Modelling of Street Canyon and Building Flow Regimes

A contribution to subproject SATURN

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Summary

The research this year has focussed upon four topics;

(1) Analysing the results from a study of the effects of geometry on the flow within a nominally 2-D street canyon (in collaboration with Ecole Centrale de Nantes (ECN), France).
(2) Assessing the findings from a study of the influence of simulated windward-facing wall solar heating on the flow pattern within a street canyon at low Froude numbers (also in collaboration with ECN).
(3) A study of the complex wind flows and dispersion characteristics at street intersections.
(4) A comparison of two building effects models (ADMS-BUILD and PRIME).

The experimental work outlined here has been carried out in wind tunnels at the University of Surrey using a range of instrumentation for wind velocity, turbulence and flow temperature measurement.

Activities during the year and Principal results

Effects of geometry on the flow in a simple two-dimensional street canyon

A comparison between numerical simulations and wind tunnel modelling has been performed to examine the variation with streamwise aspect ratio (width/height, W/H) of the mean flow patterns in a street canyon, Kovar-Panskus et al (2002a). For this purpose a two-dimensional (2-D) cavity was subjected to a thick turbulent boundary layer flow perpendicular to its principal axis. Five different test cases, W/H=0.3, 0.5, 0.7, 1.0 and 2.0, have been studied experimentally with flow measurements taken using pulsed-wire anemometry. The results show that the skimming flow regime, with a large vortex in the canyon, occurred for all the cases investigated. For the cavities with $W/H \leq 0.7$ a weaker secondary circulation developed beneath the main vortex. The narrower the canyon, the smaller the wind speed close to the cavity ground, giving increasingly poor ventilation qualities. The corresponding numerical results were obtained with the Computational Fluid Dynamics (CFD) code CHENSI that uses the standard k-ε model. The intercomparison showed good agreement in terms of the gross features of the mean flow for all the geometries examined, although some detailed differences were observed. In particular, the centre of the main vortex was 5%-15% higher and more downstream in the cavity in the predictions than in the experiments, indicating a tighter and less diffuse vortex. Further work is required to clarify the influence of initial conditions on the flow regimes in canyon configurations and to achieve a suitable parameterisation of those conditions.

Effect of solar-induced wall heating on the flow regime in a two-dimensional canyon

A wind tunnel study has been undertaken to assess the influence of solar-induced wall heating on the airflow pattern within a street canyon under low-speed wind conditions, Kovar-Panskus et al (2002b). This flow is normally dominated by large-scale vortical motion, such that the wind moves downwards at the downstream wall. In the present work the aim has been to examine whether the buoyancy forces generated at this wall by solar-induced heating are of sufficient strength to oppose the downward inertial forces and, thereby, change the canyon flow pattern. Such changes will also influence the dispersion of pollutants within the street. In the experiments the windward-facing wall of a canyon has been uniformly heated to simulate the effect of solar radiation. Four different test cases, representing different degrees of buoyancy (defined by a test Froude number, Fr), have been examined using a simple, 2-D, square-section canyon model in a wind tunnel. For reference purposes, the neutral case (no wall heating), has also been studied. The approach flow boundary layer conditions have been well defined, with the wind normal to the main canyon axis, and measurements have been taken of canyon wall and air temperatures and profiles of mean velocities and turbulence intensities. Analysis of the results shows clear differences in the flow patterns. As Fr decreases from the neutral case there are reductions of up to 50% in the magnitudes of the reverse flow velocities near the ground and in the upward motion near the upstream wall. A marked transition occurs at $Fr \approx 1$, where the single dominant vortex, existing at higher Fr values, weakens and moves upwards whilst a lower region of relatively stagnant flow appears. This transition had previously been observed in numerical model predictions but at a Fr at least an order of magnitude higher.

The results from the present study indicate that the heating of the windward-facing wall does appear to have some influence on the generation of a very weak secondary flow close to the ground of the canyon at very low Froude numbers. However, so far there is little evidence that the buoyancy forces induce a widespread upward motion, except in a very thin layer near the heated wall, as also noted from field experiments in Nantes, France. Hence, it is not possible to clearly state that the effect of wall heating will be significant in terms of the canyon flow field and the motion and dispersion of pollutants. Further work is planned to examine the possible three-dimensionality of the canyon flow regime with wall heating, together with 3-D simulation, based on the CFD code CHENSI for predicting such flows.

Flow and dispersion at an urban intersection

A wind tunnel study of dispersion at a simple urban intersection comprising two perpendicular streets has been carried out. Concentration and flow field measurement were undertaken to determine the importance of the exchange of pollutants between the streets and to investigate source-receptor relationships at the intersection, Robins and Savory (2002).

The results show that significant exchanges occur at intersections between two streets and that as a consequence pollution emitted in one street can penetrate far into the other. A further consequence is the development of persistent structure in the concentration field within a street, with receptors on opposite sides being primarily affected by entirely separate sets of sources. The exchanges are driven by minor departures from symmetry in the geometry or orientation of the intersection and are likely to be the norm in practice. As the effects of the exchanges are not confined to the immediate vicinity of the intersection, they need to be addressed in the analysis of urban air quality, whether by calculation or by monitoring. The successful inclusion of such effects in dispersion models will rest heavily on the provision of a realistic empirical description of the air exchanges at the intersection and their dependence on wind direction. Such information is likely to be site-specific. Detailed studies of dispersion processes at both generic and realistic intersections are required to develop further understanding of the processes involved and to pave the way for improved dispersion models. In all probability, such research will involve both experimentation and computations (CFD).

Further analysis of the results currently available will concentrate on the effect of wind direction on the concentration field and air exchanges. Annual average concentration fields can then be investigated and their sensitivity to the line source strengths in each street and the form of the wind rose established.

A comparison of building effects models

There are presently two relatively sophisticated models available for treating the effects of buildings within practical dispersion models, namely the Atmospheric Dispersion Modelling System (ADMS-BUILD) and the Plume Rise Model Enhancements (PRIME) code. Both approaches comprise a series of sub-models for predicting flow and dispersion within defined regions upwind, around and downwind of a building and the recent work at Surrey has examined the key components of each model, identifying their similarities and assessing the consequences of their differences, Robins (2001).

ADMS-BUILD and PRIME are very similar at the conceptual level but important differences in their detail can lead to significant differences in predictions. Although both have been extensively tested, their performance has not been evaluated against common data sets. Undertaking such an exercise is perhaps best left until PRIME is integrated into the AERMOD dispersion code as performance is linked to the underlying dispersion model. The nature of PRIME and BUILD is such that for some applications solutions may be sensitive to small changes in problem specification, whereas in other cases performance may be far more robust. Furthermore, the complexities of real applications cannot be treated directly and at some stage the geometry must be reduced to a single, block-shaped building. Some guidelines for converting small arrays into effective obstacles have been developed but these are far from comprehensive. The implication is that an evaluation of the variability in predicted concentrations as a function of perturbations to the problem specification forms an essential part of model application, or indeed validation studies. Overall, a factor of three or somewhat better precision would seem to be a realistic expectation of any advanced building effects model, provided it is being applied to a situation where one large building clearly dominates.

Although much has been achieved in the development of building effects models, clearly more must be done both in optimising existing methods and developing improved algorithms. At the same time, a large, reliable data set for assessing model performance needs to be assembled, ideally one that is accepted by all model developers. This set should cover the whole problem space over which models might be applied. Inevitably there will be important omissions and weaknesses in the data set and their identification will provide a clear pointer for future experimental research effort.

Aims for the coming year

Further analysis of the street intersection data will be carried out an presented. In the case of the heated cavity research programme a comparison will be made between the experimental data obtained and numerical simulations carried out by ECN using 3-D CHENSI. Further experiments on this topic, in collaboration with ECN, are planned for 2002.

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