ARCHITECTURE DEPARTMENT **CHINESE UNIVERSITY OF HONG KONG**

MASTER OF ARCHITECTURE PROGRAMME 2002-2003 DESIGN REPORT

WIND RESPONSIVE DEVELOPMENT IN DENSE URBAN ENVIRONMENT

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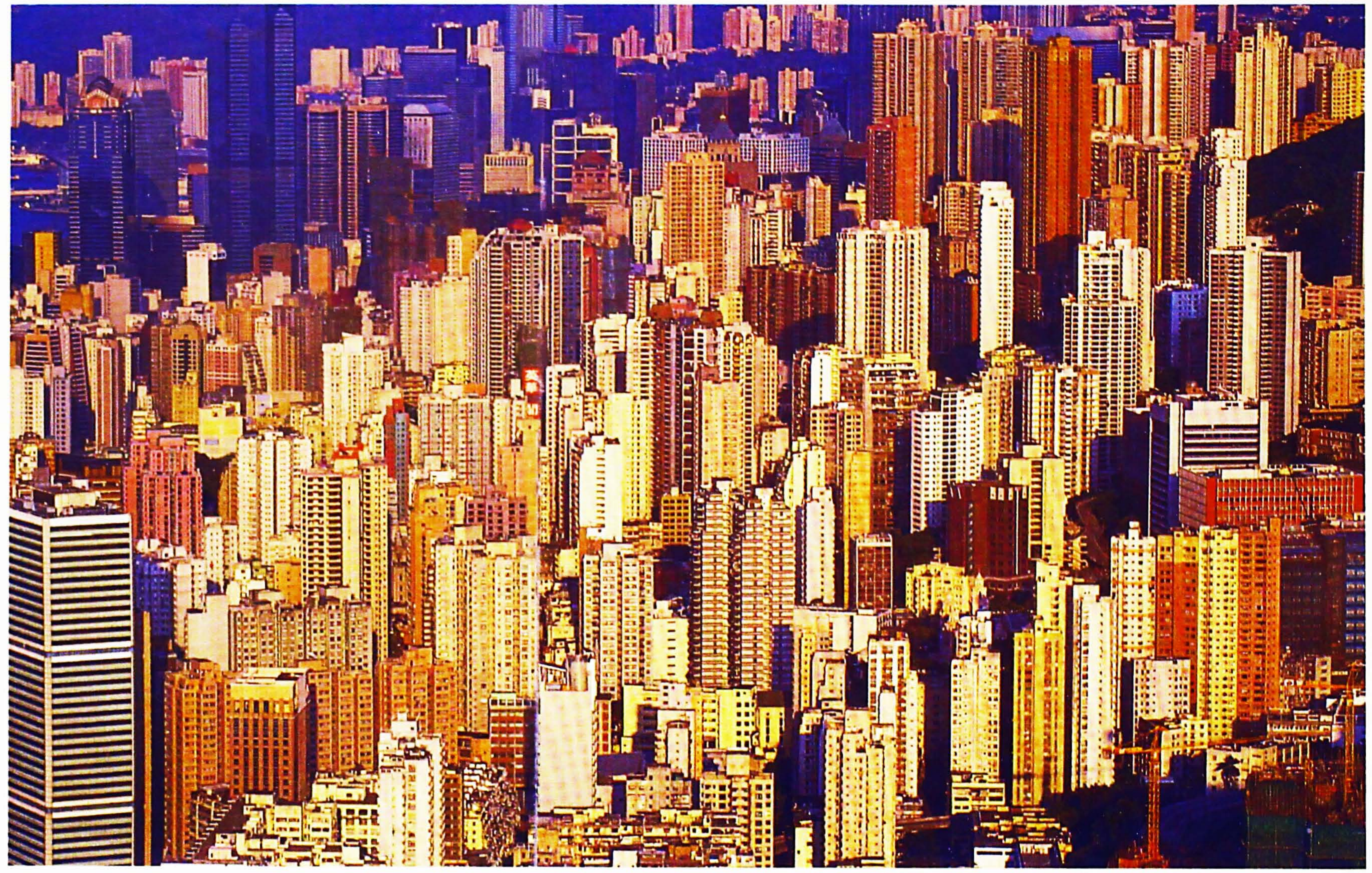
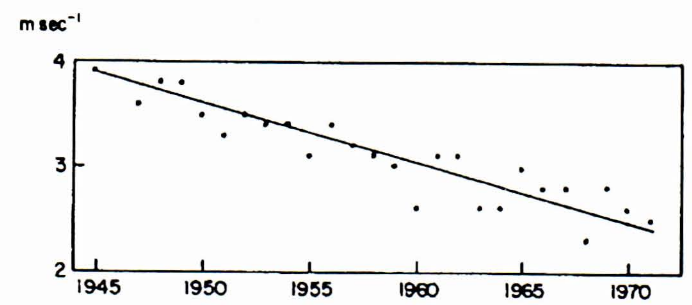
CONTENTS

The livability and comfort of a built environment depend heavily on the surrounding climate, but one of the climatic issues climatic issues which having tremendous impact to city life but at the same time being interfered seriously by the dense urban environment is the wind condition. The undesirable modification is getting much serious as the city is getting larger and denser. Wind speed declination in many highly density cities have been solidly observed, especially for those having significance growth in building development. In general, the mean wind speed in city will be decreased as buildings within are getting taller and being packed denser, which means the aerodynamic roughness of the city increased. Wind speed will be dragged down more and more seriously as it is getting closer and closer to the ground. The aerodynamic roughness caused by the city is a factor hardly to be avoided as the existence of city is importance to human civilization, what we should do is to understand the buildings impacts to the micro wind environment in order to have better management of the wind resource. Urban environment is not necessary to be badly ventilated although lower wind speed should be expected when compared to countryside or suburban. It depends on how effective the urban topology, buildings geometry and group formation are designed to benefit wind flow within city.

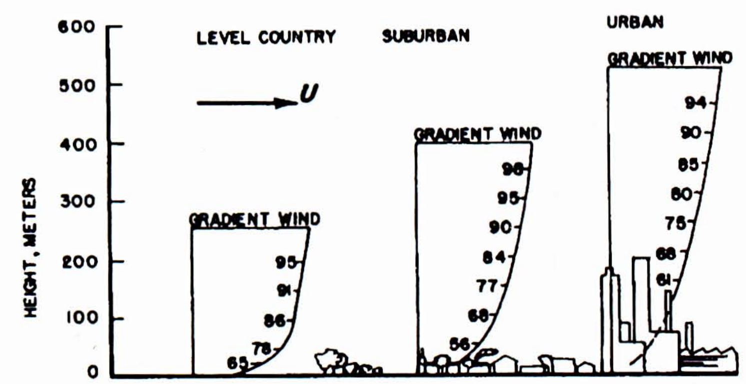


Wind Speed Declines as City Growth



Time series of mean annual wind speed in the growing city of Gansevitchi, U. S. S. R. (based on data by Rubinshtein, 1979).

Vertical Wind Speeds over Terrain of Different Roughness



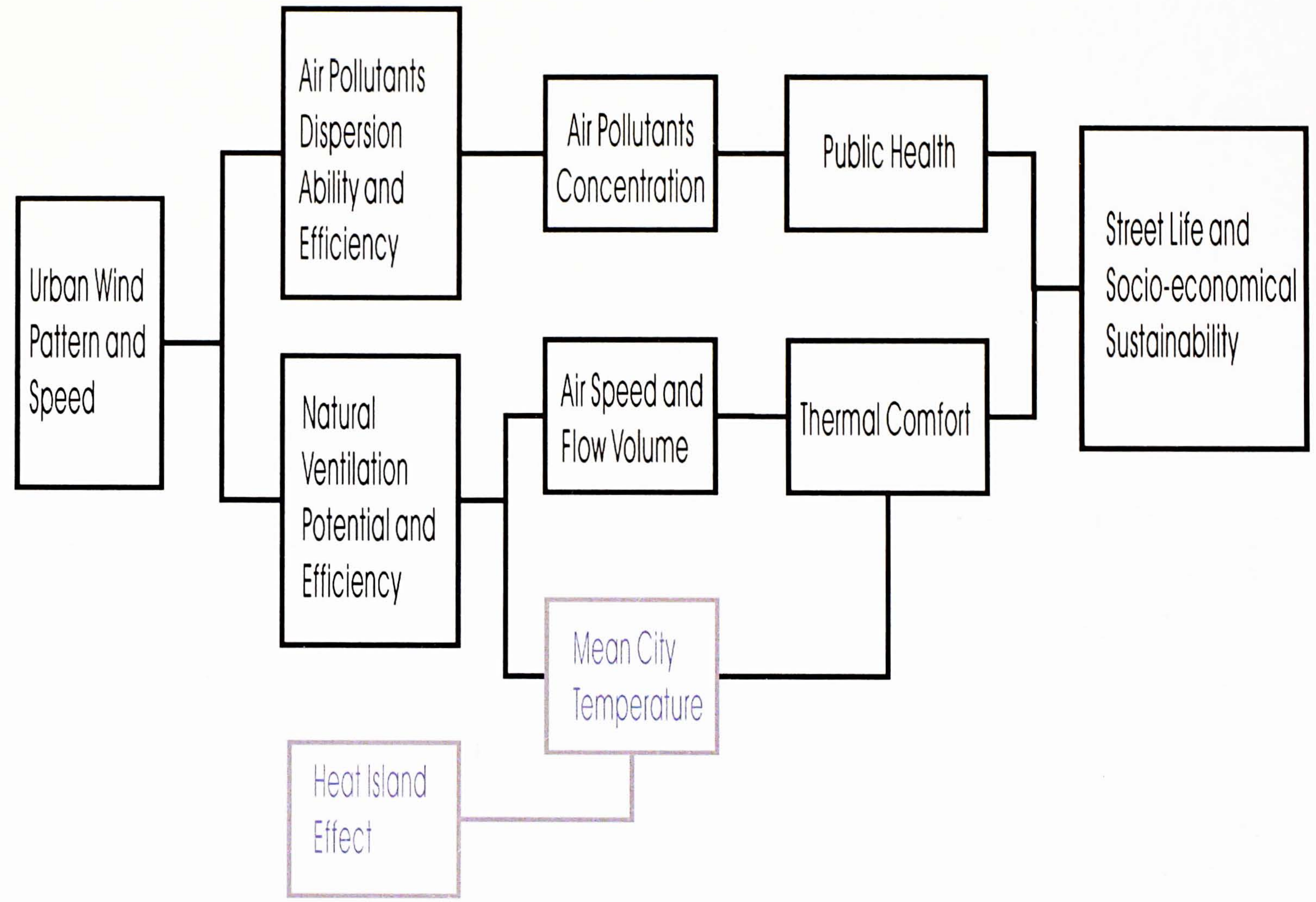
Vertical wind speeds, in percent of the gradient wind at various heights over terrain of different roughness (after Davenport, 1965).

Source: The Urban Climate *by H.E. Landsberg*

The high density urban environment of Hong Kong is experiencing difficulty in natural ventilation as the urban plan and buildings configuration are simply not responsive for the wind. Take my experimental site - Causeway as an example, as proved by wind measurement data collected from the site as well as by computational fluid dynamic simulation done on the existing site model, wind within the urban canyons especially at street level is very minimal in average around 0.5 m/s. When the existing wind condition is view beside other factual data such as the air pollution condition in the site, it created a picture which we should have great concern.

Poorly ventilated street level space lost its development potential and attraction to people as air quality and thermal comfort are all closely bonded with the wind condition. The management of the urban wind should be highlighted in future city development.

Vision and Logic



PROJECT OBJECTIVES

The general urban ventilation problem cannot be solved by one or two well designed buildings but by means of a combined effort make between all city elements. This thesis project is to study the interaction between urban wind and built environment, improve natural ventilation and pollutants dispersion in the urban street canyon by the manipulation of urban wind by means of urban planning and architectural design. The objectives of the project included **figuring out the key wind modifying factors** which are applicable in urban planning and design, develop air flow strategy for **improving natural ventilation and pollutants dispersion efficiency at street level**, at the same time to explore possible **design potentials and development opportunity** together with the proposed air flow strategy.

For the design project, I would like to work out an urban ventilation strategy for a redevelopment project in Causeway Bay to apply and demonstrate the major finding of the **key urban wind modifiying factors** from the research to manipulate and utilize the very limited wind resource within the dense urban environment. The design is going to generate a better wind environment in the development especially at ground and lower leveled outdoor space.

Background Research on Wind Phenomenons

The research begins with a study of available literature to build up knowledge on URBAN WIND PHENOMENONS. Study will be focused in urban wind field with particular interest in the air flow pattern in urban canopy sub-layer or called obstructed sub-layer. As the canopy sub-layer has its own flow field driven and determined by the interaction of the flow field above (the free surface layer) and the uniqueness of local effects as topography, urban typology, geometry, configurations, density and dimensions, the interactions between them will be examined. Desirable wind condition on street level will also be figured out to satisfy both comfort and pollutants removal purpose.

Case Study

Causeway bay, as a densely developed commercial and residential area with extremely concentrated human activities; it contained some of the most typical urban problems with no exception in including the ventilation and pollution problems. As it is the record holder of the highest roadside air pollution index (Yee Wo Street station) among all roadside monitor stations, the cause of the problem and its relation with the local urban wind field will be investigated. The formation of the urban plan and topology that affecting its own urban wind field nowadays in Causeway Bay will be analyzed. CFD simulation of the urban wind condition in Causeway Bay centered at Yee Wo Street will be conducted to

Methodology

The approach of the project can be concluded in five phases of work which are: Background Study > Case Study > Analysis > Generalization > Application investigate the urban wind field pattern existed in the current urban configuration and its effect to the local climate.

Analysis

Possible causes behind of the current urban ventilation problem will be analyzed. Hypothetical generic wind modifying factors will be developed with reference and support by development urban wind phenomenon and fluid dynamic theories. The hypothesis will be tested and refined through a serious of computational fluid dynamic simulation and data analysis.

Generalization

The hypothetical wind modifying factors will be generalized in a form of comprehensive recommendation which can be understand and used in most urban development project and adoptable by the Architectural / Planning discipline.

Application

The applicability and practically of the key urban wind modifiying factors will be tested and demonstrated in an urban redevelopment project.The design is aimed to provide a better wind environment in the development especially at ground and lower leveled outdoor space by manipulating and utilizing the limited wind resource within the dense urban environment.

Understanding Urban Wind

Understand to the nature and characteristic of urban wind is essential in conducting the proposed research. Factors that having significant influences on wind speed and wind flow pattern over or below the urban canopy will be summarized and discussed. In order to figure out the parameter for assessing the desirableness of the ventilation effect, the effect of air speed on thermal comfort and urban temperature will be discussed too. Effect of wind speed and flow pattern on street-level偲 pollutants dispersion will also be discussed.

Influential Extend of Earth Surface to Atmosphere

Influence of the surface roughness of the earth is limited to the troposphere, the lowest 10km layer of the atmosphere of our planet Earth. But in the scale time of one day, this influence is restricted to smaller zone, the planetary or the *atmospheric boundary layer.*

Wind Layers Over Cities

When the air flows from the rural to the urban environment, it must adjust to the new boundary conditions defined by the cities. This results to the development of a two layers vertical structure over a city, the **urban canopy** which is extended from the ground surface up to the buildings height and the **urban boundary layer** which is extended above the roof tops.

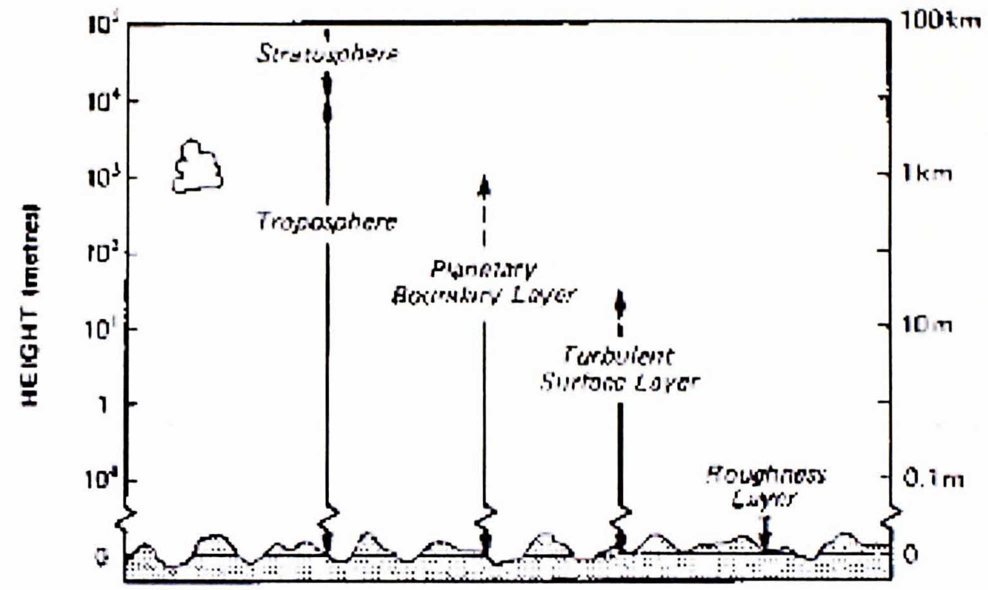


Figure 1. Vertical structure of the atmosphere (Oke,1999)

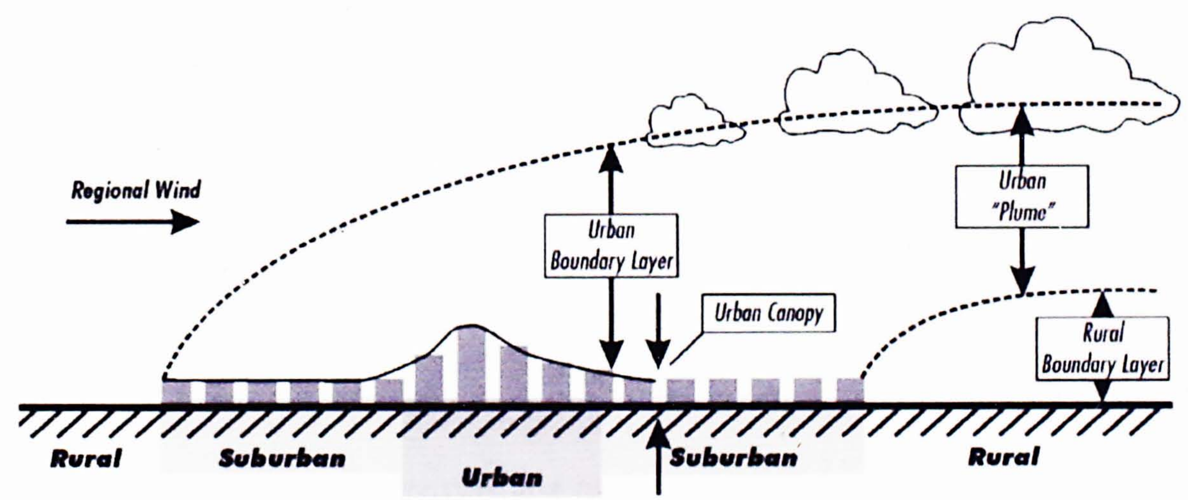


Figure 2. Schematic representation of the urban atmosphere illustrating a two-layer classification of urban modification (Oke)

Surface Drag to Wind Field in Boundary Layer
The speed of the free wind decreases progressively downward as a result of friction with the earth surface. Several empirical formulae, of different forms, have been developed to describe the variation of the mean wind speed with height (Munn 1970).

In modeling the urban effect on the wind speed, use is being made of model describing the vertical profile of the wind, from the gradient wind level down to the ground. The urban effect is expressed by modifications of the parameters of the models. A parameter which is greatly affected by the urban structure is the Aerodynamic roughness.

Chandler (1976) has presented a graphical illustration of the changes in the vertical wind velocity profile over urban, suburban and open rural areas.

Givoni pointed out the limitation of the logarithmic mathematical wind models for estimating the urban wind conditions near the ground because of the high turbulent nature of the urban wind at that layer in reality

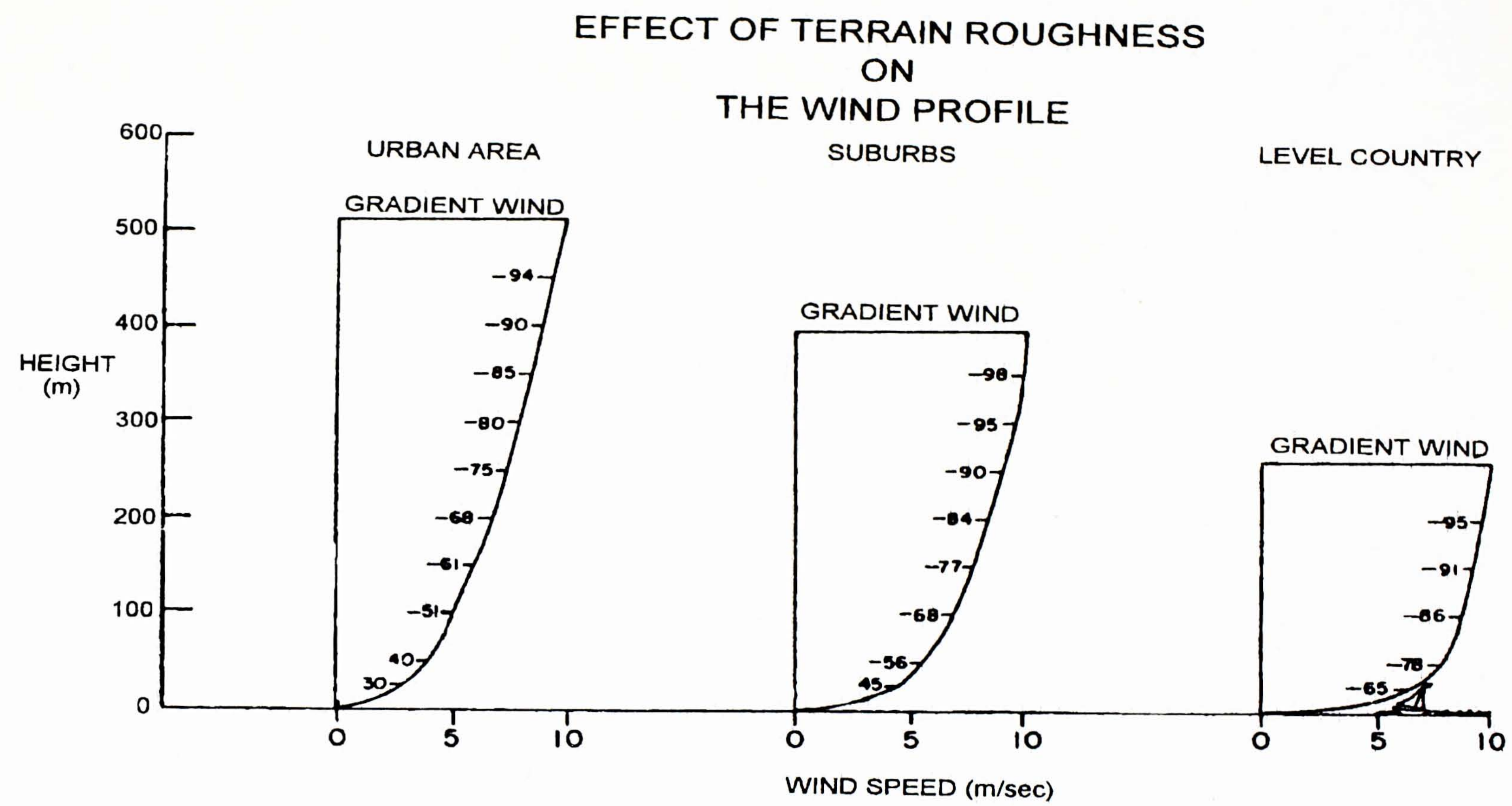


Figure 3b. Diagrammatic wind speed profiles above different terrain roughness; percentage of the gradient wind speed. (Chandler 1976)

URBAN WIND PATTERN - MICROSCALE WINDS IN URBAN ENVIRONMENT

The urban canopy has it own flow field driven and determined by interaction of the flow field above and the uniqueness of local effects as topography, building geometry and dimensions, streets, traffic and other local features.

Air flow around isolated building

The flow pattern around buildings is complex and depends on the geometry of the building. A simplification of the airflow pattern given by a barrier placed normal to the flow is shown in Figure 4a.

Figure 4b is a general classification of the flow zones. In the displacement zone the flow is displaced up and over the barrier. After the barrier the flow separates in a more turbulent zone, the wake zone. Behind the barrier, the cavity zone is characterized by semi-stationary lee eddy vortexes.

A wind tunnel study showed the pattern of airflow around an isolated flat-roof building is showed in Figure 5. Upon encountering the impermeable building the air is either deflected over the top, or down the front (Figure 5a) or around the sides (figure 5c). The air pushing against the building gives relatively high pressures over much of the surface of the windward wall. Maximum pressure occurs near the upper middle part of the wall where the wind is actually brought to a standstill, and pressure

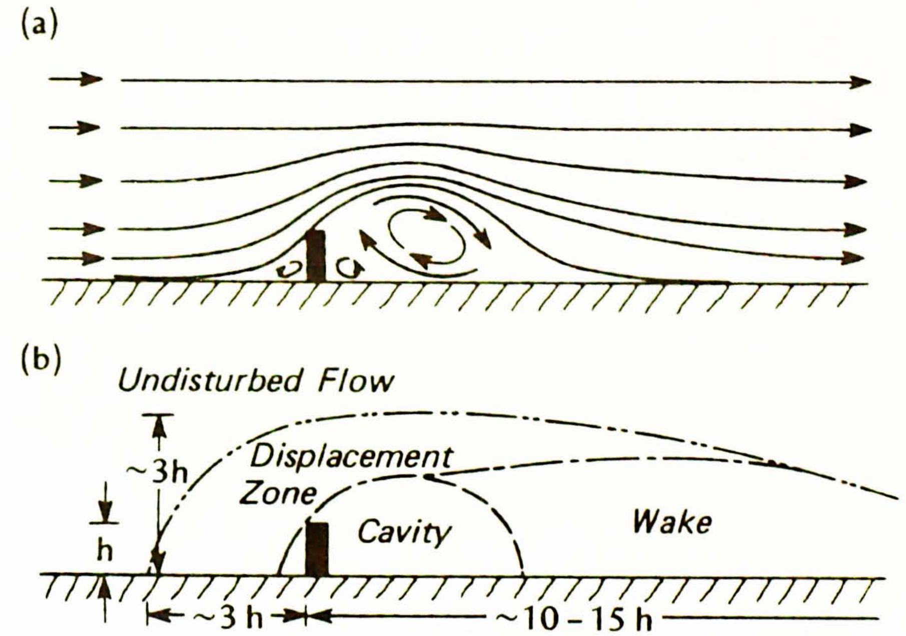


Figure 4. (a) Streamline and (b) flow zone associated with typical pattern of airflow around a solid barrier of height h. (Oke 1999)

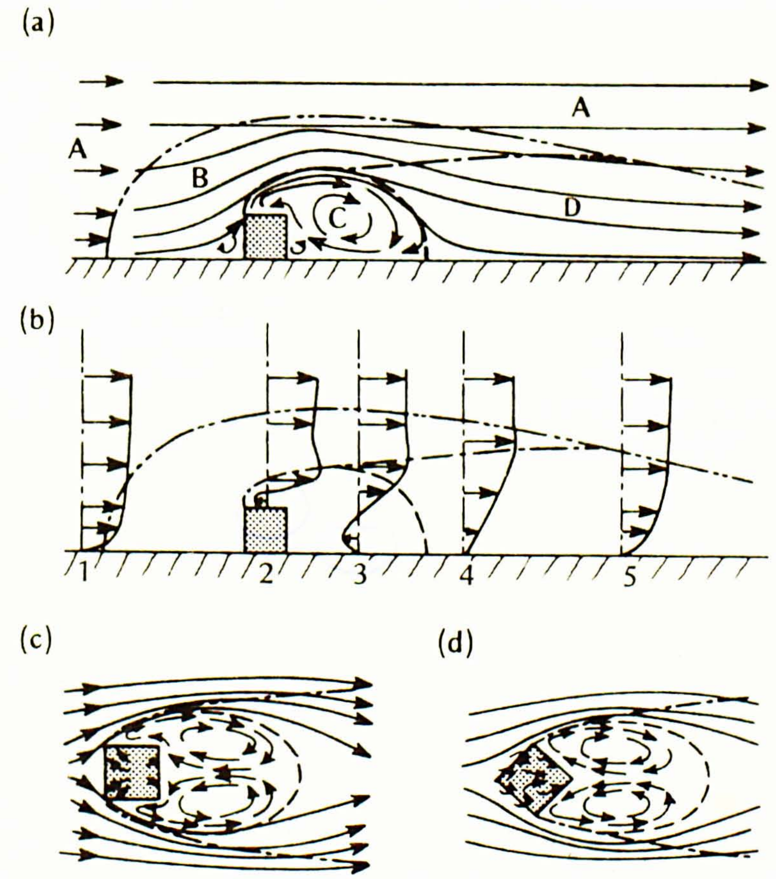


Figure 5. Flow pattern around an isolated flat-roof building. Side view of (a) streamlines and flow zones, and (b) velocity profiles and flow zones with the building oriented normal to the flow. Plan view of streamlines around building orientated (c) normal, (d) diagonally to the flow. (Oke, modified after Halitsky) (Notice that the flow zone indicated is this figure is the same as for a case of a barrier (Figure 4) : A-undisturbed Flow; B-displacement zone; C-cavity zone; D-wake zone.)

decreases outwards from this stagnation point (Figure 5b). Near the outside edges of the windward face the accelerating flow actually produces areas where the pressure is below that of the undisturbed atmosphere (i.e. suction). If the building has sharp corners the flow accelerating over the top and around the sides becomes separated from the surface. Therefore the sides, roof and leeward wall experience suction. Since air moves from high to low pressure, these areas are characterized by reverse flows (i.e. in the opposite direction to the main stream). This is responsible for the lee eddy circulation in zone C (figure 5a) which extends up into the strong suction zone above the roof. In plan view (Figure 5c) the cavity zone is characterized by a double eddy circulation at ground-level which incorporates the side wall suction areas into a horseshoe-shaped pattern.

The wind velocity profiles associated with this flow pattern are shown in Figure 5b. In the undisturbed upwind flow (profile 1) the standard logarithmic shape is evident. Immediately over the building (profile 2) the profile is sharply distorted. In the displacement layer above the wake boundary there is a pronounced jet of high velocity air as the streamlines converge. Below this the velocity decreases very sharply, and in the lowest layers the roof return flow is seen. Leeward of the building (profile 3), the jet is less pronounced as the streamlines begin to diverge, and the cavity zone lee eddy give a return flow near the ground. Averaged over the depth of the cavity velocities are obviously less than in the corresponding upwind layer, but it should be point out that these data hide the fact that it is more turbulent. At greater distances downwind (profiles 4 and 5) the shelter is progressively lost, and the jet merges with the flow which is readjusting towards its undisturbed form. Full adjustment has not been attained at profile 5 because the velocity gradient near the surface is not as steep as at profile 1. This indicates that residual turbulence in the wake is continuing to facilitate momentum transport at a rate greater than normal for the terrain.

Other building shapes and orientations produce variations upon this basic pattern. If the same cubic form is orientated diagonally with respect to the wind (Figure 5d) there are two windward and two leeward walls oriented obliquely to the flow. This tends to reduce the strength of the suction zoned especially on the roof but the double-eddy pattern still results in a horse shape in the downwind zone

Wind Perpendicular to Street Canyon

The airflow patterns in urban canyons are characterized by three main parameters, as shown in Figure 6 : *H* the mean height of the buildings in the canyon, *W* the canyon width and *L* the canyon length.

When the predominant direction of the air flow is approximately normal to the long axis of the street canyon, three type of air flow regime are observed as a function of the building (L/H) and canyon (H/W) geometries (Figure 7). When the buildings are widely spaced (H/W <0.4 for cubic and H/W <0.3 for row buildings), their flow fields do not interact (Figure 7a). At closer spacing (H/W >0.7 for cubic and H/W >0.65 for row buildings), the bolster and cavity eddies will be disturbed, the regime changes to one referred to as wake interference flow (Figure 7b). This is characterized by secondary flows in the canyon space, where the downward flow of the cavity eddy is reinforced by the deflection down the windward face of the next building downstream. At even greater H/W and density, a stable circulatory vortex is established in the canyon, because of the transfer of momentum across a shear layer of roof height, and a transition to a skimming flow regime occurs, in which the bulk of the flow does not enter the canyon (Figure 7c).

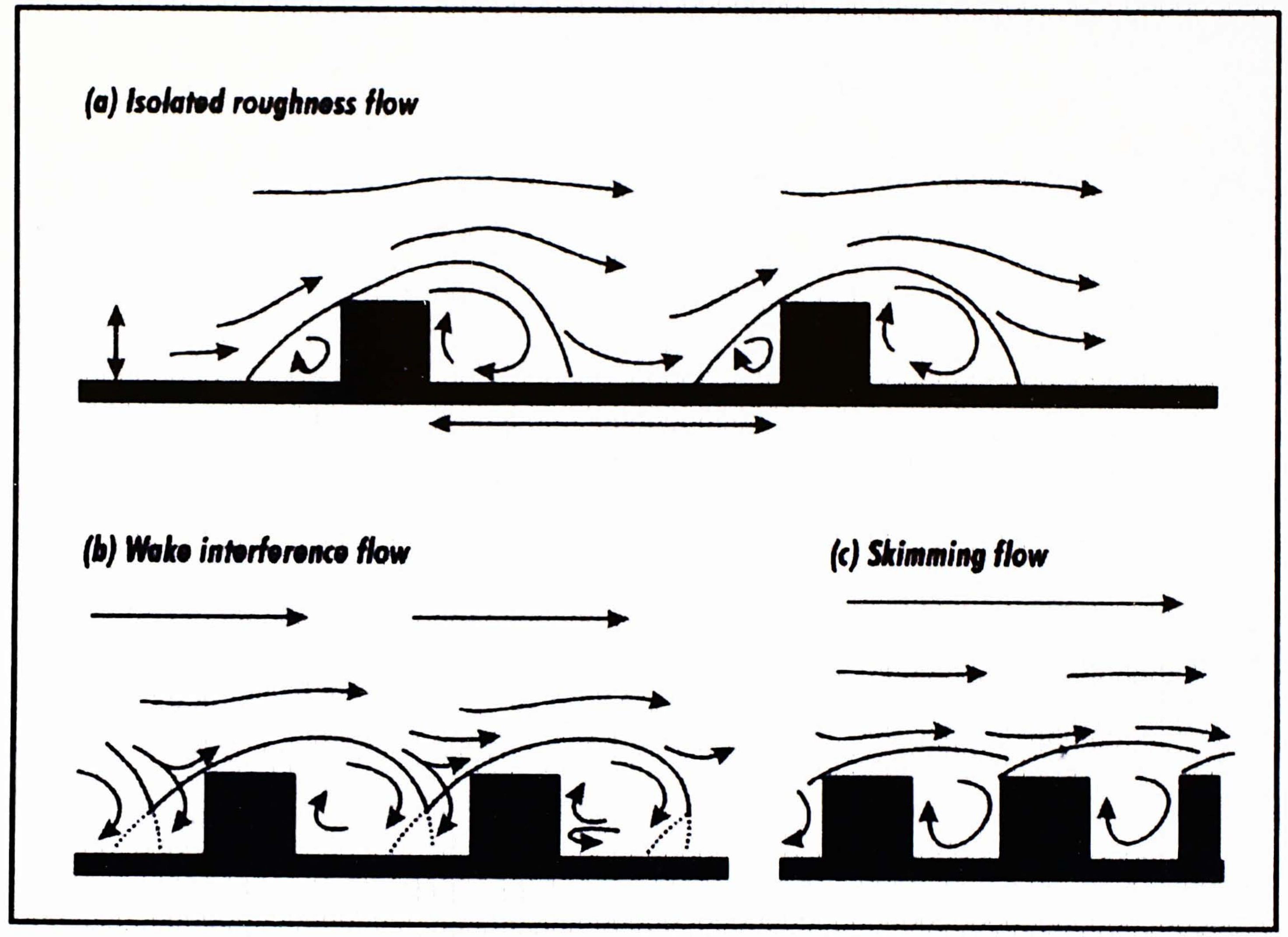


Figure 7. The flow regime associated with air flow over building arrays of increasing H/W (Oke)

The air flow in the canyon can be seen as a secondary circulation feature driven by the above-roof imposed flow. If the wind speed out of the canyon is below some threshold value (varies according to the H/W ratio), the coupling between the upper and secondary flow is lost (Nakamura and Oke). De Paul and Shieh reported that, for wind speeds higher than the threshold value, the speed of the vortex increases with the speed of the cross-canyon flow. Arnfield and Mills, who worked in an asymmetric canyon with a mean H/W value close to 1.52, found that there was no evidence of dependence between the vortex speed and the horizontal or total wind velocity in step-down and step-up configuration canyons.

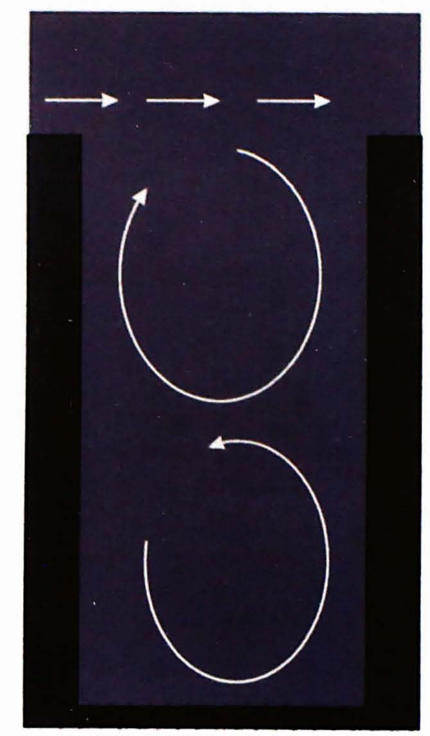


Figure 8. In deep canyons, wind tunnel research has shown that two vortices are developed, an upper one driven by the ambient air flow and a lower one driven in the opposite direction by the circulation higher up ((Chang, Wang & Lin)

Wind Along the Street Canyon

Parallel ambient flow generates a mean wind along the canyon axis (Nakamura & Oke), with possible uplift along the canyon walls as the air flow is retarded by friction at the building walls and the street surface(Nunez & Oke).

Wind at an Angle to the Street Canyon

When the flow above the roof is at some angle to the canyon axis, the vortex presents a Corkscrew motion with an elongation along the street (Figure 9). (Oke)

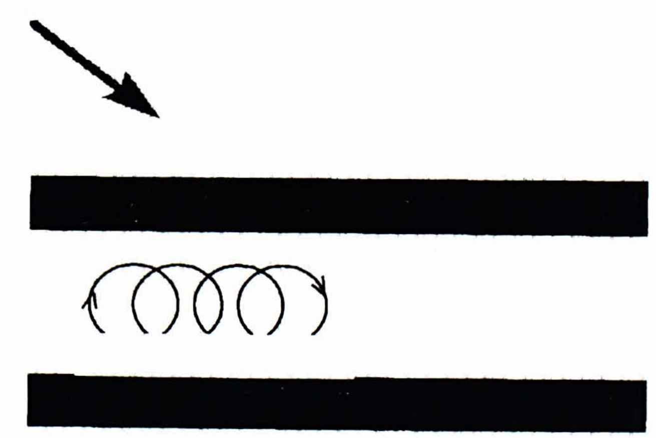


Figure 9 . Corkscrew type of flow

High Low Combined Building Group

In Figure 10a,wind tunnel model showed airflow pattern around tall building with lower building windup. Figure 10b show three main regions have increased wind speed at pedestrian level. The numbers in the wind speed likely to be encountered as a ratio of the velocity at the same height in the open. The increased winds and turbulence found in the stippled areas can create both hostile or pleasant environment depend on the overall climate. In cold climates thermal comfort is decreased because of the increased loss of body heat. The increase in chill-factor may make such areas unbearable in winter. Conversely in hot climates the increased ventilation may be favorable.

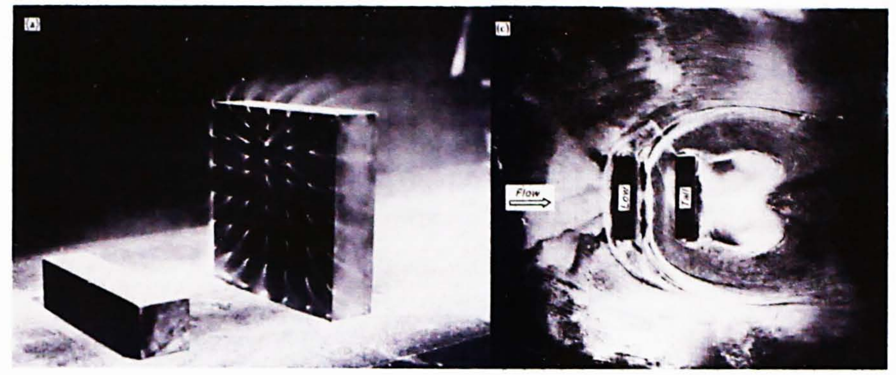


Figure 10a. Wind tunnel model showed airflow around tall building with lower building windup (Penwarden & Wise)

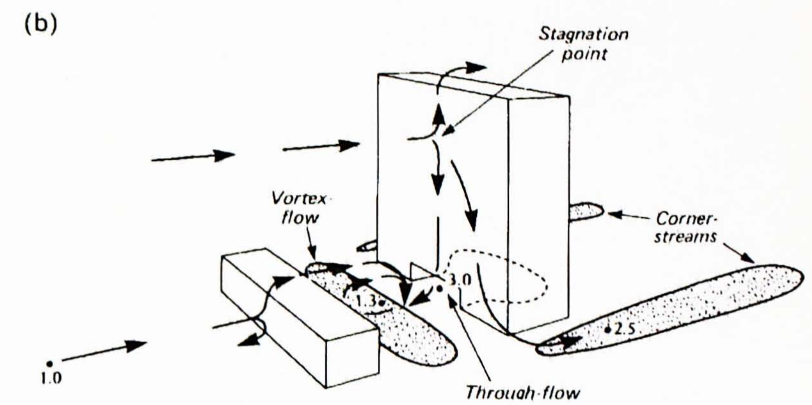


Figure 10b. Illustration of the three main regions of increased wind speed at pedestrian level (stippled)

The ground-level effect of the streaming down the windward face is believed in helping in diluting street level air pollutants by some researchers (Figure 11). However, it is also believed that it pose a potential threat to the safety of pedestrians, especially if they are old or infirm. Some partial solutions are illustrated in Figure 12 to minimize its effect. One approach is to minimize the ground-level effect of the streaming down the windward face. One approach is to place the main building slab on a podium of one or two storey in height (Figure 12a). High wind is then confined to the roof of the podium. This can be further helped if the tower is raised off the podium to provide an elevated through-flow (Figure 12b). In the same way a canopy and vent space provide some ground-level shelter (Figure 12c).

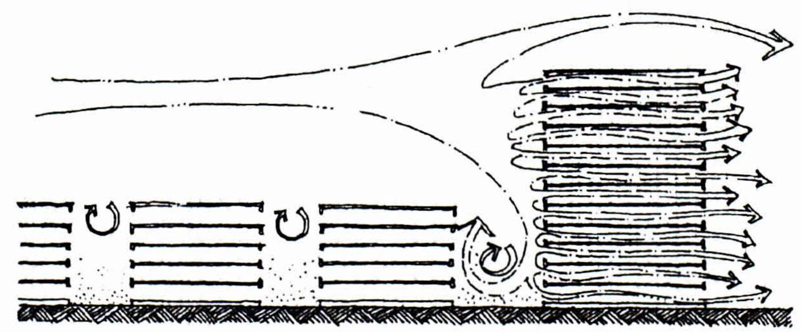


Figure 11. Wind speed near ground level in front of a high-rise building is increased, helping in diluting street level air pollutants. (Givoni)

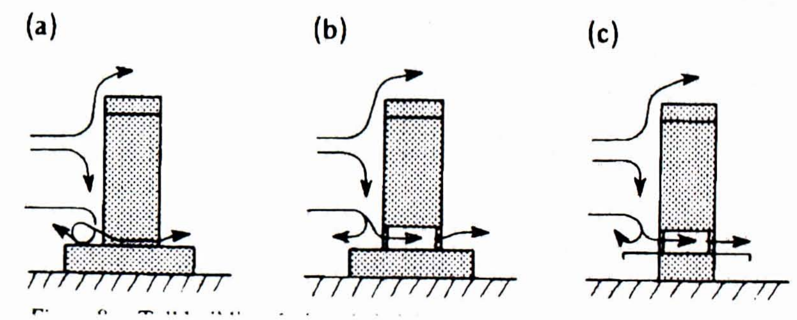


Figure12. Tall building designs helpful in alleviating undesirably increased wind speed at pedestrian level (Oke, modified after Hanlon)

Effect of Air Speed on Thermal Comfort

Major climate factors in effect with thermal comfort included the ambient air temperature, humidity and air speed. The preferred ambient air temperature for neutral thermal sensation at a relatively humidity of 50%, an air velocity of 0.25 m/s and a metabolic rate of 1.2 met is about 25 to 26C. The relative humidities of 30-70% are considered comfortable. The effect of airspeed on comfort depends on the environmental temperature and humidity, as well as on the clothing.

At temperatures below about 33C, increasing air velocity reduces the heat sensation due to the higher convective heat loss from the body and the lowering of the skin temperature. At temperatures between about 33 and 37C, air velocity does not affect significantly the thermal sensation, although it might have very significant effect on discomfort from excessive skin wetness, depending on the humidity level and the type of clothing. At temperatures above about 37C, increased air velocity actually increases the thermal sensation of heat, although it still reduces skin wetness and so might be desirable. Alleviation of discomfort due to skin wetness is best achieved, in the absence of dehumidification, by maintaining a high-enough airspeed over the body, so that the required evaporation can be obtained with smaller wetted area of the skin. (Givoni).

Figure 14 shows the preferred air velocity and ambient air temperature combinations for a comfortable environment.

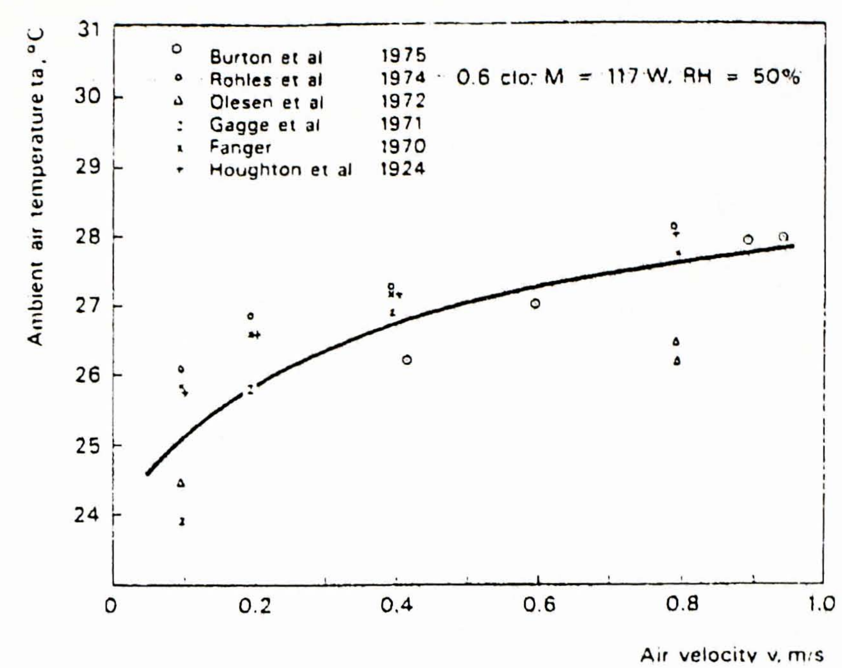


Figure 14. Preferable air velocity at various ambient air temperatures

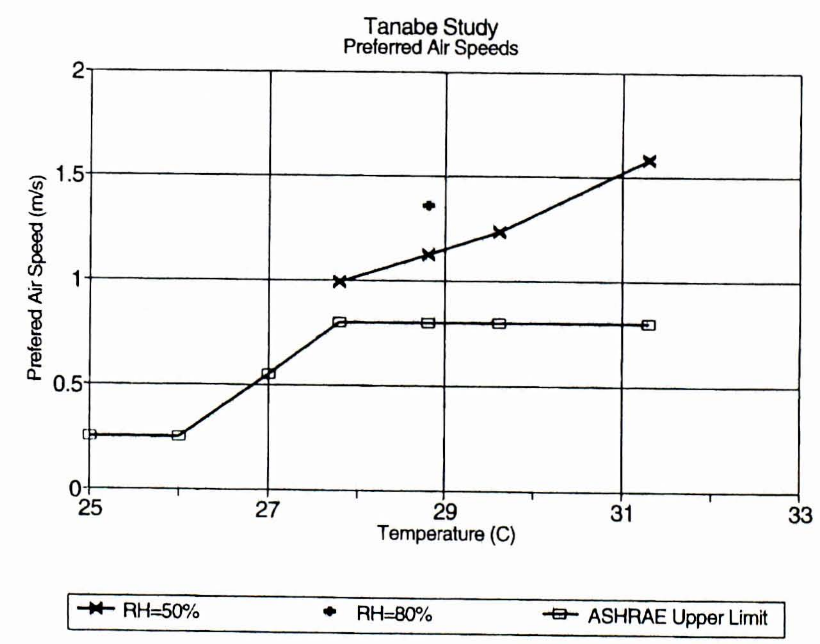


Figure 15. Preferred airspeed of the subjects as a function of the temperature (Tanabe 1988)

Tanabe(1988) has studied the comfort reactions of Japanese subjects to various airspeeds, up to 1.6m/s and at temperatures from 27 to 31C with relative humidity of 50 percent. The preferred airspeed increased with higher temperatures, from 1m/s at 27C to 1.6 m/s at 31C (Figure 15).

In Wu comfort study of air speed effect at different humidities / temperatures sets showed that at 31C and humidity ratio of 14.5 gr/kg, the subject felt less comfortable than at higher temperatures 32 and 33C but with lower humidity. At very still air (0.1m/s) humidity had more of an effect than temperature, but at airspeeds higher than 0.25m/s, lower discomfort was experience at 32C and 12gr/hr than at 33C and 11gr/hr.
At all three combinations of temperature and humidity increasing the airspeed reduced systematically the thermal sensation. It is notable that even a temperature of 33C with WBT of 20.6C with an airspeed of 1.5m/s was considered comfortable by 68 percent of the subjects.

In general, it could be believed that the increase in air speed have positive effect to count balance the thermal discomfort impact from high ambient temperature and relative humidity in certain range. The increase of air speed in urban canyons can also enhance the possibility of effective ventilative cooling inside buildings.

TABLE 1-1. MEAN THERMAL SENSATION VOTES (5=COMFORTABLE)

	DBT/WBT/H.R. (gr/kg)		
Speed	31/23.3/14/5	32/21.7/12	33/20.6/11
0.1 (m/s)	7.2±0.61	7.1±1.10	6.6±2.20
0.25	6.4±0.97	6.1±1.10	6.2±1.00
0.5	6.4±0.91	5.8±1.00	6.0±0.84
1.0	5.9±0.84	5.7±1.10	5.7±1.00
1.5	5.8±0.87	5.5±0.98	5.6±0.96

(adapted from Wu 1988)

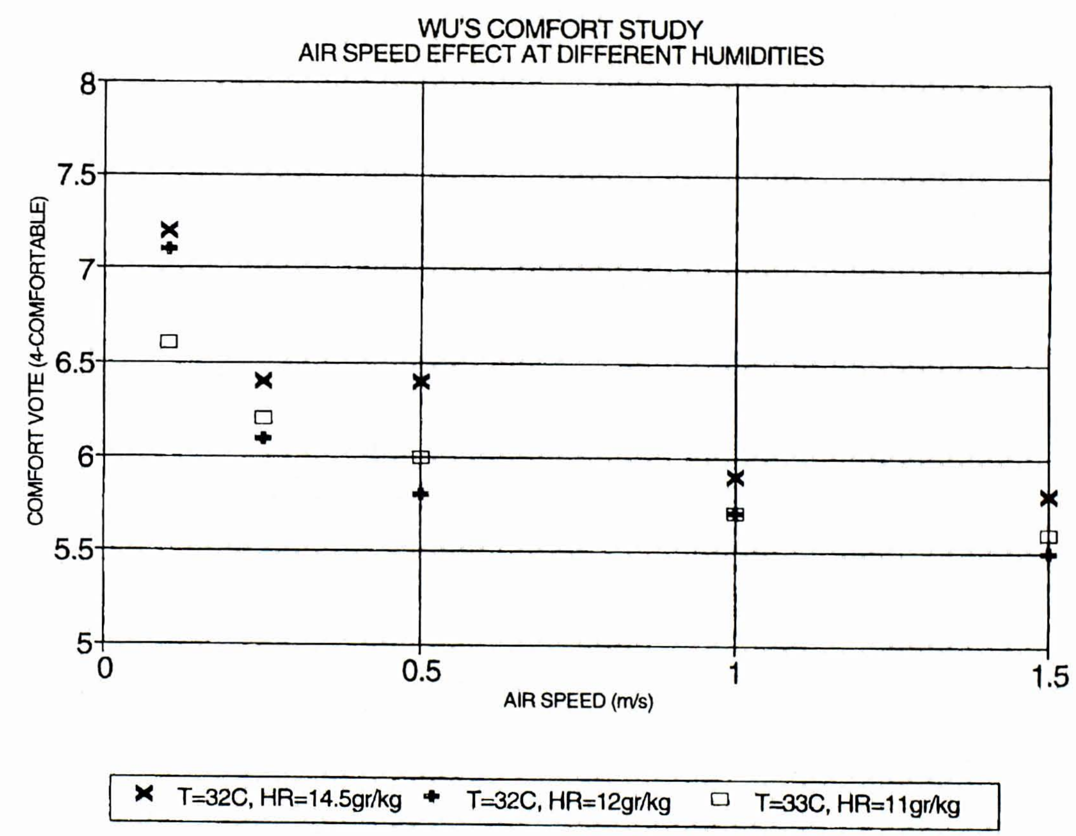


Figure 1-4. *Comfort data of Wu as a function of the airspeed.*

Effect of Wind Speed on Air Pollutants

The ventilation conditions in the urban space as a whole, and in particular in major streets with high vehicular traffic, have significant impact on the concentration of air pollutants at the street level. The higher the velocity and turbulence of the wind at street level, the greater is the mixing of the highly polluted low-level air with cleaner air flowing above the urban canopy. This mixing process and its relation to the wind speed was measured by Georgii (1970) and is shown in Figure 19 & 20.

Influence of Building on Pollution dispersion

Wind and turbulence are vital to the dispersion of air pollutants. In areas characterized by low buildings the exchange between street-level where car pollutants are emitted, and above roof-level depends upon the width of the streets relative to the height of the building. If the streets are narrow air exchange is restricted (Figure 21a) compared with that in a more open arrangement where the vortex circulation aids street-level flushing (Figure 21b) . Serve problems can arise in the downwash behind a tall building. This can be due to a source placed in the suction zone above the roof of the tall building (Figure 21c), or located near the surface in the eddy of the cavity zone (Figure 21d). The former situation can be alleviated by constructing a taller stack so that the effluent is carried downwind in the displacement zone flow, but there is no simple remedy for the latter, short of eliminating the source.

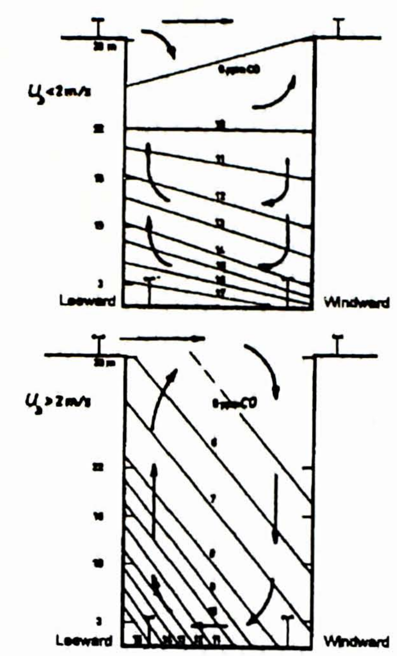


Figure 19. Effect of wind speed in CO concentration (ppm) within streets. (Georgii 1970)

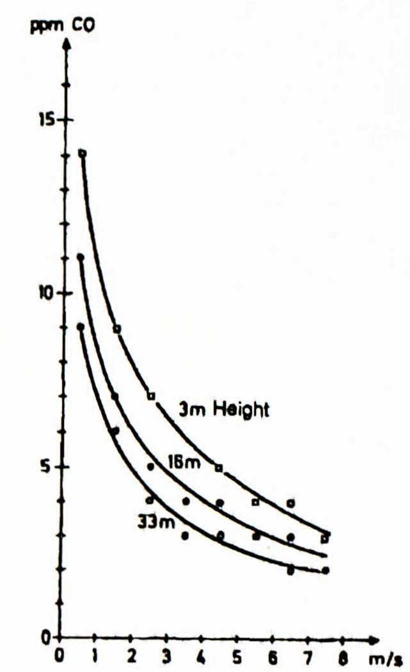


Figure 20. CO concentration as a function of wind speed and height above the street. (Georgii 1970)

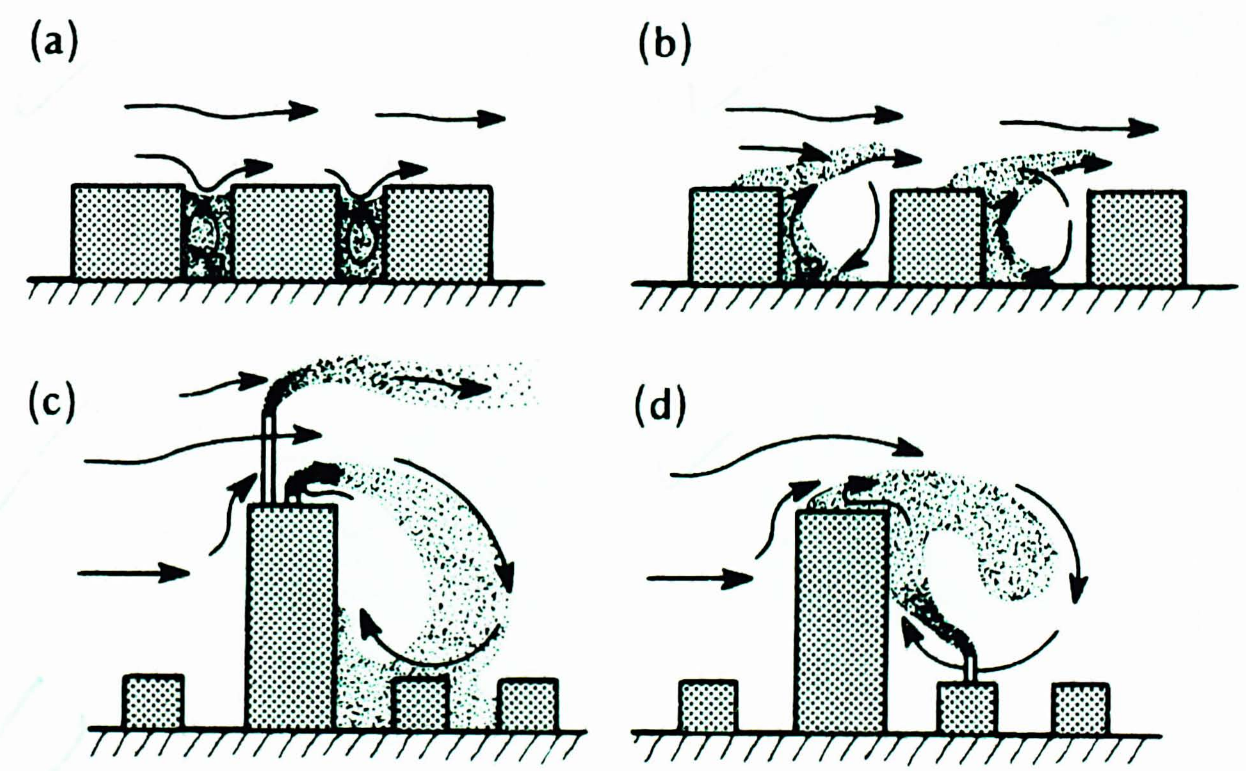
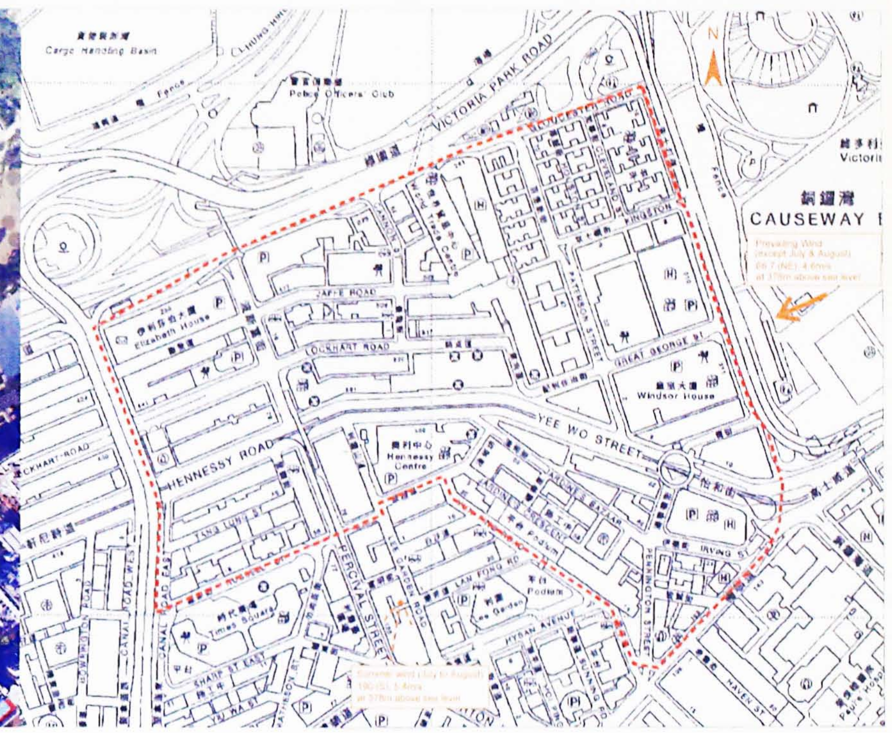
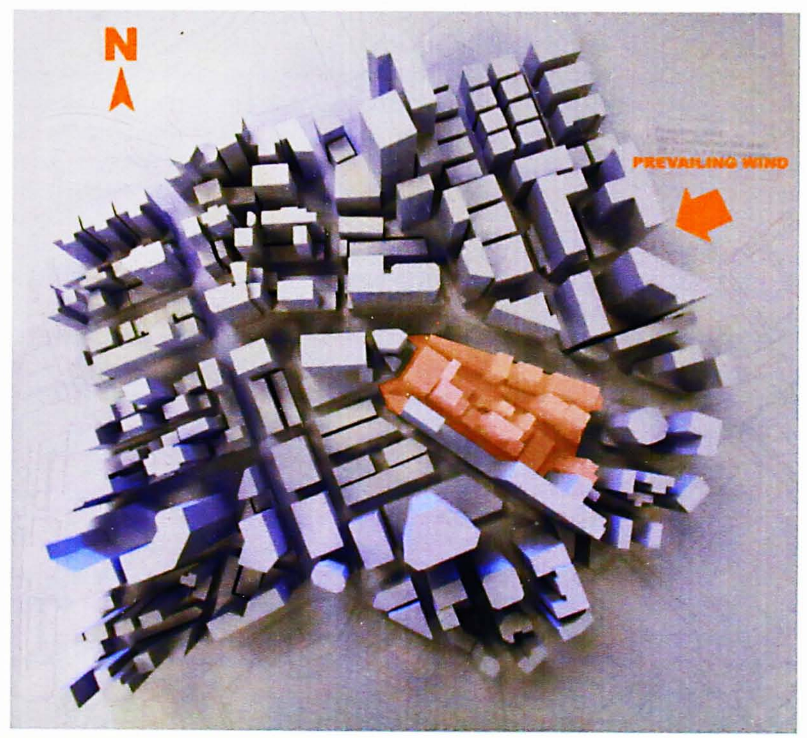


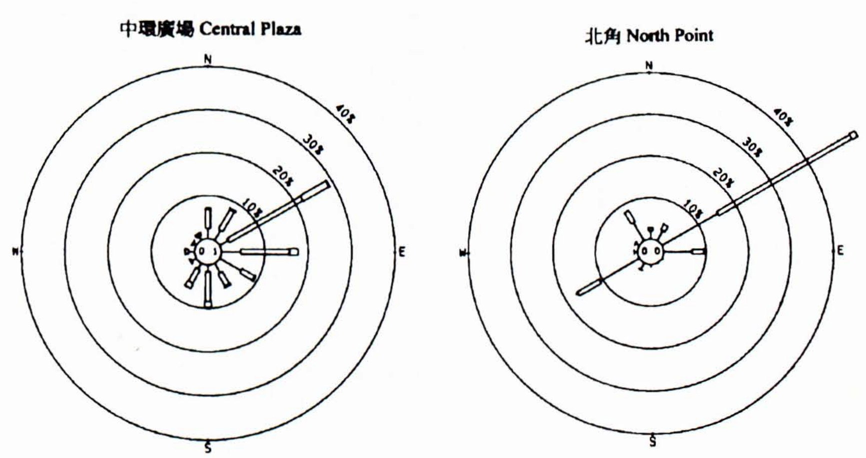
Figure 21. The influence of building air flow on pollution dispersion (Oke)

Site Condition

Land sales and developement of Causeway Bay is far ahead of proper town planning ordinance, the first land sales happened in 1841 but the first town planning ordinance was not enacted until 1939. Until 1973, the planning restriction were confined to the use of land, however it have no attempt to control the density and volume of development. The development of Causeway Bay is quite fragmented and spontaneous in the early stage, land divided up in small piece to benifit easier and quicker land sales. Buildings were demonlished and rebuilded through history, together with the growth of Hong Kong economy, they are getting taller and taller but still on the same land division and planning from the old time. Nowaday, density was controlled either by the lease conditions or the first schedule to the building regulation Cap123. Most area of Causeway Bay belonged to mixed commerical and residential development zone. Similar land use introduce similar plat ratio for the small divided-up but closely packed pieces of land with similiar sizes. The result is generating closely packed tall buildings with similar volume and similar height in the city. The monotonic and uniform urban topology in high density development created great problem in urban ventilation.



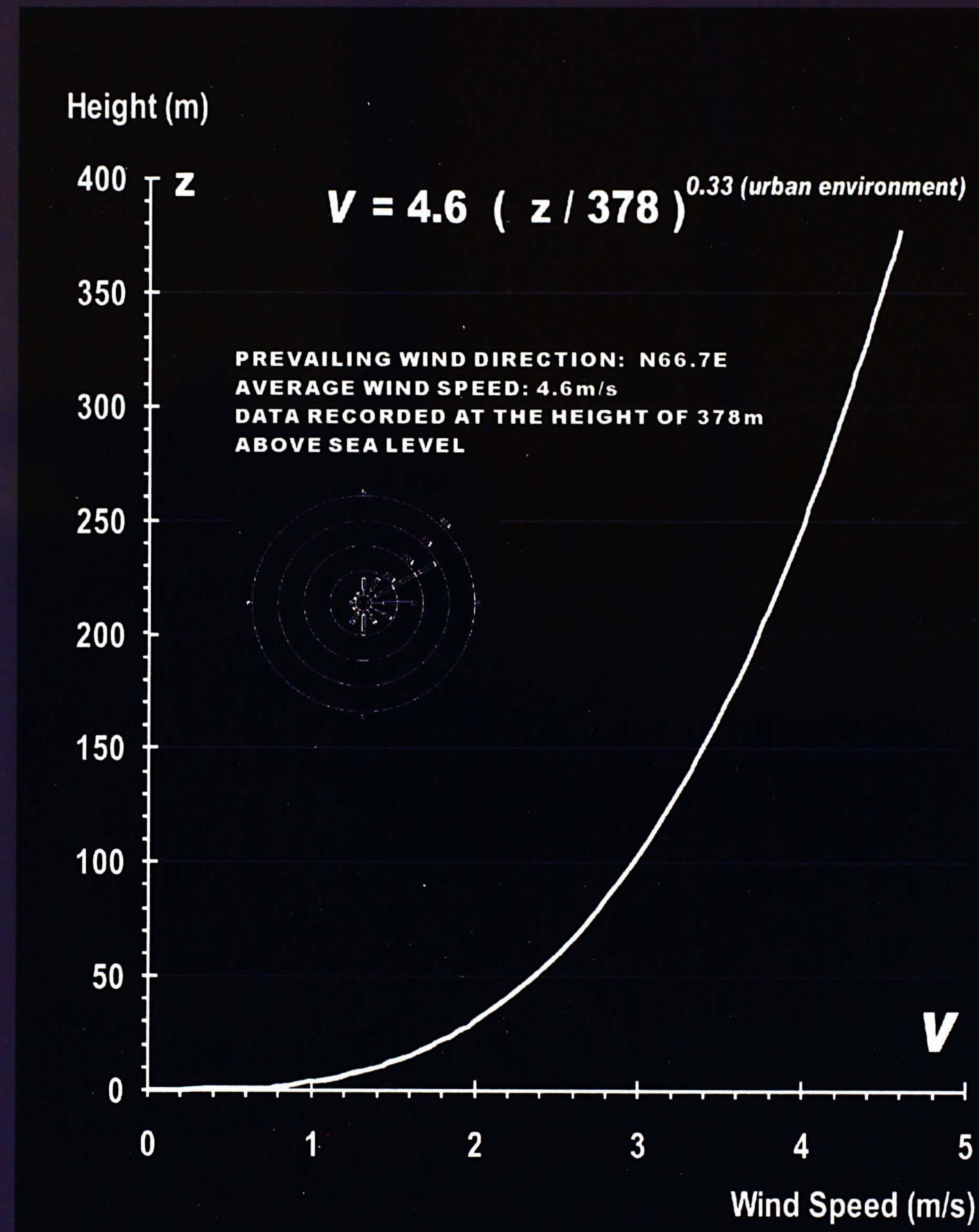




Aunnal wind rose Data from nearby automatic weather stations by Hong Kong Observatory in 2000

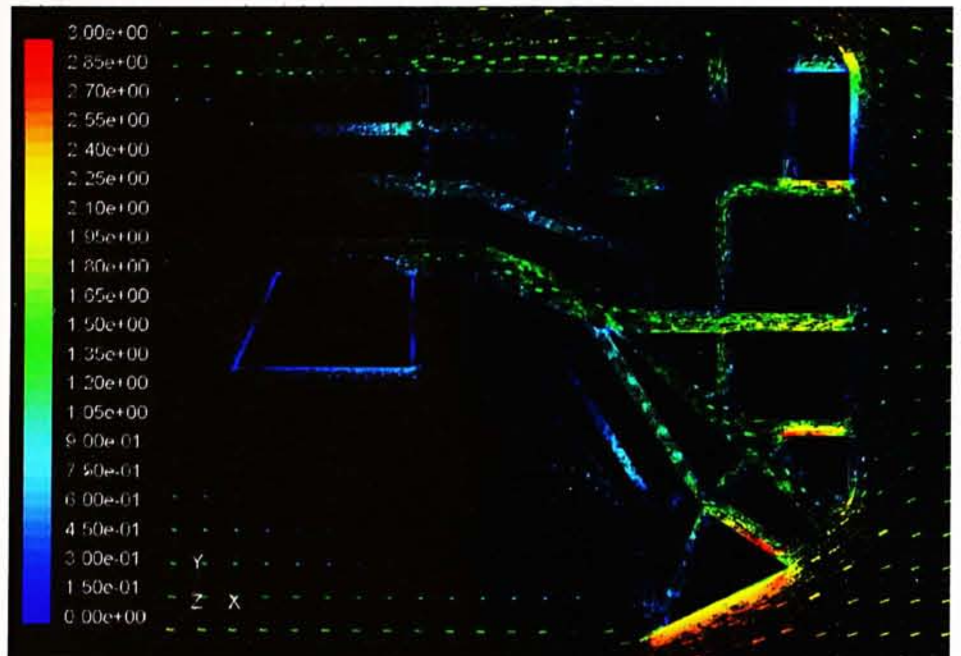
Wind Environment Simulation

Computational Fluid Dynamic (CFD) simulation will be the key tool for investigating and analzing the wind environment in this project. As urban wind is having different speed in different level of height because of the terrain roughness generated by buildings, wind speed is dropping when it is approach to the ground level. A commonly accepted equation for simulating this atmospheric boundary layer effect is shown in the diagram on the right. 4.6m/s is the average wind speed of the prevailing wind collected at the automatic weather station at the height of 378m above sea level, the index 0.33 is set for the urban environment. By putting these figures in the equation, wind speed (*V*) at different height (z) can be calculated. It is worth to notice that from the vertical wind profile it shows the drop of wind speed is getting more and more seiously when approaching to ground level. Low speed wind should be expected as the major type of wind resource at street level.



VERTICAL URBAN WIND PROFILE & ANNUAL WIND ROSE DIAGRAM

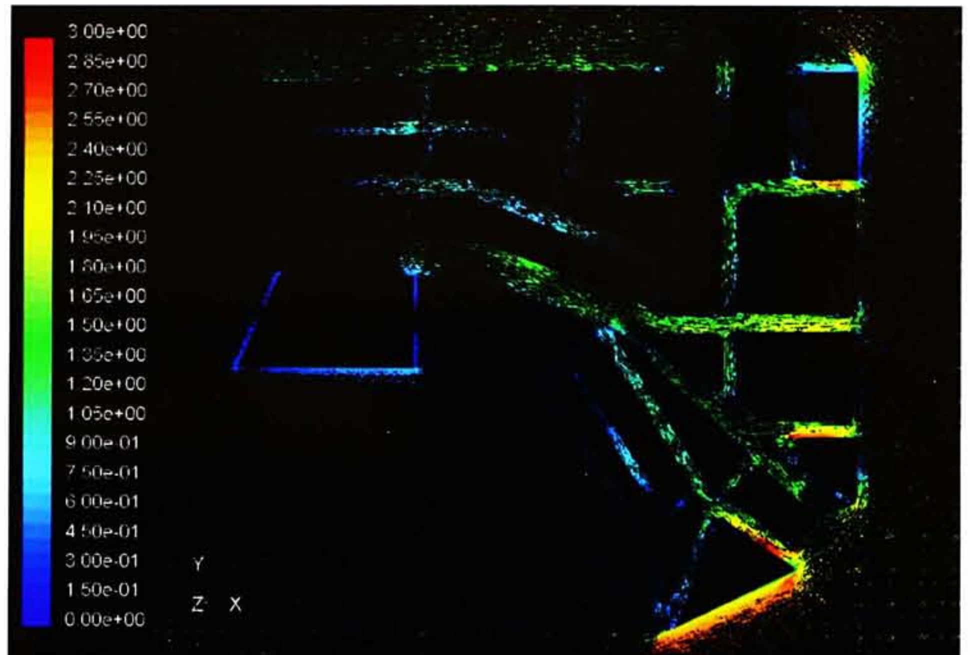
Computational Fluid Dynamic Simulation of Existing Urban Topology



Velocity Vectors Colored By Velocity Magnitude (m/s)

Horizontal Cut Plane at 1.5m Above Ground

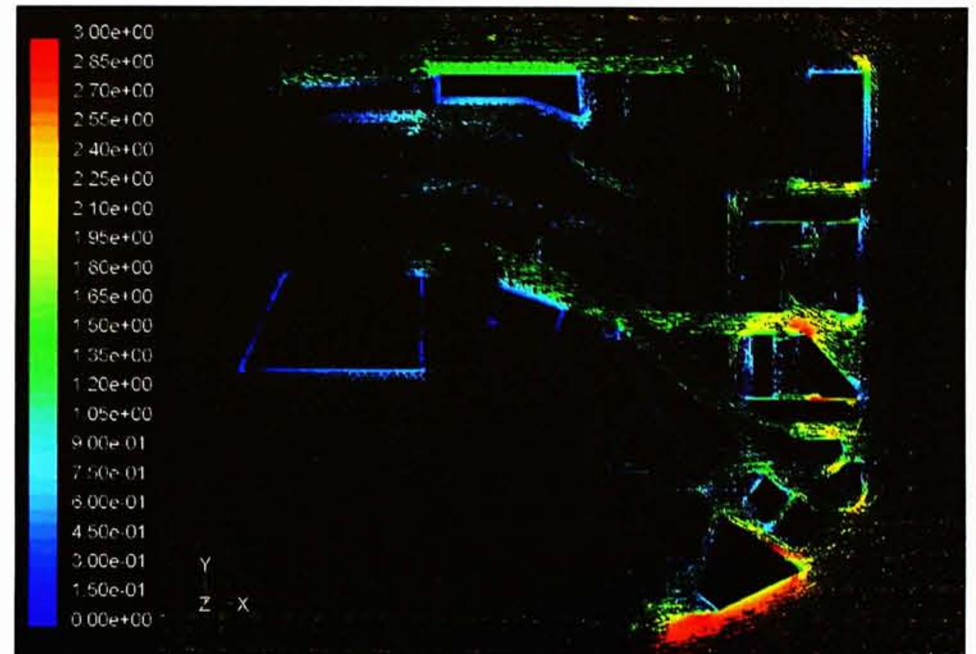
VELOCITY VECTORS



Velocity Vectors Colored By Velocity Magnitude (m/s)

Horizontal Cut Plane at 5m Above Ground

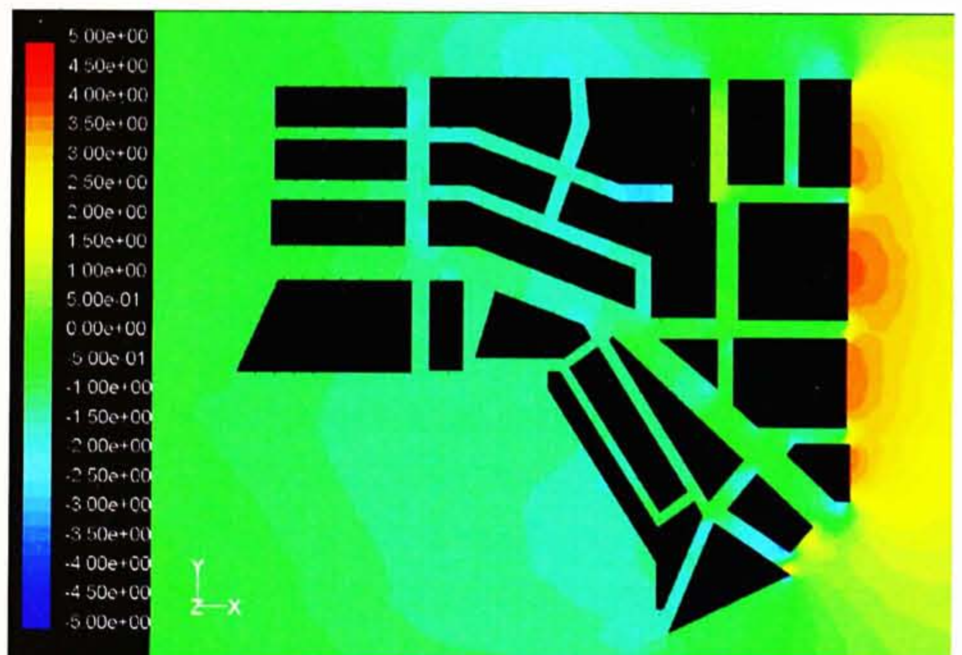
VELOCITY VECTORS



Velocity Vectors Colored By Velocity Magnitude (m/s)

Horizontal Cut Plane at 25m Above Ground

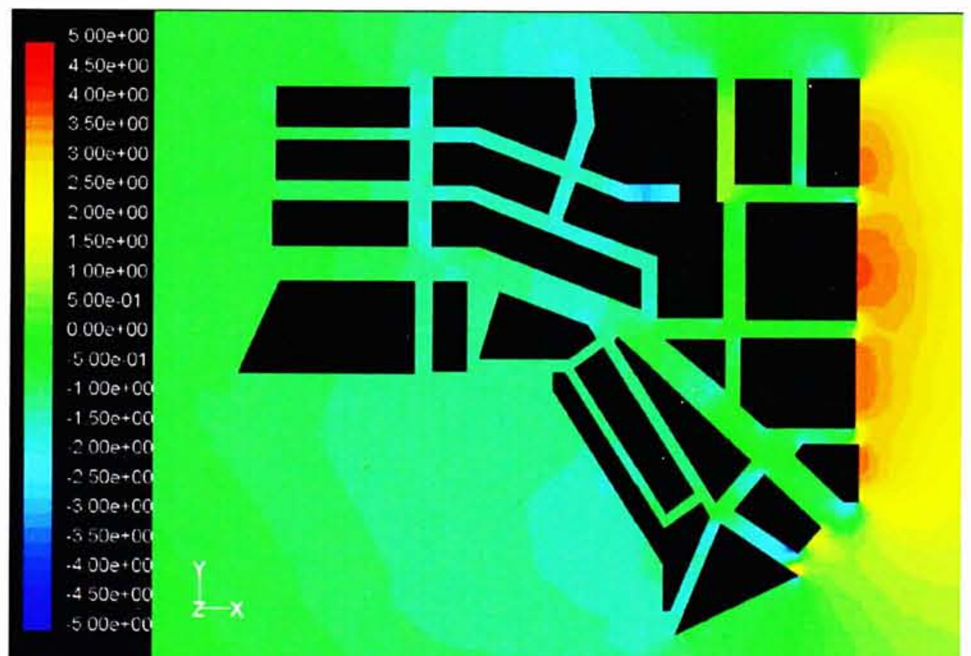
VELOCITY VECTORS



Contours of Static Pressure (pascal)

Horizontal Cut Plane at 1.5m Above Ground

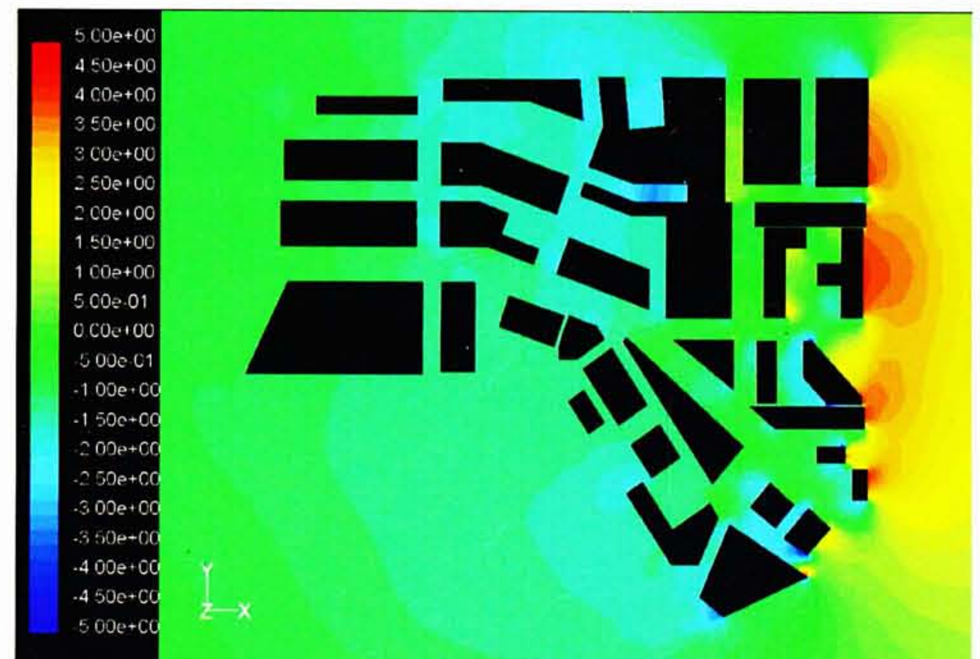
STATIC PRESSURE



Contours of Static Pressure (pascal)

Horizontal Cut Plane at 5m Above Ground

STATIC PRESSURE



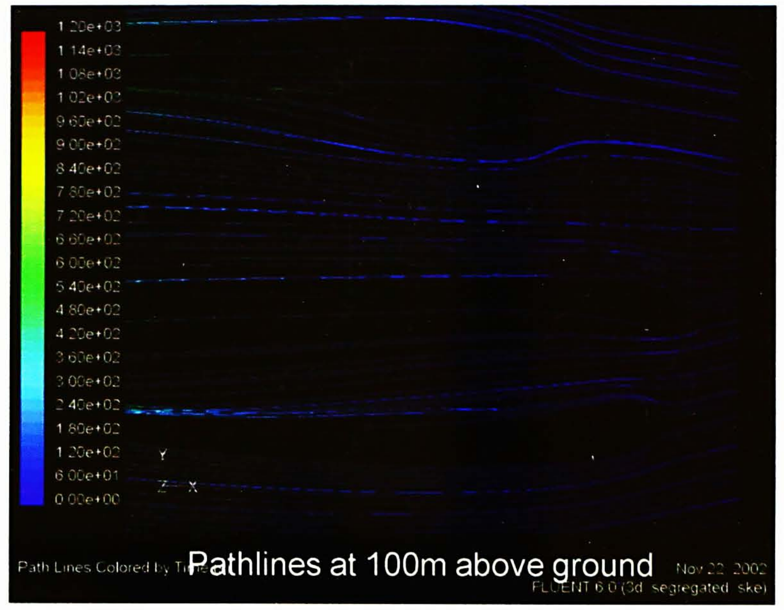
Contours of Static Pressure (pascal)

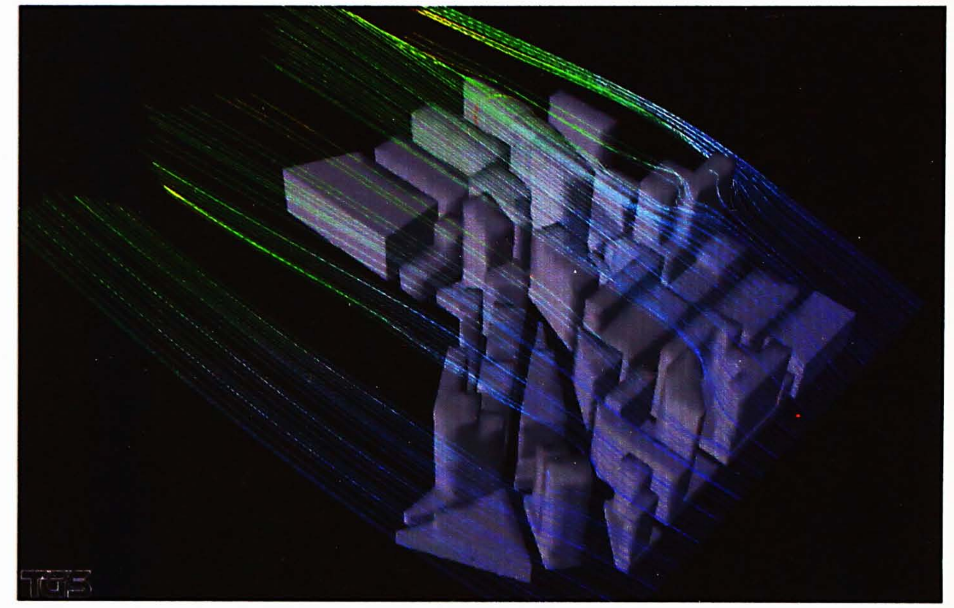
Horizontal Cut Plane at 25m Above Ground

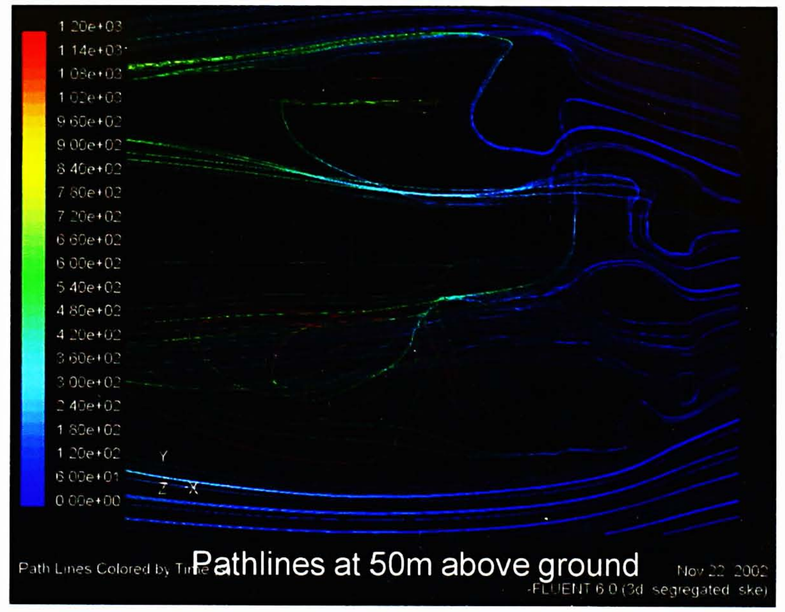
STATIC PRESSURE

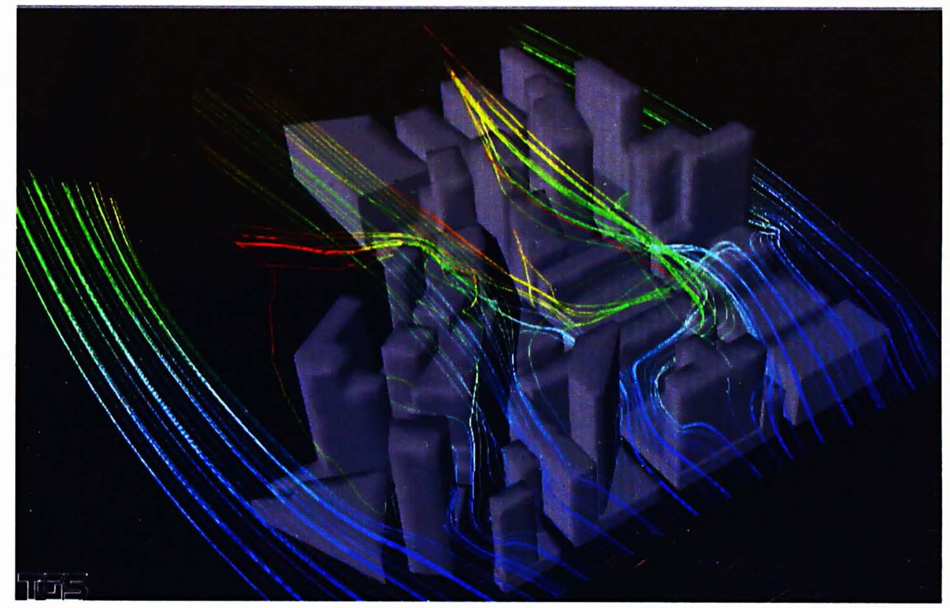
Analysis of Existing Urban Wind Pattern

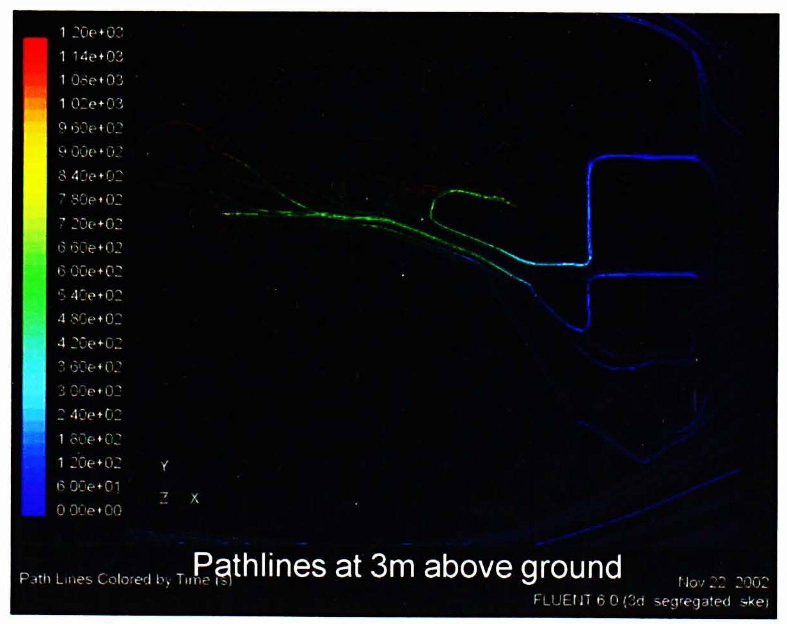
From the CFD simulation results, it can be noticed that wind speed within Causeway Bay is very limited especially at street level. Apart from the major wind corridors which having about 1.5m/s, the rest is normally below 0.5m/s. The major setback of the existing urban topology to the wind condition is a nearly continuous wall of buildings with minimal in-between spacing (in compare to the length of the buildings) built along the city edge on the north-east side. It generated positive pressure in front of this wall of buildings to block the prevailing wind from entering the city. At low level, where most building extended its footprint to maximum with their podiums, streets are narrow, it further reduce the flow potential as wind flow in channel space. Wind flow within streets which are along the prevailing wind direction only, the wider the street, the higher the possible wind speed available. At mid-level, as space between buildings increased, wind is not flow in channels as in the lower level. Wind flow pattern is quite responsive to the building geometry and the overall composition of the building group. Deflection or up and down movement can be observed in responding to the building shape, orientation as well as height variation among group of buildings. At high level, only few tall skyscrapers reach this level and they are far apart from each others, wind pattern at this level is basically having very minimal modification.

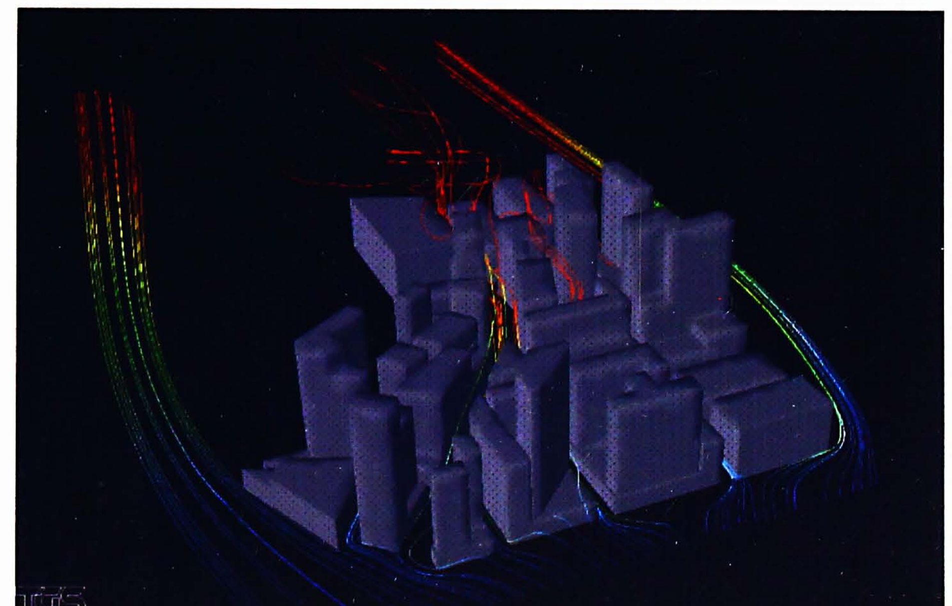

Pathlines at 100m above ground




Pathlines at 50m above ground

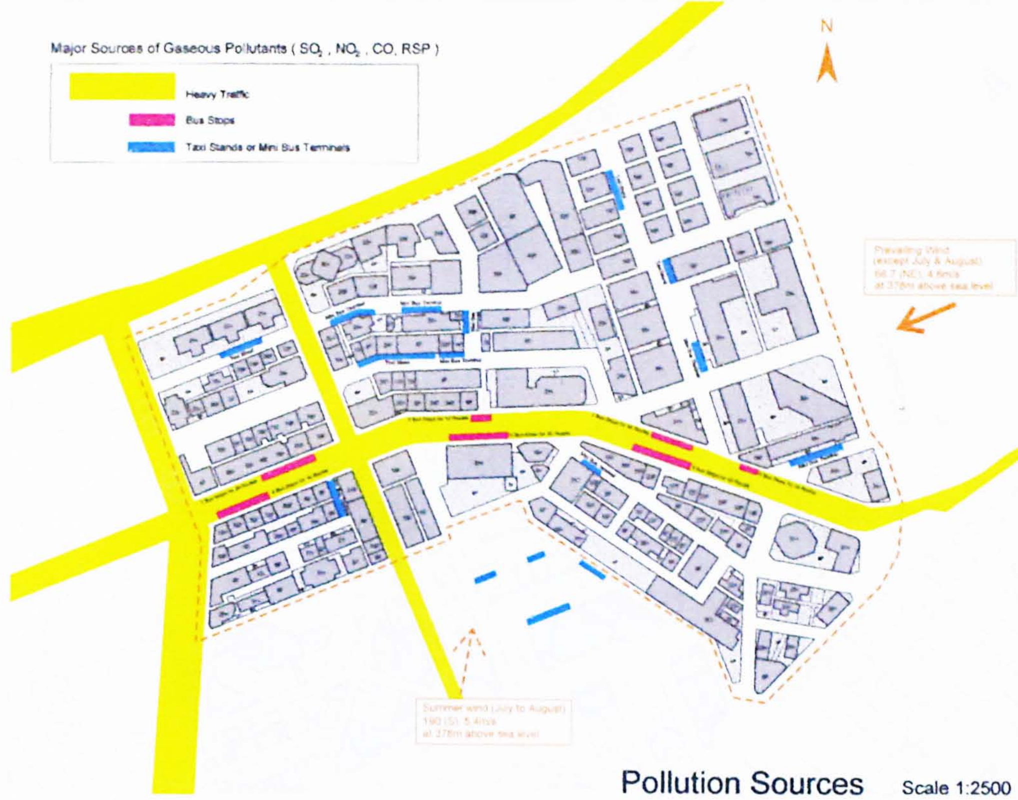



Pathlines at 3m above ground



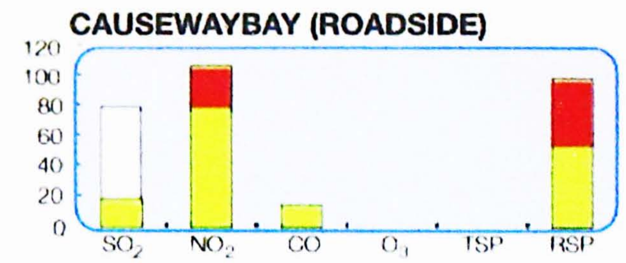
Environmental Condition Survey

From analyse the road side pollutants concerntation together with the wind direction and other climatic data, the followings can be concluded. In general, the Air Pollutation Index (API) issued by Environmental Protection Department (EPD) was recorded high in winter period and recorded low in summer period for the Causeway Bay roadside station. Concentration of air pollutations are sustaintially lower in the summer period can be explained by the higher temperature in summer that induces a larger mixing height of low level air and helps to disperse the air pollutants. The rains in the summer also help to washout pollutants. However, in winter time, because the lacking of heavy rainfall and high temperature, the only means for pollutants dispersion is the natural ventilation performed by the prevailing wind coming from the north-east. However, the current urban wind condition especially at ground level is not good enough to accomplish the task. Causeway recorded the highest pollutants concentration among the three roadside stations in Hong Kong and it never complie with the annual Air Quality Objective for NO2 and respirable suspended particulates (RSP). For improving the air quality of Causeway Bay, enhancing the urban wind environment for winter period is particularly improvement. Prevailing wind from the N66.7E will be the major study focus in this thesis.

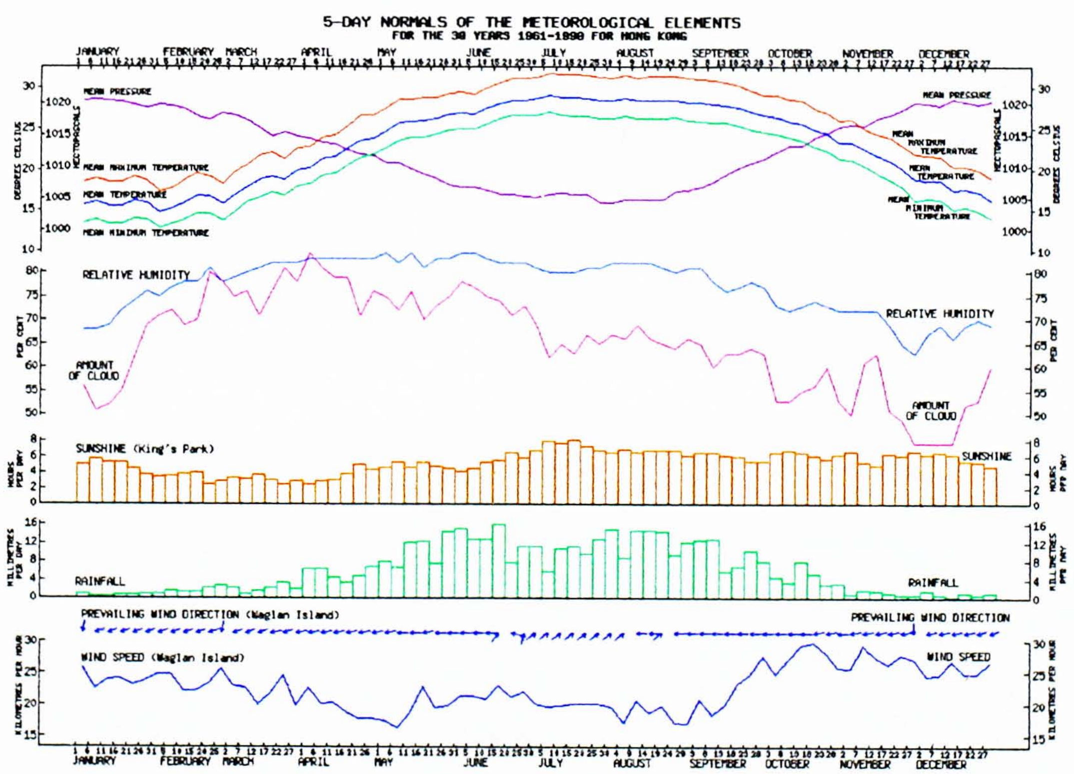


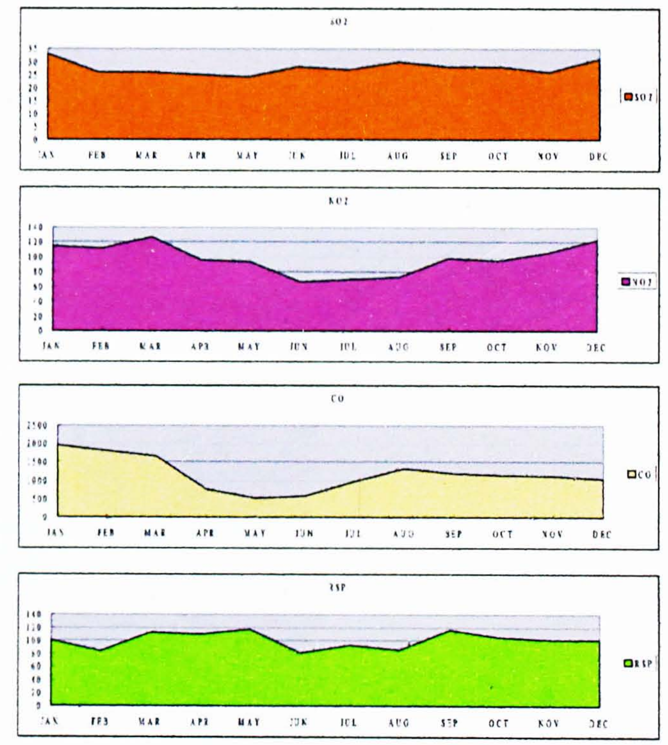
Pollution Sources Scale 1:2500

Roadside Air Quality Monitoring Station at Yee Wo Street in Causeway Bay

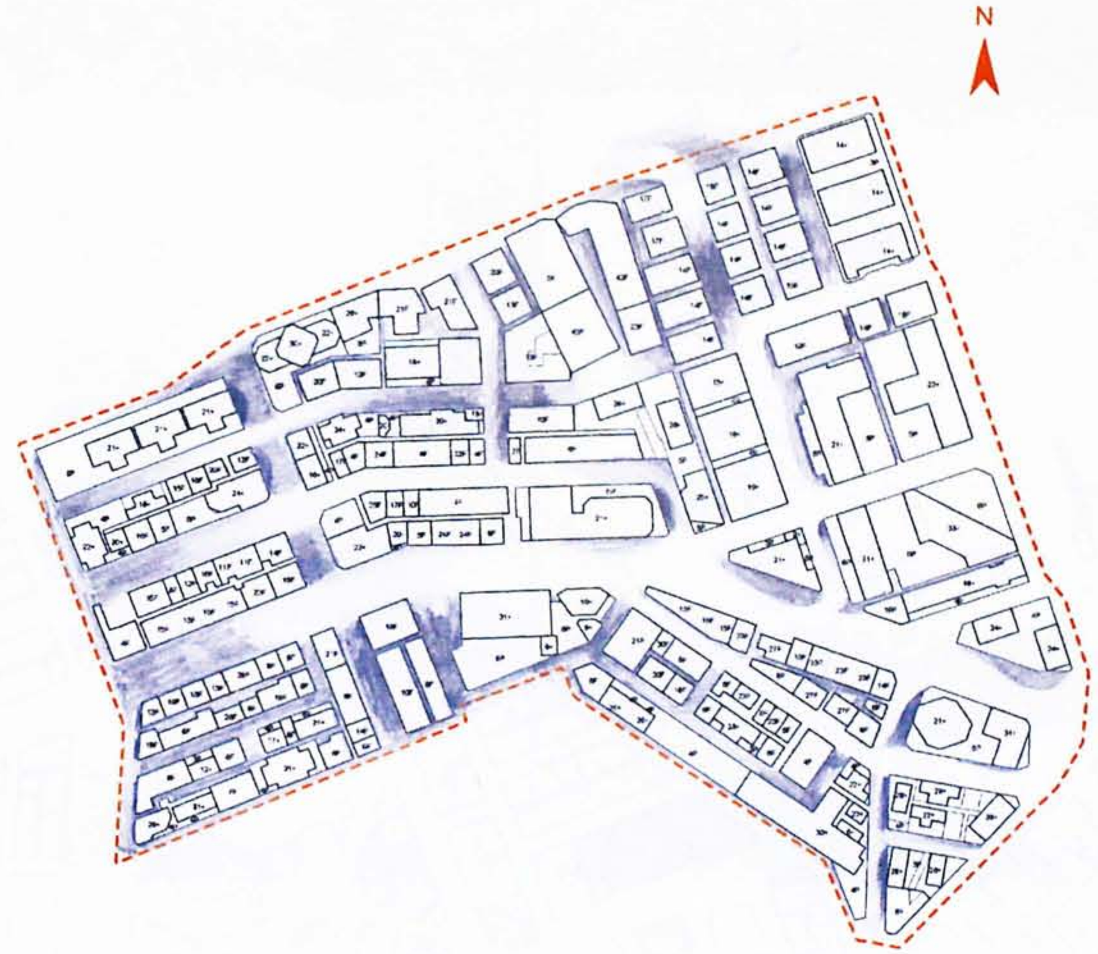


Annual Pollutant Concentrations and Objectives of Causeway Bay in 2001

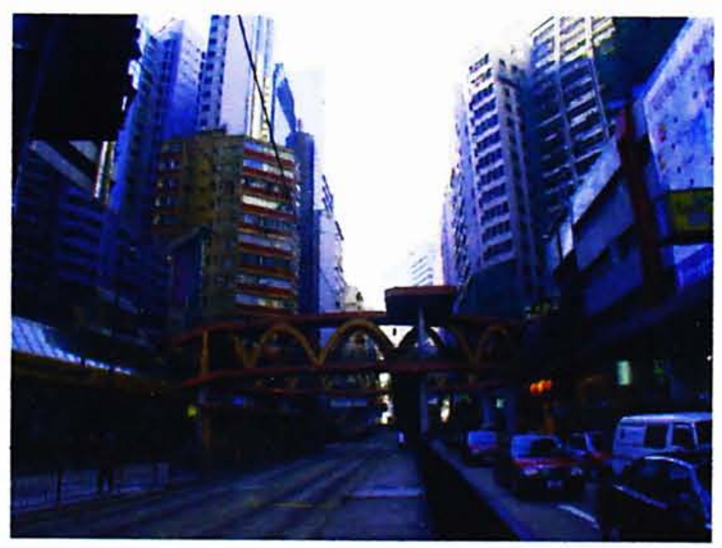




Environmental Condition Survey



Problematic Ventilation Hot Spots Scale 1:2500



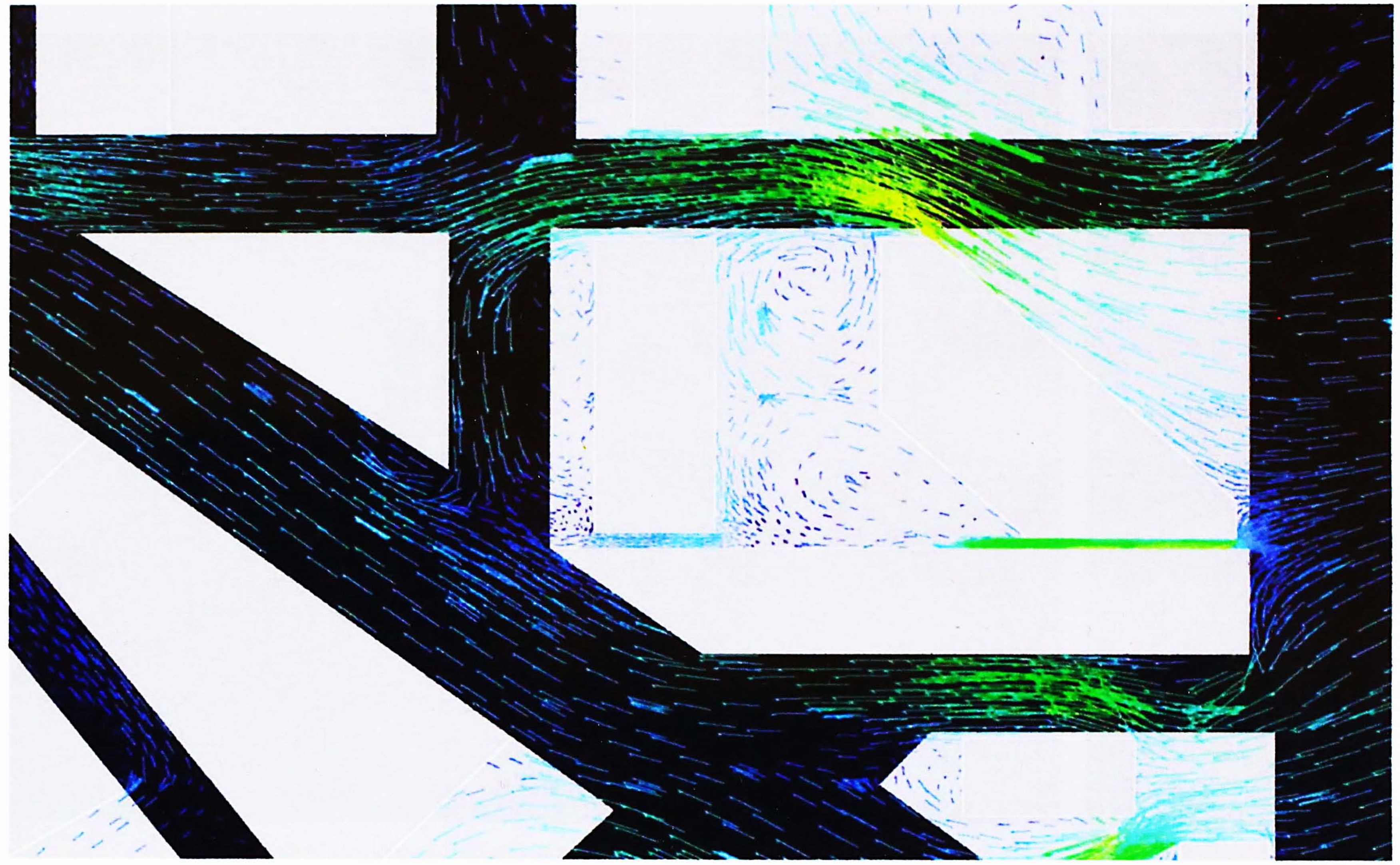
Hypothetical Wind Modifying Factors

Composition
Composition of a group of buildings can determine the size and amount of wind shadow created among them. Building group with varied height can enhance the permeability for air movement, certain specific building group profile such as low-high combination can induce vertical wind movement between buildings which helps catching wind down from higher level to lower level.

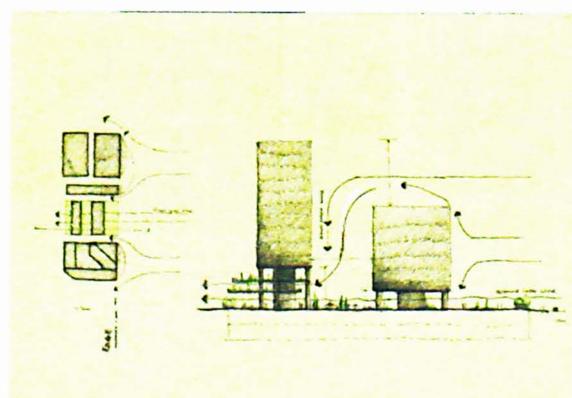
Spacing
As governed by the rule of boundary layer, the narrower the channel the higher the resistance will created for the flow. Spacing between buildings is absolutely the basic and fundamental key to modify the wind environment within city. The ratio between street width and the building height also determined the mixing ability between low level air and high level air.

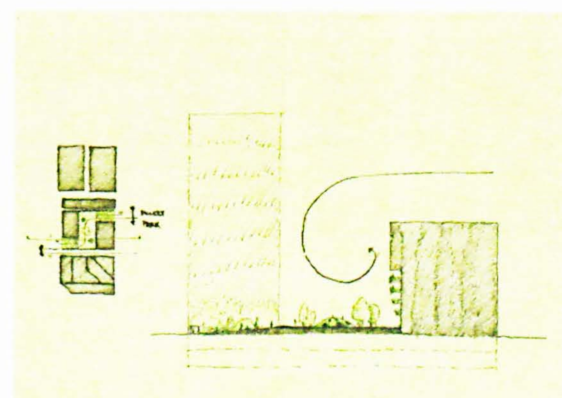
Geometry
Wind turbulent and wind shadow is having a direct relation with the building geometry and its orientation. Shape and orientation of a building can also help to deflect wind to location where lack of it in order to balance the wind distribution within a building group.

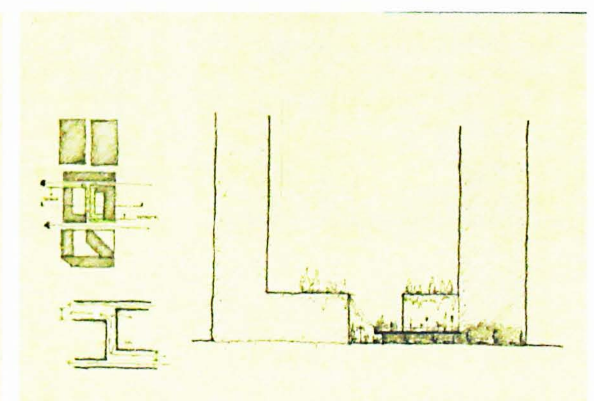
Opening
Elevated ground floor, voids and openings in building can definitely increase the permeablility of a building. Strategically arrangment of openings and elevated ground floor can form effective wind paths for ventilating the site.



Ventilation within city can only be Enhanced through the Combine Effort from Different City Elements All Together:
i.e. Composition of Building Group, Spacing between Buildings, Building Geometry and Openings in Buildings...

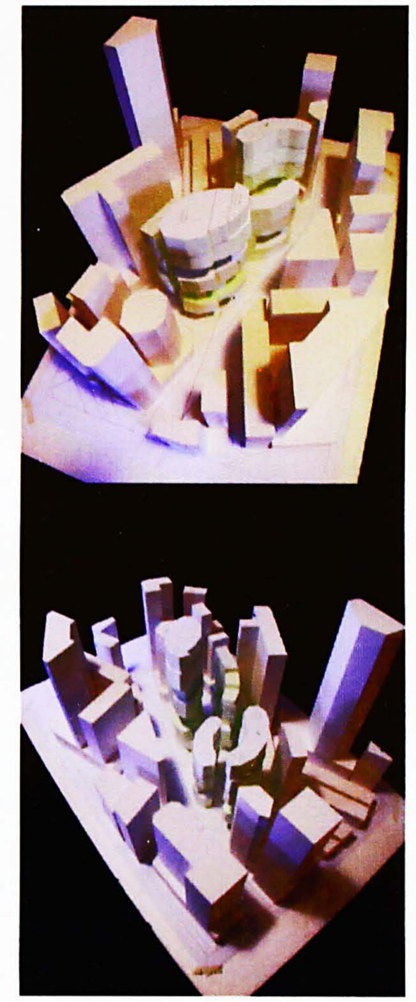


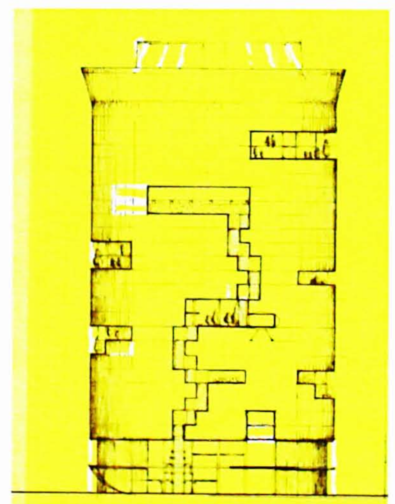


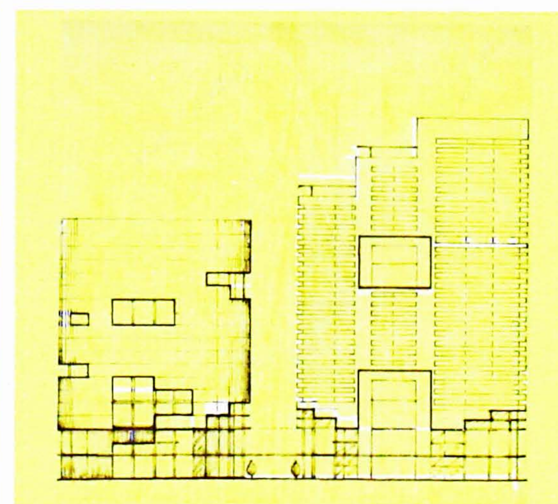


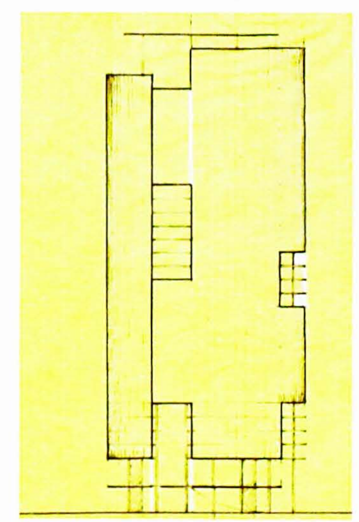
The Design Project

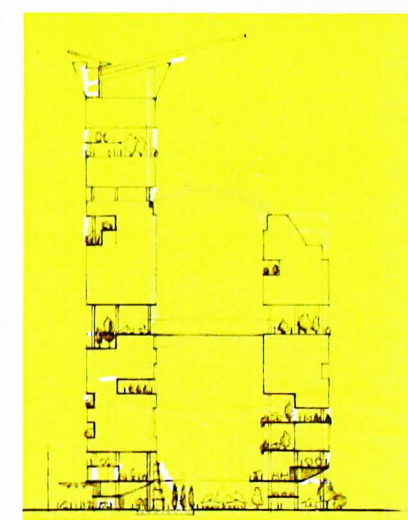
It is a redevelopment project with wind responsive design to utilize the limited wind resource effectively in the dense urban environment of Causeway Bay. Apart form fulfilling the basic requirements of the mixed development for leisure, commerical and residential purpose, the project is focused on generating a good ventilated environment for the ground and lower leveled open space to support outdoor activities such as food court, landscape gardens as well as hawker stands area, at the same time maintaining similar density of the existing development. The design is basically trying to examine and demostration the validity and practicality of the hypothetical wind modifying factors which are **composition**, **spacing**, **geometry** and **opening** respectively in an architectural and urban planning project. The design development consisted series of Design--CFD simulation--Analysis cycles to seek improvement and refinement in the design.











Stage One

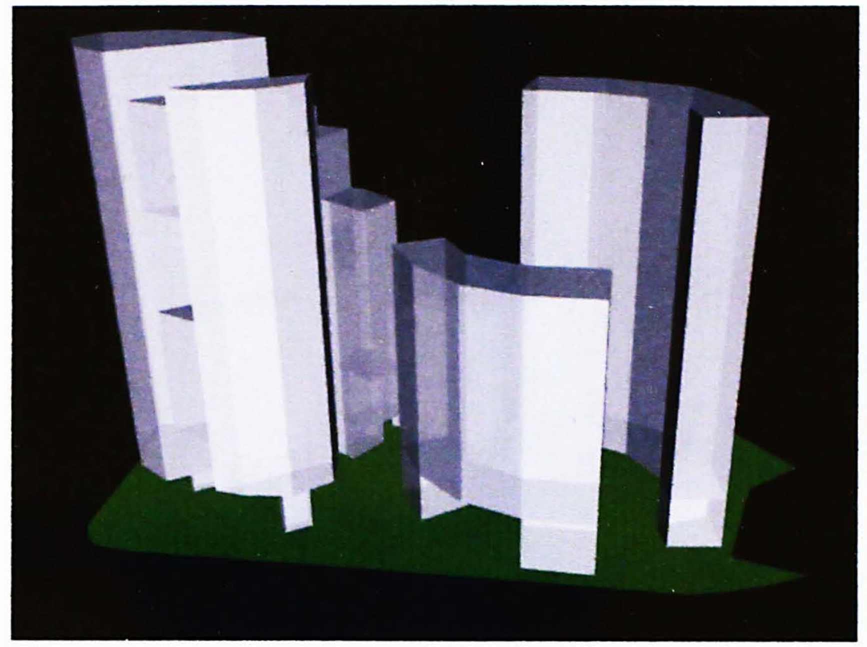
Design concepts under test included:

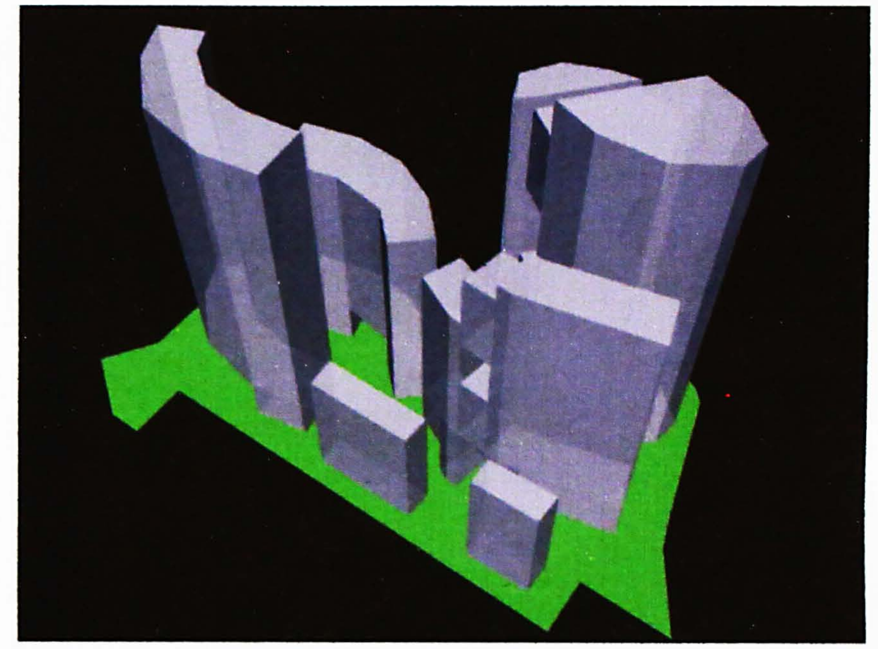
Air flow pattern with the conceptual composition and orientation of the designed building group in respond to the prevailing wind in general

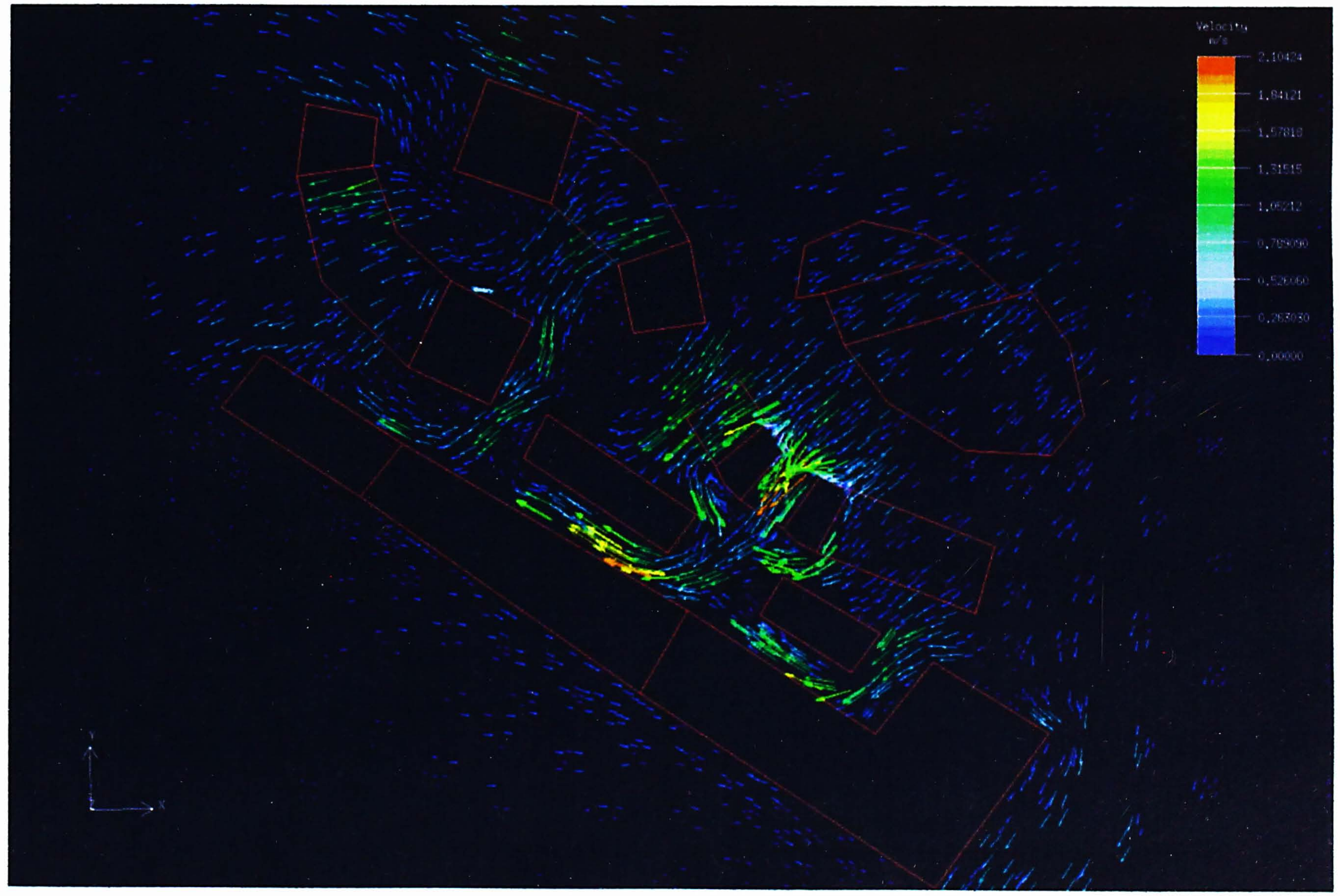
The design of the High-Low Combination of mall1 and mall 2 for catching high level wind down to supply courtyard space between them

The effectiveness of openings in buildings and elevated ground level to promote air flow

The effect of the designed building geometry to turbulance and wind shadow generation and also to wind distribution.







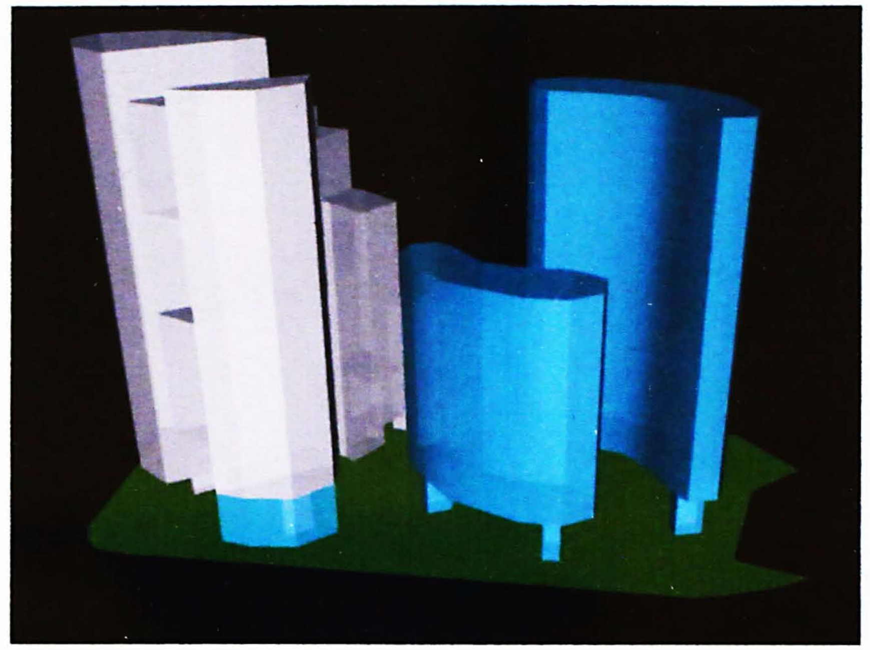
Stage Two

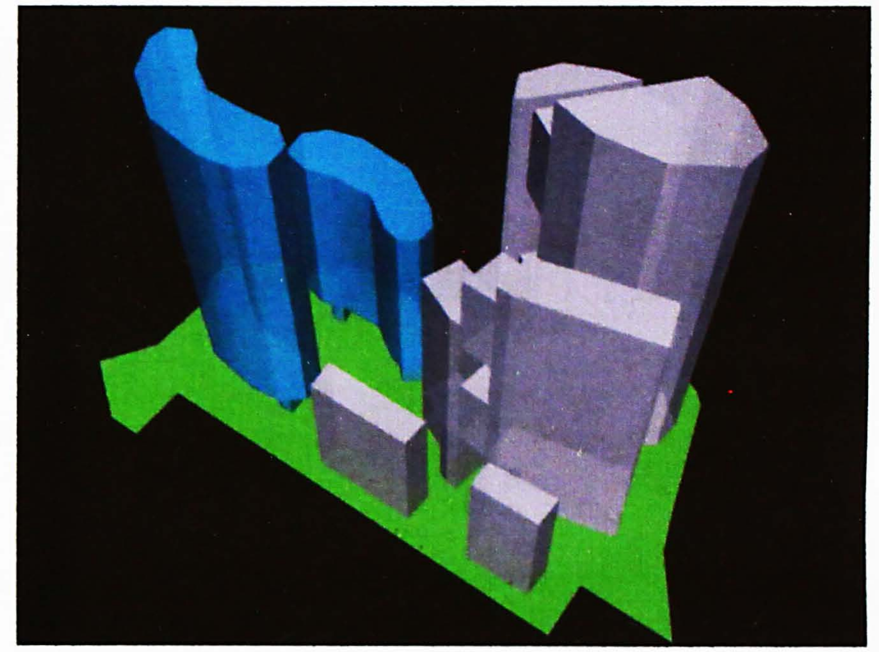
Design adjustments and developments included:

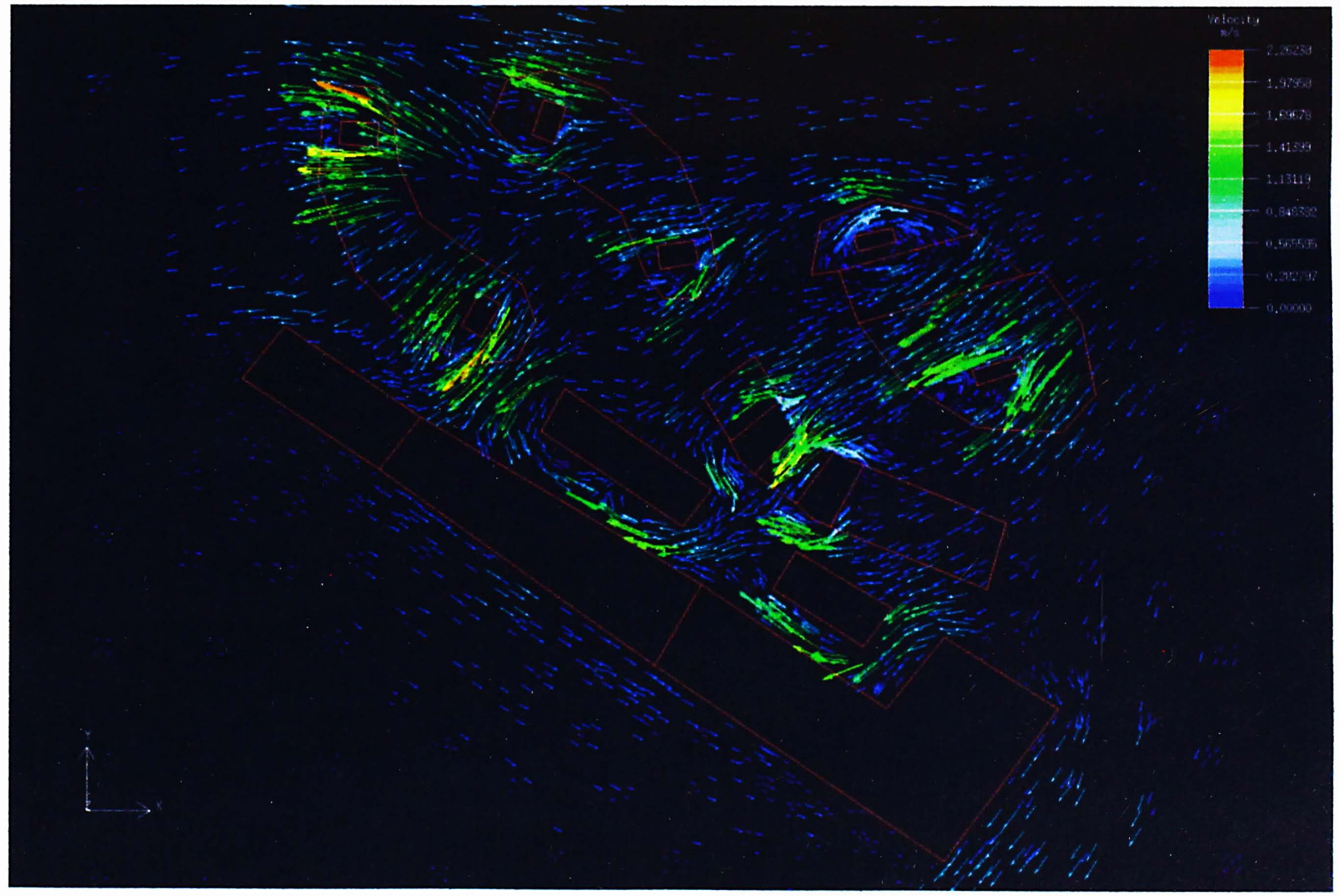
Changing the both ends of mall1 and mall2 from rectangular to round-shaped to minimize wind shadow and turbulance observed in stage one simulation.

The size of the building cores in mall1 and mall2 at ground level is reduced to improve better low level flow.

A curved facade at the elevated level of the office tower is added to deflect wind flow to enter the void under mall2







Stage Three

Design adjustments and developments included:

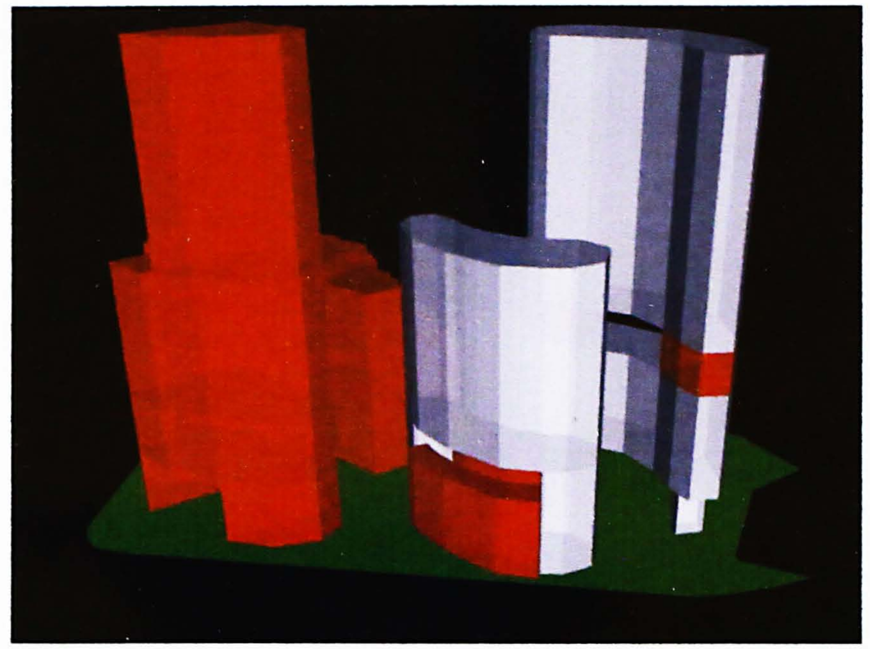
The residential buildings are grouped into one larger building to get better spacing better buildings.

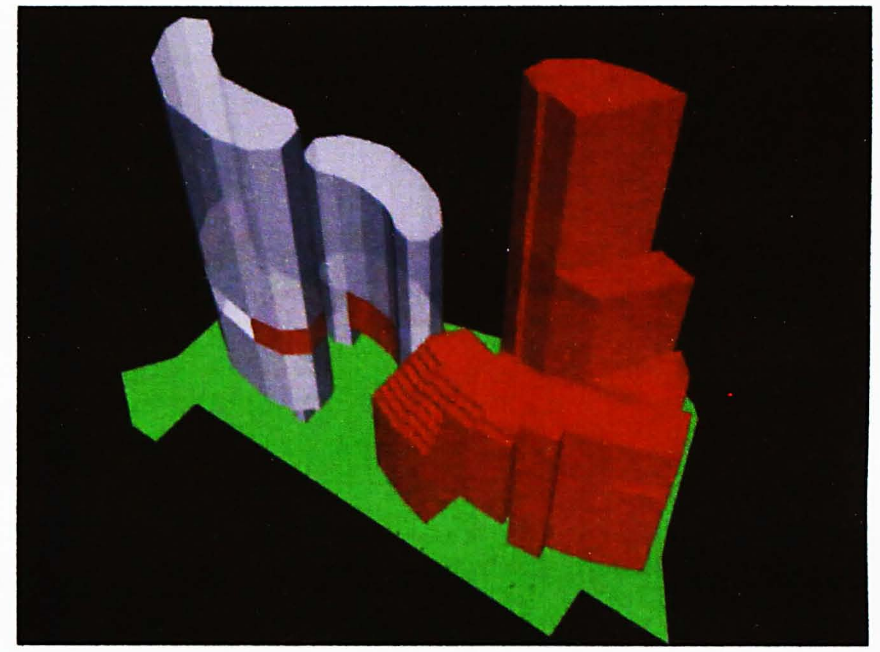
Excessive opening at mid-level of the office tower is cancelled as it is not very effective in enhancing the flow. But instead geometry of the office tower is changed to stepping down shape to enhance air speed at mid and high level. The planes of the building skin at the stepping down shape is set to parallel the prevailing wind direction for maximizing the flow.

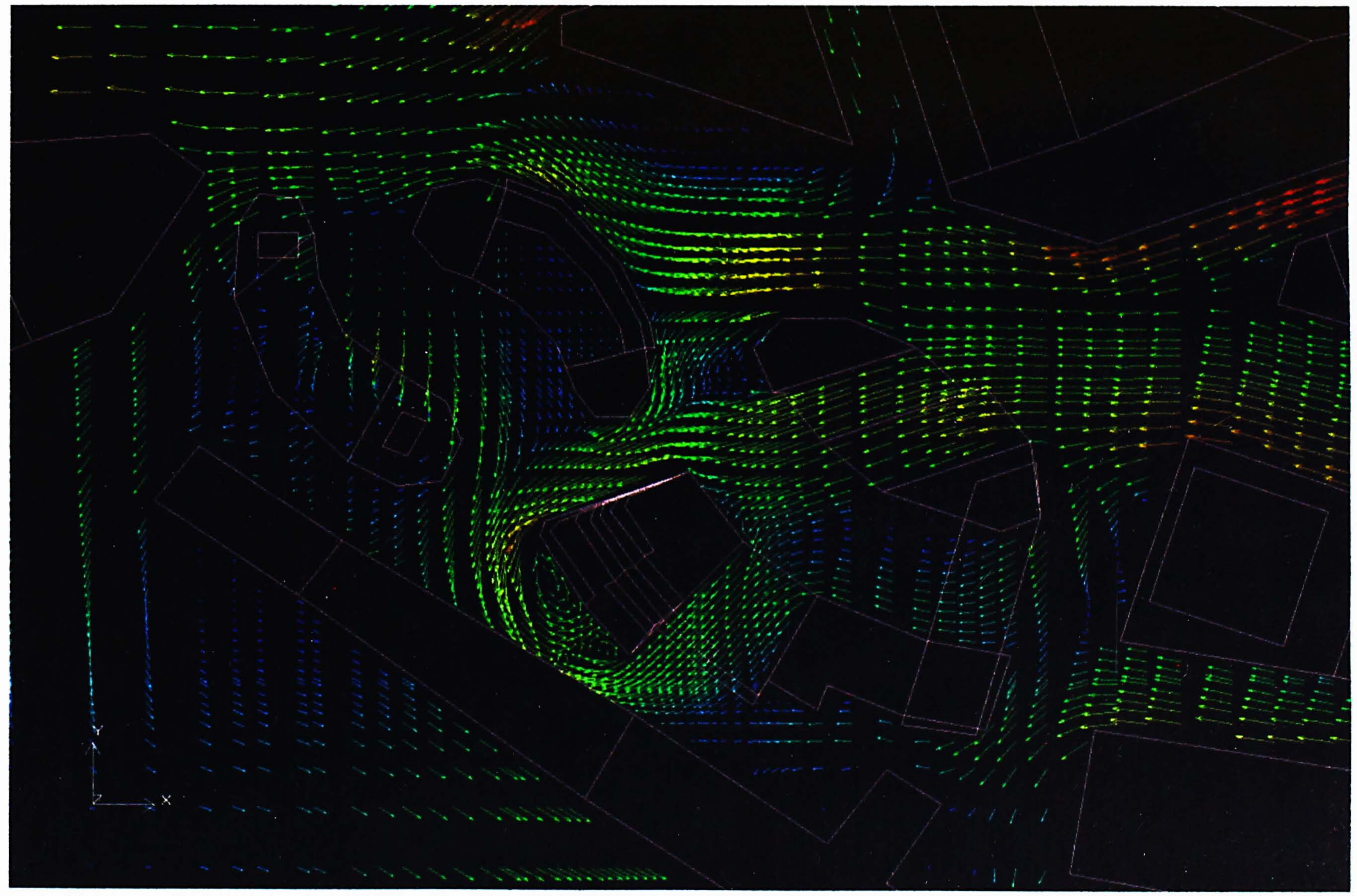
Void under mall2 is blocked and but an opening at mid-level is introduced for catching fresher air at mid-level and transfer it down to supply the countyard space between mall1 and mall2.

Sky garden is introduced at the mid-level (lower than the roof of mall2) of mall1

Surrounding buildings of the existing is added for a more completed simulation. The overall composition and the geometry will be tested to ensure a balanced and even wind distribution is achieved.







Stage Four

Design adjustments and developments included:

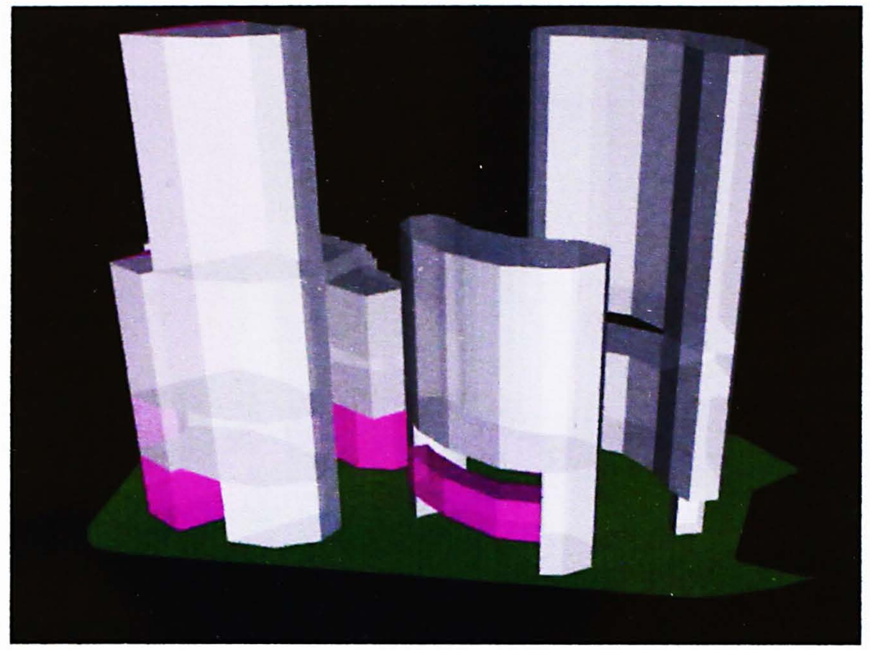
Changing the angle of the planes at the stepping down shape of the office tower to deflect wind slightly for hitting wall of the residential building more perpendicularly to generate an effective downwash wind to ventilate the countyard space between the office tower and the residential building.

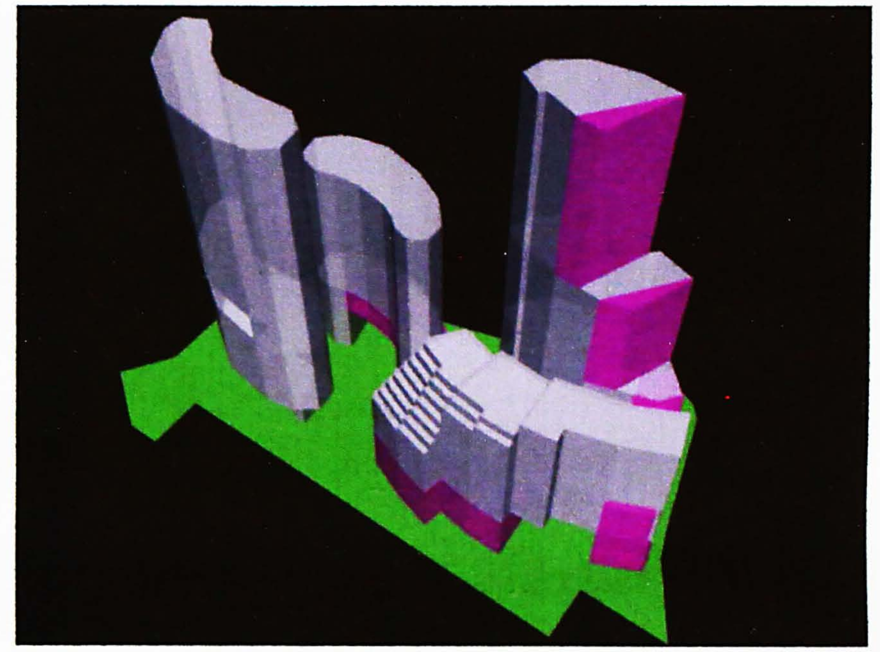
Bridging part which link the residential building to the office tower is lowered for letting wind pass over its top to assist to generate the downwash wind mentioned for the countyard.

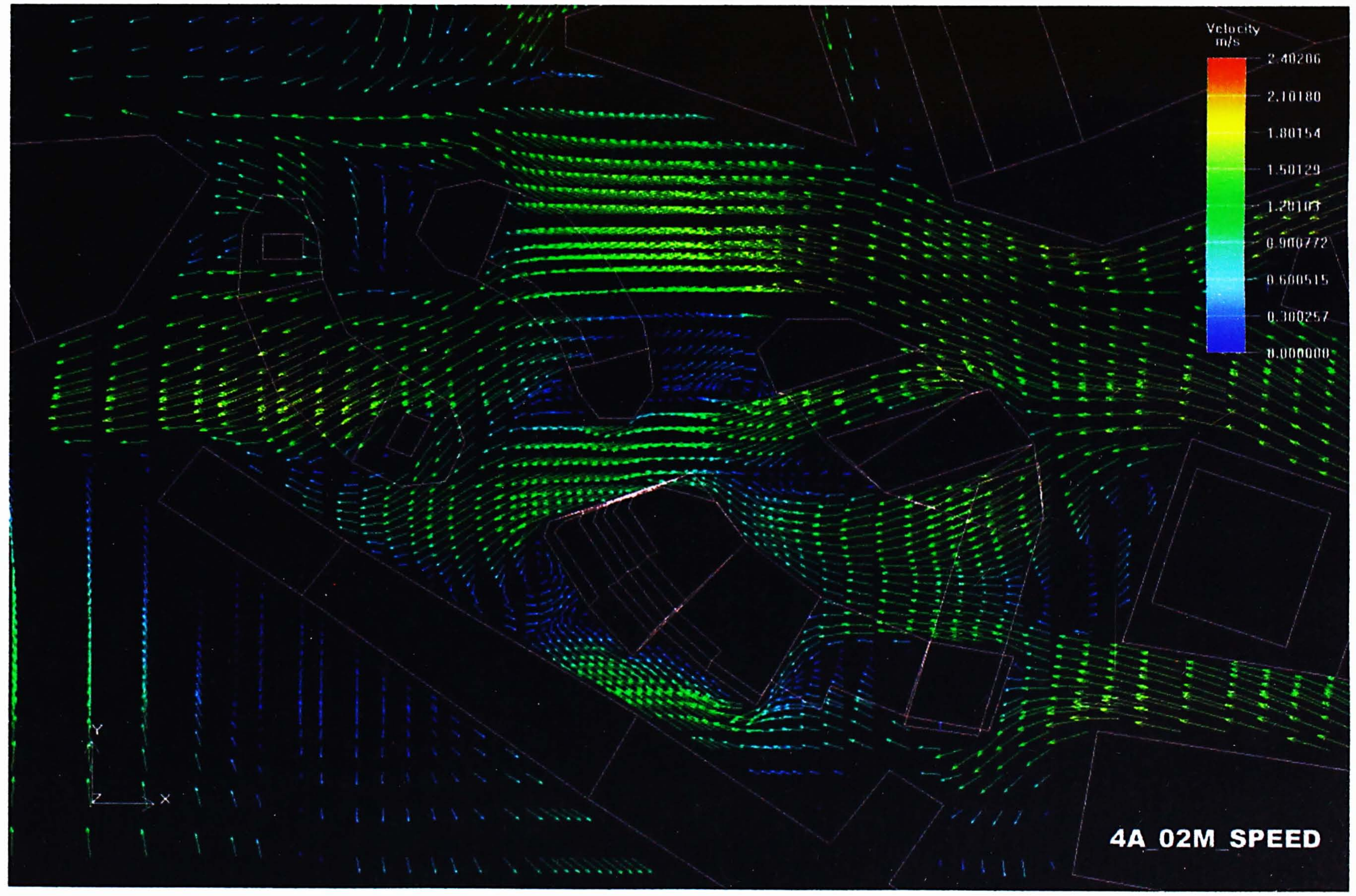
Void under the residential building is shifted to the east for re-direct the flow path on groun level for a more balanced wind distribution.

Void at the base of the office tower is narrowed and re-oriented to ventilate the open space at the center of the development to correct the interference it have done to the countyard space infront of residential in stage three.

Void at ground level of mall2 is reopened and trying to work with the opening at mid-level together to ventilate the countyard between mall1 and mall2.





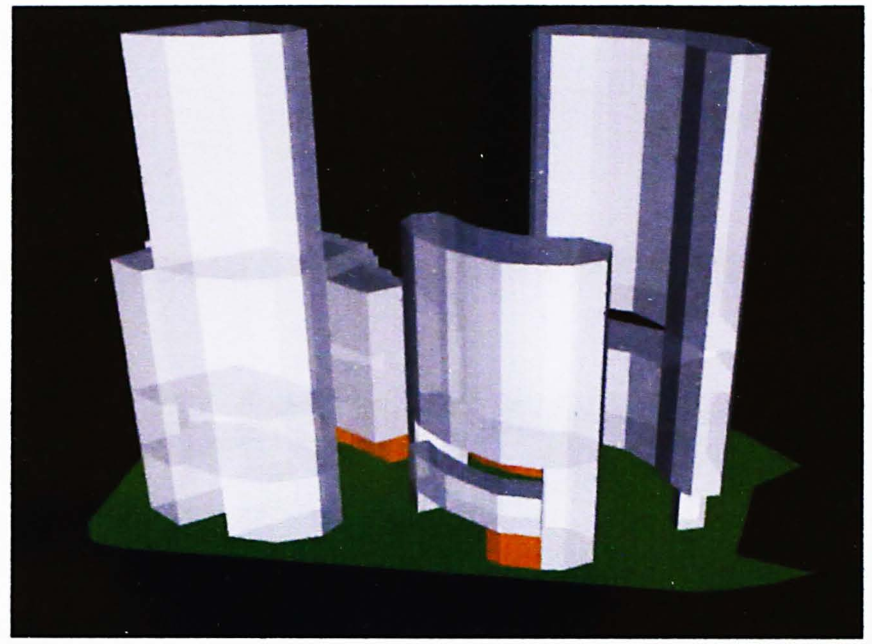


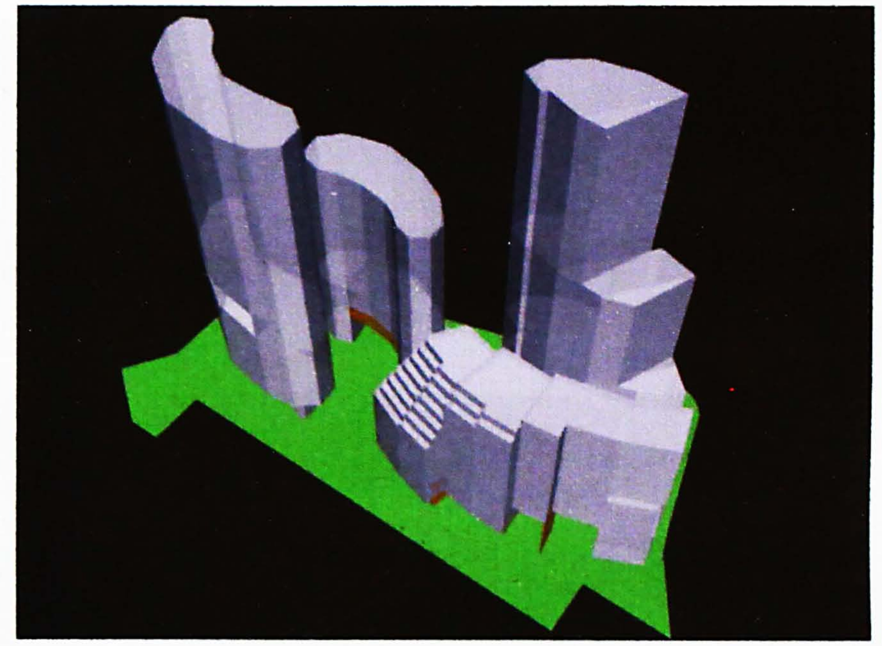
Stage Five

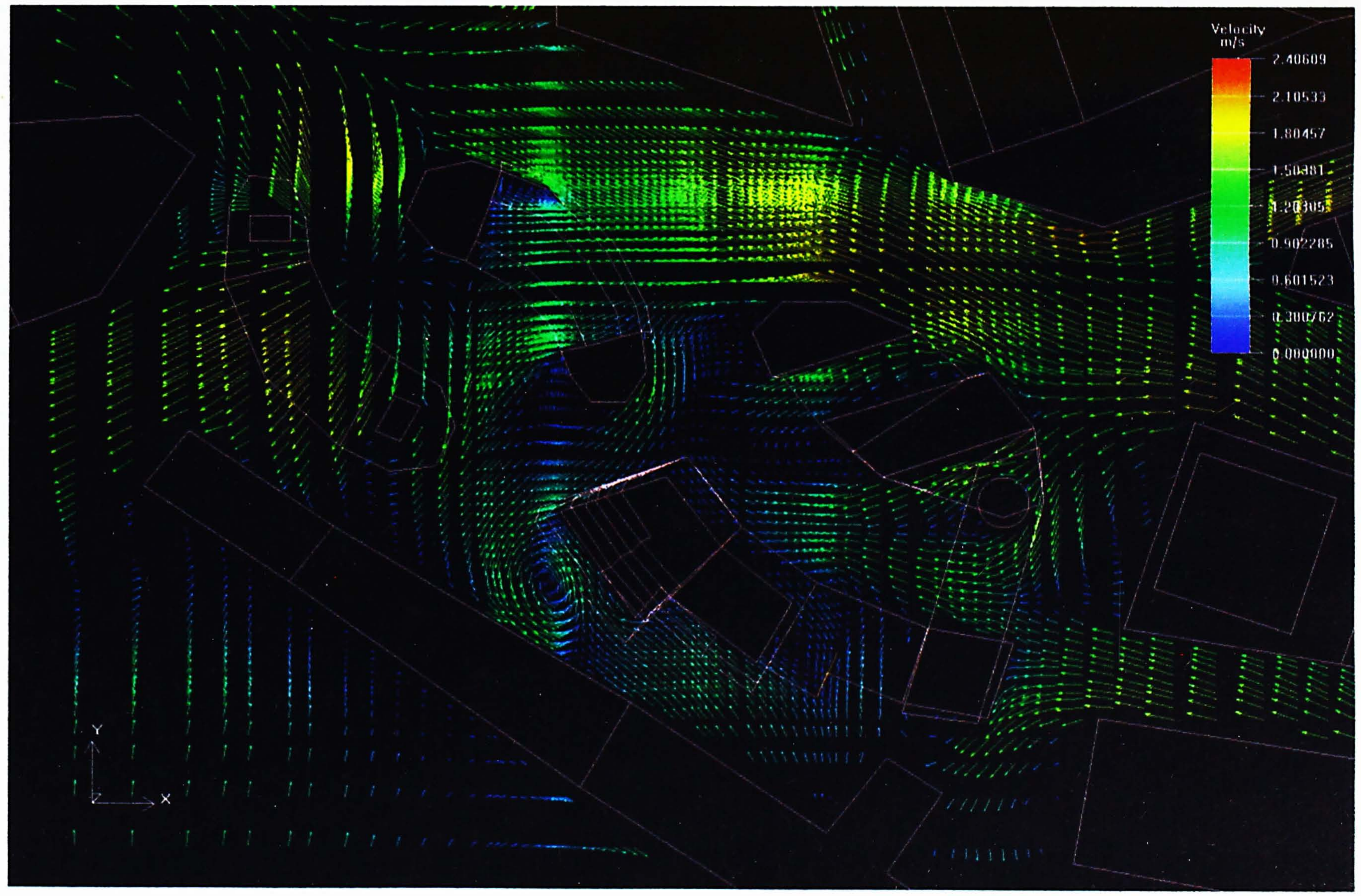
Design adjustments and developments included:

Testing the minimal size of void opening at ground level of mall2 is needed for getting a well ventilated environment for the countyard space between mall2 and mall1 (to minimize polluted air from road traffic to getting in countyard)

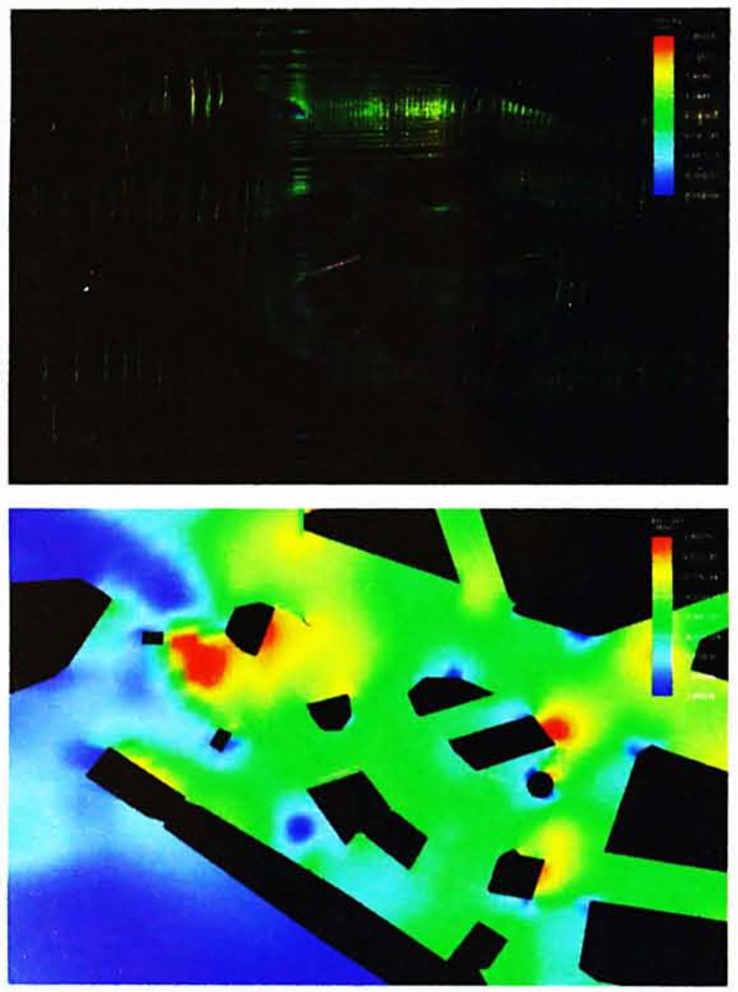
Lower level of the residential is recessed to further enhance the wind flow at ground level.



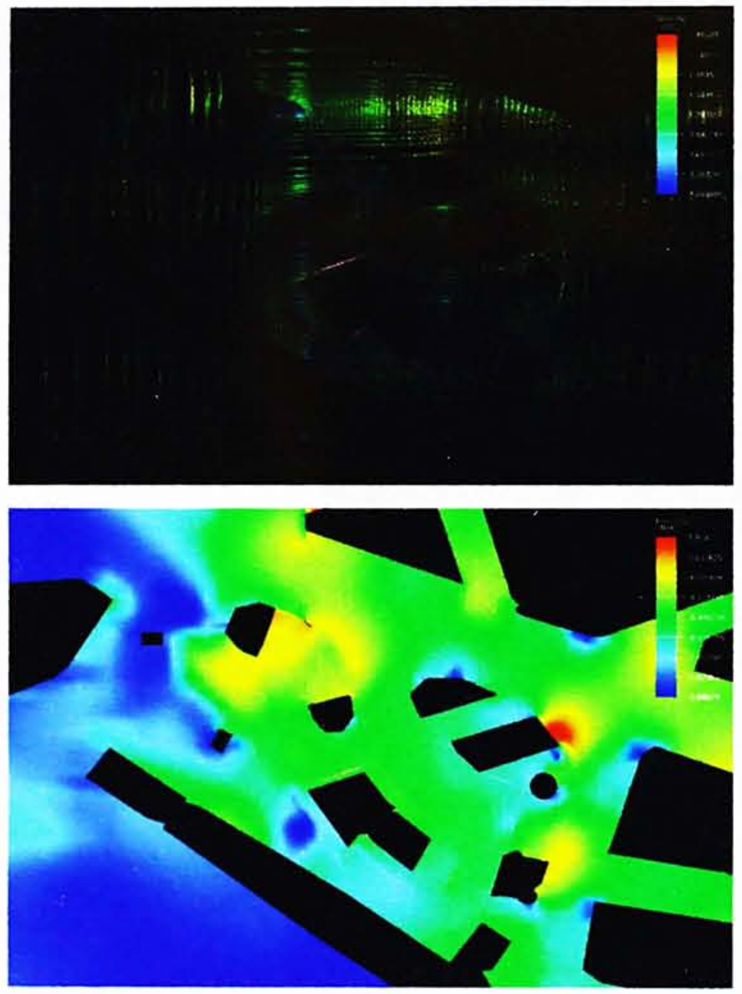




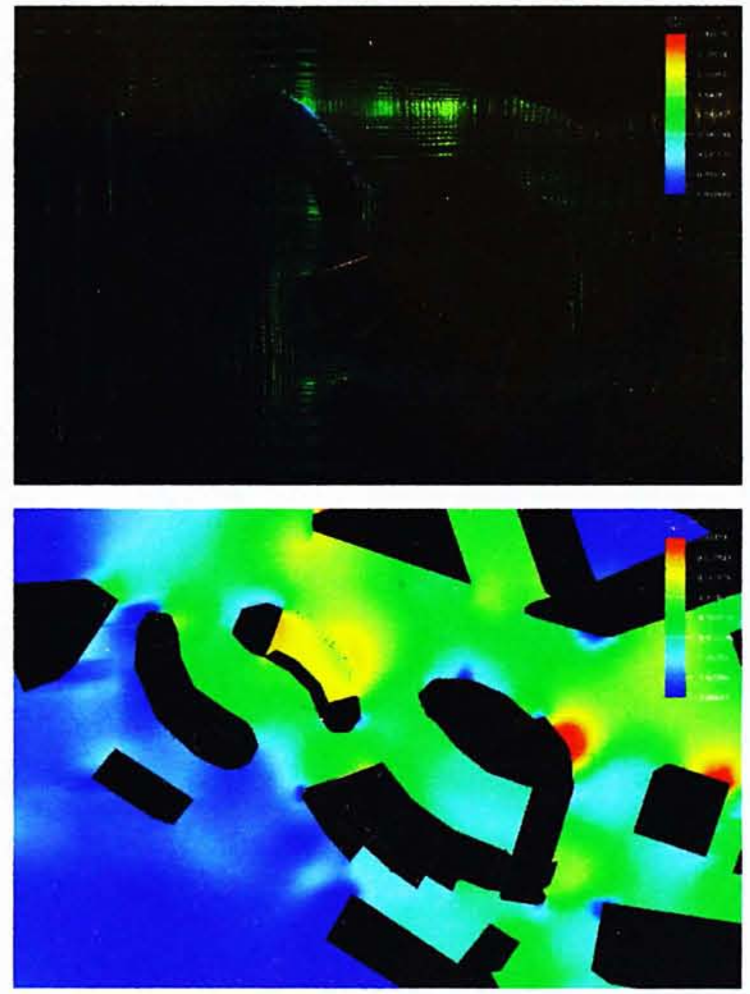
Stage Five - Wind and Pressure Distribution at different level



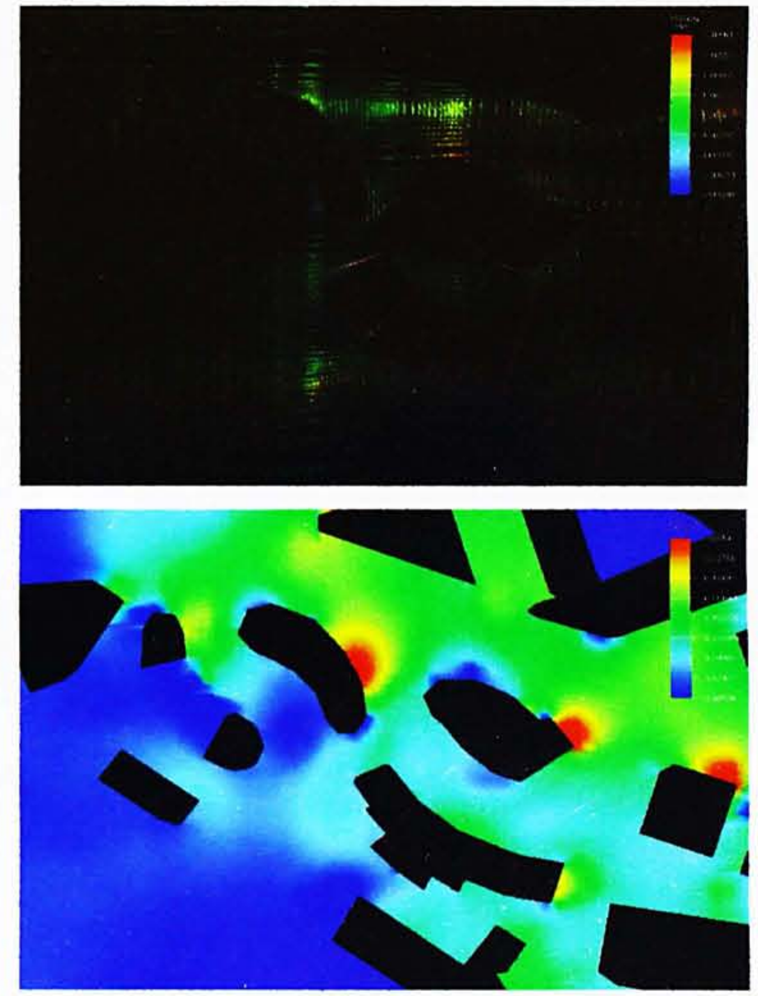
at 2m



at 10m

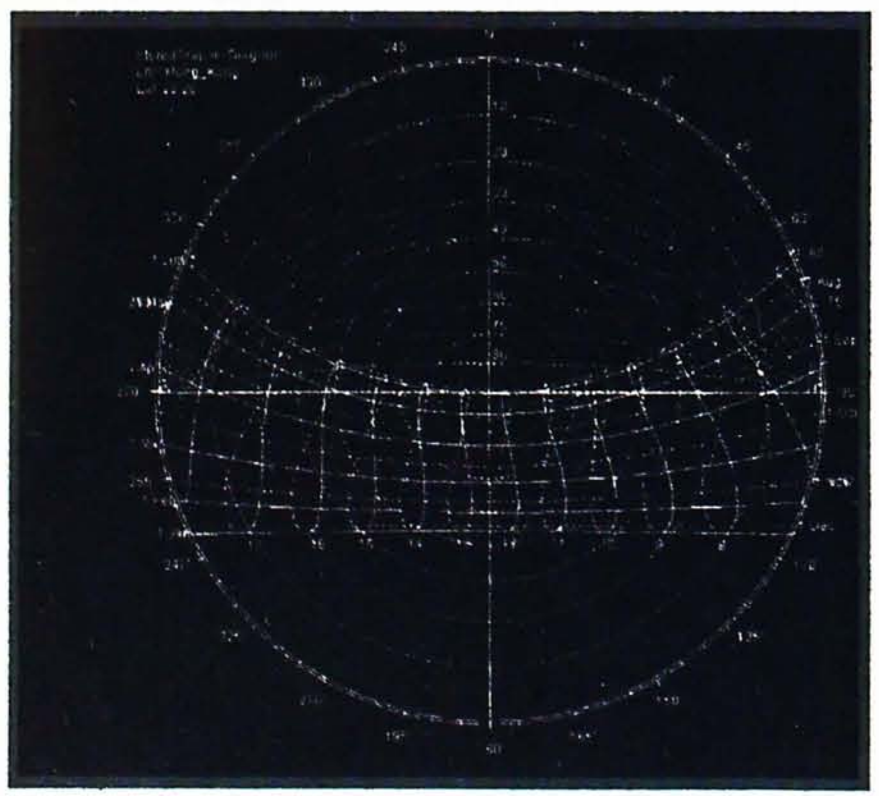


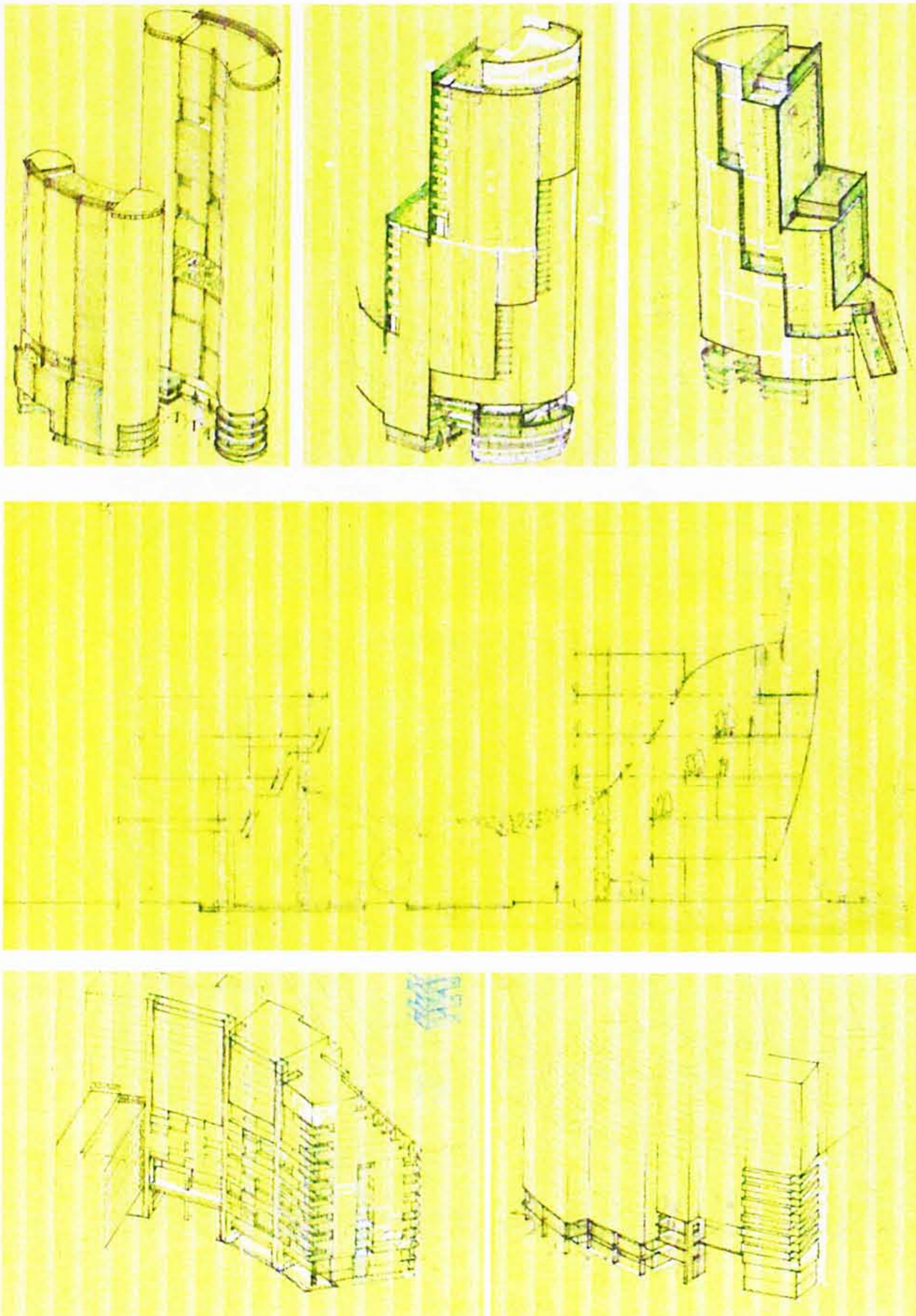
at 30m



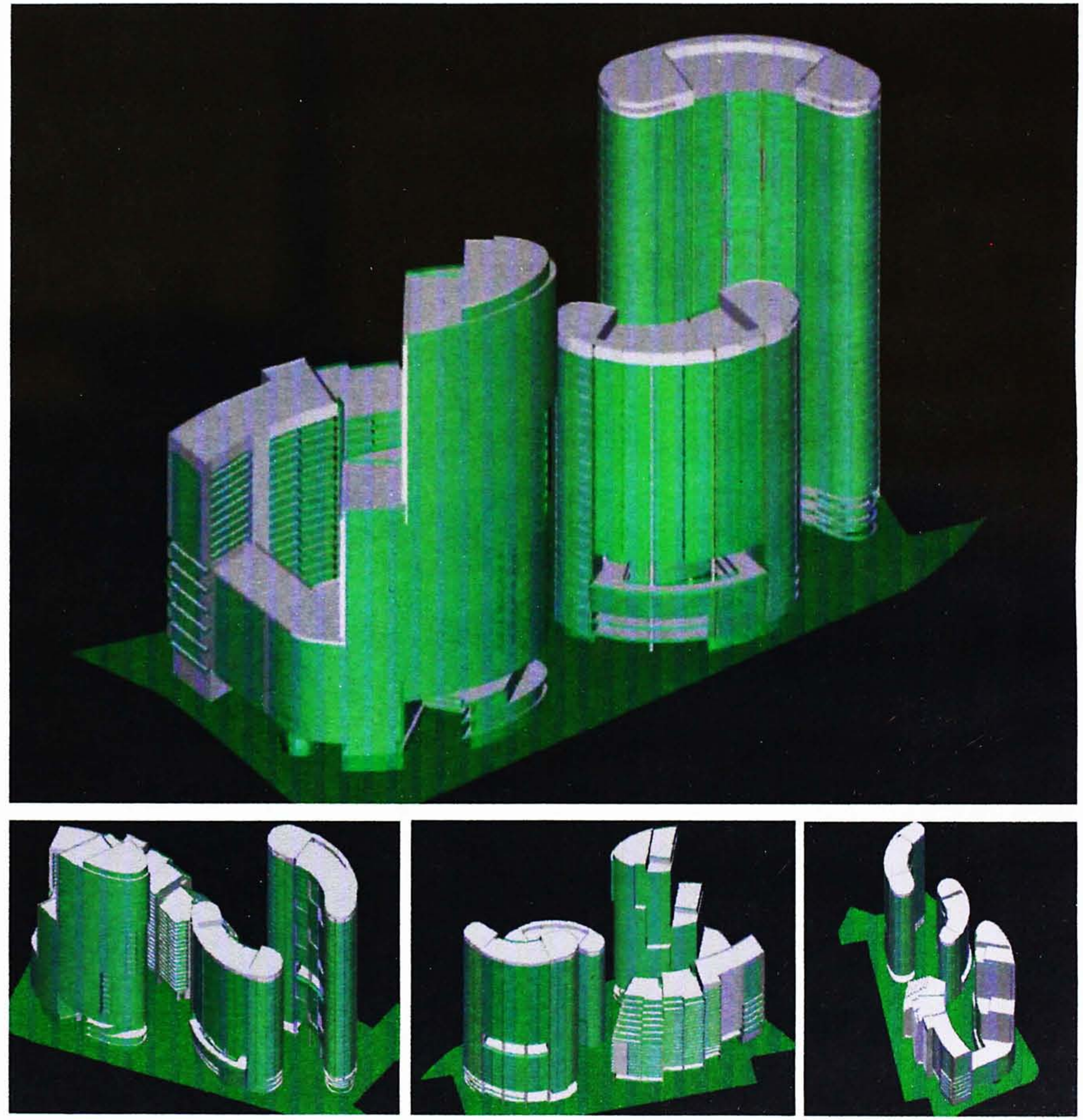
at 60m

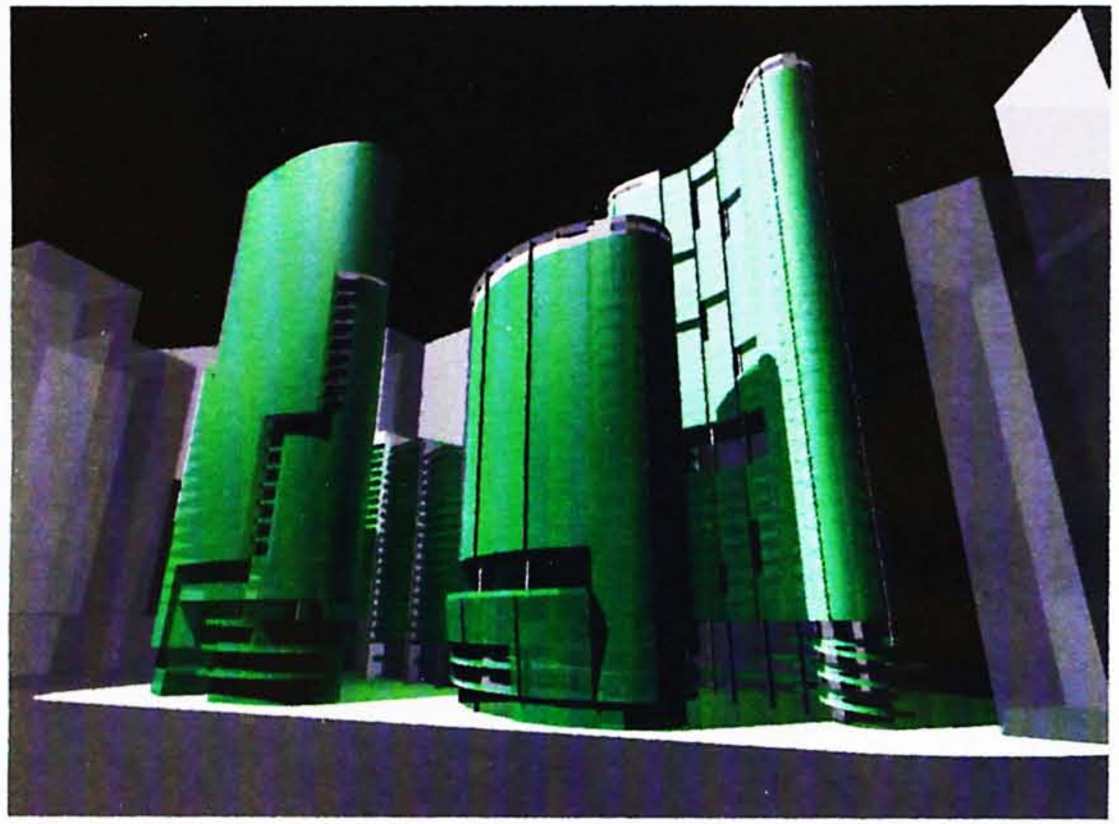
Summer Interblock Shading

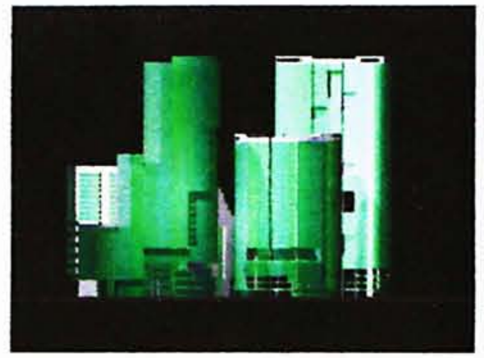


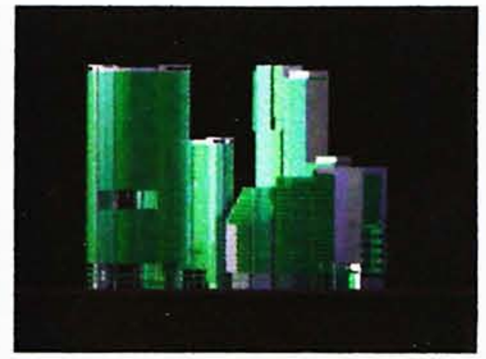


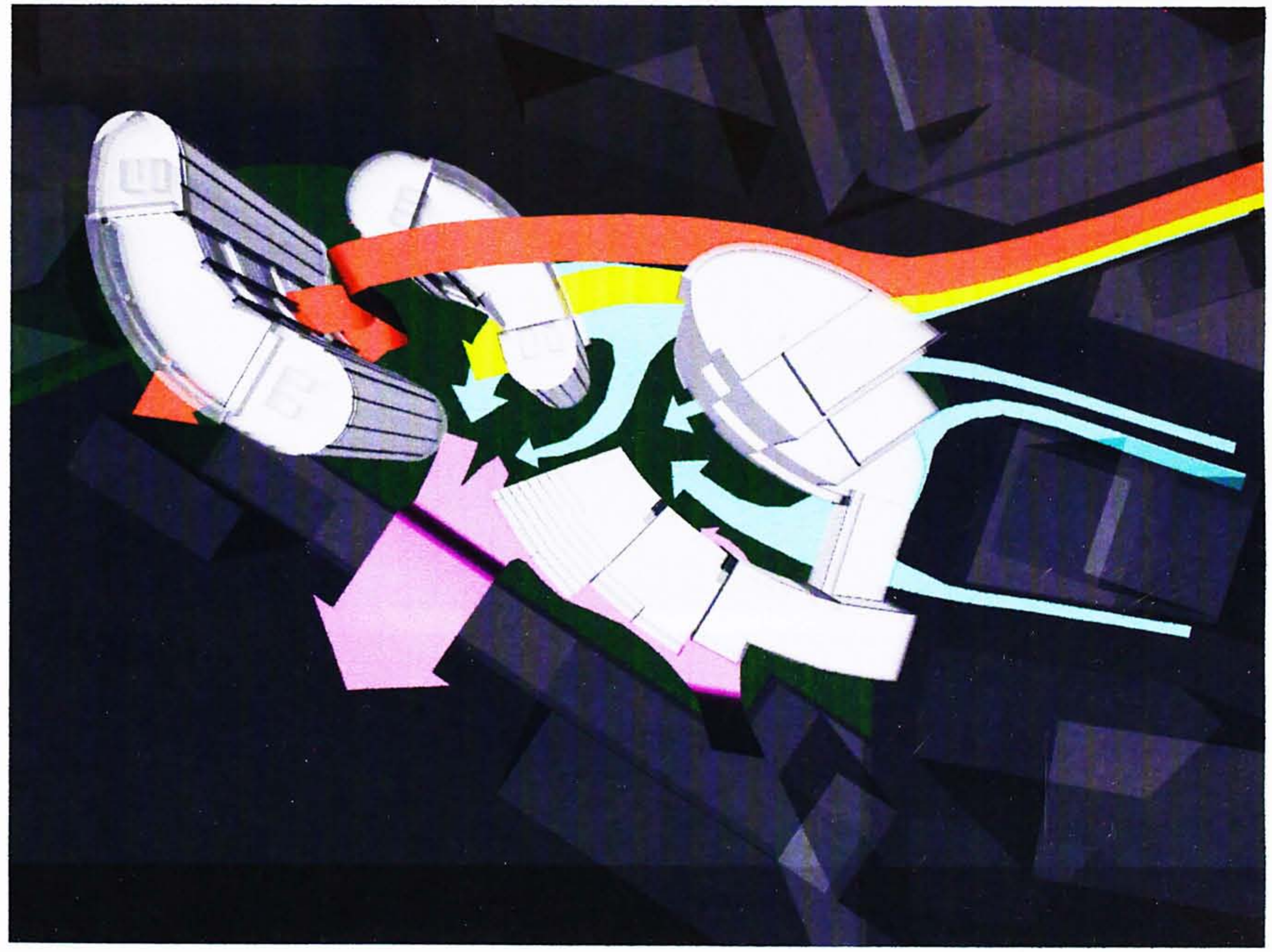
Refined Model



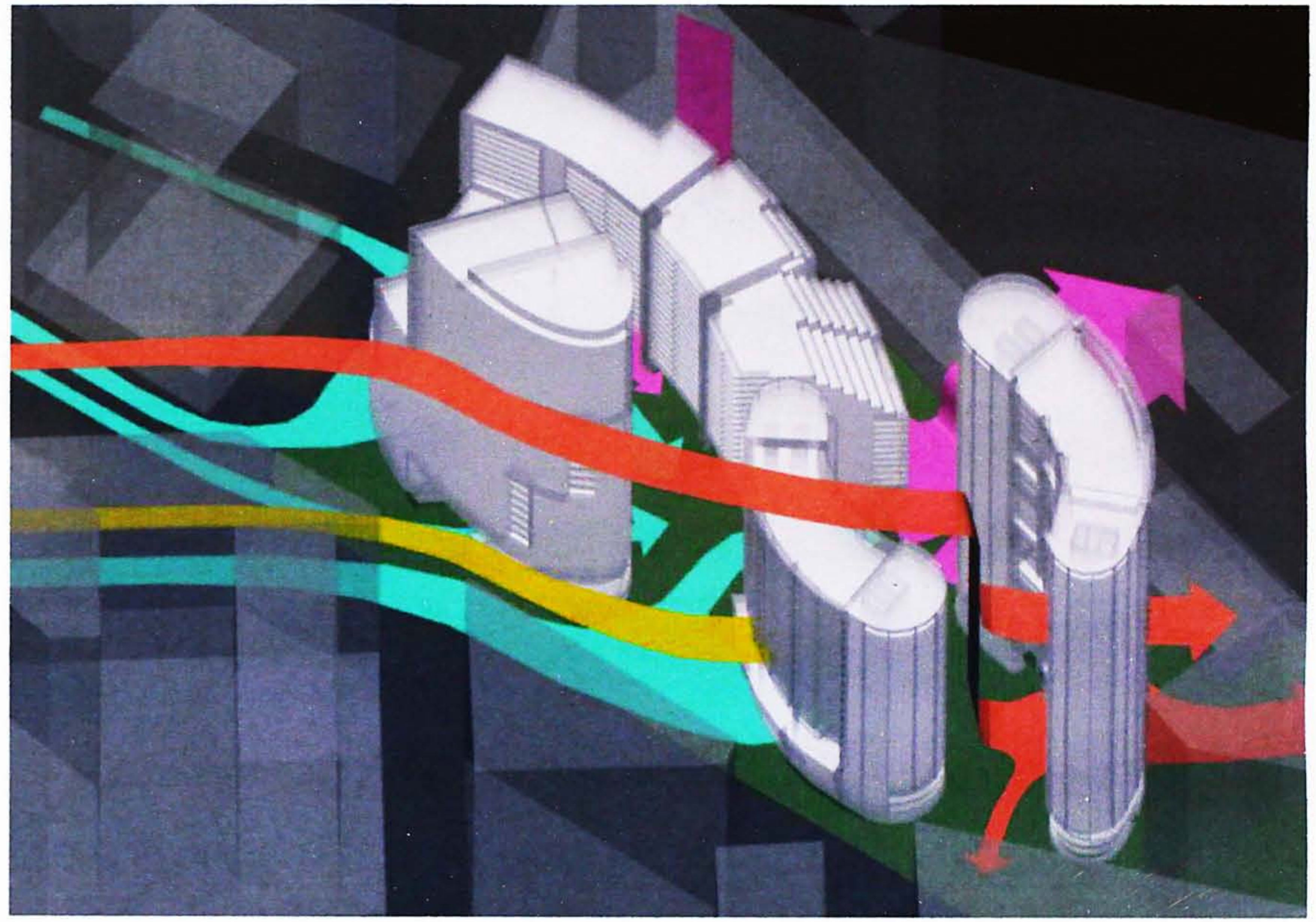


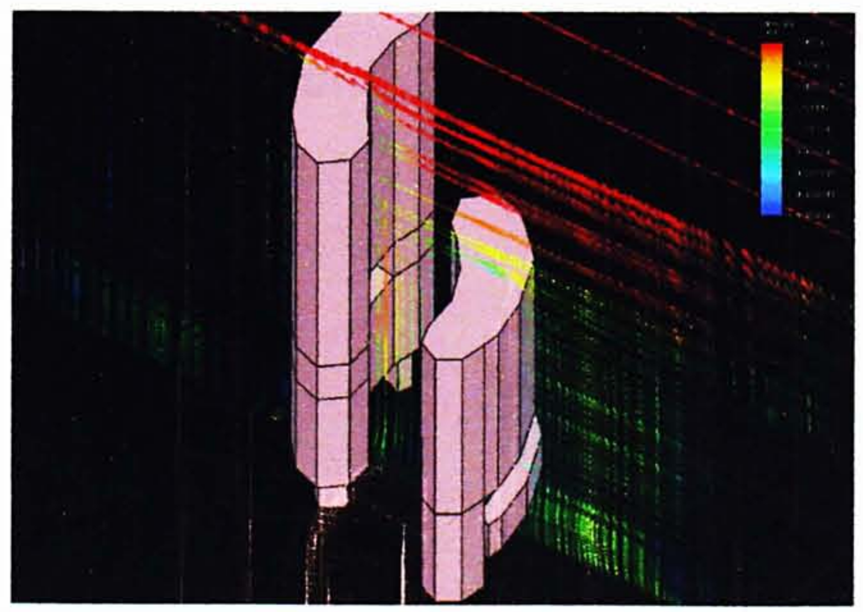


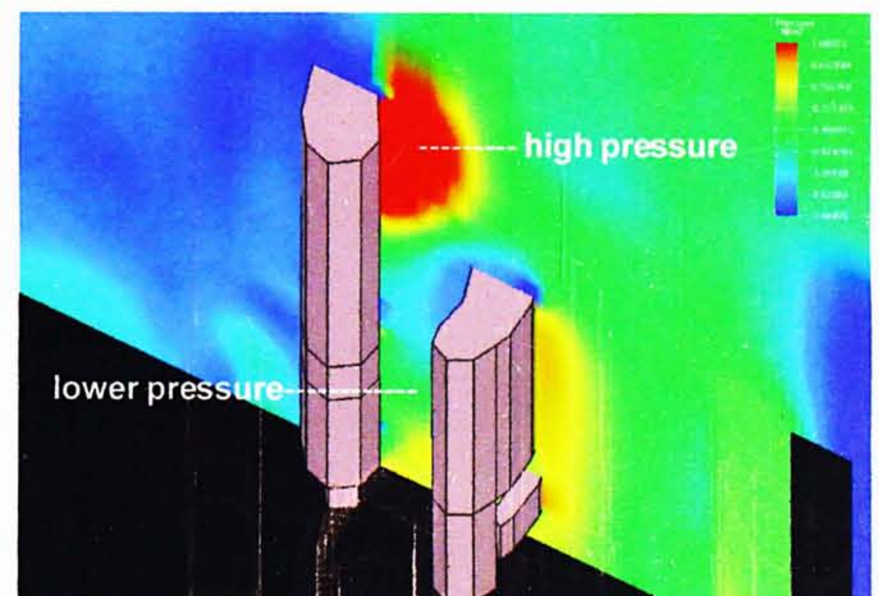


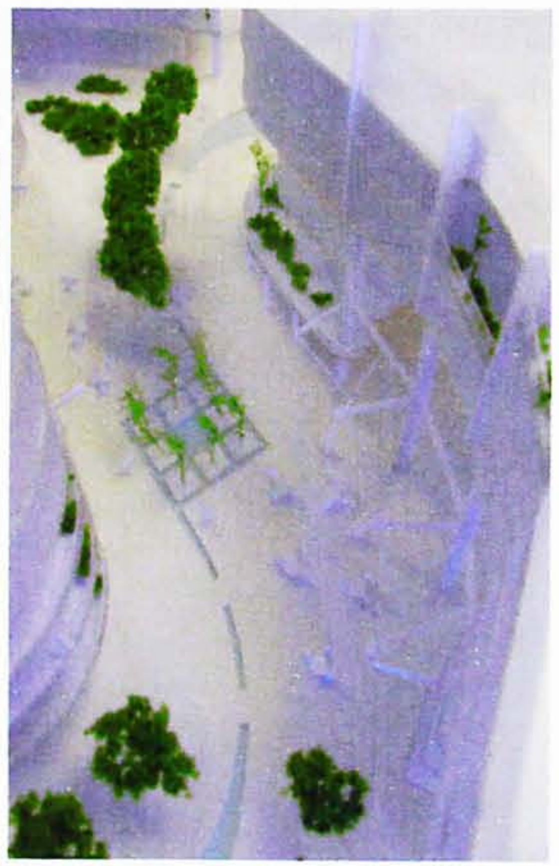


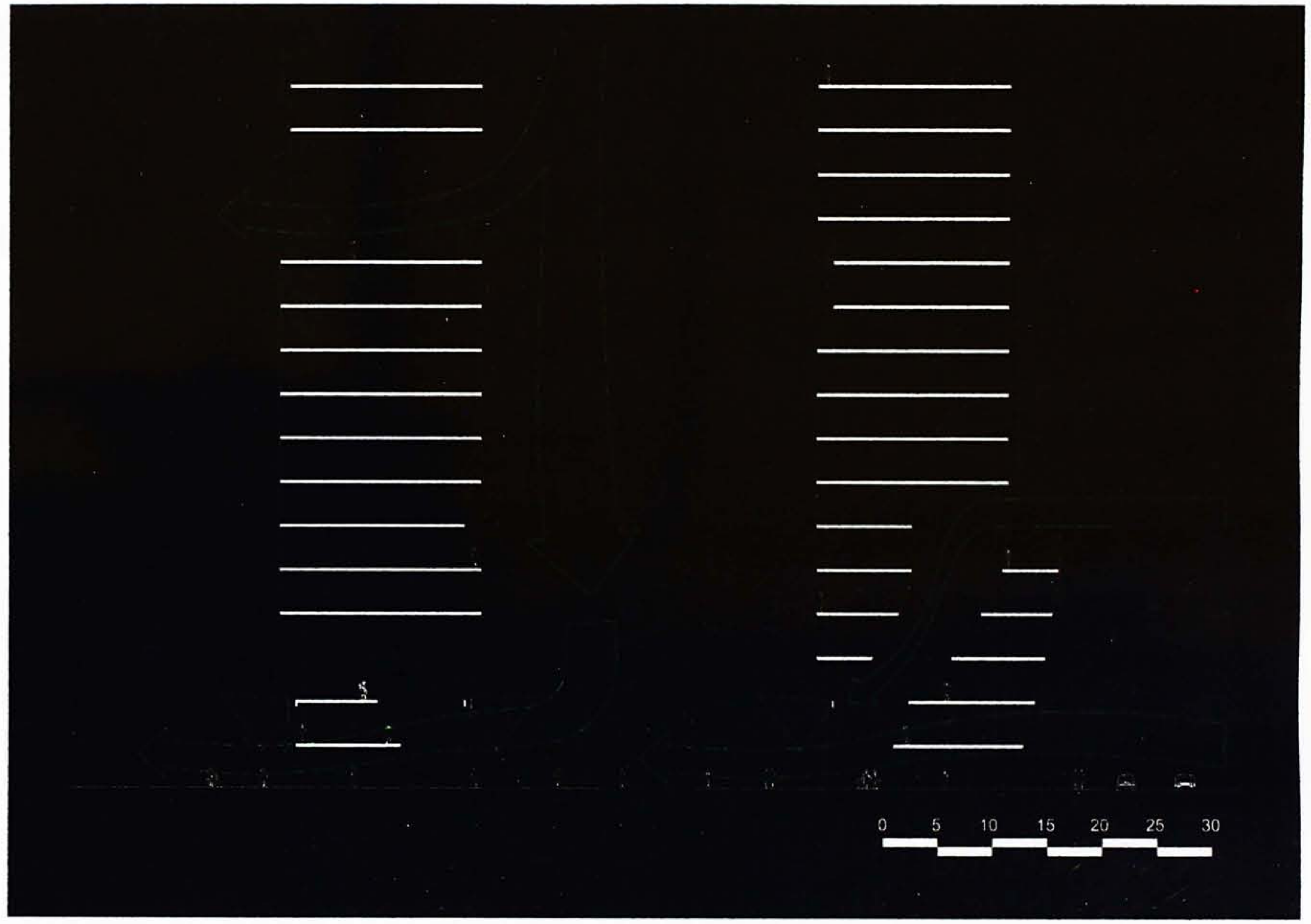
Low-High Building Group Combination generate downwash wind to ventilate orginally wind shadowed area





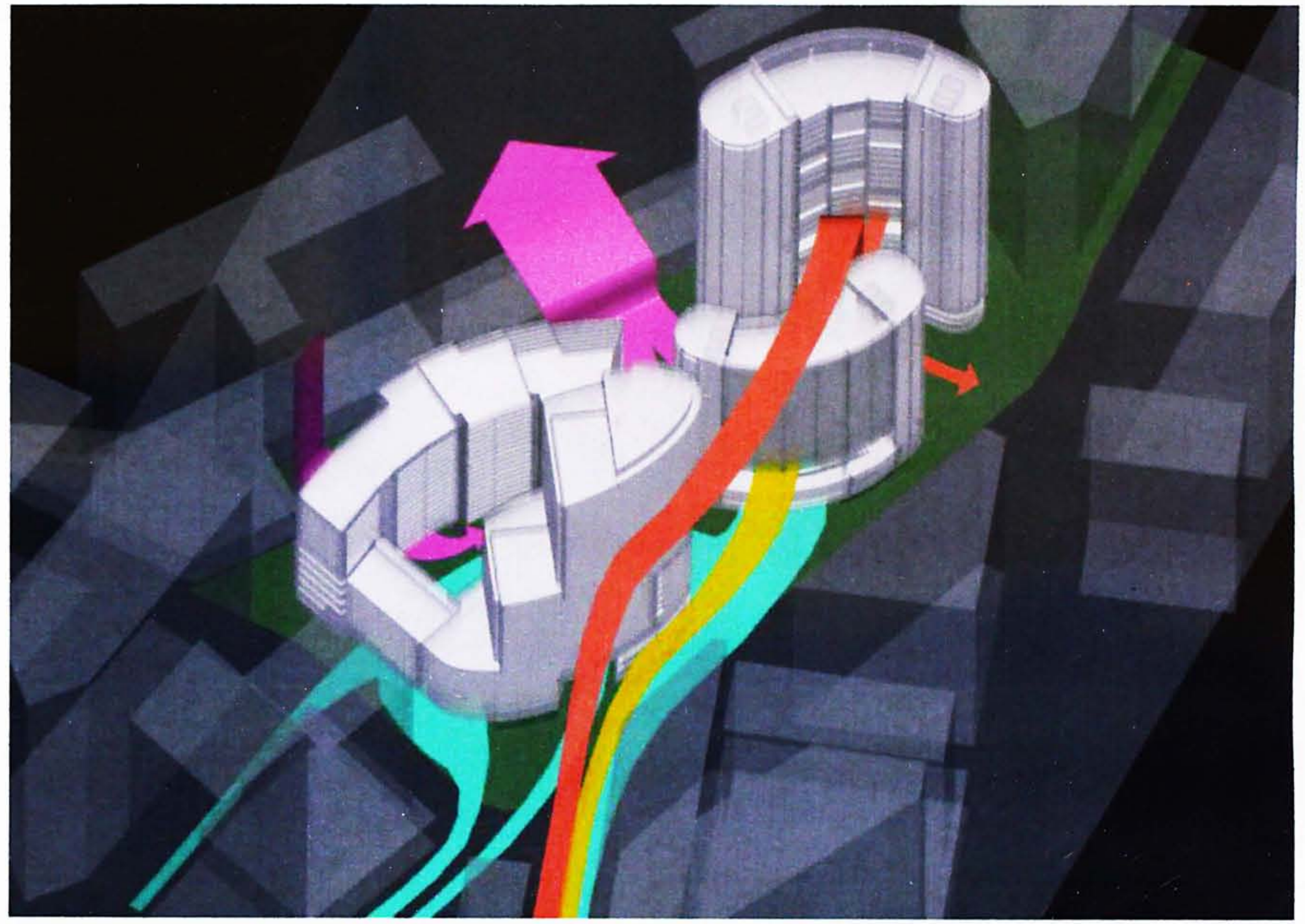


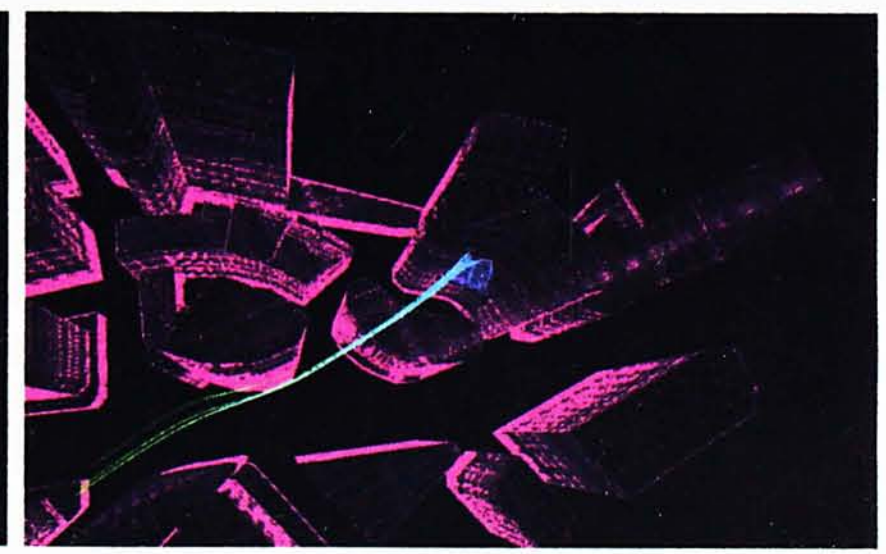


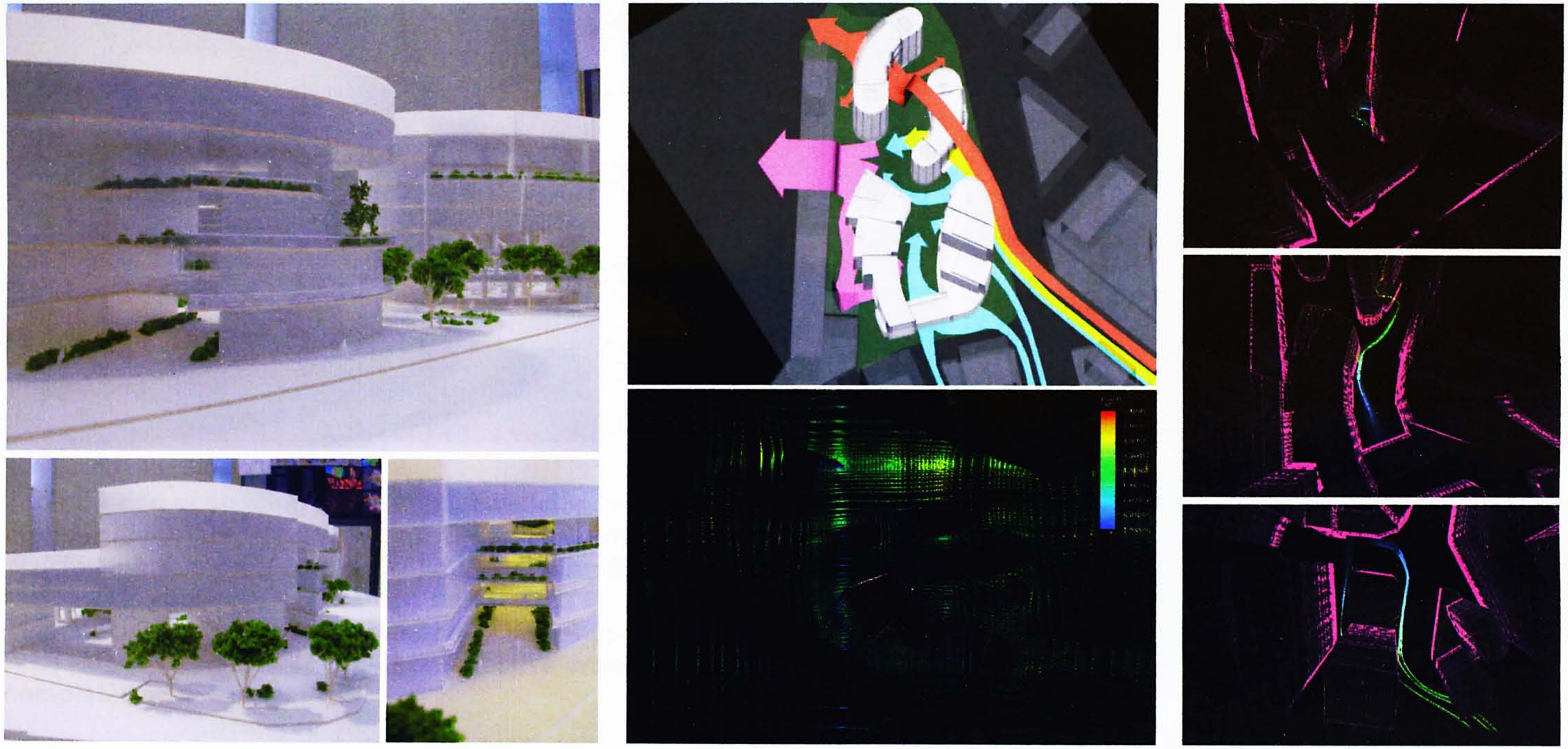


Mid-level Opening for catching wind down from higher level to lower level.

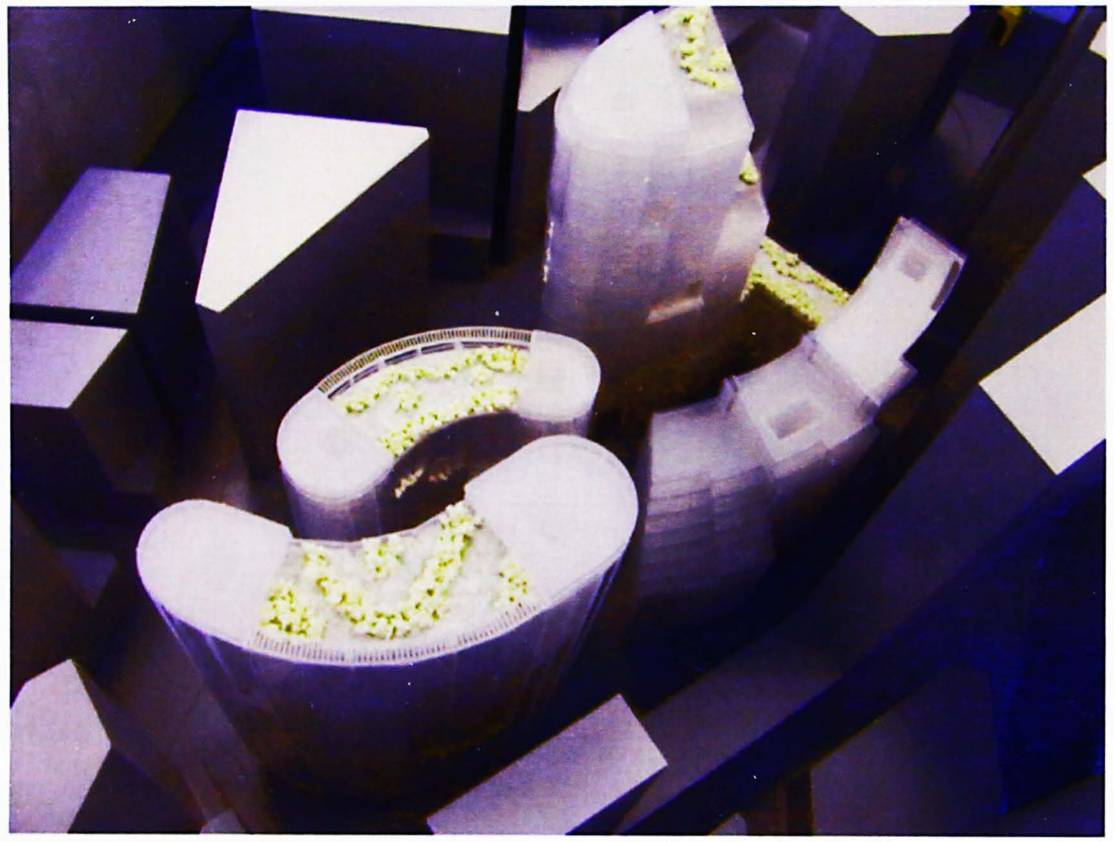
Building Geometry and Composition of building group help deflecting wind to decided location

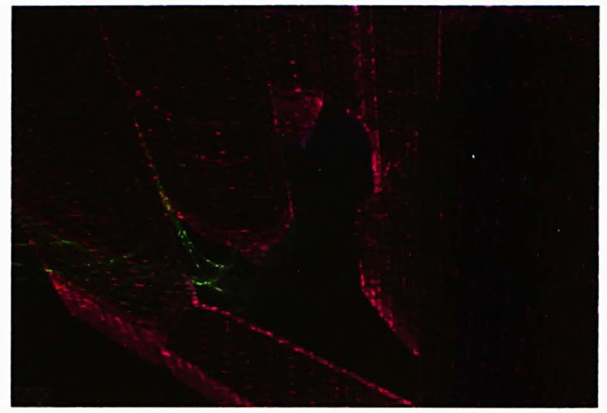


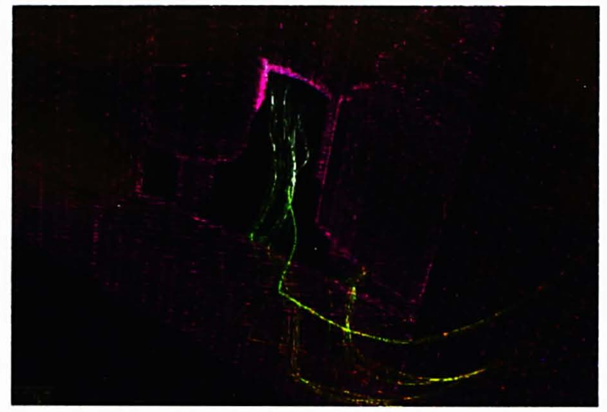


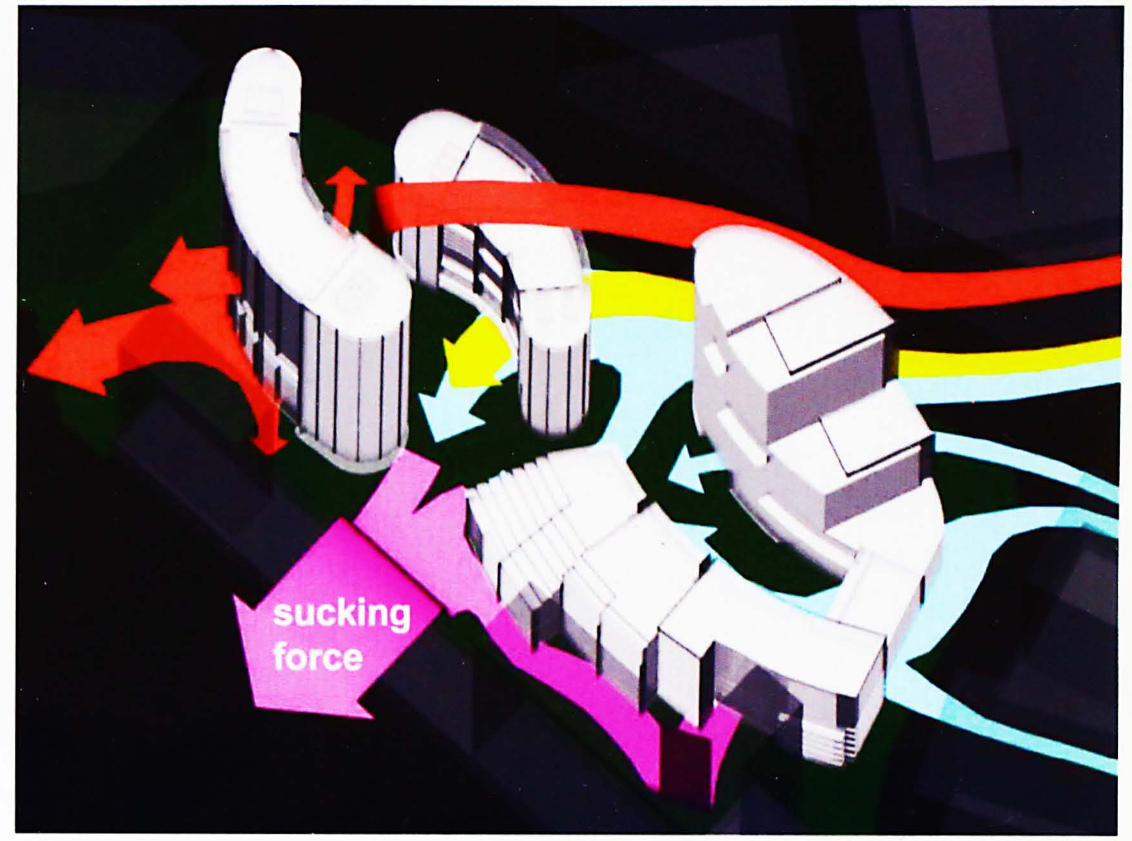


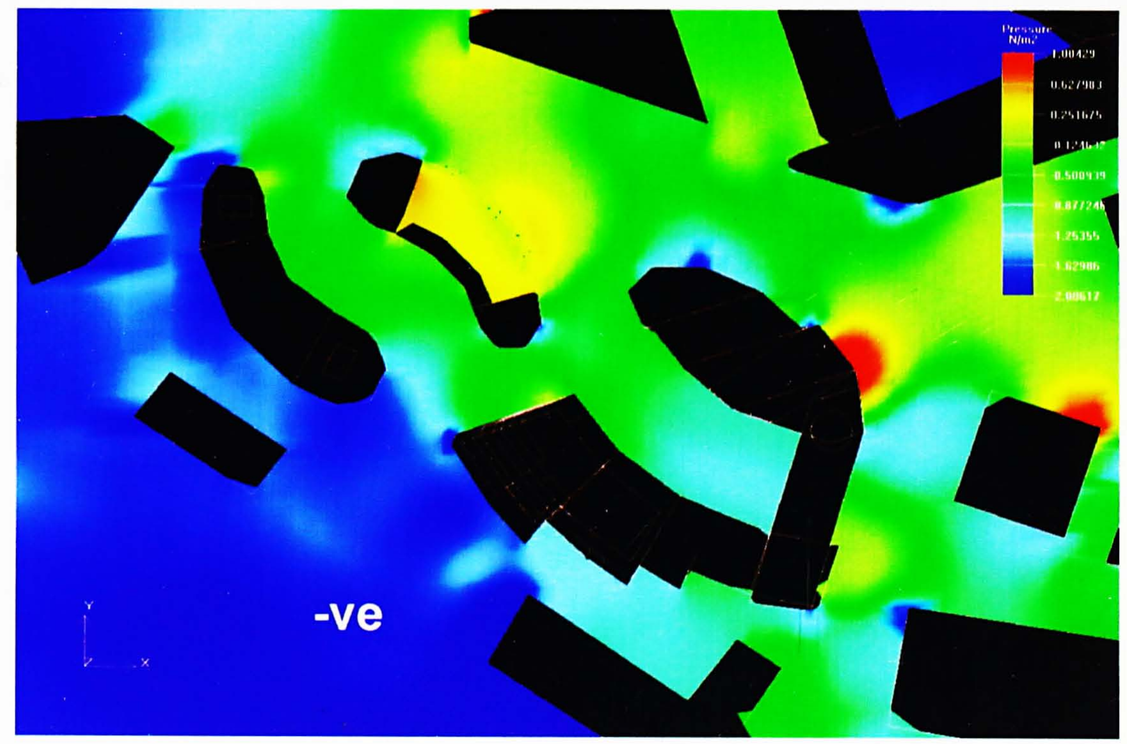
Elevated ground level facilitated better ground level wind flow and penetration for predestrian.



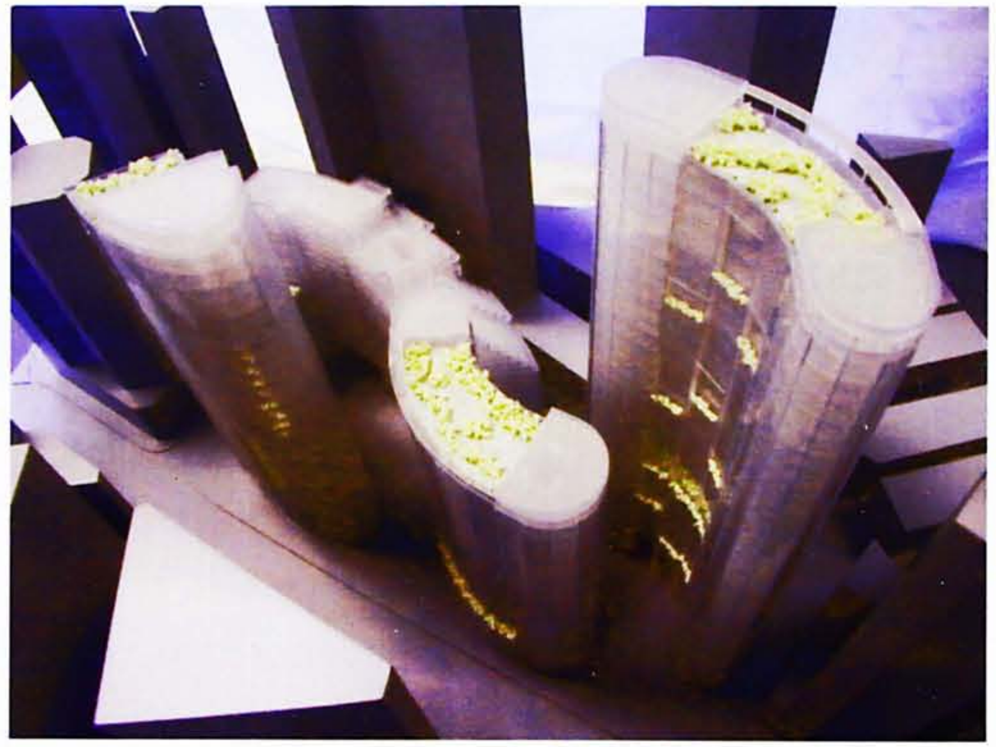
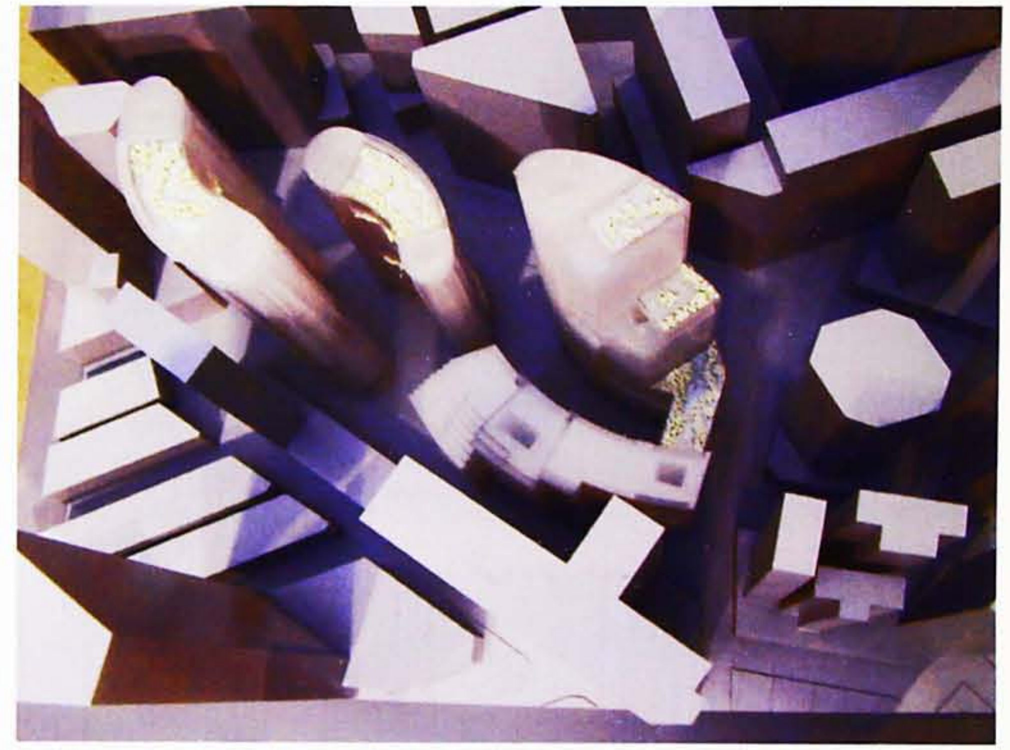




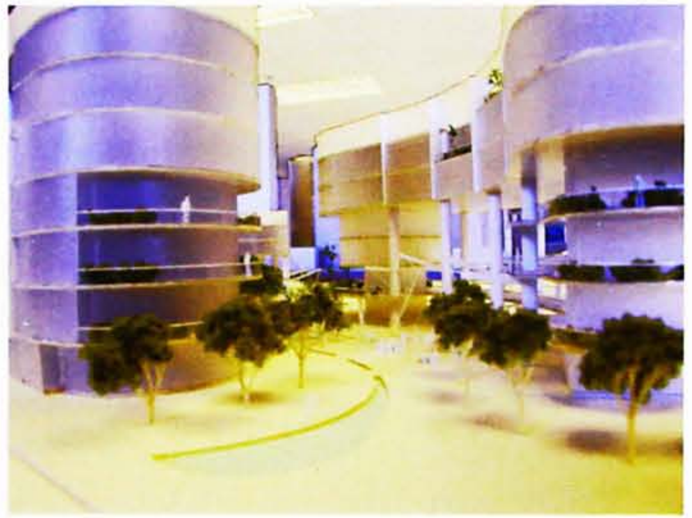
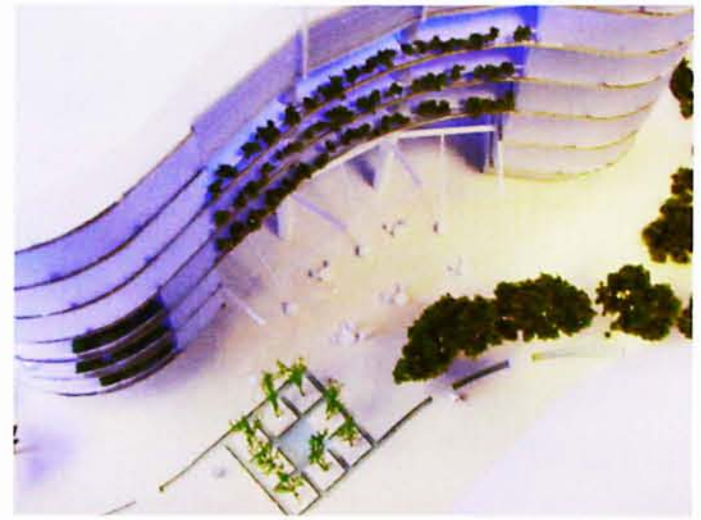
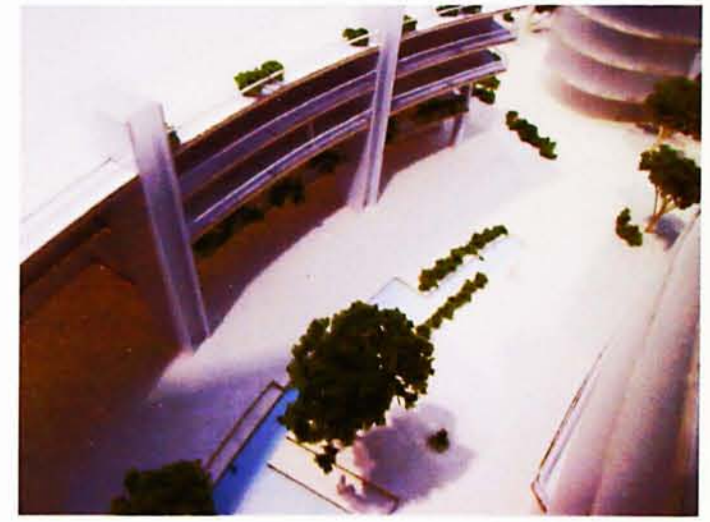


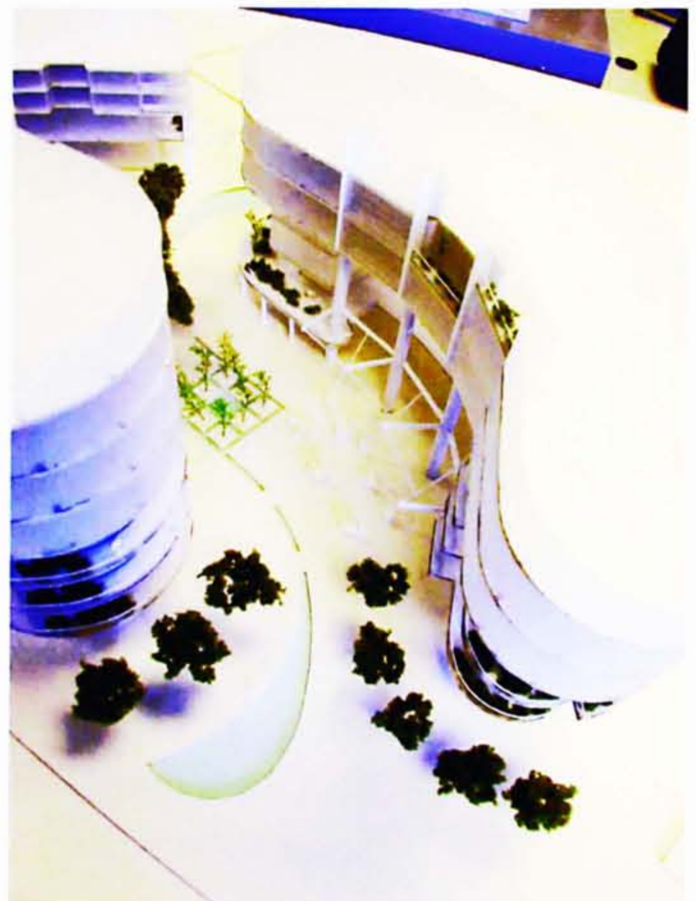


Composition of building group can be designed to take advantage from the surrounding built environment. By paying attention to the pressure distribution and providing appropriate spacing for the flow path, sucking action by negative pressure can be created. It is a wonderful means to induce ventilation even for area hardly be ventilated in conventional way. With pull and push force together, effective cross ventilation can then be completed.





CONCLUSION

Hopefully this project helps generating in-sights for future wind responsive planning in Hong Kong. Actually, urban ventilation should be done in city scale for seeking fundamental improvement in the urban wind environment. Wind condition can only be enhanced through the combine effort from different city elements all together.

Wind responsive design does not necessarily mean fancy and expensive design especially in the scale of urban planning, it could be simple, affortable and manageable by applying simple but effective wind modifying factors.

Land divided in small pieces with similar size should no longer be encouraged for future development as it does not only limit the room for buildings to respond to the nature but also generate monotone buildings with similar heights and and similar volumn which is very bad for urban ventilation.

The orientation of city grid which is now respond only to the shore line should also be considered to align with the prevailing wind for getting better wind flow within city.

Density could be maintained in wind responsive development by increase the height of buildings but freeing up more space between buildings.

Height of buildings should be managed in a way to encourage variation of height within group of buildings. Plot ratio should not be the only guide for height control.

Once street ventilation in urban environment is successfully achieved, better air quality in urban environment can then be possible, and hopefully one day we can feel comfort to open up our windows and able to breath fresher air even in urban area.