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Journal of Wind Engineering
and Industrial Aerodynamics 94 (2006) 491–522

JOURNAL OF wind engineering AND industrial aerodynamics

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Airflow and pollutant transport in street canyons

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Received 16 May 2004; received in revised form 14 November 2005; accepted 13 January 2006
Available online 3 March 2006

Abstract

In this work the dispersion of gaseous and particulate exhaust emissions in different street canyons were studied. For two-dimensional sections of canyon models airflow, pollutant dispersion and deposition patterns in the streets and on the surrounding buildings were analyzed. Effects of building size, street width, and wind velocity on the pollutant transport were examined. While the stress transport turbulence models were used in most of the analysis, the predictions of other turbulence models were also examined. Depending on wind speed, building height, and street width, it was found that large recirculation regions in canyons might form. Under certain conditions, also pollutants emitted from vehicle exhaust may trap inside the street canyon. Variations of transport and deposition of emitted particulate pollutants with particle size and relaxation time were also studied. It was shown that the amount of deposited particles in street canyons reduces when the wind speed increases. The simulation results were compared with the available wind tunnel experiments and favorable agreement was found.

Keywords: Pollutant transport; Street canyon

1. Introduction

Emissions caused by industrial plants, exhausts of motor vehicles including automobiles, trucks, and trains and private households reduce the air quality in densely populated areas. Among these, the automotive exhaust is the major source of air pollution in the street canyons of major cities. Despite significant improvements in fuel and engine technology, present day urban air environments are still mostly dominated by traffic emissions [1].

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doi:10.1016/j.jweia.2006.01.012

Tight emission limitations, cleaner fuels, better engine designs, retiring old vehicles and so on are among the policies that could help reducing the severity of air pollution and the associated health hazards in major population centers.

Knowledge of the sources of pollution and the amount of emission from each are critical for developing plans for environmental emission control. In recent years progress has been made in qualification of the environmental damages due to vehicular emissions and the associated costs [2]. These include wide variety of health effects that range from eye irritation, to heart and lung diseases, and even premature death. Particulate emissions also impair visibility, damage ecosystems of national parks, wilderness areas, and water bodies, and could reduce crop production. The pollutants emitted from motor vehicles have a particularly severe impact on the health of the inhabitants, which are now common in most large cities. These include the automobile drivers, pedestrians, as well as people living in the nearby buildings.

According to Henry et al. [3] particulate pollutants generated by fossil fuels and emissions from car engines cause, roughly 60,000 deaths in the United States each year, accounting for about 3% of the annual loss of life. Tsuda et al. [4] noted that there is no threshold for fine-particle pollution below which no deaths occur. Accordingly, even air pollution levels that are well within legal limits are hazardous to human life, especially older people, and those with chronic heart and lung ailments.

The city street canyons have long been recognized as an air pollution hot spot due to their potential for trapping vehicle-emitted pollutants. The quantity of pollutants emitted in a certain area, as well as their transport and dispersion, and the background level determine the local concentration. Transport and dispersion of pollutants depend on the local airflow conditions in the street canyon and the wind velocity. Airflow directions and velocities are the result of interaction of the outer flow and the type, size and arrangement of the buildings and their surroundings. There have been a number of vehicle-derived air pollution modeling and monitoring studies carried out for city street canyons with the intentions of understanding the processes involved. Vehicle exhaust emissions take place close to the street surface and then disperse because of wind mean speed and turbulence. Vertical mixing of the pollutants in street canyons delays pollutant transport to the main stream.

Field measurements as well as, numerical and experimental models have been used for studying airflow and pollutant dispersion in street canyons. Meroney et al. [5] and Kastner-Klein and Plater [6] used atmospheric boundary layer wind tunnel studies of pollutant dispersion in street canyons. These experiments included an isolated street canyon and urban environment with many equally spaced buildings. Uehara et al. [7] performed wind tunnel experiments on the effect of thermal stratification and the flow inside street canyons. Wahlin et al. [8] reported the results of their study on fine and ultra-fine particles emission from engine exhaust, and their effects on human health.

Recently, computational fluid dynamics (CFD) approaches have been increasingly used to simulate pollutant dispersion in street canyons. Sini et al. [9] used the CHENSI code, which solves the Navier–Stokes averaged equations and includes a $k-\varepsilon$ turbulence model, to simulate the airflow in an isolated two-dimensional street canyon. Leitl and Meroney [10] evaluated the pollutant concentrations in two- and three-dimensional urban street canyons using the standard and the RNG $k-\varepsilon$ turbulence models. Ahmadi and Li [11] simulated the airflow and particulate pollutant transport near an isolated building using a Lagrangian particle tracking method. Using the PHOENICS code, Hassan and Crowther