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Numerical modeling of flows and pollutant dispersion within and above urban street canyons under unstable thermal stratification by large-eddy simulation

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Recently, with the ever increasing urban areas in developing countries, the problem of air pollution due to vehicular exhaust arouses the concern of different groups of people. Understanding how different factors, such as urban morphology, meteorological conditions and human activities, affect the characteristics of street canyon ventilation, pollutant dispersion above urban areas and pollutant re-entrainment from the shear layer can help us improve air pollution control strategies. Among the factors mentioned above, thermal stratification is a significant one determining the pollutant transport behaviors in certain situation, e.g. when the urban surface is heated by strong solar radiation, which, however, is still not widely explored. The objective of this study is to gain an in-depth understanding of the effects of unstable thermal stratification on the flows and pollutant dispersion within and above urban street canyons through numerical modeling using large-eddy simulation (LES).

In this study, LES equipped with one-equation subgrid-scale (SGS) model is employed to model the flows and pollutant dispersion within and above two-dimensional (2D) urban street canyons (flanked by idealized buildings, which are square solid bars in these models) under different intensities of unstable thermal stratifications. Three building-height-to-street-width (aspect) ratios, 0.5, 1 and 2, are included in this study as a representation of different building densities. The prevailing wind flow above the urban canopy is driven by background pressure gradient, which is perpendicular to the street axis, while the condition of unstable thermal stratification is induced by applying a higher uniform temperature on the no-slip urban surface. The relative importance between stratification and background wind is characterized by the Richardson number, with zero value as a neutral case and negative value as an unstable case. The buoyancy force is modeled by Boussinesq approximation and the intensity of stratification is controlled by the gravitational acceleration. The urban characteristic is modeled by periodic boundary conditions at the domain inlet-outlet and spanwise extent, so as to simulate the infinitely long and wide urban area. Pollutant dispersion is modeled by scalar transport with the pollutant area source on the ground of the first street canyon and by open boundary condition at the domain outlet.

The numerical models are solved with incremental time steps until it reaches the pseudo steady-state. Afterwards, a set of data is collected for each model such that the temporal averages of mean and fluctuating field variables do not vary significantly if more time steps are included. It is found that the ventilation performance is improved and the plume dispersion in shear layer is enhanced when the stratification is more unstable. The mean flows, turbulent transports of pollutant and momentum, pollutant concentration fields in different unstable stratifications will be discussed with profile and contour plots. The ventilation performance of a street canyon evaluated by air exchange rate (ACH) and pollutant exchange rate (PCH) at roof level and the plume dispersion characterized by the mean plume height and dispersion coefficient in shear layer will also be discussed.