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Evaluation of the thermal performance of the geometry of the domed roof

Jamal Abed al Wahid Jassim
Middle Technical University, Iraq

ABSTRACT

Domed roofs were used for mulching roofs of buildings in Iraq and other countries for them adequate thermal performance. This study aims to evaluate to determine the thermal performance the most suitable roof configuration, reduce indoor air temperature and be useful through hot seasons, taking into account all factors such as radiative heat transfer, solar radiation, wind moving around as well as openings in the dome. Field measurements and research on the performance of the domes were carried out in the city of Baghdad using a computer energy simulation program (Ecotect). Results showed that the thermal performance of a domed building examined is better than that of a flat-roofed building and keeps indoor air relatively cool during the summer. Domed formation has a clear effect on the quantity of received and absorbed solar radiation and the intensity of wind movement around the dome, as well as the negative air flow inside the building. It's good for human comfort.

Keywords: Sustainability; Energy simulation; Hot and dry climate; Thermal environment; Domed ceiling.

Corresponding Author:

Jamal Abed al Wahid Jassim

Middle Technical University, Iraq
E-mail: Jamalalsudany@mtu.edu.iq

1. Introduction

Use the traditional domed ceiling around the world to cover large roof areas. The presence of domes causes the hot air to rise up and keep the ocean temperature moderate, the winds move around the dome and the transfer the load to the surrounding air increases loss of heat accumulated on surface of the dome as a result of solar radiation, the remainder is absorbed by the material of the dome structure and transferred by the convection to the internal air the difference in the geometry of domed surfaces contributes to an increase in wind speed over them [1]. Which leads to an increase in convective heat transfer. Designing buildings as the largest energy consumer compared to other sectors [2]. Reducing energy use in this sector takes priority to reduce carbon emissions [3]. The roof structure is one of the main parts of the building, it has a great impact on energy consumption. Today's buildings need to reduce dependence on mechanical cooling and heating devices based on climate determinants, in this way we reduce the rate of use of fossil fuels and achieve a higher level of thermal comfort conditions. More than two-thirds of Iraq is located in the hot, dry region, and it needs cooling equipment in the summer. Theories and concepts on the quality of the relationship between the shape and the thermal environment have been presented from different points of view to arrive at the ideal shape of the building. The building was one of the forms of adaptation between the internal environment represented by climatic treatments and its requirements and the external influences of the environment [4,5]. The effect of forces around the form is a principle of achieving the ideal form (Sue Ruff.; David Crichton. & Fergus Nicol, 2009) [6].
The difference in domed formation and a cycle in reducing the thermal gain of the roof and the extent of the shape's response to the transmission of solar radiation as a fundamental effect on the thermal gain needs to be studied. Many researchers have been conducted that focused on investigating the negative strategies for optimization configuration depressed energy and building temperature control, and the organized can be an Active supplementary aid. The study Al-Jawadi, Miqdad Haidar, Jamal Abdul

Wahid Al-Sudany, 2010 [1]. We showed the effect of domes on the internal thermal environment of the building in summer and winter, either by Haghighat, F. & Bahadori. M. N, 2011 [7]. We showed that the temperature of the indoor environment with domed ceilings is lower compared to buildings with flat roofs. Either R. J. Mainstone, 1983 [8]. Showed that the decrease in temperature inside the domed building is the main reason for the reflection of the sky and the height of the vaulted ceiling [9]. The role of air flow through openings above the domed was investigated. In another study, they found that the dome ceiling receives more than solar radiation a level roof," A. K. Faghih, M. N. Bahadori". 2009 [10]. As for "A. M. Akbarpoor, A, H. Poshtiri & F. Biglari". 2021 [11]. An integrated cooling system (EAHE) and a domed roof have been tested to show the system qualifies for achieving thermal comfort. As for B. Vasigh, & T. Shiri, 2021 [12]. The shading on the roofs of the dome and the falling and absorbing solar radiation were examined in cold and hot dry climates. The shape of the dome, the type of arch and its height were designed based on thermal conditions. As for M. M. Tavako, M. Yaghoub, G. Ahmadic, 2021 [13]. Measured the features of the air flow velocity wind tunnel around the building, discussed impact of dome location, and made recommendations for designing or constructing buildings with a range of domes. These and other studies represent attempts at thermal performance of the vaulted ceiling, but they do not address the formation of the dome, which determines the most thermally appropriate shape.

1.1. Traditional architecture and domes

Domes are an architectural component similar to the upper half of the hollow ball. Domes were built in "ancient Mesopotamia" and spread in different parts of the world to cover large spaces, and are used in various functional Islamic architectural styles that represent meanings and spatial symbolic connotations in addition to aesthetic qualities, which played an important role in providing passive cooling of the building. In traditional architecture, it was considered the only solution for optimal design, integrated with extreme climatic conditions. The presence of a vaulted ceiling covered with glazed tiles and the possibility of ventilation through windows at the base of the dome. Figure 1 shows the different shapes of domed roofs for a number of mosques. Advances in mathematics, production techniques and materials have given rise to new types of domes, which can be utilised in contemporary architecture in hot and dry regions.

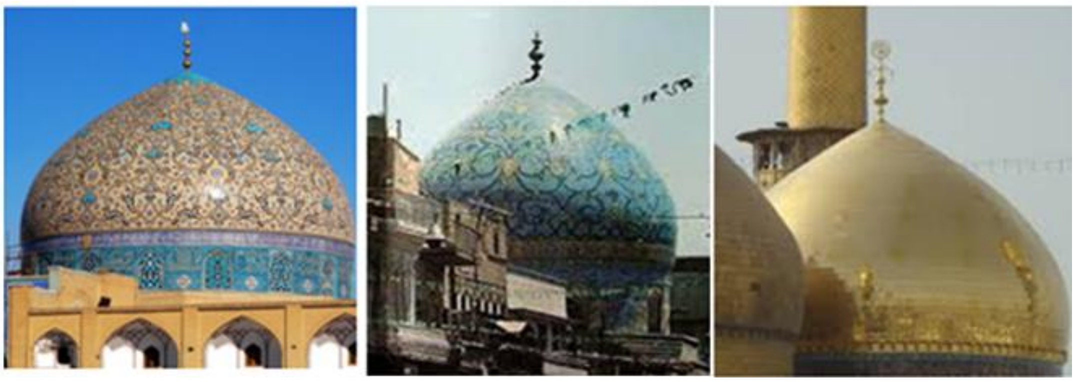

Figure 1. Various forms of domes

1.2. Climate characteristics

The city of Baghdad lies within the hot dry regions at latitude (33◦30'N, 44◦40'E), 34.1 m above sea level. Baghdad's climate is considered a desert climate, and summer is characterised by high temperatures. The high temperatures in Baghdad in recent years have accompanied the phenomenon of light dust storms. The temperature in the daytime reaches 50 °C, and in the winter 9 °C, solar radiation throughout the year, in summer the average sunshine is 12:30 hours/day and in winter 6.30 hours/day, the relative humidity (RH) in June 23% and In December, 72%. The average annual precipitation is 50-200 mm Climatology Atlas No.II for Iraq, Baghdad, 2014 [14]. Nearly entire safeguard of direct sunlight and air movement control that penetrates building is required to realize the thermal comfort requirements of this climate.

2. Equations supported

Each point on the surface of the dome is exposed to different direct solar radiation angles from its neighboring point. Estimation of the solar radiation receiving into a vaulted roof, and the division of the surface into several small roofs, Figure 2 Solar geometries on an inclined surface [15]. Total solar radiation received from a vaulted roof is calculated. For this purpose, many formulas are adopted. In Eq. (1), the solar irradiance (Qs) are assumed to be measured hourly and equal to the rate in the center of the specified radiation hours. Thermal transfer between surrounding air and external surface of the dome are determined in Eq. (2) [16]. The velocity of the movement of air near the surface of the dome was determined numerically and experimentally. Determine ambient air temperature using Eq. (3) [17]. The transmission of thermal radiation to external surface of the dome, the sky and earth definition from the Eq. (ASHRAE, ASHRAE Handbook-Fundamentals, 1997) [18]. Note that it is supposed to be equal to 0.85. Many equations are adopted for this purpose. The second method is numerical simulation using a computer energy simulation program (Ecotect). (www.torrents.net/torrent/269050/Autodesk-Ecotect-Analys) [19].

$$\mathbf{Q_{abs} = Q_s + Q_c + Q_{rs} + Q_{ra}} \quad (1)$$

$$\mathbf{Q_C = h_o\, A(T_{ao} - T_w)} \quad (2)$$

$$T_{ao} = \left(\frac{T_m + T_n}{2}\right) + \left(\frac{T_m - T_n}{2}\right).\ Cos180\left(\frac{t-15}{12}\right)) \quad (3)$$

$$Q_{rs} = \epsilon\sigma\left(T_S^4 - T_\pi^4\right)\left(\frac{1+cos\beta}{2}\right) \quad (4)$$

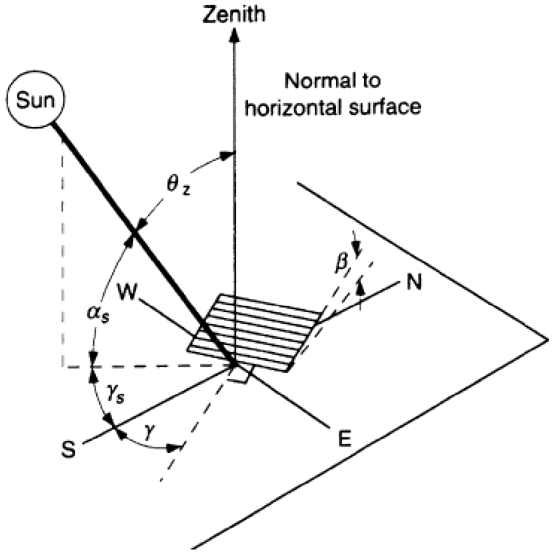

Figure 2. Solar radiation geometry on an inclined surface (J.A. Duffie, W.A. Beckman, 2006) [15].

3. Research methodology

This study focused on the hot, dry climate, the city of Baghdad, different shapes of domed roof were used, and they were classified into nine types depending on the method of formation, height, radius of the base 4.0 meters, as shown in Figure 3, field measurements were made for one of the study models in Baghdad. For three consecutive days 15, 16 and 17 for the times 9 AM, 1 PM and 3 PM for the months January, July, September 2020 using the Hot Wire Thermo-Anemometer Model 407123, the air movement on the surface of the dome INNOVA 3320, Table 4. Analysis of the first step To develop and build the calculations model with the help of the (Auto CAD) program to determine the area exposed to solar radiation, and the program (Ecotect) was applied to build a study of nine file models, (Ecotect) weather data for a program that does not contain data for the city of Baghdad. They have been included in the program for this purpose.

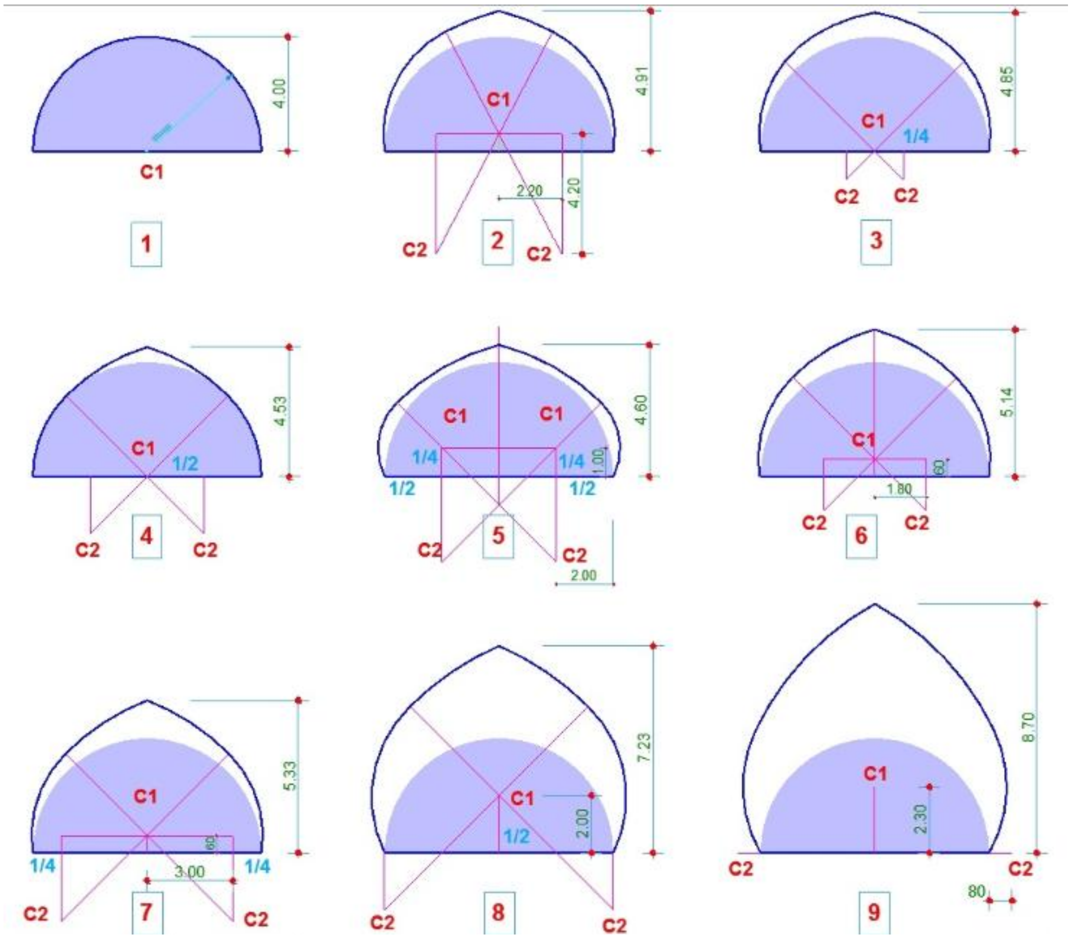

Figure 3. Shapes of domes

Table 1. Variation of the area exposed to solar radiation for domes models (July2020)

Dome shape	D. 1	D. 2	D. 3	D. 4	D. 5	D. 6	D. 7	D. 8	D. 9
Total area	703.803	740.312	829.808	745.673	836.806	878.288	1053.856	1092.093	1419.821

Table 2. Receive solar energy for domes, heat transmitted in summer and heat loss in winter

dome shape		D. 1	D. 2	D. 3	D. 4	D. 5	D. 6	D. 7	D. 8	D. 9
Solar- received	Solar-received (Summer)	495.721	530.369	605.252	523.306	598.459	631.702	637.601	805.251	862.749
	Solar-received (Winter)	180.501	198.545	227.416	195.178	226.548	253.687	242.406	337.948	361.670
Absorbed and Heat loss	Absorbed (Summer)	16440.326	18157.77	20557.33	18080.35	20806.87	21883.798	22501.97	29200.28	31244.671
	Loss (Winter)	6633.104	7464.80	8956.351	7536.341	9457.063	9541.820	10148.09	14169.31	15161.702

Table 3. Wind speed and thermal resistance of the outer surface [Researchers]

Shape	wind (m s^{-1}) speed	(m^{2}KW^{-1}) *Rso*
D. 1	3.12	0.0573
D. 2	3.35	0.0534
D. 3	3.20	0.0559
D.4	3.55	0.0504
D.5	3.60	0.0497
D. 6	3.96	0.0452
D.7	3.71	0.0482
D.8	3.62	0.0494
D.9	3.65	0.0490

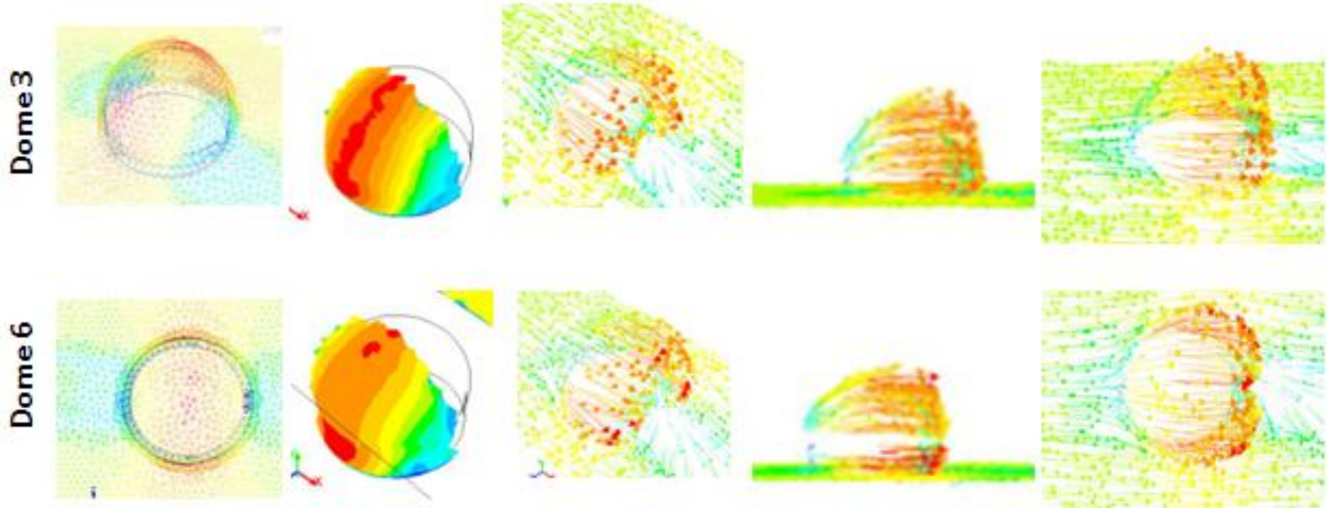

Figure 4. The difference in the speed and pattern of Air moving to models dome

Table 4. Difference in direction of wind and energy received (July 2020)

Wind direction	Dome	Max. Ht (MJ/day)	Absorbed Ht αn = 0.8	Absorbed Ht αn = 0.4
South	D.1	132.4	63.7 %	44.5%
	D.3	135.1	64.9 %	45.4%
	D.6	122.6	57.8 %	34.5%
	D.9	159.2	76.4 %	44.8%
North	D.1	132.4	66.1%	36.3%
	D.6	122.6	61.2%	33.6%
East	D.1	132.4	65.3%	36.2%
	D.6	122.6	60.4%	33.4%
West	D.1	132.4	68.7%	38.2%
	D.6	122.6	63.6%	35.4%
No wind	D.1	132.4	74.3%	48.7%
	D.6	122.6	68.7%	45.0%

Table 5. Numerical simulation, thermal network method and variation of the indoor air temperature coefficient depending on the roof.

Wind direction	Type of Roof	Roof absorbs Coefficient	Shape Factor	Thermal Network	Numerical Simulation	Practical Measurements
			Maximum Temperature (°C)	Maximum Temperature (°C)	Maximum Temperature (°C)	Maximum Temperature (°C)
South	Dome 1	0.8	41.60	43.20	41.10	40.70
	Dome 1	0.4	37.70	40.63	38.10	37.55
	Dome 6	0.4	40.50	43.58	41.20	39.90
	Flat	0.8	44.55	44.90	44.80	44.30
Ambient air temperature			38.10	38.10	38.10	38.10

4. Results and discussion

To achieve the aim of the research was conducted field readings for a dome model in the city of Baghdad were adopted in the design of a computer program selected to represent the number of forms 9 models, domes that have been tested by the dome begins hemisphere and share a radius of 4 m base and different in form and height. Table 1 shows the projected area of the vertical exhibition of solar radiation and different area for each model during daylight hours. Using solar radiation data for the city of Baghdad, Table 2. Shows solar radiation between the elected models in terms of exposure to solar radiation increases gradually with increasing elevation angle of the sun spreads has achieved model 9. 213. 66m2 area received more solar model 1. An area of 100.36 m2 less up to 42.49%. The total average hour of solar radiation received by these species per unit area is always less than the flat roof during the months of daylight in the summer. The cold season has made the model 9 received the most models 1 at least up to 49.95%, Because of the difference in energy received for the roof. When calculating the thermal absorption and this is what concerns us and described in the Table 2 Depending on the value of standardised building materials domed roof with thermal conductivity U-value=1.085w/m2k Assuming that the fourteenth day of each month represents readings that month during, the year. A comparison between the forms of energy domes and set out their findings in Table 2. Measuring speed of air move at various points on a roof of the dome using a variable (Hot-Wire thermo-anemometer model 407123). And described in the Table3 and figure 6. Determine the thermal resistance of external surfaces. The used numerical simulation of three-dimensional wind flow around the domed roof elected [2]. Table 4. Energy Received and Absorbed Ht.

5. Conclusion

According to the analysis made, the conclusion could be the following drawn: Thermal performance under study for a dome roof is more appropriate than that of a flat roof on hot days, with the shape of the dome differing. Wind direction in flow is not an important criterion, lowering the building temperature. Negative caused air to flowing into the building from openings in the dome works better and is beneficial for human comfort on hot days. In this study, assuming that traditional architecture for many years has had less need for fossil fuels, and fulfils human comfort conditions; Leveraging elements of traditional architecture in reducing energy consumption with new solutions and sustainable building design has been investigated. Thermal performance of dome models with different domed formation due to the difference in the area exposed to solar radiation and the difference in the absorbed energy of domed models. Increasing the speed and pattern of wind movement leads to reducing the thermal resistance of the outer surface and removing heat accumulation from the surface of the dome. Approaching the mathematical engineering proportionality system of the dome can achieve the design of different configurations of the dome and choose what is suitable for the design. It was given better competence in achieve summer and at the same time higher competence in winter.

Receptive designs of dome formation must match the climatic constraints. There are several options for the designer. The appropriate formation of the dome can be selected, as well as achieving an efficient thermal performance of the domed ceiling to reach a sustainable design.

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