"Shape Factor" New Concept as a Determinant The Thermal Behavior of the Domed Roof: A Comparative Study

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Abstract—Domes used widely to cover the roofs of buildings, including mosques, The purpose of this paper is to study the role of the formation of the domed roof of the thermal behavior and find a formula a relationship by which to reach to determine the landmarks most efficient shape that are not addressed by the previous concepts. This research method is based on field research and simulation modeling to investigate this aim, By comparing the number of elected domes, where it has been conducting field measurements during the recording for three days of temperatures and air move around the model of the domes in a city of Baghdad. The results were applied field measurements to develop computer baseline model experimentally and selecting nine shapes domed to identify of the area prone to solar radiation and the measure of receiving and absorbing of models. Later, the investigation of the performance of the domes using computer energy simulation program (Ecotect). The results of the analysis and simulation indicate that the formation of domed roof has a clear impact on the amount of solar radiation absorbed and received and the behavior of the air to move around the dome. Results were compared with the thermal parity concepts (S/V) It gave the index can not be adopted in the formation domed because he has achieved the worst thermal behavior, And compared with different characteristics and reached research to a new concept "Shape Factor" Represented by the relationship of height with the radius of its base(H/R)Where it showed the form incompetent thermally has achieved ratio (1.3) At the same time it approached on the system mathematical geometric proportionality of Islamic architecture generated from $\sqrt{2}$ Index to form thermally of competence with the ability to achieve different designs for Dome. This means that the dome over what seemed like Least higher the most appropriate in the thermal behavior because it has less area exposed to solar radiation and the highest air move.

Index Terms — Domed ceiling, Energy simulation, Flat roof, Hot and dry climate, Shape, Thermal performance. .

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1 Introduction

The Domed roofs used for long periods to cover for large spaces. It is one of the architectural elements the most distinguished in Islamic architecture, play expressive and symbolic role at the same time. As well as its role in reducing the total heat gain of the roof, in order to reduce spending on energy put forward theories and concepts in architecture from the quality of the relationship between shape and the environment from different views to devise ideal shape of the building. Architectural shape one of the images of adaptation and the outcome of the deal is the environment external influences and internal influences are the human and requirements [1]. The principle of the ideal shape is a homonym to try to impact forces around the shape of an approach to a climatic performance required [2]. Domed roof played a role in reducing the total heat gain of the roof, but the difference in the shape and characteristics of domed the extent of shape a response to solar radiation as an influence environmental effects need to study. Miqdad H. & Jamal A, (2010) [3]. Studied the importance of domed roofs in reducing the total heat gain of the building in the summer and warm, dry areas as well as aspects of symbolic and aesthetic. Haghighat & Bahadori, (2011) [4]. Installed the thermal performance of the domed roofs is better than flat roofs, especially when it is covered with a glazed tiled dome with openings to flow the air inside the building. Basharat Jamil, & M. Ahmad Jamil, (2011) [5]. He explained that the building is dome shaped behavior in temperate climates acceptable in the summer and winter. Faghih & M. N. Bahadori. (2009) [6]. Verified experimentally that the air flows between the opened windows and aperture at the top of the dome. Mohammad Javad, M. & Mahya, H, (2013) [7]. Explained that the thermal performance of the domed roofs of at least rise more suitable because it has less space. Faghih, A. & Bahadori, M. N. (2009) [8]. Studied insolation receive and absorbed four surfaces of the dome and comparison with flat roof before. It is shown that domed roofs and received more solar radiation. Mohammad javad et al. (2015) [9]. Studied analyze wind speeds at the domed roofs and the efficient use of energy through the experimental verification of Wind Pressures on a Hemispherical Dome result with other relevant for calculating computer studies and in the wind tunnel model and the possibility of using accounts were held instead of the actual measurement. In any case, these studies and other studies been attempts to evaluate the thermal performance of the domed ceiling compared with the flat roof, which can be changed to different considerations such as size, shape, color, and materials that cover the dome. Did not address the formation domed properties of the thermal behavior relationship defines the shape domed optimum and best suited thermally.

The purpose of this research evaluating the role of the formal properties of the domed roof of the thermal behavior in the hot dry areas, including the city of Baghdad, and the creation of a relationship determines the most efficient form. And adopt a database could be used in designing sustainable housing in the future. This could include studying various environments.

To achieve this objective has been conducting field measurements and analysis of mathematical thermal behavior of forms domes toward the solar radiation effects and to estimate the effects of air mov-

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ing around the dome on the solar radiation overall uptake of roof as example of the method of quantitative evaluation by designing designing software program making easy calculations, Followed by the using computer energy simulation, "ECOTECT" and testing of nine different types of domes and comparing simulation results to verify the accuracy of the results. The study results will be beneficial in the evaluation of the thermal behavior of the domed ceiling and reduce energy consumption, and can help the designer to make a decision in the form of a dome. And embrace and employ traditional concepts in contemporary forms.

1.1 Domes and traditional architecture

Domes used in different parts of the world to cover a wide area, and used in the patterns of different functional Islamic architecture, including mosques, shrines and schools, khans, has mastered Islamic architecture to show the beauty of the dome to represent the meanings and connotations and symbolic connotations spatial, different configurations and types including double crust domes and domes conical. And played another important role in the reduction of the total heat gain from the ceiling, And to provide passive cooling of the building, Many studies have indicated to the importance of domed ceiling in reducing the overall heat gain to the building in the summer in the tropics dry as well as aspects of symbolic and aesthetic, it was sometimes considered the only solution for the design of optimal in traditional architecture and dealing with climate parties. Having a domed roof covered in glazed tiles and the possibility of ventilation through windows at the base of the dome. Fig. 1 shows the pictures different shapes of domed roofs of a number of mosques. Has made use of contemporary architecture in hot, dry areas, in addition to the aesthetic qualities, but there are many questions raised in the recent period because they represent a large area, and this means that they receive the largest solar radiation, these questions and other questions need to be answered.

Fig. 1. Shows the pictures different shapes of domed roofs of a number of mosques

2 Climate Characteristics

Baghdad is part of the hot dry areas are located at latitude (33°30'N, 44°40'E) above sea level 34.1 m, to reach the temperature in the daytime summer 50°C, and in winter 9°C, Solar radiation throughout the year, average sunshine hours 12:30 hours / day in summer and 6.30 hours / day in the winter, and the relative humidity (RH) of 23% in June and 72% in December. Annual rainfall 50-200 mm [10]. That required almost full protection from direct solar radiation and control of the air currents entering the building in achieving comfort in such a climate.

3 Governing Equations

Solar radiation the most effected factor for shape the building and the elevation angle of the sun through the seasons of the year has a big role in determining the value of connecting direct radiation to the surface, the diffuse solar radiation is non-directional radiation affects the building of all the trends, but its value affected by the change inclination angle, vertical surface depends on the quality of neighborhoods and the shape and the feel of the direct radiation of radiation angle, To calculate solar radiation received by domed roof. Researchers interested in the domes of two methods adopted for evaluation the thermal performance on buildings domed First method rely on the roof of the dome are divided into small strips spaces on the network Thermal represents a number of small surfaces [11]. Treated surface flat diagonal elements depending to the degree of inclination on the roof of the dome and its location. Figure 2 Geometry of solar above the a diagonal surface [12]. Determine the area of each part and the value of solar radiation to show those parts, the sum total of these elements accounts, Internal radiation determines the spaces meshed, The method has been neglected part of these elements will be facing the solar radiation and the other part is located in the shade, and every point of the surface of the dome is exposed to direct solar radiation angles different from its neighboring point. Estimating insolation received by a domed roof, the division of the roof surface to several small surfaces, and received small surfaces of solar radiation. It was supposed every element of those small surface elements be flat. By integrating insolation received by these small spaces is calculating the total solar radiation received by the dome-shaped roof. Figure 3 shows the network are arranged on the surface of the dome(meshed area), many of equations the depend for this purpose [13]. The second method of numerical simulation using a computer simulation program including energy program (Ecotect) [14].

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

Where: Q_{abs} = absorbed heat on each mesh
Q = *heat* transfer

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

$$h_o = \sqrt{h_n^2 + [2.38 V_W^{0.89}]^2} \quad (3)$$

Where: ho = Convection heat transfer coefficient
A = area

$$\frac{V_h}{V_{400}} = \left[\frac{h}{400}\right]^{0.28} \quad (4)$$

Where: V_h = Wind velocity at elevation h
H, h = height

$$h_n = 1.810 \frac{\sqrt[3]{|\Delta T|}}{1.382 + |Cos\beta|} \quad (5)$$

Where: h_n = natural convection heat transfer coefficient

$$\frac{\Delta T_{ai}}{\Delta t} = \frac{\sum h_i A(T_{Wi} - T_{ai})}{mC_v} \quad (6)$$

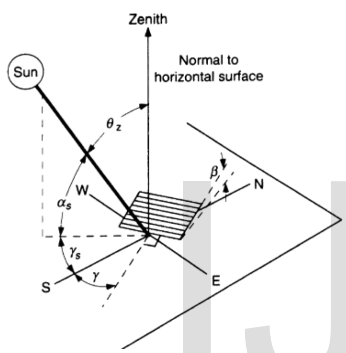

Fig. 2. Geometry of solar on a tilted surface [11]

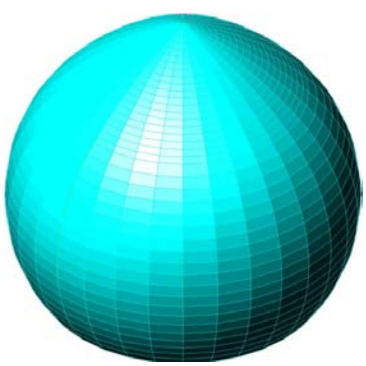

Fig. 3. Network arranged on the surface dome (meshed area)

4 Research Methodology

Study mosques and building plans containing designs documented domed ceilings were classified into nine types depending on the method of formation of figure 4, radius 4.0 m in different heights by forming a dome 4.00-8.70 m in surface area 100.36-213.66 m^2 in size 134.40-373.84 m^3, figure 5 shows a three-dimensional geometric configuration of the dome, Conducted field measurements to one study models for thermal performance naturally under the hot dry conditions in the city of Baghdad. Information field measurements were used to develop the foundation of the computer simulation model line, the program has been applied (Ecotect) to build a study of nine models model. Has been conducting field measurements in three days monthly January, July, September of 2015 in the city of Baghdad, using temperature monitoring record data. 'Thermal comfort data logger INNOVA' and the movement of air on the surface of the dome using a device (model 407123 Hot-Wire thermo-anemometer). The field measurement, analysis of the first step of the development and construction of model calculations with the help of the program (Auto CAD) to select the area exposed to solar radiation the adoption of a new method, the researchers did not address it depends on the area of the vertical projection on account of solar radiation at each hour of the solar radiation. Table 1 shows the difference in projected area of the Dome of the models for the study. Adoption of a uniform material value of the building with domed ceilings thermal conductivity U-Value = 1.085 w/m^2 kg, and solar radiation data for the city of Baghdad in central Iraq [10]. Assuming that the days 15,16,17 of each month represent readings during the month in three months, Table 2 shows solar energy received for models domes and the heat absorbed in summer and loss in winter, and used a three-dimensional numerical simulation of the flow of wind around the vaulted ceilings elected within the prevailing trend of the different winds at every point on the surface of the dome [15]. Figure 6 show difference in the speed and pattern of Air moving to models domes, to make a comparison of the energy forms between the shapes of domes. Where is the next step, check out the thermal performance of the formations domes. The study has been created models used software program energy simulation (Ecotect), a tool that it included a large group of simulation and analysis. This program is more suited to achieve the goals of research for its potential use in the domed forms. It is one of the few tools that cover the sults of thermal performance in a simple and accurate to some extent. Weather data file (Ecotect) does not contain information from Baghdad. It has been included in the program to this end. Evaluate the thermal performance of the three months of the year January, July, September because of the existence of a difference in the climatic conditions during the months, and three days 15, 16, 17 and three different times 9 am, 1 pm and 3 pm, Table 4 Maximum ceived and absorbed Ht (In August 2015) And the percentage of energy absorbed depending on the thermal resistance of the surface and the difference in wind direction for a number of domes Table 6. Comparison of results of field accounts and read the program within the prevailing wind.

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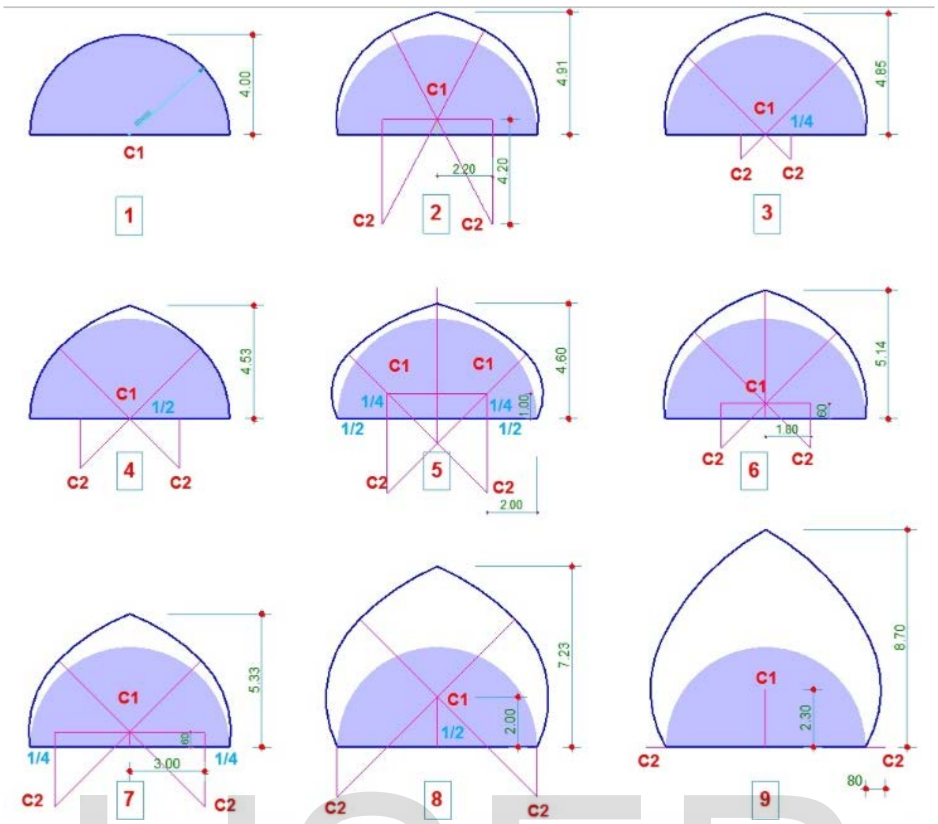

Fig. 4. Shapes dome selected

Fig. 5. Three-dimensional geometric configurations of the dome

TABLE 1
DIFFERENCES FROM DOME AREA, DEPENDING ON ANGLE OF THE FALL OF THE SOLAR RADIATION MODELS FOR STUDY (JULY2015)

A 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

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TABLE 2
SOLAR ENERGY RECEIVED FOR MODELS DOMES AND HEAT ABSORBED IN SUMMER AND LOSS IN WINTER

A 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)	496.721	531.369	606.252	524.306	599.459	632.702	638.601	807.251	863.749
	Solar-received (Winter)	181.501	199.545	228.416	198.178	227.548	254.687	242.406	338.948	362.670
Absorbed and Heat loss	Absorbed (Summer)	16450.326	18167.77	20567.33	18090.35	20816.87	21893.798	22601.97	29210.28	31254.671
	Loss (Winter)	6643.104	7474.80	8966.351	7556.341	9467.063	9551.820	10158.09	14179.31	15171.702

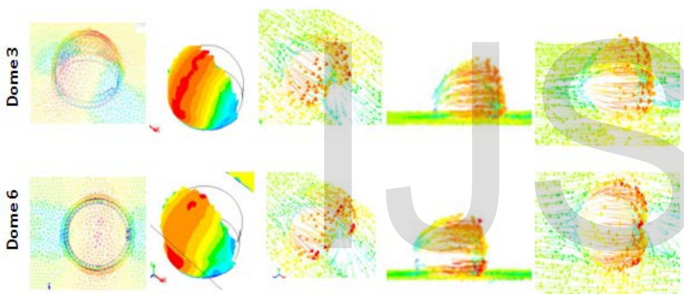

Fig. 6. The difference in the speed and pattern of Air moving to models dome

TABLE 3
MEASURED BY WIND SPEED THERMAL RESISTANCE OF THE EXTERNAL SURFACE [SEARCH]

Shape	wind speed (m s^{-1})	*Rso* (m^2KW^{-1})
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

s

TABLE 4
ENERGY RECEIVED AND ABSORBED HT (JULY 2015) FOR A NUMBER OF DOMES SELECTED DIFFERENT DIRECTION OF AIR.

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
THE DIFFERENT DEGREE OF THE INTERNAL AIR TEMPERATURE COEFFICIENT DEPENDING ON THE CEILING, USING NUMERICAL SIMULATIONS AND THE METHOD OF THERMAL NETWORK

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

TABLE 6
COMPARED TO THE DESIGN CHARACTERISTICS OF THE MODELS DOMES

Dome Shape	Area (S)	Radius (R)	Volume (V)	High (H)	Area/Volume S/V	(Shape Factor) H/R
D.1	100.36	4.00	134.40	4.00	0.746	1.00
D.2	118.14	4.00	170.18	4.91	0.694	1.227
D.3	12118.	4.00	170.20	4.85	0.694	1.212
D.4	101.92	4.00	137.18	4.53	0.742	1.132
D.5	120.28	4.00	1.6271	4.60	0.700	1.150
D.6	120.08	4.00	173.96	5.14	0.690	1.285
D.7	120.00	4.00	173.30	5.33	0.692	1.332
D.8	181.62	4.00	303.98	7.23	0.597	1.807
D.9	213.66	4.00	373.84	8.70	0.571	2.175

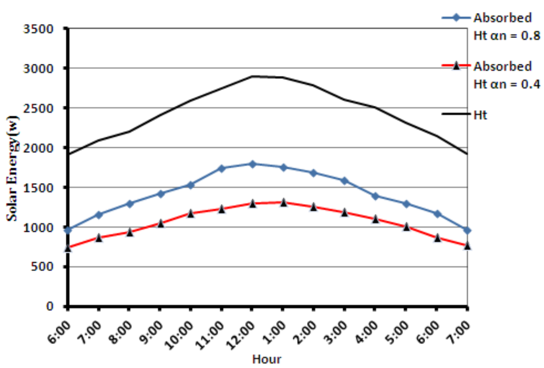

Fig. 7. Solar radiation received and absorbed by the model 6 with different thermal resistance of the surface of the different patterns of wind speed

5 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. 213.66m^2 area received more solar model 1. An area of 100.36 m^2 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 standardized building materials domed Roof with thermal conductivity U-value=1.085w/m^2k 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 Tables 2. Measuring speed of air move at various points on a roof of the dome using a variation (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 [15]. Table 4. Energy Received and Absorbed Ht (July 2015) for a Number of Domes Selected Different Direction of

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Air. The difference in values energy absorbed because the different from the area received by solar radiation and the different thermal resistance than the exterior of the roof (Rso) the difference in wind speed around those configurations. Has wind speed recorded on the model 6 rate of 4.30 ms^{-1}, while the model 9 log rate of 3.65 ms-1, Increasing the air speed in all areas dome Face to reduce the thermal resistance of the external surface of the dome (An increase in heat loss operation of the ceiling) And therefore relieve overcrowding heat on the surface, In addition the existence of shaded areas of the dome during the hours of insolation which generates a difference in pressure, The difference in the form of the dome affects the speed and pattern of Air move Created pneumatic positive pressure at the front of the winds And the negative pressure in the opposite face of the Lee ward And receives an increase in the average speed and a decrease in the severity of the disorder with height. The difference in wind speed were offset the thermal resistance of different surface which ranged from 0.0452 m^2Kw^{-1} to 0.0573 m^2Kw^{-1}. Table 5 A different Degree of the Internal air temperature coefficient depending on the ceiling, using numerical simulations and the method of thermal network. When comparing the computer program adopted in the study, with one computer energy simulation programs Results (Ecotect) Note a few differences between the value pairs when compared with the results of readings field less than the differences that the program achieves a high rate of credibility. Table 6 shows compared to the design characteristic of the models domes the temperature of the domed roof the previous level of new roads and the way adopted by the research. When comparing the height of the dome with the radius of the base (H/R) The expression of the term (Shape Factor) When the ratio (1.3) has achieved a form less heat gain and loss, That proportionality be inversely when compared with the ratio (S/V) within the concept of (Thermal Cube) By decreasing proportions with increasing size 0.571-0.749 .figure 5 compared to the design characteristic of the models domes can explain more precisely using the concept of heat capacity, The concept of heat capacity of any material expresses the appropriate heat to raise the temperature of the unit volume of material one degree heat, The amount of heat capacity change with the volume of space as is evident in the heat capacity of the size 173.96 m^3has been 266,854 * 10^3 kj / m^3. And the size 373.84 m^3 has been 573.469 * 10^3 kj / m^3. The differences (S/V) are 0.571-0.746 and achieved a model 9 ratio 0.571. It is at least part of this concept, which represents the highest percentage among the new concept, Who are allowed to move away from the border, So is the new concept is the most suitable for the formation of domed. The concept of (H / R) ranged between 1.00-2.175 so it can adopt the ratio (1.3) Reference limits in perfect form, called the concept (Shape Factor), Which came out with the best Research translation thermal loads to achieve the ideal shape compared to the concept of thermal cube, That came with previous studies indicated in the table 6 the existence of differences in the readings limits 0.973%.

6 Conclusion

In order to clarify the reason for the adoption of the design characteristics of the dome within the concept of the shape factor represent the link between the height of the dome and the radius H/R In determining the thermal behavior of the domed roof, The difference in area exposed to solar radiation depends on the formation of domed ceiling at the same time led to differences in the energy absorbed for models domes. The difference in area received to solar radiation depends on the formation of domed ceiling at the same time led to differences in the energy absorbed for models domes. The increase in the speed and pattern of air movement depends on the shape factor that lead to reducing the thermal resistance of external surface and remove heat from the surface of the dome congestion, domed roof perform best when the shape factor closer to 1.3 that apply with experimental readings and computer simulations. While there is no effect it is obvious at different wind direction. That there is an inverse relationship between the shape factor of the increases and decreases with the thermal behavior of the domed roof, When different ratio requires technique processors to improve the thermal behavior including the use of glazed tiles to cover the dome. The concept (Thermal Cube) which achieves equal thermal efforts on the facets of the building that came with previous studies, cannot be adopted in the formation domed because he has achieved the worse thermal behavior. So can the adoption ratio (1.3) Reference limits in perfect shape, called the concept (Shape Factor). At the same time it approached on the system mathematical geometric proportionality of Islamic architecture generated from √2. Through this percentage can achieve the design of various configurations of the dome and choose what is suitable for the design has been given the best efficiency in summer at the same time achieved the highest efficiency of winter.

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