Computer-Aided Analysis of Urban Block Spatial Morphology: Security Challenges and Solutions in PM Pollution Modeling

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Abstract:
The correlation between spatial form and PM pollution has been extensively studied at the street-canyon scale. In fact, the spatial form of urban neighborhoods, seen as individual units, collectively creates a street-canyon scale space, which also has a certain correlation with the distribution and diffusion efficiency of PM. The application of digital technology in engineering design enables simulation and analysis of correlations for more environmentally sustainable designs. Based on CFD, this article establishes models at the street-canyon scale and when there are overpasses to analyze the distribution and diffusion efficiency of PM under different forms. The research results demonstrate that changes in the form of the street-canyon can alter the distribution of airflow and turbulence, thereby influencing the distribution and diffusion efficiency of PM. The more streamlined the street-canyon form, the smaller the corresponding PM ground concentration and the higher the diffusion efficiency. Additionally, overpasses also affect the distribution and diffusion of particulate pollutants. The higher the height and narrower the bridge deck of the overpass, the smaller the corresponding PM ground concentration and the higher the diffusion efficiency. In summary, the findings of this study provide valuable insights for street-canyon design.

Keywords: block form, PM, CFD, turbulence distribution, digital technology

INTRODUCTION

With the deepening of urbanization, various forms of urban blocks have emerged. The morphology of these blocks is significantly correlated with the distribution and diffusion efficiency of PM (particulate matter) pollution [1]. So far, most studies on the correlation between morphology and PM pollution have focused on urban street canyons [2]. As the name suggests, urban street canyons are formed by continuous and tall buildings on both sides of a street, creating canyon-like spaces. Street canyons are one of the most important morphological and characteristic spaces in urbanization. Based on the concept of street canyons, if each neighborhood is seen as a cellular unit, streets form the spaces between these cells. Different combinations of cellular units result in various urban block spatial morphologies. As the morphology of blocks becomes more complex, the correlation between block morphology and PM pollution presents significant research value [3]. In the atmospheric environment, the upper atmospheric air enters street canyons, where wind speed is reduced and turbulence is created, significantly affecting the transportation, diffusion, and dilution of pollutants like PM. Therefore, the morphology of street canyons significantly influences the concentration and diffusion efficiency of PM pollutants. Compared to street canyon morphology, block morphology involves more complex combinations of canyon forms, resulting in more intricate turbulence and airflow patterns, ultimately altering the concentration and diffusion efficiency of PM pollutants [4].

Most research on the correlation between spatial morphology and PM pollution focuses on street canyons. Gu Zhaolin conducted large-eddy simulations of green street canyons under different atmospheric stabilities, using large-eddy simulation methods to model and analyze airflow in street canyons [5]. Studies on air movement and pollutant diffusion in urban street canyons used physical models and mathematical simulations for analysis [6]. Zhang Yunwei [7] analyzed vehicular-induced airflow in urban street canyons using large-eddy simulations. Wang Jiwu [8] modeled Hangzhou's Zhongshan Road, studying the relationship between urban street canyon spatial morphology and pollutant diffusion through modeling. Other scholars primarily used fluid dynamics modeling methods [9,10] to analyze various factors affecting airflow and turbulence in street canyons, ultimately establishing relationships between PM pollution concentration and diffusion efficiency.

PM pollutants are major air pollutants, with larger particles causing severe haze. In most industrial cities, excessive industrial emissions of PM pollutants often lead to haze, affecting urban residents' lives and being a primary cause of respiratory diseases [11].

Research has shown that particulate matter, foul-smelling stimulants, and toxins can induce negative mental health outcomes [12], causing emotional changes such as anxiety and irritability in the short term. Long-term exposure to polluted environments can reduce happiness and even lead to psychological disorders and depression [13]. In terms of improvement research, Cui Wenjing [14] proposed the concept of "breathing for wellness" in the study of elderly rehabilitation spaces in community parks, suggesting that fresh air positively affects emotions, perception, and creativity. Patricia Baker [15] argued that pure air provides multisensory experiences that promote physical and mental health, with vision, hearing, and smell being crucial senses in recognizing clean air.

Currently, in large and medium-sized industrial cities, excessive PM pollutants have already formed a haze pattern [16]. To reduce the impact of PM pollutants on human health, analyzing different urban block morphologies' effects on PM pollution distribution and diffusion before planning blocks can aid in various planning aspects, improving residents' quality of life. This study employs CFD modeling methods [17] to establish more complex spatial morphologies at the block scale, based on street canyon research, and considers the correlation between various morphologies and PM pollution in scenarios with overpasses.

EXPERIMENTAL SIMULATION SETUP AND METHODS

By using CFD modeling software FLUENT, we can treat each district in a city as the most basic cellular unit, and easily construct a variety of block distribution models. FLUENT software provides us with an effective tool for analyzing airflow movement and pollutant distribution and diffusion in complex urban environments, with its powerful computational capabilities and accurate simulation effects.

In the modeling process, we first need to define the geometric shape, size, and location of each community based on actual geographical information and urban planning data. These communities can be residential, commercial, industrial, or other types of functional areas, and their layout and morphology directly affect the airflow movement and pollutant dispersion in the city.

Once the model is established, we can use FLUENT for simulation. By setting appropriate meteorological conditions such as wind speed, wind direction, temperature, and pollution source information such as emission intensity and emission height, FLUENT can simulate the flow of air between blocks, as well as the diffusion path and concentration distribution of pollutants in the air.

During the simulation process, FLUENT uses a series of numerical algorithms and physical models to ensure the accuracy and reliability of the simulation results. For example, it can describe the motion law of fluids by solving the Navier-Stokes equation, while using turbulence models to simulate complex airflow movements. In addition, FLUENT also provides rich post-processing functions that allow us to visually view and analyze simulation results, such as velocity vector diagrams, pollutant concentration distribution diagrams, and so on.

By using FLUENT to construct a block distribution model and simulate airflow movement and pollution distribution, we can gain a deeper understanding of airflow characteristics and pollutant diffusion laws in urban environments. This helps us develop more effective urban planning strategies, optimize urban spatial layout, improve urban air quality, and enhance the quality of life for residents.

FLUENT Software Modeling

FLUENT, as the most widely used computational fluid dynamics (CFD) research and analysis software, plays a pivotal role in the field of fluid dynamics analysis. Whether in the aerospace, water conservancy and hydropower, or engineering design industries, FLUENT has won the favor of researchers and engineers with its excellent simulation capabilities and accurate analysis results.

Before using FLUENT software for modeling analysis, it is usually necessary to use Gambit software for preprocessing. Gambit software has powerful modeling capabilities, allowing precise construction of the model structures required for research. At the same time, Gambit also has the ability to perform grid division, which can be used to perform reasonable grid division based on the complexity and scale characteristics of different models to ensure the accuracy and reliability of subsequent simulation calculations.

Compared to street canyon models, block models typically have higher complexity and larger scales. Street canyon models mainly focus on the narrow space between two parallel streets, while block models involve the spatial layout and building distribution of the entire block. Therefore, when constructing block models, it is necessary to consider more carefully factors such as the shape, size, arrangement of buildings, and the width and direction of streets. To deal with this complexity, this article uses an unstructured grid division method. Unstructured grids can better adapt to complex geometric shapes and reduce computational costs while ensuring computational accuracy.

After completing the model construction and grid division, the FLUENT software can be used to set the boundary conditions and physical models of the Gambit modeling. The boundary conditions include airflow velocity, pressure, temperature, and other parameters at the inlet, outlet, wall, etc., while the physical models involve turbulence models, radiation models, chemical reaction models, etc. By setting appropriate boundary conditions and physical models, the airflow movement law, pollutant distribution, and diffusion trend in the model can be solved.

Grid Division and Boundary Definition

In the process of Gambit modeling, grid division is a crucial step that directly affects the accuracy and efficiency of subsequent simulation calculations. In order to more accurately simulate the airflow movement and pollutant distribution in the near-field region of a street block, we adopted a structured grid division method. This method can generate a regular and orderly grid system, which is convenient for calculation and analysis.

Specifically, we have encrypted the grid in the near-field area of the street block. This means that in these key areas, we have arranged more dense grid points to more accurately capture the changes in airflow and pollutants. Through this encryption process, we can obtain a structured grid analysis system with a resolution ranging from 10 to 30 meters. Such a grid system can ensure both high computational accuracy in the near-field area and reasonable computational efficiency throughout the entire street block.

Figure 1 shows the schematic diagram of the generated grid system. It can be clearly seen from the figure that the grid in the near-field region is significantly denser than other regions, forming a refined analysis area. Such a grid division method not only helps us to better understand the airflow and pollutant distribution laws in the near-field region, but also provides a solid foundation for subsequent FLUENT simulation analysis.

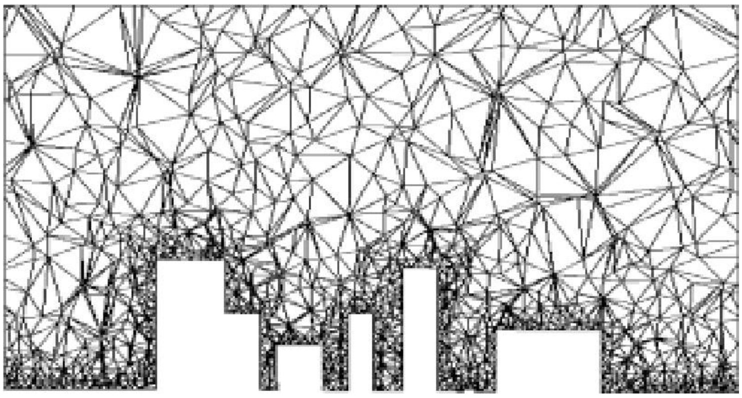


Figure 1. Structured grid analysis system.

In our study, we employed the Species Transport model to simulate the distribution and diffusion of PM pollutants, with a primary focus on PM2.5, the primary component of haze and fog. The pollutant source was configured as a linear source with a height of 2 meters and a width of 15 meters. The emission intensity of this source was set to 0.05 mg/(m^2*s), reflecting the rate at which pollutants are released into the atmosphere.

The Species Transport model is a powerful tool that enables us to comprehensively analyze the transport, diffusion, and transformation processes of pollutants in the atmospheric environment. By using this model, we can gain a deeper understanding of how PM2.5 particles behave in the street block, taking into account factors such as wind speed, direction, and turbulence.

The linear pollution source, with its specified dimensions and emission intensity, represents a realistic scenario in urban environments, where emissions from various sources, such as road traffic or industrial activities, contribute to the overall PM pollution level. By accurately modeling these sources, we can better predict and assess the potential impact of PM pollution on human health and the urban environment.

CFD Condition Setup and Iterative Calculation Process

The modeling results from Gambit software are imported into FLUENT software for CFD condition setup and iterative calculation, solving the following control equations:

(1) Continuity Equation

$$\frac{\partial \overline{U}_i}{\partial x_i} = 0, i = 1,2 \tag{1}$$

(2) Momentum Conservation Equation

$$\frac{\partial \overline{U}_i}{\partial t} + \overline{U}_j \frac{\partial \overline{U}_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \overline{\rho}}{\partial x_i} - \frac{\partial\left(\overline{u_i u_j}\right)}{\partial x_j} + v\nabla^2 \overline{U}_i, j = 1,2 \tag{2}$$

(3) Mass Conservation Equation

$$\frac{\partial \rho}{\partial t} - \frac{\partial(\rho u_i)}{\partial x_i} = S_m \tag{3}$$

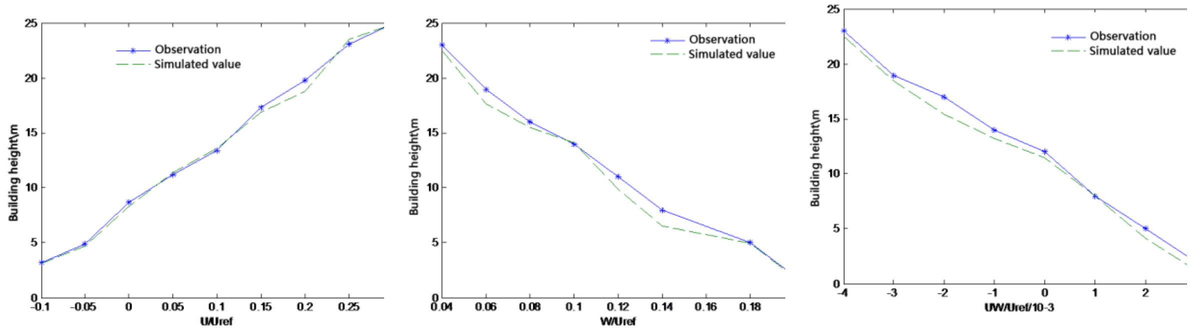
(4) Standard $k-\varepsilon$ Equation

$$\begin{cases} \frac{\partial k}{\partial t} + \overline{U}_j \frac{\partial k}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{v_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right) + v_t\left(\frac{\partial \overline{U}_i}{\partial x_j} + \frac{\partial \overline{U}_j}{\partial x_i}\right)\frac{\partial \overline{U}_i}{\partial x_j} - \varepsilon \\ \frac{\partial \varepsilon}{\partial t} + \overline{U}_j \frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{v_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right) + \frac{\varepsilon}{k}\left[C_{\varepsilon_1} v_t \left(\frac{\partial \overline{U}_i}{\partial x_j} + \frac{\partial \overline{U}_j}{\partial x_i}\right)\frac{\partial \overline{U}_i}{\partial x_j} - C_{\varepsilon_2}\varepsilon\right] \\ v_t = C_\mu \frac{k^2}{\varepsilon}, C_\mu = 0.09, C_{\varepsilon_1} = 1.44, C_{\varepsilon_2} = 1.92, \sigma_k = 1.0, \sigma_\varepsilon = 1.3 \end{cases} \tag{4}$$

Where $\overline{\rho}$ represents the pressure of the fluid over average time, ρ, v represent the density of the fluid and its viscosity during motion, respectively; u_i, u_j represent the fluctuating velocity coefficients in the i and j directions, respectively; $\overline{u_i u_j}$ represents the fluid's fluctuating shear stress, x_i, x_j represent the coordinates in the i and j directions, respective; $\overline{U_i}, \overline{U_j}$ represent the fluid's average time velocities in the i and j directions, respectively.

Validation of FLUENT Experimental Results

To demonstrate the significance of using FLUENT software for analyzing the correlation of PM pollutants in street block scale spatial forms, this study conducted an experiment based on FLUENT software to simulate the wind tunnel experiment by Chang et al. [18]. The experimental results are shown in Figure 2 below. The results indicate that the simulation results from FLUENT software are consistent with the observed results from the wind tunnel experiment. In the figure, U_{ref} represents the wind speed in meters per second (m/s), $U^{'}W^{'}$ represents the turbulent flux, U, W represent the results for horizontal and vertical wind speeds, respectively. The validation using this well-known wind tunnel experiment demonstrates the feasibility and practical significance of employing FLUENT software for studying the correlation between street block forms and PM pollution.



(a) Comparison of horizontal wind speed results
(b) Comparison of vertical wind speed results
(c) Comparison of turbulent flux results.

Figure 2. Comparison of FLUENT software validation with wind tunnel experiment result

EXPERIMENTAL DESIGN AND RESULTS ANALYSIS

Experiments and Results Analysis of Different Street Block Forms

Typically, the street patterns between residential areas exhibit diverse characteristics, with the most common ones including parallel roads, peninsula-shaped circular roads, and curved roads. These different street patterns not only affect the overall layout of the city, but also have a significant impact on airflow movement and pollutant dispersion.

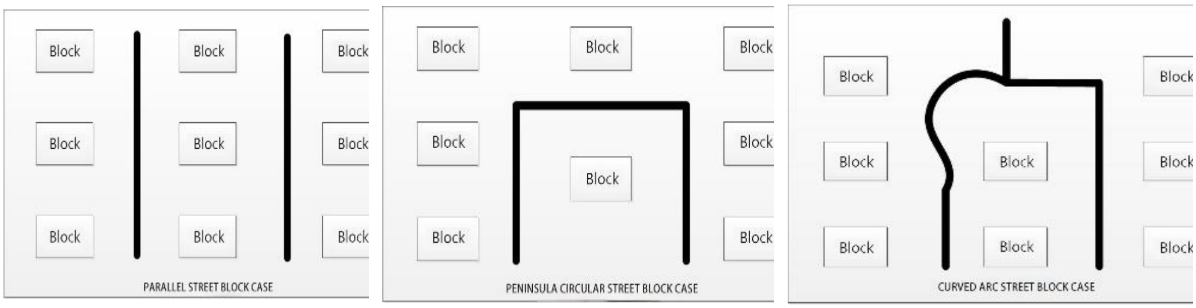
Parallel roads are the simplest and most common street form, often consisting of a series of parallel straight segments that provide orderly traffic flow for the city. This form of road is widely used in urban planning and construction, especially in residential and commercial areas, and is highly favored for its simple and clear layout.

The Peninsula Ring Road is a relatively unique street form that usually forms a circular structure around a central area or green space. This road form helps to alleviate traffic pressure and improve traffic efficiency, while also providing a rich walking and cycling experience for citizens. Peninsula Ring Roads are common in large residential areas or commercial complexes, and their unique layout adds a unique touch to the urban landscape.

Curved roads are a more flexible street form that are often designed according to topography and urban planning needs. This road form not only beautifies the urban landscape, but also improves traffic flow and reduces traffic congestion to a certain extent. Curved roads are common in urban centers or scenic areas, and their elegant curves add a touch of liveliness to the city.

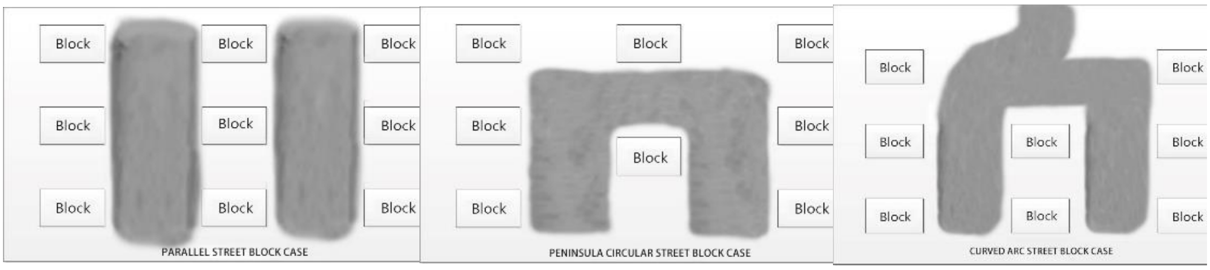
In order to study the impact of these different street patterns on airflow movement and pollutant diffusion in greater depth, the author constructed simplified models of the three patterns based on satellite image data, as shown in Figure 3 below. In the simplified model, we fixed the width of the street and set different length values to simulate various scenarios that may occur in actual cities.

(a) Parallel street block master plan
(b) Peninsula circular street block master plan
(c) Curved arc street block master plan



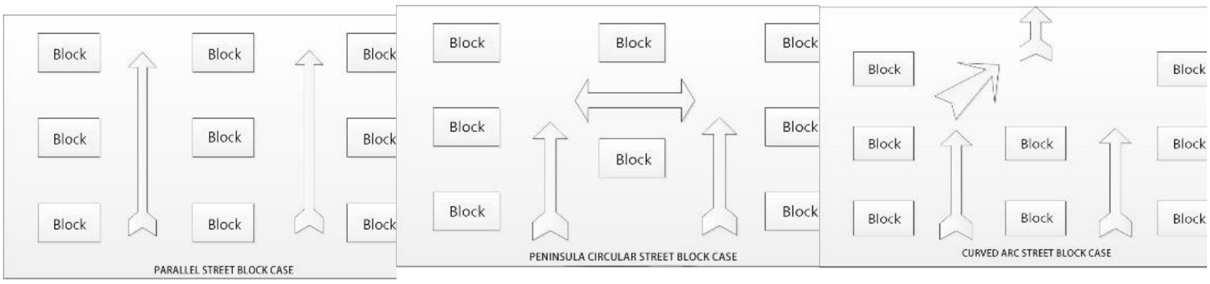
(a1) Parallel street block case (b1) Peninsula circular street block case (c1) Curved arc street block case

Figure 3. Three different street block forms and their simplified cases.



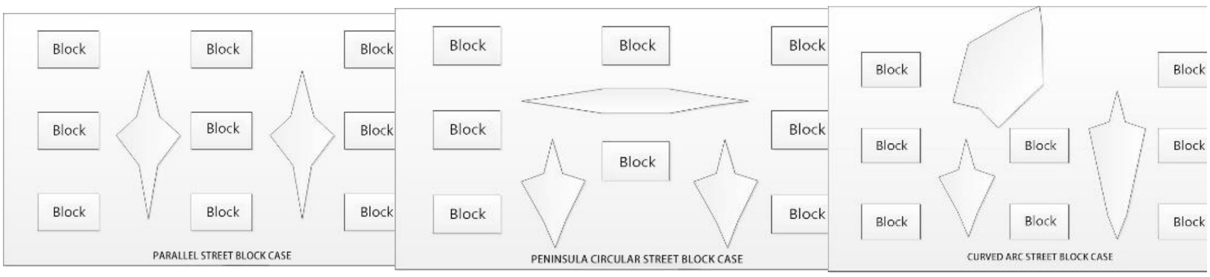
(a) Parallel street block case (b) Peninsula circular street block case (c) Curved arc street block case

Figure 4. Pollutant distribution in street block form.



(a) Parallel street block case (b) Peninsula circular street block case (c) Curved arc street block case

Figure 5. Wind flow field distribution in street block form



(a) Parallel street block case (b) Peninsula circular street block case (c) Curved arc street block case

Figure 6. Turbulent energy distribution in street block forms

For the three different street block form cases, this study assumes the wind source to be westerly with a speed of 5 m/s, the ground as a traffic area source, and the pollutant as PM2.5. The intensity of the pollution source is set at 0.5 mg/m2s.

Using the FLUENT software, the above-mentioned pollution and wind sources were set, and iterations were conducted for three types of street block spatial forms. The iterative results provided the PM pollutant concentration mass (where the darker the color, the higher the concentration), wind flow field distribution, and turbulent energy distribution maps for the three street block spatial forms.

From the results in Figure 4, it is observed that in terms of PM pollutant distribution, the peninsula circular street block has the highest PM pollutant concentration (5.0 mg/m^2s), followed by the curved arc street block (4.0 mg/m^2s), and the parallel street block has the lowest concentration (3.0 mg/m^2s). The distribution of pollutants is mainly concentrated in the windward area and near the ground source, while the leeward area has a lower concentration of PM pollutants. This result is consistent with studies on PM pollutant concentration distribution and diffusion in street canyons. In terms of pollutant distribution range, based on areas with a concentration greater than 1.0 mg/m^2s, the peninsula circular street block has the widest PM pollutant distribution range, followed by the curved arc street block, and the parallel street block has the smallest.

Combining the wind flow field distribution in Figure 5 and the turbulent energy distribution in Figure 6, this paper concludes that the main factors affecting the concentration distribution of PM pollutants in street blocks include average wind flow field and turbulence transporting and dispersing PM pollutants. Generally, the average wind's ability to transport pollutants is the main factor affecting the overall pollutant distribution. The form of the peninsula circular street block often creates a semi-circular wind speed dead zone due to the tall buildings in the area. Additionally, since the PM2.5 pollution source is set as ground emission and the general wind direction on the ground is from windward to leeward, the leeward side of the peninsula circular street block is greater than that of the curved arc street block. As the wind direction in parallel streets is almost unobstructed, it facilitates the wind to enter the street block and transport pollutants, thus the distribution and diffusion of pollutants conform to the basic principle of wind direction. Turbulent energy has a certain diffusive effect on pollutants [19], and as the peninsula circular street block is a semi-closed form, it has the widest range of high-value turbulent energy distribution, resulting in the smallest distribution range of PM pollutants. In fact, the average wind and turbulent energy's roles in transporting and diffusing pollutants are relative. For the traffic area source set in this paper, although the peninsula circular street block form has the greatest turbulent energy, the turbulence is at a higher position and farther from the pollutant traffic area source, resulting in poorer turbulence diffusion efficiency for PM dispersion.

Experimental Analysis of Urban Block Forms with Elevated Bridges

As an important part of urban modernization, viaducts can not only effectively alleviate the pressure of ground transportation and reduce the occurrence of congestion, but also help to improve the traffic flow of the entire city. However, with the increasing number of cars, the traffic flow on viaducts is also increasing, which leads to the increasingly prominent problem of automobile exhaust emissions. Therefore, the morphology of blocks containing viaducts is more complex than ordinary blocks, and the distribution and diffusion law of PM pollutants are also more complex.

In order to further explore the correlation between the morphological changes of blocks containing viaducts and PM pollutants, this article designs six different examples. These examples fully consider various factors, including wind speed, viaduct height, bridge width, as well as different scenarios of PM2.5 ground and bridge sources. Through these examples, we can more comprehensively analyze the impact of the spatial morphology of viaducts on PM pollution.

First, we considered the impact of different wind speeds on the diffusion of PM pollutants. At low wind speeds, pollutants are more likely to accumulate near the viaduct, resulting in higher local pollution concentrations; at higher wind speeds, pollutants are more likely to be dispersed, reducing pollution to the surrounding environment.

Secondly, the height and width of the viaduct are also important factors that affect the distribution of PM pollutants. Different heights of the viaduct can lead to changes in the vertical distribution of pollutants in space, while different widths can affect the horizontal diffusion range of pollutants.

Finally, we also considered the different scenarios of PM2.5 ground sources and bridge sources. Ground sources mainly come from emissions from surrounding roads and buildings, while bridge sources mainly come from emissions from vehicles on the viaduct. The pollutants from these two sources interact during the diffusion process, jointly affecting the PM pollution level of the entire street block.

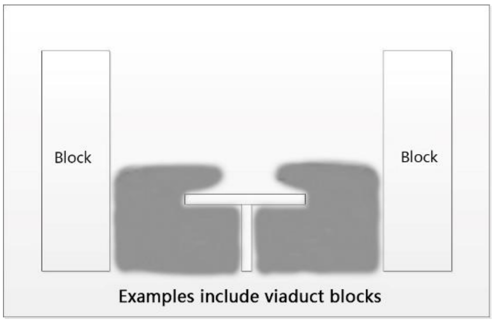
Table 1 below details the specific conditions of these six different cases, including wind speed, bridge height, bridge width, and specific parameters for PM2.5 ground and bridge sources. Through in-depth analysis of these cases, we can more accurately understand the correlation between the morphology of blocks containing elevated bridges and PM pollution, providing a scientific basis for urban planning and environmental governance.

Table 1. Different scenarios for urban block forms with elevated bridges

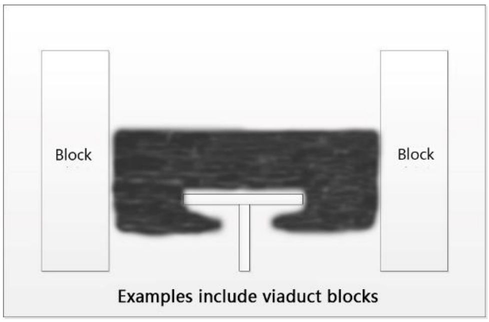
NO.	Bridge Height (m)	Bridge Width (m)	Wind Speed (m/s)	PM2.5 Emission	
				Bridge Source (mg/m2s)	Ground Source (mg/m2s)
Case 1	15	20	2	0	0.5
Case 2	15	20	2	0.5	0
Case 3	15	20	2	0.5	0.5
Case 4	30	20	2	0.5	0.5
Case 5	15	30	2	0.5	0.5
Case 6	15	20	5	0.5	0.5

Figure 7 presents the concentration distribution of PM pollutants for the six scenarios described in the above table, where areas with higher PM2.5 concentrations are indicated by darker colors.

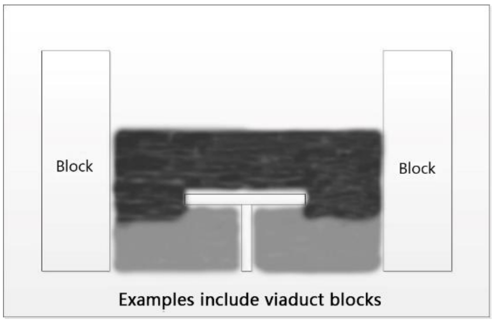
Images (1)-(3) reflect the PM pollution conditions under different pollution source scenarios. Image (1) shows the distribution and diffusion of PM2.5 pollutants when there is only a ground-level pollution source. Image (2) shows the distribution and diffusion of PM2.5 pollutants when there is only a bridge-level pollution source. Image (3) shows the distribution and diffusion of PM2.5 pollutants when both pollution sources are present. A comparison of these images reveals that since the bridge-level pollution source is higher than the ground-level source, it is more significantly influenced by wind flow and turbulence. As a result, compared to the ground-level source, the bridge-level source diffuses faster, has a broader distribution range, but a lower concentration per unit volume (bridge source at 1.0mg/m2s, ground source at 1.5mg/m2s). With both pollution sources present, due to the superposition of the bridge and ground sources, the concentration distribution tends to be more concentrated in ground-level areas.



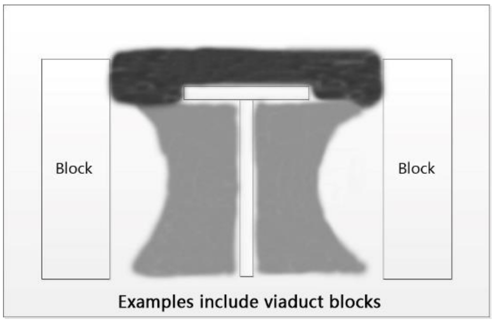
(1) Case 1



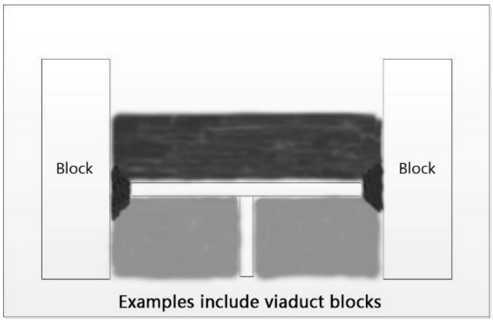
(2) Case 2



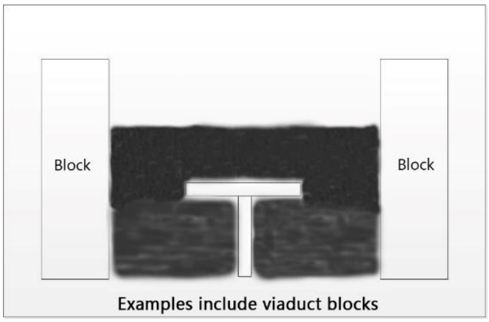
(3) Case 3



(4) Case 4



(5) Case 5



(6) Case 6

Figure 7. Distribution of PM2.5 Pollutants in Street Blocks with Elevated Bridges Under Different Parameters.

The comparison of images (3) and (4) reveals the correlation between the height of the elevated bridge and the distribution and diffusion of PM pollutants. Raising the height of the elevated bridge increases the height of the bridge source, leading to greater diffusion. Therefore, compared to the scenarios with a lower bridge, the concentration per unit volume is lower in a higher bridge scenario (bridge height 15m with a concentration of 0.43mg/m2s, bridge height 30m with a concentration of 0.32mg/m2s). Practically, while vehicles on elevated bridges generate pollution sources, they also produce significant noise, which affects the normal life of residents in the surrounding neighborhoods. Hence, the height of the elevated bridge should be chosen with a compromise in mind. It is generally considered that if normal PM2.5 emission concentration conditions are met, the noise should be minimized as much as possible.

The comparison of images (3) and (5) reflects the correlation between the width of the elevated bridge and the distribution and diffusion of PM pollutants. In contrast to the bridge's height, the width of the elevated bridge reduces the concentration of PM pollutants per unit volume from a horizontal perspective. Normally, increasing the width of the elevated bridge can more evenly enhance the diffusion efficiency of PM2.5 pollutants. Similar to the design of the bridge's height, there are certain limitations in the design process of the bridge's width, which generally should not exceed two-thirds of the street width. Therefore, a compromise should also be considered in the design of the bridge's width, ensuring certain limitations while meeting the conditions of PM2.5 emission concentration.

The comparison of images (3) and (6) allows for an analysis of different wind speed conditions and their impact on the distribution and diffusion of PM pollutants. Wind speed is a major factor in generating turbulence. An increase in wind speed does not significantly boost the wind speed in neighborhoods with elevated bridges, but the coverage of the elevated bridge over the neighborhood creates greater turbulence as the wind speed increases. This, in turn, causes a slower reduction in the concentration of PM pollutants in the neighborhood, ultimately reducing the diffusion efficiency of PM pollutants. The average wind and turbulence generated under the influence of the elevated bridge demonstrate that the average wind's capacity to transport pollutants is more significant compared to the diffusion effect of turbulence on pollutants.

CONCLUSIONS

As urban modernization continues to evolve, PM pollution has become a significant environmental issue. The concentration distribution and diffusion of PM pollution are closely related to the spatial morphology of city blocks. This paper focuses on three common block morphologies, simplified into example models, and includes scenarios with elevated bridges. Using CFD modeling techniques and the FLUENT software, the study analyzes the correlation between various block spatial morphologies and PM pollution.

The analysis shows that factors determining PM pollution concentration distribution in different block morphologies include: the average wind created between blocks for pollutant transport, the turbulence generated by the average wind for pollutant diffusion, and the distribution points of pollution sources. Among these, the average wind has the most significant impact, followed by turbulence, and the distribution points of pollution sources have the least impact. Model simulations reveal that the block morphology with the strongest average wind field, the parallel block space, is more conducive to the average wind's transport function, resulting in the lowest average volumetric concentration of pollutants. Semi-enclosed block morphologies produce weaker average wind and transport function, about 40% lower than parallel blocks.

The presence of elevated bridges in city blocks, introducing bridge and ground-level pollution sources, increases the concentration of pollutants per unit volume. Additionally, the height and width of the elevated bridge influence the diffusion of pollutants, with higher and wider bridges facilitating faster diffusion. However, practical construction of elevated bridges needs to consider other factors as well. Wind speed also plays a supportive role in the diffusion of pollutants.

After detailed modeling and simulation with FLUENT software, we obtained a series of in-depth results. These results suggest that the relationship between the spatial morphology of a neighborhood and PM pollution is quite complex, involving numerous variables. However, it is the powerful simulation capabilities of FLUENT software that enable us to accurately capture this complex correlation.

It is worth mentioning that despite the existence of multiple variables and complexities, the simulation results of FLUENT software are basically consistent with the actual situation. This fully demonstrates the accuracy and reliability of this software in simulating atmospheric environmental pollutant transport. By comparing the simulated data with the actual monitoring data, we found that the error between the two is within an acceptable range, which further verifies the reliability of the simulation results.

Based on these simulation results, we can provide valuable references for the design of street space patterns. For example, when designing new blocks or renovating old ones, we can refer to the distribution pattern of PM pollutants in the simulation results to adjust the layout of buildings, the direction of streets, and the configuration of green vegetation reasonably, so as to achieve the goal of reducing PM pollution and improving air quality. In addition, we can also use simulation results to predict the changing trend of PM pollution under different spatial patterns, providing a scientific basis for formulating targeted environmental management policies.

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