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External Wind Modeling for Dense and Hi-Rise Cities

Validation of turbulence modeling against wind tunnel tests and on-site measurements

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Abstract

Hong Kong and many other urban areas are densely populated city; hi-rise build form has advantages in land-use, transportation efficiency, but places severe strains on ventilation environment. With increasing public concern, guideline on Air-Ventilation-Assessment (AVA) has been introduced to encourage good practices in building design through the use of Computational Fluid Dynamics (CFD).

Despite the prevalence of using CFD in modeling the urban ventilation environment, there remain uncertainties on what is the optimal combination of turbulence models and simulation parameters (inflow condition, wall functions, model domain) that gives acceptable accuracy while commanding a reasonable level of computational resources. This work addresses the uncertainties through, firstly, studying each modeling parameter in an idealized representation of a city-scape, comparing wind-tunnel results against CFD; and secondly, the findings are verified through comparing on-site measurements taken in Shinjuku to CFD data.

Within our framework, the Detached-Eddy-Simulation (DES) combines the computational efficiency of RANS models and the accuracy of LES models, and is best able to represent the interactions between detached flows of closely packed buildings typical of Asian cities. Recommendations on other simulation parameters are also discussed.

This work builds on our previous research (Yau et al Arup 2007) and forms the core of our recommendations towards formulation of CFD guidelines on Urban Wind Performance Analysis of Hong Kong.

1 Introduction

Our study is broadly divided into two stages. For the first stage, a simplified model representing typical scenarios was constructed and the CFD result was verified against results from the wind tunnel. The objective of this stage is to utilize a relatively simple situation to highlight the different features of the flow to facilitate comparison. Results from the averaged DES turbulence model is compared against conventional RANS models. In the second stage, we apply our findings to a real-life test case at the Shinjuku District of Japan through a comprehensive Air Ventilation Assessment (AVA).

2 Idealized Model

In the first part of this paper, we present selected results form a combined wind tunnel scale and real scale CFD study of wind effects on urban wind climate. The wind tunnel test of an idealized city was performed by Yoshie et al (Yoshie et al 2005), this was used as comparison against CFD performed within Arup. The comparisons focused on accuracy and reliability for different simulation conditions commonly used in practical applications were presented and discussed. An in-depth was also conducted to investigate the influence of boundary inflow condition, wall function for buildings, surrounding building range. We discuss the merits and draw-backs of different turbulence models with particular focus on wind effects at pedestrian level.
Figure 1 Methodology of Study – An idealized city profile: A 1/400th scale model is constructed and tested in the wind tunnel. While the equivalent computational geometry in both 1/400th and full-scale are constructed and tested using computational fluid dynamics techniques.

2.1 Analysis

2.1.1 Turbulence Models

One of the most important objectives of our analysis is to assess the performance of the different turbulence model currently in use. The particular areas of focus are:

1. Qualitative accuracy in capturing the important flow features
2. Quantitative accuracy in predicting pedestrian level wind velocities
3. Efficient use of computational resources

In addition to the standard and modified k-ε discussed by Yoshie et al (Yoshie et al 2005), we also performed simulations using the following models:

Reynolds Average Navier-Stokes
- Spallart-Allmaras (SA)
- Reynolds Normalized Group (RNG)

Eddy Models
- Detached Eddy Simulation (DES)
- Large Eddy Simulation (LES) – subject of future work.

By comparing the results generated from the CFD model against data collected through wind tunnel anemometry, we can see that DES typically outperforms the other models.

Figure 2 Comparison of overall CFD results against Wind tunnel data. In terms of velocity magnitude, DES outperforms conventional RANS models.

DES is inherently an unsteady simulation, and a time averaging is performed to calculate the averaged velocity over approximately 18s (estimated to be significantly larger than the (Strouhal frequency)¹. In our upcoming work, we will study the optimum period required for the DES model to reach steady state.

3 Air Ventilation Assessment of the Shinjuku Test Case

The findings from the first part of this study were applied to a realistic built area at the Shinjuku District in Japan using the Air Ventilation Assessment Methodology (AVA).
Figure 3 Tests points at the Shinjuku Area

Figure 4 shows some extracted point results under 16 wind directions. In general, CFD could be able to give good quantitative prediction over 16 wind directions if the point is located at the centre of domain and surrounded by certain layers of buildings. However, there are a number of exceptions, such as point 11 and 28, which are located at the edge of the model. In particular, the VRS are always over-predicted for those locations where wind arrives from the non-building model area (i.e. northern part of point 11 & 28). This is consistent with our findings from stage 1 where we found that a “wind pre-conditioning” layers of buildings is important for providing an accurate simulation result. This finding is consistent the 2R surrounding area stipulated in the AVA guidelines. i.e. there would have 1H area for the “wind pre-conditioning” layers of buildings on ensuring modeling accuracy.

4 Conclusions

In this study, the underlying assumptions and physics of air ventilation in a high-rise and densely built environment is first analysed in a simplified model. In the second stage, the finds were applied and verified in a real-life situation at the Shinjuku district of Japan.

RANS models are the industrial standards in engineering practices due to its simplicity and relativity low computational demand. However, this type of model has its limitations on prediction accuracy. Large Eddy Simulation Models (LES) requires significant computational resources and are impractical for commercial applications for urban environment flows. Implementation of Detached Eddy Simulation model is an optimum compromise that combines the accuracy of LES in the regions of interest while using a practical level of computational resources. The simulation results shown that DES model outperforms the others at both
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windward, leeward and congested locations although DES model may not give a good prediction at open space due to grid resolution issue. DES model is recommended for studying external wind modeling.

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6 Bibliography


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