

The Effects of High-Rise Buildings Arrangement on Pedestrian-Level Wind Comfort in Tehran District 22

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Abstract

High-Rise buildings with their particular features can affect the surrounding environment and create new microclimates. In windy conditions, the spaces between building blocks change into passages and affect wind velocity, intensity, and other parameters. The importance of this effect is different at each level of building height. The Pedestrian-Level is the lowest and one of the important areas. Markets, playgrounds, and pedestrian access are located in this area, and any unwanted microclimate changes like high velocity and turbulence in this level can create discomfort and dangerous conditions for residents. So this research tries to consider the pedestrian-level wind comfort in some High-Rise building complexes arrangement that are located in Tehran district 22 with Computational Fluid Dynamics (CFD) modeling and reaching a suitable arrangement pattern. It has collected the required data through field study and librarian databases and then compared them with standard guidelines and analyzed them by comparative comparison method. As a result, a linear arrangement that placed crossover to wind direction for providing wind comfort and preventing wind danger has been suggested in this region.

Keywords: High-Rise Building, Wind Comfort, Building Arrangement, Pedestrian Level, CFD, Tehran.

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List of acronyms		U_e	effective wind
PLW	Pedestrian-level wind	CFD	Computational Fluid Dynamics
U	mean wind speed	k	peak factor
U_0	reference location wind statics	σ_u	root mean square (rms)
U_{THR}	threshold value	U_{pot}	potential wind speed

1- Introduction

High-Rise building, also called high-rise, multistory building tall enough to require the use of a system of mechanical vertical transportation such as elevators. The skyscraper is a very tall high-rise building. The first high-rise buildings were constructed in the United States in the 1880s. They arose in urban areas where increased land prices and great population densities created a demand for buildings that rose vertically rather than spread horizontally, thus occupying less precious land area (Britannica, 2013). So a High-Rise building is an essentially building with a small footprint, small roof area, and very tall facades. And what differentiates it from the conventional low rise and medium rise buildings is that it needs special engineering systems due to its height or: A High-Rise is any structure where the height can have a significant impact on evacuation (Ibrahim, 2007, p. 2000). When the wind blows toward an architectural site, building structures, indoor and outdoor areas will be affected from it. For example, it can affect ventilation and thermal condition of indoors, and as a side-load on structures. One of the important wind's blowing effects, is on outdoors and landscapes that pedestrians attend in it. These landscapes must be had a safe and comfortable wind condition like standard wind speed for human activities such as scrolling, traversing, sitting, reading newspaper and etc. A non-standard wind condition in these places not only harms the space ventilation but also can be dangerous for pedestrians. Nowadays, many urban authorities only grant a building permit for a new high-rise building after a wind comfort study has indicated that the negative consequences for the pedestrian wind environment remain limited (B. Blocken, Stathopoulos, & van Beeck, 2016, p. 50). A PLW comfort study should be performed by a combination of three types of information/data: (1) statistical meteorological data; (2) aerodynamic information; and (3) a comfort criterion. The aerodynamic information is needed to transform the statistical meteorological data from the weather station (meteorological site) to the location of interest at the building site (B. Blocken et al., 2016, p. 51). Wind statistics at the meteorological site can be expressed as potential wind speed (U_{pot}), i.e. corresponding to a terrain with aerodynamic roughness length $z_0 = 0.03$ m. The aerodynamic information usually consists of two parts: the terrain-related contribution and the design-related contribution. The terrain-related contribution represents the change in wind statistics from the meteorological site to a reference location near or at the building site, i.e. the transformation of U_{pot} to U_0 . The design-related contribution represents the change in wind statistics due to the local urban design, i.e. the transformation of U_0 to the local wind speed U . Information on transformation procedures to determine terrain-related contributions can be found in e.g. Refs. The design-related contribution (i.e. the wind flow conditions around the buildings at the building site) is generally obtained by either wind-tunnel testing or numerical simulation with Computational Fluid Dynamics (CFD). Wind comfort criteria generally exist of a threshold value U_{THR} for the effective wind speed U_e and a maximum allowed excrescence probability P of this threshold. The effective wind speed is defined as:

$$U_e = U + k \sigma_u$$

where U is the mean wind speed, k the peak factor (generally between 0 and 3.5) and σ_u the root mean square (rms) wind speed (B. Blocken et al., 2016, p. 51). Now the questions that rises are: Does the arrangement of the High-Rise buildings effects on Pedestrian-Level wind comfort? And which arrangements are suitable for the High-Rise buildings that are located in Tehran district 22? The

hypothesis of this research says yes, these arrangements can effects on wind comfort in Pedestrian-Level and some of them can provide better condition than others. Thus the aim of this research is reaching to most suitable shape of arrangement for these buildings. It can provide a suitable Pedestrian-Level wind comfort, create an alive landscape and prevents from making a uncomfortable and dangerous space. This Analytical- descriptive method research has tried to shape its technical frame from newest and up to date standards, guidelines and researches for reaching to suitable required wind speed. This research collects its required documentary and architectural data from librarian and field study then analyzes them with CFD method by DesignBuilder software to achieve its aims.

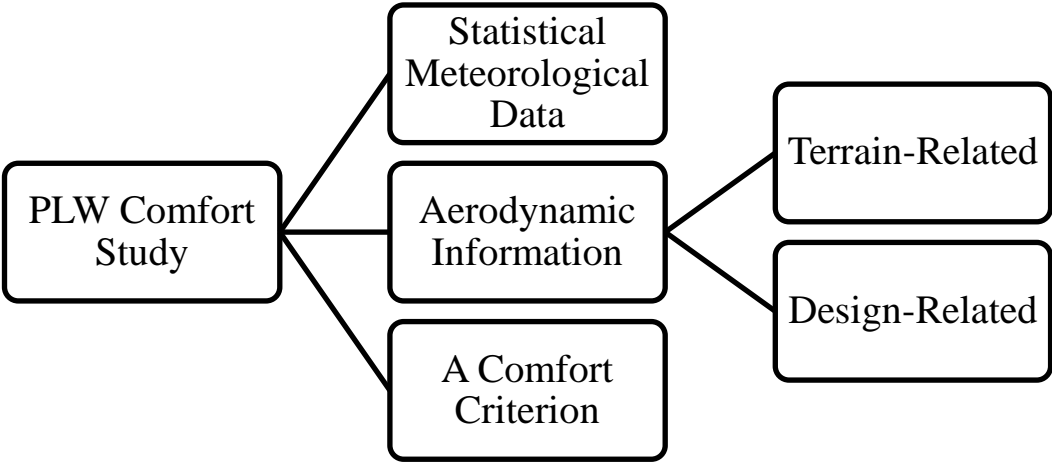


Diagram 1: PLW Study Process (Authors)

2- Overview

In recent years several researches have done on the wind comfort in pedestrian level, for example Ted Stathopoulos in his paper dealt with the aerodynamics of pedestrian level wind conditions, their experimental and computational assessment in the urban environment, as well as with the criteria used for outside human comfort in different parts of the world (Ted Stathopoulos, 2009). In Bert Blocken, Janssen WD and Twan Van Hooff’s paper a flowchart has been presented that encompasses the three cases. It outlines the basic steps to be followed in assessing and if necessary, improving the wind comfort and wind safety (Bert Blocken, Janssen, & van Hooff, 2012). The paper of Mohamed Fadl and John Karadelis has presented a CFD simulation for the evaluation of pedestrian wind comfort and safety in urban areas, the use of CFD in assessing and optimizing engineering design solutions related to environmental concerns has been demonstrated through several case studies (Fadl & Karadelis, 2013). Calautit, Hughes, O’Connor and Shahzad they have did a numerical and experimental investigation to investigate the performance of a wind tower with Heat Transfer Devices (HTD) (Calautit, Hughes, O’Connor, & Shahzad, 2015). So knowing the built environment behavior is useful to designing high quality complexes for architects. Urban designing of Tehran district 22 (错误!未找到引用源。) as a modern and newest area in Iran that is under construction in west side of the Iran’s Capital, not exception from this rule. Consequently, if the guidelines of pedestrian-level wind comfort has used in designing, it can improve wind comfort quality of residents that lives in this complexes and makes better urban areas. This research tries to achieve the suitable pattern for Hi-Rise buildings arrangement that provides wind comfort for pedestrian at Tehran 22 district. Here you can see some researches that related to this research in table 1.

Table 1 : Research Overview (Authors)

Author(s)	Publication	Year
Blocken, Bert Janssen, WD van Hooff, Twan	CFD simulation for pedestrian wind comfort and wind safety in urban areas: General decision framework and case study for the Eindhoven University campus	2012
Calautit, John Kaiser Hughes, Ben Richard O'Connor, Dominic Shahzad, Sally Salome	CFD and Wind Tunnel Study of the Performance of a Multi-Directional Wind Tower with Heat Transfer Devices	2015
Calautit, John Kaiser Hughes, Ben Richard Shahzad, Sally Salome	CFD and wind tunnel study of the performance of a uni-directional wind catcher with heat transfer devices	2015
Fadl, Mohamed Karadelis, John	CFD Simulation for Wind Comfort and Safety in Urban Area: A Case Study of Coventry University Central Campus	2013
Ted Stathopoulos	Wind and Comfort	2009

3- Theoretical Framework

3-1- Wind behavior and building Arrangement:

High-Rise buildings are dominant elements in urban architecture due to their scale and purpose, and should be the focus of sustainable design (Ali & Armstrong, 2008). The microclimate parameters in outdoor spaces, including the air temperature, wind speed, relative humidity, solar radiation etc., are significantly influenced by various configurations of urban texture, such as plot ratio, site coverage, building height, and building arrangement etc (Deng, Wong, & Zheng, 2016). Wind is fundamentally caused by heat radiated by the sun. Radiation, thermodynamic and mechanical phenomena transform the thermal energy imparted to the atmosphere into mechanical energy associated with air motion, giving rise to various types of wind (Simiu, 2011, p. 109). Wind flows that affect buildings and other structures are characterized by two fundamental features: (1) the increase of the wind speed with height, and (2) the atmospheric turbulence (Simiu, 2011, p. 117). Each type of building arrangement has its positive and negative features that depend on our site climatic condition. For example the side-by-side building arrangement has its advantages: it facilitates most pleasing views of beaches, gardens and other scenic sights to many residents; passages between buildings can be used as access roads; and it makes easy to connect the buildings with sky bridges or sky decks. The arrangement has its concerns also: the surrounding wind environment is a prime example, as most of this type of development is designed with shopping malls and recreational areas at the lower levels of buildings. Typically, wind conditions at the base of a tall building are unpleasant and sometimes can be dangerous for pedestrians (Tse, Weerasuriya, Zhang, Li, & Kwok, 2017).

3-2- Pedestrian-level comfort:

In particular near high-rise buildings, high wind velocities are often introduced at pedestrian level that can be experienced as uncomfortable or sometimes even dangerous (Fadl & Karadelis, 2013, p. 364). Uncomfortable wind conditions have proven detriment to the success of new buildings (Bert Blocken & Carmeliet, 2004, p. 109). Wise (1970) reported about shops that are left untenanted because of the windy environment that discouraged shoppers. Lawson and Penwarden (1975) report dangerous wind conditions to be responsible for the death of two old ladies after being blown over by sudden wind gusts near a high-rise building. Many urban authorities today recognize the importance of pedestrian wind comfort and wind safety and require such studies before granting building permits for new buildings or new urban areas (Bert Blocken et al., 2012). Velocity and intensity of wind in pedestrian level is very important. If the wind not penetrates into the building complex, its air comes

unpleasant and if blows with high velocity, can harms the pedestrians and in winter make the environment cooler. Pedestrian comfort criteria are based on mechanical wind effects without consideration of other meteorological conditions (temperature, relative humidity). These criteria provide an assessment of comfort, assuming that pedestrians are appropriately dressed for a specified outdoor activity during any given season. Five pedestrian comfort classes and their corresponding gust wind and speed ranges are used to assess pedestrian comfort (Table) (Fadl & Karadelis, 2013, p. 366).

Table 2: Wind Comfort classes (Fadl & Karadelis, 2013, p. 366)

Comfort Classes	Description	Location types (Examples)
Sitting	Occurrence: > 70% of the time. Acceptable for sedentary activities, including sitting.	Outdoor Cafés, Patios, Terraces Benches, Gardens, Fountains, Monuments.
Standing	Occurrence: > 80% of the time. Acceptable for standing, strolling, etc.	Building Entrances, Exits Children's Play Areas
Walking	Occurrence: > 80% of the time. Acceptable for walking, or rigorous activities	Public/private Sidewalks Pathways. Public / Private Vehicular Drop-Off Zones
Uncomfortable	Occurrence: > 20% of the time. Unacceptable for walking	
Dangerous	Occurrence: > 0.01% of the time. Dangerous to walk	

3-3- Computational fluid dynamics (CFD):

Wind studies of architectural and urban plans are rarely conducted due to the high technical and scientific skills that CFD simulations and wind-tunnel tests require (Reiter, 2010, p. 858). 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 modeling techniques like the Computational Fluid Dynamics (CFD) (Fadl & Karadelis, 2013, pp. 364-365). Computational fluid dynamics (CFD) has in recent years made useful strides and may be expected to become increasingly important in future. The latter can provide significant cost benefits for assessing and optimizing engineering design solutions related to environmental 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 modeling (Fadl & Karadelis, 2013, p. 365). CFD modeling has been used by environ-metrics to assess comfort levels with respect to wind climate, based on evaluating the wind flow fields around buildings, as well as the associated outdoor thermal comfort, air ventilation, snow accumulation, rain infiltration and other microclimatic conditions (T. Stathopoulos & Baskaran, 1996). This research is being models by Design Builder software that uses energy plus engine for its calculations.

3-4- Guidelines:

The below table (table 3) contains some standard codes about wind parameters in building complexes.

Table 3: Wind Comfort and Danger Guidelines (Authors)

No	Reference	Wind Speed	Grade	Activity			
				Traversing	Strolling	Sitting	
1	(NEN8100, 2006)	<2.5	A	Good	Good	Good	
		2.5-5.0	B	Good	Good	Moderate	
		5.0-10	C	Good	Moderate	Poor	
		10-20	D	Moderate	Poor	Poor	
		>20	E	Poor	Poor	Poor	
		0.05-0.30	Limited Risk	Acceptable	Not Acceptable	Not Acceptable	
Wind Danger P _(THR) >15 m/s (in % hours per year		≥0.30	Dangerous	Not Acceptable	Not Acceptable	Not Acceptable	
Author		Dangerous Wind Speed				Short	long
2	(Lawson, 1978)	-		U > 7.6 m/s	U > 5.3 m/s	U > 3.6 m/s	U > 1.8 m/s
3	(Melbourne, 1978)	U+3.5σ _u > 23 m/s		-	U 3.5su > 16 m/s	U 3.5su > 13 m/s	U 3.5su > 10 m/s
4	(Isyumov & Davenport, 1975)	U > 15.1 m/s (U > 8 Bft)		U > 9.8 m/s	U > 7.6 m/s	U > 5.3 m/s	U > 3.6 m/s

4- Aims and Methodology

This research aims to collect typically some High-Rise building complexes in Tehran district 22 for extracting common arrangement patterns in this area, then models them with CFD method and compares the results for choosing most suitable pattern of arrangements for this area to providing wind comfort in pedestrian-level.

5- Findings

5-1- Site interview

The district 22 of Tehran city is the newest urban area in Iran country that is developing with new standards and contains many High-Rise building complexes. This is the western district of city and had located in front of the main wind stream from west. Daily population growth and economical extensive developments and etc. have great reflection in physical changes of Tehran, and one of its results is the formation of District 22, which with any doubt was the greatest and vastest urban development linked to Tehran. With approximately 10000 Hectares area, this region has been created for resolve definition of western areas of Tehran and also displacing the people who live in central Tehran's worn-out regions and accommodation parts of Tehran city's population. In District 22, which was has been foreseen in the Comprehensive plan of Tehran, Municipality of Tehran decided to add the North-West lands of Tehran into the services area of the city, so in 1370 and according to the recommendation of High Council of Urban, the Master plan of District 22 was put on the Bavand

Company agenda, with aiming of restoring the lost concepts such as identity, legibility of orientation and positioning for perfect urban spaces. In 1373, studies made by Bavand Company were approved as the Master Plan of District 22. After the approval of master plan, its implementation was faced by various issues, which according to the actual necessity was reviewed by Bavand and Arman Shahr Company again, and the new master plan was approved by Section 5 Commission, and finally after years of effort and study, the Master Plan of District 22 was delivered by Section 5 Commission in 1379/06/08, and Municipality of District 22 was officially activated (District 22 Municipality, 2018).

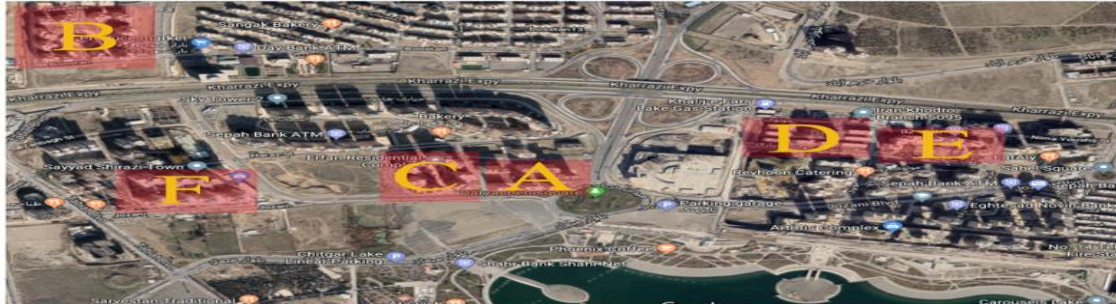


Figure 1: Building Complexes Locations (Authors)

Table 4: Complexes Properties (Authors)

No	Complex Name	Blocks Arrangement	Arrangement Form			Picture
			Shape	Rows	Placement	
A	Ahrar Zaman		Linear	2	Across	
B	Baqeri		Square	Close	Across	
C	Erfan		Circle	Close	Across	
D	Golestan		Square	Open	Across	
E	SarvNaaz		Arch	1	Across	
F	Sayad		Linear	2	Across	

6- Calculations

6-1- CFD Modeling Conditions

Table 5: Domain Boundray Conditions (Authors)

Grid Properties		Wind Behavior		Building Complex Exposure	Site Domain Factors		
Type	Spacing (m)	velocity (m/s)	Direction (°)	Suburban	Length	Width	Height
Uniform	1.00	35	330		1.50	1.50	1.50

Table 6: Wind Speed Categories (Authors)

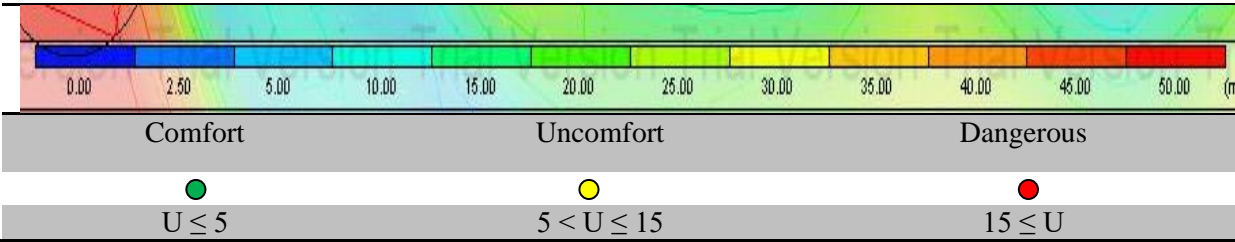
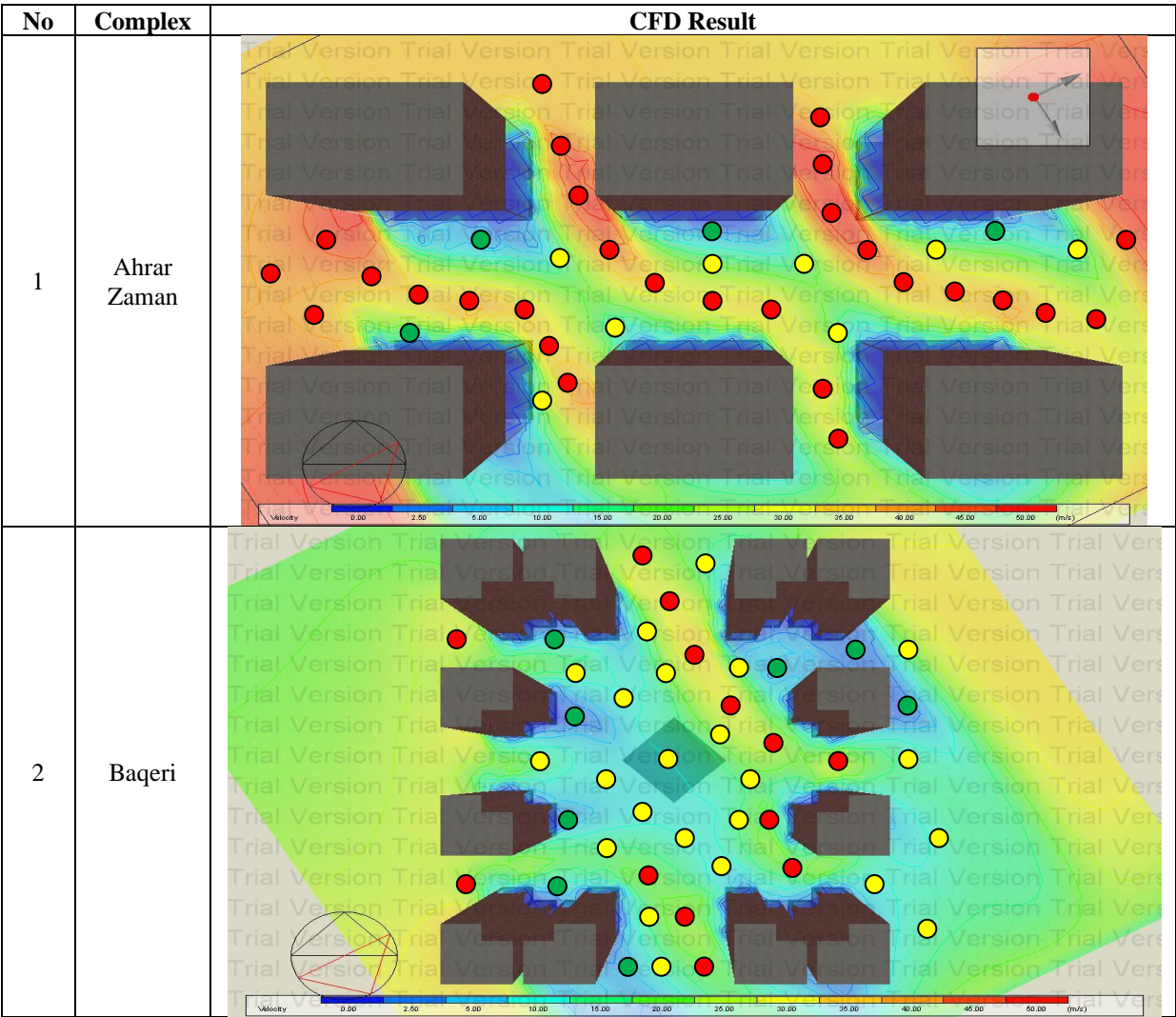
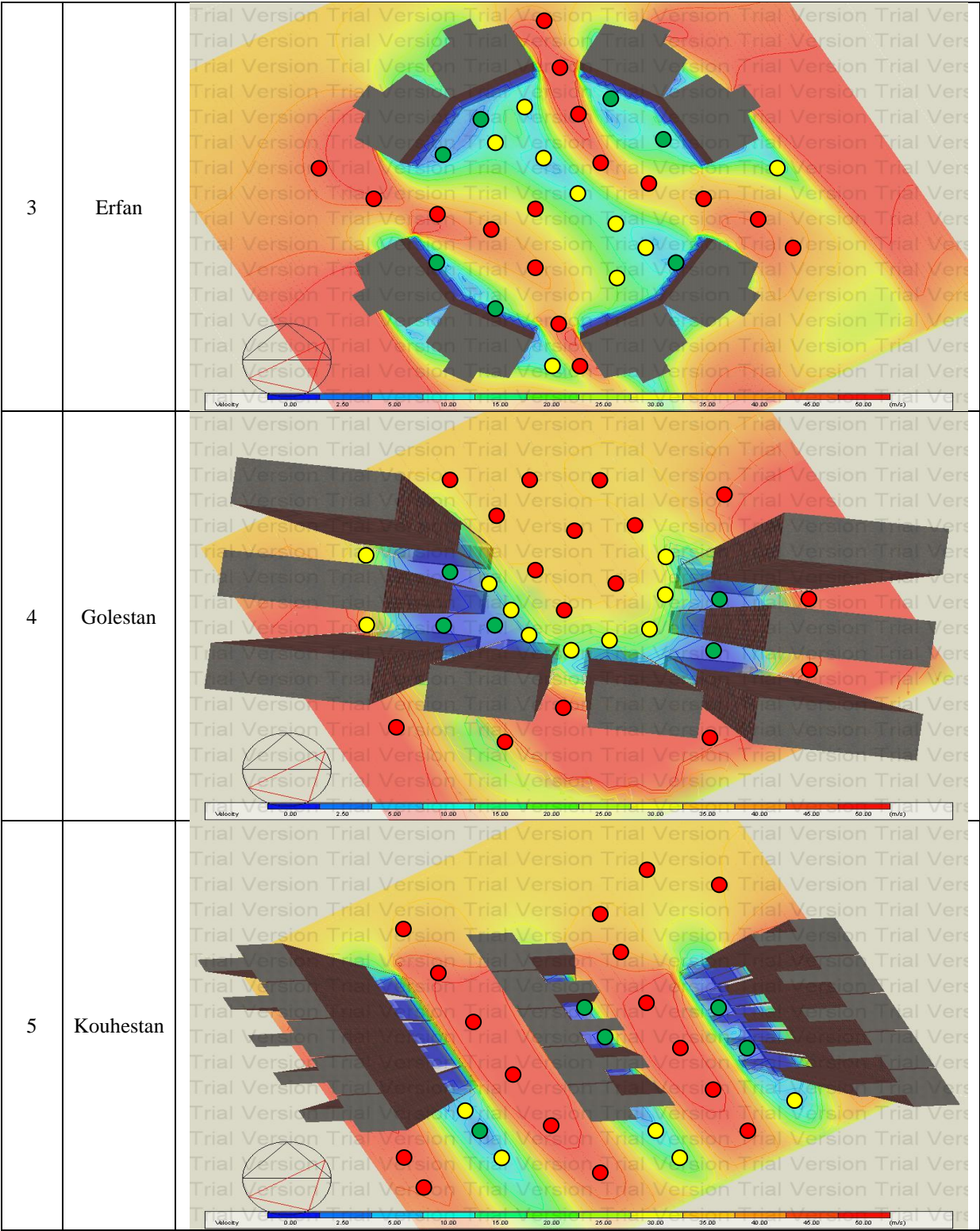
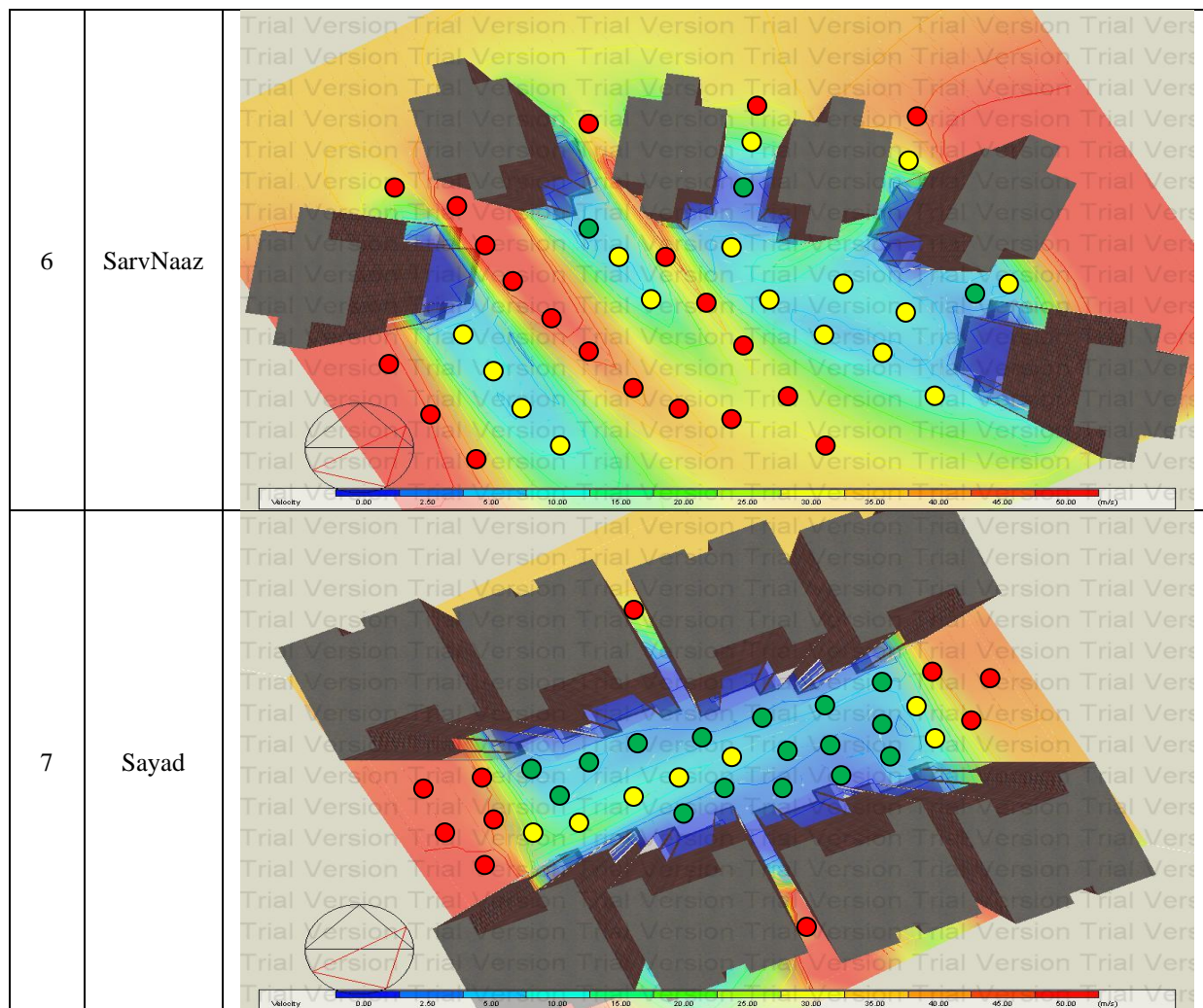


Table 7: CFD Results (Authors)







7- Discussion

According to CDF results have been shows in table (7) wind penetrates to Ahrar Zaman (1), Erfan (3), Golestan (4) and Kouhestan (5) complexes and additional to making dangerous areas, don't leave any walking corridor for crossing the landscape between building blocks. The red points show this dangerous wind blowing that obstacle any pedestrian activities in these complexes. The yellow points in pictures show a uncomfort condition in that areas. Whereas this areas not suitable for sitting but makes safe islands for scrolling and traversing and designers can use them for designing pass roads in the landscape. These areas can be seen in Baqeri (2) and SarvNaaz complexes. And finally in Sayad (7) complex the biggest area with green points can be seen that provides wind comfort for sitting, scrolling and traversing for pedestrians. Whereas the wind comfort area not fully coverage this landscape but it is the only complex that don't have any dangerous wind condition in it.

8- Conclusion

For building a live landscape in High-Rise building complexes the Wind Comfort in Pedestrian-Level must be provided and this will not issues unless wind comfort studies had done before architectural design. For this purpose CFD modeling based on guidelines can be used. According of this research results based on extracted patterns of High-Rise building arrangements, except sayad complex, the others have wind misbehavior in their landscapes. Based on mean wind velocity and direction in

Tehran district 22 the 2 rows linear arrangement of sayad complex with it's partly crossover placement in front of wind direction could provide a suitable wind comfort in pedestrian level. Therefore a linear arrangement that placed crossover to wind direction for providing wind comfort and preventing wind danger is been suggested in this region. Although windbreakers can be used if will necessary.

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