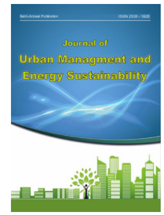
International Journal of Urban Management and Energy Sustainability (IJUMES)

Homepage: http://www.ijumes.com



ORIGINAL RESEARCH PAPER

CFD Simulation of Airflow and Pollutant Dispersion in Urban Street Canyons with Different Building Setback Configurations

Zohreh Deymad[1], Hamideh Jafari[2*], Ali Aram[3]

1 Department of Urban Planning and Architecture, Yas.C., Islamic Azad University, Yasuj, Iran

*2*Department of Art and Architecture, ST.C., Islamic Azad University, Tehran, Iran*

3 Department of Civil Engineering, Yas.C., Islamic Azad University, Yasuj, Iran

ARTICLE INFO

Article History:
Received 2026-04-20
Revised 2026-07-08
Accepted 2026-08-02

Keywords:
Airflow, outdoor air quality, building setback configuration, Computational Fluid Dynamics, pollutant dispersion, urban street canyon

ABSTRACT

Air quality in urban open spaces is significantly shaped by urban morphology, airflow behavior, and pollutant emission sources, and it plays a critical role in protecting public health and improving the thermal comfort of urban residents. Accordingly, this study addresses the problem of how building setback position and configuration influence airflow and traffic-related pollutant distribution in urban street canyons, with the aim of identifying the most effective geometric arrangements for improving outdoor air quality. Research methodology in this study is based on a computational fluid dynamic CFD-based numerical simulation to evaluate airflow behavior and pollutant dispersion under different street-canyon configurations. In this framework, building setback position and configuration were treated as the independent variables, while airflow velocity and pollutant concentration were considered the main indicators of air quality. The analysis included one reference canyon without setbacks and nine alternative cases with different setback arrangements on the opposing building facades. The findings show that the street-center region had the highest level of pollutant accumulation because of weaker ventilation conditions, whereas the windward-sidewalk region generally benefited from more favorable airflow patterns. The results also demonstrate that setback configuration plays a decisive role in air-quality performance. Among all examined cases, the best-performing configuration increased the overall mean airflow velocity by 52.4% and reduced the overall mean pollutant concentration by 25.8% compared with the reference case. In addition, this configuration achieved local pollutant reductions of 46.9% at the windward sidewalk and 36.8% at the street center.

DOI: 10.22034/ijumes.2024.737688

Running Title: CFD Simulation of Airflow and Pollutant Dispersion in Urban Street Canyons

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
23	19	02

*Corresponding Author:
Email: *hamideh.jafari6310@iau.ir*
Phone: 00989173875507
ORCID: https://orcid.org/0009-0006-9430-1788

INTRODUCTION

Cities, as the primary centers of human settlement and activity, face numerous environmental challenges, among which outdoor air quality has become one of the most critical concerns. The quality of air in urban open spaces is strongly influenced by urban morphology and the spatial configuration of the built environment (Oke, 1988; Hang et al., 2009). In this context, urban street canyons the elongated spaces enclosed by buildings along both sides of a street play a fundamental role in controlling airflow patterns, pollutant transport, and ultimately the environmental quality and livability of urban areas (Santamouris, 2013). Previous studies have demonstrated that the geometry and proportions of street canyons significantly influence natural ventilation and the accumulation or dispersion of air pollutants (Soulhac et al., 2011). Therefore, understanding the influence of urban morphological characteristics on air quality within street canyons is essential for sustainable urban planning and design. The primary objective of this study is to investigate the influence of urban street canyon geometry on outdoor air quality. Although various morphological parameters can be used to characterize street canyon geometry, this research specifically focuses on building setback configurations along the opposing façades of the canyon. In urban design literature, such façade recesses are commonly referred to as building setbacks. Accordingly, building setback configuration is adopted in this study as the principal geometric parameter representing street canyon morphology. Two independent variables are considered: setback location and setback configuration. Setback location is examined under three scenarios: setbacks located on the windward façade, the leeward façade, and both façades. Setback configuration is represented by three different patterns consisting of eight, four, and two setbacks along each façade. The corresponding setback lengths are 10 m, 25 m, and 55 m, respectively, while the setback depth is maintained constant at 5 m in all simulation scenarios. Outdoor air quality within the street canyon is considered the dependent variable and is evaluated using two performance indicators: airflow velocity, representing ventilation performance, and traffic-related pollutant concentration, representing air quality. One reference canyon without setbacks and nine canyon configurations with different setback arrangements were analyzed and compared. The study employs Computational Fluid Dynamics (CFD) simulations to investigate airflow behavior and pollutant dispersion within the street canyon. The simulation results are analyzed comparatively against the reference model to quantify the effects of different setback configurations.

Accordingly, this study seeks to answer the following research questions:

•How does the location of building setbacks along street canyon façades influence outdoor air quality within the canyon?

•How does the number of building setbacks affect airflow velocity and the dispersion of traffic-related pollutants within urban street canyons?

MATERIALS AND METHODS

Rapid urbanization has been one of the most significant global transformations in recent decades. The world's urban population increased from 751 million (30% of the global population) in 1950 to 4.2 billion (55%) in 2018, and is projected to reach 6.4 billion (68%) by 2050 (WHO, 2016). This unprecedented urban growth, accompanied by industrial development and increasing anthropogenic emissions, has led to a substantial deterioration in urban air quality. Currently, more than 80% of the global urban population is exposed to air pollution levels exceeding recommended limits, resulting in millions of premature deaths each year from air pollution-related diseases (Lelieveld et al., 2015). Urban air pollution originates from multiple sources, including industrial activities, transportation systems, and building construction (Zheng et al., 2022). Among these, road traffic is recognized as one of the dominant contributors to particulate matter and gaseous pollutant emissions, making it the primary source of air pollution in most urban environments (Heidari et al., 2025; Jo et al., 2009). The adverse impacts of traffic emissions become more pronounced in urban street canyons, where dense building configurations restrict airflow and promote pollutant accumulation within the canyon space (Zhang et al., 2020).

Previous studies have demonstrated that the geometry of urban street canyons including the aspect ratio (W/H), façade symmetry, and building height plays a critical role in determining airflow characteristics and pollutant dispersion patterns (Oke, 1988; Yazid et al., 2014). In addition, other urban morphological parameters, such as the building surface-to-volume ratio, floor-area ratio, façade configuration, overall building arrangement, and the presence of open spaces or ventilation corridors, can substantially modify airflow behavior and enhance natural ventilation within street canyons (Cui et al., 2023; Blocken, 2015).

Besides urban morphology, environmental factors such as wind direction, wind speed, thermal conditions, and the location of pollutant emission sources also significantly influence airflow and pollutant dispersion (Zheng et al., 2022; Jo et al., 2009). Previous research has shown that increasing the distance between buildings and pollution sources, together with providing unobstructed airflow pathways, can effectively reduce pollutant concentrations and improve natural ventilation (Heidari et al., 2025). Furthermore, urban green infrastructure including vegetation, street trees, and green roofs has been identified as an effective strategy for enhancing airflow while mitigating pollutant concentrations within urban environments (Blocken, 2015; Cui et al., 2023). Overall, previous studies indicate that urban air quality is governed by the combined effects of urban morphology and environmental conditions. While considerable attention has been devoted to the influence of street canyon geometry on airflow and pollutant dispersion, the specific effects of different building setback configurations have received comparatively limited investigation. In particular, the influence of setback location and configuration on ventilation performance and pollutant removal has not been systematically quantified. To address this research gap, the present study employs CFD simulations to evaluate how different building setback arrangements affect airflow velocity and traffic-related pollutant dispersion within urban street canyons, thereby providing practical design recommendations for improving outdoor air quality and reducing pedestrian exposure to pollutants.

Methodology

This study investigates the influence of building setback configurations along the opposing façades of urban street canyons on outdoor air quality within the canyon. Building setbacks are considered the independent variable and are characterized by two parameters: setback location and setback configuration. Outdoor air quality is treated as the dependent variable and is evaluated using two performance indicators: airflow velocity, representing natural ventilation performance, and traffic-related pollutant concentration, representing the level of air pollution within the street canyon. A Computational Fluid Dynamics (CFD) approach was adopted to simulate airflow and pollutant dispersion under different geometric configurations. CFD has become one of the most reliable and widely applied numerical techniques for analyzing complex airflow patterns and pollutant transport in urban environments (Blocken, 2015; Tominaga & Stathopoulos, 2013). Its application enables the systematic evaluation of multiple design scenarios while maintaining consistent environmental conditions, thereby providing a robust framework for comparative analysis.

The following sections describe the computational domain, boundary conditions, mesh generation, and simulation settings adopted in this study.

FINDINGS AND DISCUSSION

Case Study Configurations

Building setback configuration was selected as the principal geometric variable. Two parameters were considered in generating the simulation scenarios: setback location and setback configuration.

Three setback locations were investigated: Windward façade, Leeward façade, and Both façades. In addition, three setback configurations were defined according to the number of setbacks along each façade:

•Eight setbacks with a setback length of 10 m,
•Four setbacks with a setback length of 25 m, and
•Two setbacks with a setback length of 55 m.

The setback depth was maintained constant at 5 m in all cases to isolate the influence of setback location and configuration. By combining these two variables, nine simulation scenarios were generated. The geometric characteristics of all case studies are summarized in Fig. 1. (Fig. 1)

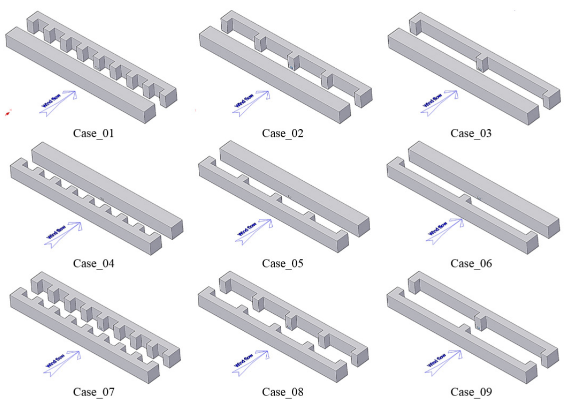


Figure 1: Research case examples (Source: Authors)

As summarized in Fig. 1, the simulation scenarios were generated by combining two geometric variables: setback location and setback configuration. Since the approaching wind direction remained identical in all simulations, setback locations were defined relative to the prevailing wind direction as follows:

-Case_01–Case_03: setbacks located on the windward façades;

-Case_04–Case_06: setbacks located on the leeward façades;

-Case_07–Case_09: setbacks located on both windward and leeward façades.

The setback configurations were categorized according to the number of setbacks along each façade:

-Case_01, Case_04, and Case_07: eight setbacks, each 10 m long;

-Case_02, Case_05, and Case_08: four setbacks, each 25 m long;

-Case_03, Case_06, and Case_09: two setbacks, each 55 m long.

To isolate the effects of setback location and configuration, the setback depth was kept constant at 5 m for all simulation scenarios.

A reference street canyon without setbacks was also established to provide a baseline for comparison. The reference canyon has a length of 125 m, building heights of 21 m on both sides, and a canyon width of 21 m, corresponding to an aspect ratio (W/H) of 1.0. The canyon consists of an 18 m-wide roadway flanked by 1.5 m-wide sidewalks on both sides. For clarity, the sidewalk adjacent to the windward buildings is referred to as the windward sidewalk, whereas the opposite sidewalk is designated as the leeward sidewalk.

The morphological characteristics of the reference canyon were maintained constant throughout all simulation scenarios. Figure 2 illustrates the geometric configuration and principal dimensions of the computational model. (Fig. 2)

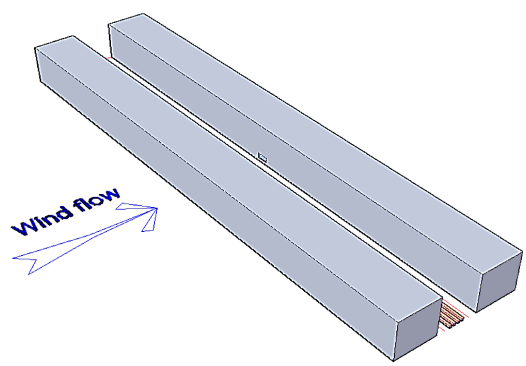


Figure 2: Plan view and three-dimensional representation of the reference street canyon (Source: Authors)

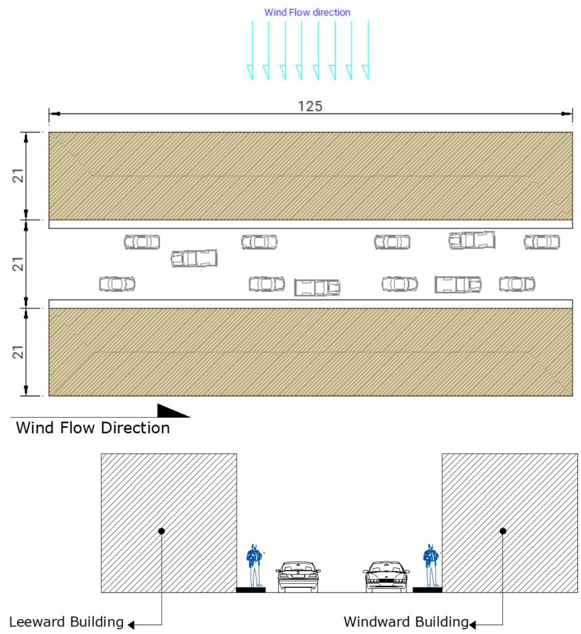
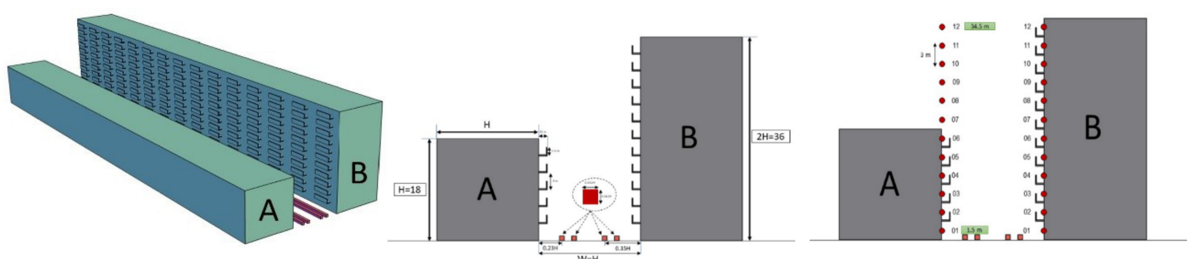


Figure 2: Plan view and three-dimensional representation of the reference street canyon (Source: Authors)

CFD Validation

Since the case studies in the present research were analyzed using Computational Fluid Dynamics (CFD) simulations, validating the numerical model was an essential step to ensure the reliability of the simulation results. For this purpose, the experimental study conducted by Sin et al. (2023) was adopted as the validation benchmark. In their study, an urban street canyon flanked by two rows of buildings was experimentally investigated under laboratory conditions. The buildings incorporated continuous and discontinuous balcony configurations on both the windward and leeward façades, and fourteen different configurations were examined according to the location of the balconies (Sin et al., 2023). In the present study, Configuration g from the work of Sin et al. was selected for validation (Fig. 3). This configuration consists of two asymmetric buildings with heights equivalent to 6 and 12 stories, constructed at a 1:150 geometric scale. Both buildings have identical plan dimensions, while their heights were defined as H = 0.12 m and 2H = 0.24 m, respectively. To simulate traffic-related pollutant emissions, four rows of rectangular emission sources with dimensions of 0.042 × 0.042 × 10 m^3 were positioned along the street between the two buildings. The numerical results used for validation were extracted from twelve measurement points distributed along two vertical sampling lines adjacent to the windward and leeward buildings. The spacing between consecutive sampling points was 3 m.



Three-Dimensional View of the Validation Model | Location and Dimensions of Pollutant Emission Sources in the Validation Model | Locations of Air Pollution Measurement Points within the Street Canyon

Figure 3: Validation model (Case g) adopted from Sin et al. (2023) for CFD validation in the present study (Source: Authors)

The comparison between the CFD validation results and the experimental data for pollutant concentration (Fig. 3) demonstrates good agreement between the numerical predictions and the experimental measurements. The mean error in pollutant concentration was approximately 8%, indicating an acceptable level of accuracy for the CFD model (Fig. 4). Therefore, the numerical model employed in this study was considered sufficiently validated for simulating the research case studies.

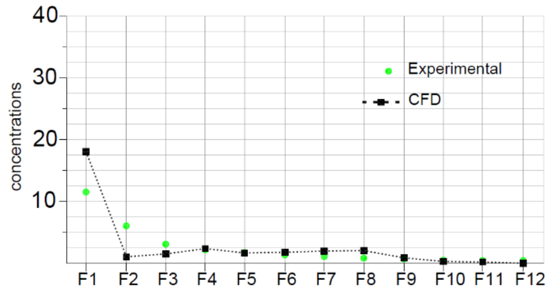


Figure 4: Comparison of Wind Tunnel Measurements and CFD Simulation Results for Model Validation (Source: Authors)

Assumptions and Boundary Conditions

•Pollutant Source:
In the present study, the pollutant source was defined as a roadway located at the center of the urban street canyon. The traffic volume was selected to represent the conditions of a typical secondary urban street, based on the report of the Technical and Civil Engineering Deputy of Tehran Municipality, which indicates an average daily traffic volume of approximately 3,500 vehicles (Tehran Municipality, 2017). Vehicle exhaust emissions include a range of pollutants, such as nitrogen oxides (NOx), ozone (O3), carbon dioxide (CO2), and particulate matter (PM2.5 and PM10). Among these, nitrogen dioxide (NO2) was selected as the representative pollutant in the present study because of its relatively high prevalence in traffic-related emissions (Mansourian et al., 2025). However, the CFD source parameters were not derived directly from the reported traffic count. Instead, the pollutant-source specification was adopted from Heidari et al. (2025), following the source definition used for a comparable street-canyon configuration. Specifically, a mass flow rate of 5 m3/s and a scalar source strength of 0.01 were imposed in Autodesk CFD 2018. These source parameters were applied consistently to all setback scenarios in order to ensure identical pollutant-release conditions and to enable a direct comparison of the relative effects of building geometry on airflow and pollutant dispersion.

•Wind Conditions:
A reference wind speed of 2.7 m/s and an ambient air temperature of 25°C were specified for all CFD simulations. The approaching wind direction was assumed to be perpendicular to the longitudinal axis of the urban canyon.

•Sampling Height:
The dependent variables, including air velocity and pollutant concentration, were evaluated at a height of 1.70 m above ground level, corresponding to the average breathing height of standing pedestrians.

Computational Domain, Boundary Conditions, and Mesh Generation

The computational domain was established following the guidelines proposed by Tominaga et al. (2008). According to these recommendations, the upstream, downstream, and lateral clearances were defined as 5H, 15H, and 5H, respectively, where H denotes the building height. Based on these criteria, the computational domain dimensions were set to 126 × 335 × 484 m^3 (Fig. 5).

The inlet boundary conditions were defined using the Atmospheric Boundary Layer (ABL) model under neutral atmospheric stability. The inlet profiles for the mean wind velocity (U), turbulent kinetic energy (k), and turbulence dissipation rate (ε) were specified according to the model proposed by Deaves & Harris (1982) and subsequently simplified by assuming a constant shear stress with height, following Richards and Hoxey (1993).

$$U(y) = \frac{u^{*}{}_{ABL}}{\kappa} \ln\left(\frac{y + y_0}{y_0}\right) \quad (1)$$

$$\mathrm{k}(y) = \frac{u^{*2}{}_{ABL}}{\sqrt{C_\mu}} \quad (2)$$

$$\varepsilon(y) = \frac{u^{*3}{}_{ABL}}{k(y + y_0)} \quad (3)$$

where y denotes the vertical coordinate, u*ABL_ is the atmospheric boundary layer (ABL) friction velocity, and κ is the von Kármán constant (≈ 0.40–0.42).

At the inlet boundary, a reference wind speed of 2.7 m/s and an ambient temperature of 25°C were prescribed, while a zero static pressure condition was applied at the outlet. The mass flow rate and scalar source strength of the pollutant source were specified as 5 and 0.01, respectively. The molecular diffusivity of NO_2 was defined as 1.54×10^{-5} m²/s using the General Scalar model in the CFD solver. The iterative solution was monitored using the convergence indicators reported by Autodesk CFD 2018. The solution was regarded as converged when these indicators reached 10-5 m/s and 10-6 m/s for the u- and v-velocity components, respectively, and 10-11 Pa for pressure. Convergence was further confirmed by the absence of meaningful changes in the predicted airflow and pollutant concentration fields during additional iterations.

All numerical simulations were performed using Autodesk CFD 2018. The airflow and pollutant dispersion were simulated by solving the three-dimensional steady Reynolds-Averaged Navier–Stokes (RANS) equations under incompressible flow conditions using the k–ε turbulence model. Steady-state, incompressible flow conditions were assumed throughout the simulations. Pressure–velocity coupling was achieved using the SIMPLE algorithm, while the governing equations were discretized using the Modified Petrov–Galerkin scheme.

Mesh-independence study

A mesh-independence study was conducted to ensure that the numerical predictions were not significantly affected by grid resolution. For this purpose, three structured hexahedral meshes with different resolutions (coarse, medium, and fine) were generated for a representative street-canyon case under the same boundary conditions used in the main simulations (Fig. 6). The hexahedral mesh was selected to preserve numerical stability and to provide an adequate representation of the airflow and pollutant dispersion fields inside the canyon. Mesh refinement was mainly applied within the canyon region, where stronger velocity gradients and larger pollutant concentration variations were expected. The three computational grids consisted of approximately 0.5, 1.2, and 2.5 million cells, respectively. The mesh sensitivity analysis was carried out by comparing the pollutant concentration profiles along the vertical centerlines of the windward and leeward building facades, together with the airflow velocity and pollutant concentration at pedestrian height (z = 1.70 m). The results demonstrated that the variation between the medium and fine meshes was minor, with maximum relative differences of about 2.1% for airflow velocity and 3.4% for pollutant concentration. In contrast, the discrepancy between the coarse and medium meshes was more noticeable (Fig. 7). Therefore, further refinement beyond the medium mesh had only a limited influence on the principal simulation outputs. Based on these results, the medium mesh was selected as the optimal grid, providing a suitable balance between numerical accuracy and computational efficiency. This mesh resolution was subsequently used for all simulation scenarios. Due to slight geometrical differences among the setback configurations, the total number of cells in the final simulation meshes ranged from 1,234,231 to 1,285,225.

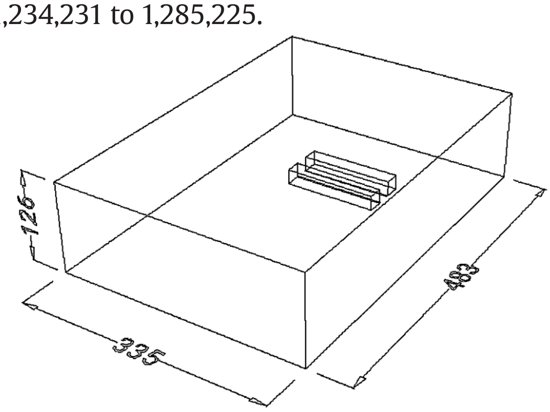


Figure 5: Computational Domain Dimensions and Boundary Conditions Used for the CFD Simulations (Source: Authors)

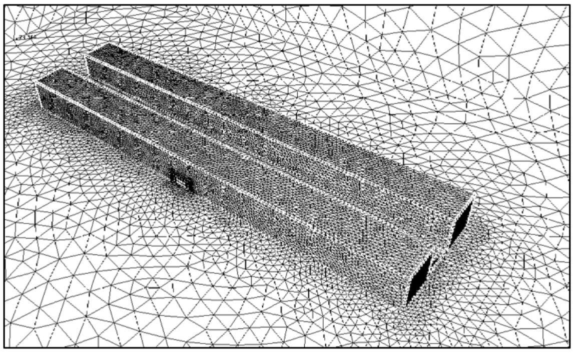


Figure 6: Hexahedral Computational Mesh Used for CFD Simulation of the Case Studies (Source: Authors)

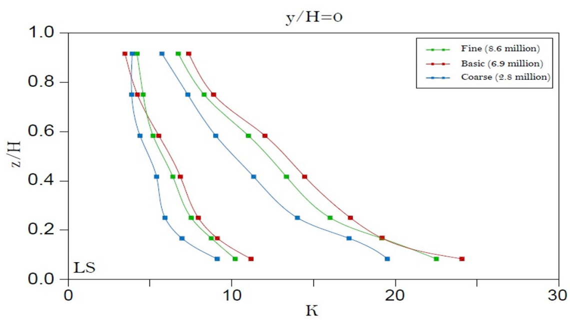


Figure 7: Grid independence analysis (Source: Authors)

RESULTS AND CONCLUSION

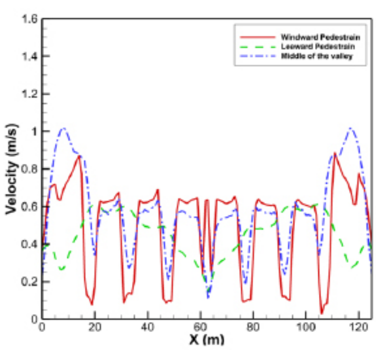
In accordance with the research objective, outdoor air quality within the urban canyon was considered the dependent variable. Based on previous studies, outdoor air quality is primarily influenced by ventilation efficiency and the concentration of airborne pollutants (Heidari & Eskandari, 2022).

Among these factors, air velocity is widely recognized as one of the most reliable indicators of natural ventilation performance. Higher airflow enhances pollutant dilution and transport, thereby reducing the accumulation of traffic-related pollutants within urban spaces (Zabardast & Riazi, 2015).

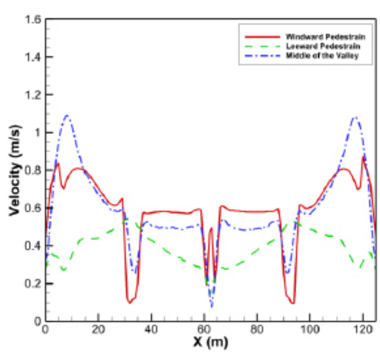
Accordingly, air velocity and pollutant concentration were selected as the two principal indicators for evaluating air quality in the urban canyon. The numerical results obtained from the CFD simulations are presented and comparatively analyzed in the following sections.

Air Velocity Distribution within the Urban Canyon|
Air velocity is one of the principal indicators used to assess natural ventilation performance, representing the rate of air movement within an urban space. In general, higher air velocity contributes to more effective ventilation and improved outdoor environmental quality (Allard & Ghiaus, 2006).

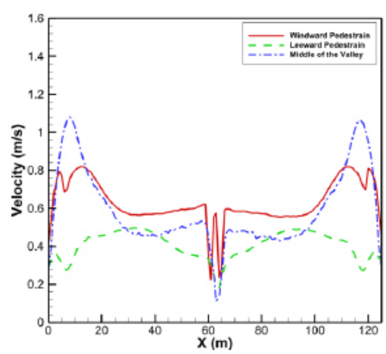
Figures 8 and 9 present the numerical distributions of air velocity along the windward and leeward sidewalks for all case studies, together with the corresponding airflow contour maps within the canyon. All reported values and contour plots were extracted at a pedestrian breathing height of 1.70 m above ground level.



Case_01



Case_02



Case_03

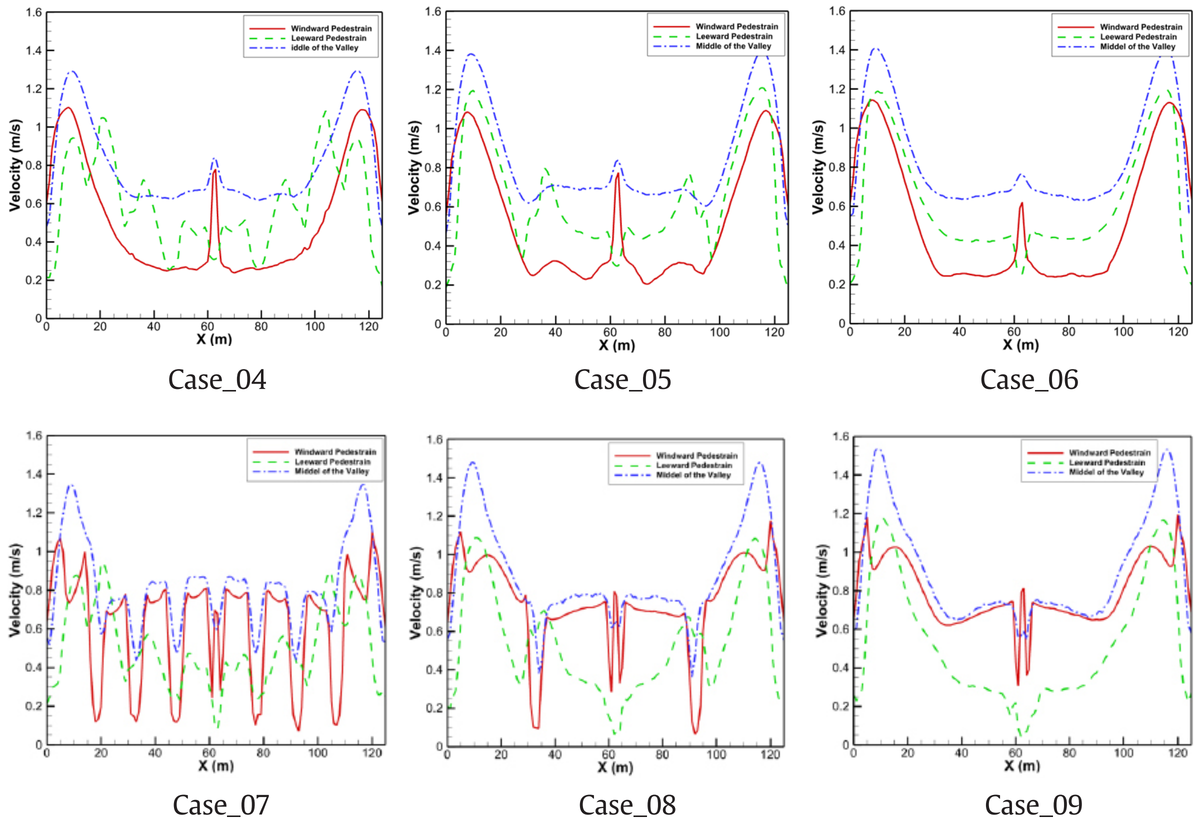


Figure 8: Longitudinal Profiles of Air Velocity Along the Urban Canyon, Including the Roadway and the Windward and Leeward Sidewalks (Source: Authors)

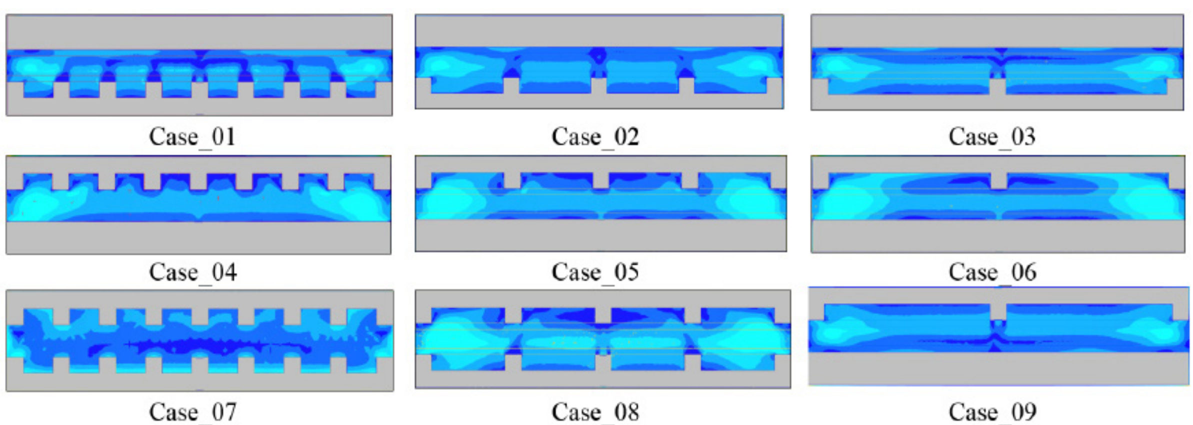


Figure 9: Air Velocity Contours in the Central Outdoor Space of the Urban Canyon for the Investigated Case Studies (Source: Authors)

Table 1: The percentage change in mean air velocity for all nine case studies relative to the reference case (Source: Authors)

Case No.	Average air velocity	U/Uref%
Case_Ref	0/47	100
Case_01	0/51	108/5106
Case_02	0/52	110/6383
Case_03	0/53	112/766
Case_04	0/65	138/2979
Case_05	0/66	140/4255
Case_06	0/68	144/6809
Case_07	0/75	159/5745
Case_08	0/8	170/2128
Case_09	0/82	174/4681

The numerical data and airflow profiles presented above lead to the following observations:
When the canyon length is divided into three equal sections, the central third consistently exhibits the lowest air velocity across all case studies, whereas the upstream and downstream thirds show relatively higher air velocities. This indicates that the central section of the canyon experiences the weakest natural ventilation, while the two end sections provide more favorable ventilation conditions.

Regarding the transverse profile of the canyon, the windward sidewalk consistently records the highest mean air velocity, followed by the roadway located at the center of the canyon. In contrast, the leeward sidewalk exhibits the lowest air velocity, indicating less effective ventilation on the sheltered side of the canyon. To further evaluate the influence of the independent variables namely, the location and the number of building setbacks the mean air velocity of each case was compared with that of the reference case. The comparative results are illustrated in (Fig. 10–13).

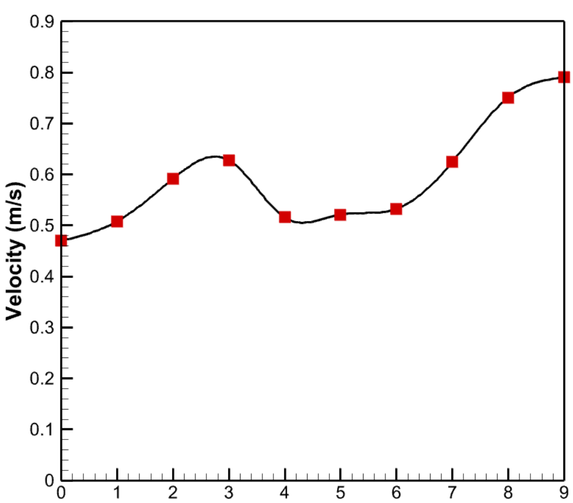


Figure 10: Mean Air Velocity on the Windward Sidewalk Compared with the Reference Case for All Case Studies (Source: Authors)

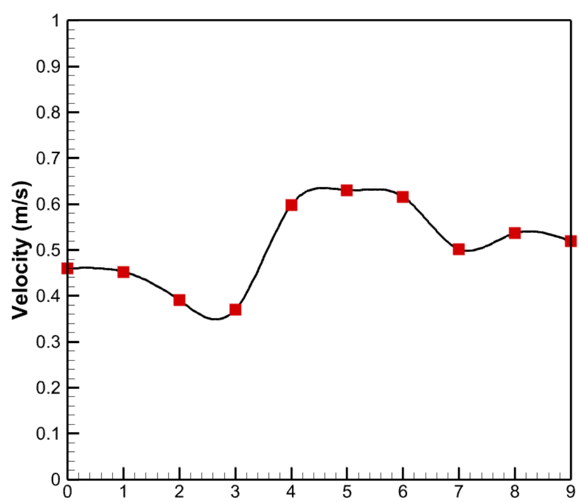


Figure 11: Mean Air Velocity on the Leeward Sidewalk Compared with the Reference Case for All Case Studies (Source: Authors)

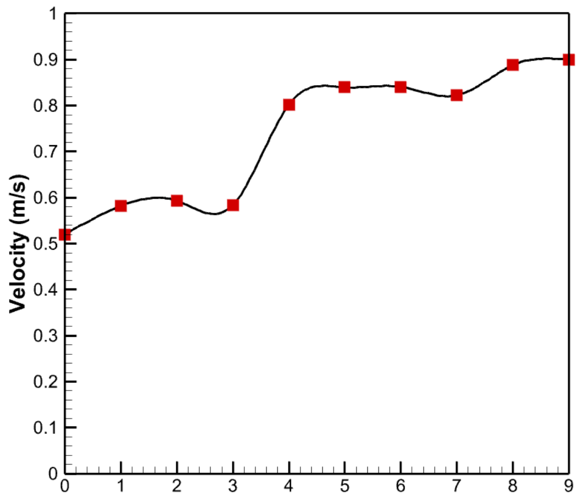


Figure 12: Mean Air Velocity Along the Roadway Compared with the Reference Case for All Case Studies (Source: Authors)

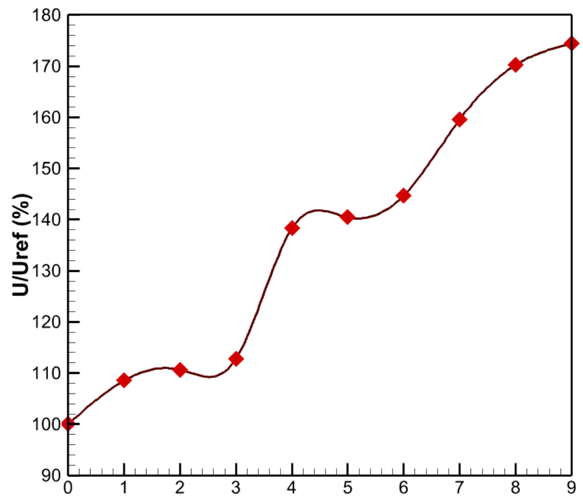


Figure 13: Comparison of the Overall Mean Air Velocity Between the Case Studies and the Reference Case (Source: Authors)

The results presented in Figures 10–113 led to the following observations:

-Windward sidewalk (Fig. 10): In Cases 01–03, the mean air velocity increased as the number of setbacks decreased, indicating that longer setbacks on the windward façade enhanced pedestrian-level ventilation. Cases 04–06 showed only minor variations in air velocity, although all values remained higher than those of the reference case. The greatest improvement occurred in Cases 07–09, where setbacks were introduced on both façades. Among these, Case 09 achieved the highest mean air velocity, representing a 68% increase compared with the reference case.

-Leeward sidewalk (Fig. 11): In Cases 01–03, the mean air velocity decreased, suggesting that setbacks located only on the windward façade adversely affected airflow along the leeward sidewalk. Cases 04–06 exhibited only slight changes, with air velocity remaining marginally higher than in the reference case. Similarly, Cases 07–09 showed little variation, indicating that setbacks on both façades had a limited influence on airflow at the leeward pedestrian zone.

- Central roadway (Fig. 12): The number of setbacks had little effect on the mean air velocity. Nevertheless, introducing setbacks on the windward façade, leeward façade, or both consistently increased the roadway air velocity compared with the reference case.

-Overall mean air velocity (Fig. 13): All setback configurations improved the average air velocity within the urban canyon relative to the reference case. The greatest improvement was observed in Cases 07–09, where setbacks were applied to both façades, while the smallest increase occurred in Cases 01–03, with setbacks only on the windward façade. Moreover, reducing the number of setbacks (thereby increasing the length of each setback) further enhanced ventilation. Case 09 produced the highest overall mean air velocity, corresponding to a 74% increase over the reference case.

Assessment of Pollutant Concentration in the Urban Canyon

Pollutant concentration is one of the primary indicators of outdoor air quality in urban environments and is commonly used to assess the distribution of airborne contaminants. In the present study, vehicular traffic along the roadway located at the center of the urban canyon was considered the pollution source, and nitrogen dioxide (NO2) was selected as the representative traffic-related pollutant because of its prevalence in vehicle emissions. In the CFD simulations, the pollutant was modeled as a passive scalar to enable a comparative assessment of dispersion patterns among the investigated setback configurations. Therefore, the concentration values presented in this section do not represent absolute ambient NO2 concentrations in ppm; rather, they correspond to scalar concentration outputs from the CFD solver and are used for relative comparison among the studied cases. Figures 14 and 15 present the longitudinal distribution of scalar concentration along the windward and leeward sidewalks, together with the corresponding contour plots of pollutant dispersion within the canyon. All results were extracted at a height of 1.70 m above ground level, corresponding to the average pedestrian breathing height.

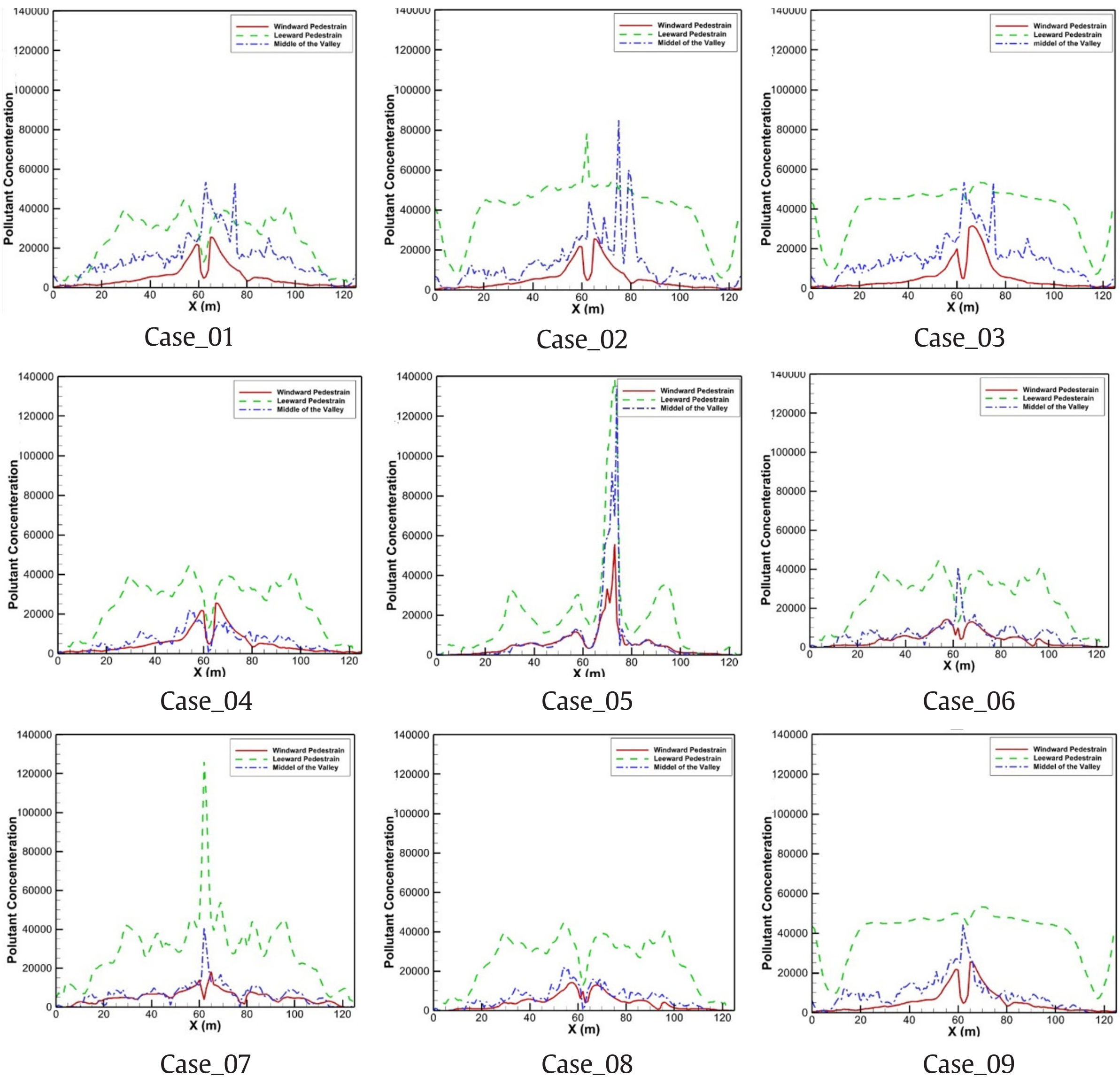


Figure 14: Longitudinal Profiles of Scalar Pollutant Concentration Along the Roadway and the Windward and Leeward Sidewalks for All Case Studies (Source: Authors)

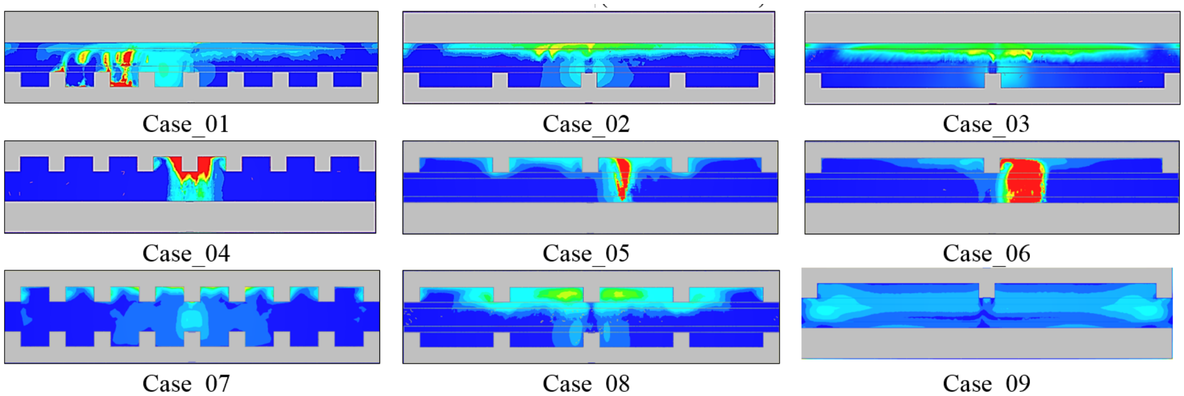


Figure 15: Contour Plots of NO_2 Concentration in the Open Space of the Urban Canyon for All Case Studies (Source: Authors)

Table 2: The percentage change in normalized scalar concentration values of NO_2 Concentration for all nine case studies relative to the reference case. (Source: Authors)

Case No.	normalized scalar concentration values of NO_2 Concentration	P/Pref%
Case_Ref	75692/67	100
Case_01	72765/67	96/13305
Case_02	70498	93/13716
Case_03	67885/33	89/68548
Case_04	73331/67	96/88081
Case_05	72799/33	96/17752
Case_06	71574/67	94/55958
Case_07	62643/67	82/76055
Case_08	59968/67	79/22652
Case_09	56169/33	74/2071

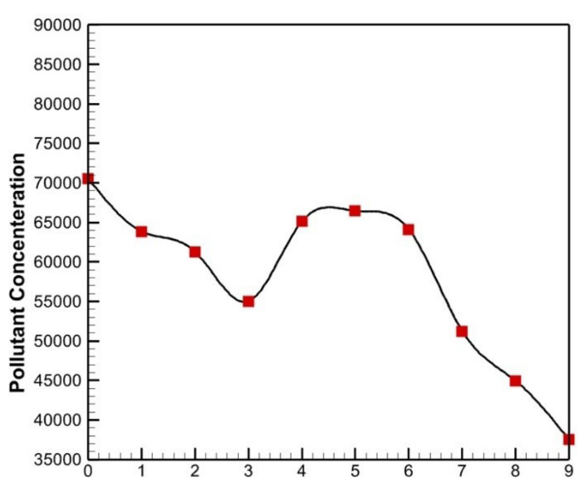


Figure 16: Average NO_2 Concentration Along the Windward Sidewalk in the Case Studies Compared with the Reference Case (Source: Authors)

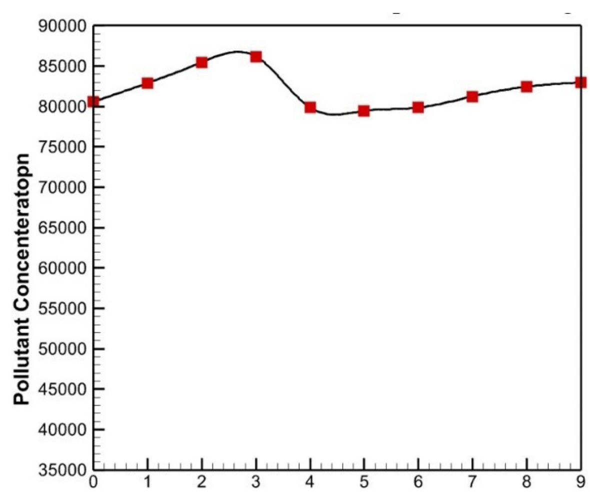


Figure 17: Average NO_2 Concentration Along the Leeward Sidewalk in the Case Studies Compared with the Reference Case (Source: Authors)

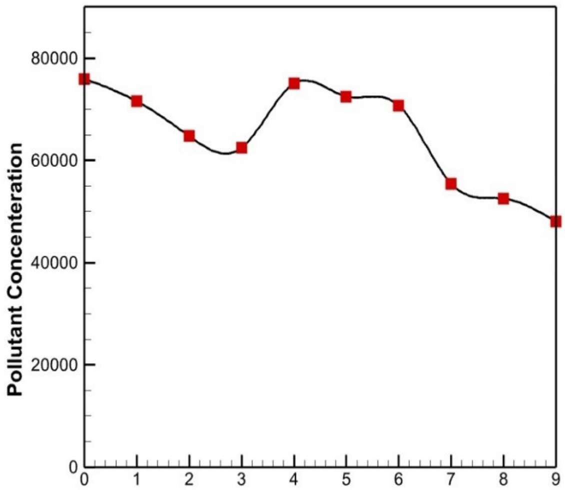


Figure 18: Average NO_2 Concentration Along the Central Roadway in the Case Studies Compared with the Reference Case (Source: Authors)

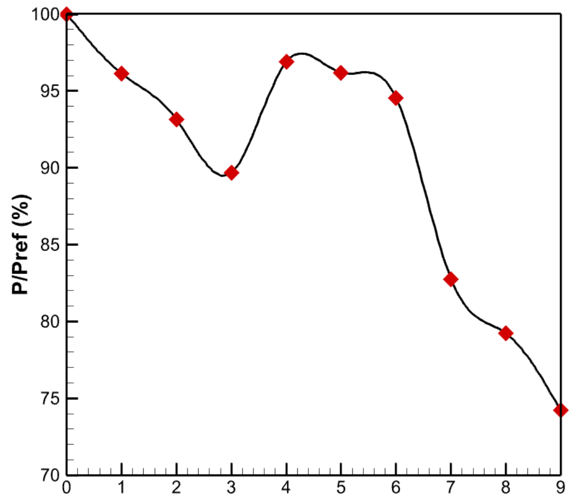


Figure 19: Comparison of the Overall Average NO_2 Concentration Between the Case Studies and the Reference Case (Source: Authors)

As shown in Figure 16, the average scalar concentration along the windward sidewalk decreased in all case studies compared with the reference case. The lowest value was observed in Case_09, corresponding to a 53% reduction relative to the reference case. A gradual decrease in scalar concentration was observed from Case_01 to Case_03, whereas the values remained nearly unchanged from Case_04 to Case_06 and decreased further from Case_07 to Case_09. These results suggest that setbacks located only on the leeward facade have a limited effect on pollutant conditions along the windward sidewalk, while setbacks located on the windward facade or on both facades more effectively promote pollutant dispersion. In addition, reducing the number of setbacks, and thus increasing the length of each setback segment, further enhanced pollutant removal along the windward sidewalk. Figure 17 shows that the average scalar concentration along the leeward sidewalk increased from Case_01 to Case_03 and exceeded the reference case in this group of scenarios. In Case_03, for example, the average scalar concentration was 7% higher than that of the reference case. In Cases_04 to Case_06, the values remained close to the reference condition, whereas a slight increase was again observed in Cases_07 to Case_09. This behavior indicates that some setback configurations may locally limit pollutant removal on the leeward side, even when the overall canyon ventilation is improved. According to Figure 18, the average scalar concentration along the central roadway was lower than that of the reference case in all scenarios and exhibited a consistent decreasing trend from Case_01 to Case_09. This trend indicates that the introduction of setbacks generally improves pollutant dispersion over the roadway, with the greatest improvement occurring in the cases with fewer but longer setback segments. At the scale of the entire canyon, Figure 19 indicates that introducing setbacks generally reduced the average scalar concentration relative to the reference case. In particular, Case_09 achieved a 74% increase in average air velocity and a 26% reduction in the canyon-wide average scalar concentration compared with the reference case. At the local scale, the same case also produced the largest improvement along the windward sidewalk, where the scalar concentration was reduced by 53%. Overall, the results demonstrate that both the location and number of setbacks play an important role in pollutant dispersion within the urban canyon. Setbacks located on the windward facade or on both facades were considerably more effective than those located only on the leeward facade, while reducing the number of setbacks further improved the overall pollutant-dispersion performance of the canyon.

CONCLUSION AND RESULTS

This study investigated the influence of urban canyon geometry, particularly façade setback configurations, on outdoor air quality using CFD simulations. The results showed that both the location and number of setbacks significantly affect airflow patterns and pollutant dispersion within the canyon. The analyses indicated that the central section of the canyon consistently experienced the lowest air velocity and the highest pollutant accumulation, whereas the upstream and downstream sections exhibited more effective natural ventilation. Across the canyon cross-section, the windward sidewalk recorded the highest average air velocity, while the leeward sidewalk exhibited the lowest, underscoring the dominant role of wind direction in controlling local ventilation and pollutant transport under the simulated conditions. With respect to setback location, introducing setbacks on the windward façade or on both façades produced the greatest improvements in ventilation and pollutant removal, whereas setbacks located only on the leeward façade had a comparatively limited influence. In addition, reducing the number of setbacks while increasing their individual length further enhanced airflow and improved pollutant dispersion. Among all investigated scenarios, Case_09, which incorporated long setbacks on both façades, showed the best overall performance, increasing the average air velocity by 74% and reducing the canyon-wide average NO_2 concentration by 26% relative to the reference case. At the local scale, this case also achieved the largest improvement along the windward sidewalk, where NO_2 concentration decreased by 53%. These findings suggest that appropriately designed façade setbacks can serve as an effective passive urban design strategy for improving natural ventilation and mitigating traffic-related air pollution in urban canyons. However, the results are based on a simplified canyon geometry, steady-state CFD simulations, and a single wind direction perpendicular to the canyon axis. Under oblique wind conditions, the airflow structure within the canyon may change substantially, which could modify the windward-leeward asymmetry observed in the present study and alter the relative effectiveness of the investigated setback configurations. Therefore, caution is required when extending these findings to more complex urban environments with different building morphologies, meteorological conditions, wind directions, or emission scenarios. Future research should investigate additional canyon aspect ratios, oblique and variable wind directions, transient atmospheric conditions, and alternative pollutant sources to further validate and generalize the proposed design recommendations.

REFERENCES

Allard, F., & Ghiaus, C. (Eds.). (2012). Natural ventilation in the urban environment: assessment and design. Routledge.

Blocken, B. (2015). Computational Fluid Dynamics for urban physics: Importance, scales, possibilities, limitations and ten tips and tricks towards accurate and reliable simulations. Building and environment, 91, 219-245. doi.org/10.1016/j.buildenv.2015.02.015

Cui, P. Y., Ji, R., He, L., Zhang, Z., Luo, Y., Yang, Y., & Huang, Y. D. (2023). Influence of GI configurations and wall thermal effects on flow structure and pollutant dispersion within urban street canyons. Building and Environment, 243, 110646. doi.org/10.1016/j.buildenv.2023.110646

Deaves, D. M., & Harris, R. I. (1982). A note on the use of asymptotic similarity theory in neutral atmospheric boundary layers. Atmospheric

Environment (1967), 16(8), 1889-1893. doi.org/10.1016/0004-6981(82)90376-6

Hang, J., Sandberg, M., & Li, Y. (2009). Effect of urban morphology on wind condition in idealized city models. Atmospheric environment, 43(4), 869-878. doi.org/10.1016/j.atmosenv.2008.10.040

Heidari, A. A., & Eskandari, H. (2022). Impact of inlet and outlet opening height variation on the air quality and ventilation efficiency in the on-top wind catcher buildings: A CFD simulation. Science and Technology for the Built Environment, 28(10), 1420-1438. doi.org/10.1080/23744731.2022.2089592

Heidari, A., Peyvastehgar, Y., Eskandari, H., & Mansourian, E. (2025). The effect of balcony configurations on ACH and pollutant concentration in symmetrical and asymmetrical street canyons. Scientific Reports, 15(1), 8894. doi.org/10.1038/s41598-025-93736-5

Jo, W. J., & Sohn, J. Y. (2009). The effect of environmental and structural factors on indoor air quality of apartments in Korea. Building and Environment, 44(9), 1794-1802. doi.org/10.1016/j.buildenv.2008.12.003

Lelieveld, J., Evans, J. S., Fnais, M., Giannadaki, D., & Pozzer, A. (2015). The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature, 525(7569), 367-371. doi.org/10.1038/nature15371

Mansourian, E., Eskandari, H., & Heidari, A. (2025). The effect of balcony geometry on improving indoor air quality in mid-rise buildings adjacent to urban highways: A case study of Shahid Chamran Highway, Tehran. Haft Hesar Environmental Studies, 14(51), 25–38. (In Persian).

Oke, T. R. (1988). Street design and urban canopy layer climate. Energy and buildings, 11(1-3), 103-113. doi.org/10.1016/0378-7788(88)90026-6

Richards, P. J., & Hoxey, R. P. (1993). Appropriate boundary conditions for computational wind engineering models using the k-ϵ turbulence model. Journal of wind engineering and industrial aerodynamics, 46, 145-153. doi.org/10.1016/0167-6105(93)90124-7

Santamouris, M. (2013). Using cool pavements as a mitigation strategy to fight urban heat island—A review of the actual developments. Renewable and Sustainable Energy Reviews, 26, 224-240. doi.org/10.1016/j.rser.2013.05.047

Sin, C. H., Cui, P. Y., Luo, Y., Jon, K. S., & Huang, Y. D. (2023). CFD modeling on the canyon ventilation and pollutant exposure in asymmetric street canyons with continuity/discontinuity balconies. Atmospheric Pollution Research, 14(1), 101641. doi.org/10.1016/j.apr.2022.101641

Soulhac, L., Salizzoni, P., Cierco, F. X., & Perkins, R. (2011). The model SIRANE for atmospheric urban pollutant dispersion; part I, presentation of the model. Atmospheric environment, 45(39), 7379-7395. doi.org/10.1016/j.atmosenv.2011.07.008

Tehran Municipality, Technical and Civil Engineering Deputy. (2017). Traffic data of Tehran highways. Tehran: Office of Studies, Planning and Programming. (In Persian).

Tominaga, Y., & Stathopoulos, T. (2013). CFD simulation of near-field pollutant dispersion in the urban environment: A review of current modeling techniques. Atmospheric environment, 79, 716-730. doi.org/10.1016/j.atmosenv.2013.07.028

Tominaga, Y., Mochida, A., Yoshie, R., Kataoka, H., Nozu, T., Yoshikawa, M., & Shirasawa, T. (2008). AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings. Journal of wind engineering and industrial aerodynamics, 96(10-11), 1749-1761. 10.1016/j.jweia.2008.02.058

World Health Organization (WHO). (2016). WHO treatment guidelines for drug-resistant tuberculosis. World Health Organization.

Yazid, A. W. M., Sidik, N. A. C., Salim, S. M., & Saqr, K. M. (2014). A review on the flow structure and pollutant dispersion in urban street canyons for urban planning strategies. Simulation, 90(8), 892-916. doi.org/10.1177/0037549714528046

Zabardast, E., & Riazi, H. (2015). Built environment indicators and their effects on air pollution: A case study of the areas surrounding fourteen air quality monitoring stations in Tehran. Fine Arts: Architecture and Urban Planning, 20(1), 55–66. (In Persian). doi.org/10.22059/jfaup.2015.56371

Zhang, Y., Gu, Z., & Yu, C. W. (2020). Impact factors on airflow and pollutant dispersion in urban street canyons and comprehensive simulations: A review. Current pollution reports, 6(4), 425-439. doi.org/10.1007/s40726-020-00166-0

Zheng, X., Montazeri, H., & Blocken, B. (2022). Impact of building façade geometrical details on pollutant dispersion in street canyons. Building and Environment, 212, 108746. doi.org/10.1016/j.buildenv.2021.108746

HOW TO CITE THIS ARTICLE

Deymad,Z , Jafari,H , and Aram,A . (2026). CFD Simulation of Airflow and Pollutant Dispersion in Urban Street Canyons with Different Building Setback Configurations. (e738225). International Journal of Urban Management and Energy Sustainability, ( ), e738225

DOI: 10.22034/ijumes.2024.737688