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Efficient Roof Shapes through Wind Flow and Indoor Temperature, Case Studies: Flat Roofs and Domed Roofs

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ABSTRACT: Characteristics of efficient roof shape is a part of configuration of efficient architecture which seems to be an ideal in contemporary architecture especially in contemporary architecture of developing countries such as Iran. This study is to investigate two roof shapes in view of air flow and indoor-temperature to find efficient roofs shapes for residential buildings in Tehran. Computational modeling and simulation methods are applied to reach this purpose. A mathematical modeling along with CFD simulation by Fluent Software is used to determine variables. For simulating velocity and pressure path lines κ-ε standard model and finite difference discretization technique is applied. Results show that a sample room with dome roof is about eight Kelvin degree cooler than the same room with flat roof. Also velocity and pressure simulations indicate that roof geometry has a major impact on reducing heat transfer of room and roof temperature. Finally the study suggests some methods for using results in an operational situation.

Keywords: Flat Roof, Domed Roof, Indoor-Temperature, CFD, Pressure Coefficient.

INTRODUCTION

Efficient architecture and efficiency in architectural design process is one of the most important issues in contemporary architecture especially in contemporary architecture of developing countries such as Iran. It is very important to explain that looking for efficient roof shapes through wind flow and indoor temperature has reached a desirable trend. This paper aims to investigate efficient roof shapes via wind flow and indoor temperature which focused on flat roofs and domed roofs as case studies of the research.

LITERATURE REVIEW

Since the energy crisis in 1970s, the energy conservation is receiving serious consideration not only in Industrial sector but also at residential scale. Climatic design in terms of satisfying the needs of human beings (thermal, luminous and acoustics), has become the important tool for both energy and environment conscious (Zuhairy et al., 1993, p. 522). In other word, making climatic design and energy efficiency is important once again (Sozen et al., 2007, p. 1810). It is now generally accepted that the use of daylight and use of passive cooling to enhance natural ventilation is one of the solutions for energy conservation (Wavewsak, 2000, p. 1810). It appears that architects and builders traditionally had to design with respect to nature and local climate. (Pourjafar et al., 2014, p. 12) This approach also decreases environmental pollution and energy consumption (Oktay, 2002, pp. 1003-04). Energy efficiency and Moisture Problems in Historic Buildings (Mahdavinejad et al., 2013c, p. 310) besides other structural and non-structural components (Mahdavinejad et al., 2012b, p. 135) impacts on residence satisfaction in building industry. With this background, the experiments and construction techniques in traditional and vernacular architecture can be so useful to achieving an appropriate climatic design.

As referring to wisdom of Islamic architecture, interaction of form and function satisfies Iranian Islamic

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principles in architecture. (Mahdavinejad, 2004, p. 58) Mahdavinejad and Mashayekhy (2011, p. 66) findings show that energy efficiency roots in traditional architecture of Iran. Traditional architecture of Iran as well as other valuable architectural styles focuses on interaction of architecture and its context. (Mahdavinejad et al., 2013a, p. 7) Literature review of the paper show that creativity and innovative process in architectural design (Mahdavinejad, 2005, p. 59) emphasize on maximum use of passive and active energy resources in building industry. Efficient adoption of ventilation and enjoyment of efficient thermal comfort are among characteristics of Traditional architecture of Iran.

As related researches showed Plan of Buildings (Mahdavinejad et al., 2013b, p. 64) and other types of openings (Mahdavinejad et al., 2011b, p. 42) play a crucial role in energy load of buildings. Natural ventilation and passive cooling have been traditionally two important features of Old Persian architectures (Yaghoubi, 1991, p. 345). Wind-catchers, courts and ceiling variability have been used in traditional architecture (Mahdavinejad & Javanroodi, 2012a, p. 66). Domed roofs as one of these features have traditionally been used throughout the Persian architecture to cover large areas (Faghih & Bahadori, 2011, p. 1254). Building domes in Iran dates back to the third millennium B.C. Since then, (Amini et al., 2014, p. 133) the architecture of Persia has produced many types of dome structures using traditional methods to make the best forms of domical shapes (Mahdavinejad, 2003, p. 24). Domed roofs in Iran are mostly built with adobe or mud bricks. Great usage of these materials in building construction is due to the abundant of such material and lack of other materials such as stone, timber, etc. (Yaghoubi, 1991, p. 346) However, their low costs and good thermal performance could have been the main reasons for their popularity.

Some researchers have assumed that these roofs were adopted out of climatic and environmental considerations, while others stressed religious and cultural issues of geometry or material (Mahdavinejad et al., 2011a, pp. 291-300). Common among these explanations was the assumption that, in hot dry climates, buildings with curved roofs maintain lower indoor temperatures during the hot summer months and reflect more radiation than flat roofs (Tang et al., 2003, p. 273). Olgyay (1973) emphasized that an advantage of domed roof was their heat flux reducing over a rounded surface compare to a flat roof. Another explanation given for the abundance of curved roofs in hot arid regions was that these absorb the same amount of radiation as compared with flat roofs, but dissipate more heat by convection. (Tang et al., 2003, p. 274). Although building orientation has a major role in final results, but because of lack of relevancy it was not mentioned in simulations.

Hadadvand et al. (2008) studied thermal behavior of vaulted roof in hot and arid climate (265-275). Their study applied numerical modeling and CFD determined air flow patterns around vaulted roof. They found that vaulted roof has a better performance in this climate according to self-shading as compared to flat roof. Faghih and Bahadori (2010) investigated air flow pattern around a domed roof in third model with RNG k-ε equations (161-168). The study shows that pressure coefficient around domed roof has a variable behavior according to its geometry. Gomez-Munoz et al. (2006) calculated solar energy which is absorbed by hemispherical domed roofs and flat roofs in Mexico (268-276). They demonstrated that the hemispherical vault receives around 35% less energy than the flat roofs for the specified conditions. Also Ogawa et al. (1993) developed a two-dimensional finite element analysis for turbulent flow over cylindrical domed roofs. Velayati and Yaghoubi (2004) and Hadadvand et al. (2008) simulated air flow over cylindrical domed roofs, assuming two-dimensional flow, and using control volume method. Blessmann (1971), Taniguchi et al. (1982), Cheung and Melbourne (1983), Toy et al. (1983), Newman et al. (1984), Savory and Toy (1986), Taylor (1991), Yaghoubi (1991),Sabzevari and Yaghoubi (1992), Tsugawa et al. (1992), Franchini et al. (2005), Faghih and Bahadori (2009) investigated air flow over domed roof buildings experimentally and Mahdavinejad et al. (2012) studied the role of form compositions in energy consumption. But the present study followed a different method to finding answers.

Air flow pattern on domed roof building till now has been investigated by means of numerical and experimental methods. Also investigations around indoor temperature subjects are not operative in Iran. But evaluating and comparing these two kinds of roofs in terms of geometry and choosing the efficient form, opposite to air flow and indoor temperature has not been mentioned enough. In order to achieve this purpose sample rooms assumed with no openings, and only roof geometry has major role in simulations. In this paper, a first attempt is made to calculate pressure coefficient, air flow and wind pressure around domed and flat roofs based on solar geometry and two dimensional equations. This allows the assessment of energy efficiency of roof geometry under Tehran climatic data. The aim of this paper was to investigating efficient form of roof in modern architecture of traditional building technologies, forms and elements.

MATERIALS AND METHOD

The paper has applied modeling and simulation methods (Mahdavinejad & Matoor, 2012, p. 32) along with analytical methods. Modeling and meshing was performed by GAMBIT software and simulations were carried out by Fluent 6.3.1 Software. A mesh independence study was carried out to determine the dependence of the flow field on the refinement of the mesh. Mesh had a resolution of 0.2 meter and 0.8 meter throughout the rest of the computational domain. CFD simulation, as a wind assessment tool, is embedded with errors and uncertainties. Thus, for validation purpose a simple cube was measurement and simulated and compared to Abohela et al. (2013) results. Cube was choosing due to simplicity of the shape and the complexity of phenomena around the cube. After validating simulation results, meshing for case studies began. At the next section numerical modeling of wind flow for validating simulations are presented.

Numerical Modeling

A Two-dimensional mathematical model has been applied to calculations. Unfortunately, heat transfer equations dealing with heat transfer through curved and flat roofs are almost impossible to solve by analytical methods due to the instability of solar radiation and ambient temperature (Tang). In engineering calculations quantities related with turbulence flows are important. Thus, equations must be obtained based on turbulence flow. For assessing mean quantities of flow, blow equation can be used:

Can be determined with equation (b):

$$\bar{\varphi} = \frac{1}{T}\int_0^T \varphi dt$$

Time zone (T) in equation (b) is a duration which would not change for continues flows through it. Regarding to equation (b) velocity and pressure in turbulence flow can be determined with equation (c):

$$u_i = \bar{u}_\imath + \grave{u}_\imath$$
$$p_i = \bar{p}_\imath + \grave{p}_\imath, i = 1{,}2$$

With replacing equation (c) in turbulence equations and movement value and after normalization these quantities would be determined through:

Equation (d):

$$\frac{\partial u_i}{\partial \mathrm{x}_i} = 0$$
$$\bar{u}_\jmath \frac{\partial \bar{u}_\imath}{\partial \mathrm{x}_i} = -\frac{\partial \bar{p}_\imath}{\partial \mathrm{x}_i} + \mu \nabla^2 \bar{u}_\imath + \frac{\partial}{\partial \mathrm{x}_i}\left(-\rho \bar{\grave{u}_\imath \grave{u}_\jmath}\right). i = 1{,}2$$

Quantity of [] is placed in equation (d) because of turbulence flow. These equations are approximate and related to problem conditions that can be used. Also differential equations in two-dimensional modeling, including continuity equations, movement value and wasting momentum can be obtained with equation (e):

Equation (e):

$$\frac{\partial(u\phi)}{\partial x} + \frac{\partial(u\phi)}{\partial x} = \frac{\partial}{\partial x}\left(\Gamma \frac{\partial \phi}{\partial x}\right) + \frac{\partial}{\partial y}\left(\Gamma \frac{\partial \phi}{\partial y}\right) + S$$

To take integral from equation (e), normalized equation must be determined as below:

Equation (f):

$$\frac{\partial}{\partial x}\left(u\phi - \Gamma\frac{\partial \phi}{\partial x}\right) + \frac{\partial}{\partial y}\left(u\phi - \Gamma\frac{\partial \phi}{\partial y}\right) = S$$

Finally table 1 shows equation which can presentφ, Γ and S in turbulence equations. Then by integration from above equations we can find air pressure, air velocity and pressure coefficient distribution.

Table 1. φ, Γ and S in Turbulence Equations

Equation	Dependent Variable	Diffusion Coefficient	Source Sentence (S)
Continuity Equation	1	0	0
M Value in X Direction	Velocity in X Direction	$\frac{1+\mu_t}{R_e}$	$-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left(\frac{\mu_t}{R_e}\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\mu_t}{R_e}\frac{\partial v}{\partial x}\right)$
M Value in Y Direction	Velocity in Y Direction	$\frac{1+\mu_t}{R_e}$	$-\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}\left(\frac{\mu_t}{R_e}\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial y}\left(\frac{\mu_t}{R_e}\frac{\partial v}{\partial y}\right)$
Kinetic Energy of Turbulence Flow	Kinetic Energy of Turbulence Flow	$\frac{1+\mu_t}{R_e\sigma_k}$	$\frac{\mu_t}{R_e}G - C_{D^{\varepsilon}}$
Wasting Momentum of Turbulence Flow	Wasting Momentum of Kinetic Energy of Turbulence Flow	$\frac{1+\mu_t}{R_e\sigma_\varepsilon}$	$C_1\frac{\mu_{t\varepsilon}}{R_e}G - C_{2\frac{\varepsilon^2}{k}}$

(Bahadori & Yaghoubi, 2008, p. 286)

CFD Simulations

Modeling and meshing of samples performed by GAMBIT software. Figures 1 and 2 are showing meshing and calculating network for flat and domed roof. The sample room is 20 meters length and 20 meters width with 3 meters height. Main roof placed on a 1 meter base in both conditions. Roof thickness is 0.3 meter and wall thickness is 0.2 meter. Climatic data is applied for hottest mean of the year in July in Tehran (Table 2). Also simulations performed just on one climatic condition because of paper comparative purposes. Moreover, all calculations were based on κ-ε standard model through Finite Difference Discretization Technique or Finite Volume Discretization Scheme.

Table 2. Climatic Data of Tehran, Choosing Hottest Month of the Year

Month	Mean Max Temperature 0C	Mean Min Temperature 0C	Mean Specific Humidity g/kgda	Mean KT Coefficient	Mean-Max Wind Velocity m/s	Mean-Min Wind Velocity m/s
March	24.4	12	5.29	0.55	12.4	6.30
April	27.4	16.5	6.12	0.55	11.4	5.7
May	33.8	21.7	6.78	0.64	6.2	3.1
June	36.8	24.6	8.38	0.64	6.8	3.4
July	35.7	24.1	8.31	0.65	5.9	2.95
August	31.4	20	6.4	0.65	5.9	2.95
September	23.8	14	5.56	0.61	4.9	2.45
October	17	8.4	4.57	0.55	9.8	4.9
November	9.9	2.6	3.8	0.50	11.1	5.55
December	8	0.5	3.3	0.51	9	1.95
January	9.8	1.6	3.47	0.53	11.6	5.8
February	14.6	5.7	4.14	0.53	12.7	6.35

[www.weather.ir] (2014-01-23)

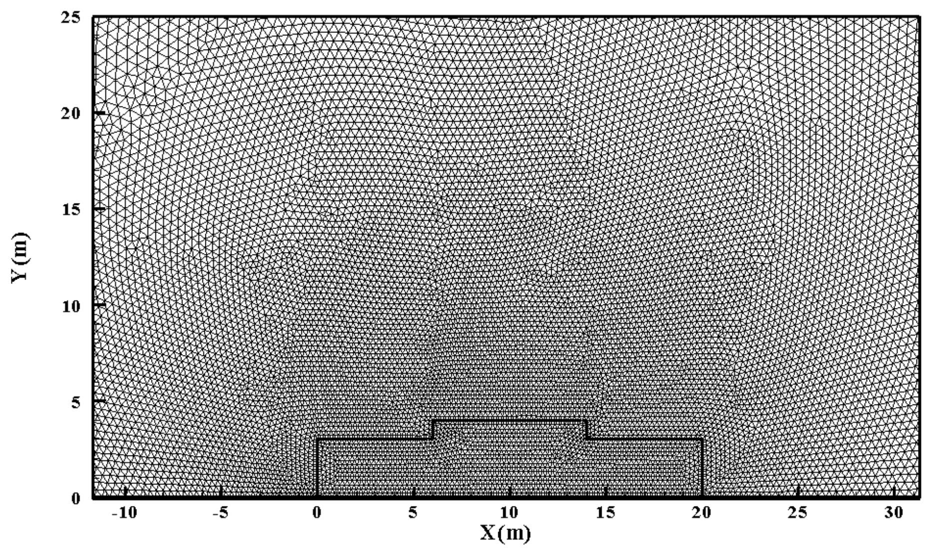

Fig. 1. Mesh Refinement Areas around the Flat Roof.

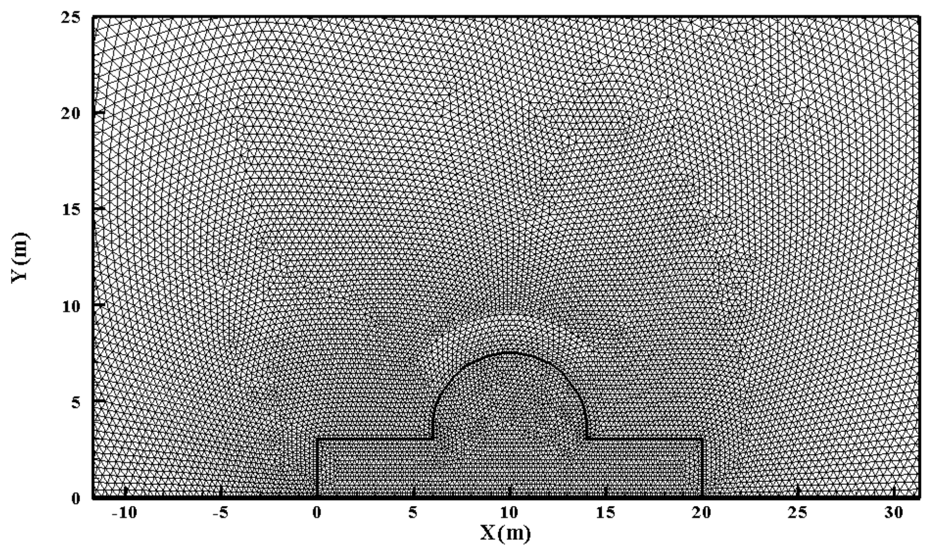

Fig. 2. Mesh Refinement Areas around the Domed Roof.

RESULTS AND DISCUSSION

Figures 3 and 4 are showing wind velocity around flat and domed roof according to climatic data on table 2. Result shows that flow patterns around flat and domed roof sample room consists of some eddies and recirculation regions. For flat roof separation start at leading edge while for domed roof separation occurs after the roof top. Path lines for domed roof with rim angle of 160 degree and flat roof at Re= 105 are presented in Fig. 3 and 4. Pressure is high in the front side of the building, because of flow stagnation and vacuum pressure maintained on the leeward wall due to flow recirculation. Pressure variation is considerable over the roof, while in the front and back side of the buildings, pressures are nearly uniform. Higher air velocities and strong pressure difference for vaulted roofs is observable by comparing the result of contours of velocity and pressure for the domed and flat roofs. As it can be seen, two major rotational movements have emerged in figure 3 and 4. A fluid rotation occurs in the front area and one in the rear area.

Fluid rotation in the back of the domed roof region is much larger and almost detaching is started from the top of the arch and in a place which is approximately 3.5 times of roof's height has reached the ground. Distribution of velocity and flow density, especially on the top of the domed roof is impressive. Speed variation for flat roof is almost different from domed roof. Pressure difference on the front and back of the sample room with flat and domed roof is almost the same. But the pressure difference on the surface of domed roof compare to flat roof is very impressive. The lowness of pressure at top of the domed roof with opening on the head causes air ventilation in the hot-arid climates buy pulling out indoor air to outside, which is not the matter of the present study. But the most important matter is high velocity of air turbulences in the back of the domed roof which causes roof cooling in the domed roof compare to flat roof. This coolness reduces heat transfer and consequently indoor-temperature of the domed roofs.

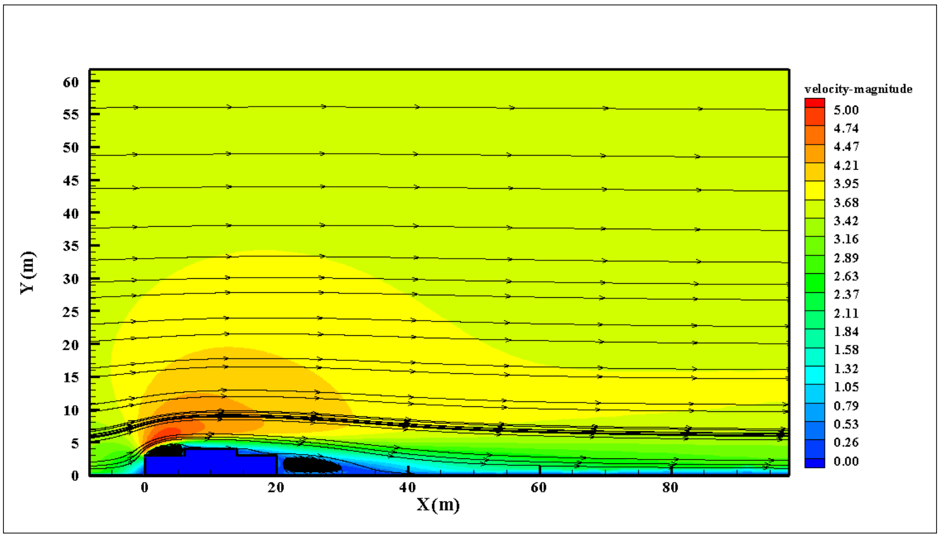

Fig. 3. Stream Wise Velocity Path Lines Passing through the Flat Roof Sample Room.

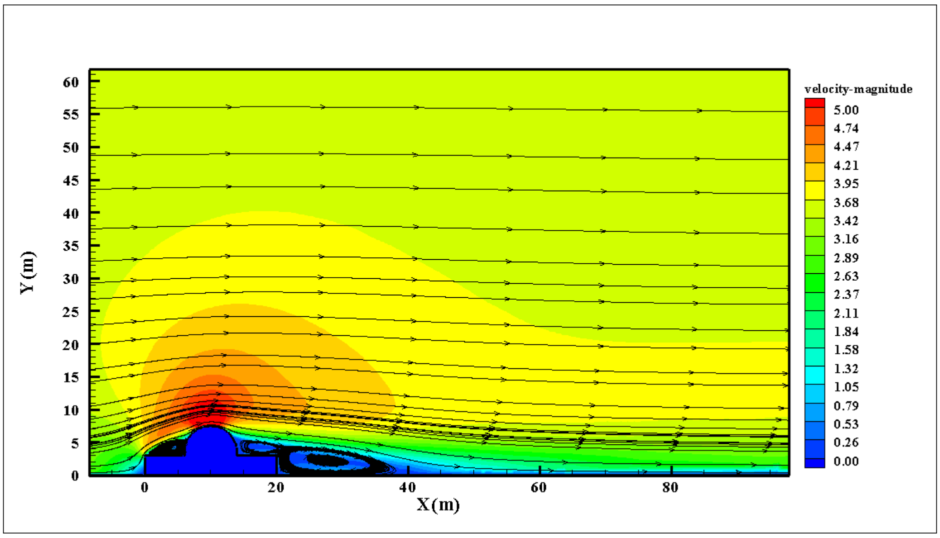

Fig. 4. Stream Wise Velocity Path Lines Passing through the Domed Roof Sample Room.

Also figure 5 and 6 show simulated static pressure for both roofs. As it is clear pressure difference in the front and back of the domed roof is larger than flat roof. This matter could cause larger air flow; if there will be openings in the sample room. Figure 7 shows distribution of pressure coefficient for Re = 105 with a similar condition for both roofs. As graph shows pressure coefficient difference on the flat roof is clearly different from domed roof. Also pressure coefficient is the highest at two separate points, one at a positive value and another at negative value. This value once again shows larger pressure coefficient difference at the domed roof compare to flat roof which can increase coolness of the roof at the day time and consequently reduces indoor temperature which is the main purpose of the study.

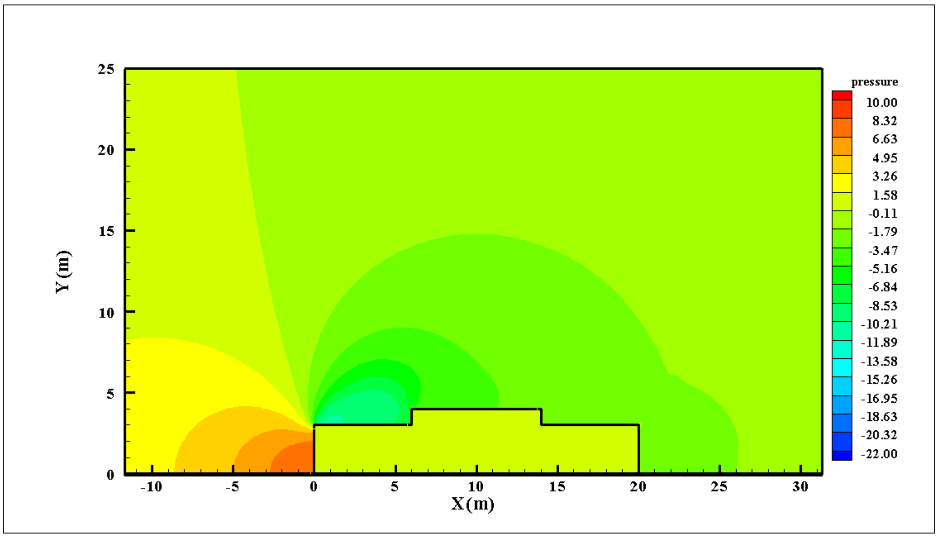

Fig. 5. Distribution of Static Pressure Differences around Flat Roof.

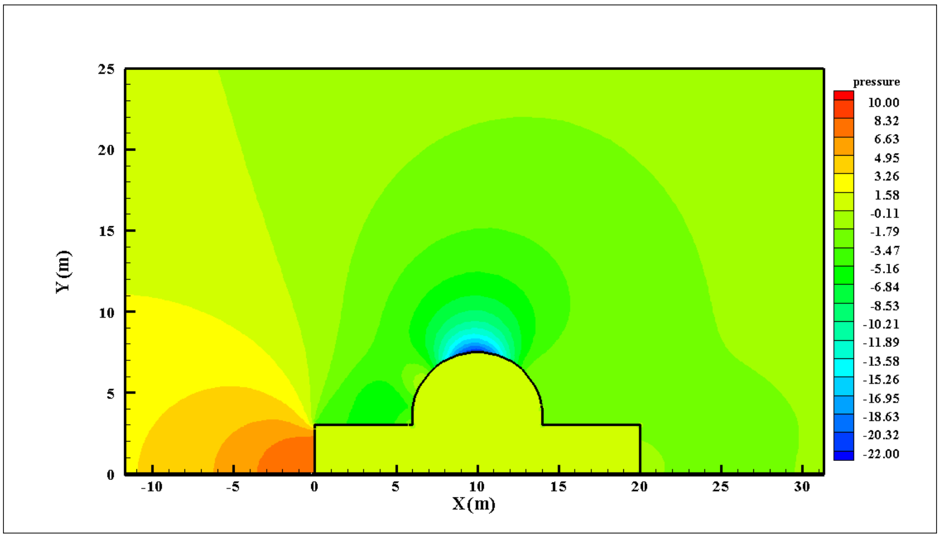

Fig. 6. Distribution of Static Pressure Differences around Domed Roof.

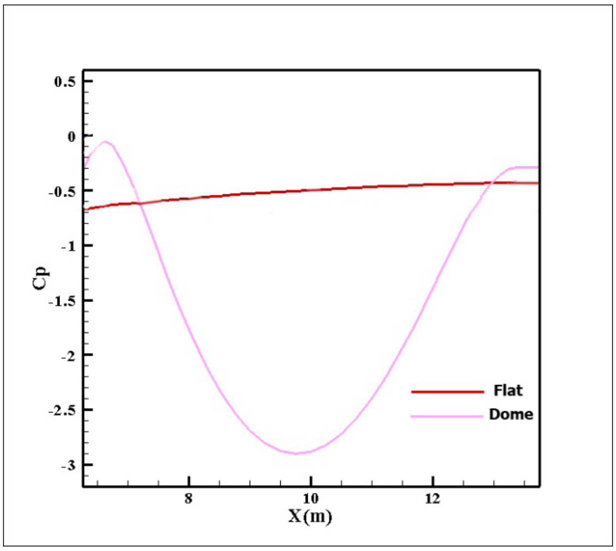

Fig. 7. Calculated Pressure Coefficient for both Flat and Domed Roofs.

But the main purpose of the study, as stated above, is determining indoor temperature of the sample room under these two roof types. Figures 8 and 9 are showing simulated temperature contour for both roof shapes. The sample room is 300 centimeters height and 2000 centimeters length. Floor temperature (or ground temperature) assumed 300 kelvin degrees and temperature layers simulated up to the roof. At the flat roof, the indoor temperature under the main roof is about 306-307 kelvin degree at 100 cm level which almost creates a thermal comfort for sitting situation on the floor. For sitting on a chair at the level of 150 to 200 cm temperature rises to 312-314 kelvin degree and at 200 to 230 cm level rises up to 316-317 kelvin degree. Finally the highest value is 322 kelvin degree and air temperature except under main roof, is uncomfortable for residents.

But comparing to domed roof simulation, in the results of figure 9 some major differences are clear. First, domed roof is 700 cm height comparing to 400 cm flat roof. At this case study, at 100 cm level air temperature is about 303-305 kelvin degree which is lower than the same value in the room with flat roof. At 150 to 200 cm level air temperature is about 309-312 which is remarkably lower than the same value at the flat roof. And finally at 380-400 cm level under main roof 316 kelvin degree temperature is noticed. All in all, these simulations show a better condition for sample roof with domed roof compare to flat roof even with no opening at all.

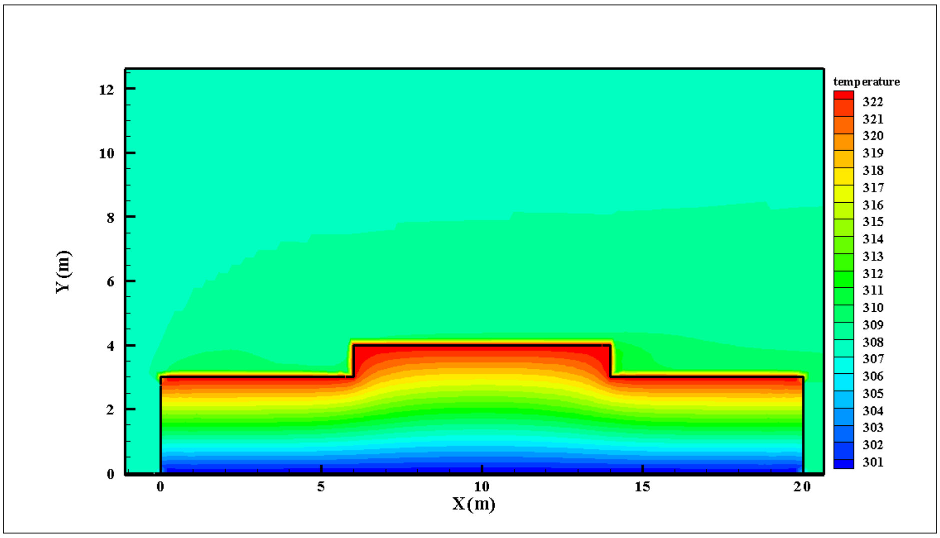

Fig. 8. Distribution of Indoor-Temperature in Sample Room with Flat Roof.

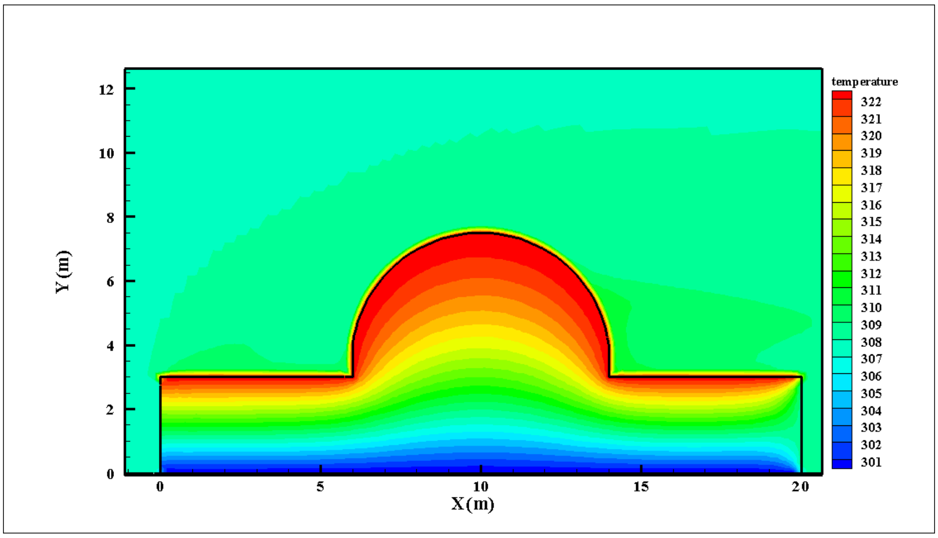

Fig. 9. Distribution of Indoor-Temperature in Sample Room with Domed Roof.

This result is more noticeable at the figure10. The graph at figure 10 is clearly showing air temperature differences from bottom up to top of the both roofs. At the same level, domed roof shows an eight kelvin degree difference comparing to flat roof (Flat roof max= 323, Domed roof max=315). But totally at all levels of the room height, air temperature at the flat roof is higher than domed roof. These results can approve velocity and pressure simulations results mentioned above, which higher velocity wind and pressure difference causes increasing coolness of the domed roof. According to Emmel's study (Mahdavinejad & Javanroodi, 2012), the heat transfer coefficient is strongly dependent on the air velocity and, the effect of temperature difference on the heat transfer coefficient is considerably smaller. This can be explained by the fact that forced convection is dominant for the wind-driven flow cases under analysis. All in all, domed roof with climatic condition explained in the present study has a better performance compare to flat roof.

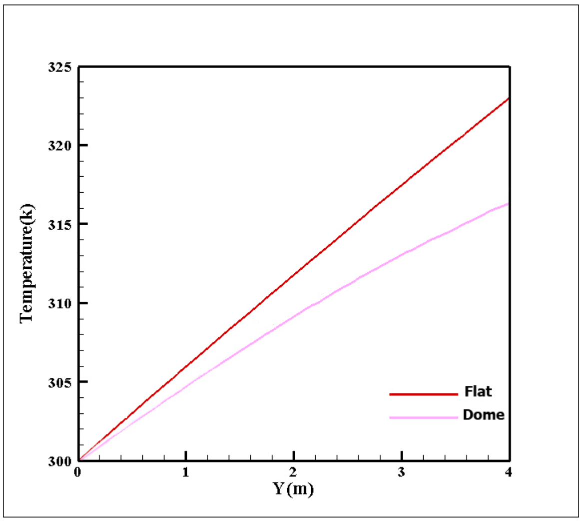

Fig. 10. Calculated Indoor Temperature for both Sample Rooms with Flat and Domed Roofs.

CONCLUTION

Analysis in this study indicates that a non-opening sample room with a domed roof, irrespective of building's type, has lower indoor air temperatures as compared to those with a flat roof during the daytime under the typical hot dry climate condition, just as many researchers claimed and observed in the past. The reason is that such roofs dissipate more heat than a flat room by convectional and thermal radiation during the night, instead of daytime, due to the enlarged curved roof surfaces, Also pressure differences at the front and back of the domed roof building is higher than flat roof building which causes higher speed turbulence flow that can increase coolness of the roof. Because of comparative nature of the present study, some variables have been excluded from calculation, for example time. But what is clear the results are rational and reliable. Paper main findings are listed below:

- Flat roof has a lower pressure coefficient difference as compare to domed roof. Static pressure at the front side of building with domed roof is higher than that in the flat roof.
- Wind velocity and pressure difference at the top of the domed roof is much higher than those in the flat roof. It means that placing a opening at the top of the dome can efficiently help natural ventilation.
- Larger pressure difference at the domed roof case study can be used by placing openings at the opposite sides of the roof for better ventilation, which in flat roof is not remarkable enough.
- Indoor temperature at the room with domed roof is about eight kelvin degrees lower than that in the room with flat roof.
- Indoor temperature at the room with domed roof at different height levels is cooler than that in the flat roof, which can be used for interior designing for different modes of sitting (at carpet or chair or etc.)

The present paper with aid of CFD and numerical modeling found that domed roofs in hot seasons have a better performance than flat roof. Therefore it can be mentioned in building modern design. But using a giant dome in modern design is not rational. Thus more investigation for finding a better solution is demanded. Especially when we account cold seasons in simulations more reliable result can be found. Therefore authors in the third author thesis at the Tarbiat Modares University are investigating more clear findings for obtaining efficient roof shape in modern architecture.

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APPENDIX

Nomenclature	
	Flow Quantity
	Turbulence Index Notation Quantity
	Temperature
	Index Notation of Velocity Components
	Index Notation of Mean Velocity Components
	Pressure Component in i Direction
	Mean Pressure Component Quantity in i Direction
	Turbulence Pressure Component Quantity
	Laminar and Turbulent Viscosity
	Fluid Density
Xi	Stream Wise and Cross-Stream Coordinates
X*	x/H
	Time
	Laminar and Turbulent Viscosity
	Constant Coefficient in Turbulence Model
	Reynolds Number Re = rm1H/m
	Turbulent Dissipation Rate
	Emittance
	Turbulent Kinetic Energy
	Diffusion Coefficient
	Source Sentence
	Total Energy which Receive on an Horizontal Surface
’	Constant Coefficient in Turbulence Model
	Stefan–Boltzmann Constant
Prt	Turbulent Prandtl Number
Λ	Thermal Conductivity
η,η0	Parameters in RNG k–e model
Cp	Pressure Coefficient

RFERENCESS

Abohela, I., Hamza N., Dudek, S. (2003). Effect of Roof Shape, Wind Direction, Building Height and Urban Configuration on the Energy Yield and Positioning of Roof Mounted Wind Turbines, Renewable Energy, Vol. 50, 1106-1118

Amini, M., Mahdavinejad, M., Bemanian M., Varzaneh, E. H. (2014). Developing a New Paradigm for Performance of Educating City Theory in Advanced Technology Mega-Cities, Case: Tehran, Iran, *Journal of Architecture and Urbanism,* 38 (2), 130-141.

Blessmann, J., (1971). Pressure on Domes with Several Wind Profiles. Wind Effects on Building and Structures, 317–326

Cheung, J.C.K., Melbourne, W.H. (1983). Turbulence Effects on Some Aerodynamic Effects of Circular Cylinder at Supercritical Reynolds Numbers, *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 14, 399–410.

Faghih Khorasani, A. Bahadori, M. N. (2011). Thermal Performance Evaluation of Domed Roofs, Energy and Buildings, Vol. 43, 1254–1263.

Faghih Khorasani, A., Bahadori, M. N. (2010). Three Dimensional Numerical Investigation of Air Flow Over Domed Roofs, *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 98, 161–168

Faghih Khorasani, A., Bahadori, M.N. (2009). Experimental Investigation of Air Flow over Domed Roofs. *Iranian Journal of Science and Technology*; Transaction B: Engineering, Vol. 33(B3), 207–216.

Franchini, S., Pindado, S., Mesegure, J., Sanz-Andres, A. (2005). A Parametric, Experimental Analysis of Conical Vortices on Curved Roofs of Low-Rise Buildings, *Journal of Wind Engineering and Industrial Aerodynamics,* Vol.93, 639–650.

Gomez-Munoz V.M., M.A. Porta-Gandara, C. Heard (2003). Solar Performance of Hemispherical Vault Roofs, *Building and Environment*, Vol. 38, 1431–1438.

Groat, L., D. Wang (2002). *Architectural Research Methods*, John Wiley and Sons Publications, US.

Hadavand M., Yaghoubi, M., Emdad H. (2008), Thermal Analysis of Vaulted Roofs, *Energy and Buildings*, Vol. 40, 265–275

Hejazi M.N. (1997). *Historical Buildings of Iran: Their Architecture and Structure*, University of London, Computational Mechanics Publications, 53-58.

Mahdavinejad, M. (2003). Islamic Art, Challenges with New Horizons and Contemporary Beliefs, *HONAR-HA-YE-ZIBA,* (12), 23-32.

Mahdavinejad, M. (2004). Wisdom of Islamic Architecture: Recognition of Iranian Islamic Architecture Principles, *HONAR-HA-YE-ZIBA,* (19), 57-66.

Mahdavinejad, M. (2005). Creativity and Innovative Educational Process in Architectural Design, *HONAR-HA-YE-ZIBA,* (21), 57-66.

Mahdavinejad, M., Bemanian M., Matoor S. (2013b). Estimation Performance of Horizontal Light Pipes in Deep-Plan Buildings, *HONAR-HA-YE-ZIBA,* 17 (4), 41-48.

Mahdavinejad, M., Bemanian, M., Abolvardi, G., Khaksar, N. (2011a). The Strategies of Outspreading Smart Materials in Building Construction Industry in Developing Countries; Case Study: Iran. In 2011 *International Conference on Intelligent Building and Management.* Proc. of CSIT, Vol. 5, 291.

Mahdavinejad, M., Ghasempourabadi, M., Ghaedi, H. (2012a). The Role of Form Compositions in Energy Consumption of High-Rise Buildings (Case Study: Iran, Tehran). *Advanced Materials Research,* 488 (1), 175-181.

Mahdavinejad, M., Javanroodi, K. (2012), Comparative Evaluation of Airflow in Two Kinds of Yazdi and Kermani Wind-Towers, *HONAR-HA-YE ZIBA*, 1 (48), 65-78.

Mahdavinejad, M., Mashayekhy M. (2011). *The Principles of Architectural Design of Mosques with Particular Reference to Socio-Cultural Activities, Armanshahr Arachitecture & Urban Development*, 3 (5), 65-78.

Mahdavinejad, M., Matoor S., Doroodgar A. (2011b). Recognition of Light-Openings in Iranian Mosques' Domes With Reference to Climatic Properties, *International Journal of Architectural Engineering & Urban Planning,* 21 (2), 61-68.

Mahdavinejad, M., Javanroodi, K., Rafsanjani, L. H. (2013c). Investigating Condensation Role in Defects and Moisture Problems in Historic Buildings. Case Study Varamin Friday Mosque in Iran, *World Journal of Science, Technology and Sustainable Development,* 10 (4), 308-324.

Mahdavinejad, M., Bemanian, M., Abolvardi, G., Elhamian, S. M. (2012b). Analyzing the State of Seismic Consideration of Architectural Non-Structural

Components (ANSCs) in Design Process (Based on IBC). *International Journal of Disaster Resilience in the Built Environment,* 3 (2), 133 – 147.

Mahdavinejad, M., Matoor, S. (2012). The Quality of Light Openings in Iranian Domes, *Naqshejahan,* 2 (2), 31-42.

Mahdavinejad, M., Qasemporabadi, M., Mohammadlouishabestary A. (2013a). Typology of Qajar Mosque-Madarasa, *Journal of Studies on Iranian-Islamic City,* 3 (11), 5-16.

Newman, B.G., Ganguli, U., Shrivasatava, S. C. (1984), Flow Over Spherical Inflated Building. *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 17, 305-327.

Ogawa, T., Suzuki, T., Fukuoka, Y., (1993). Large Eddy Simulation of Wind Flow around Dome Structures by the Finite Element Method. *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 46, 461–470.

Oktay, D. (2002). Design with the Climate in Housing Environments: An Analysis in Northern Cyprus, *Building and Environment*, Vol. 37, 1003–1012.

Olgyay, V. (Ed.) (1973). *Design with Climate*, 2nd Edition. Princeton University Press, Princeton, 7.

Pourjafara, M., Amini, M., Varzaneh, E. H., Mahdavinejad, M. (2014). Role of Bazaars as a Unifying Factor in Traditional Cities of Iran: The Isfahan bazaar, *Front. Archit. Res.,* 2014, 3 (1), 10-19.

Sabzevari A, Yaghoubi M. (1992). Air Flow Behavior in and Around Domed Roof Buildings. *Wind Eng*. 16 (1), 27–34.

Savory, E., Toy, N. (1986). Hemispheres and Hemispherical Cylinders in Turbulent Boundary Layers. *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 23, 345–364.

Sozen, M. S., Gedık, G. Z. (2004), Evaluation of Traditional Architecture in Terms of Building Physics: Old Diyarbakır Houses, Turkey, *Building and Environment*, Vol. 42, 1810–1816.

Tang R., I.A. Meir, Y. Etzion (2003). An Analysis of Absorbed Radiation by Domed and Vaulted Roofs as Compared with Flat Roofs, *Energy and Building*, Vol. 35, 539–548.

Taniguchi, S., Sakamoto, H., Kiya, M., Arie, M. (1982). Time-Averaged Aerodynamic Forces Acting on a Hemisphere Immersed in a Turbulent Boundary. *Journal of Wind Engineering and Industrial Aerodynamics,* Vol. 9, 257–273.

Taylor, T.J. (1991). Wind Pressures on a Hemispherical Dome. *Journal of Wind Engineering and Industrial Aerodynamics,* Vol. 40, 199–213.

Toy, N., Moss, W.D., Savory, E. (1983). Wind Tunnel Studies on a Dome in Turbulent Boundary Layers. *Journal of Wind Engineering and Industrial Aerodynamics,* Vol. 11, 201–212.

Tsugawa, T., Hongo, T., Suzuki, M., (1992). Experimental Study of Wind Pressure and Wind Force Characteristics on Dome Shaped Open Able Roofs. *Journal of Wind Engineering and Industrial Aerodynamics,* Vol. 41–44, 1509–1510.

Velayati, E., Yaghoubi, M., (2004). Analysis of Wind Flow around Various Domed-Type Roofs. IMEC, Kuwait.

Waewsak J., Hirunlabh J., Khedari, J. (2000). Designing of a Thai Bio-Climatic Roof, Worm Renewable Energy Congress, 1830-1835

Yaghoubi M.A. (1991). Air Flow Patterns around Domed Roof Buildings, *Renewable Energy*, Vol. 1, 345-350

Zuhairy, A.A., Sayigh, A.A.M. (1993). The Development of the Bioclimatic Concept in Building Design. *Renewable Energy*, Vol. 3, 521-533.