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Air Ventilation Assessment (AVA) for Building Developments

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Introduction

Pedestrian level wind environment has long been the focus of many major world cities concerning the safety and comfort of pedestrian due to unacceptably strong winds. More recently, natural ventilation and air quality has captured the attention of the general public and government authorities concerning the health and well-being of city inhabitants.

Air ventilation assessment (AVA) is a major initiative introduced in 2006 by the Government of the Hong Kong Special Administrative Region (HKSAR) to address the alarming deterioration in the past decades of air quality in Hong Kong. The catalyst for the introduction of AVA was the outbreak of Severe Acute Respiratory Syndrome (SARS) in 2003 from which many people died.

This paper outlines the contributions of wind engineering in the implementation of AVA, particularly in the process of expert evaluation, and in developing wind tunnel test techniques and analysis methodologies for site wind availability study and detailed AVA study. A case study is used to highlight the role and importance of each of the suggested critical elements and each step of the proposed analysis procedure in the wind tunnel simulation. The case study also provides a relevant benchmarking to verify the achievability of the proposed air ventilation guideline that the mean wind speed of the development site should be at least or more than 1.5 m/s at pedestrian level in an existing urban area in Hong Kong. The impact of the interaction between the prevailing wind climate of and the urban fabric on air ventilation performance is discussed.

Research on Pedestrian Level Wind Environment with Particular Reference to Air Ventilation Assessment (AVA)

Although a suite of systemic design guideline has been incorporated into Section 11: “Qualitative Guidelines on Air Ventilation” of Chapter 11: “Urban Design Guidelines” of the Hong Kong Planning Standards and Guidelines, the planning, building and wind engineering solutions suggested are mostly based on personal and professional experience, which are often subjective. Therefore, there is a genuine need for sound scientific research on pedestrian level wind environment around buildings in order to guide decision making which impacts on the quality of the live environment.

The wind flow pattern around buildings is very complicated and has been investigated for many years. A comprehensive review conducted by Blocken and Carmeliet (2004) highlighted the significant amount of attention that has been given to studying outdoor human comfort since the 1960s. Pedestrian level wind environment studies have been conducted with the major focus on the discomfort conditions caused by strong winds near buildings. However, most of these studies focused on the high wind speed areas, which generally are restricted to comparatively small areas such as near building corners. Furthermore, very few systematic studies have been conducted to characterise the effects of modern building configurations, such as a row of buildings or building with a podium, on the low wind speed area covering a comparatively large extent of area downstream of the building.

Tsang *et al.* (2012) conducted a detailed study on wind-structure interactions that govern the effects of building configurations on the pedestrian level wind environment. Complex parameters such as urban terrain conditions with a range of surrounding buildings were not included in the study. Instead, the Study focused on isolated buildings in order to clearly identify building effects under a more generalized condition. The effects of four building parameters: height h, width b, separation between buildings s and podium were investigated.

The Study investigated natural air ventilation under weak wind conditions based on the mean wind speed distribution over a large extent of area downstream of the test buildings. The results show that a single wider building created a larger sheltering effect which enlarged the extent of the two downstream low wind speed zones. This adversely affected the natural air ventilation conditions around the building. On the other hand, a taller building redirected more upper level wind to pedestrian level, improving the near-field air ventilation conditions.

In the studies of building separation effects, i.e. a row of buildings, it was observed that the near-field low wind speed zones were improved as the separation was increased. In the far-field area, it was found that the wind flow on the downstream side of the buildings is governed by two opposing flows – the backflow created by the vertical and horizontal recirculation and the flow passing through the building separations. When the backflow is much stronger, such as for zero building separation, a region of strong wind flow exists at the downstream far-field area and the local wind direction is opposite to the approaching wind direction. When the flow passing through the building separations is stronger, such as when the building separation is greater than half of the building width, the wind direction is the same as the approaching flow and wind speed is increased at both near-field and far-field areas. However, when these two opposing flows are similar in magnitude, such as for building separations that are less than half of the building width, the flow becomes highly turbulent, creating a large area of low mean wind speed which worsens the potential for natural ventilation.

The inclusion of a podium was found to have generally adverse effects on the air movement in both the downstream near-field and far-field areas by obstructing the approaching wind at pedestrian level. As a result, podia are not recommended for regions where favorable natural air ventilation conditions are required at pedestrian level.

Implementation of Air Ventilation Assessment (AVA)

In view of developing understandings of wind-structure interaction that governs wind flow within urban areas populated with high-rise buildings, air ventilation assessment (AVA) methodology has been developed to evaluate the wind environment at locations within heavily built-up areas with complex topography, such as those commonly found in Hong Kong. AVA is usually conducted in the following stages:

a) Expert evaluation;

b) Site wind availability study; and

c) Detailed AVA study, employing either computation fluid dynamics (CFD) or wind tunnel testing.

The assessment methodologies adopted for expert evaluation, site wind availability study and detailed AVA using wind tunnel test techniques are briefly outlined hereunder. The wind tunnel test techniques adopted are expected to demonstrate compliance with current international best practice techniques.

Expert Evaluation

An expert evaluation is usually the first step of an AVA study on a proposed development site and is conducted to qualitatively assess the likely pedestrian level wind conditions within the assessment area and to facilitate the identification of potential adverse wind effects. The primary objectives of an expert evaluation are to:

1. Make reference to any existing wind data and comment on their reliability for qualitative assessment of the prevailing wind conditions, on an annual basis or during summer months, of the site;

2. Analyse key features of a proposed development site and the surrounding areas that are likely to affect the wind characteristics at the site and vice versa;

3. Identify possible problems and issues in air ventilation terms which may affect the design of the proposed development; and

4. Provide qualitative assessment of the prima facie merits or demerits of the design schemes.

These objectives are best met by the active participation and interaction of the relevant professionals in the design team, including architects, planners, engineers, landscape architects and wind engineering specialists, from the early concept stage of the design process to exploit the strengths and minimise the adverse effects caused by the weaknesses of the design concept and/or design strategy, considering the limitations posed by the site characteristics and targeted project site zoning and/or building guidelines, or the proposed usage of the project site.

The consultant conducting an expert evaluation requires knowledge of the project site, the surround topographies and buildings, the prevailing wind climate for the region and preferably also the site wind availability, and wind-structure interaction principles. An expert evaluation may firstly be started with site visits. Through site visits, architects, planners and wind engineers can appreciate the existing characteristics of a proposed development site including far-field and local topographies, street alignment, width and gradient, and layout of existing buildings in regions immediately adjacent to a proposed development site. The site characteristics may have significant impacts on pedestrian level wind speeds and air ventilation performance within a proposed development and the corresponding assessment area.

An expert evaluation may also be aided by appreciations of proposed development site characteristics through an examination of a smaller scale topographical model and, preferably, a larger scale detailed model of a proposed development site and the assessment and surrounding areas, and a study of plans and drawings supplied by clients.

Based on information gained from the site visit and a study of the plans of the proposed building development for the project site, a qualitative assessment is made on the expected pedestrian level wind conditions. The parameters used in the assessment include: far-field and local topographies, prevailing wind climate for the region, known or expected site wind availability, street alignment, width and gradient, proposed new buildings and remaining existing buildings in terms of density, height, separations/gaps and other features such as podia, setbacks and open spaces. The assessment focuses on identifying the strengths and weaknesses, if any, of the proposed development and its interaction with existing buildings, the effects of surrounding topographical features on local wind flow characteristics, in terms of pedestrian level wind climate and in particular their potential impacts on air ventilation. If necessary, an assessment will also be made by comparing the expected pedestrian level wind conditions for the proposed development with the existing pedestrian wind conditions to assess the impact of the proposed development on the project site. If potential adverse impacts are identified, such as areas of stagnant wind and/or design features that are likely to adversely affect major pedestrian access ways and/or designated open spaces, appropriate available remedial strategies will be suggested to mitigate those adverse effects. The expected pedestrian level wind conditions associated with the strengths and weaknesses of the proposed development and the effectiveness of suggested remedial strategies will be the focus of further detailed AVA studies.

Site Wind Availability Study

For proposed development sites which do not have significant topographical feature that create dominant localised wind flows, the local statistical wind climate model, including directionality, usually are adequate to specify the site wind availability. If necessary, a modified site wind availability can be determined by appropriate adjustments based on codified wind profiles matching the terrain of the test site. For sites affected by significant topography, such as those commonly found in Hong Kong with its complex mixture of mountains, open water, green areas and urban fabric, a site wind availability study is conducted by using wind tunnel test technique comprises a topography study and an analysis of the topographical study results integrating with the local wind climate statistics.

In the assessment of the environmental wind conditions at pedestrian level, the primary concerns are of pedestrian comfort and safety, commensurate with the intended use of a particular area including public access ways, shopping precincts, outdoor dining, and public plazas and parks for leisure activities. This basic framework of assessment is also employed for AVA. The assessment procedure and prediction of wind conditions at pedestrian level for AVA purposes are based on annual, and sometimes seasonal, directional wind speeds corresponding to the local wind climate statistics.

A topographical model is constructed, usually at a linear scale of between 1:2000 and 1:3000, to include all topographical features and buildings and structures within and up to 10 km upstream of the proposed development site. Greater details within a zone of up to approximately 500 m to 1000 m from the boundary of the proposed development site are included in the topographical models to more accurately capture the effects of buildings and other structures within that zone on the proposed development site wind characteristics. Outside the zone, the topographical model will include roughness representative of the surrounding areas to simulate the representative far field effects. The mean wind speed profile of the wind flow approaching the proposed development site is simulated in accordance with specifications given in the relevant wind code.

Measurements of the three components of wind speed using a Cobra probe are taken at 22.5° intervals for the full 360° azimuth (i.e. 16 wind directions) at a range of heights above the proposed development site ground elevation to determine the profiles of wind speed, turbulence intensity and yaw angle of wind flow above the proposed development site. In order to only measure far-field effects of the surrounding terrain and topography, an appropriate region around the proposed development site are removed during the measurements; the effects of that removed region are modelled directly in the wind tunnel tests conducted for the detailed study stage of AVA.

The site wind test results are then integrated with the local statistical wind climate to define the site wind availability in the form of a site-specific probabilistic wind model that reflects the site wind characteristics. Where necessary, this site-specific probabilistic wind model can be adjusted to reproduce seasonal characteristics such as summer and/or winter winds, for other specialised analyses such as pedestrian thermal comfort assessment.

Detailed AVA Study

A detailed environmental wind study is conducted to determine the effects of proposed building developments on the local pedestrian level wind conditions within the assessment area. Depending on the size of the proposed development site and assessment area, and the size of the wind tunnel test section, a detailed model is constructed, usually at a linear scale of between 1:400 and 1:500, to include all nearby topographical features and buildings and structures within a radius of not less than 500 m, and sometimes up to a radius of 1 km, of the project site.

The primary objectives of detailed AVA study are to 1) assess the site wind availability of a proposed development site in detail; 2) determine wind velocity ratios of all test points and identify potential problematic areas; and 3) provide a summary of possible mitigation for those problematic areas.

Hot-film/hot-wire thermal anemometer, Cobra probe, Irwin sensor and Kanomax1560 anemometer system are flow measurement systems that have been used for wind speed measurements in detailed AVA studies. Each of these instruments has its own special features and capabilities that suit individual AVA study.

Pedestrian level wind speeds are measured at selected test points within the assessment area. Depending on the size of the proposed development site and the assessment area, the total number of test points can be as many as several hundred.

Pedestrian level wind velocities are measured at each test point for 16 wind directions ranging from 22.5° to 360° (i.e. north) at increments of 22.5° using a suitable multi-channel anemometer system at a height of approximately 2 m above ground level at prototype scale. Signals from the multi-channel wind speed measurement system are sampled using dedicated computers for a period equivalent to approximately one hour at prototype scale.

The mean wind speed at each test point is determined and expressed as a wind velocity ratio (VR) normalised by the approaching upper level wind at a suitable reference height (e.g. 500m), as expressed below:

$$VR_{500i,j} = \frac{V_{p,i,j}}{V_{500i}} \quad (1)$$

where $V_{p,i,j}$ is the mean wind speed in m/s at pedestrian level (i.e. measured at 2 m above ground at each test point and under the influence of buildings and other urban features); $V_{500,i}$ is the reference mean wind speed in m/s (i.e. mean wind speed at a height of 500 mPD directly above the centre of the modelled area for each of the 16 measured wind directions (ith)). Directional wind velocity ratios were determined for the 16 wind directions for each test point location and they are used as an indicator of the wind characteristics at each location.

The directional velocity ratios (VR) are integrated with the site-specific probabilistic wind model developed for the project site to produce the overall wind velocity ratio of the j-th test point ($VR_{w,j}$), which accounts for the probability of occurrence (p_i) of winds approaching the proposed development from each of the 16 measured wind directions.

$$VR_{w,j} = \sum_{i=1}^{16} p_i \times VR_{500i,j} \quad (2)$$

With careful use and appropriate interpretation, these velocity ratios can be used to assess the air ventilation performance of a proposed design scheme compared with that for existing buildings, and/or to compare the air ventilation performance of different design schemes for the same project site. At test points where strong winds are evident, the corresponding wind velocity ratios are used to assess pedestrian comfort and safety based on internationally accepted criteria for pedestrian level environmental wind.

A Case Study

The Central district of Hong Kong was chosen as the study area. Central is a typical commercial district in Hong Kong, where the urban fabric is characterised by high-rise buildings with unique and irregular shapes. The street pattern is also irregularly oriented due to geographical features and the arrangement of built-up areas. Figure 1 shows the plan view of Central, with the study area marked by a circle. The north side of the study area has an open exposure to Victoria Harbour; the south side borders on the foothills of Victoria Peak; the east and west sides are linked to adjacent commercial districts in Central and Wanchai. This case study is a practical example to demonstrate the application of the proposed AVA guideline and to assess the likelihood of achieving the AVA target mean wind speed of 1.5 m/s in an existing built-up area in Hong Kong.

Figure 1. Plan view of Central and locations of 16 test positions.

The pedestrian level wind environment study was conducted in the high-speed section of WWTF using a 1:400 scale model of the region within a radius of 600 m around the study area. Hot-film anemometers were used to measure mean wind speeds at 16 test positions, as shown in Figure 1, for 16 approach wind directions. Using the previously described procedures, integrated velocity ratios (VR), with reference to gradient height (500 mPD), of each test position at pedestrian level are summarised in Table 1. The velocity ratios of these 16 positions are within a range of 0.14 to 0.29 and the spatial average is 0.24.

As an example, the VR plot for Position 2, located at the waterfront area, is shown in Figure 2. It demonstrates that the VR for winds approaching over Victoria Harbour are higher than those from directions corresponding to wind flow above the nearby built-up areas. The sudden increase in VR at 157.5^o is associated with a small park located in front of this position at that wind direction, highlighting the potential value of including small open areas to improve the air ventilation in a built-up area.

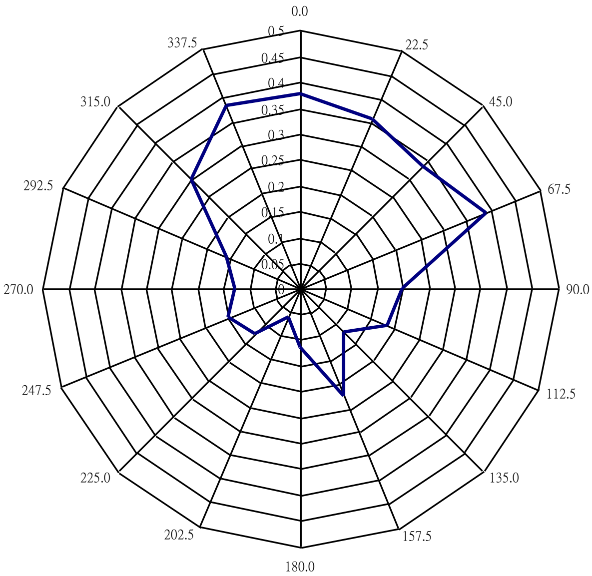

Figure 2. Velocity Ratio plot for position 2.

Although velocity ratios give a general idea of air ventilation at each position, it is easier to appreciate the magnitude of wind conditions through the consideration of likely sustained wind speeds. This requires the integration of the measured VR with an appropriate wind climate model, which can be done on annual or seasonal bases. Based on the relationship between mean wind speed and the corresponding probability of exceedance, a summary of mean wind speeds with a 50% probability of exceedance at each test position is presented in Table 1. Likewise, the probability of occurrence of a mean wind speed greater than or equal to 1.5 ms^{-1} can also be calculated, as presented in Table 1. The spatially averaged mean wind speed at pedestrian level over this study area is more than 1.52 m/s for 50% of the time, on average, on an annual basis. In this case study, this satisfies the suggested air ventilation guideline.

Conclusion

This paper outlined the contributions of wind engineering in the implementation of air ventilation assessment (AVA), particularly in the process of expert evaluation, and in developing wind tunnel test techniques and analysis methodologies for site wind availability study and detailed AVA study. The wind tunnel modelling requirements and analysis procedures for detailed AVA study in a complex terrain such as Hong Kong has also been highlighted.

A case study of the Central district of Hong Kong was conducted and the results presented. Velocity ratios and mean wind speed distributions were determined and compared at 16 measurement positions. Directional velocity ratio plot was introduced for detail wind environment analysis. By examining the directional velocity ratio plot at each position, the impacts of surrounding buildings and exposure to prevailing winds on the local wind flow characteristics can be evaluated reliably. Although spatially averaged velocity ratios provide a general idea of the wind environment of the assessment area, it is more comprehensive and more beneficial in terms of mitigation strategy to assess directional wind speed or velocity ratio distribution for each test point individually with respect to relevant guidelines or acceptance criteria for AVA and/or pedestrian environment wind.

Table 1. Velocity Ratios for 16 test positions.

Position	Given probability	Mean wind speed (m/s) corresponding to a probability of exceedance of 50%	Given mean wind speed (m/s)	Probability of exceeding 1.5 m/s mean wind speed	VR
1	50.00%	1.71	1.50	56.07%	0.26
2	50.00%	1.74	1.50	56.81%	0.26
3	50.00%	2.00	1.50	60.33%	0.29
4	50.00%	1.24	1.50	39.62%	0.21
5	50.00%	1.29	1.50	41.38%	0.22
6	50.00%	1.30	1.50	41.70%	0.19
7	50.00%	1.53	1.50	50.83%	0.23
8	50.00%	1.68	1.50	54.59%	0.27
9	50.00%	1.70	1.50	54.35%	0.26
10	50.00%	1.78	1.50	56.50%	0.29
11	50.00%	1.96	1.50	63.73%	0.28
12	50.00%	1.49	1.50	49.80%	0.23
13	50.00%	0.92	1.50	18.97%	0.14
14	50.00%	1.66	1.50	56.12%	0.27
15	50.00%	1.15	1.50	34.91%	0.18
16	50.00%	1.22	1.50	38.15%	0.23
Ave		1.52			0.24

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