Hong Kong Housing Authority

Tuen Mun Area 54 Site 2 Phase 1 & 2

Air Ventilation Assessment - Initial Study

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ARUP

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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 Tuen Mun Area 54 Site 2 Phases 1 & 2.

1.2 Objective of the Study

The objective of the study is to investigate the air ventilation performance of the proposed developments using the methodology for Air Ventilation Assessment (AVA) 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 AVA study is to compare the wind performance of two schemes:

1. **Baseline Scheme** – Reference scheme with five residential housing blocks and a commercial centre fulfilling the Building Department's PNAP APP-152 guidelines.

2. **Proposed Scheme** – it consists of the five residential housing blocks and commercial centre with wind enhancement features.

The deliverables of this study can be summarised as follows:

- Evaluation of the wind microclimate to determine the typical wind characteristics of the site;
- Identification of the air ventilation performance of the Development and surrounding area for different schemes;
- Assessment of air ventilation performance at focus areas; and
- Identification of good design features and obvious problem areas and proposal of relevant mitigation measures.

2 Background Information

2.1 Site and Surrounding Area Characteristics

Tuen Mun Area 54 Site 2 is located in a relatively low-density urban area just west of Yuen Long Highway within a kilometre of the Siu Hong MTR Station on the West Rail line. The significant nearby development is the extensive Siu Hong Court to the east and southeast, which includes 20 high-rises, the tallest of which exceed 100 mPD. A future development of five high-rises is also being planned southwest of the site, and was modelled in this study. There are also pockets of low-rise constructions such as village houses in Tsz Tin Tsuen. To the northwest of the site is a mountainous region and to the southeast open undeveloped area. The immediate topography surrounding the site however is mainly flat, with moderate urban development.

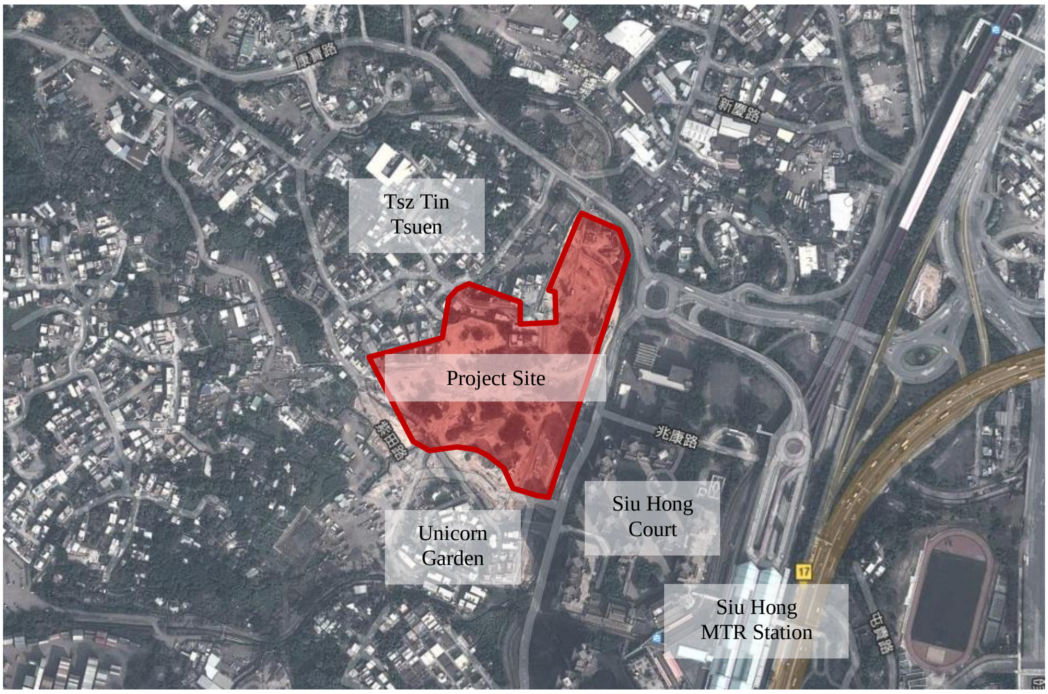


Figure 1 Location of the Project Site and Surrounding Development

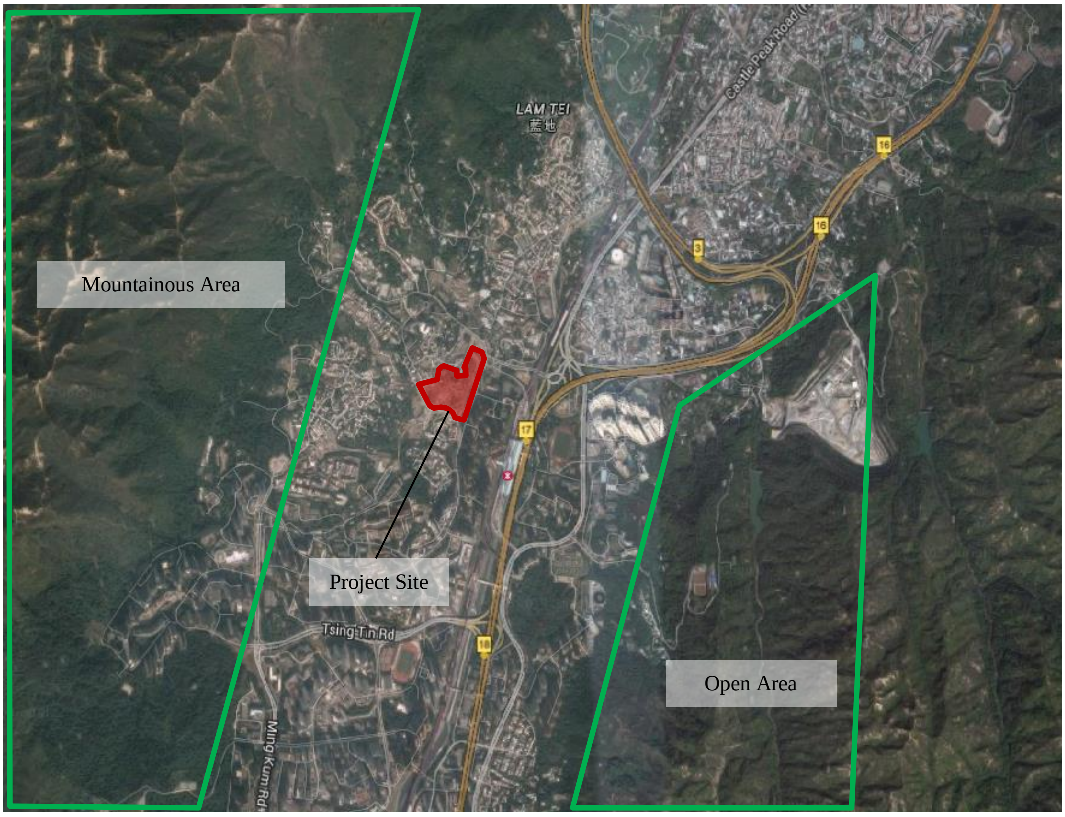


Figure 2 Location of Study Area and Surrounding Topography

2.2 Studied Scenarios

Two cases were investigated in the AVA study: the Baseline Scheme and the Proposed Scheme.

2.2.1 Baseline Scheme

This is a reference scheme with five residential housing blocks, a commercial centre, several one storey commercial buildings and a car park. Reference scheme with five residential housing blocks and a commercial centre fulfilling the Building Department's PNAP APP-152 guidelines. The building heights of the residential housing blocks range approximately between 106mPD and 120mPD. There are two wind corridors designed in Baseline Scheme, with width of around 14m and 24m respectively.

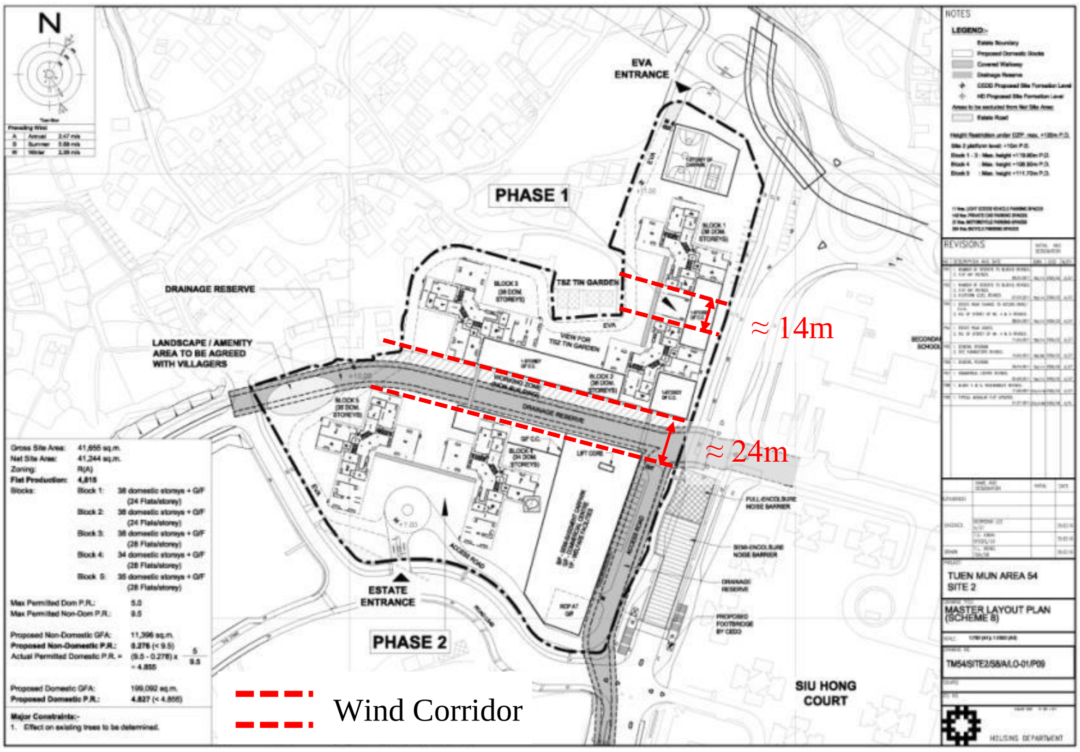


Figure 3 Master Layout Plan for Baseline Scheme

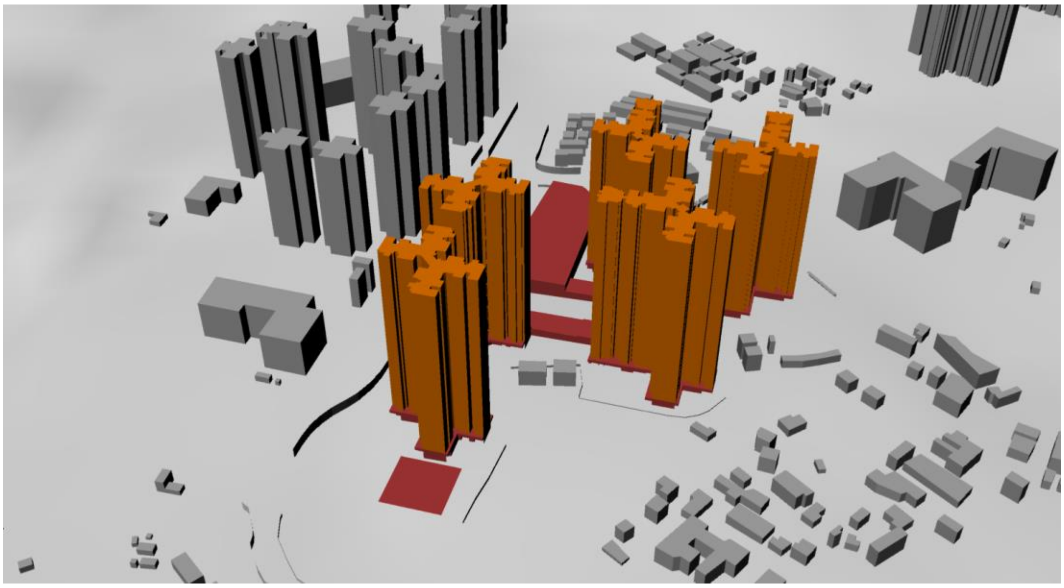


Figure 4 Baseline Scheme at Northerly View

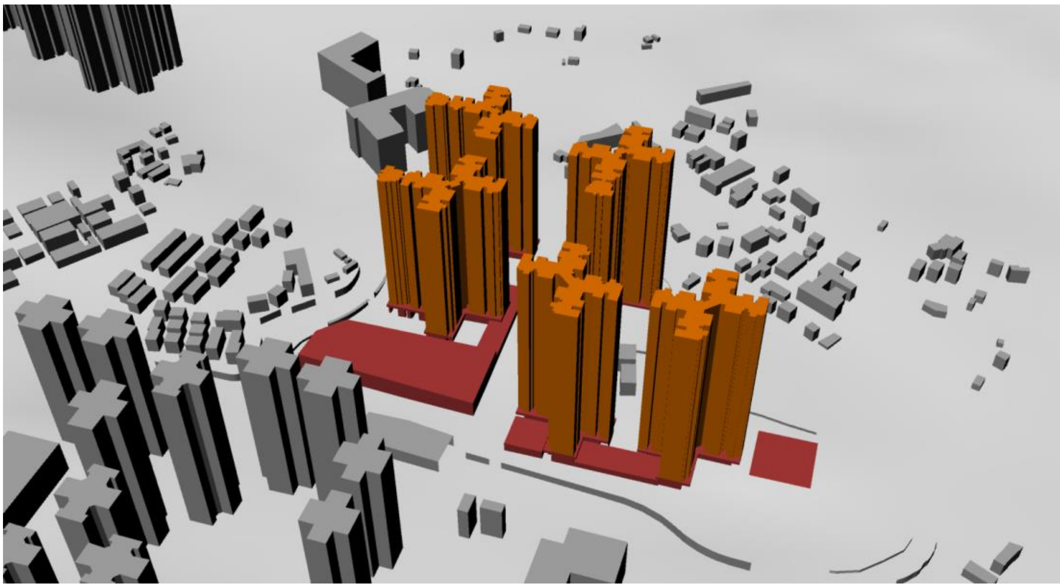


Figure 5 Baseline Scheme at Easterly View

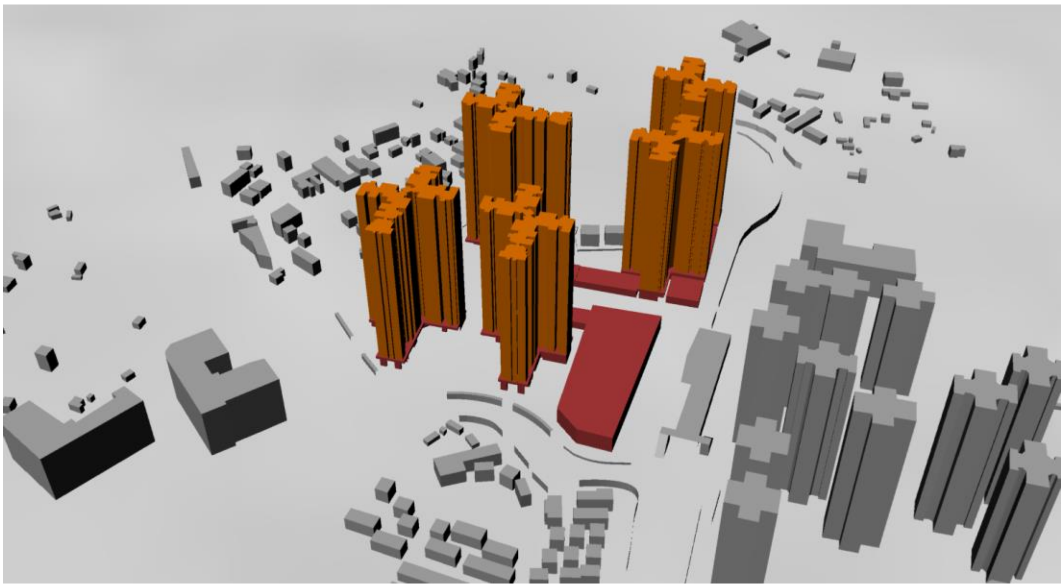


Figure 6 Baseline Scheme at Southerly View

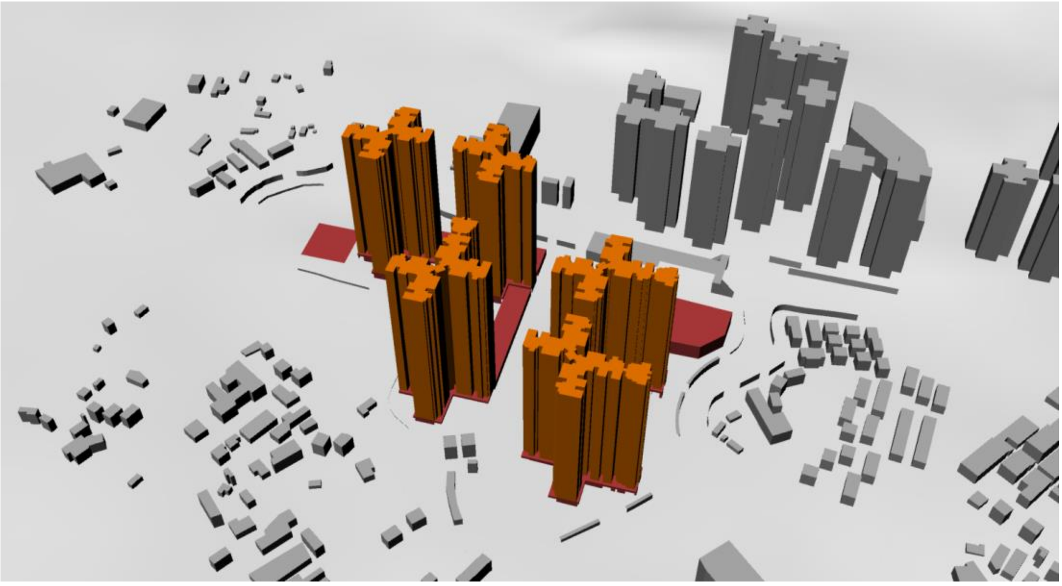


Figure 7 Baseline Scheme at Westerly View

2.2.2 Proposed Scheme

Similar to the Baseline Scheme, the Proposed Scheme also consists of five residential housing blocks with the building height ranging from around 106 mPD to around 120 mPD, while retails are located at the center of the site. Two wind corridors have been also implemented in the Proposed Scheme. The width of the wind corridor between Blocks 1 and 2 are wider (around 24m) as compared to the Baseline Scheme, hence it could facilitate the wind penetration to the leeward regions. For the wind corridor between Blocks 2 and 4, the minimum width is similar to the Baseline Scheme. The ground floor empty bay at Block 1 would further increase the width of the wind corridor at ground level, thus would further enhance the wind permeability.

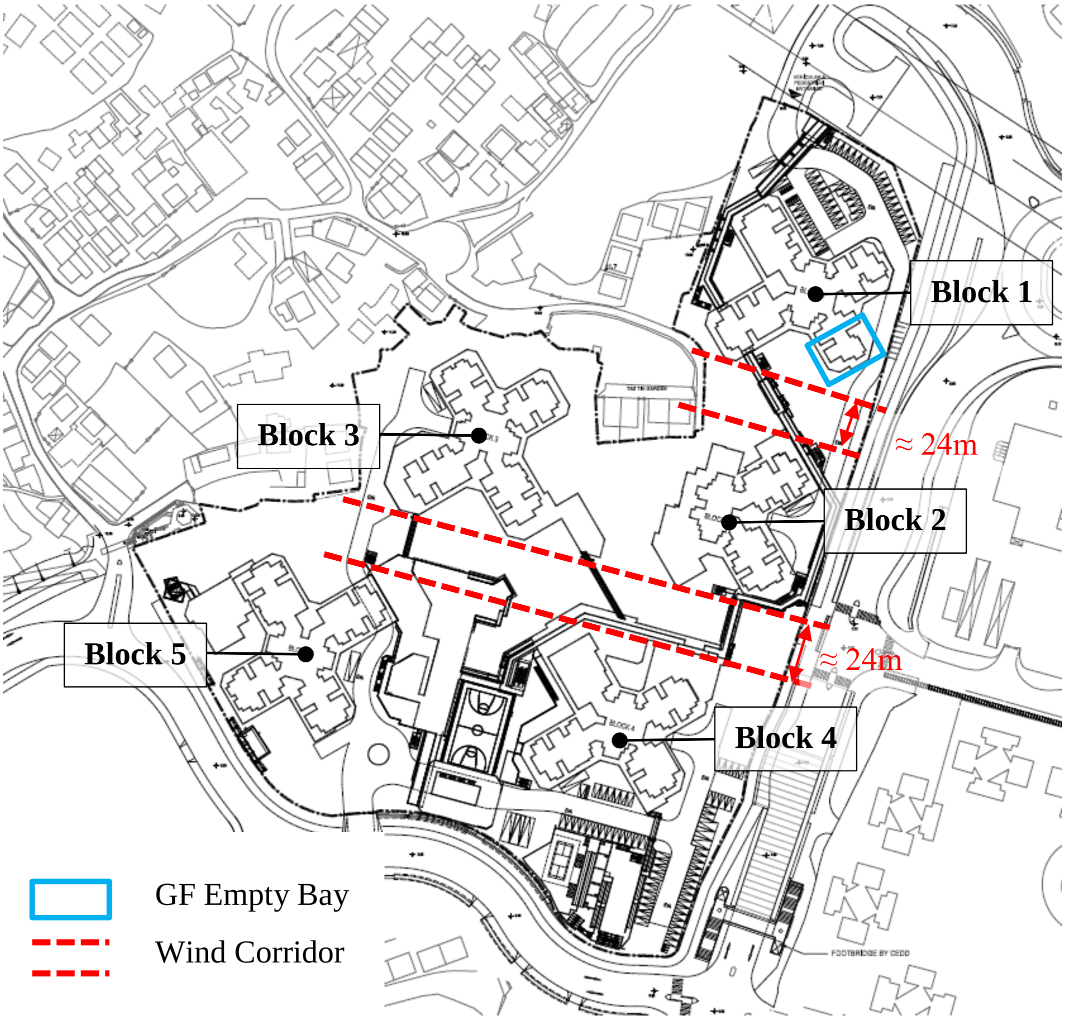


Figure 8 Master Layout Plan for Proposed Scheme

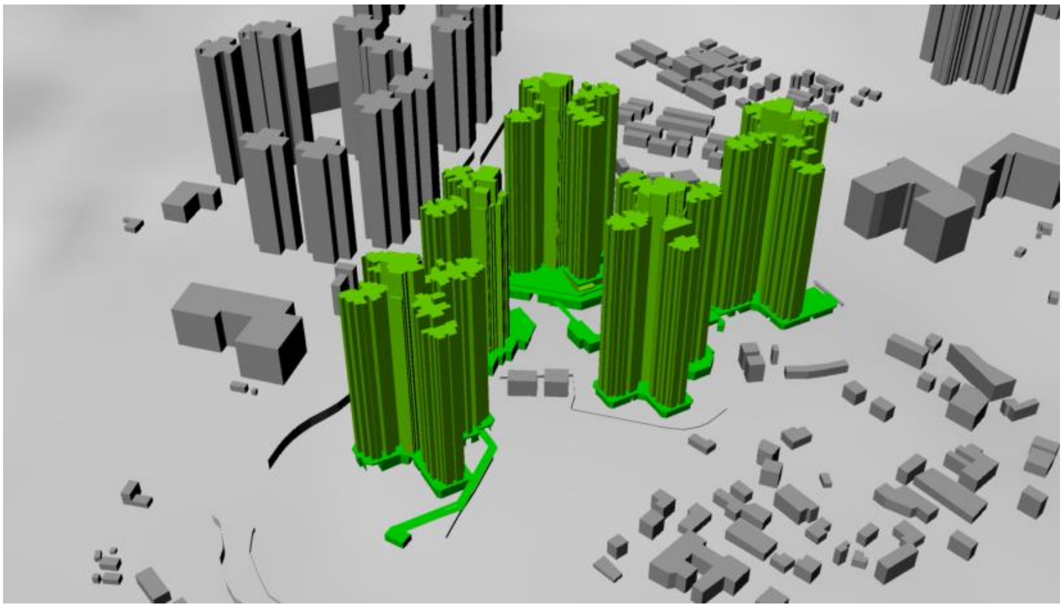


Figure 9 Proposed Scheme at Northerly View

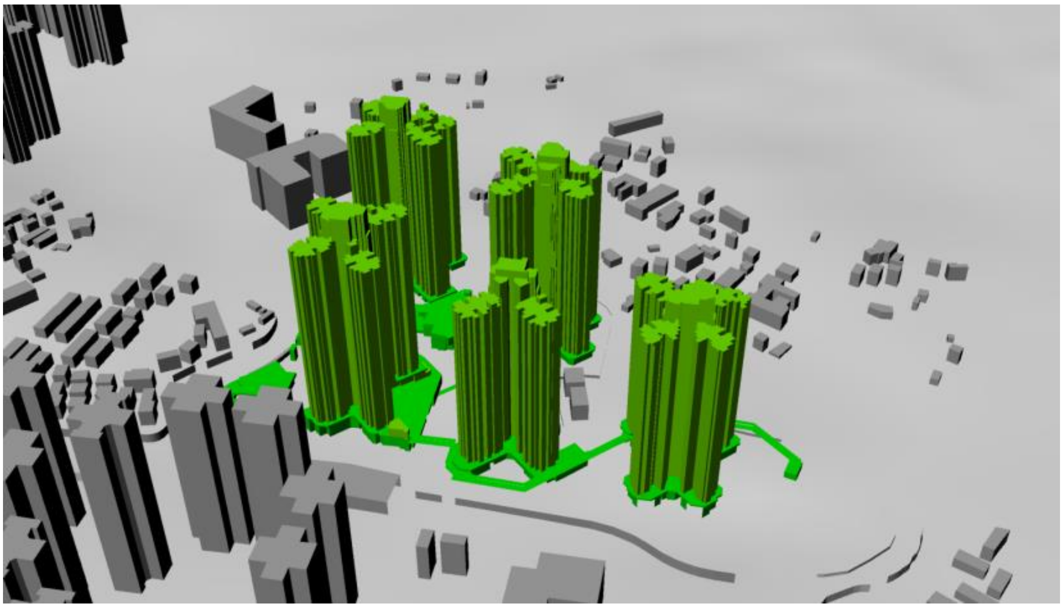


Figure 10 Proposed Scheme at Easterly View

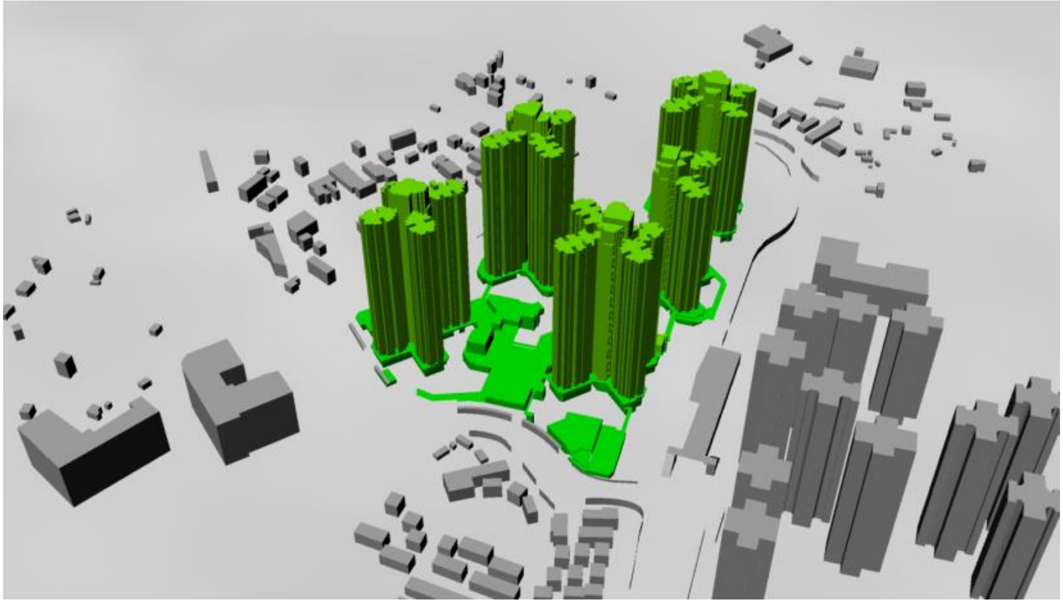


Figure 11 Proposed Scheme at Southerly View

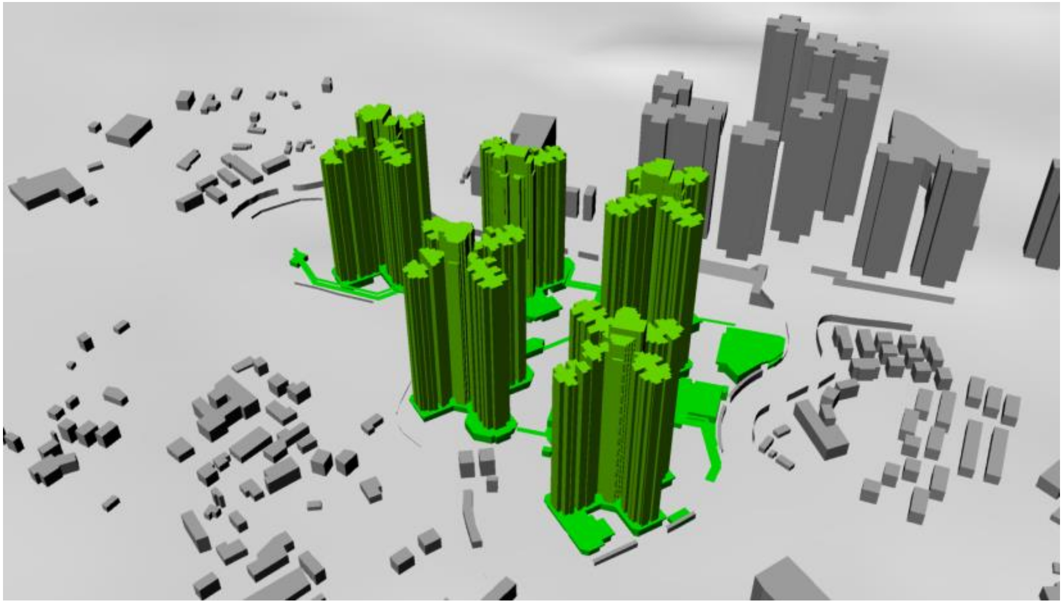


Figure 12 Proposed Scheme at Westerly View

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 a report *Experimental Site Wind Availability Study for Tuen Mun, Hong Kong* in Tuen Mun conducted by the CLP Power Wind/Wave Tunnel Facility (WWTF) at The Hong Kong University of Science and Technology, as part of the “Urban Climate Map and Standards for Wind Environment – Feasibility Study”. Rather than using lower level wind rose, the wind roses at 200mPD was selected for this study, as the wind data at this level would capture the topographical effect while it is less influenced by the ground features such as building clusters.

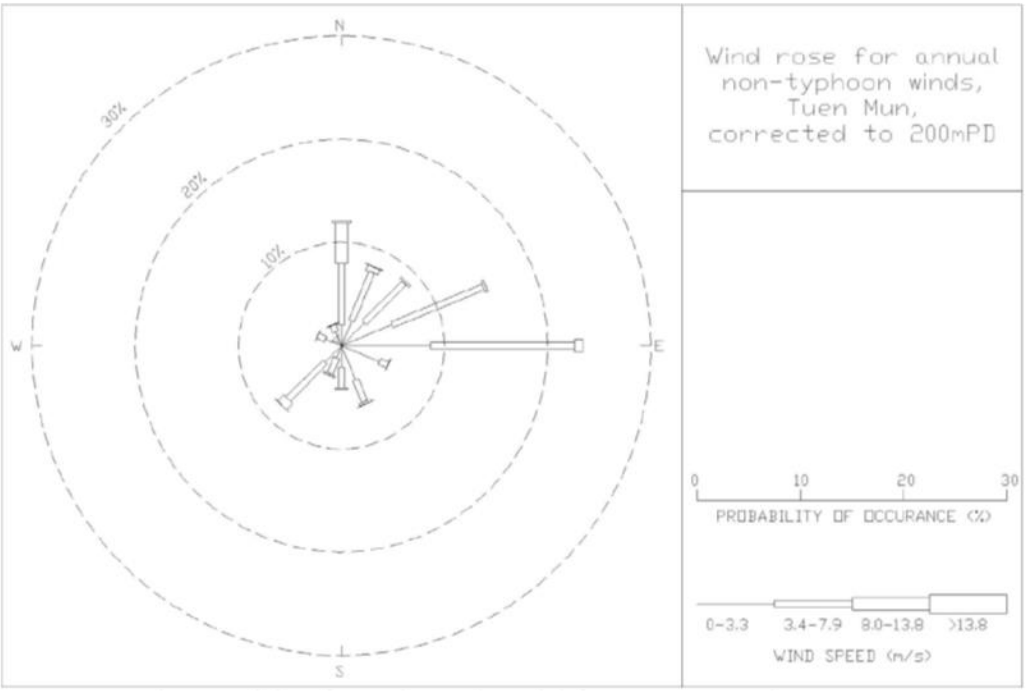


Figure 13 Wind Profile Based on the Wind Tunnel Test

3.1.1 Annual Wind Frequency

Table 1 Annual wind frequency of the wind directions considered in this study

Wind Angle	% of Occurrence	Wind Angle	% of Occurrence	Wind Angle	% of Occurrence	Wind Angle	% of Occurrence
N	**12.1**	E	**23.4**	S	4.3	W	0.0
NNE	**8.3**	ESE	**4.9**	SSW	3.1	WNW	2.5
NE	**8.8**	SE	0.0	SW	**8.2**	NW	1.0
ENE	**15.1**	SSE	**6.1**	WSW	0.0	NNW	2.2

Results show that the prevailing wind directions **N**, **NNE**, **ENE**, **E**, **ESE**, **SSE**, **S** and **SW** have corresponding frequency of occurrences of 12.1%, 8.3%, 8.8%, 15.1%, 23.4%, 4.9%, 6.1%, and 8.2% respectively. Total wind frequency is 86.9% over an annual basis, well exceeding the 75% annual wind frequency requirement stated in the Technical Circular of AVA.

3.1.2 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 in the 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

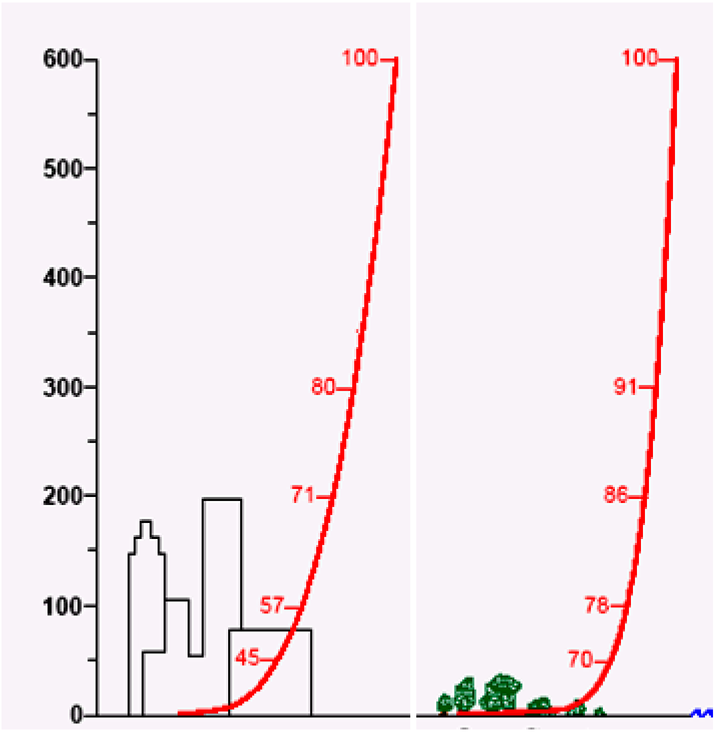


Figure 14 Wind Profile applied in the AVA Initial Study

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 centre or high-rise	~0.50

As the study area is in a low rise semi-rural area, n-value of seven of the eight selected wind directions would be 0.35 while the N wind direction would be 0.15.

3.2 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 ≈115m) from the site boundary (Assessment Area). Further, the model area was built to include another 115 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, such as Siu Hong Couirt at SE and new development of 5 blocks at SW.

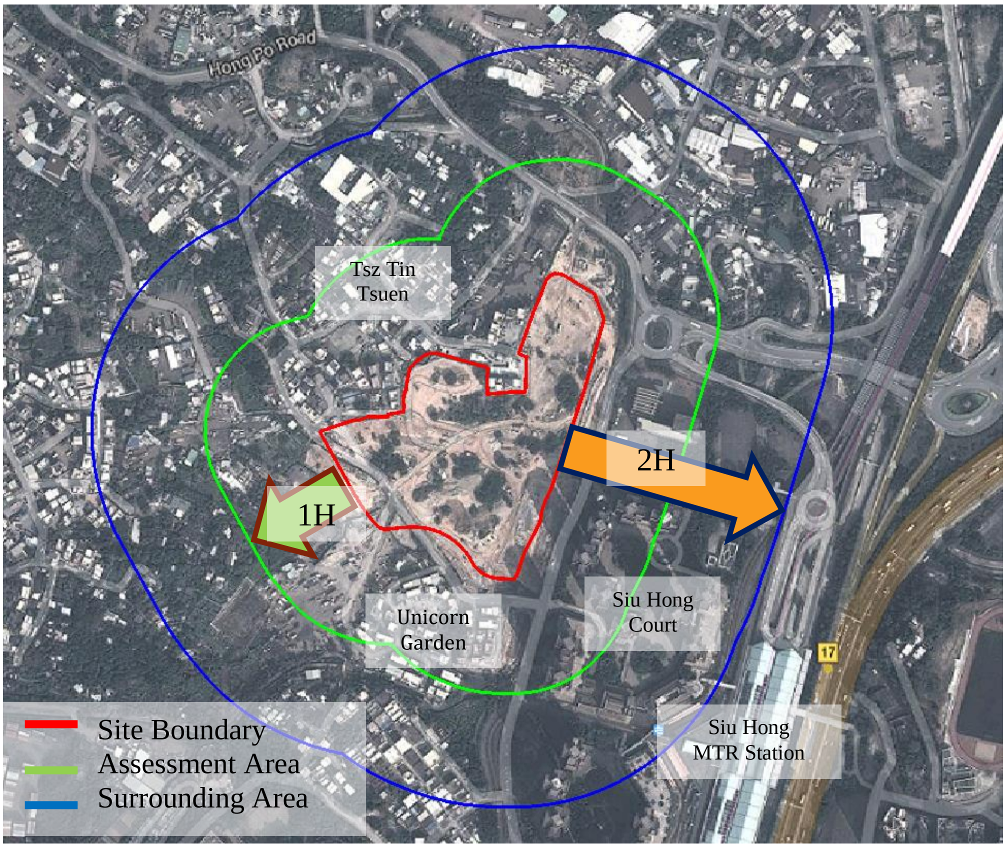


Figure 15 Site boundary, Assessment Area and Surrounding Area for the study (Image Source: Google Earth)

3.3 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.

3.4 Test Point for Local and Site Ventilation Assessment

Monitoring test points are placed around and in the vicinity of the site of the Development to determine the ventilation performance. There are two types of test points in the study:

3.4.1 Perimeter Test Points

Perimeter test points are the points positioned on the site boundary of the Development. In accordance with the Technical Circular for AVA, 38 Perimeter points (red spots) are positioned alongside the site boundary as shown in the following figure and each point is spaced around 10-50m apart.

3.4.2 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. In accordance with the Technical Circular for AVA, 96 Overall test points (green spots) are selected and shown in the following figure:

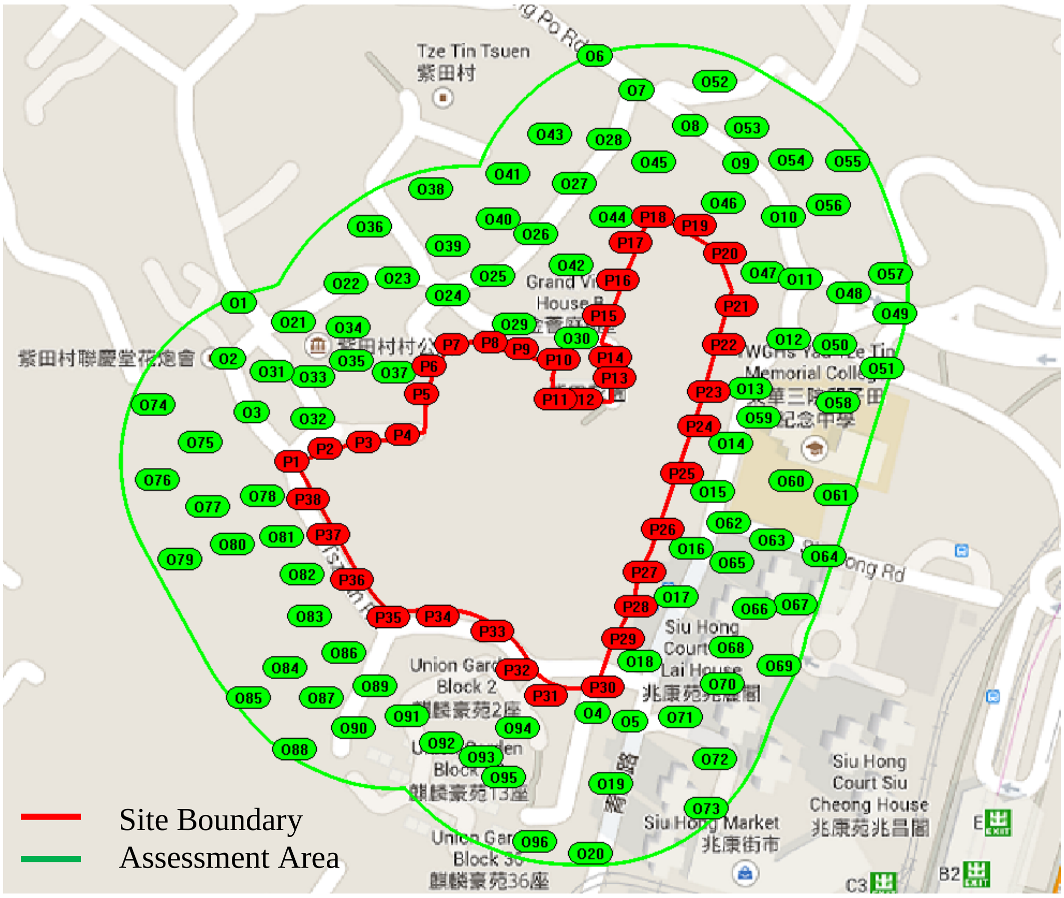


Figure 16 Demarcation of Test Points for Site Air Ventilation Assessment

3.5 Assessment Tools

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 detail. 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.

3.5.1 CFD Model

Following the Technical Circular for AVA, buildings within Surrounding Area need to be built in the CFD model. All permanent structures at least 10m tall or three storeys within a 2H radius were included in the model. In addition, high rises in Siu Hong Court to the southeast and in the proposed development at Tuen Mun Area 54 Site 3 & 4, and Site 4A to the southwest, which were outside the 2H radius but deemed significant to the site wind condition, were also built into the model.

All in all, the total CFD domain models 1,900m x 1,900 m x 800m of landscape and development and contains just fewer than 3,000,000 cells. It covers the site of the 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. The expansion ratio is 1.3 while the maximum blockage ratio is 3.5%. A prism layer of 2m above ground (a total of 4 layers each 0.5m thick) is incorporated in the meshing so as to better capture the approaching wind. By referring to the CAD drawings of the Baseline Scheme and Proposed Scheme given by the Client, the CFD models are constructed as shown below:

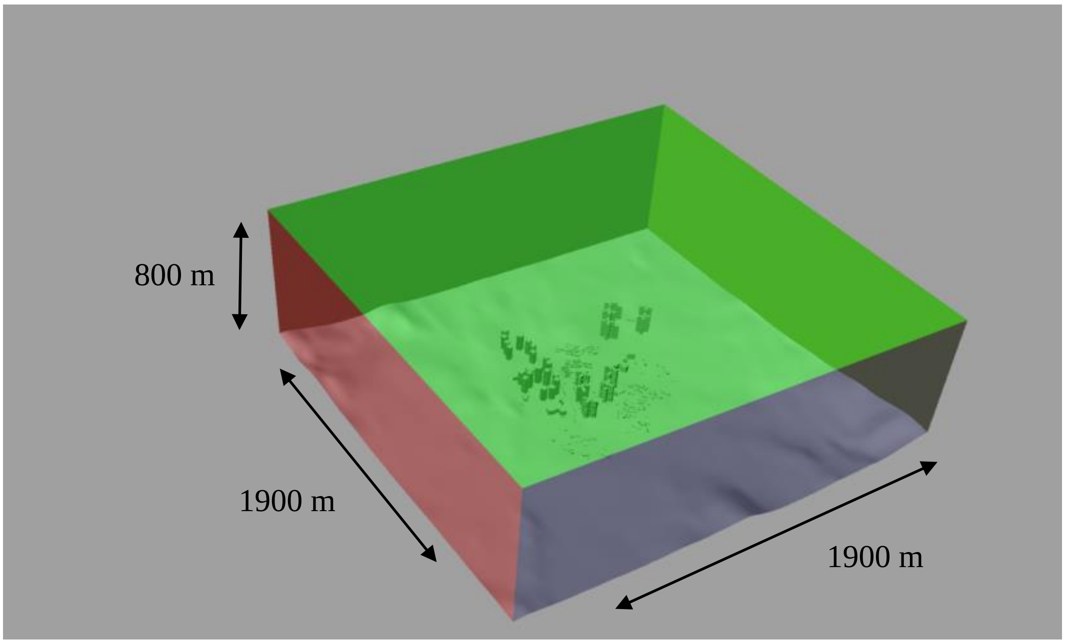


Figure 17 Domain of the CFD Model

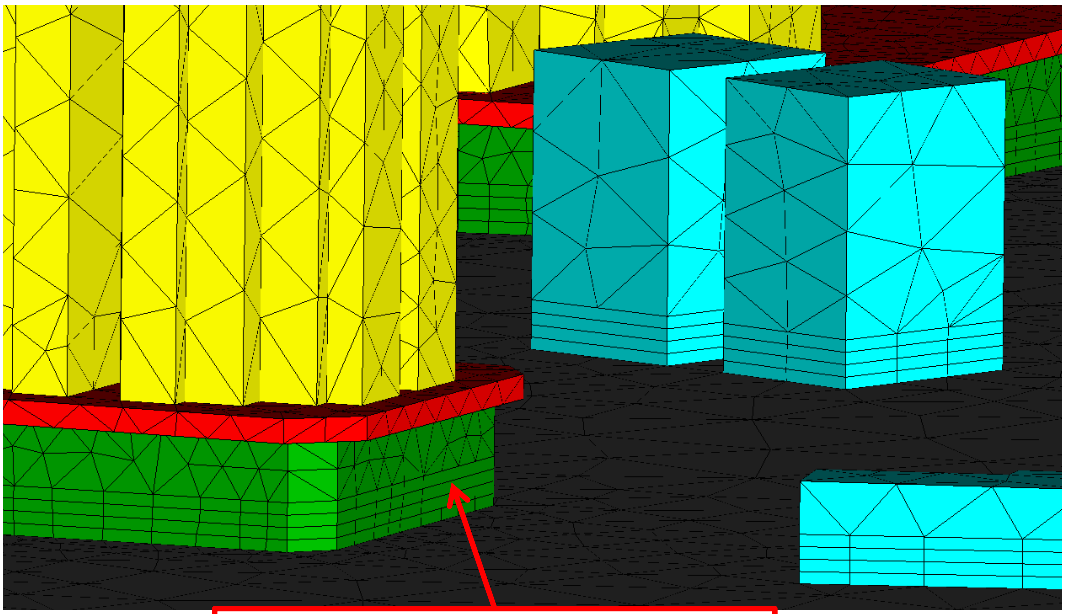


Figure 18 Prism Layer of the CFD Model

3.5.2 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, realizable k – ε turbulence modelling method is applied. This technique provides more accurate representation of the levels of turbulence that can be expected in an urban environment.

3.5.3 Calculation Method

The Segregated Flow model solves the flow equations in a segregated manner. The linkage between the momentum and continuity equations adopted the predictor-corrector approach. A collocated variable arrangement and a Rhie-and-Chow-type pressure-velocity coupling are combined with a SIMPLE-type algorithm. A higher order differencing scheme is applied to discretize the governing equations. The convergence criterion is set to 0.0005 on mass conservation. The calculation will repeat until the solution satisfies this convergence criterion.

The prevailing wind direction as mentioned in Section 3.1.1 is set to inlet boundary of the model with wind profile as detailed in Section 3.1.2. The downwind boundary is set to pressure with value of atmospheric pressure. The top and side boundaries are set to symmetrical planes. In addition, to eliminate the boundary effects, the model domain is built beyond the Surrounding Area as required in the Technical Circular.

3.5.4 AVA Study parameters

CFD simulations have been conducted to study the wind environment. As specified in the Technical Circular, indicator of ventilation performance should be the Wind Velocity Ratio (VR), defined as the ratio of the wind velocity at the pedestrian level (2m above ground) to the wind velocity at the top of the wind boundary layer. Site spatial average velocity ratio (SVR) and a Local spatial average velocity ratio (LVR) should be determined. The details of the assessment result for the scheme would be presented in the next section.

Table 2 Terminology of the AVA Initial Study

Terminology	Description
Velocity Ratio (VR)	The velocity ratio (VR) represents the ratio of the air velocity at the measurement position to the value at the reference points.
Site spatial average velocity ratio (SVR)	The SVR *(red spots)* represent the average VR of all perimeter test points at the site boundary which identified in the report.
Local spatial average velocity ratio (LVR)	The LVR *(**green spots** and red spots)* represent the average VR of all points, i.e. perimeter and overall test points at the site boundary which identified in the report.

4 Result and Discussion

4.1 Overall Pattern of Ventilation Performance

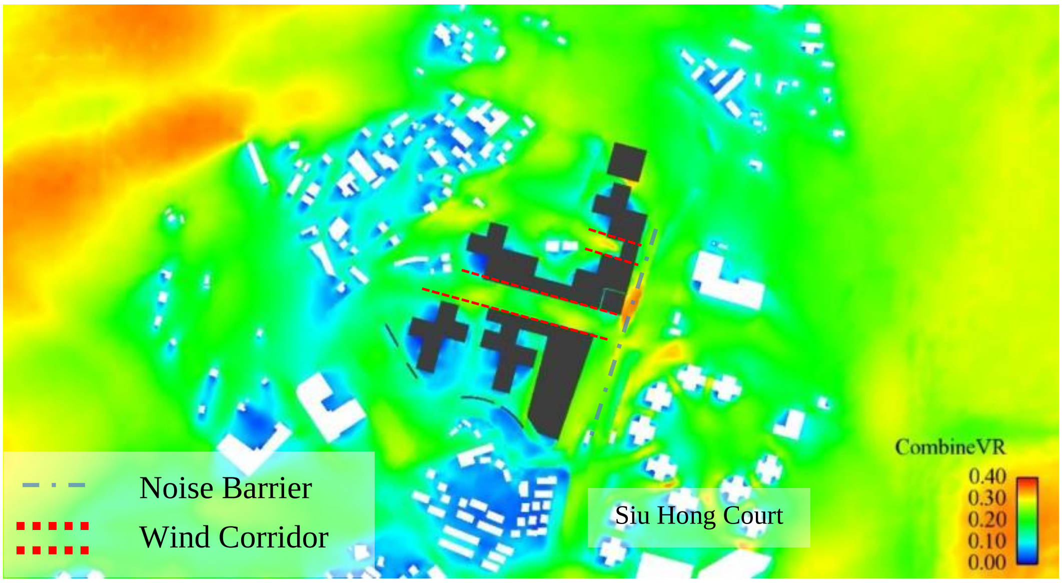


Figure 19 Combined VR for Baseline Scheme

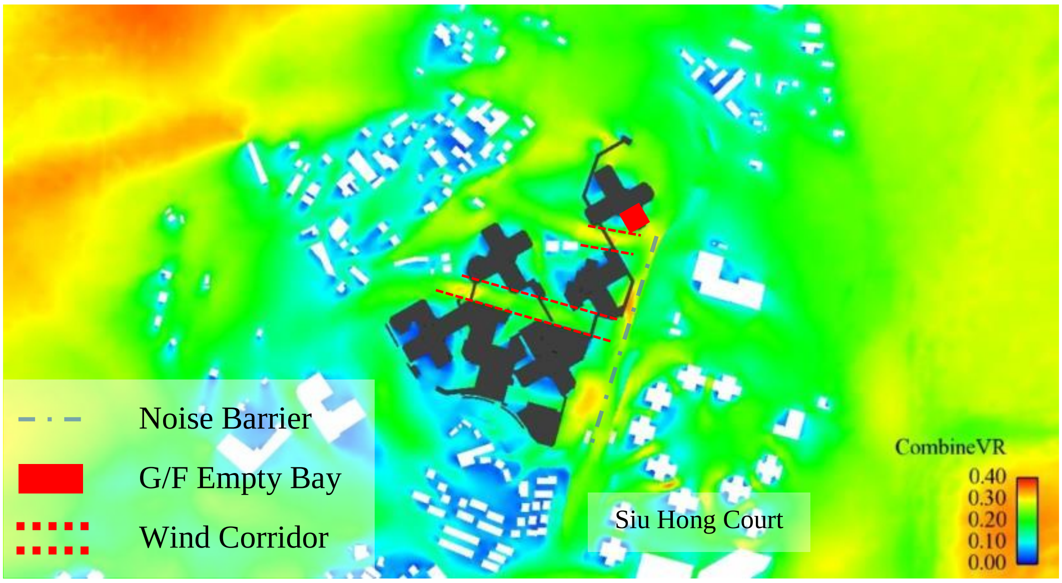


Figure 20 Combined VR for Proposed Scheme

For the annual condition, eight wind directions were selected, accumulating to 86.9% occurrence frequency. The integrated effect of these winds indicates the overall wind ventilation performance. Annual wind is dominated by E (23.4%) and ENE (15.1%), directions. The above contour plots show that:

- The annual prevailing wind are mainly coming from E and ENE directions, and the west side of the development site shows a relatively lower average VR compared to the east side;
- Two wind corridors (Figure 20 - red dotted line) and one empty bay (Figure 20 – red square box) are preserved across the Development to allow the dominant E wind to penetrate through the site freely and enhance the ventilation at the Tsz Tin Tsuen ;
- The Siu Hong Court to the southeast is a significant barrier for the incoming winds to enter the Development from ESE and SSE directions;
- 7.5m noise barrier situated along Tsing Lun Road would block a portion of the easterly wind entering the Development, while diverts some of the wind toward the south.

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 shown in Figure 16).
• **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 green points as shown in Figure 16).

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

Table 3 Comparison of the Velocity Ratio for Baseline and Proposed Scheme

	Baseline Scheme	Proposed Scheme
SVR	0.19	0.20
LVR	0.18	0.18

Results show that the Proposed Scheme has a higher SVR than the Baseline Scheme, while the LVR is the same for both schemes. This implies that the Proposed Scheme's ventilation performance at its immediate vicinity is slightly better than the Baseline Scheme, while the overall ventilation performance at the surrounding region is quite similar. This is mainly due to both schemes consists of five residential towers with two wind corridors implemented in the design. Hence, their overall ventilation performance is similar. Nevertheless, the Proposed Scheme has a wider wind corridor between Blocks 1 and 2, which slightly enhance the wind permeability and facilitate the ventilation performance at some immediate vicinity areas. Thus, the SVR achieve a slightly higher VR under the Proposed Scheme.

4.3 Directional Analysis

The directional analysis has been carried out for each wind directions. There are eight prevailing wind directions analysed in this AVA Initial Study, i.e. N, NNE, NE, ENE, E, ESE, SSE, and SW winds.

4.3.1 N Wind Direction

The ventilation environment under N wind condition is generally similar between the two schemes. The incoming wind would penetrate through the development via the building separations, while a portion of wind would flow around the site towards the leeward region (Green Arrow at Figure 21 and Figure 22). Under Baseline Scheme, Block 4 is set back towards west. As a result, a larger amount of the wind would be diverted towards southeast of the site (Purple Arrow in Figure 21), and enhances the ventilation environment at the south portion of Tsing Lun Road (Purple Circle in Figure 21).

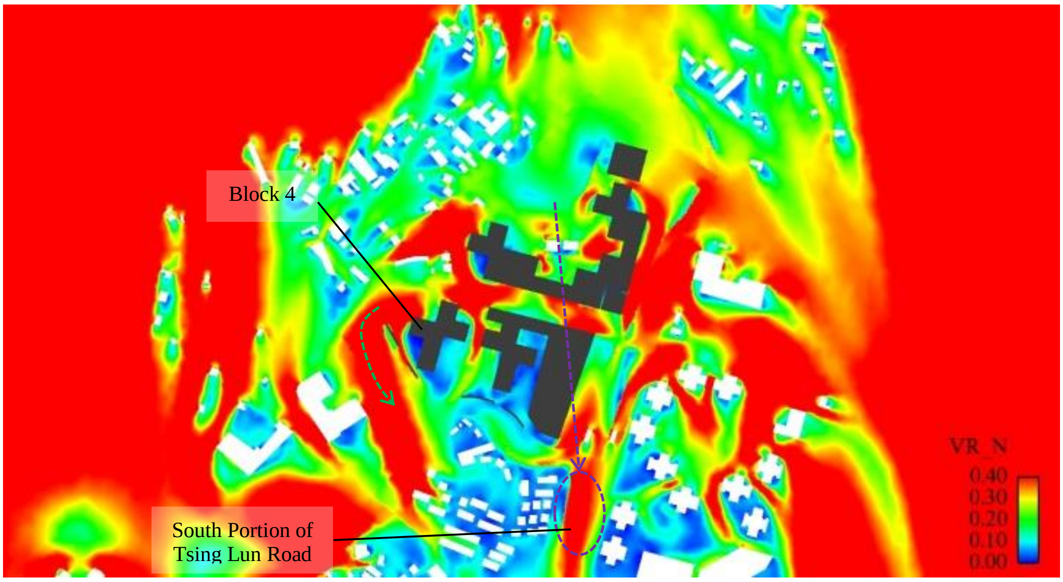


Figure 21 VR Contour Plot for Baseline Scheme under N Wind

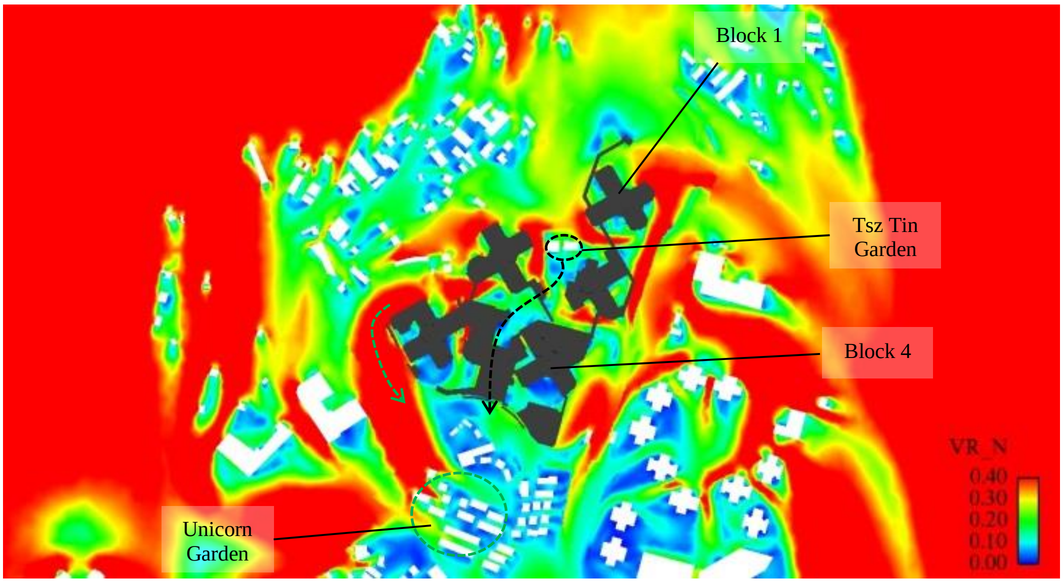


Figure 22 VR Contour Plot for Proposed Scheme under N Wind

4.3.2 NNE Wind Direction

Under Proposed Scheme, Block 1 would downwash the wind towards the region near Hong Po Road (Orange Arrow and Circle in Figure 24), and thus enhance the VR along the road. Furthermore, Block 4 would downwash the wind towards the east of the site (Purple Arrow and Circle in Figure 24). As the results, the wind environments of Tsing Lun Road has been slightly enhanced.

Under Baseline Scheme, Block 1 would also downwash the incoming wind towards the east of the site and enhances the ventilation at the region near the Secondary School Site (Blue Arrows in Figure 23). Meanwhile, a small portion of wind would further channel along Tsing Lun Road and thus the northern portion of the road would achieve a higher VR under the Baseline Scheme. In addition, the orientation of Block 3 could help to downwash the wind towards Tsz Tin Garden and thus slightly enhance the ventilation of the area. The building footprint of Block 5 is slightly setback from the site boundary and hence the incoming wind would flow across the setback area towards the Proposed School Site (Red Arrow in Figure 23). As the result, Tsing Lun Road, Secondary School Site, Tsz Tin Garden and Proposed School Site would have a slightly better ventilation environment under Baseline Scheme.

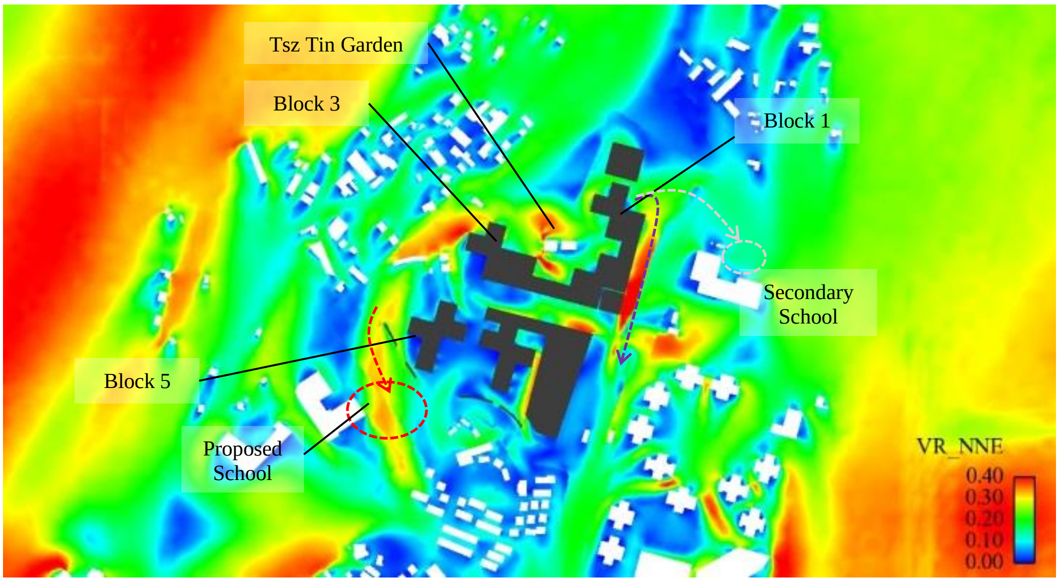


Figure 23 VR Contour Plot for Baseline Scheme under NNE Wind

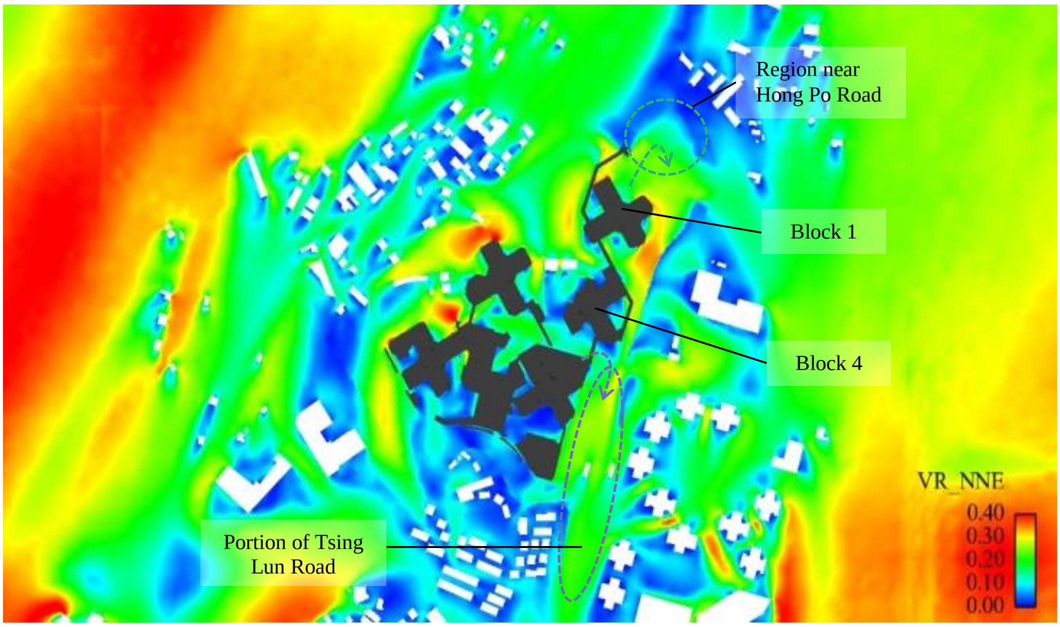


Figure 24 VR Contour Plot for Proposed Scheme under NNE Wind

4.3.3 NE Wind Direction

Similar to NNE wind condition, Block 1 of the Proposed Scheme would downwash the wind to the Hong Po Road and head towards to two directions, i.e. towards Tsz Tin Road (Black Arrow in Figure 26) and towards Tsing Lun Road (Red Arrow in Figure 26). In this connection, the wind environments of Tsz Tin Road, Hong Po Road and Tsing Lun Road have been enhanced.

Under Baseline Scheme, Block 3 would downwash the a portion of wind towards Tsz Tin Garden (Blue Circle in Figure 25), while the setback of Block 4 would allow prevailing wind penetrate to the region near Unicorn Garden (Purple Arrow and Circle in Figure 25). As the results, the Tsz Tin Garden and Unicorn Garden achieved a higher VR as compared with the Proposed Scheme.

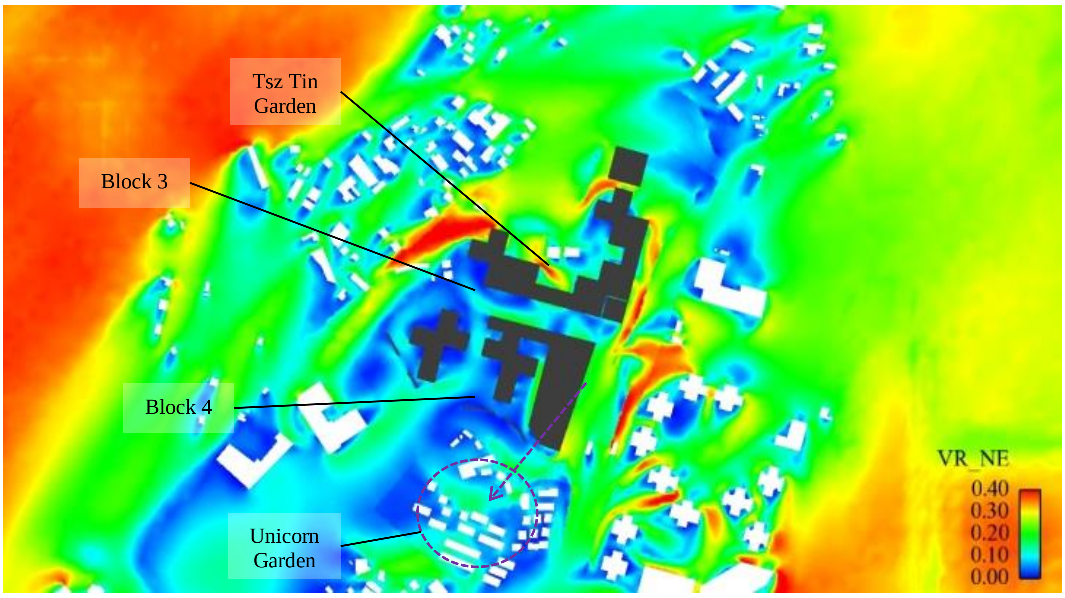


Figure 25 VR Contour Plot for Baseline Scheme under NE Wind

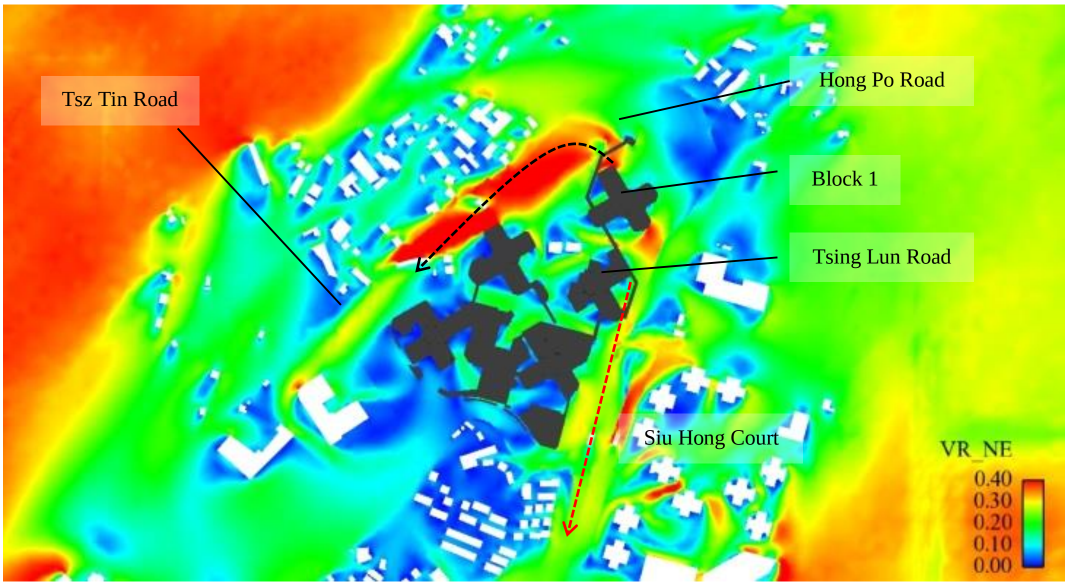


Figure 26 VR Contour Plot for Proposed Scheme under NE Wind

4.3.4 ENE Wind Direction

Under ENE wind condition, a portion of the incoming wind would penetrate through the building separation of the Development and penetrate towards the Tsz Tin Tsuen under both schemes.

Under Proposed Scheme, the wider wind corridor at the northern portion of the development allows greater amount of the winds penetrate through the site (Black Arrow in Figure 28). Furthermore, the ground floor empty bay further enlarge the wider wind corridor wide at ground level and facilitate the wind penetration. Compared with the Proposed Scheme, the Baseline Scheme has a smaller separation at the northern wind corridor and resulting less portions of the wind could penetrate through the site (Purple Arrow in Figure 27). Thus, Tsz Tin Tsuen achieved a higher VR under the Proposed Scheme.
For the Proposed Scheme, a portion of winds diverted by Tsz Tin Tsuen flow towards southwest direction and joined the approaching wind that penetrated through the center wind corridor (Green Arrow in Figure 28). The combined air stream travel at the edge of Tsz Tin Tsuen towards Tsz Tin Road and Proposed School Site. As the results, the ventilation performance at the Tsz Tin Tsuen, Tsz Tin Road and Proposed School Site have been slightly enhanced.
Furthermore, Block 4 of the Proposed Scheme would divert a portion of approaching wind towards Unicorn Garden (Red Arrow in Figure 28). In the contrast, the setback of Block 4 under the Baseline Scheme allows the approaching wind skim over the low-rise podium block and further flow along the gap between Unicorn Garden and Proposed School Site (Orange Arrow in Figure 27). Thus, Unicom Garden achieved a slightly higher VR under the Proposed Scheme.

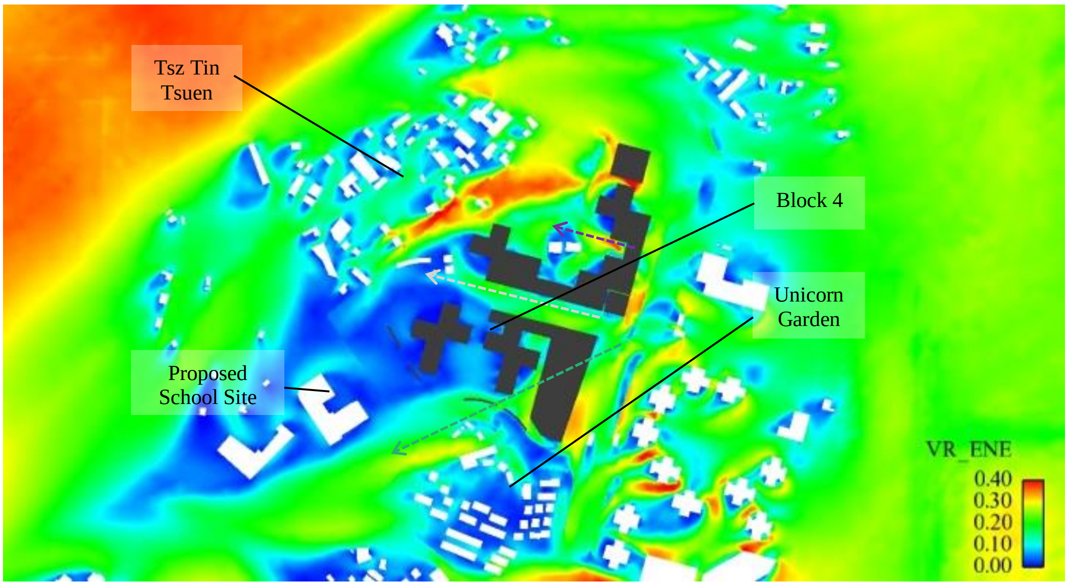


Figure 27 VR Contour Plot for Baseline Scheme under ENE Wind

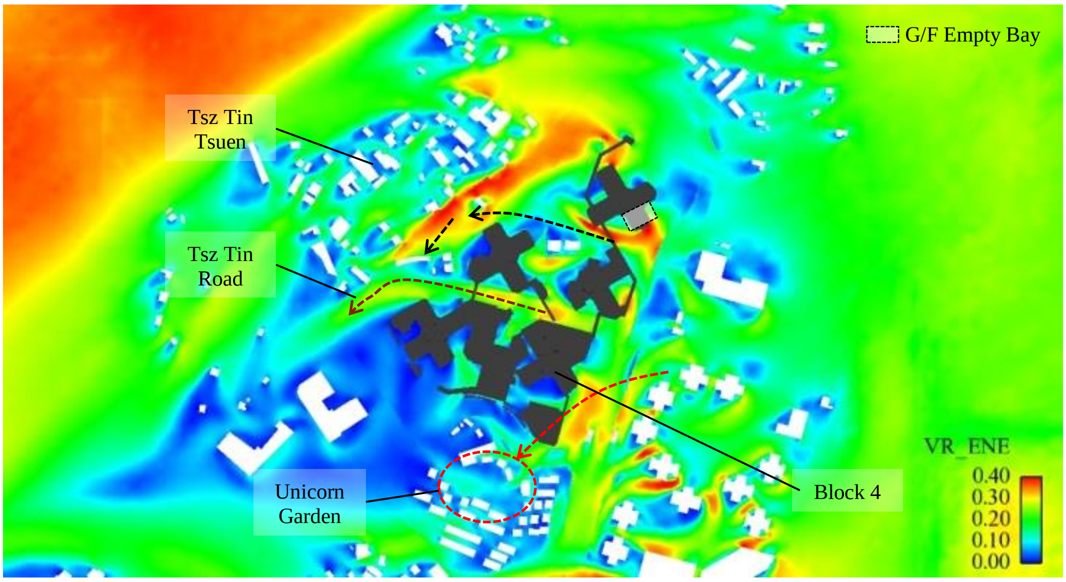


Figure 28 VR Contour Plot for Proposed Scheme under ENE Wind

4.3.5 E Wind Direction

Similar to the ENE wind condition, the wider wind corridor and the ground floor empty bay at the Proposed Scheme helps to enhance the ventilation performance at the Tsz Tin Tsuen, while a portion of wind diverted by Tsz Tin Tsuen flow towards southwest direction (Black Arrow in Figure 30). The approaching wind penetrates through the center wind corridor (Green Arrow in Figure 30) would joined southwest air stream at the edge of Tsz Tin Tsuen and continuous to flow towards to the Tsz Tin Road. At the same time, the building disposition of Block 4 would divert a portion of the wind towards Unicorn Garden (Red Arrow in Figure 30). In this connection, slightly higher VR was observed at Tsz Tin Road, Tsz Tin Tsuen and Unicorn Garden.

Under Baseline Scheme, the width of the northern wind corridors is smaller as compared to the Proposed Scheme (Grey Arrow in Figure 29). Hence, relatively less wind would flow towards Tsz Tin Tsuen. The continuous podium under Blocks 1 and 2 would divert the low level wind along Tsing Lun Road (Orange Arrow in Figure 29). Thus, a slightly higher VR is achieved at the Secondary School and Tsing Lun Road. Meanwhile, the setback at the Block 4 allows the approaching wind flow (Purple Arrow in Figure 29) towards the Proposed School Site and thus enhance the ventilation performance at area.

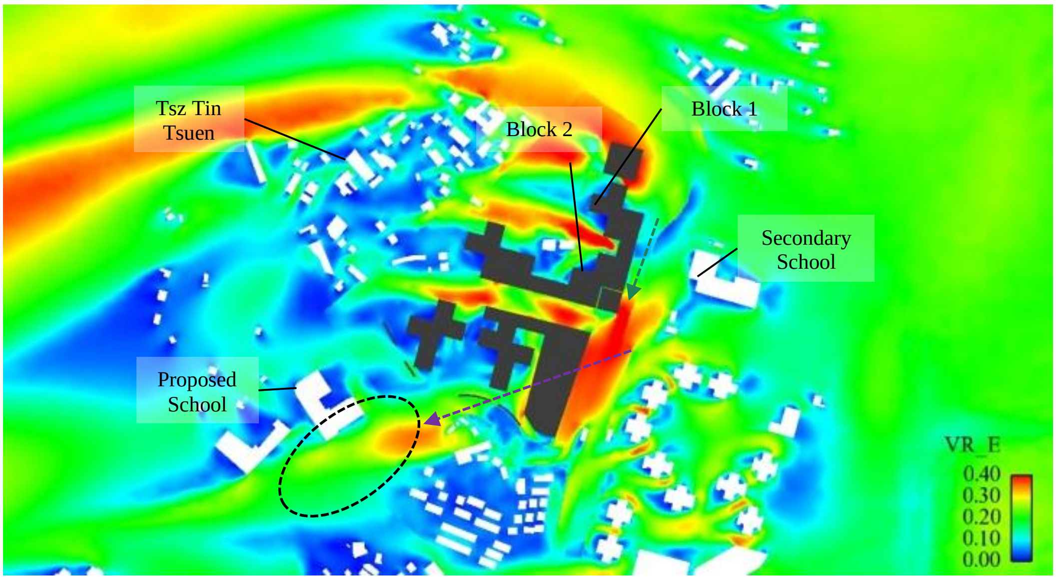


Figure 29 VR Contour Plot for Baseline Scheme under E Wind

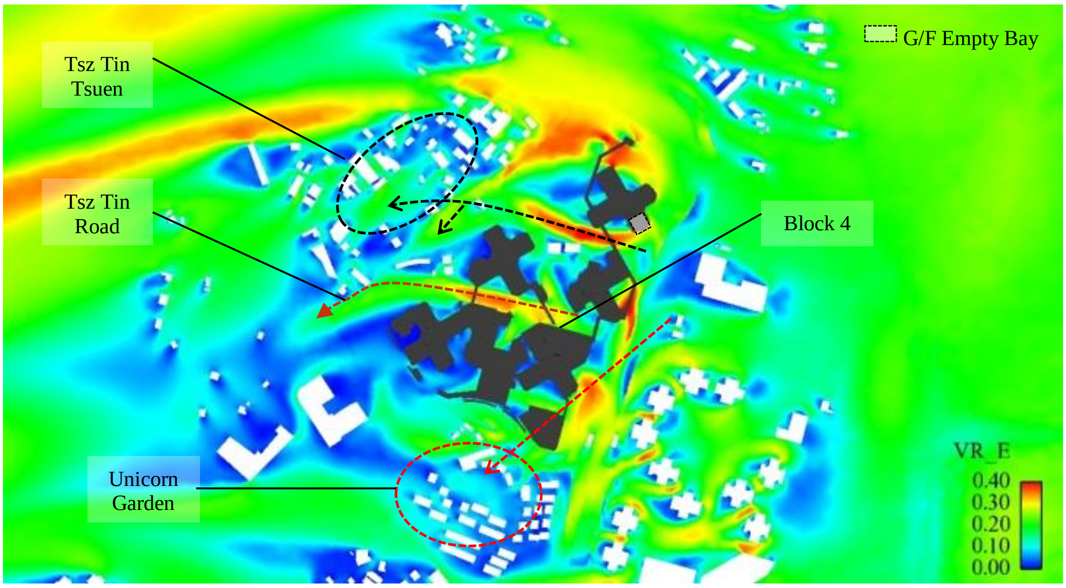


Figure 30 VR Contour Plot for Proposed Scheme under E Wind

4.3.6 ESE Wind Direction

Under the Baseline Scheme, the approaching wind penetrates through the two wind corridors of the site towards Tsz Tin Tsuen (Purple Arrow at Figure 31). Under the Proposed Scheme, the approaching wind penetrates through wider wind corridors between Blocks 1 and 2 towards Tsz Tin Tsuen (Black Arrow at Figure 32). The ground floor empty bay can further enlarge the wider wind corridor wide at ground level and facilitate the wind penetration. The center wind corridor and the building separation of Blocks 4 and 5 also allow wind penetrate to the Tsz Tin Tsuen (Orange Arrow at Figure 32). As compared to the Baseline Scheme, larger portion of wind could penetrate through the project site to the Tsz Tin Tsuen and thus the area could achieve a slightly higher VR under the Proposed Scheme.

Furthermore, Block 5 of the Proposed Scheme split the approaching wind into two parts, one through the building gap towards Tsz Tin Tsuen (Orange Arrow at Figure 32) and the other flow along the Tsz Tin Road (Blue Arrow at Figure 32). In the contrast, the Blocks 4 and 5 of the Baseline Scheme are situated closely together, hence most of the approaching wind came from SE direction are further diverted towards Tsz Tin Road (Red Arrow at Figure 31). As the results, the Tsz Tin Road achieved a slightly higher VR under the Baseline Scheme as compared to the Proposed Scheme.

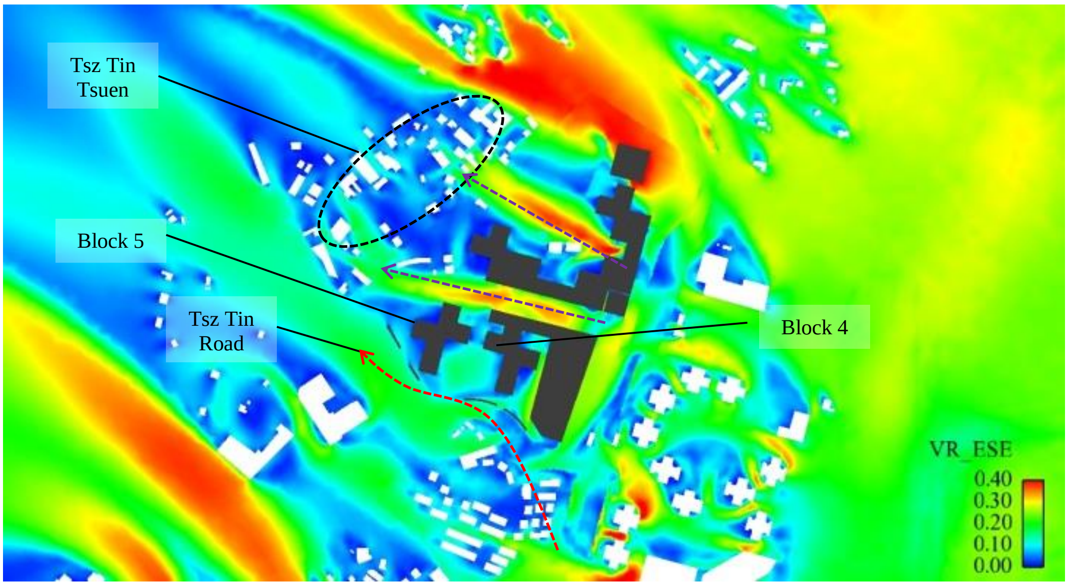


Figure 31 VR Contour Plot for Baseline Scheme under ESE Wind

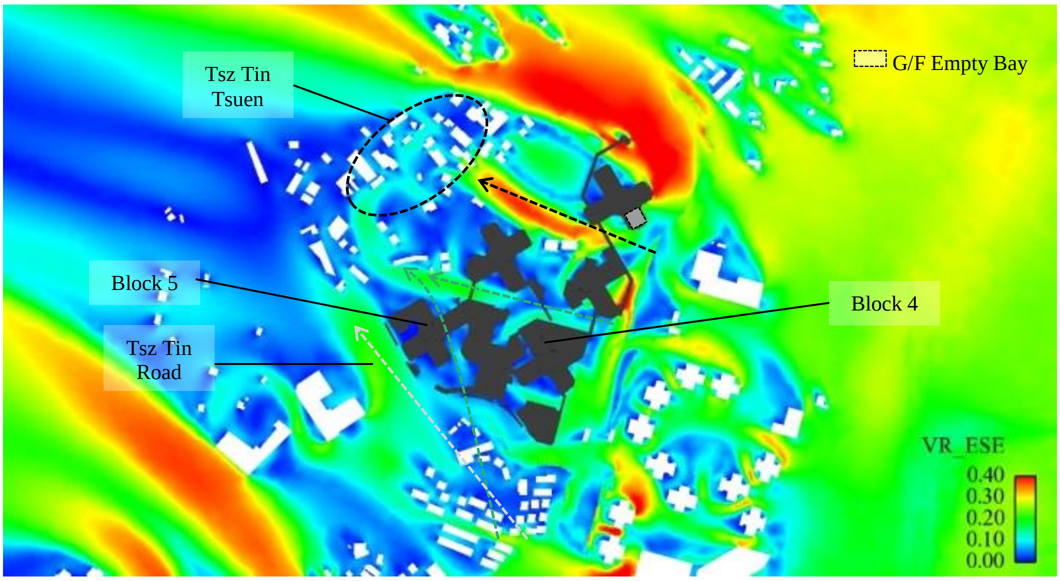


Figure 32 VR Contour Plot for Proposed Scheme under ESE Wind

4.3.7 SSE Wind Direction

Under Proposed Scheme, the incoming wind would penetrate through the building gap between Block 4 and 5 (Red Arrow in Figure 34), and enhances the ventilation environment at Tsz Tin Tsuen. Furthermore, the wider building gap between Blocks 1 and 3 helps to divert more incoming wind to the street level of Tsz Tin Garden (Purple Arrow in Figure 34). Under Baseline Scheme, Blocks 4 and 5 diverted the incoming wind towards west (Black Arrow in Figure 33) and north directions (Orange Arrow in Figure 33). The south-easterly wind flow along Tsz Tin Road and slightly enhanced the VR at the southwest of Tsz Tin Tsuen, while a small portion of wind would skim over the low-rise commercial centre and flow through the building separation between Blocks 2 and 3 (Orange Arrow in Figure 33). In this connection, the results show that the Tsz Tin Garden achieved a slightly higher VR under the Proposed Scheme, while slightly higher VR is achieved at the Tsz Tin Road under the Baseline Scheme.

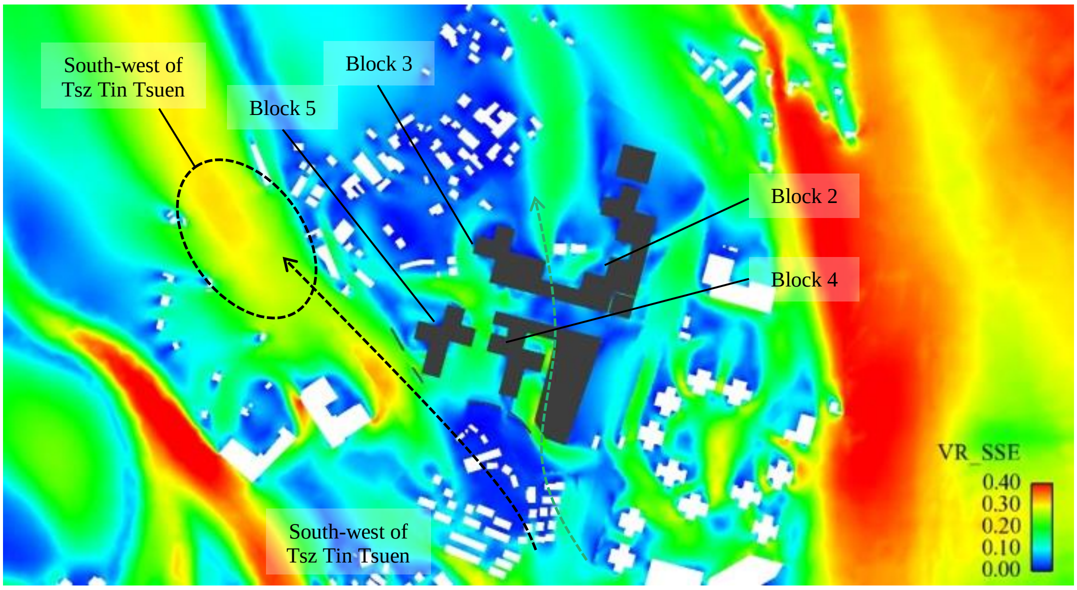


Figure 33 VR Contour Plot for Baseline Scheme under SSE Wind

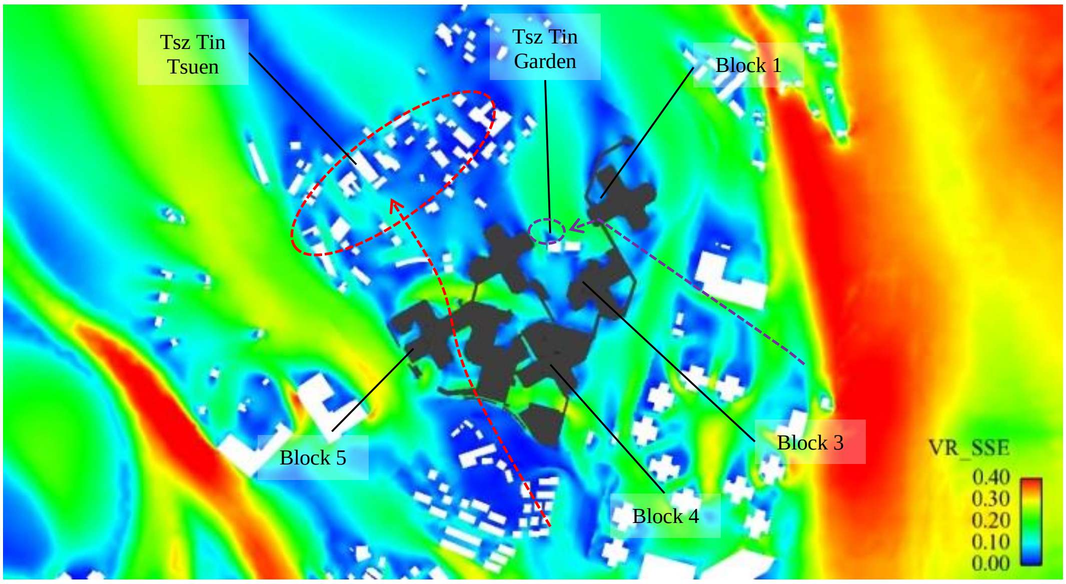


Figure 34 VR Contour Plot for Proposed Scheme under SSE Wind

4.3.8 SW Wind Direction

Block 4 of the Proposed Scheme helps to downwash a portion of the incoming wind (Black Arrow in Figure 36) to the Tsing Lun Road. As a result, the ventilation environment at the North Portion of Tsing Lun Road and the village would be slightly better under Proposed Scheme (Black and Orange Circle in Figure 36).

Under Baseline Scheme, a portion of the wind would be downwash by Blocks 4 and 5, and diverted Tsz Tin Road towards southeast and northwest directions (Red Arrow in Figure 35). Meanwhile, a portion of the wind would be downwash to Tsz Tin Garden by Block 2 (Orange Arrow in Figure 35). Consequently, slightly higher VR was observed at Tsz Tin Road and Tsz Tin Garden under Baseline Scheme, while slightly higher VR is observed at the village area under the Proposed Scheme.

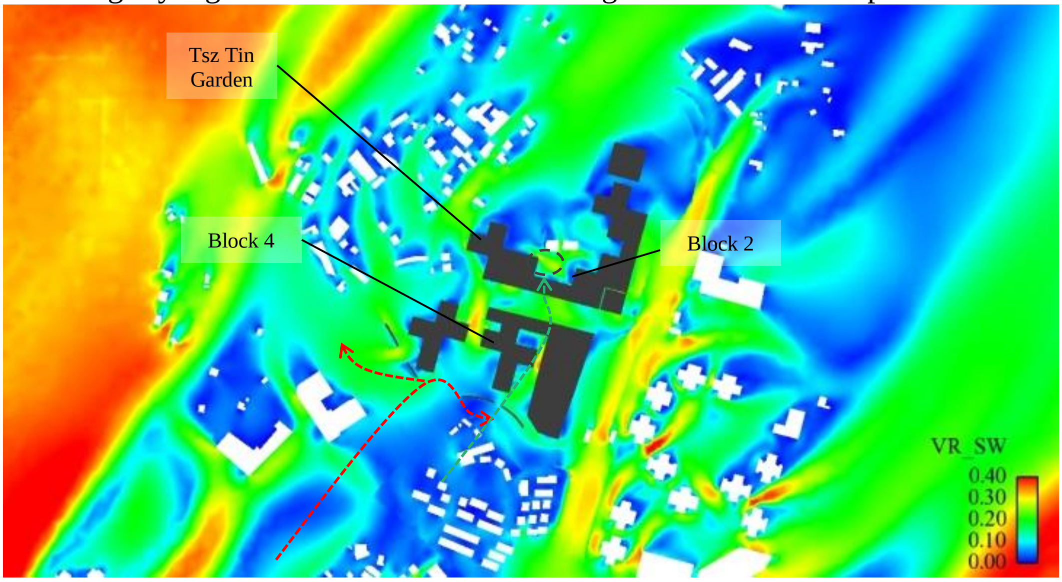


Figure 35 VR Contour Plot for Baseline Scheme under SW Wind

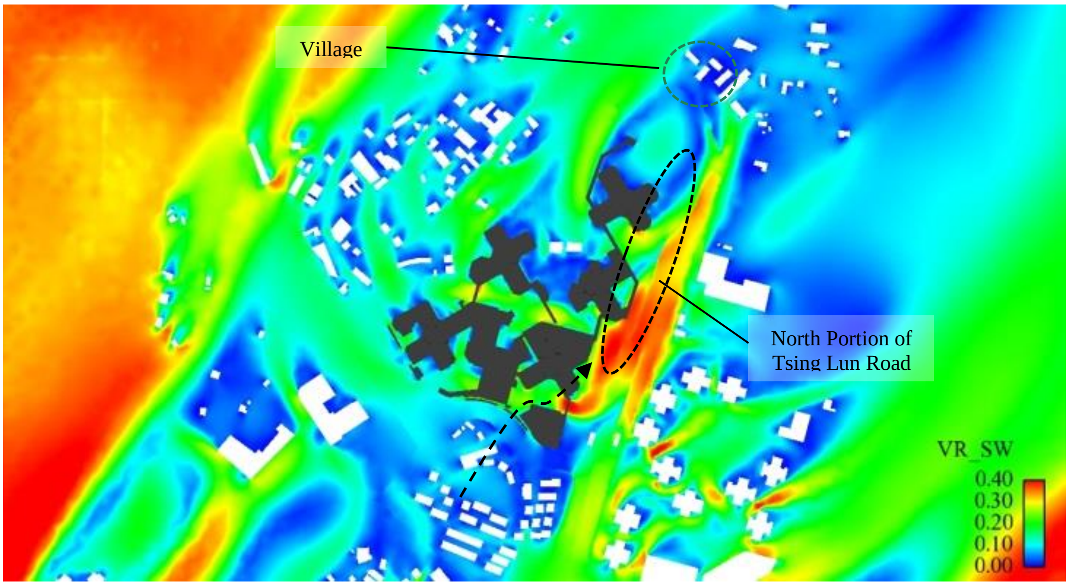


Figure 36 VR Contour Plot for Proposed Scheme under SW Wind

4.4 Focus Area

To further assess the Development's impact on the wind environment of its immediate vicinity, several focus areas were identified. Figure 37 indicates the locations of the focus areas and Table 4 shows relevant test points and their spatial average velocity ratio.

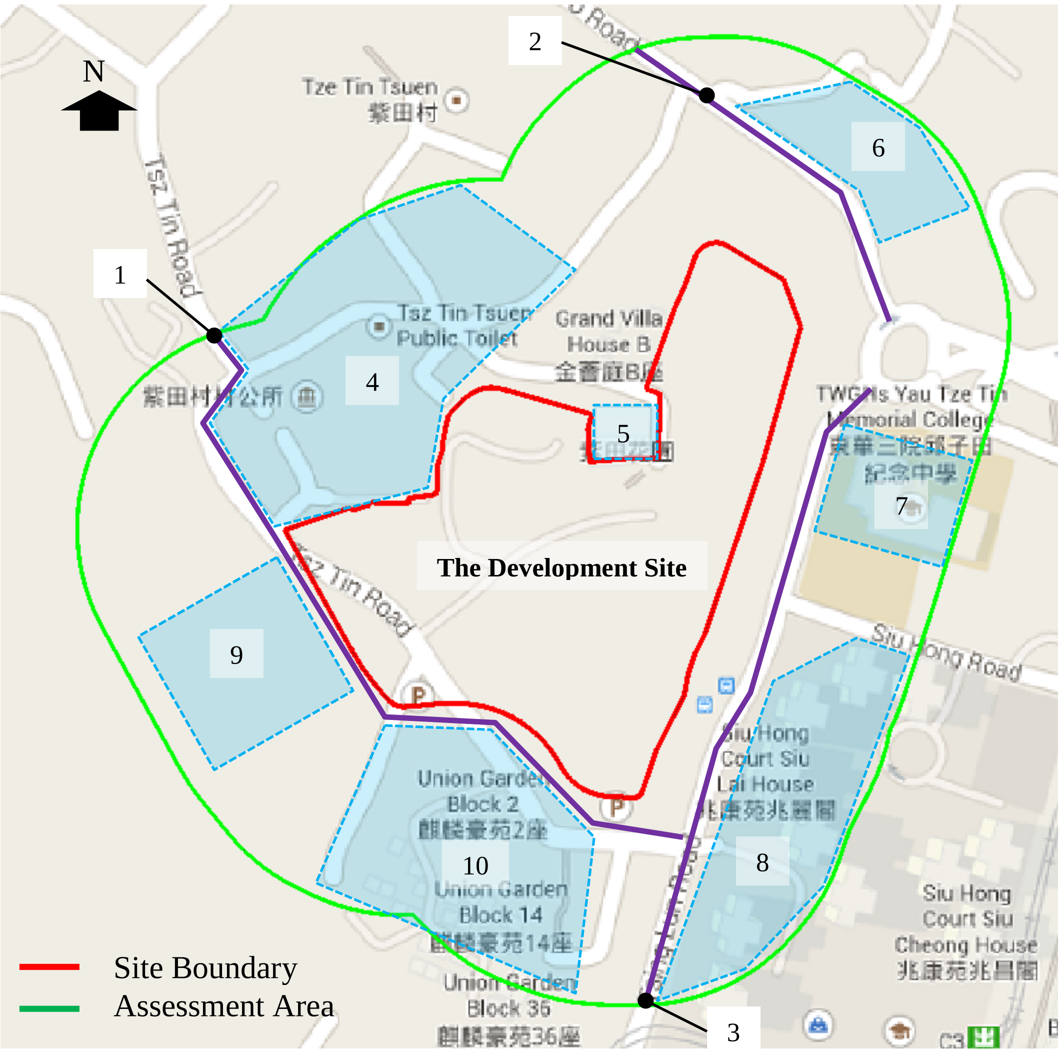


Figure 37 Locations of Focus Areas

Table 4 Focus Areas

No.	Focus Area	Test Points	Average Velocity Ratio	
			Baseline Scheme	Proposed Scheme
1	Tsz Tin Road	O1 - 3, P1, P31 - 38, O4 - 5	0.13	0.14
2	Hong Po Road	O6 - 11	0.20	0.20
3	Tsing Lun Road	O5, O12 - 20	0.20	0.20
4	Tsz Tin Tsuen	O1 - 3, O21 - 26, O31 - 40	0.16	0.17
5	Tsz Tin Garden	P10 - 14, O30	0.20	0.21
6	Village	O53 - 56	0.13	0.13
7	Secondary School Site	O58 - 61	0.19	0.19
8	Siu Hong Court	O66 - 73	0.18	0.18
9	Proposed School Site	O77 - 83	0.14	0.14
10	Unicorn Garden	O89 - 96	0.11	0.11

The Proposed Scheme achieved a slightly higher VR at Tsz Tin Road, Tsz Tin Tsuen, and Tsz Tin Garden. The results indicated that the Proposed Scheme achieved a slightly ventilation performance as compared to the Baseline Scheme at these areas. This is mainly due to the ground floor empty bay at Block 1 and wider wind corridor between Blocks 1-2 facilitate wind penetration and thus slightly enhances the ventilation performance at the leeward region.

For other focus areas, such as Hong Po Road, Tsing Lun Road, Village, Secondary School Site, Siu Hong Court, Proposed School Site and Unicorn Garden have the same VR values for both scheme, thus the results indicating that the ventilation performance at these areas are quite similar.

5 Wind Enhancement Features

The Proposed Scheme incorporates several design features to improve the ventilation performance of the site and surrounding area.

5.1 Wind Corridors

Similar to the Baseline Scheme, two wind corridors have been reserved in the Proposed Scheme to facilitate the wind penetration for the Development. Furthermore, the wind corridor between Blocks 1 and 2 (Red Dotted Line at Figure 38) are wider as compared to the Baseline Scheme. As the results, these design benefit the flow of the easterly wind through the site.

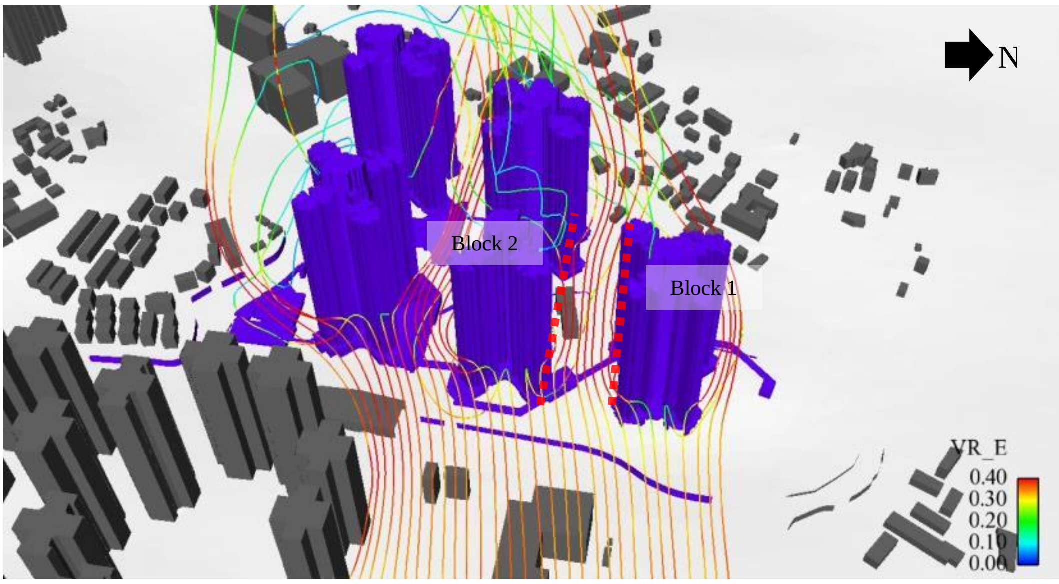


Figure 38 East Wind Passing Through Wind Corridors

5.2 Empty Bay

To improve air ventilation at the pedestrian level, ground floor level empty bay was incorporated into Block 1. The ground floor empty bay in Block 1 combined with wider wind corridor between Blocks 1 and 2 have enlarged the wind permeability of the Development and helps wind penetrate to the Tsz Tin Tsuen as demonstrated in Figure 39.

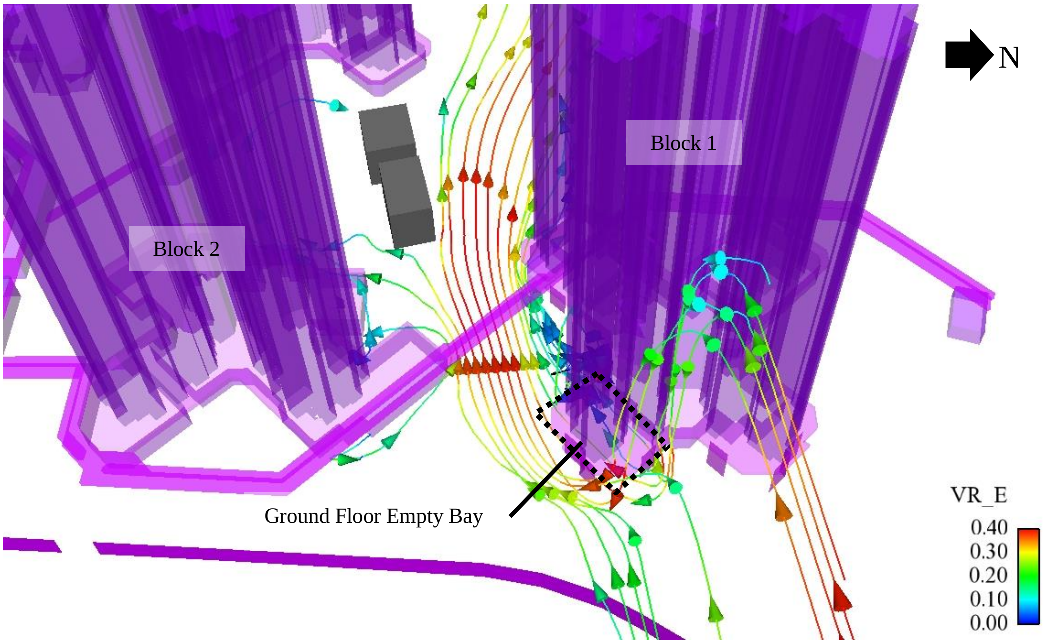


Figure 39 East Wind Passing Through Wind Corridors

6 Expert Review on Minor Design Update

Proposed Scheme considered in this study consist 3 pedestrian footbridges (as shown in Figure 8 to Figure 12). Nevertheless all the footbridges are omitted in the latest design. Since the design changes would enhance the wind permeability in the Proposed Scheme, thus, it is expected that this minor design change would not have significant adverse impact in terms of ventilation performance of the surroundings.

7 Conclusion

The Development at Tuen Mun Area Site 2 is located in a relatively low-density urban area to the west of Siu Hong Court and Yuen Long Highway. To assess the ventilation performance of the Development and areas immediately surrounding the site, an AVA Initial Study (the Study) was conducted.

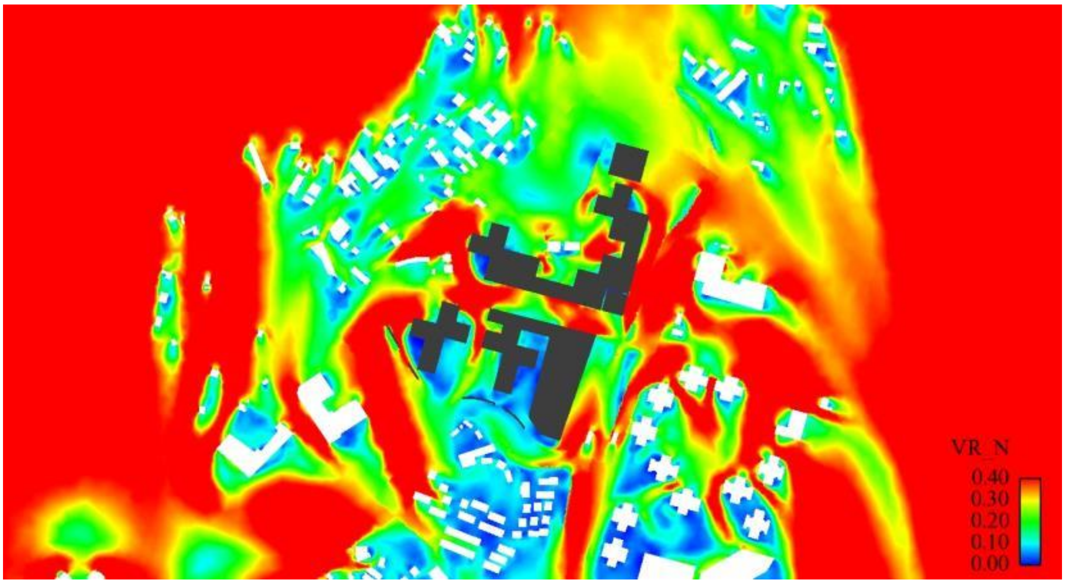
A series of CFD simulations using realizable k – ε turbulence modelling were performed using the Air Ventilation Assessment (AVA) methodology for Initial Study as stipulated in the Technical Circular and Technical Guide. Eight wind directions were selected: N, NNE, NE, ENE, E, ESE, SSE and SW, which totally cover 86.9% of wind availability in a year. Two scenarios, 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, altogether 38 perimeter test points, 96 overall test points were selected to assess the air ventilation performance at the surrounding existing developments and within the project site of the Development. The major findings of this study can be summarized as follows:

- The SVRs are 0.19 for the Baseline Scheme and 0.20 for the Proposed Scheme respectively. This implies that the ventilation performance of the Proposed Scheme is better than the Baseline Scheme in the immediate vicinity.
- The LVR are 0.18 and 0.18 for the Baseline Scheme and the Proposed Scheme respectively.
- Results show that higher VR are achieved at Tsz Tin Road, Tsz Tin Tsuen, and Tsz Tin Garden. For other focus areas, the same VR values are obtained for both schemes.

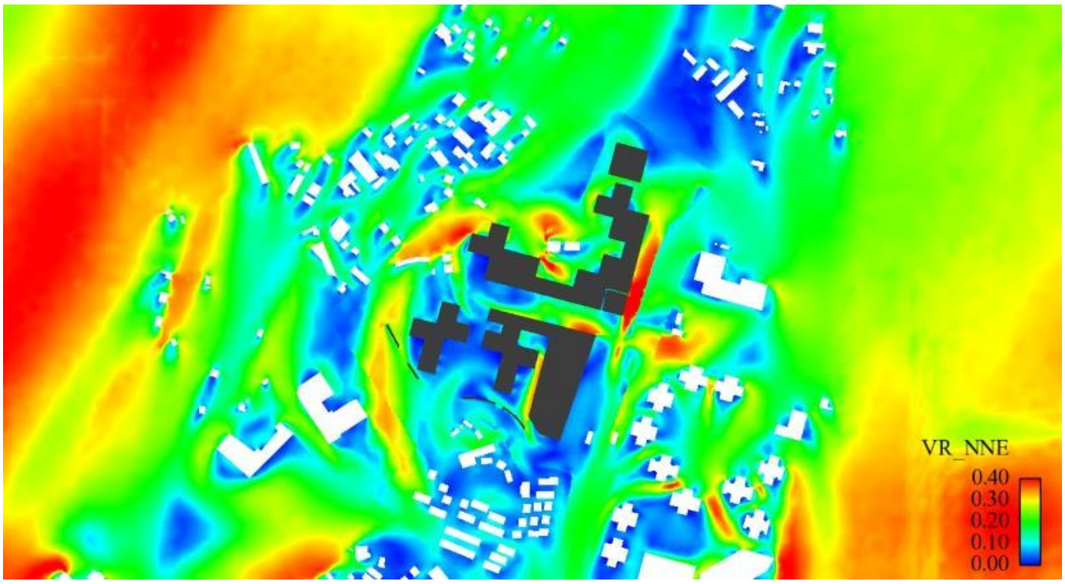
Appendix A

Directional VR Contour Plots

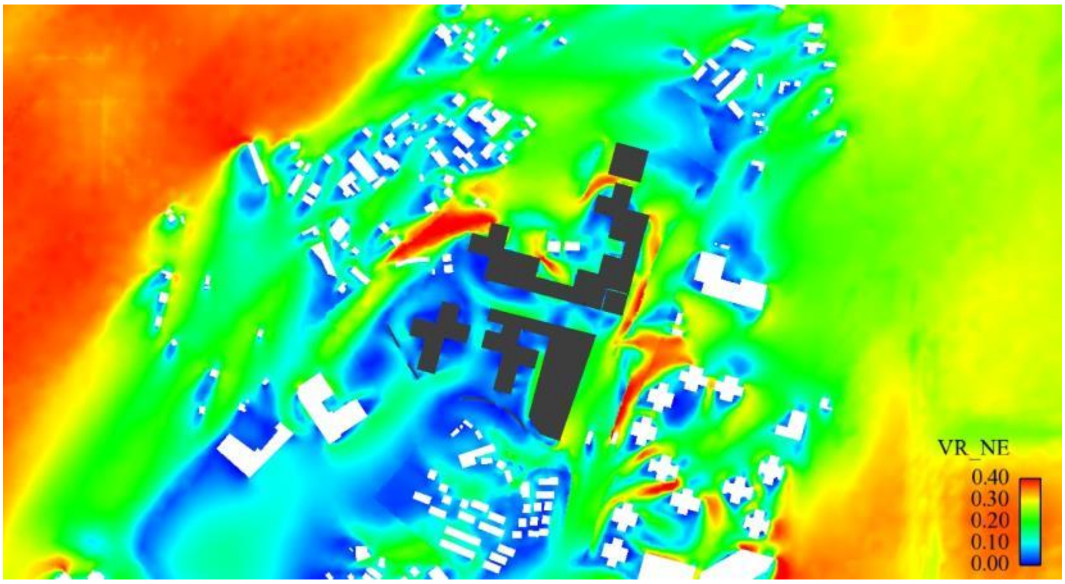
A1 Baseline Scheme Directional VR Contour Plots



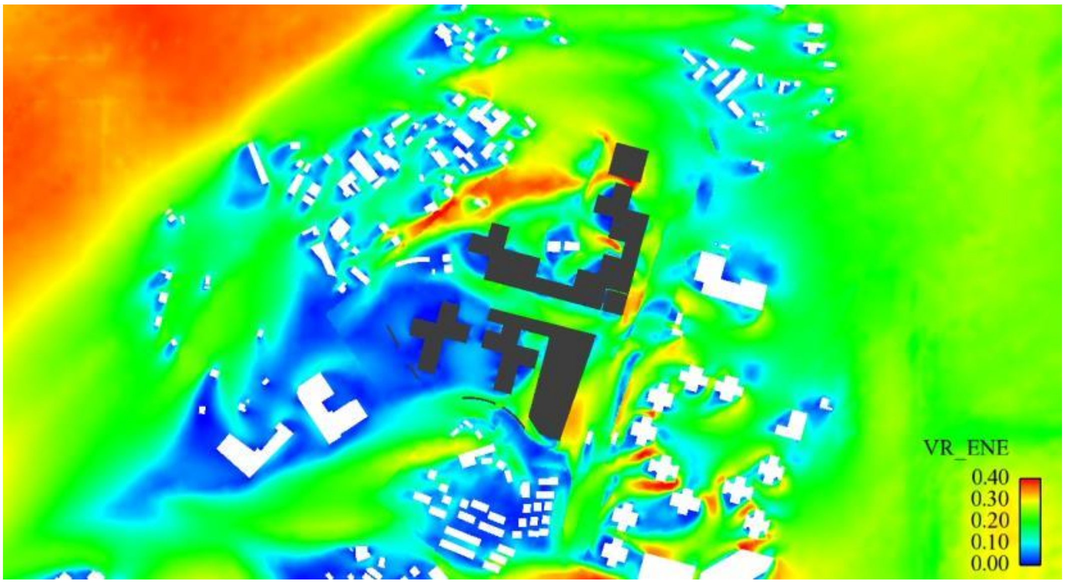
N Direction (Baseline Scheme)



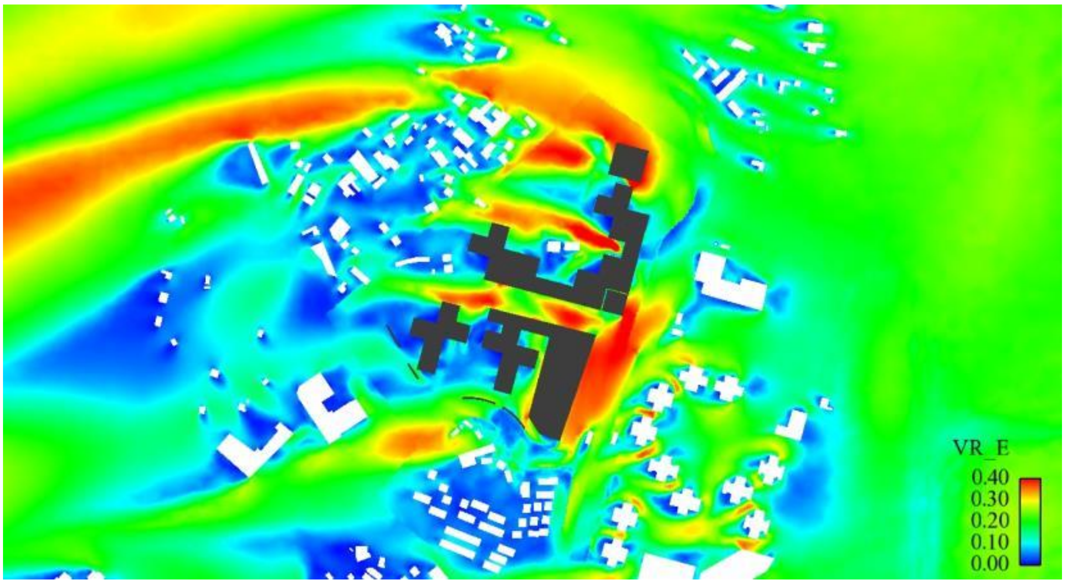
NNE Direction (Baseline Scheme)



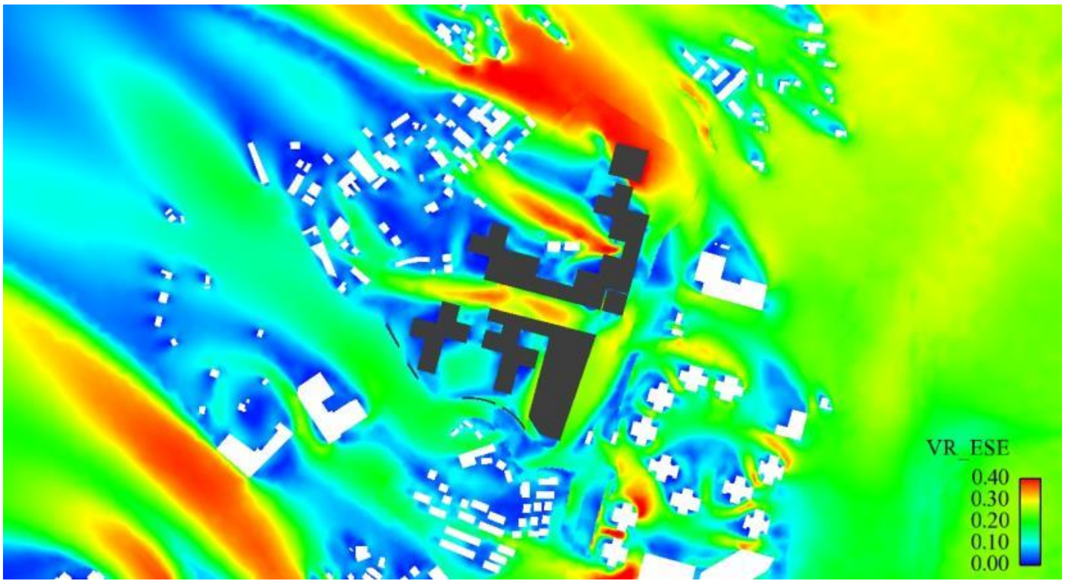
NE Direction (Baseline Scheme)



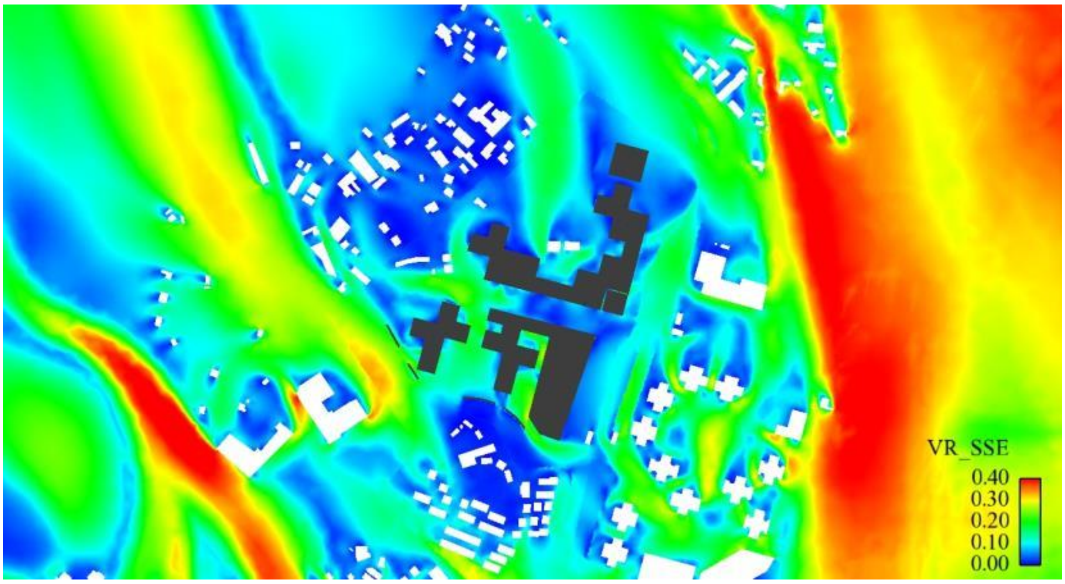
ENE Direction (Baseline Scheme)



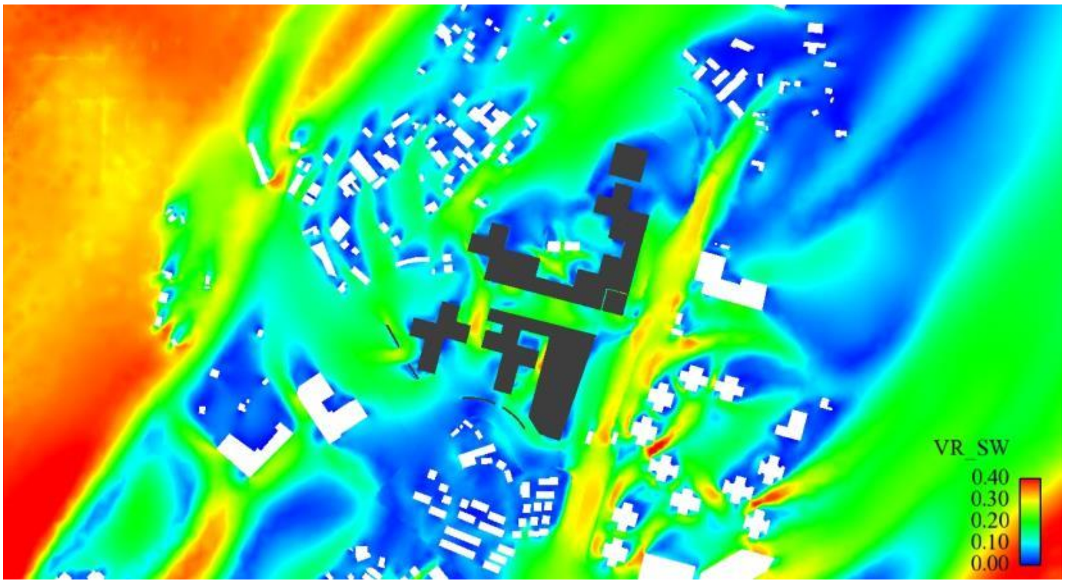
E Direction (Baseline Scheme)



ESE Direction (Baseline Scheme)

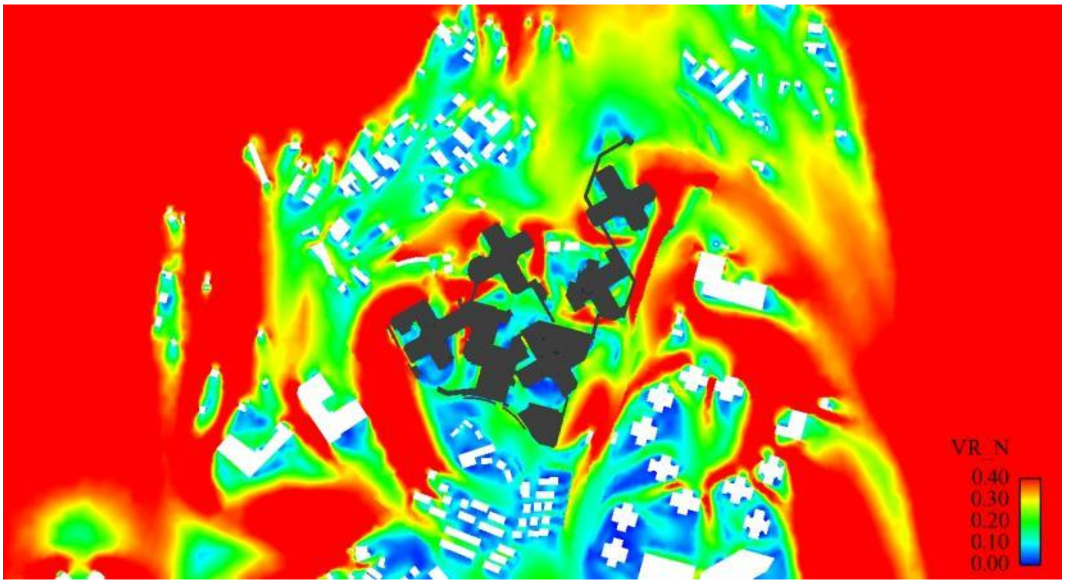


SSE Direction (Baseline Scheme)

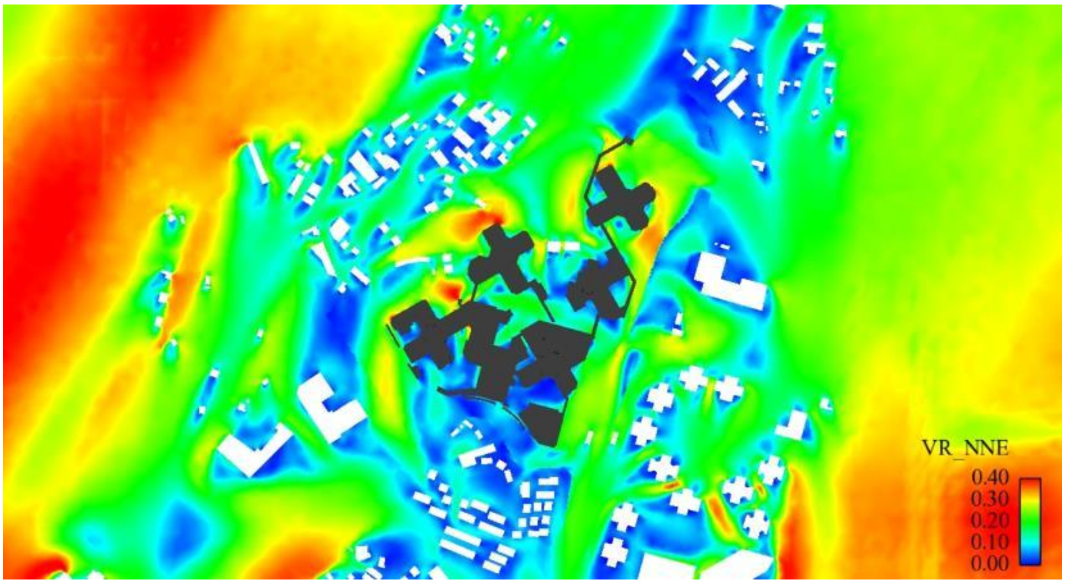


SW Direction (Baseline Scheme)

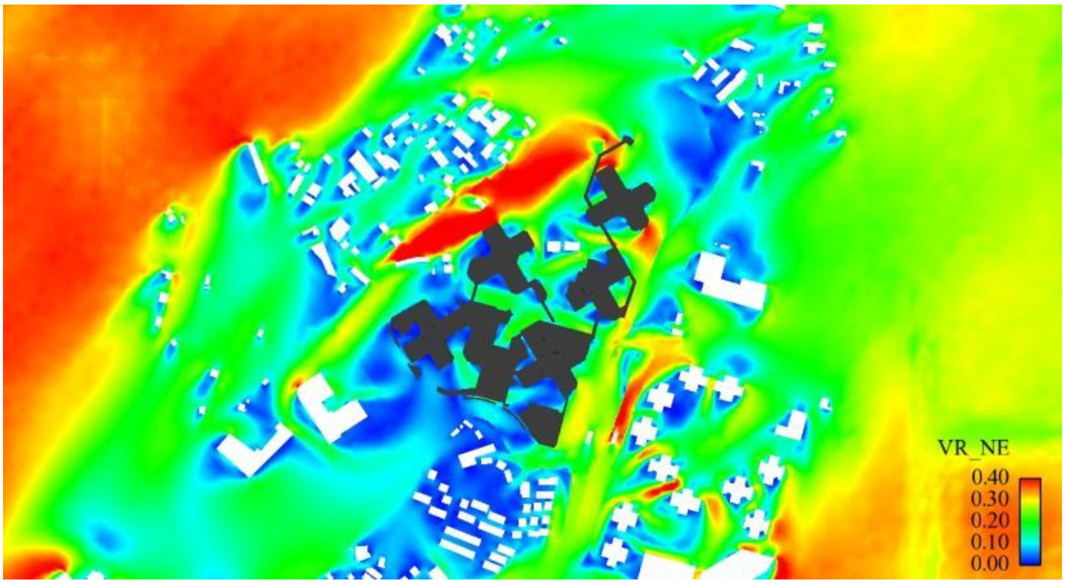
A2 Proposed Scheme Directional VR Contour Plots



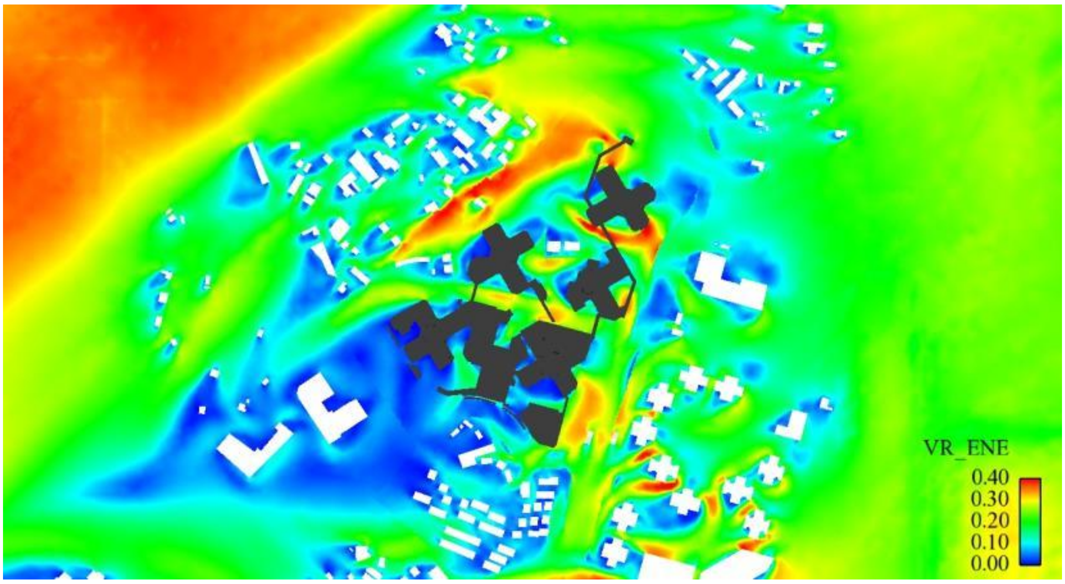
N Direction (Proposed Scheme)



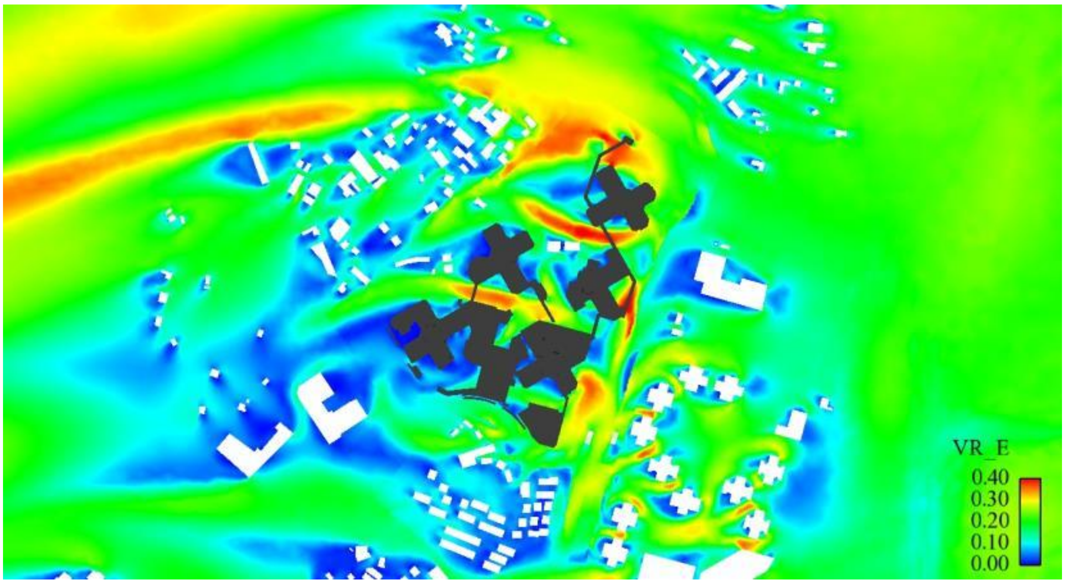
NNE Direction (Proposed Scheme)



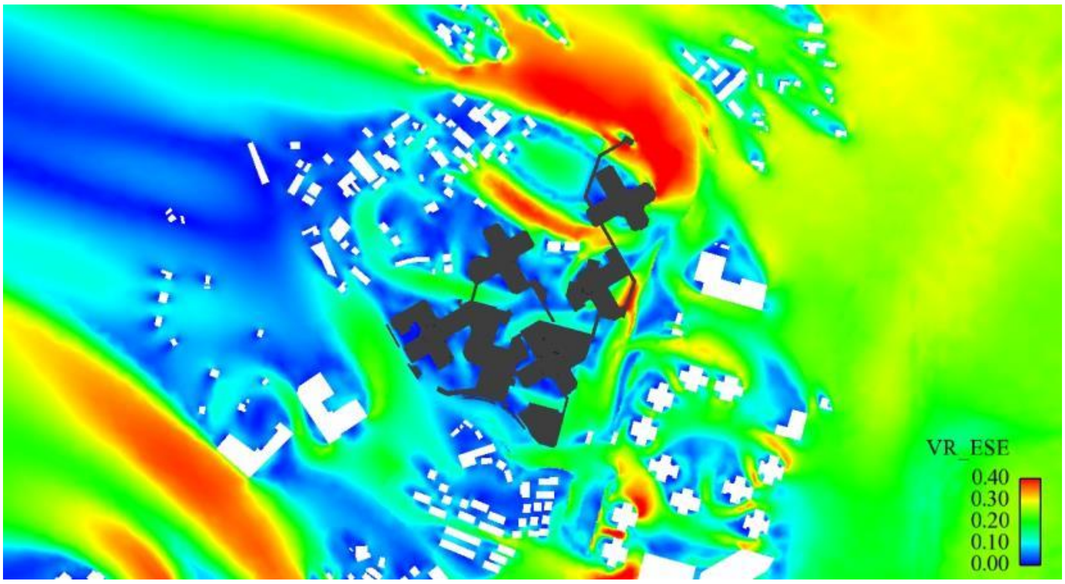
NE Direction (Proposed Scheme)



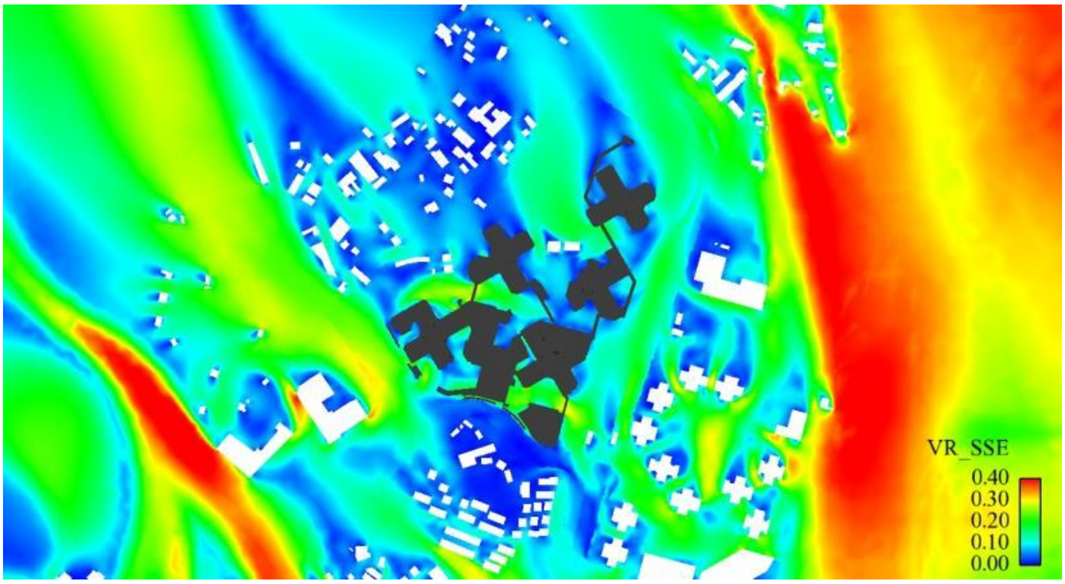
ENE Direction (Proposed Scheme)



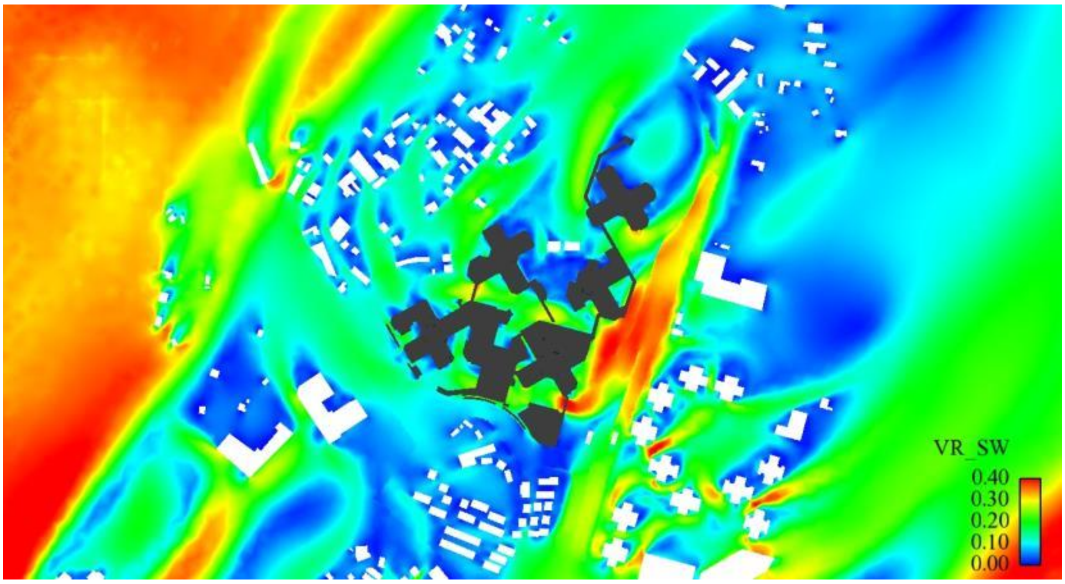
E Direction (Proposed Scheme)



ESE Direction (Proposed Scheme)



SSE Direction (Proposed Scheme)

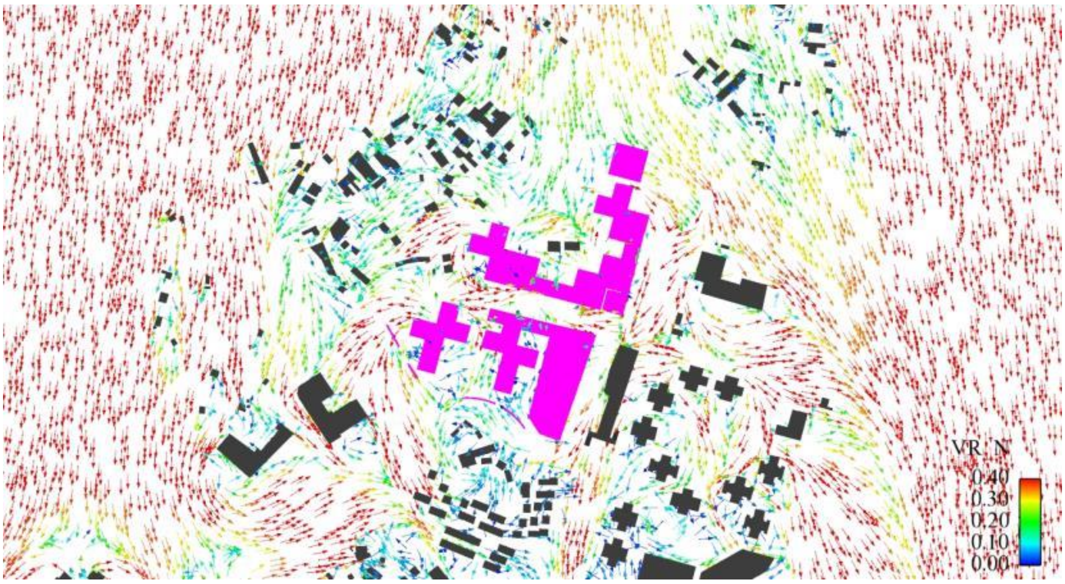


SW Direction (Proposed Scheme)

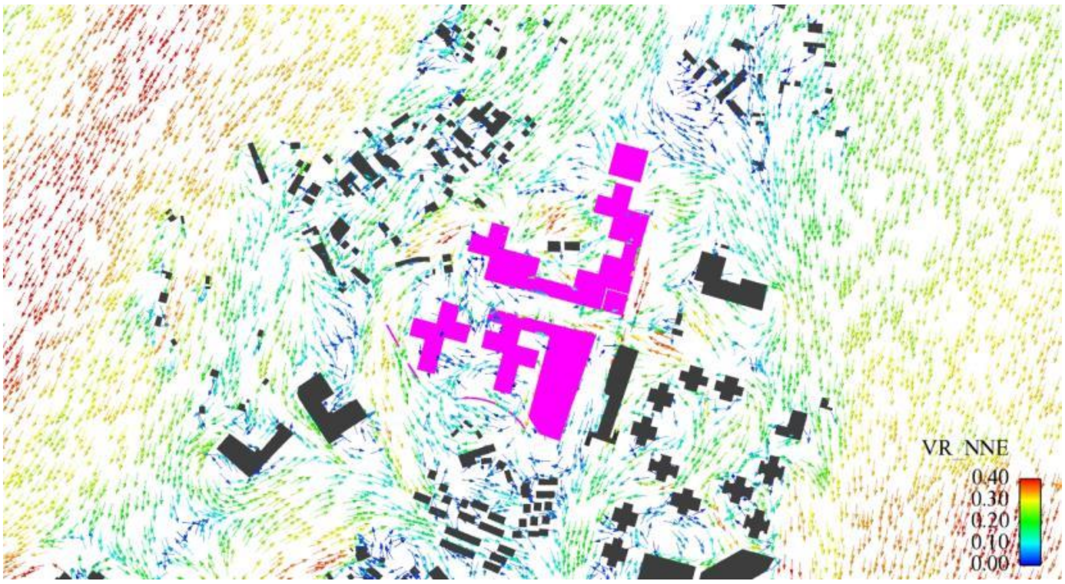
Appendix B

Directional VR Vector Plots

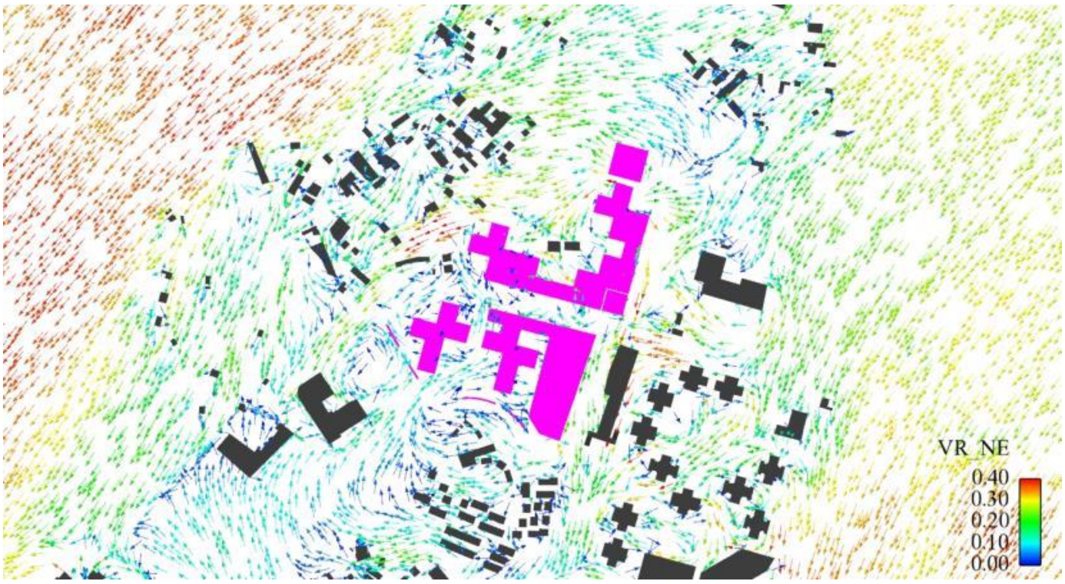
B1 Baseline Scheme Directional VR Vector Plots



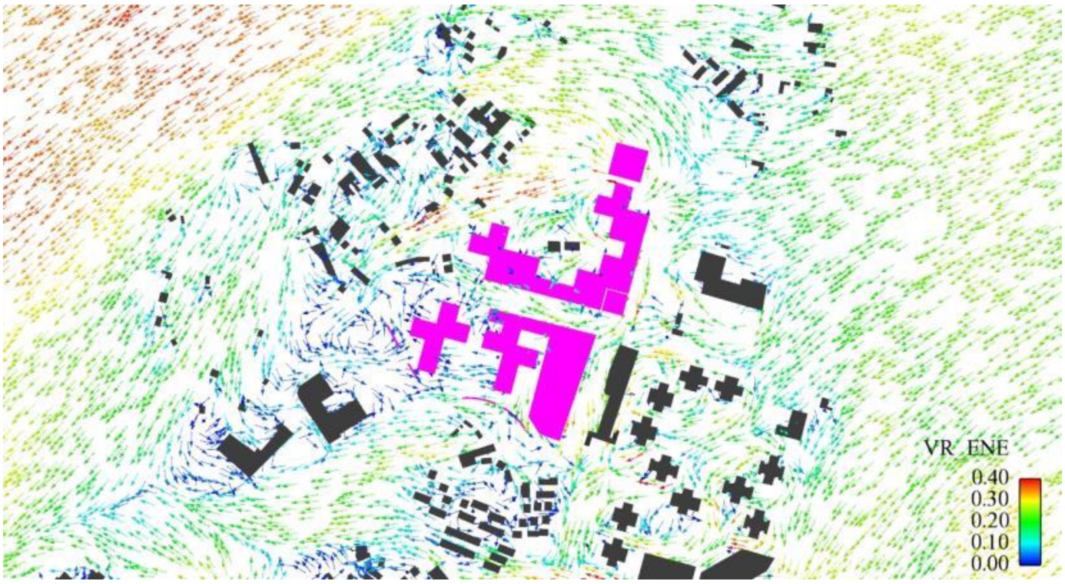
N Direction (Baseline Scheme)



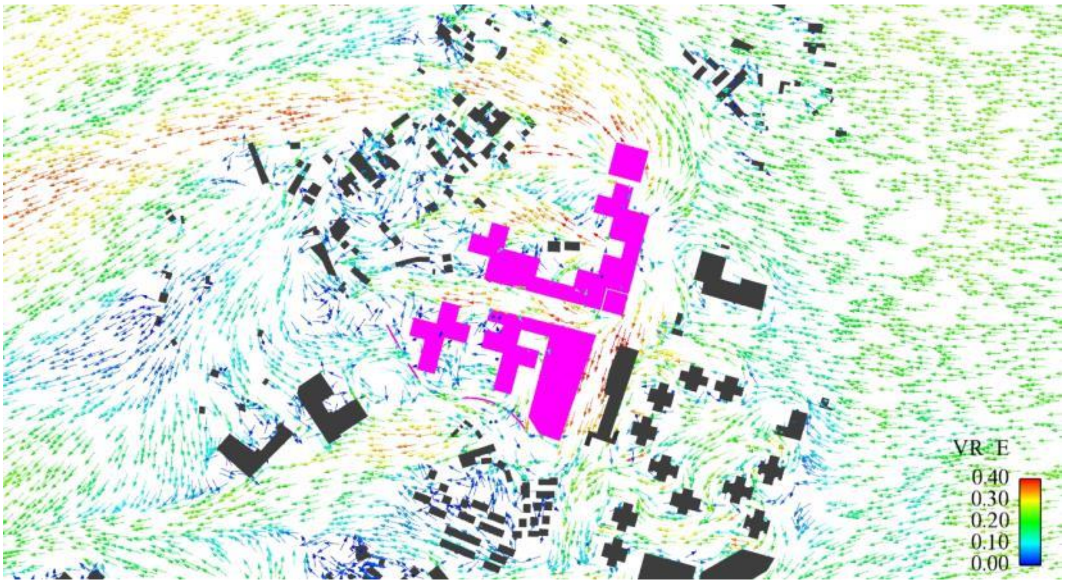
NNE Direction (Baseline Scheme)



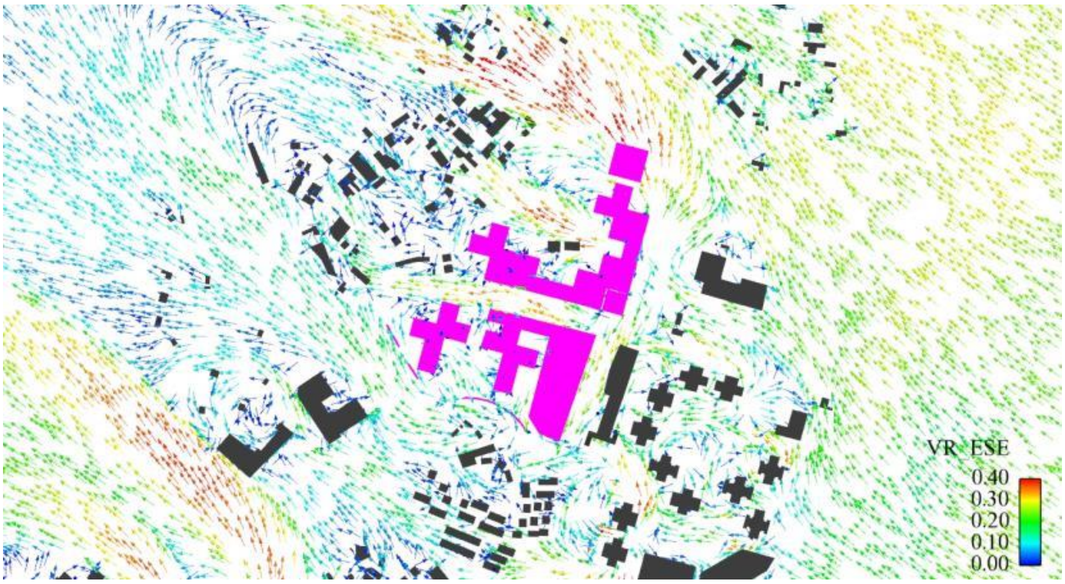
NE Direction (Baseline Scheme)



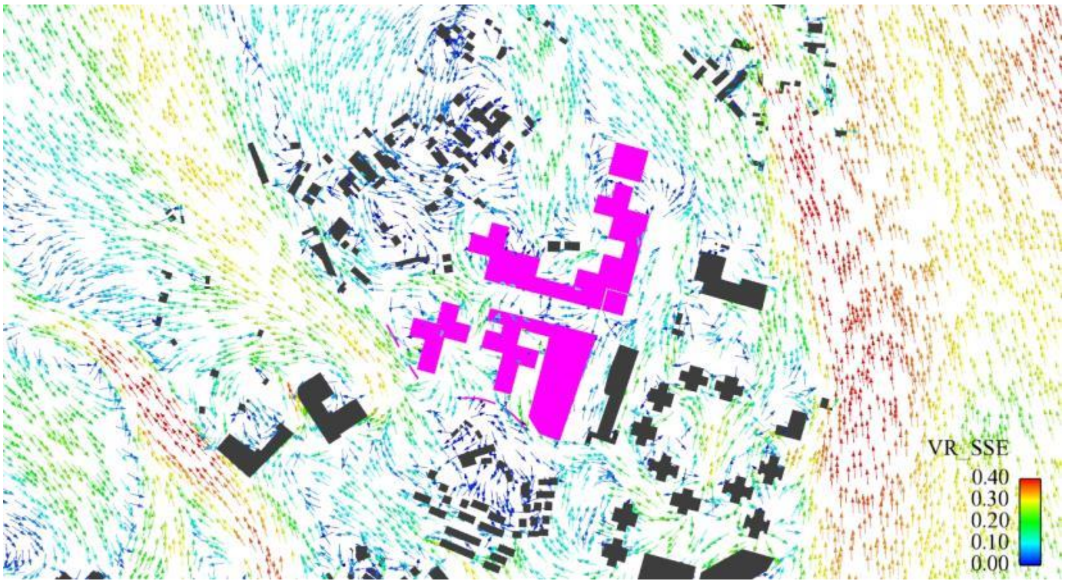
ENE Direction (Baseline Scheme)



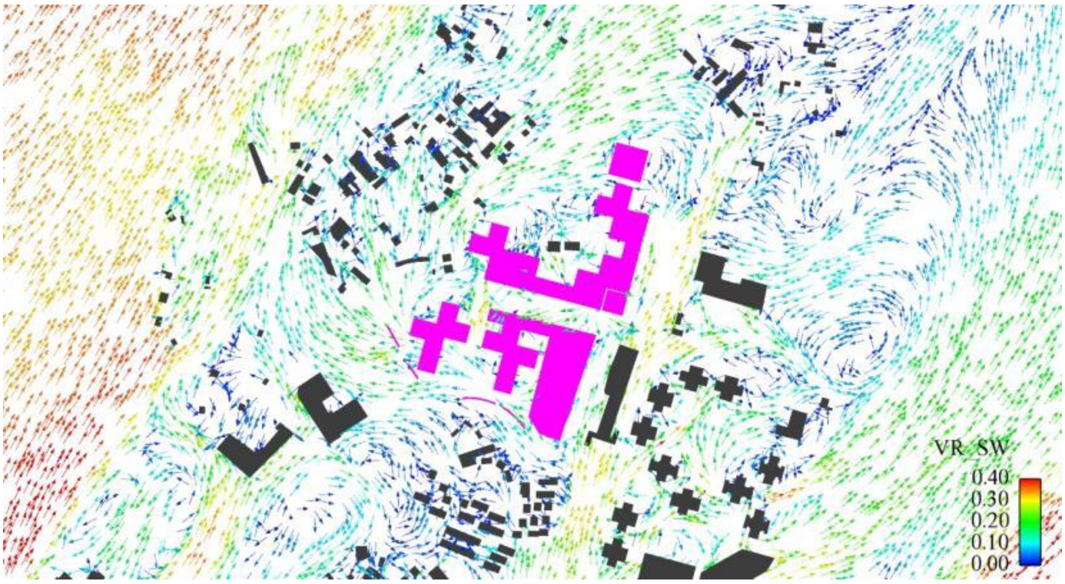
E Direction (Baseline Scheme)



ESE Direction (Baseline Scheme)

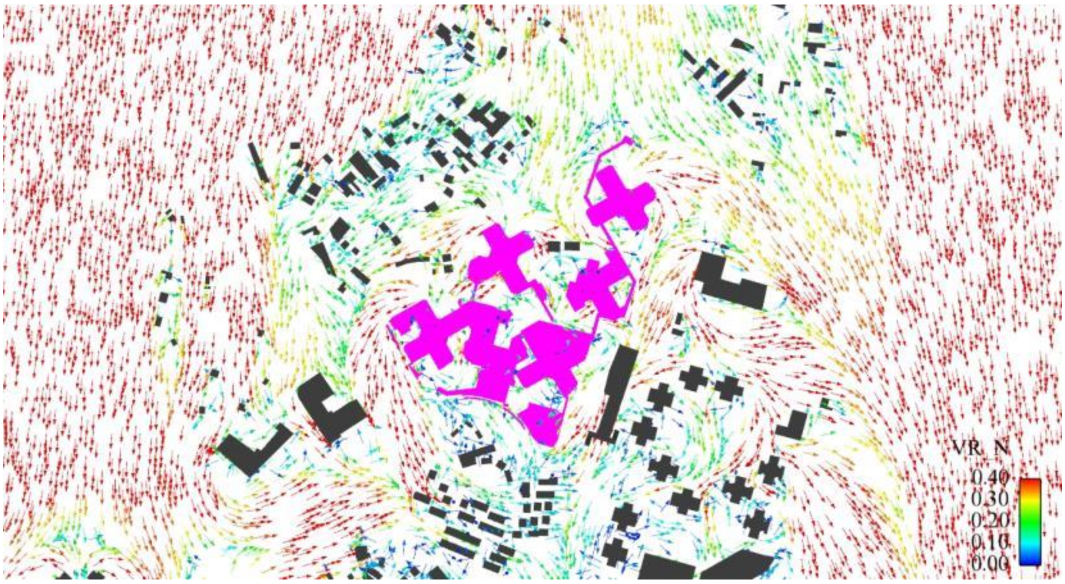


SSE Direction (Baseline Scheme)

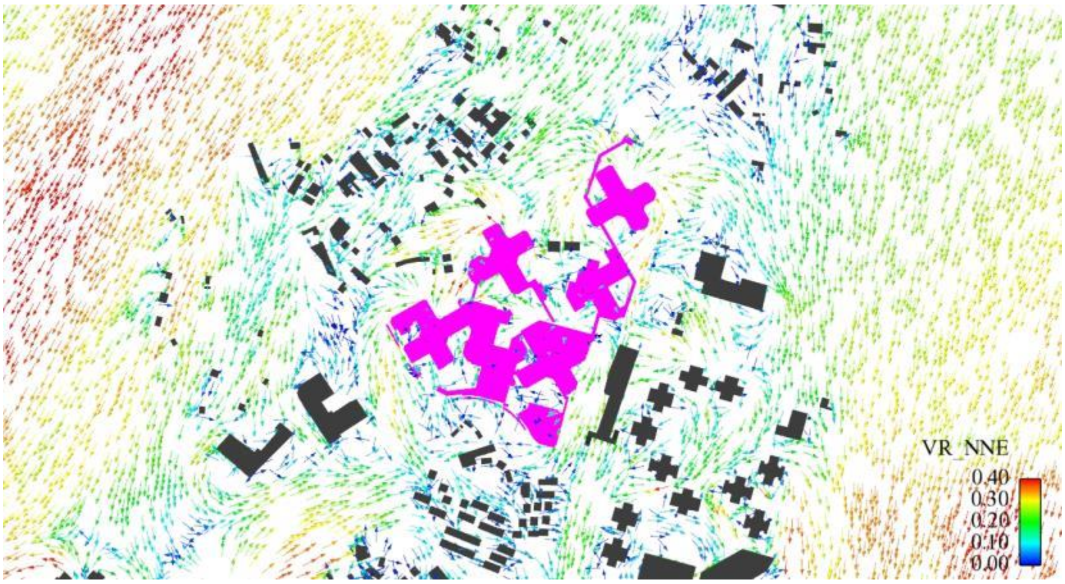


SW Direction (Baseline Scheme)

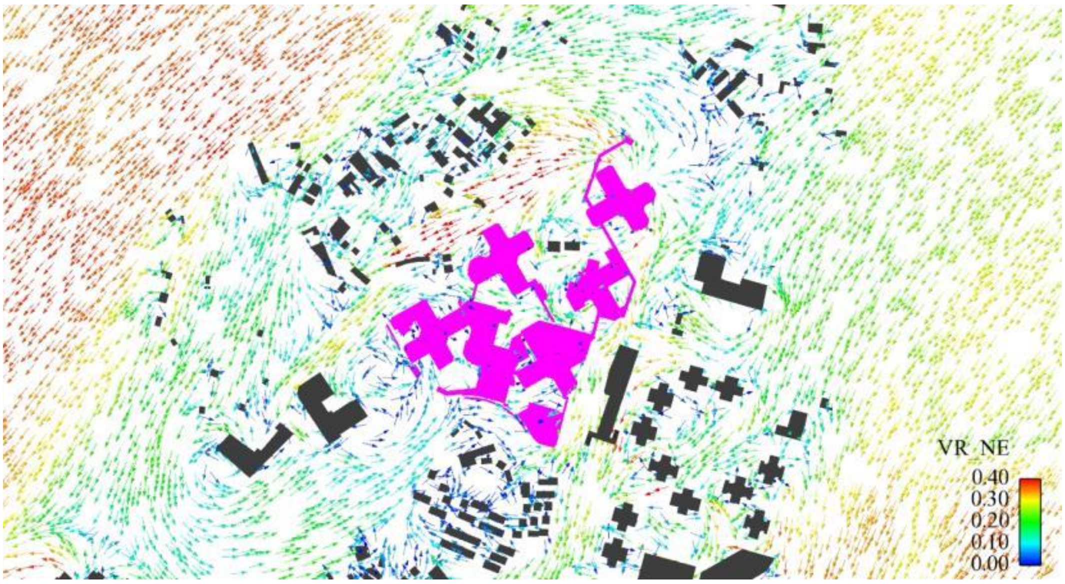
B2 Proposed Scheme Direction VR Vector Plots



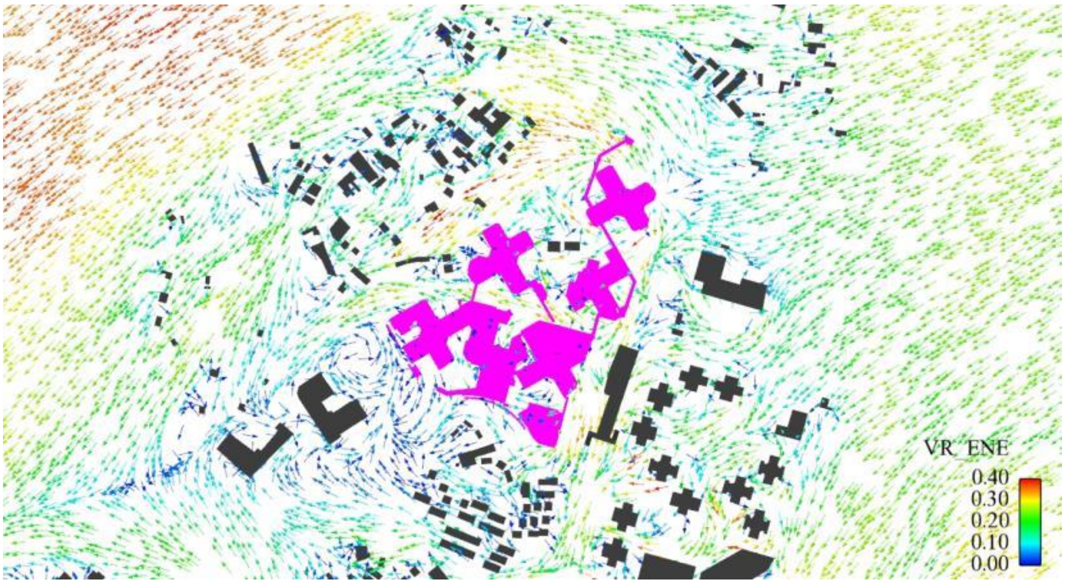
N Direction (Proposed Scheme)



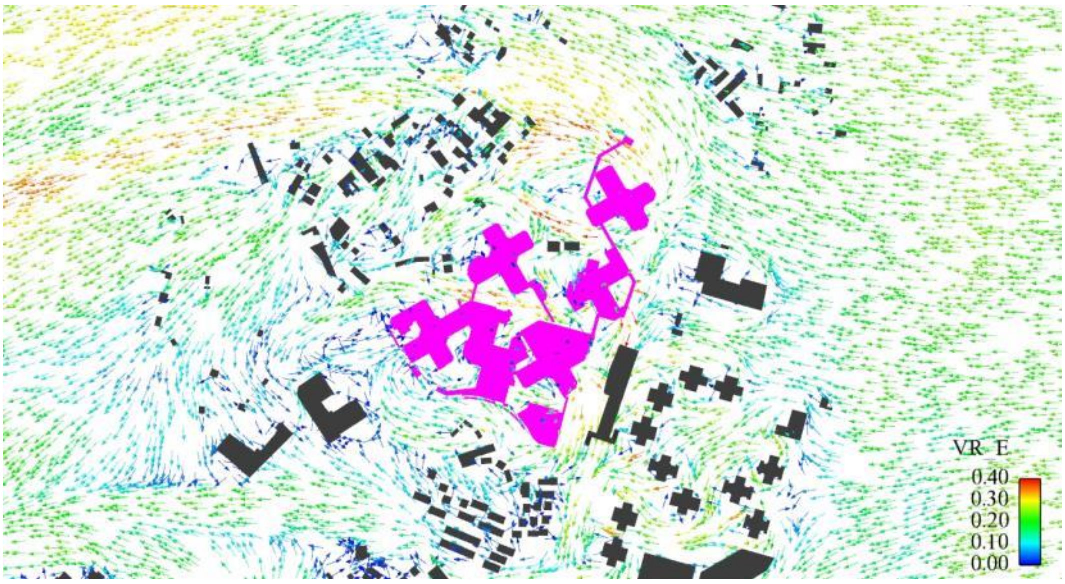
NNE Direction (Proposed Scheme)



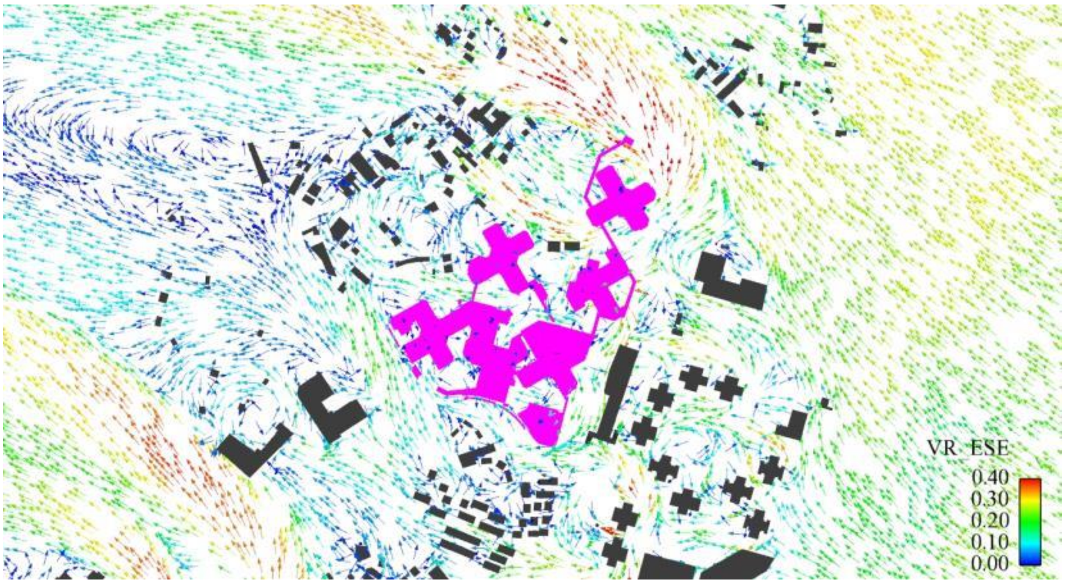
NE Direction (Proposed Scheme)



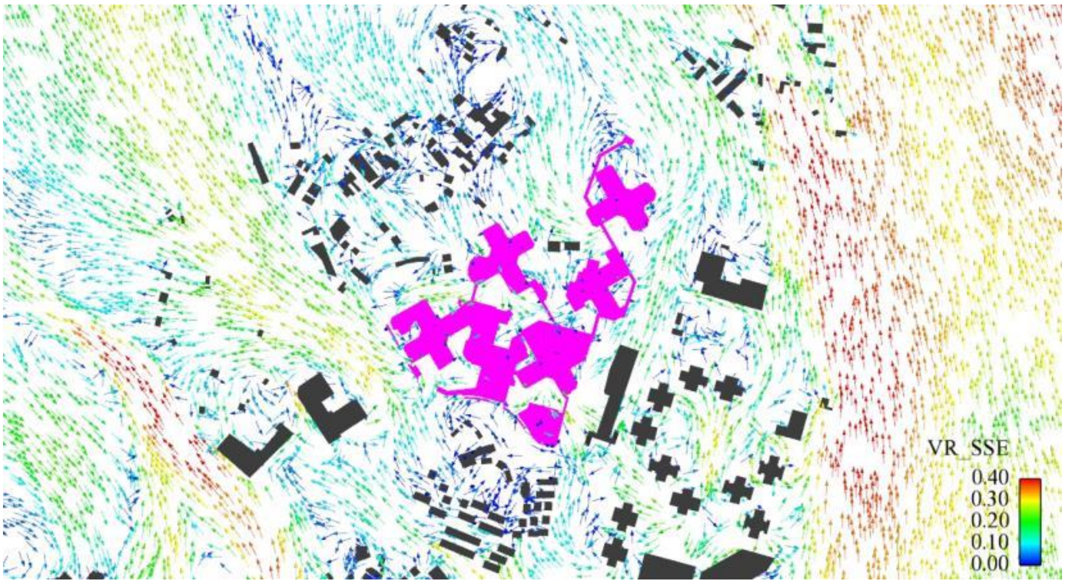
ENE Direction (Proposed Scheme)



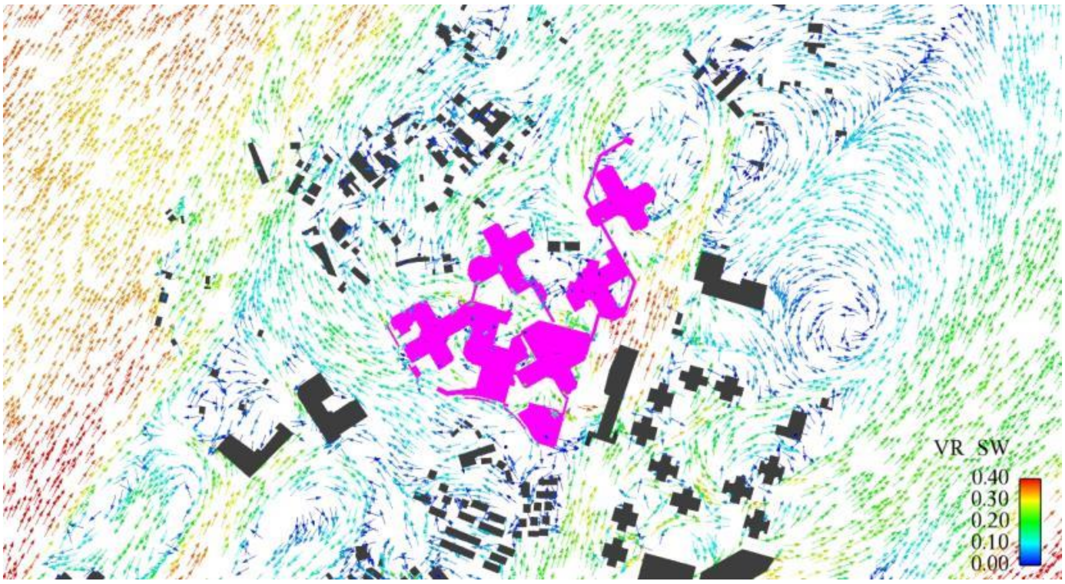
E Direction (Proposed Scheme)



ESE Direction (Proposed Scheme)



SSE Direction (Proposed Scheme)



SW Direction (Proposed Scheme)

Appendix C

Velocity Ratio Table of the Test Points

C1 Test Point for Baseline Scheme

Table C1 VR Value for the Overall Points of Baseline Scheme

Direction	NNE	NE	ENE	E	ESE	SSE	SW	N	Combined
Frequency	*0.08*	*0.09*	*0.15*	*0.23*	*0.05*	*0.06*	*0.08*	*0.12*	*0.87*
O1	0.18	0.14	0.14	0.13	0.08	0.07	0.12	0.25	**0.15**
O2	0.15	0.16	0.13	0.03	0.12	0.13	0.12	0.24	**0.12**
O3	0.15	0.12	0.09	0.07	0.03	0.13	0.14	0.22	**0.12**
O4	0.05	0.15	0.19	0.06	0.12	0.06	0.19	0.23	**0.13**
O5	0.16	0.17	0.22	0.26	0.10	0.05	0.29	0.35	**0.22**
O6	0.17	0.16	0.22	0.24	0.32	0.10	0.16	0.35	**0.23**
O7	0.16	0.15	0.18	0.24	0.30	0.12	0.21	0.31	**0.22**
O8	0.14	0.17	0.21	0.24	0.28	0.15	0.19	0.25	**0.21**
O9	0.02	0.05	0.13	0.19	0.27	0.19	0.13	0.31	**0.17**
O10	0.02	0.08	0.16	0.24	0.32	0.23	0.05	0.27	**0.18**
O11	0.10	0.03	0.13	0.19	0.25	0.20	0.26	0.33	**0.18**
O12	0.10	0.15	0.09	0.13	0.19	0.06	0.27	0.34	**0.16**
O13	0.19	0.25	0.17	0.11	0.13	0.18	0.29	0.50	**0.22**
O14	0.16	0.19	0.08	0.19	0.02	0.16	0.27	0.48	**0.21**
O15	0.11	0.04	0.11	0.32	0.14	0.13	0.30	0.42	**0.22**
O16	0.07	0.08	0.12	0.38	0.08	0.09	0.30	0.06	**0.18**
O17	0.13	0.11	0.11	0.31	0.03	0.10	0.28	0.12	**0.18**
O18	0.15	0.17	0.18	0.24	0.03	0.14	0.31	0.32	**0.21**
O19	0.19	0.19	0.21	0.15	0.11	0.08	0.29	0.42	**0.21**
O20	0.18	0.09	0.28	0.13	0.25	0.09	0.24	0.42	**0.21**
O21	0.14	0.22	0.16	0.03	0.05	0.04	0.15	0.13	**0.11**
O22	0.18	0.19	0.19	0.13	0.06	0.04	0.15	0.16	**0.15**
O23	0.21	0.21	0.19	0.20	0.15	0.04	0.09	0.25	**0.18**
O24	0.24	0.31	0.35	0.25	0.21	0.03	0.24	0.25	**0.25**
O25	0.24	0.29	0.36	0.35	0.25	0.02	0.20	0.17	**0.27**
O26	0.21	0.23	0.26	0.32	0.17	0.13	0.08	0.08	**0.21**
O27	0.20	0.27	0.28	0.36	0.40	0.18	0.20	0.27	**0.28**
O28	0.15	0.20	0.23	0.30	0.37	0.07	0.22	0.21	**0.23**
O29	0.26	0.23	0.29	0.29	0.32	0.02	0.07	0.15	**0.22**
O30	0.30	0.26	0.16	0.31	0.32	0.06	0.08	0.18	**0.22**
O31	0.14	0.20	0.12	0.06	0.14	0.07	0.06	0.12	**0.11**
O32	0.19	0.26	0.15	0.12	0.16	0.11	0.19	0.24	**0.17**
O33	0.13	0.25	0.31	0.09	0.10	0.04	0.15	0.24	**0.17**
O34	0.17	0.12	0.09	0.03	0.05	0.03	0.13	0.18	**0.09**
O35	0.19	0.33	0.33	0.06	0.02	0.01	0.14	0.30	**0.18**
O36	0.11	0.10	0.14	0.07	0.06	0.02	0.15	0.16	**0.11**
O37	0.33	0.43	0.20	0.06	0.03	0.03	0.17	0.46	**0.21**

O38	0.17	0.18	0.18	0.24	0.03	0.01	0.12	0.20	**0.17**
O39	0.06	0.05	0.03	0.04	0.19	0.01	0.09	0.18	**0.07**
O40	0.13	0.18	0.14	0.16	0.11	0.01	0.13	0.10	**0.13**
O41	0.15	0.23	0.27	0.33	0.34	0.06	0.05	0.29	**0.24**
O42	0.12	0.25	0.32	0.33	0.09	0.18	0.17	0.19	**0.24**
O43	0.16	0.20	0.26	0.31	0.36	0.17	0.13	0.16	**0.23**
O44	0.16	0.23	0.27	0.26	0.20	0.07	0.21	0.09	**0.20**
O45	0.14	0.20	0.24	0.31	0.37	0.09	0.21	0.21	**0.23**
O46	0.05	0.11	0.20	0.25	0.32	0.12	0.11	0.25	**0.19**
O47	0.10	0.03	0.10	0.22	0.30	0.10	0.09	0.30	**0.16**
O48	0.12	0.03	0.15	0.20	0.28	0.21	0.04	0.32	**0.17**
O49	0.16	0.16	0.18	0.20	0.27	0.32	0.04	0.20	**0.18**
O50	0.15	0.09	0.12	0.17	0.21	0.13	0.05	0.35	**0.16**
O51	0.14	0.18	0.14	0.18	0.28	0.28	0.08	0.36	**0.20**
O52	0.14	0.17	0.13	0.17	0.20	0.19	0.21	0.27	**0.18**
O53	0.02	0.18	0.12	0.19	0.31	0.22	0.14	0.29	**0.18**
O54	0.01	0.06	0.06	0.15	0.25	0.24	0.10	0.11	**0.11**
O55	0.01	0.15	0.06	0.17	0.14	0.10	0.03	0.03	**0.09**
O56	0.07	0.03	0.11	0.17	0.20	0.19	0.05	0.20	**0.13**
O57	0.11	0.18	0.15	0.13	0.23	0.27	0.08	0.20	**0.16**
O58	0.15	0.07	0.06	0.14	0.11	0.13	0.09	0.44	**0.15**
O59	0.08	0.20	0.24	0.19	0.27	0.16	0.03	0.53	**0.22**
O60	0.28	0.29	0.19	0.18	0.16	0.04	0.07	0.40	**0.21**
O61	0.21	0.14	0.08	0.20	0.21	0.07	0.18	0.36	**0.19**
O62	0.36	0.38	0.06	0.10	0.21	0.11	0.26	0.26	**0.19**
O63	0.33	0.26	0.21	0.24	0.31	0.02	0.32	0.22	**0.24**
O64	0.12	0.07	0.13	0.22	0.27	0.04	0.07	0.33	**0.17**
O65	0.23	0.37	0.17	0.22	0.23	0.17	0.26	0.50	**0.27**
O66	0.19	0.02	0.16	0.23	0.13	0.17	0.17	0.61	**0.23**
O67	0.35	0.33	0.23	0.13	0.17	0.13	0.15	0.60	**0.26**
O68	0.07	0.05	0.16	0.07	0.18	0.21	0.11	0.19	**0.12**
O69	0.20	0.19	0.18	0.20	0.12	0.23	0.11	0.34	**0.20**
O70	0.16	0.27	0.20	0.23	0.18	0.12	0.41	0.18	**0.22**
O71	0.18	0.29	0.14	0.09	0.29	0.22	0.24	0.08	**0.16**
O72	0.03	0.17	0.11	0.04	0.30	0.25	0.10	0.22	**0.12**
O73	0.03	0.10	0.04	0.22	0.14	0.16	0.31	0.14	**0.14**
O74	0.13	0.14	0.19	0.08	0.14	0.27	0.14	0.35	**0.17**
O75	0.19	0.17	0.10	0.07	0.14	0.26	0.15	0.21	**0.14**
O76	0.19	0.22	0.16	0.12	0.13	0.26	0.12	0.28	**0.18**
O77	0.13	0.07	0.01	0.05	0.15	0.23	0.14	0.26	**0.11**
O78	0.03	0.29	0.07	0.06	0.16	0.25	0.15	0.36	**0.15**
O79	0.21	0.15	0.07	0.10	0.04	0.07	0.03	0.38	**0.14**
O80	0.14	0.20	0.10	0.14	0.06	0.14	0.13	0.17	**0.14**
O81	0.08	0.06	0.01	0.10	0.12	0.15	0.17	0.35	**0.13**

O82	0.29	0.06	0.03	0.19	0.22	0.35	0.11	0.56	**0.22**
O83	0.06	0.16	0.07	0.20	0.08	0.19	0.07	0.11	**0.13**
O84	0.23	0.11	0.16	0.25	0.17	0.07	0.18	0.37	**0.21**
O85	0.15	0.08	0.05	0.15	0.19	0.30	0.20	0.42	**0.18**
O86	0.19	0.09	0.12	0.31	0.16	0.22	0.07	0.45	**0.22**
O87	0.28	0.09	0.23	0.32	0.09	0.06	0.05	0.61	**0.26**
O88	0.10	0.05	0.14	0.11	0.17	0.11	0.11	0.26	**0.13**
O89	0.03	0.08	0.29	0.33	0.12	0.11	0.04	0.37	**0.22**
O90	0.29	0.04	0.08	0.07	0.09	0.09	0.05	0.55	**0.16**
O91	0.09	0.14	0.09	0.06	0.09	0.12	0.07	0.34	**0.12**
O92	0.06	0.17	0.06	0.01	0.09	0.03	0.06	0.05	**0.06**
O93	0.12	0.08	0.02	0.07	0.05	0.02	0.05	0.10	**0.06**
O94	0.02	0.16	0.13	0.07	0.12	0.03	0.08	0.09	**0.09**
O95	0.09	0.06	0.02	0.05	0.02	0.01	0.07	0.09	**0.05**
O96	0.12	0.02	0.08	0.02	0.24	0.09	0.18	0.08	**0.08**

Table C2 VR Value for the Perimeter Points of Baseline Scheme

Direction	NNE	NE	ENE	E	ESE	SSE	SW	N	Combined
Frequency	*0.08*	*0.09*	*0.15*	*0.23*	*0.05*	*0.06*	*0.08*	*0.12*	*0.87*
P1	0.05	0.31	0.12	0.15	0.03	0.11	0.17	0.29	**0.16**
P2	0.24	0.25	0.06	0.26	0.26	0.12	0.17	0.24	**0.20**
P3	0.16	0.09	0.06	0.17	0.23	0.20	0.12	0.08	**0.13**
P4	0.11	0.02	0.13	0.16	0.22	0.23	0.14	0.25	**0.16**
P5	0.28	0.02	0.11	0.10	0.12	0.17	0.10	0.52	**0.18**
P6	0.39	0.40	0.18	0.04	0.08	0.14	0.20	0.56	**0.23**
P7	0.32	0.41	0.34	0.32	0.02	0.10	0.23	0.40	**0.30**
P8	0.25	0.24	0.20	0.36	0.14	0.07	0.02	0.21	**0.22**
P9	0.26	0.04	0.13	0.36	0.25	0.08	0.05	0.26	**0.21**
P10	0.41	0.17	0.23	0.28	0.31	0.12	0.03	0.39	**0.26**
P11	0.32	0.22	0.03	0.04	0.08	0.10	0.19	0.36	**0.15**
P12	0.06	0.12	0.04	0.03	0.09	0.11	0.19	0.05	**0.07**
P13	0.22	0.11	0.27	0.43	0.36	0.05	0.13	0.21	**0.26**
P14	0.21	0.08	0.25	0.38	0.31	0.06	0.14	0.26	**0.25**
P15	0.01	0.16	0.03	0.09	0.10	0.10	0.10	0.11	**0.08**
P16	0.07	0.13	0.20	0.25	0.07	0.06	0.12	0.11	**0.16**
P17	0.04	0.17	0.17	0.02	0.23	0.01	0.17	0.09	**0.10**
P18	0.09	0.19	0.27	0.38	0.40	0.06	0.18	0.18	**0.25**
P19	0.02	0.16	0.21	0.34	0.37	0.10	0.06	0.23	**0.21**
P20	0.04	0.07	0.21	0.30	0.36	0.08	0.04	0.28	**0.20**
P21	0.25	0.22	0.20	0.23	0.28	0.01	0.03	0.31	**0.21**
P22	0.28	0.28	0.20	0.15	0.22	0.05	0.13	0.46	**0.22**
P23	0.36	0.32	0.26	0.08	0.17	0.08	0.22	0.51	**0.24**
P24	0.38	0.25	0.16	0.17	0.07	0.11	0.25	0.61	**0.26**
P25	0.44	0.33	0.33	0.36	0.23	0.07	0.17	0.59	**0.35**
P26	0.28	0.38	0.28	0.40	0.31	0.07	0.14	0.19	**0.28**
P27	0.10	0.27	0.23	0.39	0.28	0.10	0.18	0.19	**0.25**
P28	0.08	0.20	0.24	0.37	0.23	0.09	0.19	0.26	**0.24**
P29	0.06	0.18	0.24	0.34	0.09	0.07	0.14	0.37	**0.23**
P30	0.05	0.22	0.27	0.13	0.07	0.13	0.17	0.42	**0.20**
P31	0.03	0.13	0.03	0.09	0.11	0.06	0.05	0.18	**0.09**
P32	0.10	0.05	0.05	0.09	0.06	0.03	0.10	0.10	**0.07**
P33	0.04	0.01	0.06	0.05	0.06	0.03	0.10	0.07	**0.05**
P34	0.08	0.03	0.15	0.20	0.13	0.01	0.04	0.11	**0.12**
P35	0.13	0.07	0.14	0.20	0.15	0.07	0.11	0.09	**0.13**
P36	0.19	0.12	0.03	0.13	0.15	0.20	0.13	0.31	**0.15**
P37	0.20	0.10	0.03	0.11	0.14	0.22	0.18	0.18	**0.13**
P38	0.30	0.05	0.03	0.05	0.13	0.18	0.17	0.62	**0.17**

C2 Test Point for Proposed Scheme

Table C3 VR Value for the Overall Points of Proposed Scheme

Direction	NNE	NE	ENE	E	ESE	SSE	SW	N	Combined
Frequency	*0.08*	*0.09*	*0.15*	*0.23*	*0.05*	*0.06*	*0.08*	*0.12*	*0.87*
O1	0.21	0.13	0.16	0.16	0.03	0.13	0.13	0.27	**0.16**
O2	0.13	0.10	0.14	0.09	0.08	0.13	0.15	0.28	**0.14**
O3	0.11	0.12	0.13	0.07	0.08	0.10	0.13	0.25	**0.12**
O4	0.10	0.17	0.21	0.14	0.18	0.06	0.08	0.14	**0.14**
O5	0.19	0.28	0.24	0.26	0.12	0.08	0.25	0.22	**0.22**
O6	0.18	0.17	0.25	0.24	0.31	0.09	0.16	0.31	**0.22**
O7	0.16	0.16	0.21	0.25	0.32	0.13	0.18	0.25	**0.21**
O8	0.10	0.19	0.19	0.24	0.33	0.16	0.19	0.22	**0.20**
O9	0.06	0.06	0.13	0.19	0.28	0.14	0.06	0.25	**0.15**
O10	0.05	0.06	0.14	0.25	0.32	0.20	0.08	0.24	**0.18**
O11	0.16	0.04	0.14	0.20	0.23	0.16	0.32	0.36	**0.20**
O12	0.08	0.15	0.10	0.14	0.21	0.03	0.25	0.21	**0.14**
O13	0.12	0.25	0.18	0.13	0.13	0.16	0.34	0.32	**0.20**
O14	0.17	0.14	0.11	0.05	0.17	0.17	0.32	0.37	**0.16**
O15	0.09	0.05	0.03	0.17	0.02	0.16	0.36	0.38	**0.17**
O16	0.05	0.06	0.22	0.16	0.09	0.18	0.39	0.27	**0.18**
O17	0.20	0.20	0.23	0.19	0.08	0.11	0.26	0.32	**0.21**
O18	0.25	0.28	0.31	0.28	0.12	0.14	0.15	0.41	**0.27**
O19	0.23	0.28	0.27	0.23	0.11	0.04	0.27	0.14	**0.21**
O20	0.22	0.18	0.20	0.13	0.26	0.09	0.24	0.16	**0.17**
O21	0.12	0.16	0.18	0.21	0.14	0.10	0.16	0.13	**0.16**
O22	0.18	0.18	0.19	0.16	0.09	0.05	0.14	0.13	**0.15**
O23	0.21	0.16	0.19	0.19	0.13	0.03	0.09	0.21	**0.17**
O24	0.26	0.36	0.30	0.20	0.25	0.03	0.23	0.26	**0.24**
O25	0.23	0.41	0.40	0.34	0.24	0.07	0.20	0.14	**0.28**
O26	0.25	0.33	0.31	0.33	0.16	0.12	0.01	0.15	**0.24**
O27	0.22	0.27	0.31	0.33	0.39	0.12	0.12	0.25	**0.27**
O28	0.16	0.24	0.24	0.28	0.37	0.06	0.15	0.22	**0.23**
O29	0.28	0.37	0.24	0.23	0.39	0.08	0.08	0.27	**0.24**
O30	0.25	0.08	0.14	0.31	0.30	0.18	0.12	0.28	**0.22**
O31	0.14	0.14	0.20	0.16	0.07	0.06	0.06	0.18	**0.14**
O32	0.21	0.23	0.17	0.11	0.15	0.04	0.21	0.28	**0.17**
O33	0.12	0.25	0.19	0.03	0.13	0.04	0.14	0.28	**0.14**
O34	0.15	0.10	0.19	0.15	0.02	0.08	0.13	0.19	**0.14**
O35	0.20	0.32	0.30	0.06	0.09	0.10	0.13	0.25	**0.18**
O36	0.11	0.10	0.20	0.08	0.12	0.03	0.16	0.15	**0.12**
O37	0.29	0.44	0.31	0.21	0.02	0.07	0.13	0.35	**0.25**
O38	0.19	0.21	0.19	0.21	0.02	0.01	0.10	0.28	**0.18**

O39	0.08	0.04	0.08	0.03	0.09	0.01	0.06	0.12	**0.06**
O40	0.18	0.15	0.17	0.17	0.02	0.03	0.10	0.11	**0.14**
O41	0.16	0.26	0.30	0.30	0.27	0.03	0.04	0.28	**0.23**
O42	0.21	0.42	0.33	0.23	0.18	0.15	0.09	0.27	**0.25**
O43	0.17	0.24	0.27	0.28	0.38	0.10	0.11	0.20	**0.23**
O44	0.19	0.33	0.34	0.34	0.26	0.07	0.23	0.18	**0.27**
O45	0.14	0.20	0.26	0.29	0.39	0.08	0.23	0.14	**0.22**
O46	0.19	0.10	0.19	0.23	0.42	0.17	0.12	0.16	**0.19**
O47	0.27	0.05	0.10	0.20	0.39	0.14	0.02	0.40	**0.19**
O48	0.15	0.02	0.15	0.20	0.29	0.16	0.04	0.34	**0.18**
O49	0.15	0.15	0.17	0.20	0.28	0.29	0.11	0.24	**0.19**
O50	0.12	0.09	0.12	0.17	0.19	0.10	0.05	0.30	**0.15**
O51	0.14	0.18	0.13	0.18	0.28	0.27	0.12	0.36	**0.20**
O52	0.12	0.16	0.13	0.17	0.20	0.16	0.16	0.25	**0.17**
O53	0.02	0.17	0.12	0.17	0.32	0.20	0.09	0.26	**0.16**
O54	0.02	0.06	0.07	0.14	0.26	0.24	0.04	0.15	**0.11**
O55	0.01	0.13	0.07	0.17	0.15	0.10	0.07	0.01	**0.09**
O56	0.08	0.03	0.10	0.18	0.21	0.20	0.17	0.24	**0.15**
O57	0.12	0.17	0.11	0.16	0.24	0.27	0.05	0.15	**0.15**
O58	0.07	0.07	0.07	0.13	0.11	0.12	0.06	0.43	**0.14**
O59	0.19	0.21	0.24	0.02	0.29	0.17	0.08	0.62	**0.21**
O60	0.25	0.29	0.17	0.19	0.17	0.02	0.10	0.47	**0.22**
O61	0.14	0.12	0.07	0.20	0.21	0.08	0.12	0.41	**0.18**
O62	0.28	0.33	0.03	0.13	0.25	0.11	0.33	0.35	**0.20**
O63	0.28	0.23	0.19	0.23	0.31	0.05	0.14	0.25	**0.21**
O64	0.15	0.06	0.11	0.22	0.28	0.07	0.03	0.34	**0.17**
O65	0.20	0.35	0.13	0.20	0.23	0.17	0.13	0.44	**0.23**
O66	0.21	0.04	0.15	0.22	0.15	0.21	0.14	0.32	**0.19**
O67	0.34	0.33	0.23	0.12	0.19	0.15	0.16	0.55	**0.25**
O68	0.08	0.05	0.17	0.05	0.19	0.14	0.03	0.03	**0.08**
O69	0.20	0.18	0.22	0.20	0.11	0.25	0.19	0.22	**0.20**
O70	0.16	0.28	0.21	0.23	0.18	0.14	0.44	0.19	**0.23**
O71	0.20	0.29	0.27	0.11	0.29	0.21	0.20	0.10	**0.19**
O72	0.10	0.28	0.13	0.03	0.31	0.23	0.13	0.15	**0.14**
O73	0.03	0.13	0.13	0.22	0.13	0.12	0.32	0.08	**0.16**
O74	0.12	0.13	0.19	0.15	0.03	0.22	0.14	0.38	**0.18**
O75	0.18	0.13	0.09	0.04	0.08	0.22	0.15	0.22	**0.12**
O76	0.21	0.18	0.13	0.09	0.06	0.26	0.13	0.32	**0.16**
O77	0.11	0.05	0.15	0.16	0.06	0.25	0.14	0.34	**0.17**
O78	0.03	0.25	0.22	0.11	0.17	0.24	0.15	0.09	**0.15**
O79	0.17	0.26	0.07	0.06	0.04	0.07	0.08	0.35	**0.14**
O80	0.10	0.25	0.05	0.12	0.02	0.17	0.12	0.24	**0.13**
O81	0.07	0.11	0.06	0.02	0.05	0.22	0.15	0.23	**0.10**
O82	0.23	0.03	0.05	0.15	0.27	0.33	0.10	0.55	**0.20**

O83	0.10	0.03	0.05	0.07	0.07	0.19	0.05	0.07	**0.07**
O84	0.16	0.17	0.08	0.07	0.15	0.08	0.18	0.36	**0.15**
O85	0.14	0.11	0.01	0.08	0.21	0.28	0.17	0.44	**0.16**
O86	0.22	0.05	0.03	0.17	0.14	0.19	0.10	0.63	**0.20**
O87	0.05	0.12	0.03	0.03	0.17	0.05	0.06	0.52	**0.12**
O88	0.19	0.11	0.06	0.14	0.11	0.13	0.03	0.34	**0.14**
O89	0.09	0.10	0.06	0.18	0.12	0.09	0.09	0.53	**0.17**
O90	0.10	0.11	0.02	0.09	0.11	0.08	0.05	0.51	**0.14**
O91	0.10	0.02	0.10	0.09	0.12	0.08	0.07	0.41	**0.13**
O92	0.11	0.04	0.14	0.11	0.05	0.02	0.08	0.18	**0.10**
O93	0.10	0.02	0.08	0.13	0.02	0.02	0.07	0.16	**0.09**
O94	0.09	0.15	0.19	0.13	0.09	0.03	0.02	0.15	**0.12**
O95	0.09	0.03	0.07	0.05	0.04	0.01	0.07	0.10	**0.06**
O96	0.11	0.10	0.06	0.03	0.24	0.09	0.16	0.12	**0.09**

Table C4 VR Value for the Perimeter Points of Proposed Scheme

Direction	NNE	NE	ENE	E	ESE	SSE	SW	N	Combined
Frequency	*0.08*	*0.09*	*0.15*	*0.23*	*0.05*	*0.06*	*0.08*	*0.12*	*0.87*
P1	0.12	0.28	0.29	0.23	0.13	0.14	0.12	0.29	**0.22**
P2	0.07	0.30	0.26	0.23	0.07	0.08	0.19	0.32	**0.21**
P3	0.19	0.10	0.19	0.24	0.17	0.13	0.09	0.35	**0.20**
P4	0.30	0.04	0.05	0.22	0.18	0.19	0.15	0.35	**0.19**
P5	0.21	0.25	0.20	0.09	0.12	0.13	0.19	0.29	**0.18**
P6	0.34	0.46	0.31	0.12	0.05	0.08	0.21	0.40	**0.25**
P7	0.35	0.42	0.27	0.20	0.03	0.07	0.22	0.35	**0.25**
P8	0.33	0.30	0.24	0.16	0.17	0.04	0.06	0.25	**0.20**
P9	0.20	0.22	0.10	0.22	0.30	0.08	0.05	0.29	**0.19**
P10	0.19	0.06	0.05	0.31	0.35	0.15	0.09	0.40	**0.21**
P11	0.19	0.02	0.05	0.12	0.10	0.11	0.10	0.35	**0.13**
P12	0.14	0.11	0.10	0.14	0.04	0.06	0.07	0.11	**0.11**
P13	0.33	0.24	0.14	0.33	0.29	0.13	0.08	0.42	**0.26**
P14	0.25	0.16	0.28	0.40	0.36	0.17	0.13	0.43	**0.30**
P15	0.25	0.19	0.05	0.09	0.08	0.12	0.25	0.31	**0.15**
P16	0.21	0.22	0.19	0.16	0.09	0.02	0.18	0.28	**0.18**
P17	0.11	0.09	0.09	0.07	0.10	0.03	0.21	0.03	**0.09**
P18	0.13	0.21	0.23	0.25	0.26	0.06	0.13	0.15	**0.19**
P19	0.32	0.25	0.25	0.32	0.44	0.11	0.11	0.19	**0.25**
P20	0.30	0.15	0.15	0.28	0.46	0.15	0.13	0.40	**0.25**
P21	0.29	0.19	0.12	0.24	0.37	0.15	0.03	0.46	**0.23**
P22	0.30	0.23	0.18	0.18	0.16	0.11	0.12	0.42	**0.22**
P23	0.33	0.34	0.32	0.13	0.08	0.07	0.20	0.49	**0.25**
P24	0.28	0.26	0.22	0.12	0.20	0.10	0.24	0.58	**0.24**
P25	0.26	0.27	0.33	0.39	0.39	0.09	0.38	0.48	**0.35**
P26	0.19	0.30	0.25	0.25	0.27	0.13	0.38	0.15	**0.24**
P27	0.26	0.29	0.21	0.16	0.23	0.12	0.34	0.24	**0.22**
P28	0.26	0.28	0.31	0.35	0.24	0.12	0.30	0.42	**0.31**
P29	0.24	0.28	0.33	0.31	0.18	0.20	0.19	0.45	**0.30**
P30	0.14	0.22	0.28	0.22	0.16	0.19	0.10	0.06	**0.18**
P31	0.12	0.17	0.24	0.18	0.20	0.02	0.03	0.14	**0.15**
P32	0.05	0.02	0.09	0.20	0.08	0.01	0.04	0.17	**0.11**
P33	0.12	0.07	0.07	0.16	0.07	0.03	0.09	0.22	**0.12**
P34	0.02	0.06	0.05	0.15	0.07	0.05	0.10	0.09	**0.09**
P35	0.12	0.07	0.06	0.11	0.10	0.03	0.09	0.07	**0.09**
P36	0.16	0.07	0.01	0.03	0.14	0.15	0.11	0.37	**0.11**
P37	0.24	0.07	0.05	0.05	0.17	0.18	0.08	0.38	**0.14**
P38	0.22	0.16	0.05	0.01	0.17	0.17	0.11	0.58	**0.16**