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Interaction between high-rise building, wind and pollution in district twenty-two of Tehran Municipality, Iran

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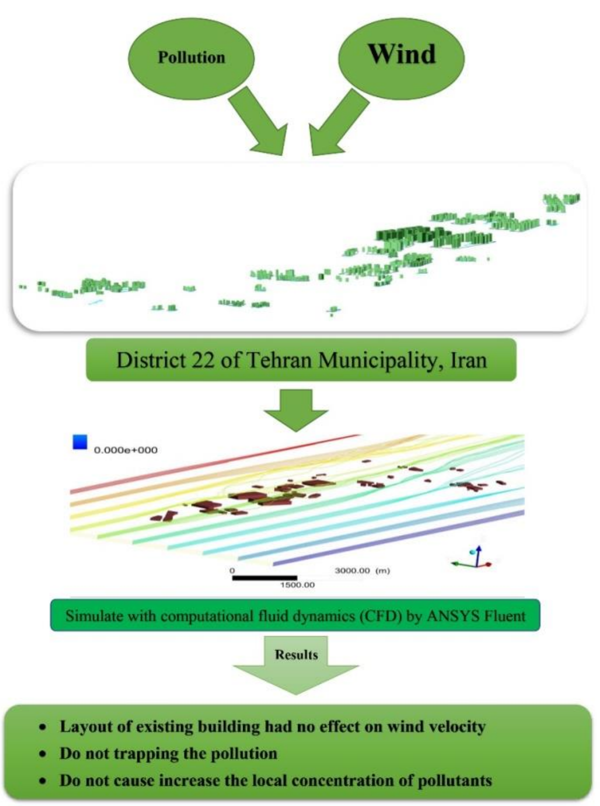
Graphical abstract



Abstract

The large cities are facing with a phenomenon called high-rise buildings which is due to the increasing of the population and also developing the cities. One of the negative impacts of high-rise buildings is the change in urban wind flow. Air pollutions is a major problem in the cities and the wind play an important role in the dispersion of air pollutions. The most probable wind direction for Tehran is west and hence district twenty-two of Tehran municipality which is located in northwest of Tehran (Capital of Iran) is in the dominant direction of wind flow. This paper presents a numerical method to investigate the interaction between the wind flow, pollution and high-rise buildings in district twenty-two of Tehran municipality. The effect of these phenomenon on the other regions is considered as well. Computational fluid dynamics (CFD) by ANSYS Fluent software has been used in order to simulate the problem. The results of this study indicate the existing buildings and their layout had no effect on wind velocity and trapping the pollution and do not cause an increasing of the local concentration of pollutants. So the geometry and layout of buildings allow the flows and environmental pollutants to pass.

Keywords: High-rise building, wind, pollution, district twenty-two of Tehran; ANSYS Fluent Software; CFD

1. Introduction

Climate change not only affects the comfort of human habitations but resulting extreme weather also constitutes a health hazard (Zhang *et al*., 2021). Air quality in cities is affected by ambient wind speed and direction, atmospheric stability, solar radiation and anthropogenic pollutant emissions (Llaguno-Munitxa and Bou-Zeid, 2018). Air pollution is the environmental problem that poses the highest risk to human health (Sefair *et al*., 2019). Information about wind flow patterns around buildings is important to architects and urban planners. As a result of the public's growing wareness of the latest scientific and engineering achievements, contemporary architects, designers and engineers should pay more attention in creating more comfortable and functional buildings and their surroundings. Urban planners constantly strive to not only maintain but also improve the quality of life of urban residents by providing a comfortable and pleasant environment. They should take urban ventilation into account to achieve harmony, balance, and quality in urban landscape design and building and function layout. Numerical simulation methods for urban ventilation analysis have disadvantages including time-consuming and complex calculations (Luo *et al*., 2017). Placing a tall building among low buildings increases the wind speed by 90% and reduces air temperature by 1°C (Shareef and Abu-Hijleh, 2020). With the advent of computational power and the introduction of numerical methods like the Finite Element Analysis, it is possible to accurately simulate the same conditions in a virtual environment using advanced modelling techniques like the Computational Fluid Dynamics (CFD) (Sakr Fadl and Karadelis, 2013). Ancient architecture use tall building structures in city to use wind effectively for thermal indoor comfort (called windcatcher) or in special usage such as cisterns (Najafi and Yaghoubi, 2015). Variation in buildings' height and placing the highest buildings in the middle of the block provided more shading effect, increased the wind speed, and consequently reduced the outdoor air temperature (Shareef and Abu-Hijleh, 2020). Nowadays the presence of tall buildings influences wind velocitys at low level in their immediate surroundings. The effects on the local microclimate may be favourable or unfavourable depending on the building shape, size, orientation and interaction with neighbouring buildings or obstacles. The faster winds at high level may be deflected down to ground level by tall buildings causing unpleasant and even dangerous conditions for pedestrians.

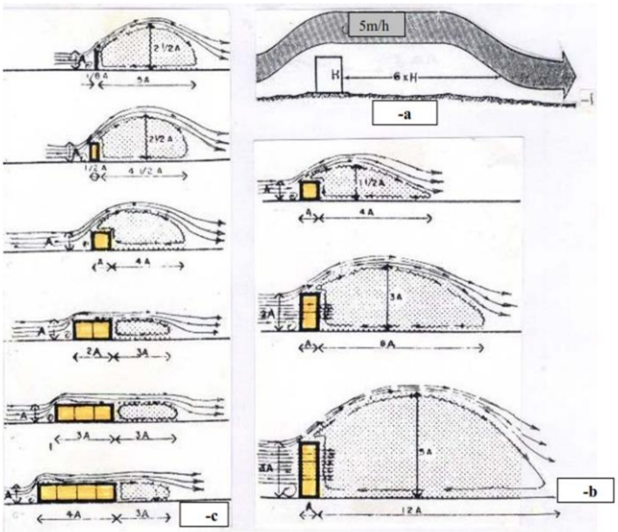


Figure 1. Wind shadow increases: a. by increasing the air velocity, b. increasing building high, c. it doesn't increase by increasing building depth- till four times of building height (Aldeberky n.d.)

Wind is composed of a multitude of eddies of varying sizes and rotational characteristics carried along in general stream of air moving relative to the earth's surface (El-Heweity *et al*., 2018). Wind may be channelled around buildings, between buildings or along avenues causing accelerated wind velocitys at pedestrian level and giving rise to pedestrian discomfort (Sakr Fadl and Karadelis, 2013). The effect of the buildings on the wind flow could be explained by three different examples, which represent simple and complex situations separately. The first case investigates the airflow towards an individual building. Here, when the airflow reaches to the building, since there exists an obstacle on the route of the airflow, its speed increases according to the continuity of flow laws. A 2D model could clearly show that the speed of the wind on the various parts of the building is different being the highest on the windward brow of the building and across the roof. Meanwhile, air is also deflected from the brow down of the face of the building (Li *et al*., 2019). Meanwhile, the distance between buildings should be long enough so as to not blocking the motion of the wind (Cengiz, 2013). Studies on a square or a rectangular cross-section building affected by wind have been made by many researchers owing to its importance. However, a single building is a very rare case in the real world. So it is important that building's wind pressure and surrounding wind field will be affected by the adjacent building. And when it comes to high-rise building, the influence will be even more serious if there is another high-rise building beside it (He and Yuan, 2014). Urban landscapes change the direction and the speed of the winds coming from surrounding. Due to this reason, there are some differences between the air flow on the cities and on the forests as well as open fields. The buildings in cites which are much taller than the average height increase the number of the calm days in the cities and also worsen the ventilation. These tall structures which are the sources of the calm air, increase temperature and vapor pressure as well. Hence, it has a negative effect on the living conditions of the city resident. However, tall building do not always reduce the speed of the winds, on the contrary, it is stated that they may improve the circulation of the wind. For this, the large brows (facades) of the buildings should be perpendicular and their narrow brows should be parallel to the direction of the wind. Meanwhile, the distance between buildings should be long enough so as to not blocking the motion of the wind (Cengiz, 2013). Many parameters can modify wind loads induced by interference from surrounding buildings, such as geometry and arrangement of buildings, terrain type and turbulence intensity of approaching flow. Possible combinations of these parameters are extremely large and, thus, are impossible to be covered exhaustively. Therefore, a more physically-based approach, such as investigating the underlying mechanisms of interference effect, would be worth adopting to solve the problem (Zu and Ming Lam, 2018). The idea of high rise building was first developed in order to use the estates of the downtown, following paying attention to the city economy, because, on one hand, tendency to plot ratio and concentration of firms, had increased the demand for land in the downtown and, on the other hand, land supply was limited at this area of the city. As a result, increase in land-use intensity (plot ratio) was provided as a solution for increasing built area under use. In fact, the phenomenon of high rise building was a response to living and activity in cities with high rise building, and today in most of the world cities, high-rise buildings are an integral part of urban life. Although designing a tall building is the final result of a complicated process whose elements interact with each other, and multiple factors including cultural, social and economic features affect it, by compliance with the principles and criteria obtained from fundamental and applied studies on architectural design, structure and urban planning (if accompanied by formulating and implementing the policies needed in other areas), the possibility of properly using tall buildings is provided. In general, given special conditions of the current century, proper and conditional use of tall buildings can be considered a realistic and desired solution for accommodating people and meeting other needs related to social and economic activities in metropolises. In fact, tall buildings can properly satisfy, under appropriate conditions, the needs and necessities of the environment, if some main criteria are considered when planning and desiging them (Rahnama *et al*., 2014). High-rise buildings are particularly influential to wind effects. Therefore, information about wind flow patterns around buildings can be important to architects and urban planners. As a result of the public's growing awareness of the latest scientific and engineering achievements, contemporary architects, designers and engineers should pay more attention in creating more comfortable and functional buildings and their surroundings. In particular, near and around high-rise buildings, high wind velocities are often introduced at pedestrian level that can be experienced as uncomfortable, or sometimes even dangerous. Traditionally, wind flow at pedestrian level can be simulated in boundary-layer wind tunnels. However, with the advent of computational power and the introduction of numerical methods like the Finite Element Analysis, it is possible to accurately simulate the same conditions in a virtual environment using advanced modelling techniques like CFD. The latter can provide significant cost benefits for assessing and optimising engineering design solutions related to en-vironmental concerns. CFD allows the investigator to analyze the full domain of the model, provides a complete picture of the problem and presents the results in an easy-to-understand graphical way, as opposed to relying on expensive and time-consuming collection of several dozens of discrete points, as it is usually the case with physical wind tunnel modelling (Sakr Fadl and Karadelis, 2013). Tall buildings have implications on the broader urban environment and infrastructure that lower buildings would not have, e.g. wind effects, sight-lines, or over-shading Several older cities around the world have experienced intense development overtop aging infrastructure that have meant significant investment is needed to maintain service and minimize the impact of increasing density and building height. They may also have an impact on energy use due to reasons of building-physics (e.g. wind exposure, temperature differences, unobstructed solar gains), infrastructure and construction (e.g. ventilation methods, heating system types), and occupant practices (e.g. window opening, lighting). There are also challenges around the embodied energy of building taller with the addition of more floors relating to higher embodied energy compared with lower buildings (Hamilton *et al*., 2017). Experemental studies using wind tunnels showed that rise in the elevation of a building increases the distance of the wind shadow, and minimizes the air flow inleeward direction (Figure 1), i.e. behind the building at the street level, while increasing the depth till four times of its height does not effect the wind shadow (Near high-rise buildings the local wind velocity is high even in summer. Highrise buildings create a turbulent flow of the gradient wind as a result of increasing the roughness of the boundary layer surface. Urban areas with higher density and buildings similar in elevations have better ventilation conditions than areas with lower density and fixed height of buildings) . Thus, a compact horizontal urban mass with gradient height, aerial spain and bended crossing allies- as was in medieval and slamic architecture- protects the ground surface from the solar radiation and allows the air flow and the nocturnal ventilation (Aldeberky, n.d.).

The findings of the Salehi *et al*. (2016) study at assessing the Impact of Urban High-rise Building on Wind Flow Performance in a district of Tehran, Iran, showed that the natural pattern of wind flow changed due to the incorrect and non-normative positioning of tall buildings; thereby, this led to the secondary effects resulted from stagnation or intensification of wind flow causing serious problems for air inlet corridor of Tehran. Therefore, appropriate principles and criteria for both the site location as well as the assessment of high-rise building observed by urban managers seem to provide bases for accurate management actions and reduce the side effects (Salehi *et al*., 2016). Most of the research has been focused on analyzing the wind velocity around a single building, however in this research, will be examined the effect of the wind velocity and pollution will be studied in the discrit twenty-two of Tehran municipality including all the buildings and blocks. For this assessment, wind velocity and pollution are simulated and analyzed through all the buildings and blocks at a district of Tehran municipality.

The research of Makhelouf (2012) shows that the large spaces between the towers promote wind circulation and therefore the dispersion of pollutants (Makhelouf, 2012). Based on the Afiq *et al*. (2012) research, air flow structure and pollutant concentration corresponding to different street canyon geometry and wind flow speed and direction. The worst air quality correspond to the highest air pollutant and reduction of air ventilation in street canyon is attributed by the perpendicular prevailing wind under low speed in deep street canyon (Afiq *et al*., 2012). Tall buildings effect on the air flow and pollution parameters is not distributed consequently the air pollution in cities are increasing. In addition to obstruction of visibility and confined spaces and also play a key role in changing winds direction (Hayati and Sayadi, 2012). Changing the height of a single building can have negative effects on pollution levels on-site. Thus, assessing the effect of building designs/heights through complex modeling (CFD or wind tunnel) may become a necessary step in designing a sustainable and healthy urban environment (Aristodemou *et al*., 2018). When two or more buildings are constructed in proximity, the fluid flow surrounding the buildings may be significantly deformed and of a significantly more complex nature than usually assumed and needs to be investigated as early as the planning stage of the project (Sakr Fadl and Karadelis, 2013). (Ramponi *et al*., 2015) and (Toparlar *et al*., 2015) found that the higher flow rate along the main streets reduces the flow rates in parallel narrower streets, negatively affecting the ventilation efficiency.

In 2016, Berardi and Wang investigated how new constructions will affect the urban microclimate, and to propose strategies to mitigate possible urban heat island (UHI) effects. The results show that the new constructions could increase the wind speed around the buildings. However, high-rise buildings will somewhat reduce the air temperature during daytime, as they will create large shadow areas, with lower average mean radiant temperature (Berardi and Wang, 2016). Due to difficulties faced while modeling the effect of wind velocity and pollution in a wide region of the cities and ensuring the effect of these phenomenon on the other regions of the cities, most of the research mentioned previously mainly focused on analyzing the wind velocity and pollutions around a single building. On the other hand, scrutiny of the effect of these problems on the other regions has not been done extensively. Therefore, in this research as a novelty, the effects of the wind velocity and pollutions are studied in a city zone including all the high-rise buildings and blocks and the effect of these parameters on the other region as well. Hence, this study provides more real an accurate simulation because all the buildings and blocks were modeled through the application of the numerical method and the effects of the exit wind velocity and pollutions from the study zone on the other regions were investigated.

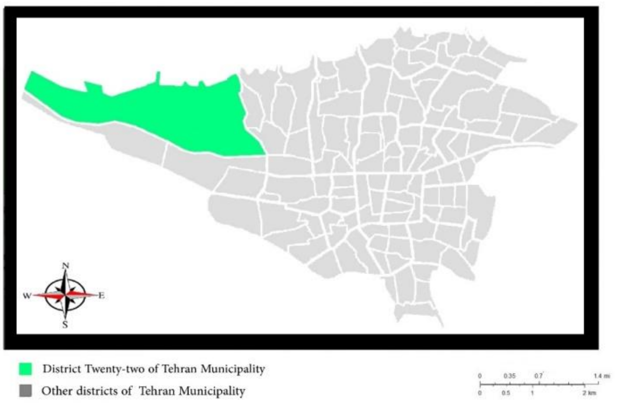


Figure 2. Location map of the district twenty-two of Tehran (Source: (Tehran Detailed Design, 2018)).

2. Study area

Tehran (Capital of Iran) is a mountainside city with an altitude of 900 to 1700 meters above the sea level. Its urban area spreads entirely over the Iranian plateau, on the slopes of a very high and dense mountain barrier (http://en.tehran.ir/, n.d.). District twenty-two of Tehran is located in the northwestern part of this city between the longitude of 51° 5′ 10" to 51° 20′ 40" and the latitudes of 35° 32′ 16" to 35° 57′ 19". This district borders the central Alborz to the north, Kan River to the east, Tehran-Karaj Highway to the south, and Vardavard Forest Park to the west. Therefore, there is a height difference of 1800 m between the northern border of district twenty-two of Tehran and end of the South Alborz (Figure 2). The Alborz, which has attracted the people of Tehran over the last 30 years, encloses the shape of Tehran's geographic space like a crescent wall. It also creates a very difficult obstacle to the physical expansion of the city from a height of 1800 m because of the gradient and mountainous bottlenecks. In the district, the highest altitude from sea level is in the straight line between the northern watershed at the Alborz and the east of Kiga Village with a height of 3,840 m and the lowest altitude is in the outlet of the Peykan Shahr with a height of 1,220 m (Tehran Detailed Design, 2018).

With the growth of urbanization and increasing population of Tehran, in 2001 district twenty-two was introduced as a new district of municipality. The area of this district is 5881 hectares which is located in northwest of Tehran. Due to the natural features of this area and its location in Tehran, it is considered as a tourist hub of Tehran. On the other hand, since there exist some scientific places in this district, it is considered as a research center at the west of Tehran. For these reasons, it can be a suitable place for all the people in the leisure time. Therefore, by increasing the presence of citizens in this region, the economic development of this place will be increased and subsequently, it can be regarded as a center of economic development.

The district can be considered as the most important airway in Tehran because of natural parks such as Chitgar Forest Park, Botanical Garden National Park, Latmal Kan Forest Park and Khargush Darreh Forest Park. For this reason, in various management of Tehran municipality, one of the main plans for maintaining and enhancing the quality and quantity of green area of the district has been considered (Tehran Detailed Design, 2018). The most probable wind direction for Tehran is west (Keyhani *et al.*, 2010). The study zone is located in northwest of Tehran and is in the prevailing direction of wind flow. As a result, the prevailing direction is western. As mentioned above and also the importance of the air corridor along the prevailing wind of the city, this region is considered as a case study that has no these conditions in another regions of Tehran.

3. Research method

To investigate the interaction between high-rise buildings and wind, wind movements around the buildings existing in the district were modeled to evaluate the effect of buildings on wind velocity. Then particle contamination was modeled in ANSYS Fluent in order to investigate whether pollutant trap in the air occurs between buildings. Combining the RANS equations with assumptions that enforce the conservation of mass and energy produces the mainstream approach used within CFD to simulate this problem in an incompressible form. Gambit 2.4.6 software was used for the grid generation.

3.1. Governing equations on turbulent 3D flow

In the present research, an incompressible and turbulent three-dimensional (3D) flow was simulated by using the continuity and momentum equations as follows (White , 2003):

$$\nabla.\vec{V} = 0 \qquad (1)$$

$$\frac{D\vec{V}}{Dt} = -\vec{\nabla}P + \vec{\nabla}.\vec{\sigma} \quad (2)$$

Where $\vec{V}$ is the velocity vector and $\vec{\sigma}$ denotes the stress tensor defined as follows:

$$\sigma_{i,j} = (\mu + \mu_t) S_{i,j} \quad (3)$$

$$S_{i,j} = \frac{1}{2}\left(\frac{\partial V_i}{\partial x_j} + \frac{\partial V_j}{\partial x_i}\right) \quad (4)$$

In the above equations, μ and μ_t represent molecular and turbulent viscities, respectively. Fluid properties are constant as the temperature and pressure range is not wide.

According to the k-ε method, the kinematic viscosity *coefficient* of the turbulent flow is defined as follows:

$$\frac{1}{\rho}\mu_t = \upsilon_t = c_\mu \frac{k^2}{\varepsilon} \quad (5)$$

The turbulent kinetic energy (k) and energy loss (ε) can be calculated using the following equations:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \mu_t S^2 + \frac{\partial}{\partial x_j}\left(\left(\upsilon + \frac{\upsilon_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right) - \rho\varepsilon \quad (6)$$

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_i}(\rho\varepsilon u_i) = c_{1\varepsilon}\left(\frac{\varepsilon}{k}\right)\mu_t S^2 + \frac{\partial}{\partial x_j}\left(\left(\upsilon + \frac{\upsilon_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right) + c_{2\varepsilon}\rho\left(\frac{\varepsilon^2}{k}\right)\mu_t - R_\varepsilon \quad (7)$$

The constants which are used in equations (6) and (7), were assumed as follows:

$$c_{2\varepsilon} = 1.92, c_{1\varepsilon} = 1.44, C_\mu = 0.09, \sigma_\varepsilon = 1.3, \sigma_k = 1.0$$

In the study of compulsory flow, the equations are solved in a stable manner by wind blow. For the points along the boundary of the wall in the turbulence model, the standard wall function method was used. The relevant equations can be summarized as follows.

$$U^* = \frac{1}{0.4187}\ln(9.793 y^*) \quad (8)$$

$$y^* \equiv \frac{\rho C_\mu^{1/4} k_p^{1/2} y_p}{\mu} \quad (9)$$

where U^* is dimensionless velocity and y^* is the dimensionless distance from the wall.

In equation (9), y_p is the distance between the point P from the wall and k_p is the turbulent kinetic energy at Point P. It is noticeable that the value of y^* should be in the range of 30 and 300 so as to show the correctness of the assumed parameter. The physical properties of the air at 23°C are shown in Table 1. SIMPLE scheme was used for pressure-velocity coupling, Also second order spatial discretization was used for pressure, momentum and turbulent kinetic energy and first order for turbulent dissipation rate.

Table 1. Physical properties used for air (at 23 °C), Source: (Cengel and Boles 2002)

ρ(kg/m³)	Cp(j/kgK)	k(W/m²K)	υ(kg/m)	β(1/K)
1.183	1006.43	0.028	2×10^{-5}	3.34×10^{-3}

Average annual temperature of Tehran is 23°C which is extracted from the Meteorological Organization's data.

3.2. Problem solving

For the CFD analysis, after defining the simulation objectives, the computational model and the appropriate physical model should be selected and then the solving method should be determined.

At this Problem, first geometric generation and gridding in the preprocessor software and running the program according to the geometry (2D or 3D), then transferring the grid from the preprocessor to the computing software (ANSYS Fluent).

3.3. Geometry and grid

The model geometry includes the buildings constructed or under construction in the study zone (Figure 3).

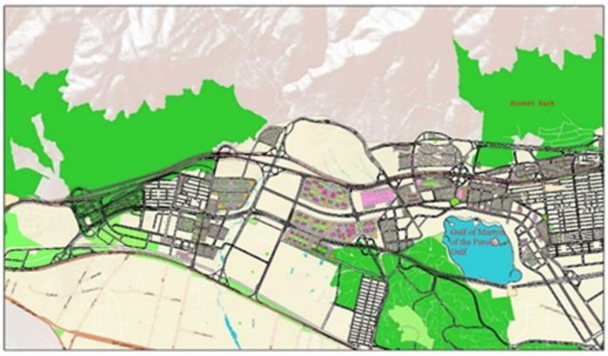


Figure 3. Distribution of buildings in the district twenty-two of Tehran (Source: (Tehran Detailed Design, 2018)).

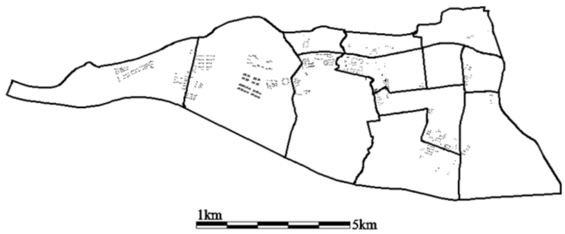


Figure 4. Distribution of blocks before integration in district twenty-two of Tehran municipality.

In order to simplify the model with regard to the extent of the study area, with a length of 1,820 m, a width of 6,100 m, and a total area of 5,797 hectares, a series of buildings close to each other separated by streets were regarded as an integrated block in the model. The shape of the blocks before and after the integration is shown in Figures 4 and 5.

What follows is a sample of the generated grid with 12.5 million cells. This grid is selected from among a set of different grids in such a way as to reduce the time and cost of computations while maintaining the accuracy. As shown in Figure 6, unstructured gird was generated for the study domain. As shown in Figure (6), fine grid cells are generated in the vicinity of ground and the buildings walls where sharper pressure and velocity gradients are expected. This also reduce the *y** level around the walls of the buildings to reach much accurate results in lower CPU time.

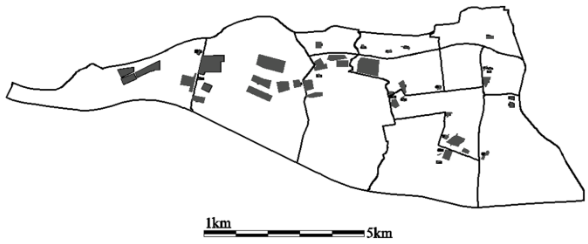


Figure 5. Distribution of blocks after integration in district twenty-two of Tehran municipality.

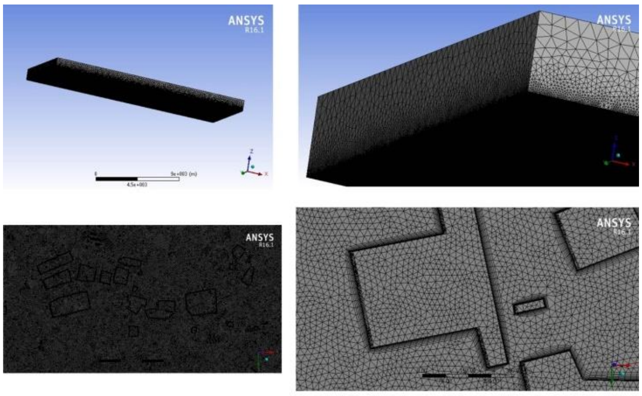


Figure 6. Generated selection grid.

The solution should be independent of grid number and size, in order to carry numerical computation precisely in lowest CPU time. For grid independency, as the domain of study is very big, in order to ensure about the independency of grid, 20 different points in the domain are selected. Pressure and velocity at these points are compared. Pressure and velocity for each point is compared with the finest grid case which we are sure about the solution results. The results of this comparison are presented in Table 2. Four cases are simulated for the grid study, grid number in the finest case was 17.3 million cells and the coarse case 10.1 million cells. According to the data presented in Table 2, the case with 12.5 million grid cells can be selected for further study.

3.4. Boundary conditions

The boundary conditions in the first mode are assumed as follows:

1. Boundary conditions are considered symmetrical for the upper and outer lateral boundaries.

2. The boundary conditions of the input velocity aim to determine the velocity and scalar characteristics of the input flow to the boundary. The velocity at the flow direction is equal to the velocity of the wind blow and other components are zero (v=0 and w=0).

It is assumed that atmospheric boundary condition is valid and the corresponding formula, Equation (10), is implemented to far field velocity profile. The wind velocity profile is presented in Equation (10) (Penwarden, 1975). Reference values in this equation are obtained from the mean measurements done at Tehran Station located in Mehrabad Airport (Table 3), (http://irimo.ir/, 2017).

The values of turbulence coefficients are calculated by the intensity method and length scale. In this modeling, according to the input velocity profile, the turbulence intensity and the length scale were calculated 0.03 and 10 m, respectively. The turbulence intensity shows the turbulence rate of the initial flow. A value of less than 1 for turbulence intensity shows weak turbulence in the flow and a value greater than 10 represents a completely turbulent flow (Wilcox, 1993).

3. It is assumed that the atmospheric boundary condition is valid in this case and the corresponding formula (Equation 10) is implemented to the far field velocity profile. The boundary condition of the output pressure was considered for the front border of the velocity input. Equation (10) is depicted in Figure 7 in the range close to the ground surface (Penwarden, 1975).

$$u = u_{ref}\left(z\right)^{0.35} \ , v,w=0 \ , u_{ref}=1.384\frac{m}{s} \quad (10)$$

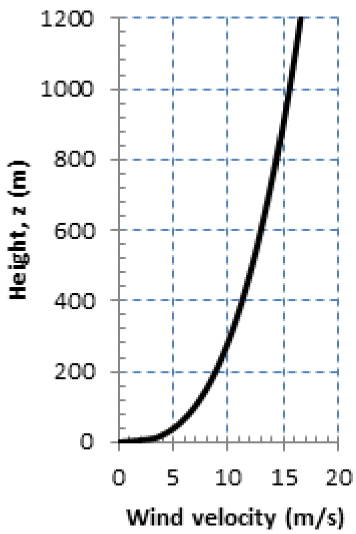


Figure 7. Air velocity profile on the border condition of input velocity.

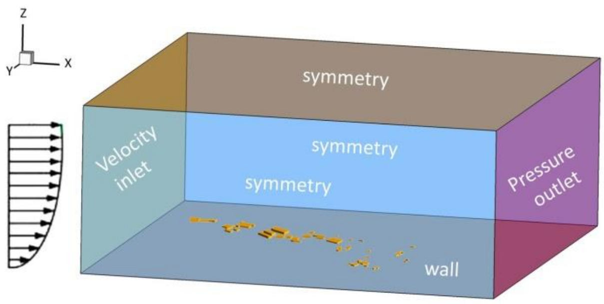


Figure 8. Boundary conditions for the first mode (For a better view, the dimensions in this figure are not actually shown).

Considering the long-term annual wind rose for Tehran, the dominant wind direction is from the west to the east. These data were extracted from Tehran Meteorological Station located at Mehrabad International Airport.

4. The boundary condition for the ground surface was considered a boundary condition of the standard wall function.

5. The boundary conditions were applied to the external surface of buildings as a standard wall function (Figure 8).

4. Results

As already mentioned, the present study aimed to investigate the interaction between high-rise buildings and wind in a district of Tehran through flow simulation in ANSYS Fluent software package. The distribution of wind velocity in horizontal sections with different heights from the ground surface is shown in Figure 9.

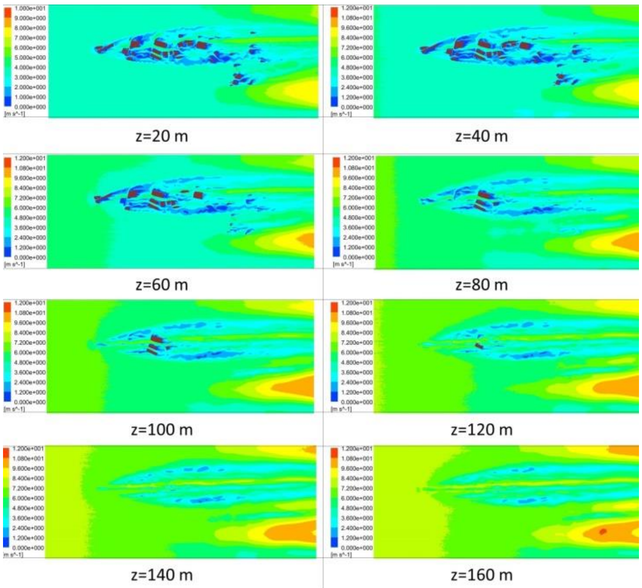


Figure 9. Distribution of wind velocity in horizontal sections with different heights of the ground surface.

The results indicate that at a height of 20 m above ground level, the minimum and maximum wind velocity (air flow velocity) around the buildings are about 0 and 4 m/s, respectively. Wind velocities below 2 m/s typically occur behind buildings (i.e. vortex area). It is also advanced from sides to about 1 km in a direction perpendicular to the mainstream. For heights below 120 m, this advance remained nearly constant (1 km), but at higher altitudes, areas with a wind velocity of less than 2 m/s are advanced approximately half a kilometer from the sides. At heights above 500 m, the presence of buildings has almost no effect on airflow and a uniform airflow is observed.

The results indicate that at a height of 40 m above ground level, the minimum and maximum wind velocity around the buildings are nearly 0 and 8 m/s, respectively. The maximum wind velocity is increased for higher altitudes due to the atmospheric boundary layer effect. The wind velocity rises to 12 m/s at a height of 160 m above ground level, while the outdoor airflow velocity must be 8 m/s based on the equation (10). This increase is due to the presence of high-rise buildings in the area. Higher wind velocities help to the faster and optimal spreading of pollutants.The results indicate that the time required for spreading the pollution from the first buildings in the wake areas to the exit of the building area at 20, 40 and 60 m at the worst points is nearly 105, 65 and 57 minutes, respectively. These results showed that the effect of buildings is not much noticeable on the sides and vortices behind the buildings are not much extensive. Therefore, it can be concluded that the presence of buildings does not disturb much of the flow, and the geometry and layout of buildings allow the passage of flows and environmental pollutants. This can be corroborated by investigating the flow lines. Some flow lines are shown in Figure 10. This figure well illustrates the proper passage of flows through and around the buildings, as the flow lines are smooth without curvature on the sidelines and in the heights. In addition, the flow lines pass through a proper path around the building with a small curvature.

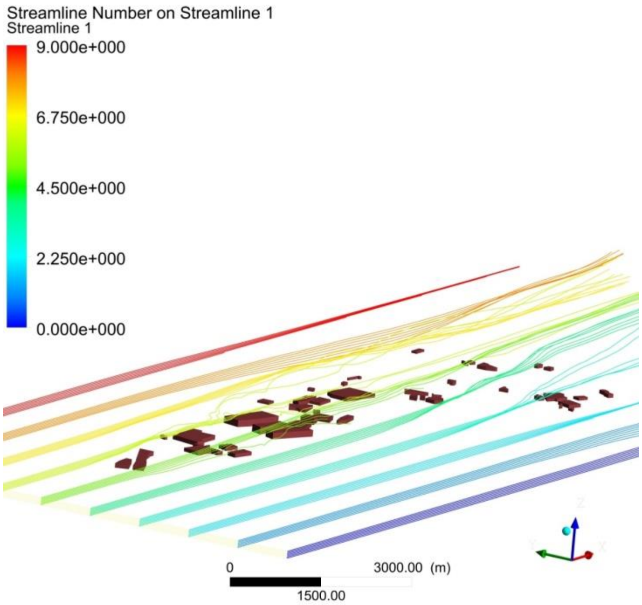


Figure 10. Flow lines around and above buildings.

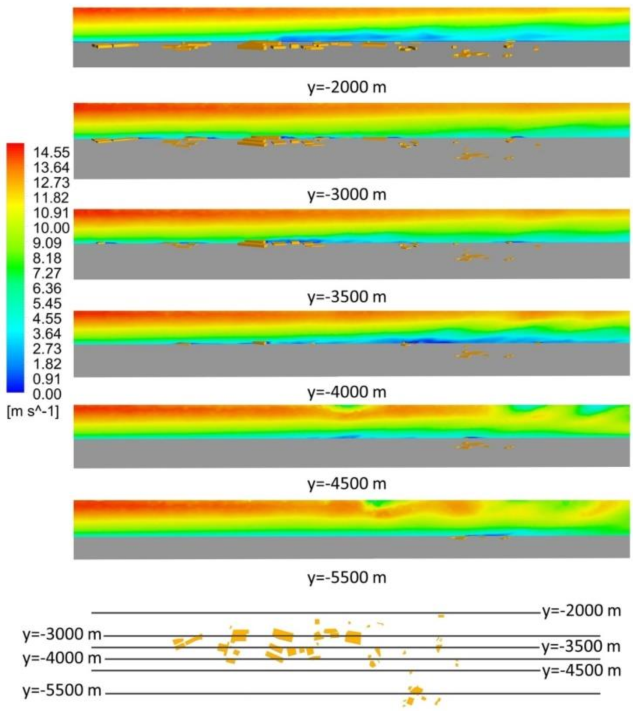


Figure 11. Velocity distribution in vertical pages.

Figure 11 shows that there is no large vortex behind the buildings. Large vortices can cause pollutant trap behind the high-rise buildings. If such a phenomenon is observed, it should be resolved by changing the geometry and layout of the buildings. However, there was no large vortex in the study area to cause the increasing local concentration of pollutants. Then the diffusion of particulate contamination was simulated in order to investigate the movement of particulate pollutants. To this end, 8 critical points were determined for remodeling.

These points were located in areas where the pollutant trap was more likely to occur due to being surrounded by buildings. If particulate pollutants get out of these areas, an appropriate flow of air and the lack of pollutant trap in the surrounding environment can be confidently ensured. These areas are shown in Figure 12. The diffusion of particulate pollutants was measured in each area at three altitudes of 20, 40, and 60 meters above the ground.

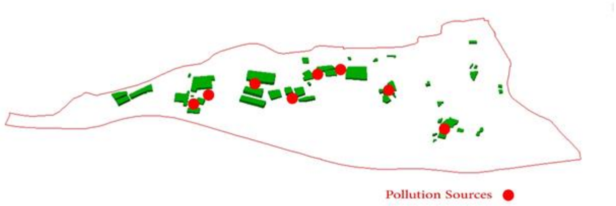


Figure 12. Location of pollution sources.

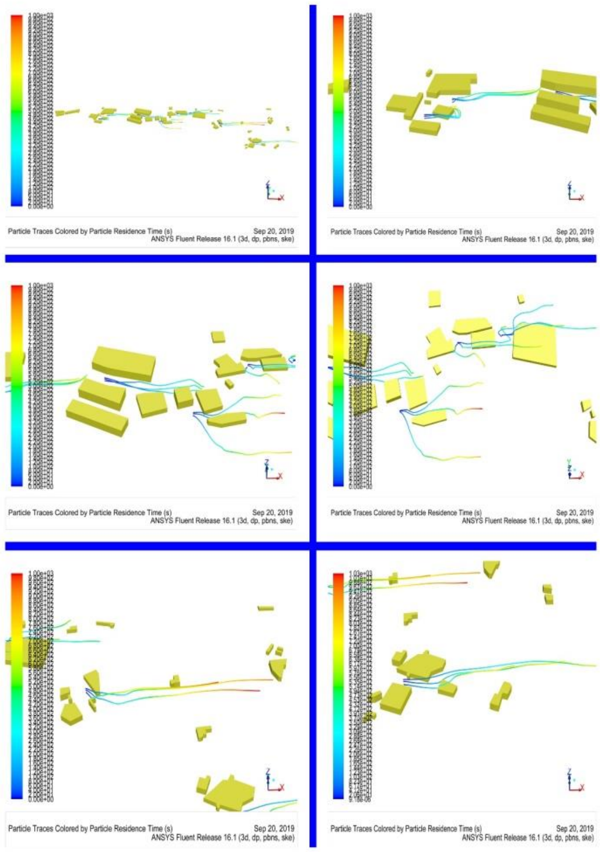


Figure 13. Result of Pollution Modelling.

Table 2. Grid study data, difference with the finest grid case (%)

Parameter	Number of cells (Millions)			
	10.1	**12.5**	**14.6**	**17.3**
Velocity (Average for 20 nominated cells)	6.14	0.21	0.01	-
Velocity (Worst case of 20 nominated cells)	31.2	2.1	0.06	-
Pressure (Average for 20 nominated cells)	5.4	0.1	0.02	-
Pressure (Worst case of 20 nominated cells)	27.4	1.6	0.07	-

Table 3. Average wind velocity at Tehran station in different months of 2010 to 2017 (m/s), Source: (http://irimo.ir/, 2017)

	January	February	March	April	May	June	July	August	September	October	November	December
2010	3	2.9	3.2	4	4.2	3.2	3.1	2.6	2.5	2.6	1.4	1.8
2011	2	3.6	2.9	3.9	4	3.8	3.3	3.2	2.7	3.1	2.3	1.9
2012	2.8	2.9	4.4	3.4	4.1	3.3	3.1	2.7	2.7	2.6	2.1	2.2
2013	2.8	3	3.8	3.5	4.2	3.9	3.4	3.2	3.1	2.8	2.1	2.8
2014	2.8	2.6	4.1	3.9	3.8	4.1	3.4	3.1	3.1	3.4	2.3	2.2
2015	2.7	2.9	3.7	4	4	3.3	3.1	2.9	2.7	2.9	2.4	2.1
2016	2.8	3	4.3	3.8	4.4	4.1	3.4	2.6	3.4	2.4	2.2	2.4
2017	2.5	3	3.5	3.4	3.5	3.8	3	2.8	2.6	2.6	2.8	2.1

Figure 10 shows how the buildings can force the air flow wind to change its path by depicting the streamlines. These show the direction in which the fluid will travel at any point in 3D. The pollution simulation results shown in Figure 13 by particle tracking are well dispersed in the main direction of the flow in all areas. As a result, the mainstream flow (Figure10) can easily carry particles out of the environment.

It was important for the authors to evaluate whether high-rise building lead to trapping pollution or not. Is it possible that pollution particles from the outside and inside of this district trap in the wakes behind the high-rise buildings? In Figure 13, for the ease of reviewing the results, different areas are shown with appropriate magnification. The particles were assumed to be carbon particles with a density of 2000 kg/m^3. For the indication of the specific heat of carbon, the NASA polynomial was employed as shown in Equation (11) and Table 4.

$$c_p/R = a_1 + a_2T + a_3T^2 + a_4T^3 + a_5T^4 \quad (11)$$

Trapping the pollution can increase the local concentration of pollutants. The results in Figure 13 shows that high-rise building did not lead to making strong wakes behind the building and successfully allow the flows and environmental pollutants to pass.

Table 4. NASA polynomial coefficients for the specific heat of carbon

α_1	α_2	α_3	α_4	α_5
1729.566	0.05597124	-0.0001867396	2.104849×10^{-7}	-7.660448×10^{-11}

5. Conclusions

In this study as an innovation, all the buildings and blocks at a city zone are modeled numerically and combined effects of high-rise building, wind flow and pollution have been investigated. In order to decrease the computing time by the software, the buildings which are close to each other were regarded as an integrated block. In addition to the investigation of the conflict between the academia and urban experts due to the concerns of the environmental activists and the effect of the constructions of high-rise buildings, the livability of Tehran were checked since the study zone is under the most probable wind direction from west as an air corridor.

The results of this study indicate the existing buildings and their layout had no effect on wind velocity and trapping the pollution and do not cause an increasing of the local concentration of pollutants. On the other hand, the geometry and layout of buildings allow the flows and environmental pollutants to pass. Hence, concerns of environmental activists about the effect of the constructions of high-rise buildings in the district are decreased. It is proposed that the results of this research can be used for collaboration between municipality as the manager of urban construction and academic centers. The authors believe that the discrepancy with the other researchers is due to the real assumptions of this study since all the buildings and blocks have been simulated and the effect of the exit wind velocity and pollutions on the other regions were examined. The authors also suggest that additional simulation is required to determine the effect of high-rise building on wind velocity and pollutions if the buildings are much more constructed.

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