APEC-WW Economy Report 2012: Hong Kong

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ABSTRACT: This report outlines the research and studies carried out in Hong Kong on wind loading guidelines and wind-related environmental problems during the last two years. The development of wind codes and legislation related to wind environment and air quality in Hong Kong is also reported.

KEYWORDS: Wind loading codes, wind loads, urban pollutant dispersion, urban wind climate, air quality standards

1 INTRODUCTION

This report summarizes wind engineering activities in Hong Kong during 2011-2012. The current Hong Kong Wind Code was introduced in 2004 and Hong Kong Government embarked on a general review of the Code. The Government continues its efforts to improve environmental wind conditions within the densely built up city fabric of Hong Kong through city planning. In tandem with increasing coverage of air ventilation assessment for building developments, the Government released for public consultation the recommended Hong Kong Urban Climatic Map and wind performance criteria for urban air ventilation. There is also development on outdoor air quality standards for Hong Kong.

Active wind engineering research is carried out at five leading universities in Hong Kong, namely, The University of Hong Kong (HKU), Chinese University of Hong Kong (CUHK), The Hong Kong University of Science and Technology (HKUST), Hong Kong Polytechnic University (HKPolyU) and City University of Hong Kong (CityU). The topics include wind loading of tall buildings and bridges, air ventilation and pollutant dispersion in city fabric, wind tunnel investigations and computational wind engineering.

The Hong Kong Wind Engineering Society was established in August 2011 and was accepted as a member organization of the International Association for Wind Engineering.

2 REVIEW OF HONG KONG WIND CODE 2004

The current wind code of Hong Kong was in force from 2004 [1] but wind codes of many other countries have been undergoing revisions since 2004 in recognition of the advancement in the field of wind engineering. In 2008, a technical committee, with members comprising representatives of various government departments, academic institutions and the Hong Kong Institution of Engineers (HKIE), was formed by the Hong Kong Buildings Department (BD) with the primary aim to consider if the 2004 Code shall be updated. After a few meetings and

extensive discussions, the committee had recommended the BD to conduct a general review of the 2004 Code. In April 2011, the BD commissioned a consultant to study the current practices of overseas wind codes, identify the latest development in wind engineering, and produce a comprehensive and up-to-date wind code of practice for building design in Hong Kong. The expected delivery date of the consultancy is August 2013. A steering committee was formed in June 2012 to give direction to the consultancy study and monitor the progress of the study.

The following main issues and topics will be addressed in this review of Hong Kong wind code. The meteorological data adopted in the 2004 Code were based on the wind data kept by the Hong Kong Observatory (HKO) covering the period between 1953 and 1994. The study will review the design wind speeds from a statistical analysis of the updated meteorological data including those after 1994. The study will also consider Monte-Carlo simulation data for the estimation of design wind speeds. Extreme wind speeds in Hong Kong are mainly due to typhoons (tropical cyclones or hurricanes). A change in the tropical cyclone activity around Hong Kong will lead to a change in extreme wind speeds. It is therefore meaningful to review the effects of climate change on tropical cyclone activity around Hong Kong. The design wind speeds specified in the 2004 Code are all-direction values and there is no provision for wind directionality. However, wind-tunnel testing of many building projects in Hong Kong employ wind climate studies for Hong Kong which enable the use of directional design wind speeds for different wind directions. A review on the determination of directional design wind speeds is considered necessary for more realistic assessment of wind effects on buildings in Hong Kong and for a consistent approach in the operation of wind tunnel testing. The review study will also consider other issues such as appropriate return periods and load factors for wind loads, design equations for wind-induced dynamic responses in the across-wind and torsional directions, building acceleration criteria occupant comfort, and provisions for wind tunnel testing.

3   WIND PROFILES IN TROPICAL CYCLONES

HKUST is carrying out an analysis of wind profiles observations in tropical cyclone events. The mean typhoon wind profile in the atmospheric boundary layer is important in meteorology and wind engineering. The study aims to unitize the typhoon wind measurements taken during 2007-2009 in Hong Kong by wind-profilers and Doppler Sonic Detection And Ranging (SODAR) in order to calculate both the hourly mean and 10-min mean wind profiles up to the height of 1000 m.

Two types of mean wind profiles are calculated, namely the hourly mean wind profiles and the 10-min mean wind profiles. Both types are fitted to the empirical profile function introduced by Vickery et al. [2], the log-law and the power-law. The hourly mean wind profile measured during the period of Typhoon Fengshen (2008) and the fitted model profiles are shown in Fig. 1. As indicated by the figure, the observed hourly mean wind profile appreciably fluctuates around the model profile predicted by both Vickery's equation and by conventional models (the log-law and the power-law). Moreover, the model profiles share the same trend, in which the mean wind velocity increases monotonically with height. While this is expected from the model profiles produced by the log-law and the power-law, the model profile calculated based on Vickery's equation conflicts its theoretical nature, which should produce a wind maximum below the height of 1000 m. The results show that the super-gradient feature, which is commonly observed for typhoon winds over the sea, is not obvious in the mean wind profiles analyzed.

To more systematically and precisely investigate the fitting results, the model parameters of the fitted model profiles are presented in Table 1. From Table 1, it can be found that the parameter H^* produced by fitting the observed hourly mean typhoon wind profile to Vickery's equation is around 918.24 km. Considering that H^* indicates the height scale of the

atmospheric boundary layer under typhoon conditions, which is also an approximate height where the super-gradient wind should be found, this unrealistic large value of H^* indicates that the profile shown in Fig. 1 below 1000 m can be accurately described by the log-law and the additional term in Vickery's equation is negligible comparing with the log-law term. Considering that the additional term is used to model the super-gradient feature of typhoon winds, the hourly mean wind profile shown in Fig. 1 and the fact that $H^* \approx 1000$ km reveals that such feature is not observed by the Siu Ho Wan station during the passage of Typhoon Fengshen (2008). In addition, it has been found that that the surface roughness derived by fitting the observed profile to the log-law is unusually high ($z_0 > 1.5$ m). The possible explanations of this phenomenon include (1) the influence of large scale topography and (2) high waves introduced by strong typhoon winds.

Table 1 Model parameters for fitting the hourly mean wind profiles

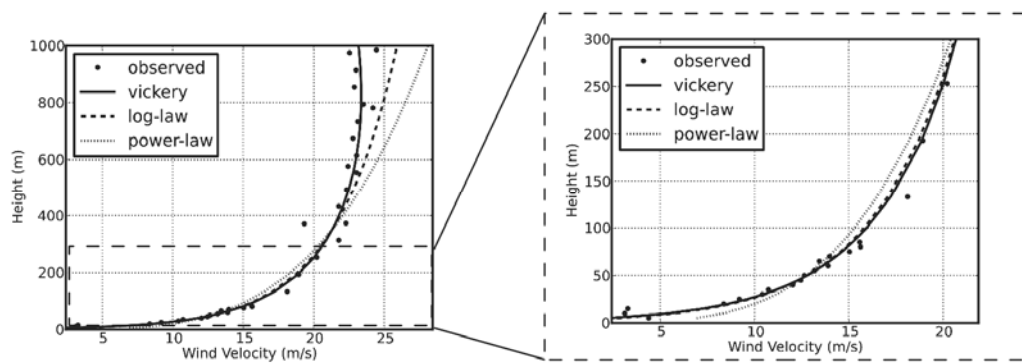| Profile Name	Vickery Function			Log-law		Power-law	
	u_* (m/s)	z_0 (m)	H^* (km)	u_* (m/s)	z_0 (m)	U_{10} (m/s)	α
Fengshen	0.62	0.015	918	0.50	0.002	11.22	0.08
Nuri1	0.92	0.289	3443	0.68	0.042	9.95	0.12
Nuri2	1.41	0.997	5711	0.94	0.118	11.19	0.15
Nuri3	1.02	0.528	3644	0.80	0.310	9.54	0.14
Molave	1.83	3.072	0.73	1.75	2.704	8.30	0.26

Figure 1. Comparison between the hourly mean wind profile observed and fitting results produced by various models from Typhoon Fengshen (2008) during 02:50 to 04:00 on 2008-6-25 in Hong Kong local time.

4 WIND LOADING OF BUILDINGS AND STRUCTURES

4.1 *Pressure characteristics for a double tower structure*

At HKUST, wind pressure characteristics on a double tower high-rise structure, which is disturbed by surrounding buildings, are investigated using large eddy simulation (LES) and 1:300 scale wind tunnel experiments. Comparisons of computational results with the experimental data are subsequently carried out to validate the reliability of LES. Comparisons are performed in detail for the mean and fluctuating pressure coefficients. To study further on the pressure coefficients on the building surfaces, parametric studies on shape coefficient and spatial correlation are performed and investigated.

For comparison with the experimental data, a 1:300 scaled model of the target double tower building is used in the computation. The main tower of the model building has

dimensions $L \times B \times H$ = 0.16m × 0.14m × 0.75m. In order to eliminate flow obstacle effect on the inflow and outflow boundary conditions, the length of inflow, outflow and side-flow of the computational domain are 5H, 12H and 5H, respectively, as shown in Fig. 2. The total height of the computational domain is 3H in order to keep the blockage ratio less than 3%. The Reynolds number based on the width L and inflow velocity $U(z)$ at $z = H$ is about 5.4×10^5. Both structured and unstructured grids were used for mesh generation.

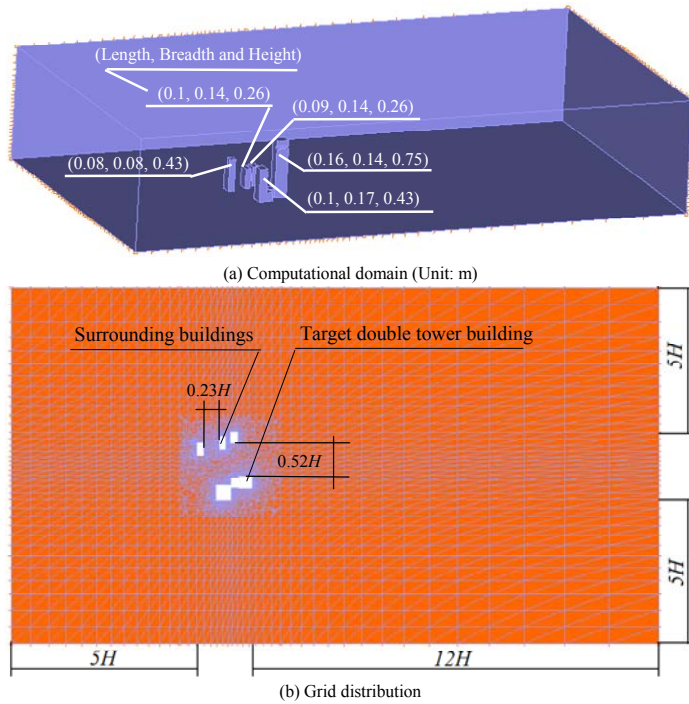(a) Computational domain (Unit: m)

(b) Grid distribution

Figure 2.　1:300 scaled numerical model: (a) computational domain and (b) grid distribution.
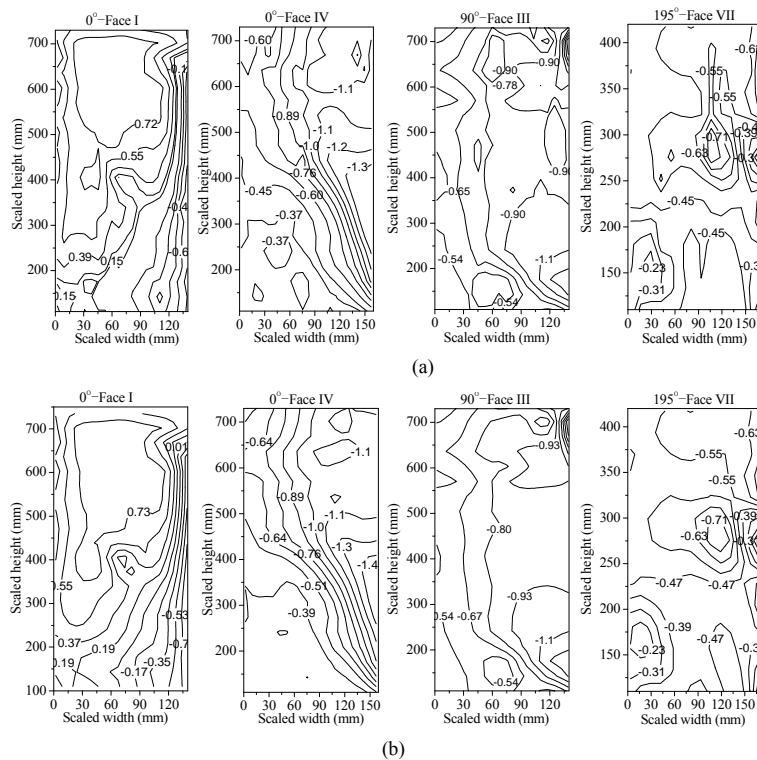

(a)

(b)

Figure 3.　Mean pressure coefficient contours: (a) numerical simulation, and (b) experimental measurements

Mean pressure coefficient contours obtained from numerical simulations and experimental results are shown in Fig. 3. It can be observed that although there were some discrepancies noted on the higher level and the rear face, the mean pressure distributions of the numerical results generally are in good agreement with the experimental results. The small discrepancies were possibly caused by the dissimilarities between the numerical and experimental studies in dealing with model boundary conditions, turbulence intensity, blocking effects, etc. It is well-known that the mean pressure coefficients on the windward face are largely positive for an isolated building. However, in this study the mean pressure coefficients were greatly affected by the interaction and obstruction effects between the main and sub-main towers and the upstream buildings. For example, the mean pressure coefficients of the main tower on the front face were negative on the lower level for 0º wind incident direction, attributed to the influence of the sub-main tower, as shown in Fig. 3. The mean pressure on the side and back faces were also greatly disturbed.

4.2 *Wind loading of noise barriers and noise enclosures on bridge*

The rapid development of infrastructure in Hong Kong has raised the public's concern about vehicular noise generated on highways and other major roads that are often located in close proximity to residential estates and public areas. To minimize the noise impact of a highway on the nearby surroundings, a large number of noise mitigation structures (NMS) have been built along the roadsides in Hong Kong. However, there are currently no specific provisions in design codes and/or standards in Hong Kong for the assessment of wind drag coefficients for some NMS. The CLP Power Wind/Wave Tunnel Facility (WWTF) at HKUST is conducting a collaborative study with the Bridges and Structures Division of the Highways Department (HyD), Hong Kong Government, to study wind drag coefficients on noise barriers/enclosures erected locally at roadsides or on highway structures. The main objective of this study is to determine and develop pressure/force coefficient data that are applicable for the design of noise barriers and noise enclosures to resist wind-induced loads in Hong Kong. The previous country [3] reports described the desk-top study and computational fluid dynamics (CFD) studies of various NMS configurations. The wind tunnel tests are described here.
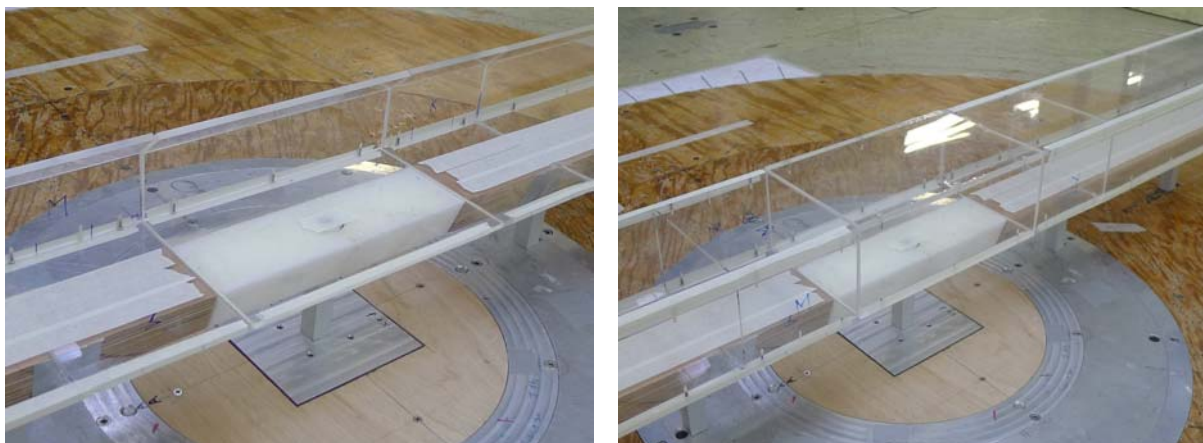

Figure 4. 1:75 scale pressure-tapped wind tunnel models of an inverted L-shaped noise barrier (right) and a noise enclosure (right).

The wind tunnel study was conducted in the WWTF's high speed test section using 1:75 scale models of the bridges, noise barriers and noise enclosures. Scale models of the bridges with noise barriers/enclosures erected were tested using the high-frequency base-balance

(HFBB) technique by mounting each test configuration on a HFBB. A dummy bridge deck was mounted at each end of the tested bridge configurations to eliminate end effects. The tested surface of the bridge decks and dummy bridge segments were fabricated from the same material and with identical cross-sections in order to have consistent surface properties and ensure proper flow simulations around the tested bridge deck. A small gap was included between the tested bridge deck and the dummy segments to ensure that only wind induced forces acting directly on the test segment were measured. For each tested bridge configuration, three force components and three moment components were measured by at the base of the model for two wind directions, 0° and 45°. Measurements were taken for a period corresponding to approximately one hour at prototype scale.

4.3 *Large-eddy simulation of wind effects on buildings*

CityU has been carrying out active research on the application of CFD to the prediction of wind effects on buildings. In this area of computational wind engineering (CWE), the group made some recent developments towards the practical application of LES to model dynamic wind loads on buildings.

A very important issue in obtaining accurate LES results is to generate a flow field as an inflow boundary condition (inflow turbulence) which satisfies prescribed spatial correlations and turbulence characteristics. Currently, there are two kinds of inflow turbulence generation methods. The first method is to numerically simulate turbulent flows in an auxiliary computational domain (often called a driver region where a fluid flow is driven) and the other method provides generation of inflow turbulence by artificial numerical models. The CityU group recently presented a general inflow turbulence generator which was proved to be able to generate a fluctuating turbulent flow field satisfying the desired spectra and spatial correlations including inhomogeneity and anisotropy [4]. The generator belongs to the second kind of method and was developed based on discretizing and synthesizing of random flow generation (DSRFG) technique.

The second important issue of LES is sophisticated SGS (subgrid-scale) turbulence modelling. Despite the development of many SGS models for high Reynolds number flows, the majority of the existing SGS models have limitations in their applications in engineering practice due to two contradictions. The first contradiction is to the low-order discretization and unstructured grid (necessarily adopted for complex engineering problems) with the test-filtering operation that has been used in most dynamic SGS models. The second contradiction is the non-equilibrium characteristics (in high Reynolds number flows and coarse grid situations) with local equilibrium assumption involved in algebraic SGS models. The wall-adapting local eddy viscosity model (WALE) model [5] is one of the exceptions of simple, robust models suitable for engineering applications. Recently, the CityU group developed a new dynamic one-equation SGS model which incorporates the WALE model [6]. The prominent features of this SGS model are: (1) one-equation model, suitable for relative coarse grid situations and simulation of high Reynolds number flows; (2) no test-filtering operation is needed in determination of dynamic parameters, suitable for relative low-order numerical discretization and unstructured or hybrid grid situations; (3) treating the production of SGS kinetic energy and energy loss in grid-scale portion due to SGS motion with different dynamic mechanisms, this is considered to be more reasonable than the local and instantaneous dynamic mechanism adopted by most existing one-equation dynamic SGS models.

The new LES approach is applied to predict fluctuating wind loads on tall buildings and long-span roofs. For example, Fig. 5 shows the along-wind and across-wind force spectra computed for Taipei 101 Tower. The target spectrum of the inflow wind velocity (von Karman spectrum) and the velocity spectrum generated by DSRFG at the building top height in the inlet boundary are also plotted in the figures. The application examples suggest that: (1) the inflow turbulence is of great importance and necessity in the accurate evaluation of the

dynamic wind loads on the tall building; (2) the new SGS model can be adapted for simulation of a wide range of flow regime, including laminar, transitional and fully turbulent flows by virtue of the dynamic SGS production term. The proposed SGS model integrated with the DSRFG technique can provide satisfactory predictions of the wind loads on the super-tall building with Reynolds number of 10^8 based on the approaching flow velocity and the width of the building. The CityU group is also working on CWE of unsteady wind-driven rain prediction by combining LES with the Eulerian multiphase model.
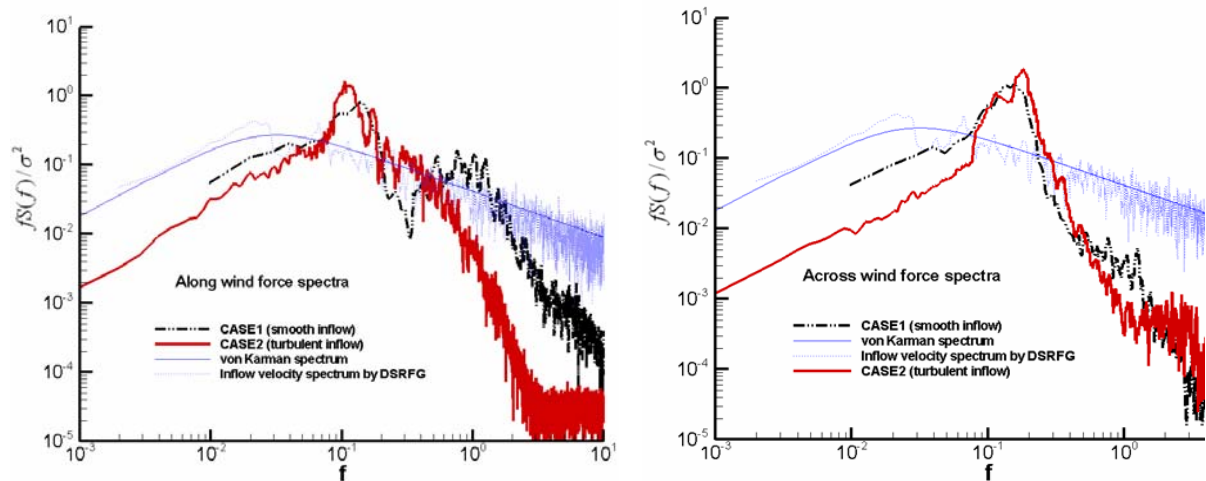

Figure 5. Computed spectra of along-wind (left) and across-wind (right) force fluctuations on Taipei 101 Tower. Wind turbulence spectra also shown.

4.3 *Full-scale monitoring of tall buildings in typhoons*

In addition to CWE, CityU is also carrying several research projects on full-scale validation of dynamic wind load on a super-tall building under strong wind in collaboration with Ove Arup Hong Kong.

In the design of tall buildings, the prediction of dynamic response subjected to strong wind plays an important role. A method is developed for predicting the modal PSD (power spectral density) that incorporates information from wind tunnel tests and mean wind data in the free field, the latter taken to be at the Waglan Island station of HKO. Field acceleration data at the roof of the building has been measured in a number of strong wind events such as typhoon or monsoon wind. Using the data in non-overlapping time segments during the event, the modal PSD of wind load at different wind speeds is identified using a Bayesian modal identification method assuming stationary response within each segment. The wind tunnel predictions are compared with the values identified from field data.

A framework was developed to validate the modal spectral density of wind load based on wind tunnel tests with the values identified from full-scale structural vibration measurements. Analysis of a super-tall building in Hong Kong with four strong wind events shows that the wind tunnel model prediction generally agrees with field identified values to within an order of magnitude for moderate to high wind speeds. At low wind speeds, the field identified values are biased to the low side and have very little correlation with the wind tunnel predictions. Confidence in the correlation and repeatability between the wind tunnel prediction and field identified values should be checked with analysis of further strong wind events for the same building and similar analysis for other tall buildings.
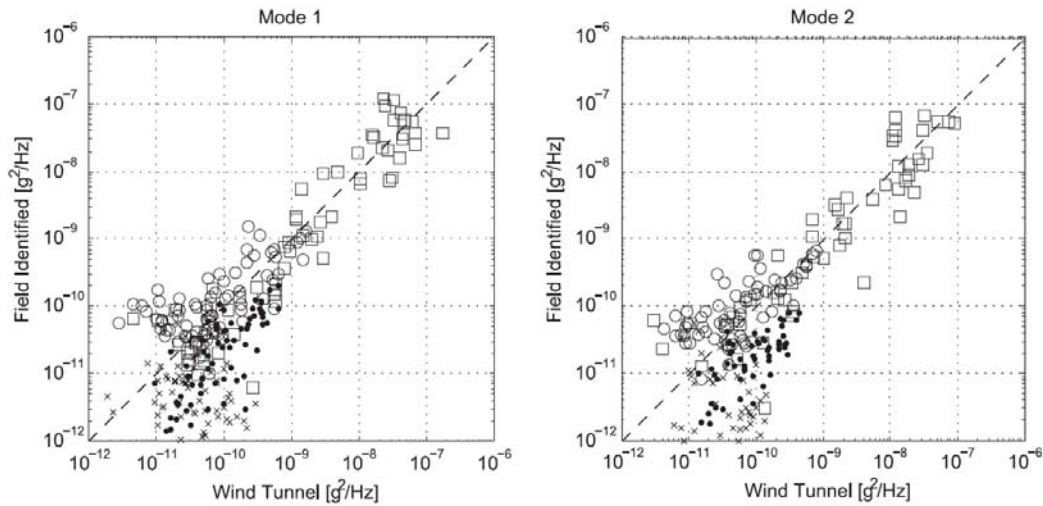
Figure 6. Field identified PSD versus wind tunnel prediction for typhoons: ∘: Goni; □: = Koppu; •: Megi; and ×: monsoons.

5 AIR VENTILATION STUDIES

Since 2006, Hong Kong Government has been taking positive actions to enhance better urban living environmental in terms of air ventilation and thermal relief of the city fabric. This is particularly important to Hong Kong with a very high density of tall building and the hot and humid summers. On the enforcement side, "Air Ventilation Assessment" (AVA) as required for all new major development projects in Hong Kong [7].

For long-term planning and improvement of the urban living environment, Hong Kong Government commissioned a study in 2006 to produce an Urban Climatic Map of Hong Kong. The map evaluated the thermal load and dynamic (wind) potential of the Hong Kong territory so that the bio-meteorological characteristics of urban Hong Kong can be better understood for planning decision making purpose. In December 2011, the first version of Hong Kong Urban Climatic Map was completed and released for public consultation [8]. Within the map, there is a layer specifically on Wind Information. It gives planners an understanding of the various wind characteristics in different part of Hong Kong. The layer was developed using Hong Kong Observatory long term wind data, as well as MM5/CALMET simulation data [9]. It depicts a simplified understanding of the wind environment of Hong Kong in the summer months for planners.

The Urban Climatic Planning Recommendation Map incorporates the wind information layer and divides Hong Kong into five Urban Climatic Planning Zones (UCPZ). Recommendations are provided for each zone on how and where the land can be developed to attain a balance between urban climate and other planning considerations (Fig. 7). Based on the UCPZ, various planning guidelines were proposed for the planners. A new section on Urban Climate and Air Ventilation will be incorporated into Hong Kong Planning Standards and Guidelines in due course.

Utilizing a morphometric understanding of the urban wind environment and based on the grid average (100m × 100m) values of Frontal Area Density, the least cost path (air path) map of Hong Kong has been developed. This supplement the Dynamic potential understanding of the Urban climatic map for planners to identify important air paths in the urban area so that better strategies may be developed to enhance or preserve them [10-11].

In addition, refinements have been proposed for the AVA methodology (dubbed AVA version 2). In a nutshell, instead of merely comparing options, a wind performance criterion of 1 m/s median hourly mean wind speed will be used [12]. For a project to demonstrate that

it does not have adverse effect on the wind environment of the surrounding areas, 80% of the test points must satisfy the wind performance criterion.

The studies on AVA system and Hong Kong Urban Climate Map are undertaken by a consultant term headed by Professor Edward Ng of the School of Architecture at CUHK [13].
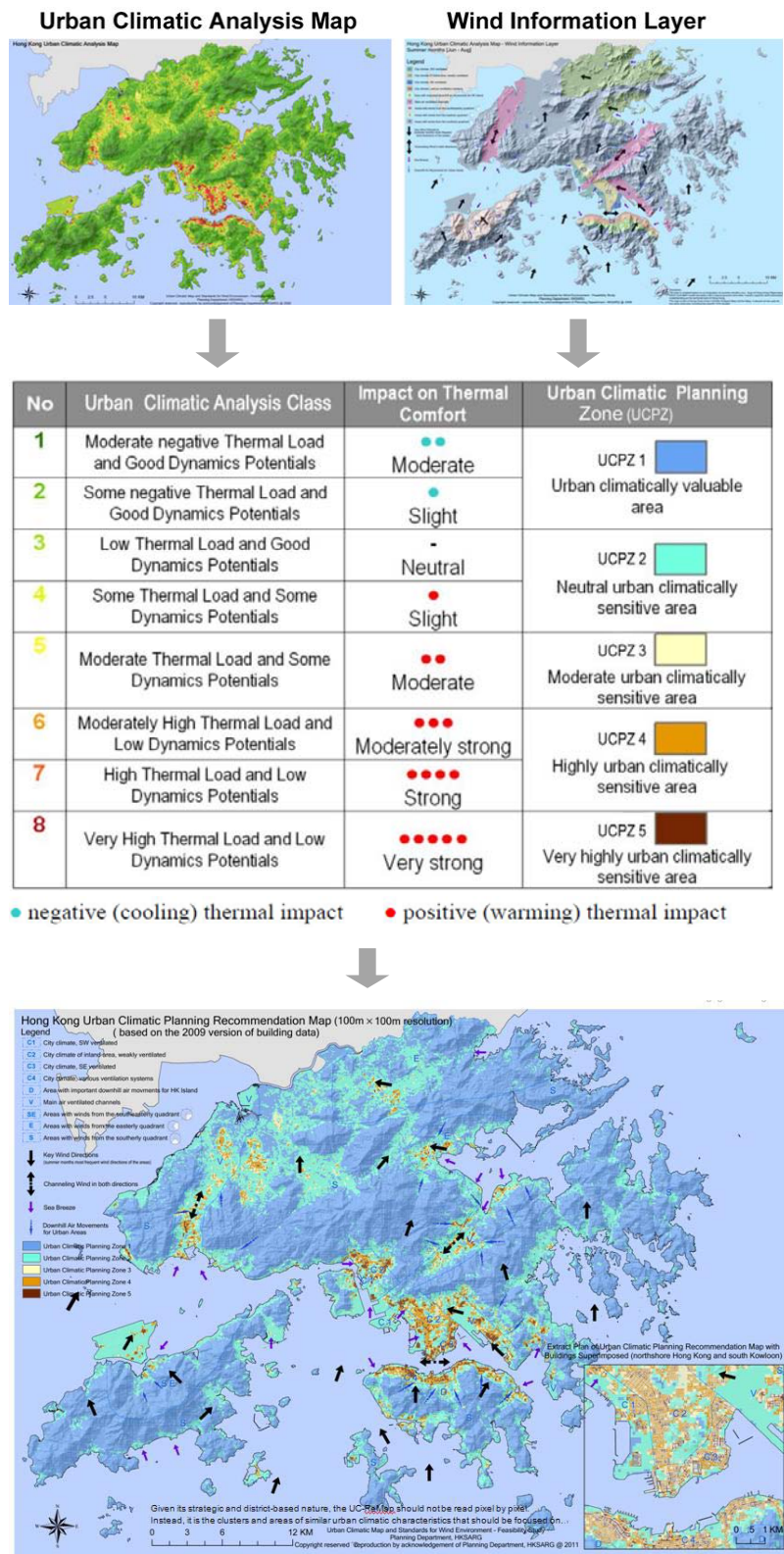

Urban Climatic Analysis Map

Wind Information Layer

No	Urban Climatic Analysis Class	Impact on Thermal Comfort	Urban Climatic Planning Zone (UCPZ)
1	Moderate negative Thermal Load and Good Dynamics Potentials	●● Moderate	UCPZ 1 Urban climatically valuable area
2	Some negative Thermal Load and Good Dynamics Potentials	● Slight	
3	Low Thermal Load and Good Dynamics Potentials	- Neutral	UCPZ 2 Neutral urban climatically sensitive area
4	Some Thermal Load and Some Dynamics Potentials	● Slight	
5	Moderate Thermal Load and Some Dynamics Potentials	●● Moderate	UCPZ 3 Moderate urban climatically sensitive area
6	Moderately High Thermal Load and Low Dynamics Potentials	●●● Moderately strong	UCPZ 4 Highly urban climatically sensitive area
7	High Thermal Load and Low Dynamics Potentials	●●●● Strong	
8	Very High Thermal Load and Low Dynamics Potentials	●●●●● Very strong	UCPZ 5 Very highly urban climatically sensitive area

● negative (cooling) thermal impact   ● positive (warming) thermal impact

Figure 7. Hong Kong Urban Climatic Planning Recommendation Map. (Source: Planning Department, Hong Kong)

6 WIND ENVIRONMENTAL STUDIES

At HKU, several research projects are being carried out on wind-induced ventilation and pollutant dispersion in the built environment.

6.1 *Fluctuating characteristic of building wake*

A study is targeted at obtaining fluctuating characteristics of lengths and sizes of the wake behind a building through measurement of unsteady velocity fields with time-resolved particle image velocimetry (PIV). Information on building wakes, especially the length and size of the wake on the ground level, is important in wind environment applications such as the effect of buildings on air ventilation, pollutant dispersion, pedestrian wind comfort, or wind shear on airport runways.

While there were many wind-tunnel and numerical investigations of building wakes, most experimental and numerical results are limited to time-averaged mean characteristics such as mean wind speeds and wake sizes. These mean wake properties can help in the assessment of wind environmental conditions around tall buildings for pedestrian comforts or pollutant dispersion efficiency in downwind regions. However, in critical situations such as dispersion of hazardous matters and building-induced wind shear events on runways, unsteady and fluctuating wake characteristics are equally important. A probability approach for risk assessment requires the fluctuating characteristics of building wakes.

As the preliminary target, the study aims to measure the statistical distribution of the unsteady wake length behind a model building. Time-resolved PIV is used to measure the unsteady velocity fields on the central vertical plane of a building wake. After some successful measurements in a water channel [14], attempts are being made to carry out wake measurements with PIV in the wind tunnel (Fig. 8). The preliminary results in water suggest that presence of small scale turbulent eddies and three-dimensionality of the flow renders estimation of the wake length from an instantaneous PIV snapshot difficult. Proper orthogonal decomposition (POD) is thus applied to filter the small-scale flow eddies and the reconstructed velocity fields with the lower modes lead to a more reliable estimation of the building wake lengths (Fig. 9).
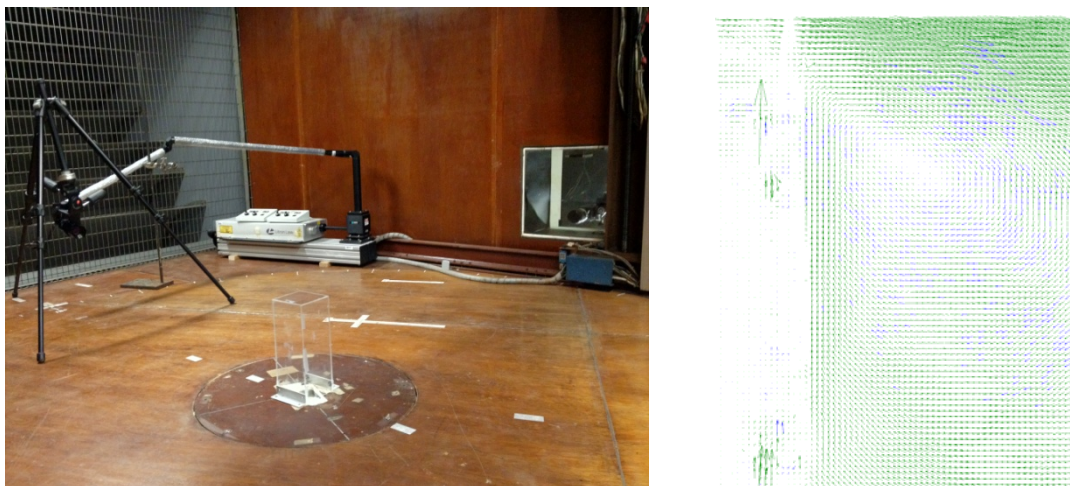

Figure 8. Building wake measurement with PIV and preliminary result of mean velocity field.
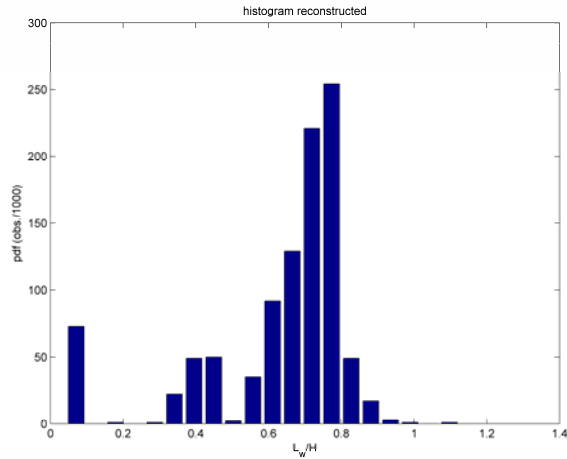
Figure 9. Probability distribution of building wake lengths estimated from reconstructed data using first 10 POD modes. Water tunnel results.

6.2 *Pollutant removal mechanism from urban street canyons*

Pollutant removal from the ground level of urban areas has long been a major research problem in the urban climate community. In the Department of Mechanical Engineering, HKU. The pollutant transport behavior from idealized urban street canyons to the urban atmospheric boundary layer (UABL) is examined using wind tunnel experiments. It was found that scaling effects were observed in the laboratory experiments in reduced-scale models even the flows had compiled with kinematic similarity. Under this circumstance, a new indicator: scale transfer coefficient, is proposed to compare the pollutant removal behaviors in physical modeling studies.

The water evaporation method [15] was used to model a layer of scalar of uniform concentration on the ground surface. The ground surface of the models in the wind tunnel was cover by soaked filter papers to maintain a layer of saturation water vapor pressure throughout a set of experiment. The saturation water vapor pressure was calculated by the Goff-Gratch equation [16]. The vertical turbulent flux of water vapor $\overline{w''\phi''}$ was measured by the water loss rate and the roof area of the street canyon.

The wind tunnel is an open-circuit type whose size of the test section is 565 mm (height) × 560 mm (width) × 1,000 mm (length). The wind speed U was varied from 2 m/s to 12 m/s. At least ten to twelve square aluminum blocks of different sizes $H = \{25.4 \text{ mm}, 50.8 \text{ mm}, \text{and } 76.2 \text{ mm}\}$ were placed at different separation in cross flows to construct idealized street canyons of different building-height-to-street-width (aspect) ratio in the range of 1/8 to 2 (Fig. 10). Under this configuration, the Reynolds number Re (= UH/v) is well over 3,400 that is supposed to be independent from molecular viscosity.
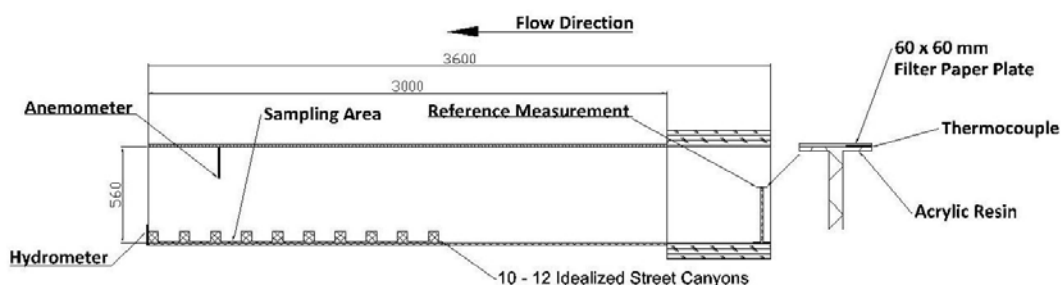

Figure 10.   Street canyon configuration in the wind tunnel to model hypothetical urban areas.

In the beginning of the experiments, the turbulent flux measurements were suffered from scaling effects, i.e., the water vapor measurements depends on the length and velocity scales even kinematic similarity was fulfilled. The scaling effects were examined in details that were reported elsewhere [17]. For fully developed flows compiled with kinematic similarity, the pollutant removal is often measured by the pollutant transfer coefficient:

$$\Omega = \overline{w''\phi''}\big/(U\Delta\Phi) \tag{1}$$

where $\Delta\Phi$ is the difference in ground-level and UABL water vapor concentrations, which, however, overlooked the scaling effects. A new indicator was thus proposed to cope with the unavoidable scaling effects in order to facilitate the comparison of pollutant removal data of different length or velocity scales. The Sherwood number in the current experiments equals:

$$Sh = \overline{w''\phi''}\big/(\kappa \times \Delta\Phi/H) \tag{2}$$

where κ is the mass diffusivity. Similar to the flows over flat plate [18],

$$Sh = ARe^{m}Sc^{n} \tag{3}$$

where Sc is the Schmit number, and m (= 4/5) and n (=1/3) are empirical modeling constants. Comparing Equations (1), (2), and (3), a new indicator, scaled pollutant transfer coefficient is proposed:

$$A = \frac{Sh}{Re^{m}Sc^{n}} = \frac{\dfrac{\overline{w''\phi''}}{\kappa \times \Delta\Phi/H}}{\left(\dfrac{UH}{\nu}\right)^{m}\left(\dfrac{\nu}{\kappa}\right)^{n}} = \frac{\dfrac{U\times\Omega\times H}{\kappa}}{\left(\dfrac{UH}{\nu}\right)^{m}\left(\dfrac{\nu}{\kappa}\right)^{n}} = \frac{U^{1-m}H^{1-m}}{\nu^{n-m}\kappa^{1-m}}\Omega \tag{4}$$

The dimensionless factor on the right-hand side of Equation (4), which is a function of the empirical constant m and n, demonstrated the (scaling) effects of length and velocity scales on the transfer coefficients. In general, the scaled pollutant transfer coefficient Equation (4) can be applied to handle scaling effects for flows in a finite Reynolds number ($10^{3} \leq Re \leq 10^{5}$). Nevertheless, similar to most asymptotic behaviors in fluid flows, it is expected that the scaling effects diminish with increasing Reynolds number.
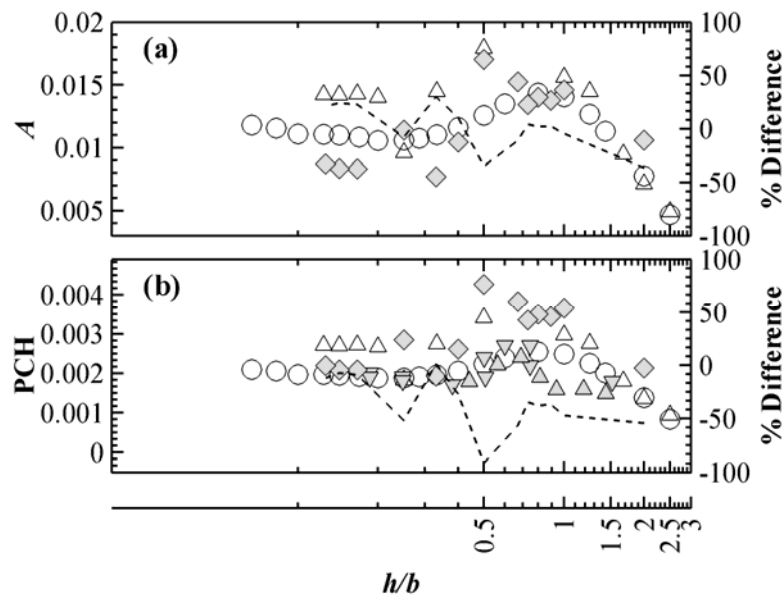

Figure 11. Variation of the overall scaled pollutant removal coefficient A for street canyons of aspect ratios: (a). 1; (b). 2; (c). 0.5; and (d). 0.25. Pollutant transfer from different surfaces, leeward façade (□), ground (Δ), windward façade (∇) and building roof (◊), are included.

Fig. 11 compares the original pollutant transfer coefficient Ω and the newly proposed scaled pollutant transfer coefficient A as a function of aspect ratio of street canyons of different sizes. Because of the unavoidable scaling effects discussed previously, the original pollutant transfer coefficient Ω exhibits a maximum difference up to 100%. Whereas, using the newly proposed scaled pollutant transfer coefficient A the difference is dropped to less than 50%, suggesting the necessity of formulating a new indicator for urban pollution studies.

7 OUTDOOR AIR QUALITY STANDARDS

Hong Kong has been criticized for poor air quality and lagging of air quality standards. The existing Air Quality Objectives (AQO) for outdoor air quality were established in 1987 and the Government seems unwilling to upgrade the standards for decades. In 2007, the Government finally carried out a study to review the AQO. Although the study and the subsequent public consultation were completed in 2009, the Government has not taken a further positive step until 2012. Probably under pressure from the green groups, the Government finally announced to adopt and put forward the new AQO proposed in the review study for legislation. The new AQO are expected to be in effect in 2014 and the Government makes a promise to further review the AQO in not less than five years.

The following table shows the proposed new AQO for Hong Kong. They are mainly based on the air quality guidelines (AQG) and the interim targets (IT) of World Health Organization (WHO). The controversial criteria pollutant of PM2.5 is added with objective levels set by the lowest interim target (IT-1).

Table 2. Proposed new AQO for Hong Kong. (Source: Environmental Protection Department).

Pollutants	Avg. Time	Existing AQOs		Proposed AQOs				
		(µg/m³)	No of Exceed-ances Allowed	WHO IT-1[3] (µg/m³)	WHO IT-2[3] (µg/m³)	WHO IT-3[3] (µg/m³)	WHO AQG (µg/m³)	No of Exceed-ances Allowed
Sulphur Dioxide	10-min	--	--	-	-	-	500	3
	24-hr	350	1	125	50	-	20	3
Respirable Suspended Particulates (PM10)	24-hr	180	1	150	100	75	50	9
	Annual	55	NA	70	50	30	20	NA
Fine Suspended Particulates (PM2.5)	24-hr	--	--	75	50	37.5	25	9
	Annual	--	--	35	25	15	10	NA
Nitrogen Dioxide	1-hr	300	3	-	-	-	200	18
	Annual	80	NA	-	-	-	40	NA
Ozone	8-hr	240 [1]	3	160	-	-	100	9
Carbon Monoxide	1-hr	30,000	3	-	-	-	30,000	0
	8-hr	10,000	1	-	-	-	10,000	0
Lead	Annual	1.5 [2]	NA	-	-	-	0.5	NA

▢ Proposed new AQOs

[1] There is no existing 8-hour AQO for ozone in Hong Kong. The figure presented above is the 1-hour AQO.

[2] There is no annual AQO for lead in Hong Kong. The figure presented above is the 3-month AQO.

[3] The WHO accepts the need for governments to set national standards according to their own particular circumstances. The WHO guidelines therefore also suggest ITs on SO2, PM10, PM2.5 and O3 to facilitate a progressive approach for achieving the ultimate AQGs and provide milestones in achieving better air quality.

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