Air Ventilation Assessment of the Oil Street Planning Area by CFD Approach

March 2009

Authors:
Professor Jimmy C.H. FUNG
Dr. Steve H.L. YIM
AN Karl

Abstract

In 2003, the Planning Department of the Hong Kong SAR Government issued a technical circular that requires building developments in Hong Kong to undertake an Air Ventilation Assessment (AVA) in order to evaluate the possible air ventilation impact on the local neighborhood. The Oil Street urban site, located near Fortress Hill, North Point, is a potential site for urban development. There has been many rapid development projects carried out in this area throughout the recent years with multiple high rise buildings currently being built or planned for the future. In this report, a computational fluid dynamics approach is carried out in order to examine the impact of a currently proposed urban building project to the wind environment at the North Point area. A control model and a simulated model would be created and the wind velocity ratio (VR) is used as a comparison indicator. The average VR at the two main roads: The King's Road and the Electric Road would be calculated and compared; the VR at the target site of planning would also be computed. Lastly, to get a macroscopic view, the VR of the whole urban area would also be compared.

1. Introduction

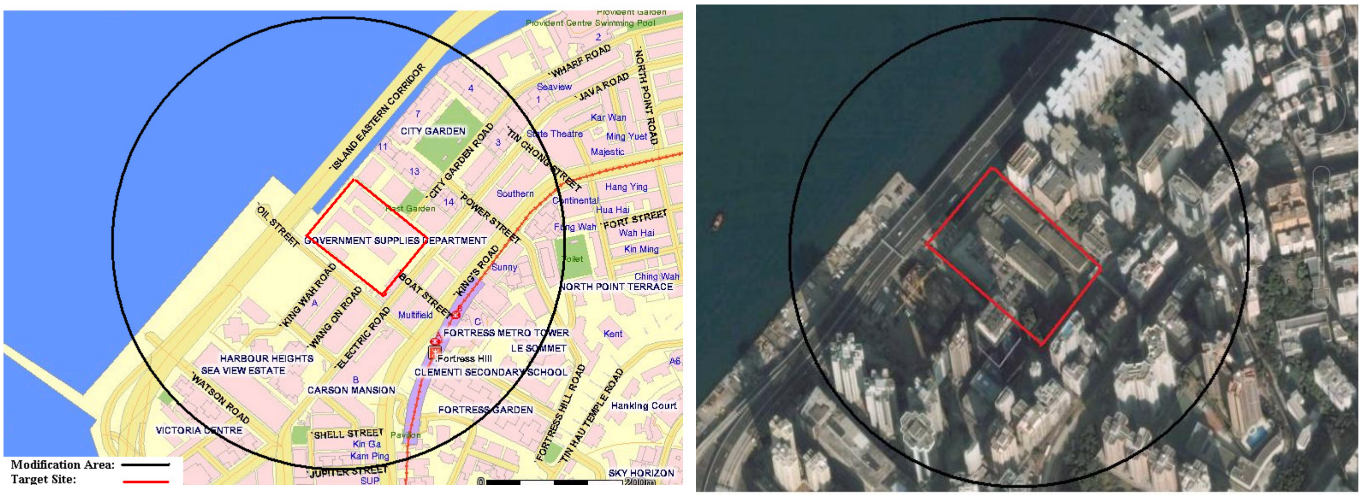
The Oil Street urban site, located near Fortress Hill, North Point, is a potential site for urban development. There have been many rapid development projects such as development carried out in this area throughout the recent years with multiple high rise buildings currently being built or planned for the future. The current group of low rising constructions of the ex-government supplies department depot on the Oil Street is planned to be reconstructed into two blocks of high rising residential buildings and commercial buildings which might affect the wind environment after their development. As a result, a detailed study using the computational fluid dynamics approach is carried out to examine the extent that the wind environment and the environment of the surroundings would be affected after the development of these high rising buildings. The study is mainly divided into three stages: Modification of geometry, building of meshing grids and finally simulation of the model and collection of data.

In this report, the geographic location of the proposed development site and its surroundings would first be examined and then the modification and grid building of the geometry shape and data of the real time model would be discussed.

1.1 Geographic Location of the Target Site

The target site is located at the waterfront area bounded by the Oil Street to the southwest and Electric Road to the southeast. To the northwest of the subject site is the waterfront. The current target site consist a group of low rising buildings which belongs to the government supplies department. The land topography is relatively flat on site and in its immediate surroundings.

Two residential buildings each of 120m in height are proposed to replace the current low rising ones. The highest building in the circular region of radius 120m with the target site as centre is the AIA commercial tower with a height of H=178m which is located to the south of our target site bounded by Electric Road and the Oil Street. Therefore, according to the modification guideline, all the buildings in the circular region of radius 2H with centre as the target site should be modified and included into the study. Therefore our modification area would have the Ex-Government Supplies Department Depot as the centre and include to the southwest end the Victoria Centre, to its northeast end the furthest building of the City Gardens and to the southeast end another high rise residential building, the Le Sommet.



(a) (b)

Figure 1(a): 2D Map (b) correspond Satellite Map of Target Site of Study and Assessment Area

1.2 Major and Tall buildings around target site

There are quite many major and relative tall buildings surrounding the study site which includes the following:

- To the northeast of the subject site is a group of high rise residential buildings, the City Gardens. These groups of buildings have height of about 85m. The City Garden Road is aligned in parallel to the coast and ends at the subject site.
- To the southeast on the opposite side of Electric Road is a hotel development which would soon be completed. The hotel site is bounded by King Wah Road and Wang On Road in which the two roads are aligned in parallel to the waterfront. The hotel development is of long frontage to the waterfront with the height reaching about 83m. It is just a street's distance from the target site.
- Just two street's distance behind the hotel development site is the high rising AIA commercial building which is of height about 178m. It is bounded by the Electric Road and Oil Street to the south.
- To the far southwest of the target site is another group of high residential buildings called the Harbour Heights, just beside it is the Manulife building and to the southwest of Harbour Heights is another group of buildings of Victoria centre. These buildings each got a height of above 100m and probably with have great impact on the wind environment.

- To the far southeast of the target site crossed the King's Road is another two high rise residential buildings with height greater than 100m called Fortress Gardens and the Le Sommet.

The above mentioned are the major tall buildings in the modification area. The other existing buildings adjacent to the hotel development site are low ones range around 20m and heights of row of buildings at the back along King's Road range from about 45m to 75m, these buildings relatively have a smaller impact on the wind environment compared to the taller ones mentioned above.

Figure 2: High rising buildings around target site **(a)** The developing Harbour Grand Hotel **(b)** The study site **(c)** City gardens **(d)** The Harbour Heights **(e)** The AIA tower **(f)** The Le Sommet

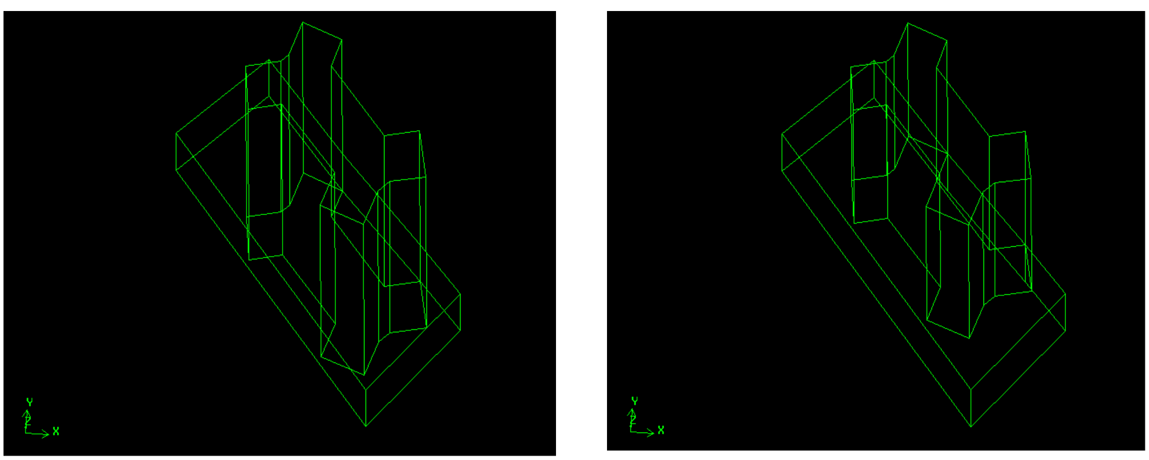
2. Modification of the Oil Street Urban Site in the CFD model

2.1 Principles and Rules of Modification of buildings in the model

Modification is a simple yet very important procedure; a good modified geometry would lead to high probability of success in the following meshing stage. Therefore, modification must be done carefully and of course the major geometry shape of buildings should be preserved after this process. As the geometry is imported and generated by CAD programs, there would be many extra vertices, small edges and doubled faces, these geometry characteristics must be cleaned up as those would lead to fail in splitting of geometry which would affect the grid building procedure which would be carried out later. Some models that represent detailed descriptions of real-world objects include details that complicate the process of creating a mesh but are often irrelevant to mathematical analyses for which a mesh is created. Those include fillets and chamfered edges, sliver-shaped faces, holes, small depressions or bumps on the surface of model faces, small geometries and sharp edges. Therefore, we have to simplify and clean up these complex geometries.

2.2 Modification of the buildings in the model

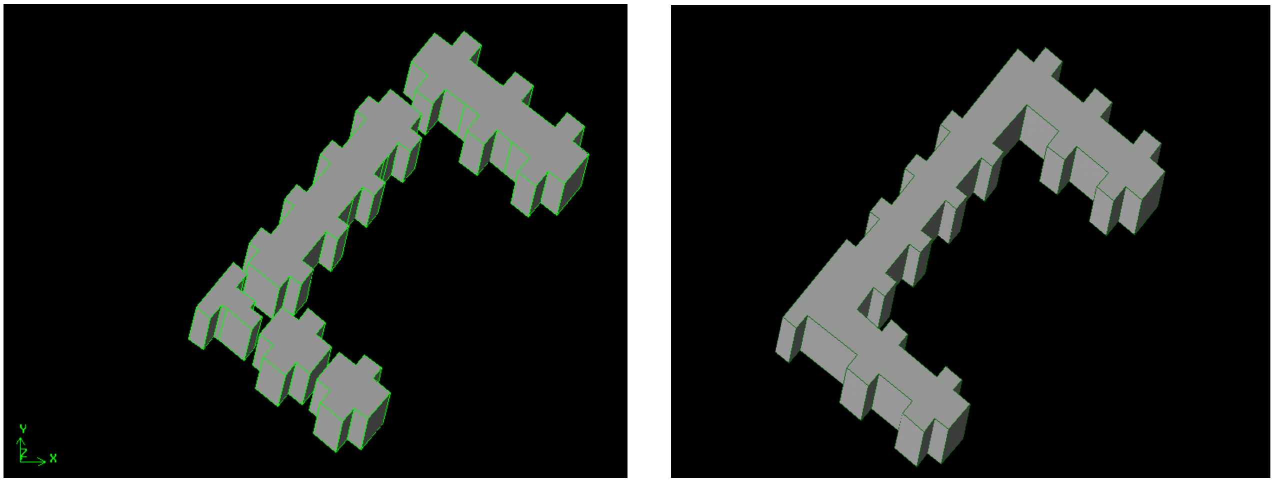
The geometry data of the Oil street site is generated by Computer automated design (CAD) programs and then imported. The principles and techniques mentioned above are carried out to clean up the geometry. Some small buildings (those with height less than 6m, width and length less than 5m) are deleted. Buildings with lanes or streets which are less than 3.5m in width would be modified and merged together. These ways of modification needs to be carried out mainly because by doing this, the probability of creating a successful mesh in the following stage would be higher and in addition the number of meshing elements and their skewness[1] would be greatly reduced. As some of the buildings in modification area got podiums, as a result, two geometry files are generated, one is for podium and another is just the buildings without podium. After modification, the podium building file is imported as ASIC file format into the building file. After that, one needs to unite the podium with their correspond buildings using the Unite function of volume modification.



(a) **(b)**

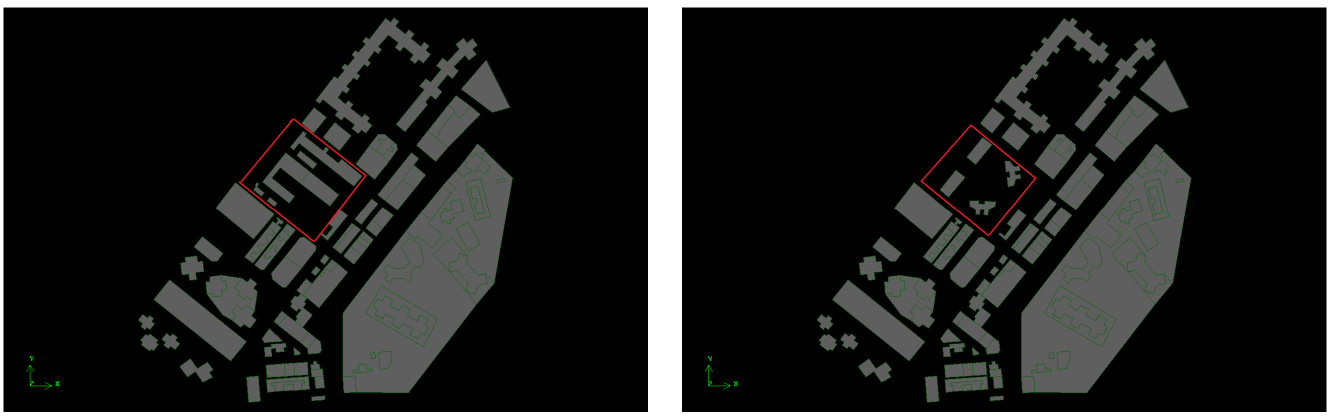
Figure 3(a): Residential building the Le Sommet before united with podium **(b)** after merged with podium

[1] An indicator of how bad a mesh element is. 0 means best element and 1 means worst element.



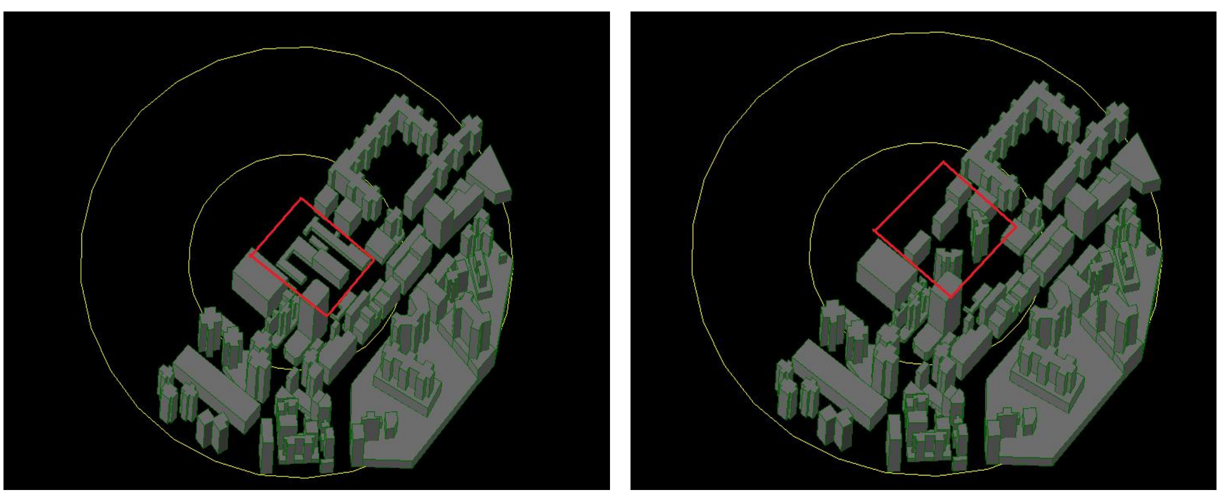
(a) **(b)**

Figure 4(a): Residential buildings the City Gardens before modified and merged **(b)** The City Gardens after merged and modified



(a) **(b)**

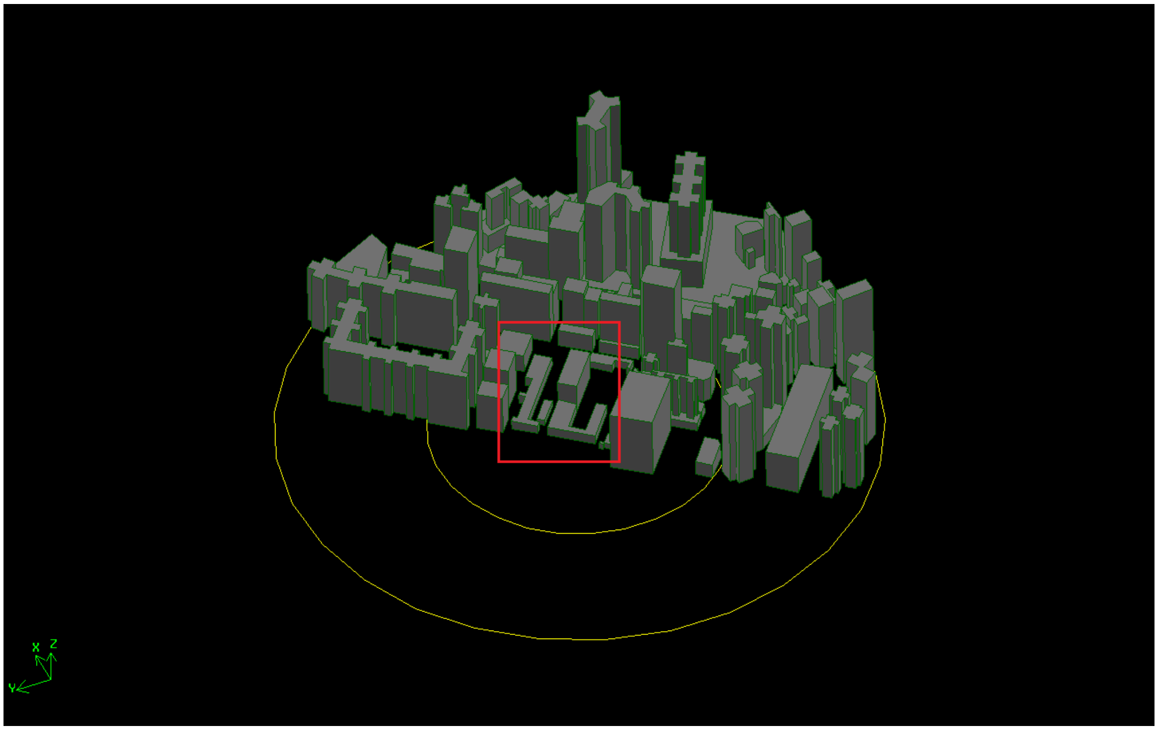
Figure 5: Top View of the target site (bounded by red) of the **(a)** Control **(b)** Proposed model



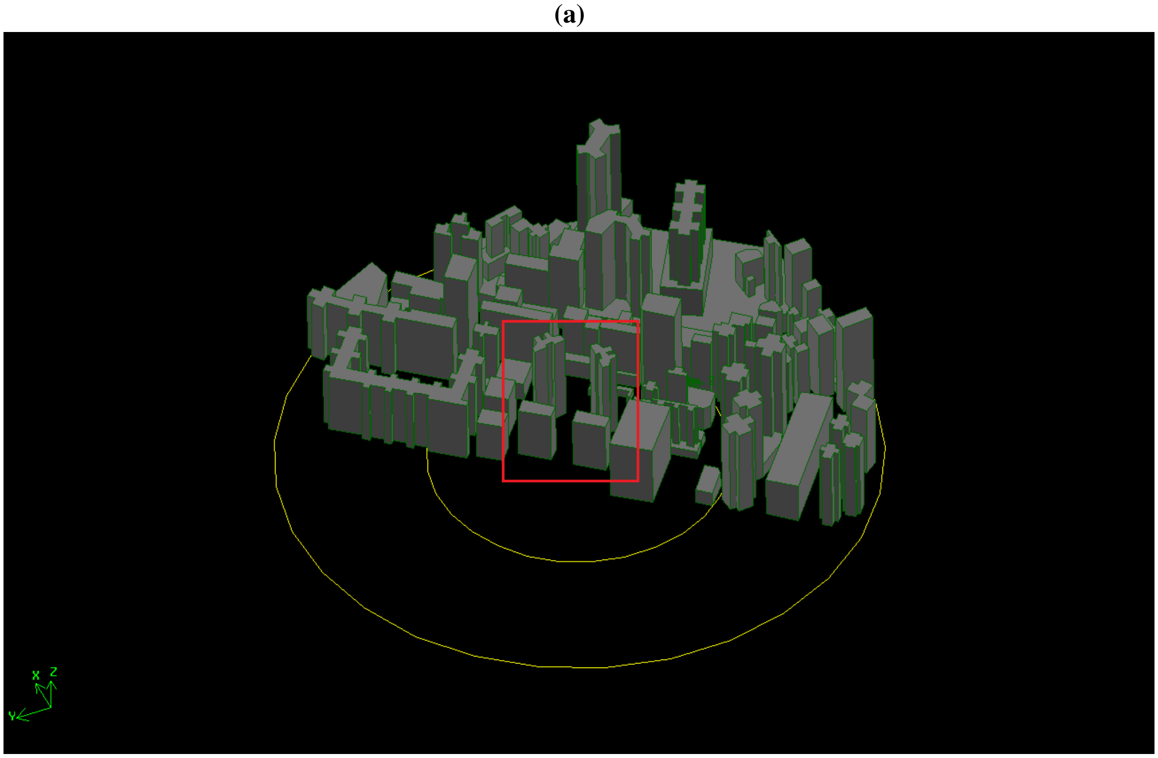
(a) **(b)**

Figure 6(a): Building Groups with podium and topography attached of the **(a)** Control **(b)** Proposed case after modification and target site bounded by red

The following figures show the great difference in height between the buildings of the target site currently and after development:



(a)



(b)

Figure 7: Different Heights comparison of the **(a)** Control **(b)** Proposed case (bounded by red)

3. Grid Building and Meshing

3.1 Meshing Guideline

A set of mesh guidelines is released and recommended for the study. The recommended guidelines are as follows:

- The domain size should be at least 5*H* for lateral, 5*H* for inflow region and 5H for outflow region.
- All surrounding buildings within 2*H* region with the target site as the centre should be taken into account.
- Buildings and podiums less than 2 storeys which is about 6m should be grouped.
- There should be 6 to 10 grid cells per street wide.
- The grid expansion ratio should be 1.5.
- Prism layer must cover pedestrian level, recommended spacing is 0.5m.

The following table shows the recommended guidelines:

Guideline	Guideline
Domain Size	(At least) Lateral : 5*H* Inflow: 5*H* Outflow: 5*H*
Surroundings	At least 2*H*
Treatment of small obstacles(outside target side)	Group buildings and podium lower than 2 storeys
Street Grid resolution	6-10 cells per street wide
Grid expansion ratio	1.5
Prismatic layer	Prism layer must cover pedestrian level, spacing recommend 0.5m

Table 1: Meshing Guidelines

* The symbol *H* above is the height of the highest building in the target study area.

3.2 Grid building of the Control and Proposed Case Model

After the modification procedure, meshing procedure is carried out. First of all, a computational domain size of inflow 12*H*, outflow 17*H* and width 10*H* and height of 10*H* is built, where *H* is 178m (the height of the AIA commercial building) in our case. A base domain with height 3m is also built as to act as the boundary layer. The created domains are then split with the buildings and the geometry after splitting is the one we need to carry out the mesh.

After splitting, there is an irregular upper geometry, the irregular lower boundary geometry and the building geometries. The upper irregular shape is first meshed so that the shared face between the upper and lower irregular shape could have a shared face mesh. Then after that the shared face mesh could be projected onto the base of the lower boundary irregular geometry and meshed with the cooper scheme with six layers each of 0.5m.

For the upper irregular shape, six size functions are attached to the four walls of the domain in order to control the skewness and number of the elements. After that the Tet/Hybrid Tgrid meshing scheme (elements created are tetrahedrons) is carried out to mesh the upper irregular geometry. We set the cells and gaps value in the size functions as 6, growth ratio is 1.5 as listed in the guideline. The following figures show the meshed domain:

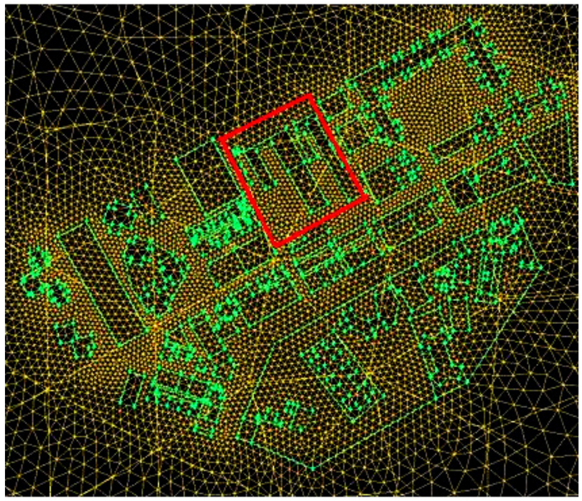


Figure 8: Top view of the meshed outer domain of building groups of the control case after modification

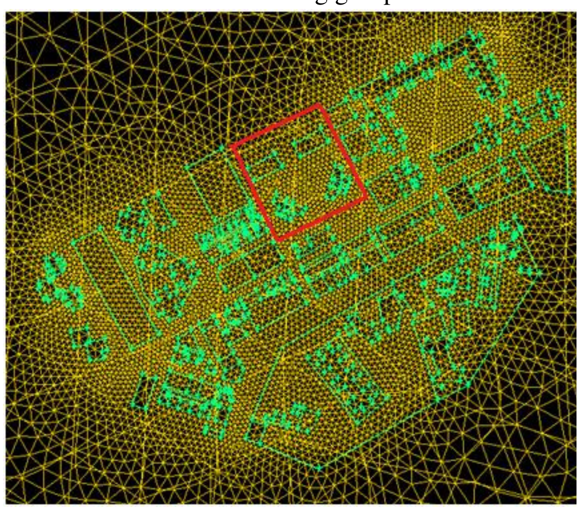


Figure 9: Top view of the meshed outer domain of building groups of the proposed case after modification

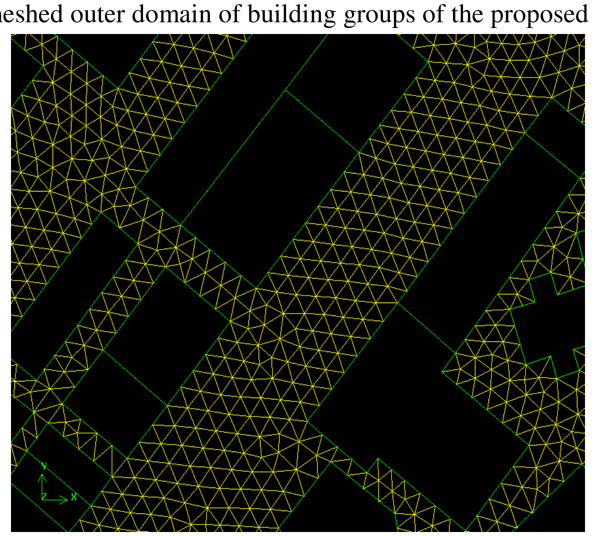


Figure 10: About six to ten grids per street wide showing the example of King's Road

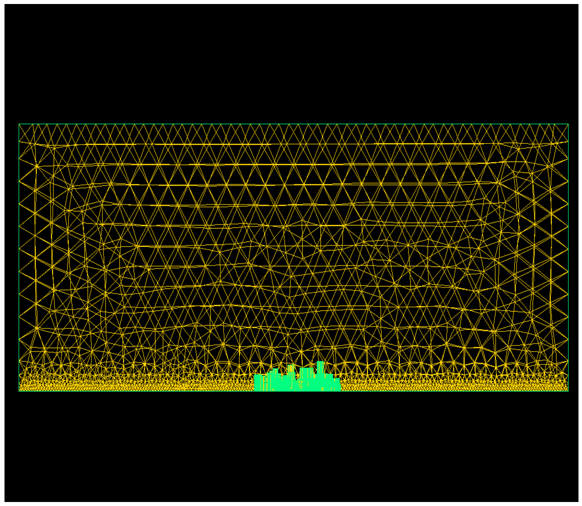


Figure 11: Side view of the meshed outer domain

4. Model Simulation

After meshing processes, the building model with meshes will be input into the CFD model. The realizable $k-\varepsilon$ model is used for both the control case and the proposed case. The inflow boundary is set as the velocity inlet and the outflow boundary is set as the zero gradient condition, lateral and top boundaries of the domain are set as the logarithmic law for smooth surface wall. A wind velocity profile is applied to the inflow boundary and second order upwind finite difference numerical schemes are implemented for momentum, turbulent kinetic energy and turbulent dissipation rate calculations.

4.1 Wind Profile

To investigate the local wind availability around the study area, an appropriate wind profile can be provided by numerical models such as MM5/CALMET system or wind tunnel experiment. Yim *et al.* (2007; 2009) coupled MM5 and CALMET to simulate wind fields over complex terrain area (Guangdong, Pearl River Delta and Hong Kong) in high resolutions with land-sea breeze considerations which provides an appropriate wind profile and representative wind rose over the study area. For wind tunnel experience, Hong Kong Planning Department (2007) used a 1:4000 scale topographical model included the surrounding area up to a distance of approximately 10 km from the Oil Street study area, to determine the effects of local topography and the surrounding urban environment on mean wind speed and turbulence intensity. The topographical study results were combined with a statistical model of the Hong Kong wind climate, based on measurements of non-typhoon winds taken by Hong Kong Observatory at Waglan Island (a relatively open station to represent the ambient wind of Hong Kong) during the period of 1953 – 2000 inclusive, to determine wind roses corresponding to annual mean wind speeds at the measurement positions. A miniature pressure probe was used to take measurements of wind speed and turbulence intensity profile.

In our study, the wind and turbulent intensity profiles are provided by the wind tunnel experience (Hong Kong Planning Department, 2007).

In order to investigate the influence of the approved buildings on the sea breeze penetrating into the inland area, the wind velocity data points are fitted by the least fitting method and set as boundary condition in the simulation. The wind velocity graph is shown as below:

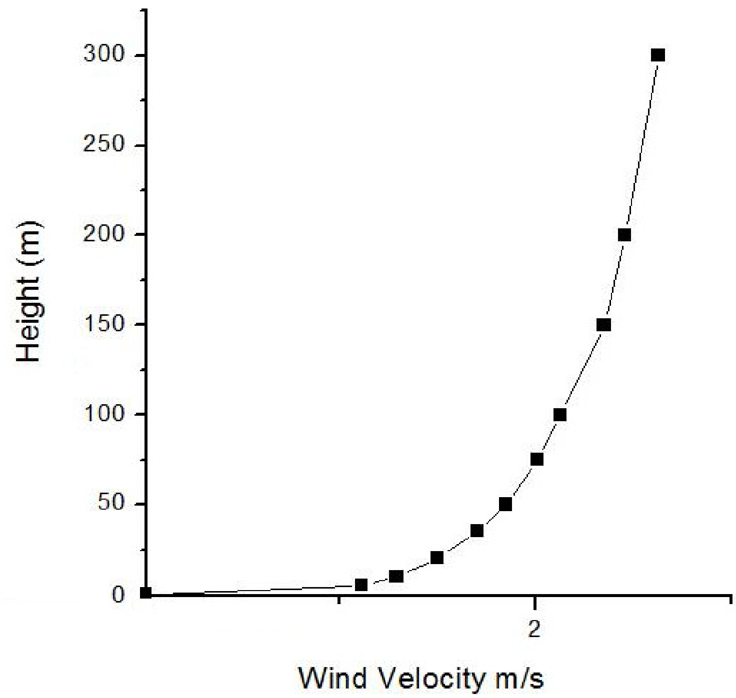


Figure 12: Graph of wind velocities correspond to different heights

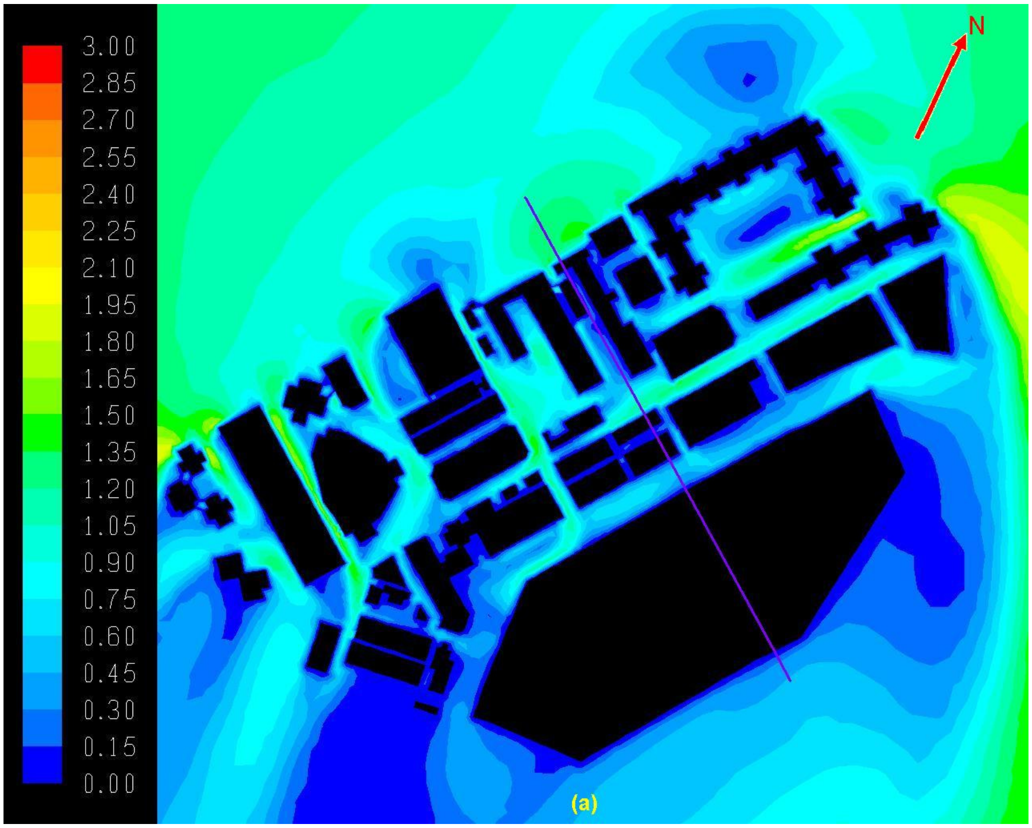
The equation obtained by least square fitting of the above data points is: $V = 0.788H^{0.2165}$ where V is the wind velocity and H is the corresponding height.

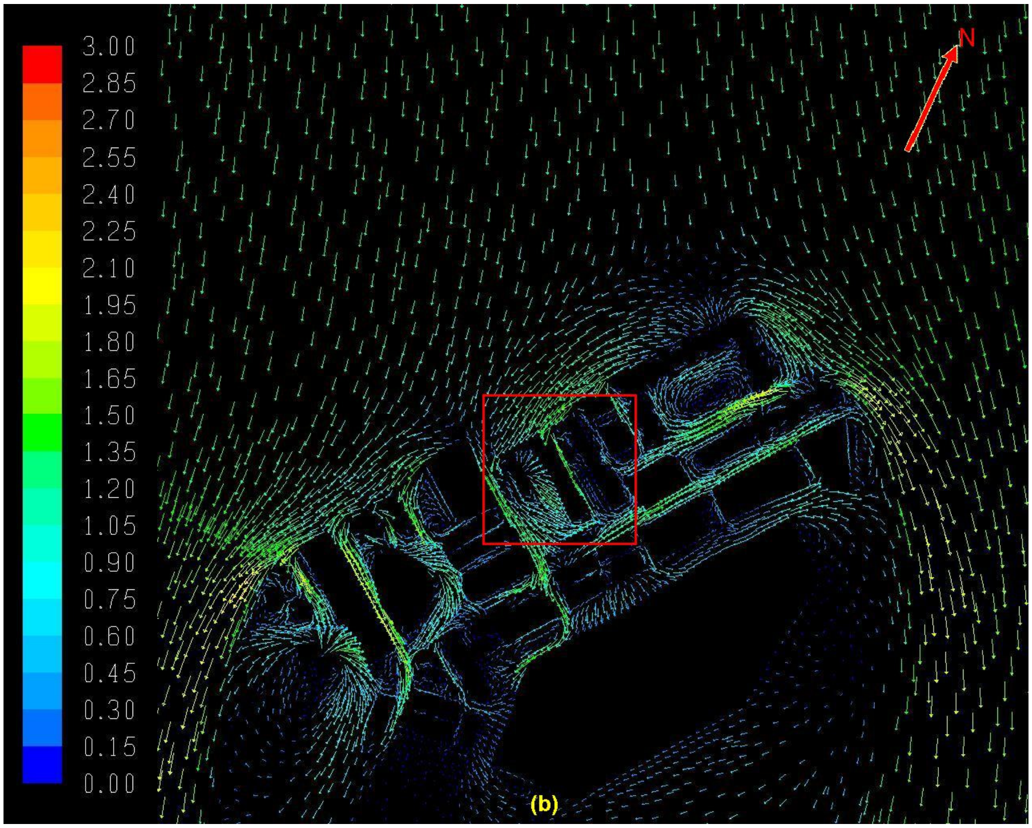
4.2 Wind Velocity Ratio (VR)

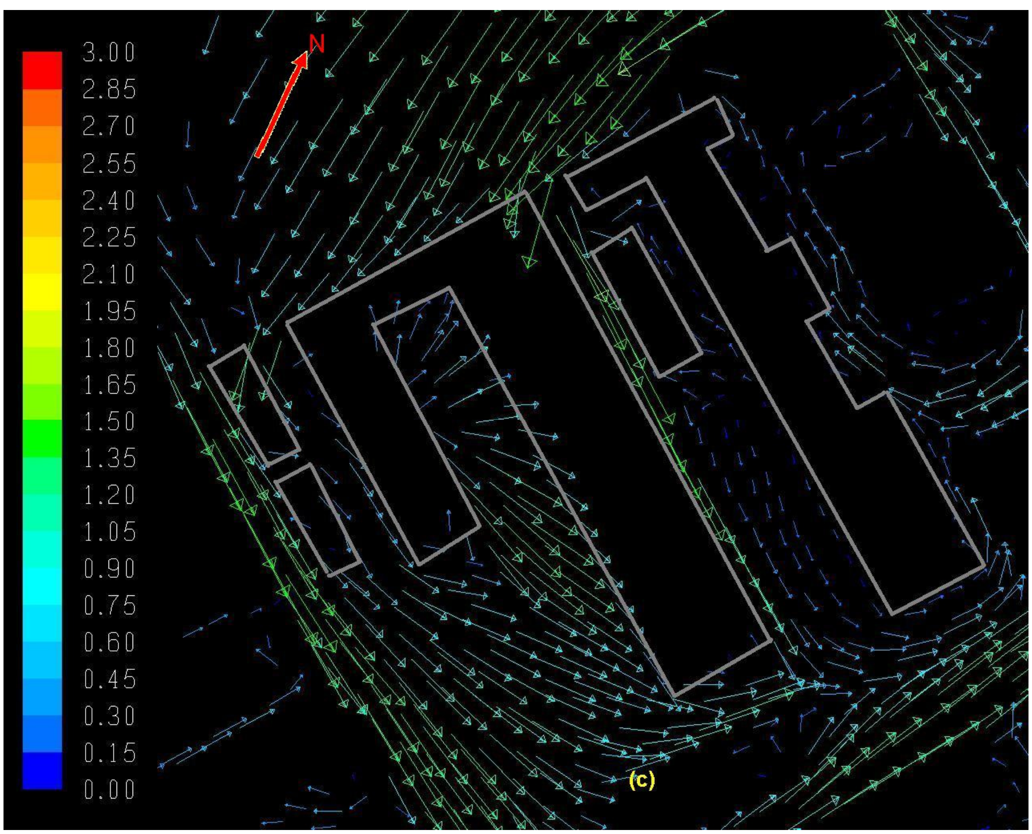
Wind Velocity ratio (VR) is the indicator of the wind availability, the higher the VR, the greater the wind availability and it is defined as $\frac{V_p}{V_\infty}$. V_p captures the wind velocity at the pedestrian level of 2m and V_∞ captures the wind velocity at the top of the wind boundary layer and is assumed to be 500m above the ground (Ng *et al.* 2004). In the study it would be obtained from the equation obtained above. A computer program is then linked to the processing software in order to get the volume average of VR of the King's road, Electric Road, the target area and the surrounding urban areas. Finally these data are obtained and compared.

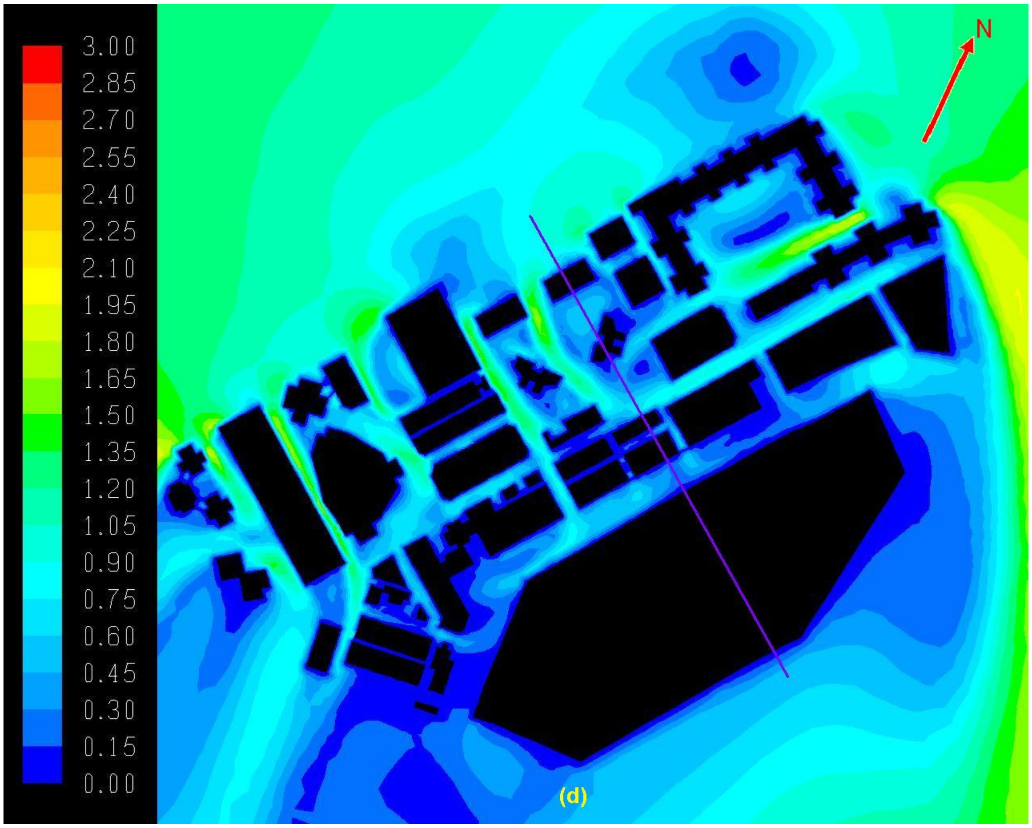
4.3 Contour, Vector Plots of Wind Velocity and Wind Velocity Ratio

The contour and vector plot diagrams of the wind velocity at the 2m pedestrian level of the control case:

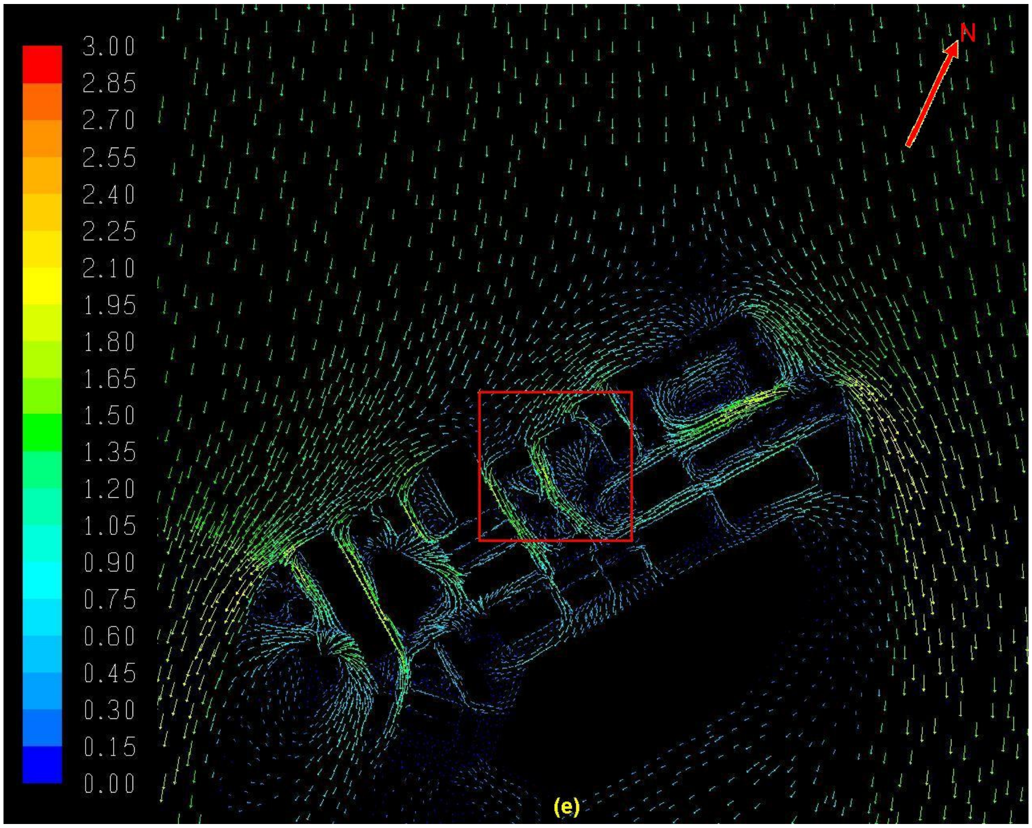


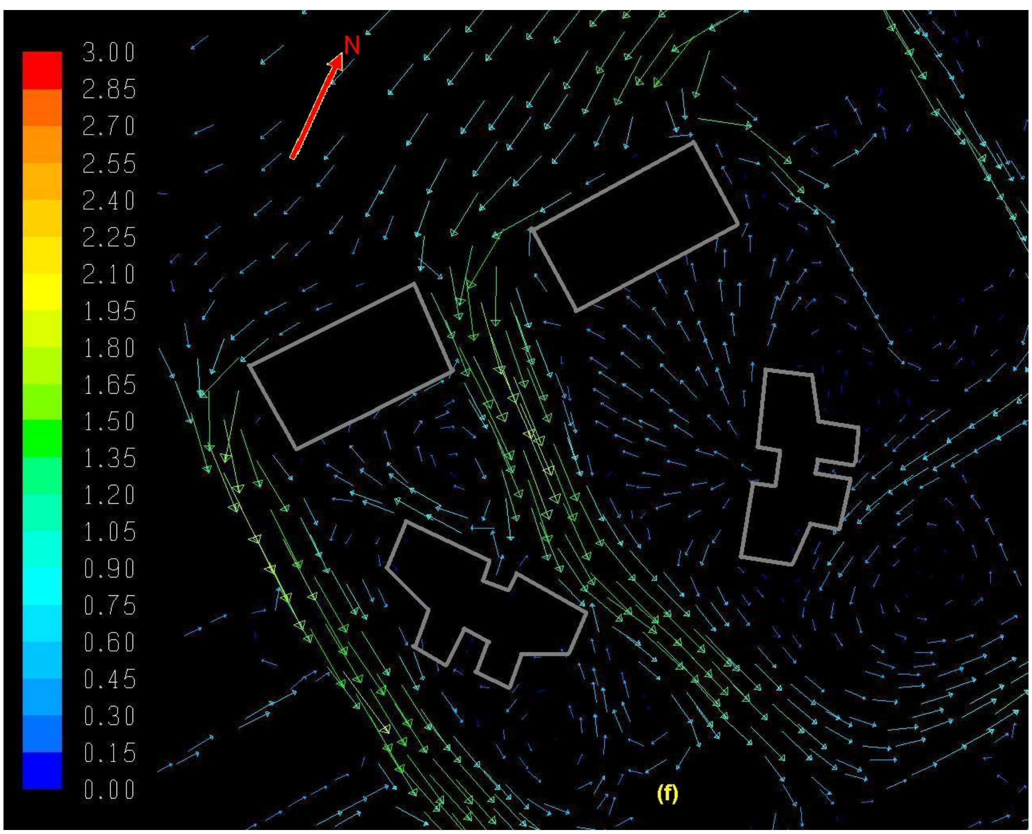

3.00
2.85
2.70
2.55
2.40
2.25
2.10
1.95
1.80
1.65
1.50
1.35
1.20
1.05
0.90
0.75
0.60
0.45
0.30
0.15
0.00
N
(b)

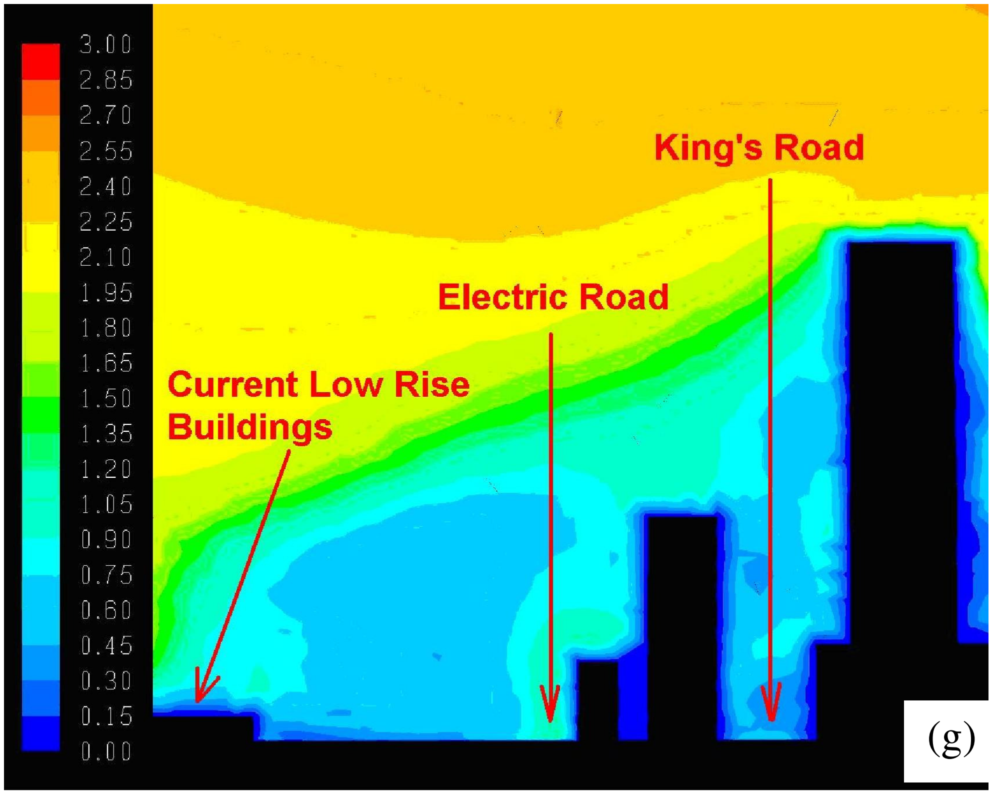

3.00
2.85
2.70
2.55
2.40
2.25
2.10
1.95
1.80
1.65
1.50
1.35
1.20
1.05
0.90
0.75
0.60
0.45
0.30
0.15
0.00
N
(c)

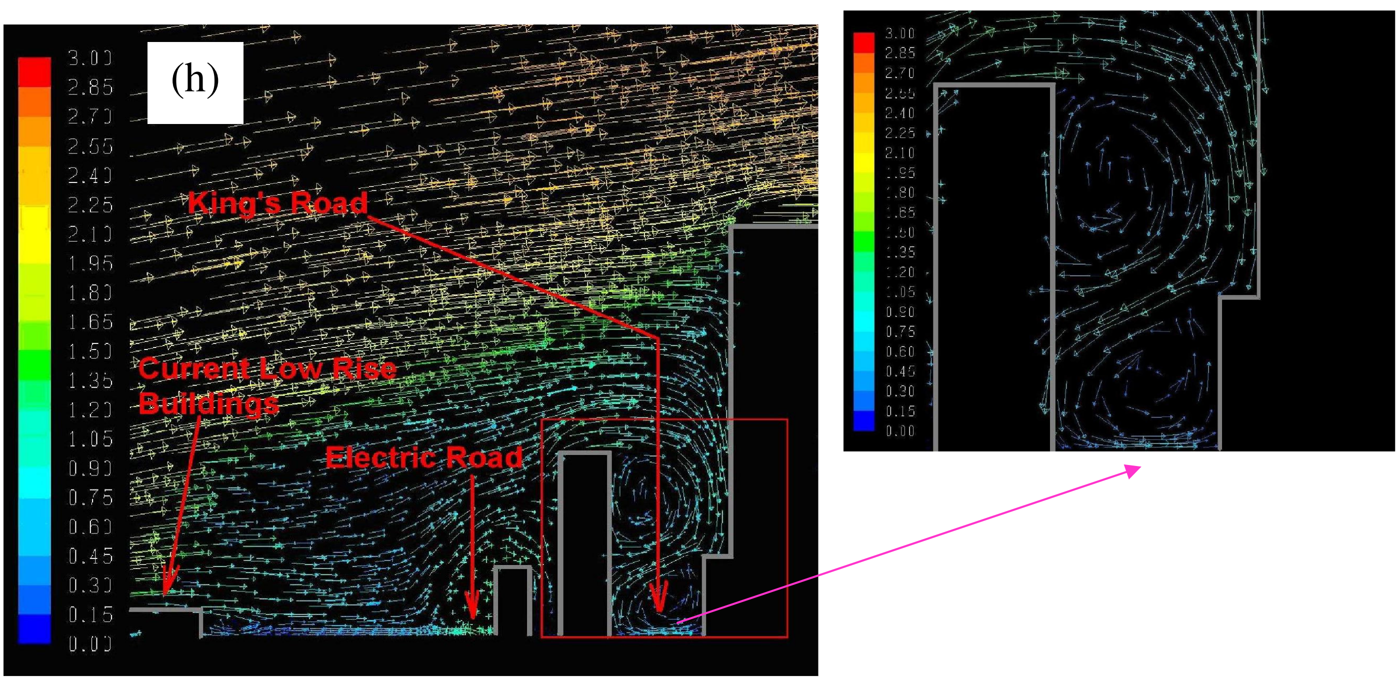


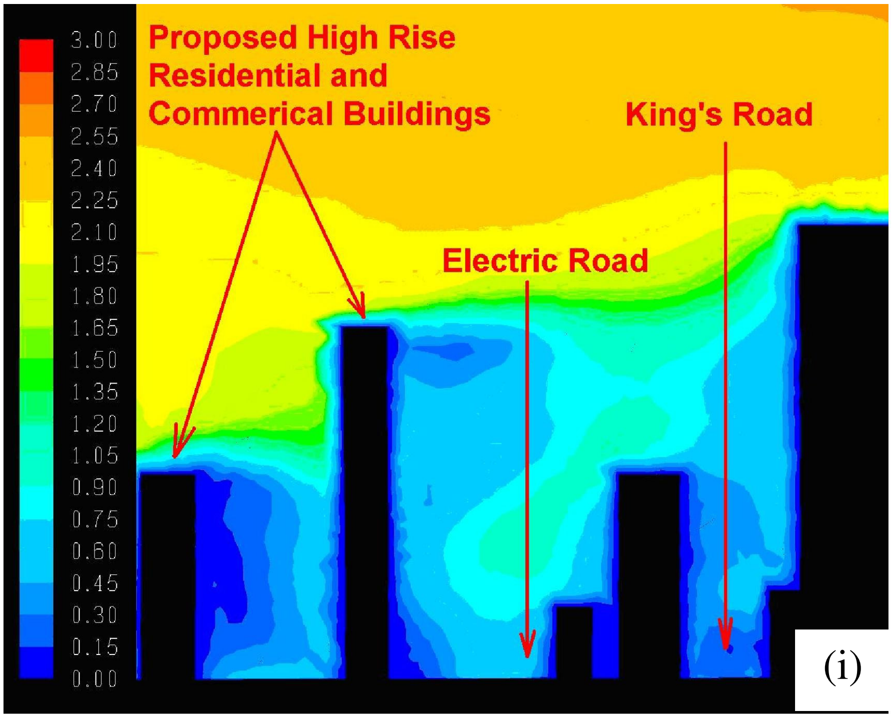
3.00
2.85
2.70
2.55
2.40
2.25
2.10
1.95
1.80
1.65
1.50
1.35
1.20
1.05
0.90
0.75
0.60
0.45
0.30
0.15
0.00
N
(d)


3.00
2.85
2.70
2.55
2.40
2.25
2.10
1.95
1.80
1.65
1.50
1.35
1.20
1.05
0.90
0.75
0.60
0.45
0.30
0.15
0.00
N
(e)


3.00
2.85
2.70
2.55
2.40
2.25
2.10
1.95
1.80
1.65
1.50
1.35
1.20
1.05
0.90
0.75
0.60
0.45
0.30
0.15
0.00
N
(f)


3.00
2.85
2.70
2.55
2.40
2.25
2.10
1.95
1.80
1.65
1.50
1.35
1.20
1.05
0.90
0.75
0.60
0.45
0.30
0.15
0.00
King's Road
Electric Road
Current Low Rise Buildings
(g)


(h)
King's Road
Current Low Rise Buildings
Electric Road



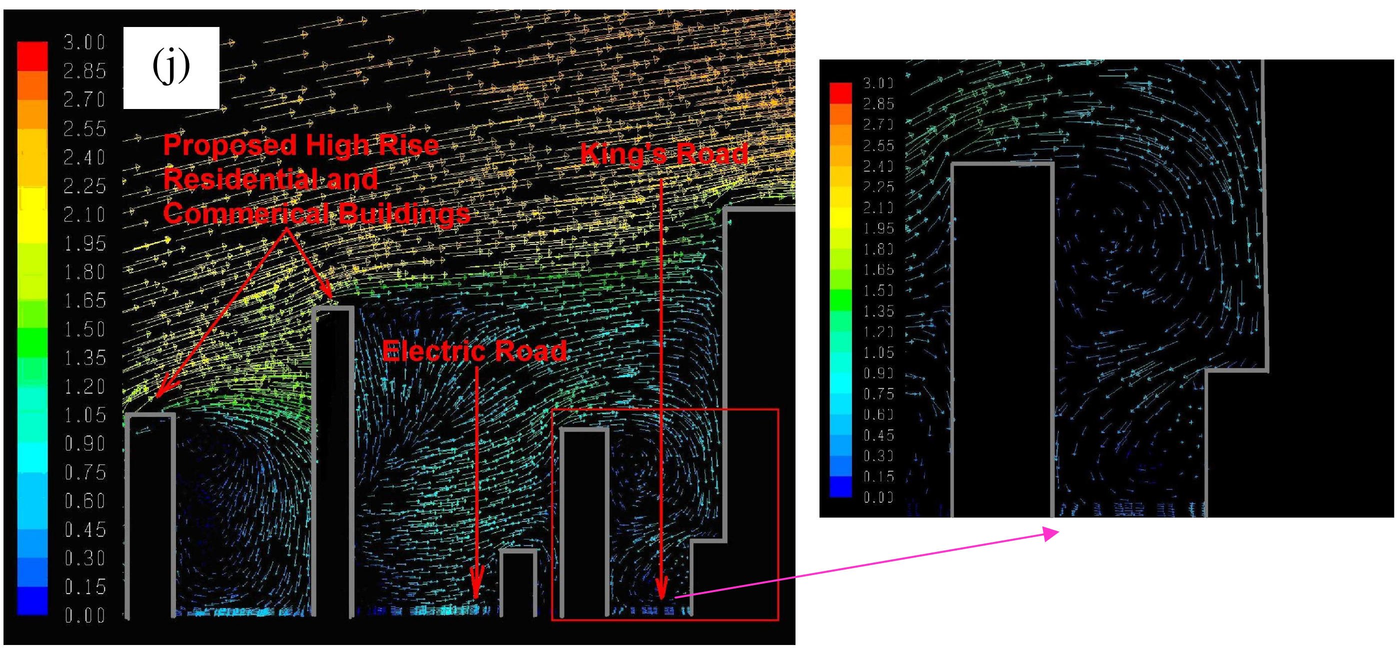


Figure 13: (a) Contour plot of 2m wind velocity magnitude of the control case. **(b)** Vector plot of 2m wind velocity magnitude of the control case **(c)** Zoomed in vector plot of the area bounded in red in (b) **(d)** Contour plot of 2m wind velocity magnitude of the proposed case. **(e)** Vector plot of 2m wind velocity magnitude of the proposed case **(f)** Zoomed in vector plot of the area bounded in red in (e). **(g)** Contour plot of side view of the control case cut along purple line in (a). (**h**) Corresponding vector plot of (e). **(i)** Contour plot of side view of the proposed case cut along purple line in (d). **(j)** Corresponding vector plot of (g).

The following map shows the region where the average spatial wind velocity and the VR are carried out:

Figure 14: Places where data are obtained and calculated

The general urban area is the region bounded by the brown line, the portion of the Electric Road and the King's Road used for calculation of VR and spatial wind velocities are bounded by the purple and green line respectively and the target site is bounded by the red line as shown in **Figure 14**.

The following are the tables showing the volume average of wind velocity and wind velocity ratio of 2m pedestrian level and 20m level of different major areas near the target site at the Oil street urban site of the proposed and control case:

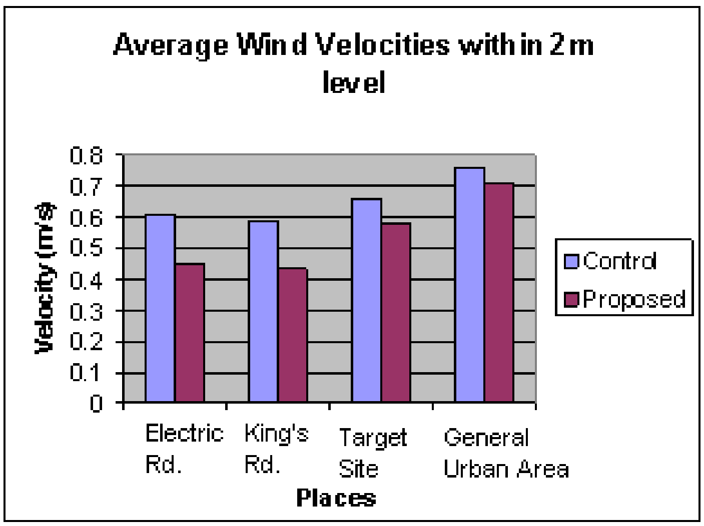
Places	Average spatial wind velocity within 2m level (m/s)	Average spatial wind velocity within 20m level (m/s)	Wind Velocity Ratio (VR) within 2m level	Wind Velocity Ratio (VR) within 20m level
Electric Road	0.45	0.45	0.14	0.14
King's Road	0.43	0.45	0.14	0.14
Target Site	0.58	0.61	0.19	0.20
General Urban Area	0.71	0.71	0.23	0.23

Table 2: Data and result of the proposed case

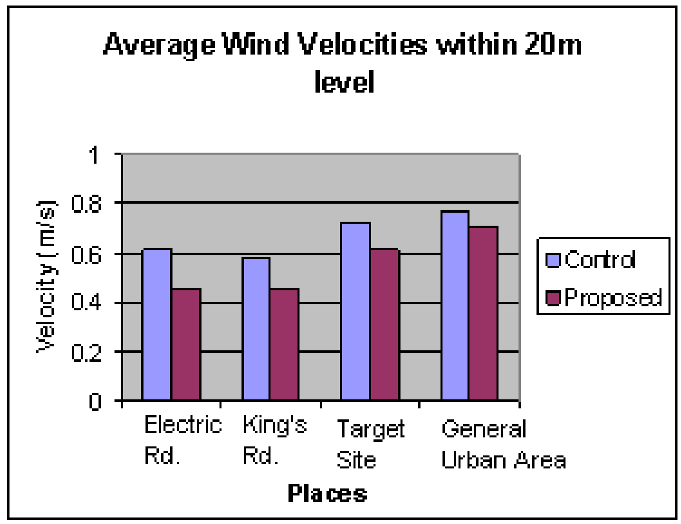
Places	Average spatial wind velocity within 2m level (m/s)	Average spatial wind velocity within 20m level (m/s)	Wind Velocity Ratio (VR) within 2m level	Wind Velocity Ratio (VR) within 20m level
Electric Road	0.61	0.61	0.20	0.20
King's Road	0.59	0.58	0.19	0.19
Target Site	0.66	0.72	0.21	0.23
General Urban Area	0.76	0.77	0.25	0.25

Table 3: Data and result of the control case

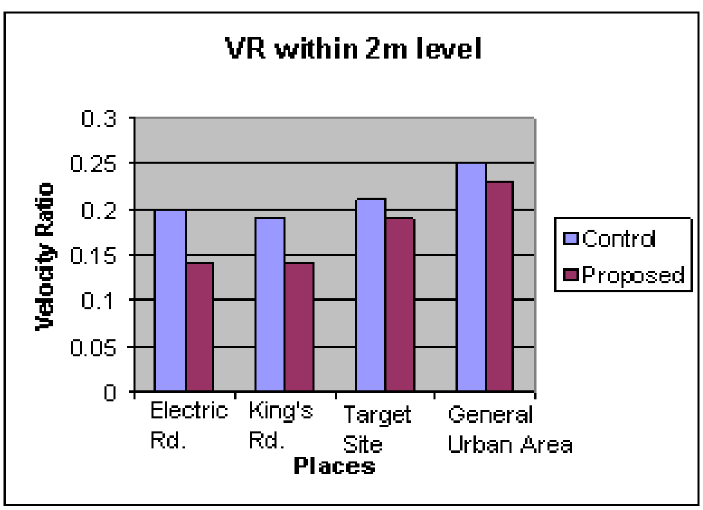
The following are some histograms showing and comparing the results in tables above:



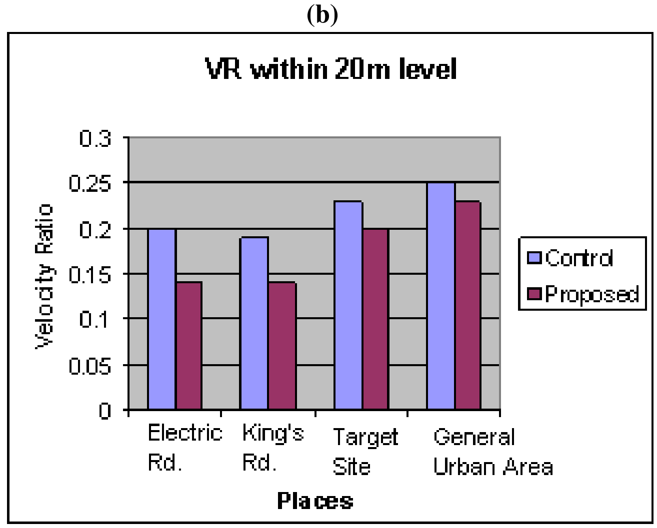
(a)



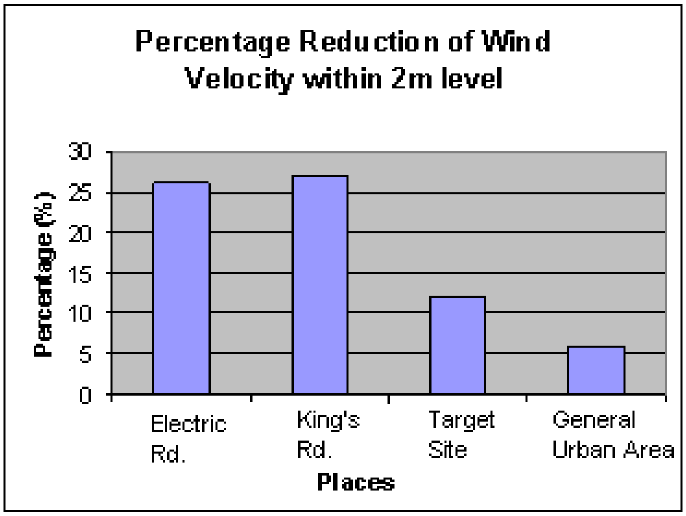
(b)



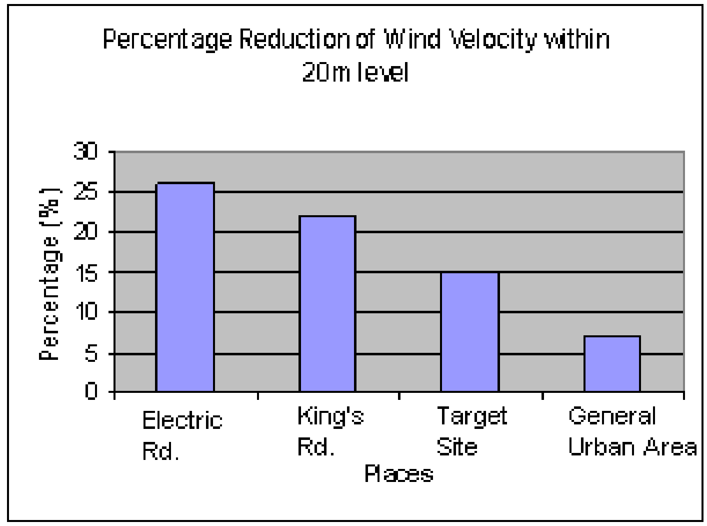
(c)



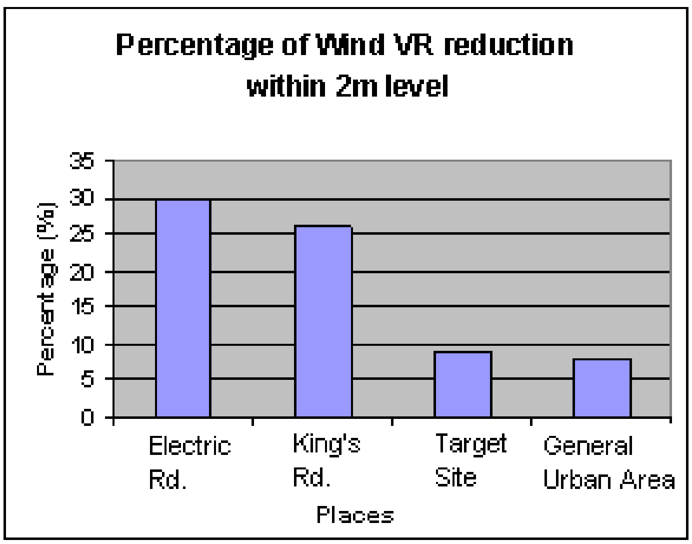
(d)



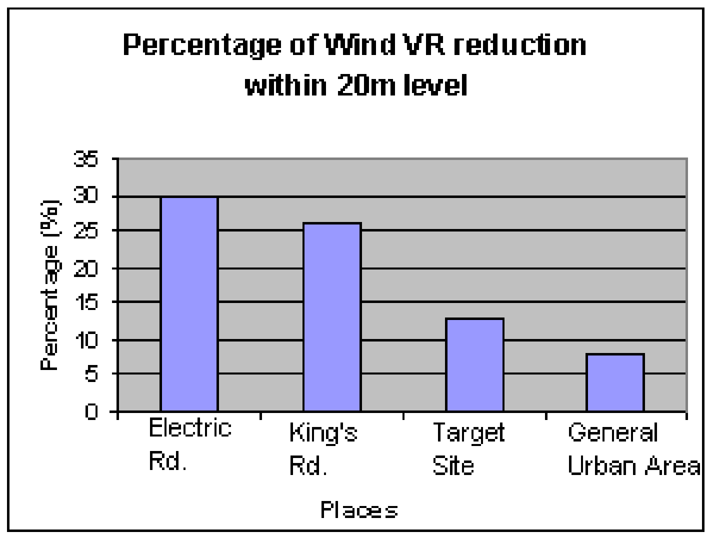
(e)



(f)



(g)



(h)

Figure 15: Histograms of **(a)** average wind velocity within 2m **(b)** average wind velocity within 20m **(c)** VR within 2m **(d)** VR within 20m **(e)** percentage reduction of wind velocity within 2m **(f)** percentage reduction of wind velocity within 20m **(g)** percentage of wind VR reduction within 2m **(h)** percentage of wind VR reduction within 20m

4.4 Results, Conclusion and discussion

In the Air Ventilation Assessment report of the Oil Street urban site by the Hong Kong planning department, wind tunnel approach is used as a study methodology and compared the wind velocity ratio between three design schemes. However, the planning department report does not take into account how much wind velocity reduction would occur after the proposed buildings are built compared to the current situation. In this report, by using CFD approach, a simulation model of the best scheme stated in the planning department report is built and percentage reduction in wind velocities would be examined and discussed.

From the contour and vector plots shown above, we can get a picture that the average wind velocities would decrease after the proposed buildings are developed as we can see there are more dark blue regions which indicates low wind velocities region in the proposed case model compared to the control case model. In addition, we can also see this clearly by the histograms shown above. In order to be more rigorous and quantitative, we calculate the average spatial velocity of the two major streets: The Electric Road and the King's Road. We see that for the current situation the average spatial wind velocity at 2m pedestrian level of Electric Road is 0.61m/s but after the development project, the average wind velocity expect to become around 0.45m/s. There is a decrease of 26 percent in the average wind velocity which is quite significant. For the King's Road, the decrease is about 27 percent which also shows a large change in wind environment. Therefore, we can conclude from the result, after the development project, the impact on the wind environment of the major two roads is quite large. In addition, there is also a reduction of about 12 percent of wind velocities near the surroundings of the target area even though the design of the proposed new buildings creates two major wind corridors intentionally to improve the wind environment. Finally, the average spatial wind velocity of the whole urban area is also computed. The average spatial wind velocity results a decrease of about 6 percent in the whole Oil Street urban area after those new buildings are developed in the future and this provides us a macroscopic picture and prediction of the impact on the wind environment after this new development.

In addition, based on a Gaussian Plume Model, the pollutant concentration is inversely proportional to wind speed.

$$C(x,y,z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(\frac{-y^2}{2\sigma_y^2}\right)\left(\exp\left(\frac{-(z-h)^2}{2\sigma_z^2}\right) + \exp\left(\frac{-(z+h)^2}{2\sigma_z^2}\right)\right)$$

where

1. C is the concentration of the emission
2. Q is the quantity or mass of the emission per unit of time
3. u is the wind speed
4. h is the height of the source above ground level
5. σ_y and σ_z are the standard deviations of a statistically normal plume in the lateral and vertical dimensions, respectively

At the Electric Road, the wind reduction is about 26 percent; the pollutant concentration will go up by approximately 35 percent. At the King's Road, the reduction of wind velocity is around 27 percent and the pollutant concentration will increase by 36 percent. At the target area and the general urban area, the pollutant concentration would raise by approximately 13 percent and 6 percent respectively. Therefore, we can conclude that the impact of the wind environment after the building development is quite significant.

5. References

Planning Department, Air Ventilation Assessment report, Oil Street Site, Executive Summary, August 2007.

Ng, E., Tam I., Ng A., Givoni B., Katzschner L., Kwok K., Murakami S., Wong N. H., Wong K. S., Cheng V., Davis A., Tsou J. Y., Chow B., Final Report – Feasibility Study for Establishment of Air Ventilation Assessment System, Technical Report for Planning Department HKSAR, June 2004, (325 pages).

Yim, S.H.L., J.C.H. Fung, A.K.H. Lau, and S.C. Kot (2007), Developing a high-resolution wind map for a complex terrain with a coupled MM5/CALMET system, J. Geophys. Res. VOL. 112, D05106, doi: 10.1029/2006JD007752, 2007

Yim S. H., Fung J. C., Lau A. K. (2009), Mesoscale Simulation of Year-to-Year Variation of Wind Power Potential over Southern China. *Energies*. 2009; 2(2):340-361

Gambit and Fluent 6.3 software manual

Acknowledgements

This work was supported by the Mathematics Department and Environmental Central Facility. And thanks must be given to my project supervisor Professor Jimmy C.H. FUNG and Dr. Steve H.L. YIM for their guidance and support.