Hong Kong Housing Authority

PRH Development at Sau Ming Road

Air Ventilation Assessment (AVA) - Initial Study Report

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Executive Summary

Introduction

Ove Arup & Partners 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 PRH Redevelopment at Sau Ming Road (The Development) to assess the ventilation performance of its surrounding associated with the proposed design. The objective of the Study is to compare the air ventilation performance between the following two schemes:

1. **Baseline Scheme** – This is an existing condition, Sau Mau Ping (central) Estate community centre with 5-storey high.

2. **Proposed Scheme** – Newly proposed development schemes consists of two wings, with a joint-users 2-storey community hall, library and study room inside. The alignment of the building is in "L" shape with 18 storeys.

Methodology

The Technical Circular No. 1/06 – Air Ventilation Assessment (Technical Circular) was issued jointly by Housing, Planning and Land Bureau (HPLB) and Environment, Transport and Works Bureau (ETWB) on 19 July 2006. It addresses the technical and implementation issues of AVA in Hong Kong. The guidance given in the circular has been adopted for this AVA study. Computational Fluid Dynamics (CFD) and an advanced turbulence modelling technique, SST k - ω turbulence model, were used to model air movement.

Outcome of the assessment

- The Site spatial average Velocity Ratios (SVR) and the Local spatial average Velocity Ratios (LVR) are both higher for the Baseline Scheme than that of the Proposed Scheme;

- Due to the small project site area, the ventilation performance of the study area is mainly governed by the topography and the surround existing building arrangement. The Proposed development would only affect limited area and the ventilation performance of the Sau Ming Road and Hiu Kwong Street are similar for both existing condition and the Proposed Scheme.

- The ventilation performance of the Sau Mau Ping Estate is shown to be better in the Proposed Scheme, due to the down wash effect of the proposed development. There is improvement in ventilation performance of Sau Mau Ping Estate by around 9.1%;

- The void podium design in the Development helps to improve the ventilation performance of the surrounding area. This increases the permeability of the whole development and enhances the local ventilation environment.

1 Introduction

1.1 Project Background

Ove Arup & Partners 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 PRH Redevelopment at Sau Ming Road Site (The Development) to assess the ventilation performance of its surrounding associated with the proposed design.

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 case 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 Development 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 an existing condition, Sau Mau Ping (central) Estate community centre with 5-storey high.
2. **Proposed Scheme** – Newly proposed development schemes consists of two wings, with a joint-users 2-storey community hall, library and study room inside. The alignment of the building is in "L" shape with 18 storeys.

The deliverables of current study can be summarised as follows:

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

2 Background

2.1 Site Characteristics

The site is located at the Sau Mau Ping which is surrounded by some high rise residential buildings with a hilly topology. It is surrounded by high rise public development at the east (Sau Mau Ping Estate) and a non-building area slope at its west and south. A relative low rise commercial centre locates at its north.

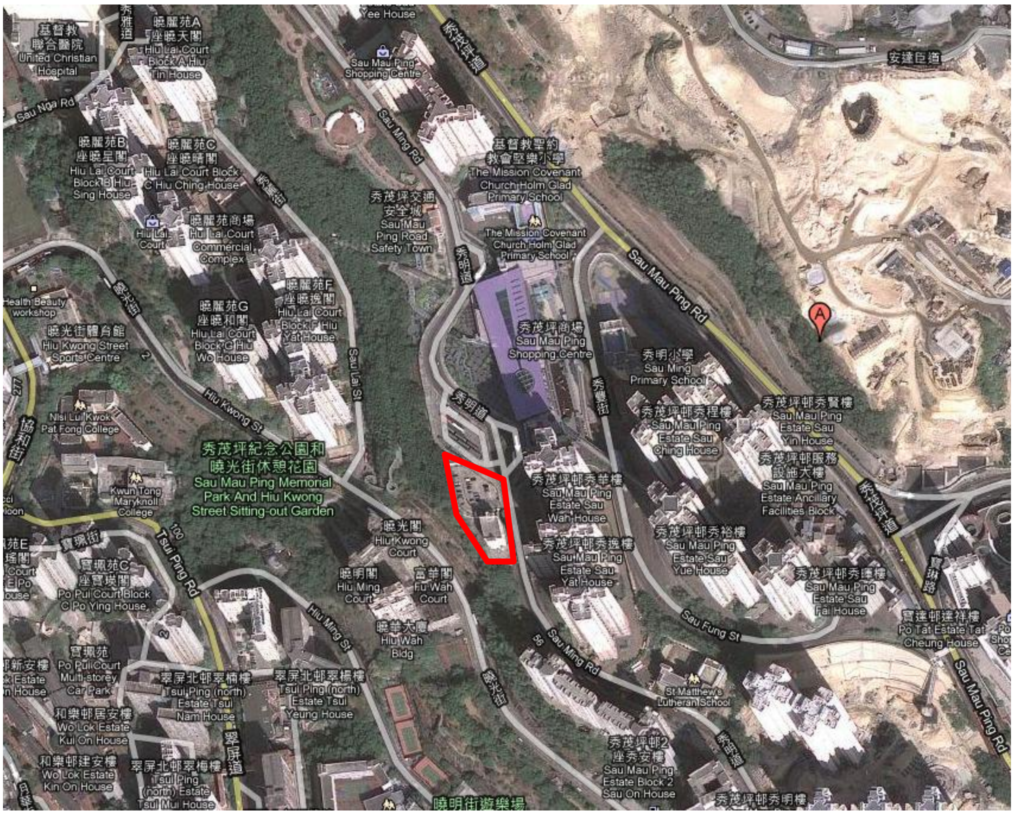


Figure 1 Locations of the Study Area and major surrounding developments

2.2 Studied Scenarios

Totally two cases were investigated in the AVA study which includes

Baseline Scheme – This is an existing condition, Sau Mau Ping (central) Estate community centre with 5-storey high.

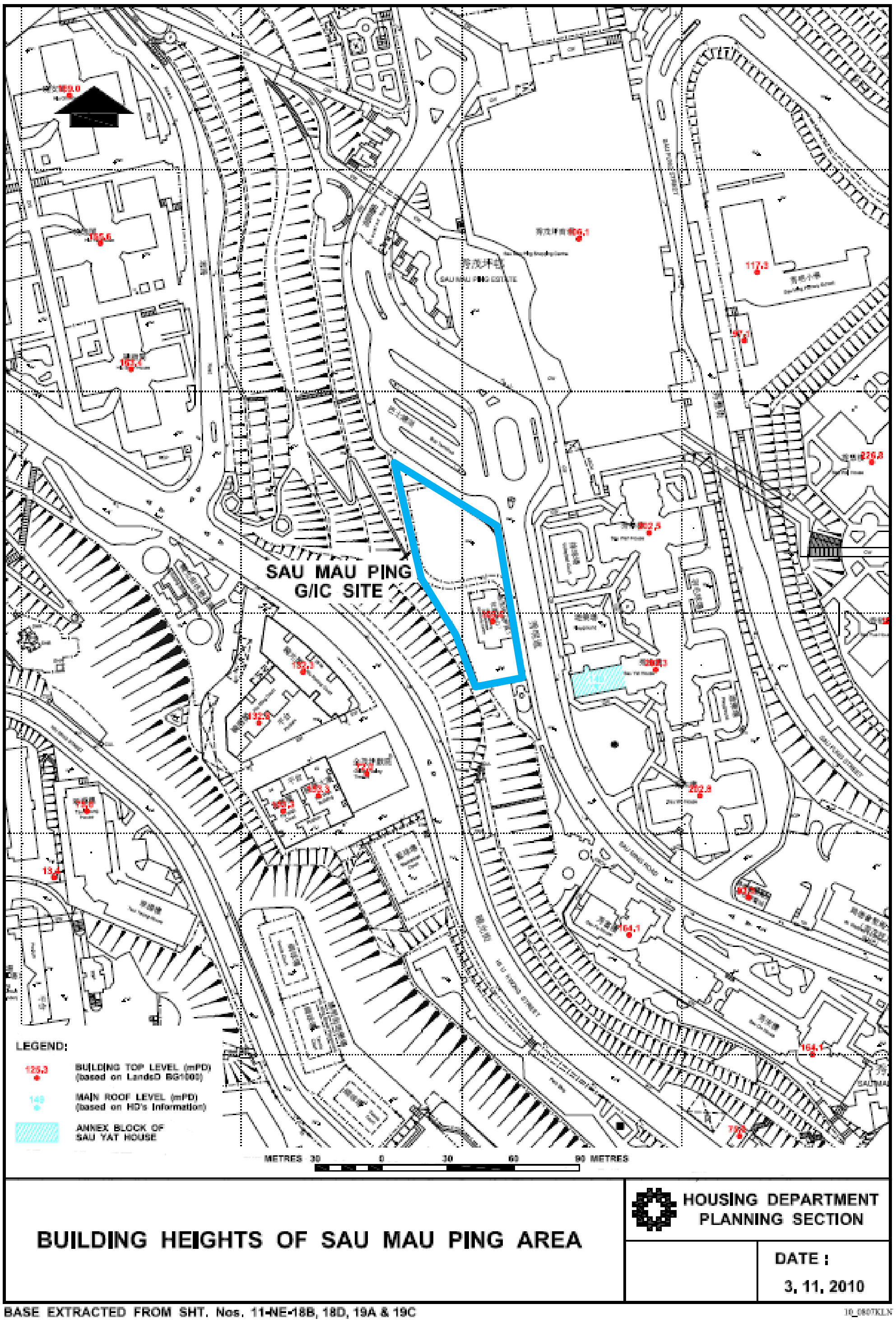


Figure 2 Master layout plan for the baseline scheme

Proposed Scheme – Newly proposed development schemes consists of two wings, with a joint-users 2-storey community hall, library and study room inside. The alignment of the building is in “L” shape with 18 storeys.

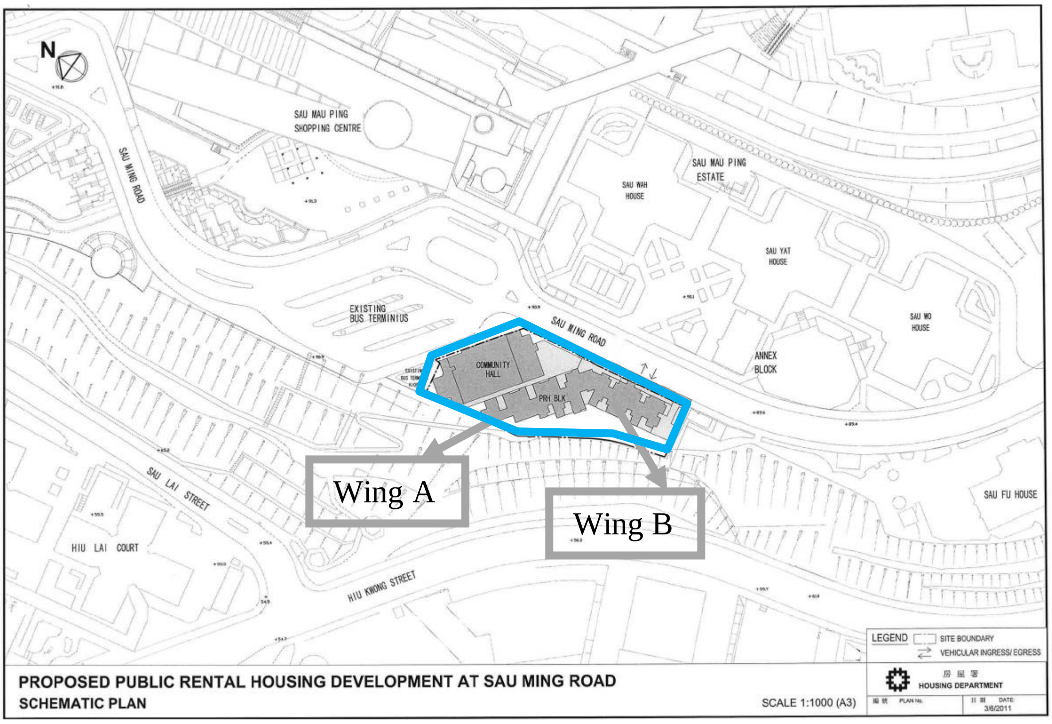


Figure 3 Master layout plan for the proposed scheme

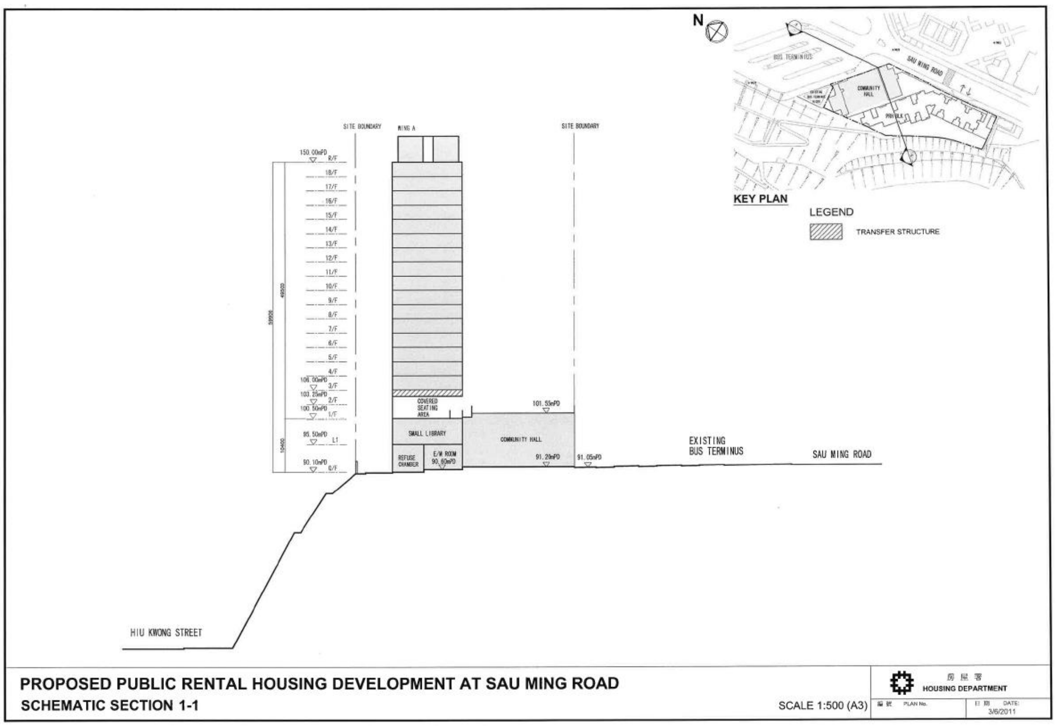


Figure 4 Schematic Section for the proposed scheme.

3 Methodology of AVA

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.

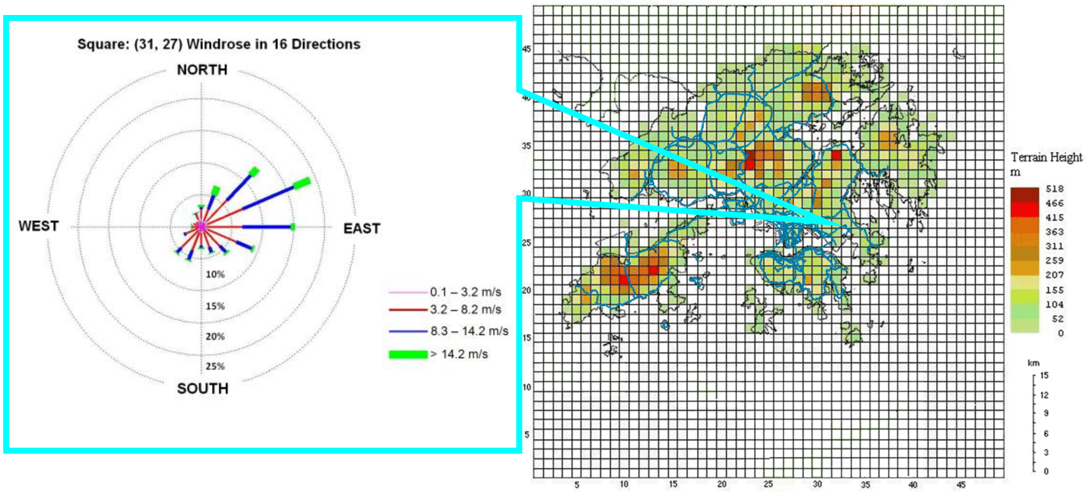


Figure 5. Wind rose based on MM5 simulation

Wind Direction	Percentage of Occurrence (%)	Wind Direction	Percentage of Occurrence (%)	Wind Direction	Percentage of Occurrence (%)	Wind Direction	Percentage of Occurrence (%)
N	*3.4*	E	***15***	S	*3.4*	W	*1.6*
NNE	***6.7***	ESE	***9.1***	SSW	***5.6***	WNW	*1.3*
NE	***12.7***	SE	***5.8***	SW	***5.7***	NW	*1.0*
ENE	***18.9***	SSE	*4.4*	WSW	*3.0*	NNW	*2.3*

Remarks: Blue number represents the prevailing wind directions for simulation with occurrence exceeding 75% of time of a year

Table 1. Annual wind frequency

Results show that the prevailing wind directions **NNE, NE, ENE, E, ESE, SE, SSW** and **SW** are having corresponding frequency of occurrences of 6.7%, 12.7%, 18.9%, 15.0%, 9.1%, 5.8%, 5.6% and 5.7% respectively. Total wind frequency is 79.5% 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:

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

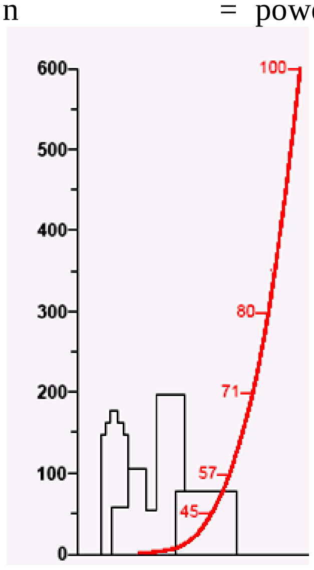


Figure 6 Wind Profile applied in the AVA Initial Study

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 high rise urban area, n-value for the eight-most frequent wind directions is 0.35. Based on this power law, the wind profiles is shown in the following figure, 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 ~60m) from the site boundary (Assessment Area). Further, the model area was built to include another 60m (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.

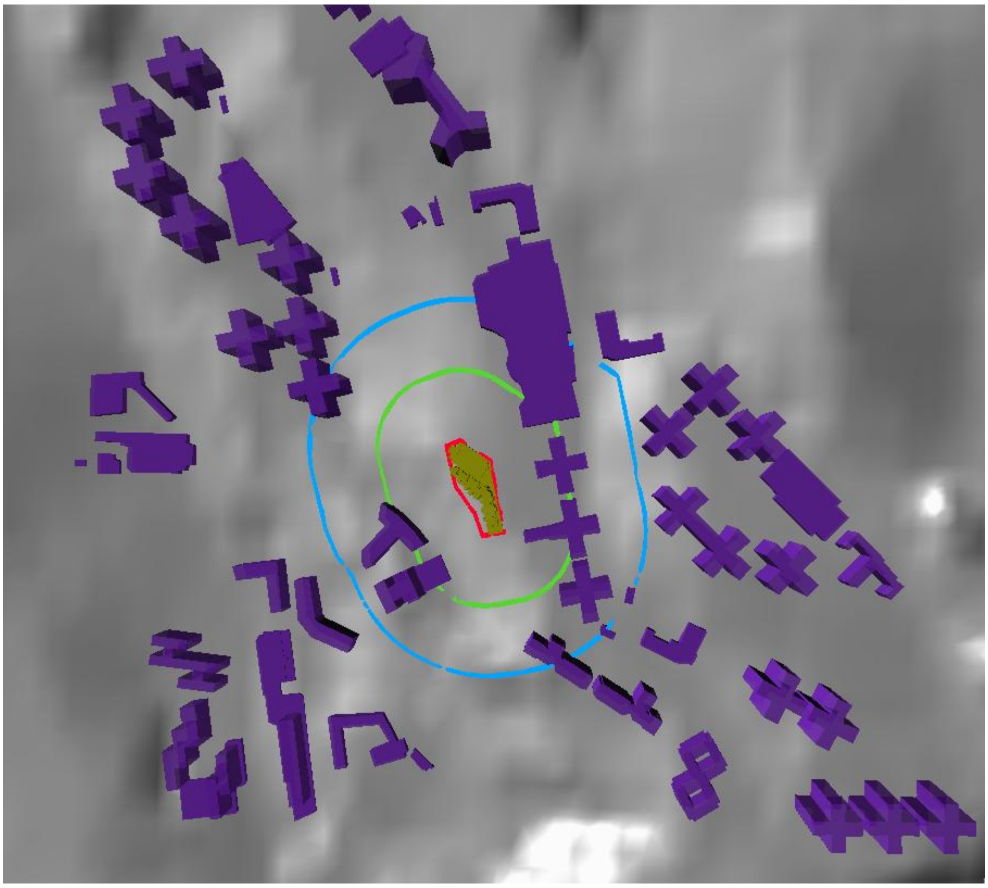


Figure 7 Site boundary (red), Assessment Area (green) and Surrounding Area (blue)

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).

Vp = 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, 15 perimeter points *(blue spots)* are positioned on the project site boundary and each point is around 10-50m in between.

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 27 overall test points *(red spots)* are selected and shown in Figure 8.

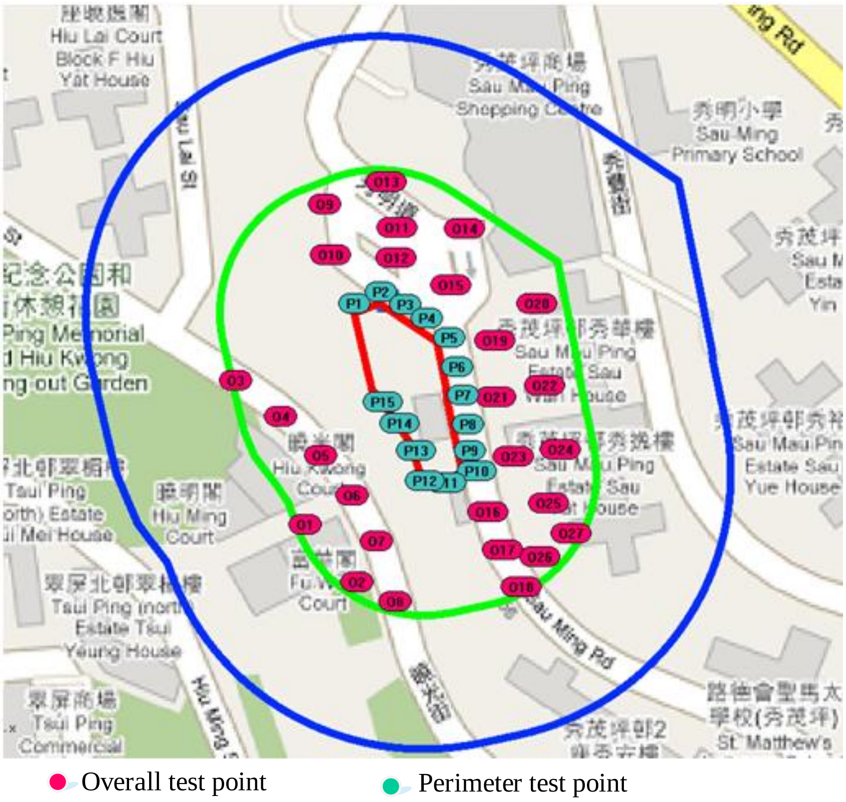


Figure 8 Demarcation of the test locations for site air ventilation assessment

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 7) 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. 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 1800m(L) x 1500m(W) x 1000m(H) (Figure 9) and each contain more than 3,500,000 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. The 3D model for the Baseline Scheme and Proposed Scheme with different viewing angle is shown in Figure 10 to Figure 17. 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 (Figure 18). The expansion ratio is 1.5 while the blockage ratio is 4.2%.

By referring to the CAD drawings of the baseline and proposed scheme given, the CFD model is constructed as shown below.

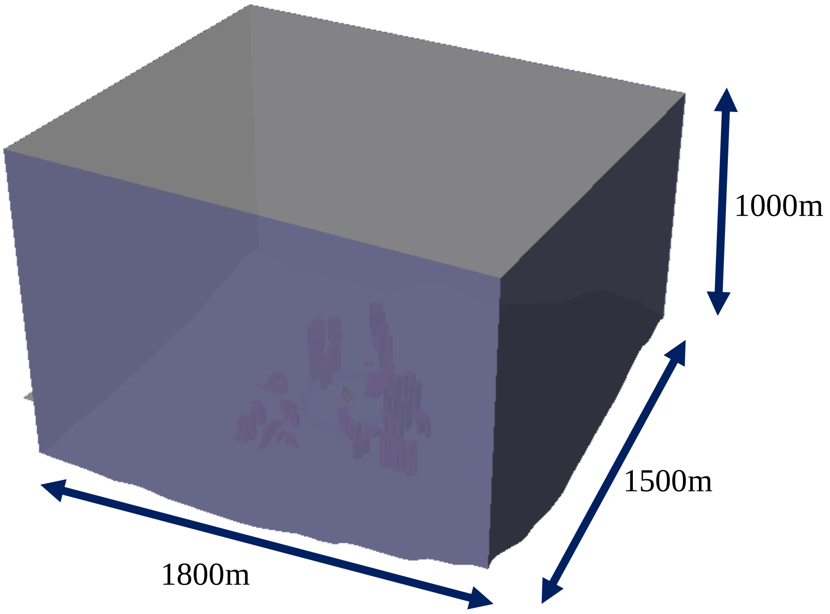


Figure 9 Domain of the CFD model

Figure 10 East view of the baseline scheme

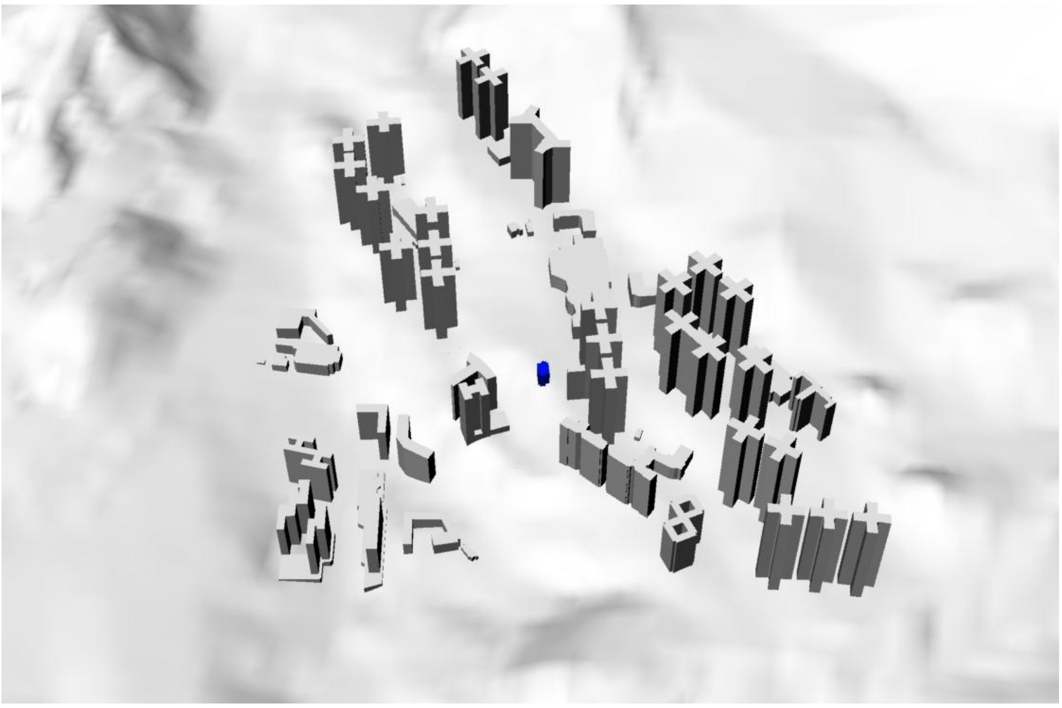


Figure 11 South view of the baseline scheme

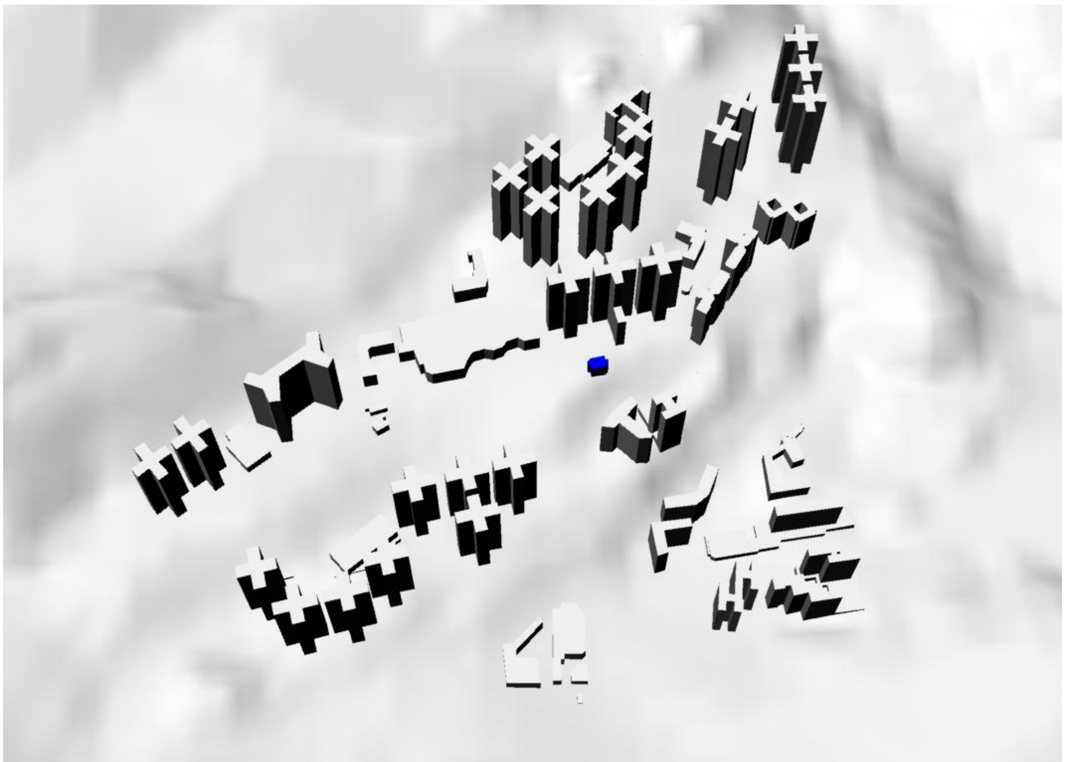


Figure 12 West view of the baseline scheme

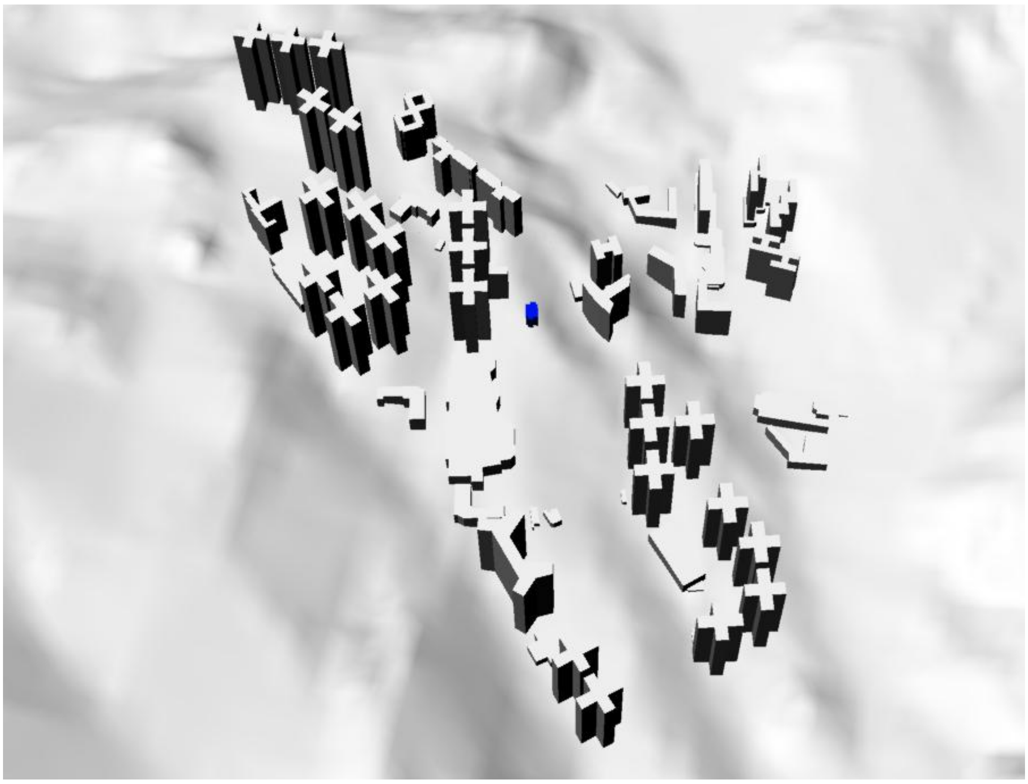


Figure 13 North view of the baseline scheme

Figure 14 East view of the proposed scheme.

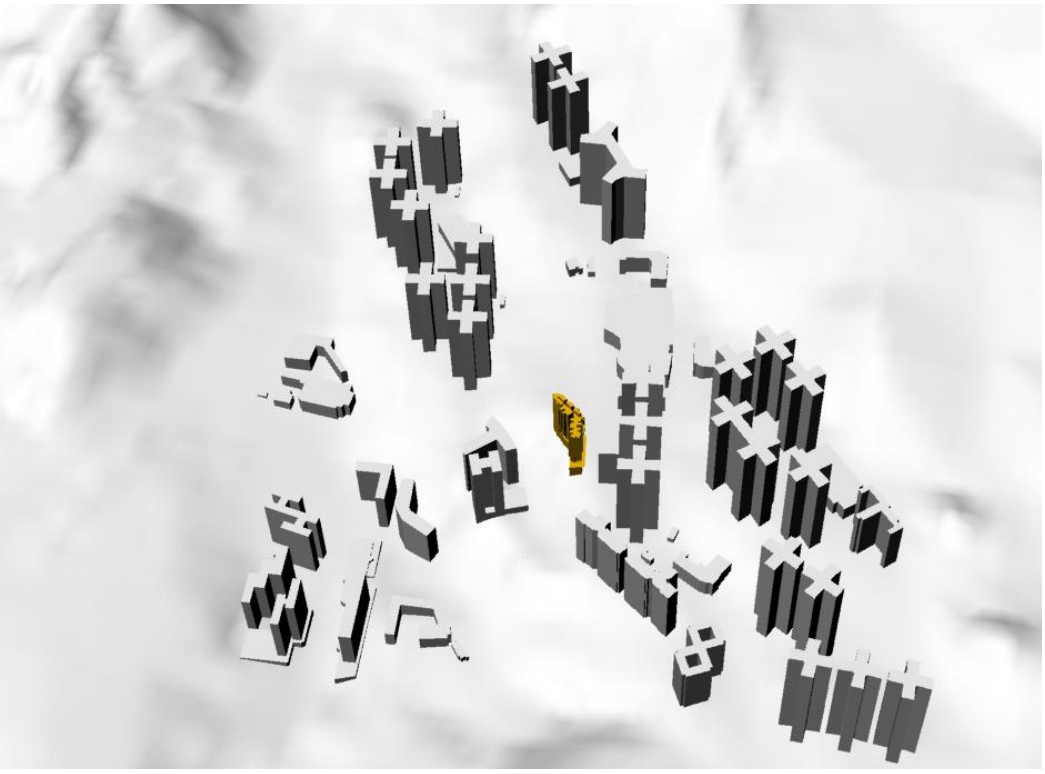


Figure 15 South view of the proposed scheme.

Figure 16 West view of the proposed scheme.

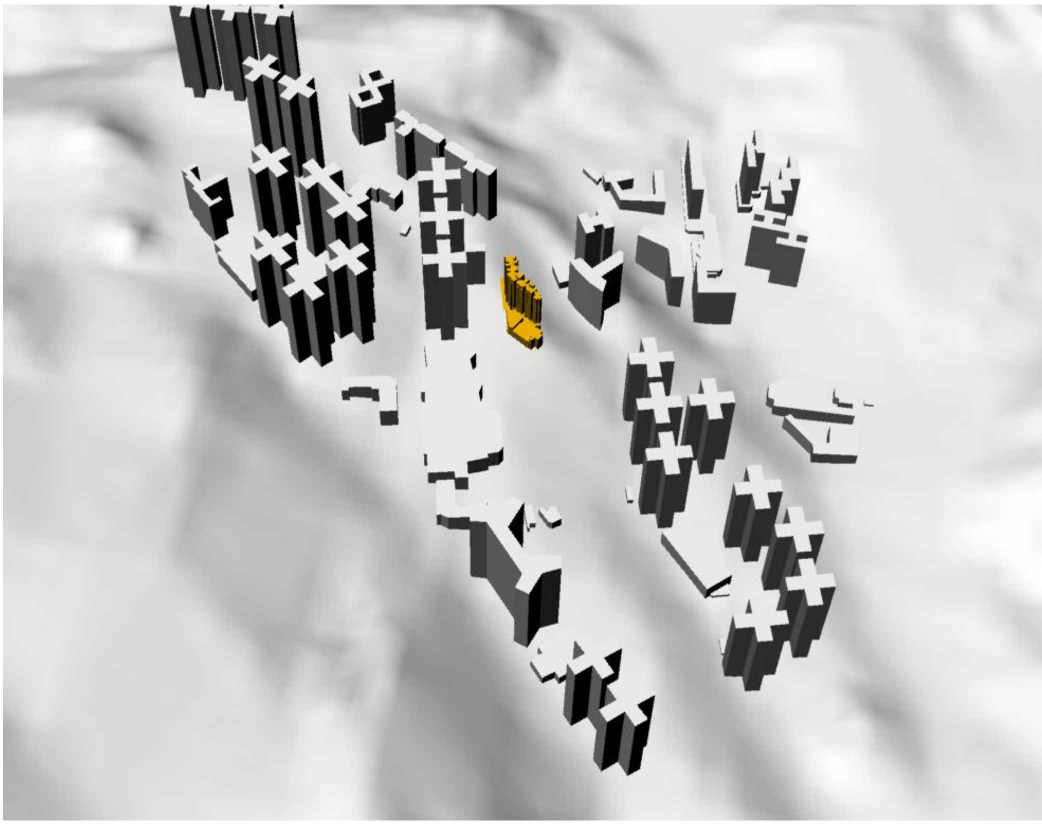


Figure 17 North view of the proposed scheme.

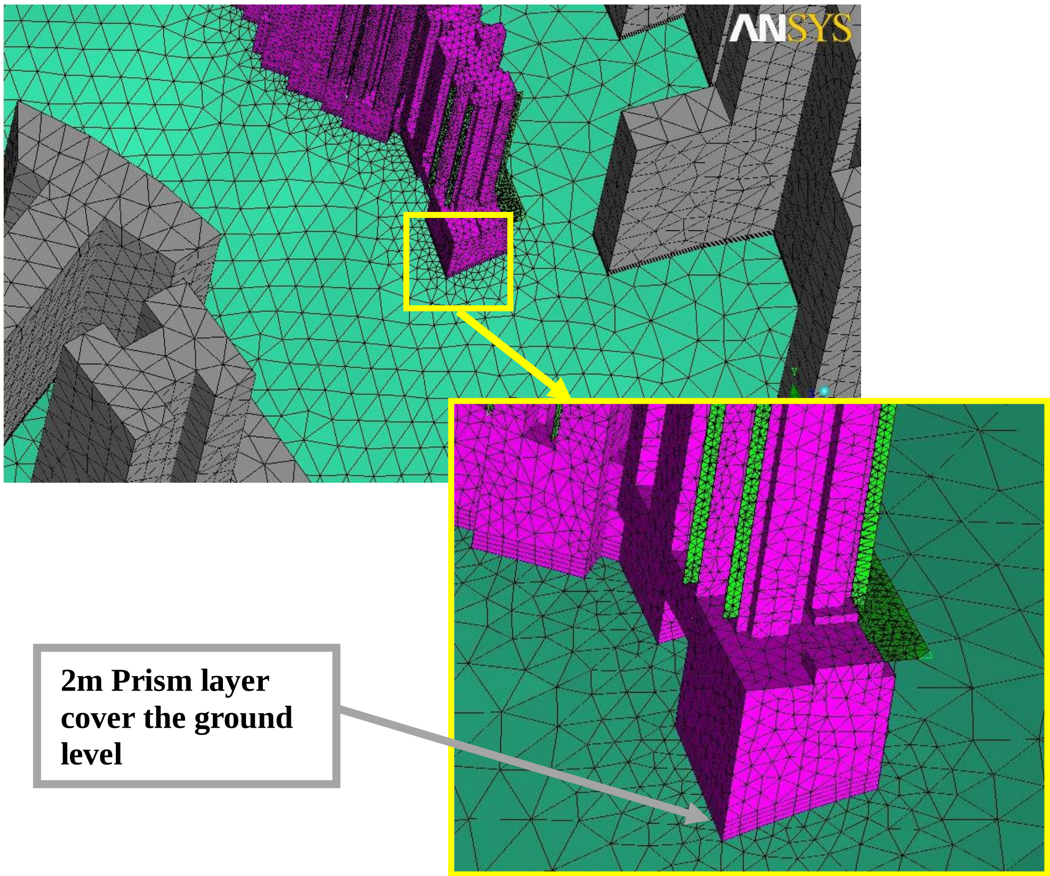


Figure 18 Prism layer for the proposed scheme

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 9).

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 19 and Figure 20 show the contour maps of VR for the Baseline Scheme and Proposed Scheme respectively.

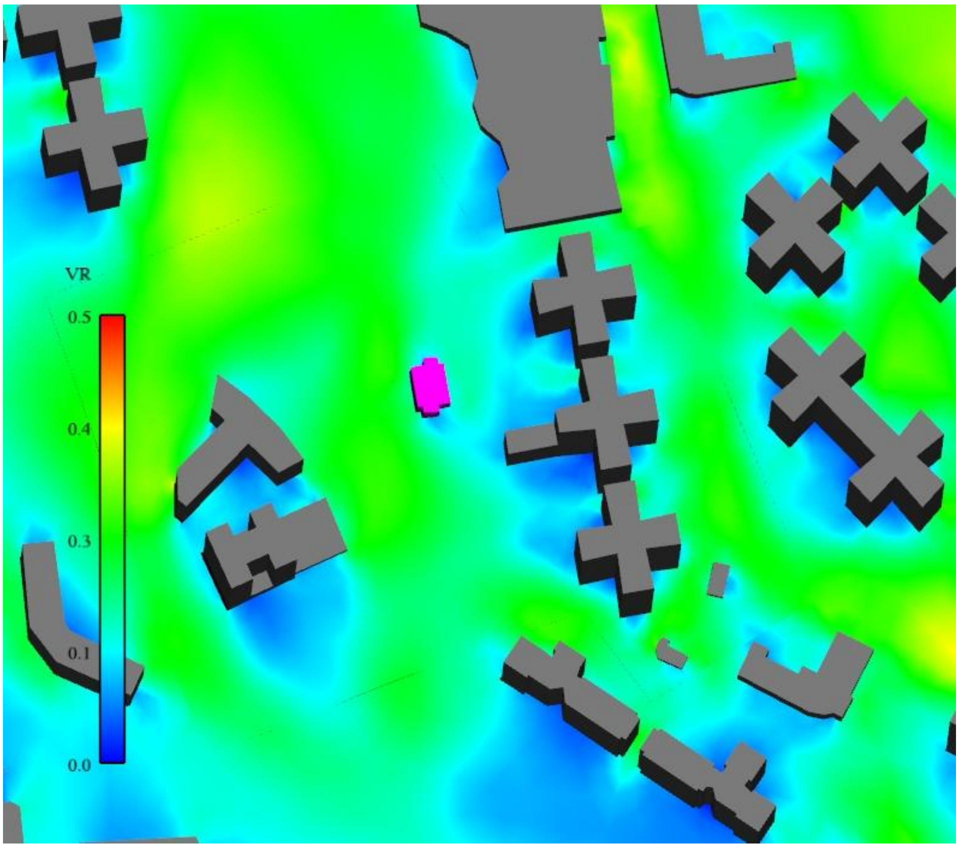


Figure 19 Contour map of the average VR for the Baseline Scheme

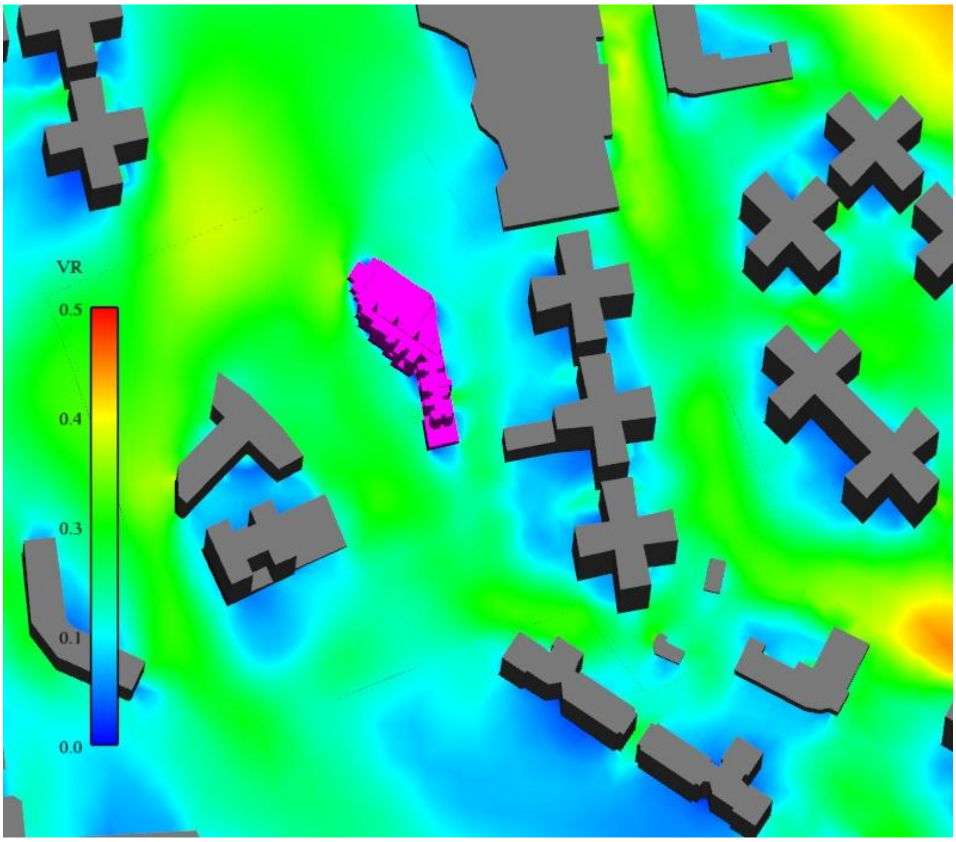


Figure 20 Contour map of the average VR for the Proposed Scheme

- The high rise and high density Sau Mau Ping Estate blocks the easterly wind, results in a lower VR along the Sau Ming Road near the site.

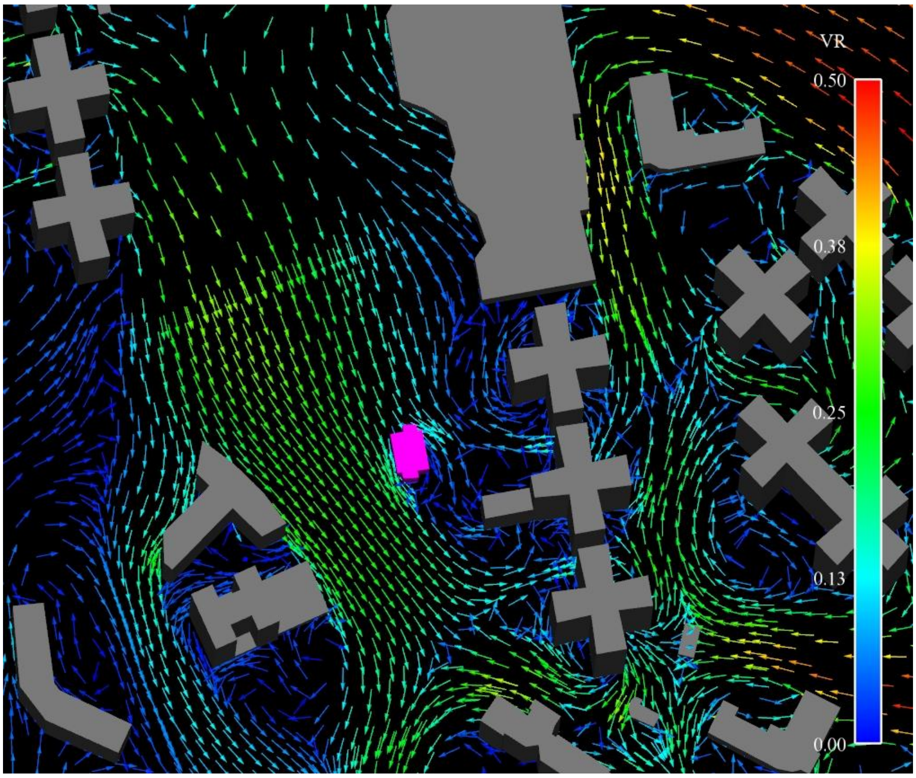
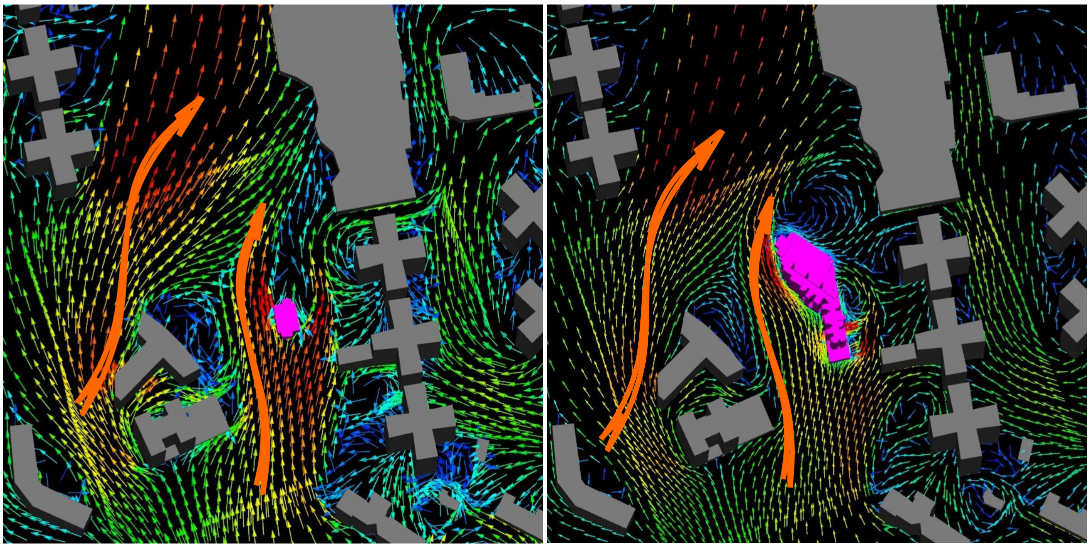


Figure 21 Vector plot of the Baseline scheme under E wind

- The ventilation condition within the Sau Mau Ping Estate under the Proposed Scheme is a little bit better than that of Baseline Scheme. It may be benefit by part of downwash effect of the high rise Proposed Scheme.
- The open area at the South of the site acts as a major wind corridor during the South-Westerly wind condition as shown in Figure 22. The alignment of the building can maintain the wind corridor and let it ventilate the downstream area. However, under such prevailing wind direction, the Bus Stop area falls within the wind shadow of the tower and result a lower VR.



Baseline Scheme　　　　　　　　　　Proposed Scheme

Figure 22 Vector plot of Baseline and Proposed Scheme under SSW wind.

- Since the development blocks are surrounded by the high-density, high rise developments; it only affects wind performance within a limited area.

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 (blue points as shown in Figure 8).
- **Local spatial average velocity ratio (LVR) -** This gives a hint of how the proposed development 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 8).

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

	Baseline scheme	Proposed scheme
SVR	0.20	0.17
LVR	0.17	0.16

Results show that both SVR and LVR of the Baseline Scheme are slightly higher than the Proposed Scheme. This implies that the proposed development would have some impact to the ventilation performance of its surroundings. Hence, the impacts in focus area would be further studied in the next section.

4.3 Focus Areas

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

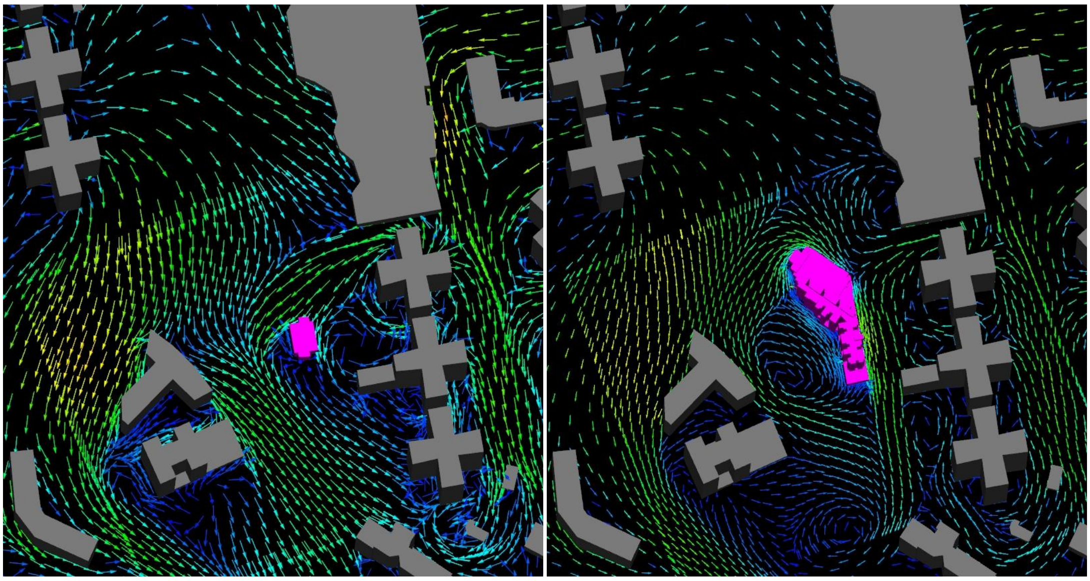
Figure 23 Locations of the focus areas and relevant test points

	Focus Area	Test point	Average Velocity Ratio	
			Baseline Scheme	Proposed Scheme
1	Sau Ming Road 秀明道	P5-P10, O13-O18	0.16	0.16
2	Bus Terminus 巴士站	O9-O12	0.23	0.21
3	Hiu Kwong Street 曉光街	O3-O8	0.22	0.22
4	Hiu Kwong Court, Fu Wah Court 曉光閣, 富華閣	O1-O2	0.12	0.12
5	Sau Mau Ping Estate 秀茂坪村	O19-O27	0.10	0.11

Table 2. Spatial average VR of different focus areas

Result shows that the ventilation performance of the Sau Ming Road Hiu Kwong Court, Fu Wah Court and the Hiu Kwong Street are similar for the Baseline Scheme and the Proposed Scheme. There is an improvement in ventilation performance of the Sau Mau Ping Estate by around 9.1%. The wind performance of the bus stop in the Proposed Scheme is a little bit worse than existing condition, but it still higher than the averaged wind performance of the site (LVR=0.17) which is acceptable.

When compare the Baseline scheme with the Proposed Scheme, there is apparent height difference. Under the North-Easterly wind (about 46.6% of wind frequency), the proposed scheme could capture the wind from high level to the pedestrian level and help to improve the ventilation performance of the Sau Mau Ping Estate as shown in the Figure 24.



Baseline Scheme Proposed Scheme

Figure 24 Vector plot of the Proposed Scheme under NE wind

4.4 Wind enhancement feature

According to the Urban Design Guidelines, the provision for higher permeability of building masses can be achieved by creating gaps between the podium and the building blocks built atop (Figure 25).The void podium deck design (Figure 26) increase the permeability of the Development. As shown in Figure 27, the void podium allows the annual dominant wind (North Easterly wind) flow through it and ventilates the downstream area.

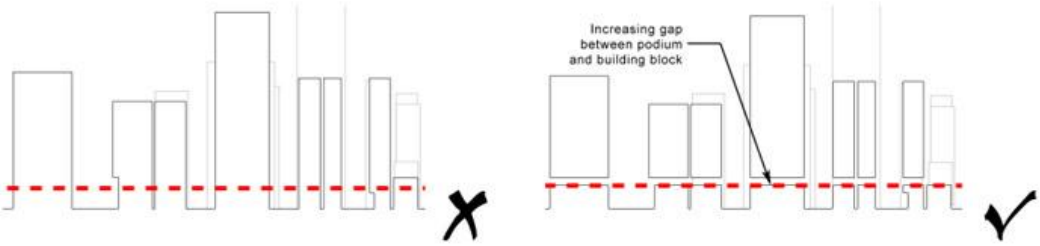


Figure 25 Gaps between the podium and the building blocks to enhance air permeability

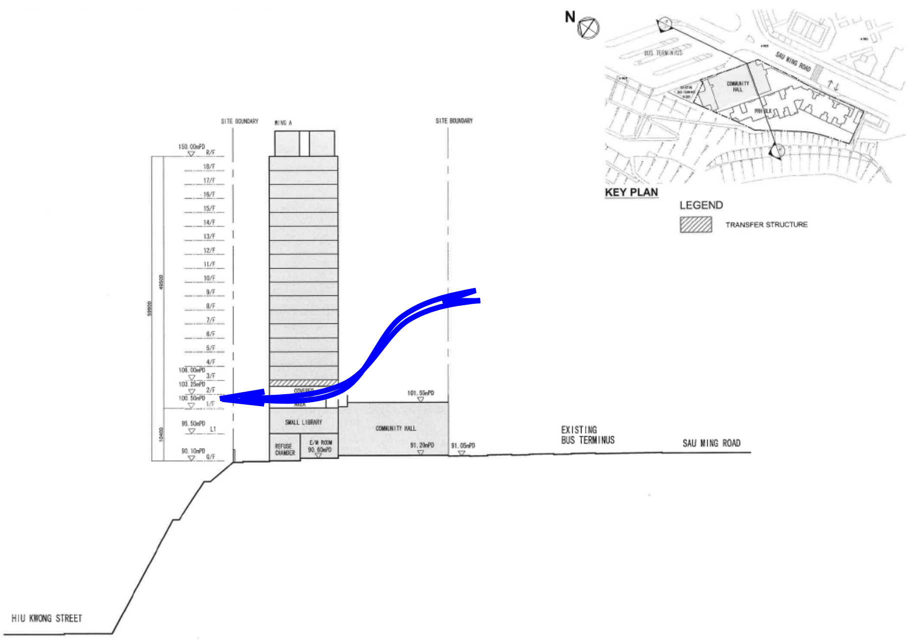


Figure 26 Void podium deck enhance the local ventilation environment

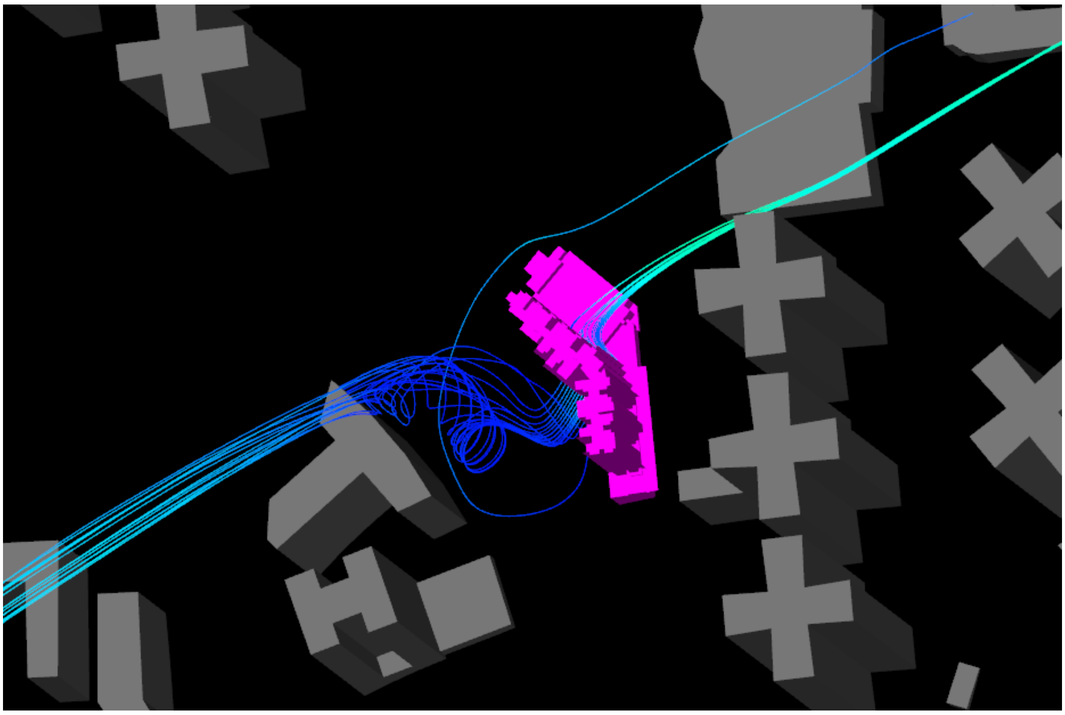


Figure 27 Velocity streamline of the Proposed Scheme under NE wind

5 Conclusion

The development is located at the Sau Mau Ping which is surrounded by some high rise residential buildings with a hilly topology. It is surrounded by high rise public development at the east (Sau Mau Ping Estate) and a non-building area slope at its west and south. A relative low rise commercial centre locates at its north.

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, SSW and SW, which totally cover 79.5% of wind availability in a year, i.e. exceeding 75% of annual wind frequency as required by the Technical Circular of AVA. Two scenarios, namely the Baseline Scheme and 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 15 Perimeter test points, 27 Overall test points were selected to assess the air ventilation performance at the surrounding existing development.

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

- The Site spatial average Velocity Ratios (SVR) and the Local spatial average Velocity Ratios (LVR) are both higher for the Baseline Scheme than that of the Proposed Scheme;
- Due to the small project site area, the ventilation performance of the study area is mainly governed by the topography and the surround existing building arrangement. The Proposed development would only affect limited area and the ventilation performance of the Sau Ming Road, Hiu Kwong Court, Fu Wah Court and Hiu Kwong Street are similar for both existing condition and the Proposed Scheme.
- The ventilation performance of the Sau Mau Ping Estate is shown to be better in the Proposed Scheme, due to the down wash effect of the proposed development. There is improvement in ventilation performance of Sau Mau Ping Estate by around 9.1%;

The void podium design in the Development helps to improve the ventilation performance of the surrounding area. This increases the permeability of the whole development and enhances the local ventilation environment.

Appendix A

Directional Velocity Ratio Contour Plot

A1 VR contour map for baseline scheme

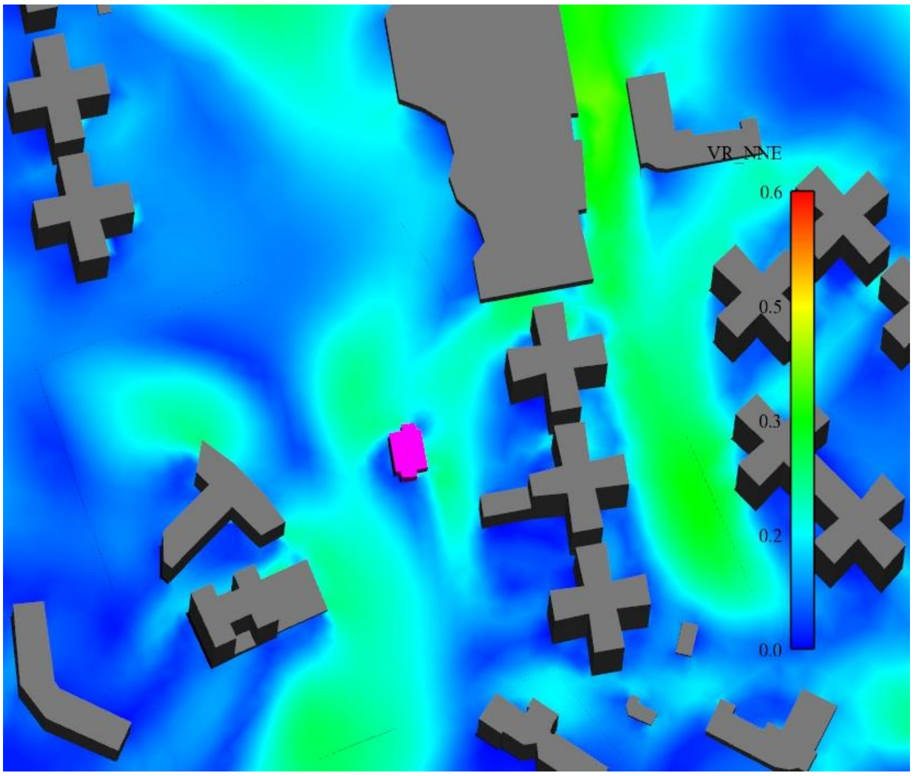


Figure A 1 Baseline Scheme (NNE wind)

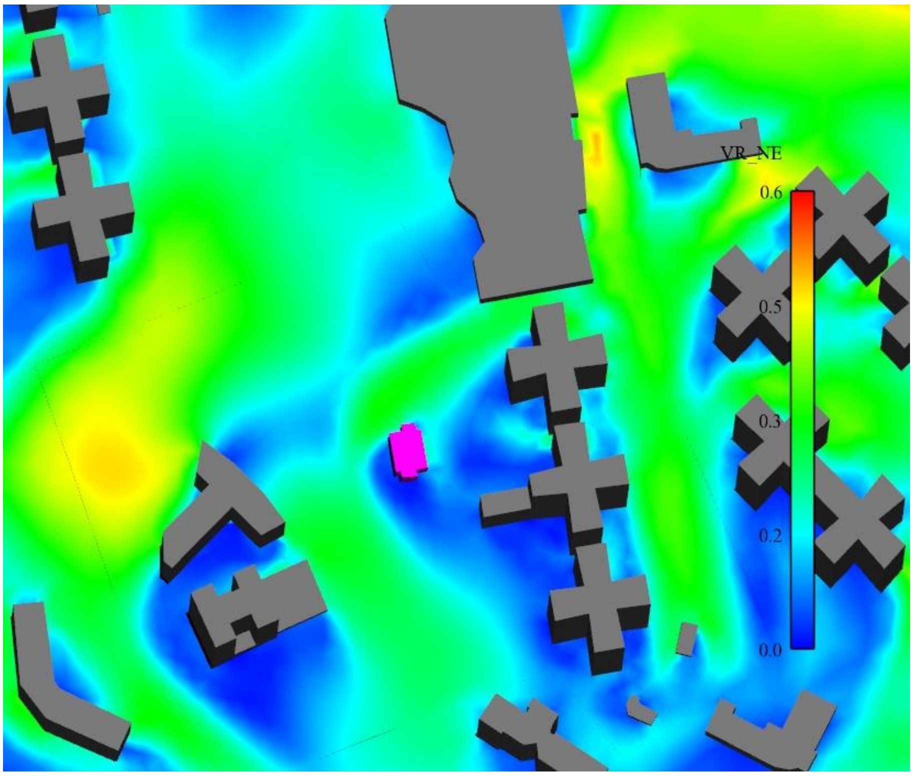


Figure A 2 Baseline Scheme (NE wind)

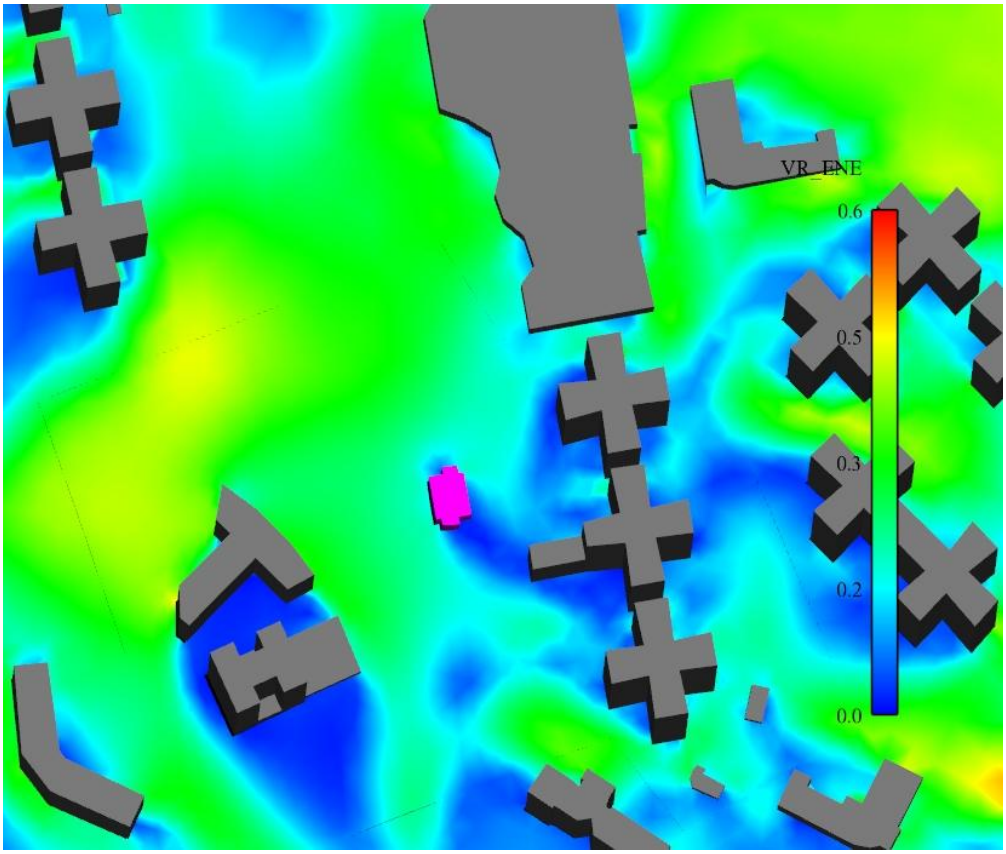


Figure A 3 Baseline Scheme (ENE wind)

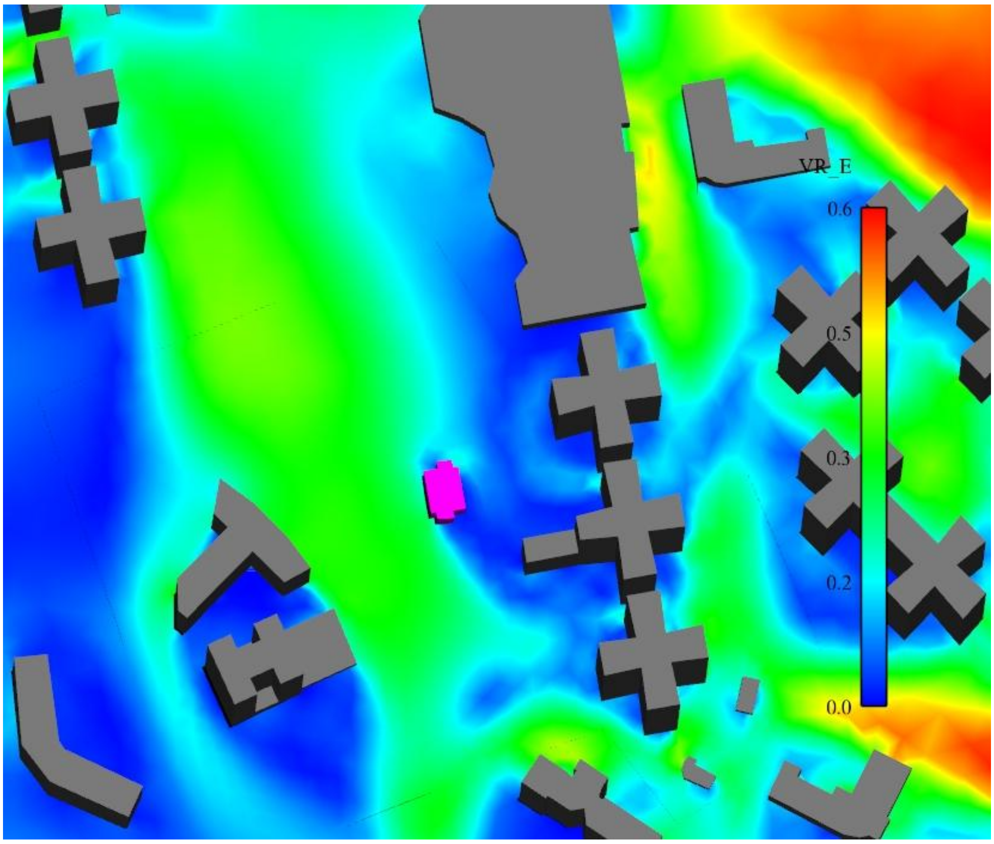


Figure A 4 Baseline Scheme (E wind)

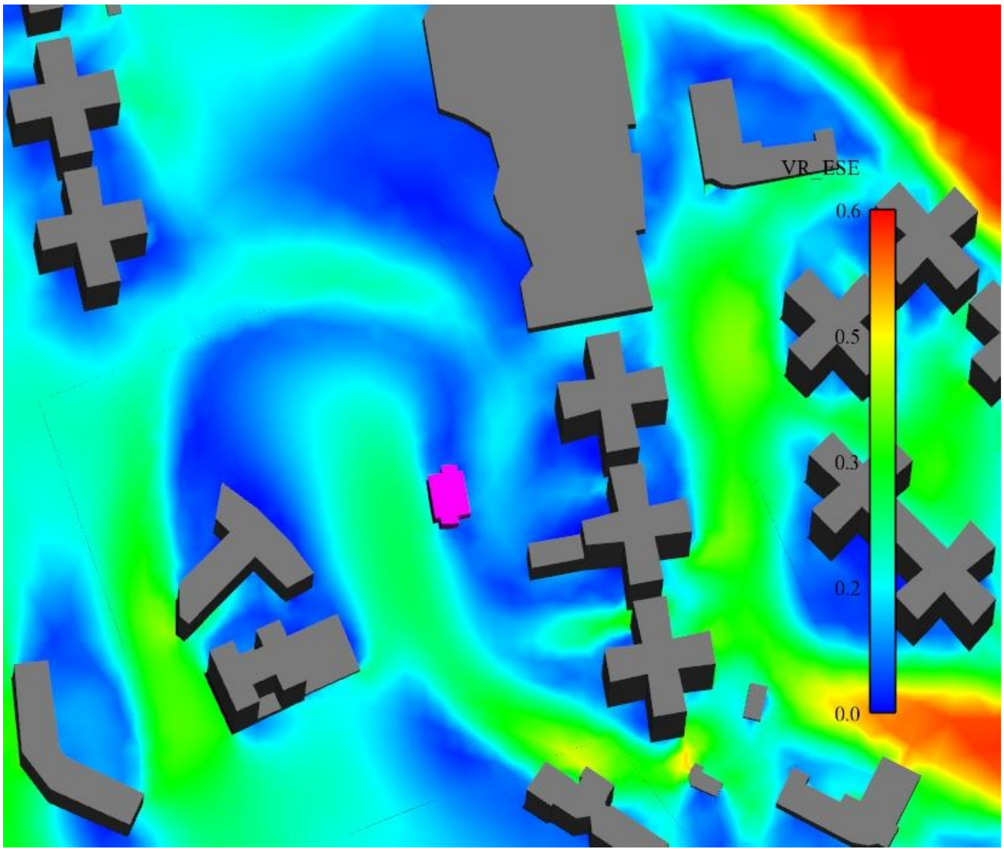


Figure A 5 Baseline Scheme (ESE wind)

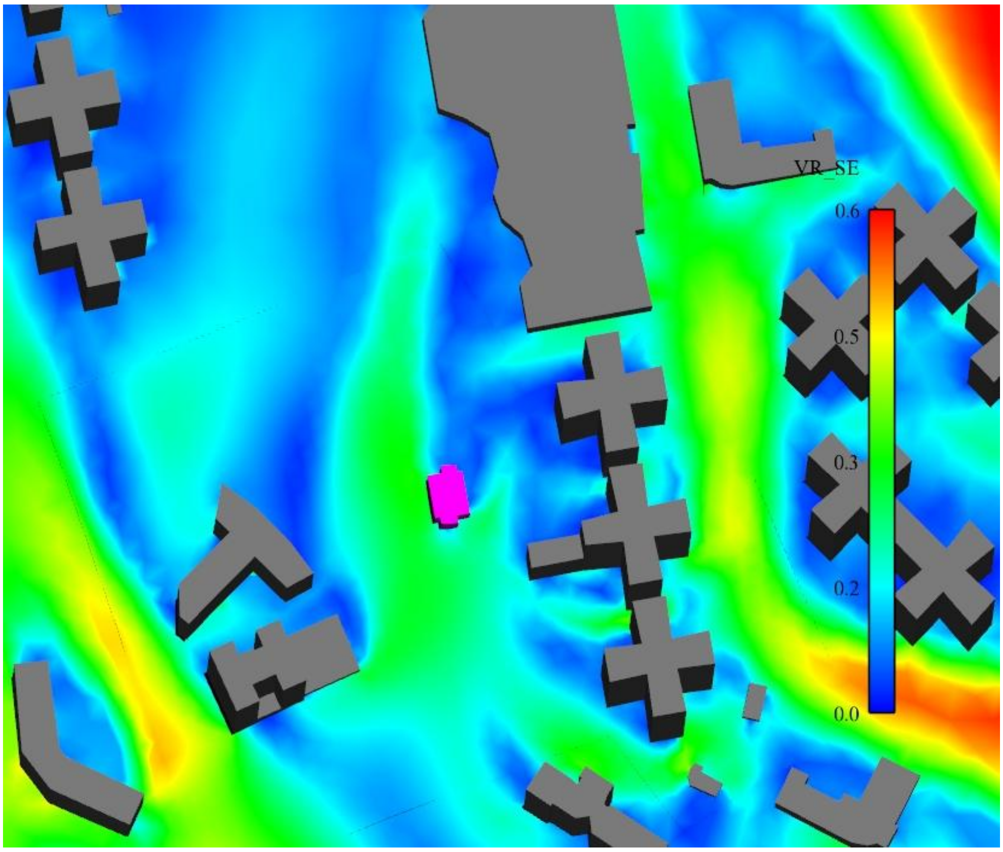


Figure A 6 Baseline Scheme (SE wind)

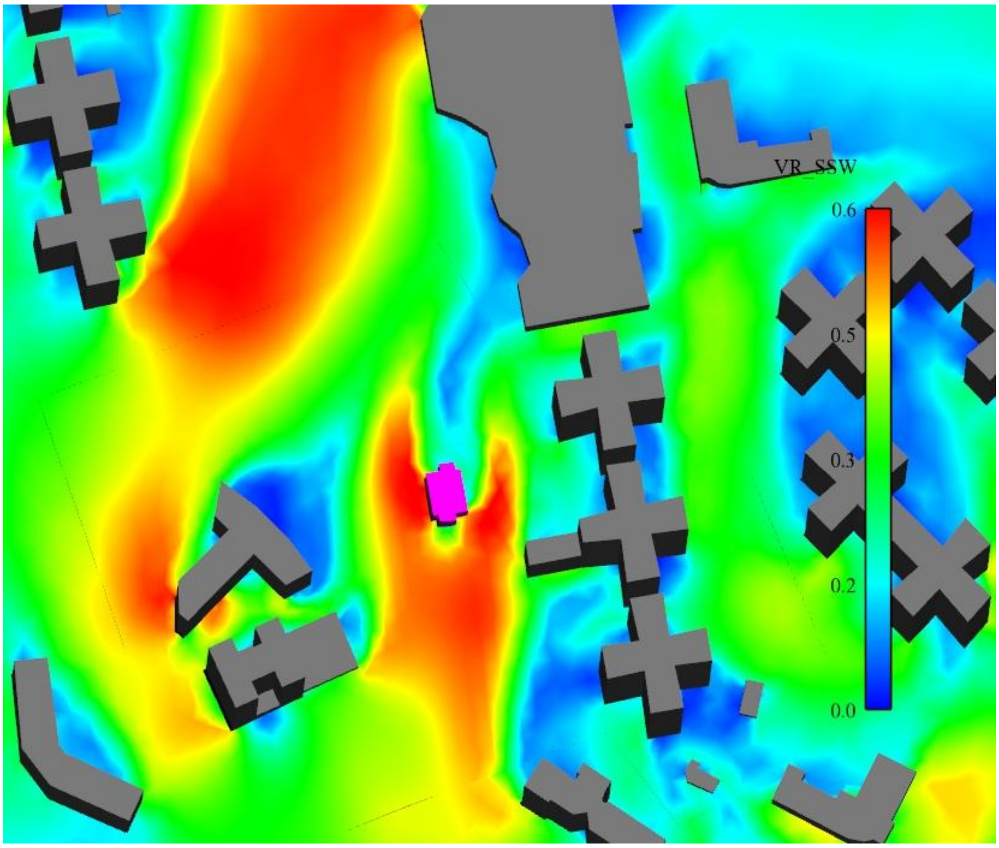


Figure A 7 Baseline Scheme (SSW wind)

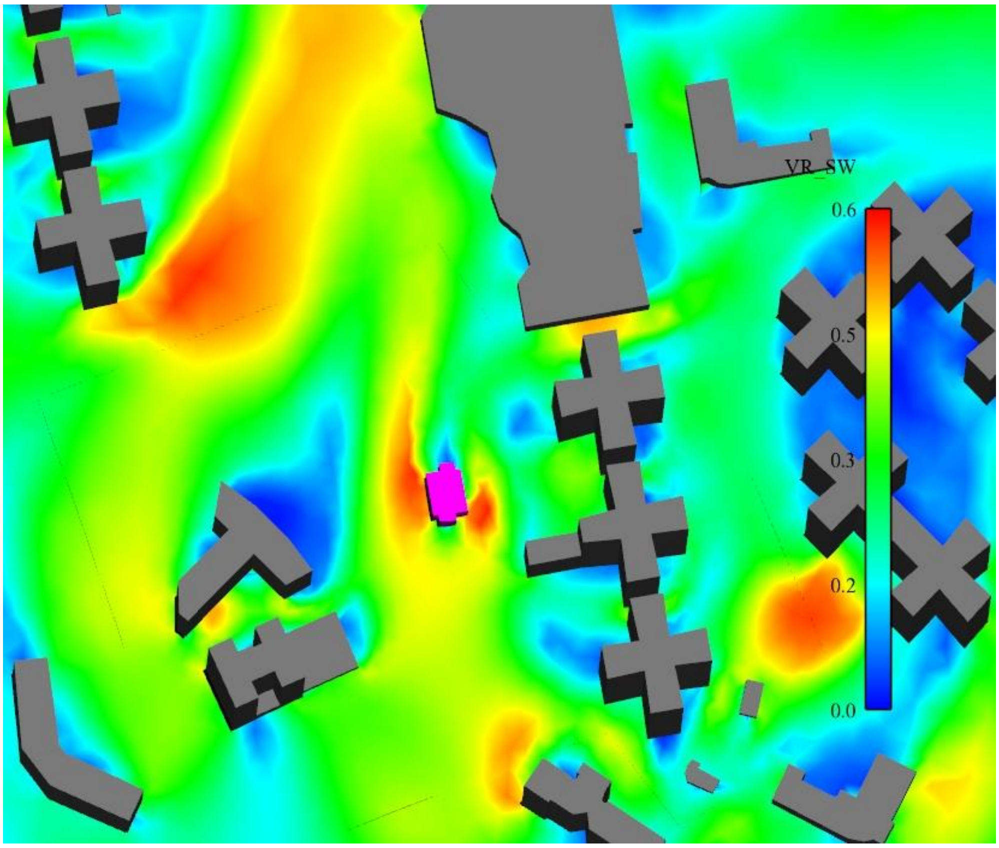


Figure A 8 Baseline Scheme (SW wind)

A2 VR contour map for proposed scheme

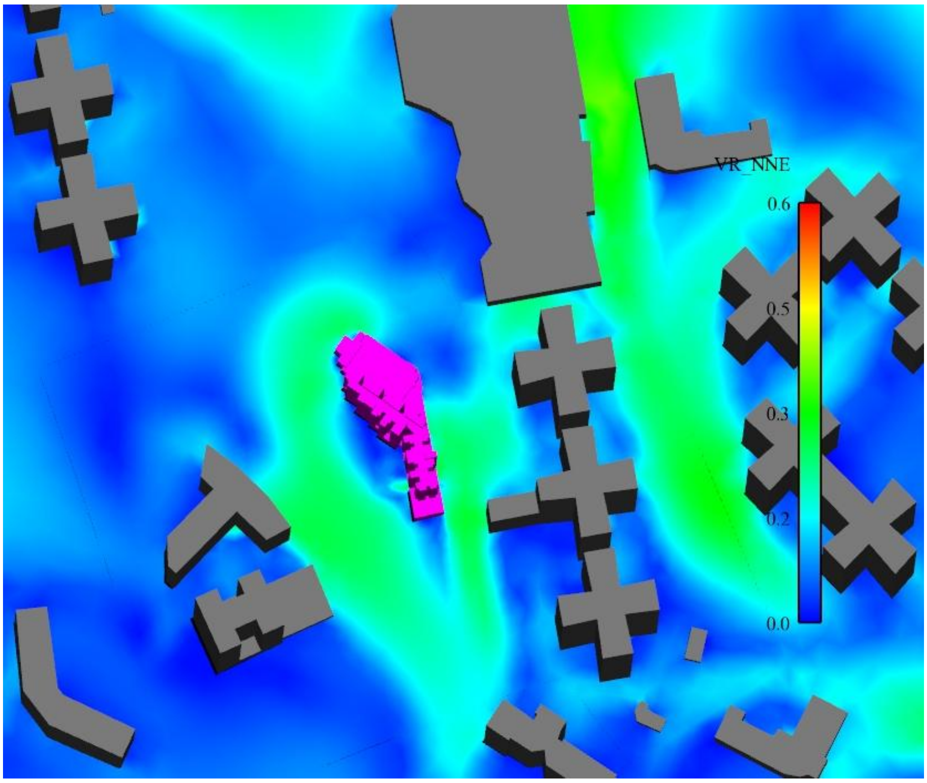


Figure A 9 Proposed Scheme (NNE wind)

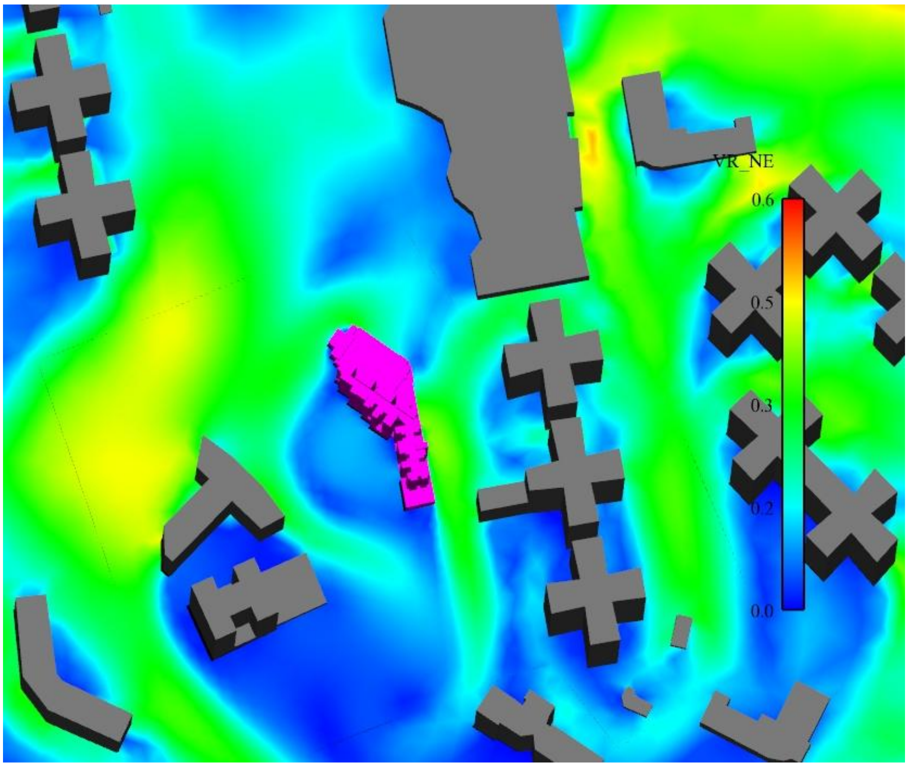


Figure A 10 Proposed Scheme (NE wind)

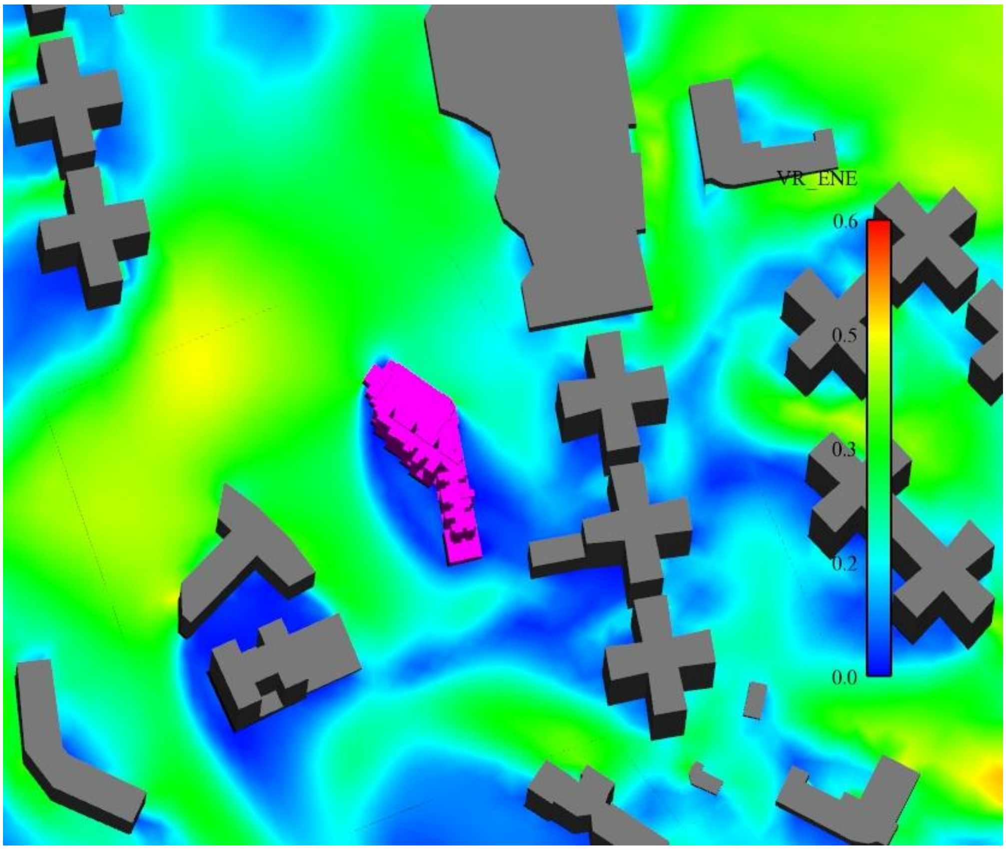


Figure A 11 Proposed Scheme (ENE wind)

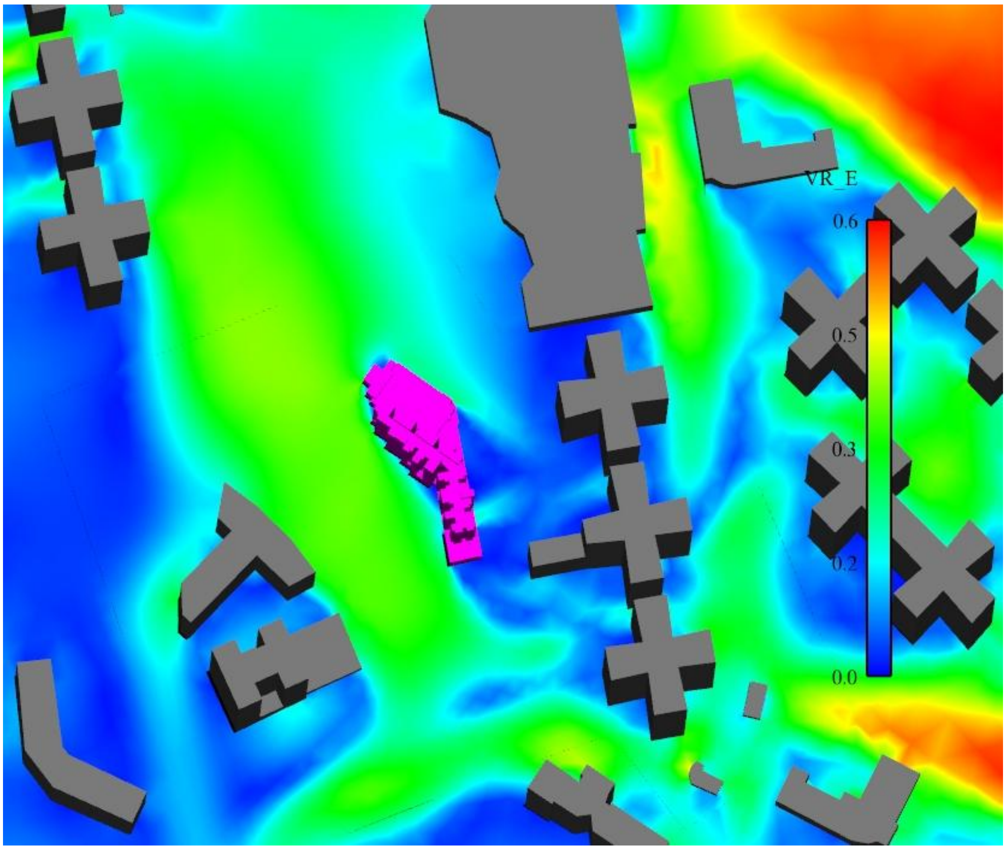


Figure A 12 Proposed Scheme (E wind)

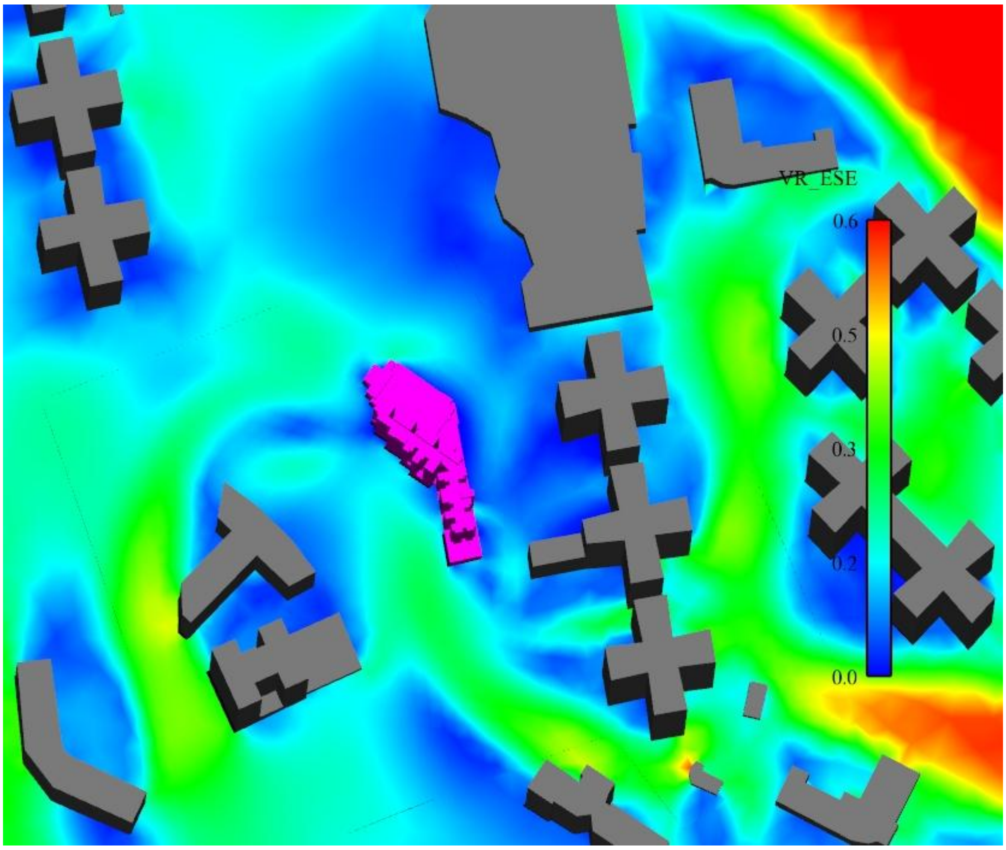


Figure A 13 Proposed Scheme (ESE wind)

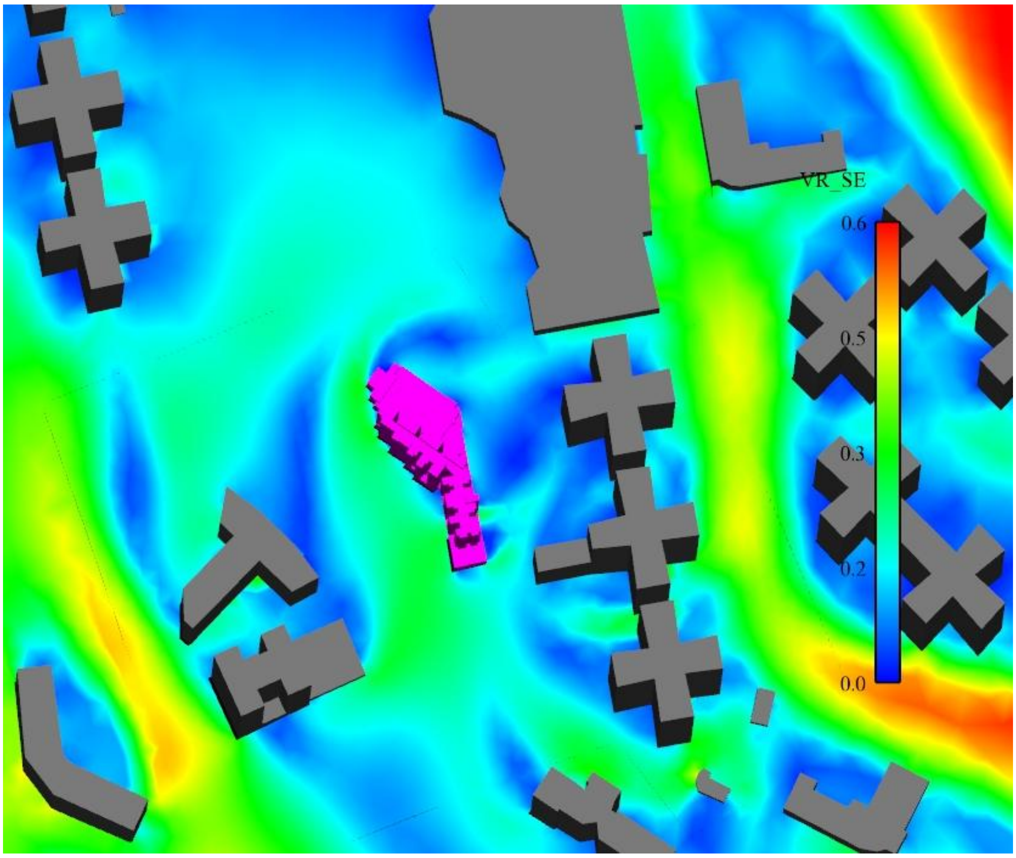


Figure A 14 Proposed Scheme (SE wind)

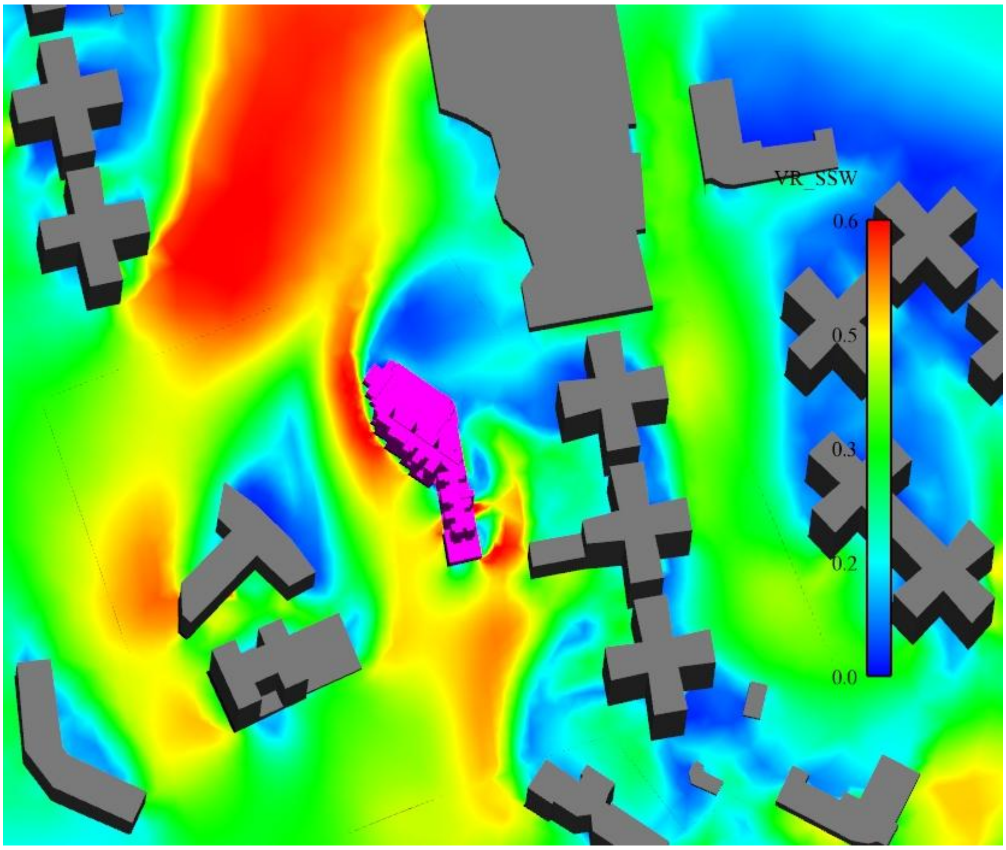


Figure A 15 Proposed Scheme (SSW wind)

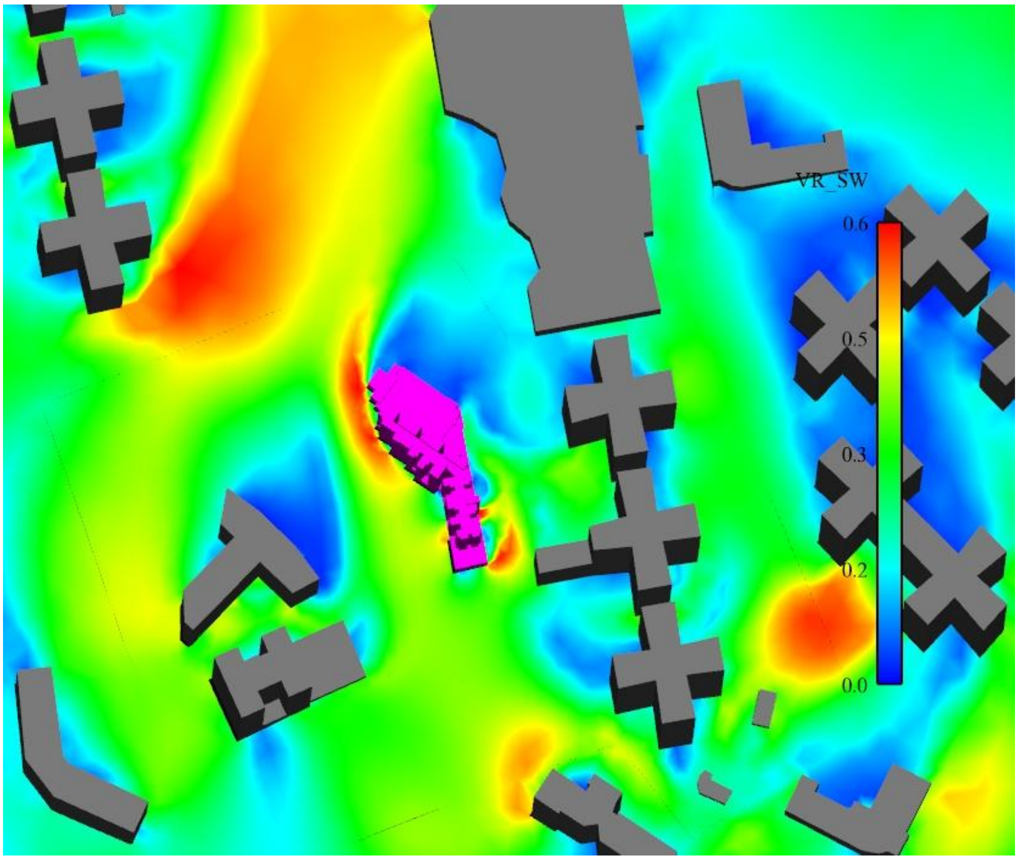


Figure A 16 Proposed Scheme (SW wind)

Appendix B

Directional Vector Plot

B1 VR vector plot for baseline scheme

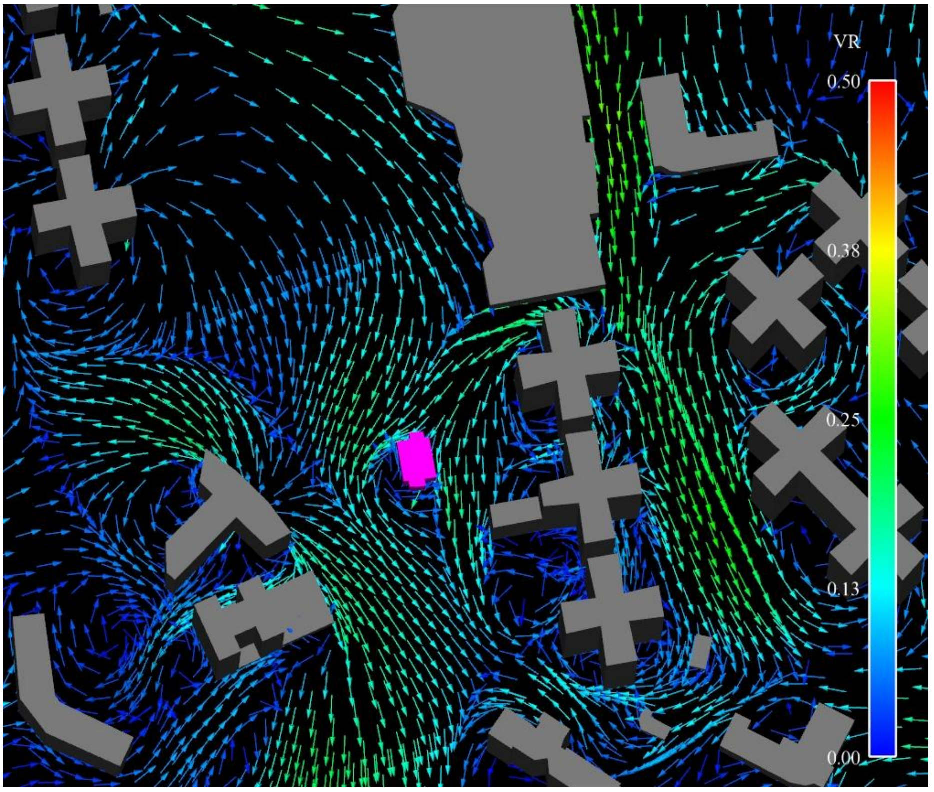


Figure B 1 Baseline Scheme (NNE wind)

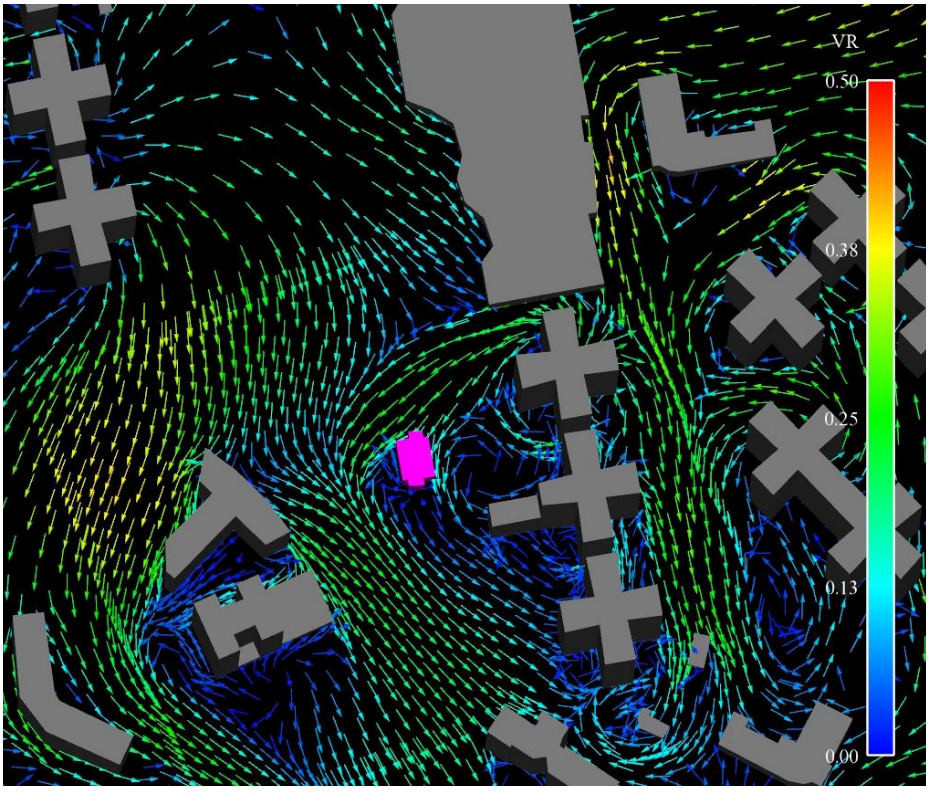


Figure B 2 Baseline Scheme (NE wind)

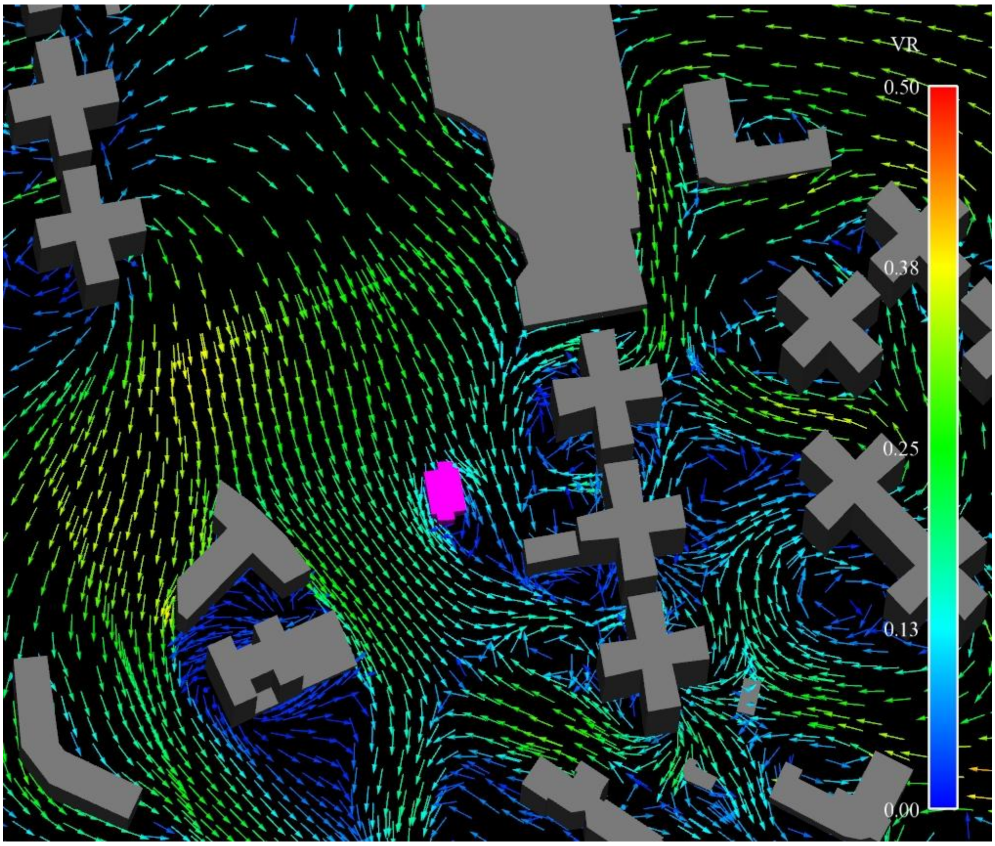


Figure B 3 Baseline Scheme (ENE wind)

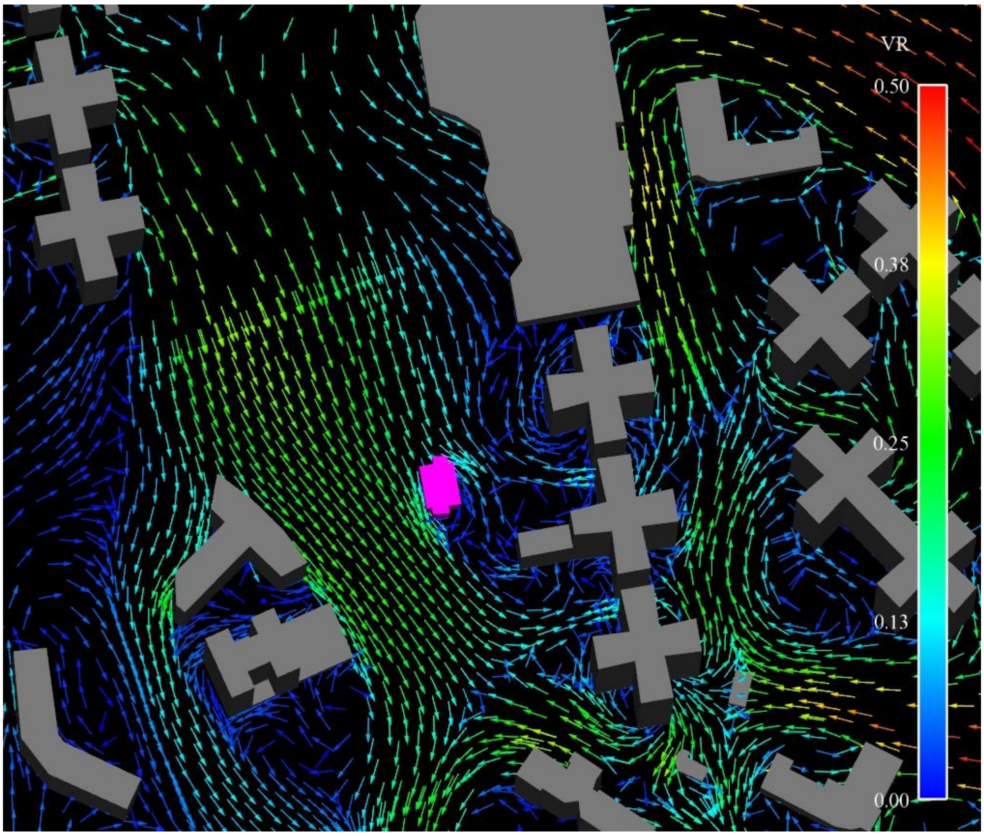


Figure B 4 Baseline Scheme (E wind)

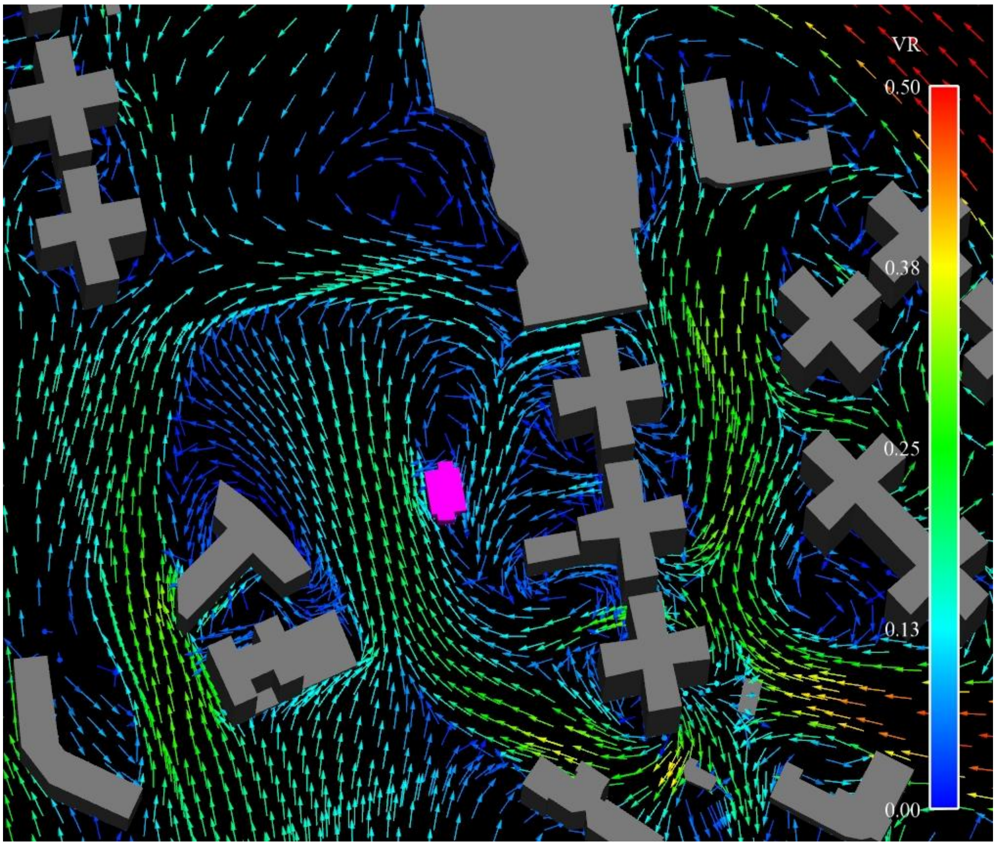


Figure B 5 Baseline Scheme (ESE wind)

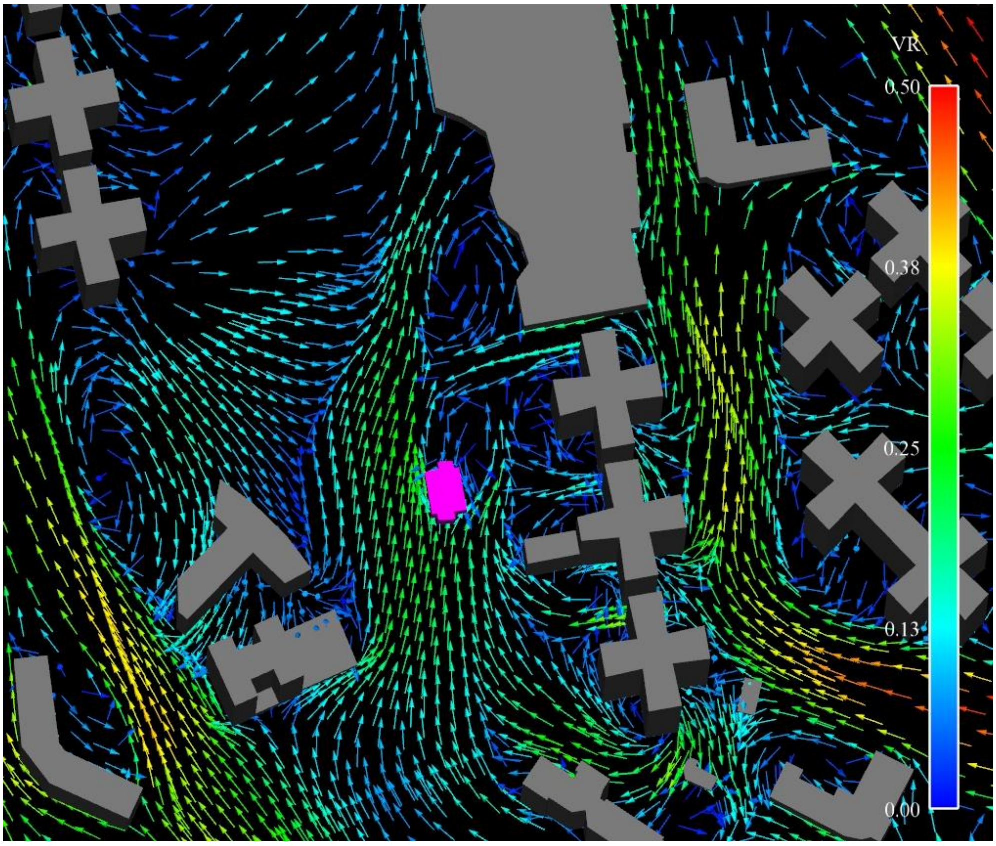


Figure B 6 Baseline Scheme (SE wind)

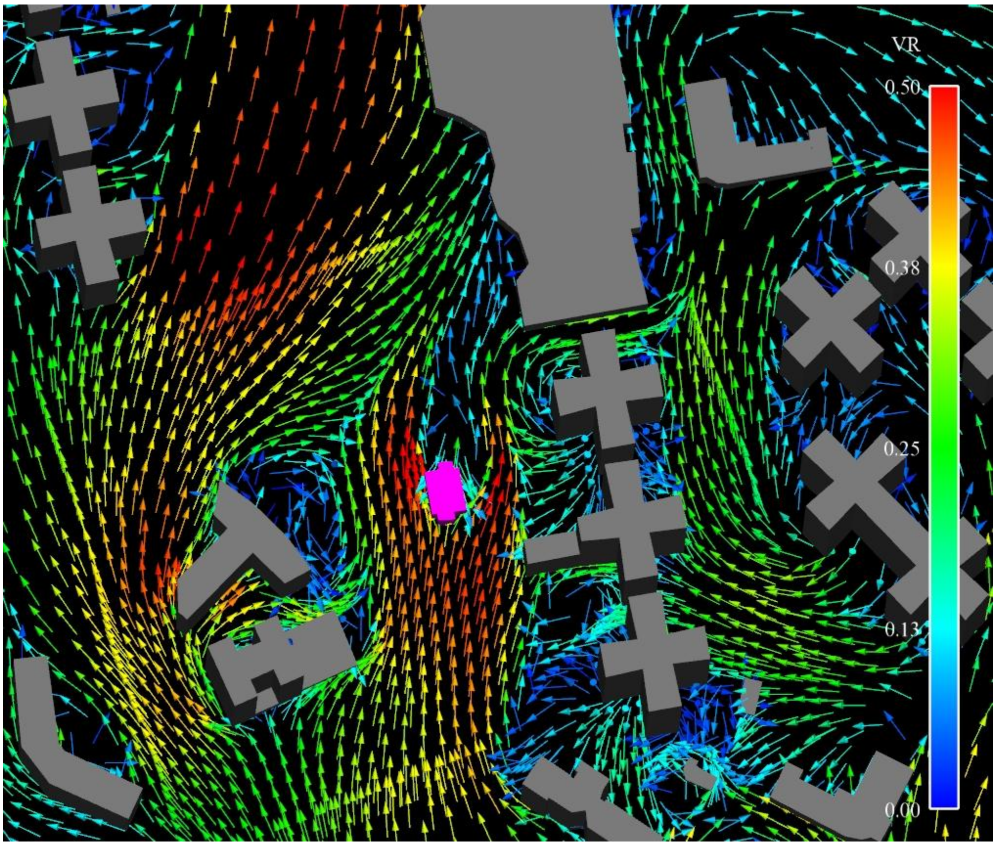


Figure B 7 Baseline Scheme (SSW wind)

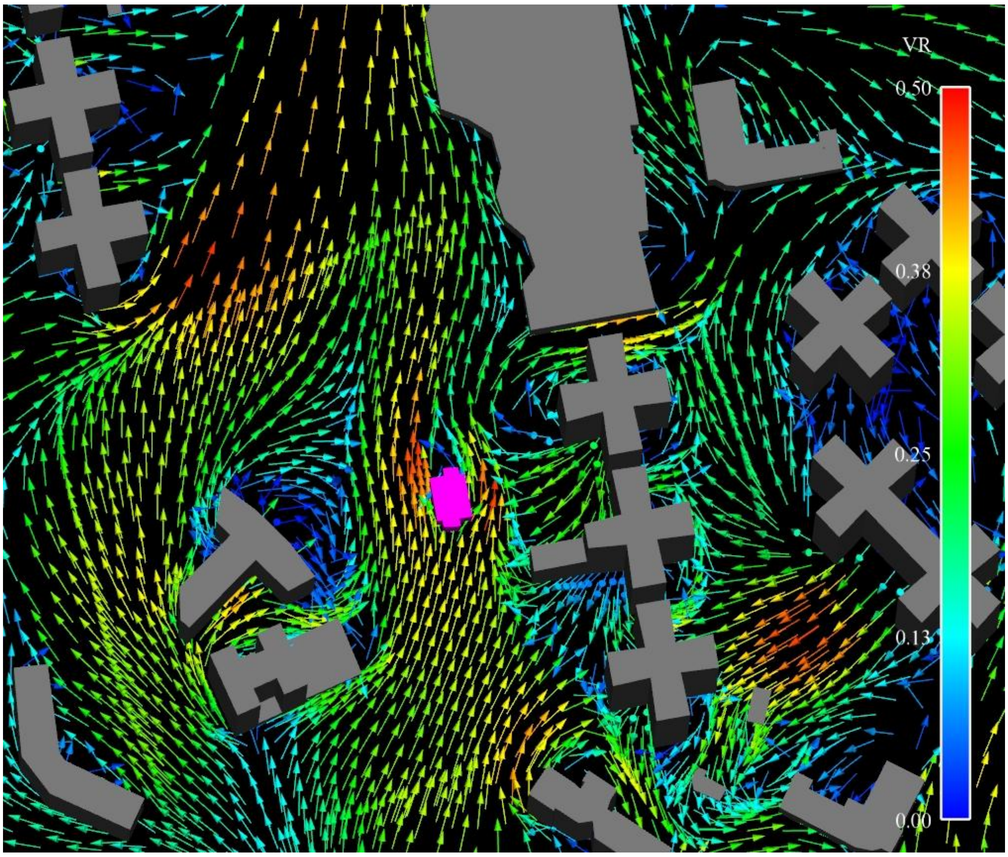


Figure B 8 Baseline Scheme (SW wind)

B2 VR vector plot for proposed scheme

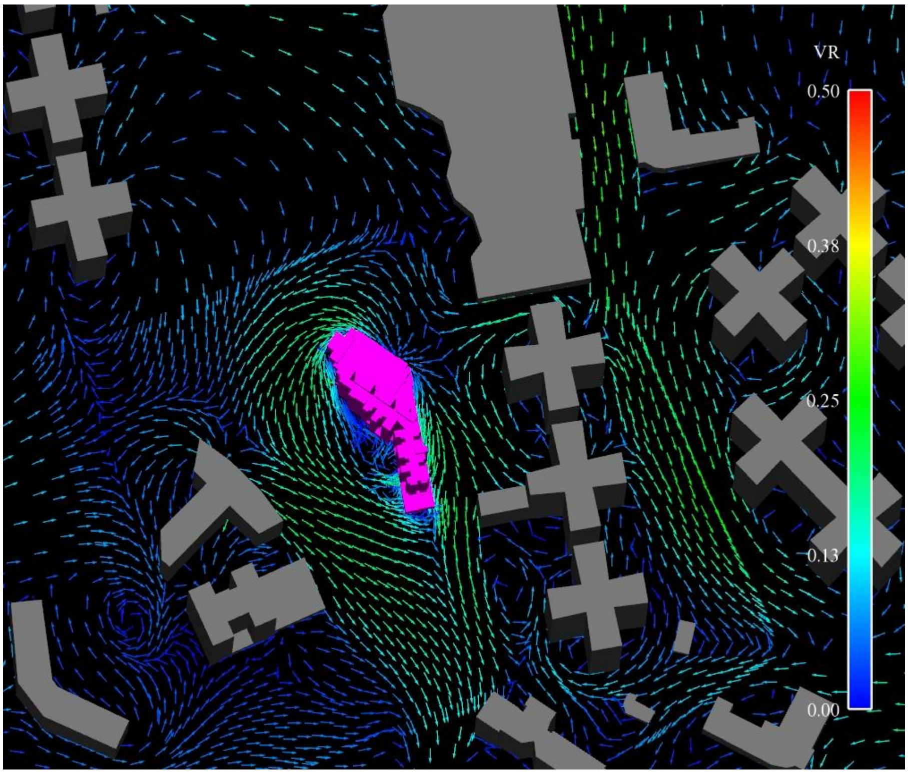


Figure B 9 Proposed Scheme (NNE wind)

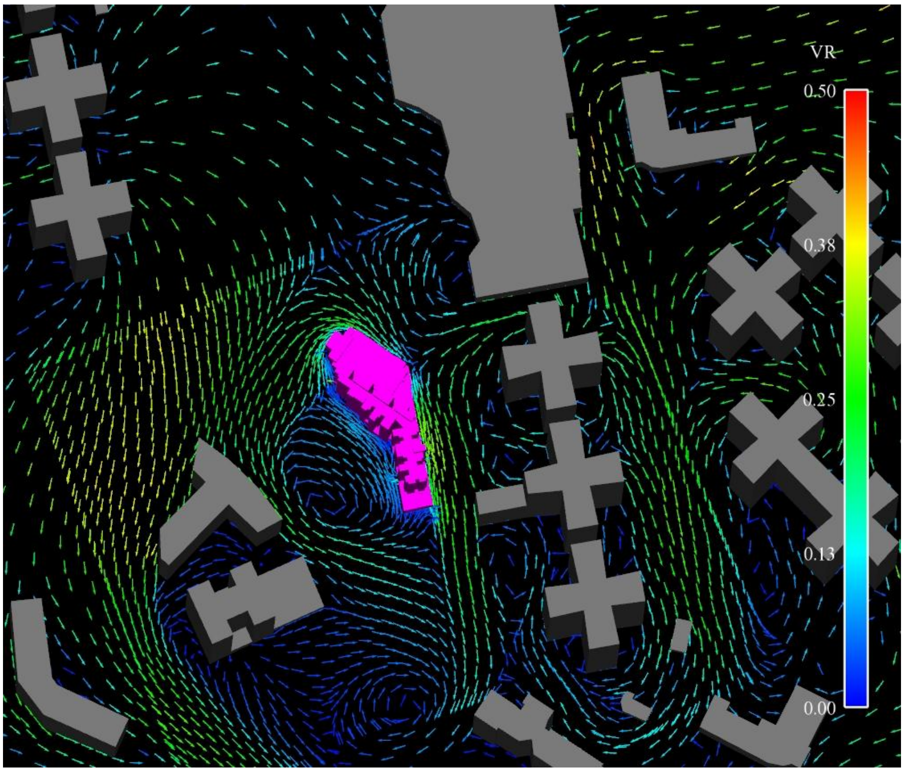


Figure B 10 Proposed Scheme (NE wind)

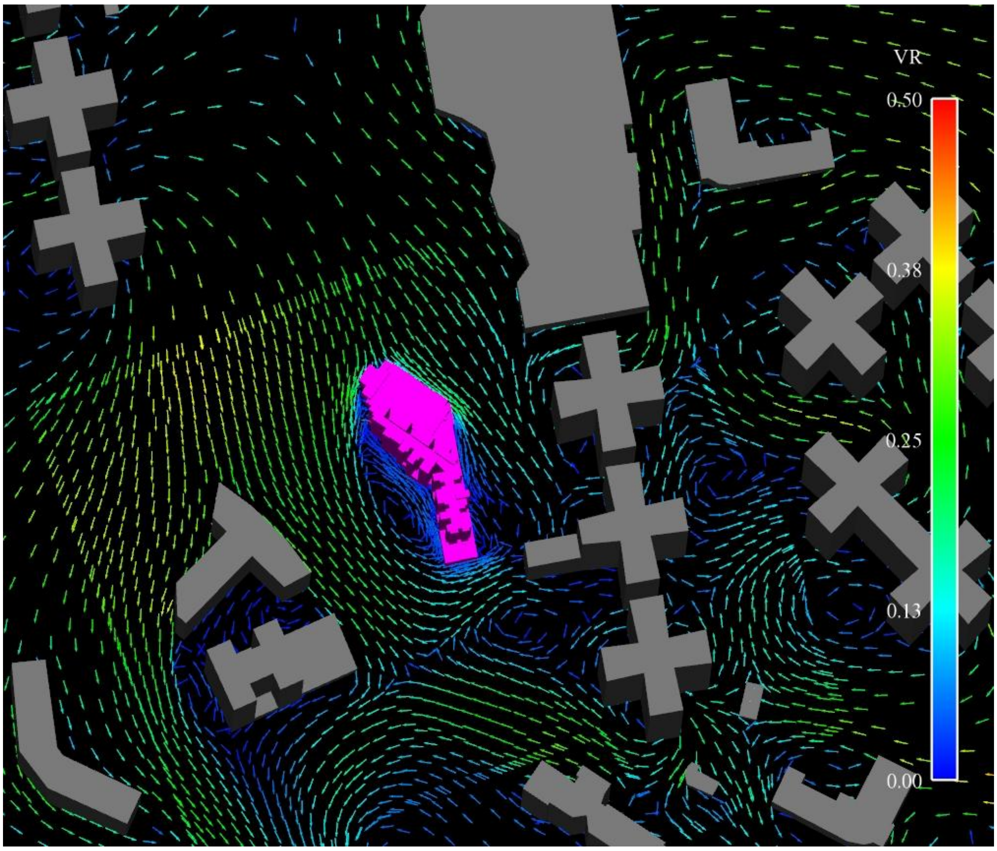


Figure B 11 Proposed Scheme (ENE wind)

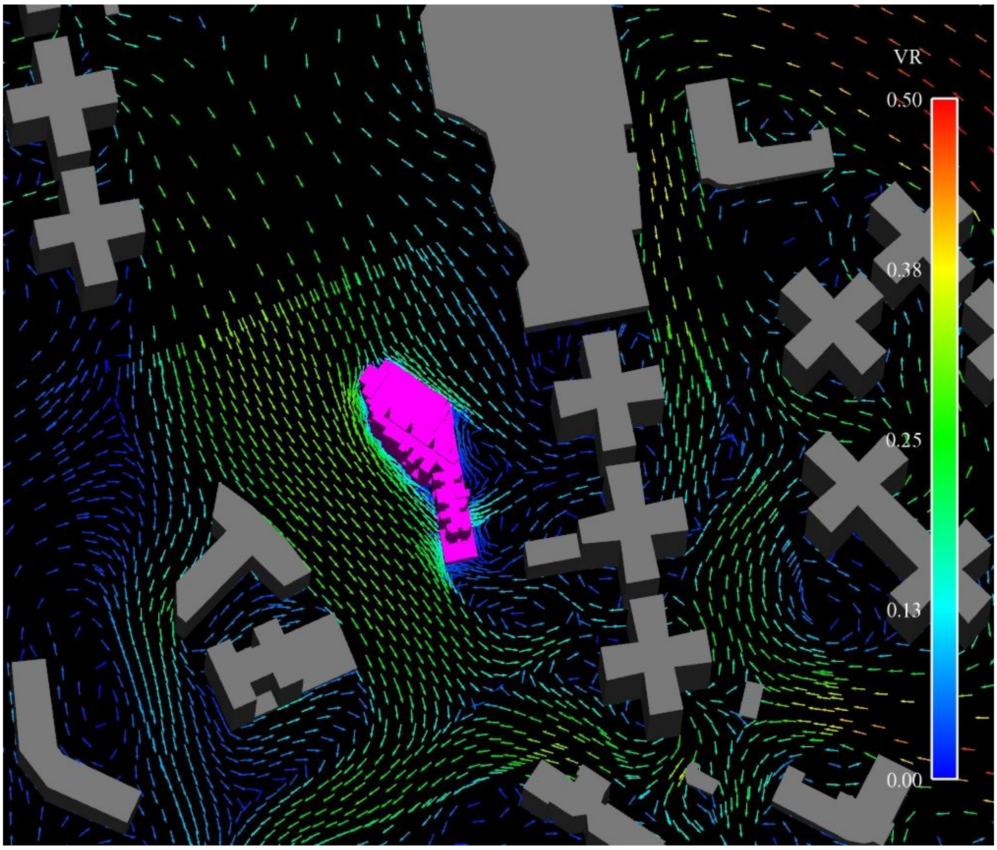


Figure B 12 Proposed Scheme (E wind)

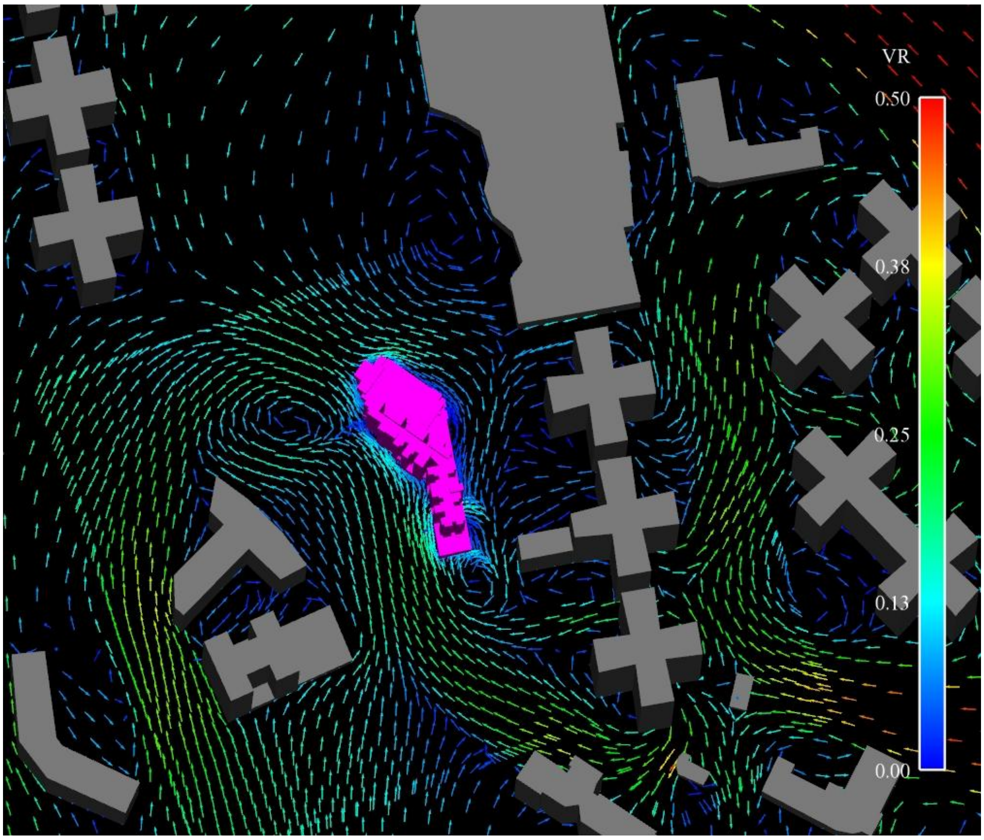


Figure B 13 Proposed Scheme (ESE wind)

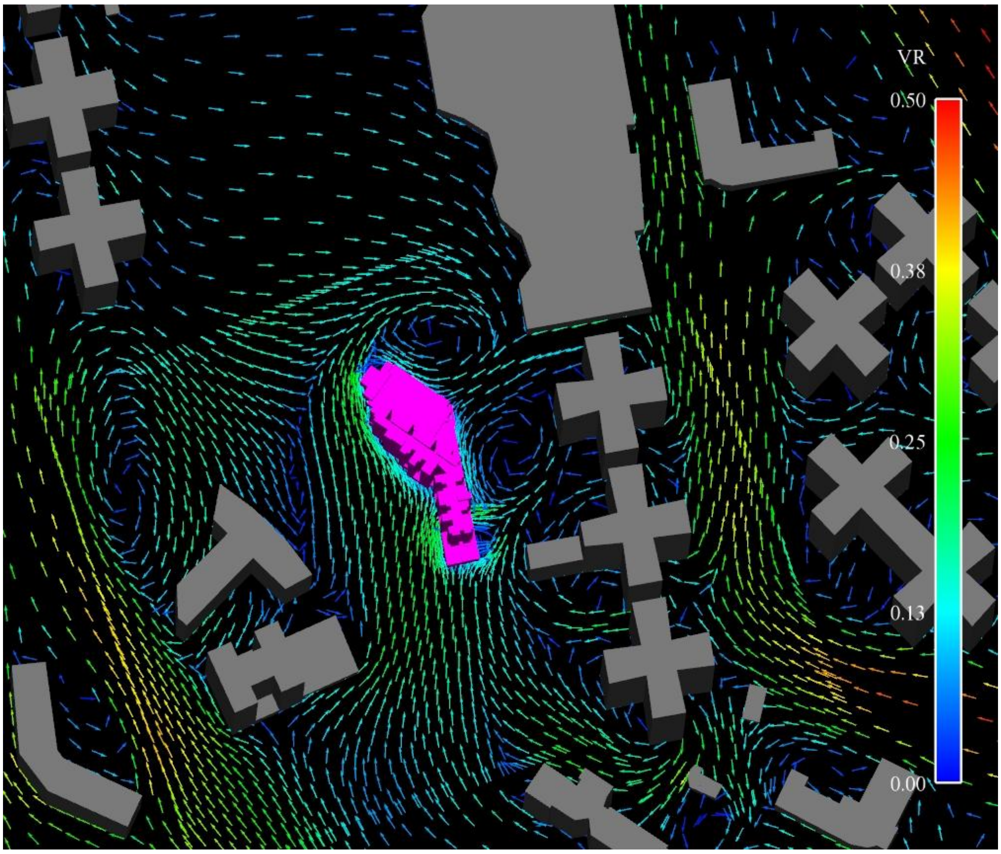


Figure B 14 Proposed Scheme (SE wind)

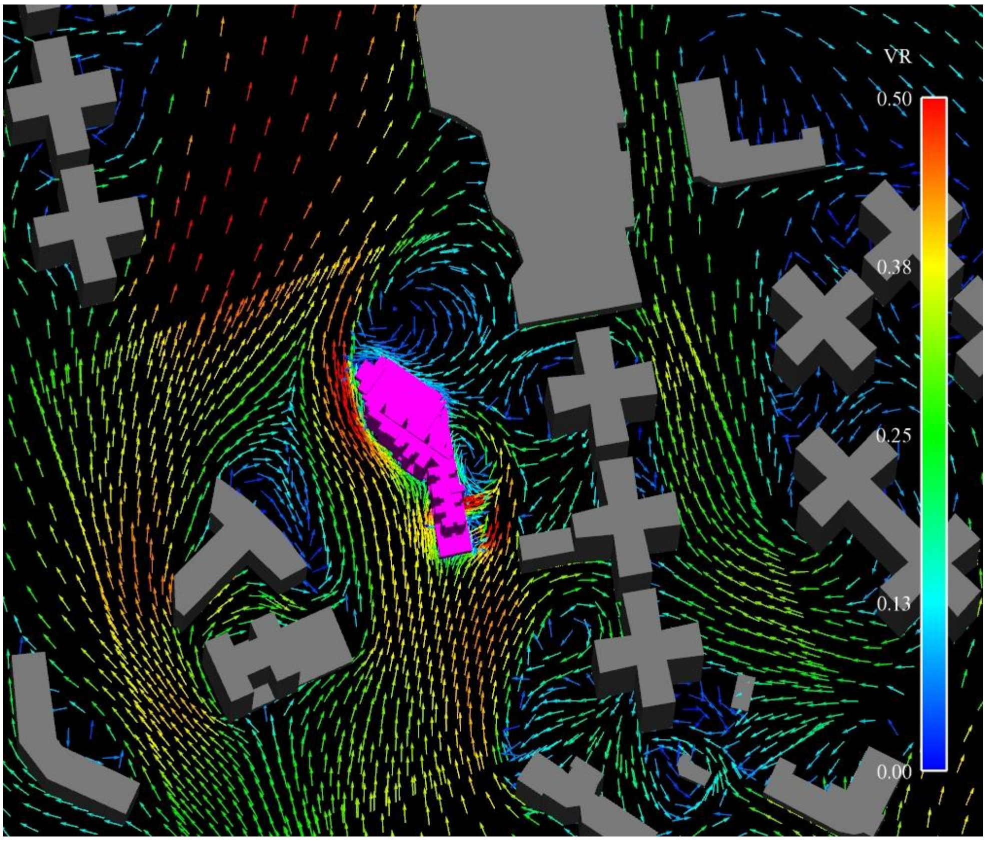


Figure B 15 Proposed Scheme (SSW wind)

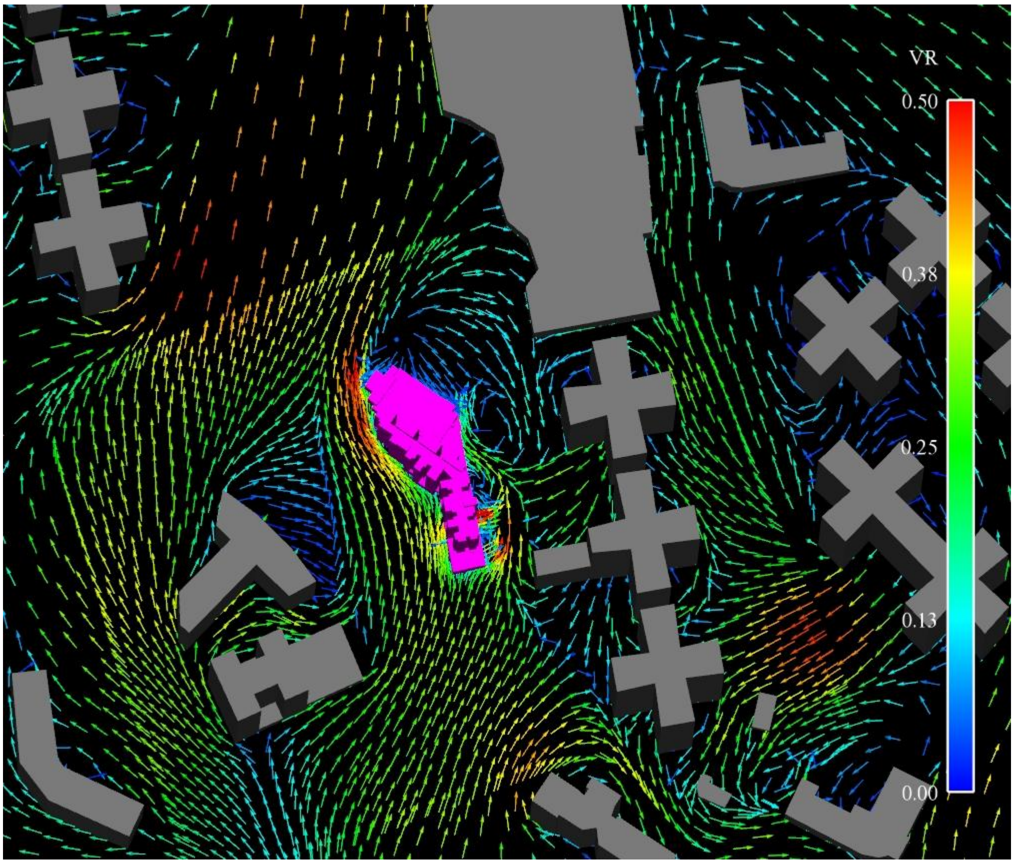


Figure B 16 Proposed Scheme (SW wind)

Appendix C

Velocity Ratio

C1 Baseline scheme

C1.1 Overall test point

	NNE	NE	ENE	E	ESE	SE	SW	SSW	Combine
Frequency	0.067	0.127	0.189	0.15	0.091	0.058	0.057	0.056	**0.795**
O1	0.14	0.12	0.04	0.04	0.05	0.09	0.35	0.33	**0.11**
O2	0.09	0.05	0.05	0.05	0.16	0.21	0.35	0.36	**0.12**
O3	0.20	0.28	0.34	0.24	0.03	0.15	0.28	0.42	**0.25**
O4	0.15	0.06	0.25	0.28	0.04	0.06	0.06	0.03	**0.15**
O5	0.12	0.20	0.28	0.32	0.10	0.08	0.06	0.07	**0.20**
O6	0.19	0.28	0.28	0.32	0.16	0.09	0.29	0.28	**0.25**
O7	0.21	0.27	0.25	0.29	0.21	0.22	0.30	0.40	**0.26**
O8	0.19	0.20	0.19	0.22	0.10	0.17	0.35	0.40	**0.21**
O9	0.09	0.21	0.29	0.26	0.16	0.09	0.42	0.52	**0.25**
O10	0.08	0.22	0.32	0.30	0.14	0.09	0.34	0.45	**0.25**
O11	0.11	0.15	0.29	0.15	0.16	0.21	0.40	0.31	**0.21**
O12	0.13	0.13	0.29	0.17	0.16	0.21	0.40	0.30	**0.22**
O13	0.12	0.18	0.30	0.12	0.03	0.18	0.39	0.34	**0.20**
O14	0.06	0.07	0.18	0.05	0.03	0.08	0.16	0.07	**0.09**
O15	0.11	0.06	0.21	0.09	0.12	0.08	0.20	0.08	**0.13**
O16	0.15	0.09	0.16	0.08	0.05	0.16	0.30	0.49	**0.15**
O17	0.11	0.14	0.17	0.17	0.12	0.13	0.23	0.29	**0.16**
O18	0.08	0.16	0.24	0.13	0.16	0.17	0.32	0.06	**0.17**
O19	0.17	0.20	0.16	0.06	0.13	0.05	0.13	0.25	**0.14**
O20	0.17	0.19	0.13	0.04	0.09	0.10	0.31	0.22	**0.14**
O21	0.14	0.08	0.12	0.06	0.09	0.12	0.25	0.40	**0.13**
O22	0.04	0.09	0.07	0.04	0.04	0.05	0.35	0.20	**0.09**
O23	0.07	0.08	0.09	0.04	0.04	0.06	0.19	0.15	**0.08**
O24	0.06	0.04	0.09	0.03	0.01	0.04	0.23	0.12	**0.07**
O25	0.03	0.04	0.04	0.06	0.05	0.11	0.18	0.14	**0.07**
O26	0.06	0.09	0.10	0.11	0.11	0.07	0.10	0.11	**0.10**
O27	0.05	0.04	0.08	0.10	0.23	0.23	0.20	0.18	**0.12**

C1.2 Perimeter test point

	NNE	NE	ENE	E	ESE	SE	SW	SSW	Combine
Frequency	0.067	0.127	0.189	0.15	0.091	0.058	0.057	0.056	**0.795**
P1	0.13	0.20	0.32	0.29	0.12	0.16	0.26	0.31	**0.24**
P2	0.15	0.15	0.31	0.23	0.09	0.22	0.37	0.31	**0.23**
P3	0.17	0.09	0.28	0.19	0.08	0.18	0.44	0.37	**0.21**
P4	0.15	0.16	0.24	0.15	0.06	0.06	0.27	0.09	**0.16**
P5	0.16	0.28	0.20	0.11	0.08	0.08	0.26	0.15	**0.17**
P6	0.17	0.23	0.18	0.10	0.11	0.06	0.31	0.21	**0.17**
P7	0.15	0.15	0.18	0.11	0.12	0.07	0.42	0.28	**0.17**
P8	0.20	0.12	0.12	0.08	0.12	0.18	0.55	0.52	**0.18**
P9	0.22	0.10	0.04	0.03	0.10	0.22	0.50	0.61	**0.16**
P10	0.20	0.08	0.04	0.03	0.08	0.18	0.41	0.55	**0.13**
P11	0.09	0.05	0.15	0.17	0.11	0.24	0.44	0.54	**0.18**
P12	0.12	0.11	0.19	0.27	0.20	0.26	0.43	0.51	**0.23**
P13	0.06	0.03	0.20	0.26	0.21	0.25	0.45	0.51	**0.22**
P14	0.11	0.13	0.20	0.25	0.23	0.30	0.54	0.60	**0.25**
P15	0.20	0.23	0.22	0.27	0.23	0.29	0.48	0.55	**0.28**

C2 Proposed scheme

C2.1 Overall test point

	NNE	NE	ENE	E	ESE	SE	SW	SSW	Combine
Frequency	0.067	0.127	0.189	0.15	0.091	0.058	0.057	0.056	**0.795**
O1	0.06	0.02	0.04	0.09	0.07	0.10	0.34	0.32	**0.10**
O2	0.05	0.05	0.09	0.09	0.17	0.22	0.34	0.36	**0.14**
O3	0.08	0.34	0.36	0.24	0.12	0.18	0.23	0.31	**0.26**
O4	0.09	0.22	0.27	0.30	0.17	0.09	0.09	0.05	**0.20**
O5	0.23	0.23	0.30	0.35	0.07	0.11	0.05	0.07	**0.22**
O6	0.26	0.21	0.28	0.34	0.10	0.10	0.25	0.22	**0.24**
O7	0.21	0.15	0.22	0.30	0.19	0.23	0.27	0.34	**0.23**
O8	0.11	0.07	0.17	0.21	0.11	0.17	0.32	0.37	**0.18**
O9	0.07	0.18	0.29	0.29	0.10	0.18	0.43	0.50	**0.25**
O10	0.13	0.16	0.32	0.32	0.14	0.17	0.41	0.47	**0.26**
O11	0.07	0.08	0.27	0.18	0.07	0.16	0.18	0.18	**0.16**
O12	0.11	0.15	0.26	0.19	0.11	0.18	0.06	0.04	**0.16**
O13	0.07	0.10	0.29	0.15	0.04	0.16	0.30	0.35	**0.18**
O14	0.04	0.06	0.16	0.07	0.04	0.09	0.13	0.16	**0.09**
O15	0.11	0.13	0.18	0.13	0.11	0.11	0.10	0.11	**0.13**
O16	0.25	0.31	0.11	0.08	0.11	0.14	0.26	0.48	**0.19**
O17	0.22	0.26	0.09	0.20	0.13	0.11	0.22	0.42	**0.19**
O18	0.17	0.12	0.20	0.15	0.16	0.16	0.31	0.13	**0.17**
O19	0.14	0.24	0.18	0.07	0.09	0.05	0.19	0.08	**0.14**
O20	0.21	0.25	0.14	0.04	0.09	0.10	0.11	0.09	**0.13**
O21	0.20	0.20	0.14	0.05	0.04	0.05	0.28	0.38	**0.15**
O22	0.07	0.10	0.05	0.04	0.03	0.05	0.35	0.22	**0.09**
O23	0.11	0.15	0.06	0.06	0.06	0.07	0.20	0.22	**0.10**
O24	0.10	0.09	0.07	0.02	0.01	0.03	0.19	0.14	**0.07**
O25	0.04	0.07	0.04	0.09	0.06	0.10	0.16	0.31	**0.09**
O26	0.05	0.09	0.07	0.11	0.09	0.07	0.10	0.18	**0.09**
O27	0.04	0.09	0.14	0.12	0.24	0.21	0.19	0.22	**0.14**

C2.2 Perimeter test point

	NNE	NE	ENE	E	ESE	SE	SW	SSW	Combine
Frequency	0.067	0.127	0.189	0.15	0.091	0.058	0.057	0.056	**0.795**
P1	0.24	0.26	0.25	0.24	0.13	0.23	0.42	0.33	**0.25**
P2	0.21	0.26	0.21	0.20	0.17	0.07	0.08	0.07	**0.18**
P3	0.13	0.21	0.22	0.21	0.14	0.13	0.07	0.09	**0.17**
P4	0.07	0.14	0.21	0.20	0.07	0.13	0.06	0.14	**0.15**
P5	0.07	0.07	0.22	0.19	0.05	0.09	0.15	0.12	**0.14**
P6	0.13	0.26	0.13	0.05	0.06	0.10	0.21	0.23	**0.14**
P7	0.21	0.34	0.06	0.04	0.07	0.09	0.32	0.09	**0.14**
P8	0.25	0.37	0.03	0.11	0.07	0.12	0.39	0.37	**0.18**
P9	0.23	0.34	0.05	0.05	0.07	0.06	0.33	0.23	**0.15**
P10	0.27	0.33	0.04	0.02	0.09	0.21	0.54	0.61	**0.20**
P11	0.04	0.03	0.05	0.05	0.10	0.10	0.17	0.21	**0.07**
P12	0.17	0.07	0.07	0.28	0.22	0.26	0.37	0.42	**0.19**
P13	0.14	0.10	0.04	0.25	0.19	0.26	0.42	0.46	**0.19**
P14	0.04	0.13	0.04	0.28	0.14	0.19	0.37	0.39	**0.17**
P15	0.08	0.12	0.04	0.31	0.14	0.20	0.45	0.48	**0.19**