



## Original Article



# Effects of Tall Buildings on Urban Airflow and Pollution

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Email: [mkmoshaver@basu.ac.ir](mailto:mkmoshaver@basu.ac.ir)**Abstract**

**Background:** Air pollution in cities is influenced by wind speed and direction, which are shaped by urban fabric elements like building density, green spaces, and land use. Tall buildings, increasingly common in modern cities, disrupt wind flow and exacerbate pollutant concentration, posing challenges for urban planners responsible for designing sustainable urban layouts.

**Methods:** This study analyzed the effects of building height on pollutant dispersion in southwest Tehran (Region 18) using computational fluid dynamics (CFD) simulations and geographic information systems (GIS). A pollution distribution map was developed in GIS, while wind speed data were simulated in Autodesk software and validated. The study examined how altering building heights impacts wind flow and pollutant concentration.

**Results:** Findings showed significant variations in wind speed and pollutant levels based on the urban layout. In areas with fewer obstacles, wind speed increased, reducing pollutant concentrations through enhanced dispersion. Conversely, dense and tall buildings reduced wind speed, leading to pollutant accumulation. The results highlight that building height and arrangement substantially influence wind patterns and air quality.

**Conclusion:** The study underscores the critical role of urban design in air quality management. By increasing wind flow, pollutant dilution can be enhanced, mitigating health risks. Urban planners must prioritize layouts that support natural ventilation and consider the impact of tall buildings on pollutant dispersion to promote healthier urban environments.

**Keywords:** Pollutant concentration, Pollutant dispersion, Building height, Wind flow, Tehran

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**Introduction**

In recent years, the rapid construction of tall buildings has raised concerns about their effects impact on urban environments, particularly with regard to ventilation and air quality. Wind speed and direction key factors affecting urban ventilation, are influenced by urban morphology, including building shape, size, and vegetation cover wind speed and direction, which affect urban ventilation, are influenced by urban morphology, including building shape, size, and vegetation cover.<sup>1-7</sup> These factors play a crucial role in shaping wind flow and pollutant dispersion,<sup>8</sup> which in turn impact public health. Air pollution is responsible for approximately 4.2 million premature deaths annually,<sup>2</sup> and exposure to particulate matter, even at low concentrations, has been linked to respiratory and cardiovascular diseases.<sup>9</sup> Cancer, which causes 110-140 deaths per million in Europe, accounts for 15% of annual deaths in Iran.<sup>10</sup> impacting public health, as air pollution accounts for 4.2 million premature deaths annually.<sup>2</sup> Respiratory and cardiovascular diseases have been linked to particulate matter, even at low concentrations.<sup>9</sup> Cancer,

responsible for 110-140 deaths per million in Europe, accounts for 15% of annual deaths in Iran.<sup>10</sup>

Over the past decades, both experimental and computational approaches have been employed to study the relationship between urban morphology and pollutant dispersion explored the relationship between urban morphology and pollutant dispersion.<sup>8</sup> Tall buildings can obstruct natural ventilation, impacting airflow from natural sources like oceans and forests.<sup>11</sup> Wind tunnel experiments and computational fluid dynamics (CFD) simulations are widely used to study airflow and pollutant behavior Wind tunnel experiments and CFD simulations have been widely used to study airflow and pollution dispersion.<sup>12,13</sup> However, experimental methods face limitations in replicating real-world conditions and often fail to provide complete flow field data.<sup>14</sup> Early studies, such as that of Carpentier and Robins, showed that building height significantly influences flow patterns.<sup>8</sup> Experimental limitations include replicating conditions and incomplete flow field analyses.<sup>14</sup> Early studies, such as Carpentier & Robins, demonstrated that building



height significantly influences flow patterns.<sup>8</sup>

Aristodemou et al<sup>15</sup> identified “dead zones” with minimal airflow about building height, while Taseiko et al,<sup>16</sup> observed an inverse relationship between wind speed and pollution. In contrast, Kubilay et al,<sup>17</sup> reported no clear correlation between air exchange rates and pollutant dispersion. Nonetheless, wind flow generally enhances pollutant dilution,<sup>1,18</sup> and urban morphology, particularly building height and density, has a pronounced effect on pollution levels at pedestrian height.<sup>19</sup> Makhelouf’s research in La Défense, Paris, emphasized that the spatial arrangement of buildings, rather than height alone, plays a critical role in determining pollution distribution.<sup>20</sup> Similarly, Eeftens et al<sup>21</sup> found that traffic-related pollutants tend to become trapped between buildings, hindering air exchange.

Yang et al<sup>22</sup> focused on the importance of comprehensive analyses of building height and density. Despite notable progress, further studies are needed to better understand pollutant dispersion under real-world conditions. In Tehran, most recent research on wind flow patterns has relied on environmental data and CFD simulations, typically focusing on isolated high-rise buildings. This study, however, differs by investigating a group of interconnected buildings located near two weather stations in District 18 of Tehran, allowing for more accurate calibration with local meteorological data. Unlike previous studies, it evaluates how variations in building height within a cluster influence urban pollution dispersion.

Despite existing research efforts, a substantial knowledge gap remains regarding how pollutants disperse in realistic urban settings with tall buildings. More parametric studies are required to address this issue. The central question of this study is: How do variations in the height of buildings within a cluster affect the distribution of air pollutants in an urban area of Tehran? The objective was to emphasize the role of urban planning in strategically arranging buildings and determining their heights to mitigate the accumulation and spread of air pollutants. Implementing such strategies can improve urban air quality, thereby benefiting both environmental sustainability and public health.

## Material and Methods

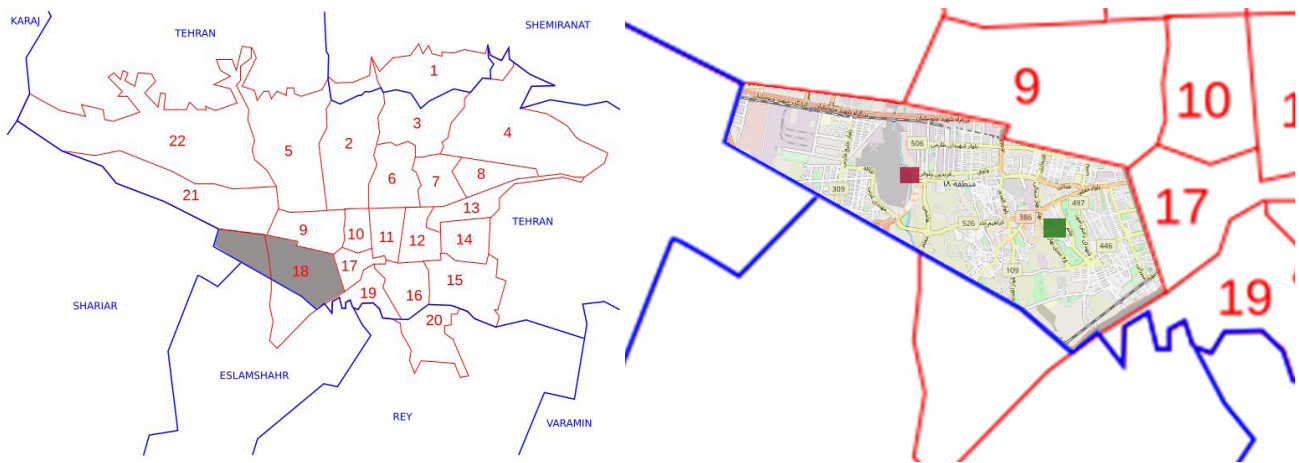
The methodology of this study is based on CFD simulations combined with GIS-based field data using spatiotemporal averaging.

According to the Tehran City Statistical Yearbook of 2019, and the number of days with unhealthy air, PM<sub>2.5</sub> suspended particles, recognized as the most impactful pollutant, were selected as the representative contaminant in the study area.<sup>23</sup> Real-time weather data for Tehran’s 22 districts were obtained from the Tehran Municipality Air Quality Control Company.<sup>24</sup>

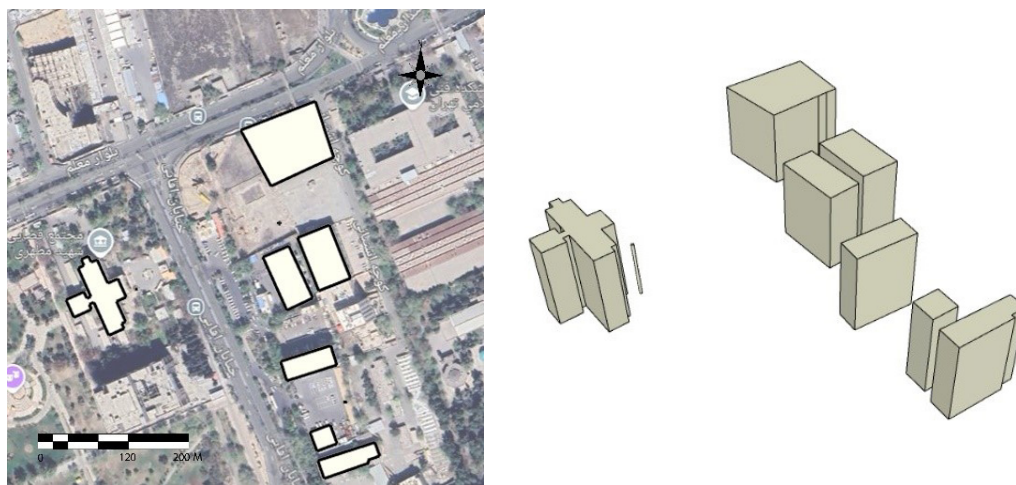
Tehran is influenced by three primary wind directions: north, east, and west winds, with the west wind typically

representing the prevailing (dominant) wind direction. Average wind speeds in the city vary between 10 and 29 km/h, depending on time and date. Data from the Tehran City Monitoring System show that May and June of 2019 recorded the highest levels of unhealthy and very unhealthy air quality indices. Moreover, statistics from 2019 to 2021 indicate that the most significant fluctuations in PM<sub>2.5</sub> concentrations occurred between February and May. Therefore, to ensure accurate analysis, the dataset used in this study focuses on these months, which exhibit the most pronounced differences in air quality.<sup>25,26</sup> Based on surveys conducted in Tehran’s most polluted regions, District 18 was identified as one of the most contaminated zones (Figure 1), particularly for vulnerable populations. As a result, this district was selected as the primary focus area for the project. For spatial accuracy, GIS-based mapping was aligned with air quality monitoring data, and two study sites were selected in close proximity to monitoring stations. Both sites shown in Figures 2 and 3, The first site is located in the Qaem area,<sup>27</sup> and the second site is in the ShadAbad area of Tehran.<sup>28</sup>

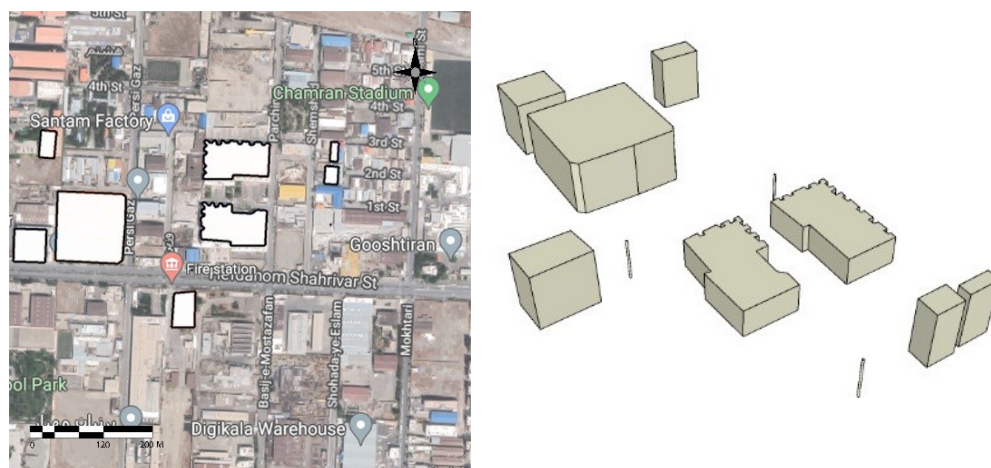
To investigate how pollutant concentrations vary with changes in building height, the initial phase of the study examined the correlation between pollutant levels and wind speed fluctuations. A pollution distribution map was generated using interpolation techniques in ArcGIS, which estimated pollutant concentrations based on known data points from meteorological stations. This statistical method enables the estimation of unknown values (pollution indices in unsampled areas) using known values from monitoring stations, allowing for the calculation of pollutant levels across the study area. However, the accuracy of the results decreases with increasing distance from the data source locations. Following this, wind speed was simulated using CFD in Autodesk software. Wind speed data at various heights were then analyzed in relation to the interpolated pollution concentration map. In the subsequent phase, the relationship between building height and wind speed was evaluated. To achieve this, the height of one building from each group was incrementally modified in 15 steps of 3 m, with wind speed recalculated after each adjustment. To ensure accuracy, the impact of these variations was analyzed separately for each of the four sides of the buildings. In the final phase, the results from the previous two stages were used to examine the relationship between pollutant concentration and building height. In this simulation, wind speed was assumed to be uniform, with a constant direction and an initial speed of 20 m/s, based on average wind data derived from the GIS system. It is important to note that these findings are relative, as the input parameters were not taken from real-time field measurements. The outcomes of this investigation include wind speed measurements at various points across the study area. To isolate the effect of building height, all other site characteristics, except the buildings themselves, were excluded from the model. The wind speed data generated from CFD simulations at a



**Figure 1.** Geographical location of the selected study sites in District 18 of Tehran: The Ghaem site is marked in green, and the ShadAbad site is marked in red



**Figure 2.** Site layout and architectural form of the selected buildings in the Ghaem area, Tehran (first study site)



**Figure 3.** Site layout and architectural form of the selected buildings in the ShadAbad area, Tehran (second study site)

height of 2 meters above ground level were then compared with interpolated pollution data from the GIS map, using both single-point and multi-point analytical approaches.

#### **Data and Model Validation**

In recent years, wind tunnel experiments and CFD simulations have extensively been used to study urban

airflow and pollutant dispersion, focusing on street canyons and building groups in 3D. These studies range from street scales (up to a few hundred meters) to neighborhood scales (up to 2 km). Findings showed that urban air pollution is influenced not only by local street and neighborhood scales but also by city-scale parameters.<sup>12</sup>

With advancements in atmospheric measurement techniques, researchers have sought ways to accurately record pollutant dispersion across various scales. Studies using different methods, CFD, simpler models, Reynolds-averaged Navier-Stokes (RANS) models, and large eddy simulation (LES), compared variables like velocity, pollutant concentration, and wind pressure coefficients to validate CFD results.<sup>2</sup> While multi-zone models show errors in areas with uneven pollutant mixing, overall results generally align with experimental data. However, CFD simulations, which require significant computational time, can take hours or days to simulate an entire building. A hybrid approach, combining multi-zone and CFD methods, can mitigate this issue. The systematic validation of simulation programs remains crucial, as demonstrated by Yuan's 2003 on-site experimental validation, which yielded positive results.<sup>13</sup> However, experimental challenges, such as uncontrollable weather conditions, make it difficult to replicate results consistently.<sup>14</sup>

One alternative approach to confirming the precision and dependability of CFD is through the use of wind tunnel experiments. Nevertheless, this method presents certain challenges, such as the difficulties associated with conducting tests across multiple distinct sites. Furthermore, it often fails to provide a comprehensive understanding of the entire flow field, which can hinder the overall assessment of fluid behaviour. These limitations focus on the need for more integrated testing methods to enhance the validation process.<sup>1</sup> One of the first studies combining experimental (wind tunnel) and numerical data was by Carpentier and Robins, which systematically investigated urban flow using simple models. They examined two groups of buildings, one with constant height and the other with variable height, and found that height was the primary factor affecting flow differences. The results showed good agreement between CFD and wind tunnel data, highlighting the significant role of building height in shaping airflow patterns.<sup>8</sup> In this research, the following aspects were thoroughly investigated:

#### *CFD Model*

- The CFD model, implemented using Autodesk software, was validated qualitatively by comparing simulated wind patterns to established wind flow principles around buildings.
- A sensitivity analysis was conducted to assess the model's response to variations in input parameters (e.g., wind speed, building height) to ensure robustness.

#### *GIS Data*

- The accuracy of GIS data, including land use, building footprints, and weather stations, was verified through comparison with high-resolution satellite imagery and ground truth data.

- The interpolation method used to create the pollutant concentration map was evaluated using statistical metrics (e.g., root mean square error) to assess its performance.

#### *Data Consistency*

- The consistency between CFD-simulated wind speeds and GIS-derived pollutant concentrations were checked for spatial and temporal coherence.
- Outliers in both datasets are identified and investigated to ensure data quality.
- To validate the comparison between pollutant levels and wind speed, several random points are selected from both the pollution dispersion map and the simulated map. A numerical average was calculated for these points, and the results are compared across all three datasets in each area. Once a consistent trend was observed among the results from all three groups, the next phase proceeds with a more detailed comparison of randomly selected points from both maps.

#### *Model-Reality Comparison*

##### *Wind Speed Validation*

- CFD-simulated wind speeds at a height of two meters are compared to real-world wind speed measurements from the weather stations.
- Correlation analysis is conducted to assess the agreement between simulated and measured wind speeds.
- To minimize inaccuracies resulting from the fixed assumption, the initial wind speed is randomly altered within a range of 15 to 25 m/s by adjusting it 15 degrees to the north and south during the simulation. Following the validation of the results, a sensitivity analysis is conducted.

##### *Pollutant Concentration Validation*

- While direct measurement of pollutant concentrations at the study sites was not conducted, the overall spatial distribution of simulated pollutant concentrations was compared to general pollution patterns in Tehran, as reported in environmental studies.
- The relationship between simulated pollutant concentrations and building height was qualitatively assessed against existing knowledge and trends in urban air pollution.

#### *Results and Discussion*

In the first section, the comparison of pollutant concentration and wind flow across three sectors for both groups is analysed. The speed analysis is relative, and the 3D model is simplified. [Figure 4](#) illustrates the pollutant concentration distribution map using GIS for the first five months of the year. [Figures 5](#) and [6](#) display simulated wind speeds on a horizontal plane at a height of 2 m. Data

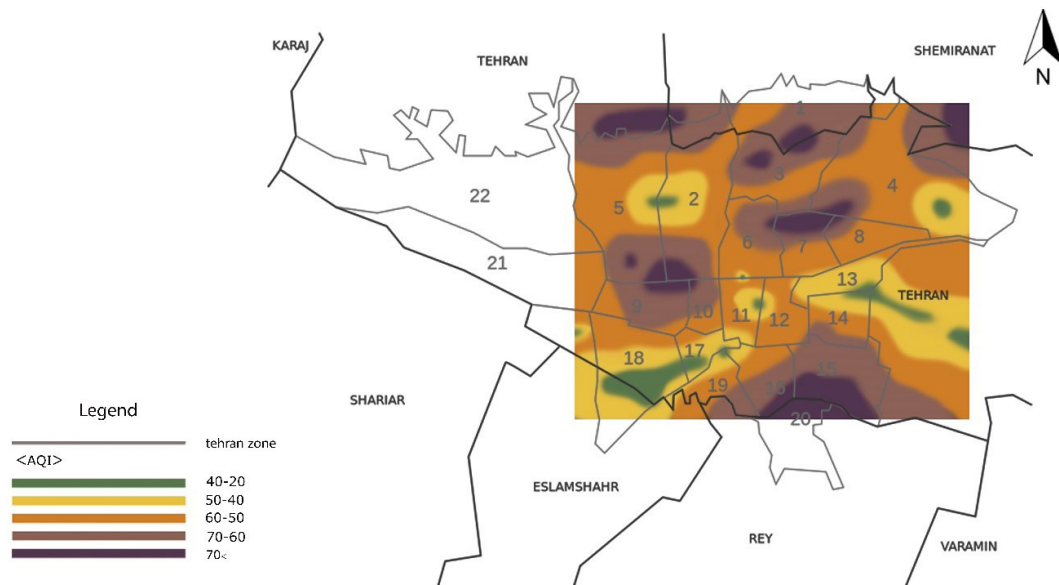


Figure 4.  $PM_{2.5}$  Particle Dispersion Map in the Months of January to May in 2021

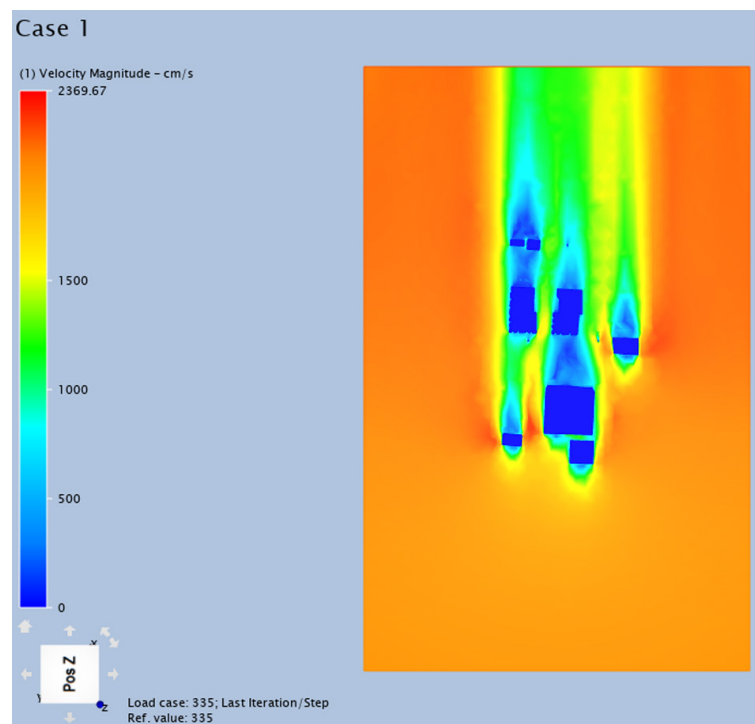


Figure 5. Simulation of Wind Speed at the Second Site, ShadAbad, Tehran

is examined in three ranges for both groups, showing that as wind speed increases in the prevailing wind direction, pollutant dispersion decreases, while trapped air currents lead to increased concentrations. In the second section, the impact of varying building heights on the four main facades is analysed. Each region is modeled as an imaginary circle with a diameter matching the length of the building's facade.

The findings from the analysis of how building height influences wind speed and flow reveal several notable patterns. To better understand these variations around buildings of different heights, wind behavior was

examined from four directions: the front, rear, and both sides of each structure. The measurement area was defined as a circular zone with a radius equal to the building's height, ensuring that all changes were evaluated relative to the previous condition.

The results show that, at the scale of tens of meters, increasing the height of an individual (non-clustered) building raises wind speed on the two lateral sides (C and D, perpendicular to the wind direction) and reduces it on the front and rear faces, specifically on side A (opposite the wind, where a stagnant zone forms) and side B (facing the wind, where flow resistance occurs). Conversely,

decreasing the building height results in reduced wind speed on the sides (C and D) and increased speed on the front and rear faces (A and B). The results of wind speed measurements at various building heights are presented in Tables 1 and 2.

Therefore, building height alone cannot determine pollution levels in an area. As shown, height changes may increase pollutant concentration in one part of an area while decrease it in another. This research can be divided into three main sections. The first focuses on the relationship between urban obstacles and wind patterns,

confirming that tall buildings significantly shape wind flow, as seen in Carpentier and Robins.<sup>8</sup> Our findings further demonstrate that changes in building height can impact the surrounding environment over ten meters. The second section addresses the effect of tall buildings on pollutant dilution, as highlighted by Chavez et al.<sup>18</sup> The third section explores wind speed changes due to tall buildings, similar to the experimental work.<sup>29-34</sup> However, our study incorporates building height, allowing for a clearer analysis of the factors affecting wind speed. The limitations of this study include discrepancies

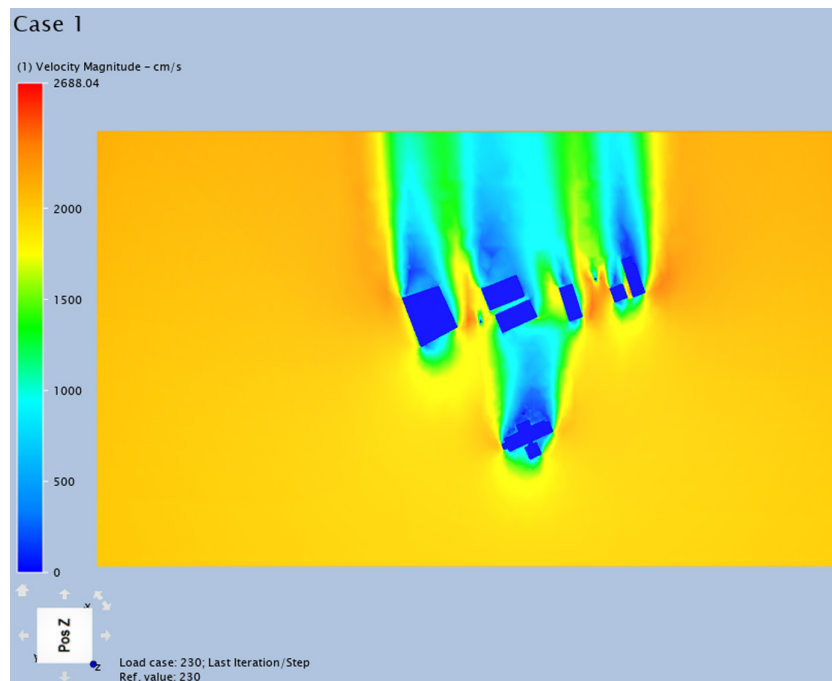


Figure 6. Simulation of Wind Speed at the First Site, Ghaem, Tehran

Table 1. Wind Speed in Areas A to D in the Area of the Building With Variable Height in the First Site, Ghaem, Tehran

Height (M)	Speed Range A (m/s)	Speed Rang B (m/s)	Speed Range C (m/s)	Speed Range D (m/s)
15	1401	223	906	890
18	1036	216	918	902
21	1031	209	929	914
24	1025	199	940	924
27	1021	193	952	936
30	1016	187	970	948
33	1011	181	981	959
36	1006	174	992	971
39	1001	168	1004	983
42	995	216	1016	994
45	990	156	1026	1005
48	984	148	1035	1015
51	973	142	1045	1026
54	966	139	1056	1034
57	809	105	962	1669
60	800	96	974	1681

Table 2. Wind speed in areas A to D in the area of the Building With Variable Height in the Second Site, ShadAbad, Tehran

Height (M)	Speed Range A (m/s)	Speed Rang B (m/s)	Speed Range (m/s)	Speed Range D (m/s)
15	912	209	812	1532
18	905	203	820	1542
21	899	197	830	1552
24	891	192	841	1563
27	885	186	850	1572
30	879	177	858	1584
33	873	171	867	1595
36	864	163	881	1606
39	856	155	891	1600
42	847	148	904	1614
45	840	138	916	1624
48	832	129	928	1633
51	825	122	938	1645
54	817	114	951	1656
57	809	105	962	1669
60	800	96	974	1681

between CFD software and experimental results, as well as the short duration of GIS measurements, which reduces the experiment's accuracy and does not capture long-term conditions. Also, challenges remain, including the lack of consideration for the validity of these methods due to their inability to fully explain airflow variations in different seasons. However, CFD and similar simulation methods are expected to enhance future urban pollution research, reduce errors, and provide clearer insights.

## Conclusion

This study clarified the influence of tall buildings on wind patterns and their critical role in pollutant dispersion. The results support the hypothesis that the relationship between wind speed and pollutant concentration generally aligns with theoretical models, though real-world conditions introduce complexity and minor deviations. The analysis revealed that variations in building height affect pollutant levels differently across zones; increasing height may reduce concentrations in one area while increasing them in another, indicating that building height alone cannot predict pollution levels. This emphasizes the need for strategic urban planning that considers not only building height but also spatial arrangement. The findings further demonstrate that, within the 15 to 60-meter range, the height of a single, isolated building affects airflow and dispersion across four key zones, depending on wind direction. In contrast, clustered buildings introduce more complex interactions, where dominant effects may overshadow others, especially when proximity becomes a significant factor. Overall, the study confirms that pollutant concentrations are closely tied to building spacing and arrangement, highlighting the importance of integrated planning approaches to improve urban air quality.

## Authors' Contribution

**Conceptualization:** Mehrdad Karimimoshaver, Shima Noori.

**Data curation:** Mehrdad Karimimoshaver, Shima Noori.

**Formal analysis:** Mehrdad Karimimoshaver, Shima Noori.

**Funding acquisition:** Mehrdad Karimimoshaver.

**Investigation:** Mehrdad Karimimoshaver, Shima Noori.

**Methodology:** Mehrdad Karimimoshaver, Shima Noori.

**Project administration:** Mehrdad Karimimoshaver, Shima Noori.

**Resources:** Mehrdad Karimimoshaver, Shima Noori.

**Software:** Shima Noori.

**Supervision:** Mehrdad Karimimoshaver.

**Validation:** Mehrdad Karimimoshaver, Shima Noori.

**Visualization:** Shima Noori.

**Writing—original draft:** Mehrdad Karimimoshaver, Shima Noori.

**Writing—review editing:** Mehrdad Karimimoshaver, Shima Noori.

## Competing Interests

The authors have no conflicts of interest to declare.

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