J2.3 LARGE-EDDY SIMULATION (LES) OF FLOW AND SCALAR DISPERSION INSIDE A STREET CANYON

Chun-Ho Liu*, Mary C. Barth and Sasha Madronich
National Center for Atmospheric Research, Boulder, Colorado

1. INTRODUCTION

A street canyon refers to a narrow street surrounded by tall buildings. We use a 3D LES to study the pollutant distribution and removal mechanism in a modeled street canyon. We consider the case when the wind flow is perpendicular to the street axis.

2. APPROACH

The LES models incompressible flow and passive scalar transport. A 3D Galerkin finite element method is used to solve the transport equations. The advection and diffusion terms in the dynamic equations are advanced in time by the Adams-Bashforth and the Crank-Nicolson schemes, respectively.

Figure 1 illustrates the LES computational domain and boundary conditions of the idealized street canyon. The domain includes a cavity topped by a free surface layer. The cavity represents a street canyon of width B between two buildings of equal height H. The aspect ratio $(\mathrm{H/B})$ is 1. A street-level continuous passive scalar line source is placed at x_s from the leeward wall to simulate vehicular emission. The details of the approach are discussed by Liu and Barth (2002).

3. RESULTS AND DISCUSSION

To evaluate the accuracy of our LES, we compare the model results to wind tunnel measurements (Pavageau and Schatzmann, 1999) in which building models were placed in the streamwise direction of a neutral wind tunnel to construct a periodic street canyon of $\mathrm{H/B}=1$. A neutral buoyancy tracer gas was used to represent a continuous scalar line source. Combining the building height, wind speed U and air at room temperature, the Reynolds number is about 12,000 which is what was prescribed in the LES.

Figure 2 shows the dimensionless mean scalar mixing ratio, $\langle\bar{c}\rangle\mathrm{UHL}/\mathrm{Q}$ (where $\bar{c}$ is scalar mixing ratio, $\langle\ \rangle$ is temporal and spatially spanwise-averaged properties, L is the street length and Q is the pollutant emission rate) profiles for $x_s/\mathrm{H}=0.5$ of the LES and the measurements (Pavageau, 1996; Meroney et al., 1996; and Pavageau and Schatzmann, 1999) on the leeward and windward walls. The LES agrees well with the measurements along the windward wall and the upper leeward wall ($z/\mathrm{H}>0.5$). However, the LES underpredicts the mean scalar mixing ratio by about 10% at the ground level leeward corner. Results of the LES show that the scalar is carried toward the leeward wall by the primary vortex (Figure 3), lifted along the wall to roof level where the scalar is either removed from the street canyon or recirculated down the windward wall towards the street in agreement with the wind tunnel measurements.

The spatial variation of the calculated dimensionless scalar mixing ratio variance, $\langle c''c''\rangle(\mathrm{UHL/Q})^2$ (where $c''c''$ and $''$ denote the scalar mixing ratio variance and the deviation from the statistical mean, respectively), which agrees well with the wind tunnel measurements, indicates two regions of large scalar variance (Figure 4), at the ground level leeward corner where rapid mixing of the emitted scalar occurs and at the roof level. The measurements show a broad maximum of scalar mixing ratio variance centered over the street canyon, while the LES shows that the maximum ($\approx$400-600) is slightly upstream at the roof level.

The minimum streamfunction (Figure 5) indicates that the primary vortex center is slightly shifted toward the windward side. The parallel iso-streamfunction contours at the roof level show that the primary vortex is isolated from the free surface layer.

The vertical scalar flux $\langle w''c''\rangle(\mathrm{HL/Q})$ at the roof level (Figure 6), which handles the scalar removal from the street canyon to the free surface layer, has a maximum located slightly upstream from the center. Because scalar fluxes indicate turbulent dispersion of the scalar, these results suggest that the scalar is removed from the street canyon by turbulent dispersion at the leeward roof level.

Additional simulations for which scalar sources were located at x_s/H = 0.29 and 0.71 show that the mean scalar mixing ratio on the leeward wall is greater (about 2-3 times) than that on the windward wall (Figure 7). For all simulations, the leeward wall is affected by both the source emission and recirculation, while the windward wall is affected by the recirculation only.

4. CONCLUSIONS

In this study, we investigate the scalar dispersion characteristics in a modeled street canyon using a 3D LES. The mean scalar mixing ratio and variance calculated by the LES are comparable to previous wind tunnel measurements. We demonstrate that the pollutant removal from the street canyon is governed by only turbulent dispersion on the leeward roof level.

5. ACKNOWLEDGEMENTS

The National Center for Atmospheric Research is sponsored by the National Science Foundation. The first

**Corresponding author address:* Chun-Ho Liu, National Center for Atmospheric Research, Boulder, CO 80305-3000;
e-mail:liuchunho@graduate.hku.hk

author thanks the Croucher Foundation, Hong Kong for their financial support.

6. REFERENCES

Liu, C.-H. and M. C. Barth, 2002: Large-eddy simulation of flow and scalar transport in a modeled street canyon, *J. Appl. Meteorol.*, accepted.

Meroney, R. N., M. Pavageau, S. Rafailidis and M. Schatzmann, 1996: Study of line source characteristics for 2-D physical modeling of pollutant dispersion in street canyon, *J. Wind Eng. Ind. Aero.*, **62**, 37-56.

Pavageau, M. 1996: Concentration fluctuations in urban street canyons – groundwork for future studies, technical report, Meteorological Institute of the University of Hamburg, 97p.

Pavageau, M. and M. Schatzmann, 1999: Wind tunnel measurements of concentration fluctuations in an urban street canyon, *Atmos. Environ.*, **33**, 3961-3971.

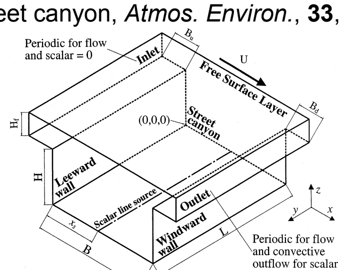

Figure 1: LES computational domain and boundary conditions for an idealized street canyon.

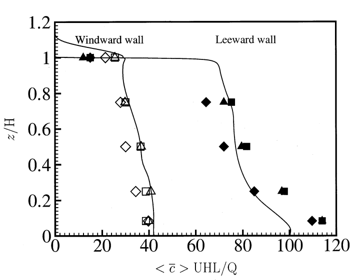

Figure 2: Dimensionless mean scalar mixing ratio on the windward and leeward walls. LES calculations: solid lines. Measurements: ■, □: Pavageau (1996), ▲, Δ: Meroney et al. (1996), and ◆, ◇: Pavageau and Schatzmann (1999).

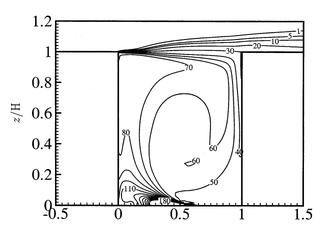

Figure 3: LES calculated spatial variation of the dimensionless mean scalar mixing ratio $\langle\bar{c}\rangle\mathrm{UHL}/\mathrm{Q}$ for $x_s/\mathrm{H} = 0.5$.

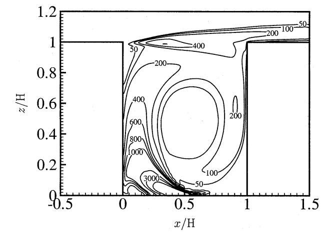

Figure 4: LES calculated spatial variation of the dimensionless mean scalar mixing ratio variance $\langle c''c''\rangle(\mathrm{UHL/Q})^2$ for $x_s/\mathrm{H} = 0.5$.

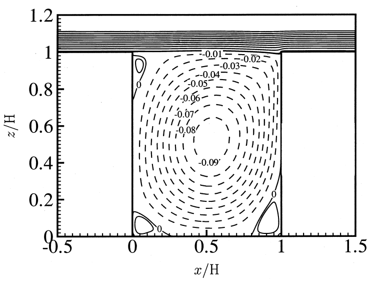

Figure 5: Spatial variation of the streamfunction. Positive (solid lines) and negative (dashed lines) streamfunction represent secondary (anticlockwise) and primary (clockwise) vortices, respectively. Streamfunction for the solid lines inside the three secondary vortices is equal to 1.00×10^{-3}.

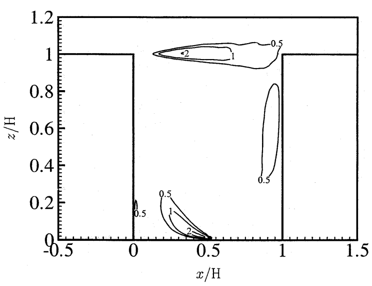

Figure 6: LES calculated spatial variation of the dimensionless vertical scalar fluxes $\langle w''c''\rangle(\mathrm{HL/Q})$

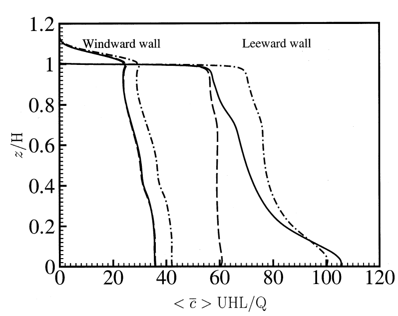

Figure 7: Dimensionless mean scalar mixing ratio on the windward and leeward walls for different source locations. $x_s/\mathrm{H} =$ 0.29 (solid lines), 0.5 (dash-dotted lines), and 0.71 (dashed lines).