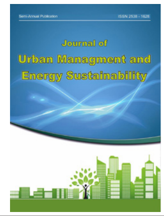
International Journal of Urban Management and Energy Sustainability (JUMES)

Homepage: http://www.ijumes.com



CASE STUDY RESEARCH PAPER

Impact of Balcony Depth and Position on Indoor Air Quality of Apartments Located Along Urban Traffic Corridors

Mohammad Ali Zare[1], Mehdi Tavakoli Kazeroni[2*], Abdolhossein Paknejadi[3]

*1 **Department of Architecture, Yas.,C., Islamic Azad University, Yasuj, Iran***
2 **Department of Architecture Engineering, Shi.,C., Islamic Azad University, Shiraz, Iran***
*3 **Department of Civil Engineering, Yas.,C., Islamic Azad University, Yasuj, Iran***

ARTICLE INFO

Article History:
Received 2025-06-01
Revised 2025-08-10
Accepted 2025-09-02

Keywords:
Balcony depth, balcony location, CFD method, indoor air quality, NO2 pollutant concentration

DOI: 10.22034/ijumes.2025.2069473.1322

ABSTRACT

Today, traffic-related pollution in cities has become a fundamental problem, especially in large urban areas. Balcony characteristics, including shape, depth, length, height of the parapet, balcony position, and so on, have different effects on ventilation quality and the concentration of pollutants entering the building. This study evaluates the role of two variables, balcony depth and its placement, on indoor air quality. For this purpose, 12 buildings with different balcony depths and placements near a metropolitan highway were chosen as case studies and simulated using CFD. The balcony placement in the case studies includes three balcony patterns: facing the prevailing wind, facing away from the prevailing wind, and on both faces; in each pattern, four depths from 0.5 meters to 2 meters were considered for the balconies. This study employs three-dimensional steady RANS equations combined with the k-ω turbulence model to solve the equations. The results show that balconies generally reduce both wind speed and the ingress of pollutants into the indoor space compared with buildings without balconies; however, increasing balcony depth on the windward side decreases the incoming wind speed but increases the concentration of pollutants entering the building. Therefore, changes in balcony depth within this range have little effect on airflow speed or pollutant concentration entering the building; ultimately, employing balconies on both the windward and leeward sides markedly reduce wind speed and pollutant concentrations entering the building, and increasing balcony depth on this side decreases the incoming wind speed while increasing the pollutant concentration entering the building.

Running Title: Balcony Depth and Position on Indoor Air Quality of Apartments Located Along Urban Traffic Corridors

NUMBER OF REFERENCES
29

NUMBER OF FIGURES
23

NUMBER OF TABLES
01

*Corresponding Author:
Email: *Me.tavakoli1356@iau.ac.ir*
Phone: +989177142863
ORCID: https://orcid.org/0000-0003-3310-9339

INTRODUCTION

With increasing urbanization and city development, the sources of pollutants in these cities have also increased to the extent that air pollution has today become one of the main challenges of urban life, especially in large cities (Coelho et al., 2022). Emissions from heavy industries, factories, power plants, and even the use of fossil fuels in homes for cooling and heating buildings are among the factors contributing to pollution in these cities (Kamali et al., 2025). However, one of the most important sources of pollutants in cities is road traffic in urban spaces (Zhao et al., 2020). The exhaust from burning fuel in these vehicles contains various particles including NO2, CO, SO2, and so on, which spread to different spaces as traffic moves through the city (Li et al., 2017). These pollutants, when exposed to urban wind, are transferred to surrounding spaces and lead to a decline in air quality in the living spaces around traffic corridors (Kamali et al., 2024). Therefore, the accumulation of these pollutants is much higher in complexes built along highways compared with other places. This has become a fundamental problem for residents of these complexes; because, on the one hand, they tend to open building openings to utilize natural ventilation flow, but on the other hand, opening windows allows pollutants to enter their living spaces. This has led residents to increasingly rely on mechanical ventilation solutions, which ultimately increases energy consumption and costs (Rahspar monfared and Azmati, 2021). Therefore, finding strategies that simultaneously enable the use of natural ventilation inside buildings while preventing pollutant entry into the building is a main objective in these kinds of studies. By 2019, multiple-dwelling houses accounted for 43.5% of the residential sector, with over 70% of these buildings located in large cities. Low-rise buildings (1–6 stories) accounted for 90.6% of the housing stock (Ahmed and Hossain, 2019). Urban areas are experiencing growing environmental challenges, including light pollution (Rahman et al., 2020; Mao, 2017), noise pollution (Wong et al., 2020), and the urban heat island effect (Santamouris, 2021). According to the existing literature, various factors such as building form, shape and geometry, block arrangement patterns, height differences between buildings, and buildings elements to buildings influence the ventilation pattern and pollutant dispersion in outdoor and indoor spaces of buildings (Meciarova et al., 2013; Di Sabatino et al., 2018; Hang et al., 2015; Miao et al., 2020). Among these, balconies and overhangs are among the elements that have a significant impact on this issue (Heidari et al., 2025). A balcony is a semi-open space that, as one of the main components of residential buildings, creates a connection between indoor closed space and the outdoor environment for residents (Bakhtiari Manesh and Bamian, 2023, Kolarik et al., 2014). In various studies related to balcony architecture, emphasis has been placed on the influence of their geometric features, including shape, depth, length, railing dimensions, and so on, on the ventilation flow entering the building. However, to date, there has been no study on the role of this issue in the concentration of pollutants entering the building alongside ventilation. Therefore, the present study aims to investigate, among the architectural features of balconies, the effect of two variables: balcony depth and its placement in the building on indoor air quality in a residential complex located beside a city highway (as the pollutant source). For this purpose, a row of five three-story buildings at a distance of 35 meters from a city highway was selected as the study area, and the middle building was considered the target building. This building had no balcony and was considered the reference sample. Then, considering the variable "balcony placement," three positions were considered: "balcony facing the prevailing wind," "balcony facing away from the prevailing wind," and "balcony on both sides." Subsequently, for each category, four balcony depths of 0.5, 1, 1.5, and 2 meters were considered, resulting in a total of 12 case studies.

The samples were simulated in CFD software, and results regarding two variables, ventilation quality and the concentration of pollutants entering the building floors, were extracted and compared with the reference sample. In light of this, the main research questions of this study can be stated as follows:

- How does the placement of balconies in mid-rise buildings located along highways affect the quality of air entering them?
- How do changes in balcony depths in buildings along urban highways affect the wind speed and concentration of pollutants entering the building?

MATERIALS AND METHODS

Research Background

So far, several studies have been conducted on the quality of ventilation in urban spaces and how traffic pollutants are emitted in these spaces (Sanchez et al. 2017), among which some have emphasized the role of balconies in this regard. The following are some of them:

- Cui et al (2020) examined the effect of 3 types of balconies on air flow and pollutant emission in an asymmetric urban valley. An urban valley is a street surrounded by two rows of parallel buildings, and an asymmetric urban valley is a situation where the buildings located on both sides of the valley differ in height. In such a case, if the building facing the wind is higher than the building facing the wind, it is called a step-down valley, and in a situation where the building located on the windward side is higher, it is called a step-up valley. However, their research results showed that the use of balconies in the step-down valley leads to improved airflow and reduced pollutant emissions in the space inside the valley compared to the step-up pattern (Cui et al., 2020).
- Zheng et al (2022) studied the effects of building facade features (balconies) on wind flow and pollutant movement patterns in symmetrical urban valleys. Their research results showed that balconies have a significant impact on wind flow and pollutant emissions in the space inside the valley and prevent wind flow and pollutant emissions from penetrating deep into the valley (Zheng et al., 2022).
- Li et al (2020) studied the effects of building setback on thermal comfort, air quality, and pollutant dispersion patterns in short-order urban valleys. Their findings showed that horizontal building setbacks in low-rise valleys simultaneously improved thermal comfort, air quality, and reduced traffic pollutant emissions in the valley space (Li et al., 2022).
- Sin et al (2023) investigated the role of continuous and discontinuous balconies on air change rate (ACH) and traffic pollutant emissions at pedestrian height in an asymmetric urban valley. Their research results showed that the use of discontinuous balconies on the street front reduced pollutant emissions in the valley space compared to continuous balconies (Sin et al., 2023).
- Jon et al (2023) investigated the effects of wind direction and discontinuous balcony location on ventilation and traffic pollutant emissions in the valley space of a street. The results of their research indicate that the ventilation of the air inside the valley with discontinuous balconies is less than that of the valley without balconies. Also, according to the results of their research, it is better to place balconies in buildings located on the back of the wind (Jon et al., 2023).
- Tong et al (2012) studied the effect of factors such as the distance of the building from the pollution source, wind direction, particle size, opening location and its size on indoor air quality. The results of their research showed that with increasing the distance of the building from the pollution source, the concentration of particles entering the building decreases (Tong et al., 2012).

As is clear from the above research, studies that have investigated the role of balconies in the emission of pollutants from vehicle traffic have all measured this issue in open space and often at the level of an urban valley. This is while no independent study has yet examined the role of balconies on the emission of pollutants into the interior of buildings; however, the only study that has examined the issue of ventilation quality and the entry of traffic pollutants into the interior of a building is the study by Tang et al. (2016), in which the subject of the study was not the balcony, and the effect of factors such as the distance from the building to the pollution source, wind direction, particle size, size and location of the opening on the air quality inside the building was measured. Therefore, in explaining the innovative aspect of the present study, it can be stated that in this study, the role of two parameters, the location of the balcony and the depth of the balcony, on the quality of ventilation and the rate of transfer of pollutants to the space inside a building located adjacent to an urban highway as a source of traffic pollutants will be examined.

Methodology

Based on what has been stated earlier, the main objective of the present study is to examine the effects of two variables, "balcony placement" and "balcony depth," on the indoor air quality of mid-rise buildings located along urban highways. By balcony placement we mean its position on either the windward or leeward side of the pollution source, and by balcony depth we mean how far the balcony protrudes from the building's exterior envelope. The dependent variable in this study is the indoor air quality, which is assessed through two indicators: wind speed and the concentration of pollutants entering the building. The following sections introduce the various dimensions related to the research methodology of this study.

DISCUSSION AND FINDINGS

Case studies

The spatial domain studied in the present research consists of a row of five four-story buildings with dimensions of 18 by 12 square meters, located along a city highway at a distance of 35 meters from it (Fig. 1). The target building in this set is the central building, which comprises three units on each floor. In this study, the middle unit on each floor is considered the study area (Fig. 2). To better measure the flow through the units, partitions inside them were removed so that the air could enter through openings on the side facing the pollution source and exit through the opposite side. The dimensions of the units on each floor are 6 by 12 square meters, and the dimensions of each of their openings are 2 by 1 square meters. These dimensions were kept constant across all case study samples.

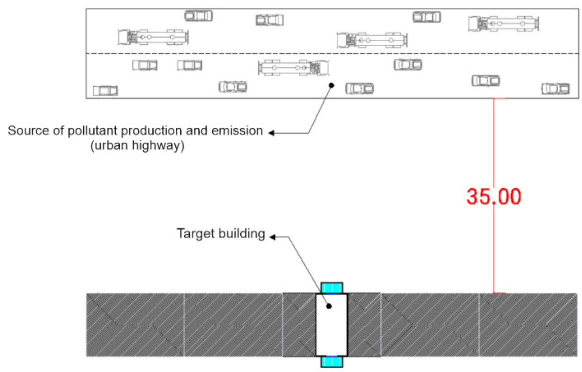


Figure 1: Study area relative to the pollution source

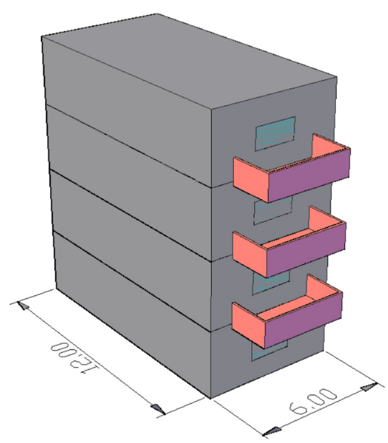
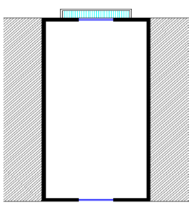
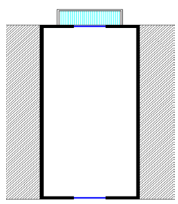
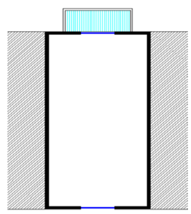
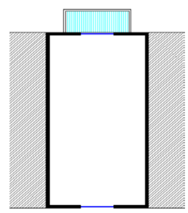
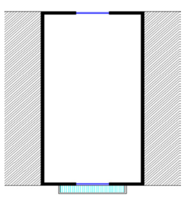
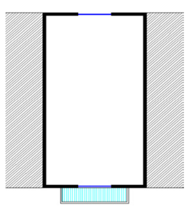
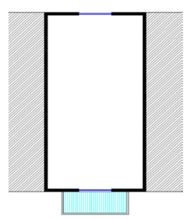
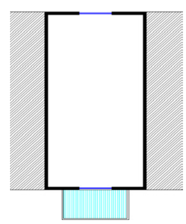
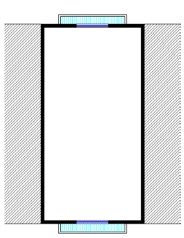
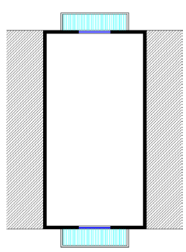
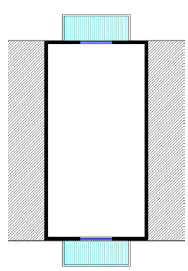
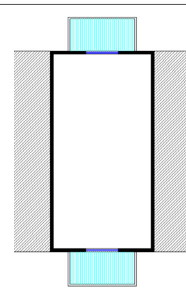


Figure 2: Target building, its dimensions and shape features

Based on what was stated above, the independent variables in the present study are "balcony location" and "balcony depth". Before introducing the case studies of the study, it is first necessary to consider a reference sample in which the aforementioned variables have not been applied. For this purpose, a four-story building according to the formal pattern of the other case studies but without any balcony or protrusion on its external wall was considered as the reference sample. In order to determine the other case studies of the study, initially, based on the balcony location variable, three positions were considered, including the placement of the balcony on the front facing the pollution source, its placement on the front behind the pollution source, and its placement on both fronts. In the next step, based on the balcony depth variable, 4 depths including 0.5, 1, 1.5, and 2 meters were applied to the positional classification of balconies. Accordingly, 12 case studies according to Table 1 were considered as the case studies of the study. It should be noted that the length of the balcony and the height of the shelter were fixed in all case studies and were considered equal to 4 meters and 1 meter, respectively.

Table 1: Characteristics of the research case samples

	Balcony Depth (m)			
	0/5	1	1/5	2
Balcony located on the front facing the pollution source	 Case_01	 Case_02	 Case_03	 Case_04
Balcony located on the front facing the source of pollution	 Case_05	 Case_06	 Case_07	 Case_08
Balcony located on two fronts	 Case_09	 Case_10	 Case_11	 Case_12

CFD validation

Given that the case studies in this study will be simulated using Computational Fluid Dynamics, validating the software used is essential. For this purpose, the empirical study by Sin et al. (2023) was used to validate CFD. In that study, a street with two rows of buildings on both sides was experimentally simulated in a laboratory setting. The buildings on both sides of the street have balconies with two continuous and discontinuous patterns, which, depending on their position on the windward facade or leeward side, were examined in 14 case studies. However, in the present study, pattern g from the samples examined in Huok Sin and colleagues' study was selected as the validation sample and analyzed (Fig. 3). This model comprises two asymmetrical buildings of 6 and 12 floors, built at a scale of 1/150. The buildings have similar lengths and widths and heights of H = 0.12 m and 2H = 0.24 m. The balcony dimensions in these buildings are 6 × 1.5 m^2 and are located along a street (the gap between the two buildings). In the street, four rectangular blocks of dimensions 0.042H × 0.042H × 10H m^3 were considered as the pollution sources. Numerical values of the indices studied in the validation sample were extracted from 12 points along two vertical axes adjacent to the buildings on both sides of the valley. The distance between any two points is 3 m. Figure 4 shows a comparison of CFD validation results with the experimental model in relation to pollutant concentration in the sample studied. As seen in the figure, there is a relatively good agreement between the CFD results and the Exp results. The mean error for pollutant concentration is 8%. Therefore, the validity of the software used for simulating the present study's case samples can be confirmed.

Pollution source specifications

The pollution source in this study is a city highway located 35 meters from the site. Four lanes of vehicles are considered as pollutant generation factors on this highway, and NO2 gas emitted from the exhaust of these vehicles is also considered as a pollutant in this study. The wind speed in this study is 2.7 m/s perpendicular to the highway and towards the buildings under study in this study. Therefore, in the analysis section, when the windward side of the building is mentioned, it means the front facing the highway (pollution source) that is directly exposed to pollutant particles, and when the leeward side of the building is mentioned, it means the facade of the opposite part of the building that is not directly exposed to the air flow and pollutants from the highway.

Computational domain, boundary conditions and mesh network

In this study, to determine the computational domain for CFD analysis of the samples, the guidelines of Tominaga et al. (2008) were used. According to this guideline, the dimensions of

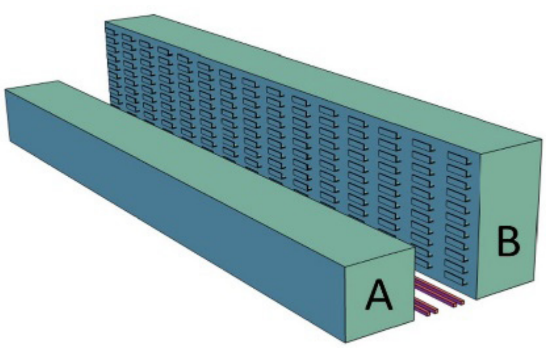


Figure 3: 3D model of the validation sample

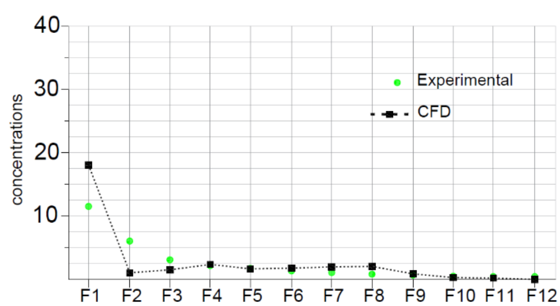


Figure 4: Comparison of wind tunnel and CFD results for CFD validation

the domain downstream and upstream are 15H and 5H, respectively, and the lateral extents are taken as 5H. With this description, the computational domain dimensions for simulating the study samples in this research are W × D × H = 432 × 540 × 288 m^3 (Fig. 5).

In this study, the atmospheric boundary layer (ABL) characteristics under neutral conditions were used to define the boundary conditions. In this regard, Richards (1989) proposed, at the domain inlet, the neutral atmospheric boundary layer velocity profiles for mean wind speed U, turbulent kinetic energy k, and turbulence dissipation rate ε, based on the Harris & Deaves (1981) model. Since the domain height is typically significantly lower than the ABL height, these profiles are generally simplified with a constant shear stress with height (Richards, 1989, Richards & Hoxey, 1993):

(1) U(y) = uABL/κ ln ((y + y0)/y0)

(2) k(y) = (uABL)^2/√(Cμ)

(3) ε(y) = (u*ABL) ^3/k(y + y0)

where y is the height coordinate, u*ABL is the ABL friction velocity, and k is a constant (von Karman constant) ≈ 0.40–0.42.

At the domain inlet, the velocity is 2.7 m/s, the temperature is 20 degrees Celsius, and the outlet boundary is set to zero static pressure. The mass flow rate is 5 and the scale 0.01 is considered for the pollutant source. Since this study treats NO2 emitted from vehicle exhaust as the pollutant, the diffusion coefficient m^2/s is 1.54e-5, entered in the General Settings section of the software. The mean remaining (ARO) values for the velocity field u and velocity field v are 10^(-6) m/s, and for pressure 10^(-8) Pa. This study uses three-dimensional steady RANS equations combined with the k-ω turbulence model to solve the equations. The solution is for a steady state, and the simulated flow is compressible. The SIMPLE algorithm was used for pressure-velocity coupling, and the 5-point discretization schemes (Peclet-Enhanced Gallagher correction) were used to solve the RANS equations. The mean residuals (ARO) for the velocity field u, 10^(-5) m/s, for the velocity field v, 10^(-6) m/s, and for pressure 10^(-11) Pa.

The mesh used in building the mesh grid in this study consists of hexahedral cells, and the total number of cells for the simulated samples ranged from 1,234,231 to 1,285,225. The use of a hexahedral mesh in this study was due to reduced shear errors and better convergence. Figure 6 shows the base mesh pattern. (Fig. 6).

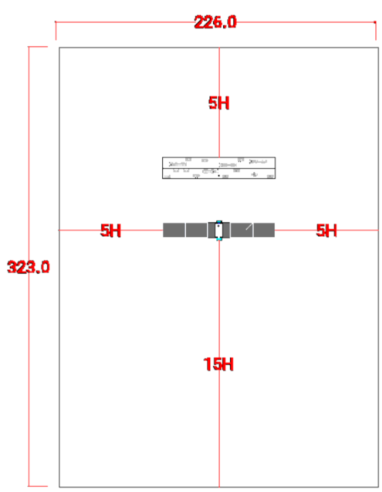


Figure 5: Dimensions and specifications of the computational domain in case study simulations

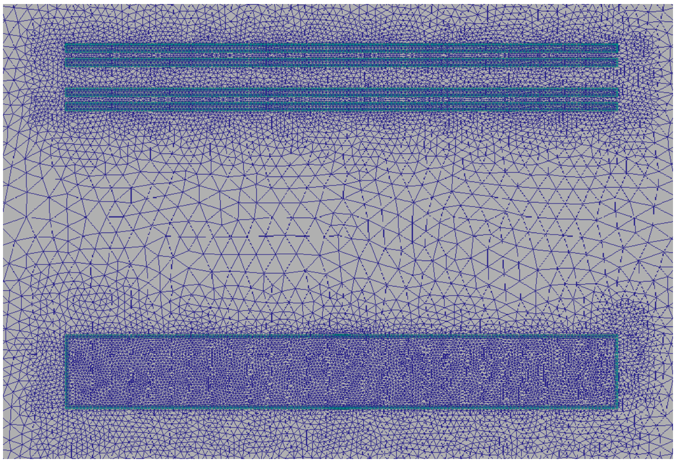


Figure 6: Mesh network pattern used in case study simulations

As mentioned earlier, the main goal of this study is to investigate the effect of balcony depth and location on indoor air quality. Therefore, the dependent variable in this study is air quality, which will be measured by two indicators: air velocity and concentration of pollutants entering the building. Accordingly, in this section, the results of CFD simulation of case studies in relation to these two indicators are examined.

Air speed analysis

The movement of air molecules in space, known in mechanics as air velocity, is one of the key indicators determining ventilation quality in a space (Heidari and Eskandari, 2022). High air velocity in a closed space can disturb comfort, while low velocity can lead to slower air exchange and thus the accumulation of pollutants in the space. Therefore, measuring the air velocity variable is essential for determining air quality in a space. In this section, the variations in air velocity across the gap between two openings on different floors of the samples are shown in Figure 7, and the air velocity contours for analyzing the airflow pattern across the floors of the buildings in the sample cases are shown in Figure 8. (Fig. 7 and 8).

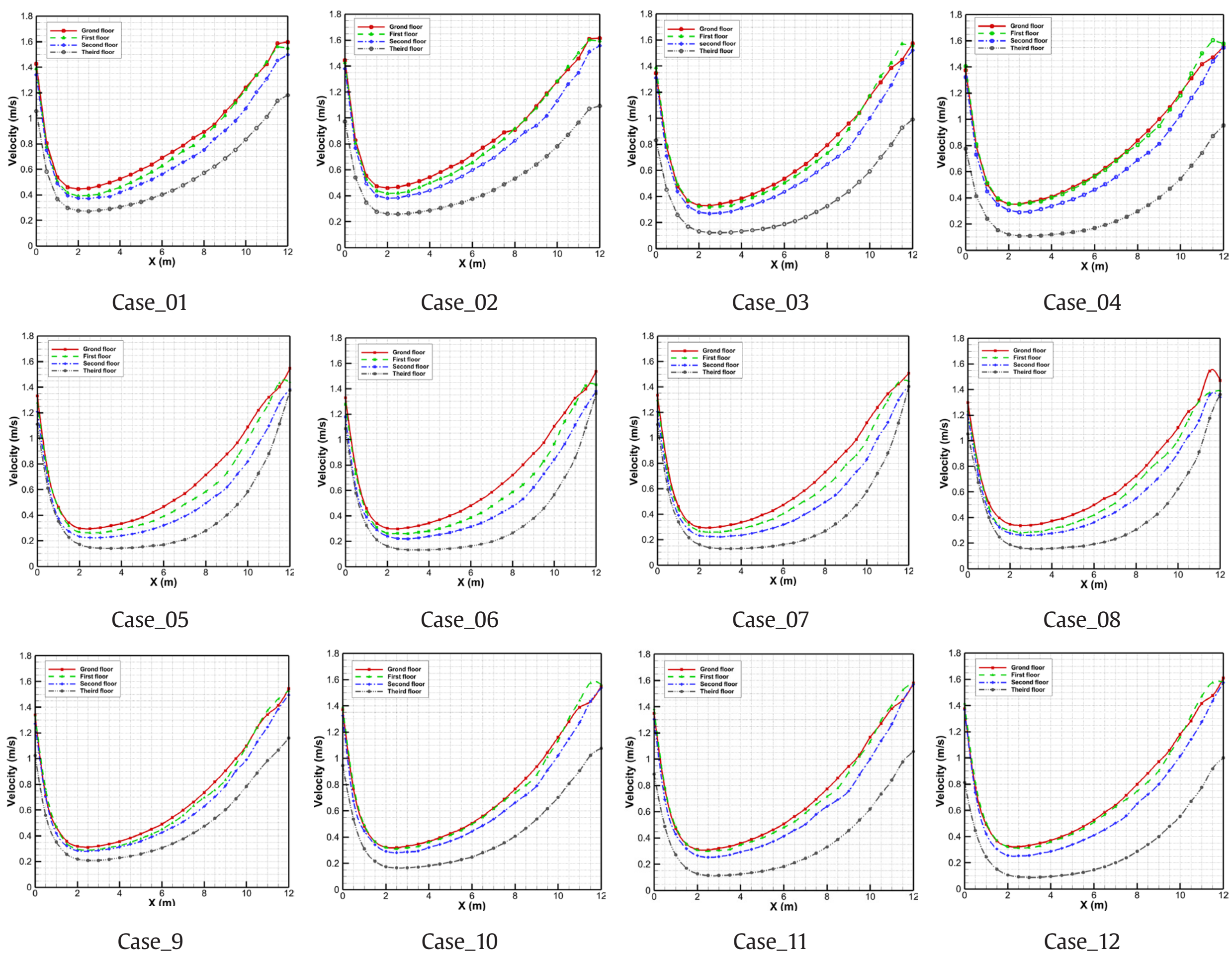


Figure 7: Air velocity changes between two openings on different floors of case studies

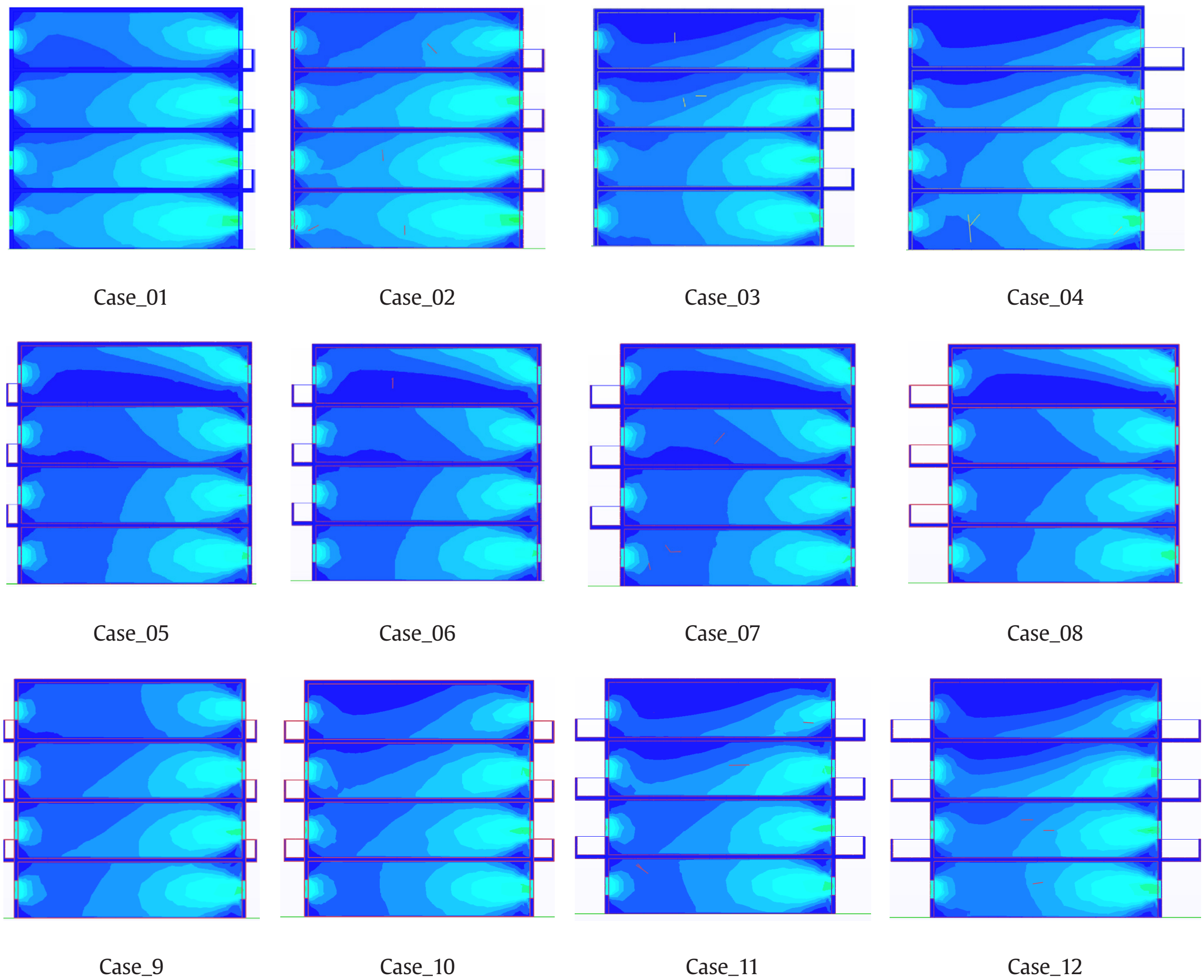


Figure 8: Air velocity contours at different levels of case examples

According to the above diagrams, it can be seen that the air velocity values on different floors of the building are different from each other, so that the highest average velocity can be seen on the ground floor and the lowest on the third floor of the building (Fig. 7). Also, by analyzing the air velocity in the interior space of different floors of the building, it can be seen that the air flow in the area of the inlet opening has a higher velocity than the area of the outlet opening. Thus, after the air flow enters the building from the windward opening, the velocity decreases to the end parts of the room, and as it approaches the windward opening in the end wall of the room, the air flow velocity suddenly increases. This is also visible in the velocity contours that are extracted vertically from the middle part of the case samples (Fig. 8). In the following, the numerical average values of the velocity component on different floors of the building are presented separately for the case samples.

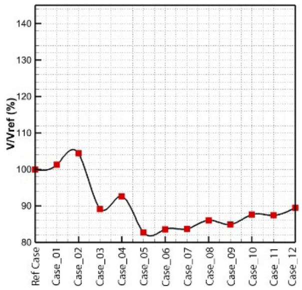


Figure 9: Percentage of average speed on the ground floor of the case samples compared to the average speed on the ground floor of the reference sample

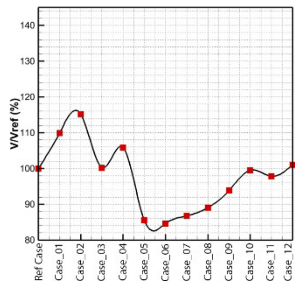


Figure 10: Percentage of average speed on the first floor of the case samples compared to the average speed on the first floor of the reference sample

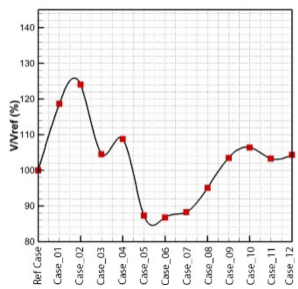


Figure 11: Percentage of average speed on the second floor of the case samples compared to the average speed on the second floor of the reference sample

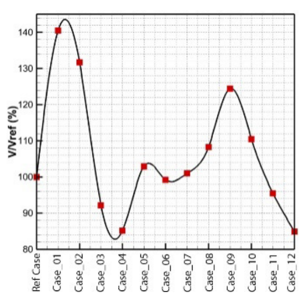


Figure 12: Percentage of average speed on the third floor of the case samples compared to the average speed on the third floor of the reference sample

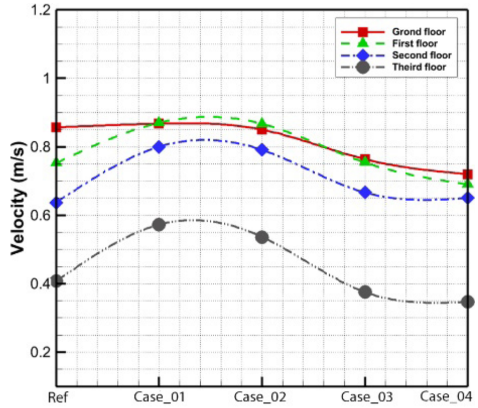


Figure 13: Average air velocity on different floors in samples with balconies located on the windward side

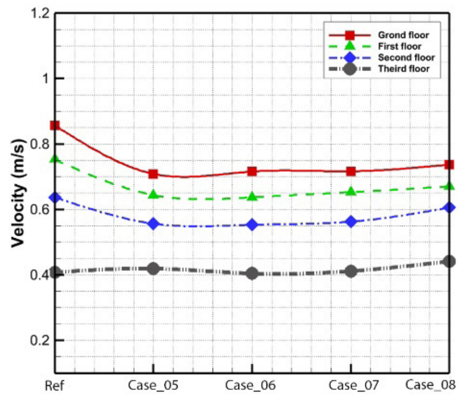


Figure 14: Average air velocity on different floors in examples with balconies located on the leeward side

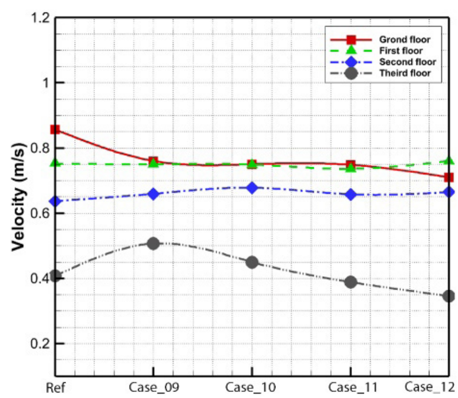


Figure 15: Average air velocity on different floors in examples with balconies located on both sides of the building

According to the above diagrams, the following points are noteworthy regarding the effect of the depth and position of the balcony on the speed of air flow entering different floors of the building in the case studies of the study:

- The use of a balcony on the windward side of the building has caused a decrease in the speed of air entering the interior space on different floors of the building compared to the reference sample. However, increasing the depth of the balcony on this side has led to a significant decrease in the speed of air entering the building on its different floors, so that the average air speed on all floors of the building in Case_01 to Case_04 was equal to 0.78, 0.76, 0.64 and 0.60 m/s, respectively.
- The use of a balcony on the leeward side of the building has generally caused a decrease in the speed of air entering the interior space compared to the reference sample; Changing the depth of the balcony on the leeward side of the building did not affect the speed of the air flow into the space inside the building, so that the average air speed on different floors of the building in Case_05 to Case_08 was 0.58, 0.57, 0.58 and 0.59 m/s, respectively.
- Using the balcony simultaneously on both leeward and windward sides led to a decrease in the speed of the air flow into the space inside the building compared to the reference example. This is while increasing the depth of the balcony on both sides of the building simultaneously had an almost imperceptible effect on reducing the speed of the air flow into different floors of the building; so that the average speed of the air flow into different floors of the building in Case_09 to Case_12 was 0.67, 0.65, 0.63 and 0.62 m/s, respectively.
- Considering the above, it can be concluded that the use of the balcony in the building generally reduces the speed of the air flow into the building; However, using a balcony on the windward side of the building had a greater effect on reducing the speed of the air entering the building than using it on the backside of the building or using it simultaneously on both sides. However, changes in the depth of the building only had an effect on reducing the speed of the air entering the building on the backside of the building, and changing this variable on the backside of the building or on both the frontside and backside of the building simultaneously had no significant effect on reducing the speed of the air entering the building.

Analysis of the concentration of pollutants entering the building

In this study, the amount of pollution entering the building is introduced as one of the indicators determining indoor air quality. As mentioned earlier, the source of pollution in this study is the highway located on the northern side of the complex, where, as cars pass through it, pollutants from fuel combustion are produced and, when exposed to the air flow, are emitted towards the study area. Among the pollutant particles emitted by cars, NO2 particles have been studied in this study. Accordingly, the cumulative density of these particles in the interior of the building has been considered as the concentration of pollutants entering the building, the results of which are shown in the images below.

According to the above graphs, the following findings can be drawn regarding the pollution index entering the building in the case studies of the study:

- In general, the use of balconies has reduced the entry of pollutants into the interior of the building on different floors; considering that the average entry of pollutants on the ground floor, first, second and third floors in all samples was 39413, 29998, 21594 and 16927 ppm, respectively, it can be concluded that the highest amount of pollutant entry was observed on the ground floor and the lowest amount was observed on the third floor.

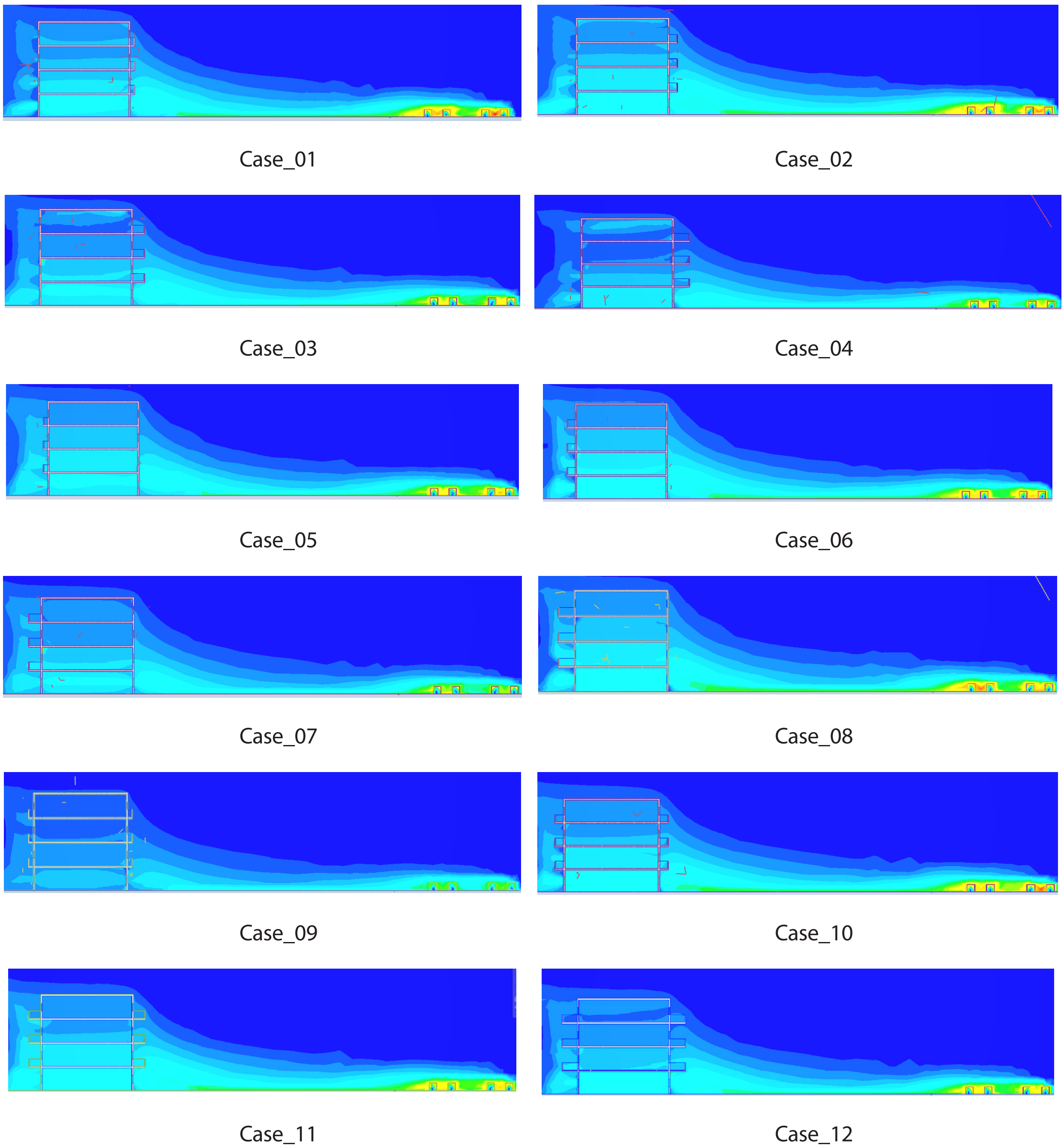


Figure 16: Concentration contours of pollutants entering different classes in case studies

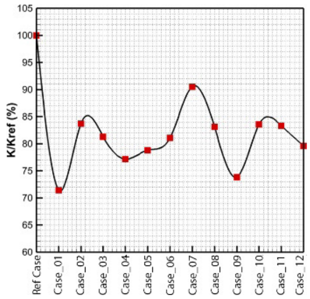


Figure 17: Percentage of average pollutant concentration on the ground floor of the case samples compared to the average ground floor concentration in the reference sample

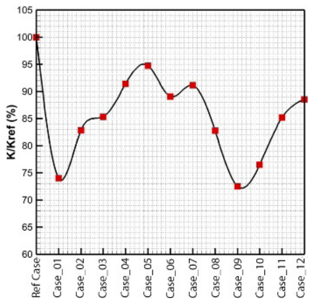


Figure 18: Percentage of average concentration of pollutants in the first class of case samples compared to the average concentration of the first class in the reference sample

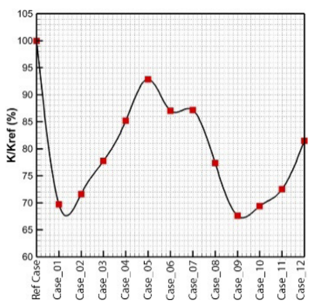


Figure 19: Percentage of average concentration of pollutants in the second class of case samples compared to the average concentration of the second class in the reference sample

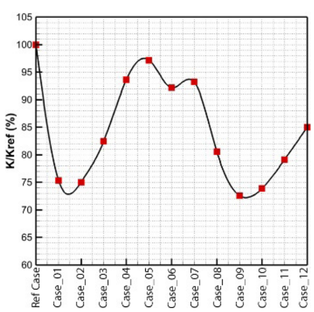


Figure 20: Percentage of average concentration of pollutants in the third class of case samples compared to the average concentration of the third class in the reference sample

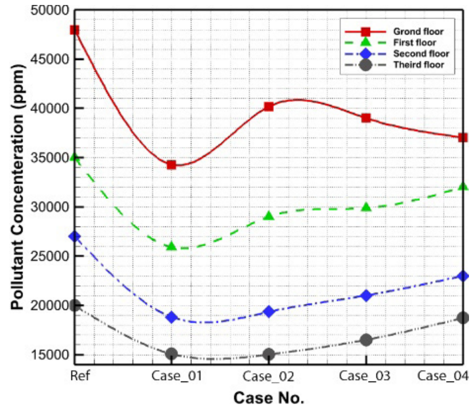


Figure 21: Average concentration of pollutants on different floors in samples with balconies located on the windward side

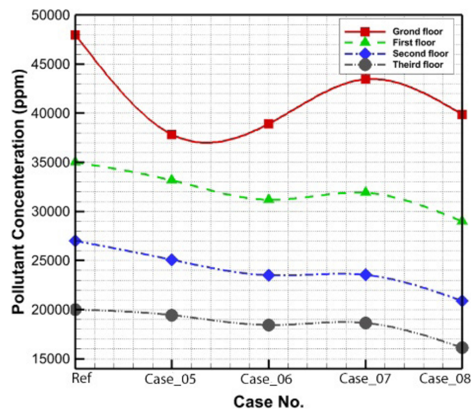


Figure 22: Average concentration of pollutants on different floors in samples with balconies located on the leeward side

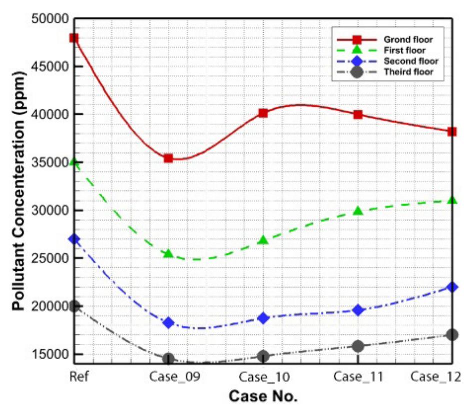


Figure 23: Average concentration of pollutants on different floors in samples with balconies located on both sides of the building

- Using a balcony on the windward side of the building has reduced the entry of pollutants into the space inside the building on different floors, however, increasing the depth of the balcony on this front has led to an increase in the concentration of pollutants entering the building on different floors, so that the average total concentration of pollutants entering the different floors of the building in Case_01 to Case_04 was 23521, 25881, 26596 and 27690 ppm, respectively.
- Using a balcony on the leeward side has reduced the entry of pollutants into the different floors of the building; however, increasing the depth of the balcony on this front has led to a decrease in the concentration of pollutants entering the building on different floors, so that the average total concentration of pollutants entering the different floors of the building in Case_05 to Case_08 was 28876, 28008, 29381 and 26464 ppm, respectively.
- Using a balcony simultaneously on both the leeward and windward sides has led to a reduction in the entry of pollutants into the space inside the building compared to the reference model. In such a case, increasing the depth of the balcony on both sides has simultaneously led to an increase in the concentration of pollutants entering the building on its different floors; so that the average concentration of pollutants entering the different floors of the building in Case_09 to Case_12 was 23396, 25105, 26307 and 27054 ppm, respectively.

According to the above findings, the most important analyses that can be stated in relation to the case indices studied in this study are as follows:

The use of a balcony in a building has caused a relative decrease in the speed of air entering the building compared to a building without a balcony. However, the data obtained from the simulation of the case examples in this study indicated that although the use of a balcony on the windward side in some examples has led to a partial increase in the speed of air entering the building compared to the sample without a balcony, in general, the use of this element on the leeward side or both sides simultaneously has led to a relative decrease in the speed of air on different floors of the building. In this regard, the data obtained show that Case_06, with a 16 percent decrease in speed compared to the sample without a balcony, has the lowest air speed, and Case_01, with a 17 percent increase in speed compared to the sample without a balcony, has the highest air speed inside the building. The data obtained regarding the concentration of pollutants entering the building also indicated that the use of a balcony generally led to a reduction in the entry of pollutants into the space in all samples compared to the sample without a balcony. In this regard, Case_09 and Case_01, with a 29 percent reduction, had the greatest prevention of pollutants from entering compared to the building without a balcony. According to the analyses conducted regarding the two variables of air velocity and concentration of pollutants entering the building, it can be concluded that among the samples examined in this study, Case_01 had the highest air velocity and the lowest concentration of pollutants entering its internal space. Given that in this example, the balcony is located on the windward side (facing the pollution source) and the depth of the balcony in this example is less than other examples in this category, it can be said that using a balcony with a shallow depth on the windward side has created the best indoor air quality. This means that it both increases the speed of the air inside the building and prevents pollutants from entering the building to a large extent.

RESULTS AND CONCLUSION

Indoor air quality in buildings is one of the most important factors affecting the health of residents and users of a space. This issue is especially important when the building in question is located in the vicinity of a pollution source. Residents of these buildings are forced to open building openings in order to use natural ventilation; however, this factor causes various airborne pollutants to enter the building, which ultimately leads to a decrease in the quality of the air inside the building. In contrast, keeping the openings closed, although it prevents these pollutant particles from entering the building, deprives the building of the blessing of natural ventilation, and in such circumstances, the use of mechanical ventilation and its high costs will inevitably be an alternative solution to this issue. Therefore, it seems that methods that, while providing proper ventilation inside the building, prevent pollutants from entering its interior space are a significant issue. This issue is introduced in the present study under the title of indoor air quality. Various factors affect the air quality inside the building, including the elements and formal components of the building. One of these elements is the building's projections, known as terraces or balconies. It is possible to use balconies on different sides of the building, and in this study, three balcony locations were considered as independent variables of the study, including the side facing the pollution source, the side facing the pollution source, and both sides. The depth of the balcony is also another independent variable of the study, and in this study, its role in the quality of the air entering the building's interior space was examined. In this regard, the most important results of this study are as follows:

- The use of balconies in general both reduces the speed and reduces the entry of pollutants into the space inside the building compared to buildings without balconies.
- Although the use of a balcony on the windward side (facing the pollution source) is accompanied by a significant decrease in wind speed and concentration of pollutants entering the building, increasing the depth of the balcony on this side reduces the wind speed entering the building and, on the contrary, increases the concentration of pollutants entering the building. Therefore, as the depth of the balcony located on the windward side decreases, the speed of air entering the building increases, which means an increase in ventilation quality. On the other hand, reducing the depth of the balcony on this side leads to a decrease in the entry of traffic pollutants into the building. Therefore, in general, it can be claimed that reducing the depth of the balcony on the windward side (facing the pollution source) improves the air quality inside the building.
- Using a balcony on the leeward side (back to the pollution source) is accompanied by a slight decrease in wind speed and concentration of pollutants entering the building. Therefore, changing the depth of the balcony in this area does not have much effect on the airflow speed or the concentration of pollutants entering the building, and therefore the air quality inside the building does not change much with the change in the depth of the balcony located on the front facing the pollution source.
- Although using the balcony simultaneously on both fronts of the building is accompanied by a significant decrease in the wind speed and concentration of pollutants entering the building, increasing the depth of the balcony on this front causes a decrease in the wind speed entering the building and an increase in the concentration of pollutants entering the building. Of course, it should be noted that the rate of change mentioned in such a case is somewhat less than in the case where the balcony is located only on the windward side (facing the pollution source). However, in such a situation, it can also be stated that if the depth of the balcony on both fronts of the building increases simultaneously, the air speed entering the building decreases and the concentration of pollutants entering the building increases. Therefore, as the depth of the balcony located on both fronts is reduced simultaneously, the quality of ventilation in the interior space increases and the entry of pollutants into the interior space is also reduced. This means that the quality of the indoor air in such conditions increases.

REFERENCES

Ahmed, F., & Hossain, M. N. (2019) 'The impact of building design on energy consumption in tropical climates: A case study in Dhaka', Building and Environment, 151, pp. 133–145.

Bakhtiari Manesh, M. and Bamian, M.R. (2023), Evaluating the Meaning-Making Principles of Modern Balconies, Interaction Between Indoor and Outdoor of Urban Houses in Kermanshah, Architecture and Urban Planning Armanshahr, 42: 31-46.

Coelho, S., Ferreira, J., Rodrigues, V., & Lopes, M. (2022). Source apportionment of air pollution in European urban areas: Lessons from the ClairCity project. Journal of Environmental Management, 320, 115899. https://doi.org/https://doi.org/10.1016/j.jenvman.2022.115899

Cui, D., Li, X., Du, Y., Mak, C. M., & Kwok, K. (2020). Effects of envelope features on wind flow and pollutant exposure in street canyons. Building and Environment, 176, 106862.

Di Sabatino, S., Buccolieri, R., & Kumar, P. (2018). Spatial Distribution of Air Pollutants in Cities BT - Clinical Handbook of Air Pollution-Related Diseases (F. Capello & A. V. Gaddi (eds.); pp. 75–95). Springer International Publishing. https://doi.org/10.1007/978-3-319-62731-1_5

Hang, J., Wang, Q., Chen, X., Sandberg, M., Zhu, W., Buccolieri, R., & Di Sabatino, S. (2015). City breathability in medium density urban-like geometries evaluated through the pollutant transport rate and the net escape velocity. Building and Environment, 94, 166–182. https://doi.org/https://doi.org/10.1016/j.buildenv.2015.08.002

Harris RI, Deaves DM. The structure of strong winds. Wind engineering in the eighties. In: In: Proceedings of the CIRIA Conference, Construction Industry Research and Information Association; 1981.

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.

Jon, K. S., Jong, S. I., Ri, S. H., Ko, J. Y., Ko, S. G., Kim, H., ... & Sin, C. H. (2024). Effects of increasing the degree of building height asymmetry on ventilation and pollutant dispersion within street canyons. Energy and Built Environment, 5(5), 727-740.

Kamali, M., Heidari, A., & Peyvastehgar, Y. (2025). Impact of buildings' configuration in an urban context on the spread pattern of NO2 and indoor air quality: a CFD simulation. Indoor and Built Environment, 34(1), 162-191.

Kamali, M.; Heidari, A.A.; Piyousegar, Y. (2024), The Effect of Building Form on Wind Speed and Pollutant Concentration in Urban Residential Fabric (Case Study: Zone 1 of Shiraz City), Journal of Urban Planning and Development, Volume 3, Issue 13: 67-82.

Kolarik, B.; Frederiksen, M.; Meyer, H.W.; Ebbehoj, N.E.; Gunnarsen, L. (2014) Investigation of the importance of tertiary contamination,temperature and human behaviour on PCB concentrations in indoor air. Indoor Built Environ, 25, 229–241.

Li, Z., Xu, J., Ming, T., Peng, C., Huang, J., & Gong, T. (2017). Numerical simulation on the effect of vehicle movement on pollutant dispersion in urban street. Procedia Engineering, 205, 2303-2310.

Li, Z., Zhang, H., Wen, C. Y., Yang, A. S., & Juan, Y. H. (2020). Effects of height-asymmetric street canyon configurations on outdoor air temperature and air quality. Building and Environment, 183, 107195.

Mao, Y., et al. (2017) 'Energy-saving strategies in residential buildings: A review of passive cooling systems', Energy and Buildings, 139, pp. 81–92.

Meciarova, L.; Vilˇcekova, S.; Burdova, E.K.; Kiselak, J. (2017) Factors Effecting the Total Volatile Organic Compound (TVOC) Concentrations in Slovak Households. Int. J. Environ. Res. Public Health, 14, 1443.

Miao, C., Yu, S., Hu, Y., Bu, R., Qi, L., He, X., & Chen, W. (2020). How the morphology of urban street canyons affects suspended particulate matter concentration at the pedestrian level: An in-situ investigation. Sustainable Cities and Society, 55, 102042. https://doi.org/https://doi.org/10.1016/j.scs.2020.102042

Rahman, M. M., et al. (2020) 'Enhancing energy efficiency in residential buildings: A review of passive cooling strategies in Dhaka', Energy Reports, 6, pp. 456–467.

Rahsapaar Monfard, R. and Azmati, Saeed. (2021), Analysis of Wind Behavior in Natural Ventilation and Energy Consumption Reduction in a Residential Building Based on Indigenous Architecture, Case Study: The Effect of Dimensions and Placement of Openings on Natural Ventilation in Amol City, Armanshahr Architecture and Urban Development, 35: 103-114.

Richards, P. . (1989). Computational modelling of wind flows around low rise buildings using PHOENIX. In Report for the ARFC Institute of Engineering Research Wrest ParkPark, Silsoe Research Institute.

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, 46–47, 145–153. https://doi.org/https://doi.org/10.1016/0167-6105(93)90124-7

Sanchez, B., Santiago, J. L., Martilli, A., Martin, F., Borge, R., Quaassdorff, C., & de la Paz, D. (2017). Modelling NOX concentrations through CFD-RANS in an urban hot-spot using high resolution traffic emissions and meteorology from a mesoscale model. Atmospheric Environment, 163, 155-165.

Santamouris, M., et al. (2021) 'Passive cooling strategies in buildings: A review and a case study', Energy, 230, pp. 120–130.

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.

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), 1749–1761. https://doi.org/https://doi.org/10.1016/j.jweia.2008.02.058

Tong, N. Y., & Leung, D. Y. (2012). Effects of building aspect ratio, diurnal heating scenario, and wind speed on reactive pollutant dispersion in urban street canyons. Journal of Environmental Sciences, 24(12), 2091-2103.

Wong, N. H., et al. (2020) 'Green building and sustainability: A study of energy savings in tropical regions', Building and Environment, 174, pp. 106–118.

Zhao, T., Yang, L., Huang, Q., Zhang, W., Duan, S., Gao, H., & Wang, W. (2020). PM2.5-bound polycyclic aromatic hydrocarbons (PAHs) and nitrated-PAHs (NPAHs) emitted by gasoline vehicles: Characterization and health risk assessment. Science of The Total Environment, 727, 138631. https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.138631

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

HOW TO CITE THIS ARTICLE
Zare, A. , Tavakoli Kazeroni, M. and Paknejadi, A. (2025). Impact of Balcony Depth and Position on Indoor Air Quality of Apartments Located Along Urban Traffic Corridors. (e728853). International Journal of Urban Management and Energy Sustainability, (), e728853
DOI: 10.22034/ijumes.2025.2069473.1322