Evaluation of CFD Simulation using RANS Turbulence Models for Building Effects on Pollutant Dispersion

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Abstract. CFD evaluations were performed to examine the applicability of the RANS methods in simulating pollutant dispersion near, within and over three typical building configurations: (1) an isolated building, (2) a building array and (3) an urban intersection. The CFD results are compared with values obtained from wind tunnel tests. In some situations major differences between the wind tunnel tests and the CFD results were observed. The main source of difference between the CFD and wind tunnel results was inadequate modelling of local flow patterns using the RANS turbulence models. Also inappropriate evaluation of high intermittent turbulent mixing in the RANS approach may lead to either over-prediction or under-prediction of the concentration level, by up to a factor of 10, depending on the case investigated.

Key words: building effects, CFD evaluation, pollutant dispersion, RANS methods, wind tunnel experiment

1. Introduction

In an urban environment, the transport and dispersion of pollutants, for near-field emission, is directly affected by the aerodynamics of buildings and thus is highly site dependent. Traditionally, information on the near-field concentrations was obtained using physical simulations such as wind-tunnel experiments. Recently, developments in Computational Fluid Dynamics (CFD) make possible an alternative tool to predict concentration fields near buildings. In fact, CFD techniques have been widely used to investigate a diversity of building-effects problems [1–5]. The Reynolds Averaged Navier–Stokes equation (RANS) methods, in which one of the turbulence models supplies the additional equation to solve the correlations of turbulent velocities, are amongst the favourite procedures used to model

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most urban dispersion problems, mainly due to their inexpensive computational costs. However, comparisons of the RANS results with wind tunnel data show that significant errors could occur in the prediction of concentrations within the aerodynamic footprint of buildings [6, 7]. These errors could come from any inappropriate application of the turbulence model, numerical schemes, grid density and so on [8, 9]. On the other hand, the inherent inconsistencies of the simple eddy-diffusivity model with realistic atmospheric dispersion may also be one of the important sources of error.

This paper presents an evaluation of RANS simulation in a few typical building effects scenarios by comparison with wind tunnel experiment results. Three turbulence models, i.e. the \( k-\varepsilon \) model, Shear Stress Transport model (SST) and the Speziale–Sarkar–Gatski Reynolds-stress model (SSG), were tested. In order to focus the investigation on the prediction error caused by the turbulence models and by the eddy-diffusivity assumption, a preliminary CFD investigation was conducted to ensure simulation independence of the grid density and numerical schemes [10]. The content of this paper is outlined as follows: the Reynolds averaged governing equation system is given in Section 2, the case details and a brief description of CFD simulation and wind tunnel experiments are demonstrated in Section 3, the corresponding analysis and comparisons are shown in Section 4 and the conclusions are given in Section 5.

### 2. Reynolds Averaged Governing Equations

For incompressible flows, under the conditions of non-buoyant force and no heat transfer, the Reynolds averaged equations, which govern flow motion and transport and dispersion of pollutants, in tensor notation, are [11]:

\[
\text{Conservation of mass: } \frac{\partial U_i}{\partial x_i} = 0 \quad (1)
\]

Averaged Navier–Stokes equations:

\[
\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} = \frac{1}{\rho} \frac{\partial P}{\partial x_i} + \frac{1}{\rho} \frac{\partial}{\partial x_j} \left( \nu \frac{\partial U_i}{\partial x_j} - u'_i u'_j \right) \quad (2)
\]

Pollutant transport equation:

\[
\frac{\partial C}{\partial t} + U_i \frac{\partial C}{\partial x_i} = \frac{\partial}{\partial x_i} \left( D \frac{\partial C}{\partial x_i} - u'_i c' \right) + S_p \quad (3)
\]

where \( x_j \) are the Cartesian coordinates, \( t \) is the time, \( \rho \) is the air density and \( \nu \) is the kinetic viscosity. \( U_i, P \) and \( C \) are the \( i \)th mean mean velocity