Hong Kong Housing Authority

Public Housing Development at North West Kowloon Reclamation Site 1 (East)

Report for Air Ventilation Assessment – Initial Study

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Job number --

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1 Introduction

1.1 Background

Ove Arup & Partners Hong Kong limited (Arup) has conducted an Air Ventilation Assessment (AVA) – Initial Study for the planning application of the proposed North West Kowloon Reclamation (NWKR) Site 1 (East) (the Development).

The application site is currently zoned "Residential (Group A)" ("R(A)") on the Approved Cheung Sha Wan Outline Zoning Plan (OZP) No. S/K5/37 with maximum building height restriction of 100mPD. A Section 16 application has been submitted and approved for minor relaxation of building height restriction to 126mPD.

Due to the detailed design development, the building layout has been revised. Hence, AVA – Initial Study has been carried out to assess the ventilation impact for the revised scheme.

The *Technical Guide for Air Ventilation Assessment for the Developments in Hong Kong (Annex A of Technical Circular No.1/06 for Air Ventilation Assessments)*[2] *(termed as AVA Technical Circular hereafter)* dated 19 July 2006 lay down the foundation of this methodology statement.

1.2 Objective of AVA Initial Study

Among all available wind data, an Initial Study will be conducted by using Computational Fluid Dynamics (CFD) techniques. It aims to achieve the following tasks:

- Initially assesses the characteristics of the wind availability of the site;
- Gives a general pattern and a rough quantitative estimate of the wind performance at the pedestrian level using Velocity VR;
- Identify the air paths within the site and ascertain their effectiveness; and
- Identify good design features and problematic areas if any and recommend mitigation measures.

2 Location and Site Characteristics

The Development is located in Cheung Sha Wan District, abutting Lai Chi Kok Road, Tonkin Street and Tung Chau Street.

The Development is located on flat land. The Development is mainly surrounded by mid to high-rise buildings with some open spaces and low-rise building clusters in between. To the northeast and east of the site, located the mid-rise Lai Kok Estate (42-48mPD) and Sham Shui Po Park respectively. To the south and southwest, are a mixture of high-rise buildings, namely Subsidised Sale Flats Development (SSF) at Fat Tseung Street West (120mPD) and West Kowloon Law Courts Buildings (88mPD), with low and mid-rise St. Margaret's Co-Educational English Secondary and Primary School (32mPD) and Ying Wa College (33mPD) and industrial buildings (~45mPD). To the immediate northwest of the site, is vegetable market with low-rise buildings (10-19mPD). Further to the northwest is high rise residential buildings, the Sparkle (158mPD). To the north of the site, are the Public Housing Development at Lai Chi Kok Road -Tonkin Street (120mPD) and Cheung Sha Wan Estate (108mPD) to the further north with sports ground in between. Figure 1 indicates the location and surrounding buildings of the Development.

The planned housing development site, NWKR Site 1 (West), is located to the immediate west of the application site. As there is no agreed development parameters, programme and layout for this site, its current condition, i.e. Vegetable Market, would be modelled and included in this AVA study.

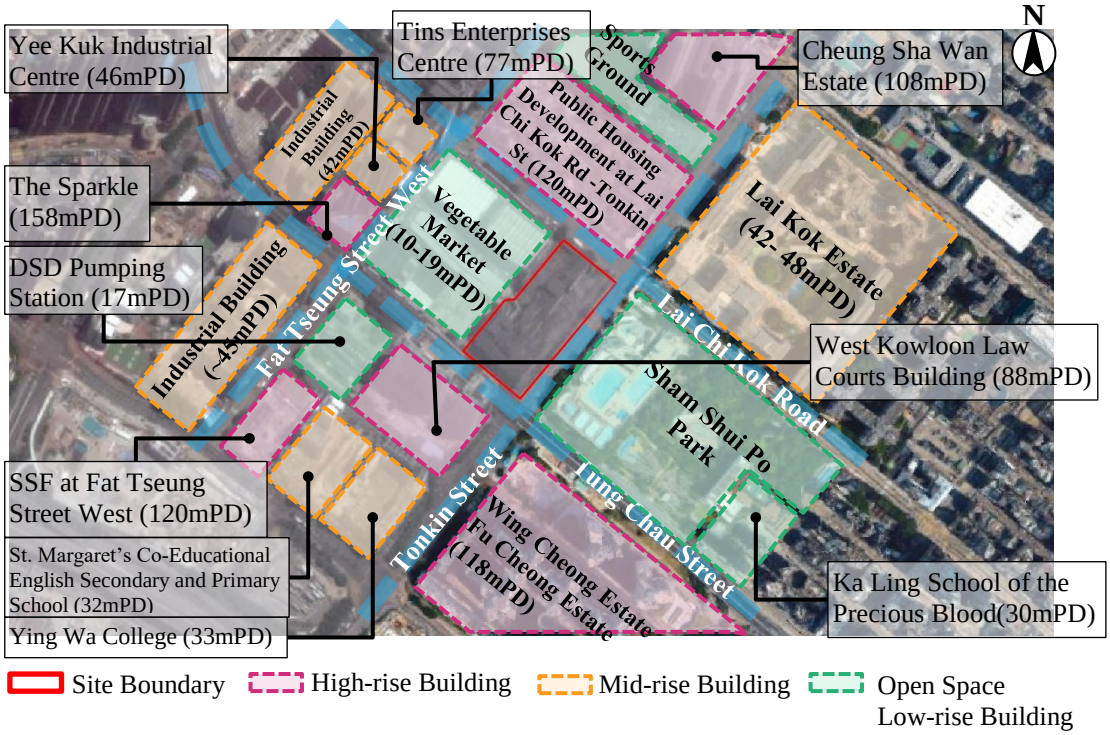


Figure 1 Site Location and Existing Surrounding Developments

2.1 Noise Barrier, Elevated Structure and Future Development

There are several fence walls, elevated structures and construction sites around the study site, which will be considered in this AVA – Initial Study. The location of these fence walls, elevated structures and construction sites are shown in Figure 2. The 3D model surrounding buildings including committed developments are shown in Figure 3 to Figure 6.

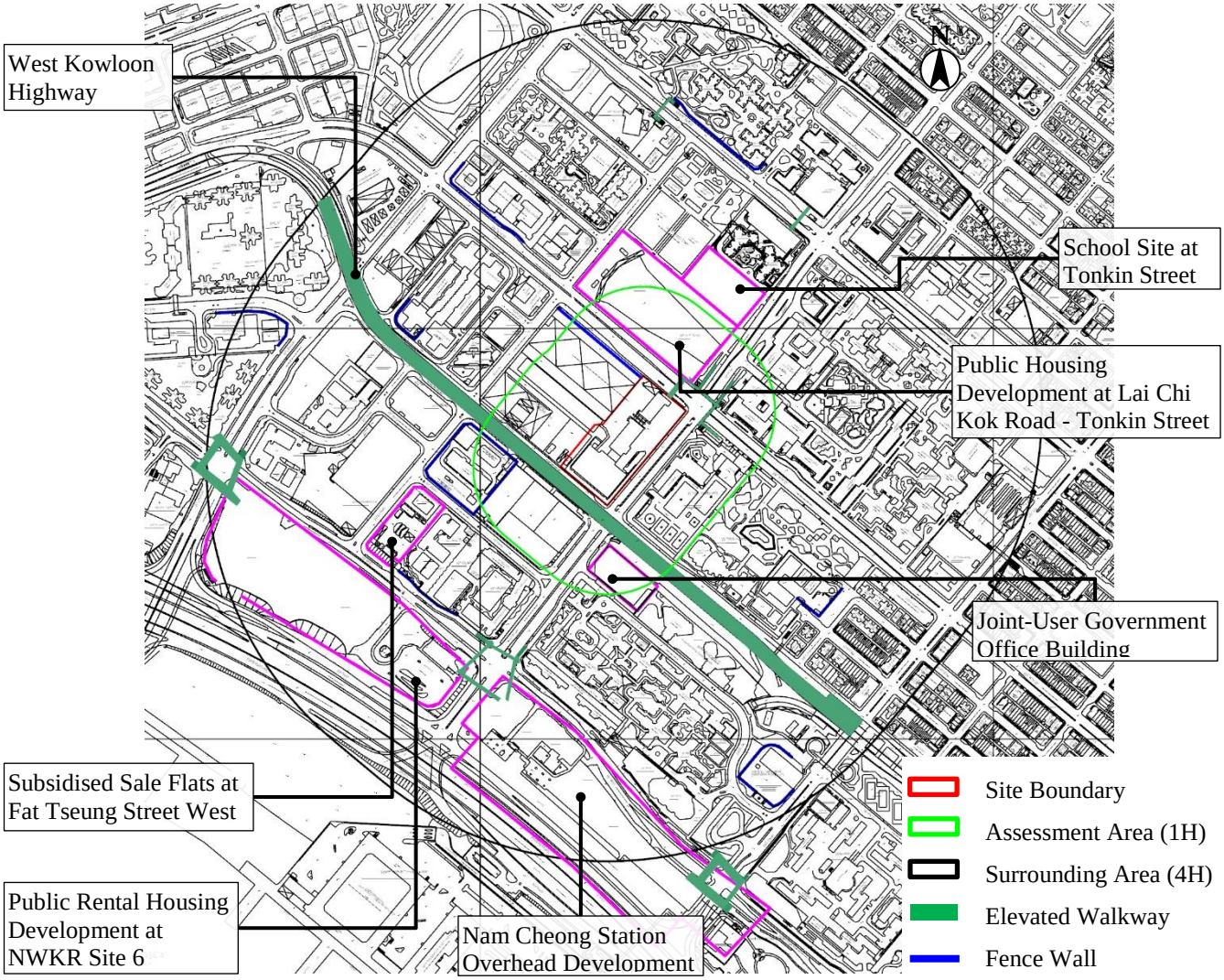


Figure 2 Location of the Fence Wall, Elevated Walkway and Construction Sites around the Application Site

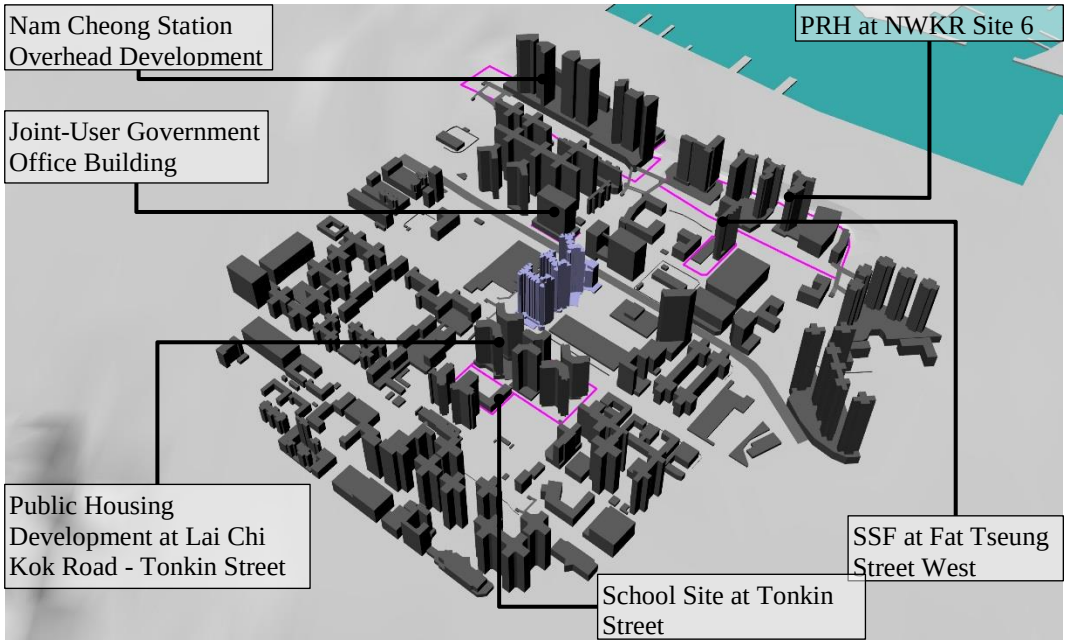


Figure 3 Northerly View of 3D Model for Surrounding Buildings

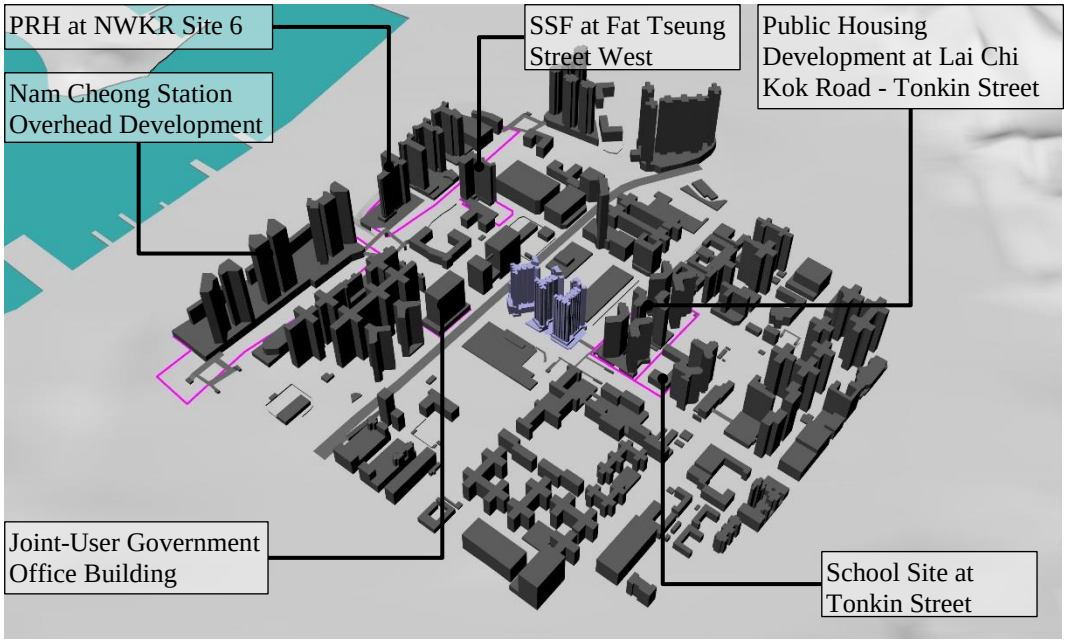


Figure 4 Easterly View of 3D Model for Surrounding Buildings

Figure 5 Southerly View of 3D Model for Surrounding Buildings

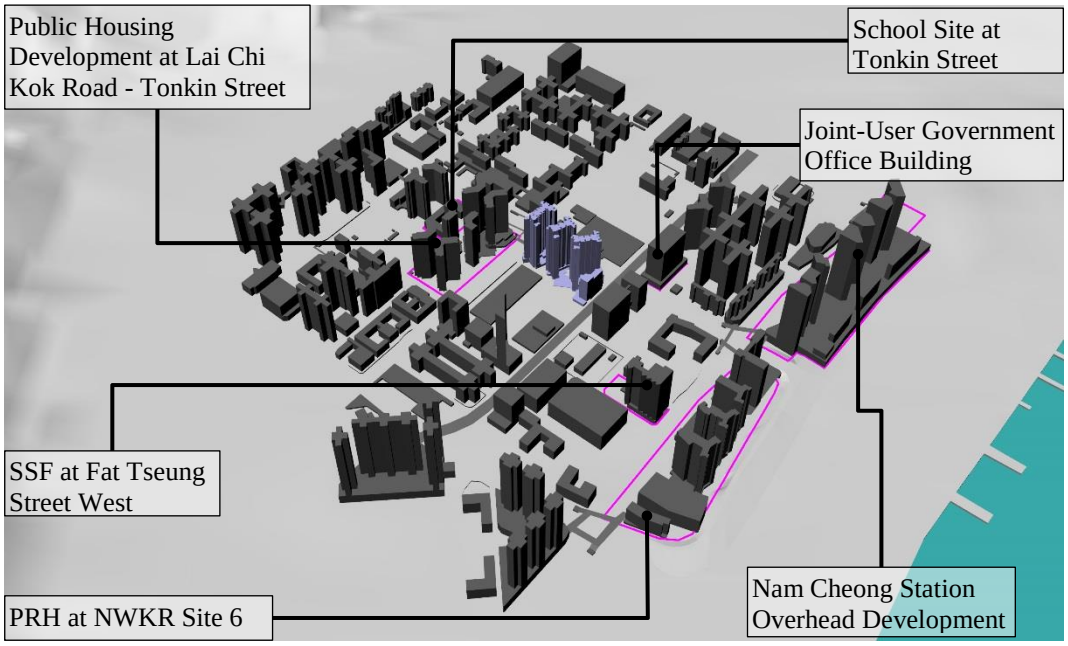


Figure 6 Westerly View of 3D Model for Surrounding Buildings

3 Wind Availability Data

As per the *AVA Technical Circular*[2], at least 75% of the time in a typical reference year (frequency of occurrence) would be studied under both annual and summer wind condition in the Initial Study when using a Computational Fluid Dynamics (CFD) modelling technique. Since the CFD approach is adopted for the present project's AVA, this criterion together with the following selected wind data are to be applied as the methodology.

The site wind availability of the application site and its surrounding is an essential parameter for AVA. As stipulated in the *AVA Technical Circular* [2] the site wind availability would be presented by using appropriate mathematical models. Planning Department (PlanD) has set up a set of simulated meso-scale data of Regional Atmospheric Modelling System (RAMS) of the territory for AVA study, which could be downloaded at Planning Department Website [3]. Simulated meso-scale data of Regional Atmospheric Modelling System (RAMS) from PlanD will therefore be adopted in this AVA Study. The location of the Development falls within the location grid (x: 076, y:046) in the RAMS database as indicated in Figure 7.

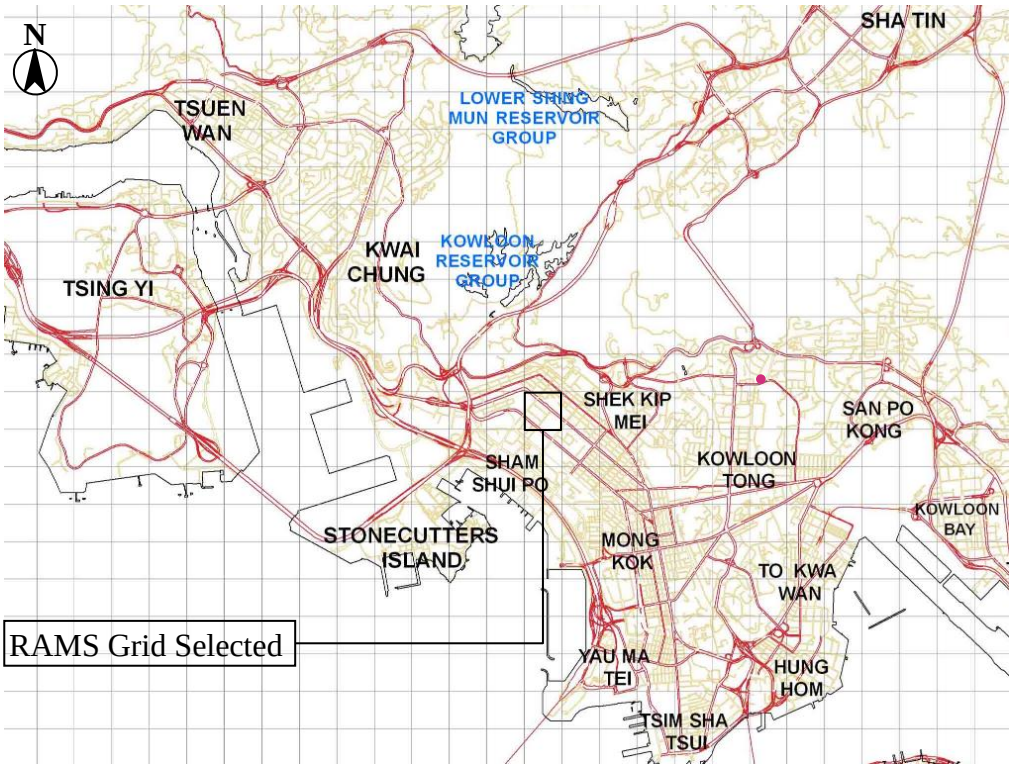


Figure 7 RAMS Grid and the Development Location

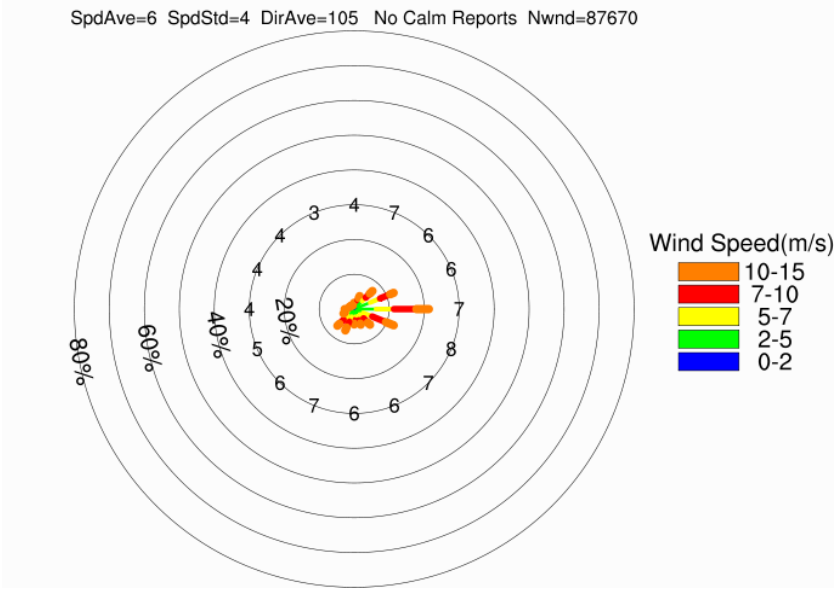


Figure 8 RAMS annual wind rose at 500mPD

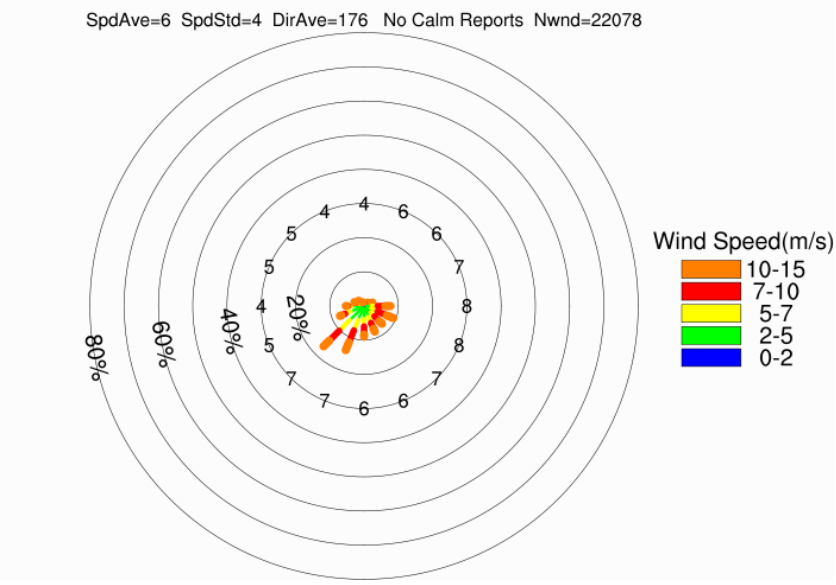


Figure 9 RAMS summer wind rose at 500mPD

3.1 Prevailing Wind Directions

As mentioned above, the RAMS wind data of location grid (x:076, y:046) is adopted for the site wind availability in this study.

3.1.1 Annual Prevailing Wind

Eight prevailing wind directions (highlighted in red colour in Table 1) are considered in this AVA Study which covers 79.1% of the total annual wind frequency. They are north-easterly (7.6%), east-north-easterly (12.4%), easterly (21.8%), east-south-easterly (12.4%), south-easterly (6.5%), south-south-easterly (4.9%), south-south-westerly (6.7%) and south-westerly (6.8%) winds.

Table 1 Annual Wind Frequency

Wind Direction	N	NNE	NE	ENE	E	ESE	SE	SSE	
Frequency	1.8%	4.3%	7.6%	12.4%	21.8%	12.4%	6.5%	4.9%	
Wind Direction	S	SSW	SW	WSW	W	WNW	NW	NNW	Sum
Frequency	4.5%	6.7%	6.8%	3.3%	2.7%	1.5%	1.4%	1.2%	79.1%

** The wind frequency showing in red colour represents the selected winds for the CFD simulation.*

3.1.2 Summer Prevailing Wind

Eight prevailing wind directions (highlighted in red colour in Table 2) are considered in this AVA Study which covers 81.7% of the total summer wind frequency. They are easterly (8.3%), east-south-easterly (9.7%), south-easterly (7.6%), south-south-easterly (8.2%), southerly (9.2%), south-south-westerly (14.2%), south-westerly (16.9%) and west-south-westerly (7.6%) winds.

Table 2 Summer Wind Frequency

Wind Direction	N	NNE	NE	ENE	E	ESE	SE	SSE	
Frequency	0.9%	1.0%	1.5%	2.8%	8.3%	9.7%	7.6%	8.2%	
Wind Direction	S	SSW	SW	WSW	W	WNW	NW	NNW	Sum
Frequency	9.2%	14.2%	16.9%	7.6%	5.3%	3.0%	2.2%	1.2%	81.7%

** The wind frequency showing in red colour represents the recommended wind direction for the CFD simulation.*

3.2 Wind Profiles

The profiles of wind speed from the PlanD RAMS database (x:076, y:046) is studied and the selected extracted. In the RAMS data the vertical profiles of the normalised mean wind speed were provided and the exact profile will be modelled in the CFD model for each corresponding wind directions to be studied. The vertical wind profile for all wind directions to be studied are shown in Figure 10 through Figure 12.

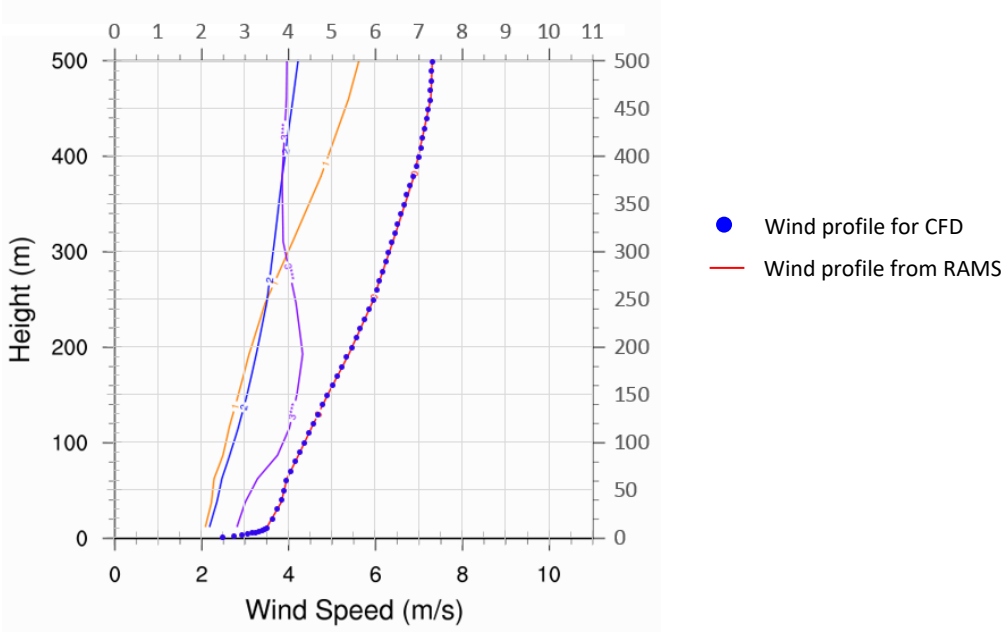


Figure 10 Vertical Wind Speed Profile of 22.5° - 112.4° winds

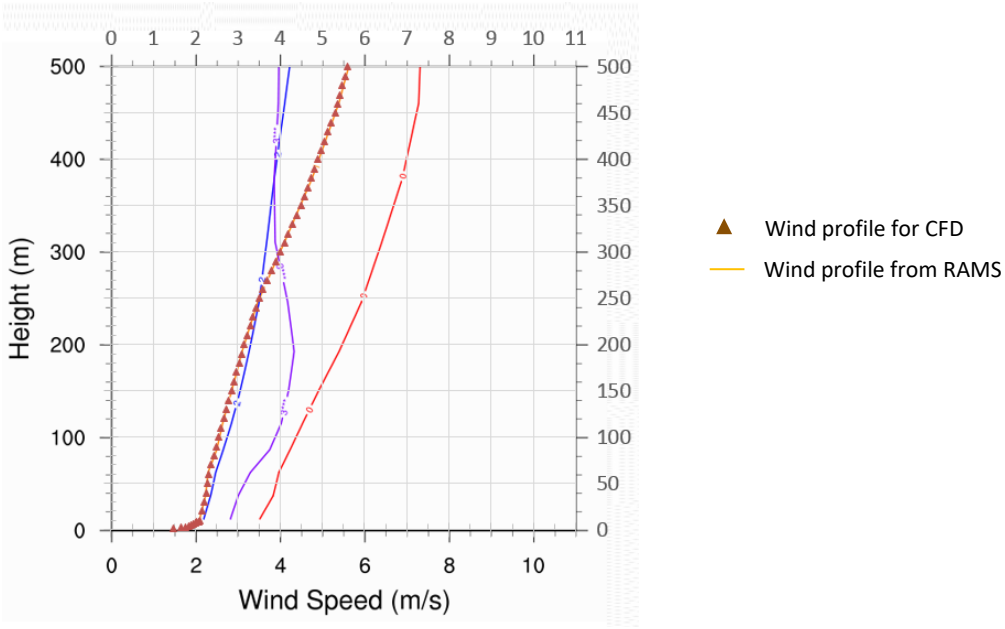


Figure 11 Vertical Wind Speed Profile of 112.5° - 202.4° winds

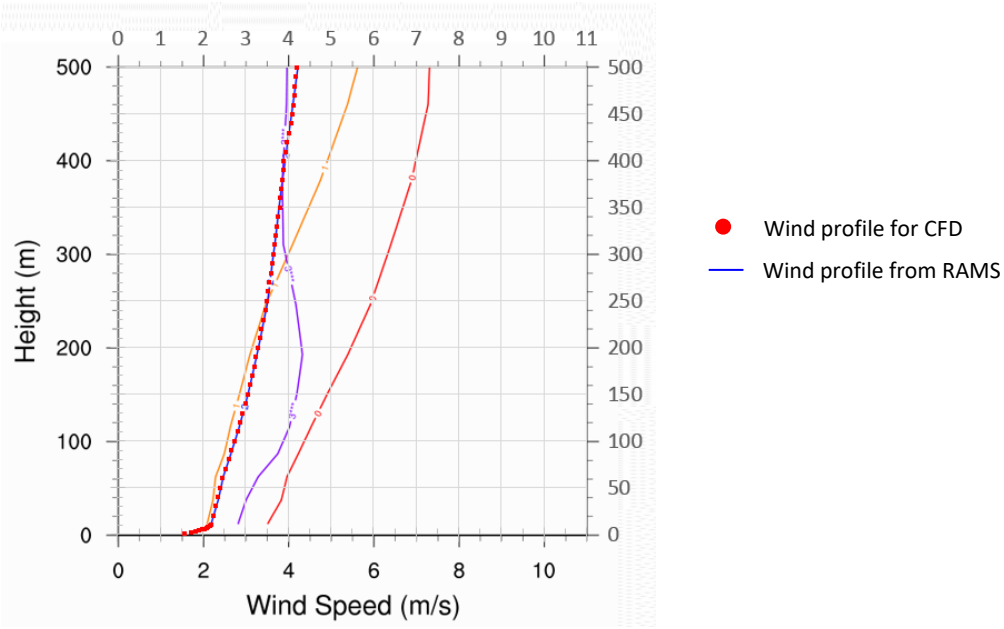


Figure 12 Vertical Wind Speed Profile of 202.5° - 292.4° winds

4 Design Schemes for Initial Study

To investigate the ventilation impacts of the revised scheme, two schemes, the Approved Scheme and Intermediate Scheme are to be analysed and compared in this AVA Initial Study.

According to the Expert Evaluation on Cheung Sha Wan Outline Zoning Plan [1] for NWKR Site 1 (East) and its adjacent NWKR Site 1 (West), two air paths along NE-SW direction and one air path along NW-SE direction with 10m-15m were suggested, as shown in Figure 13. To fulfil the requirement, two air paths of 15m along NW-SE was provided across Site 1 (East) for both schemes. In addition, considering that Site 1(East) accounts for roughly one third of the two sites, one air path of 7.5m wide running along NE-SW boundary was provided, as shown in Figure 15 and Figure 20.

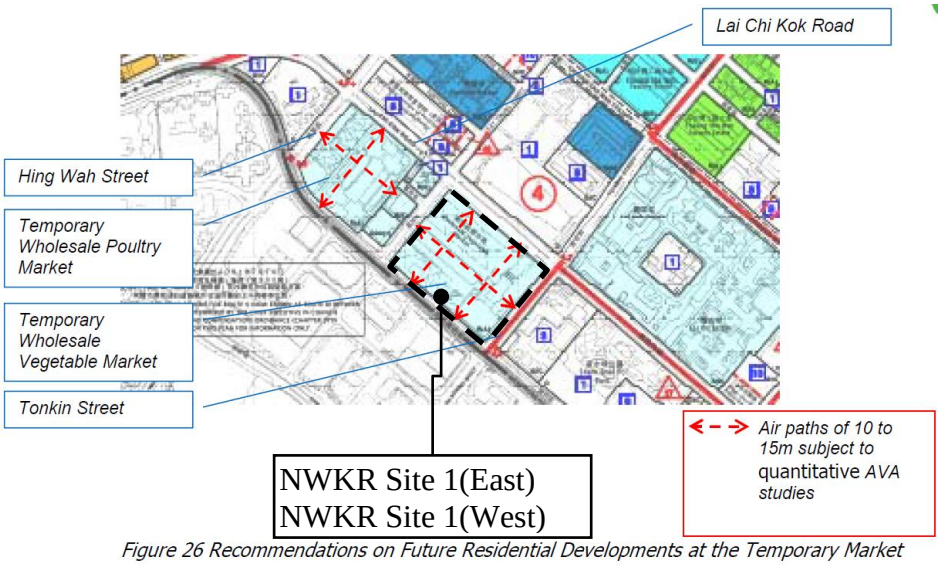


Figure 26 Recommendations on Future Residential Developments at the Temporary Market Sites

Figure 13 Image Extracted from AVA – Expert Evaluation for Cheung Sha Wan Outline Zoning Plan

4.1 Approved Scheme

Approved Scheme is the scheme approved under Section 16 application in 2017. The key development parameters of Approved Scheme are presented in Table 3. The master layout plan is shown in Figure 14 and Figure 15. Detailed drawings are show in Section A1 of Appendix A.

The major features of Approved Scheme are listed as below:

- Two building separations of 15m between Block 1, Block 2 and Block 3 for better ventilation.
- 7.5m setback from western boundary at G/F and above podium level.
- Building separation of 32m between Block 2 and Block 3.

Table 3 Development Parameters of Approved Scheme

Development Parameter	Approved Scheme
Plot Ratio	Domestic 7.5 Non-domestic 1.5
Maximum Building Height	126mPD
No. of Flats	2533

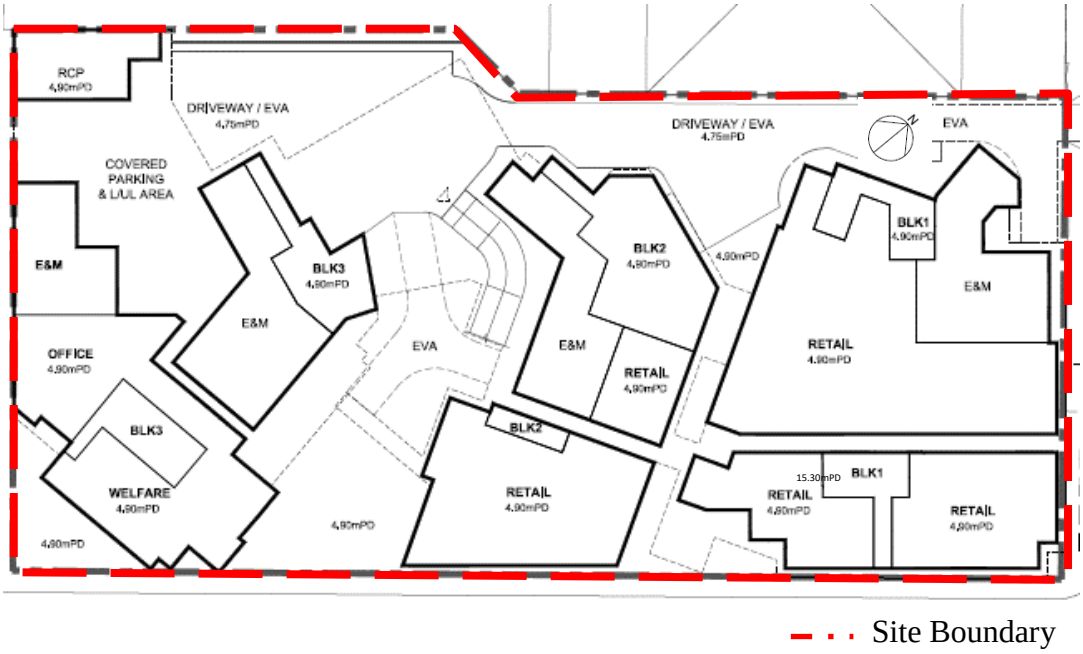


Figure 14 Approved Scheme – Ground Floor Layout

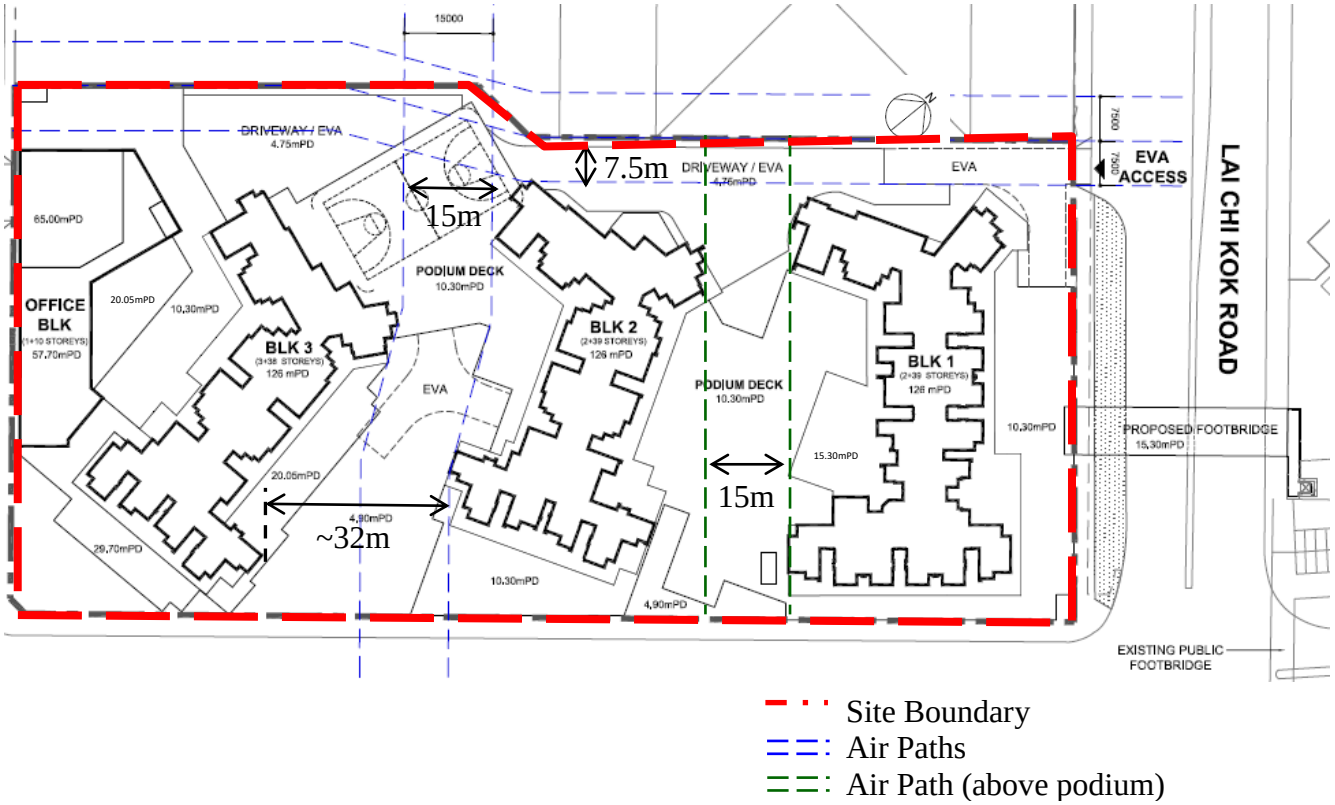


Figure 15 Approved Scheme - Master Layout Plan

By referring to the CAD drawings of the Approved Scheme, the 3D model was constructed as shown in Figure 16 to Figure 19.

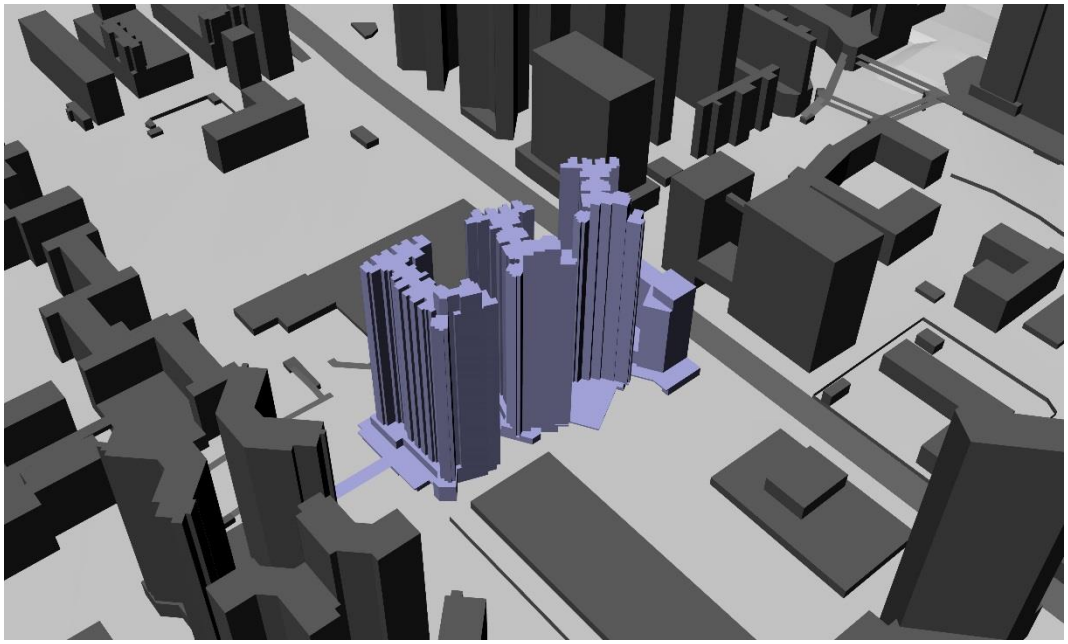


Figure 16 Northerly view of Approved Scheme

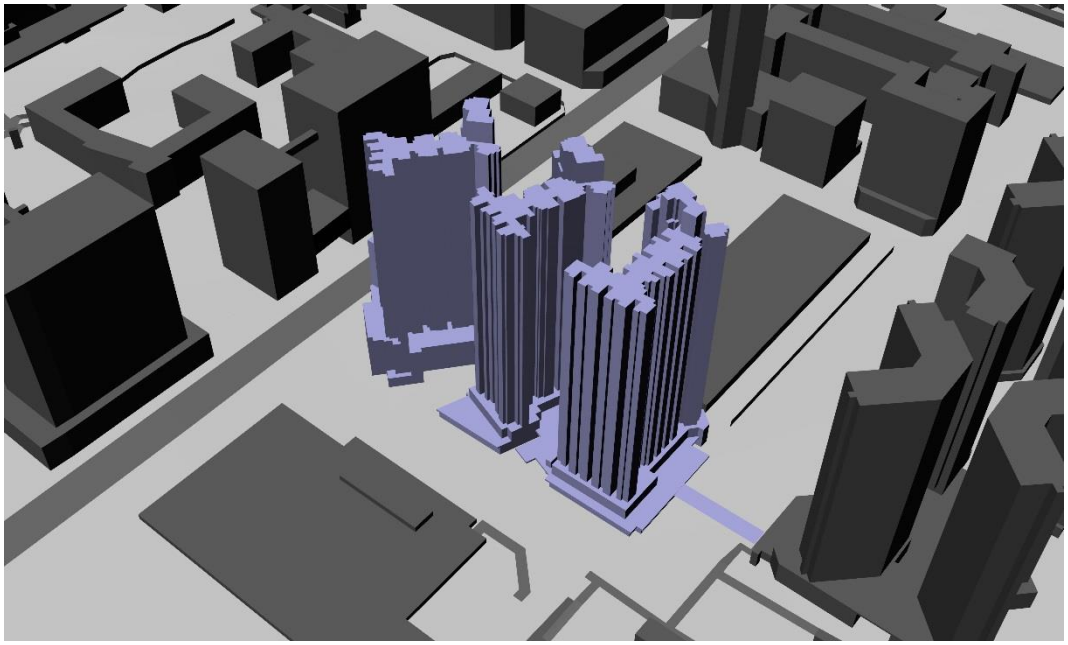


Figure 17 Easterly view of Approved Scheme

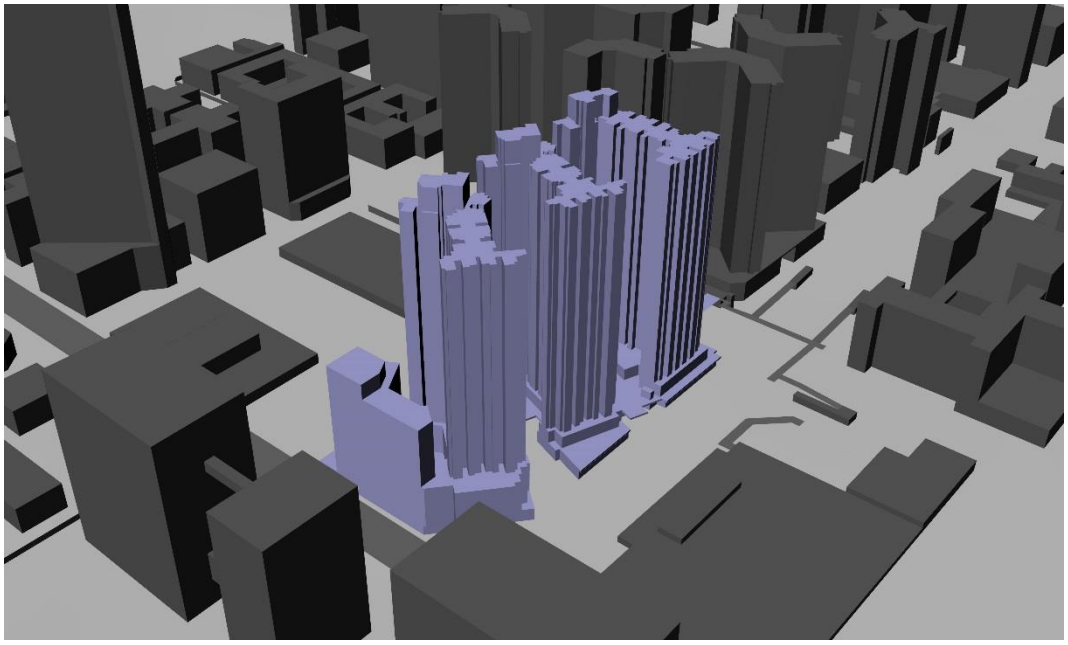


Figure 18 Southerly view of Approved Scheme

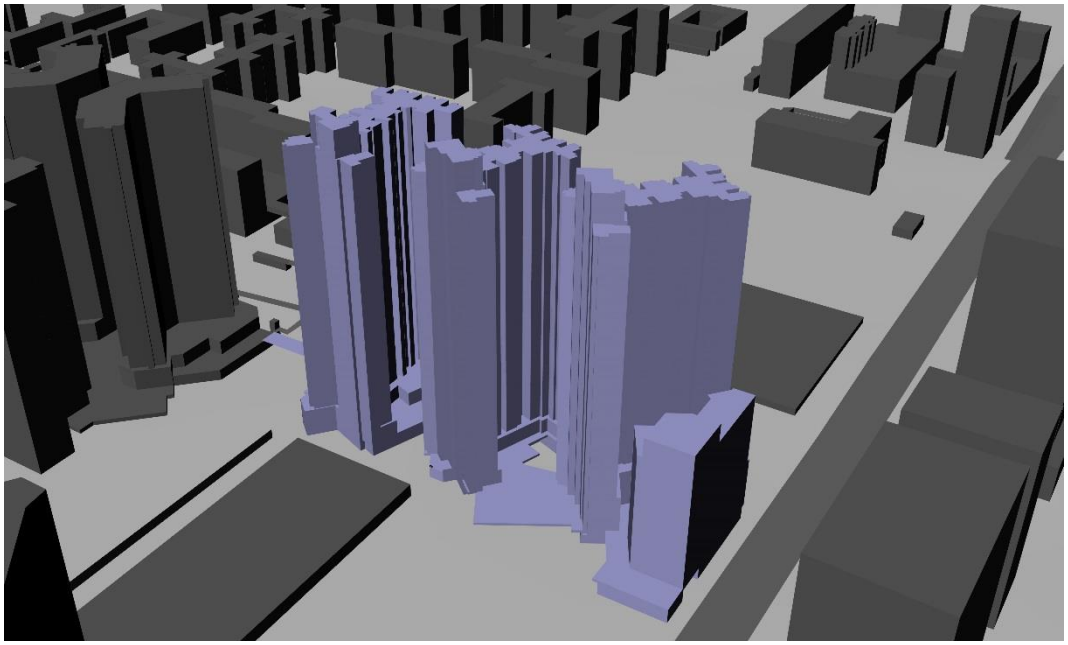


Figure 19 Westerly view of Approved Scheme

4.2 Intermediate Scheme

Intermediate Scheme is the revised scheme with same height but revised building form. The two building separations of 15m and 7.5m setback from western boundary are also provided in Intermediate Scheme. The key development parameters of Intermediate Scheme are presented in Table 4. The master layout plan is shown in Figure 20. Detailed drawings are show in Section A2 of Appendix A.

The major changes made in Intermediate Scheme as compared to Approved Scheme are listed as below:

- Rotated orientation of the eastern wing of Block 3.
- Empty bay design at 1/F between office tower and Block 3.
- Wider building separation of 8m between office tower and Block 3 at junction of Tung Chau Street and Tonkin Street above 5/F.

Table 4 Development Parameters of Intermediate Scheme

Development Parameter	Intermediate Scheme
Plot Ratio	Domestic 7.5 Non-domestic 1.5
Maximum Building Height	126mPD
No. of Flats	2553

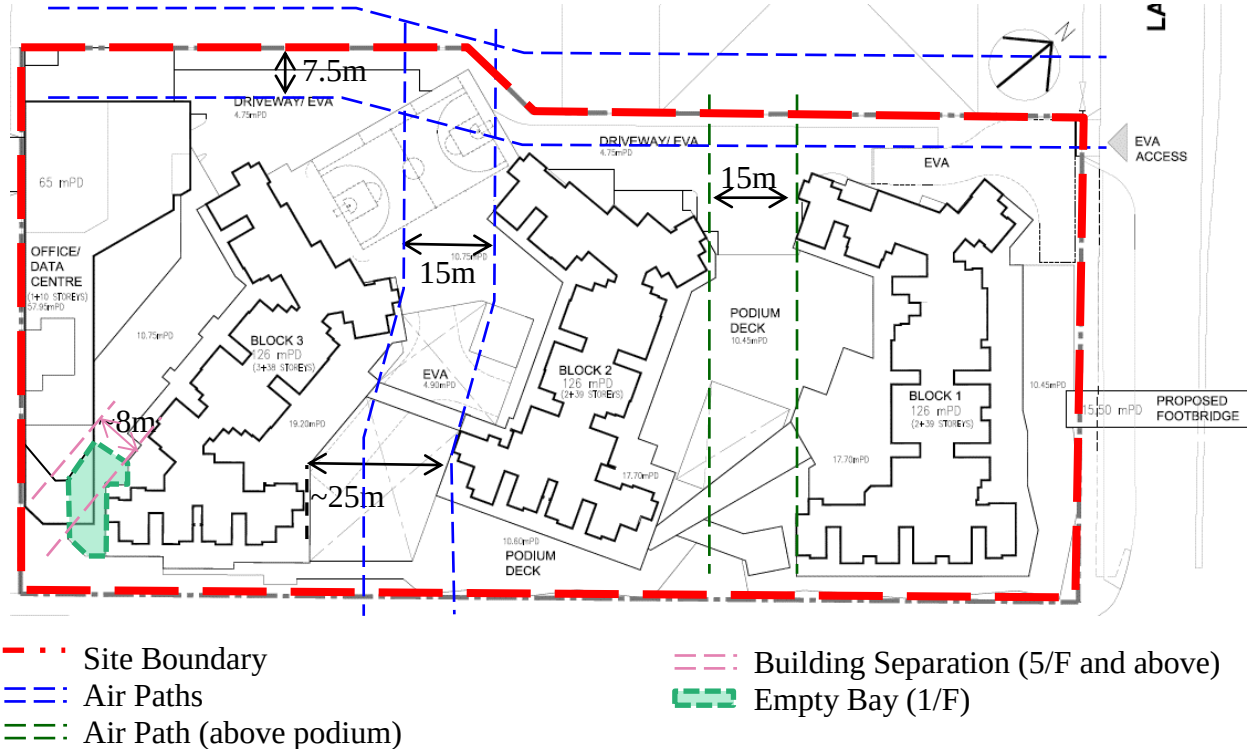


Figure 20 Intermediate Scheme - Master Layout Plan

By referring to the CAD drawings of the Intermediate Scheme, the 3D model was constructed as shown in Figure 21 to Figure 24.

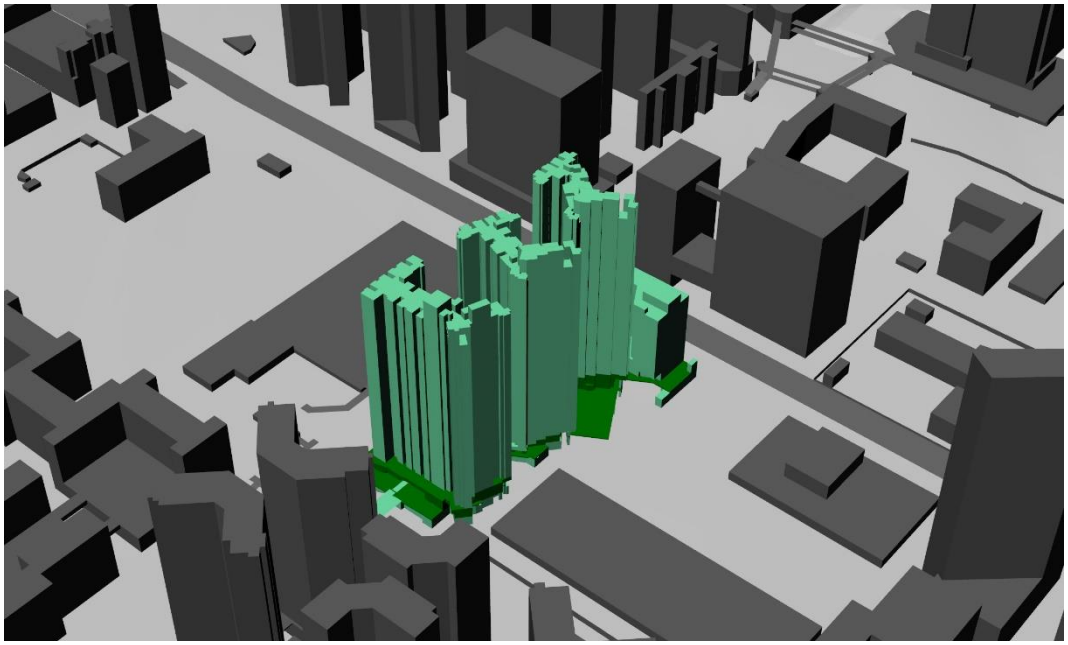


Figure 21 Northerly view of Intermediate Scheme

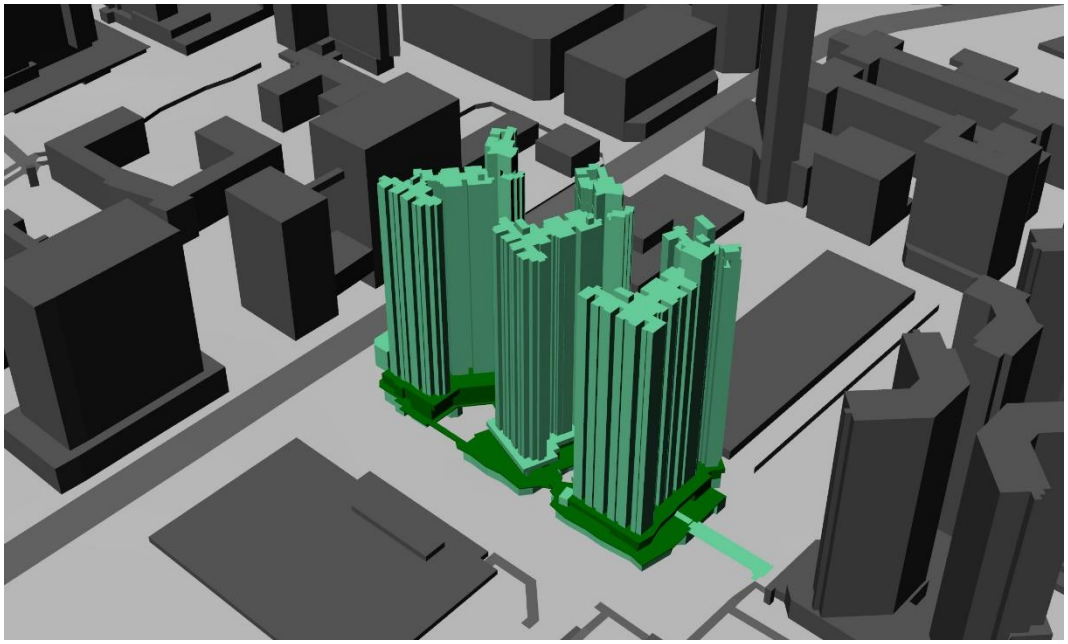


Figure 22 Easterly view of Intermediate Scheme

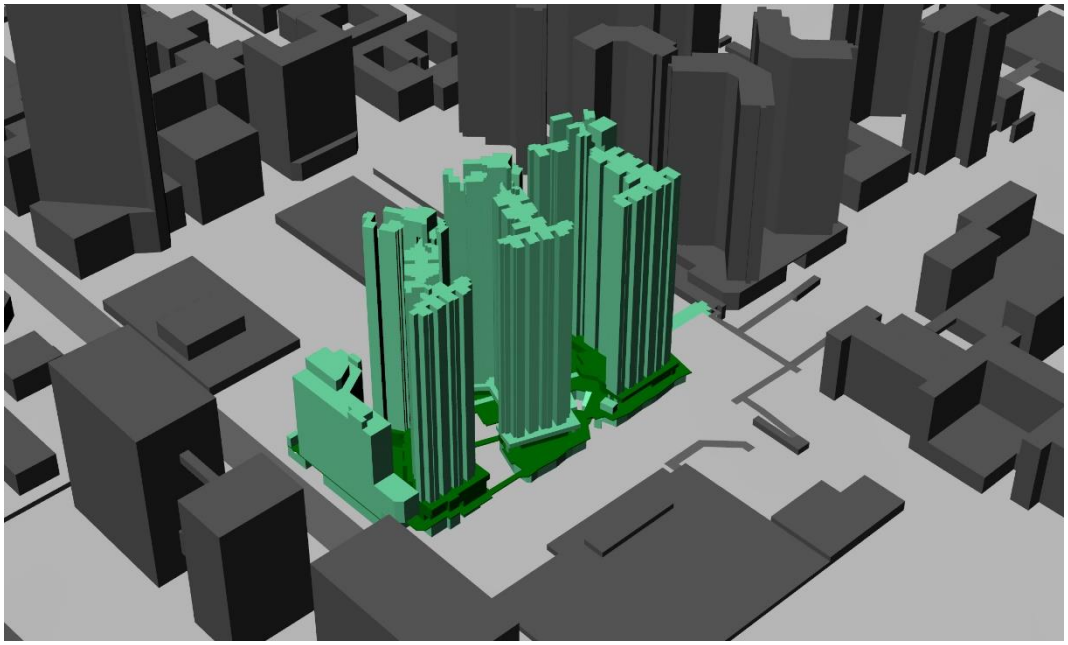


Figure 23 Southerly view of Intermediate Scheme

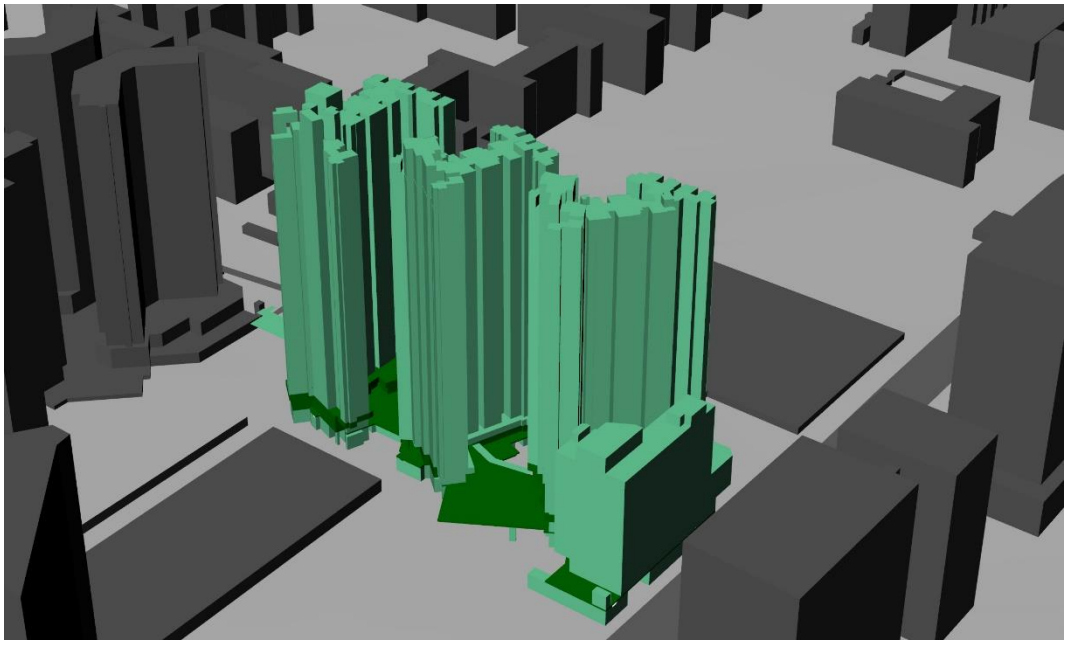


Figure 24 Westerly view of Intermediate Scheme

5 Methodology

5.1 Assessment and Surrounding Areas

With the building height of the proposed development is around 130m, the Assessment Area and the Surrounding Area are respectively span 130 (1H) and 260m (2H) away from the site boundary of the Study Area. As several high-rise buildings are located close to the 2H boundary, the surrounding area is extended to roughly 4H to cover these high-rise buildings. The proposed Assessment Area and the Surrounding Area are indicated as below. The computational domain would be about 3900m (L) x 3900m (W) x 2500m (H) as shown in Figure 26.

Figure 25 Site boundary (red), Assessment Area (green) and Surrounding Area (black)

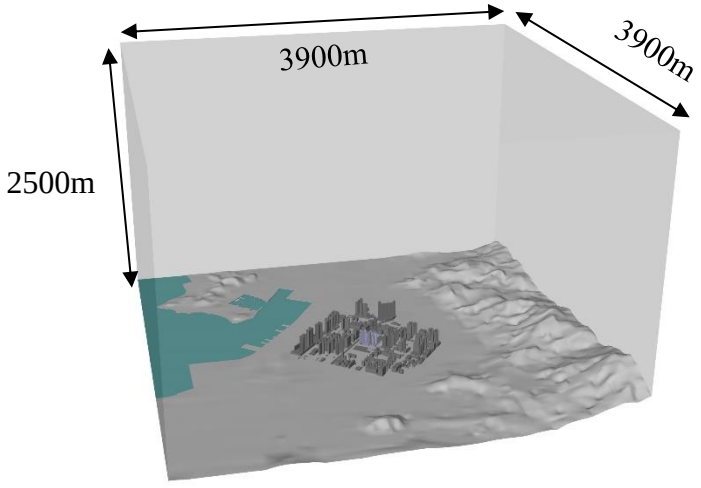


Figure 26 3D View of the Domain

5.2 Technical Details for CFD simulation

5.2.1 Assessment Tools

Computational Fluid Dynamics (CFD) technique is utilized for this AVA 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, will be simulated under selected wind directions as stated in Section 3 for annual and summer wind conditions.

5.2.2 CFD Model

Following the AVA Technical Circular, buildings within Surrounding Area shall be built in the CFD model. In order to simulate the approaching wind turbulence effect in a more accurate manner, the CFD model is built to include the highways or bridges as they may affect the approaching wind, even it is falling outside the Surrounding Area. In addition, the model domain is built far beyond the Surrounding Area as required in the Technical Circular in order to eliminate the boundary effects. Therefore, the studied size of CFD model of the development is approximately 3900m (Length) x 3900m (Width) x 2500m (Height) which contains more than 5,000,000 cells as shown in Figure 27.

The computational domain 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. The site topography would be modelled within the whole computational domain. Body-fitted unstructured grid technique is used to fit the geometry and reflect the complexity of the development geometry. A prism layer of 3m above ground (totally 6 layers and each layer of 0.5m thick, shown in Figure 28 is incorporated in the meshing so as to better capture the approaching wind and wind condition at pedestrian level. A mesh expansion ratio of 1.3 is adopted and the blockage ratio was less than 2%.

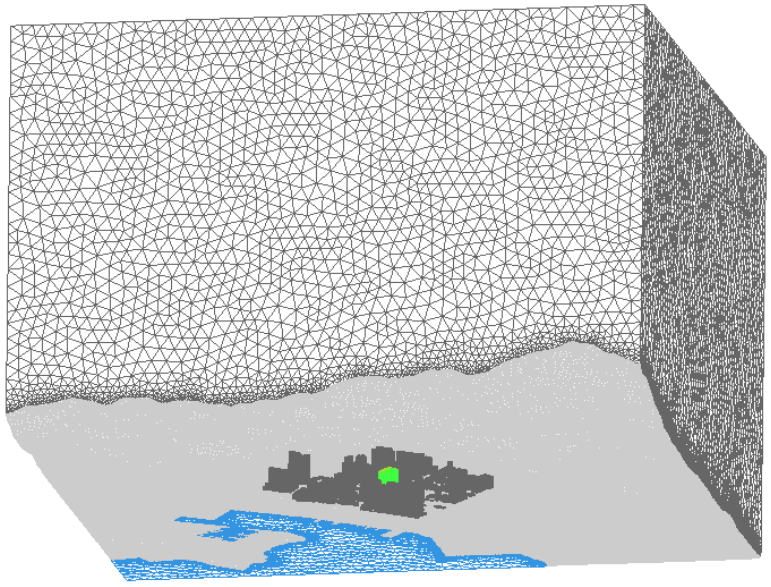


Figure 27 Mesh of Computational Domain

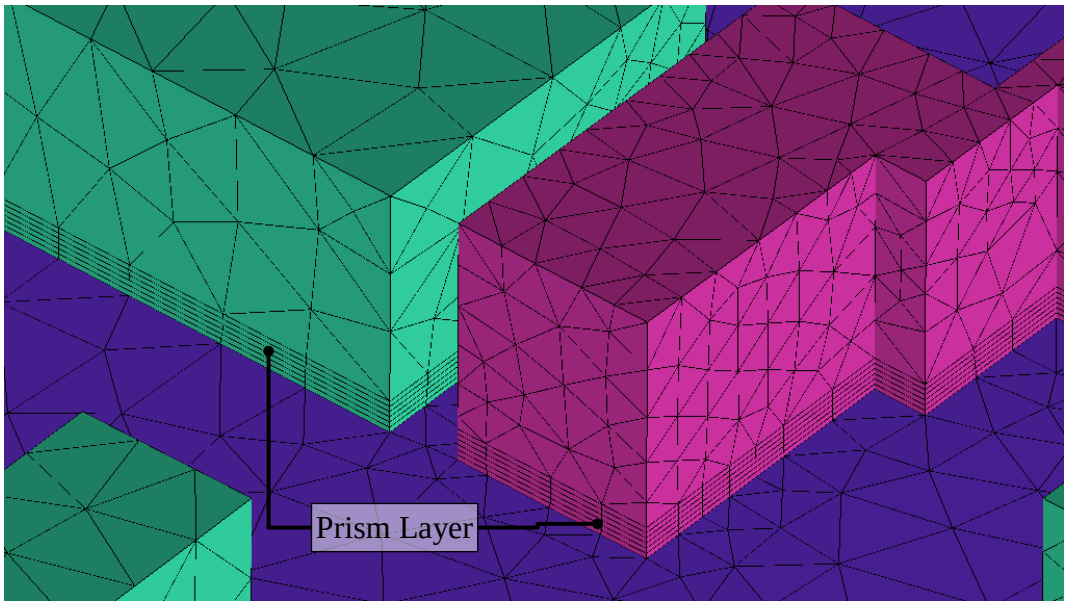


Figure 28 Prism Layers

Table 5 Detail parameters to be adopted in the CFD

	CFD Model
Model Scale	Real Scale model
Model details	Only include Topography, Buildings blocks, Streets/Highways, no landscape is included
Domain	3900m(L) x 3900m(W) x 2500m(H)
Assessment Area	≥ 1H area
Surrounding building Area	≥ 2H area
Grid Expansion Ratio	The grid should satisfy the grid resolution requirement with maximum expansion ratio = 1.3
Prismatic layer	6 layer of prismatic layers and 0.5m each (i.e. total 3m above ground)
Inflow boundary Condition	Incoming wind profile as measured from RAMS
Outflow boundary	Pressure boundary condition with dynamic pressure equal to zero
Wall boundary condition	Logarithmic law boundary
Turbulence Model	Realisable k-ε turbulence model
Solving algorithms	Rhie and Chow SIMPLE for momentum equation Hybrid model for all other equations
Blockage ratio	< 2%
Convergence criteria	Below $1.0E^{-4}$

5.3 AVA Indicator

The wind speed information at pedestrian level (2m above ground) will be acquired to determine the Wind Velocity Ratio (*VR*) as stipulated in the *AVA Technical Circular*[2] and as defined as follows:

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

where V_p is the wind speed at the pedestrian height (2m above ground) and V_∞ is the wind velocity at the top of the boundary layer (defined as the height where wind is unaffected by urban roughness and determined by the topographical studies). Measurement will be taken within the Assessment Area.

The Average VR is defined as the weighted average VR with respect to the percentage of occurrence of all considered wind directions. This gives a general idea of the ventilation performance at the considered location at both annual and summer wind condition.

5.3.1 Assessment Parameters

CFD simulations will be 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.

Table 6 Terminology of the AVA Initial

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 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 represent the average VR of all points, i.e. perimeter and overall test points at the site boundary which identified in the report.

5.4 Locations of Test Points

As per the technical circular, two types of test points – perimeter test point and overall test point will be adopted to assess the wind performance within the Assessment Area. Special test points are supplemented to assess the effectiveness of the air paths. The allocation of these test points will be distributed evenly as stated in the *AVA Technical Circular* [2].

5.4.1 Perimeter Test Points

A total number of 30 perimeter test points (**Red spots**), namely P points, are positioned at intervals of around 15m along the project site boundary in accordance with the *AVA Technical Circular*[2]. The locations of perimeter test points are shown in Figure 29.

5.4.2 Overall Test Points

A total number of 69 overall test points (**Black spots**), namely O points, are evenly distributed in open areas within the assessment area, such as the streets and places where pedestrian frequently access. Their locations are shown in Figure 29.

5.4.3 Special Test Points

A total number of 12 special test points are identified in the Approved Scheme and Intermediate Scheme, namely S points. They are evenly distributed at areas accessible by pedestrian at ground level (**Green Spots**), and at the podium level (**Blue Spots**). Their locations are shown in Figure 30 and Figure 31.

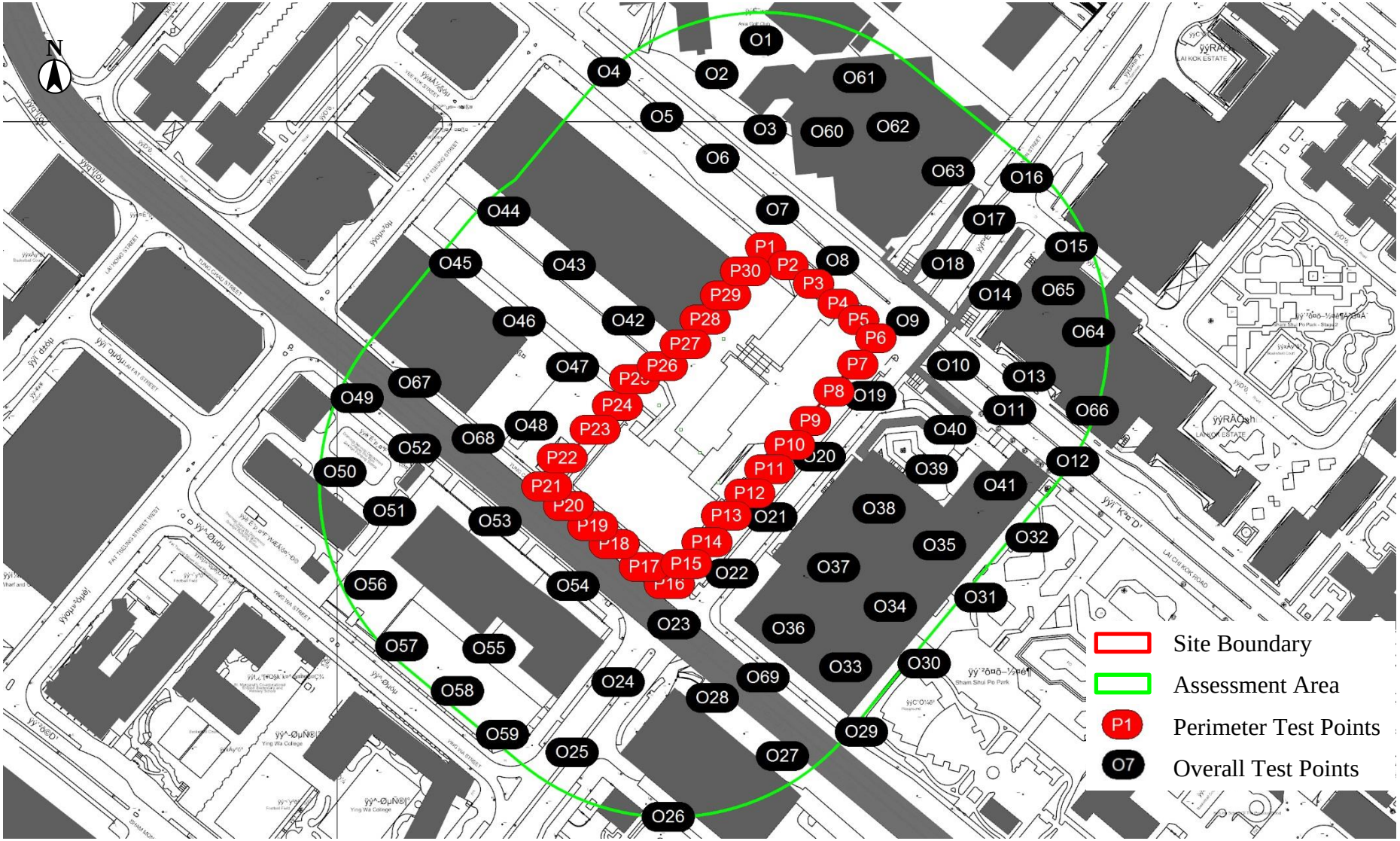


Figure 29 Location of Perimeter and Overall Test Points

Figure 30 Location of Special Test Points for Approved Scheme

Figure 31 Location of Special Test Points for Intermediate Scheme

5.5 Focus Areas

Within the proposed Assessment Area given in Figure 25, a total of 14 focus areas are proposed with 10 of them located outside the application site and 4 of them located within the application site. The associated test points for focus areas are tabulated in Table 7. The location of the focus areas area shown in Figure 32 and Figure 33.

Table 7 Focus Areas and Corresponding Test Points

	Focus Area	Test Points
1	Tonkin Street	O9, O16-O25
2	Lai Kok Estate	O13-O15, O64-O66
3	Sham Shui Po Park	O29-O41
4	Public Housing Development at Lai Chi Kok Road – Tonkin Street	O1-O3, O60-O63
5	Lai Chi Kok Road	O4-O12
6	Vegetable Market	O42-O48, P22, P24, P26
7	Tung Chau Street	O23, O27-O29, O49, O52-O54, O67-O69, P17, P19, P21
8	Drainage Service Department (DSD) Pumping State	O49-O52
9	West Kowloon Law Courts Building	O53-O59
10	Joint-User Government Office Building	O26-O28
11	Air Path between Block 2 and Block 3	S1–S4
12	Air Path between Block 1 and Block 2	S9-S11
13	Podium Deck between Block 2 and Block 3	S5-S8
14	Air Path along NE-SW Site Boundary	P1, P21-P30

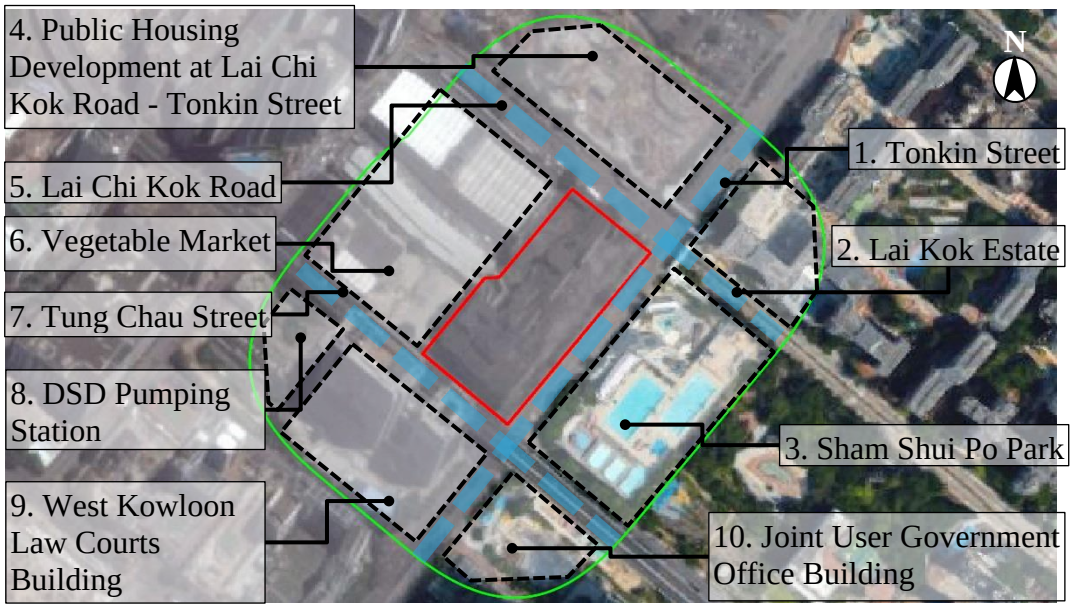


Figure 32 Location of Focus Areas outside the Application Site

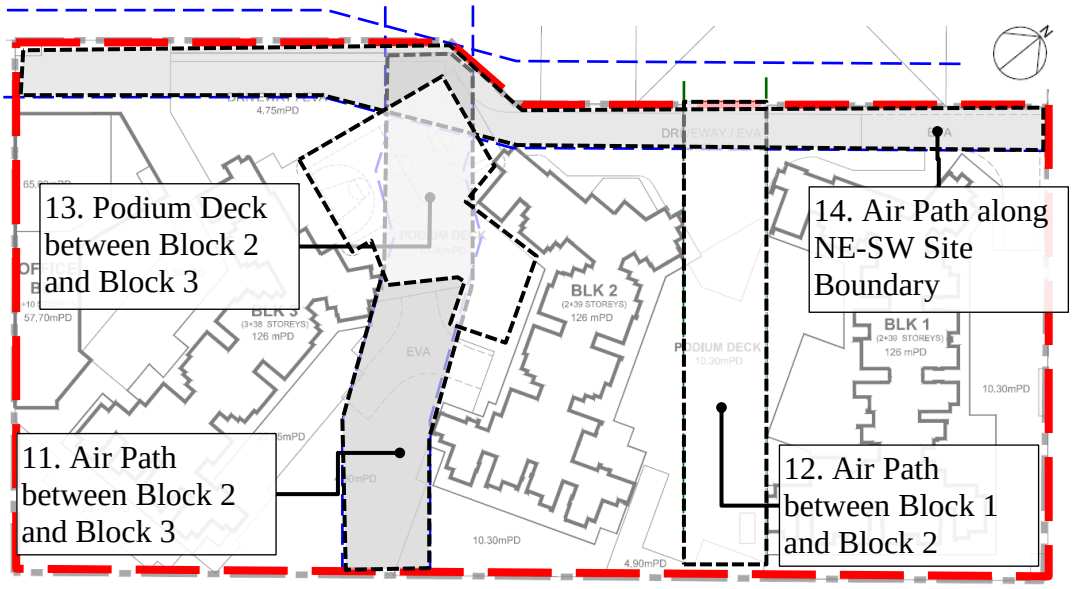


Figure 33 Location of Focus Areas within the Application Site

6 Results and Discussion

The contour and vector plots for each studied wind directions may refer to Appendix B and Appendix C of this report.

6.1 Annual Weighted Average

The contour plots of annual weighted VR for the Approved Scheme and Intermediate Scheme are shown below.

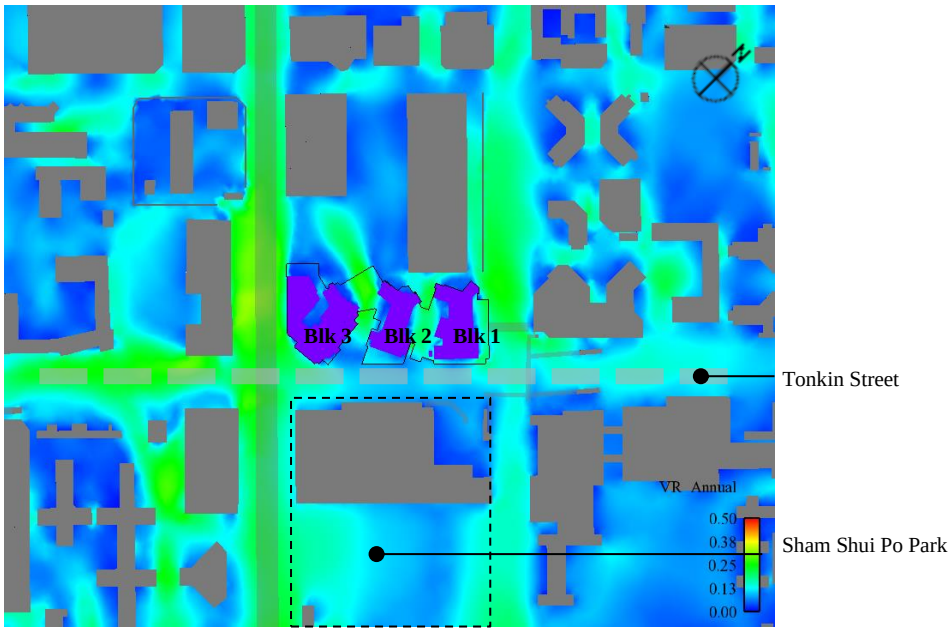


Figure 34 Contour Plot for Annual Weighted Average VR for Approved Scheme

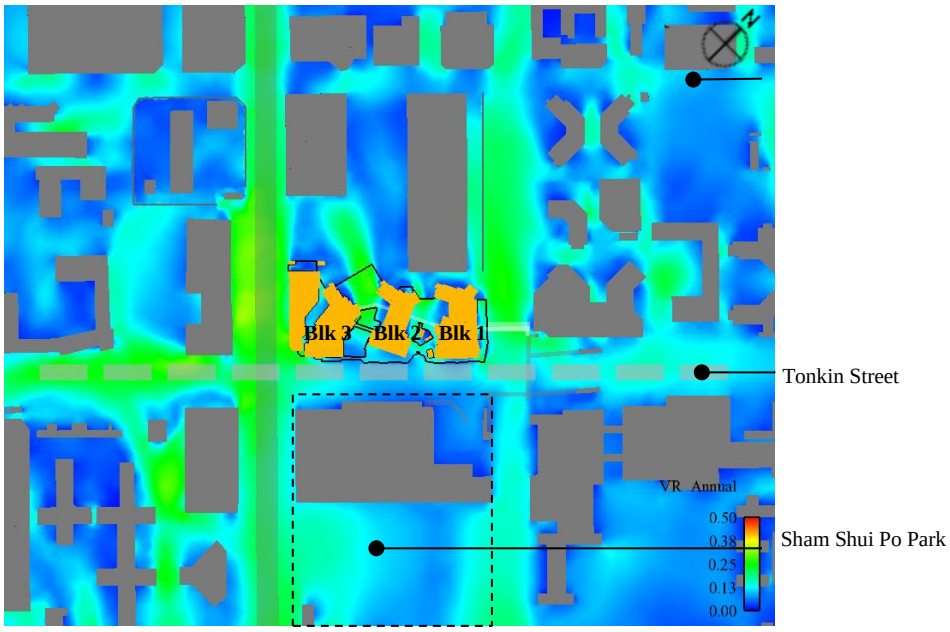


Figure 35 Contour Plot for Annual Weighted Average VR for Intermediate Scheme

The overall ventilation performance would be similar between both schemes. Two 15m wide building separations between Block 1, Block 2 and Block 3 are provided under both Approved and Intermediate Scheme. Most of the annual wind from NE and SE quadrants would come from the Sham Shui Po Park and reach the site. The building separations is roughly aligned with incoming wind direction, which would facilitate wind penetration.

The rotated eastern wind of Block 3 under Intermediate Scheme would divert the NE quadrant to pass through the building separation between Block 2 and Block 3 while the façade of Block 3 under Approved Scheme would divert the NE wind to reach the junction of Tonkin Street and Tung Chau Street.

6.2 Summer Weighted Average

The contour plots of summer weighted VR for the Approved Scheme and Intermediate Scheme are shown below.

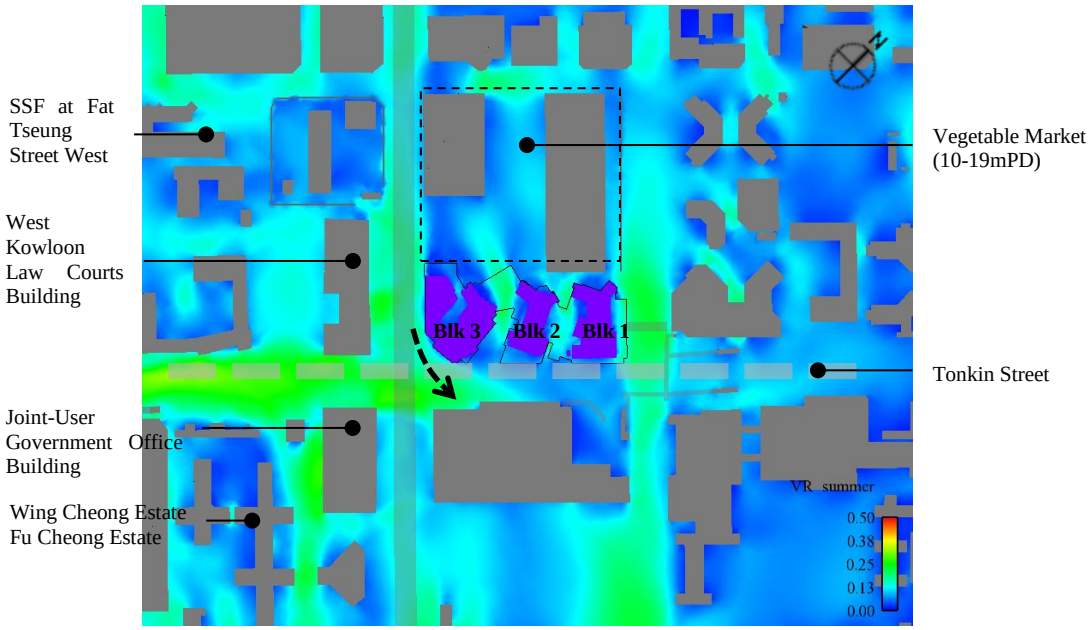


Figure 36 Contour Plot for Summer Weighted Average VR for Approved Scheme

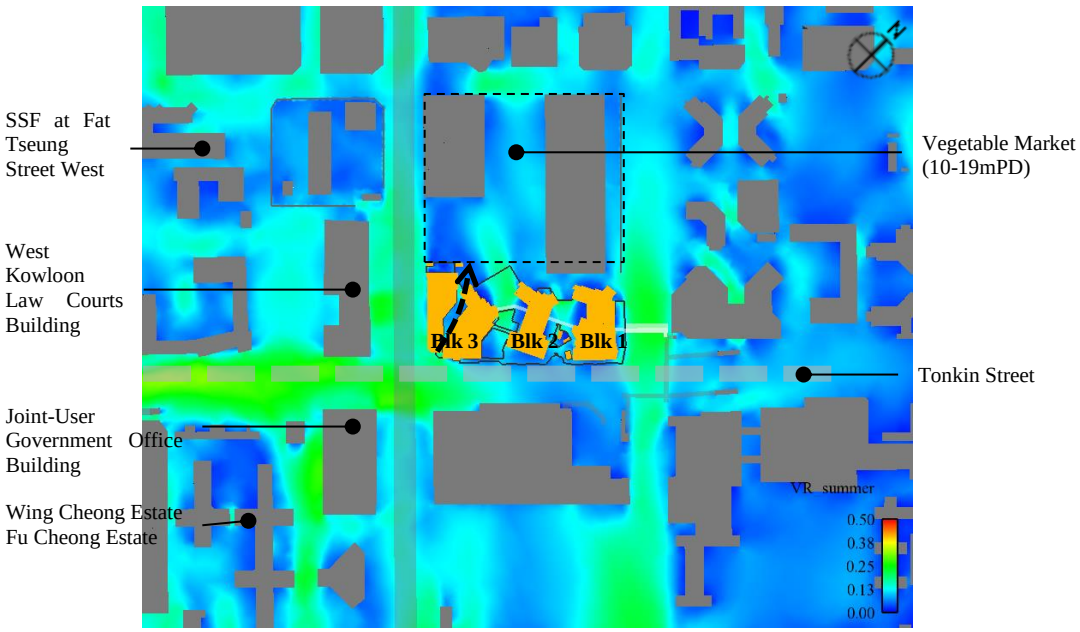


Figure 37 Contour Plot for Summer Weighted Average VR for Intermediate Scheme

The majority of the summer prevailing wind comes from SW quadrants. Under these wind directions, the application site would be located at the leeward side of the existing buildings. With the high-rise residential buildings, namely the PRH at NKWR Site 6, Nam Cheong Station Overhead Development, Wing Cheong Estate and Fu Cheong Estate, SSF at Fat Tseung Street West and West Kowloon Law Courts Building, planned Joint-User Government Office Building and mid-rise industrial buildings located at the upwind locations and would dominate the ventilation performance in this area. The overall ventilation performance for Approved Scheme and Intermediate Scheme would be similar.

The step height profile between office block and Block 3 would induce downwash effect under SW quadrant wind. The downwashed wind would travel along the façade to reach the Vegetable Market.

Under Approved Scheme, the incoming SW quadrant wind would be diverted by the façade of Block 3 and office building and travel more towards east to reach the Sham Shui Po Park.

On the other hand, with the wider building separation between office tower and Block 3 under Intermediate Scheme, a portion of the wind would infiltrate through the building separation from the southeast corner, illustrated by black arrow in Figure 37.

6.3 Directional Analysis

6.3.1 NE Wind Direction

Under NE wind, the majority of the incoming would travel along Tonkin Street. A portion of incoming wind would first reach north-eastern façade of Block 1 and the podium below, shown as black arrow in Figure 38 and Figure 39. Due to the step height profile between the Development and the Public Housing Development at Lai Chi Kok Road and Tonkin Street, downwash effect would be induced by the northern façade of Block 1. The downwashed wind would be diverted to travel along Lai Chi Kok Road.

On the other hand, some of the incoming wind would continue to travel along Tonkin Street. The Development would inevitably block some of the incoming NE wind from along Tonkin Street, creating a calmer wind environment at the Vegetable Market. However, the air paths within the Development under both schemes would allow the incoming wind along Tonkin Street to penetrate across the Development.

The NE wind skimming over Sham Shui Po Park would be capture by the façade of Block 3 under Approved Scheme, hence the VR near the junction of Tonkin Street and Tung Chau Street would be slightly higher, highlighted in black circle in Figure 38.

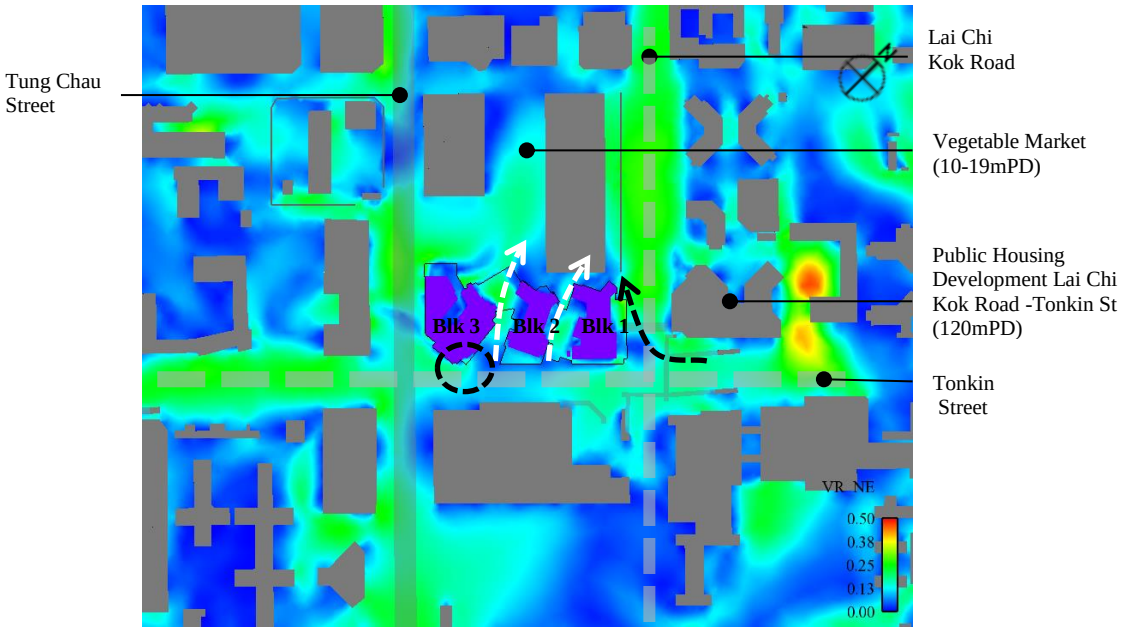


Figure 38 Contour Plot of VR for Approved Scheme under NE Wind

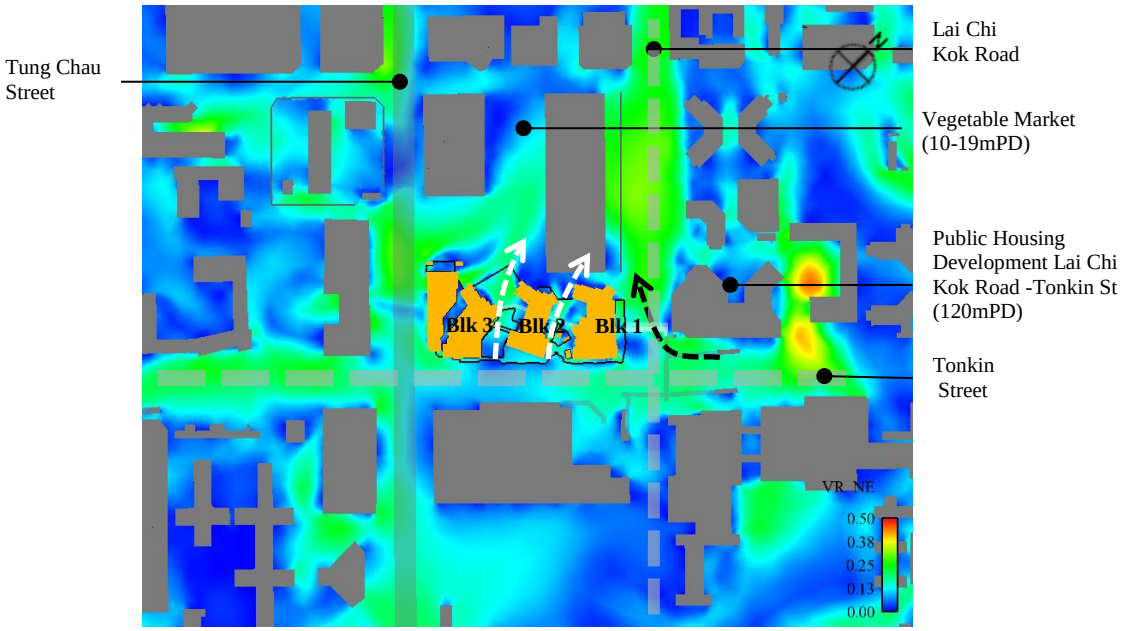


Figure 39 Contour Plot of VR for Intermediate Scheme under NE Wind

6.3.2 ENE/E Wind Direction

The wind pattern under ENE and E wind are similar. ENE wind would be discussed below as an example. With the similar building deposition, the ventilation performance would be similar under both Approved Scheme and Intermediate Scheme.

Similar to NE condition, the incoming wind would travel along Tonkin Street. Some portion of the wind would be diverted by the northeastern façade of Block 1 and travel along Lai Chi Kok Road while another portion of incoming wind would continue to travel along Tonkin Street, illustrated by white arrows in Figure 40 and Figure 41. Although, the Development would inevitably block some of the incoming wind for the Vegetable Market in downwind area, the wind shadow would be slightly alleviated through the two air paths provided by building separations under both schemes, shown as black arrows in Figure 40 and Figure 41. The stream of air passing through the air path between Block 1 and Block 2 would then skim over the low-rise market buildings to reach the northwest part of the Vegetable Market and Fat Tseung Street West.

With the rotated eastern wing of Block 3, some of the ENE wind diverted by the façade of Block 2 would be captured by the façade eastern wing of Block 3, illustrated by pink arrow in Figure 41. Hence, more wind would be diverted by Block 3 to pass through the building separation while the VR at the junction of Tonkin Street and Tung Chau Street would be slightly lower, white circled area in Figure 41.

On the other hand, the façade of Block 3 under Approved Scheme would divert the incoming wind continue to travel along Tonkin Street. Hence, the VR at the junction of Tonkin Street and Tung Chau Street would be slightly enhanced, white circled area in Figure 40.

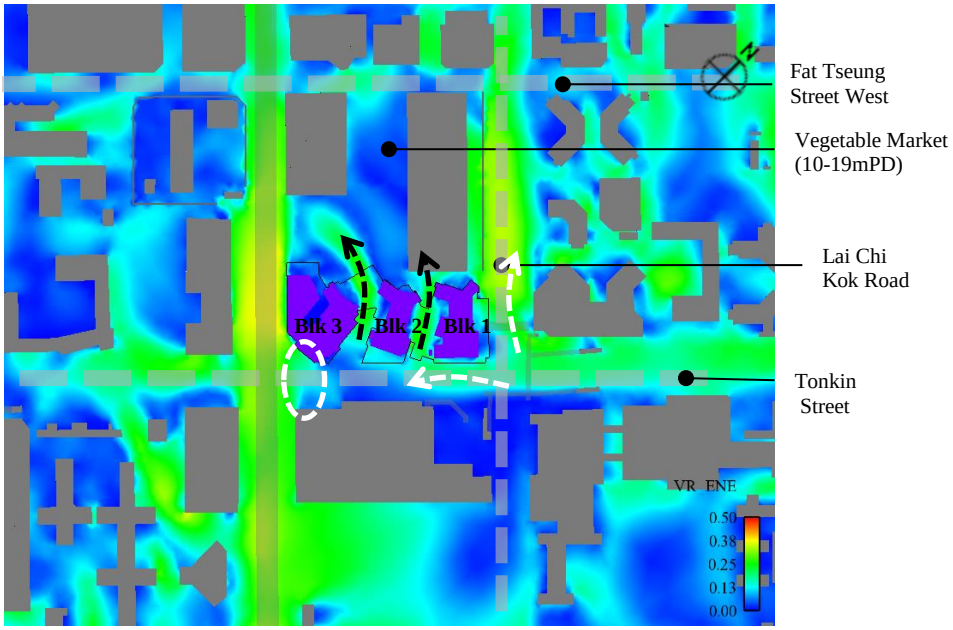


Figure 40 Contour Plot of VR for Approved Scheme under ENE Wind

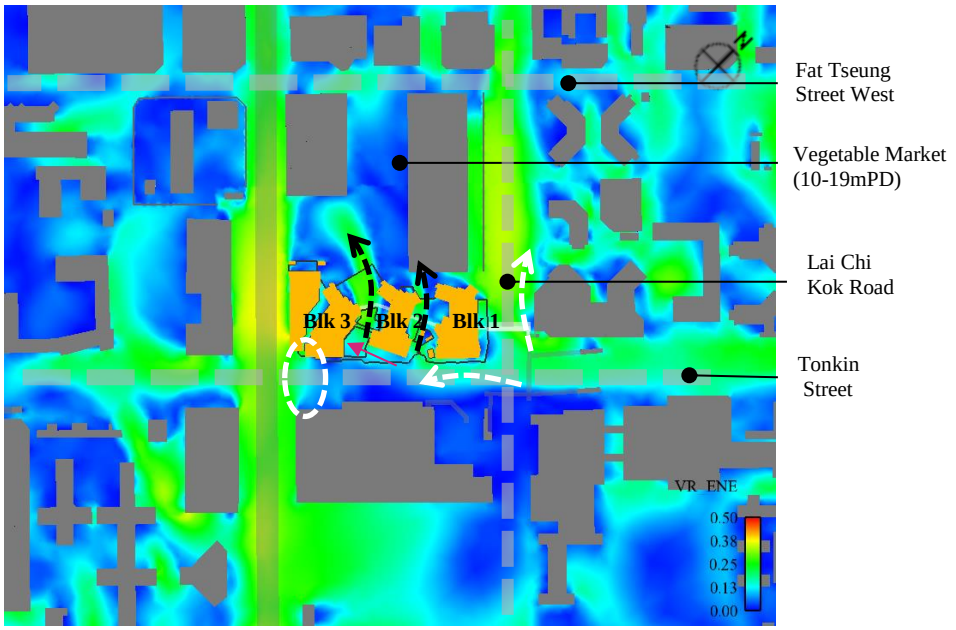


Figure 41 Contour Plot of VR for Intermediate Scheme under ENE Wind

6.3.3 ESE/SE Wind Direction

The wind pattern would be similar for both ESE and SE winds. The ESE wind would be discussed below as an example.

With the similar deposition of the towers and same building height, the ventilation performance would be similar under both schemes with some difference in localized area.

The ESE incoming wind would mainly travel along Lai Chi Kok Road, Tung Chau Street and skim over the low-rise building in Sham Shui Po Park. Similar to NE quadrant winds, the air paths provided within the Development site would promote the wind penetration across the site and reach the areas at downwind location, shown as black arrow in Figure 42 and Figure 43.

With the slightly higher permeability at Ground Floor of Intermediate Scheme, some of the wind would infiltrate through the building gaps and help to alleviate the wind shadow created by the Development slightly, highlighted by black circled area in Figure 43.

The rotated façade of eastern wing of Block 3 under Intermediate Scheme would diverted more wind to travel through the 15m building separation between Block 2 and Block 3 while the façade alignment of Approved Scheme would capture more wind to reach Tonkin Street, where the VR would be slightly higher.

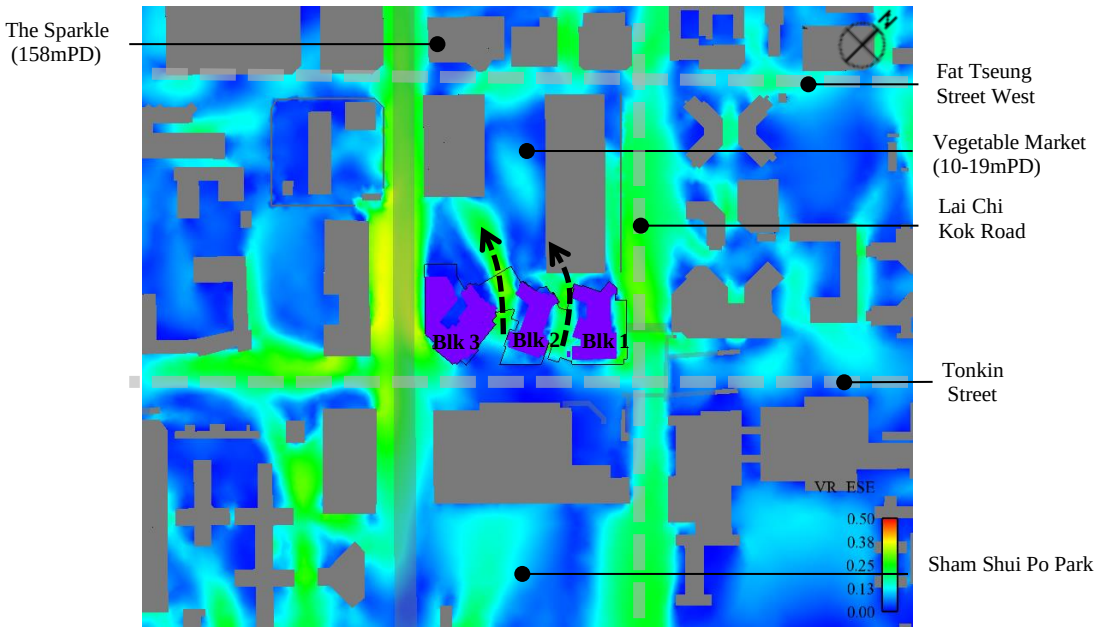


Figure 42 Contour Plot of VR for Approved Scheme under ESE Wind

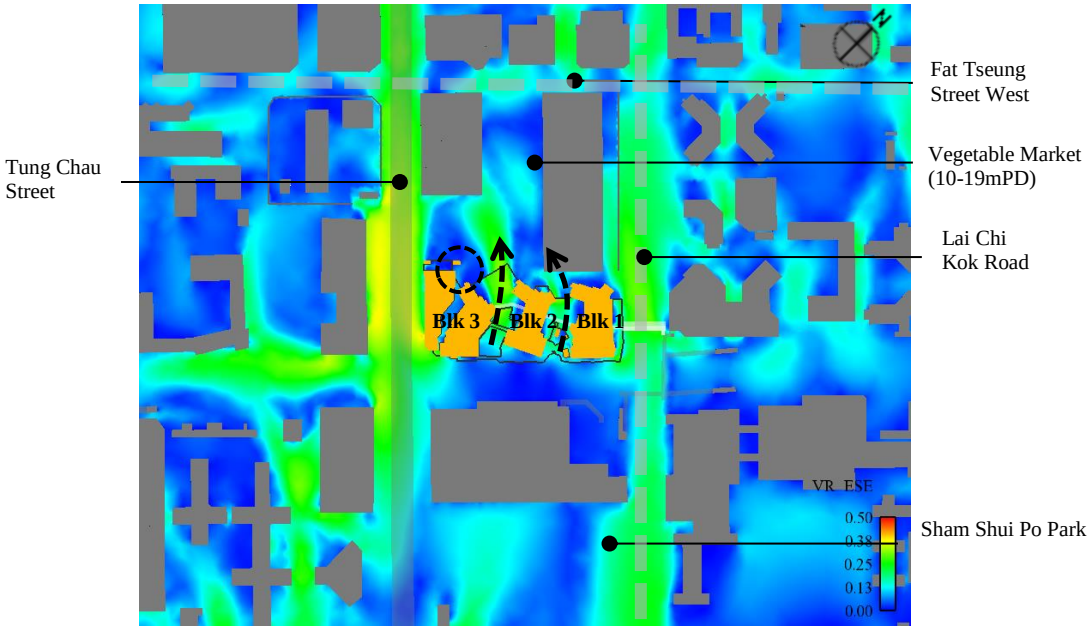


Figure 43 Contour Plot of VR for Intermediate Scheme under ESE Wind

6.3.4 SSE Wind Direction

The incoming SSE wind would be diverted by Fu Cheong Estate at upwind location and approach the application site from the open space in Sham Shui Po Park, shown as black arrow in Figure 44 and Figure 45. The incoming wind would be separated by the Development to travel along Lai Chi Kok Road and Tung Chau Street.

In addition, some of the incoming wind would penetrate across the site through the air paths provided and ventilate the vegetable market at leeward side, shown as white arrows in Figure 44 and Figure 45.

With the rotated eastern wing of Block 3 under Intermediate Scheme, the building line would be setback by around 8m, as compared to Approved Scheme, which would result in a longer façade aligned with Tonkin Street. Hence, slightly higher VR would be achieved at localized area on Tonkin Street, as highlighted by black circled area in Figure 45.

On the other hand, the façade of eastern wing of Block 3 with office block under Intermediate Scheme would create a longer frontage under SSE wind. Hence, the wind would be diverted more towards Tonkin Street, where lower VR would be observed along the southern boundary of the Development site.

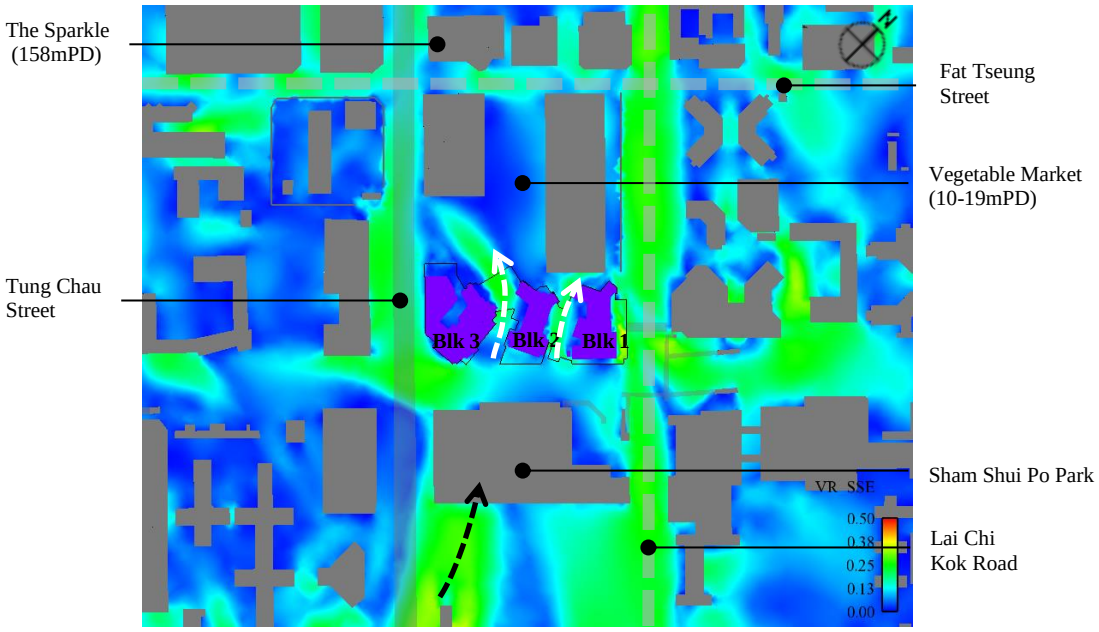


Figure 44 Contour Plot of VR for Approved Scheme under SSE Wind

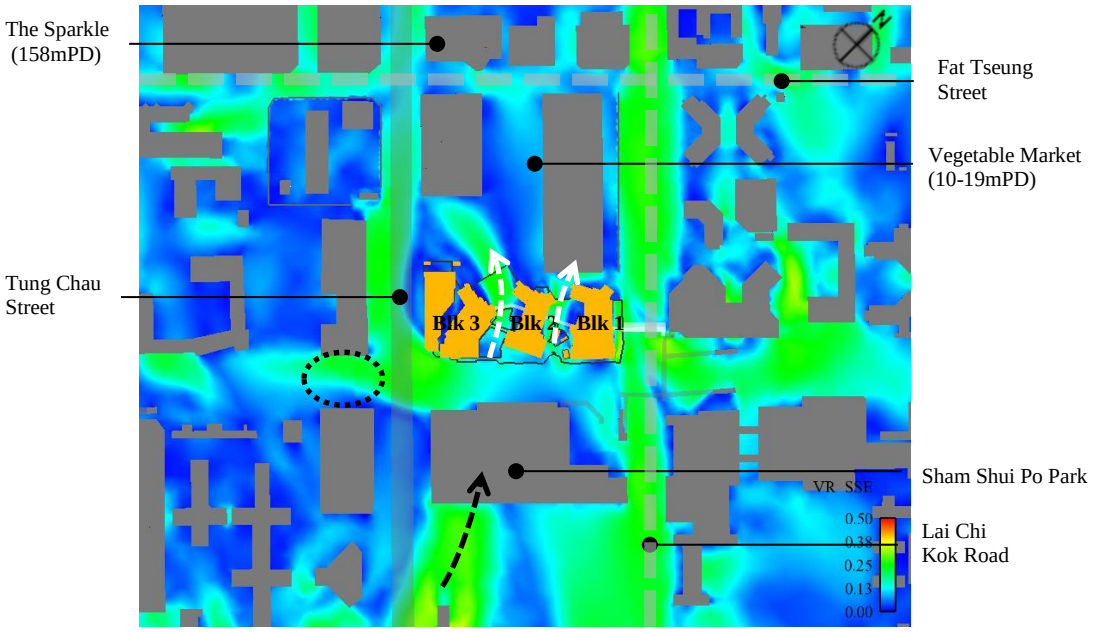


Figure 45 Contour Plot of VR for Intermediate Scheme under SSE Wind

6.3.5 S Wind Direction

Under S wind condition, with the high-rise residential building, namely PRH at NWKR Site 6 (130-139mPD) and Nam Cheong Station Overhead Development (182mPD), Wing Cheong Estate (118mPD), Fu Cheong Estate (118mPD) and mid-rise West Kowloon Law Courts Building (88mPD) occupying the upwind location from the southeast to the southwest quadrants of the application site, the incoming wind would be shielded by these surrounding buildings and a slightly calm wind environment would be resulted. The relatively open space in Sham Shui Po Park to the southeast of the site would act as the main wind entrance for the site, illustrated by black arrow in Figure 46 and Figure 47. The overall ventilation performance in surrounding areas are similar under both Approved Scheme and Intermediate Scheme.

The incoming wind would be captured by the façade of Block 3 under Intermediate Scheme, which would then be diverted to travel through the building separation between Block 2 and Block 3 while another stream of air would continue to travel along Tonkin Street, illustrated by white arrows in Figure 47. Although similar phenomenon would also take place under Approved Scheme, with larger building façade facing incoming wind direction, slightly more permeable design at G/F under Intermediate Scheme, more wind would be captured and downwashed to reach the pedestrian level and higher VR would be observed locally, highlighted in black circled area in Figure 47.

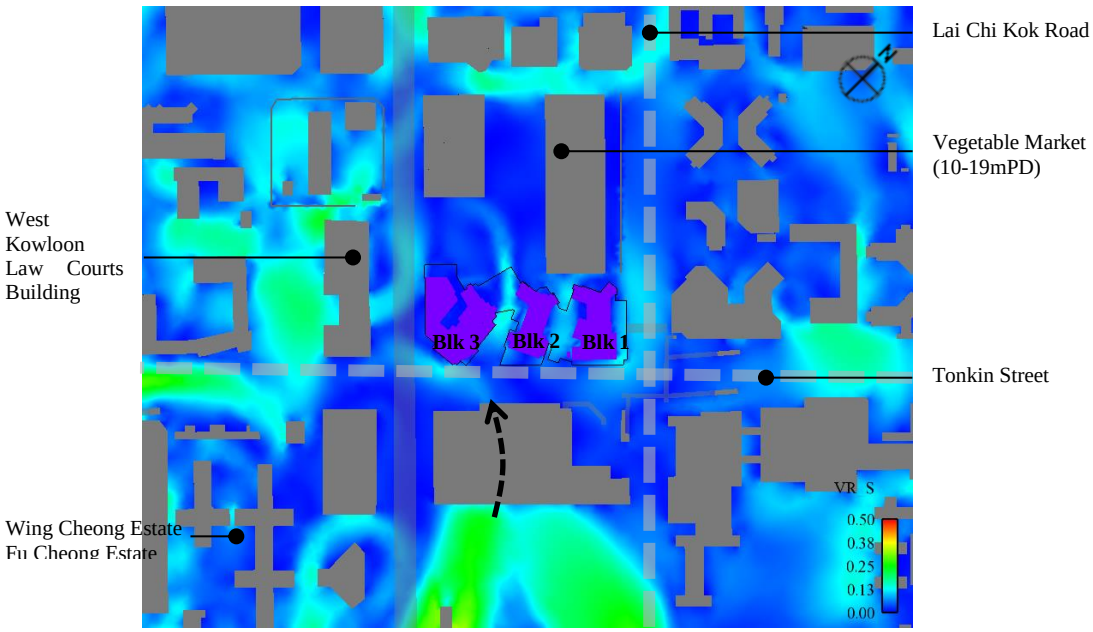


Figure 46 Contour Plot of VR for Approved Scheme under S Wind

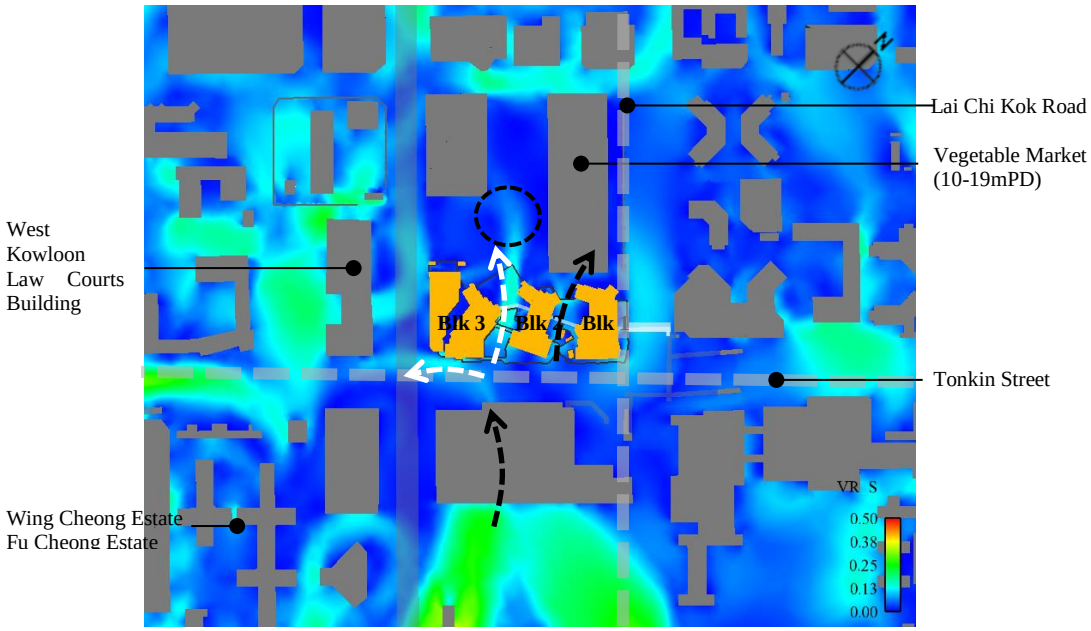


Figure 47 Contour Plot of VR for Intermediate Scheme under S Wind

6.3.6 SSW Wind Direction

Similar to S wind, the incoming wind would be shielded by existing building, such as the West Kowloon Law Courts Building (88mPD) located to the immediate southwest of the site, SSF at Fat Tseung Street West (120mPD) and PRH at NWKR Site 6 (130-139mPD) at further distance to the southwest of the site. Hence, the wind environment would be dominated by these surrounding buildings within the surrounding area. Some of the air would pass through the building separation in West Kowloon Law Courts Building and a stream of air would travel along Tonkin Street to reach the site. With the step height profile between office tower and Block 3, some of the higher-level wind from SSW direction would be downwashed by the southern façade of Block 3, which would then travel along the façade to reach Vegetable Market. The overall ventilation performance in surrounding areas are similar under both Approved Scheme and Intermediate Scheme.

Under Approved Scheme, more wind would be diverted by the façade of office tower and Block 3 to travel more towards the eastern part to the Development site and reach the Sham Shui Po Park, where the VR would be enhanced, illustrated by orange arrow in Figure 48.

With the wider building separation between office tower and Block 3 under Intermediate Scheme, the incoming wind from Tonkin Street would tend to travel through the building separation, illustrated by black arrow in Figure 49. With the longer southern façade under Intermediate Scheme, more wind would be captured and diverted to reach the Vegetable Market, where higher VR would be observed, highlighted with white circled area in Figure 49. Furthermore, with the setback and more streamlined building line of Block 3 under Intermediate Scheme, the incoming wind would continue to travel along the façades of Block 3, Block 2 and Block 1 along Tonkin Street.

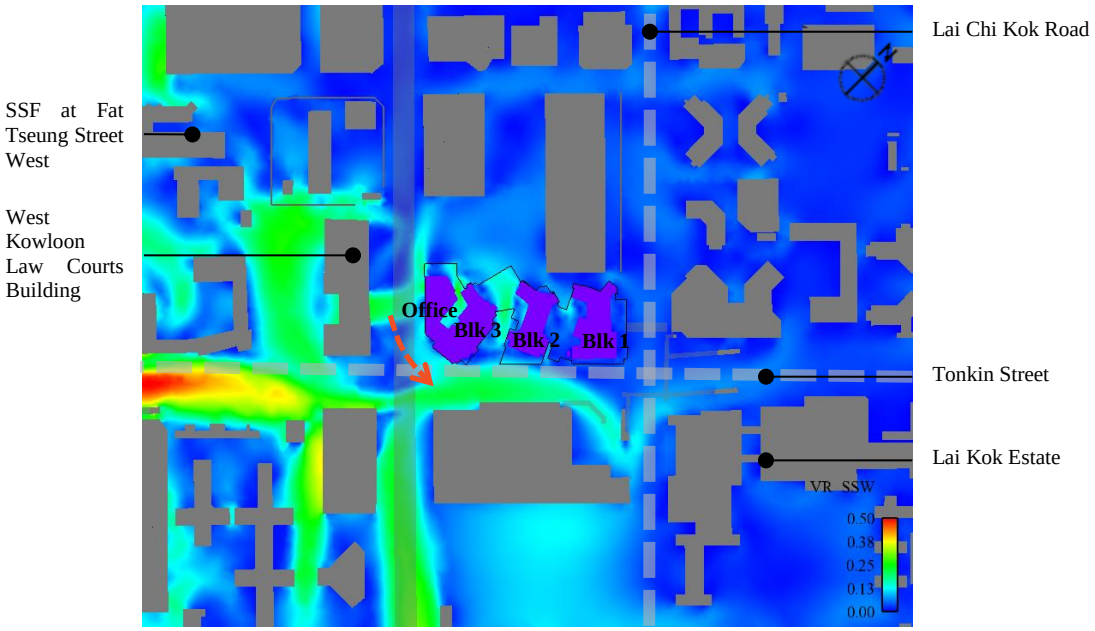


Figure 48 Contour Plot of VR for Approved Scheme under SSW Wind

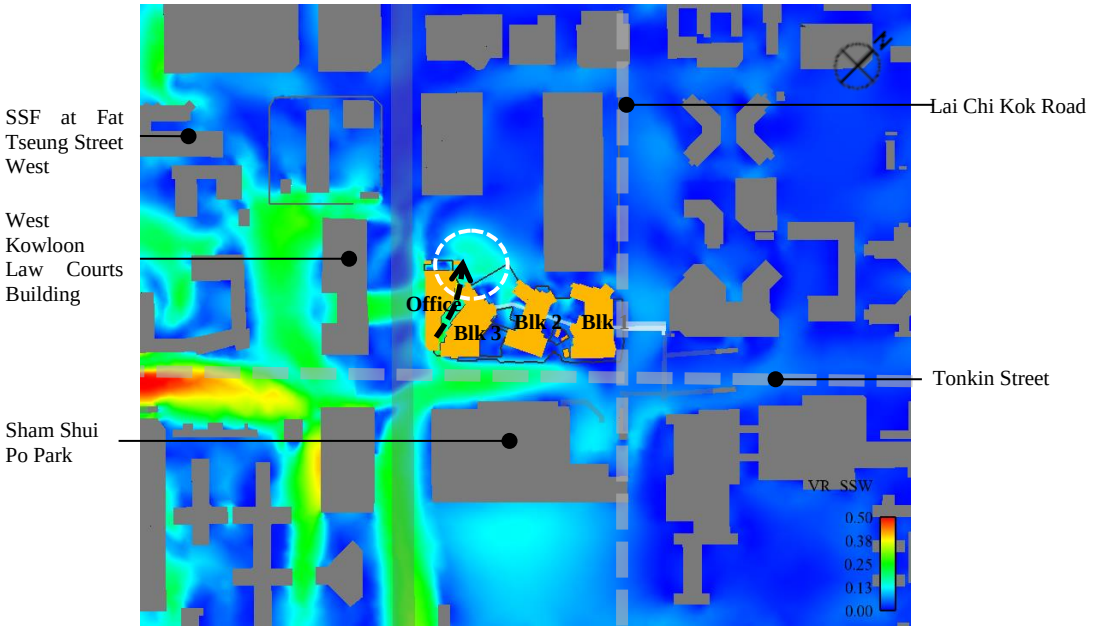


Figure 49 Contour Plot of VR for Intermediate Scheme under SSW Wind

6.3.7 SW Wind Direction

The wind pattern under SW and WSW winds are similar. The ventilation performance under SW wind would be discussed as example.

With the existing building, such as the West Kowloon Law Courts Building (88mPD) located to the immediate southwest of the site, SSF at Fat Tseung Street West (120mPD) and PRH at NWKR Site 6 (130-139mPD) located at further distance to the southwest of the site, the incoming wind would be shielded by these buildings and result in a relatively calmer wind environment. The ventilation

performance would be dominated by these buildings and the ventilation performance would be similar for both schemes.

With the relative lower buildings, such as the industrial buildings (~45mPD), located to the southwest of the application site. The incoming SW wind would skim over the industrial buildings and reach the façade of The Sparkle (158mPD). The wind would be subsequently downwashed and diverted by the façade of The Sparkle and travel towards the Vegetable Market, the application site and the Public Housing Development site at Lai Chi Kok Road – Tonkin Street, shown as black arrows in Figure 50 and Figure 51.

On the other hand, the incoming SW wind would also travel along Tonkin Street and reach the Sham Shui Po Park to the southeast of the application site.

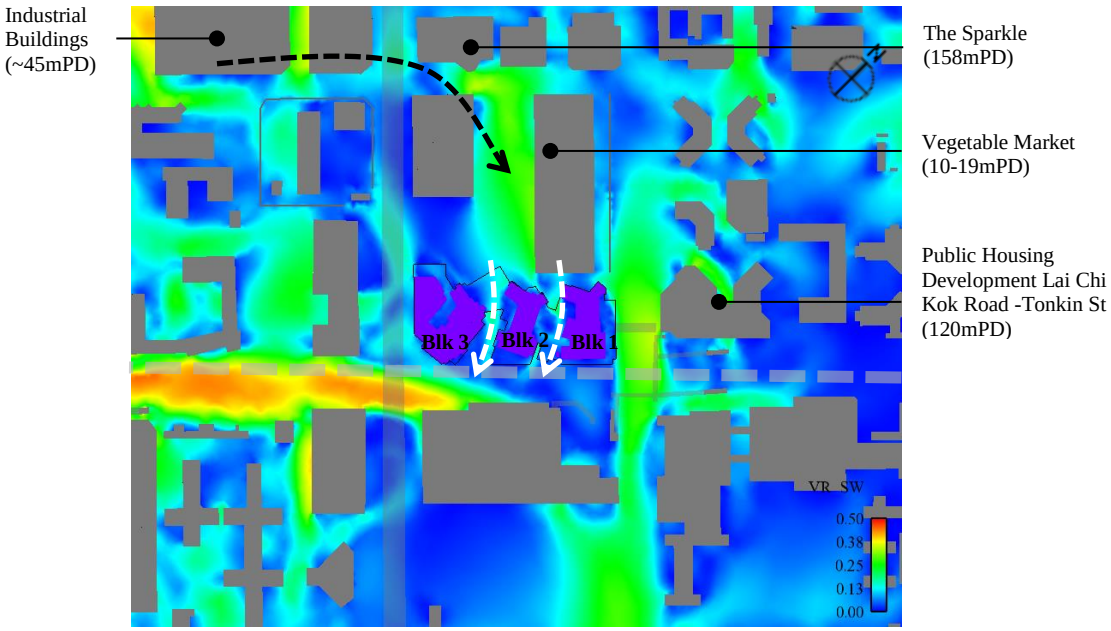


Figure 50 Contour Plot of VR for Approved Scheme under SW Wind

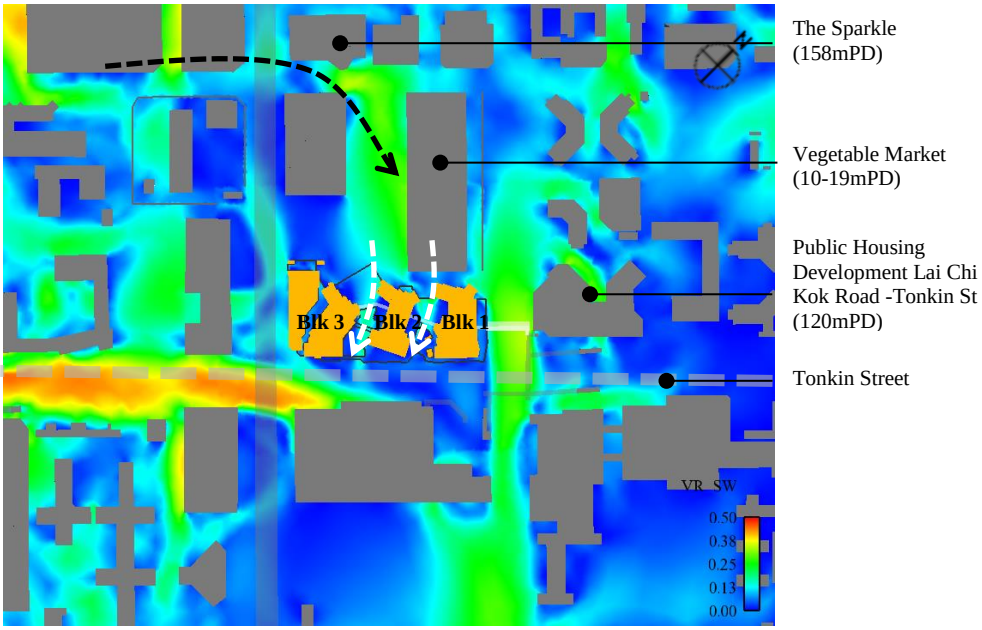


Figure 51 Contour Plot of VR for Intermediate Scheme under SW Wind

6.4 VR Results of Test Points

Table 8 summarizes the values of SVR and LVR among Approved Scheme and Intermediate Scheme. The VR of individual test points may refer to Appendix D of this report.

Table 8 Comparison of the SVR and LVR among Approved Scheme and Intermediate Scheme

	Annual Weighted VR		Summer Weighted VR	
	Approved Scheme	**Intermediate Scheme**	**Approved Scheme**	**Intermediate Scheme**
SVR	0.15	0.15	0.11	0.12
LVR	0.14	0.14	0.12	0.12

Under annual condition, Intermediate Scheme obtained similar SVR and LVR comparing to Approved Scheme. The result indicate that the Intermediate Scheme would achieve similar wind environment at both the close proximity to study site and within surrounding area.

Under summer condition, Intermediate Scheme obtained slightly higher SVR but similar LVR comparing to Approved Scheme. Winds from the southwest quadrant accounts for majority of summer winds in terms of frequency. Due to the existing buildings, such as PRH at NKWR Site 6, Nam Cheong Station Overhead Development, Wing Cheong Estate, Fu Cheong Estate, SSF at Fat Tseung Street West and West Kowloon Law Courts Building and some mid-rise industrial

buildings located at the upwind location of the Development, the wind would be shielded and dominated by these surrounding buildings. Hence, a similar LVR would be achieved by both Approved Scheme and Intermediate Scheme. The longer southern façade of Block 3 under Intermediate Scheme would divert more downwashed SW quadrant winds to reach the western boundary, hence slightly higher SVR would be observed under Intermediate Scheme.

6.5 Focus Areas

There is a total of 14 focus areas identified for this study, focus areas 1-10 are outside of the Development and focus areas 11-14 are within the Development. Table 9 summarized the Spatial Average VR (SAVR) for each focus areas under annual and summer conditions.

With densely built-up area at the upwind location of the Development site, the surrounding wind environment, especially under SW quadrant winds would be dominated by the existing buildings. Similar to Approved Scheme, the Intermediate Scheme adopt same building height, similar building deposition as well as two 15m building separation across the Development site. Hence, the ventilation performance at all focus area outside the ventilation Development site are similar under both Approve Scheme and Intermediate Scheme.

Within the Development site, as the rotated eastern wing of Block 3 under Intermediate Scheme would capture more NE quadrant wind to pass through the building separation between Block 2 and Block 3 hence the VR at ***Podium Deck between Block 2 and Block 3*** would be slightly higher, as compared to Approved Scheme.

Subsequently, some of the capture wind would reach the ground level of western boundary. In addition, the longer southern façade of Block 3 under Intermediate Scheme would capture more SSW wind. Together with the wider building separation between office tower and Block 3, the wind would be diverted towards the western boundary, hence the ***Air Path along NE-SW boundary*** would achieve slightly higher VR.

Table 9 Spatial Averaged VR (SAVR) for Each Focus Area

Focus Areas		Annual Condition		Summer Condition	
		Approved Scheme	Intermediate Scheme	Approved Scheme	Intermediate Scheme
1	Tonkin Street	0.17	0.17	0.16	0.16
2	Lai Kok Estate	0.07	0.07	0.07	0.07
3	Sham Shui Po Park	0.12	0.12	0.12	0.12

Focus Areas		Annual Condition		Summer Condition	
		Approved Scheme	Intermediate Scheme	Approved Scheme	Intermediate Scheme
4	Public Housing Development at Lai Chi Kok Road - Tonkin Street	0.13	0.13	0.12	0.12
5	Lai Chi Kok Road	0.19	0.19	0.16	0.16
6	Vegetable Market	0.09	0.09	0.09	0.09
7	Tung Chau Street	0.23	0.23	0.15	0.15
8	Drainage Service Department (DSD) Pumping Station	0.14	0.14	0.11	0.11
9	West Kowloon Law Courts Building	0.17	0.17	0.16	0.16
10	Joint-User Government Office Building	0.21	0.21	0.16	0.16
11	Air Path between Block 2 and Block 3	0.22	0.22	0.17	0.17
12	Air Path between Block 1 and Block 2	0.20	0.20	0.15	0.15
13	Podium Deck between Block 2 and Block 3	0.20	0.22	0.14	0.15
14	Air Path along NE-SW Site Boundary	0.12	0.13	0.10	0.10

7 Wind Enhancement Features

Comparing to Approved Scheme, the two air paths under Intermediate Scheme would also be effective in facilitating wind penetration under various wind directions, such as ENE, E, SSE, S and WSW. The ventilation performance at leeward side would be similar between two schemes. The effect of the air path is illustrated below.

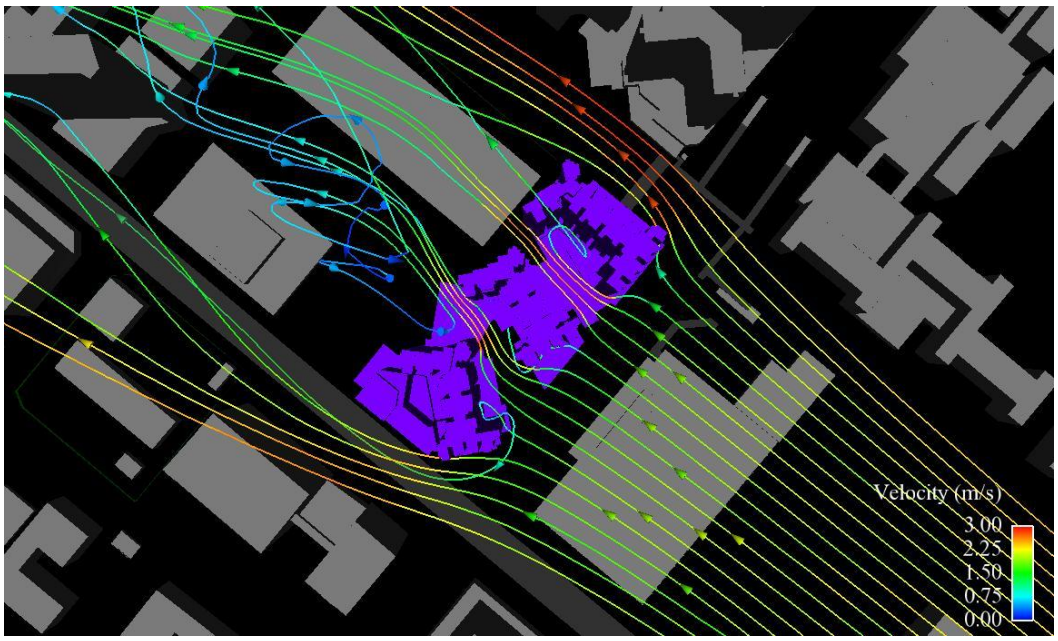


Figure 52 Wind Penetration through Air Path under SE Wind (Approved Scheme)

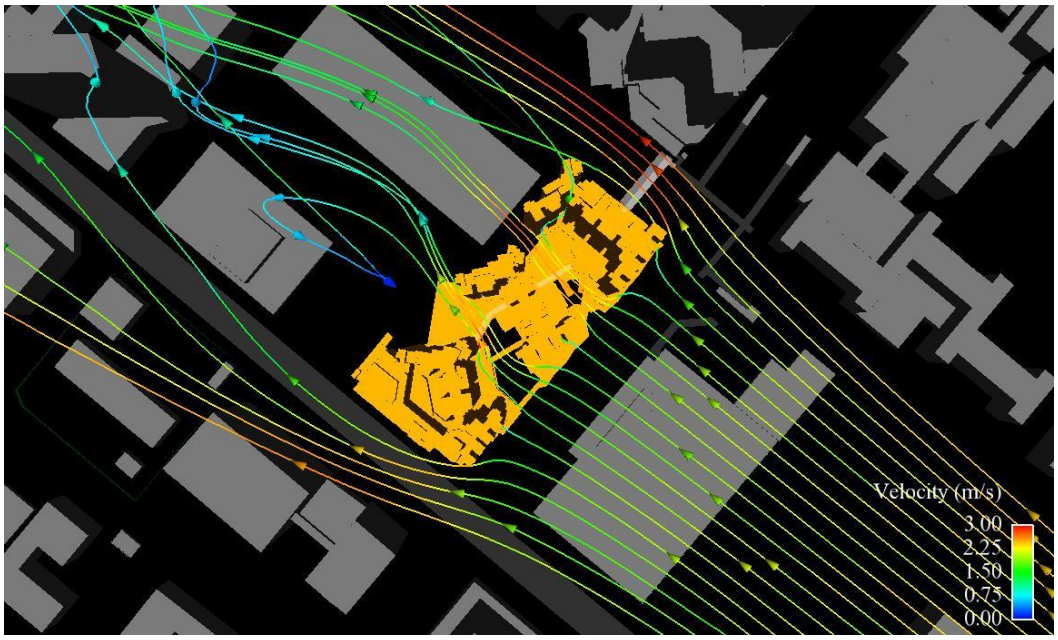


Figure 53 Wind Penetration through Air Path under SE Wind (Intermediate Scheme)

8 Proposed Scheme

The Intermediate Scheme was further revised during detailed design stage and a Proposed Scheme was formulated. Additional flats have been added and while the building height is kept the same. The planning parameters have been shown in Table 10. The master layout plan is shown in Figure 54 with the difference in typical floor highlighted in yellow circled area.

Table 10 Development Parameters of Proposed Scheme

Development Parameter	Proposed Scheme
Plot Ratio	Domestic 7.5 Non-domestic 1.5
Maximum Building Height	126mPD
No. of Flats	2591

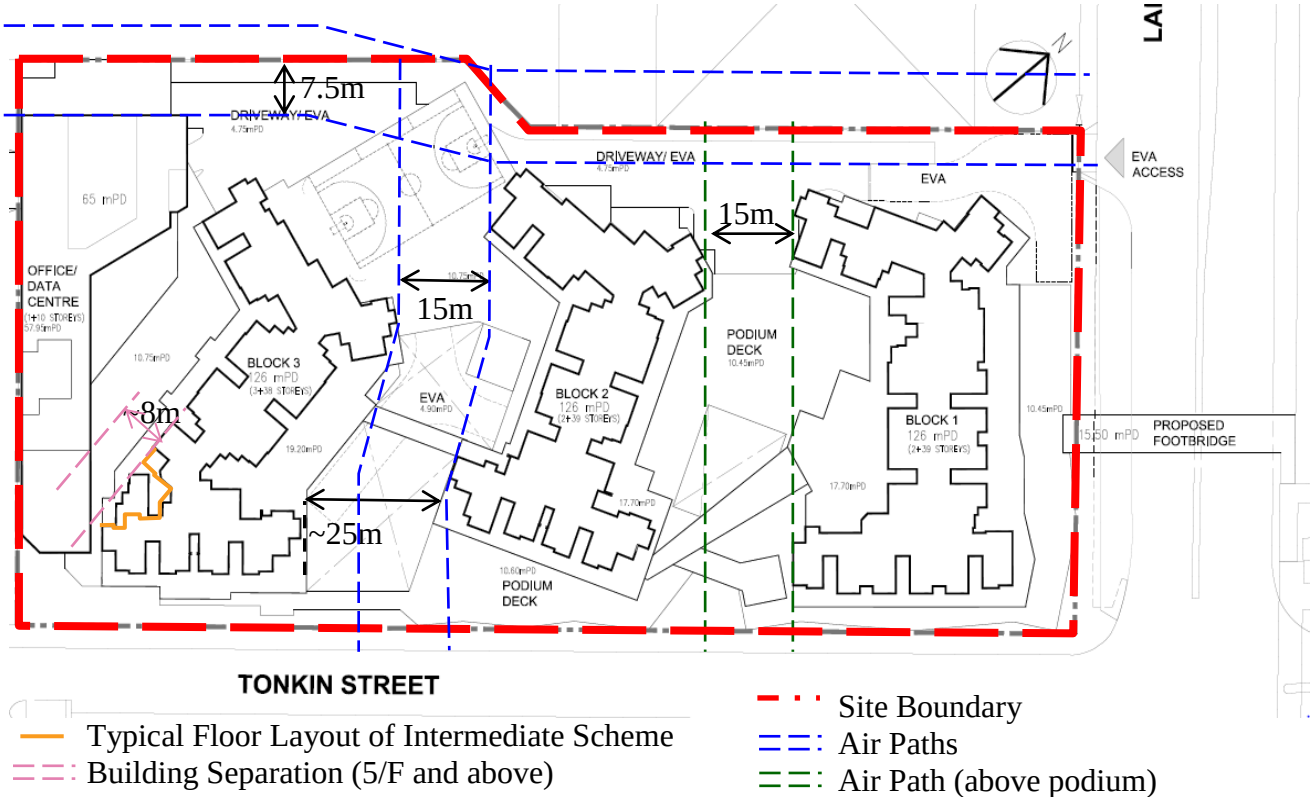


Figure 54 Proposed Scheme - Master Layout Plan

As shown in Figure 54, the location of the additional flat is located at leeward side, which is within the wind shadow area for both annual and summer prevailing winds. The addition of this flat would not change the permeability under the wind directions for both annual and summer wind conditions. Furthermore, the wind

enhancement features such as two air paths of minimum 15m are maintained. Hence, it is expected that the ventilation performance of the Proposed Scheme would be very similar as compared with Intermediate Scheme. The addition of the flat would not significantly alter the wind pattern or wind performance within the assessment area.

9 Conclusion

9.1 Overview

An Air Ventilation Assessment (AVA) – Initial Study was conducted to assess the ventilation performance of Approved Scheme and Intermediate Scheme in accordance with the AVA Technical Circular No. 1/06.

Two schemes were assessed using Computational Fluid Dynamics (CFD) techniques. A series CFD simulation using Realizable k-ε turbulence model were performed under annual and summer wind conditions with reference to the AVA Technical Circular No. 1/06. For annual wind condition, NE, ENE, E, ESE, SE, SSE, SSW and SW were selected which gives total wind frequency of 79.1% over a year while E, ESE, SE, SSE, S, SSW, SW and WSW were selected for summer condition, which gives total wind frequency of 81.7%.

The Velocity Ratio (VR) as proposed by the AVA Technical Circular No.1/06 was employed to assess the ventilation performance under different schemes and its impact to the surroundings.

With reference to the AVA Technical Circular No. 1/06, 30 perimeter test points and 69 overall test points were allocated to assess the overall ventilation performance in the Assessment Area. Another 12 special test points were allocated for both Approved and Intermediate Schemes respectively, to assess the ventilation performance within the Study Site.

9.2 Results

The results showed that, with the similar building deposition and building height the ventilation performance under the Approved Scheme and Intermediate Scheme would be similar.

- Under annual condition, Intermediate Scheme obtained a similar SVR and LVR comparing to Approved Scheme, indicating that the wind environment at close proximity and overall ventilation performance would be similar for both schemes.
- Under summer condition, Intermediate Scheme obtained a slightly higher SVR and similar LVR comparing to Approved Scheme, indicating that overall wind environment would be similar for both schemes while a slightly higher ventilation performance would be achieved near the site boundary.

The Intermediate Scheme was further revised with slightly change in building layout of Block 3 and a Proposed Scheme was formulated. As the changes would be minimal, comparing to the Intermediate Scheme and the two 15m air paths as wind enhancement features are maintained. The ventilation performance would be very similar between the Proposed Scheme and Intermediate Scheme.

The two 15m air path between Block 1 and Block 2, Block 2 and Block 3 are effective in facilitating wind penetration, which would allow the wind penetration under various wind directions.

10 Reference

[1] Term Consultancy for Expert Evaluation and Advisory Services on Air Ventilation Assessment Services under Agreement No. PLNQ 35/2009, September 2010 (http://www.pland.gov.hk/pland_en/info_serv/ava_register/ProjInfo/AVRG55_AVA_FinalReport.pdf)

[2] Annex A of Technical Circular No. 1/06 issued by the Housing, Planning and Lands Bureau pertaining specifically to Air Ventilation Assessments, 19th July, 2006

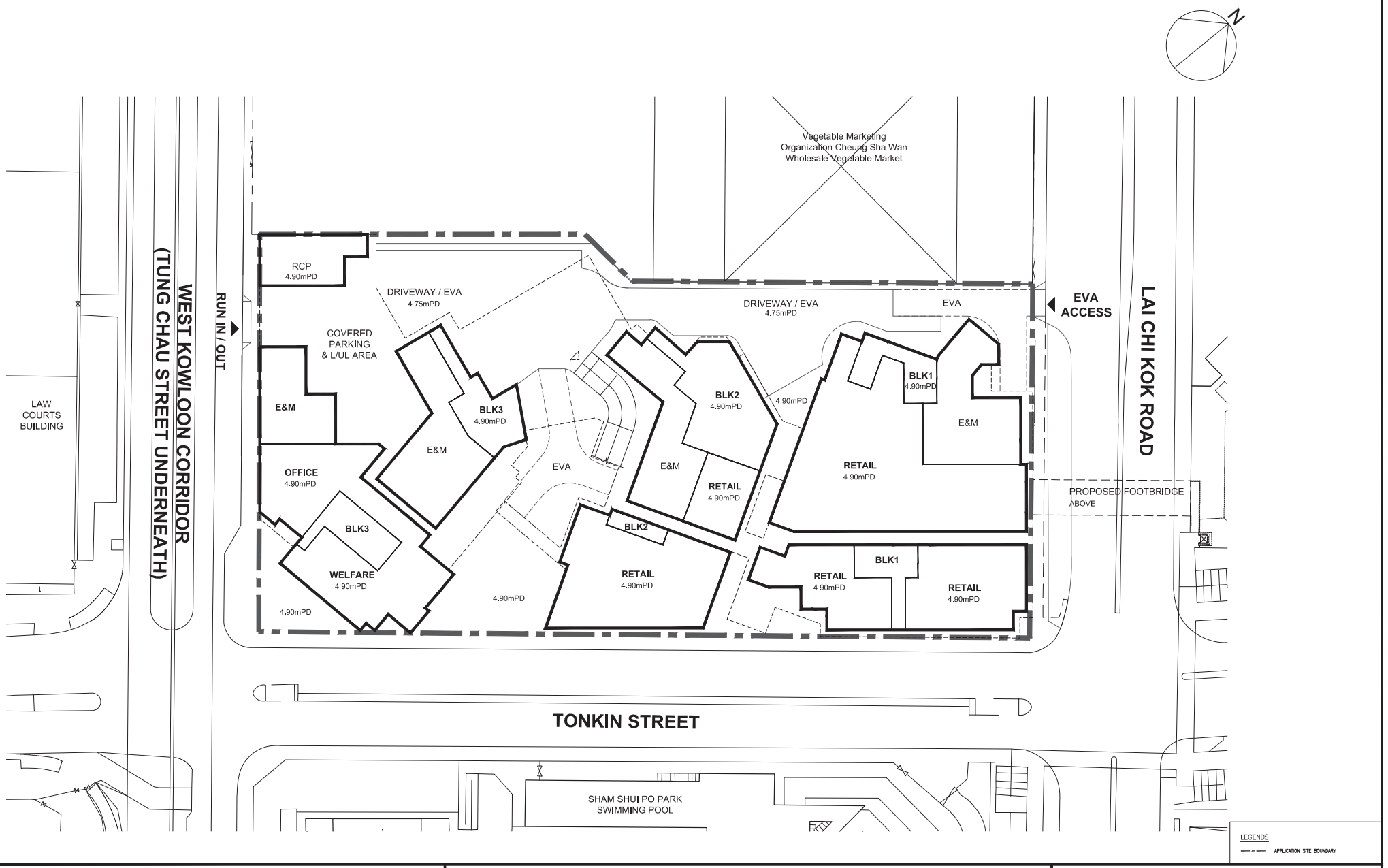
(https://www.devb.gov.hk/filemanager/en/content_679/hplb-etwb-tc-01-06.pdf)

[3] Planning Department RAMS Data (http://www.pland.gov.hk/pland_en/info_serv/site_wind/site_wind/)

Appendix A

Master Layout Plan of Approved and Intermediate Schemes

A1 Approved Scheme



NORTH WEST KOWLOON RECLAMATION SITE 1 (EAST)

DRAWING TITLE

FLOOR PLAN (G/F)

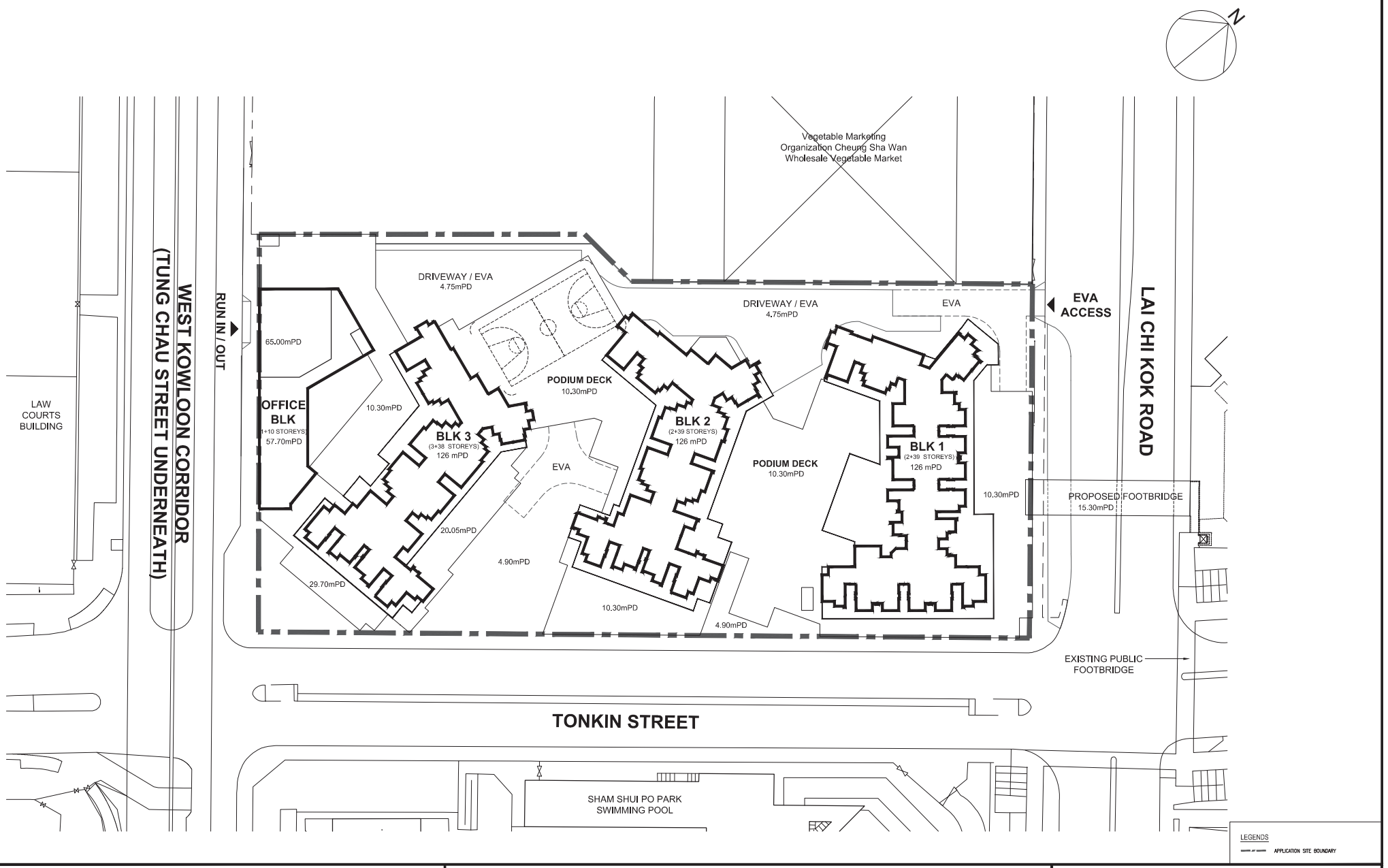
0 10 20 30 40m

SCALE 1:400 (A1) 1:800 (A3)

HOUSING DEPARTMENT

DRAWING NO.
PLAN 7

DATE:
08/2017



NORTH WEST KOWLOON RECLAMATION SITE 1 (EAST)

DRAWING TITLE

MASTER LAYOUT PLAN

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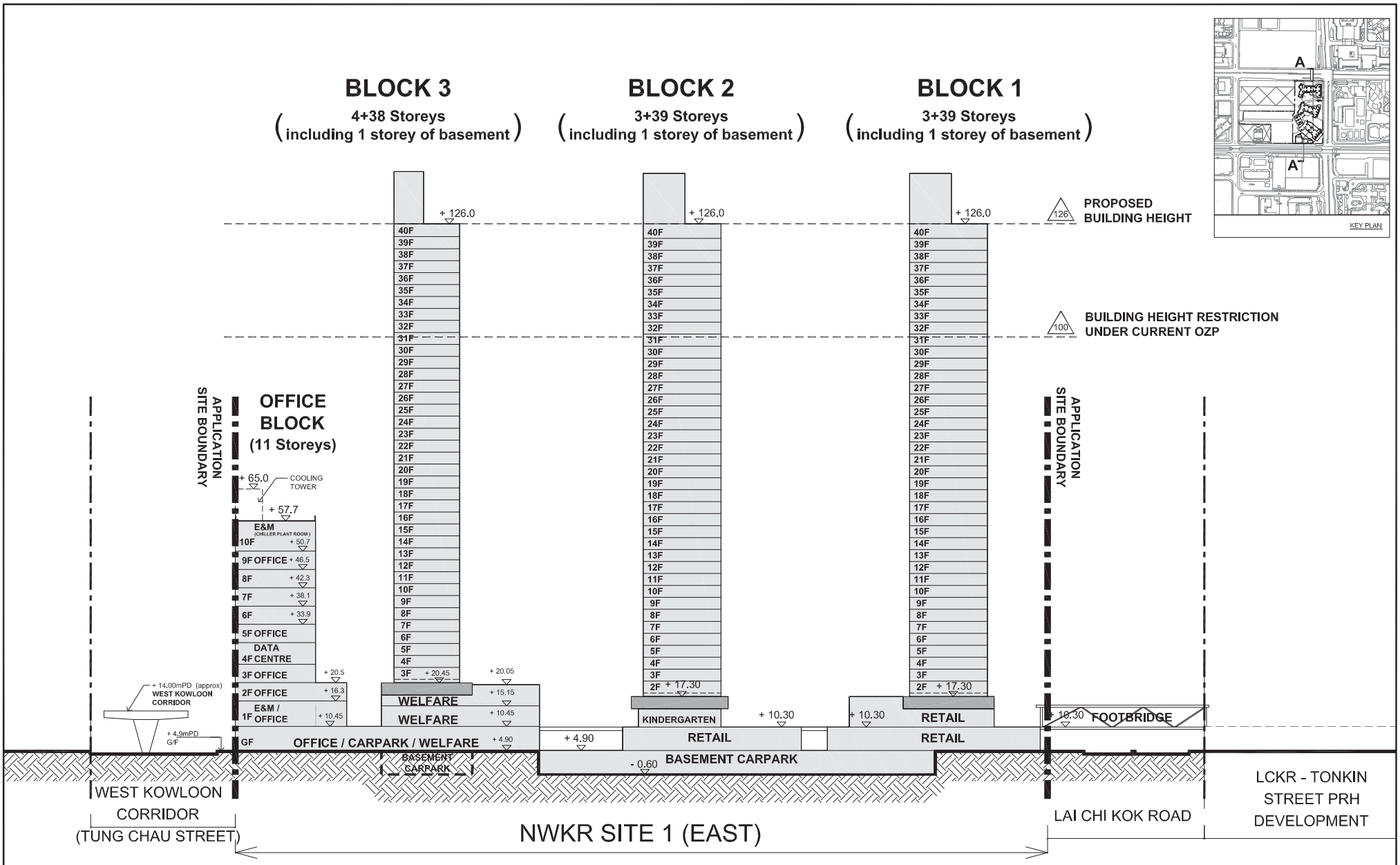
SCALE 1:400 (A1) 1:800 (A3)

HOUSING DEPARTMENT

DRAWING NO.
PLAN 4

DATE:
08/2017



NORTH WEST KOWLOON RECLAMATION SITE 1 (EAST)

DRAWING TITLE

SECTION

0 10 20 30 40m

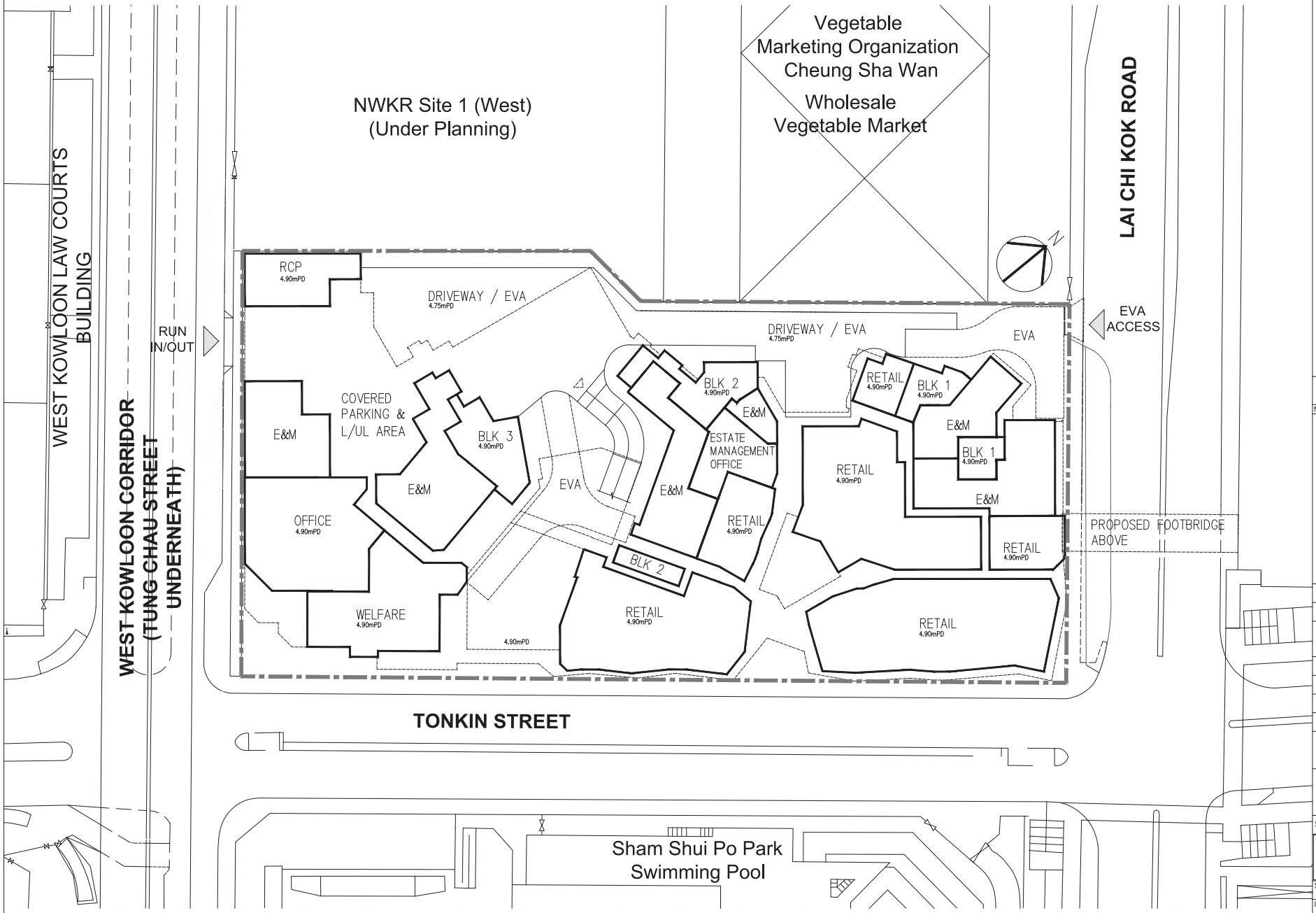
SCALE 1:400 (A1) 1:800 (A3)

房 屋 署
HOUSING DEPARTMENT

DRAWING NO. PLAN 5

日期 DATE: 09/2017

A2 Intermediate Scheme



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8/F, GUARDIAN HOUSE, 32 OI KWAN ROAD, WANCHAI, HONG KONG.

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ENDORSED			
CHECKED			
DRAWN			

PROJECT
PUBLIC HOUSING DEVELOPMENT AT NORTH WEST KOWLOON RECLAMATION SITE 1 (EAST)

DRAWING TITLE
FLOOR PLAN(G/F)

SCALE 1:400(A1);1:800(A3)

DRAWING NO.
PLAN 5

SOURCE

ICU NO.

AutoCAD 2000 A1 594 x 841

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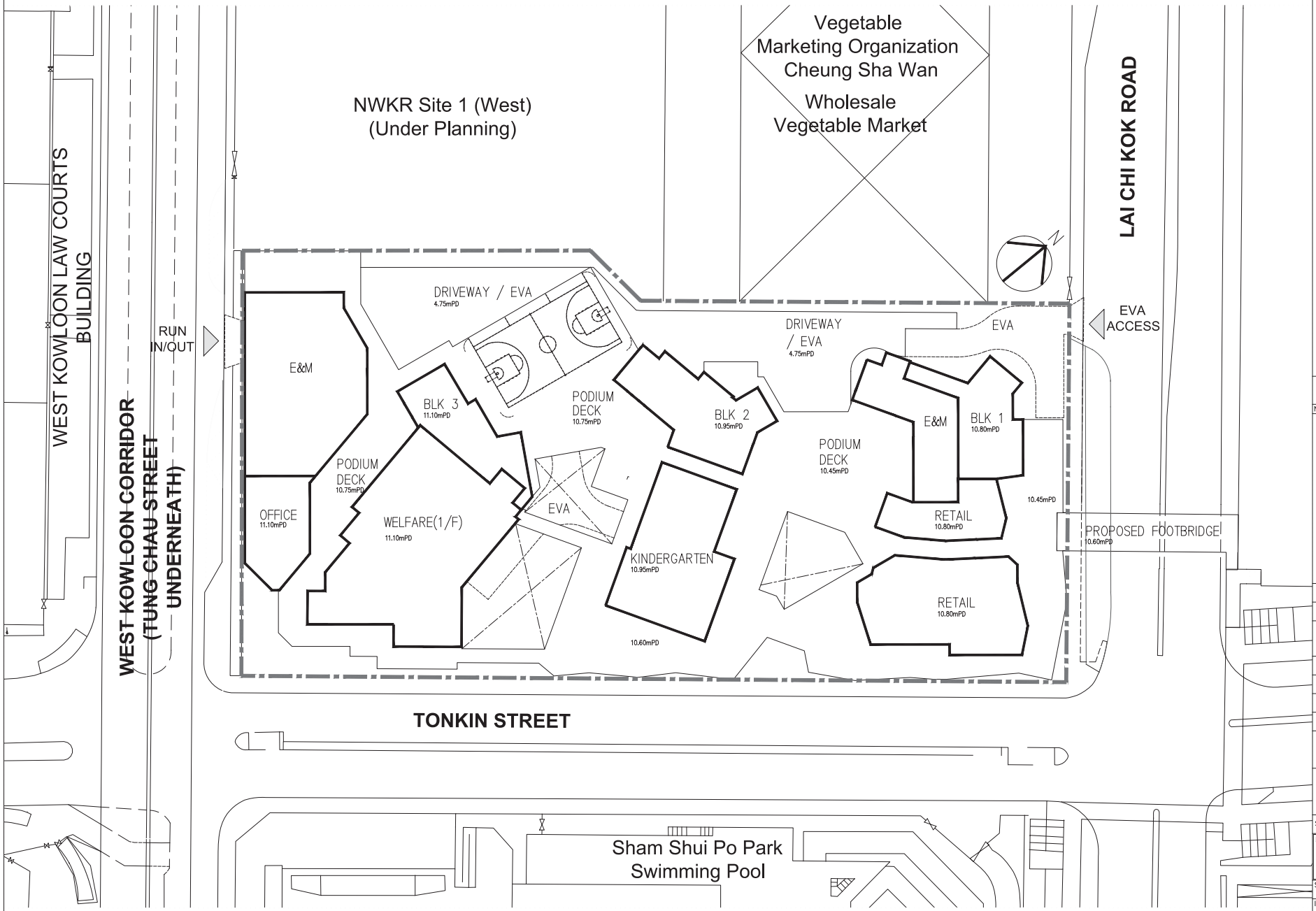

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APPLICATION SITE BOUNDARY

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	NAME AND DESIGNATION	INITIAL	DATE
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PROJECT
PUBLIC HOUSING DEVELOPMENT AT NORTH WEST KOWLOON RECLAMATION SITE 1 (EAST)

DRAWING TITLE
FLOOR PLAN (1F)

SCALE 1:400 (A1); 1:800 (A3)

DRAWING NO.
PLAN 6

SOURCE

ICU NO.

AutoCAD 2000 A1 594 x 841

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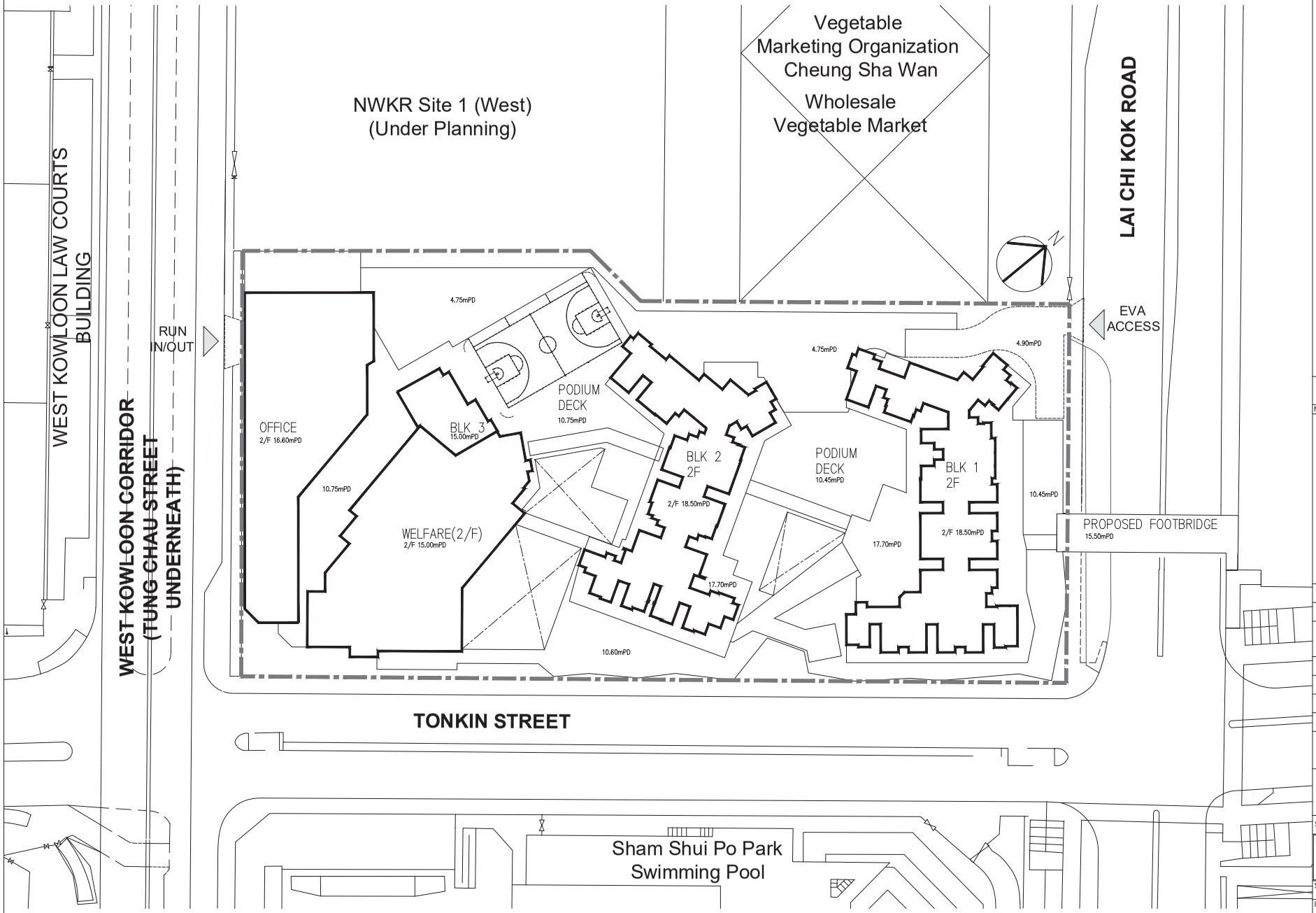

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APPLICATION SITE BOUNDARY

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	NAME AND DESIGNATION	INITIAL	DATE
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PROJECT
PUBLIC HOUSING DEVELOPMENT AT NORTH WEST KOWLOON RECLAMATION SITE 1 (EAST)

DRAWING TITLE
FLOOR PLAN (2F)

SCALE 1:400 (A1); 1:800 (A3)

DRAWING NO.

SOURCE

ICU NO.

AutoCAD 2000 A1 594 x 841

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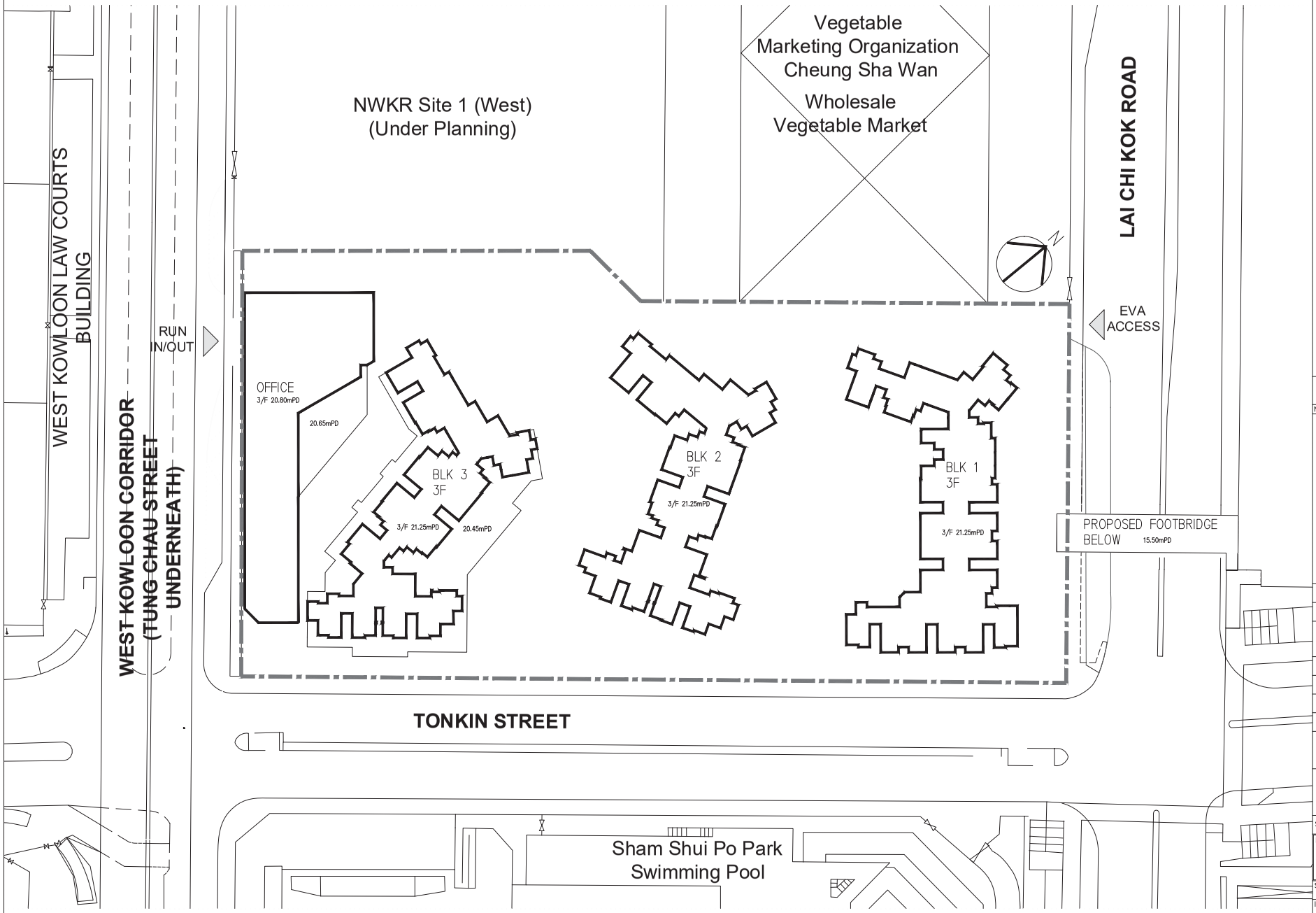

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	NAME AND DESIGNATION	INITIAL	DATE
AUTHORISED FOR ISSUE BY HD			
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PROJECT
PUBLIC HOUSING DEVELOPMENT AT NORTH WEST KOWLOON RECLAMATION SITE 1 (EAST)

DRAWING TITLE
FLOOR PLAN (3F)

SCALE 1:400 (A1); 1:800 (A3)

DRAWING NO.

SOURCE

ICU NO.

AutoCAD 2000 A1 594 x 841

HOUSING DEPARTMENT

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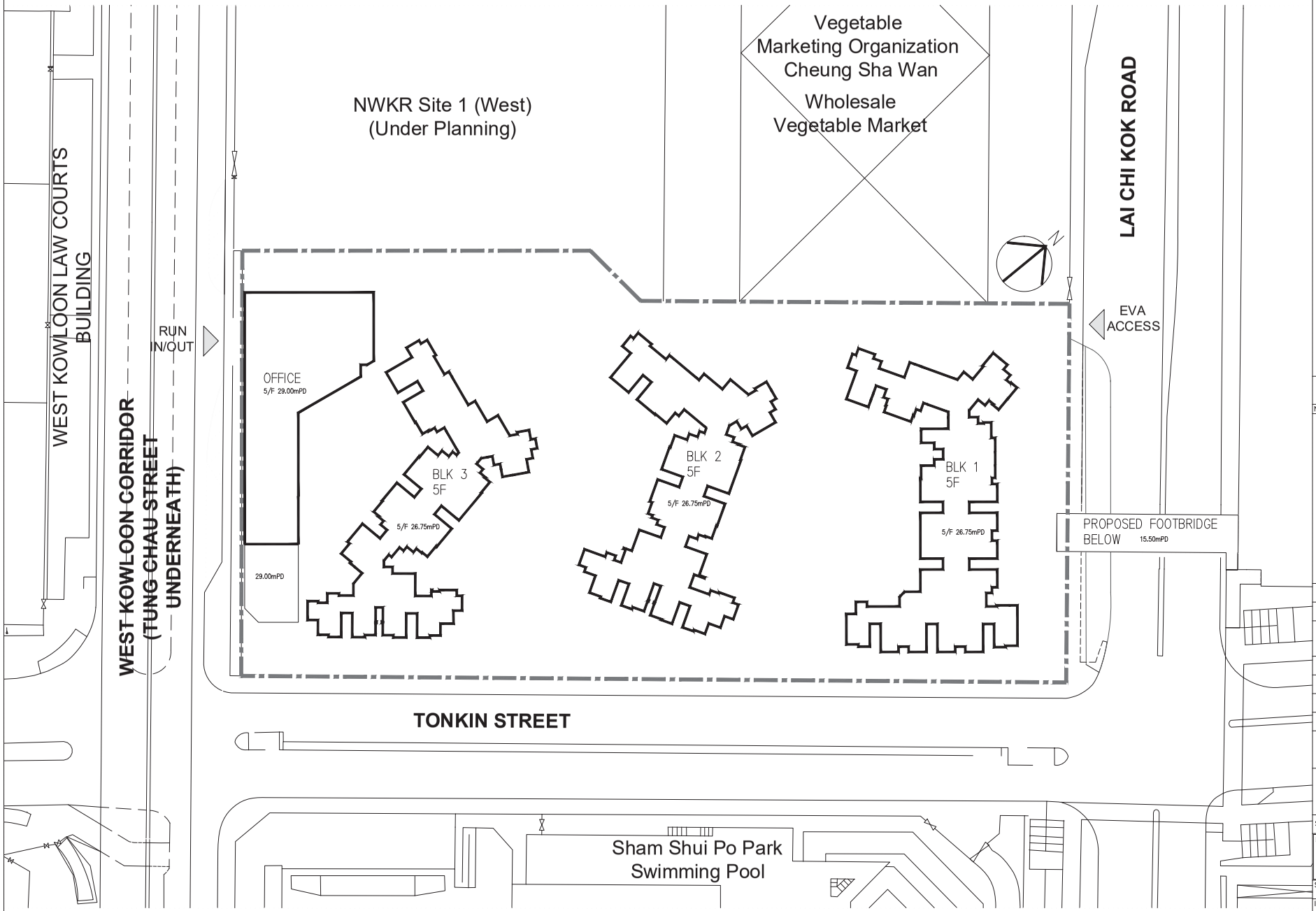

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PROJECT
PUBLIC HOUSING DEVELOPMENT AT NORTH WEST KOWLOON RECLAMATION SITE 1 (EAST)

DRAWING TITLE
FLOOR PLAN (5F)

SCALE 1:400 (A1); 1:800 (A3)

DRAWING NO.

SOURCE

ICU NO.

AutoCAD 2000 A1 594 x 841

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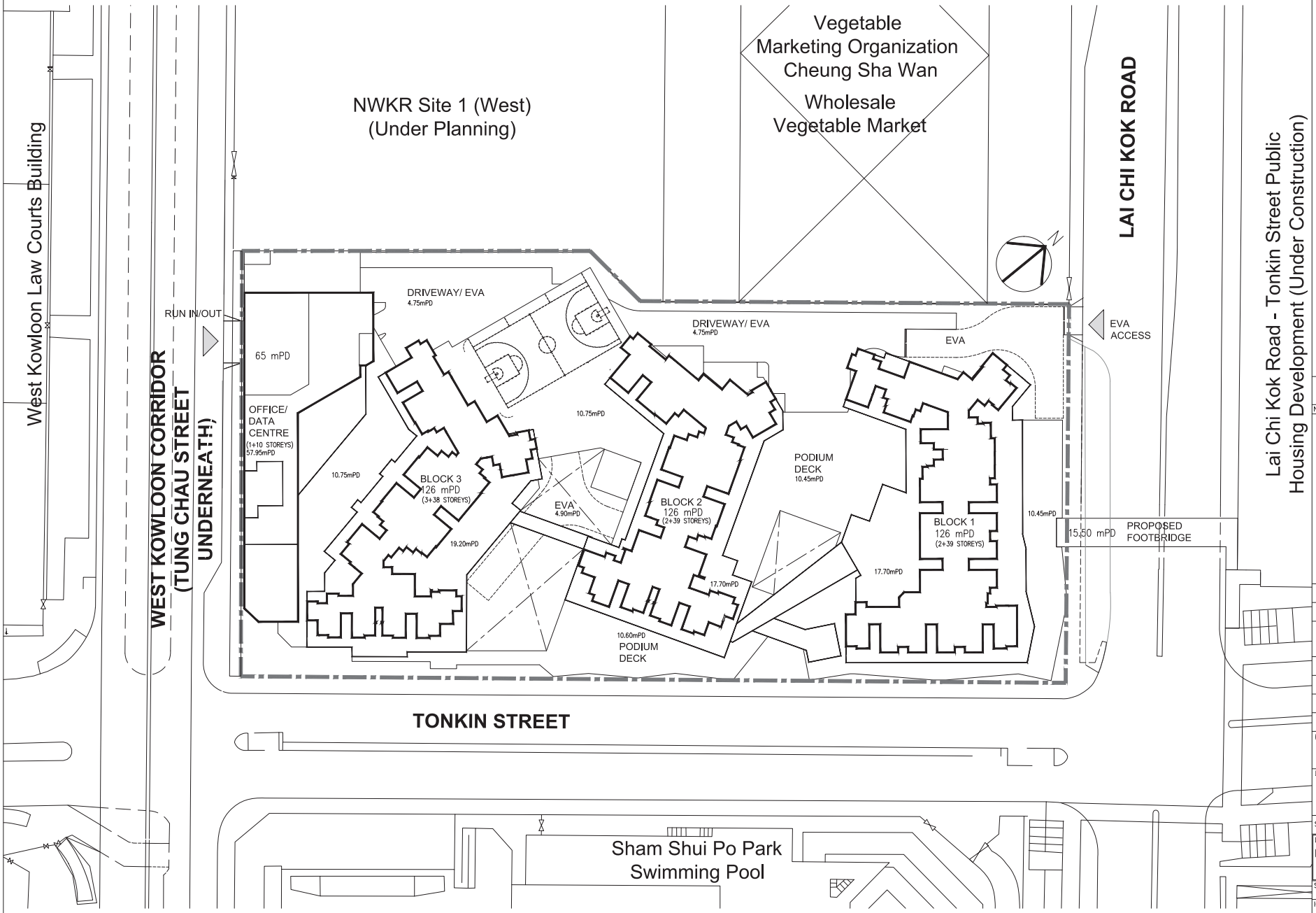

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ENDORSED			
CHECKED			
DRAWN			

PROJECT
PUBLIC HOUSING DEVELOPMENT AT NORTH WEST KOWLOON RECLAMATION SITE 1 (EAST)

DRAWING TITLE
MASTER LAYOUT PLAN

SCALE 1:400 (A1); 1:800 (A3)

DRAWING NO.
PLAN 2

SOURCE

ICU NO.

AutoCAD 2000 A1 594 x 841

HOUSING DEPARTMENT

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Appendix B

Contour Plots of Velocity Ratio

B1 Approved Scheme

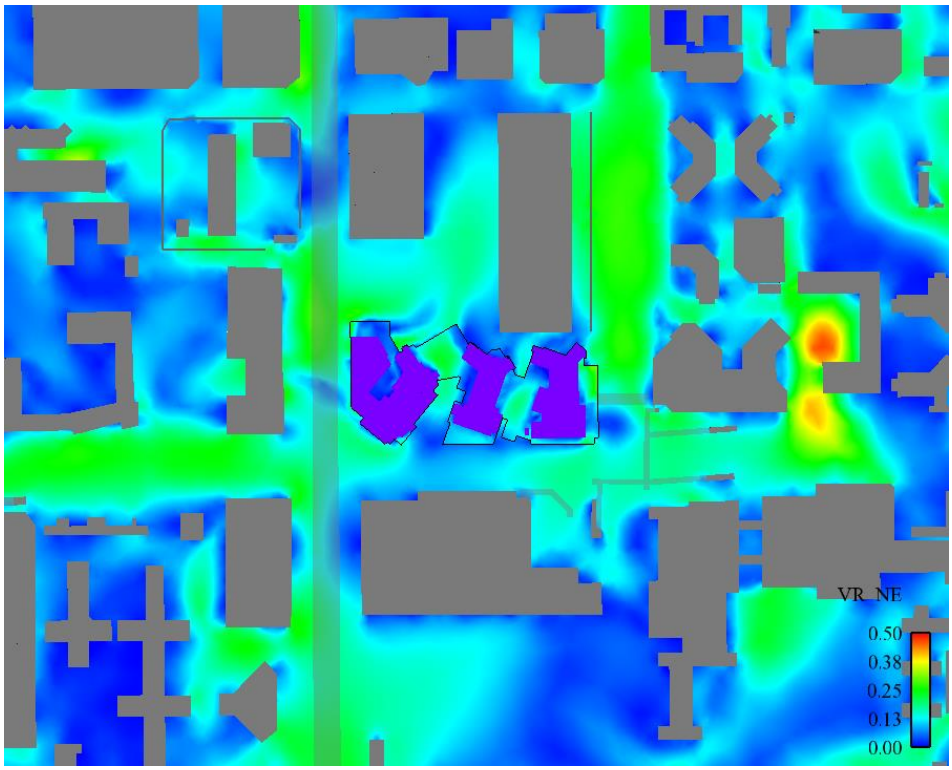

Figure B1 Contour Plot of VR under NE Wind

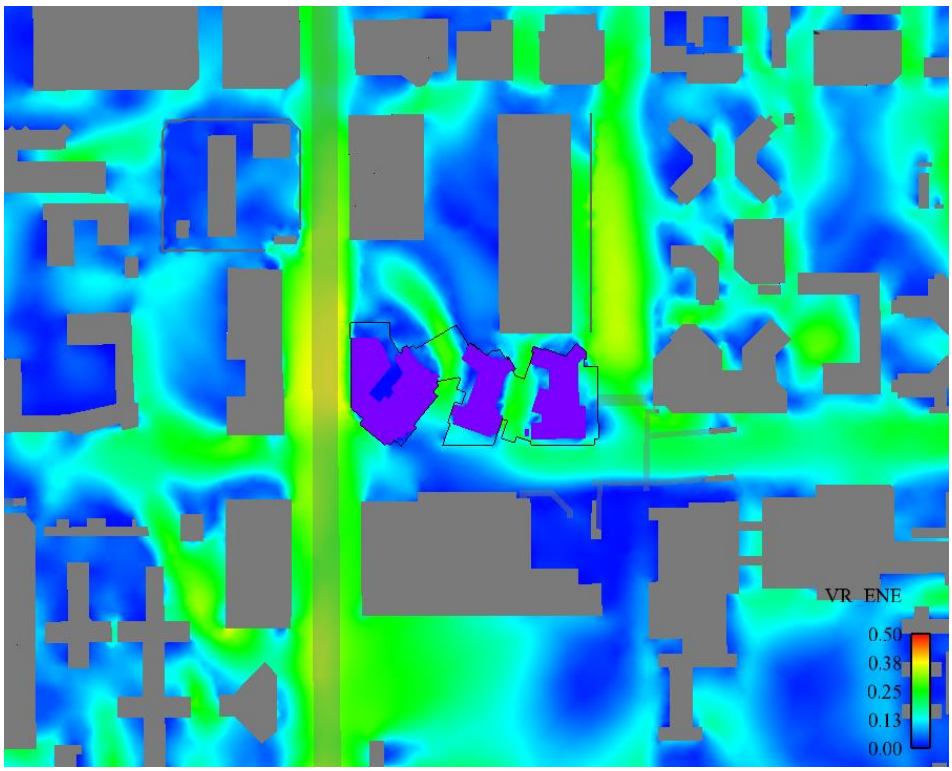

Figure B2 Contour Plot of VR under ENE Wind

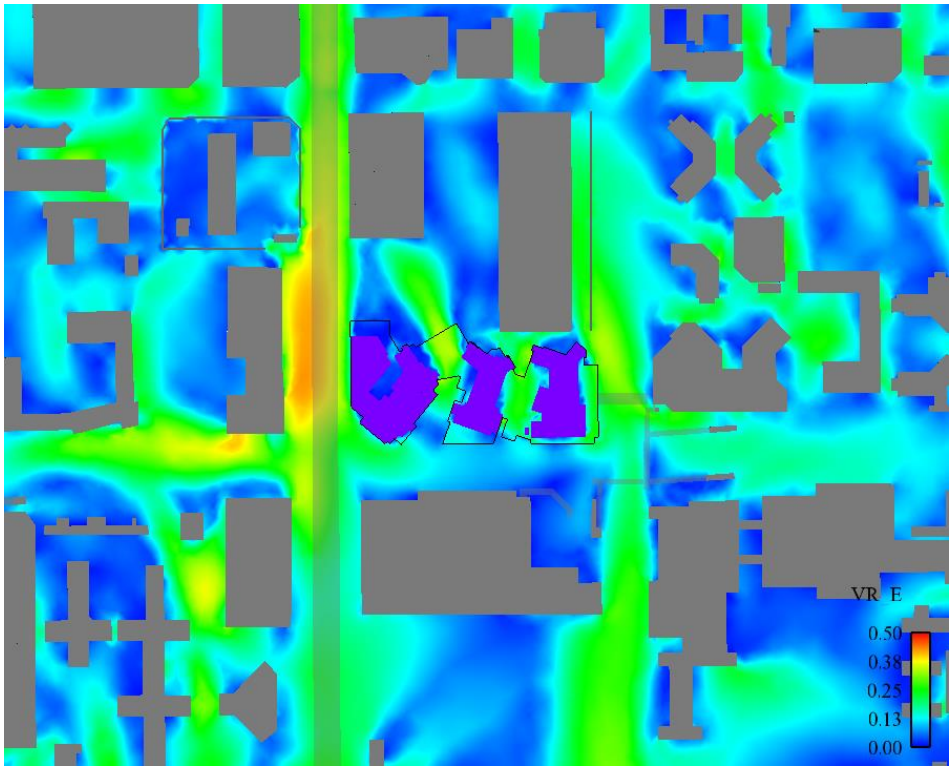

Figure B3 Contour Plot of VR under E Wind

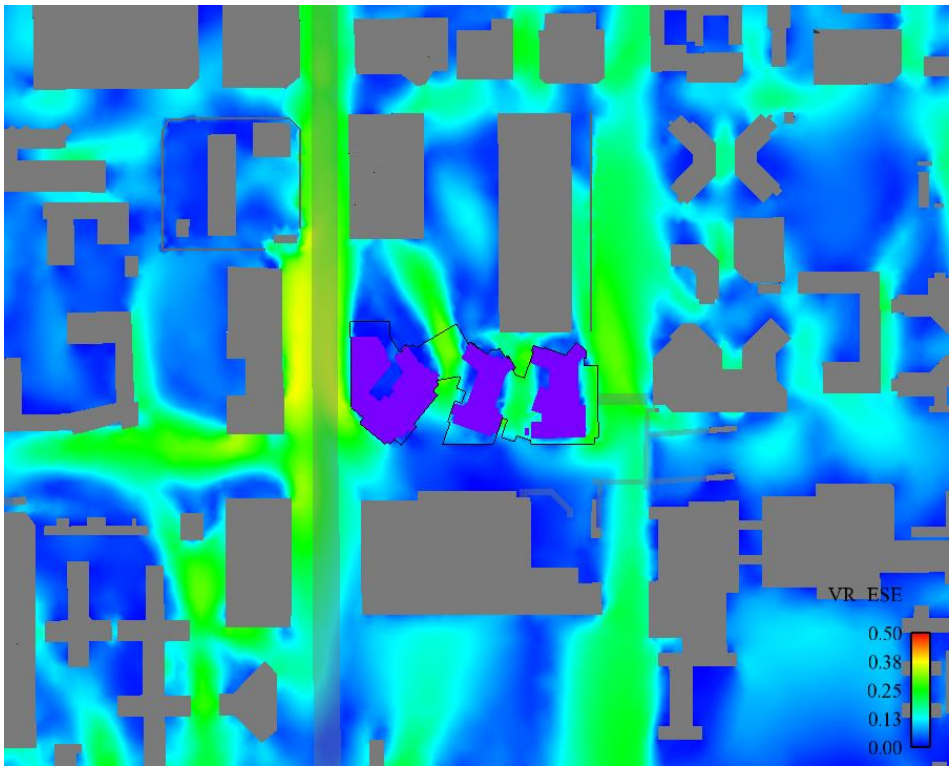

Figure B4 Contour Plot of VR under ESE Wind

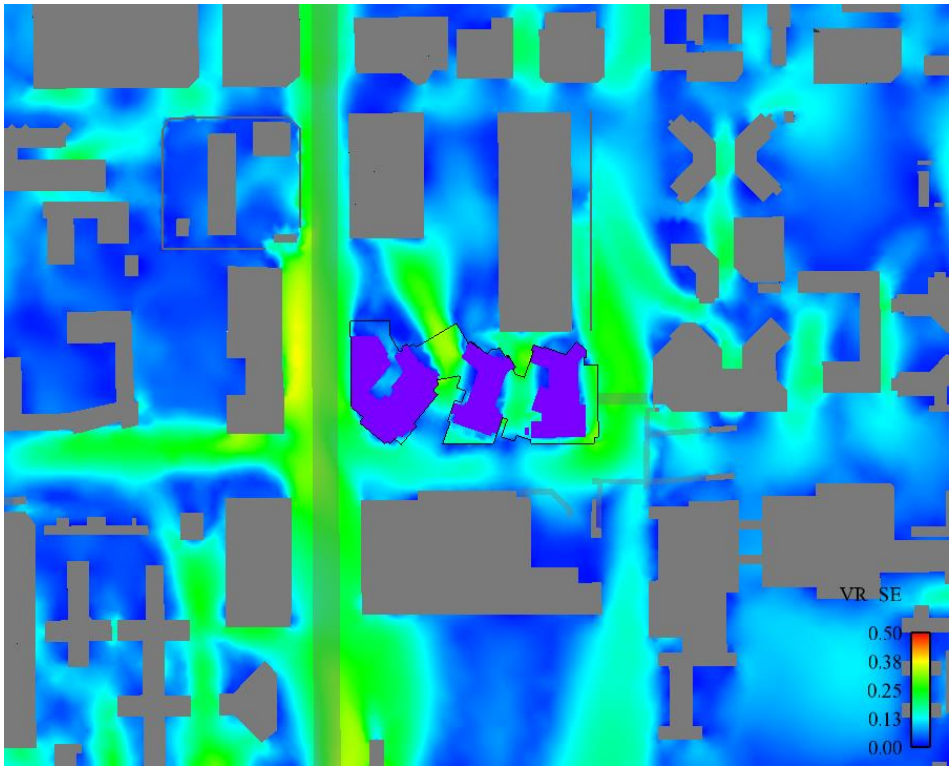

Figure B5 Contour Plot of VR under SE Wind

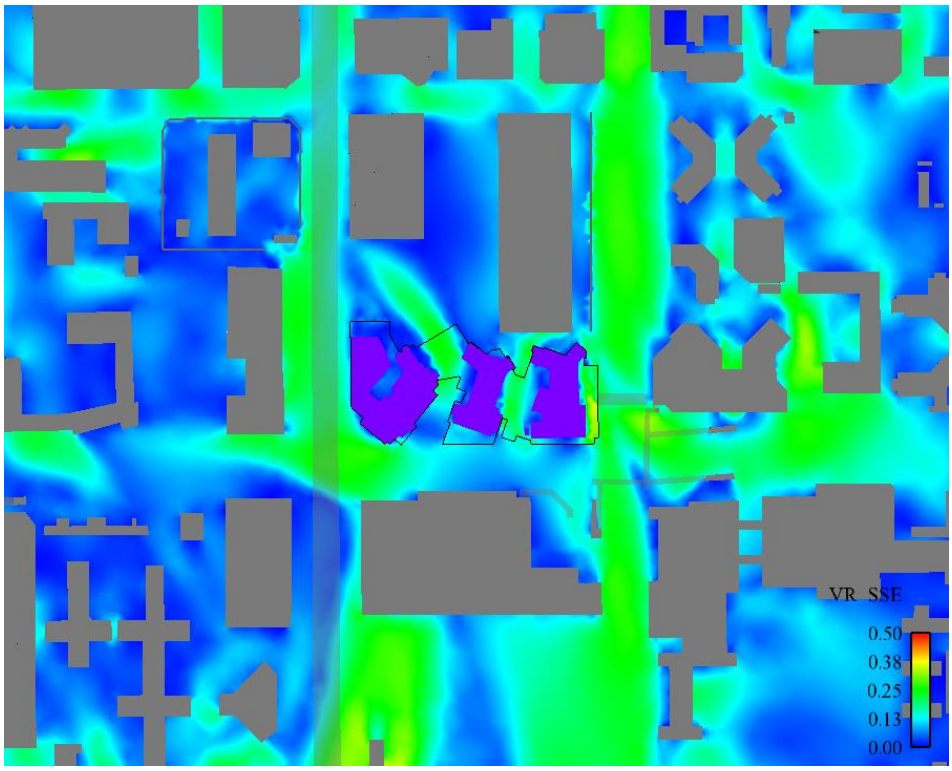

Figure B6 Contour Plot of VR under SSE Wind

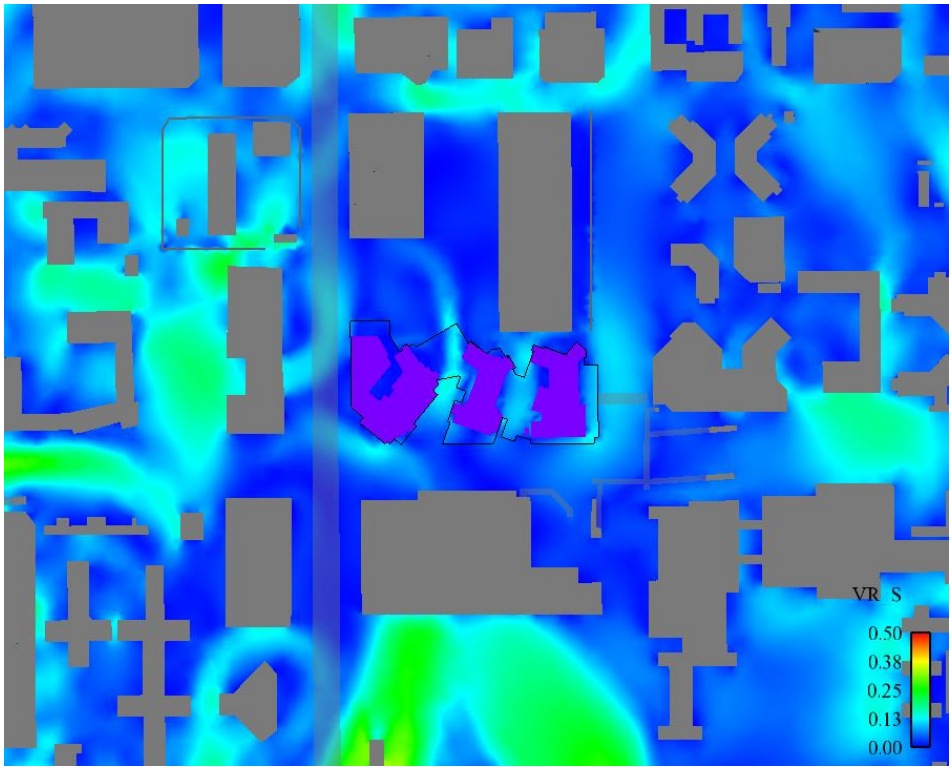

Figure B7 Contour Plot of VR under S Wind

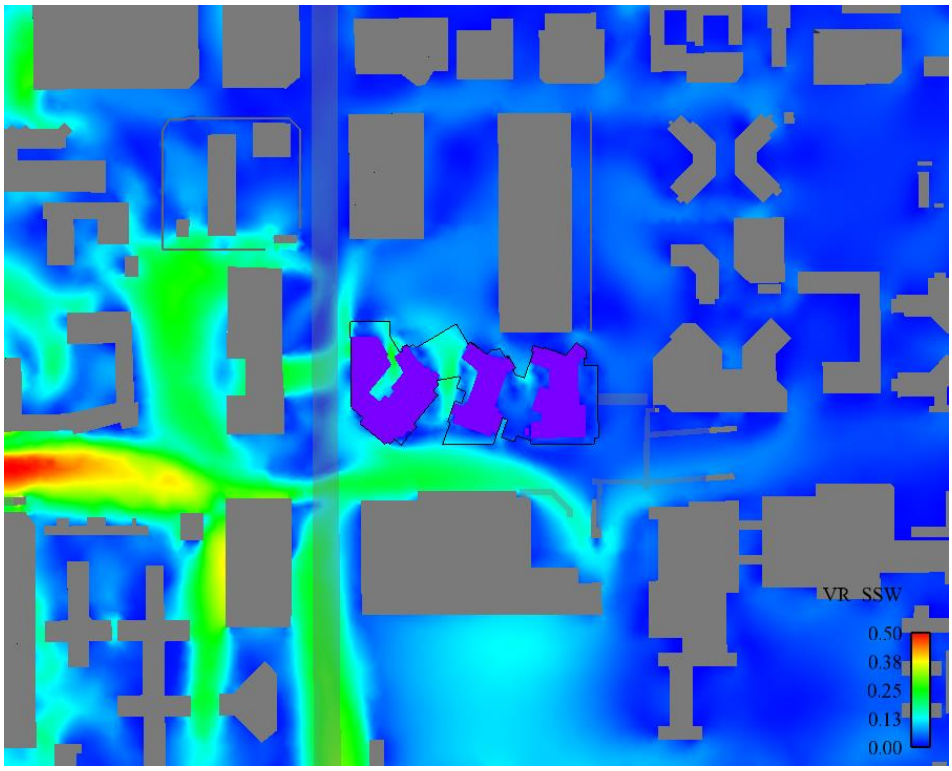

Figure B8 Contour Plot of VR under SSW Wind

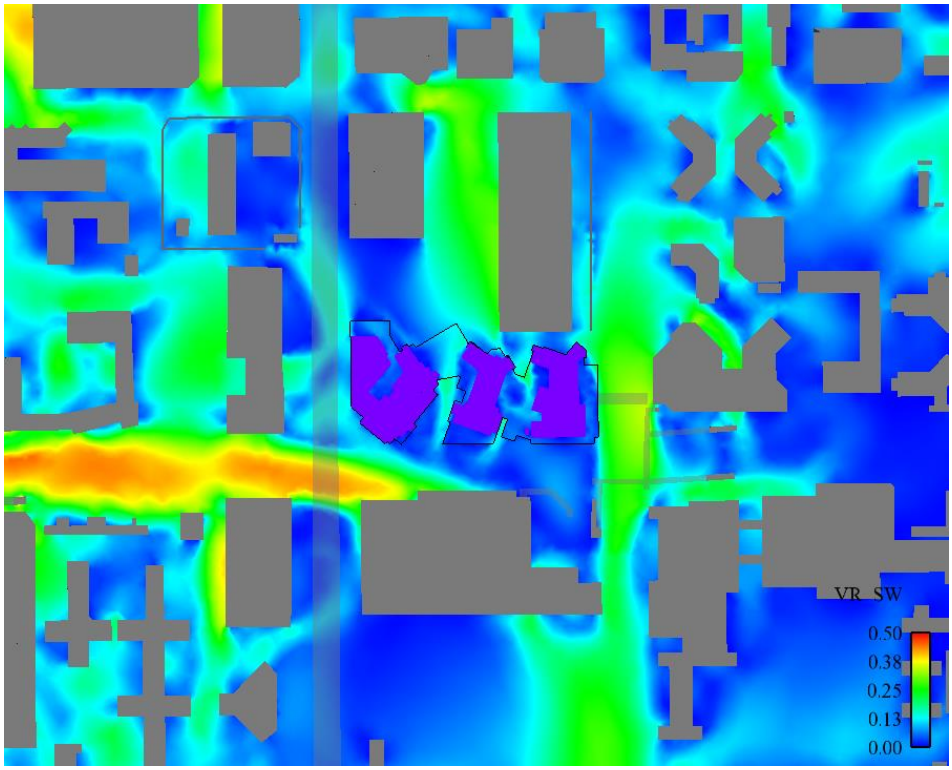

Figure B9 Contour Plot of VR under SW Wind

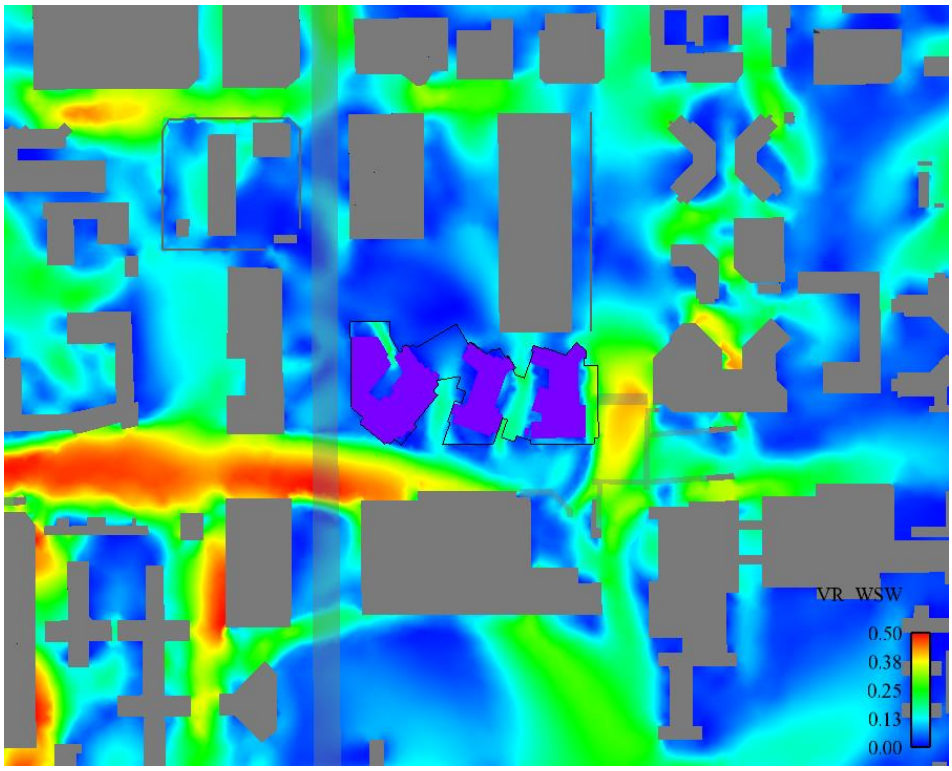

Figure B10 Contour Plot of VR under WSW Wind

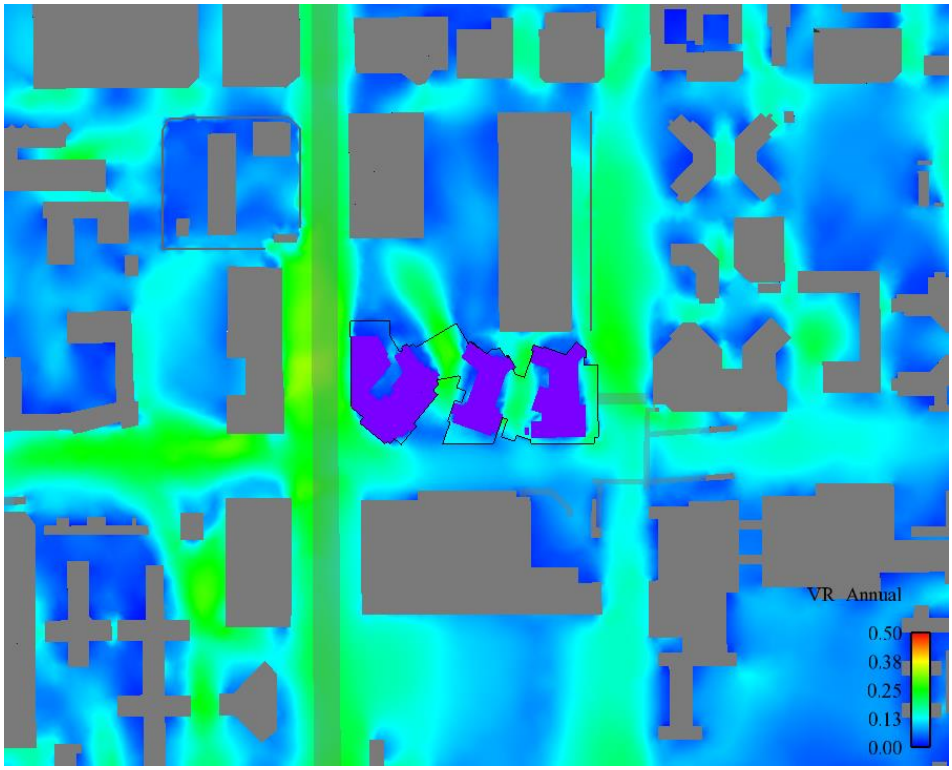

Figure B11 Annual Weighted Average Contour Plot of VR

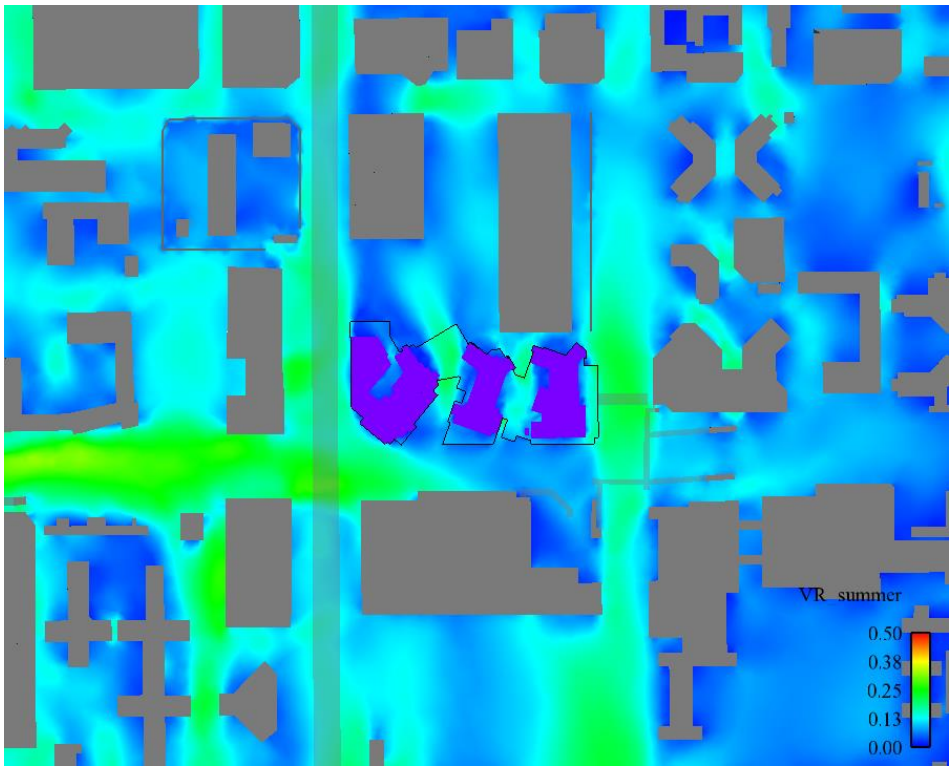

Figure B12 Summer Weighted Average Contour Plot of VR

B2 Intermediate Scheme

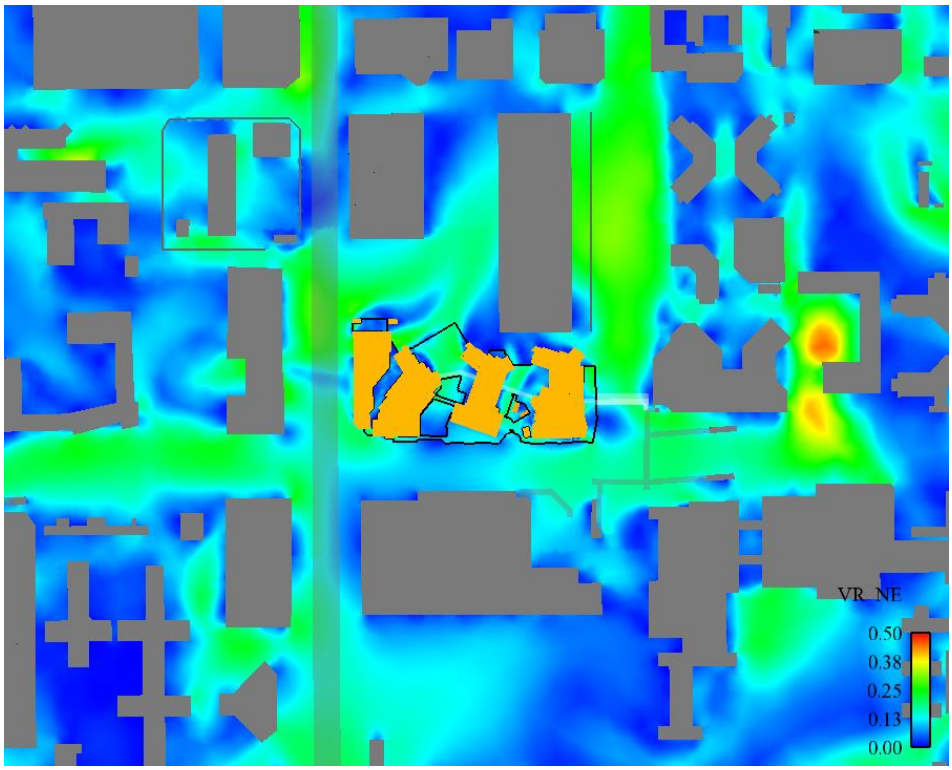

Figure B13 Contour Plot of VR under NE Wind

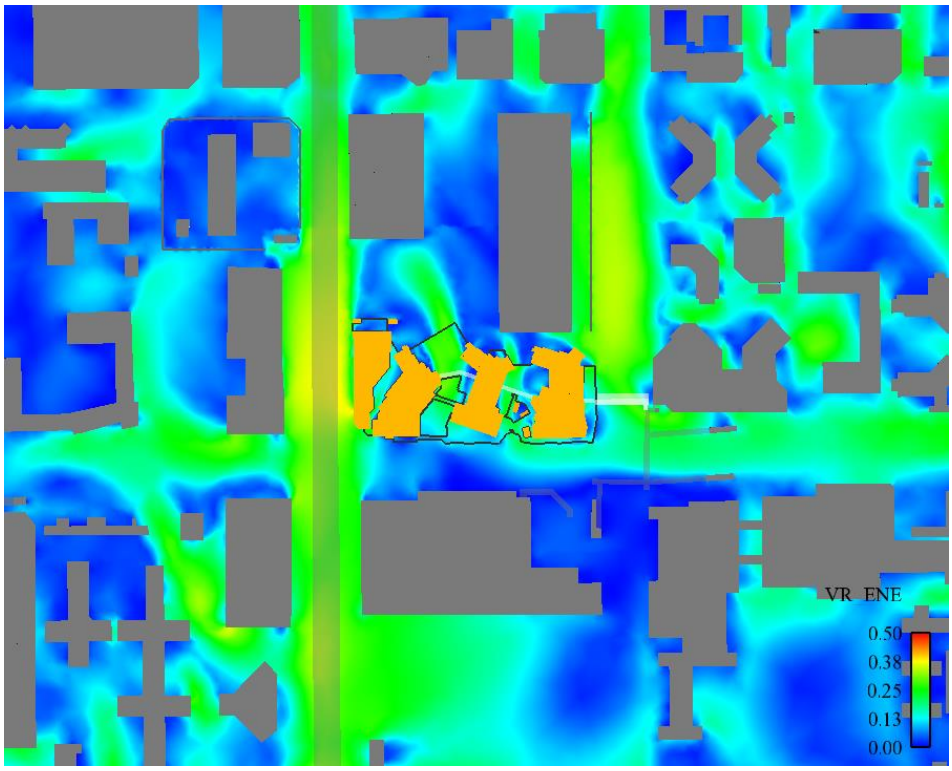

Figure B14 Contour Plot of VR under ENE Wind

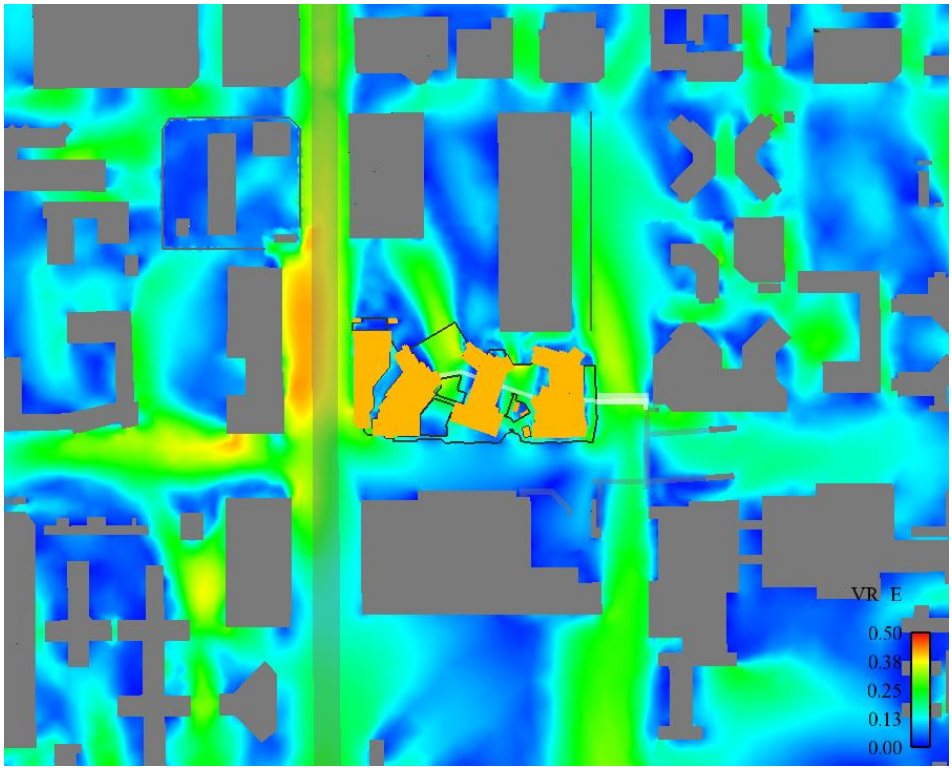

Figure B15 Contour Plot of VR under E Wind

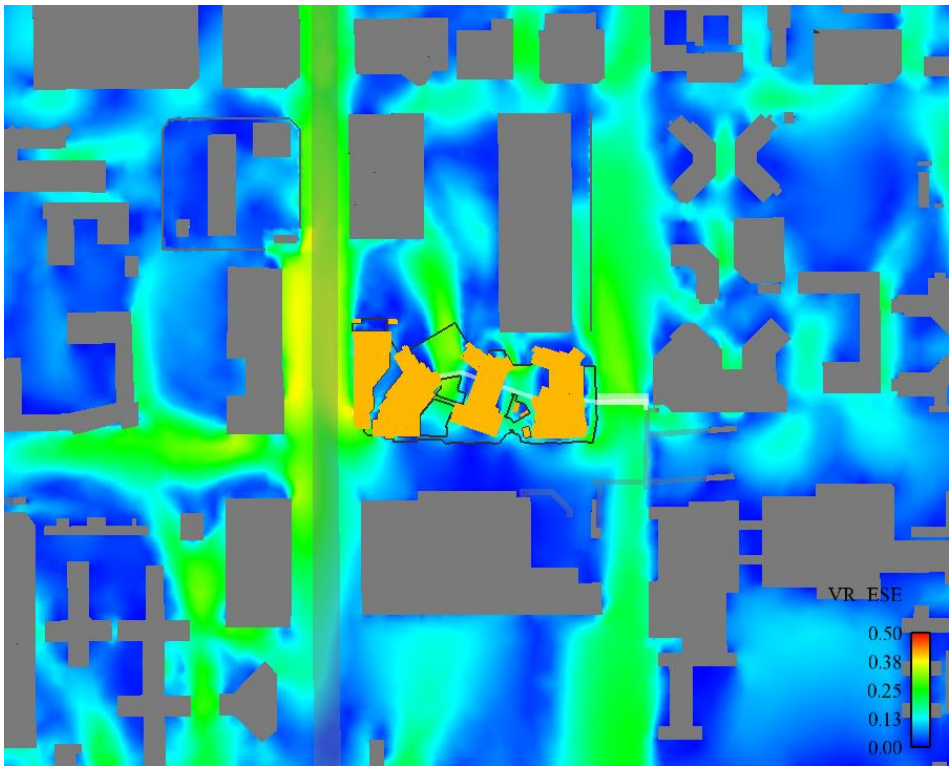

Figure B16 Contour Plot of VR under ESE Wind

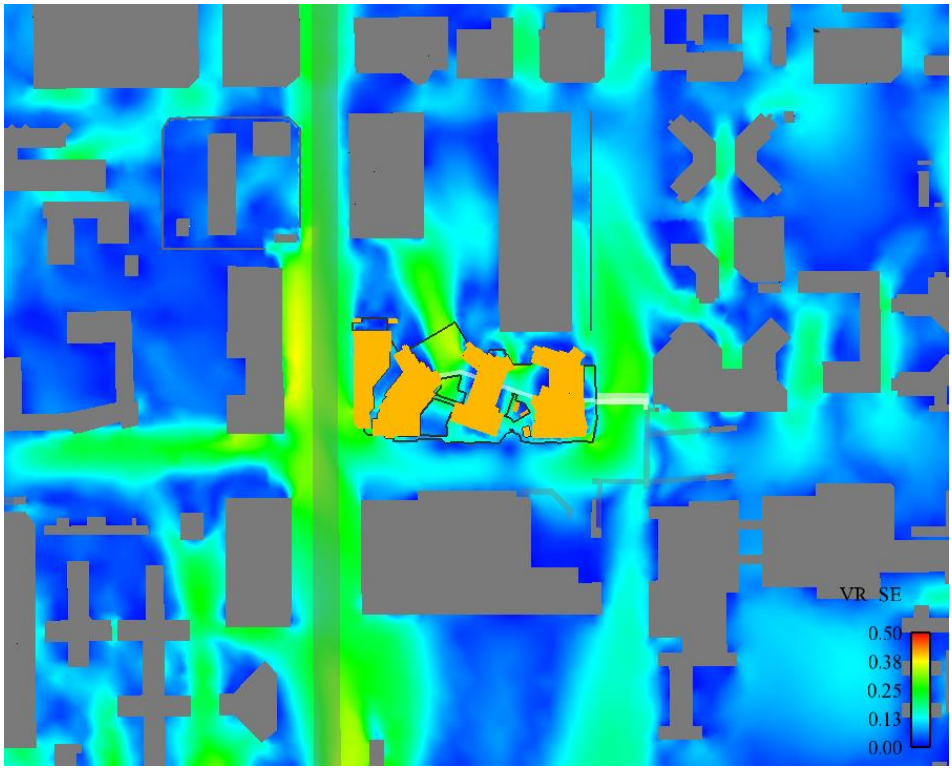

Figure B17 Contour Plot of VR under SE Wind

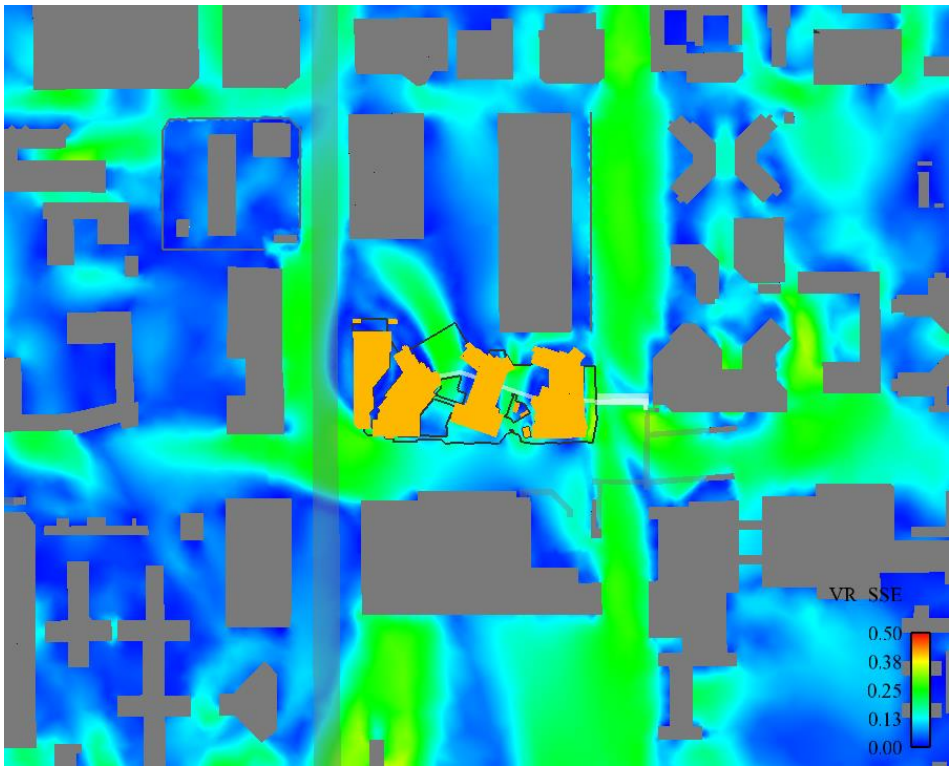

Figure B18 Contour Plot of VR under SSE Wind

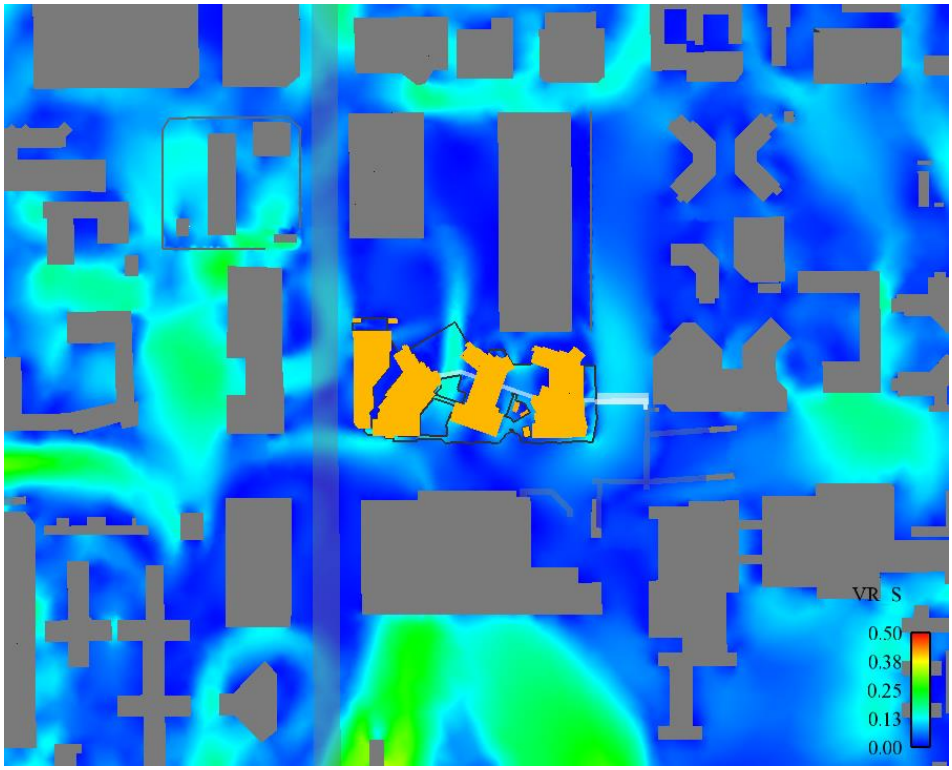

Figure B19 Contour Plot of VR under S Wind

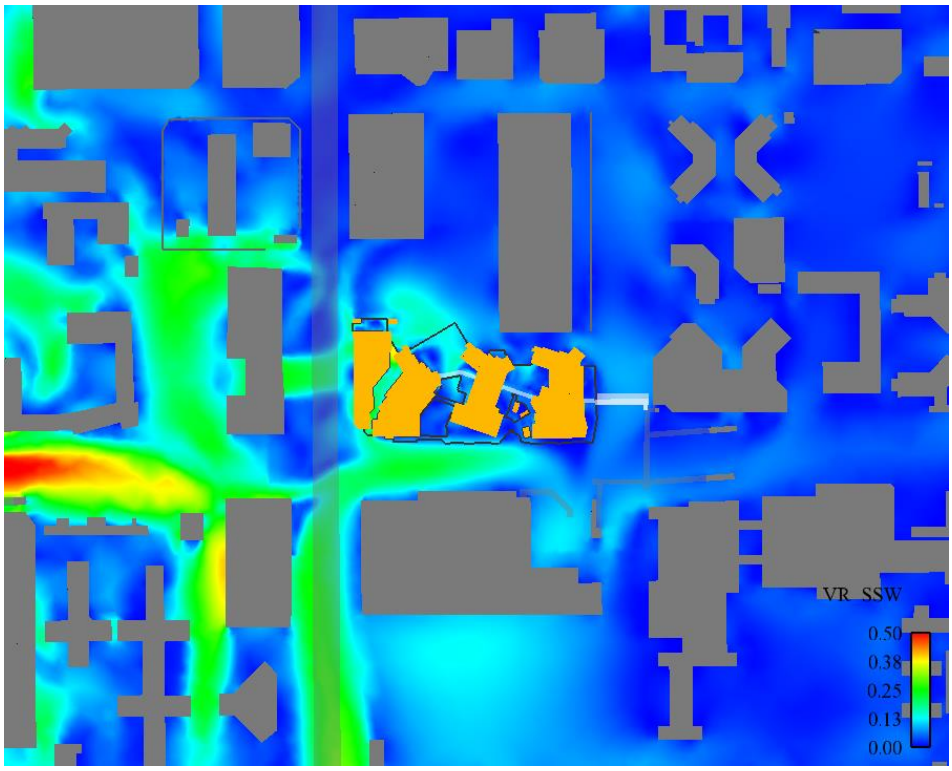

Figure B20 Contour Plot of VR under SSW Wind

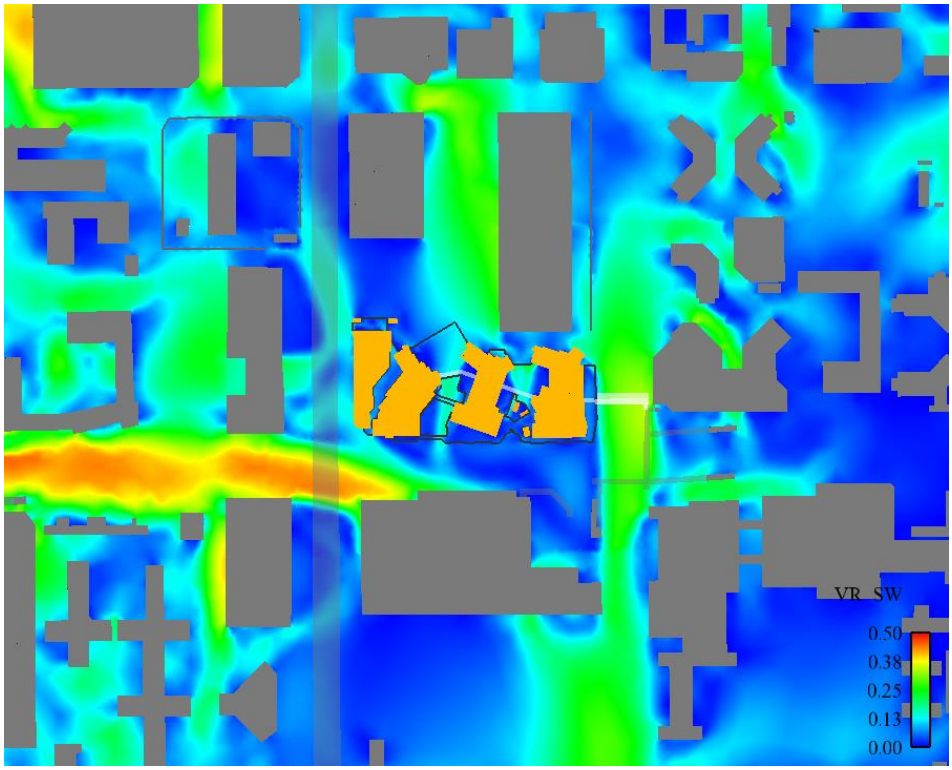

Figure B21 Contour Plot of VR under SW Wind

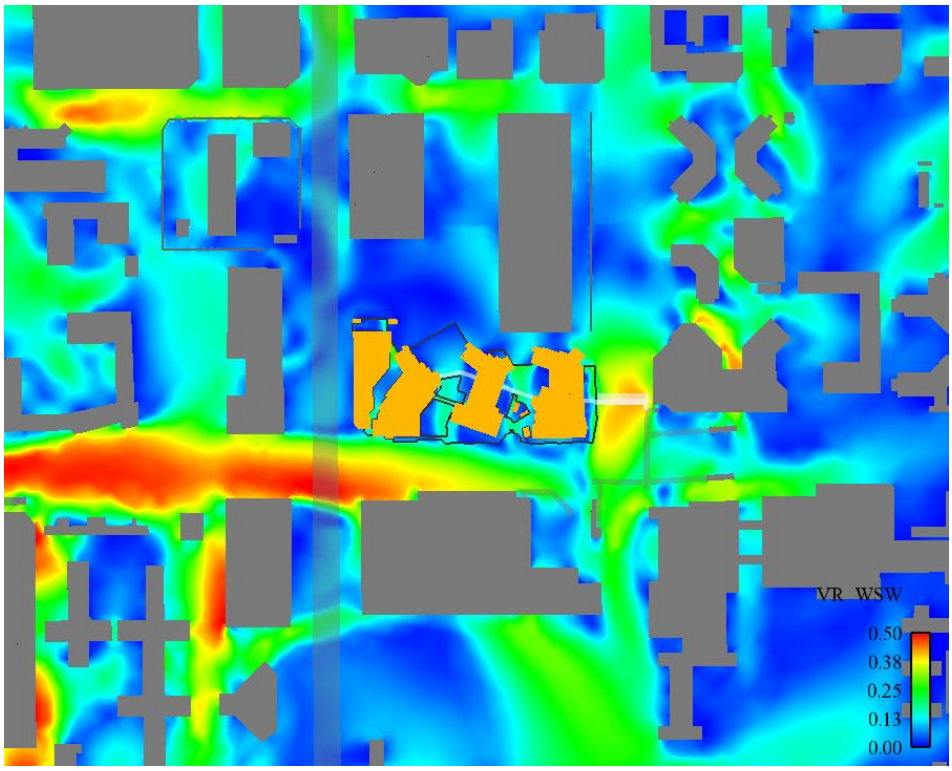

Figure B22 Contour Plot of VR under WSW Wind

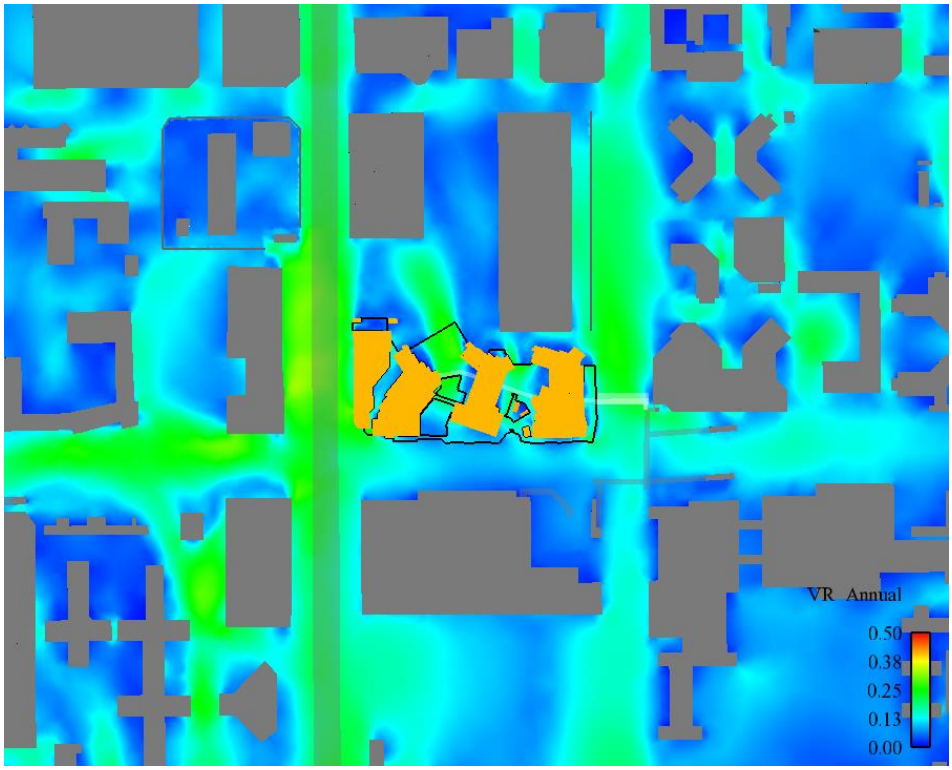

Figure B23 Annual Weighted Average Contour Plot of VR

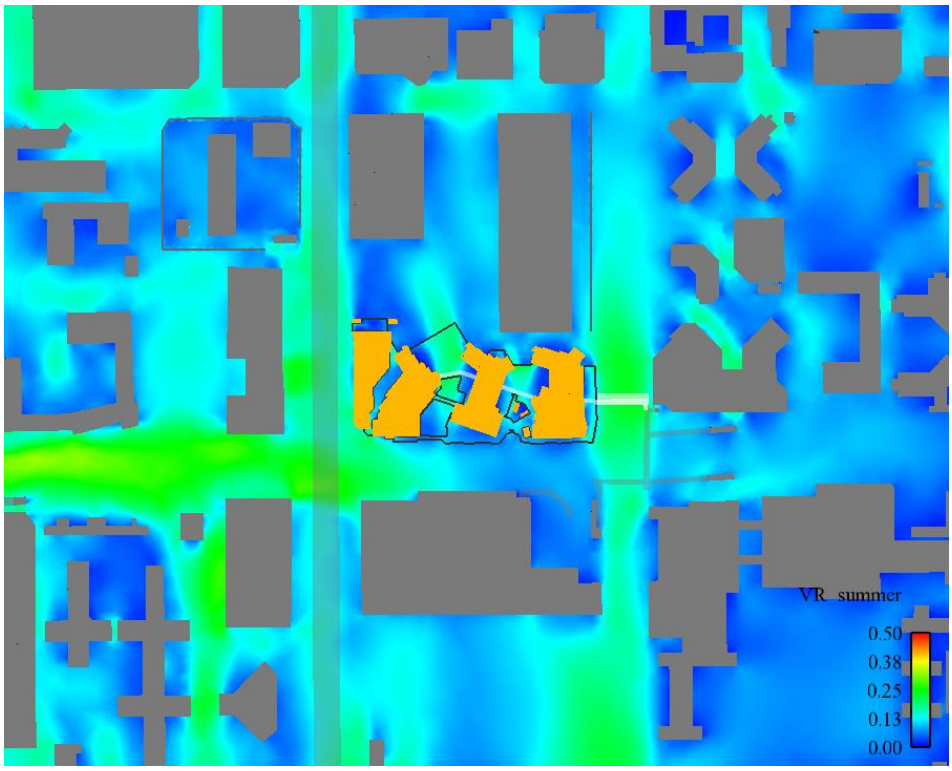

Figure B24 Summer Weighted Average Contour Plot of VR

Appendix C

Vector Plots of Velocity Ratio

C1 Approved Scheme

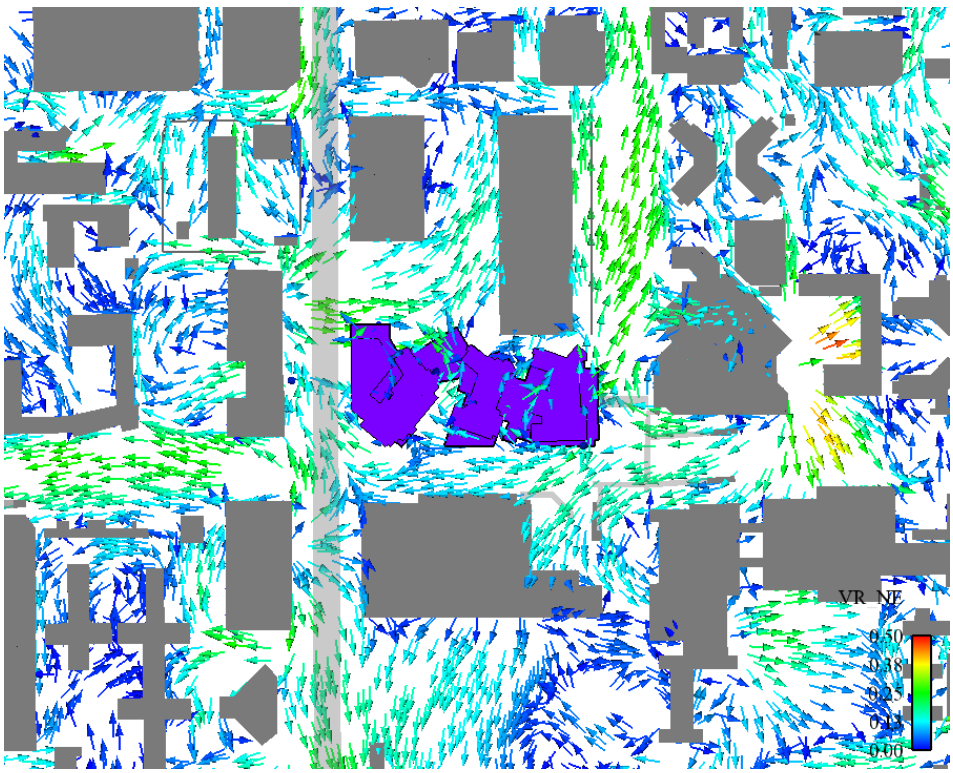

Figure C1 Vector Plot of VR under NE Wind

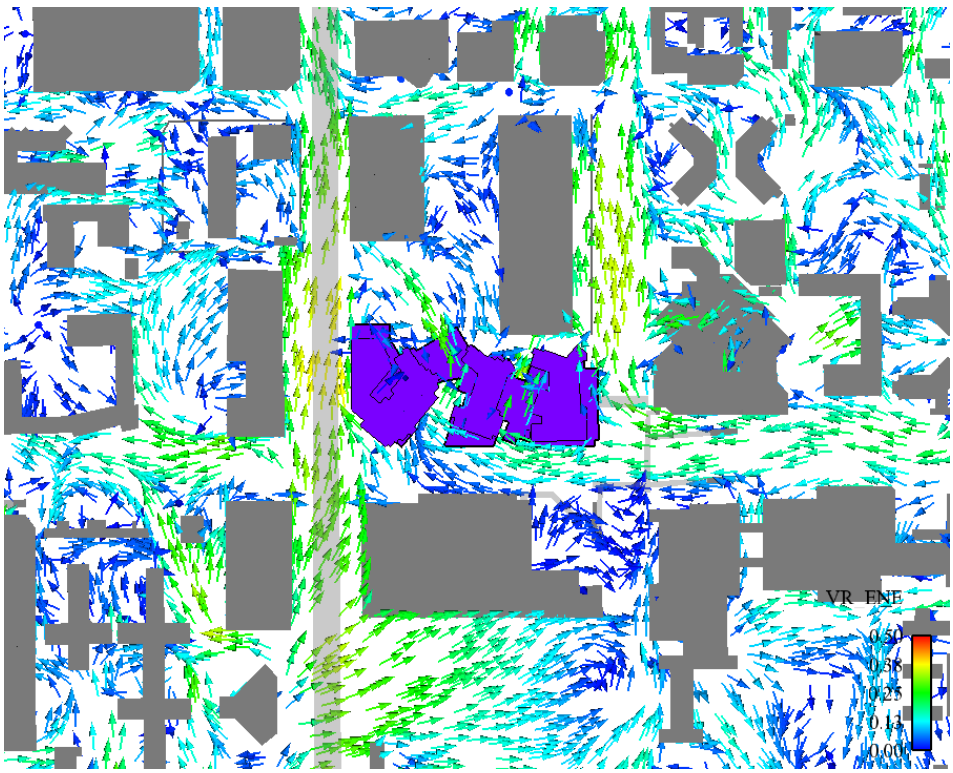

Figure C2 Vector Plot of VR under ENE Wind

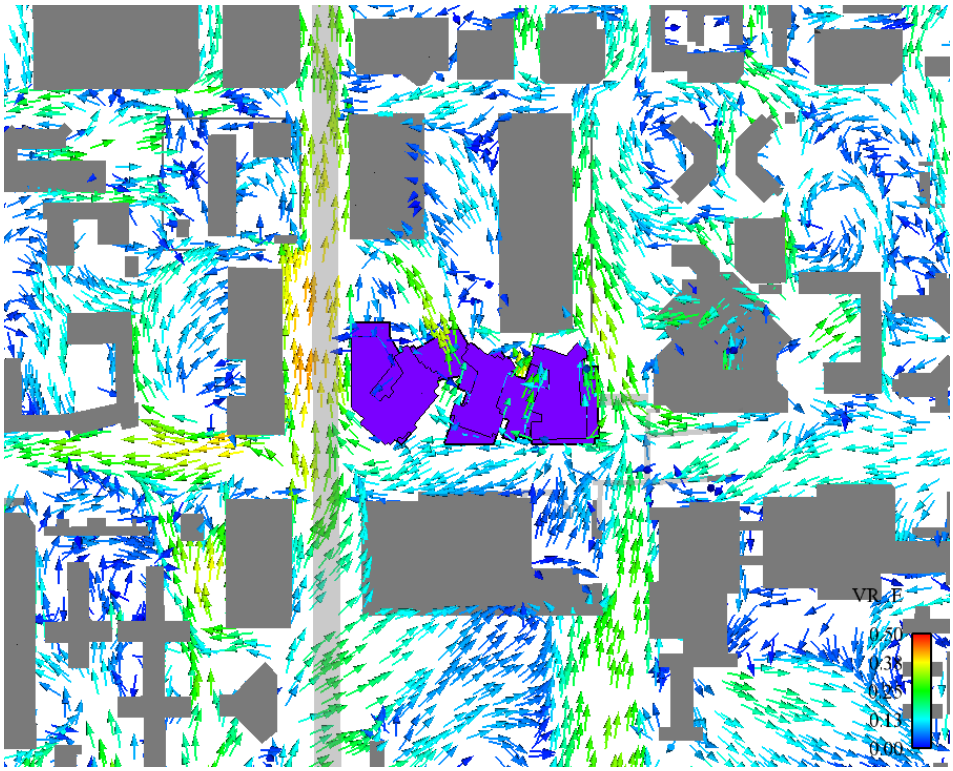

Figure C3 Vector Plot of VR under E Wind

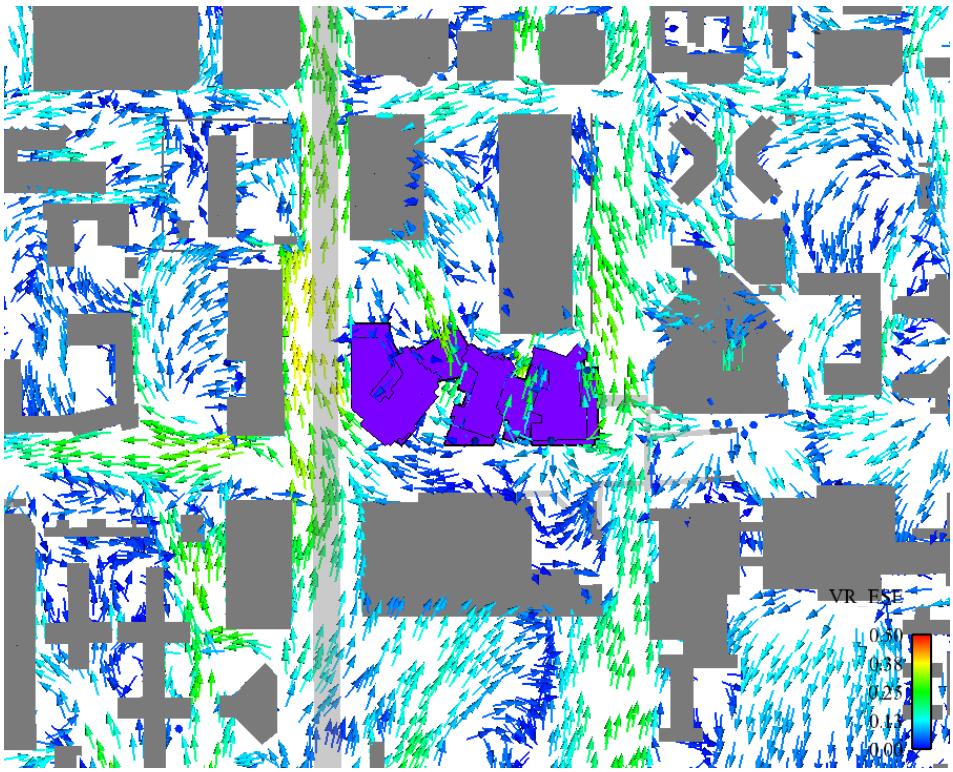

Figure C4 Vector Plot of VR under ESE Wind

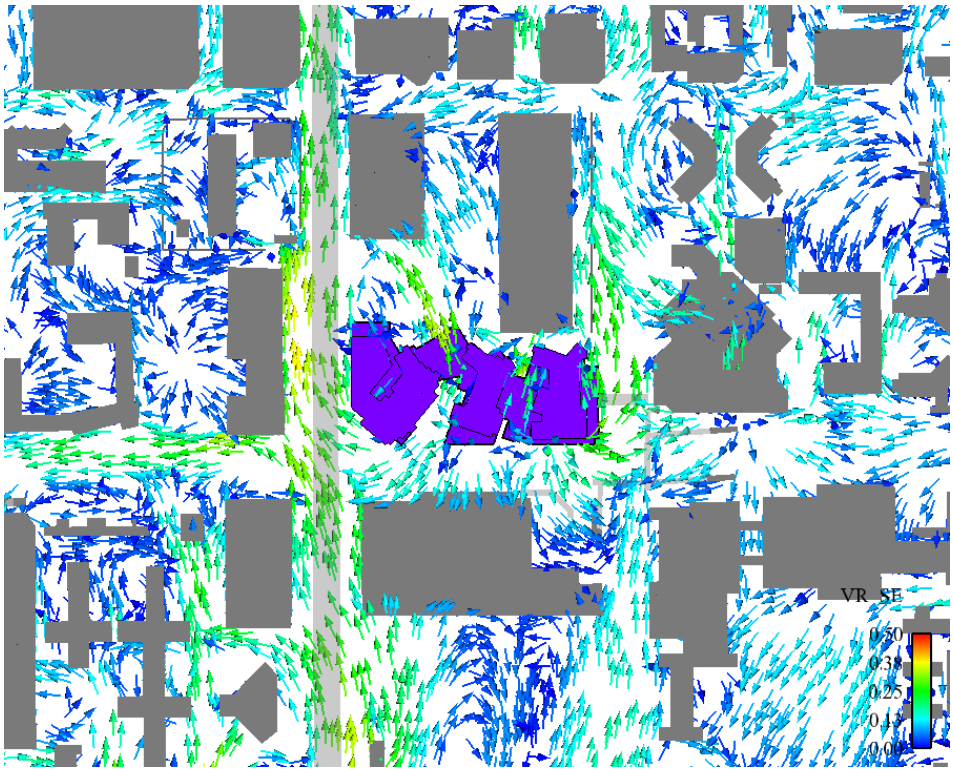

Figure C5 Vector Plot of VR under SE Wind

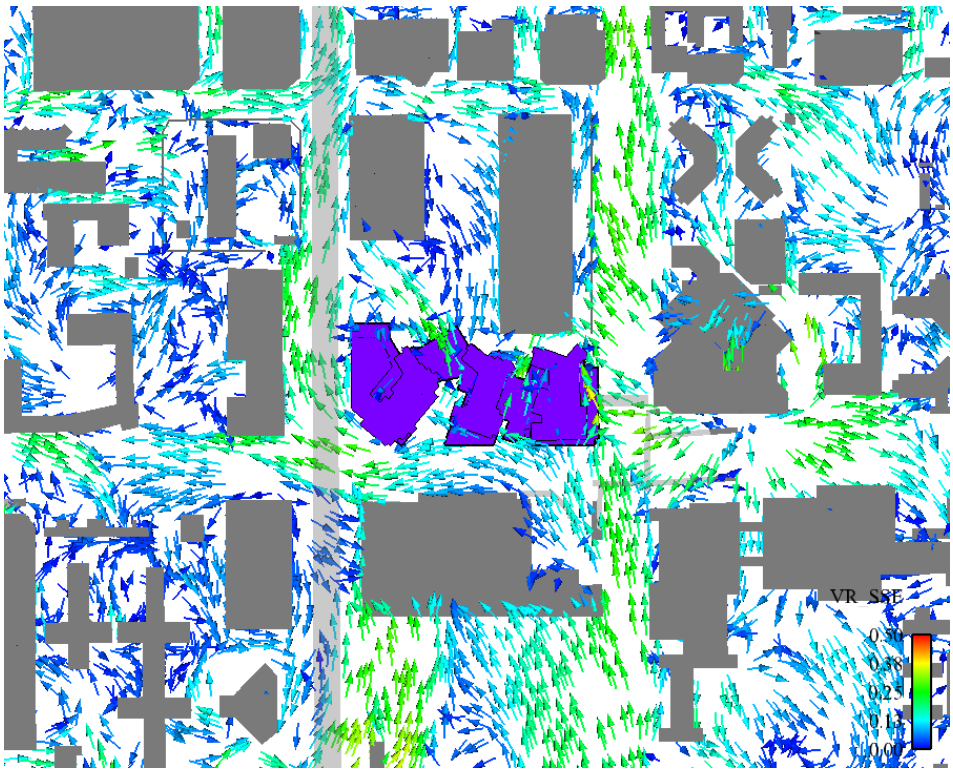

Figure C6 Vector Plot of VR under SSE Wind

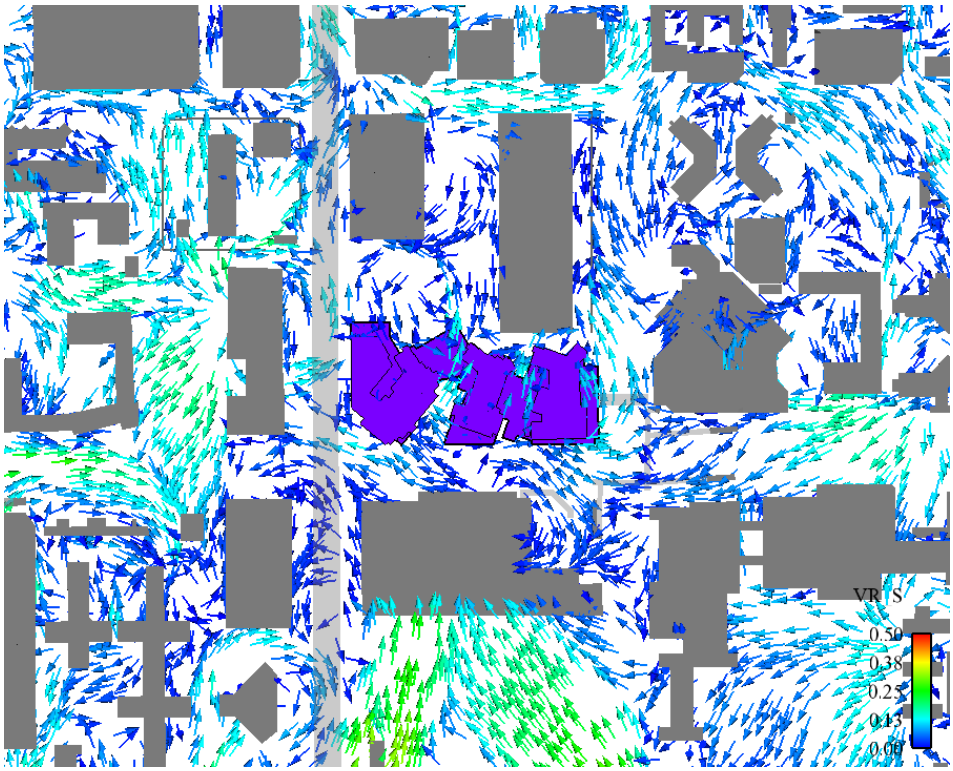

Figure C7 Vector Plot of VR under S Wind

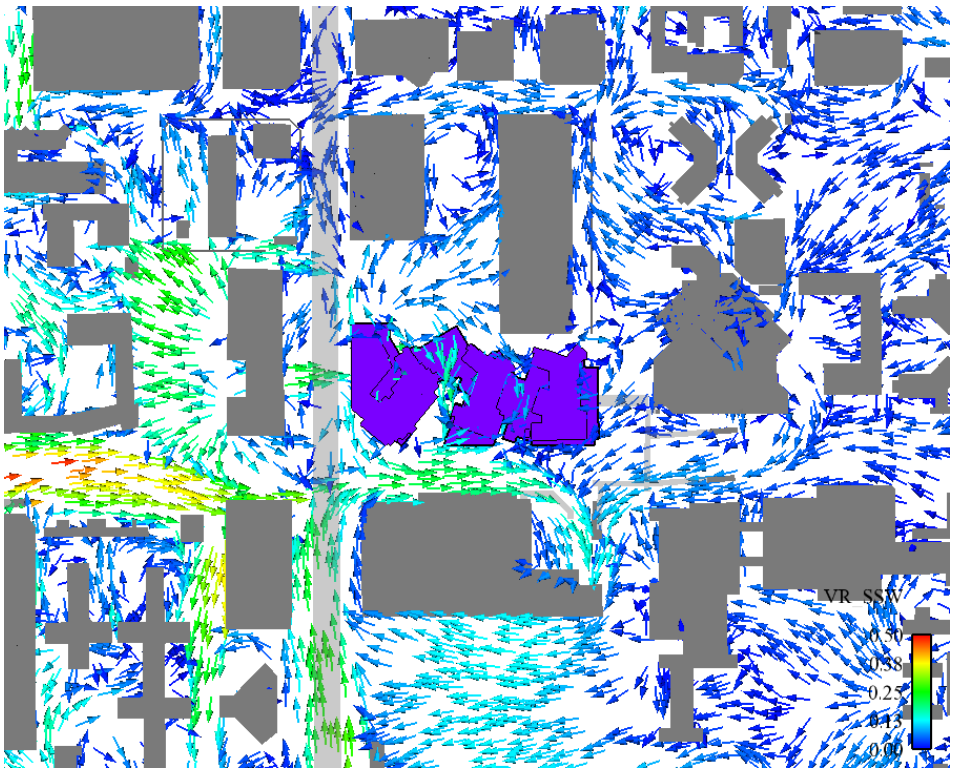

Figure C8 Vector Plot of VR under SSW Wind

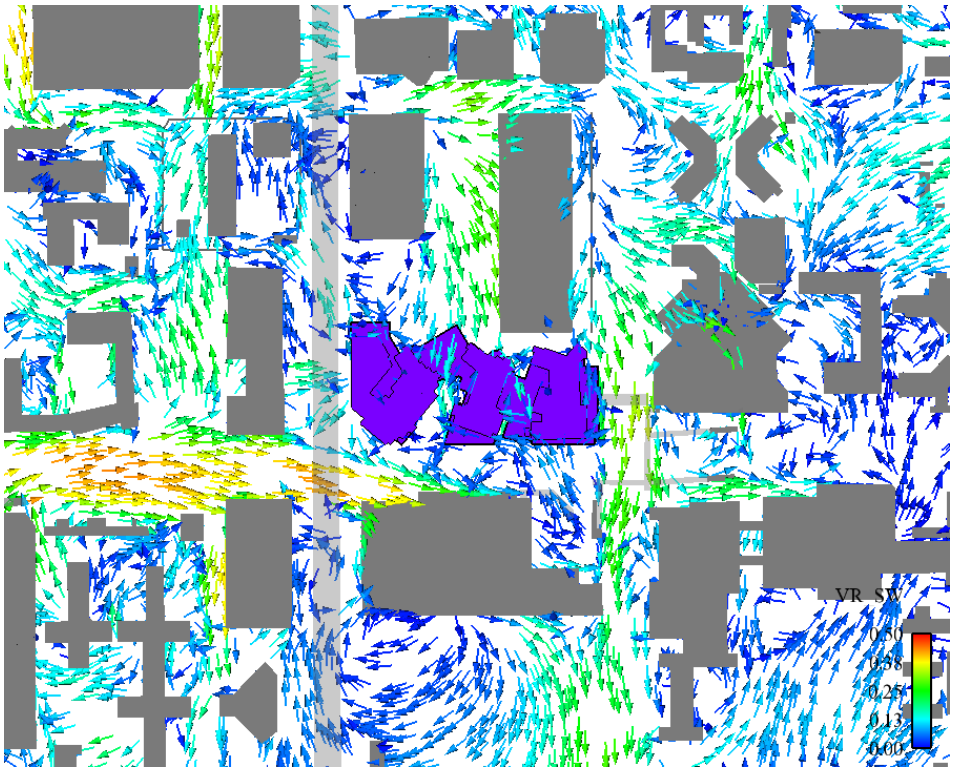

Figure C9 Vector Plot of VR under SW Wind

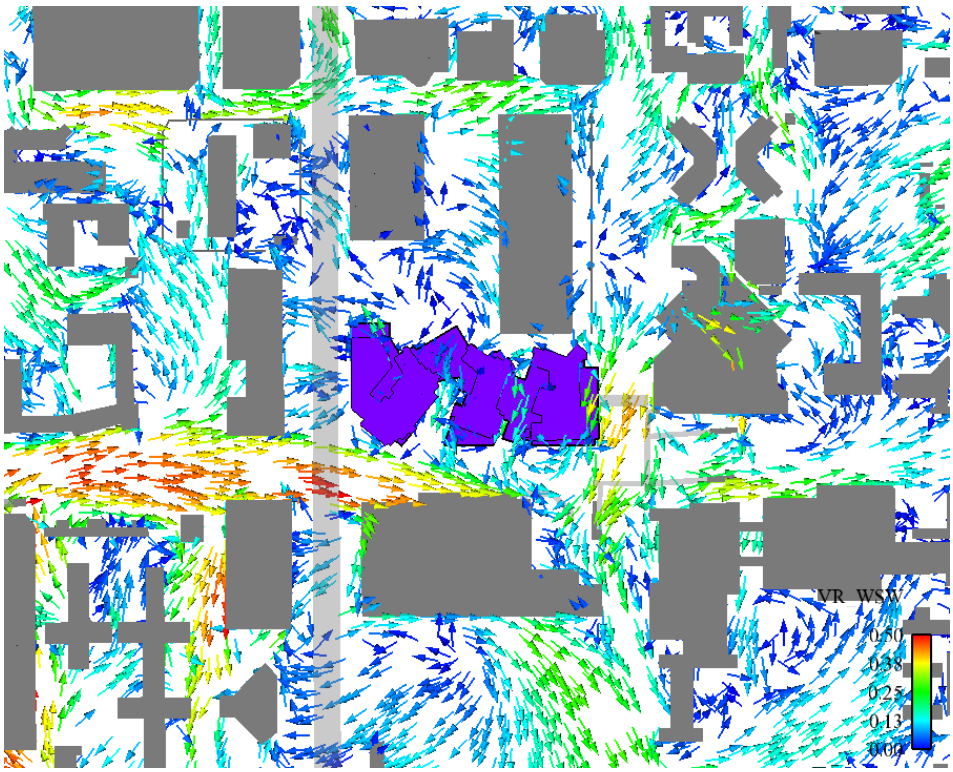

Figure C10 Vector Plot of VR under WSW Wind

C2 Intermediate Scheme

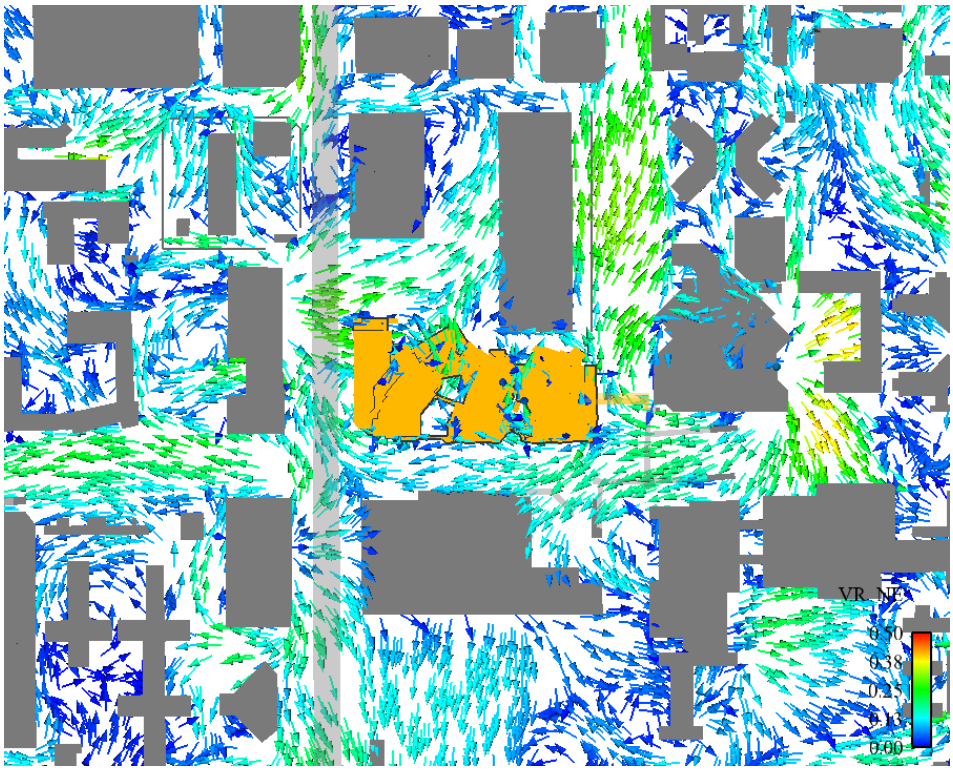

Figure C11 Vector Plot of VR under NE Wind

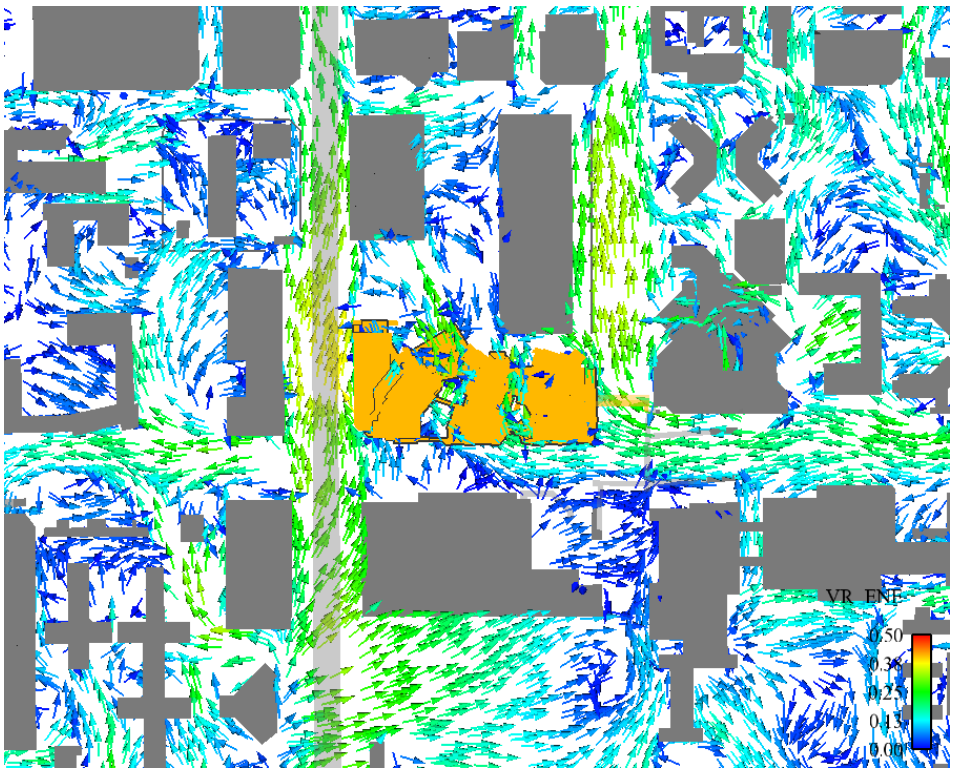

Figure C12 Vector Plot of VR under ENE Wind

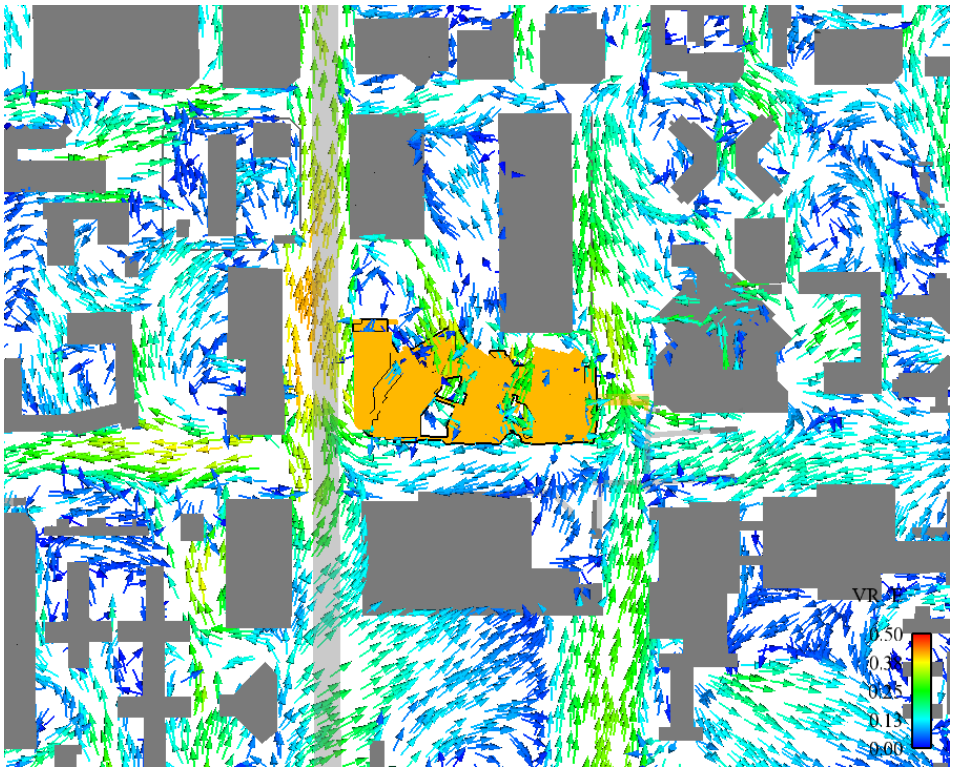

Figure C13 Vector Plot of VR under E Wind

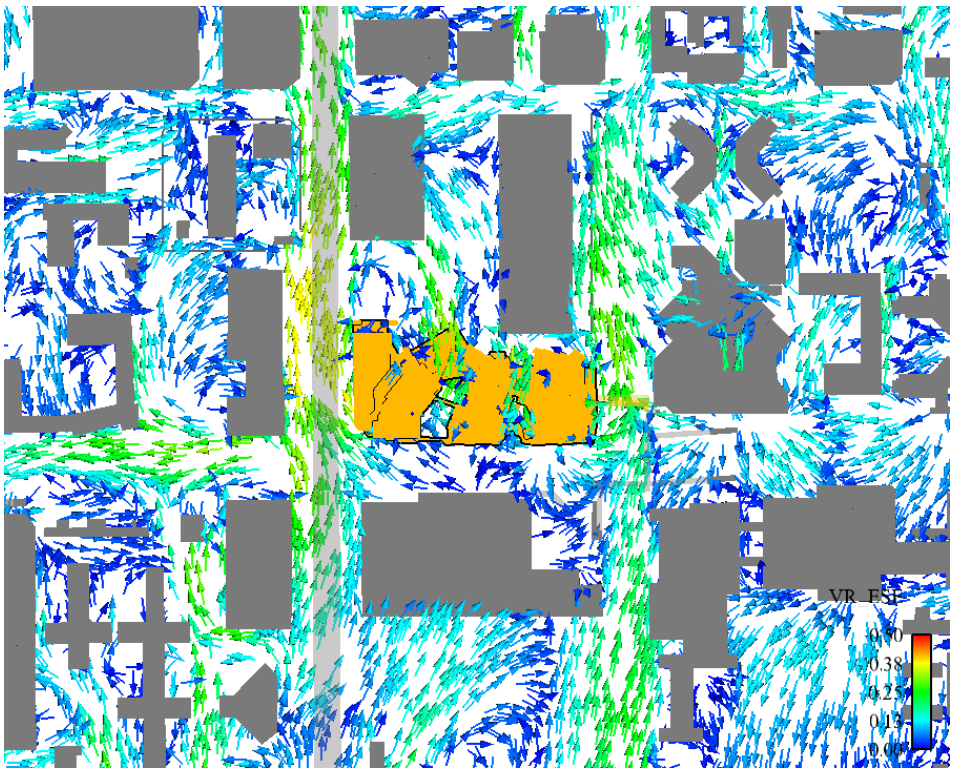

Figure C14 Vector Plot of VR under ESE Wind

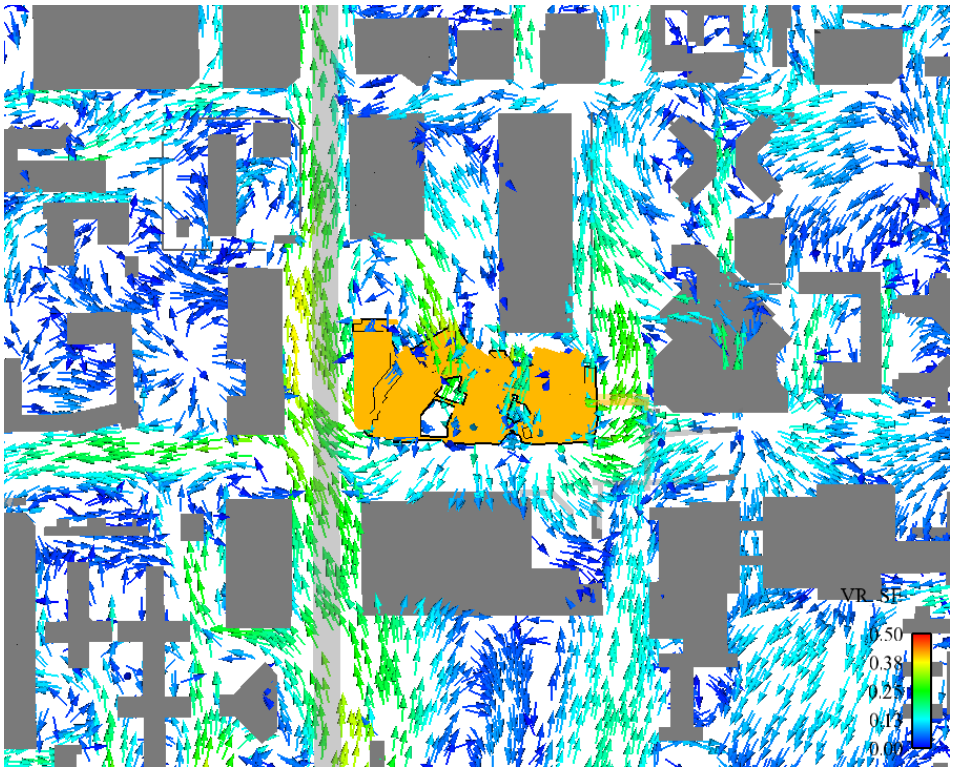

Figure C15 Vector Plot of VR under SE Wind

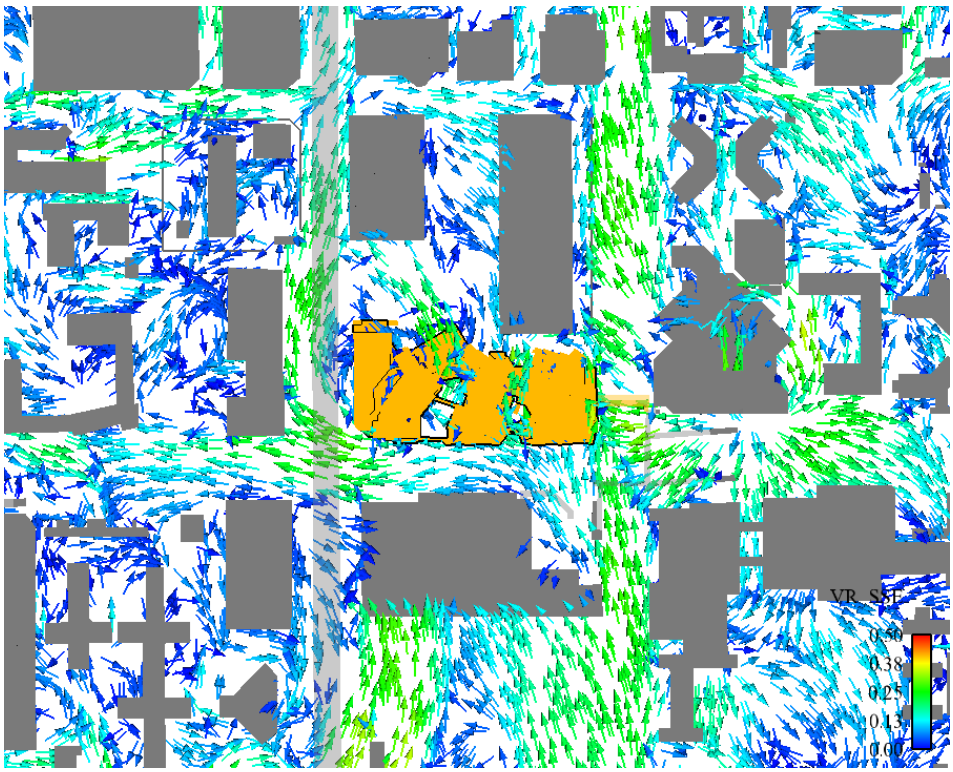

Figure C16 Vector Plot of VR under SSE Wind

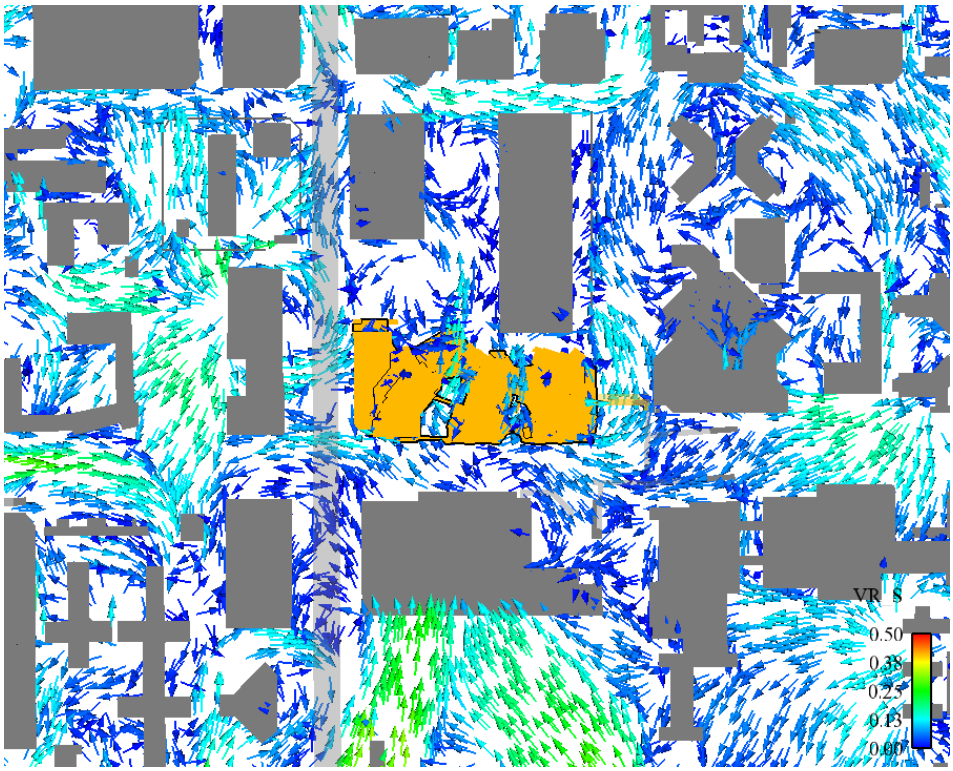

Figure C17 Vector Plot of VR under S Wind

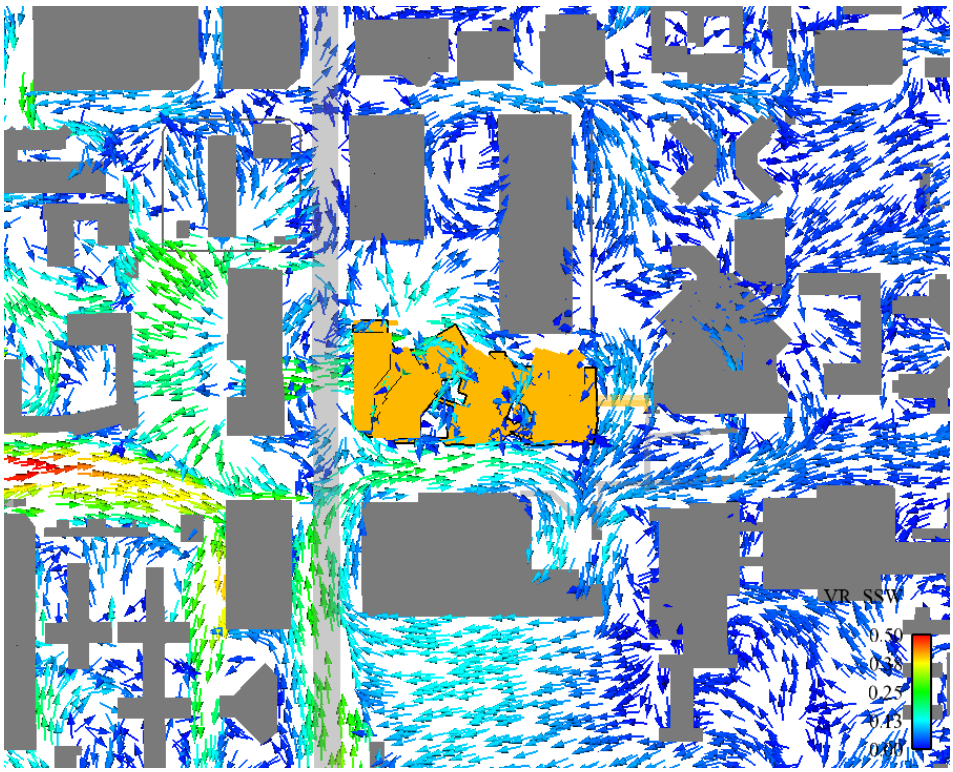

Figure C18 Vector Plot of VR under SSW Wind

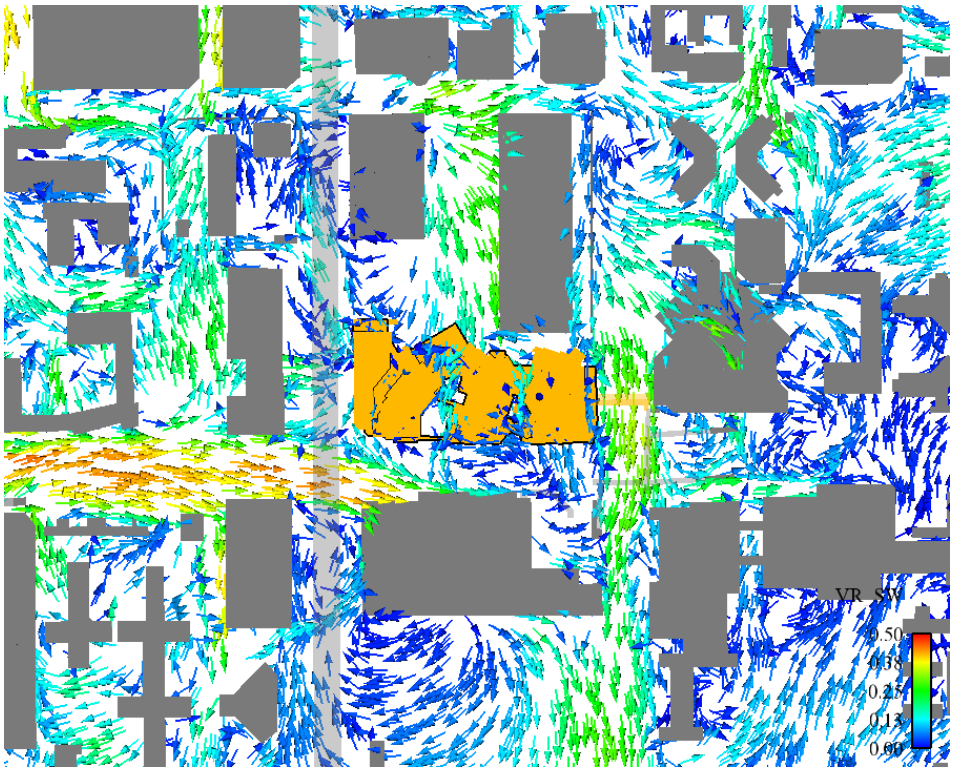

Figure C19 Vector Plot of VR under SW Wind

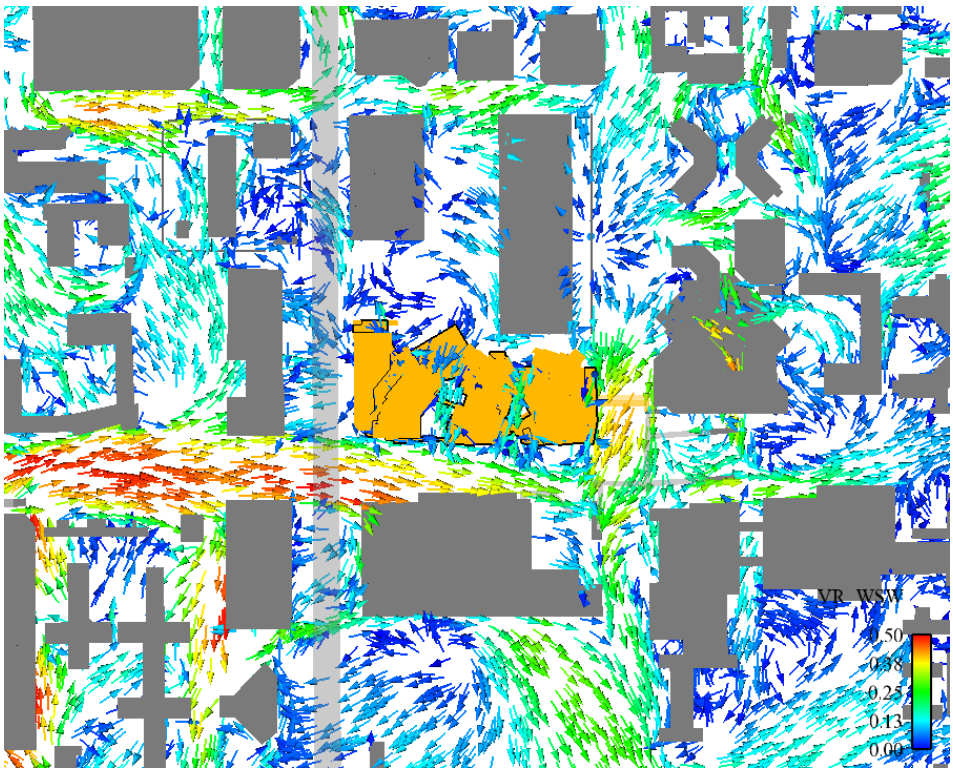

Figure C20 Vector Plot of VR under WSW Wind

Appendix D

Velocity Ratio at Test Points

D1 Approved Scheme

Table D1 Velocity Ratio of Perimeter Test Points

Direction	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW
P1	0.15	0.29	0.33	0.28	0.25	0.18	0.10	0.04	0.20	0.20
P2	0.19	0.29	0.32	0.27	0.24	0.19	0.10	0.05	0.23	0.29
P3	0.19	0.22	0.25	0.22	0.19	0.25	0.08	0.02	0.20	0.25
P4	0.14	0.11	0.19	0.20	0.22	0.22	0.08	0.02	0.20	0.28
P5	0.04	0.03	0.19	0.19	0.19	0.27	0.08	0.02	0.22	0.34
P6	0.15	0.17	0.21	0.23	0.28	0.17	0.11	0.05	0.08	0.26
P7	0.09	0.18	0.11	0.13	0.18	0.04	0.08	0.03	0.03	0.09
P8	0.06	0.16	0.08	0.05	0.05	0.10	0.04	0.05	0.04	0.06
P9	0.07	0.19	0.13	0.09	0.06	0.15	0.03	0.02	0.06	0.02
P10	0.06	0.12	0.09	0.03	0.06	0.10	0.05	0.05	0.12	0.05
P11	0.08	0.11	0.10	0.03	0.04	0.12	0.02	0.12	0.02	0.02
P12	0.06	0.11	0.10	0.05	0.04	0.14	0.03	0.13	0.02	0.10
P13	0.07	0.04	0.13	0.03	0.13	0.11	0.02	0.11	0.04	0.01
P14	0.10	0.05	0.12	0.07	0.08	0.14	0.08	0.10	0.02	0.06
P15	0.20	0.19	0.23	0.20	0.18	0.25	0.12	0.15	0.12	0.19
P16	0.19	0.26	0.24	0.25	0.21	0.26	0.11	0.12	0.09	0.21
P17	0.19	0.30	0.28	0.31	0.24	0.18	0.03	0.12	0.13	0.06
P18	0.11	0.34	0.30	0.30	0.24	0.16	0.03	0.11	0.12	0.07
P19	0.12	0.25	0.23	0.17	0.18	0.13	0.01	0.06	0.08	0.05
P20	0.20	0.33	0.28	0.24	0.22	0.13	0.07	0.18	0.12	0.08
P21	0.19	0.32	0.28	0.24	0.22	0.12	0.09	0.19	0.15	0.01
P22	0.12	0.05	0.04	0.02	0.03	0.06	0.02	0.02	0.02	0.05
P23	0.07	0.01	0.03	0.03	0.01	0.03	0.03	0.10	0.03	0.03

Direction	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW
P24	0.13	0.20	0.30	0.18	0.31	0.25	0.02	0.11	0.09	0.01
P25	0.18	0.05	0.05	0.09	0.04	0.03	0.12	0.09	0.12	0.02
P26	0.04	0.06	0.11	0.12	0.09	0.05	0.03	0.06	0.10	0.05
P27	0.08	0.12	0.22	0.21	0.21	0.06	0.07	0.05	0.03	0.09
P28	0.06	0.06	0.05	0.05	0.08	0.08	0.03	0.03	0.12	0.15
P29	0.11	0.18	0.18	0.13	0.13	0.18	0.06	0.01	0.04	0.06
P30	0.07	0.15	0.03	0.04	0.04	0.08	0.05	0.07	0.13	0.12

Table D2 Velocity Ratio of Overall Test Points

Direction	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW
O1	0.11	0.06	0.08	0.15	0.19	0.14	0.04	0.02	0.15	0.18
O2	0.06	0.15	0.16	0.05	0.05	0.05	0.03	0.06	0.18	0.24
O3	0.19	0.14	0.11	0.18	0.15	0.17	0.04	0.06	0.14	0.08
O4	0.26	0.29	0.15	0.20	0.11	0.27	0.05	0.03	0.03	0.13
O5	0.28	0.32	0.17	0.21	0.15	0.28	0.04	0.06	0.11	0.07
O6	0.27	0.34	0.17	0.22	0.18	0.27	0.05	0.06	0.18	0.02
O7	0.27	0.35	0.26	0.26	0.25	0.26	0.09	0.02	0.25	0.18
O8	0.20	0.26	0.32	0.30	0.27	0.16	0.11	0.06	0.31	0.39
O9	0.14	0.18	0.17	0.16	0.20	0.12	0.07	0.05	0.29	0.38
O10	0.16	0.01	0.17	0.14	0.08	0.24	0.02	0.10	0.27	0.31
O11	0.10	0.01	0.25	0.19	0.13	0.25	0.02	0.04	0.21	0.14
O12	0.04	0.03	0.28	0.22	0.16	0.27	0.05	0.05	0.21	0.21
O13	0.04	0.04	0.19	0.15	0.10	0.13	0.03	0.05	0.09	0.18
O14	0.18	0.03	0.06	0.06	0.04	0.17	0.06	0.07	0.17	0.21
O15	0.04	0.14	0.02	0.04	0.08	0.11	0.03	0.04	0.09	0.14
O16	0.18	0.18	0.17	0.13	0.10	0.20	0.07	0.07	0.03	0.11
O17	0.16	0.20	0.18	0.09	0.09	0.19	0.05	0.06	0.01	0.06

Direction	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW
O18	0.19	0.22	0.16	0.10	0.11	0.25	0.03	0.04	0.06	0.16
O19	0.18	0.18	0.07	0.09	0.17	0.10	0.07	0.03	0.07	0.15
O20	0.12	0.10	0.09	0.02	0.12	0.09	0.03	0.17	0.02	0.09
O21	0.10	0.04	0.12	0.03	0.15	0.11	0.04	0.21	0.08	0.25
O22	0.11	0.10	0.15	0.10	0.14	0.20	0.06	0.23	0.33	0.41
O23	0.16	0.30	0.27	0.23	0.28	0.26	0.03	0.03	0.37	0.42
O24	0.21	0.20	0.30	0.20	0.19	0.13	0.04	0.09	0.43	0.44
O25	0.24	0.20	0.29	0.22	0.11	0.09	0.12	0.21	0.39	0.44
O26	0.14	0.21	0.31	0.24	0.18	0.06	0.02	0.32	0.32	0.41
O27	0.19	0.24	0.14	0.19	0.15	0.07	0.03	0.22	0.04	0.08
O28	0.14	0.29	0.28	0.29	0.24	0.03	0.02	0.13	0.01	0.03
O29	0.13	0.28	0.18	0.10	0.21	0.23	0.03	0.05	0.02	0.09
O30	0.12	0.22	0.12	0.15	0.10	0.22	0.25	0.10	0.02	0.01
O31	0.12	0.17	0.05	0.10	0.05	0.13	0.16	0.13	0.04	0.18
O32	0.05	0.08	0.14	0.09	0.03	0.17	0.13	0.12	0.16	0.28
O33	0.11	0.22	0.13	0.16	0.19	0.28	0.11	0.07	0.02	0.04
O34	0.13	0.18	0.09	0.14	0.03	0.14	0.24	0.05	0.11	0.29
O35	0.15	0.09	0.05	0.08	0.03	0.15	0.14	0.02	0.39	0.40
O36	0.07	0.24	0.12	0.17	0.17	0.29	0.07	0.04	0.18	0.31
O37	0.09	0.12	0.03	0.10	0.03	0.09	0.21	0.04	0.46	0.46
O38	0.15	0.04	0.03	0.08	0.02	0.05	0.08	0.04	0.23	0.30
O39	0.14	0.02	0.05	0.02	0.02	0.04	0.02	0.04	0.04	0.05
O40	0.13	0.02	0.09	0.06	0.04	0.17	0.04	0.15	0.04	0.16
O41	0.12	0.04	0.16	0.13	0.04	0.17	0.04	0.09	0.17	0.27
O42	0.13	0.08	0.03	0.05	0.03	0.09	0.03	0.05	0.24	0.09
O43	0.16	0.02	0.11	0.11	0.10	0.06	0.02	0.06	0.28	0.09
O44	0.13	0.03	0.02	0.02	0.02	0.09	0.03	0.03	0.26	0.13
O45	0.01	0.07	0.06	0.06	0.04	0.02	0.01	0.04	0.15	0.04

Direction	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW
O46	0.08	0.08	0.05	0.04	0.11	0.02	0.01	0.03	0.17	0.01
O47	0.15	0.10	0.24	0.25	0.24	0.04	0.04	0.06	0.13	0.02
O48	0.16	0.10	0.09	0.08	0.08	0.11	0.04	0.06	0.02	0.04
O49	0.05	0.22	0.29	0.26	0.24	0.16	0.09	0.04	0.08	0.03
O50	0.14	0.04	0.07	0.05	0.05	0.07	0.09	0.04	0.03	0.02
O51	0.15	0.06	0.05	0.05	0.01	0.01	0.22	0.22	0.06	0.06
O52	0.10	0.23	0.30	0.28	0.27	0.17	0.06	0.04	0.14	0.02
O53	0.26	0.34	0.42	0.37	0.36	0.24	0.04	0.07	0.02	0.07
O54	0.15	0.36	0.43	0.38	0.37	0.23	0.10	0.20	0.15	0.07
O55	0.17	0.05	0.05	0.04	0.06	0.09	0.18	0.06	0.21	0.18
O56	0.16	0.13	0.14	0.08	0.03	0.03	0.17	0.27	0.15	0.13
O57	0.11	0.11	0.11	0.07	0.03	0.06	0.14	0.27	0.15	0.14
O58	0.09	0.05	0.07	0.05	0.03	0.05	0.21	0.22	0.24	0.13
O59	0.06	0.18	0.20	0.15	0.04	0.02	0.15	0.22	0.17	0.23
O60	0.21	0.27	0.24	0.15	0.18	0.09	0.05	0.01	0.27	0.32
O61	0.13	0.13	0.13	0.07	0.02	0.11	0.02	0.02	0.07	0.12
O62	0.11	0.11	0.10	0.14	0.18	0.21	0.08	0.06	0.28	0.41
O63	0.16	0.12	0.12	0.01	0.05	0.09	0.06	0.05	0.21	0.37
O64	0.05	0.04	0.04	0.02	0.01	0.03	0.01	0.02	0.09	0.18
O65	0.10	0.01	0.03	0.01	0.05	0.04	0.02	0.03	0.09	0.10
O66	0.02	0.07	0.14	0.10	0.11	0.09	0.05	0.03	0.03	0.02
O67	0.07	0.31	0.33	0.27	0.15	0.15	0.03	0.02	0.02	0.03
O68	0.15	0.32	0.33	0.31	0.20	0.10	0.06	0.06	0.09	0.11
O69	0.06	0.27	0.19	0.17	0.25	0.04	0.01	0.11	0.02	0.08

Table D3 Velocity Ratio of Special Test Points

Direction	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW
S1	0.09	0.13	0.07	0.10	0.07	0.05	0.07	0.12	0.01	0.17
S2	0.17	0.24	0.24	0.23	0.22	0.17	0.13	0.17	0.17	0.17
S3	0.19	0.31	0.35	0.33	0.34	0.27	0.12	0.19	0.18	0.15
S4	0.20	0.29	0.33	0.31	0.32	0.23	0.14	0.13	0.13	0.10
S5	0.18	0.26	0.33	0.30	0.33	0.23	0.09	0.15	0.12	0.05
S6	0.17	0.11	0.25	0.10	0.23	0.23	0.04	0.13	0.07	0.03
S7	0.24	0.28	0.32	0.29	0.31	0.25	0.05	0.16	0.11	0.08
S8	0.09	0.12	0.14	0.13	0.14	0.10	0.10	0.03	0.02	0.04
S9	0.10	0.19	0.12	0.12	0.09	0.16	0.07	0.03	0.07	0.18
S10	0.18	0.26	0.27	0.23	0.21	0.22	0.11	0.05	0.11	0.17
S11	0.10	0.24	0.27	0.22	0.20	0.20	0.09	0.09	0.07	0.21
S12	0.14	0.25	0.32	0.30	0.30	0.23	0.12	0.07	0.13	0.15

D2 Intermediate Scheme

Table D4 Velocity Ratio of Perimeter Test Points

Direction	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW
P1	0.15	0.29	0.30	0.25	0.18	0.13	0.09	0.05	0.18	0.19
P2	0.18	0.29	0.28	0.24	0.16	0.20	0.08	0.08	0.20	0.25
P3	0.14	0.18	0.20	0.18	0.14	0.22	0.07	0.01	0.11	0.23
P4	0.12	0.12	0.21	0.21	0.21	0.22	0.09	0.05	0.16	0.32
P5	0.04	0.07	0.17	0.17	0.16	0.23	0.07	0.05	0.14	0.35
P6	0.15	0.13	0.21	0.22	0.27	0.17	0.11	0.06	0.04	0.34
P7	0.12	0.15	0.11	0.12	0.16	0.04	0.07	0.01	0.03	0.11
P8	0.09	0.15	0.08	0.06	0.08	0.10	0.03	0.04	0.05	0.10
P9	0.11	0.18	0.12	0.08	0.04	0.15	0.04	0.10	0.05	0.10
P10	0.08	0.10	0.08	0.05	0.06	0.11	0.05	0.14	0.06	0.06
P11	0.08	0.11	0.10	0.01	0.03	0.13	0.01	0.12	0.05	0.12
P12	0.05	0.07	0.10	0.06	0.01	0.13	0.05	0.14	0.15	0.16
P13	0.07	0.07	0.11	0.04	0.09	0.13	0.06	0.13	0.04	0.19
P14	0.13	0.05	0.17	0.09	0.13	0.20	0.10	0.17	0.01	0.26
P15	0.17	0.15	0.22	0.19	0.20	0.25	0.12	0.16	0.13	0.27
P16	0.18	0.25	0.22	0.23	0.23	0.26	0.12	0.08	0.10	0.25
P17	0.18	0.31	0.32	0.33	0.28	0.23	0.01	0.08	0.12	0.05
P18	0.10	0.33	0.31	0.31	0.24	0.06	0.04	0.11	0.11	0.07
P19	0.12	0.31	0.28	0.27	0.19	0.08	0.05	0.09	0.08	0.06
P20	0.20	0.33	0.29	0.28	0.20	0.06	0.08	0.16	0.11	0.06
P21	0.18	0.33	0.29	0.28	0.20	0.02	0.10	0.13	0.14	0.06
P22	0.08	0.03	0.04	0.02	0.02	0.05	0.01	0.10	0.04	0.01
P23	0.07	0.04	0.07	0.05	0.06	0.02	0.03	0.12	0.02	0.03
P24	0.18	0.07	0.26	0.12	0.27	0.23	0.05	0.15	0.08	0.03

Direction	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW
P25	0.18	0.19	0.16	0.25	0.16	0.08	0.14	0.12	0.11	0.04
P26	0.02	0.05	0.08	0.07	0.07	0.02	0.03	0.09	0.12	0.05
P27	0.02	0.11	0.17	0.19	0.19	0.07	0.06	0.09	0.16	0.05
P28	0.08	0.05	0.08	0.07	0.08	0.01	0.04	0.05	0.09	0.11
P29	0.10	0.14	0.21	0.11	0.10	0.18	0.05	0.01	0.05	0.05
P30	0.14	0.20	0.16	0.06	0.10	0.14	0.04	0.06	0.09	0.09

Table D5 Velocity Ratio of Overall Test Points

Direction	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW
O1	0.13	0.15	0.18	0.19	0.21	0.16	0.04	0.02	0.15	0.14
O2	0.08	0.12	0.15	0.04	0.05	0.05	0.03	0.03	0.16	0.22
O3	0.20	0.15	0.11	0.17	0.11	0.14	0.02	0.05	0.13	0.09
O4	0.27	0.30	0.17	0.19	0.10	0.26	0.05	0.07	0.02	0.12
O5	0.30	0.32	0.18	0.21	0.14	0.27	0.05	0.06	0.11	0.07
O6	0.29	0.33	0.19	0.21	0.17	0.26	0.06	0.03	0.19	0.04
O7	0.27	0.33	0.24	0.24	0.25	0.24	0.10	0.05	0.24	0.17
O8	0.22	0.27	0.32	0.30	0.27	0.12	0.11	0.09	0.31	0.39
O9	0.16	0.18	0.18	0.16	0.21	0.10	0.08	0.05	0.30	0.35
O10	0.16	0.02	0.16	0.14	0.07	0.23	0.02	0.10	0.27	0.27
O11	0.09	0.02	0.24	0.18	0.12	0.25	0.02	0.02	0.22	0.21
O12	0.05	0.02	0.27	0.21	0.15	0.26	0.05	0.03	0.22	0.23
O13	0.03	0.02	0.19	0.14	0.09	0.13	0.03	0.03	0.07	0.15
O14	0.18	0.01	0.05	0.05	0.04	0.17	0.06	0.06	0.17	0.22
O15	0.04	0.13	0.01	0.01	0.07	0.12	0.03	0.02	0.08	0.13
O16	0.19	0.18	0.18	0.13	0.10	0.20	0.07	0.07	0.04	0.07
O17	0.18	0.19	0.18	0.08	0.11	0.20	0.05	0.04	0.05	0.08
O18	0.21	0.21	0.16	0.10	0.11	0.25	0.03	0.03	0.05	0.15

Direction	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW
O19	0.18	0.13	0.06	0.09	0.17	0.11	0.07	0.08	0.07	0.15
O20	0.13	0.07	0.09	0.02	0.10	0.09	0.02	0.14	0.01	0.28
O21	0.10	0.05	0.10	0.03	0.13	0.13	0.05	0.22	0.09	0.36
O22	0.10	0.08	0.11	0.10	0.11	0.20	0.04	0.22	0.34	0.43
O23	0.14	0.30	0.26	0.23	0.29	0.25	0.03	0.02	0.39	0.44
O24	0.18	0.20	0.29	0.20	0.18	0.22	0.05	0.10	0.45	0.44
O25	0.22	0.21	0.30	0.24	0.12	0.11	0.13	0.12	0.40	0.45
O26	0.16	0.21	0.32	0.24	0.18	0.06	0.02	0.34	0.31	0.40
O27	0.16	0.24	0.12	0.19	0.15	0.08	0.02	0.24	0.04	0.08
O28	0.14	0.29	0.28	0.28	0.24	0.04	0.03	0.15	0.03	0.04
O29	0.12	0.28	0.15	0.09	0.21	0.15	0.03	0.09	0.02	0.08
O30	0.09	0.22	0.11	0.14	0.10	0.23	0.25	0.12	0.02	0.02
O31	0.10	0.17	0.05	0.10	0.05	0.13	0.16	0.13	0.03	0.22
O32	0.07	0.09	0.15	0.09	0.04	0.17	0.13	0.10	0.16	0.28
O33	0.08	0.22	0.11	0.15	0.19	0.28	0.11	0.01	0.01	0.06
O34	0.09	0.18	0.08	0.13	0.03	0.15	0.24	0.01	0.10	0.33
O35	0.11	0.12	0.05	0.09	0.02	0.16	0.14	0.12	0.36	0.38
O36	0.03	0.24	0.11	0.16	0.17	0.29	0.06	0.04	0.18	0.34
O37	0.06	0.14	0.03	0.09	0.02	0.10	0.21	0.03	0.45	0.45
O38	0.12	0.09	0.03	0.08	0.02	0.05	0.08	0.05	0.27	0.30
O39	0.11	0.05	0.05	0.03	0.02	0.03	0.02	0.12	0.09	0.09
O40	0.10	0.05	0.10	0.06	0.04	0.18	0.03	0.11	0.03	0.13
O41	0.10	0.05	0.17	0.12	0.04	0.17	0.04	0.09	0.21	0.24
O42	0.11	0.05	0.05	0.05	0.06	0.08	0.01	0.04	0.22	0.09
O43	0.17	0.04	0.10	0.11	0.11	0.07	0.01	0.03	0.26	0.08
O44	0.12	0.04	0.02	0.01	0.01	0.09	0.02	0.02	0.24	0.13
O45	0.01	0.07	0.04	0.06	0.04	0.04	0.01	0.04	0.14	0.04
O46	0.05	0.07	0.10	0.15	0.14	0.01	0.04	0.02	0.15	0.01

Direction	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW
O47	0.14	0.21	0.26	0.25	0.26	0.12	0.02	0.08	0.12	0.02
O48	0.21	0.05	0.11	0.06	0.07	0.05	0.03	0.05	0.02	0.02
O49	0.04	0.22	0.30	0.27	0.23	0.14	0.09	0.02	0.09	0.03
O50	0.12	0.05	0.09	0.07	0.09	0.08	0.09	0.07	0.03	0.02
O51	0.13	0.04	0.07	0.05	0.02	0.02	0.24	0.27	0.08	0.07
O52	0.04	0.22	0.30	0.26	0.24	0.15	0.05	0.02	0.14	0.02
O53	0.25	0.33	0.42	0.38	0.36	0.25	0.03	0.09	0.03	0.08
O54	0.17	0.36	0.42	0.37	0.35	0.23	0.11	0.21	0.15	0.08
O55	0.21	0.05	0.11	0.02	0.06	0.08	0.17	0.10	0.20	0.17
O56	0.14	0.12	0.14	0.09	0.03	0.02	0.17	0.28	0.14	0.13
O57	0.12	0.11	0.12	0.08	0.02	0.07	0.14	0.25	0.15	0.14
O58	0.13	0.06	0.06	0.06	0.05	0.04	0.20	0.19	0.22	0.13
O59	0.07	0.18	0.20	0.15	0.04	0.02	0.15	0.21	0.16	0.22
O60	0.16	0.24	0.23	0.14	0.17	0.08	0.04	0.05	0.29	0.37
O61	0.12	0.13	0.12	0.06	0.02	0.10	0.02	0.03	0.06	0.12
O62	0.09	0.12	0.11	0.16	0.18	0.20	0.08	0.07	0.27	0.39
O63	0.17	0.11	0.10	0.02	0.05	0.09	0.06	0.06	0.20	0.35
O64	0.04	0.04	0.03	0.02	0.01	0.01	0.01	0.02	0.09	0.15
O65	0.10	0.01	0.03	0.01	0.05	0.04	0.02	0.01	0.07	0.07
O66	0.03	0.06	0.13	0.10	0.11	0.09	0.05	0.02	0.03	0.01
O67	0.05	0.30	0.30	0.28	0.14	0.17	0.04	0.02	0.02	0.03
O68	0.15	0.33	0.32	0.32	0.18	0.12	0.06	0.06	0.10	0.12
O69	0.07	0.27	0.17	0.17	0.25	0.05	0.01	0.14	0.06	0.10

Table D6 Velocity Ratio of Special Test Points

Direction	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW
S1	0.07	0.15	0.07	0.12	0.05	0.07	0.07	0.03	0.08	0.15
S2	0.19	0.28	0.28	0.28	0.26	0.21	0.15	0.02	0.15	0.17
S3	0.20	0.32	0.37	0.34	0.35	0.27	0.15	0.08	0.16	0.14
S4	0.19	0.30	0.33	0.33	0.32	0.24	0.14	0.11	0.11	0.10
S5	0.20	0.28	0.34	0.31	0.34	0.24	0.12	0.14	0.11	0.06
S6	0.15	0.26	0.28	0.19	0.27	0.23	0.03	0.06	0.02	0.05
S7	0.20	0.28	0.30	0.29	0.30	0.25	0.09	0.10	0.10	0.10
S8	0.12	0.16	0.17	0.15	0.16	0.10	0.09	0.10	0.01	0.09
S9	0.14	0.20	0.22	0.20	0.18	0.15	0.09	0.06	0.05	0.16
S10	0.07	0.12	0.25	0.20	0.18	0.17	0.09	0.06	0.15	0.19
S11	0.21	0.20	0.27	0.21	0.20	0.20	0.08	0.07	0.15	0.20
S12	0.01	0.20	0.28	0.21	0.22	0.24	0.09	0.06	0.10	0.12