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The Form of Residential Buildings on Local Winds: Air Pollution Reduction

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ABSTRACT: This article addresses the analysis of the mechanism of natural air flow around the residential buildings and the effect of the form of residential buildings on air flow among four building forms in Tehran. The aim of this research is to study the effect of the form of residential buildings on the mechanism of natural air flow with the purpose of optimally utilizing clean air. The research method is to use computer modeling and model analysis in the related software and conclusions have been achieved using comparison of outputs of the models produced. Accordingly, four samples were first selected from software forms and modeled in one commercial micro-climate simulator software. They were tested by entering Tehran climatic data and results were extracted as simulation images. Since the analysis was conducted in one hour interval in the morning of the 23rd of December 2013 among four selected forms. The results helped us to choose the optimal form among these cases. Thus, a general rule was not given regarding the case that the selected form is the best in all aspects. Research achievements indicate that building forms have a significant effect on local winds and air pollution reduction. Therefore, the general form of buildings affects the degree and type of pollution dispersion due to carbon dioxide and the retention effect of suspended particles.

Keywords: *Air flow, Local winds, Residential Building Form, Pollution Dispersion, Retention of Suspended Particles.*

INTRODUCTION

Considering the climate and environmental comfort is one of the old basic concepts in Iranian thoughts and its expression can be seen in the wisdom of Islamic architecture. Consideration of fundamental concepts in climatic design dominates a part of criticism and analysis in the process of architectural learning. It means that considering the particular climatic aspects is of high importance.

In the recent decades, new theories have been proposed based on urbanism problems and expansion of cities, often focusing on stable urbanism and architecture. (Mahdavinejad, Bemanian & Matoor, 2012) Expansion of cities with constructing tall buildings is a characteristic of most of the big cities in the recent century. In Iran, it is almost a half century that we have observed the presence of tall buildings and zone with high density especially in metropolis Tehran. (Mahdavinejad et al., 2014). Although these buildings can respond to some of today issues such as increase in urban population and lack of housing, they created new problems. Concepts proposed in contemporary era with an emphasis on contemporization of the domestic housing pattern of Tehran (Mahdavinejad, Ghasempourabadi & Ghaedi 2012), attempt to establish a reconciliation of teaching based on Iranian traditional architecture and the needs of contemporary cities. On the other hand, the main problem is that tall buildings, if inappropriately located, inhibit the wind flow, increasing "retention effect", "air pollution" and formation of "heat islands" in various regions in a city.

Literature Review

Wind: Significant studies have already been done regarding the effect of air flow (Mahdavinejad & Abedi, 2011) on the degree and type of energy consumption. Sun radiation and change

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in local air flow (Mahdavinejad et al., 2012) also affect the degree and type of energy consumption. Based on definition, Moein dictionary, wind is a blast created by movement of warm air to the cold air. In general, wind is a horizontal movement of air causing establishment of equilibrium among regions with different atmospheric pressure. Wind has a high turbulence at low height (in the first 500 meter layer). Thus, its speed and direction are variable at a certain location. This turbulence is different with that the plane experiences, named uniform movement. Air flow is generally a factor having direct and indirect effects on thermal comfort and its ranges (Mahdavinejad & Javanroodi, 2014). The significant point is that it is used consciously and inactively (Mahdavinejad, Mashayekhi & Ghaedi 2012) in Iranian traditional architecture. The effect of air flow and particularly local air flow on the energy pattern in the building based on the thermal behavior of building roof (Mahdavinejad et al., 2013) is another topic, representing the significant effect of air flow.

Building Forms and Wind Flow: When the wind hits a barrier such as a building or a hill, a high pressure region with high velocity is created, and at the leeward side of the barrier, a low pressure region with low velocity is generated (Razjooyan, 2009). As the wind goes up when hitting barriers, the wind velocity increases. Wind is deviated when hitting earthy barriers such as foothills. However, it does not stop (Brown & DeKay, 2010). When the wind is compressed, its acceleration increases according to Venturi effect, for example, when the wind passes through a gap between two buildings or a mountain pass (Razjooyan, 2007). A wind changing its direction due to earth surface roughness, encounters turbulence and velocity reduction behind the barrier (Fig.1). A wind flowing through a notch attempts to pass above the narrow valleys and gradually reaches wider valleys (Brown & DeKay, 2010). "Katiabatic winds" phenomenon is occurred alternatively in narrow and long steep valleys in mountain region. These winds are light while they are important for residents comfort in warm regions having a regional wind.

Aerodynamic Effect: Wind patterns change in complicated ways when hitting a building form. Architecture aerodynamic science addresses wind behavior and velocity in architectural environment (Gandmer & Giu, 1994). Since the time that the construction of tall buildings has changed the uniformity of old textures, and altered the air flow of surrounding environment, this science has been of interest. As today social and economic procedures will lead to significant changes in present textures, consideration of the architectural aerodynamic principles to control the wind, whether in terms of utilizing wind advantages or avoiding its difficulties and controlling the energy loss, becomes necessary (Razjooyan, 1993).

Building Complexes and Architectural Aerodynamics: Form of the building affects hillside and the method of wind movement (Camuffo, 1998). If several buildings are placed in the vicinity of each other in a way that its aerodynamic zones are different with aerodynamic zones of a single building, they form a building complex. These buildings affect each other. For example,

If several buildings are placed in a row, it is likely that the positive pressure zone of the windward face of second and third buildings is eliminated and negative pressure zone of the wakes of all buildings are connected together.

If two buildings placed adjacent to each other so that the windward zone (positive pressure) of one of them is in contact with the wake zone (negative pressure) of another one, cross flow of windward zone (positive pressure) toward the wake zone (negative pressure) is established.

Knowledge of wind behavior in building complexes for design compatible with the climate is necessary (Rahnamaee, 1990). Therefore, single buildings can be seldom designed in practice in a way that their aerodynamic zones are not affected from the present construction, or they do not affect the aerodynamic zone of their surrounding buildings (Carmona & Steve, 2009). Since architects always intend to create novel works due to tendency to creativity and innovation, construction of various and several building complexes is explainable. However, exact and coherent theoretical basis defining wind behavior in all of the building complexes is necessary. On the contrary, significant information regarding the studies conducted in wind tunnel, which can be the basis of foundations, is available for enthusiasts. These studies indicate that the way of locating buildings in relation to others and the direction of wind is an important factor able to be the basis of classification (Hedman & Jaszewski, 1984). The height is also one of the main factors of architecture aerodynamics. (Fig.1)

MATERIALS AND METHODS

Problem Explanation: Urban spaces are parts of open and public spaces of the cities being typically the expression of collective life nature, i.e., a place where citizens are present. Today the issues of compatibility with the climate and ecological stability proposed as climatic design, having especial comprehensiveness regarding architectural and urban design principles, have a particular importance. Issues such as thermal comfort, saving in energy consumption and controlling its exchange between human and artificial and natural environment is an essential component of this knowledge in urban studies. In addition, conditions of supplying user comfort in complexes and activity spaces imply the necessity of recognition and study of different effective factors in designing spaces compatible with the climate.

Lack of criteria for the design fitted to the environment and climate in Iranian urban design literature, clearly explains the necessity to outline a problem based on "how wind (as one of important climatic factors) and urban form affect each other and its role on urban space quality". This research intend to proceed in this path, take into account the climatic problems in urban plans, and supply the human comfort. Solving the problem, the following research questions are proposed:

Research Questions:

I. How can the air flow affect the dispersion of environmental pollution?

II. How can we design residential complexes based on climatic principles of effect in air flow on pollution dispersion in the

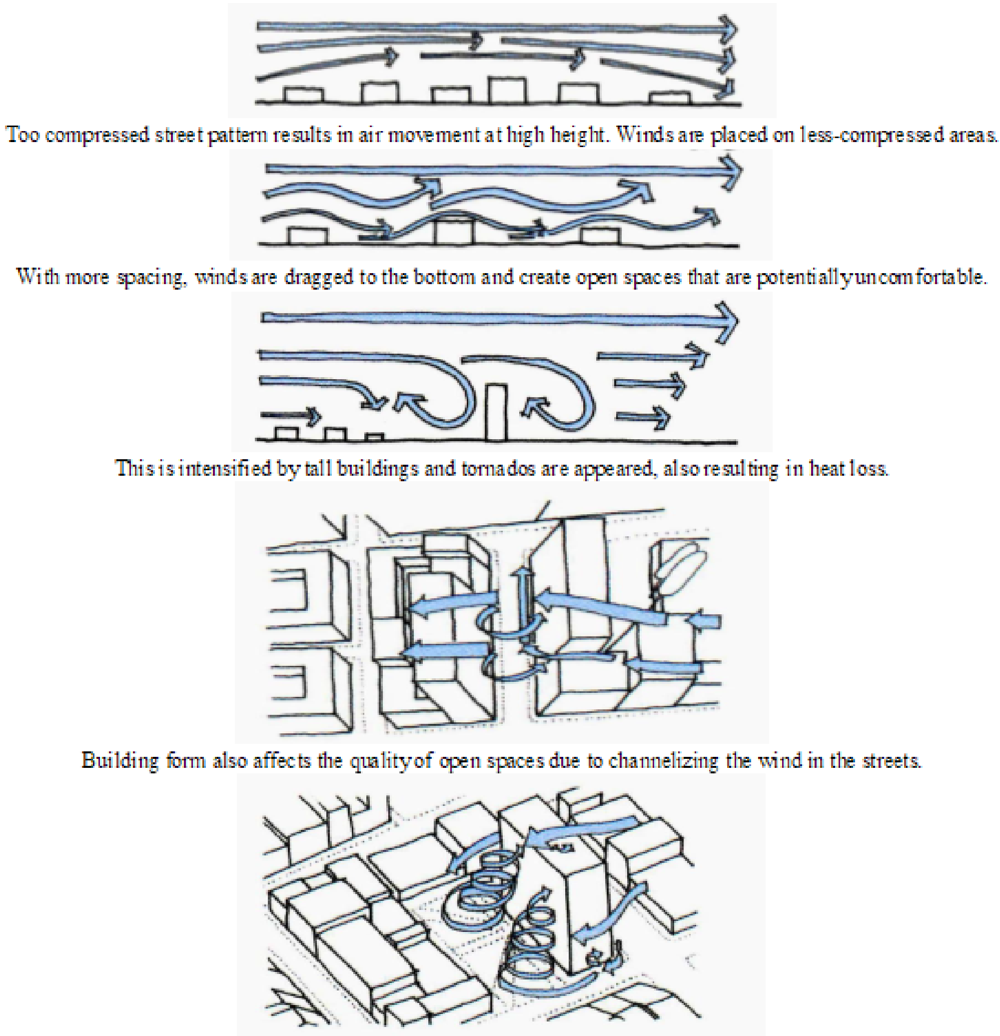


Fig. 1: wind in the urban spaces. (sourceSource: Davis , 2005, 52)

environment?

Research Method: Considering the characteristics of this research, various methods are used in different steps. Research seeks the design of a model in large scale for suitable orientation of the town with the aim of pollution reduction. Guideline of this research is empirical and semi-empirical and established as analytical-explanatory research method. To succeed in this method, computer software is selected as the research tool and library studies are the method of data collection. The present research is mainly based on simulation. However, several methods are utilized in research process due to multi-segment nature. In order to achieve suitable strategies to promote the climatic comfort in open space of residential complexes, documentary, and library studies. Regarding the climate, climatic elements, thermal comfort and parameters effect on climatic comfort have been first addressed. Also, useful thermal comfort indexes in analyzing comfort conditions and theoretical foundations of designing residential complexes in promotion of thermal comfort are investigated. Then, using observational methods and field researches, four options were addressed for the form of residential complexes to simulate in the software. Computer simulation method is employed using the climatic software ENVI-met (Bruse, 2007) as well as selecting the optimal recommended option. Simulation using this software is for climatic analysis, addressing the study and analysis of the present situation in terms of wind behavior etc. Finally, it has addressed selection of the best sample among the options to optimally use the natural air flow.

RESULT AND DISCUSSION

Modeling the Form of Residential Buildings: In this research, a single model for locating four selected building forms is initially designed. In the model created for the four selected forms, all of the items including the location of residential blocks in the site, area of each block, method of access to the site as well as access to the inside of blocks, location of green space and its occupation percentage, material of sidewalk cover and green space have been considered as constant so that the only variable of residential buildings is the form. Therefore, studying the effect of form of residential complexes on the procedure of natural air flow using the mentioned software can be addressed. A constant model designed for this type of arrangement is shown in the Fig. 2.

It is attended in the simulation that all of the common parameters such as green space and location of residential blocks in all options, the same modeling boundaries are used.

In addition, to increase the accuracy of calculations, some parts of the surrounding green space are also simulated in order for the findings related to the wind flow to involve a relatively acceptable accuracy. In the model created, building blocks with the height of 30 m (10 floors), streets, garden inside the central yard of the site with low height green space, a fountain in the center and tree cover around the blocks with the height of 7m is specified. Asphalt is considered for street floor and paving and concrete are considered for yards relative to the pattern type.

After the modeling steps, keeping constant the different items, and achieving the recommended model specified in Fig. 2, it is necessary to model them in the related software. Fig. 3 to 6 of the created models. Four selected forms in the software were used to investigate the main variable being the building forms,. In this software, by entering initial data required for model process, their output including wind velocity, wind speed changes, and wind direction are achieved. It is noteworthy that the focus in this modeling is on intensive middle open space in the site, and change in wind velocity and direction in this part of the yard is significantly affected by the form of residential blocks that will be explained later.

Initial data required for model process is entered in this step. The data are in the height of 2 m in terms of geographical location (Tehran), including longitude and latitude, temperature conditions of the air, velocity and direction of wind, specific humidity and relative humidity and the amount of gas pollution and suspended particles. Calculation time interval in this simulation model was 9 o'clock at the beginning of winter, (12.23.2013). Input atmospheric data was extracted from the nearest barometry station of region 3 and Gheitarieh neighborhood, Tehran.

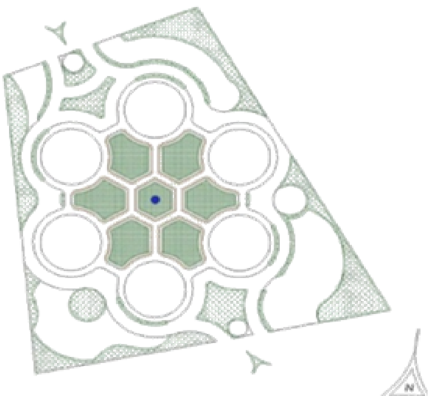


Fig. 2: General raw form to locate 4 selected options.

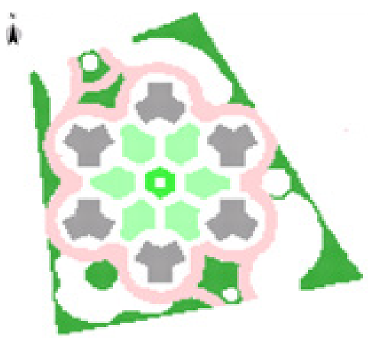


Fig.3: Physical input characteristics in microclimate simulation model in the study domain in the first option.

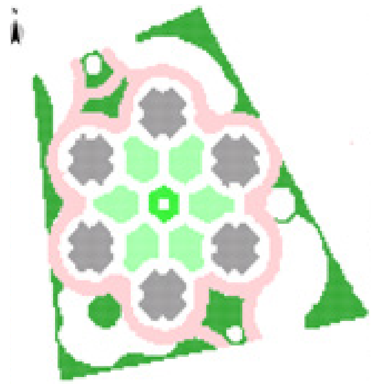


Fig.4: Physical input characteristics in microclimate simulation model in the study domain in the second option.

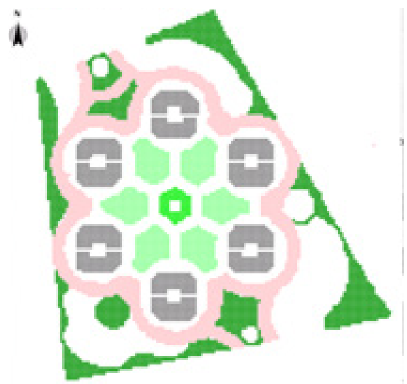


Fig.5: Physical input characteristics in microclimate simulation model in the study domain in the third option.

Fig.6: Physical input characteristics in microclimate simulation model in the study domain in the fourth option.

Wind Speed Changes

Wind speed changes related to the first option is shown in Fig. 7. The degree of wind speed changes in the domain seemed to be in the high range and is suitable. These variations were estimated in the range of 12.59% to 108.65%.

Figure 8 has estimated wind speed changes for the second option which is in the range of 12.16% to 104.81%. Estimation of wind speed changes is simulated in Fig. 9. The degree of these variations is from 12.75% to 122.63%. Fig. 10 has shown wind speed changes for the fourth option. These variations are in the range of 15% to 117.79%.

Retention of Suspended Particles

Analysis associated with the retention of suspended particles PM10 for four selected forms have subsequently been determined (Figs. 11, 12, 13, 14)

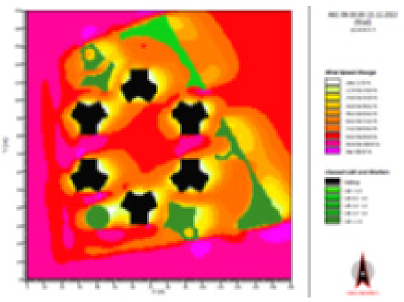


Fig.7: Analysis of velocity variations related to the first option.

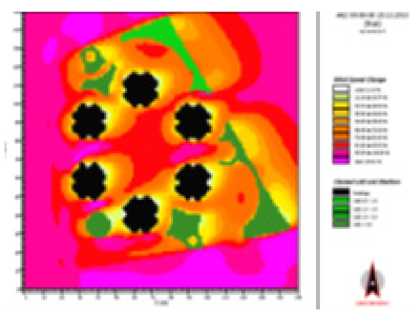


Fig.8: Analysis of velocity variations related to the 2nd option.

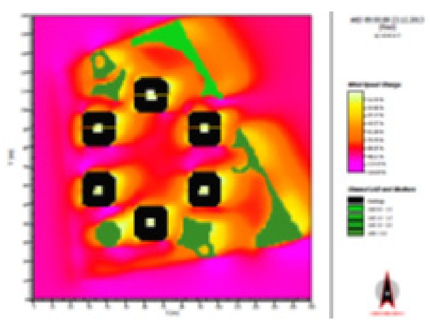


Fig.9: Analysis of velocity variations related to the 3rd option.

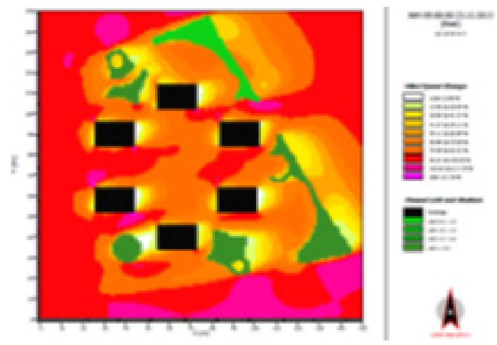


Fig.10: Analysis of velocity variations related to the 4th option.

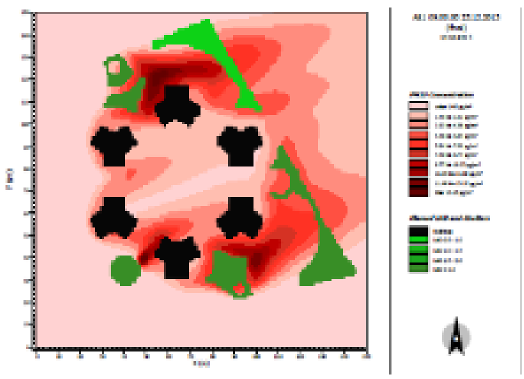


Fig.11: Analysis of the degree of retention of suspended particle PM10 related to the first option.

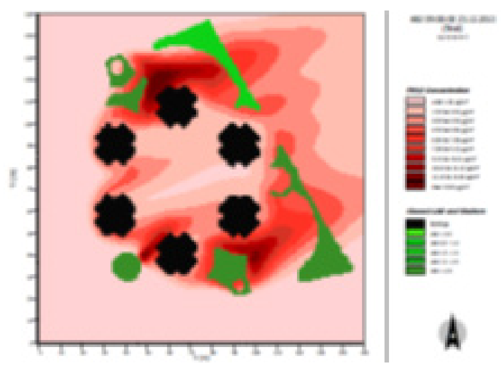


Fig.12: Analysis of the degree of retention of suspended particle PM10 related to the second option.

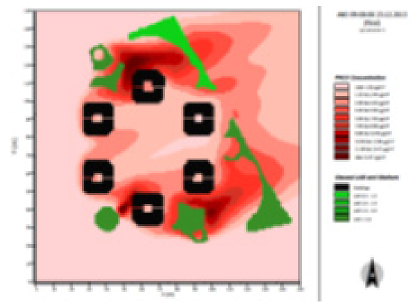


Fig.13: Analysis of the degree of retention of suspended particle PM10 related to the third option.

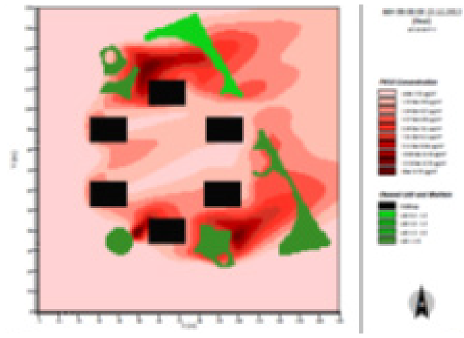


Fig.14: Analysis of the degree of retention of suspended particle PM10 related to the fourth option.

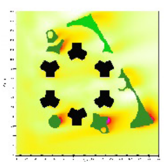
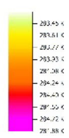
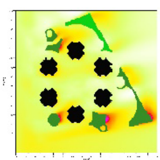
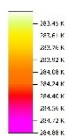
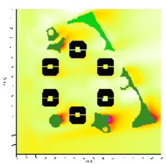
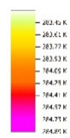
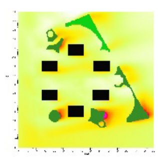
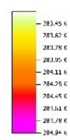
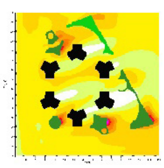
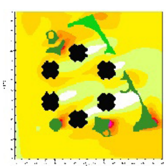
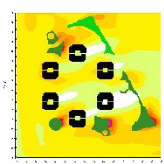
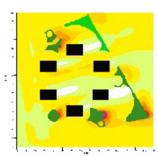
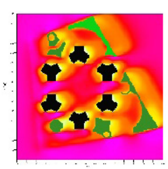
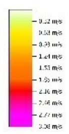
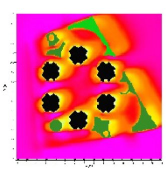
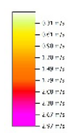
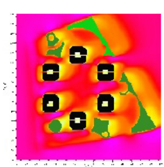
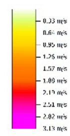
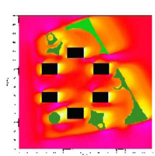
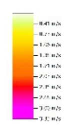
Total and Final Comparison to Select the Optimal Form

Considering what has already been mentioned regarding the selected options and brief comparison mentioned with respect to each option regarding wind speed changes and the degree of retention of suspended particles, the result shows that there is a priority in the selection with the order of option numbers among the four selected options. The form of residential complexes in the first option results in larger air flow velocity in the center of the site than the other three options. This velocity was even more remarkable compared to the second option. In the case of wind direction, we observed movements and variations along with the natural air flow in the first option either in the center of the site or around the buildings. This has been eliminated in the fourth option considering the modeling conditions and keeping all of the design items constant. The reason of these differences may be attributed to the building form. The option selected as an optimal form among the four cases is the first option thus far. However, it is necessary in this stage that the other items are considered such as temperature, humidity and the amount of suspended particles. The comparison between these options can be shown in Tables 1 and 2. Considering the values obtained from the modeling results, the appropriate option can be selected. It should be taken into account that the speedier the wind moves, the more various wind direction emerges. For example, the selected day, on December 23, the higher the temperature and the less the retention interval of suspended particles, the more we close to the appropriate option. In general, taking into account the comparison in Table 2, the first option is selected as the most appropriate form among the four selected forms.

The result is just limited to the simulation analysis in this study. It does not mean that this is the best real option, but it is appropriate because it is effective in the field of air pollution and conventional forms. The purpose of the present study is to investigate the effect of form of selected residential complexes on the natural air flow procedure with the aim of optimally utilizing clean air. It is attempted that the characteristics of wind analysis and its effects on the urban space are determined, in addition to achieving an optimal design pattern among the selected options with respect to the wind. Therefore, the findings are presented based on analysis conducted in the software and the obtained results, with an emphasis on theoretical sketches. Research questions are then answered through examining the effect of form of residential complexes on air flow to analyze the wind behavior around the residential buildings and their public spaces in the selected domain located in Gheitarieh. Four common options were selected from the residential complexes sample. Thus, in order to study them, modeling was done in the ENVI-met software by keeping other items constant. As previously mentioned, items such as percentage and arrangement of green space, the area occupied by each block, flooring material as well as vegetation in all of the options was kept constant. Finally, considering the problem that is to investigate the effect of the form of residential complexes on the procedure of natural air flow by optimally utilizing clean air. Taking into account the items we analyzed the four options in the software, and the first selected item was triple-wing form.

Concerning about the answer to the questions proposed for the first question with respect to the effect of air flow on the dispersion of environmental pollution, studies conducted regarding the wind behavior in different textures and architectural aerodynamic conditions are presented. Answering the second question regarding the design of residential complexes considering wind climatic principles, wind behavior in the samples has been investigated using the modeling of residential complexes samples and their public spaces in the climatic-body software ENVI-met. In order to extend the subject, the procedure of providing comfort inside the building and natural ventilation of indoor air should then be investigated in addition to the simulation of different samples of urban forms in climatic software to determine the optimal patterns and forms responsible to the wind in this scale so that a comprehensive form is achieved and provides comfort and inner natural ventilation to design their outer form appropriate to natural air stream

Table 1. Comparison of temperature, humidity, wind speed and its changed, wind direction and particle retention of the option.

	ALT. 1		ALT. 2		ALT. 3		ALT. 4	
23.12.2013 Morning (am - 10 9)	Contours	Data key	Contours	Data key	Contours	Data key	Contours	Data key
TEMPRATURE								
HUMIDITY								
WIND SPEED								

Continiue of Table 1. Comparison of temperature, humidity, wind speed and its changed, wind direction and particle retention of the options.

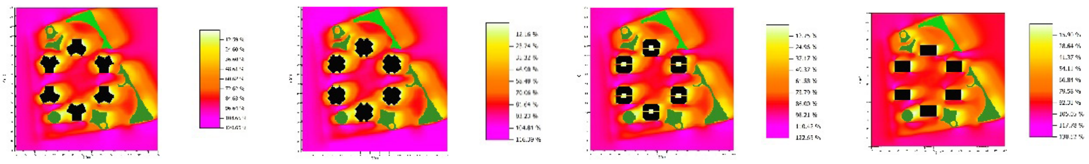
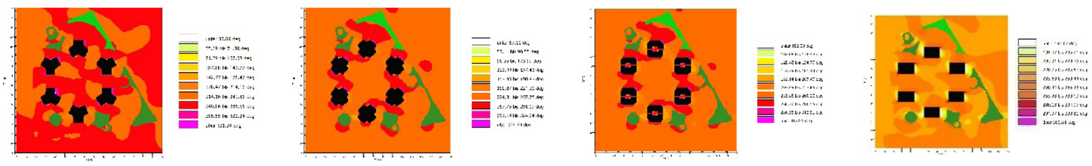
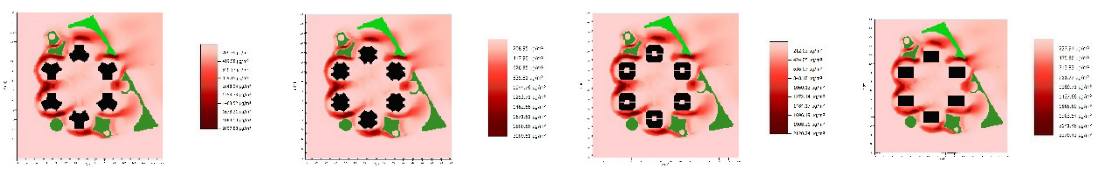
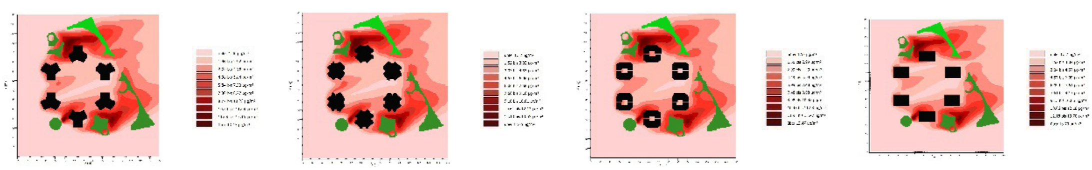
23.12.2013 Morning (am -10 9)	ALT. 1 (Contours / Data key)	ALT. 2 (Contours / Data key)	ALT. 3 (Contours / Data key)	ALT. 4 (Contours / Data key)
WIND SPEED CHANGED				
WIND DIRECTION				
TOTAL DEPOSED PM10				
PM10 CONCENTRA-TION				

Table 2: Comparison of temperature, humidity, wind speed and its changed, wind direction and particle retention of the options.

Morning 23.12.2013 (am -10 9)		ALT. 1	ALT. 2	ALT. 3	ALT. 4
TEMPRATURE (K)	Max	283.45	284.88	284.89	284.94
	.Min	284.88	283.45	283.45	283.45
	.Ave	**289.165**	**284.165**	**284.17**	**284.195**
HUMIDITY (g/kg)	Max	7.25	7.25	7.26	7.29
	.Min	6.48	6.47	6.48	6.51
	.Ave	**6.865**	**6.86**	**6.87**	**6.9**
WIND SPEED (m/s)	Max	3.08	2.97	3.13	3.33
	.Min	0.32	0.31	0.33	0.41
	.Ave	**1.7**	**1.64**	**1.73**	**1.87**
WIND SPEED CHANGED (%)	Max	120.65	116.39	122.63	130.52
	.Min	12.59	12.16	12.75	15.90
	.Ave	**66.62**	**64.275**	**67.69**	**73.21**

Table 2: Comparison of temperature, humidity, wind speed and its changed, wind direction and particle retention of the options.

Morning 23.12.2013 (am -10 9)		ALT. 1	ALT. 2	ALT. 3	ALT. 4
WIND DIRECTION (deg)	Max	321.24	324.64	312.91	309.81
	.Min	35.69	57.11	102.08	191.07
	.Ave	**178.465**	**190.875**	**207.495**	**250.44**
TOTAL DEPOSED PM10 (µg/m^2)	Max	2097.88	2089.51	2120.24	2379.43
	.Min	209.79	208.95	212.02	237.94
	.Ave	**1153.835**	**1149.23**	**1166.13**	**1308.685**
PM10 CONCENTRATION (µg/m^3)	Max	13.15	13.65	13.47	13.70
	.Min	1.46	1.52	1.50	1.52
	.Ave	**7.305**	**7.585**	**7.485**	**7.61**

CONCLUSION

The results of this study indicate that considering the wind direction, wind shadow, turbulence loop of the wind, Venturi effect and channelization phenomenon in residential building design can help more efficient design in the field of productivity in energy consumption and design “efficient energy architecture”.

Comparison of the results obtained from research theoretical literature and analysis obtained from the modeling indicate that controlling the shadows created around the tower in the direction of wind control is possible for using items such as adjusting the building height, the length of wind shadow (length of the wind shadow of the building with the height of 15 to 35 m is equivalent to 4 times greater than its height), and the place of the smallest vertical image of the windward tower. Controlling the formation of turbulence ring phenomenon in front of tall buildings is possible for reducing the tower height to less than 15 m, avoiding construction of short buildings (approximately 10 to 15) in front of tall buildings, increasing environment density near to the tower particularly toward the prevailing wind, creating protrusion in building faces especially in face of tall building toward the prevailing wind, and applying horizontal canopies at the foundation of tall buildings especially steep canopies. The effect of channeling phenomenon is controlled by locating building rows with 45 to 90 ° angle relative to wind direction, creating protrusion and notch in the buildings and prediction of distance more than twice the average body heights between two building rows. The results emphasize on the significant effect of total form of the buildings on the behavior of local wind flow and its significant role on the promotion of air quality.

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