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Numerical simulation of dispersion in urban street canyons with avenue-like tree plantings: Comparison between RANS and LES

Salim Mohamed Salim*, Siew Cheong Cheah, Andrew Chan

Division of Environment, Faculty of Engineering, University of Nottingham Malaysia Campus, Semenyih, 43500 Selangor, Malaysia

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ABSTRACT

Previous CFD studies on pollution dispersion problems have largely centred on employing Reynolds-averaged Navier–Stokes (RANS) turbulence closure schemes, which have often been reported to overpredict pollutant concentration levels in comparison to wind tunnel measurement data. In addition, the majority of experimental and numerical investigations have failed to account for the aerodynamic effects of trees, which can occupy a significant proportion of typical urban street canyons. In the present work, the prediction accuracy of pollutant dispersion within urban street canyons of width to height ratio, $W/H = 1$ lined with avenue-like tree plantings are examined using two steady-state RANS models (the standard k-ϵ and RSM), and Large Eddy Simulation (LES) to compare their performance against wind tunnel experiments available on the online database CODASC [1]. Two cases of tree crown porosities are investigated, one for a loosely ($P_{vol} = 97.5\%$) and another for a densely ($P_{vol} = 96\%$) packed tree crown, corresponding to pressure loss coefficients of $\lambda = 80\ \mathrm{m}^{-1}$ and $\lambda = 200\ \mathrm{m}^{-1}$, respectively. Results of the tree-lined cases are then compared to a tree-free street canyon in order to demonstrate the impact of trees on the flow field and pollutant dispersion, and it is observed that the presence of trees reduces the in-canyon circulation and air exchange, and increases the overall concentration levels. Between the two numerical methods employed, LES performs better than RANS, because it captures the unsteady and intermittent fluctuations of the flow field, and hence, successfully resolves the transient mixing process within the canyons.

1. Introduction

Air quality is a major concern for residents of dense urban areas, where buildings act as artificial obstacles to wind flow and reduces flow circulation within cities. The flow patterns that develop around individual buildings govern the flow distribution and pollutant dispersion around the building. The superposition and interaction of flow patterns associated with adjacent buildings govern the final distribution of façade pressures and the movement of pollutants in urban and industrial complexes. Traffic emissions commonly constitute the chief source of air pollution in big cities and have serious detrimental effects on the population's health and comfort. Rapid urbanization and new legislations have resulted in increased research to enable regulators and urban planners to mitigate pollution problems with the aim of improving city livability and air quality.

To that effect, a number of experimental and numerical studies have been performed for the flow and transport of pollutants released about single buildings and clusters of buildings, but the street canyon remains the most widely examined configuration in urban air quality problems. The readers are referred to some comprehensive reviews available in the literature [2–4]. These reviews concluded that although considerable progress has been made in the CFD community, the current status is far from meeting the great needs of assessing and monitoring air quality and much work has to be done in order to increase confidence in using CFD as a stand-alone tool. This is due in part to the fact that selection of a turbulence model greatly influences prediction accuracy of dispersion processes, which has not been addressed properly because majority of the previous studies have adopted the standard k-ϵ model [5].

Initial studies on the numerical prediction of flow and pollutant dispersion within street canyons were performed using two-dimensional (2D) steady-state Reynolds-averaged Navier–Stokes (RANS) equations and their corresponding turbulence closure schemes [6–8]. As computer resources advanced, the investigations were extended to three-dimensional modeling in order to capture the inherent nature of turbulence, and although improvements over 2D modeling were reported, the numerically calculated

* Corresponding author. Tel.: +60 389248601; fax: +60 389248017.
E-mail address: salim@alumni.nottingham.ac.uk (S.M. Salim).

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