

# Wind Tunnel Simulation on the Pedestrian Level and Investigation of Flow Characteristics Around Buildings

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Wind flow has a significant role in the design of buildings in urban spaces. The purpose of this study is to determine the wind velocity at the Pedestrian-Level Conditions (PLC) of a tall building in urban environments. At first, this paper discusses wind aerodynamic investigation based on the architectural design. Then, patterns of wind flow behaviour at pedestrian level and shape optimization strategies are considered. Wind tunnel test and CFD approach are conducted to study the wind condition and characteristics at a Golsar street in Rasht. The Suggested tall new building in this research, is located in the centre of the site with an area about of 11000 m<sup>2</sup>. In order to evaluate the wind velocity, the predicted results are compared with actual building specifications data to study the discrepancy between the two phases. The results of the first phase for actual building specifications data showed that wind velocity is more than comfortable environment (<7 m/s). In the next phase, to reduce the vortices and wind velocity to an acceptable level of comfort, planting the tree around the site is used to solve the problem. Moreover, frequency oscillations and wind velocity have been measured; then simulation results are also compared. The findings showed that planting trees in urban environments can be as acceptable as possible, it reduces the wind velocity and its vortices at the pedestrian to the comfort level for sitting and walking activities (>6 m / s).

**Keywords:** Wind tunnel simulation, Flow characteristics, Pedestrian-Level, Air flow around buildings.

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## 1. Introduction

There are several related parameters for the buildings design in urban spaces. Due to environmental conditions, climatic characteristics and the impact these factors affecting in the develop of urban design, it is important to improve the comfort level. Hence wind potential (wind aerodynamic), is one of the significant factors the buildings design [1, 2]. Wind flow is moving air and is affected by variations in pressure of air within the atmosphere. The movement of air is always from the high pressure area to the low pressure area. The greater the difference in pressure, the faster the air flows and a natural movement of air of any velocity [3, 4]. Wind forces are often the governing factor for the tall buildings design and the strength of the building envelope, being even more dominant than the forces due to earthquakes. In time, with developments and innovations in structural systems and the increase in the strength-to-weight ratio of the structural elements, the weight of buildings decreased and wind loads began to be important [5-8].

Design approaches for controlling wind-induced building sway in tall structure and super tall buildings and protecting serviceability can be divided into three major approaches including the "architectural design", the "structural design" and the "mechanical design" and their respective subgroups [9-11]. Aerodynamic architectural design always tends to increase the effects of wind aerodynamic on buildings

and on the other hand, decreasing the vortices, wake region and the leeward side and the turbulent shear layers that separate these two major flow regions. In general, aerodynamic design is controlled in buildings of more than 40 floors [12]. Moreover, air flow patterns around buildings in Built up areas can be quite complex, especially when there are multiple buildings in close proximity to one another. The effects of air flow on pedestrians at ground level are of particular concern, and should be evaluated carefully to ensure pedestrian safety. As wind strikes the surface of a building, the flow typically splits as it flows over and around the building. This results in jetting off of the windward corners and strong vortex formation downstream of the leeward face as the flow streams reattach. Depending on the wind velocity, these flow phenomena can cause pedestrian discomfort, and in extreme cases, be dangerous.

This paper carried out to assess wind effect on the pedestrian-level wind (PLW) with wind tunnel test in the Golsar street in Rasht city. The proposed new tall building in this research, is located in the center of the site with an area about of 11000 m<sup>2</sup>. In the study sites, residential and commercial buildings with a maximum height of 9 meters (3 Floors) and in a region that generally have a suburban development can be seen in it. Finally, the simulation and optimization of the wind effect on the PLW, and the measurement of the CFD simulation results with the human comfort were evaluated.

## 2. Material and methods

In order to construct 3D models, AutoCAD 2014 software was deployed and also to numerically simulate wind tunnel Autodesk Flow Design 2014 is used. Building samples were entered into the software via format FBX. To investigate the wind flow pattern, the fluid flow was chosen as plane 2D so that the effect of cross section could be evaluated in relation to building models. The study site is located in the Rasht city. According to the weather data of Rasht (2005-2014), the wind velocity is 9.8 (~10) m/s and the prevailing wind direction also west. Flow Design uses a transient flow solver, so some of the will see some variations as the simulation runs. When the results quit changing within a tolerance based on the model size, the voxel (grid) size, and the flow speed, the Status changes to Stabilized. This means that either the flow has reached a steady-state condition and is no longer changing or, in the case of physically transient flows, the time-dependent variations are periodic and repeating.

For 'Autodesk Flow Design' validation, Autodesk Company has conducted a wind tunnel empirical study titled "Design Preliminary Validation Brief" (2014) and compare it with ANSYS Fluent. The results gained were contrasted with numerical simulation conducted by Flow Design. The results shows that the closing error of this software with empirical test and numerical simulation came out to be about 6% which is indicative of its validation [13]. Simulations were run to obtain velocity data with mesh size (resolution) settings: medium grid size (120%). Typically, the size of the wind tunnel is

defined by environmental key factors. Although simulations typically reach "Stabilized" at a time just past 1 tunnel length, it has been found that medium resolution simulations (such as  $Res=120$ ) require slightly longer durations for drag coefficient to fully develop.

## 3. Theoretical frame work

### 3.1. Wind effects on buildings and urban spaces

In tall and flexible buildings, aerodynamic behavior generally becomes important. The wind loads of tall buildings can be mitigation by architectural forms and aerodynamic modifications that variation the flow behavior around the building. Aerodynamic-based design can be divided into two types, "aerodynamic architectural design" and "aerodynamic architectural modifications" and their subgroups. Aerodynamic architectural design is realized by taking into consideration matters such as "building orientation (position)", "aerodynamic form", "plan variation" and "aerodynamic top" as part of the basic design. Aerodynamic architectural guidelines have an effective duty in reducing the effect of wind on tall buildings [14-20]. This reduction is generally in the region of 20–30 per cent, but can even exceed 50 per cent [21]. These approaches are described below. According to Ottawa (2009) and Toronto (2013) tall building design guidelines adopted, tall structur buildings have three essential parts or sides of interest that are integrated into the whole of the design: a "base or podium"; a "middle" or "tower", and a "top" [22, 23] (Fig. 1).

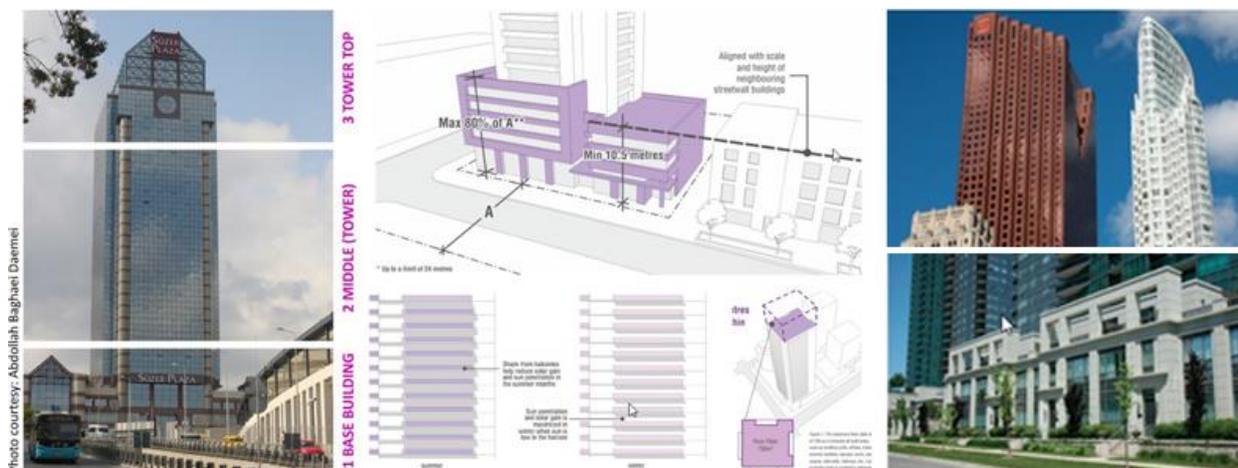


Fig. 1. Regardless of building style, a tall building has three main components [22, 23]

The determination of the acceptable sway limits of tall buildings is an important topic that has been extensively researched. Since wind speed and wind pressure increase according to the building height, wind loads become important as the building height increases. In general, structural design tends to be controlled by wind loads in tall and flexible buildings. Wind motion is usually horizontally and behavior is less vertical. That's while, the impact of "topography" will be effective in wind motion in urban spaces. Surface friction forces the surface wind to slow and turn near the surface of the Earth, blowing directly towards the low pressure, when compared to the winds in the nearly frictionless flow well above the Earth's surface.

This layer, where surface friction slows the wind and changes the flow orientation, is define as the urban boundary layer (UBL) [24]. Solar heating during the day due to insolation thickens the UBL at the surface become increasingly mixed with winds aloft. Vertical wind shear (wind gradient) will be increased overnight due to the dissociation of the surface winds from the wind at higher UBL

by radiant cooling. Both liquids and gases as a fluid could flow in two different forms namely laminar and turbulent. Laminar flow refers to a fluid flow which is flowing in parallel layers without any interruptions between them. Fluids tend to stick to their path with no combination to sidelong layers at low velocities. No eddies and swirling or any other vertical current across the main current of the laminar flow are expected to happen. The particles of this kind of flow move regularly and in parallel to the nearest particles moving over the solid surface [25].

In fact, laminar flow is known as a flow with high momentum diffusion and low momentum convection. According to the velocity and viscosity of the fluids, they may show laminar flow or turbulent flow, when streaming though the pipes or in between of two flat plates. Laminar flow occurs at low velocities just under the region which the flow is turbulent over that. Turbulent flow is an unstable flow containing eddies leading to mixing in sidelong.

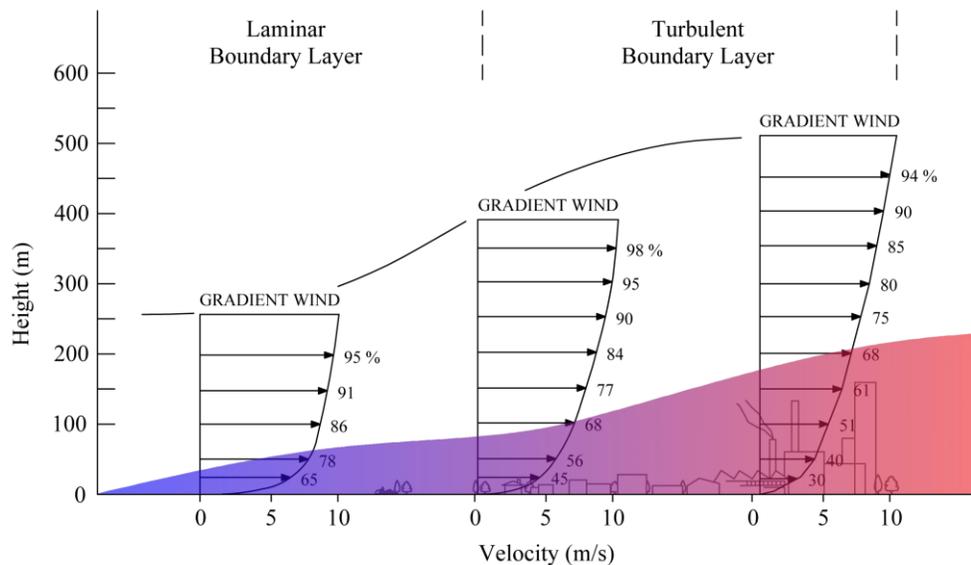


Fig. 2. The boundary layer in urban spaces [25]

According to Fig. 2, in the suburbs, due to the lack of topography, the wind in the lower layers (near the earth's) has a high velocity. Despite for the height of buildings in urban environments, as the wind flows to a higher elevation, the wind velocity increases. On the other hand, regardless of the type of storm, the wind near the earth's surface

is slowed by friction and forms a planetary UBL within which the mean speed increases with height and the air is quite turbulent [26,27]. The same UBL simulation is typically used for determining local loads on the building envelope and for examining wind speeds in pedestrian areas [5].

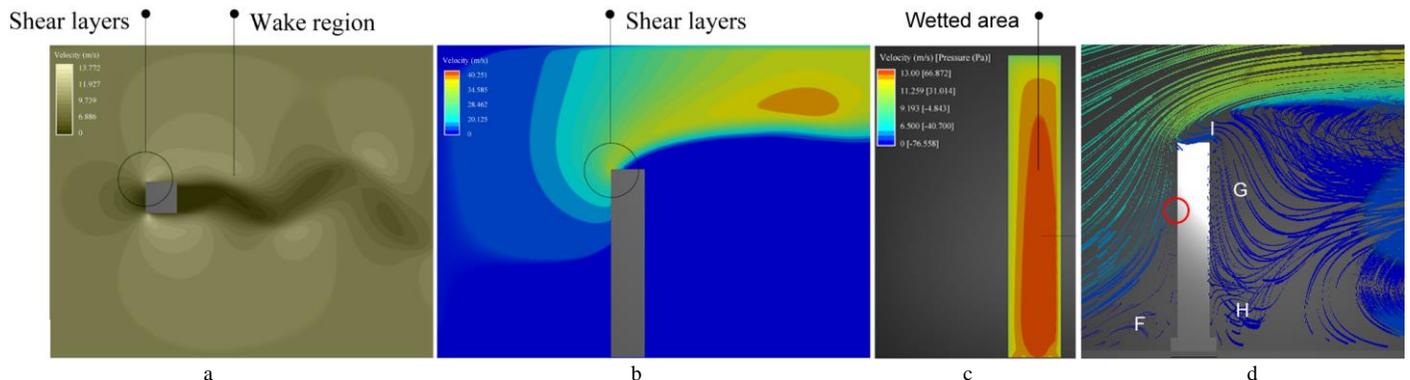
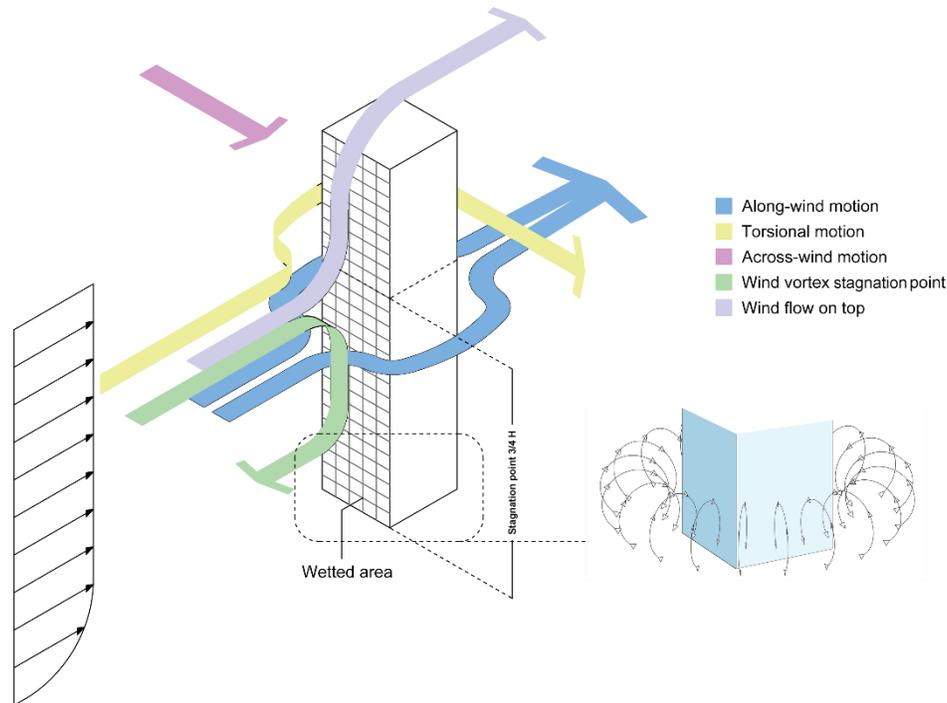


Fig. 3. (a) Wind behavior in Square footprint plan; (b) Increase wind velocity in aerodynamic top; (c) vortices shedding past on the building; and (d) wind pressure and wetted area in front of building (Simulated by Author)

Figure 3 shows the streamlines of wind velocity in vertical plane at center of building. These streamlines describe many other features of flow namely separation zone in the upstream corner (point F), recirculation zone (point I), head of the arch vortex (point G), and the reattachment line (point H). Wind flow at two thirds of the tower height comes to rest and forms the stagnation point. This characteristic is displayed in Figure (3) by red circle. It occurs at height of 200m for Blue building. This result is complying with Blocken et al (2011) whose stated that the stagnation point locates within 60%-70% (2/3 or 3/4 height) of the building height is a point where the wind starts to diverge and this point is known as 'stagnation point' (Fig. 3). In the following, the wind affects at about 3/4 of the tall building height. Also in the top, the wind flows up the facade and

over the tall building top (roof); In podium, it flows down to form a turbulence model and vortices in wetted area (front of the building) before moving round the windward corners and the sides of the building [28].

According to Moonen et al. (2012) and Mohamed et al. (2013) revealed that this point is the best point or zone for assessment in passive natural cooling design. because, in the case of UBL wind profile regions, the stagnation is proportional to the square of the speed, thus the center of the wind profile gives the average speed, which located at 3/4 of the tall building's height [29, 30]. wind effects on tall buildings can essentially be determined into three motions (Fig. 4).



**Fig. 4.** The types of wind motion on tall building [25]

According to Figure 4, In tall buildings, usually the across-wind motion and torsional motion are more critical than the along-wind motion. However, because of the importance of the across-wind and torsional motions of a building, many existing building codes only suggest procedures to provide the along-wind effects of tall building [11, 25].

### 3.2. Design approaches against wind excitation

At every step that tall building design takes toward the sky, today's architects and engineers encounter new difficulties. As the height of modern skyscrapers rises with developments in the field of structural system design and the use of high-strength materials, their weight and rigidity decrease, and their slenderness and flexibility – and thus their sensitivity to wind loads – increase. Wind loads, which cause large lateral drift, play a decisive role in tall buildings design and can be even more critical than earthquake loads. As a result, the wind loads and lateral drift to which tall buildings are subject have become an important problem. Design approaches for controlling wind-induced building sway in tall buildings and protecting serviceability can be introduced into major approach including the “architectural design”, the “structural design” and the “mechanical design” and their respective subgroups [26].

### 3.3. Aerodynamic architectural design

building geometry, the flow profile and turbulence of the UBL, and the aerodynamic forces of around buildings are important factors to determine wind flow pattern in the urban canyon. For the simplest situation, where there is no other tall building nearby, illustrates the typical wind flows that occur. Because wind velocity in the UBL are higher at greater elevations, flow that effects the windward facade of the building generates higher positive pressures near the roof than at the podium of the building. On the windward face there is therefore a downwards flow from the point highest pressure at roughly the three-quarter height, through a stagnation point in the center of the face, towards the base where the pressure is lower [5, 25, 26]. Aerodynamic technique a method that is integrated with design guidelines in the initial process. All the wind loads evaluation are available in this phase and the outcomes can be most affective. Nevertheless, the

challenge with the suitable assessment on the impacts of different aerodynamic layouts on wind loads mitigations, so that an optimized balance among many design aspects can be achieved. A series of CFD simulation are generally important to serve this goal [31]. Aerodynamic architectural design is realized by taking into consideration matters such as “building orientation (position)”, “aerodynamic form”, “plan variation” and “aerodynamic top” as part of the basic design [14-20].

### 3.4. Pedestrian-level wind conditions

Downdrafts and vortices formed at the base of tall buildings lead to zones of accelerated winds. To determine how this can affect human it is worth noting that the flow velocity approaching the top of a 200m tall building in urban canyon surroundings would typically be about 100 to 200 percent higher than at ground level. The building deflects these stronger winds down to ground level. Bearing in mind that wind forces are proportional to speed squared, the force felt by a pedestrian at street level could be magnified by a factor of four to nine as they near the building. There are a number of ways of reducing this type of effect. Changes to the building massing are the most effective, for example setting the building back from the surrounding streets on a podium, thus keeping the accelerated winds up at podium level, leaving the street level protected; or creating a series of setbacks that face the prevailing wind direction and break up the downwards flows.

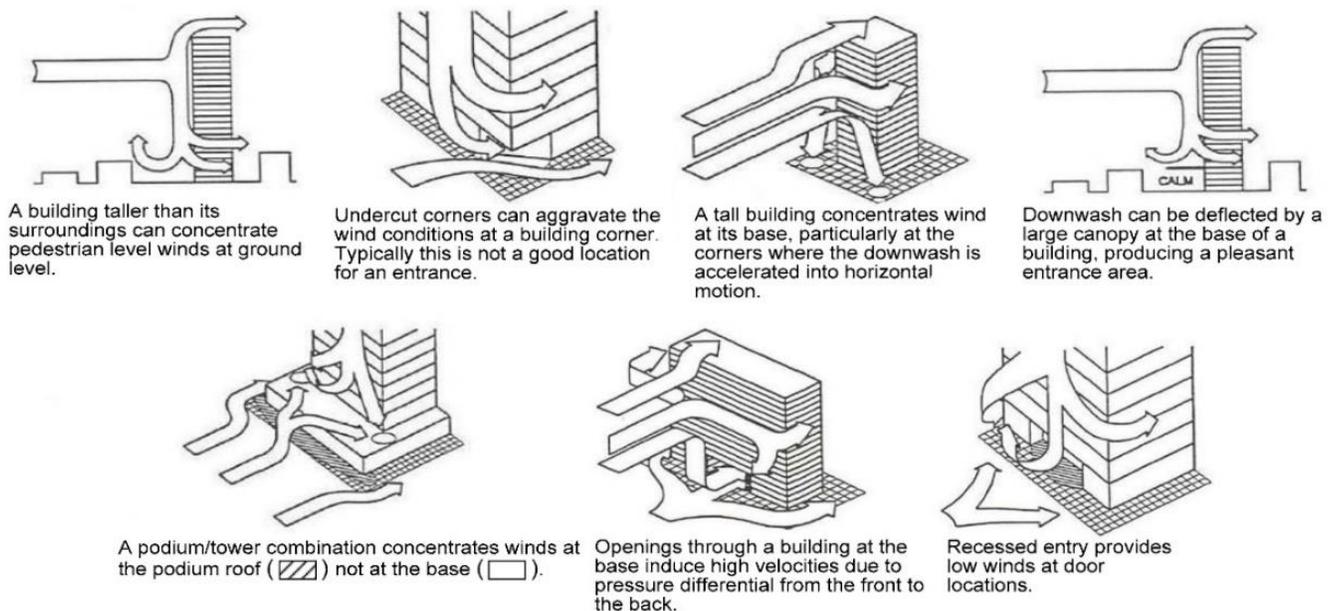
If massing changes are not possible then landscaping, screens, colonnades, and overhead trellises or canopies can be effective in creating local sheltered areas. Criteria for assessing the appropriateness of wind conditions for pedestrians are divided into two categories: safety and comfort. The criteria and methods of assessment have been reviewed by the American Society of Civil Engineers in the document exterior people comfort. Wind tunnel tests are usually needed for precise studies of pedestrian level winds but computational methods are increasingly in use, especially for initial massing studies. With respect to safety, the ASCE (2003) suggests that gust speeds above 25 meters per second, enough to blow some people over, should be limited to no more than two or three occurrences per year, corresponding to a probability of occurrence per

hour of less than 0.1 percent. For comfort it is important to consider the type of activity occurring at each location in a building and to vary the criteria depending on the activity. The ASCE document suggests, for example, that in areas where pedestrians are expected primarily to be walking from one location to another the mean wind speed should be kept to less than 5.4 meters per second for at least 80 percent of the time. At a location where people are expected to stand, such as at a street waiting for a taxi, the criterion is reduced to 3.9 meters per second, and where they will be sitting, for example an outdoor cafe or a swimming pool, it is further reduced to 2.6 meters per second.

These should be regarded as guidelines only, since people's tolerance of wind varies quite widely and they are likely to be more tolerant in geographic regions that are inherently windy. Some local calibration is therefore desirable for each city [32]. Wind-induced noise occurs when the wind flows past building elements that cast off small vortices at frequencies that fall within the audible range, this being called Aeolian noise (the humming of telephone wires is an example). On buildings this can happen at small recesses and slots in the curtain wall system or off balcony railings, louvers, and suchlike. In the case of railings and louvers, they may also vibrate due to the vortex shedding, which can magnify the noise by further strengthening the vortices. Another mechanism for noise is the blowing of wind over a slot or hole that connects to an enclosed inner

volume. The classic example of this mechanism, known by the scientific name Helmholtz resonance, is the humming noise generated by blowing over the open end of an empty bottle. The air of the internal volume acts like a spring for the mass of air around the mouth, which oscillates in and out, causing sound waves to radiate at the natural frequency of the "mass-spring" system. Another source of noise is the flow of air through small cracks at elevator doors within the building or through other small slots in the envelope. These flows result from stack effect as well as wind, creating pressure differences both between the indoor and outdoor of the building, and between various interior zones of the buildings.

The stack effect is most severe when there are large temperature variation between the indoor and outdoor, which make the interior air either positively buoyant for cold exterior temperatures or negatively buoyant for warm exterior temperatures [5, 33-35]. The effects of airflow on pedestrian-level wind of particular concern, which should be investigated to verify the safety of pedestrians [36-38]. The result is that the wind flows to the corners and forms some strong vortices in the bottom (building podium), and the fluid flows through around building and flows along the parallel flows along and behind the building. These vortices can provide an upsetting condition for pedestrians [39, 40].



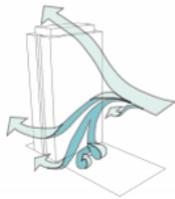
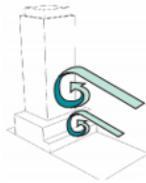
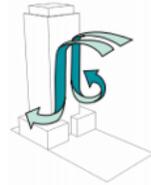
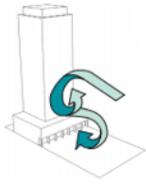
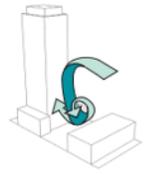
**Fig. 5.** Improve conditions based on wind design for pedestrians [41]

Figure 5 shows the proposed design strategies to determine the flow patterns on the base of the tall building (podium) and PLW. Furthermore, Toronto tall building design guideline (2013) suggested patterns to show the wind behavior in pedestrian level in below of tall buildings. Adverse wind effects can be reduced through the human behavior of the podium tall buildings [42]. The use of aerodynamic form such as set-back at the podium is a particularly suitable technique to dissipate down drafts. Architectural guidelines including

projecting cornices, screens, terraces, overhangs, and permanent canopies can also be applied to mitigate the impacts of high velocity flow around the podium and within top of buildings (Table 1).

The following table 2 from (Shane, 2011) lists a range of comfort classes based on wind speeds and limiting criteria. These classes attempt to quantify pedestrian comfort assuming suitable attire. They only consider wind speed and do not account for other weather conditions such as temperature and humidity [43].

**Table 1.** Wind motions in pedestrian level [42]

					
Wind flowing down the building face causes accelerated wind speeds near the windward corners.	Tall and wide facades that face the prevailing winds are often undesirable.	Towers that step back from base buildings can be used to reduce undesirable downward wind flows.	The proportion of base building step backs and their influence on the wind is affected by the height of the surroundings.	Base building roof areas that are inaccessible to pedestrians can be used to mitigate against downward wind flows and improve conditions at grade.	Landscaped base building roof areas can further reduce wind speeds at grade.
					
The use of horizontal canopies on the windward face of base buildings is beneficial. Parapet walls can increase the canopy's effectiveness.	Sloped canopies only partially deflect downward wind conditions.	Colonnaded base buildings can be used on windward facades to control downward wind flows.	Colonnades provide pedestrians a choice of calm or windy areas (breezes are welcome on hot days).	Buildings create a low wind pressure area immediately downwind.	A low building upwind of a tall building increases the downward flow of wind, causing accelerated winds near the windward corners of the tall building.

**Table 2.** Wind conditions with different human behaviors [43].

Comfort Class	Wind Conditions	Activity Description
Sitting	Wind speed < 3.9 m/s Occurs > 70 % of the time	Acceptable for sedentary activities.
Standing	Wind speed < 6.1 m/s Occurs > 80 % of the time	Acceptable for standing, strolling, and other slow movements.
Walking	Wind speed < 8.3 m/s Occurs > 80 % of the time	Acceptable for walking, running, and other rigorous activities.
Uncomfortable	Wind speed > 8.3 m/s Occurs > 20 % of the time	Unacceptable for walking.
Dangerous	Wind speed > 25 m/s Occurs > 0.01 % of the time	Dangerous for walking.

**4. General equation**

**4.1. Drag force**

To address drag coefficient, in fluid dynamic it is usually shown as  $C_D$ ,  $C_x$  &  $C_w$ , which is a dimensionless quantity, to specify drag quantity (the drag force) or resistance of an object against a fluid flow like water or air. In the drag force equation (Equation 1), lower drag coefficient results in lower aerodynamic tension. Hence, we could state that drag coefficient always depends on the specific surface. Figure 5 shows drag coefficient in different shapes. This quantity could be mathematically defined by equation 1:

$$C_D = \frac{2F_D}{\rho v^2 A} \tag{1}$$

Now if we want to express a definition for Reynolds number, it would be a quantity of the fluid mechanics that shows the ratio of inertia to viscous force. In other words, applications of this number are for defining whether a fluid flow is laminar or turbulent. If Reynolds number is lower than a specific amount ( $Re < 2100$  or  $2300$ ), the flow would be laminar, if the flow is variable and transient, Reynolds number is  $2300 < Re < 5000$ , but for the Reynolds of  $Re > 5000$ , the flow is turbulent. This specific value is entitled critical Reynolds number and  $Re_{crit}$  is used to represent it. The critical Reynolds number differs for different geometries. Following equation shows Reynolds number definition.

$$Re = \frac{\rho v L}{\mu} \tag{2}$$

## 4.2. Wind velocity estimation equation

The equation introduced by ASHRAE (2009) could be used to define wind velocity and boundary layer in stories. From this equation, wind velocity at different points could be calculated [44]. In the following, Table 3 shows urban and atmosphere boundary layer parameters in urban spaces.

$$V_H = V_m \times \left(\frac{\delta_m}{H_m}\right)^{a_m} \times \left(\frac{H}{\delta}\right)^a \quad (3)$$

**Table 3.** Atmosphere boundary layer parameters [44]

Region texture	Texture coefficient	The region wind gradient height in meters ( $\delta$ )
Group one (sea levels and wide deserts)	0.10	210
Group two (rural areas and weather stations)	0.14	270
Group three (forest areas and suburbs)	0.22	370
Group four (huge urban areas)	0.33	460

## 4.3. Bernoulli equation

The Bernoulli equation or Bernoulli principle in fluid mechanics shows the relationship between pressure and flow velocity in the free flow area around an object and also stands as the mathematical form of the energy conservation law in fluids. Simply put, in a flowing flush, an increase in flow speed leads to a reduction in pressure if the height of the fluid remains steady. Conditions for utilizing Bernoulli equation are:

- The flow is steady
- Viscosity is negligible
- Fluid components are free from vortex flow

So, the Bernoulli equation would be as equation 4:

$$p + \frac{1}{2} \rho V^2 = C \quad (4)$$

A tall 9-floor building is suggested as a case study in this research. The site is located in Rasht city. According to the study entitled "Feasibility study on extended tall buildings in Rasht" (2015) to create a coordination in dividing building to the tall and low-rise buildings, a 6-story building including ground floor is known as a tall building [45]. Accordingly, analyses were confined to floors 6<sup>th</sup> to 9<sup>th</sup>. The height of each floor is 3.24 meters and the whole building height is equal to 29.16.

## 5. CFD simulation based on the findings

### 5.1. Simulation details and analysis methods

The applied approach of this research is library studies, and the analysis is based on CFD simulation results. On this basis, the theoretical framework of the research was studied at the first stage. Wind tunnel Autodesk Flow Design 2014 was used to simulate wind tunnel numerically and also, STL models were generated for import into Flow Design. Information entered into the software could be extracted from Table 4. In order to clearly show the flow, the resolution level of the simulation was set at 120%. These simulated wind loads were used to estimate along-wind responses of a tall building, which are less narrow-banded processes, based on the state-space variable approach. Furthermore, the Flow Design solver uses an LES (Large Eddy Simulation) turbulence model to account for turbulence within the wind tunnel. LES is a mathematical model for turbulence used in computational fluid dynamics of the atmospheric boundary layer [46,47].

**Table 4.** Configuration of Flow Design Software

Mesh size (Resolution) (%)	Fluid Status	Time (s)	Analysis Type	Wind Speed (m/s)	Wind Direction	Wind Tunnel Size	Turbulence Model
120	Stabilized	40	3D	10	West (Along wind)	300x300x1300	LES

To evaluate Autodesk Flow Design software, the Autodesk organization has made various simulations and compared to the actual empirical tests. According to their report published in 2015, the focal aspect of this software is on machines and architectural studies [48]. Evaluation in an architectural manner was assessed by a research entitled "Flow Design Preliminary Validation Brief" (2014) comparing to the results of Fadl and Karadelis (2013) [49]. For this comparison, an actual building located in Coventry University Central Campus has been simulated in Flow Design and Fluent environments under the same conditions. Outcomes of the research revealed an offset error by 6% from this software to experimental tests and computational simulations by Fluent which makes the software results acceptable. Moreover, Baghaei Daemei et al., (2019) conducted a research with titled "Study on wind aerodynamic and

flow characteristics of triangular-shaped tall buildings and CFD simulation in order to assess drag coefficient" in which used Autodesk Flow Design 2014 software to simulate wind aerodynamics around shaped-rectangular tall buildings [50].

### 5.2. Site design and layout

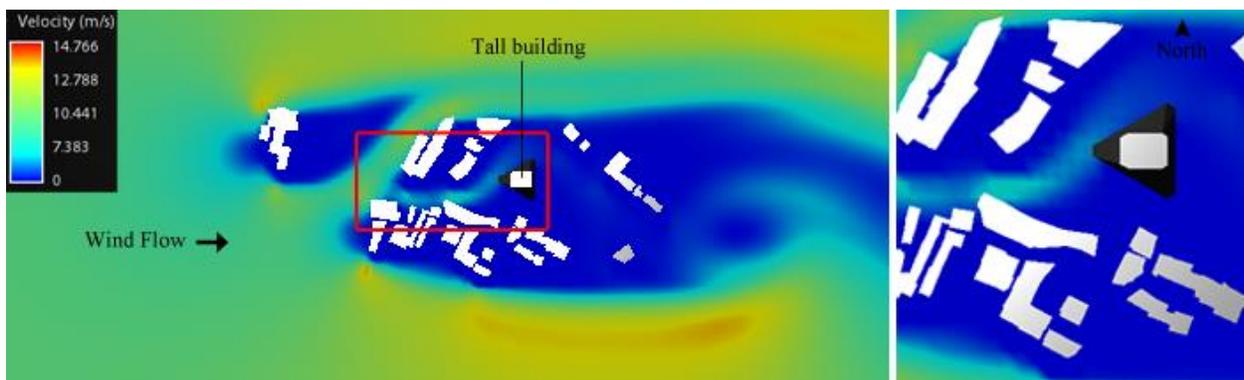
As stated, attention to wind aerodynamic aspects in tall buildings design and pedestrian level is very important. For this reason, wind tunnel simulation was carried out on a site plan with a building model. This model has 47 floor (about 150 m) was located on a real site specification in the Golsar street in Rasht city. In the study sites, residential and commercial buildings were at a maximum height 9 meters (3 floors). Figure 6 shows the site location (a) and Wind Rose diagram in Rasht map (b).



**Fig. 6.** (a) Rasht wind rose diagram and (b) Site location.

By investigation in the site conditions through aerial maps, buildings around were modeled. Modeling adjacent buildings was done for this reason, so that the results of CFD simulation match the actual conditions. Figure 7 shows the wind tunnel simulation results of the existing conditions. This simulation has been evaluated

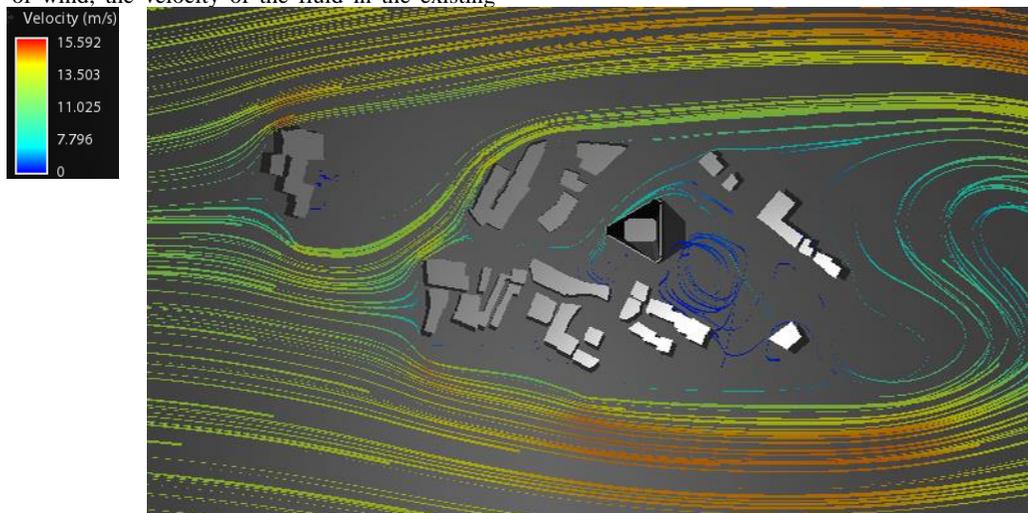
in pedestrian level. The wind velocities from the ground up to a maximum height of 10 meters was investigated. Because the height of wind measurements in Rasht meteorological, Max. Up to 10 are shown.



**Fig. 7.** The simulation results of the wind current situation on the pedestrian level

According to Figure 7, it was observed that in the current situation conditions of site, the wind flows around the buildings and when entering into the site, has a speed of about 7 to 10 m/s with a blue color spectrum. As the simulation results showed that vortices are being made around the building. The following results were obtained there are vortices around the building. Due to the existing modeling, buildings in this simulation based on the current situation conditions, the laminar flow of wind, the velocity of the fluid in the existing

collision with the buildings is reduced and the corners continue to flow along the free streamline. But its velocity is very high. This phenomenon is called "shear layer" that usually provided to as wind gradient, is a various in flow velocity and orientation over a relatively short distance in the urban environment. In the following, the shear layer around the buildings varies from 12 to 14 m/s, which is very high in urban environments on the pedestrian level (Fig. 8).



**Fig. 8.** Wind shear layer and vortices on the pedestrian level

According to Shane (2011), the speed for pedestrian comfort should be less than 7 m/s. Otherwise, there will be severe discomfort. It seems that the solution method that was chosen by planting trees and vegetation, it can be comforted to reduce the velocity, as well as prevent the formation of vortices as far as possible. So, vegetation and planting of trees around the site and on the inflow of wind were used.

These planting trees and vegetation with two variable heights of 15 m and 7 m, were considered to move the flow from the top of the building, and the intensity of the vortices around the site is reduced. Moreover, trees of 7 meters make it possible to move wind flows around the site at required velocity conditions (Fig. 9).

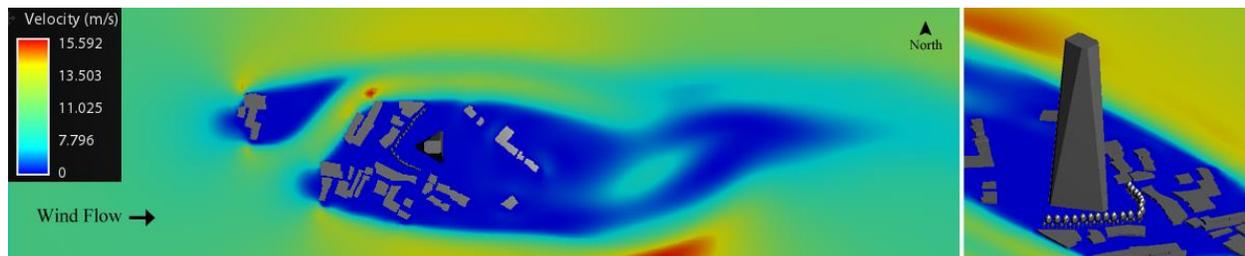


Fig. 9. Wind velocity reduction and pedestrian-level problem solving

According to Fig. 9, it is observed that trees and vegetation with different heights, as a buffer in the wind direction, were able to reduce

the wind velocity to a comfortable level. Also, the resulting vortices were reduced to the optimal on the pedestrian level (Fig. 10).

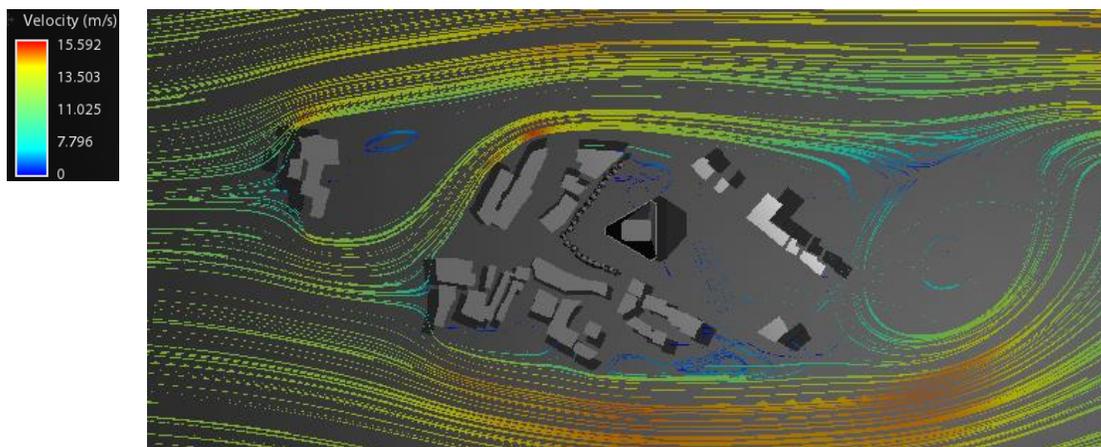


Fig. 10. Reducing the vortices on the pedestrian-level wind

Figure 8 shows, planting trees in its proper position, it was able to control the intensity and direction of the wind among urban buildings. Wind velocity to acceptable levels for sitting, standing and walking activities were accepted. So, the air flow accelerates around the corners of the building. This causes a high speed separated region off the corner and a calmer stagnation region on the sides of the building. These effects can have a significant effect on pedestrians, and should be reviewed carefully to ensure safety.

## 6. Discoution and conclusion

Based on background study and numerical CFD simulation, it became clear that attention to the wind aerodynamics and its use in the architecture design and urbanism, to develople human outdoor comfort on PLW of urban environments and reduce winf force on tall buildings it can be effective. It was also observed that the investigation of Wind comfort standardization at pedestrian level is very important for the convenience and safety urban areas. tall buildings can define high flow velocity at the PLW, which can lead to unpleasure or even unsafety conditions. on the other hand, the assess and recognize of suitable wind and human comfort criteria be critical to the reliable evaluation of the PLW. In Fact, tall buildings

the stronger for the aerodynamic force at the building podium and the greater the need for reducing turbulence and vortices. Furthermore, comfort level in the urban environment and also performance and health, referring respectively to PLW and thermal pleasure, pollutant dispersion are of interest. It is observed that based on simulation, paying attention to wind aerodynamic in addition to tall buildings can also be very effective in designing low-rise building in urban environments. The main purpose of this study is predict wind speeds for determining the pedestrian levels of comfort at the base building. Using the data collected from field studies, it was considered as the initial input of the analysis. It should be kept in mind that the wind speed was adjusted so that the occupants' activities would not be compromised. In order to evaluate of wind velocity, the predicted results are compared with actual building specifications data to study the discrepancy between the two phases. The results of first phase for actual building specifications data showed that wind velocity more than comfortable environment ( $<7$  m/s). So it was necessary to bring the amount to a comfortable level with the viable mechanism. Methods for problem solving, planting a tree with two variable heights was considered. These trees were modeled in front of the flow of fluid into the site. on the other side another simulation was performed to compare the CFD simulation findings with the actual

condition. The findings showed that using this method, the vortices inside the site were reduced to an acceptable level, and the wind speed was acceptable in the comfortable level (less than 6 m/s for sitting, walking and walking activities).

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