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Optimum Form, Aspect Ratio and Orientation of Building Based on Solar Energy Receiving in Hot-Dry Climate;
Case Studies of Isfahan, Semnan, Kashan and Kerman Cities, Iran

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A B S T R A C T

The form, size and orientation of the building are the most important effective parameters on internal climate and have direct effect on thermal performance of the building. The aim of this research is to investigate the amount of received radiation energy of vertical surfaces in buildings and to determine the appropriate form, aspect ratio and orientation of building in accordance with the hot-dry climate in the cities of Isfahan, Semnan, Kashan and Kerman. In this research, six polygonal forms, including square, rectangle with North-South and East-West orientation, hexagonal, octagonal, hexadecagon, and triacontadigon (circle) were studied. All the investigated forms had the same floor area and height, oriented to the South. The aspect ratios of the rectangular form were 1:1.2, 1:1.4, 1:1.6, 1:1.8, 1:2, and the orientation of the optimum aspect ratios were 180º, 165º, 150º, 135º, 120º, 105º SE and SW. Using the "Law of Cosines" computational method, the amount of received radiation energy on vertical surfaces was calculated, for different months and in 32 geographic directions, in terms of the cold and hot periods of the year. The results show that the best forms of the buildings in Isfahan, Semnan, Kashan and Kerman cities is the rectangle with East-West orientation. The most suitable aspect ratio for the EW rectangular form in studied cities is 1:1.6 and the best orientation for the determined aspect ratio is 180º south.

Keywords: Form, aspect ratio and orientation of building, Hot-dry climate, Solar Energy.

1. Introduction

Due to running out of fossil fuel resources, low efficiency and high cost of their environmental problems, optimizing energy consumption and using renewable energies, are inevitable. Nowadays, by properly design of the form and orientation of urban buildings and spaces, the needed energy for providing heat, cooling and lighting, could be reduced. In order to achieve a sustainable shape and form of the building in terms of energy efficiency, it is necessary to design the exterior envelope of the buildings so that they receive the maximum solar radiant energy in the cold period of the year and the minimum solar energy in the hot period.

Due to the special geographic conditions and hot dry climate of the central plateau of Iran, designing and construction of buildings and urban spaces in these regions, are based on receiving minimum energy in hot months of the year, through appropriate orientation, decreasing the area of surfaces facing radiation and maximizing the amount of shading on surfaces. This study aims to determine the optimal form, aspect ratios and orientation of building in accordance with the region's climate through surveying the amount of radiation energy received by vertical surfaces of buildings in the cities of Isfahan, Semnan, Kashan and Kerman.

Building form has a significant effect on energy use in buildings. Choosing a good building shape and orientation are two of the most critical elements of an integrated design. Selecting the optimal building geometry is a critical early step in the design of sustainable buildings [1]. Globally, a significant proportion of the building energy is consumed for achieving the required thermal and

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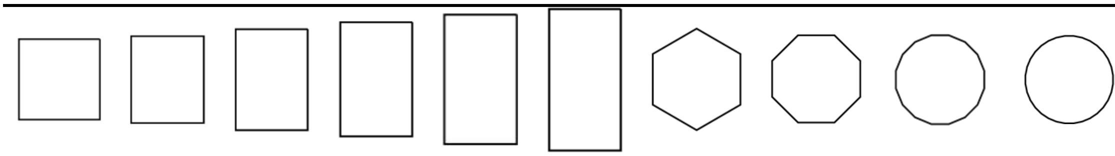
optical comfort [2-3]. In addition to the building materials, the building form and the other associated factors heavily affect the indoor thermal comfort and the lighting energy of any air-conditioned or naturally ventilated building. The most important parameters affecting the thermal comfort and lighting energy requirement of the indoor environment are the building shape, orientation and the window to wall ratio (WWR) of the building. These parameters are interrelated and a proper combination is required to achieve the optimal thermal comfort and energy efficiency [4-6].

Most of studies about the relationship between building form and energy, emphasize on the approaches of management to reduce energy consumption in buildings. The studies investigated the relationship between building form and energy consumption, which can be categorized into two types of research: One is to compare the influences of different building forms on energy use, whereas the other is to develop simple models for estimating the energy use of various building forms [7]. Since the development of energy simulation tools, the effect of the shape and form of the building on energy performance has been widely studied. Several studies have shown that there is a correlation between compression (the ratio of the area of external envelope to the volume) of the building and its energy consumption, and the forms with high compression rates have lower energy consumption, especially in cold and hot climate [8-9]. Al-Anzi et al. [9], used compression as an index in assessing the effect of shape on the energy performance of a building. The research of Depecker et al. [10], aimed at relating the heating consumption of the buildings with their shape. Their research results showed that the energetic consumption is inversely proportional to the compactness (weak shape coefficient) in case of cold severe and scarcely sunny winters. Depecker et al. [10] and also Albatici and Passerini [11], indicated that more compactness, does not necessarily lead to less heating energy demand in warm climates. Tajuddeen and Ango [12], investigated on suitable aspect ratios of building forms (compact forms) in an office building in hot-dry climate. They focused on, firstly, examining the thermal performance of different building forms of the same floor area against their volume to surface ratio (V/S) and secondly, the forms were further optimized with different aspect ratios extended along East-West orientation. Their study showed that forms with higher V/S perform better, and also 20% solar radiation on the West surface could be further reduced during summer period when optimized with an optimum aspect ratio of 1:2.5, as compared to aspect ratio (1:1); Also, cylindrical and cubic forms appeared to consume less energy. Jazayeri and Aliabadi [13], in their research on the effect of building aspect ratio on the energy performance in cold and semi-arid climates, concluded that the aspect ratio of 1:3.3 is the optimal ratio for buildings with small windows on their East and West façades while a less elongated shape with the aspect ratio of 1:2 was shown to perform better for buildings with an equal window to wall ratio (WWR) in all facades. These findings showed that the optimal aspect ratio of a building can be different when the WWR of each façade is changed. In examining the impact of the aspect ratio on energy efficiency in multi-storey residential buildings in Canada, the results showed that the aspect ratio and orientation have a major impact on energy efficiency. The best aspect ratios in studied cities were the ratio of 1:1.3 and 1:1.5 with East-West orientation [1]. Koranteng and Abaitey [14], indicated that for energy performance of residential buildings the square form is the most energy efficient whiles elongated forms used much energy and the forms warm up when they are oriented towards the East and West. Hachem et al. [15], in geometric form effects on solar potential of housing units, stated that the number of shading facades in-self shading geometries and their relative dimensions are the major parameters affecting solar incident and transmitted radiation. They showed that the Ratio of shading to shaded facade lengths and the angle between these two facades affect the solar radiation incident on facades and roofs. Şaylan et al. [16], in an investigation on Solar energy potential in big cities of Turkey, concluded that During summer, the monthly mean solar energy potential on vertical surfaces comes from the east and west directions more than other orientations in all the cities. However, during winter, it comes from the south, and the highest solar energy is received in Izmir, where the average annual global radiation attains its maximum. Additionally, north oriented surfaces produce between 65% and 75% lower total solar energy than other orientations in all the cities. Aksoy and Inallib [17], conducted a research on building passive design parameters in a cold region. They concluded that for heating demand, buildings with a square shape have more advantages, and the most suitable orientation angles are 0∘ and 80∘ for buildings having shape factors (the ratio of building length to building depth) 2/1 and 1/2, respectively. Tokbolat et al. [18], showed that orientation of a building can significantly affect the energy usage rate. The South and North facing directions are found to be the most energy efficient (initial orientation is 35º toward the North-East). The research of Ling et al. [19], in hot-humid climate, revealed that the circular shape with W/L ratio 1:1 is the most optimum shape in minimizing total solar insolation. The square shape with W/L ratio 1:1 in a North-South orientation receives the lowest annual total solar insolation compared to other square shapes. This optimum shape (CC 1:1) receives the highest amount of solar insolation on the east-orientated wall, followed by the south, west and north-orientated walls respectively.

2. Materials and Methods

In order to determine the best form, aspect ratio and orientation of building in terms of receiving sun's radiation, firstly, the hour angle, the declination angle, the azimuth angle and the altitude angle were calculated at different hours of the day in the cities studied. Then, The amount of received radiation energy on vertical surfaces has been calculated and processed through theoretical and actual calculation, using the "Law of Cosines" computational method for different months and in 32 geographic directions, in terms of the cold and hot periods of the year. In this research, six polygonal forms, including square, rectangle with North-South and East-West orientation, hexagonal, octagonal, hexadecagon, and triacontadigon (circle) were studied. All the investigated forms had the same floor area and height with orientation to the South. The studied aspect ratios in rectangular form were 1:1.2, 1:1.4, 1:1.6, 1:1.8 and 1:2 and the investigated orientations for the optimal aspect ratio, were 180º, 165º, 150º, 135º, 120º and 105º Southeast and Southwest. The best aspect ratio and orientation of building is determined, based on the maximum amount of differences between received energy, in cold and hot periods of the years or the minimum amount of sunlight energy in the hot period.

Table 1. The ratio between the external envelope area of different forms and square form

Square	**Rectangle with NS & EW Orientation**					**Hexa**	**Octa**	**Hexadeca**	**Triaconta**
	1:1.2	**1:1.4**	**1:1.6**	**1:1.8**	**1:2**				
									
1.00	1.004	1.014	1.027	1.043	1.06	0.93	0.91	0.892	0.888

2.1. Study Area

Based on Koppen-Geiger climate classification system, the cities of Isfahan, Semnan, Kashan and Kerman are located in hot-dry climate (BSks). These cities have hot-dry climate, with cold winters and hot and dry summers [20]. The climatic characteristics of these areas are the high temperature difference between summer and winter, as well as the high temperature difference between day and night. Low humidity and the clear sky cause high temperature fluctuations between day and night around 20 °C in the summer.

Table 2. Geographical-climatic characteristics of the studied cities [21]

City	**Latitude**	**Longitude**	**Elevation (m)**	**Annual Temp. (ºC)**			**Ave. RH (%)**
				Max.	**Min.**	**Ave.**	
Isfahan	32º 37' N	51º 40´ E	1550	23.4	9.1	16.2	40
Semnan	35º 35´ N	53º 33´ E	1130	23.8	12.4	18.1	41
Kashan	33º 59´ N	51º 27´ E	982.3	26.1	12.1	19.1	40
Kerman	30º 15´ N	56º 58´ E	1753	24.7	6.9	15.8	31

By using hourly changes of temperature in every month and thermal comfort zones for humans, the months when a person needs heat or cold were determined. Considering the comfort base temperature (21ºC), the daily temperature in the cities of Isfahan, Semnan, Kashan and Kerman is less than comfortable condition, respectively in 53%, 44%, 46% and 49% of the year, and it is more than it in 47%, 56%, 54% and 51% of the year, respectively. Considering that the hot periods in the studied cities are more than the cold periods, determining the optimal form, aspect ratio and building orientation, is based on receiving minimum solar energy in the hot duration of the year.

2.2. Method of Calculating Radiation Energy

The amount and intensity of the beam or wave reached a surface is equal to the multiplication of the amount and intensity of the beam in a perpendicular position by the cosine of the angle between the normal direction (the line perpendicular to the surface) and the stretch of radiated beam. This equation is known as the "Law of Cosines". The amount of direct solar radiation reaching a surface on earth is calculated according to the following equation [22].

$$I_S = I_N \times \cos\theta \quad (1)$$

where I_S, is the intensity of the radiation on the surface (BTU/H/FT2); I_N, is the intensity of the sun's radiation on the perpendicular surface to the sun's ray (BTU/H/FT2); and also θ is the angle between the sun's ray and the perpendicular line to the surface. In the above relation, the value of I_N is calculated by the following equation [23].

$$I_{DN} = I^{\circ} \exp(-\alpha / \sin h) \quad (2)$$

where I_{DN}, is the heat produced by direct and perpendicular sunlight; I°, is the solar constant; α, is the extinction coefficient [23] and h, is the angle of the sun's radiation. Also, θ, is the angle of intersection between the sun and the line perpendicular to a vertical surface (wall), which is determined by the spherical cosine formula [22].

$$\cos\theta = \cos h \times \cos(Z-N) \quad (3)$$

where h, is the altitude angle of the sun's radiation; Z, is the azimuth angle and N, is the direction angle to the wall,

which is on the clockwise direction from the North and it is measured in degrees.
To determine the azimuth angle and the radiation angle of the sun at each hour of the day in equation 2 and 3, at first, it is necessary to calculate the solar hour angle and declination angle during the day. The beginning point of hour angle measurement is the solar noon. The measure of the angle varies from +180º to -180º. The measure of the hour angle in the northern hemisphere is positive in the morning and negative in the afternoon. Considering that the Earth rotates around its own axis every 24 hours, an angle passes 15º longitude per hour, so the hour angle is obtained as follows:

$$\omega=15\times(12-T) \quad (4)$$

where ***T***, is the desired time.
The declination is the angular position of the solar noon with respect to the plane of equator, and its measure varies between +23.45º and -23.45º; it is calculated by the following equation:

$$\delta=23.45\times\sin[360((364+n)/365)] \quad (5)$$

where ***n,*** is the number of days from the beginning of the solar year.
The length of the day is the time between sunrise and sunset. The day's length is symmetric to the solar noon, and the Earth moves around its own axis 15º per hour. The length of the day is calculated from the following equation.

$$T_d=2/15\,\mathrm{Arccos}(-\mathrm{tag}\delta\times\tan Ø) \quad (6)$$

where ***δ***, is the declination angle and ***Ø***, is the latitude in degrees.

The altitude angle is the vertical angle between the horizon and the line connecting to the sun; Its measure varies from 0° to 90º. This angle is obtained by the following equation:

$$\mathrm{Sin}h=(\cos Ø\times\cos\delta\times\cos\omega)+(\sin Ø\times\sin\delta) \quad (7)$$

where ***δ***, is the declination angle; ***Ø***, is the latitude in degrees and ***ω*** is the hour angle of noon.
The solar azimuth angle is the angular displacement from the South of the beam radiation projection on the horizontal plane; Its measure varies from +180º to -180º. This angle is negative from the South to the East, and positive to the West. The azimuth angle is calculated by the following equation:

$$\mathrm{Sin}Z=(\cos\delta\times\sin Ø)/\cos h \quad (8)$$

where ***δ***, is the declination angle; ***Ø***, is the latitude and ***h***, is the solar altitude in degrees.

3. Results and Discussion

Using the "Law of Cosines" computational method, firstly, the amount of direct energy received by vertical surfaces, has been calculated theoretically in each hour of the day and toward 32 directions for the studied cities, then the amount of actual direct energy received by vertical surfaces has been obtained from the multiplication of theoretical received energy by the average percentage of sunshine hours in different months. Finally, based on the minimum thermal comfort temperature, the amount of received energy was calculated separately for hot and cold periods. Table 3 shows the average and percentage of sunshine hours.

Table 3. The day length and percentage of sunshine hours in studied cities [21]

		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Isfahan	Ave. day length*	10.3	11.1	12.1	13.1	13.8	14.1	13.8	13	11.6	11	10.2	9.9
	Ave. sunshine hours	6.8	7.5	7.9	8.1	10	11.2	11.3	11	10	9.4	7.5	6.6
	sunshine hours (%)	66.2	67.1	65.1	61.8	72	79.6	81.8	84.3	86.4	85	73.3	66.6
Semnan	Ave. day length*	10	11	12.1	13.2	14	14.4	14	13.1	11.6	10.9	10	9.6
	Ave. sunshine hours	5.7	6.3	6.7	7.4	9.2	10.9	10.9	10.9	9.8	8.7	6.8	5.6
	sunshine hours (%)	57	57.1	55.8	56	65.4	75.7	77.9	82.9	84.6	79.6	67.6	58.7
Kashan	Ave. day length*	10.2	11.1	12.1	13.1	13.9	14.2	13.9	13.1	11.6	11	10.1	9.8
	Ave. sunshine hours	5.5	6.3	6.5	7.3	9	10.3	10.6	10.5	9.3	8.3	6.3	5.4
	sunshine hours (%)	54.2	56.6	54.1	55.8	65.1	72.6	76.2	80.3	79.9	75.5	62.1	55.7
Kerman	Ave. day length*	10.4	11.2	12.1	13.0	13.7	13.9	13.7	12.9	11.6	11.1	10.3	10.1
	Ave. sunshine hours	6.5	6.9	7	7.6	9.6	10.5	10.8	10.8	10.0	9.4	8.0	6.8
	sunshine hours (%)	62.5	61.4	58.2	58.5	70.1	75	79.4	84	85.6	84.5	77.6	67.7

*The day length is calculated by the writers.

In tables 4 and 5, the total (annual) energy received by vertical surfaces is calculated and actualized by the percentage of sunshine duration's coefficient. Also in these tables, the amount of energy received by the vertical walls in cold and hot period and the differences between them are calculated.

Table 4. The energy received by vertical surfaces in Isfahan and Semnan (BTU/H/FT2)

Orientation	Isfahan						Semnan					
	Total	period				Dif.	Total	period				Dif.
		Cold	%	Hot	%			Cold	%	Hot	%	
North	472.7	81.4	17.2	391.2	82.8	-309.8	396.3	42.6	10.8	353.7	89.2	-311
11.25	666	154.2	23.2	511.8	76.8	-357.5	573.3	83.2	14.5	490.1	85.5	-407
22.5	1194	339.2	28.4	854.7	71.6	-515.5	1036	193	18.6	843	81.4	-650
33.75	1890.3	624.3	33	1266.1	67	-641.8	1665.2	393.6	23.6	1271.5	76.4	-877.9
45	2746	1015.7	37	1730.3	63	-714.6	2427.5	693.9	28.6	1733.6	71.4	-1039.7
56.25	3699.7	1588.9	42.9	2110.9	57.1	-522	3303.5	1033.2	31.3	2270.3	68.7	-1237
67.5	4681.8	2225.8	47.5	2456	52.5	-230.1	4216.2	1528.2	36.2	2688.1	63.8	-1159.9
78.75	5627	2832.2	50.3	2794.8	49.7	37.3	5103.7	2011	39.4	3092.7	60.6	-1081.8
East	6412.9	3293.8	51.4	3119.1	48.6	174.6	5856.1	2391.2	40.8	3464.9	59.2	-1073.7
101.25	7203.5	3954.2	54.9	3249.3	45.1	704.9	6628.3	2947.1	44.5	3681.2	55.5	-734.1
112.5	7774.3	4439.5	57.1	3334.7	42.9	1104.8	7206.9	3382.6	46.9	3824.3	53.1	-441.7
123.75	8189.3	4920.8	60.1	3268.5	39.9	1652.3	7645.3	3845.1	50.3	3800.2	49.7	44.8
135	8460.2	5296.4	62.6	3163.7	37.4	2132.7	7953.7	4189.8	52.7	3763.9	47.3	426
146.25	8609.7	5585.6	64.9	3024.1	35.1	2561.5	8163.2	4529.8	55.5	3633.5	44.5	896.3
157.5	8660.2	5857.2	67.6	2803	32.4	3054.2	8256.4	4768.7	57.8	3487.7	42.2	1281
168.75	8592.3	6078.1	70.7	2514.2	29.3	3563.8	8238.6	4895.9	59.4	3342.7	40.6	1553.1
South	8554.6	6034.2	70.5	2520.4	29.5	3513.7	8212.2	4911.1	59.8	3301.1	40.2	1610.1
-168.75	8592.3	5888.9	68.5	2703.4	31.5	3185.5	8238.6	4856.8	59	3381.8	41	1475
-157.5	8660.2	5594.9	64.6	3065.3	35.4	2529.6	8256.4	4514.3	54.7	3742.2	45.3	772.1
-146.25	8609.7	5147.9	59.8	3461.7	40.2	1686.2	8163.2	4023.9	49.3	4139.4	50.7	-115.5
-135	8460.2	4646.7	54.9	3813.5	45.1	833.2	7953.7	3507.3	44.1	4446.3	55.9	-939
-123.75	8189.3	4095.7	50	4093.6	50	2.1	7645.3	3113.3	40.7	4532.1	59.3	-1418.8
-112.5	7774.3	3633.1	46.7	4141.2	53.3	-508.1	7206.9	2685.3	37.3	4521.6	62.7	-1836.3
-101.25	7203.5	3148	43.7	4055.4	56.3	-907.4	6628.3	2245.1	33.9	4383.3	66.1	-2138.2
West	6412.9	2576.6	40.2	3836.2	59.8	-1259.6	5856.1	1770.9	30.2	4085.3	69.8	-2314.4
-78.75	5627	2084.1	37	3542.9	63	-1458.8	5103.7	1380.9	27.1	3722.7	72.9	-2341.8
-67.5	4681.8	1556.7	33.2	3125.1	66.8	-1568.5	4216.2	966.7	22.9	3249.5	77.1	-2282.7
-56.25	3699.7	1050.4	28.4	2649.3	71.6	-1598.9	3303.5	606.3	18.4	2697.2	81.6	-2090.9
-45	2746	643.9	23.4	2102.1	76.6	-1458.2	2427.5	340.8	14	2086.6	86	-1745.8
-33.75	1890.3	347.9	18.4	1542.4	81.6	-1194.5	1665.2	161.1	9.7	1504	90.3	-1342.9
-22.5	1194	170.4	14.3	1023.6	85.7	-853.2	1036	109.6	10.6	926.4	89.4	-816.7
-11.25	666	59.9	9	606.1	91	-546.2	573.3	67.9	11.8	505.4	88.2	-437.5

Table 5. The energy received by vertical surfaces in Kashan and Kerman (BTU/H/FT2)

Orientation	Kashan						Kerman					
	Total	period				Dif.	Total	period				Dif.
		Cold	%	Hot	%			Cold	%	Hot	%	
North	414.6	37	8.9	377.5	91.1	-340.5	496	64.6	13	431.4	87	-366.8
11.25	590.2	80	13.6	510.1	86.4	-430.1	687.4	117.5	17.1	569.9	82.9	-452.4
22.5	1060.2	198.3	18.7	861.9	81.3	-663.6	1216.1	297.7	24.5	918.4	75.5	-620.7
33.75	1682.9	395.4	23.5	1287.5	76.5	-892.1	1913.9	545.1	28.5	1368.9	71.5	-823.8
45	2441.9	704.2	28.8	1737.7	71.2	-1033.5	2761.9	960.5	34.8	1801.4	65.2	-840.9
56.25	3289.8	1046.5	31.8	2243.4	68.2	-1196.9	3692.5	1397.8	37.9	2294.7	62.1	-896.9
67.5	4162.4	1748.5	42	2413.9	58	-665.3	4640.4	1974.8	42.6	2665.6	57.4	-690.8
78.75	5000.5	1998.1	40	3002.4	60	-1004.3	5544.2	2538.7	45.8	3005.5	54.2	-466.8
East	5698.5	2358.4	41.4	3340.1	58.6	-981.8	6282.8	2929.5	46.6	3353.4	53.4	-423.9
101.25	6402.6	2889.1	45.1	3513.5	54.9	-624.4	7012.5	3531.2	50.4	3481.3	49.6	49.9
112.5	6912.7	3296.4	47.7	3616.3	52.3	-319.9	7520.6	3973.9	52.8	3546.7	47.2	427.2
123.75	7282.6	3717.3	51	3565.3	49	152	7873.9	4412.5	56	3461.4	44	951.1
135	7523.7	4032.9	53.6	3490.8	46.4	542	8083.8	4744.3	58.7	3339.6	41.3	1404.7
146.25	7658.7	4339.1	56.7	3319.6	43.3	1019.4	8172.1	5051.1	61.8	3120.9	38.2	1930.2
157.5	7700.3	4583.4	59.5	3116.9	40.5	1466.5	8170	5294.4	64.8	2875.5	35.2	2418.9
168.75	7639.3	4693.3	61.4	2946	38.6	1747.3	8069.6	5414	67.1	2655.6	32.9	2758.4
South	7602.3	4644.7	61.1	2957.5	38.9	1687.2	8023.5	5362.4	66.8	2661.2	33.2	2701.2

Orientation	Kashan						Kerman					
	Total	period				Dif.	Total	period				Dif.
		Cold	%	Hot	%			Cold	%	Hot	%	
-168.75	7639.3	4594.2	60.1	3045.2	39.9	1549	8069.6	5236.2	64.9	2833.4	35.1	2402.9
-157.5	7700.3	4276.6	55.5	3423.7	44.5	852.8	8170	4888.3	59.8	3281.7	40.2	1606.6
-146.25	7658.7	3822.3	49.9	3836.5	50.1	-14.2	8172.1	4391.5	53.7	3780.5	46.3	611
-135	7523.7	3348.9	44.5	4174.9	55.5	-826	8083.8	3877.3	48	4206.5	52	-329.1
-123.75	7282.6	2988.5	41	4294.1	59	-1305.6	7873.9	3479.5	44.2	4394.4	55.8	-914.8
-112.5	6912.7	2596.2	37.6	4316.4	62.4	-1720.2	7520.6	3052.1	40.6	4468.5	59.4	-1416.4
-101.25	6402.6	2187.9	34.2	4214.6	65.8	-2026.7	7012.5	2598.3	37.1	4414.2	62.9	-1815.8
West	5698.5	1741.1	30.6	3957.4	69.4	-2216.4	6282.8	2089.5	33.3	4193.4	66.7	-2103.9
-78.75	5000.5	1371.2	27.4	3629.3	72.6	-2258.1	5544.2	1659.9	29.9	3884.3	70.1	-2224.4
-67.5	4162.4	970.8	23.3	3191.6	76.7	-2220.8	4640.4	1187.1	25.6	3453.4	74.4	-2266.3
-56.25	3289.8	616.9	18.8	2673	81.2	-2056.1	3692.5	759.6	20.6	2932.9	79.4	-2173.4
-45	2441.9	354.3	14.5	2087.5	85.5	-1733.2	2761.9	440.1	15.9	2321.8	84.1	-1881.7
-33.75	1682.9	168.9	10	1514	90	-1345.1	1913.9	206.2	10.8	1707.7	89.2	-1501.5
-22.5	1060.2	86.2	8.1	974	91.9	-887.8	1216.1	102.2	8.4	1113.9	91.6	-1011.7
-11.25	590.2	61.3	10.4	528.9	89.6	-467.6	687.4	91.7	13.3	595.7	86.7	-504

According to the results of tables 4 and 5 the highest amount of annual received energy in the cities of Isfahan, Semnan and Kashan are at 157.5º SE and SW and in Kerman is at 146.25º SE and SW. The lowest amount of annual received energy in the all cities are at the North and 15° NE and NW. The least amount of energy receiving in hot period, in the cities of Isfahan (29.3%), Kashan (38.6%) and Kerman (32.9%) are at 168.75° SE and in Semnan (40.2%) is at 180º South. Also, the highest amount of differences between received energy in cold and hot periods of the years in Isfahan, Kashan and Kerman are at 168.75º SE and in Semnan is at 180º south. The amount of energy received by the vertical surfaces of polygonal forms is calculated in terms of cold and hot periods and presented in tables 6 and 7.

Table 6. The energy received by the vertical surfaces of different forms in Isfahan and Semnan (BTU/H/FT2)

Form		Isfahan						Semnan					
		Total	period				Dif.	Total	period				Dif.
			Cold	%	Hot	%			Cold	%	Hot	%	
Square		5463.3	2996.5	54.8	2466.8	45.2	529.8	5080.2	2279	44.9	2801.2	55.1	-522.3
EW Rectangle	**1:1.2**	5376.7	3002.1	55.8	2374.6	44.2	627.5	5009.5	2297	45.9	2712.4	54.1	-415.4
	1:1.4	5305	3006.7	56.7	2298.3	43.3	708.5	4950.9	2312	46.7	2638.9	53.3	-327
	1:1.6	5243.8	3010.7	57.4	2233.1	42.6	777.6	4900.8	2324.7	47.4	2576.1	52.6	-251.4
	1:1.6	5191.9	3014	58.1	2177.9	41.9	836.1	4858.5	2335.5	48.1	2523	51.9	-187.5
	1:2	5146.7	3016.9	58.6	2129.8	41.4	887.2	4821.6	2344.9	48.6	2476.6	51.4	-131.7
NS Rectangle	**1:1.2**	5549.8	2990.9	53.9	2558.9	46.1	432	5151	2260.9	43.9	2890	56.1	-629.1
	1:1.4	5621.5	2986.3	53.1	2635.2	46.9	351	5209.5	2246	43.1	2963.5	56.9	-717.6
	1:1.6	5682.8	2982.3	52.5	2700.4	47.5	281.9	5259.6	2233.2	42.5	3026.3	57.5	-793.1
	1:1.6	5734.6	2979	51.9	2755.6	48.1	223.4	5301.9	2222.4	41.9	3079.5	58.1	-857.1
	1:2	5779.8	2976.1	51.5	2803.7	48.5	172.3	5338.9	2213	41.5	3125.9	58.5	-912.9
Hexagonal		5538.7	2974	53.7	2564.7	46.3	409.3	5142.7	2253.8	43.8	2888.9	56.2	-635.1
Octagonal		5533.2	2948.6	53.3	2584.6	46.7	364	5135.4	2231	43.4	2904.4	56.6	-673.4
Hexadecagon		5555.4	2962.8	53.3	2592.5	46.7	370.3	5157.2	2249.8	43.6	2907.4	56.4	-657.6
Triacontadigon		5557.5	2967.7	53.4	2589.8	46.6	377.9	5161.1	2255.9	43.7	2905.2	56.3	-649.2

Table 7. The energy received by the vertical surfaces of different forms in Kashan and Kerman (BTU/H/FT2)

Form		Kashan						Kerman					
		Total	period				Dif.	Total	period				Dif.
			Cold	%	Hot	%			Cold	%	Hot	%	
Square		4853.4	2195.3	45.2	2658.1	54.8	-462.8	5271.3	2611.5	49.5	2659.8	50.5	-48.4
EW Rectangle	**1:1.2**	4776.4	2208.6	46.2	2567.8	53.8	-359.2	5179.1	2620.8	50.6	2558.3	49.4	62.5
	1:1.4	4712.6	2219.6	47.1	2493	52.9	-273.5	5102.7	2628.5	51.5	2474.2	48.5	154.2
	1:1.6	4658.1	2229	47.9	2429.2	52.1	-200.2	5037.5	2635	52.3	2402.4	47.7	232.6
	1:1.6	4612	2236.9	48.5	2375.1	51.5	-138.2	4982.3	2640.6	53	2341.7	47	298.9

	1:2	4571.8	2243.8	49.1	2327.9	50.9	-84.1	4934.1	2645.5	53.6	2288.6	46.4	356.8
NS Rectangle	**1:1.2**	4930.5	2182	44.3	2748.5	55.7	-566.4	5363.5	2602.2	48.5	2761.4	51.5	-159.2
	1:1.4	4994.3	2171	43.5	2823.2	56.5	-652.2	5439.9	2594.5	47.7	2845.4	52.3	-250.9
	1:1.6	5048.8	2161.6	42.8	2887.1	57.2	-725.5	5505.1	2587.9	47	2917.2	53	-329.3
	1:1.6	5094.9	2153.7	42.3	2941.2	57.7	-787.5	5560.3	2582.3	46.4	2978	53.6	-395.7
	1:2	5135.1	2146.8	41.8	2988.3	58.2	-841.6	5608.5	2577.5	46	3031	54	-453.5
Hexagonal		4923	2175.2	44.2	2747.8	55.8	-572.6	5350.8	2589.1	48.4	2761.7	51.6	-172.5
Octagonal		4918.1	2152.7	43.8	2765.4	56.2	-612.8	5347.1	2558.5	47.8	2788.6	52.2	-230.1
Hexadecagon		4938.5	2186.1	44.3	2752.4	55.7	-566.3	5366.9	2577.4	48	2789.5	52	-212.1
Triacontadigon		4940.9	2185.9	44.2	2755	55.8	-569.2	5368.8	2583.4	48.1	2785.4	51.9	-202

According to the results of tables 6 and 7, the maximum amount of received energy by vertical surfaces is related to the rectangular form with North-South orientation and the least is related to the rectangular form with the East-West orientation. In the North-South rectangle, due to the larger eastern and western surfaces and much more time of receiving radiation by these surfaces, the amount of received energy during hot period of the year is higher than other forms but, these forms have different performance due to the shift of angles in surfaces. Due to the hot climate of the studied cities, the best form of building is determined, based on minimum amount of energy receiving in hot period. The least amount of energy in hot period in the studied cities is related to the rectangular form with East-West orientation and the highest amount of energy in the hot period is related to the rectangular form with the North-South orientation. Therefore, according to the established criteria, the best forms of building in the studied cities, are the the rectangular form with East-West orientation and then the square form.

Thermal emission and absorption depends on some factors such as surface area, the difference between internal and external temperature, and the overall heat transfer coefficient of walls. According to Fourier's law, for two materials with equal temperature and conductivity coefficient, the amount of energy transfer has a direct relation with the external area. Therefore, under constant temperature and conductivity coefficient of the surfaces, by increasing the aspect ratio of the form, the area of external surfaces increases and the amount of obtained and transferred energy from the walls increases by the same ratio.

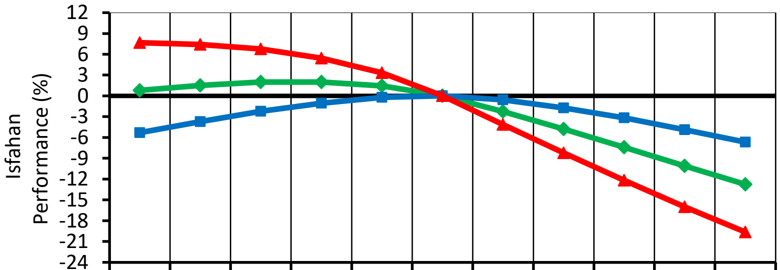
The form’s optimal aspect ratio, is a ratio by which, the amount of energy loss in the cold season and absorbed energy during the hot season is minimum. According to the balance principle between received and lost energy, the minimum amount of absorbed energy in the cold period for the aspect ratios of 1:1.2 to 1:2, in relation to the square form, are 1.004, 1.014, 1.027 , 1.043 and 1.06 percent, and the maximum absorbed energy in hot period are 0.996, 0.986, 0.973, 0.957, and 0.94 percent, respectively. The ratio of energy received by rectangle to square form during cold and hot periods is presented in table 8.

Table 8. The ratio of energy received by rectangle to square form during cold and hot periods (%)

period	**City**	**EW regtangle**					**NS regtangle**				
		1:1.2	**1:1.4**	**1:1.6**	**1:1.8**	**1:2**	**1:1.2**	**1:1.4**	**1:1.6**	**1:1.8**	**1:2**
Cold	**Isfahan**	1.002	1.003	1.005	1.006	1.007	0.998	0.997	0.995	0.994	0.993
	Semnan	1.008	1.014	1.02	1.025	1.029	0.992	0.986	0.98	0.975	0.971
	Kashan	1.006	1.011	1.015	1.019	1.022	0.994	0.989	0.985	0.981	0.978
	Kerman	1.004	1.006	1.009	1.011	1.013	0.996	0.993	0.991	0.989	0.987
Hot	**Isfahan**	0.963	0.932	0.905	0.883	0.863	1.037	1.068	1.095	1.117	1.137
	Semnan	0.968	0.942	0.92	0.901	0.884	1.032	1.058	1.080	1.099	1.116
	Kashan	0.966	0.938	0.914	0.894	0.876	1.034	1.062	1.086	1.106	1.124
	Kerman	0.962	0.93	0.903	0.88	0.86	1.038	1.07	1.097	1.12	1.14

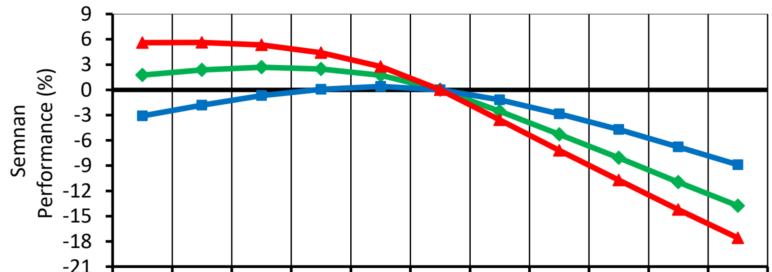
Therefore, considering the amount of energy lost and gained in the cold period in Isfahan, Semnan, Kashan and Kerman cities, the optimal aspect ratio is 1:1.2 for EW regtangular form. Also, regarding the minimum heat energy received in hot period, the optimal aspect ratio is 1:2 for EW regtangular form.

Based on the highest amount of the relation “(the difference between maximum required and received energy × hot period in percent) + (the difference between minimum required and received energy × cold period in percent)”, the best aspect ratio for EW rectangle in studied cities is 1:1.6. Figs. 1 to 4 show the performance of different aspect ratios of rectangle form compared to the square form in receiving energy. Table 9 shows the amount of energy received by optimal aspect ratios, in different orientations in studied cities.



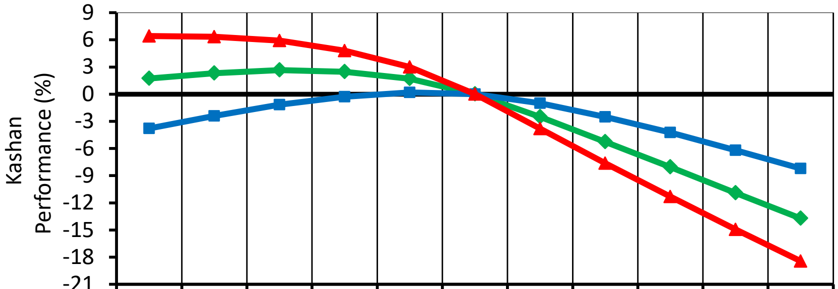
	1:2	1:1.8	1:1.6	1:1.4	1:1.2	1:1	1:1.2	1:1.4	1:1.6	1:1.8	1:2
	EW rectangle					Square	NS rectangle				
Isfahan-Total	0/78	1/51	2/00	1/99	1/46	0/00	-2/25	-4/79	-7/40	-10/11	-12/78
Cold period	-5/32	-3/72	-2/23	-1/06	-0/21	0/00	-0/59	-1/74	-3/17	-4/88	-6/68
Hot period	7/66	7/41	6/77	5/43	3/34	0/00	-4/13	-8/23	-12/17	-16/01	-19/66

Fig.1 Energy performance in rectangle and square forms in Isfahan (%)



	1:2	1:1.8	1:1.6	1:1.4	1:1.2	1:1	1:1.2	1:1.4	1:1.6	1:1.8	1:2
	EW rectangle					Square	NS rectangle				
Semnan-Total	1/76	2/35	2/68	2/48	1/72	0/00	-2/52	-5/28	-8/08	-10/96	-13/76
Cold period	-3/11	-1/82	-0/69	0/05	0/39	0/00	-1/19	-2/85	-4/71	-6/78	-8/90
Hot period	5/59	5/63	5/33	4/39	2/77	0/00	-3/57	-7/20	-10/74	-14/23	-17/59

Fig.2 Energy performance in rectangle and square forms in Semnan (%)



	1:2	1:1.8	1:1.6	1:1.4	1:1.2	1:1	1:1.2	1:1.4	1:1.6	1:1.8	1:2
	EW rectangle					Square	NS rectangle				
Kashan-Total	1/72	2/32	2/66	2/46	1/71	0/00	-2/51	-5/26	-8/06	-10/92	-13/73
Cold period	-3/79	-2/41	-1/17	-0/29	0/20	0/00	-1/00	-2/51	-4/23	-6/19	-8/21
Hot period	6/42	6/35	5/91	4/81	3/00	0/00	-3/80	-7/61	-11/32	-14/95	-18/42

Fig.3 Energy performance in rectangle and square forms in Kashan (%)

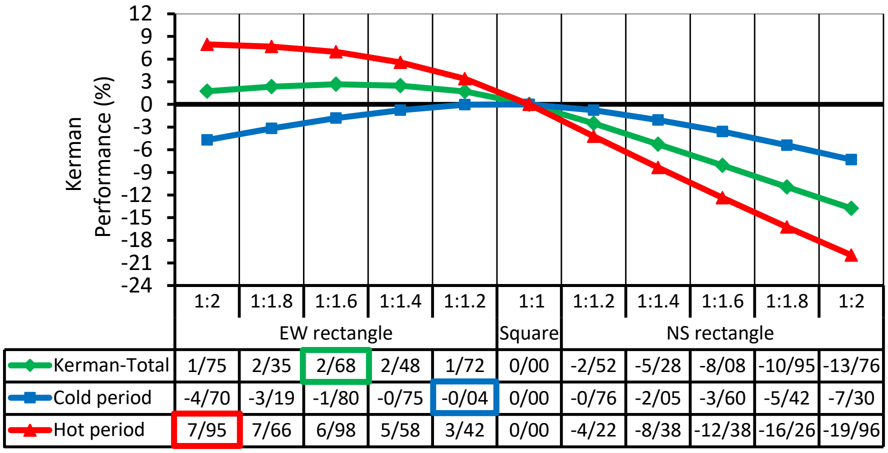


Fig.4 Energy performance in rectangle and square forms in Kerman (%)

Table 9. The received energy by the EW rectangle, based on optimal aspect ratios (BTU/H/FT2)

A.R= 1:1.6		Southwest					180°	Southeast				
		-105°	-120°	-135°	-150°	-165°		+165°	+150°	+135°	+120°	+105°
Isfahan	Total	5723.1	5699.1	5603.1	5487.9	5340.5	5244.1	5340.5	5487.9	5603.1	5699.1	5723.1
	period Cold	2999	2920.5	2884.6	2930.7	3014.2	3010.6	3025	2947.1	2916.7	2952.1	3015.3
	%	52.4	51.2	51.5	53.4	56.4	57.4	56.6	53.7	52.1	51.8	52.7
	period Hot	2724.2	2778.6	2718.4	2557.2	2326.3	2233.5	2315.5	2540.8	2686.4	2747	2707.8
	%	47.6	48.8	48.5	46.6	43.6	42.6	43.4	46.3	47.9	48.2	47.3
	Difference	274.8	142	166.2	373.5	687.9	777.2	709.5	406.2	230.3	205.1	307.5
Semnan	Total	5302	5278.9	5190.6	5109.1	4991.9	4901.1	4991.9	5109.1	5190.6	5278.9	5302
	period Cold	2234.2	2195.1	2164	2234	2344	2324.6	2312.3	2264.2	2202	2223	2278.5
	%	42.1	41.6	41.7	43.7	47	47.4	46.3	44.3	42.4	42.1	43
	period Hot	3067.9	3083.8	3026.6	2875	2647.9	2576.5	2679.5	2844.9	2988.6	3055.9	3023.6
	%	57.9	58.4	58.3	56.3	53	52.6	53.7	55.7	57.6	57.9	57
	Difference	-833.7	-888.8	-862.6	-641	-304	-251.9	-367.2	-580.7	-786.6	-832.9	-745.1
Kashan	Total	5089.4	5069.1	4982.8	4882.5	4750.9	4658.4	4750.9	4882.5	4982.8	5069.1	5089.4
	period Cold	2179.6	2128.7	2090.8	2147.4	2250.5	2228.9	2246.9	2186.8	2129.3	2149.4	2207.1
	%	42.8	42	42	44	47.4	47.8	47.3	44.8	42.7	42.4	43.4
	period Hot	2909.8	2940.4	2892	2735	2500.4	2429.5	2504	2695.6	2853.4	2919.7	2882.3
	%	57.2	58	58	56	52.6	52.2	52.7	55.2	57.3	57.6	56.6
	Difference	-730.1	-811.7	-801.2	-587.6	-249.9	-200.6	-257.2	-508.8	-724.1	-770.3	-675.1
Kerman	Total	5546.9	5523.2	5422.9	5299.3	5141.3	5037.9	5141.3	5299.3	5422.9	5523.2	5546.9
	period Cold	2609	2544.1	2485.6	2528.1	2632.1	2635	2652.5	2588.4	2525.5	2549	2619.4
	%	47	46.1	45.8	47.7	51.2	52.3	51.6	48.8	46.6	46.2	47.2
	period Hot	2938	2979.1	2937.3	2771.2	2509.2	2402.9	2488.8	2710.8	2897.3	2974.2	2927.6
	%	53	53.9	54.2	52.3	48.8	47.7	48.4	51.2	53.4	53.8	52.8
	Difference	-329	-435	-451.7	-243.1	122.9	232.2	163.6	-122.4	-371.8	-425.2	-308.2

According to the results of table 9, in surveyed aspect ratios, the maximum amount of energy received by vertical surfaces is related to the orientations of 105º SE and SW and the minimum amount relates to the 180º South orientation. As the form has further rotation toward East or West, the amount of received energy increases during hot period and decreases during the cold period. So that the amount of energy received during the hot period at 105º SE and SW in Isfahan, Semnan, Kashan and Kerman cities are about 21%, 17%, 18% and 22% higher than the South direction, respectively. Considering the hot climate of the studied cities, the best building orientation is determined due to the receiving minimum energy in hot period. Therefore, the best orientation for the selected aspect ratios in the cities of Isfahan, Semnan, Kashan and Kerman is 180º south.

4. Conclusion

The aim of this research is to investigate the amount of received radiation energy of vertical surfaces in buildings and to determining the appropriate form, aspect ratio and orientation of building in the cities of Isfahan, Semnan, Kashan and Kerman with hot-dry climate. In this research, six polygonal forms, including square, rectangle with

North-South and East-West directions, hexagonal, octagonal, hexadecagon, and triacontadigon with equal area and height, were investigated. The amount of received radiation energy on vertical surfaces was calculated using the "Law of cosine" computational method for different months and in 32 geographic directions, in terms of the cold and hot periods of the year. The results show that The least amount of energy in hot period in the studied cities is related to the rectangular form with the East-West orientation and the highest amount of energy in the hot period is related to the rectangular form with the North-South orientation. In order to get optimum amount of solar energy, the best forms of building in Isfahan, Semnan, Kashan and Kerman cities, is the rectangular form with the East-West orientation. The most appropriate aspect ratio for the rectangle with East-West orientation in studied cities is 1:1.6. The most suitable orientation for the selected aspect ratios in studied cities is 180º south. The research result is applicable in designing architectural and urban spaces which are climate compatible. This research also enables better planning and managing building energy consumption through controlling the amount of received radiation based on the time when heating and cooling are required.

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