II-22 Characteristics of Wind Field in a Street Canyon

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Introduction

Studying the wind field inside a street canyon is of crucial importance for the study of heating characteristics of below roof-top levels in the urban area and the dispersion of toxic gases and pollutants discharged to the street canyon. Considering this problem, the aim of this study is to give detail view to the wind field in a North-South oriented street canyon through simultaneous integrations of the two-dimensional Navier-Stokes equations and equation of heat transfer using LES model coupled with solutions of heat diffusion equations for roof, walls and road.

Governing Equations and Initial Boundary Conditions

The non-dimensional filtered Navier-Stokes equations, continuity equation and equation of heat transfer with the Boussinesq approximation for the natural convection in a street canyon can be written in tensor form as follows:

$$\frac{\partial u_i}{\partial t} + \frac{\partial}{\partial x_j}(u_i u_j) = -\frac{\partial p}{\partial x_i} - \frac{1}{R_e}\frac{\partial \tau_{ij}}{\partial x_j} + \frac{R_a}{P_r R_e^2 T}\delta_{i3}, \tag{1}$$

$$\frac{\partial u_j}{\partial x_j} = 0, \tag{2}$$

$$\frac{\partial T}{\partial t} + \frac{\partial}{\partial x_j}u_j T = \frac{1}{P_r}\frac{\partial}{\partial x_j}H_j, \tag{3}$$

where u_i are filtered velocity components in the horizontal and vertical directions, t time, p pressure, T filtered temperature, τ_{ij} and H_j are the subgrid scale (SGS) Reynolds stresses and heat fluxes respectively; R_e ($= Uh/\nu$) Reynolds number, P_r ($= \nu/\kappa$) Prandtl number, R_a ($= gh^3\Delta T/\nu\kappa$) Rayleigh number and $\Delta T = T - <T>$ with h a characteristic height, U a characteristic velocity, $<T>$ the horizontal average temperature, ν and κ the kinematic viscosity and heat diffusivity respectively.

The SGS Reynolds stresses and heat fluxes were approximated using Smagorinsky (1963) model. The prognostic equation for the SGS turbulence energy k is as follows

$$\frac{\partial k}{\partial t} = -\overline{u_i\frac{\partial k}{\partial x_i}} - \overline{u_i' u_j'}\frac{\partial u_i}{\partial x_j} + \frac{R_a}{R_e^2 P_r \Delta T}\overline{w'T'} - \frac{\partial[\overline{u_i'(k+p')}]}{\partial x_i} - \varepsilon. \tag{4}$$

The closure assumptions made here in order to solve (4) are the downgradient diffusion assumption and the Kolmogoroff hypothesis

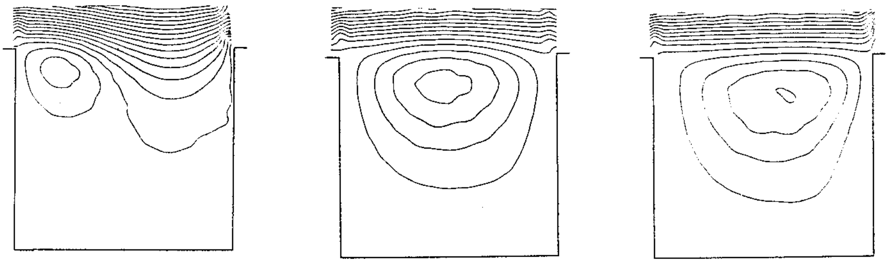
$$\varepsilon = \frac{ck^{3/2}}{l}, \tag{5}$$

The SGS eddy viscosity was evaluated as

$$\nu_m = (cl)^2 S, \tag{6}$$

where

$$S^2 = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)^2. \tag{7}$$



Streamlines in the Street Canyon after 27 s
Street Canyon Height: 30 m, Width: 30 cm
Outside Wind Velocity: 2 m/s

Streamlines in the Street Canyon after 62 s
Street Canyon Height: 30 m, Width: 30 cm
Outside Wind Velocity: 2 m/s

Streamlines in the Street Canyon after 92 s
Street Canyon Height: 30 m, Width: 30 cm
Outside Wind Velocity: 2 m/s

Figure 1: Streamlines in the Street Canyon at Different Times from the Beginning of the Computation

In the near solid boundary regions, log law velocity was assumed.
The boundary conditions for the Navier Stokes Equations are non-slip on the solid surfaces and zero normal gradients of velocity components across the downwind and upper boundaries. At the upwind boundary, a parabolic velocity profile is specified. For the Heat Transfer Equation (3), zero normal gradients of air temperature are specified at the entrance and exit, given free atmospheric temperature at the upper boundary and the conditions on the solid boundary were obtained by solving equations of heat diffusion inside roof, wall and below the road surface. The energy balance at surfaces of road and walls is the coming net radiation R_{net} to the surface equals to the summation of conduction heat minus sensible heat. R_{net} is determined as

$$R_{net} = (S + s\psi_{sky\rightarrow A})(1 - \alpha_A) + R_a\psi_{sky\rightarrow A} + \sum_i (S_i + s_i\psi_{sky\rightarrow i})\alpha_i\psi_{i\rightarrow A} + \sum_i R_i\psi_{i\rightarrow A} - \varepsilon\sigma T_A^4 \tag{8}$$

where S and s are the direct and diffused solar radiation respectively, $\psi_{sky\rightarrow A}$ the view factor from a point A for the sky, α_A the albedo of the surface at point A, R_a the longwave radiation from the sky, S_i and s_i the direct and diffused solar radiation to a surface element i of the surrounding environment respectively, α_i the albedo of the element i, $\psi_{i\rightarrow A}$ the view factor from the point A for the element i, R_i the longwave radiation emitted by the element i, ε the emissivity of the surface and σ the Stefan-Boltzmann constant.
The initial condition is wind velocity set equal to zero through out the computational domain and suddenly, wind starts to blow from the upwind boundary. The solutions then starts until the steady state of the wind field is achieved.

Solution Scheme and Results

The system of Equations (1-4) for the wind velocity and air temperature fields was discretized in finite volume form on a non-uniform, non-staggered grid (Ca et al, 1993). A second order centered space differences are used for all viscous-like terms (including the SGS terms) and the pressure gradient and divergence terms. A third order upwind method based on the QUICK algorithm is used for the non-linear terms and an implicit second order Crank-Nicholson differencing is used in time.
Results of computation of stream lines of the wind field at different times from the beginning of the computation are depicted in Figures 1. It can be seen that a large eddy is created in the street canyon. The eddy firstly is created in the upwind corner of the street canyon and continue to extend in the size until the flow achieve the steady state after about 60 seconds from the beginning of the computation. Results (not shown) also reveal that the number of large eddies in the street canyon depends on the ratio between the wall height and the road width. If the outside wind is strong, the flow inside the street canyon is not affected much by the thermal convection and the pattern of the flow field does not change much within one day.

References

Ca V.T., Asaeda T. & Armfield S. 1993. *Australian Convection Workshop*, 1-4.

Smagorinsky J. 1963. *Monthly Weather Review* . **91.** 99-164.