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ScienceDirect
Atmospheric Environment 40 (2006) 5640–5658
ATMOSPHERIC ENVIRONMENT
www.elsevier.com/locate/atmosenv

Recent progress in CFD modelling of wind field and pollutant transport in street canyons

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Received 14 October 2005; received in revised form 28 March 2006; accepted 20 April 2006

Abstract

With rapid development in computer hardware and numerical algorithms, computational fluid dynamics (CFD) techniques are widely utilized to study the wind field and pollutant transport in urban street canyons. The recent advancements and achievements in street-canyon pollution research using mathematical modelling approaches are reviewed in this paper. The standard, renormalized-group (RNG), and realizable $k-\varepsilon$ turbulence closure schemes are the most commonly used Reynolds-averaged Navier–Stokes (RANS) models in street-canyon flow research, including the studies on the effects of street-canyon aspect ratio, building configuration, ambient wind direction, inflow turbulence intensities, vehicle-induced turbulence, and thermal stratifications. Another approach to turbulence simulation inside street canyons is large-eddy simulation (LES) which can handle a broad range of turbulent motions in a transient manner. These two approaches have their merits and the choice between them will be a compromise between accuracy and cost. Several guidelines on this choice as well as some comments on the 2D and 3D CFD simulations are given.

The outputs from wind field models can be used with pollutant transport models to calculate the pollutant distribution inside street canyons. The most commonly employed pollutant transport models include Lagrangian, Eulerian, and Lagrangian/Eulerian hybrid models. The advantages and shortcomings of these models are summarized. Several other modelling concerns, such as chemically reactive pollutant dispersion and boundary conditions treatment, are also discussed.

Keywords: $k-\varepsilon$ turbulence model; Large-eddy simulation (LES); Lagrangian particle dispersion model (LPDM); Eulerian dispersion model; Photochemical reactions; Thermal effects

1. Introduction

The study on wind flow and pollutant transport inside and over urban street canyons have attracted great concern during the past two decades mainly due to increasing urban pollutants and their adverse impacts on human health. Field measurements, laboratory-scale physical modelling and computational fluid dynamics (CFD) techniques are the common tools used to study the wind flow and pollutant distributions in street canyons. Recently, Vardoulakis et al. (2003) reviewed the measurements

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1352-2310/$ - see front matter
doi:10.1016/j.atmosenv.2006.04.055

and modelling techniques for wind flow and pollutant transport within street canyons. However, there are relatively limited discussions on the aspect of CFD modelling. Moreover, quite a number of important works, including numerical techniques and findings, have been published after that review paper. In fact, with the ever-increasing computational power, high resolution CFD models have become a useful tool to explain the detailed processes occurring in urban street canyons. It is now feasible, using state-of-the-art computers, to simulate building-scale flow and dispersion in real urban setting (Lee et al., 2001). Hence, there is a need for a separate review of CFD modelling studies on street-canyon pollution problems. This paper discusses the various CFD modelling approaches and the findings with an intention to give some insights into future modelling directions.

2. The problem and its solution approaches

A "street canyon" generally refers to a relatively narrow street in-between buildings that line up continuously along both sides. It constitutes the basic geometric unit of urban areas. This unit is also bounded by the ground surface at the bottom and the roof level at the top. It has a distinct climate where micro-scale meteorological processes dominate (Oke, 1988) and the air ventilation and pollutant removal are solely through the roof level. The most important features of street-canyon micro-climate are the wind-induced flow patterns, such as air recirculation. These unique micro-scale meteorological processes not only affect the local air quality but also the comfort of the city inhabitants (Bottema, 1993).

The wind flow pattern inside street canyons depends on their geometry, in particular, the building-height-to-street-width (aspect) ratio (H/W, where H is the building height and W is the street width). Based on field measurements and mathematical modelling results, Oke (1988) identified three flow regimes for wind direction perpendicular to the street axis in neutral stratification (Fig. 1). For widely spaced buildings ($H/W<0.3$), the flow fields associated with the buildings do not interact, which results in the isolated roughness flow (IRF) regime. At closer spacing ($0.3<H/W<0.7$) the wake behind the upwind building is disturbed by the recirculation created in front of the windward building. This is the wake interference flow (WIF) regime. Further reducing spacing ($H/W>0.7$) results in the skimming flow (SF) regime. In this case a stable recirculation is developed inside the canyon and the ambient flow is decoupled from the street flow. Under this circumstance the vehicular pollutants at the street level could not be easily ventilated resulting in high pollutant concentration and poor air quality. The strength of the wind-induced recirculations inside street canyons mainly

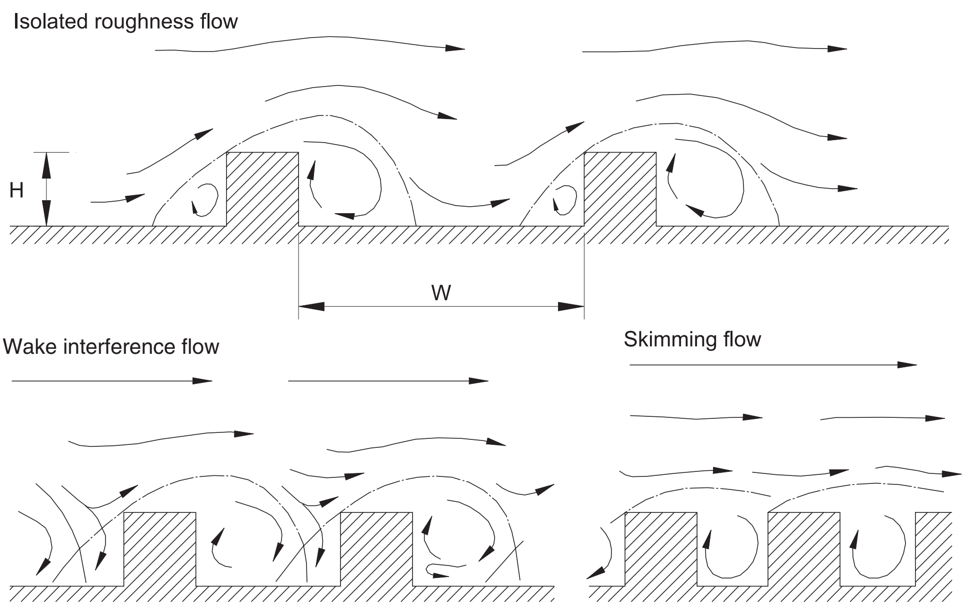

Fig. 1. Three flow regimes associated with different building-height-to-street-width ratios H/W (after Oke, 1988).