Flow Over an Array of Very Tall Buildings with Random Heights

Donnchadh MacGarry, Zheng-Tong Xie and Christina Vanderwel
Department of Aeronautics and Astronautics, University of Southampton

Large-Eddy Simulations (LES) in PALM-4U were used to investigate building slenderness effects in an urban environment setting. A staggered array of cuboid buildings with random heights was selected for the investigation, converting the geometry used by Cheng & Castro (2002) into a full-scale version. Defining the aspect ratio (AR) as the ratio of the building width to the building height, these buildings have an $AR = 1$ on average. The aspect ratio was then modified to $AR = 0.25$ in two ways; by increasing the vertical dimensions by a factor of four and by reducing the horizontal dimensions by a factor of four. This maintained the same packing density as the $AR = 1$ building array, as well as the maximum building height and standard deviation of the heights when normalised by the mean building height. Two types of inlet boundary conditions were used in the simulations. A cyclic inlet-outlet boundary condition was used in the validation and verification of the simulation design. It was then used in the comparison of the slenderness effects and approaching wind direction effects. A synthetic turbulence generation (STG) inlet condition, using an inlet profile design based on Sessa et al. (2020), was used to verify the results of the cyclic inlet-outlet boundary condition for wind approaching from a single direction, and to conduct turbulence length-scale analysis in the wake.

Results from the cyclic inlet-outlet gave near identical results in the flow for both $AR = 0.25$ designs, giving evidence that the changes to the flow are purely due to the aspect ratio of the buildings, i.e. slenderness effects. The vertical profiles of the spatially averaged velocity and turbulent quantities normalised by the friction velocity were smaller in magnitude within the canopy layer for the $AR = 0.25$ buildings. A cause of this was due to a skimming regime that was occurring over these high-rise buildings, which couldn't re-energise the flow within the canopy layer, in particularly below the mean building height. Adjusting the approaching wind direction produced a notably larger spread in these profiles for the $AR = 1$ buildings than it did for the $AR = 0.25$ buildings. Furthermore, it was seen that the spatially averaged deflection angle of the flow around buildings was reduced for the $AR = 0.25$ buildings. The slenderer buildings were notably less sensitive to wind direction effects. A possible cause for this was due to the height dimension being significantly longer than the cross-section dimensions, thus reducing the influence that the shape of the cross-section has on the flow. Turbulence integral length-scale analysis in the wake of the buildings when using the STG inlet provided further insight into this observation. The integral length-scales observed in the wake of the $AR = 0.25$ buildings were notably larger than those for the $AR = 1$ buildings. The integral length scales in the flow over the slenderer buildings were much larger than the building's cross section size, and thus the energetic eddies were less affected by the cross-section geometry. This helps explain why the slenderer buildings were less sensitive to the various approaching wind directions tested in the simulations with the cyclic inlet-outlet. Castro et al. (2006) stated that the integral length scales in the wake can be approximated by the building's width. However, the integral length scales estimated in this current study suggest that height of the building must be accounted for as well, becoming increasingly important the slenderer the building becomes. Further work in this investigation is currently on-going, using wavelet analysis to understand vortex shedding and examining the dispersive shear stress in the flow.

References

Castro IP, Cheng H, & Reynolds R, 2006, *Turbulence over urban-type roughness: deductions from wind-tunnel measurements*. Bound.-Layer Met., 118, pp.109-131.

Cheng H & Castro IP, 2002, *Near Wall Flow Over Urban-like Roughness*. Bound.-Layer Met., 104, pp. 229–259

Sessa V, Xie ZT, & Herring S, 2020, *Thermal Stratification Effects on Turbulence and Dispersion in Internal and External Boundary Layers*. Bound.-Layer Met., 176, pp. 61-83.