iJournals: International Journal of Software & Hardware Research in Engineering
ISSN:2347-4890, ijournals.in/ijshre
Volume 13 Issue 3, March 2025

Effect of thermal conditions on urban bioaerosol diffusion

Author: Yuchen He

Affiliation: North China Electric Power University, China

E-mail: heyuchen@ncepu.edu.cn

DOI: 10.26821/IJSHRE.13.03.2025.130301

ABSTRACT

The diffusion characteristics of urban biogenic aerosols are closely related to public health risks. In this study, Beijing Zhongguancun, a densely populated area, was selected as the research object. A numerical model was established based on typical meteorological parameters to compare and analyze the effects of stable and unstable thermal conditions on the urban flow field and the diffusion of biogenic aerosols. The study found that in stable thermal conditions, the lateral and longitudinal diffusion of biogenic aerosols was relatively weak, and the range of high concentration areas near the ground was larger; while in unstable thermal conditions, the vertical turbulence enhancement promoted the rapid departure of aerosols from the near-ground activity area, the high concentration area was reduced, but the diffusion area was larger.

Keywords: Bioaerosol diffusion, Thermal conditions, Numerical simulation, Urban wind farm, Biosafety

1. INTRODUCTION

Over the past few decades, the public health risks posed by diseases transmitted through the air have continuously drawn global attention [1-2]. Take COVID-19 as an example; its ability to spread via bioaerosols has led to tens of millions of infections and millions of deaths worldwide. With the acceleration of urbanization, the population aggregation effect has significantly increased the load of microbial pollutants in the atmosphere [3]. Among them, bioaerosols, as important carriers of infectious diseases, have demonstrated their potential threat in many recent public health incidents [4]. Currently, the diffusion mechanisms of pathogenic bioaerosols have not been fully understood. The difference of thermal conditions plays a significant role in regulating the diffusion process of bioaerosols [5], and the systematic assessment of the spatial distribution characteristics and exposure risks of urban bioaerosols has become a key scientific issue in public health management.

2. METHOD

2.1 Case description

This study takes the high-density population area of Zhongguancun in Beijing as the research object and establishes a numerical model using typical meteorological parameters in July 2024 (dominant wind direction: south wind, temperature: 20℃, relative humidity: 70%, wind speed: 2m/s). To ensure the flow field fully develops, the distances from the building cluster to the inlet, outlet, side, and top boundaries of the computational domain are set at 5H, 15H, 5H, and 5H respectively [6-7]. To explore the impact of different thermal conditions on the urban flow field and the diffusion of bioaerosols, two comparative scenarios are set up: Case 1 uses a wall temperature of 15℃ to represent stable thermal conditions, and Case 2 uses a wall temperature of 25℃ to represent unstable thermal conditions.

2.2 Turbulence model and Discrete phase model

This study conducts numerical simulation using Fluent and turbulence analysis with the RNG k-ε model. The general form of the governing equations is as follows [8-9]:

$$\partial(\rho\varphi)/\partial t+\nabla\cdot(\rho\varphi\vec{u})=\nabla\cdot(\Gamma_{\varphi}\nabla\varphi)+S_{\varphi}$$

where ρ is the air density, $\vec{u}$ is the air velocity vector, φ shows each of the three velocity components, Γ_{φ} is the effective diffusion coefficient of φ and S_{φ} is the source term.

The wind speed distribution at the entrance of the calculation domain is [10]: $U(z)=U_{ref}(z/H_{ref})^{\alpha}$

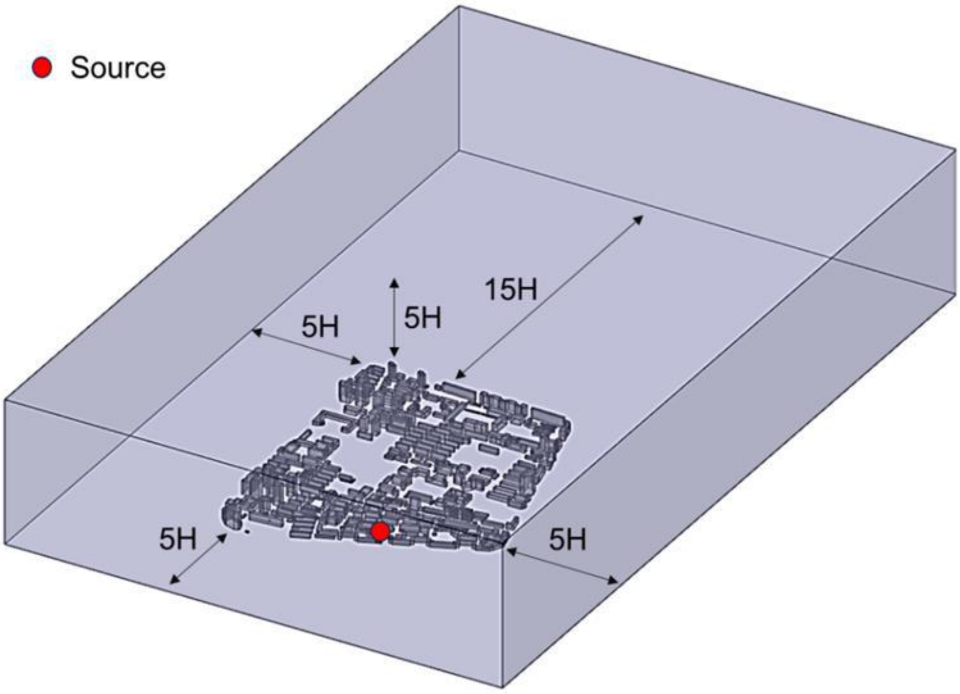

Fig 1: Model, boundary conditions, and bioaerosol release points of the study area

The average wind speed at a height of 10 m is represented by U_{ref}, z is the height of wind speed measurement, measured in meters, α is the roughness coefficient and α is set to 0.3.

The Lagrangian particle discrete random walk model is adopted to simulate the propagation of bioaerosols, and the expression is as follows [11]:

$$d\vec{u}_p / dt = F_D(\vec{u} - \vec{u}_p) + \vec{g}(\rho_p - \rho) / \rho_p + \vec{F}$$

Here, $\vec{u}$ and $\vec{u}_p$ denote the velocities of the airflow and the biological aerosol particles; ρ and ρ_p represent the densities of the airflow and the biological aerosol particles; $\vec{g}$ stands for gravity; and $\vec{F}$ indicates the additional force acting on the biological aerosol particles. The time step for the unsteady calculation is set to 1 second. For each time step, the calculation is iterated 20 times, and a total of 900 seconds of particles are released.

3.RESULT

3.1 Distribution of flow field

The figure shows the wind speed distribution of two cases of the pedestrian layer (y = 1.6m). The airflow flows from the left side and impacts the building complex. It can be clearly seen that many vortices are generated on the backwind side of the buildings, and the airflow is blocked, resulting in lower wind speed. While the two open areas in the middle have no obstruction, the wind speed is higher. Due to the larger width of the buildings at the upwind side, the wake flow shows a significant contraction. With the increase in height, the wind speed gradually increases, and the variation of wind speed on the same plane also gradually weakens.

The development of wind speed in the vertical region clearly shows the influence of different thermal conditions. In Case 2, the wall temperature is higher than the air temperature, and the vertical development is more intense. While in Case 1, the wall temperature is lower than the air temperature, and the upward trend of the airflow is weaker than that in Case 2. Under unstable thermal conditions, the intensity of turbulence increases, and the velocity of the flow field also becomes greater.

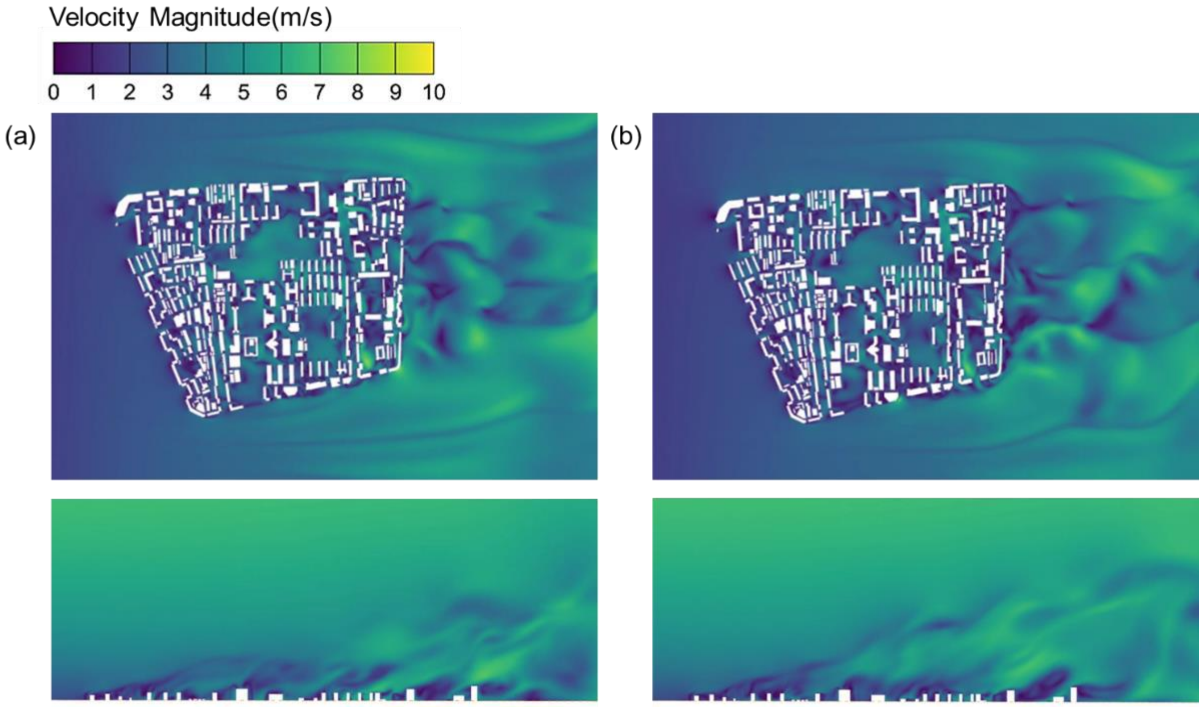

Fig 2: Velocity distribution of flow field(y=1.6m) (a) Case1 (b) Case2

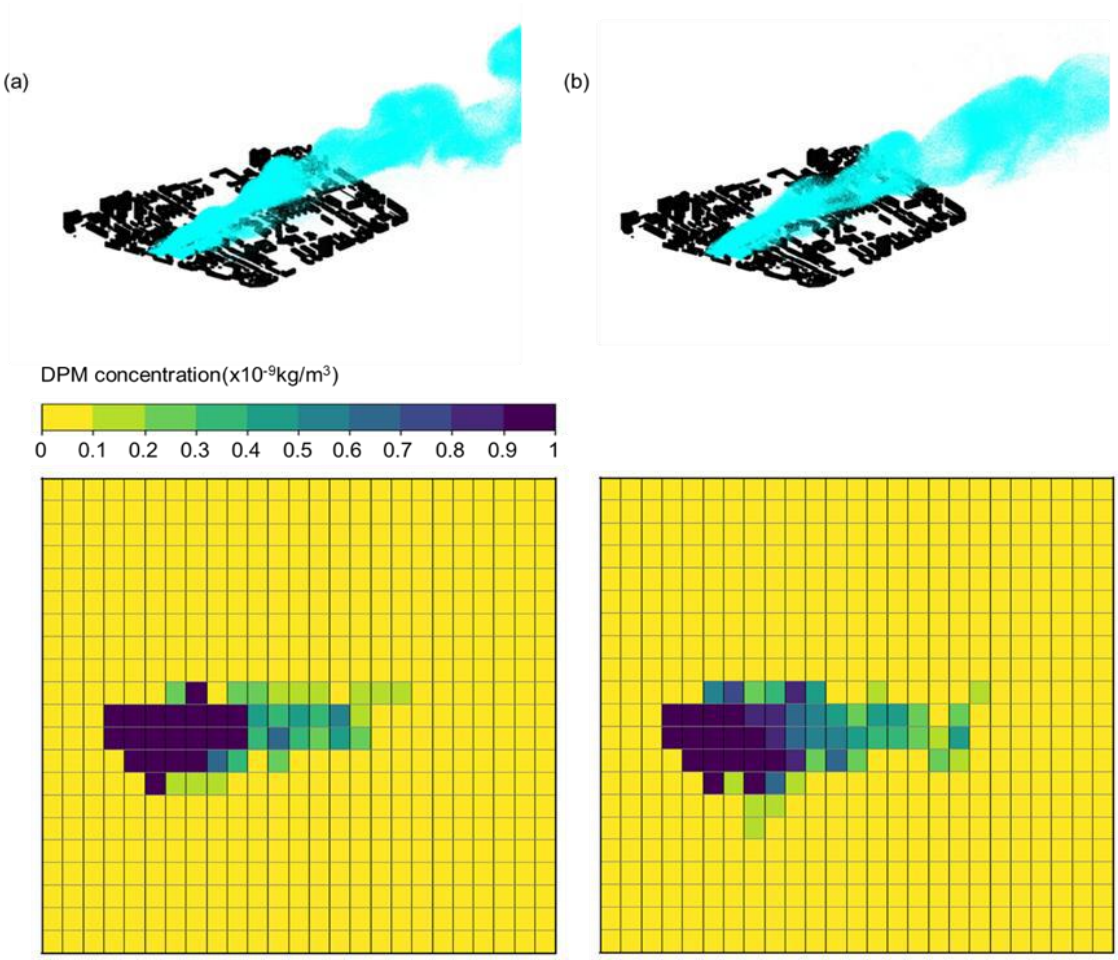

Fig 3: Bioaerosol particle diffusion and pedestrian layer concentration distribution(y=1.6m)

3.2 Bioaerosol diffusion and concentration distribution

From the diffusion map of biological aerosol particles and the concentration distribution map of pedestrians, it can be seen that the concentration is the highest near the release source, gradually decreasing along the wind direction. Moreover, due to the dense buildings near the release source, the diffusion of biological aerosol is hindered, resulting in a higher concentration. Additionally, the concentration of biological aerosol at the tail of buildings is very low, indicating that the upward airflow has played a role, causing it to leave the near-ground active area. The distribution of aerosols varies under different thermal conditions. In case 1, which is in a stable thermal condition, the lateral and longitudinal diffusion is weaker than that in case 2 under unstable thermal conditions. However, case 2 has a stronger vertical diffusion, and the aerosol escapes more quickly, resulting in a larger high-concentration area in case 1 than in case 2.

4. CONCLUSION

This study reveals the differential impacts of different thermal conditions on the diffusion of urban biogenic aerosols through numerical simulation. Under stable thermal conditions (Case 1), the vertical movement of air flow is weak, and biogenic aerosols tend to remain near the ground, resulting in an expansion of the high-concentration area range. In contrast, under unstable thermal conditions (Case 2), enhanced vertical turbulence accelerates the diffusion and escape of aerosols, reducing the risk of exposure near the ground. Moreover, the disturbance of building layout on the local flow field significantly affects the distribution characteristics of aerosols. Dense building areas are prone to concentration accumulation due to blocked air flow.

5. REFERENCE

[1]. Heesterbeek, H., Anderson, R. M., Andreasen, V., Bansal, S., De Angelis, D., Dye, C., et al. “Modeling infectious disease dynamics in the complex landscape of global health.” *Science* 347.6227 (2015): aaa4339.

[2]. Smith, Richard D. “Responding to global infectious disease outbreaks: lessons from SARS on the role of risk perception, communication and management.” *Social science & medicine* 63.12 (2006): 3113-3123.

[3]. Singh, N.K., Sanghvi G., and Yadav, M.eds. “Bioaerosols Emission from Anthropogenic Sources: Influencing Factors, Microbial Diversity, Epidemiological Threats, and Control Approaches.” *Elsevier*, 2023.

[4]. Shammi, M., Rahman, M. M., and Tareq, S. M. “Distribution of bioaerosols in association with particulate matter: a review on emerging public health threat in Asian megacities.” *Frontiers in Environmental Science* 9 (2021): 698215.

[5]. Liu, Z., Cao, H., Hu, C., Wu, M., Zhang, S., He, J., et al. “Modeling the infection risk and emergency evacuation from bioaerosol leakage around an urban vaccine factory.” *NPJ Climate and Atmospheric Science* 6.1 (2023): 6.

[6]. Juan, Y. H., Rezaeiha, A., Montazeri, H., Blocken, B., Wen, C. Y., and Yang, A. S. “CFD assessment of wind energy potential for generic high-rise buildings in close proximity: Impact of building arrangement and height.” *Applied Energy* 321 (2022): 119328.

[7]. Liu, S., Pan, W., Zhang, H., Cheng, X., Long, Z., and Chen, Q. “CFD simulations of wind distribution in an urban community with a full-scale geometrical model.” *Building and environment* 117 (2017): 11-23.

[8] Ramponi, R., Blocken, B., de Coo, L. B., and Janssen, W. D. “CFD simulation of outdoor ventilation of generic urban configurations with different urban densities and equal and unequal street widths.” *Building and Environment* 92 (2015): 152-166.

[9]. Blocken, B., Janssen, W. D., & van Hooff, T. “CFD simulation for pedestrian wind comfort and wind safety in urban areas: General decision framework and case study for the Eindhoven University campus.” *Environmental Modelling & Software* 30 (2012): 15-34.

[10]. Zhang, S., Kwok, K. C., Liu, H., Jiang, Y., Dong, K., and Wang, B. “A CFD study of wind assessment in urban topology with complex wind flow.” *Sustainable Cities and Society* 71 (2021): 103006.

[11]. Zhou, Y., and Ji, S. “Experimental and numerical study on the transport of droplet aerosols generated by occupants in a fever clinic.” *Building and environment* 187 (2021): 107402.