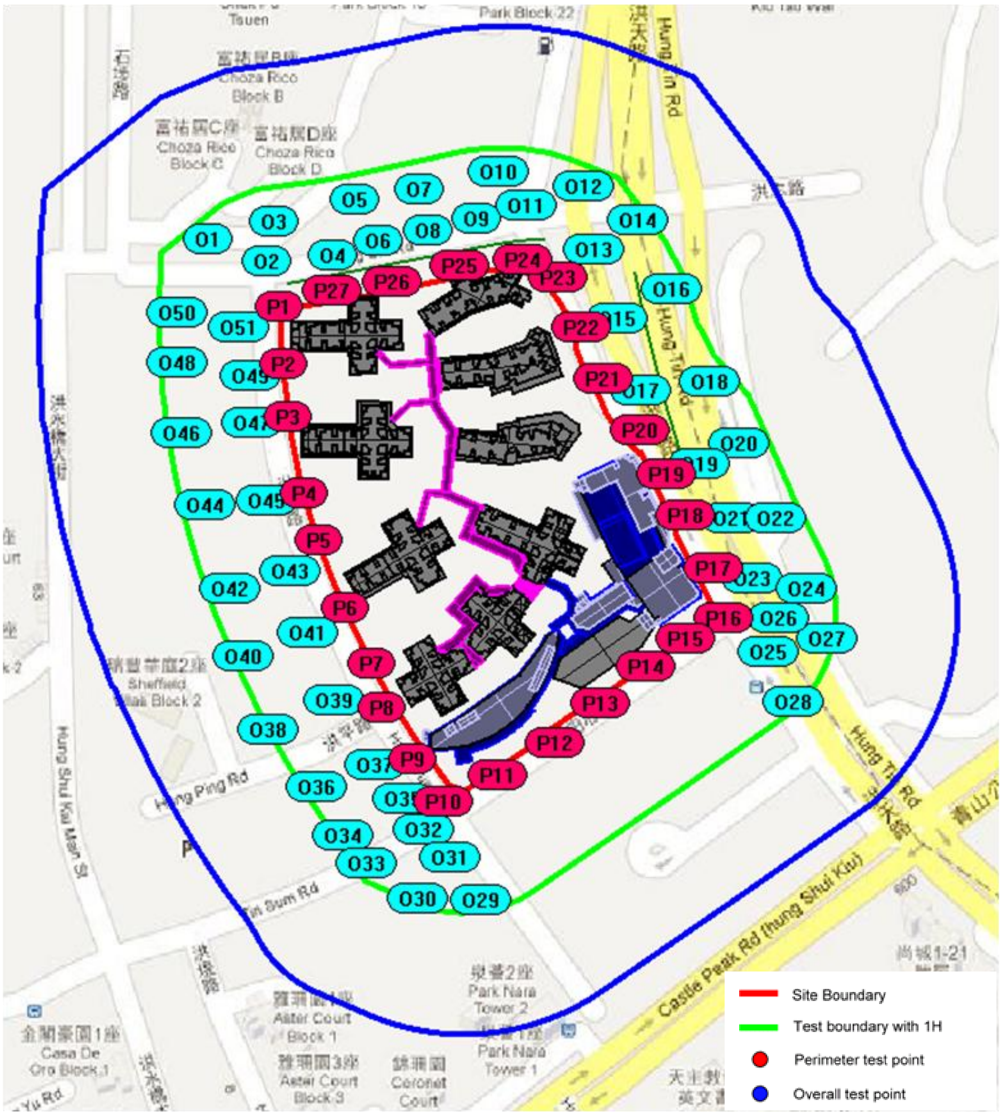


Figure 7 Demarcation of the Test Locations for Site Air Ventilation Assessment

3.6 Assessment Tool

Computational Fluid Dynamics (CFD) technique was utilized for this Study. With the use of three-dimensional CFD method, the local airflow distribution can be visualized in details. The velocity distribution within the flow domain, being affected by the site-specific design and the nearby topography, was simulated under the prevailing wind conditions considered.

3.6.1 CFD Model

Following the Air Ventilation Technical Circular, buildings within surrounding area (Figure 6) need to be built in the CFD model. In order to simulate the approaching wind turbulence effect more accurately, the CFD model is built to include the buildings that may affect the approaching wind, even it is falling outside the surrounding area, such as Shek Po Tsuen. In addition, the model is built further large to eliminate edge effect of air acceleration. Therefore, the buildings size of CFD models of the Development for 2 schemes are approximately 1750m(L) x 1500m(W) x 900m(H) and each contain more than 2,500,000 cells. It covers the entire development and provides sufficient consideration on surrounding topography. The model contains information of the surrounding buildings and site topography via Geographical Information System (GIS) platform. Body-fitted unstructured grid technique is used to fit the geometry and reflect the complexity of the development geometry. A prism layer of 2m above ground (totally 4 layers and each layer is 0.5m) is incorporated in the meshing so as to better capture the approaching wind. The expansion ratio is 1.5 while the blockage ratio is 6%.

By referring to the CAD drawings of the Baseline and Proposed Schemes given, the CFD model is constructed as shown below.

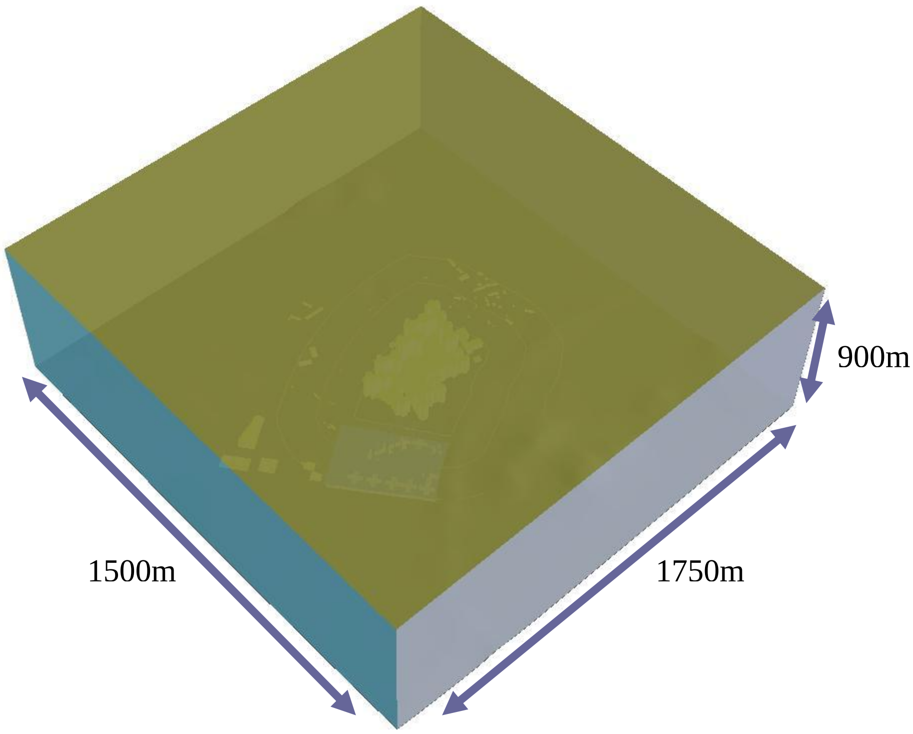


Figure 8 Domain of the CFD Model

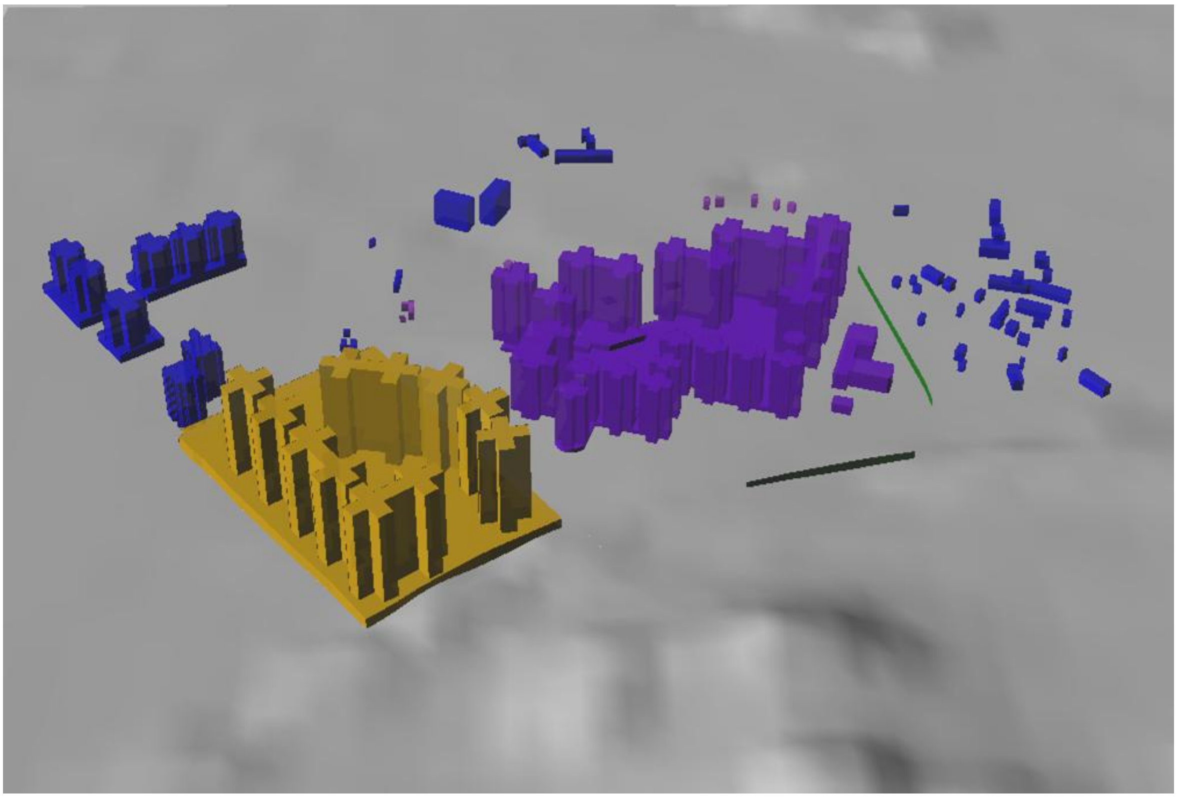


Figure 9 Easterly View of the Baseline Scheme

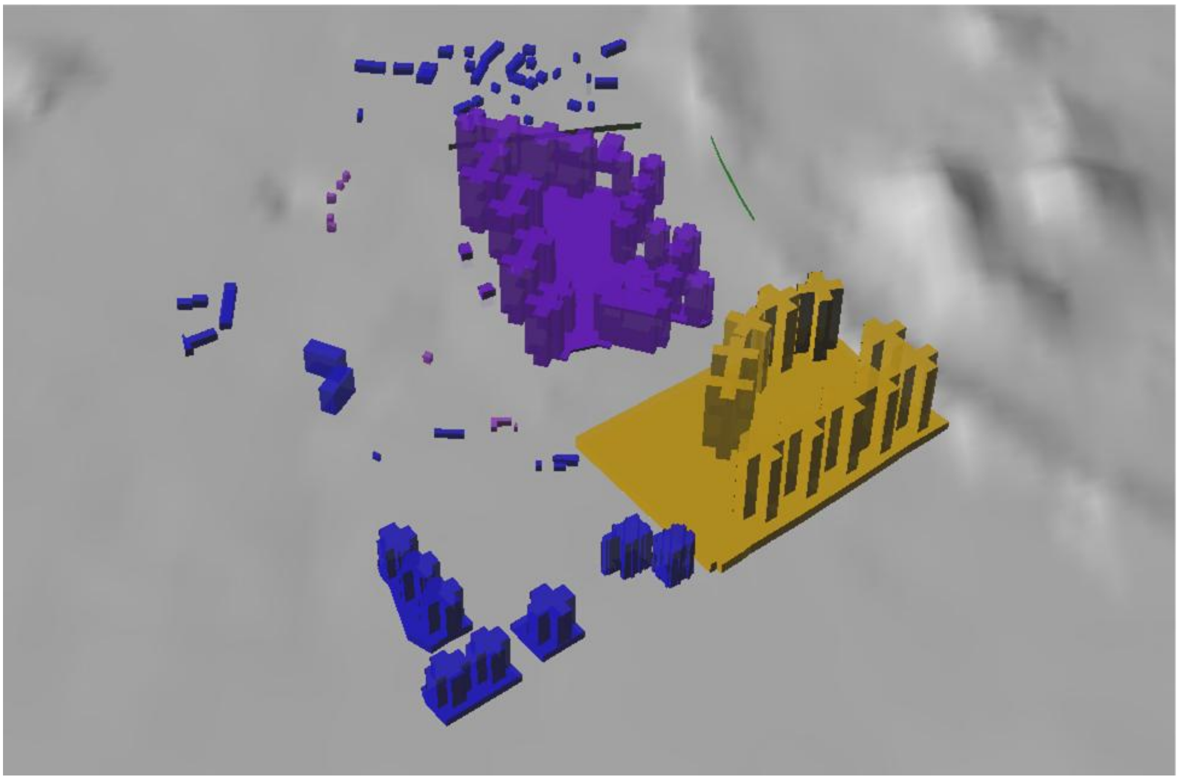


Figure 10 Southern View of the Baseline Scheme

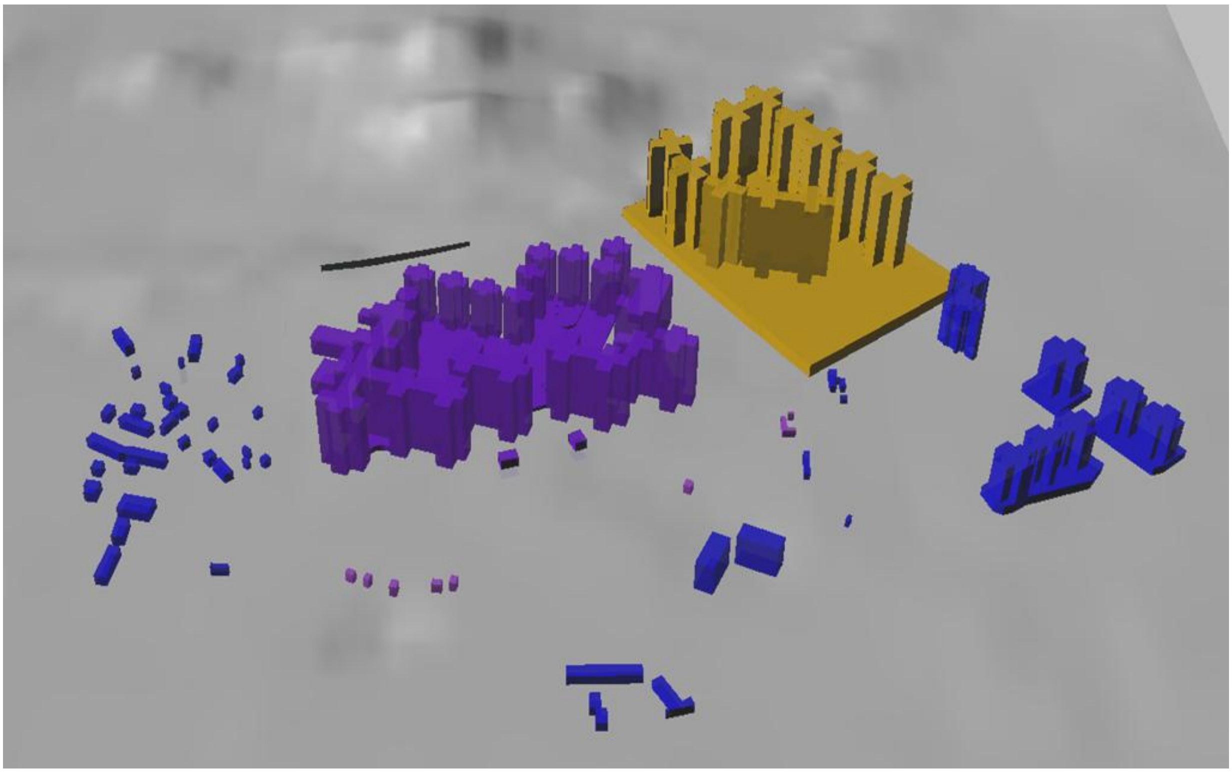


Figure 11 Westerly View of the Baseline Scheme

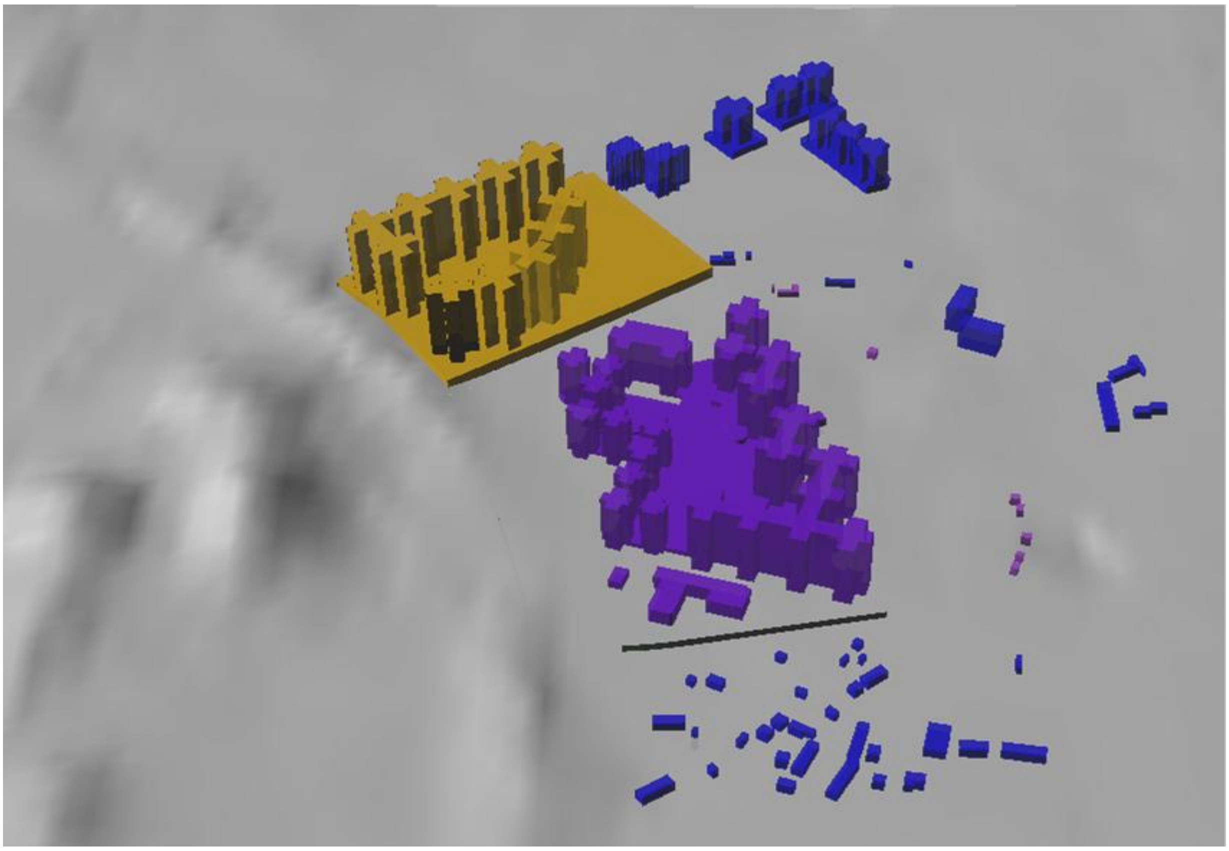


Figure 12 Northern View of the Baseline Scheme

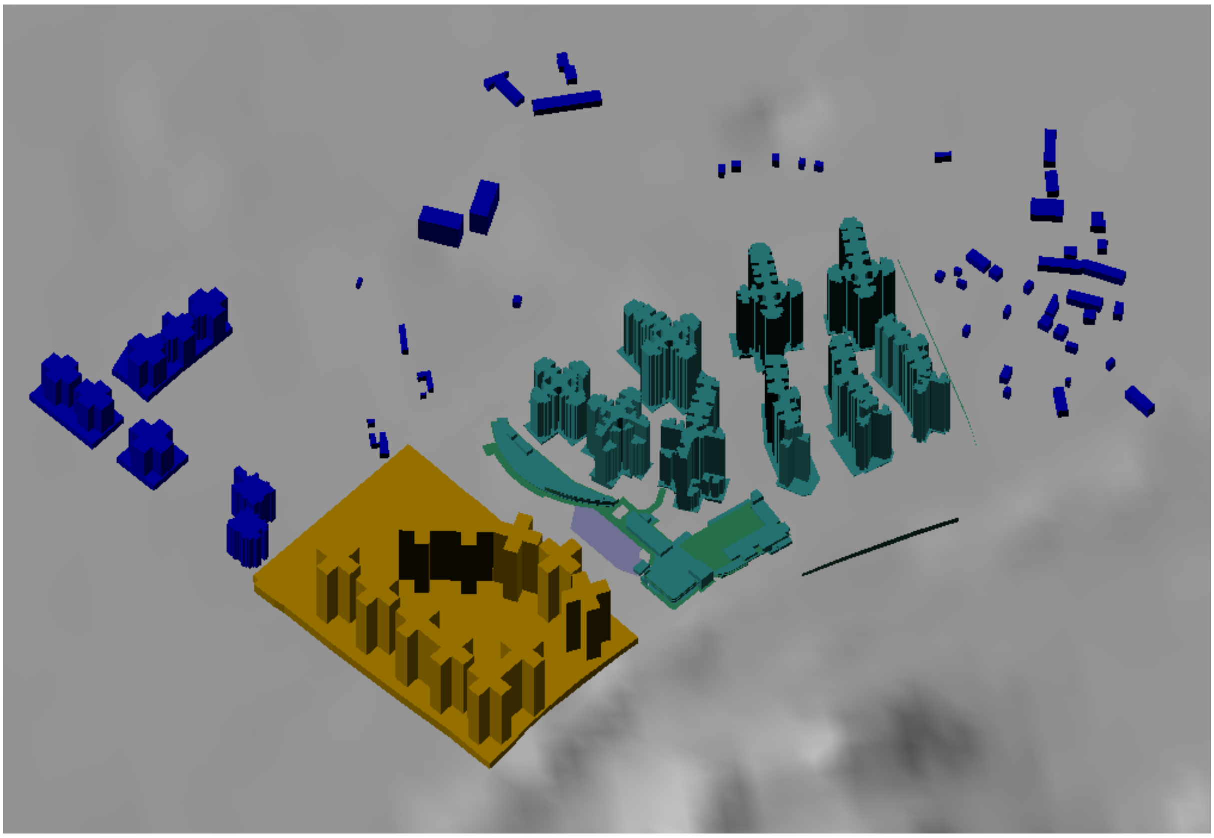


Figure 13 Easterly View of the Proposed Scheme

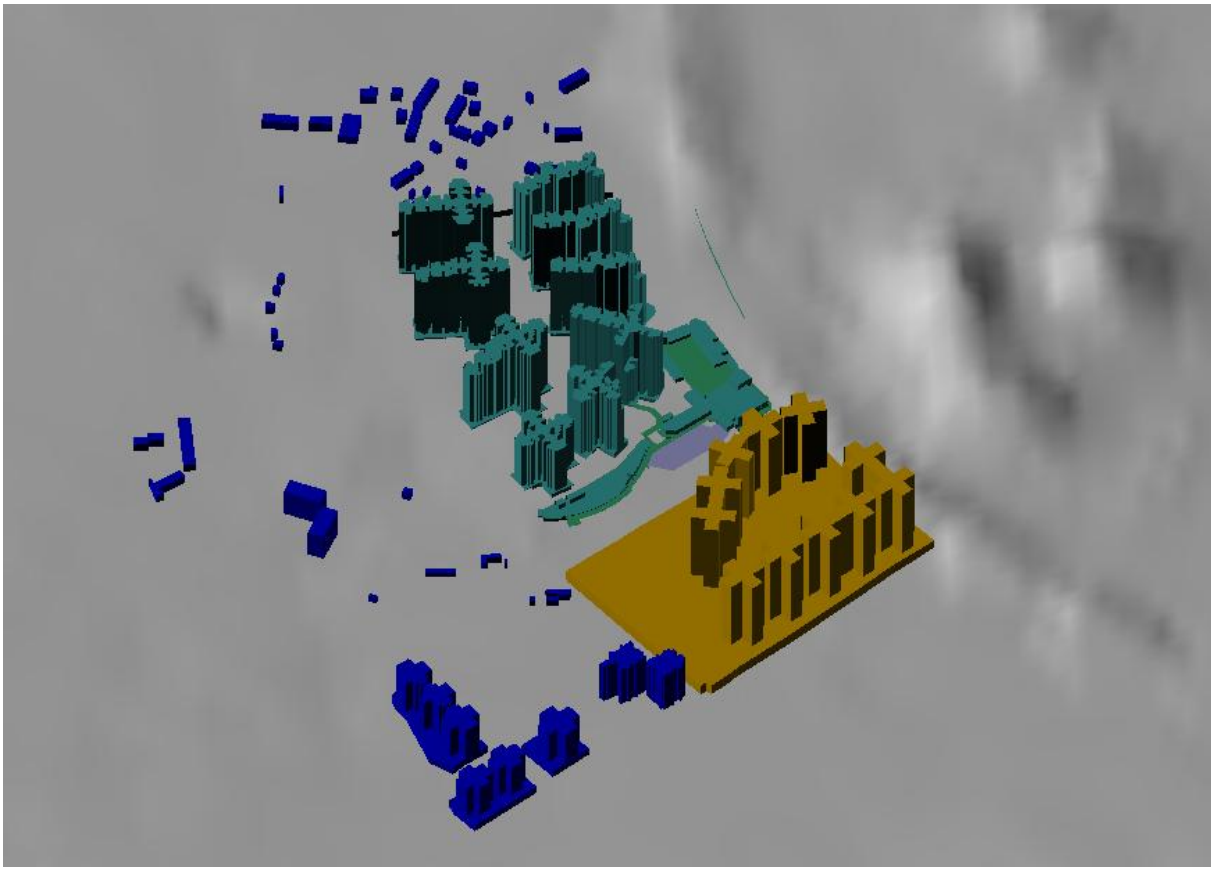


Figure 14 Southern View of the Proposed Scheme

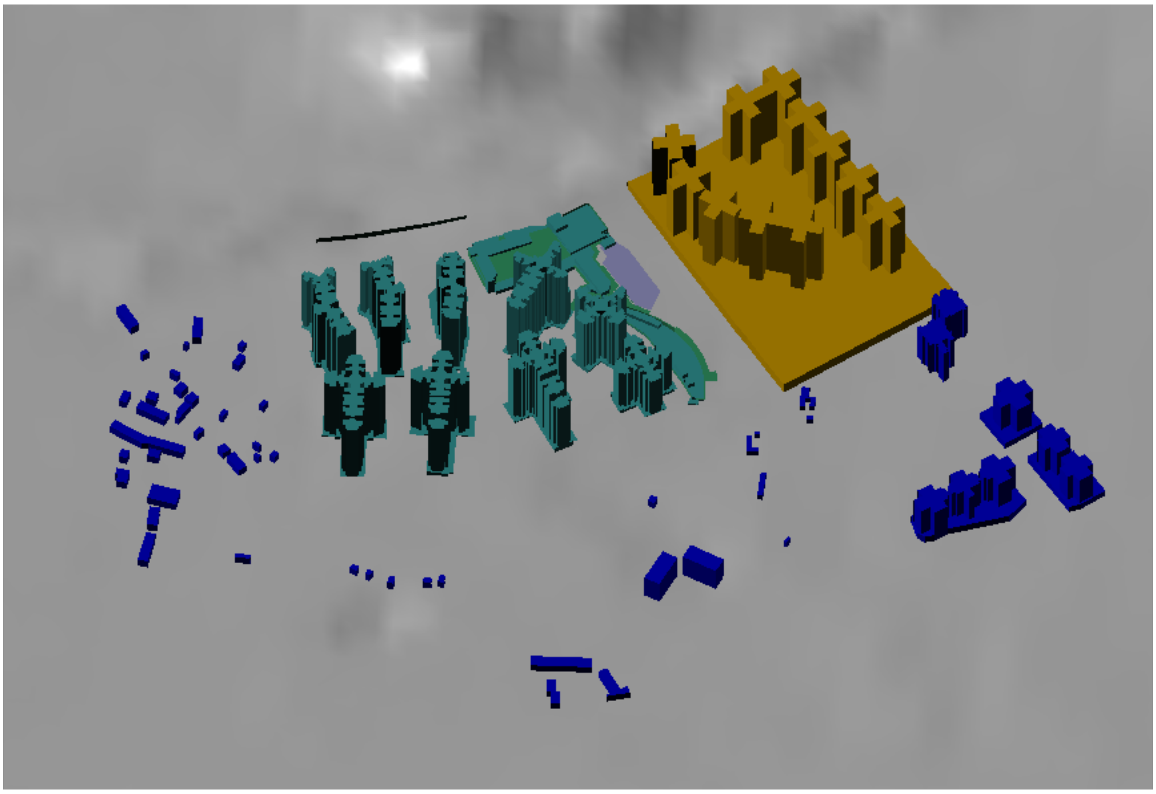


Figure 15 Westerly View of the Proposed Scheme

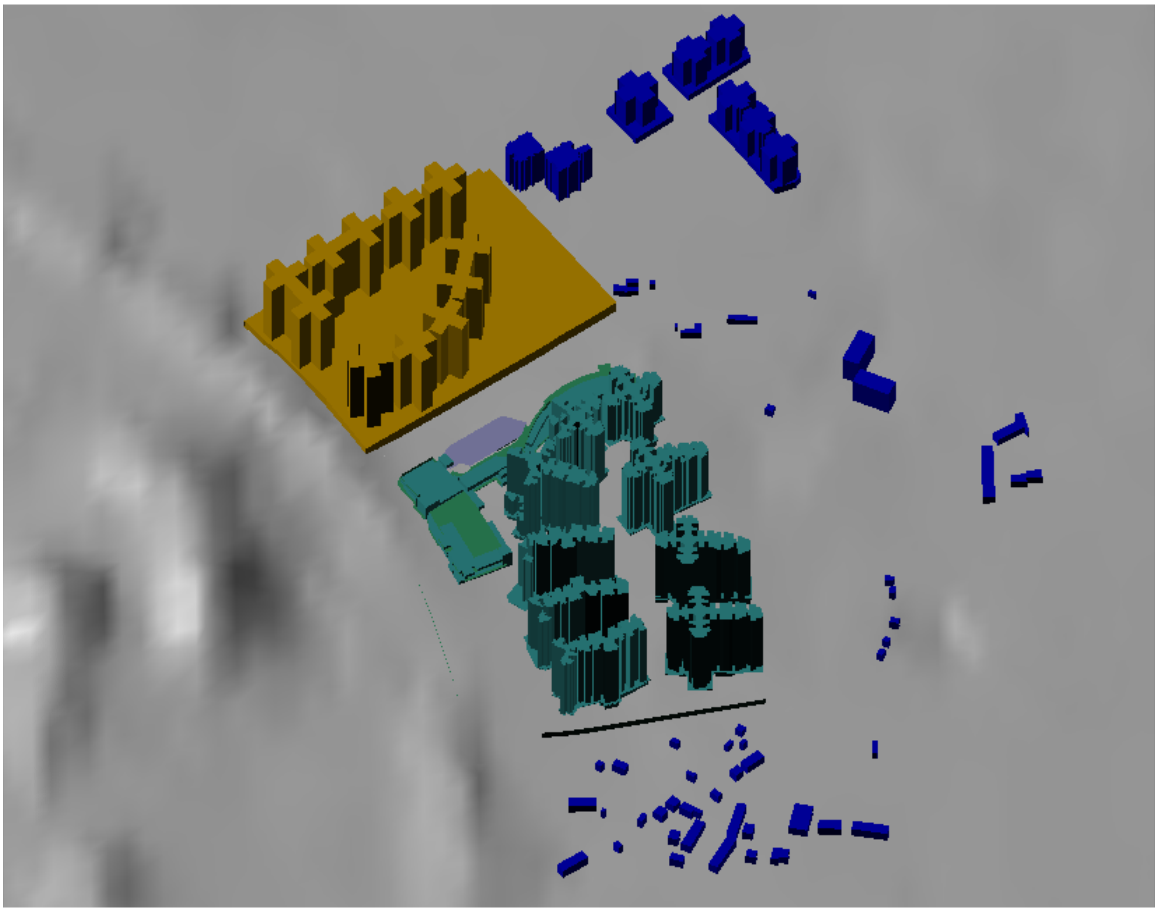


Figure 16 Northern View of the Proposed Scheme

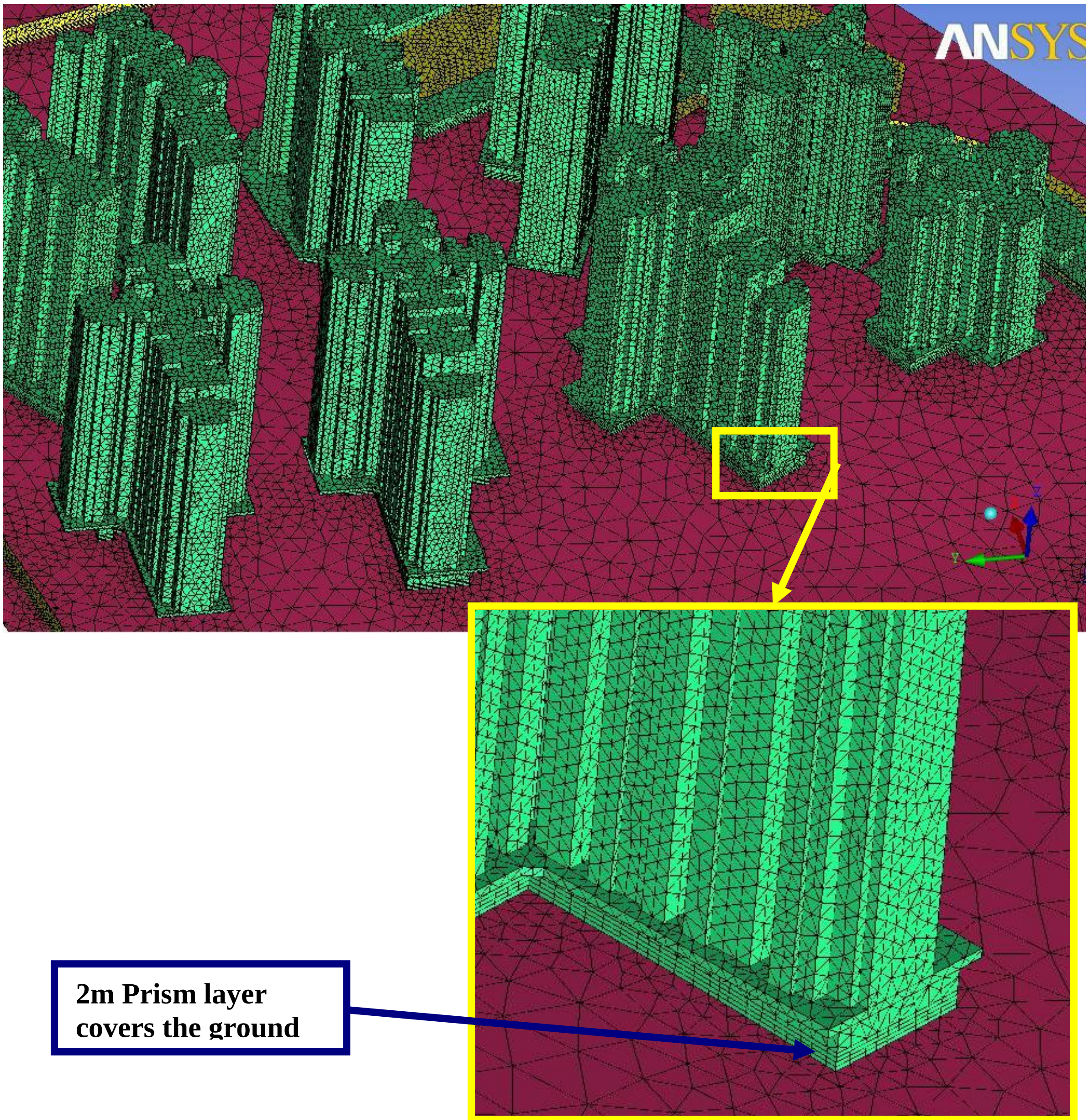


Figure 17 CFD Models for the Proposed Scheme

3.6.2 Turbulence Model

As highlighted in recent academic and industrial research literatures by CFD practitioners, the widely used standard k - ε turbulence model technique may not adequately model the effects of large scale turbulence around buildings and ignores the wind gusts leading to the relatively poor prediction in the recirculation regions around building. Therefore in this simulation, SST k – ω turbulence modelling method is applied. This technique provides more accurate representation of the levels of turbulence that can be expected in an urban environment.

3.6.3 Calculation Method

The SIMPLE algorithm was adopted to solve the pressure-velocity linked equations. The SFCD differencing scheme was applied to discretize the momentum equation and other equations. The convergence criterion is 0.0005 on mass conservation. The calculation loop will repeat until the total errors satisfy this convergence criterion.

The prevailing wind direction is set to inlet boundary with wind profile as mentioned in Section 3.2. The downwind boundary is set to pressure with value of atmospheric pressure. The top and side boundaries are set to symmetry. In addition, to eliminate the boundary effects, the model domain is built beyond the Surrounding Area as required by the Technical Circular (refer to Figure 8).

4 Result and Discussion

4.1 Overall Pattern of Ventilation Performance

In order to provide an overall picture of the wind environment for the purpose of this AVA study, contour plots of the average VR are plotted at 2m above the ground. This, in comparison with the results at the discrete test points, provides a more complete picture as it shows the overall pattern of ventilation performance and it is easier to assess the physical reasons for some of the predictions of the VR results of the test points. Figure 18 and Figure 19 show the contour maps of VR for the Baseline Scheme and Proposed Scheme respectively.

- As the wind mainly comes from NE, ENE and E directions (40.8%), the west side of the development site shows a lower average VR compared to the east side.
- Higher VR is observed at the Road (e.g. Hung Chi Road) that is parallel to the prevailing wind directions (i.e. NE, ENE and E). Moreover, the noise barriers at the two sides of the road bounded the wind. Thus, higher wind velocity is observed.
- The south-east, west and north portions surrounding the Development are relatively sparse and low-rise buildings. They do not induce obvious wind obstruction effect to the open space of the surrounding area.
- The wind corridors within the site and the empty bays in ground floor level further enhance the ventilation performance within the site. (Refer to Figure 21)
- The Proposed Scheme without a podium design gives advantage on the ventilation at the open space within the Development.
- Higher wind speed is recorded in between the building gaps of Block 4 to Block 7 and between Block 8 to 9 under ENE to SE wind direction in the Proposed Scheme.

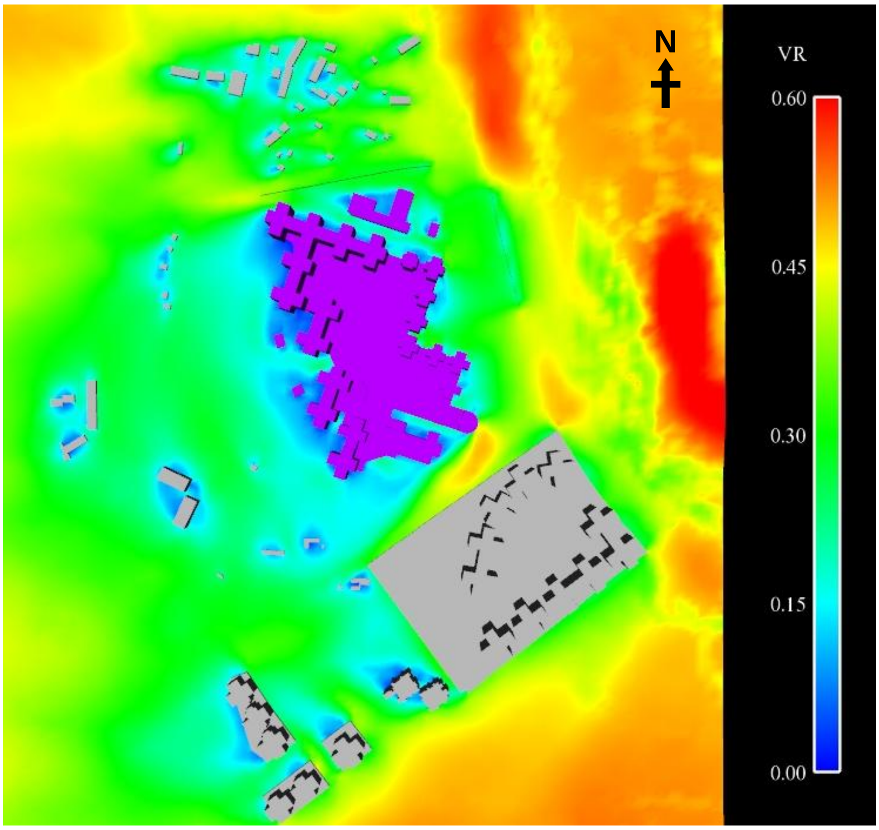


Figure 18 Contour Map of the Average VR for the Baseline Scheme

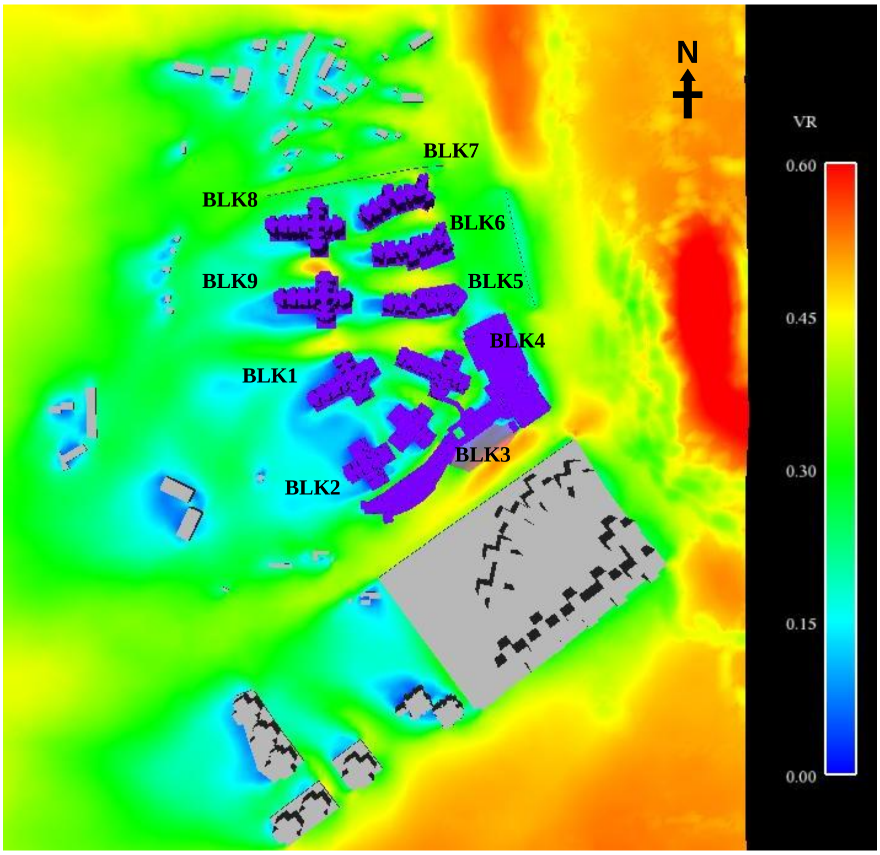


Figure 19 Contour Map of the Average VR for the Proposed Scheme

4.2 SVR and LVR

As specified in the Technical Guide, two ratios were determined to give a simple quantity to summarize the ventilation performance:

- **Site spatial average Velocity Ratio (SVR)** - This gives a hint of how the development proposal impacts the wind environment of its immediate vicinity. This is the average of VR values of all perimeter test points (red points as shown in Figure 7).
- **Local spatial average Velocity Ratio (LVR)** - This gives a hint of how the development proposal impacts the wind environment of the local area. This is the average of VR values of all overall and perimeter test points (red and blue points as shown in Figure 7).

The following table summarizes the values of SVR and LVR for the two studied schemes.

Table 4 Comparison of the Velocity Ratio for Baseline and Proposed Schemes

	Baseline Scheme	**Proposed Scheme**
	Spatial Average	Spatial Average
SVR	0.28	0.31
LVR	0.29	0.32

The results indicate that the ventilation performance of the Proposed Scheme is better than the Baseline Scheme. The major reason is the enhancement measures adopted in the Proposed Scheme. The incorporation of the wind corridors favours the air flow through the site and thus enhances the ventilation performance of the development.

4.3 Focus Areas

To further assess the impact of the Development on the wind environment of its immediate vicinity, some focus areas were identified. The following figure indicated the locations of the focus areas and the relevant test points.

Figure 20 Locations of the Focus Areas

Table 5 Spatial Average Velocity Ratio of different Focus Areas

Focus Area	**Test point**	**Average Velocity Ratio**	
		Baseline Scheme	**Proposed Scheme**
Zone 1	O29-O51	0.21	0.26
Zone 2	O1,O3, O5, O7, O10	0.33	0.33
Zone 3	P10-P16	0.38	0.45
Zone 4	P1-P9	0.16	0.20
Zone 5	O2, O4, O6, O8, O9, O11	0.34	0.35

Results show that higher average velocity ratios are achieved in most of focus areas for the Proposed Scheme including Zone 1, 3, 4 and 5. The Proposed Scheme leads to an improvement of 23.8% and 25.0% in VR in Zone 1 and Zone 4 respectively. It is due to the large building separations of the development which leads to more permeable for wind to pass through the site under the dominant annual prevailing wind directions.

The VR for the Baseline and Proposed Schemes are the same in Zone 2. The result indicates that the Proposed Scheme would not introduce adverse effect to this area environment when compared with the Baseline Scheme.

5 Wind Enhancement Design

5.1 Ground Floor Empty Bay

The implementation of empty bay at ground floor favours the air ventilation performance of the whole development. The height of the empty bay is up to 4.6m AFFL. The following figure shows the location of the empty bays and Figure 22 shows the streamline of air flowing through the empty bay.

Figure 21 Locations of Empty Bays at Ground Floor

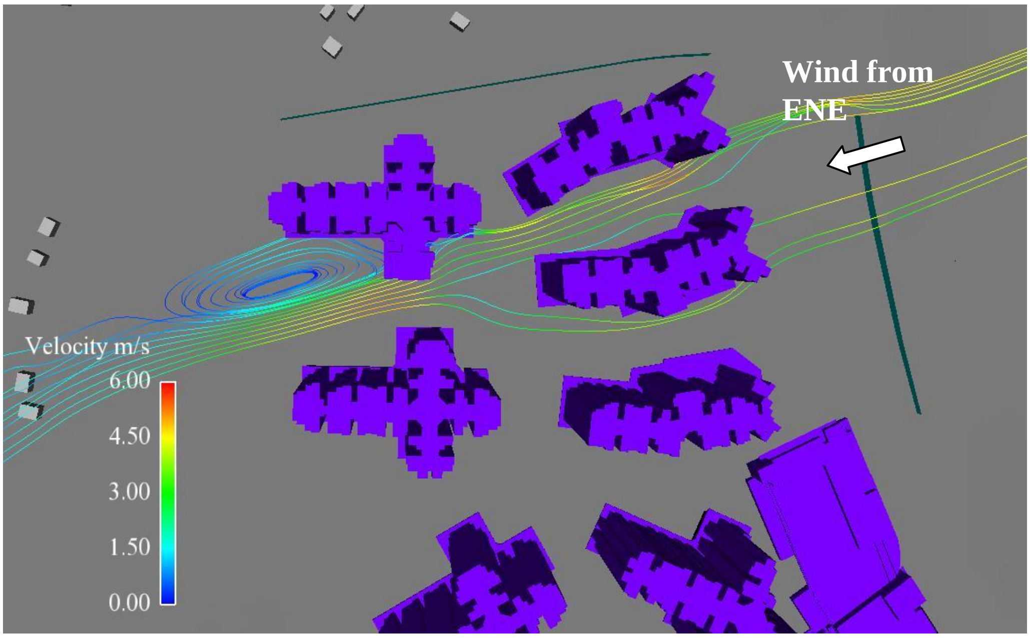


Figure 22 Streamline Diagram of the Air Flow through the Empty Bay

5.2 Large Building Separation

The following figure shows the building separation of the development for the Proposed Scheme. It shows that the minimum separation between the buildings is 12m while the largest is 34m. The building separations enhance the wind permeability of the site and improve the ventilation environment of the surrounding area.

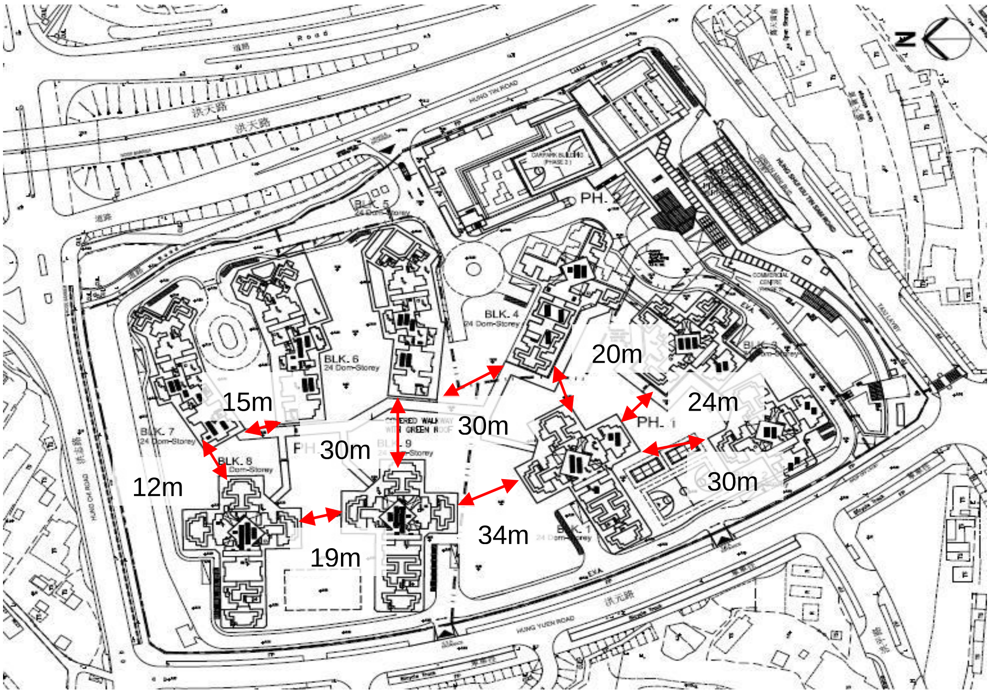


Figure 23 Building Separation of the Proposed Scheme

5.3 Wind Corridor and Podium Free Design

Wind corridors are introduced in the Proposed Development to induce more wind to pass through the development. The podium free design also allow more open space at grade and further enhances the ventilation of the site and the area of the surrounding focus areas.

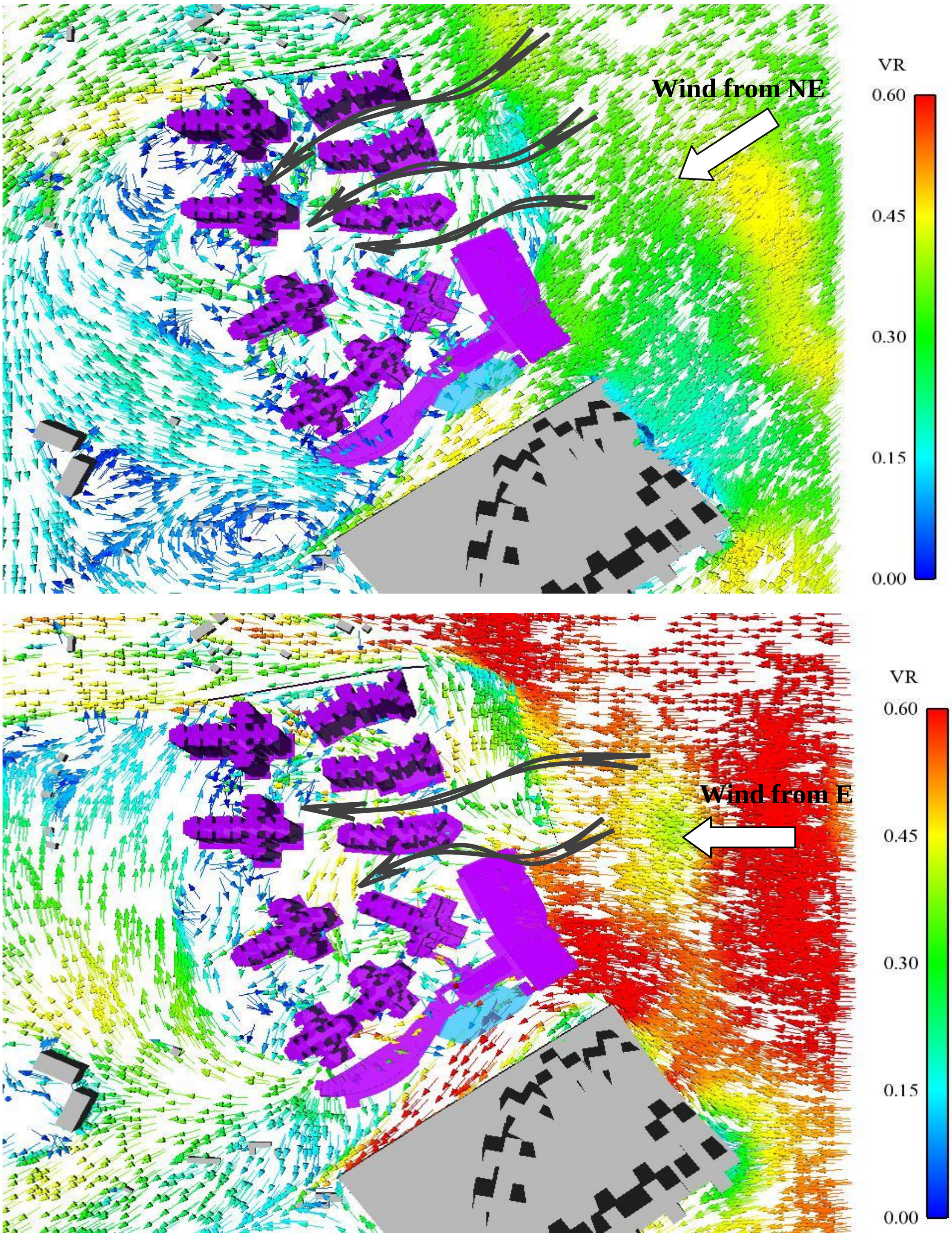


Figure 24 Wind Corridors within the Site

6 Conclusion

The Development is located in an area of comparatively low rise semi-rural developments to the north of Castle Peak Road, about 1½ miles west of Yuen Long. To assess the ventilation performance of the Development and areas immediately surrounding the site, an AVA Initial Study (the Study) was conducted.

A series of CFD simulations using SST k – ω turbulence modelling were performed using the Air Ventilation Assessment (AVA) methodology for Initial Study as stipulated in the Technical Circular and Technical Guide. Eight wind directions were selected: NNE, NE, ENE, E, ESE, SE, SSE and SSW, which totally cover 80.1% of wind availability in a year. Two scenarios, namely the Baseline Scheme and the Proposed Scheme, were studied.

The Velocity Ratio (VR) as proposed by the Technical Circular was employed to assess the ventilation performances of the Development and surrounding environment. With reference to the Technical Guide, totally 27 perimeter test points and 51 overall test points were selected to assess the air ventilation performance at the surrounding existing developments.

The major findings of this study could be summarized as follows:

- The most dominant wind directions are NE, ENE and E, which together account for 40.8% of wind frequency;
- The Site spatial average Velocity Ratios (SVRs) are 0.28 for the Baseline Scheme and 0.31 for the Proposed Scheme respectively. The Local spatial average Velocity Ratios (LVRs) are 0.29 and 0.32 for the Baseline Scheme and the Proposed Scheme respectively. This implies that the ventilation performance of the Proposed Scheme is better compared with the Baseline Scheme;
- To further assess the impact of the Development on the wind environment of its immediate vicinity, five focus areas were identified. Results show that improvement of the average velocity ratios is achieved in most of focus areas for the Proposed Scheme.
- The wind enhancement design adopted in the Proposed Scheme improves the ventilation performance of the development. They include:
    - Podium free design is introduced for better wind penetration.
    - Dedicated wind corridors are provided along prevailing wind directions for minimal disturbance of wind flow to its surrounding areas.
    - Large and sufficient building separations minimize “wall effect” crossing the site.
    - The ground floor empty bays also improve air ventilation performance.

Appendix A

Directional VR Contour

A1 Baseline Scheme VR contour

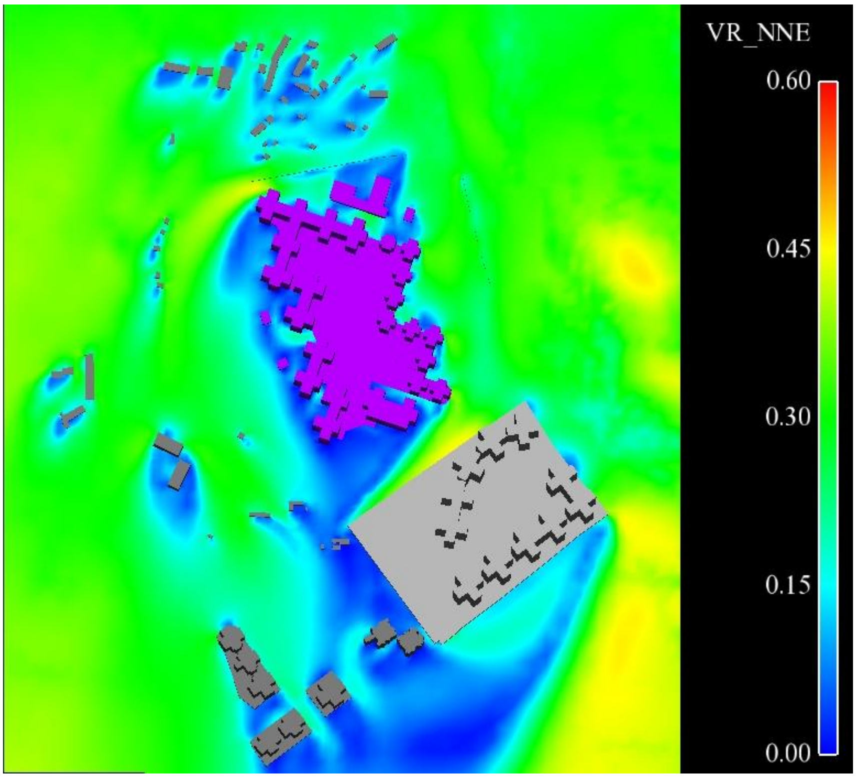


Figure A 1 Baseline Scheme (NNE wind)

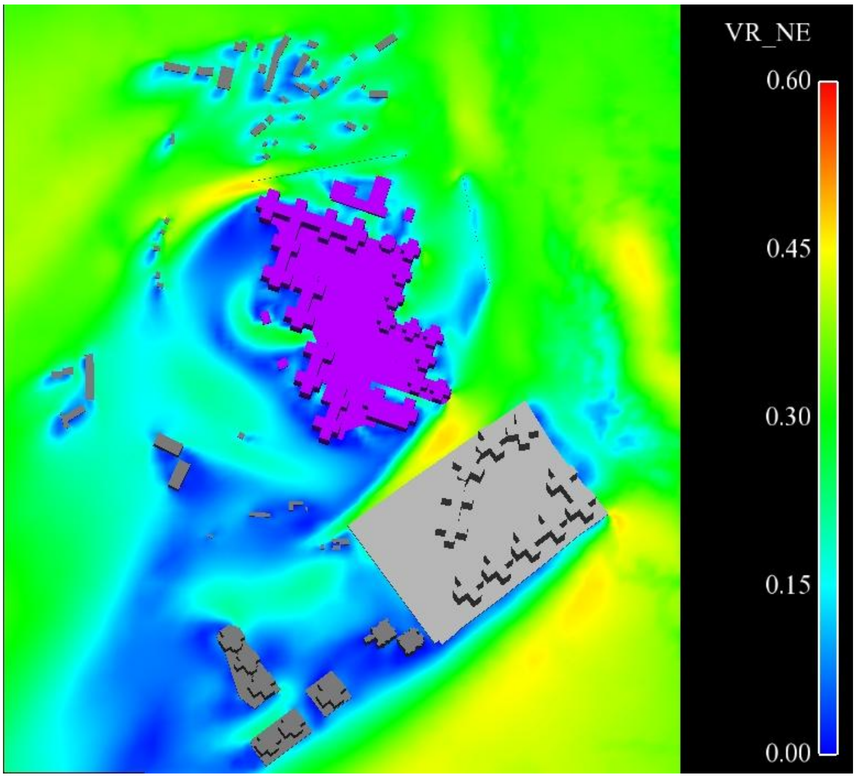


Figure A 2 Baseline Scheme (NE wind)

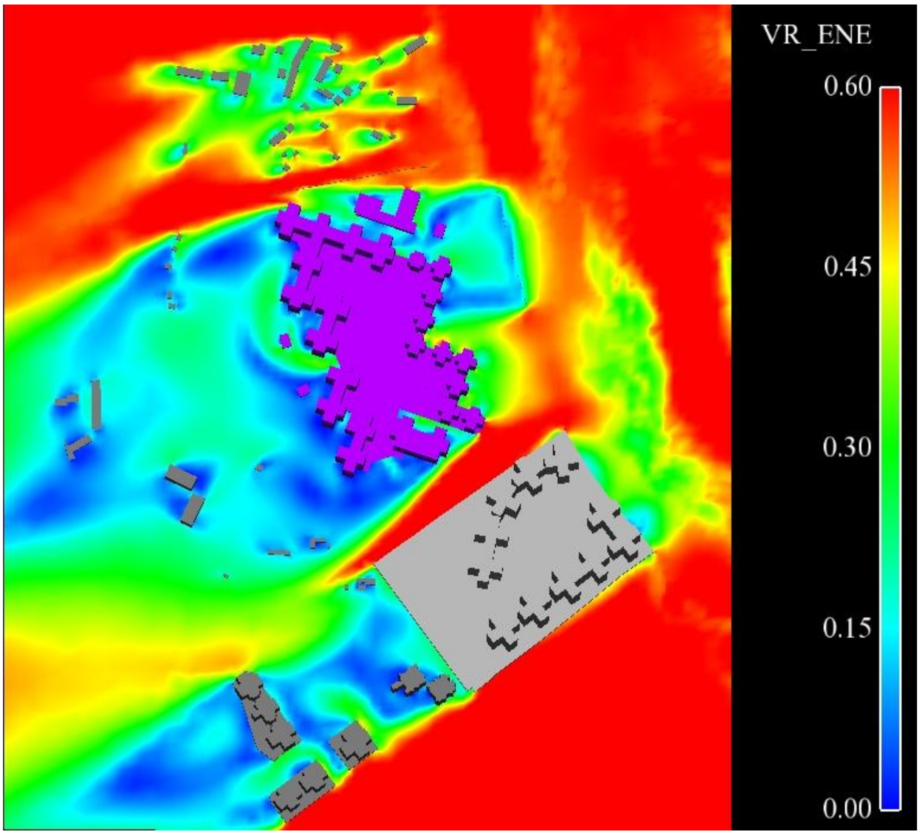


Figure A 3 Baseline Scheme (ENE wind)

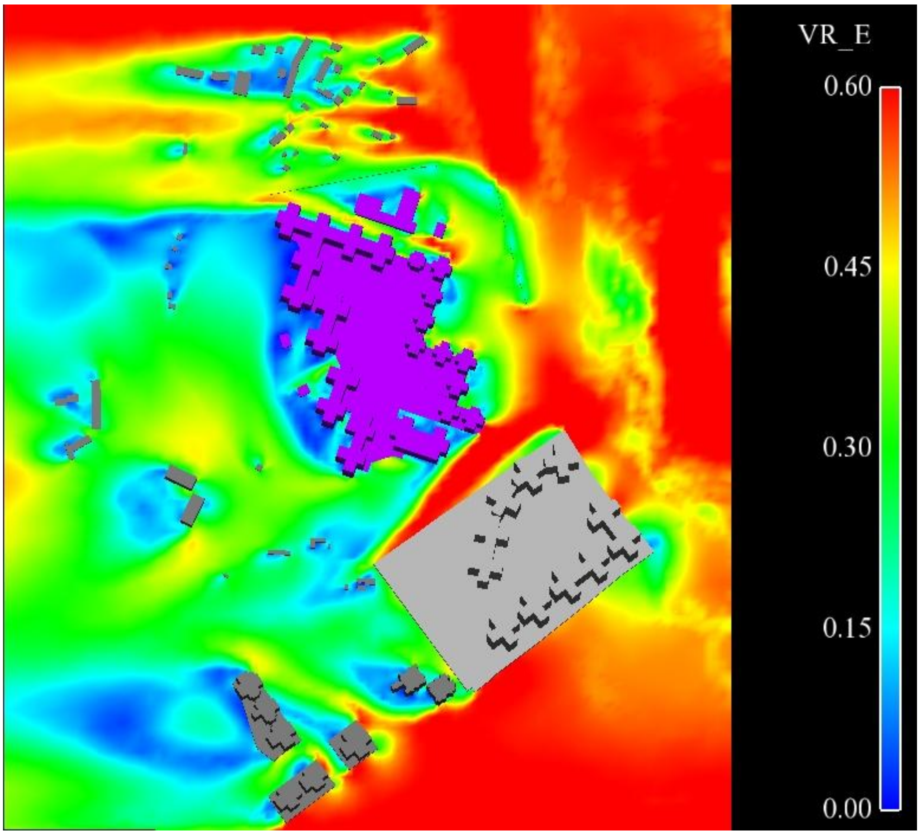


Figure A 4 Baseline Scheme (E wind)

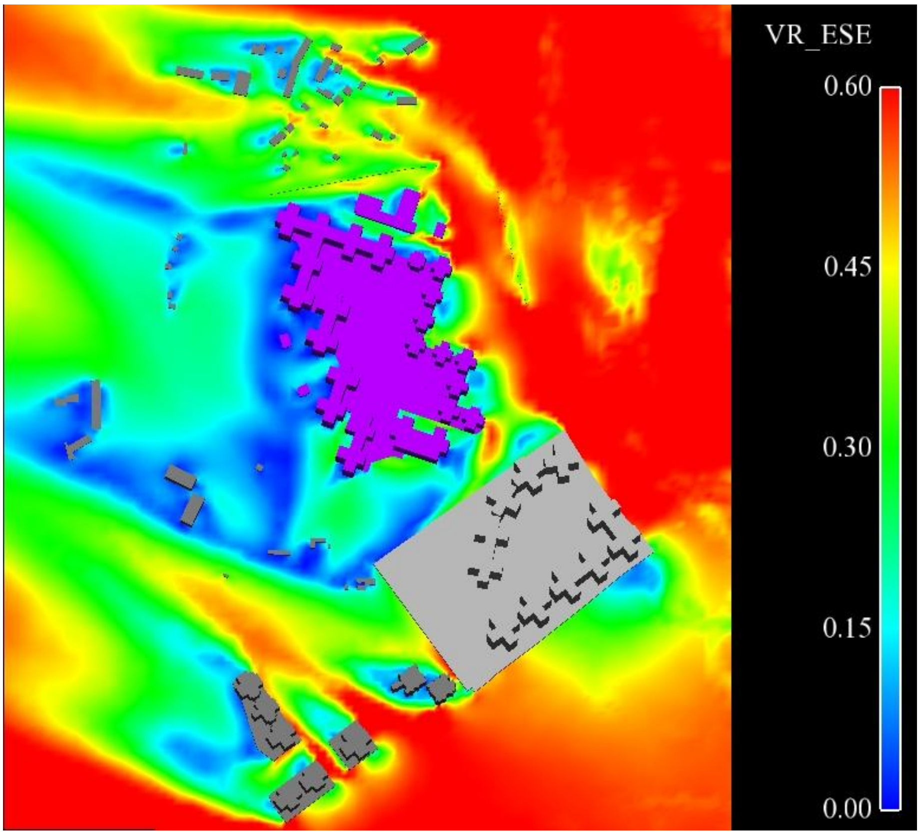


Figure A 5 Baseline Scheme (ESE wind)

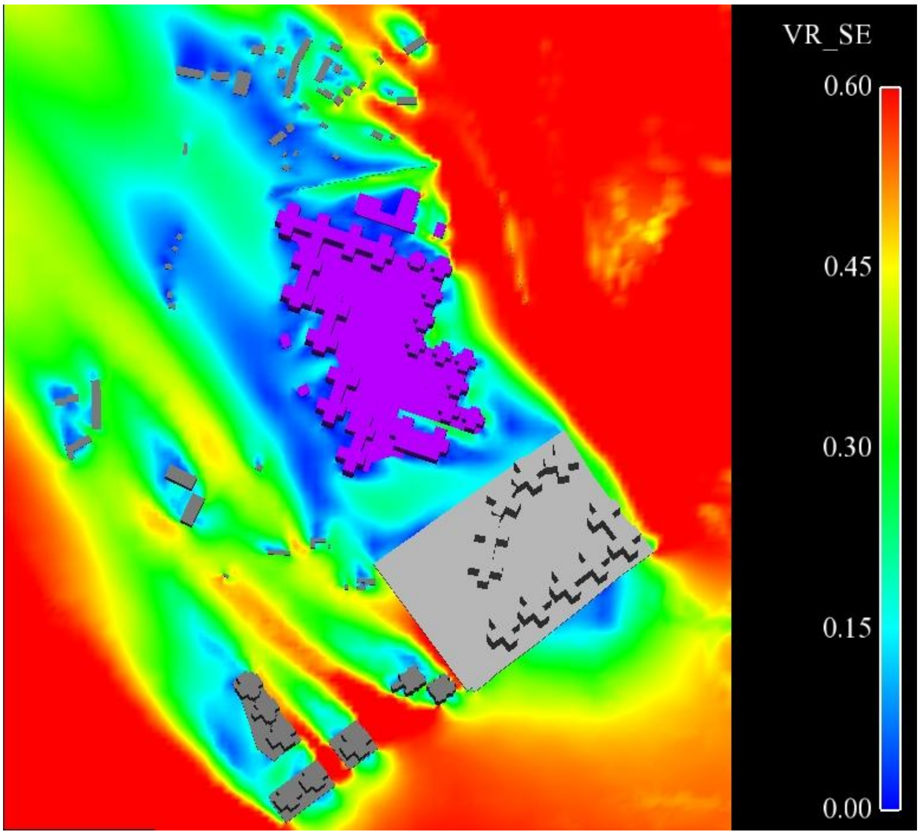


Figure A 6 Baseline Scheme (SE wind)

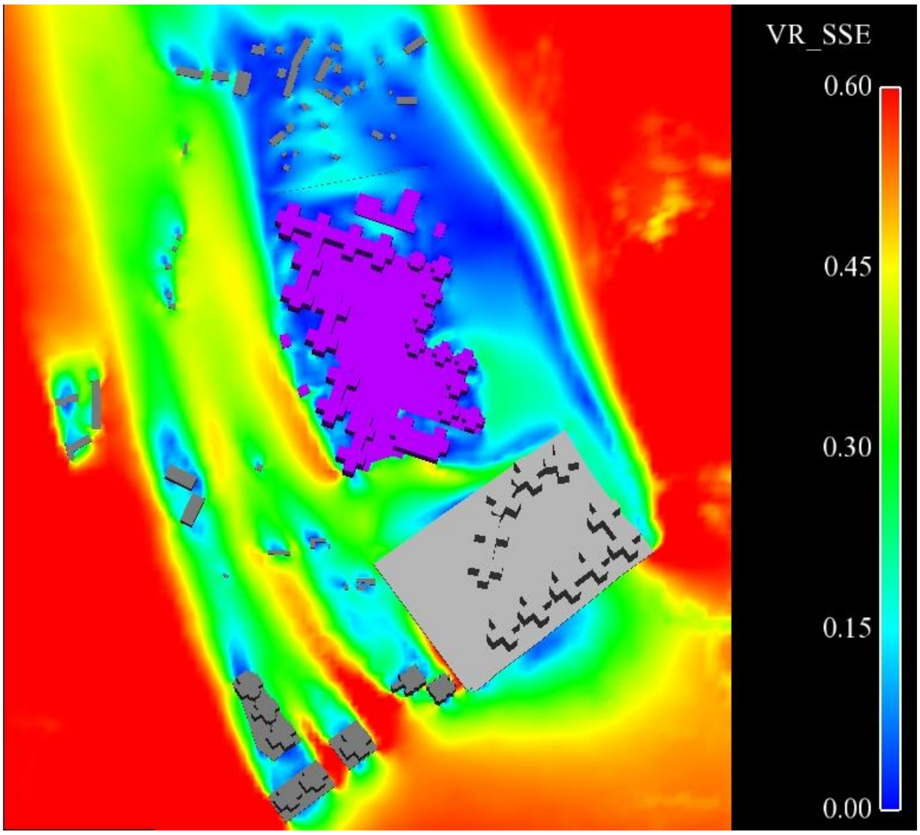


Figure A 7 Baseline Scheme (SSE wind)

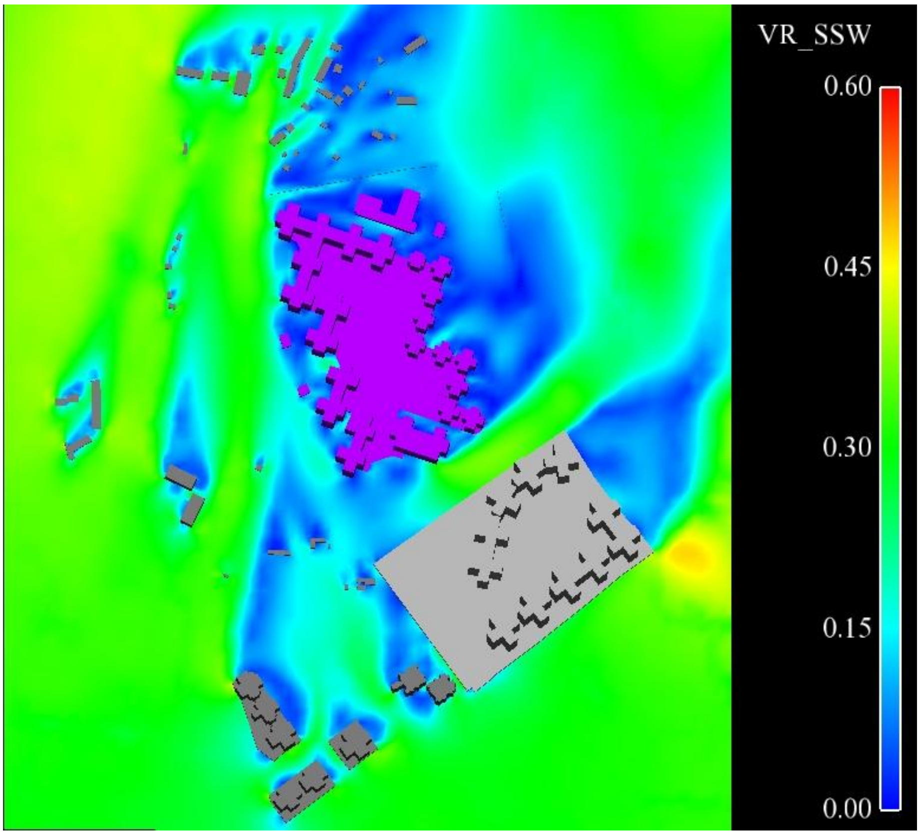


Figure A 8 Baseline Scheme (SSW wind)

A2 Proposed Scheme VR contour

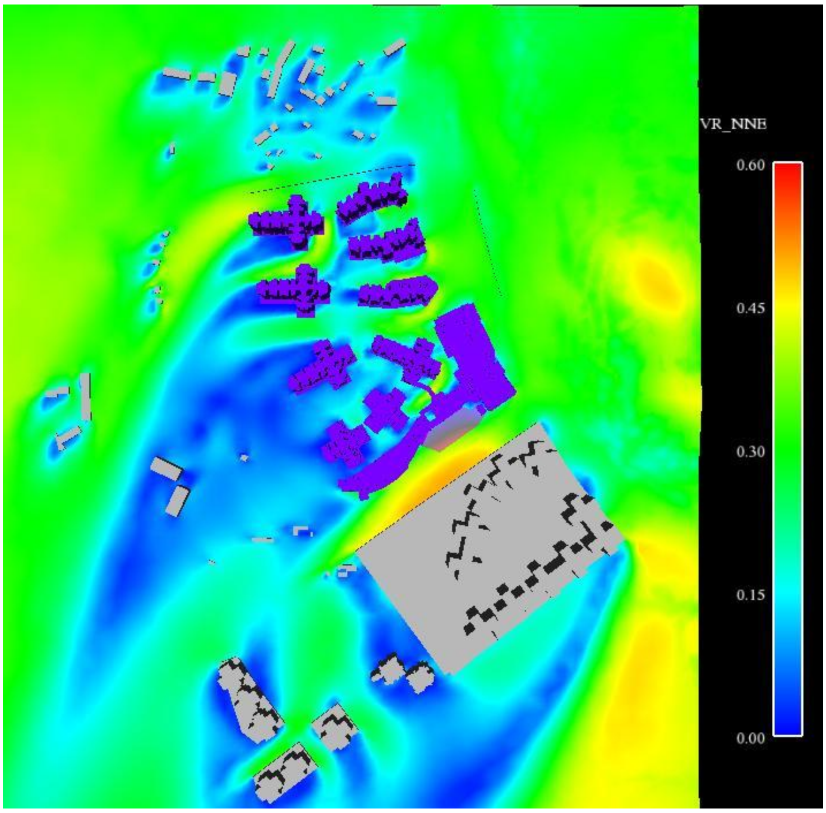


Figure A 9 Proposed Scheme (NNE wind)

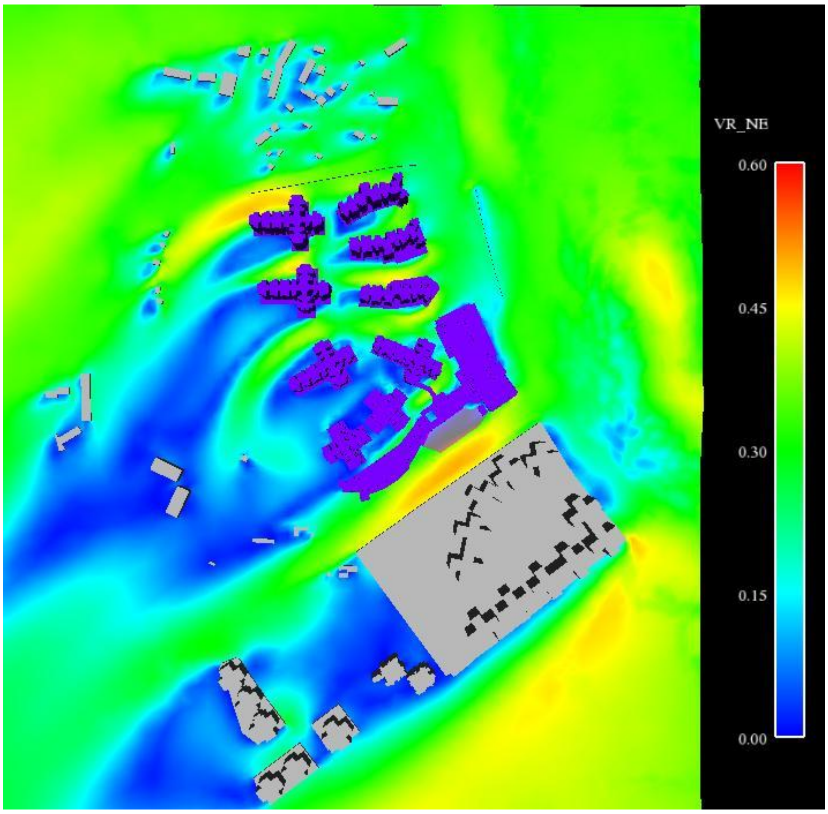


Figure A 10 Proposed Scheme (NE wind)

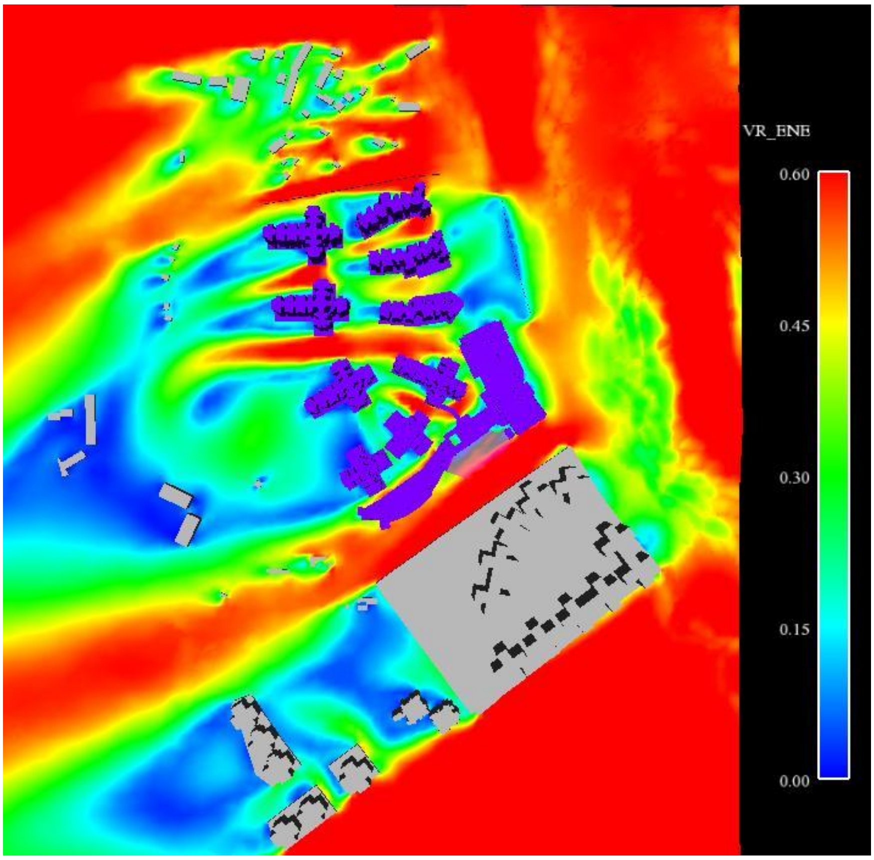


Figure A 11 Proposed Scheme (ENE wind)

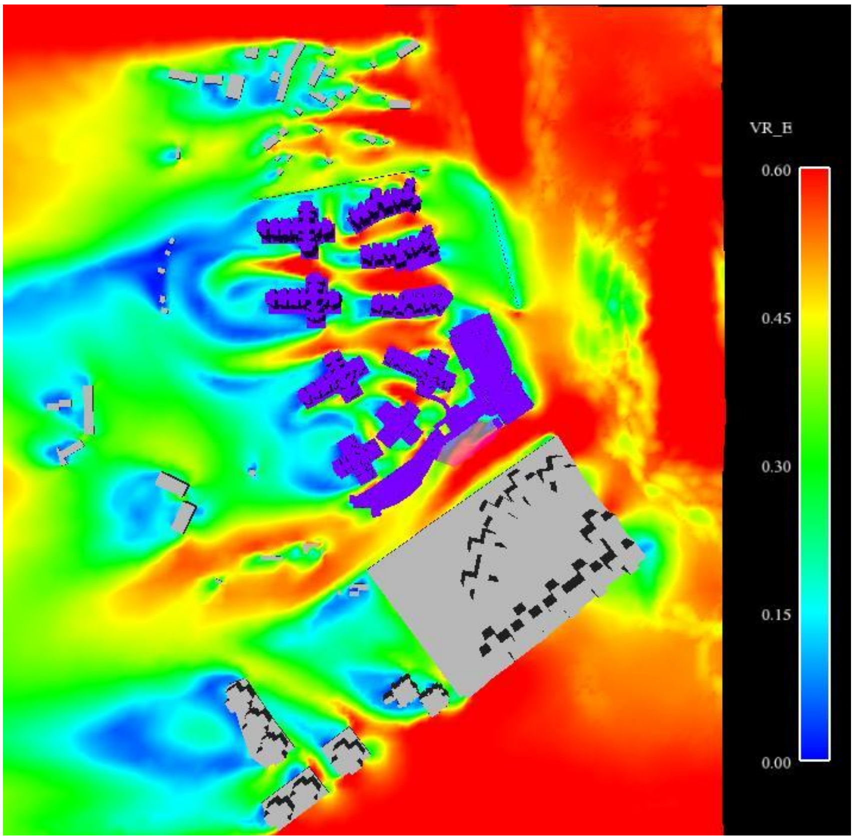


Figure A 12 Proposed Scheme (E wind)

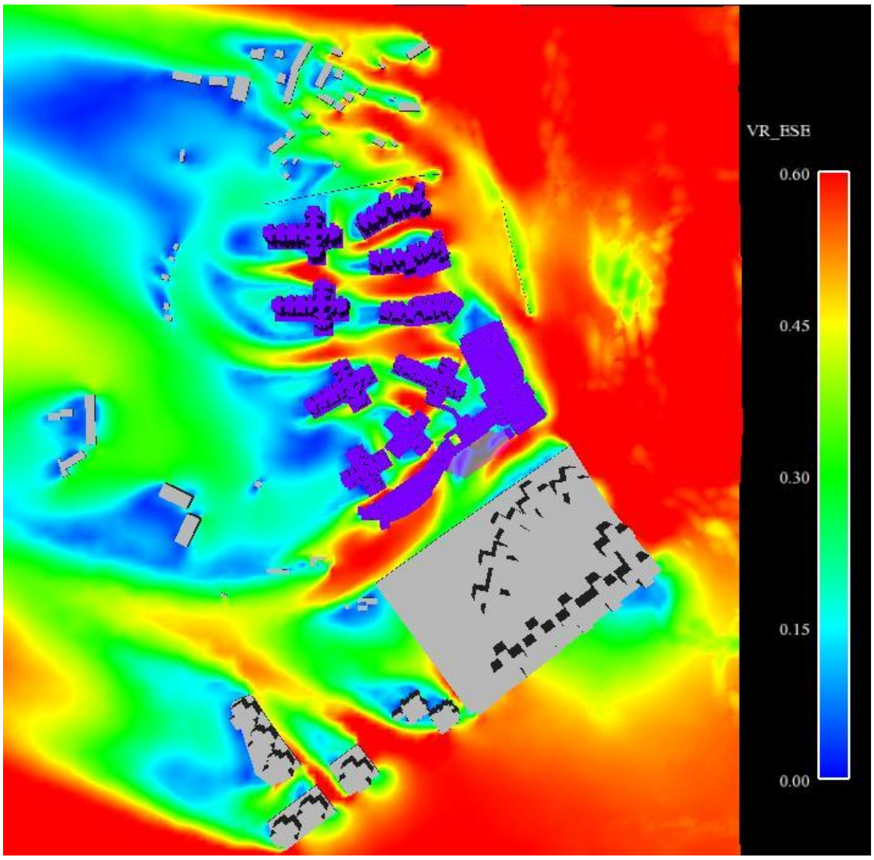


Figure A 13 Proposed Scheme (ESE wind)

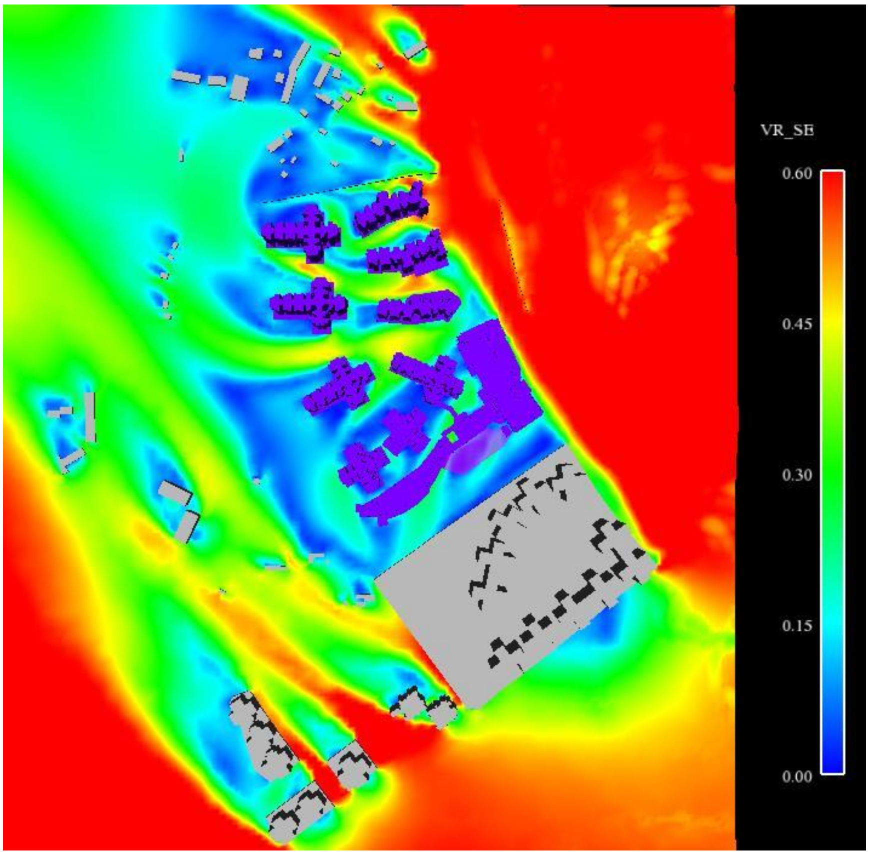


Figure A 14 Proposed Scheme (SE wind)

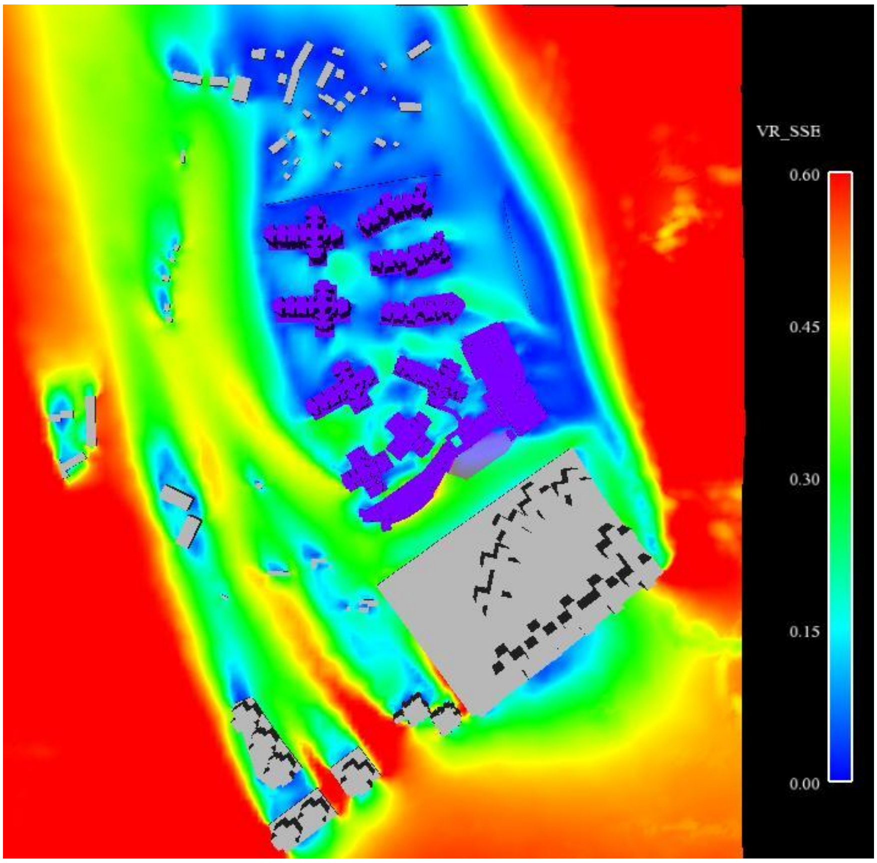


Figure A 15 Proposed Scheme (SSE wind)

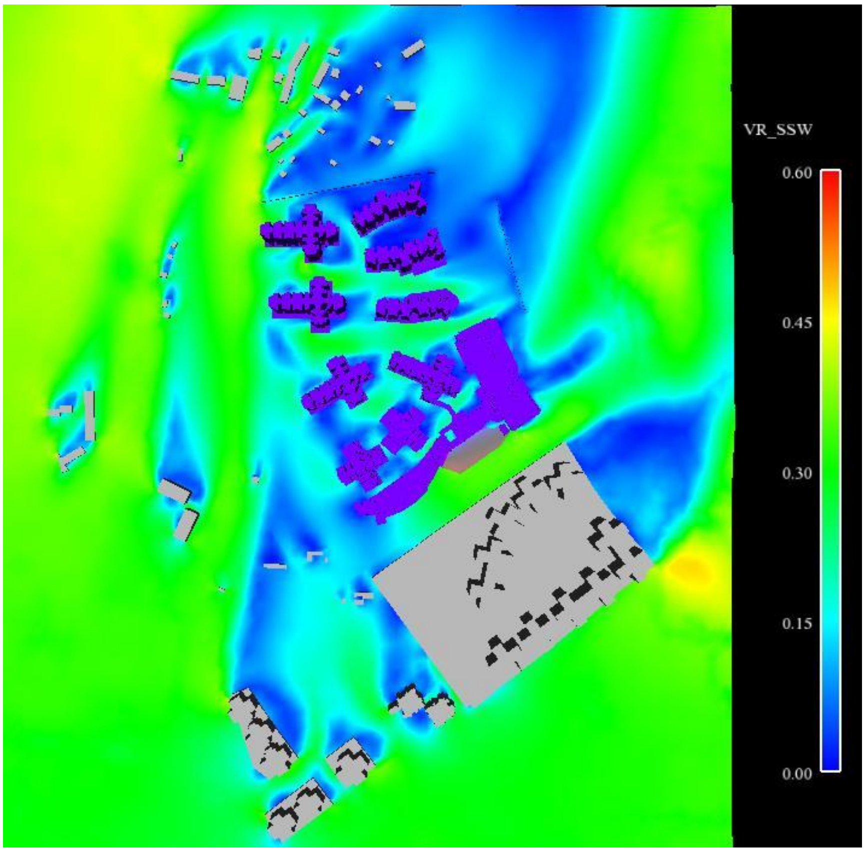


Figure A 16 Proposed Scheme (SSW wind)

Appendix B

Vector Plot

B1 Baseline Scheme Vector Plot

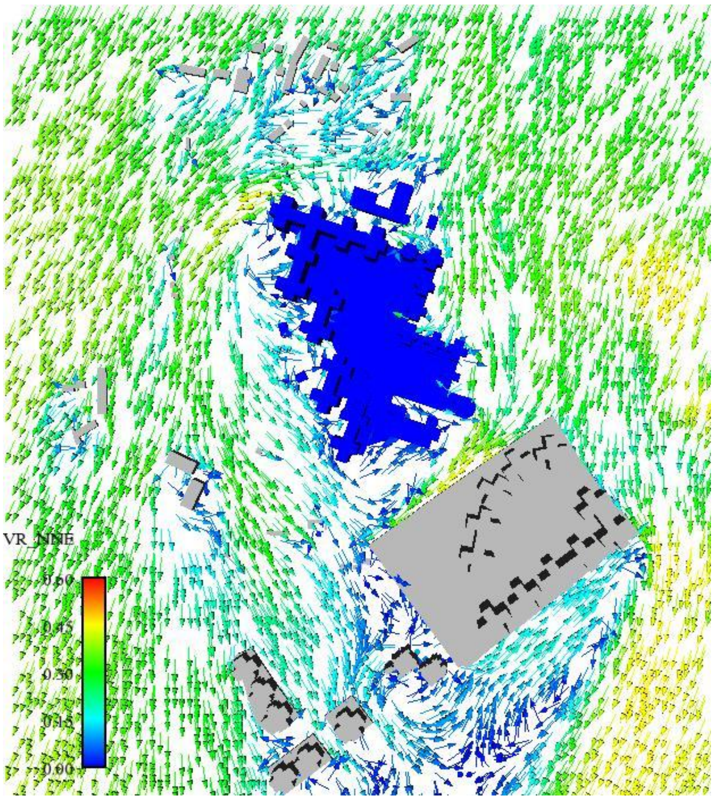


Figure B 1 Baseline Scheme (NNE wind)

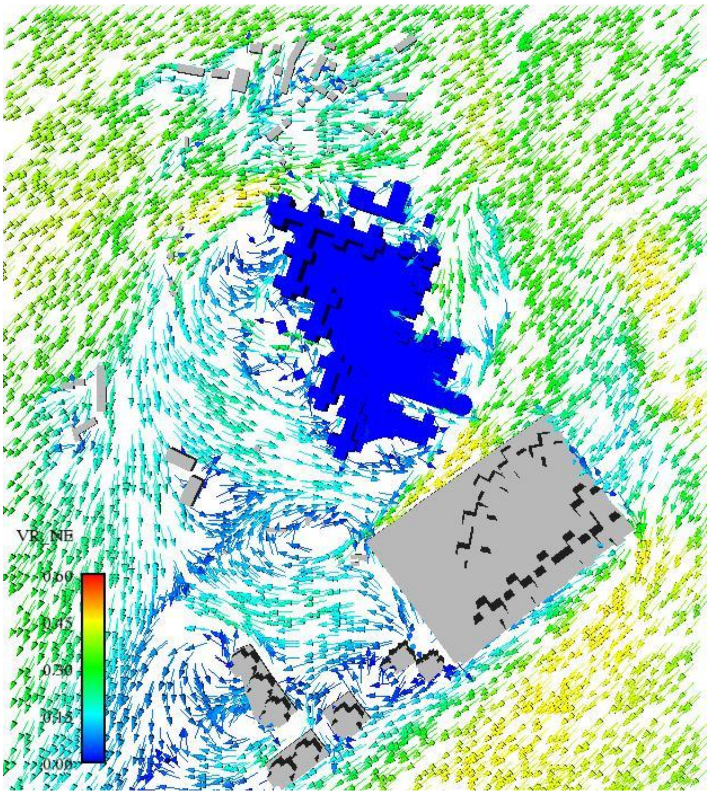


Figure B 2 Baseline Scheme (NE wind)

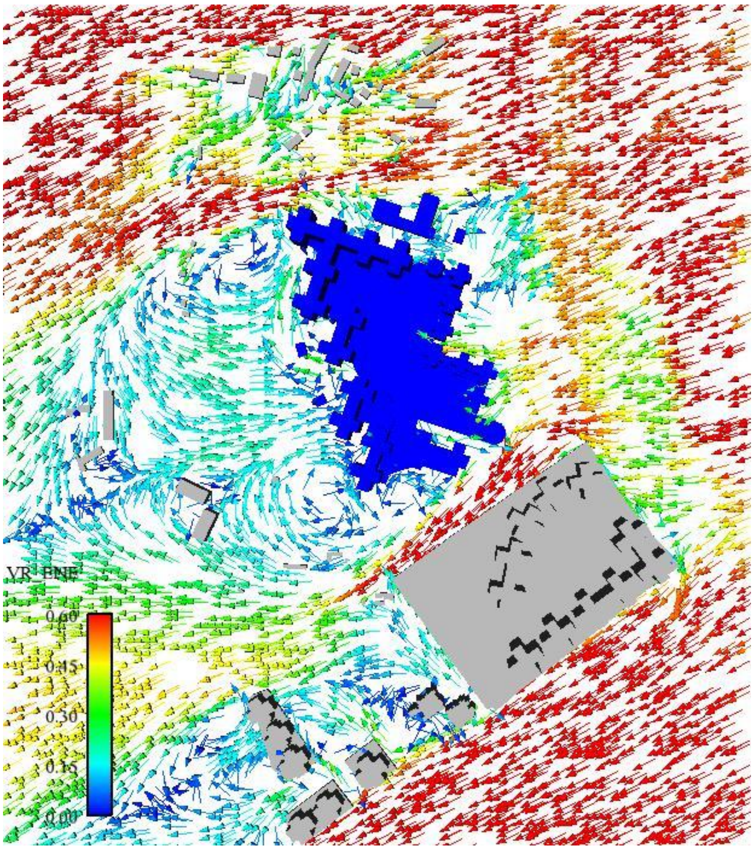


Figure B 3 Baseline Scheme (ENE wind)

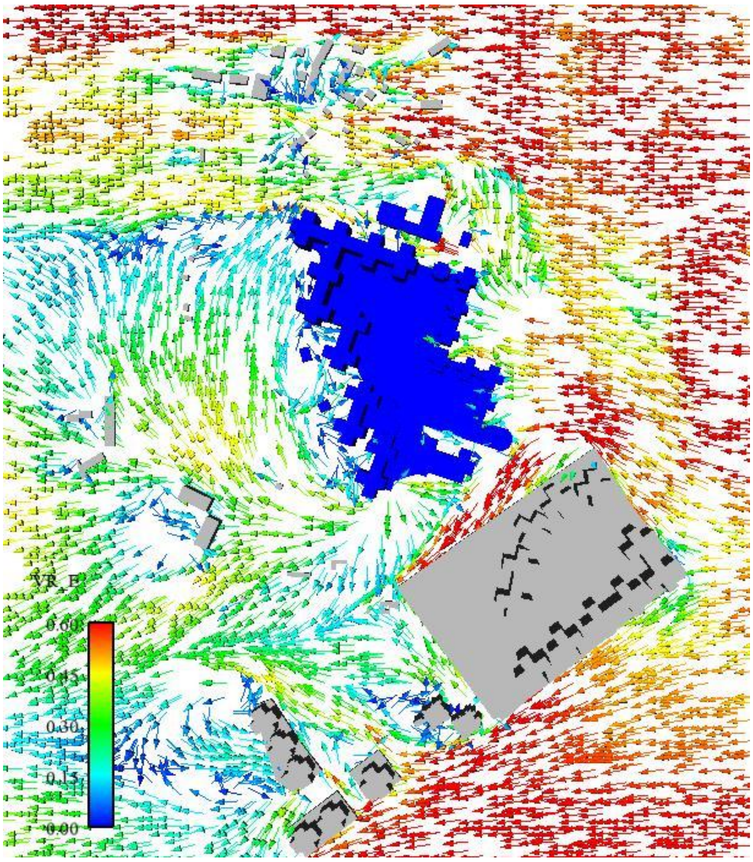


Figure B 4 Baseline Scheme (E wind)

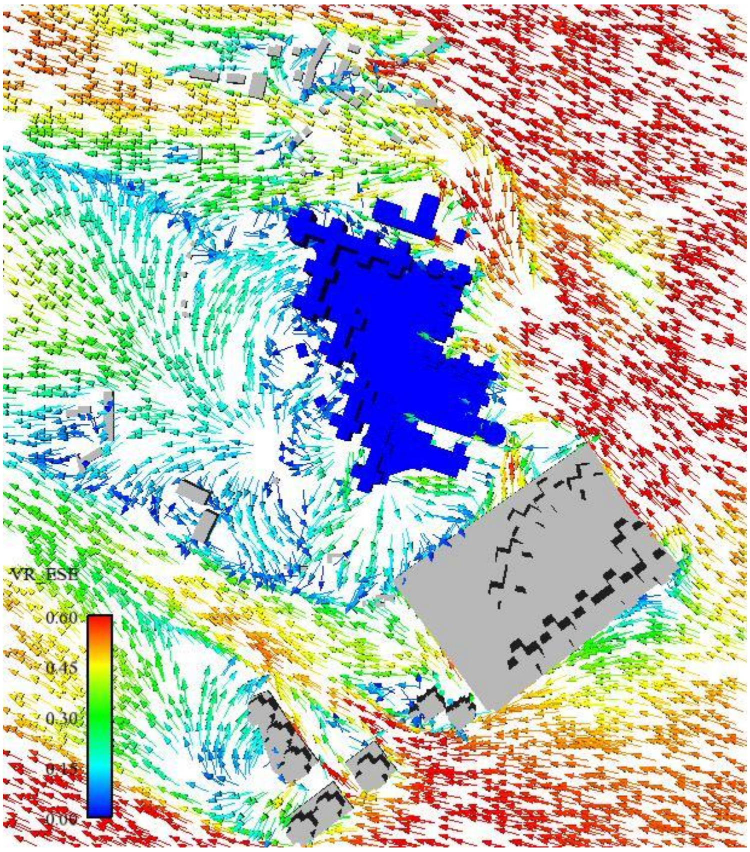


Figure B 5 Baseline Scheme (ESE wind)

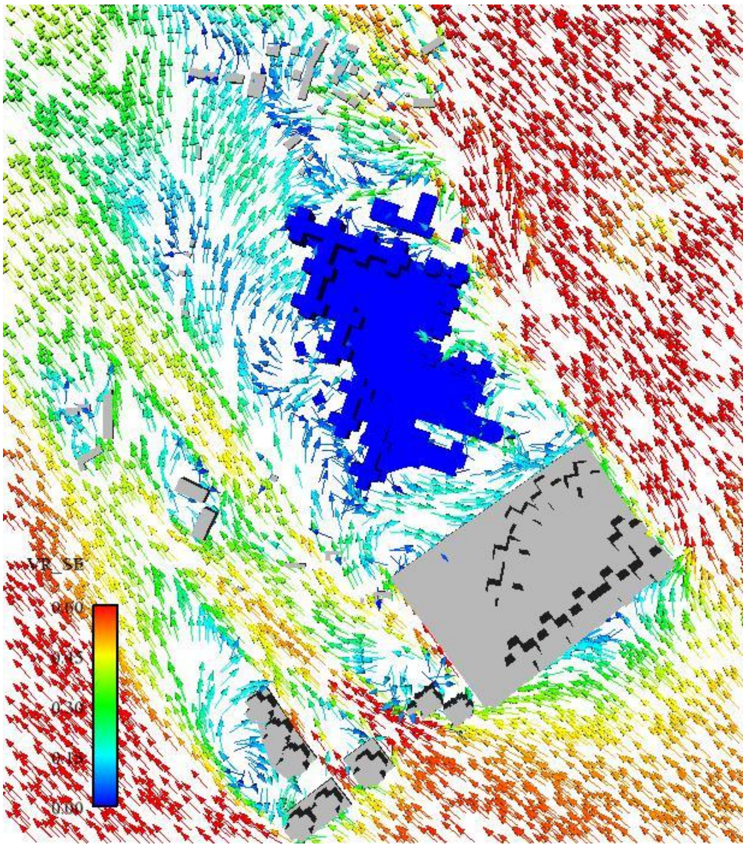


Figure B 6 Baseline Scheme (SE wind)

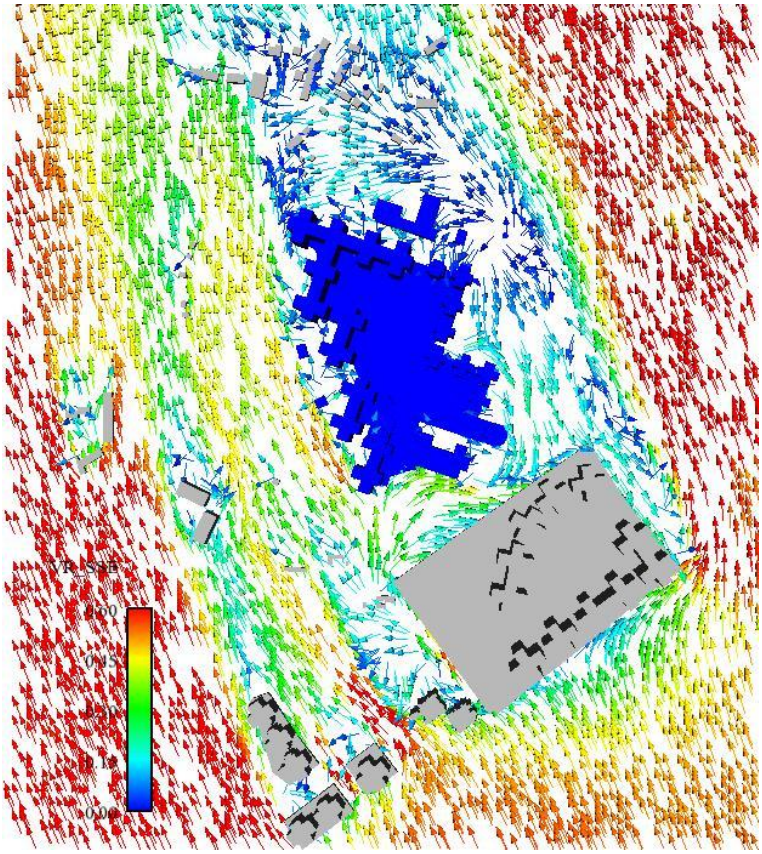


Figure B 7 Baseline Scheme (SSE wind)

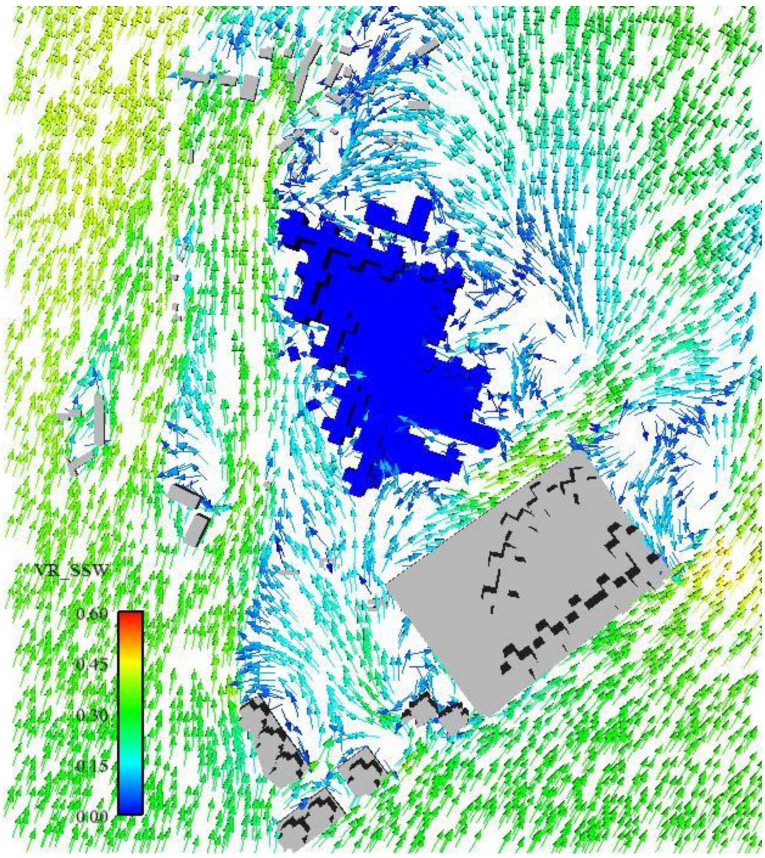


Figure B 8 Baseline Scheme (SSW wind)

B2 Proposed Scheme Vector Plot

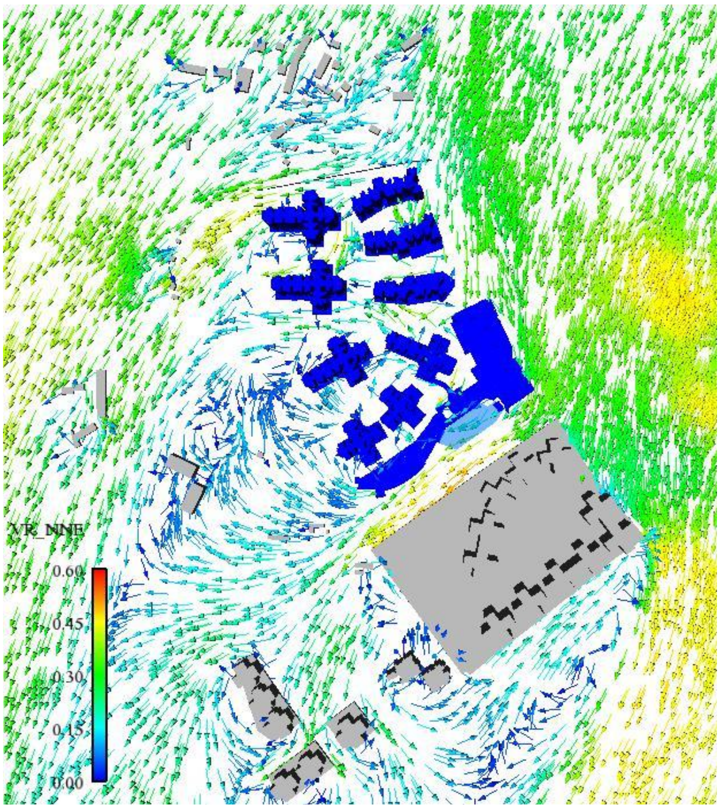


Figure B 9 Proposed Scheme (NNE wind)

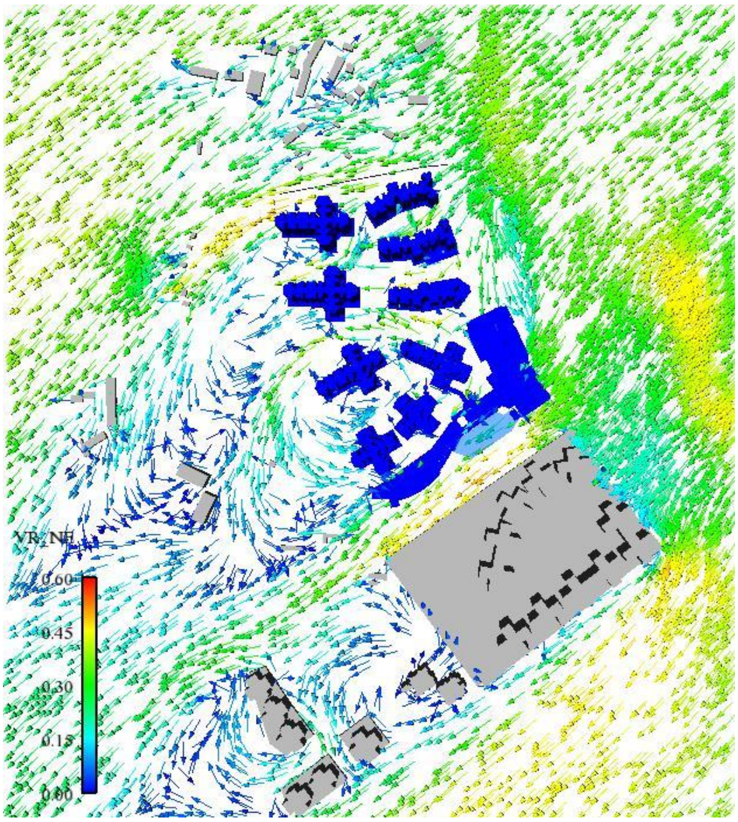


Figure B 10 Proposed Scheme (NE wind)

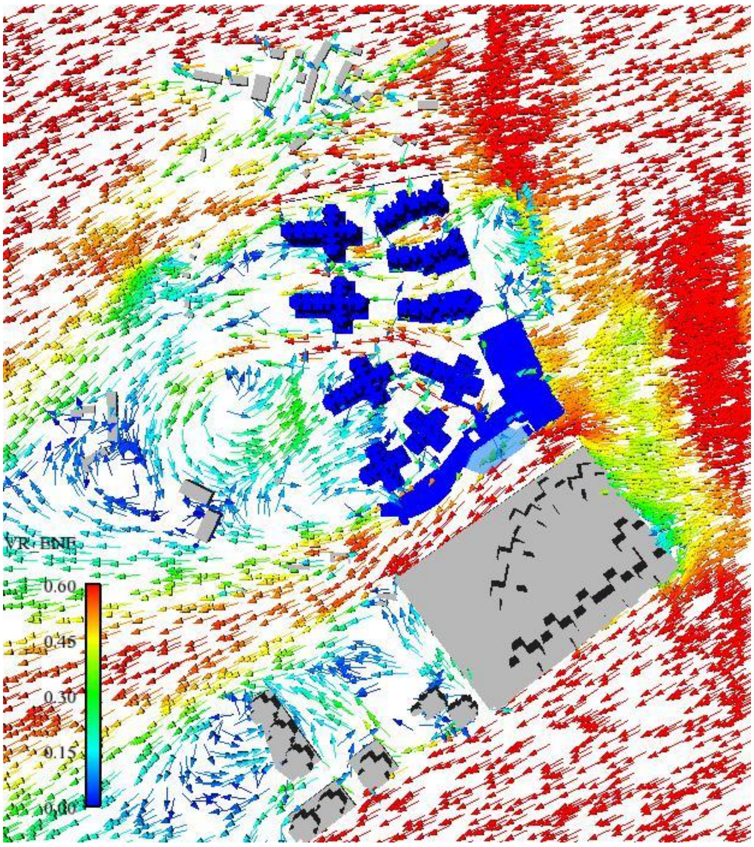


Figure B 11 Proposed Scheme (ENE wind)

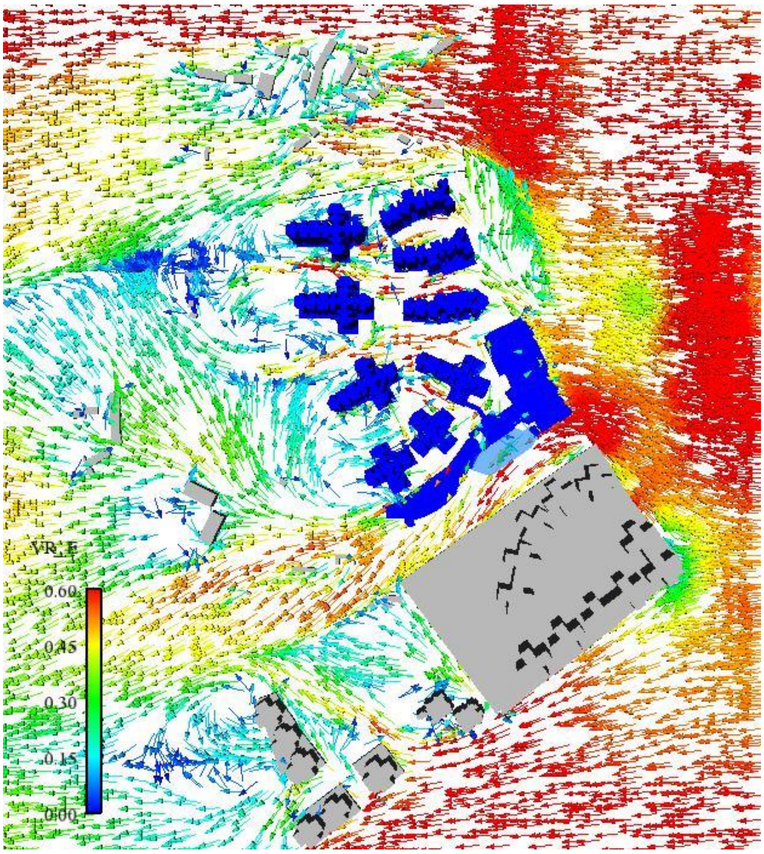


Figure B 12 Proposed Scheme (E wind)

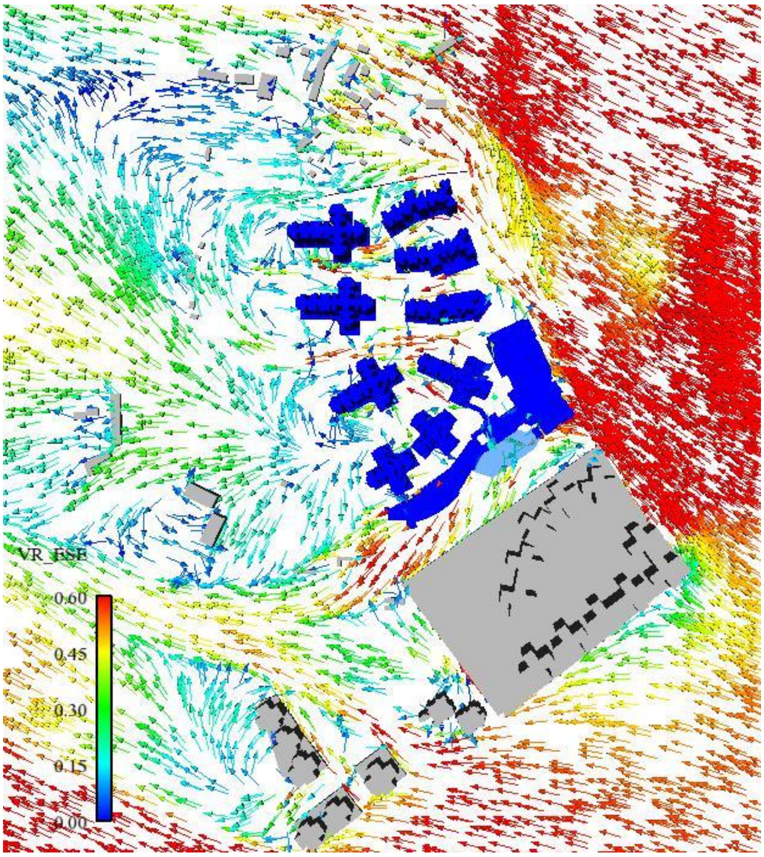


Figure B 13 Proposed Scheme (ESE wind)

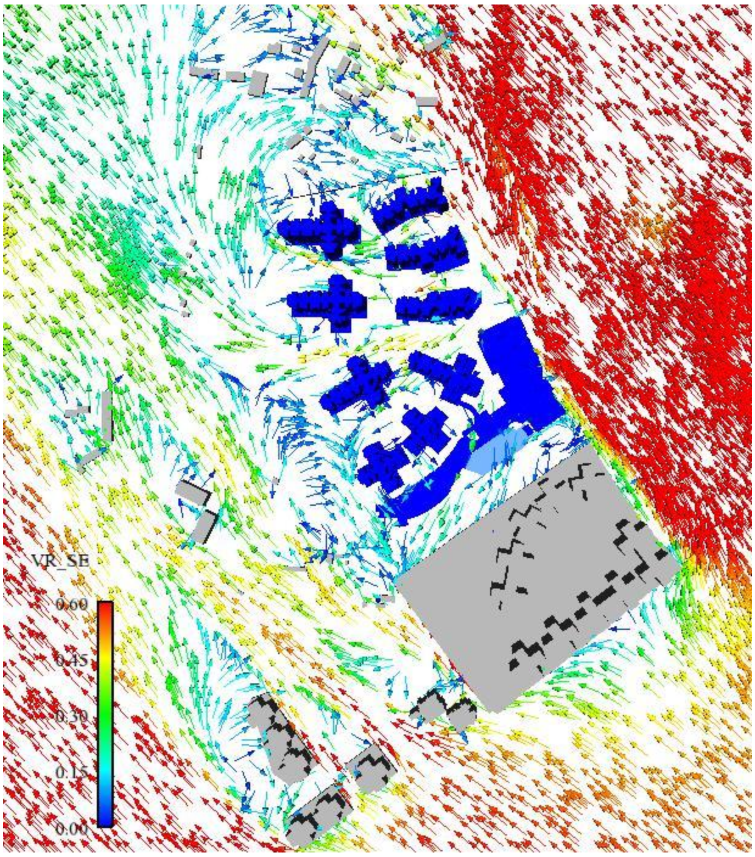


Figure B 14 Proposed Scheme (SE wind)

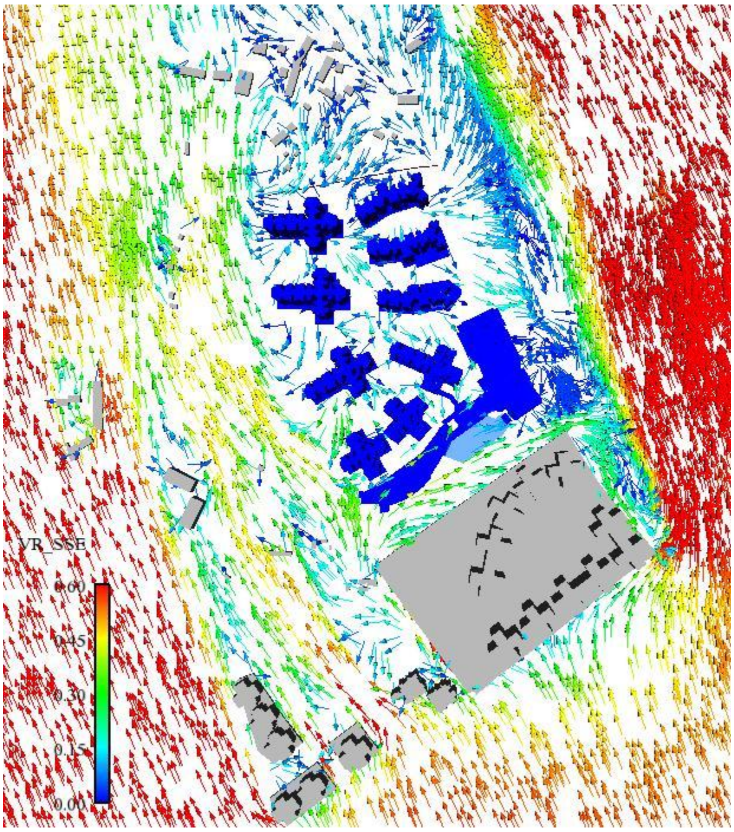


Figure B 15 Proposed Scheme (SSE wind)

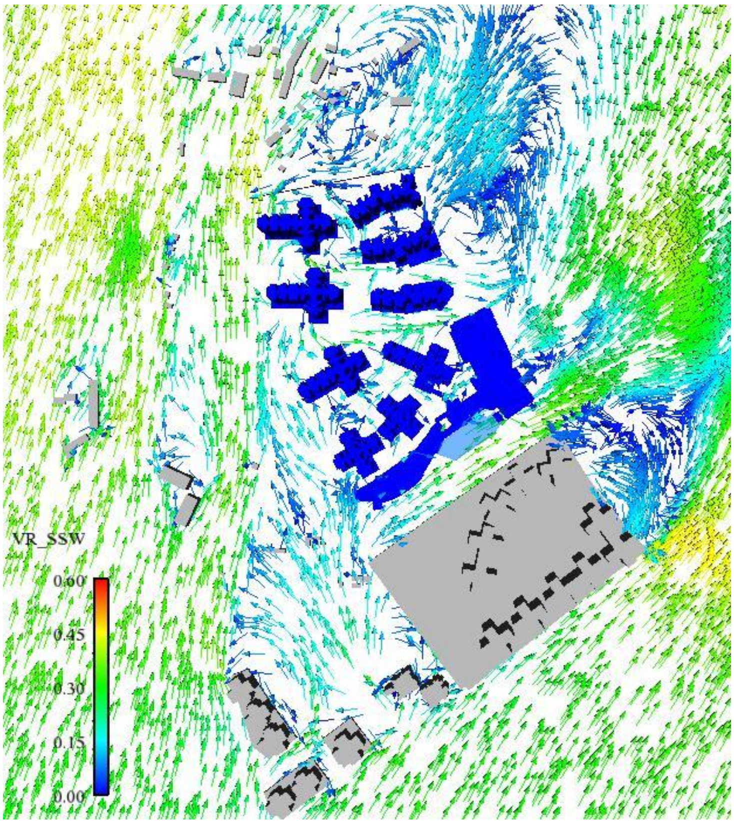


Figure B 16 Proposed Scheme (SSW wind)

Appendix C

Velocity Ratio

C1 Velocity Ratio for the Baseline Scheme

Baseline Scheme – Perimeter test points

	E	ENE	ESE	NE	NNE	SE	SSE	SSW	Combine
Frequency	0.12	0.16	0.11	0.13	0.09	0.07	0.07	0.06	0.80
P1	0.40	0.37	0.41	0.20	0.11	0.19	0.12	0.34	0.28
P2	0.05	0.04	0.12	0.11	0.13	0.17	0.20	0.26	0.12
P3	0.10	0.08	0.25	0.12	0.08	0.16	0.29	0.28	0.16
P4	0.10	0.02	0.18	0.04	0.01	0.08	0.22	0.13	0.09
P5	0.06	0.24	0.20	0.12	0.10	0.09	0.33	0.13	0.16
P6	0.10	0.09	0.08	0.07	0.06	0.07	0.43	0.17	0.11
P7	0.06	0.03	0.07	0.06	0.23	0.07	0.44	0.15	0.12
P8	0.10	0.10	0.12	0.33	0.20	0.10	0.53	0.18	0.19
P9	0.09	0.14	0.05	0.21	0.25	0.15	0.35	0.12	0.16
P10	0.07	0.07	0.37	0.13	0.16	0.08	0.34	0.12	0.18
P11	0.10	0.19	0.63	0.40	0.07	0.17	0.17	0.15	0.28
P12	0.32	0.43	0.74	0.66	0.13	0.16	0.21	0.25	0.42
P13	0.40	0.47	0.76	0.68	0.35	0.14	0.31	0.36	0.49
P14	0.35	0.42	0.73	0.67	0.38	0.12	0.12	0.37	0.45
P15	0.26	0.34	0.64	0.62	0.19	0.08	0.13	0.34	0.38
P16	0.25	0.30	0.62	0.70	0.66	0.30	0.17	0.33	0.46
P17	0.31	0.34	0.54	0.61	0.68	0.60	0.18	0.26	0.46
P18	0.27	0.31	0.51	0.52	0.62	0.66	0.16	0.05	0.41
P19	0.24	0.11	0.51	0.52	0.62	0.66	0.12	0.08	0.38
P20	0.30	0.15	0.11	0.37	0.57	0.63	0.09	0.03	0.27
P21	0.32	0.24	0.22	0.41	0.58	0.62	0.04	0.09	0.32
P22	0.25	0.26	0.14	0.43	0.61	0.65	0.02	0.10	0.31
P23	0.25	0.27	0.35	0.37	0.61	0.63	0.03	0.11	0.34
P24	0.06	0.26	0.52	0.31	0.45	0.35	0.06	0.09	0.30
P25	0.07	0.24	0.51	0.18	0.42	0.32	0.14	0.10	0.28
P26	0.19	0.23	0.23	0.12	0.32	0.23	0.13	0.05	0.20
P27	0.33	0.38	0.48	0.47	0.23	0.09	0.08	0.06	0.31

Baseline Scheme – Overall test points

	E	ENE	ESE	NE	NNE	SE	SSE	SSW	Combine
Frequency	0.12	0.16	0.11	0.13	0.09	0.07	0.07	0.06	0.80
O1	0.31	0.31	0.54	0.41	0.30	0.22	0.39	0.33	0.37
O2	0.27	0.34	0.56	0.40	0.29	0.19	0.16	0.39	0.36
O3	0.19	0.21	0.37	0.28	0.30	0.13	0.05	0.36	0.25
O4	0.27	0.35	0.61	0.37	0.37	0.10	0.10	0.03	0.33
O5	0.15	0.25	0.51	0.50	0.44	0.08	0.15	0.11	0.32
O6	0.20	0.27	0.53	0.32	0.40	0.09	0.14	0.07	0.30
O7	0.12	0.20	0.39	0.43	0.44	0.25	0.11	0.13	0.29
O8	0.17	0.25	0.57	0.39	0.33	0.09	0.13	0.10	0.30
O9	0.20	0.29	0.60	0.52	0.43	0.21	0.06	0.11	0.35
O10	0.18	0.28	0.59	0.62	0.47	0.58	0.06	0.12	0.40
O11	0.23	0.29	0.58	0.60	0.52	0.61	0.05	0.12	0.41
O12	0.25	0.28	0.53	0.56	0.54	0.58	0.14	0.18	0.41
O13	0.26	0.30	0.53	0.24	0.48	0.63	0.07	0.16	0.36
O14	0.31	0.38	0.67	0.68	0.69	0.69	0.28	0.20	0.52
O15	0.30	0.26	0.16	0.35	0.57	0.65	0.02	0.13	0.30
O16	0.30	0.31	0.49	0.52	0.56	0.64	0.23	0.11	0.42
O17	0.30	0.17	0.15	0.32	0.51	0.62	0.05	0.08	0.27
O18	0.32	0.31	0.48	0.48	0.57	0.64	0.21	0.08	0.41
O19	0.32	0.31	0.55	0.53	0.62	0.69	0.06	0.06	0.43
O20	0.35	0.32	0.52	0.49	0.61	0.69	0.29	0.10	0.44
O21	0.33	0.33	0.51	0.56	0.66	0.73	0.06	0.14	0.44
O22	0.29	0.26	0.41	0.44	0.56	0.66	0.38	0.22	0.40
O23	0.31	0.31	0.52	0.62	0.69	0.71	0.06	0.32	0.46
O24	0.29	0.24	0.44	0.57	0.69	0.77	0.42	0.13	0.45
O25	0.21	0.17	0.45	0.65	0.77	0.56	0.19	0.09	0.41
O26	0.28	0.25	0.53	0.65	0.76	0.76	0.08	0.06	0.45
O27	0.23	0.18	0.34	0.48	0.62	0.72	0.40	0.09	0.38
O28	0.21	0.12	0.26	0.44	0.57	0.32	0.20	0.06	0.28
O29	0.04	0.15	0.18	0.34	0.32	0.48	0.24	0.05	0.22
O30	0.07	0.15	0.22	0.15	0.25	0.45	0.18	0.19	0.20
O31	0.05	0.09	0.17	0.18	0.16	0.31	0.23	0.14	0.16
O32	0.08	0.06	0.47	0.09	0.12	0.20	0.29	0.13	0.19
O33	0.15	0.07	0.40	0.15	0.11	0.44	0.20	0.17	0.21
O34	0.18	0.06	0.17	0.21	0.02	0.44	0.30	0.16	0.17
O35	0.13	0.10	0.14	0.13	0.23	0.20	0.33	0.15	0.16

	E	ENE	ESE	NE	NNE	SE	SSE	SSW	Combine
Frequency	0.12	0.16	0.11	0.13	0.09	0.07	0.07	0.06	0.80
O36	0.27	0.11	0.13	0.31	0.08	0.41	0.30	0.10	0.20
O37	0.15	0.16	0.07	0.22	0.24	0.09	0.34	0.13	0.17
O38	0.30	0.18	0.14	0.36	0.10	0.40	0.35	0.29	0.24
O39	0.20	0.15	0.08	0.35	0.07	0.07	0.42	0.13	0.17
O40	0.26	0.20	0.20	0.38	0.09	0.31	0.36	0.32	0.25
O41	0.20	0.15	0.13	0.25	0.08	0.09	0.45	0.16	0.18
O42	0.26	0.18	0.19	0.36	0.19	0.23	0.39	0.28	0.25
O43	0.18	0.07	0.11	0.20	0.05	0.05	0.47	0.24	0.15
O44	0.27	0.13	0.21	0.28	0.22	0.15	0.41	0.24	0.23
O45	0.19	0.19	0.13	0.24	0.11	0.06	0.45	0.30	0.19
O46	0.35	0.14	0.18	0.21	0.22	0.11	0.43	0.25	0.22
O47	0.11	0.07	0.15	0.17	0.15	0.13	0.45	0.34	0.17
O48	0.36	0.38	0.18	0.12	0.09	0.10	0.42	0.29	0.23
O49	0.20	0.03	0.05	0.14	0.17	0.18	0.42	0.35	0.16
O50	0.34	0.40	0.64	0.10	0.13	0.14	0.43	0.28	0.33
O51	0.40	0.35	0.25	0.11	0.05	0.21	0.39	0.36	0.25

C2 Velocity Ratio for the Proposed Scheme

Proposed Scheme – Perimeter test points

	E	ENE	ESE	NE	NNE	SE	SSE	SSW	Combine
Frequency	0.12	0.16	0.11	0.13	0.09	0.07	0.07	0.06	0.80
P1	0.42	0.49	0.40	0.08	0.15	0.05	0.07	0.38	0.28
P2	0.16	0.07	0.19	0.13	0.11	0.14	0.08	0.25	0.14
P3	0.30	0.32	0.40	0.14	0.19	0.13	0.09	0.27	0.25
P4	0.21	0.12	0.58	0.11	0.24	0.30	0.12	0.09	0.25
P5	0.04	0.35	0.10	0.34	0.10	0.19	0.12	0.17	0.19
P6	0.07	0.05	0.16	0.15	0.19	0.13	0.22	0.17	0.14
P7	0.09	0.13	0.14	0.17	0.10	0.14	0.20	0.16	0.14
P8	0.09	0.14	0.12	0.09	0.18	0.19	0.41	0.17	0.16
P9	0.12	0.14	0.43	0.42	0.40	0.20	0.30	0.09	0.28
P10	0.27	0.34	0.56	0.51	0.62	0.15	0.33	0.11	0.40
P11	0.43	0.42	0.60	0.45	0.55	0.18	0.25	0.17	0.43
P12	0.48	0.48	0.70	0.54	0.33	0.13	0.27	0.27	0.45
P13	0.47	0.49	0.74	0.63	0.39	0.14	0.26	0.34	0.49
P14	0.41	0.47	0.76	0.68	0.42	0.10	0.24	0.35	0.49
P15	0.34	0.41	0.70	0.67	0.44	0.07	0.23	0.36	0.46
P16	0.29	0.34	0.61	0.65	0.69	0.30	0.18	0.34	0.47
P17	0.32	0.31	0.45	0.49	0.55	0.56	0.04	0.18	0.39
P18	0.28	0.28	0.42	0.43	0.52	0.61	0.03	0.14	0.36
P19	0.30	0.15	0.43	0.43	0.52	0.61	0.05	0.09	0.34
P20	0.31	0.19	0.10	0.40	0.56	0.61	0.18	0.14	0.30
P21	0.35	0.28	0.17	0.28	0.51	0.53	0.12	0.09	0.29
P22	0.29	0.23	0.17	0.37	0.52	0.60	0.14	0.04	0.29
P23	0.23	0.22	0.38	0.34	0.52	0.59	0.07	0.07	0.32
P24	0.12	0.26	0.58	0.52	0.62	0.59	0.04	0.02	0.39
P25	0.20	0.38	0.39	0.30	0.27	0.28	0.05	0.05	0.27
P26	0.18	0.32	0.20	0.34	0.31	0.18	0.03	0.09	0.23
P27	0.34	0.47	0.42	0.17	0.11	0.04	0.04	0.07	0.25

Proposed Scheme – Overall test points

	E	ENE	ESE	NE	NNE	SE	SSE	SSW	Combine
Frequency	0.12	0.16	0.11	0.13	0.09	0.07	0.07	0.06	0.80
O1	0.30	0.31	0.50	0.41	0.16	0.23	0.39	0.35	0.35
O2	0.27	0.28	0.46	0.26	0.22	0.08	0.18	0.44	0.29
O3	0.18	0.23	0.40	0.32	0.14	0.15	0.12	0.42	0.26
O4	0.30	0.35	0.64	0.42	0.16	0.06	0.14	0.08	0.33
O5	0.17	0.28	0.57	0.54	0.36	0.12	0.15	0.10	0.34
O6	0.23	0.28	0.58	0.43	0.14	0.14	0.08	0.07	0.29
O7	0.14	0.24	0.45	0.43	0.46	0.07	0.12	0.03	0.29
O8	0.20	0.32	0.70	0.50	0.39	0.14	0.08	0.08	0.36
O9	0.18	0.34	0.71	0.53	0.49	0.14	0.09	0.12	0.39
O10	0.17	0.31	0.65	0.69	0.61	0.54	0.09	0.11	0.44
O11	0.20	0.30	0.63	0.57	0.61	0.53	0.09	0.14	0.42
O12	0.23	0.26	0.51	0.55	0.52	0.61	0.08	0.12	0.39
O13	0.25	0.27	0.50	0.23	0.46	0.60	0.08	0.09	0.33
O14	0.30	0.35	0.65	0.64	0.64	0.67	0.12	0.12	0.48
O15	0.31	0.26	0.19	0.30	0.49	0.61	0.12	0.06	0.29
O16	0.31	0.31	0.48	0.50	0.53	0.63	0.10	0.04	0.39
O17	0.33	0.22	0.13	0.27	0.48	0.61	0.12	0.10	0.27
O18	0.33	0.30	0.46	0.45	0.54	0.63	0.06	0.15	0.39
O19	0.33	0.31	0.52	0.51	0.59	0.68	0.09	0.21	0.43
O20	0.36	0.33	0.51	0.47	0.58	0.68	0.18	0.28	0.44
O21	0.34	0.33	0.49	0.52	0.62	0.71	0.04	0.08	0.42
O22	0.31	0.27	0.40	0.41	0.54	0.65	0.31	0.10	0.38
O23	0.34	0.32	0.51	0.59	0.66	0.70	0.03	0.31	0.45
O24	0.31	0.25	0.43	0.55	0.68	0.77	0.33	0.22	0.44
O25	0.22	0.18	0.45	0.64	0.77	0.56	0.21	0.07	0.41
O26	0.30	0.27	0.52	0.64	0.75	0.76	0.13	0.12	0.46
O27	0.24	0.19	0.34	0.47	0.61	0.72	0.34	0.03	0.37
O28	0.21	0.13	0.26	0.43	0.57	0.31	0.26	0.09	0.29
O29	0.12	0.10	0.12	0.32	0.26	0.48	0.26	0.05	0.20
O30	0.18	0.13	0.13	0.11	0.10	0.49	0.20	0.19	0.17
O31	0.14	0.11	0.14	0.18	0.11	0.28	0.24	0.14	0.16
O32	0.31	0.38	0.58	0.53	0.60	0.12	0.30	0.14	0.42
O33	0.18	0.35	0.57	0.57	0.52	0.48	0.17	0.17	0.41

	E	ENE	ESE	NE	NNE	SE	SSE	SSW	Combine
Frequency	0.12	0.16	0.11	0.13	0.09	0.07	0.07	0.06	0.80
O34	0.13	0.12	0.42	0.42	0.30	0.47	0.24	0.16	0.29
O35	0.09	0.27	0.58	0.52	0.60	0.10	0.33	0.15	0.37
O36	0.14	0.07	0.41	0.54	0.16	0.40	0.28	0.11	0.28
O37	0.13	0.06	0.38	0.49	0.30	0.13	0.33	0.13	0.26
O38	0.10	0.10	0.14	0.28	0.21	0.37	0.35	0.28	0.21
O39	0.09	0.19	0.19	0.14	0.17	0.09	0.41	0.13	0.17
O40	0.11	0.18	0.29	0.29	0.25	0.27	0.36	0.34	0.26
O41	0.04	0.13	0.27	0.16	0.11	0.08	0.46	0.15	0.18
O42	0.07	0.05	0.14	0.20	0.21	0.12	0.44	0.32	0.17
O43	0.05	0.31	0.26	0.15	0.14	0.09	0.28	0.21	0.20
O44	0.15	0.08	0.47	0.24	0.22	0.28	0.46	0.29	0.27
O45	0.18	0.13	0.59	0.14	0.39	0.38	0.31	0.29	0.31
O46	0.38	0.25	0.22	0.07	0.25	0.30	0.46	0.28	0.25
O47	0.21	0.21	0.38	0.07	0.18	0.07	0.29	0.38	0.23
O48	0.41	0.45	0.37	0.08	0.18	0.19	0.43	0.28	0.30
O49	0.22	0.11	0.14	0.29	0.29	0.17	0.28	0.38	0.22
O50	0.33	0.34	0.54	0.18	0.13	0.25	0.44	0.28	0.32
O51	0.45	0.49	0.40	0.11	0.09	0.23	0.32	0.40	0.31