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EFFECT OF UPSTREAM BUILDING ON THE POLLUTANT DISPERSION IN URBAN CANOPY WITH CHANGES THERMAL STABILITY

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Abstract: Upstream building and atmospheric stability are critical parameters in dispersing and transporting pollutants in an urban canopy. These parameters' effects can be seen locally in each building's vicinity and the pollutants' transport from one region of the urban environment to another further away. Near-field pollutant dispersion is a cause of concern for most health physicists and regulatory agencies. Therefore, the main goal of this study was to investigate and evaluate the influence of the upstream building on wind flow and near-field pollutant dispersion in the urban canopy under different atmospheric thermal stabilities. Gaseous pollutants' diffusion flow and dispersal were modeled using a computational fluid dynamics model (CFD). The CFD models were incorporated with three-dimensional standard and RNG k-ε turbulence models and were solved using Reynolds-averaged Navier–Stokes equations. The modeled results were validated against the wind tunnel experimental data. The results showed that the streamwise and spanwise velocities are significantly lower inside the building arrays than outside. The strong wind shear was observed near the building height at the center of the building arrays. The increases in the turbulent kinetic energy converged inside the building arrays. The pollutant concentration levels close to the ground level were higher under stable conditions than under unstable and neutral conditions. Pollutant concentration inside the building arrays increased with stable conditions and decreased with unstable conditions.

Key words: *Atmospheric stability; Pollutant dispersion; CFD models;Wind tunnel; Upstream building*.

INTRODUCTION

The wind flow and near-field pollutant dispersion in the urban canopy are influenced by the geometrical features of buildings, which affect the dispersion of pollutants within and above the building arrays. This effect can be seen locally in each building's vicinity and the pollutants' transport from one region of the urban environment to another further away. Near-field pollutant dispersion is a cause of concern for most health physicists and regulatory agencies. Pollutants emitted from the point source within the recirculation region may re-enter the building from which they are emitted and affect an adjacent building. Previous studies have considered the effect of the different roof shapes on the building configurations in the urban area (e.g., Yassin et al., 2005, 2008a, b; Yassin, 2009, 2010, 2011; Kellnerova et al., 2012; Yassin and ohab, 2012a,b, 2013a,b,c,d; Yassin and Kassem, 2014; Hang et al., 2015; Wen and Malki-Epshtein, 2016; Llaguno-Munitxa et al., 2017; Ntinas et al., 2018, Yassin et al., 2018, 2021). Recently, Zhang et al. (2021) investigated the impact of the change in triangular roof angles on the diffusion of gaseous pollutants and particulate matter by the Euler–Lagrangian method. Results indicate that the lowest concentration of pollutants is when a single vortex exists. Klukova et al. (2021) discussed the effects of the roof shape and its height with the location of the source on the pollutant dispersion in urban arrays using CFD models. The results show that roof height, shape, and the source location have an essential effect on the advective and pollutant distribution and transport between the studied street canyons and urban arrays. The main aim of this study is to compute the dispersion of vehicle emissions in and out of the urban canopy. In particular, the investigation is made into the effect of the upstream buildings on pollutant dispersion.

METHODOLOGY

Computational Models

The computational simulation used in the study is CFD models based on using Reynolds-averaged Navier–Stokes equations with k-ε turbulence models. The computational model was conducted using ANSYS FLUENT software, Version 2020 R1 (ANSYS, 2020), which is a widely used model that

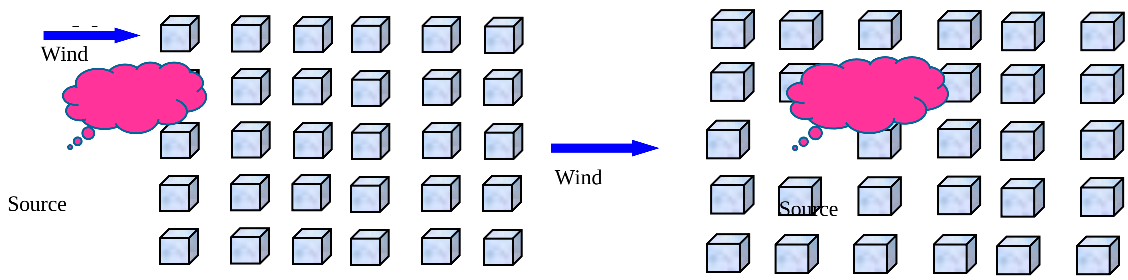

Fig. 1 building array models and point sources at the upstream distance and building

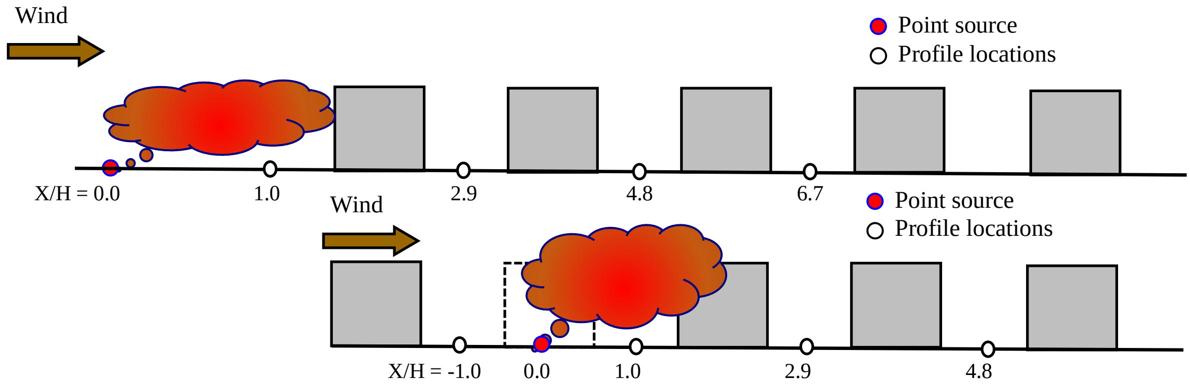

Fig. 2. Profile locations and point sources outside and inside building's array.

incorporates several turbulence models. ANSYS FLUENT software for the computational is based on a finite volume approach for solving the flow and pollutant dispersion equations. The flow's computational description is based on the pseudo-steady-state incompressible RANS equations equipped with two turbulence models: the standard κ-ε turbulence model (Launder, 1974) and the RNG turbulence model (Yakhot, 1992). The equations were solved on a staggered grid using a finite volume following the semi-implicit method for the pressure-linked equations (SIMPLE) described by Patankar (1980).

Building models Configurations

Figure 1 displays building array models and point sources at the upstream distance and building. The equivalent height of the building model (H) was 100 mm. This study used 30 three-dimensional cubical building models (0.75 H × 0.75H × 0.75H) with 6-row and 1-column buildings under approaching wind flow perpendicular to the row buildings, where x, y, and z denote the horizontal, lateral, and vertical axes. The distance gap between the buildings was H. The gas pollutant is emitted from a point source with a diameter of 0.067 H. The pollutant source location outside and inside the building arrays was as follows: (a) Hs = 0.0 at X/H=-1.5 distance upstream of the first array of the buildings, (b) Hs = 0.0 at X/H=0.0 inside the building's array. Fig. 2 shows the profile locations and point sources outside and inside the building's array.

Computational Domain

The computational domain of the building arrays' configurations was built using hexahedral elements with a finer resolution within the entire building area. The expansion rate between two consecutive cells was below 1.2. The grid in the simulation domain consisted of 2382693 cells, 5176261 faces, and 701640 nodes. The domain was discretized into 231.33 x 129.33x 106.67 cells. The distance of the simulation boundaries from the inlet, outlet, lateral, and upper domain was 6.67 H, 13.33 H, 16 H, and 14 H, respectively.

RESULTS AND DISCUSSIONS

Computational Simulation Validation

The computational simulation data in the study was validated using the experimental data used in the study was obtained from then the thermal diffusion wind tunnel experiments by Yassin (2013a, b). The dimensionless concentration was provided as $K = C^* U_H H2/Q$, where C* measured the actual concentration. U_H is the free streamwise velocity at building height H. Q is the source volume flow rate. The computed and measured dimensionless concentration K out and in the building's array are shown in Fig.3. It can be observed clearly that the CFD models match reasonably well with the experimental data. Therefore, the K-ε turbulent model is applicable for the computational simulation of the pollutant dispersion in and out building's array. However, the standard κ-ε turbulence model results are in the best agreement with the experimental flow data.

Dispersion Simulation

The pollutant concentration contours in the urban canopy in the vertical plane at Y/H=0.5 and the horizontal plane at the human level are presented in Figures 4-5. It can be shown that concentrations were expected to decrease with distance from the source. Compared to the effect of atmospheric thermal stability on the pollutant concentration, the flow suppresses' vertical motion, and the lateral movement of the flow increases under stable conditions. Consequently, the upright spreading of the pollutant plume reduces, and the lateral spread of the plume rises. The concentration levels close to the ground level were higher under stable conditions than under unstable and neutral conditions due to the lateral flow transferring the contaminant from the building. Pollutant concentration inside the building arrays increased with stable conditions. It decreased with unstable conditions due to the air change inside the building arrays. It is affected mainly by the turbulence mixing between the inside arrays and the free stream and by the intensity of the recirculation vortex, which changed significantly in stable conditions. The pollutant concentration is higher under the neutral condition than in the unstable one and lower than in the stable one. Compared to the upstream building's effect on the pollutant concentration, the upstream building's pollutant concentration levels were lower than those without the upstream building inside and outside the building arrays. This is because the movement of the large recirculation vortex in the upstream building zone was weak. The minimum value of the pollutant concentration was inside the building arrays. In the case without the upstream building, more pollutants move at the upwind building's side face, whereas, with the upstream building, more pollutants move to the leeward wall when the source is emitted from the ground level Hs/H=0.0 and move to the windward wall when the source is emitted from the source height Hs/H=1.0. The variation in pollutant concentration in the source zone outside and inside the building arrays was lesser under stable, neutral, and unstable conditions than in the inside. On the other hand, at the human level, the pollutant dispersion under stable conditions is distributed quite symmetrically to that under neutral and unstable conditions. The lateral dispersion of the pollutant concentration along with the downstream direction increased far away from the source.

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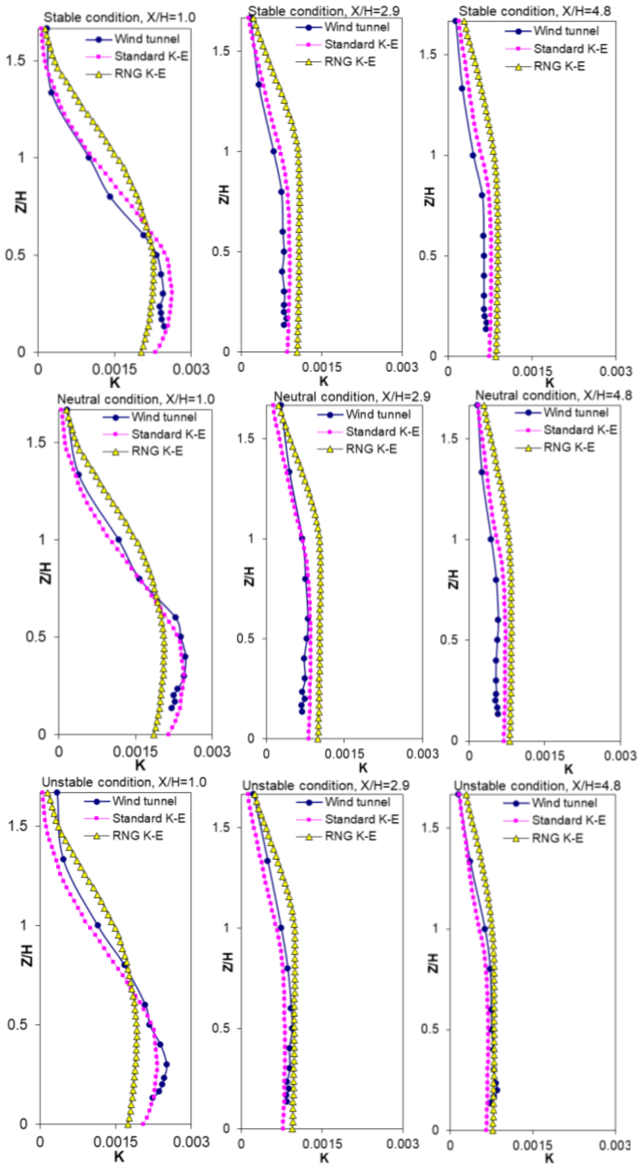

Fig. 3. The simulated and wind tunnel data of the dimensionless pollutant concentration

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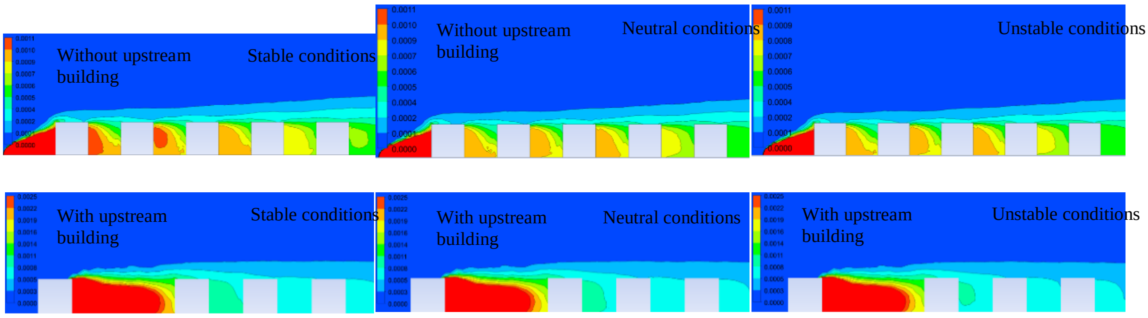

Fig.4. Dimensionless pollutant concentration under changing atmospheric thermal stability in the *x-z* at Y/H=0.5.

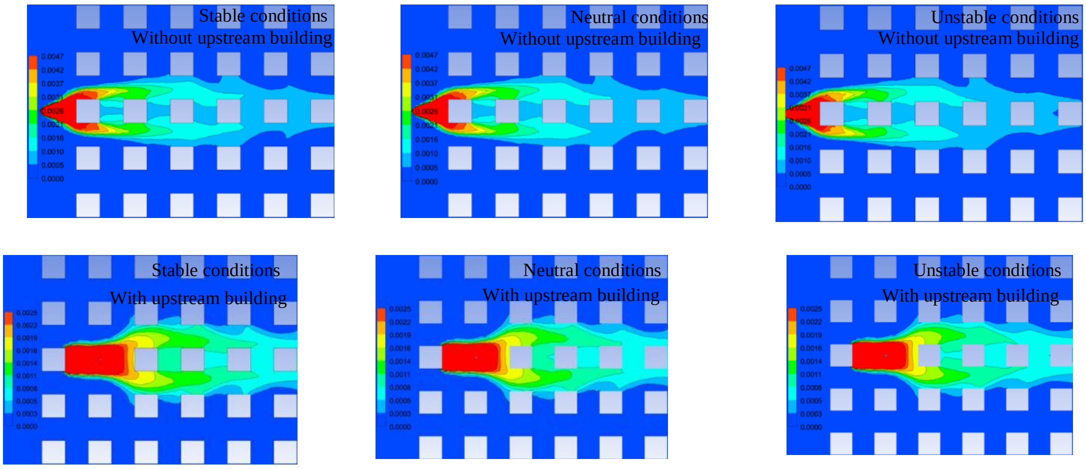

Fig. 5. Dimensionless pollutant concentration under changing atmospheric thermal stability in the *x-y* at the human level.

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