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Integrating twisted wind profiles to Air Ventilation Assessment (AVA): The current status

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ABSTRACT

Twisted wind flows generated by the complex terrain of Hong Kong induce two types of complication to Air Ventilation Assessment (AVA), first, imposing a false boundary condition on the wind tunnel tests done for AVA and, second, creating an ambiguity in determining the approaching wind direction in calculating the probability of occurrence of winds. The latter issue is partially solved using correction methods in post-analysis of AVA but the accuracy of these methods is not yet accessed. This study employs two twisted wind profiles to test an urban area in a boundary layer wind tunnel to investigate the influence of twisted wind flows on the outcomes of AVA and to estimate the accuracy of three common correction methods: No-Shift, Threshold, and Proportional methods. The results reveal significant differences in wind speeds at the pedestrian level for twisted and conventional wind flows at locations with low building densities. The discrepancies in wind speeds are minimum at the locations where the density of buildings is high. The indicators calculated by the No-Shift method frequently deviate from those of the twisted wind flows, while the Threshold and Proportional methods routinely over-predict the indicators of AVA.

1. Introduction

The Air Ventilation Assessment (AVA) was stipulated by the Hong Kong Government in 2006 after the 2003 SARS (Severe Acute Respiratory Syndrome) outbreak [1–6]. Established as a mandatory test for major government and semi-government projects on the development and redevelopment of urban areas, the AVA monitors the projects' effects on external air movements in an attempt to maintain an acceptable macro wind environment [1–3]. Currently, AVA is implemented in the private sector entirely on a voluntary basis, but the number of private projects that adopt AVA continues to grow, as AVA helps better plan a project at its initial design stage [6].

The AVA systematically combines data of wind speed, influences from the complex terrain of Hong Kong, and the pedestrian level wind (PLW) field at any site of interest to assess the acceptability of the macro wind environment. AVA's main evaluation criterion is to check whether mean wind speed at the pedestrian level (typically about 1.5 m–2 m above ground) exceeds 1.5 m s^{-1} [1]. The mean wind speed of 1.5 m s^{-1} is the minimum wind speed required to maintain outdoor thermal comfort on a hot, humid summer day in Hong Kong [7]. This criterion takes a different approach than other existing wind ordinances: other criteria tend to cap the allowable wind speed to prevent pedestrian discomfort, even danger, caused by windy conditions [8–10].

The AVA explicitly includes the influence from complex terrain on the urban PLW field because of the complex terrain of Hong Kong is found to have immense influences on wind speeds and turbulence intensities in built-up areas that are located even few kilometres downstream of mountains [11]. In addition, the hilly terrain of Hong Kong frequently produces twisted wind profiles: at different heights within the profile winds have various directions [12–14]. The authors of this paper have used twisted wind profiles in a series of wind tunnel tests on isolated buildings [16], arrays of buildings [16], and a real urban area [17], and have demonstrated the profiles' considerable influence on the PLW fields in built-up areas. This influence is even more critical on AVA as reported by Tse et al. [12] after analysing data of 256 wind profiles obtained from 13 previous AVAs. In their analysis, Tse et al. [12] revealed that more than 10% of wind profiles have directional deviations larger than 20° (as much as 40°) within the lower 500 m of the atmospheric boundary layer (ABL).

Twisted wind profiles induce two types of complication for AVA: First, if the twisted wind profiles are not taken as boundary conditions and consequent flow modifications in the PLW field are neglected (see Refs. [15–17]), then the reliability of any AVA outcomes will be

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significantly affected. Although few studies attempted to improve the accuracy of AVA by addressing special environmental conditions such as unstable atmospheric stability [18,19], the existence of highly complex terrain [20], the presence of buildings with different heights [21], and heterogeneous urban morphology and surface roughness [22] but to the best of the authors' knowledge, no AVA has ever used twisted wind profiles as a boundary condition. This omission is partially attributable to inadequate understanding on simulation techniques, as only limited information has been made available by several studies on yacht sail's aerodynamics [23–26] and a few PLW studies done by the authors [15–17]. Constraints in cost, time, and resources pertaining to simulating twisted wind profiles give further reasons for omitting them from AVA.

Second, wind directions in the twisted wind profiles vary a great deal and cause ambiguity in calculating indicators of AVA, which require the probabilities of wind occurring in any given directions to be determined. Currently, the AVA only adopts corrections methods in post-analysis to adjust these probabilities according to the how wind directions vary in the twisted wind profiles, but these correction methods are empirical: neither their accuracy nor impact on the outcome of AVA is assessed. In fact, without any AVA data obtained using twisted wind profiles, neither the accuracy nor the impact of these correction methods can be assessed, and this needs to be remedied by incorporating twisted wind profiles into AVA, something that has been unavailable to the wind engineering community until now.

The goal of this paper is threefold: (1) to incorporate twisted wind profiles as a boundary condition into the wind tunnel tests done for AVA; (2) to evaluate the influence of twisted wind profiles on the outcomes of AVA; and (3) to estimate the accuracy of correction methods currently used in AVA. Each sub-goal is achieved by testing a real urban area in a boundary layer wind tunnel (BLWT) according to AVA guidelines. Two twisted wind profiles with different yaw angles are systematically integrated into AVA, and the impact of twisted wind flows on the outcomes of AVA is estimated by comparing wind speeds under the two twisted wind profiles with wind speeds measured in a conventional wind flow, which has similar wind speeds and turbulence intensity but without any wind twists. Several indicators are calculated based on pedestrian-level wind speeds in the two types of wind flow (i.e., conventional and twisted winds) and are adjusted using the correction methods. The two sets of indicators (original and adjusted) are then compared to estimate the accuracy of the correction methods and their impact on the outcomes of AVA.

In Section 2, the procedures of implementing AVA are introduced with details of assessment techniques, main indicators, and the evaluation process. The correction methods are described in Section 3 in terms of calculation procedures, underlying assumptions, and limitations. Section 4 provides details of the experimental setup including the selected urban area, approaching wind profiles, and measurement techniques. Section 5 analyzes the PLW field using the main indicators calculated for the two types of wind flows and the correction methods. Finally, some limitations of the current study are discussed in Section 6 and several conclusions are stated in Section 7.

2. Methodology

2.1. Assessment criteria

The influence of twisted wind flows on the outcomes of AVA is evaluated by calculating three indicators: wind velocity ratio (*VR*), directional wind velocity ratio (VR_w), and spatially average wind velocity ratio (SAVR) [1–3]. *VR* reflects the wind conditions modified by the project using a ratio between mean wind speeds measured at the pedestrian level and approaching upper-level wind at a suitable reference height (e.g. 500 m), as defined in Equation (1);

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

In Equation (1), $V_{p,i,j}$ is the mean wind speed in m/s at the pedestrian level (i.e. measured at 2 m above ground) in the *i*th wind direction at a test point *j* under the influence of buildings and other urban features; $V_{500,i}$ is the reference mean wind speed in m/s at a height of 500 m directly above the centre of the modelled area in the *i*th wind direction.

VR_w is estimated in Equation (2) by combining the *VR* value in each wind direction with the corresponding probability of occurrence of wind calculated from the probabilistic wind climate model of Hong Kong.

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

where, p_i is the probability of occurrence of wind in the *i*th wind direction.

The spatially average velocity ratio (*SAVR*) estimates pedestrian-level wind conditions in the subzones of a project site [6]. To calculate the *SAVR*, the project site is first divided into a number of subzones based on buildings' characteristics (e.g., height). Then the *SAVR* value for each sub-zone is estimated using Equation (3).

$$SAVR = \sum_{j=1}^{n} \frac{VR_{w,j}}{n} \quad (3)$$

where, *n* is the number of test points within the sub-zone.

The probability of occurrence of wind (p_i) used for calculating VR_w and *SAVR* can be estimated using a probabilistic wind climate model of the nearest anemometer station to the site. Fig. 1 shows a probabilistic wind climate model constructed using non-typhoon wind speeds recorded for the period January 1953 to May 2000 at the Waglan Island meteorological station. In Fig. 1 and 0° indicates north and the 16 wind directions from 0° to 337.5° are marked at 22.5° intervals. The magnitudes of wind speed are marked by different colors and the radial distances indicate the probability of occurrence of winds at contour levels of 2%. According to Fig. 1, both the highest wind speeds about 26 m s^{-1} as well as the highest probability of occurrence of wind about 24% is found in the east direction. However, the mean wind speed at the 200 m height on Waglan Island is estimated to be 5–6 m s^{-1}, and combining that with the minimum required wind speed of 1.5 m s^{-1} would result in VR_w = 0.3, which is the minimum acceptable VR_w value in AVA.

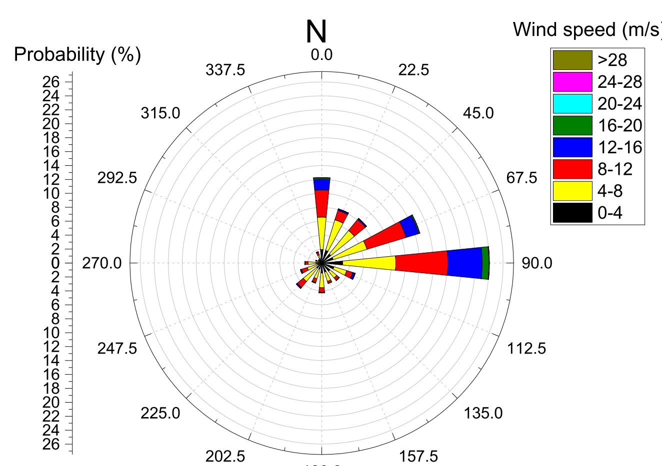

Fig. 1. Directional probability distribution of annual non-typhoon wind speed of Hong Kong (radial distance represents the probability of occurrence of wind).