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# NUMERICAL STUDY ON POLLUTANT DISPERSION IN URBAN STREET CANYON

GUIXIANG CUI, YI LIU, XUELING CHENG, ZHAOSHUN ZHANG

*Department of Engineering Mechanics*

*Tsinghua University, Beijing, China*

## Abstract

The dispersion of car exhaustion in street canyon is studied by LES and unsteady RANS. Both velocity field and distribution of pollutant concentration are computed. The influence of the geometry of building blocks on the pollution is investigated.

## 1. Introduction

The prediction of the pollutant dispersion is of great significance for the air quality in urban area<sup>[1, 2]</sup>. The source of the pollution comes from the emission released by the motor vehicles at the street floor. The large eddy simulation is used to predict the unsteady flow as well as the dispersion of pollutants in the street canyon. Unsteady RANS, so-called VLES is also applied to this flow and the results show that LES and VLES give similar results in 2D cases and they are acceptable for the environmental problem.

## 2. The governing equation

The governing equations for LES can be written as

$$\frac{\partial \bar{u}_i}{\partial x_i} = 0 \quad (1)$$

$$\frac{\partial \bar{u}_i}{\partial t} + \frac{\partial (\bar{u}_i \bar{u}_j)}{\partial x_j} = -\frac{1}{\rho} \frac{\partial \bar{p}}{\partial x_i} + \nu \frac{\partial^2 \bar{u}_i}{\partial x_i \partial x_i} - \frac{\partial \tau_{ij}}{\partial x_j} \quad (2)$$

$$\frac{\partial \bar{c}}{\partial t} + \bar{u}_j \frac{\partial \bar{c}}{\partial x_j} = D \frac{\partial^2 \bar{c}}{\partial x_i \partial x_i} - \frac{\partial M_j}{\partial x_j} \quad (3)$$

in which  $\tau_{ij}$  and  $M_i$  are the subgrid stress and mass flux respectively.

The total shear stress, i.e. the subgrid stress plus molecular viscous stress, is closed by the RNG-based Smargorinsky model <sup>[3]</sup> as follows

$$\tau_{ij} + \tau_{ij}^m = -(\nu_{eff} \bar{S}_{ij} + \delta_{ij} \tau_{kk} / 3) \quad (4)$$

in which  $\nu_{eff} = \nu + \nu_t$ . The effective viscosity is defined as

$$\nu_{eff} = \nu \left[ 1 + H(\nu_s^2 \nu_{eff} / \nu^3 - C) \right]^{1/3} \quad (5)$$

with  $\bar{S}_{ij} = (\partial \bar{u}_i / \partial x_j + \partial \bar{u}_j / \partial x_i) / 2$ ,  $\nu_s = (C_{rng} V^{1/3})^2 \sqrt{2 \bar{S}_{ij} \bar{S}_{ij}}$  and  $H(x) = x$  when

$x > 0$ ,  $H(x) = 0$  otherwise. The  $V$  is the grid volume and  $C_{rng} = 0.157$ ,  $C = 1.00$ .

The subgrid mass flux, including the molecular diffusion, is closed by a gradient model such that

$$M_i = D_t \frac{\partial \bar{c}}{\partial x_i} \quad (6)$$

where the turbulent diffusion coefficient is defined as  $D_t = \nu_{eff} / Sc_t$ , in which

$Sc_t$  is the turbulent Schmidt number and assumed to be 1.0.

When we use  $k-\epsilon$  model to close the subgrid Reynolds stress and mass flux, it is so-called VLES. The  $k$ - and  $\epsilon$ -equations with standard coefficients are ignored and can be found elsewhere <sup>[4]</sup>. Same formulae as eq. (6) is used for average mass flux.

The finite volume method is applied for the numerical solution with QUICK scheme and the time advance is second order Runge-Kutta integration.

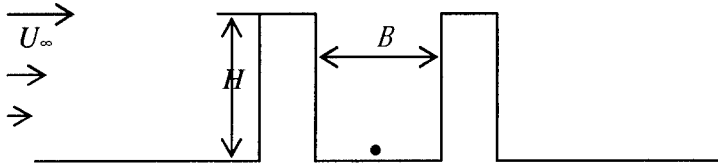
### 3. The testing cases

#### 3.1 Two dimensional street canyon

The geometry of the street canyon is illustrated in Figure 1. The upstream wind speed which is assumed to be varied with time period of 8 minutes, i.e.

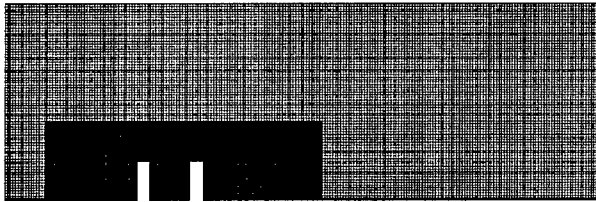
$U_\infty(y, t) = U_0(y) \sin(2\pi t / 480)$ . The pollutant is located at the street floor and

assumed as a constant, presumably the pollutant concentration equals to 1.0 at a local spot and zero outside of the spot.



**Figure 1** The illustration of the street canyon, ● is the spot of the pollution

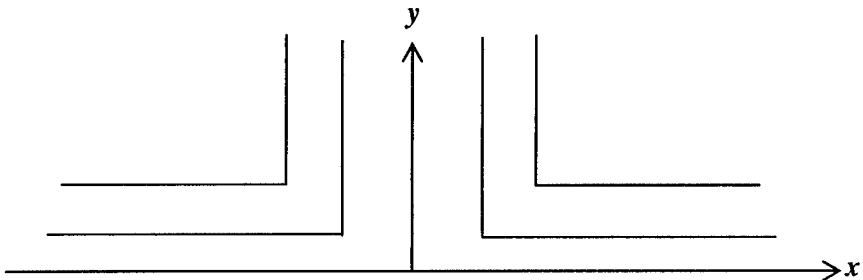
The computational domain and grid meshes are sketched in Figure 2 for  $B/H=1$ . The mean velocity and Reynolds stress profiles are given at the inlet and the fully developed flow condition is posed at the outlet. The wall function is used at the solid walls and free stream condition is given on the upper boundary.



**Figure 2** The computational domain and the grid meshes

**3.2 Street canyon on the cross road**

The cross road is illustrated in Figure 3. A symmetrical condition is added in respect to the plane at  $y=0$ . The car exhaust is simplified as a line source in the middle of the street and it located at  $y$  axis at the floor of street canyon, i.e.  $z=0$ . The geometry and flow parameters of the testing cases are listed in Table 1.



**Figure 3** The plane layout of street canyon on cross road

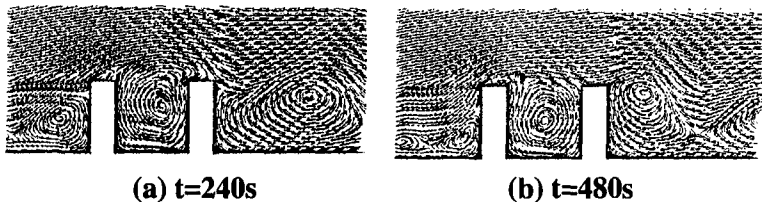
**Table 1 The geometry and flow parameters**

	Case A1	Case A2	Case B1	Case B2
B/H	1	3	1	3
Reynolds number	$10^6$	$10^6$	$10^6$	$10^6$
Turbulent model	LES	LES	$k-\varepsilon$	$k-\varepsilon$
3D cross road	yes	no	no	no
H (meter)	30	30	30	30

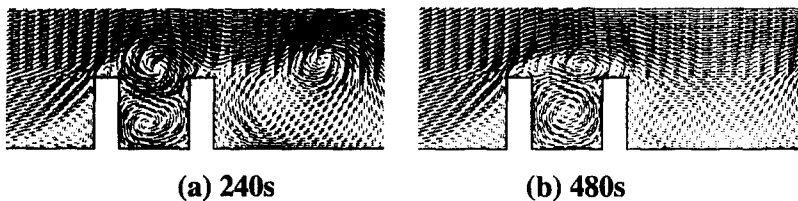
#### 4. The results

##### 4.1 Case A1 and B1

The flow fields at two typical time-steps are presented in Figure 4 and 5. It clearly shows a vortex in the street canyon that transports the pollutant outside of the canyon. The iso-contours of concentration are shown in Figure 6 and 7.



**Figure 4 The flow field for  $B/H=1$  by  $k-\varepsilon$  model**



**Figure 5 The flow field for  $B/H=1$  by LES**

Note that the velocity and concentration fields are phase averaged on six periods in LES. The flow patterns inside the street canyon are nearly same in both LES and VLES, however more vortices outside of the canyon in LES, particularly at the corners of the building.

Results of the concentration distributions are in good agreement between LES and VLES inside the street canyon and the concentration is greater on the lee side of the front building and smaller at the front of the back building. The concentration distributions are different greatly outside the street canyon between LES and VLES, this is due to the different flow fields.

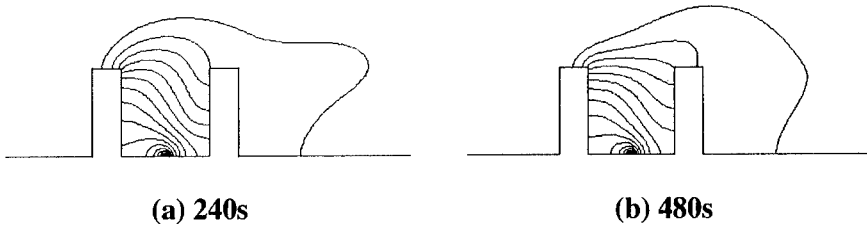


Figure 6 The iso-contours of concentration for  $B/H=1$  by  $k-g$  model



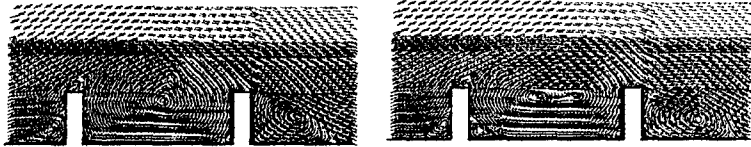
Figure 7 The iso-contours of concentration for  $B/H=1$  by LES

4.2 Case A2 and B2

The results for  $B/H=3$  are presented in Figure 8 and Figure 9. It is clearly shown that the pollutants are transported more quickly out of the street canyon for the wider spacing of the building block.

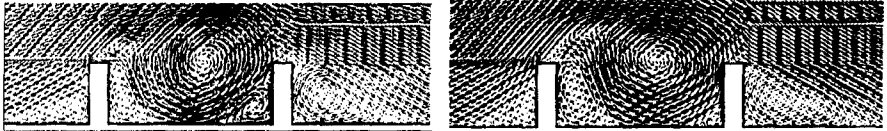
Compared with Figure 4 and 5, Figure 8 and 9 clearly show that the bigger vortices are formed in the wider street canyon. It is useful for transporting the pollutants outside of the canyon and reduced the concentration of pollution on both front and back buildings, as shown in Figure 10 and 11.

Compared between LES and VLES results it is found that the main large vortices are nearly same inside the canyon but flow patterns are different in the outside.



(a) 240s

(b) 480s

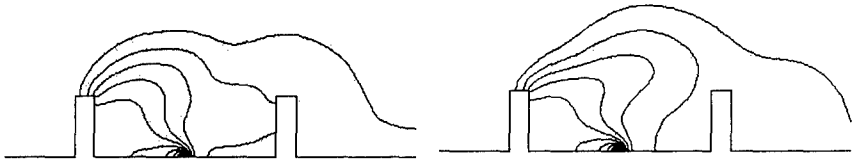
**Figure 8** The flow field with  $B/H=3$  by  $k-g$  model

(a) 240s

(b) 480s

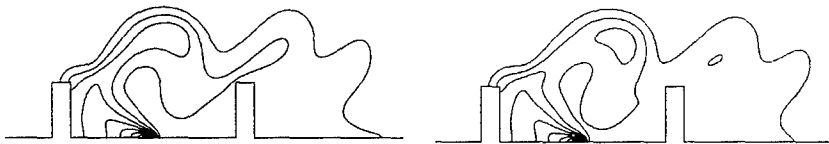
**Figure 9** The flow field with  $B/H=3$  by LES

Larger differences between LES and VLES prediction of concentration occur due to the wider spacing between front and back buildings. We believe that the LES has better resolution and it may be approximate to practical situation.



(a) 240s

(b) 480s

**Figure 10** The iso-contours of concentration for  $B/H=3$  by  $k-g$  model

(a) 240s

(b) 480s

**Figure 11** The iso-contours of concentration for  $B/H=3$  by LES

4.3 Integral flux

Integral flux, shown in Figure 12, is a useful design parameter in building engineering and defined as the integration of the vertical mass flux.

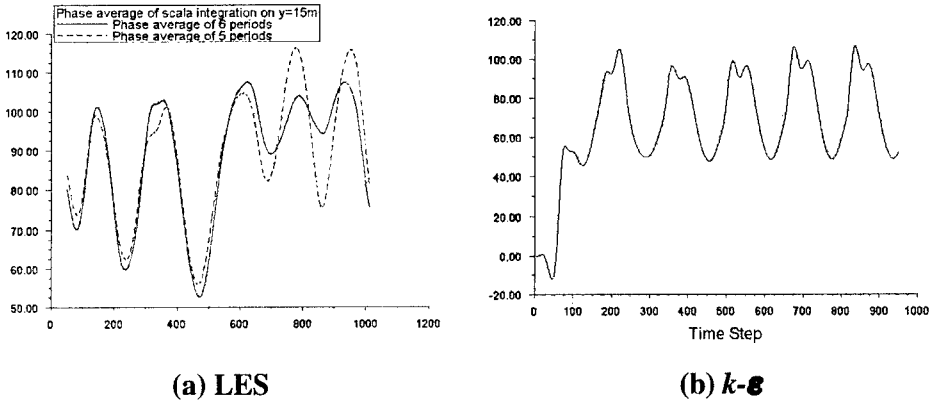
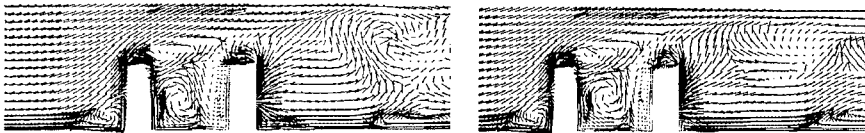


Figure 12 The integration flux  $\int_0^B \overline{w'c'} dx$

Both LES and  $k-\epsilon$  model show the same periodicity as the free stream velocity. On average the agreement between LES and  $k-\epsilon$  model is good but the peak values are different. It is due to the different flow and concentration fields.

4.3 Three dimensional dispersion at cross road

The typical velocity and concentration fields are presented in Figure 13 and 14. The velocity fields are in fairly agreement between LES and  $k-\epsilon$  models, however the difference is obvious outside of the street canyon.



(a) LES on cross section at  $y=100$       (b)  $k-\epsilon$  on cross section at  $y=100$   
 Figure 13 Velocity field by LES and  $k-\epsilon$



The similar situation appears in the concentration field as shown in Figure 14. Inside the street canyon the concentration distributions are quite similar but big difference occurs outside of the canyon.

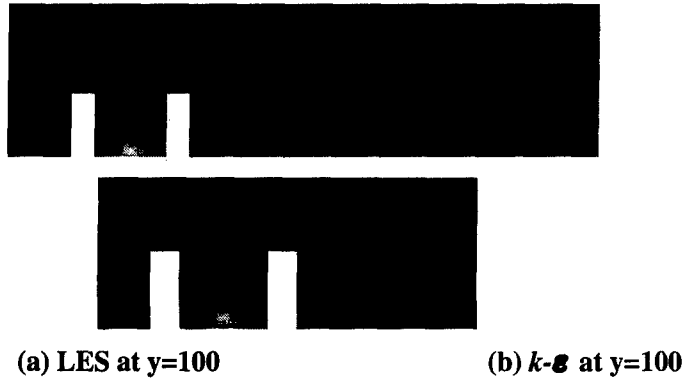


Figure 14 Iso-contours of concentration in 3D street canyon by LES and  $k-g$

### 5. Concluding remarks

Both LES and VES give similar results for flow and concentration fields inside the street canyon in both 2D and 3D cases. However LES has better resolution in flow field than VLES and is expected to have better prediction for more complicated street canyon. On the other hand LES spend more computation time than VLES, 5-8 times more. Therefore the computational efficiency of LES must be improved and the models for unsteady RANS should be also consider in order to satisfy the complex 3D flows.

### Acknowledgement

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### 6. Reference

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