PARAMETERISATION OF FLOWS AND POLLUTANT TRANSPORT OVER IDEALISED URBAN ROUGHNESS

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Atmospheric flow over urban areas basically is a type of turbulent flow over roughness. The flows and pollutant transport process, especially at the lower part of the boundary layer (BL), is strongly modified due to the presence of building geometry. The aerodynamic resistance exerted by the surface roughness reduces the mean velocity in the lower BL but enhances the turbulence intensity. Moreover, the near-wall impingement structures over rough surfaces are attributed to the flow dynamics aloft, leading to increasing aerodynamic resistance and BL depth. However, the dependence on surface morphology and BL depth is not yet well understood. There is apparently a lack of systematic studies on how the building roughness affects street-level ventilation and pollutant transport. In the practical perspective, there is a need for formulating a simple and reliable ventilation and pollutant dispersion estimate for rectifying the elevated pollutant concentrations in urban areas.

Previous studies by the authors, using large-eddy simulation (LES), have shown that the aerodynamic resistance exerted by idealised building roughness could be parameterised by a single dimensionless parameter, friction factor f. Friction factor, which is the ratio of drag (form and shear) to dynamic pressure, is a measure of the aerodynamic resistance over a rough surface. It is defined as

$$f = \tau_w/(\rho U_m^2/2)$$

where U_m is the mean velocity of the aloft BL. Practically, form drag usually dominates over shear stress in fully developed turbulent BL flows, indicating its dependence on the geometry of roughness elements. Using f, it was demonstrated that the ventilation performance (measured by air-exchange rate ACH) is a linear function of f regardless of the separation between roughness elements. Afterwards we extended the use of f in pollutant transport over urban roughness. It was revealed that the pollutant dispersion strongly depends on f in which the vertical dispersion coefficient σ_z increases with increasing f. However, the geometry of the roughness elements used in both studies was rather simple (ribs) so only a narrow range of f was tested that might be insufficient to elucidate the full-range behaviour. Besides, the effect of aloft BL depth on the ventilation and transport behaviour was neglected. In view of the existing limitation, this study is conceived that attempts to formulate a quick and reliable estimate to ventilation and pollutant transport over rough surfaces. Practically, it is purposely to demonstrate the feasibility of using f in the parameterisation of street-level ventilation and pollutant dispersion, such as the effects of building shape, obstacle orientation, and aloft BL depth, could be unified. A systematic parametric test, consisting of computational fluid dynamic (CFD) and experiments, are performed.

As a pilot trial, the CFD study is performed. The Renormalisation Group (RNG) k-ϵ turbulence model is adopted and steady-state scenarios are considered. A two-dimensional (2D) domain is simulated in which the wind direction is set normal to the roughness elements, representing the worst case for pollutant removal. Two different sets of simulation are conducted. Firstly, the focus is put on the effect of surface morphology, thus, the surface roughness elements are constructed by eight types of idealised building geometry and the separation between the roughness elements is varied systematically aiming to simulate the full range of f. A total of 114 CFD cases are conducted. Secondly, we aim to test the effect of aloft BL depth on the ventilation behaviour, thus, both the roughness-element separation and the aloft BL depth are varied, ranging between 6h to 1,200h (where h is the building height).

Wind tunnel experiments are conducted in an open-circuit wind tunnel. The width and depth of the tunnel are 560 mm. The 2-m-long test section is connected with the upstream section to facilitate fully-developed flows. A turbulent BL, whose characteristics are similar to those in the atmospheric BL, is simulated by means of Lego™ roughness elements. The surface roughness is fabricated by 25-mm aluminium square bars, which are fully spanned the wind tunnel and are aligned normally to the prevailing flow. Depending on the separation of roughness elements, hypothetical urban surfaces, consisting up to 40 identical rows, are fabricated to simulate the infinitely large urban surfaces. Six types of urban surfaces are modelled by varying the separation between the aluminium bars. In-house made X-hot wires are used to measure the mean and fluctuating velocities. Apart from the conventional vertical-profile measurements, roof-level velocity data across a unit of the sample street canyon (centre-to-centre between the upstream and downstream buildings) are collected in order to estimate the ventilation performance.

In the preliminary analysis, we utilise *f*, ACH and σ_z to quantify the aerodynamic resistance, street-level ventilation and pollutant plume dispersion for idealised 2D rough surfaces and attempt to determine their correlation as well. Both CFD and experimental results show that the ventilation and dispersion coefficient are mainly governed by turbulent transport (over 60%). Moreover, the results demonstrate that the turbulent components of ACH and σ_z are linear functions of the square root of (ACH'' µ $f^{1/2}$; Figure 1) and forth root (σ_z µ $f^{1/4}$; Figure 2) of friction factor, respectively, regardless of the surface geometry and the BL depth aloft. In view of the dominated turbulent transport, it is proposed that *f* could serve as an estimate to predict the minimum ventilation rate and pollutant dispersion of urban roughness. Although the configurations for both CFD and experimental simulations are simplified that might not fully represent the real situations, the results obtained facilitate the development of parameterisation which could be extended to realistic configuration. Additional experimental and modelling works are undertaken to enrich our understanding of the transport processes over urban roughness and further examine our hypothesis as well.

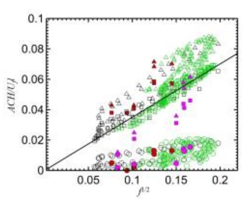

Figure 1. Ventilation plotted against square root of friction factor.

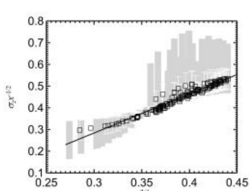

Figure 2. Vertical dispersion coefficient plotted against forth root of friction factor.