ISSN: 2008-5079 / EISSN: 2538-2365
DOI: 10.22034/AAUD.2020.222272.2147

Optimal Aspect Ratio and Orientation of the Building, Based on Solar Energy Receiving in Different Climates, Iran

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Received 4 March 2020; Revised 10 August 2020; Accepted 2 September 2020; Available Online 21 December 2021;

ABSTRACT

The design of climate compatible buildings that use solar energy efficiently causes to reduce fossil fuels' consumption. The aim of this research is to determine the most appropriate aspect ratio and orientation of the buildings for receiving optimal solar radiation in the cities of Ardabil, Rasht, Kerman and Bushehr with cold, temperate, hot-dry and hot-humid climates, respectively. In this research, the square and rectangular forms with North-South and East-West orientation were studied. All of the studied forms had the same floor area and elevation with orientation to the South. The aspect ratios of the rectangle form were 1:1.2 to 1:3 (by step 0.2), and the orientation of the studied optimum aspect ratios were 180^{o} to 105^{o} (by step 15^{o}) SE and SW. The amount of direct energy received by vertical surfaces of buildings is calculated and processed, using the "Law of Cosines" computational method, for different months and in 24 geographic directions, in terms of the cold and hot periods of the year. The maximum amount of energy received by vertical surfaces in cold and hot periods is related to the rectangular form with East-West and North-South orientation, respectively. The results of the research show that the appropriate form of the buildings in studied cities is the rectangle with East-West orientation. The most suitable aspect ratio for EW rectanglular form is 1:1.2 in Ardabil, 1:1.4 in Rasht and 1:1.6 in Kerman and Bushehr cities. The best orientations for the determined aspect ratios in Ardabil is 165^{o} SE and in Rasht, Kerman and Bushehr cities is 180^{o} South.

Keywords: Aspect ratio, Building orientation, Vertical surfaces, Solar Energy performance.

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1. INTRODUCTION

In recent years, due to the energy crisis and the destructive environmental impact of fossil fuels, the use of renewable energies, especially solar energy, is considered to save and reduce the consumption. If buildings are designed in accordance with solar radiation and climatic conditions of the region, there will be a lot of savings in fossil fuels consumption. The form of the building has a great influence on its climatic compatibility, as well as adjusting the critical conditions of inside/outside heat transfer. The best form of the building is a form that loses the least amount of heat in winter, and also receives the least amount of heat from the sun and surrounding area in summer. In cold climate, the maximum use of solar radiation is considered, and buildings in this climate should be oriented in such a way to receive maximum solar energy throughout the year; on the other hand, in hot climate, the orientation of buildings should be in such a way to minimize the intensity of sunlight on external walls and receive the least solar annual energy. This study aims to determine the optimal aspect ratios and orientation of building through surveying the amount of direct energy received by vertical surfaces of buildings in the cities of Ardabil, Rasht, Kerman and Bushehr with cold, temperate, hot-dry and hot-humid climates, respectively.

2. RESERCH BACKGROUND

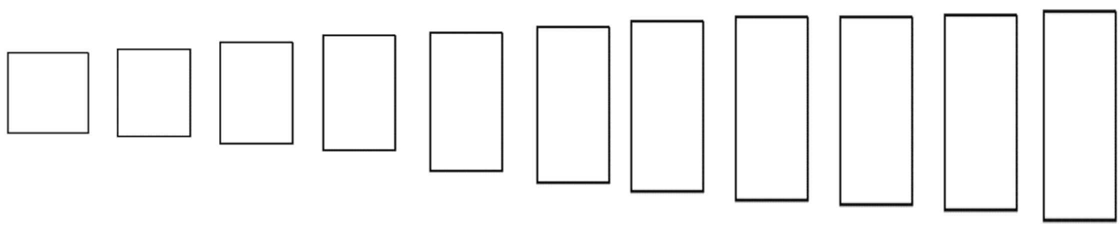
Most of studies about the relationship between building form and energy, emphasis on energy consumption and management control and reducing the demands of fossil fuels. The studies were conducted on the relationship between building form and energy consumption, which can be categorized into two types 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 (Wei et al. 2016). 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 (Ourghi et al. 2007; Al-Anzi et al. 2009; Depecker et al. 2001). Building shape also has a significant impact on building and energy costs (Mingfang, 2002; Ourghi et al. 2007; Pacheco et al. 2012). Al-Anzi et al. (2009) used the compression as an index in assessing the effect of shape on energy performance of a building. The form and external envelope of the building are the most important effective parameters on internal climate (Hemsath and Bandhosseini Alagheband 2015; Oral and Yilmaz 2003) and the size and orientation of the external envelope have direct effect on thermal performance of the building. Determining the form, orientation and the proper structure of external envelope can reduce the building energy consumption by 40% (Wang et al. 2006). Other researches indicated that the circle shape is the most favorable form in the tropical climate (Rashidi and Embi 2016; Chia et al. 2007). Krem (2012) showed that the placement of the structural vertical core/walls in the east and west sides and building footprints with an aspect ratio of 1:3 (Sides configuration) lead to significant reduction in the energy demand in the four major climatic zones (cool, temperate, tropical and arid zones) of the United States. Tajuddeen and Ango (2017), 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 (2018) 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 a comprehensive study, Mc keen and Fung (2014) investigated the effect of aspect ratio on energy requirements of multi-unit residential buildings in Canada and confirmed that the 1.3 to 1.5 range is ideal in different cities of that country. In a study on the effects of building envelopes on received solar radiation on residential energy consumption, on the case of SW and SE Orientation in Shiraz, the results showed that houses with an optimum climate orientation, such as Southeast and Northwest, have the proper condition in terms of the amount of received and consumed energy (Barzegar and Heidari 2012; Barzegar et al. 2012). In a study of the relationship between the form of residential buildings and their energy consumption in the hot and dry climate of Semnan city (in Iran), the results showed that in the case of non-shaded forms (square, rectangular and trapezoidal), the square form has better performance than the rectangle, and then the rectangle with the aspect ratio of 1:3 is more suitable form. Among the shading shapes (L, U, H, and T), the L shape with a depth ratio of 2 to 3 and the orientation of the wings to the West and North and the angle between the wings of 70 degrees is the best option in terms of energy efficiency (Zarghami et al. 2016). Karbalaee doree and Hejazi zadeh (2017), investigated the optimizing building orientation in the city of Kashan, based on climatic conditions and showed that the ideal orientation of the main facade of one-way buildings faces 180º South. The appropriate orientation for two-sided buildings is North-South and for four-sided buildings is +150º and -30º. Farajzadeh and Abbasi (2012), in optimization of the direction of buildings of Qir town in relation to sun radiation using the cosine method, determined that 150º to 165º Southeast for one-way buildings, 165º Southeast and 15º Northwest, as the most ideal orientations and 180º as the acceptable orientation for two-sided builings. In optimizing the orientation of the open spaces and building constructions for cold climate, based on sunshine in Borujerd city, the results showed that the best orientations of buildings in Borujerd for optimizing energy consumption, are South-North, and then 15º west (Hedayatian and Goodarzi, 2016). Zamani et al (2016), showed that the best building orientations in order to receive optimum solar energy during cold and hot periods of the year are 135º and 225º azimuth. In optimizing the orientation of buildings against radiation in Shiraz city, the results show that the optimal orientations for the building are of the South and 165º SE and SW; Among these orientations, considering the facades of one-way and two-sided buildings, the South is the most desirable orientation, due to the maximum energy absorption during cold period of the year and less energy absorption during the hot period of the year (Karami Kord Alivand and Narengi Fard, 2017).

3. METHODOLOGY

In order to determine the best aspect ratio and orientation of building in terms of receiving sunlight, the hour angle, the declination angle, the azimuth angle and the altitude angle in different hours of the day were deternined using Q-BASIC software. The amount of received direct radiation energy on vertical surfaces were calculated and processed through theoretical and actual calculation, using the "Law of Cosines" computational method for different months and in 24 geographic directions, in terms of the cold and hot periods of the year. In this research, the square and rectangular forms with North-South and East-West orientations were investigated. The aspect ratios of the case studies in rectangular form were 1:1.2 to 1:3 (by step 0.2) and the orientation of the studied optimum aspect ratios were 180º to 105º (by step 15º) Southeast and Southwest. All the investigated forms had the same floor area and height. The best aspect ratio and orientation of building are determined, based on the maximum amount of differences between received energy, in cold and hot periods of the years or the maximum amount of sunlight energy received in the cold period.

Table 1: The ratio between the external envelope area of rectangle and square form

Square	Rectangle with NS and EW Orientation									
	1:1.2	1:1.4	1:1.6	1:1.8	1:2	1:2.2	1:2.4	1:2.6	1:2.8	1:3
1.00	1.004	1.014	1.027	1.043	1.06	1.078	1.097	1.116	1.135	1.153



3.1. Study Area

Based on Koppen Climate Classification System, the cities of Ardabil, Rasht, Kerman and Bushehr, are located in cold (Dfb), temperate (Cfb), hot-dry (BSks) and Subtropical (Csa-BShs) climates, respectively (Ganji 1954).

Table 2: Geographical-climatic characteristics of the studied cities

	Latitude	Longitude	Elevation (m)	Annual Temp. (ºC)			Ave. RH (%)
				Max	Min	Ave	
Ardabil	38º 15′ N	48º 17′ E	1332	15.3	2.8	9.05	71
Rasht	37º 15′ N	49º 36′ E	-6.9	20.6	11.3	15.9	82
Kerman	30º 15′ N	56º 58′ E	1753	24.7	6.9	15.8	31
Bushehr	28º 59′ N	50º 50′ E	22.5	32.9	17.6	25.3	65

(IRIMO, 2018)

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 Ardabil, Rasht, Kerman and Bushehr is less than comfortable condition, respectively in 65%, 58%, 49% and 25% of the year, and it is more than it in 35%, 42%, 51%, and 75% of the year, respectively. Considering that the duration of cold months in Ardabil and Rasht cities are more than hot months, determining the optimal aspect ratio and building orientation, is based on receiving maximum solar energy in the cold season of the year. Also considering that the duration of hot months in the Kerman and Bushehr cities are more than the cold months, determining the optimal aspect ratio and building orientation, is based on receiving minimum solar energy in the hot season of the year.

3.2. 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 equations (Table 3).

Table 3: The equations of calculating direct solar radiation energy

$I_S=I_N\times\cos\theta$	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 relation 1, the value of I_N is calculated by the equation 2 (Ashrae 1995).
$I_{DN}=I^\circ \exp(-\alpha /\sinh)$	I_{DN}, is the heat produced by direct and perpendicular sunlight; I°, is the solar constant; α, is the extinction coefficient (Ashrae 1995) and h, is the angle of the sun's radiation.
$\cos\theta=\cos h\times\cos(Z-N)$	**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 (Watson & Labs 1983). **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.
$\omega=15\times(12-T)$	ω, is the solar hour angle; T, is the desired time. 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 15 degrees longitude per hour.
$\delta=23.45\times\sin[360((364+n)/365)]$	δ, is the declination angle during the day. 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. n, is the number of days from the beginning of the solar year.
$T_d=2/15\text{ArcCos}(-\text{tag}\delta\times\tan\text{Ø})$	T_d, is The day's length, which is symmetric to the solar noon, and the Earth moves around its own axis 15º per hour. δ, is the declination angle and $Ø$, is the latitude in degrees.
$\sin h=(\cos Ø\times\cos\delta\times\cos\omega)+(\sin Ø\times\sin\delta)$	**h**, is the altitude angle of the sun's radiation. The altitude angle is the vertical angle between the horizon and the line connecting to the sun; Its measure varies from zero to 90º.
$\sin Z=(\cos\delta\times\sin Ø)/\cos h$	**Z**, is the azimuth angle. 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.

4. RESULTS AND DISCUSSION

The amount of radiant energy received by the vertical surfaces was calculated for different months and in 24 geographical directions for the studied cities. At first, the total received energy is calculated theoretically and then, for formula actualization, it is multiplied to the different month's coefficient (the percentage of sunshine hours(, in order to determine the actual amount of energy on vertical surfaces. Table 4 shows the average and percentage of sunshine hours.

Table 4: The percentage of sunshine hours in studied cities

		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Ardabil	Ave. day *length	9.8	10.9	12.1	13.3	14.3	14.7	14.2	13.3	11.6	10.8	9.8	9.3
	Ave. sunshine hours	4.9	5.3	5.5	6	7.9	9.5	9.8	8.8	7.3	6.2	5.1	4.7
	sunshine hours (%)	49.6	48.5	45.5	44.8	55.5	64.6	68.6	66.8	63	57.3	52.4	50.4

		Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Rasht	Ave. day *length	9.9	11	12.1	13.3	13.6	14.6	14.2	13.2	11.6	10.9	9.9	9.4
	Ave. sunshine hours	3.1	3.1	2.9	4	5.6	6.8	7.1	5.8	4.4	4	3.2	3
	sunshine hours (%)	30.8	28.1	24	30.1	41.3	46.5	50.2	44.1	38.2	36.4	32.6	31.5
Kerman	Ave. day *length	10.4	11.2	12.1	13	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	9.4	8	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
Bushehr	Ave. day *length	10.5	11.3	12.1	12.9	13.5	13.8	13.5	12.9	11.6	11.2	10.5	10.2
	Ave. sunshine hours	6.6	6.8	7	7.6	9.5	10.7	10.2	10.5	9.5	9.3	7.5	6.4
	sunshine hours (%)	63.1	60.6	58.1	59.1	70	77.8	75.7	81.5	82.1	83.3	72	62.4

*The day length is calculated by the writers. (IRIMO, 2018)

In tables 5 and 6, the total (annual) received direct energy by vertical surfaces is calculated and actualized by the percentage of sunshine hours coefficient. Also in these tables, the amount of energy received by the vertical surfaces in cold and hot period and the amount of differences between them are calculated.

Table 5: The amount of energy received by vertical surfaces in Ardabil and Rasht cites (BTU/H/FT2)

Orientation	Ardabil						Rasht					
	Total	Period				Dif.	Total	Period				Dif.
		Cold	%	Hot	%			Cold	%	Hot	%	
North	310.7	162.3	52.2	148.4	47.8	14	229.4	62.7	27.3	166.6	72.7	-103.9
+15	555.9	313.3	56.4	242.6	43.6	70.7	405.2	124.5	30.7	280.7	69.3	-156.2
+30	1140.2	693.8	60.9	446.4	39.1	247.4	813.6	277.6	34.1	536	65.9	-258.3
+45	1922.7	1163.8	60.5	758.9	39.5	405	1341.8	521.7	38.9	820.1	61.1	-298.4
+60	2858.7	1791.4	62.7	1067.3	37.3	724.1	1959.8	825.8	42.1	1134	57.9	-308.3
+75	3840.5	2512.7	65.4	1327.8	34.6	1184.9	2588	1220	47.1	1368	52.9	-148
+90	4716.2	3142	66.6	1574.3	33.4	1567.7	3132.6	1579.7	50.4	1552.9	49.6	26.8
+105	5548.1	3863.4	69.6	1684.7	30.4	2178.7	3636	1997.7	54.9	1638.4	45.1	359.3
+120	6157.6	4448.2	72.2	1709.4	27.8	2738.7	3984.4	2362.7	59.3	1621.7	40.7	740.9
+135	6588	4859.5	73.8	1728.5	26.2	3131.1	4205.1	2655	63.1	1550.1	36.9	1104.9
+150	6854	5224.2	76.2	1629.7	23.8	3594.5	4320.5	2934.3	67.9	1386.2	32.1	1548.1
+165	6929	5329.4	76.9	1599.6	23.1	3729.7	4316.7	3087.7	71.5	1228.9	28.5	1858.8
South	6908.4	5204.7	75.3	1703.7	24.7	3501	4279.1	3088.7	72.2	1190.4	27.8	1898.3
-165	6929	5025.3	72.5	1903.6	27.5	3121.7	4316.7	3035.6	70.3	1281.1	29.7	1754.4
-150	6854	4650.2	67.8	2203.8	32.2	2446.4	4320.5	2814.4	65.1	1506.1	34.9	1308.3
-135	6588	4162.5	63.2	2425.5	36.8	1737.1	4205.1	2516	59.8	1689.1	40.2	826.9
-120	6157.6	3578	58.1	2579.6	41.9	998.4	3984.4	2192.5	55	1791.9	45	400.6
-105	5548.1	2962	53.4	2586.1	46.6	375.9	3636	1820.7	50.1	1815.3	49.9	5.4
-90	4716.2	2289.6	48.5	2426.7	51.5	-137.1	3132.6	1411.9	45.1	1720.8	54.9	-308.9
-75	3840.5	1622.9	42.3	2217.5	57.7	-594.6	2588	1042	40.3	1546.1	59.7	-504.1
-60	2858.7	1030.1	36	1828.6	64	-798.6	1959.8	671.8	34.3	1288	65.7	-616.2
-45	1922.7	581.9	30.3	1340.8	69.7	-758.8	1341.8	389.4	29	952.4	71	-563
-30	1140.2	273.1	24	867.1	76	-594	813.6	189.2	23.3	624.4	76.7	-435.2
-15	555.9	199.7	35.9	356.2	64.1	-156.5	405.2	96.9	23.9	308.3	76.1	-211.5

Table 6: The amount of energy received by vertical surfaces in Kerman and Bushehr cites (BTU/H/FT2)

Orien-tation	Kerman						Bushehr					
	Total	Period				.Dif	Total	Period				.Dif
		Cold	%	Hot	%			Cold	%	Hot	%	
North	496	64.6	13	431.4	87	-366.8	531.7	13.3	2.5	518.3	97.5	-505
+15	830	159.2	19.2	670.8	80.8	-511.6	879.5	53.5	6.1	826	93.9	-772.5
+30	1667	463.3	27.8	1203.7	72.2	-740.4	1734.1	174.8	10.1	1559.3	89.9	-1384.4
+45	2761.9	960.5	34.8	1801.4	65.2	-840.9	2827.1	420.4	14.9	2406.7	85.1	-1986.3
+60	4014.8	1596.9	39.8	2417.9	60.2	-820.9	4058.4	768.6	18.9	3289.8	81.1	-2521.2
+75	5249	2326.3	44.3	2922.7	55.7	-596.4	5245.6	1223.5	23.3	4022.1	76.7	-2798.6
+90	6282.8	2929.5	46.6	3353.4	53.4	-423.9	6211.7	1548.9	24.9	4662.9	75.1	-3114
+105	7196.9	3702.6	51.4	3494.3	48.6	208.3	7038.2	2004	28.5	5034.2	71.5	-3030.2
+120	7777.9	4269.2	54.9	3508.7	45.1	760.6	7521.6	2215.4	29.5	5306.1	70.5	-3090.7
+135	8083.8	5010.1	62	3073.8	38	1936.3	7724.7	2357.9	30.5	5366.8	69.5	-3008.8
+150	8185.2	5163.6	63.1	3021.6	36.9	2142	7732.5	2608.3	33.7	5124.1	66.3	-2515.8
+165	8100.5	5372.7	66.3	2727.8	33.7	2644.9	7570.4	2820	37.2	4750.4	62.8	-1930.5
South	8023.5	5362.4	66.8	2661.2	33.2	2701.2	7458.8	2775.2	37.2	4683.6	62.8	-1908.4
-165	8100.5	5147.6	63.5	2952.9	36.5	2194.8	7570.4	2593.8	34.3	4976.6	65.7	-2382.8
-150	8185.2	4523.3	55.3	3661.9	44.7	861.3	7732.5	2168	28	5564.4	72	-3396.4
-135	8083.8	3877.3	48	4206.5	52	-329.1	7724.7	1744.5	22.6	5980.2	77.4	-4235.7
-120	7777.9	3343.4	43	4434.6	57	-1091.2	7521.6	1395.1	18.5	6126.4	81.5	-4731.3
-105	7196.9	2746.6	38.2	4450.3	61.8	-1703.7	7038.2	1064	15.1	5974.1	84.9	-4910.1
-90	6282.8	2089.5	33.3	4193.4	66.7	-2103.9	6211.7	786.5	12.7	5425.2	87.3	-4638.7
-75	5249.0	1493.5	28.5	3755.5	71.5	-2262	5245.6	534.4	10.2	4711.2	89.8	-4176.8
-60	4014.8	898.4	22.4	3116.4	77.6	-2218	4058.4	331.2	8.2	3727.3	91.8	-3396.1
-45	2761.9	440.1	15.9	2321.8	84.1	-1881.7	2827.1	144.4	5.1	2682.6	94.9	-2538.2
-30	1667	161.1	9.7	1505.9	90.3	-1344.8	1734.1	23.6	1.4	1710.5	98.6	-1686.8
-15	830	77.2	9.3	752.8	90.7	-675.6	879.5	0	0	879.5	100	-879.5

According to the results of tables 5 and 6, the highest amount of annual received energy in Ardabil is at 165º SE and SW and in the cities of Rasht, Kerman and Bushehr are at 150º SE and SW. The lowest amount of annual received energy in the all cities are at the North and 15º NE and NW. The highest amount of energy receiving in cold period, in Ardabil (76.9%) is at 165º SE and in the cities of Rasht (72.2%), Kerman (66.8%) and Bushehr (37.2%) are at 180º South. Also, the highest amount of differences between received energy in cold and hot periods of the years in Ardabil is at 165º SE and in the cities of Rasht, Kerman and Bushehr, are at 180º South. The amount of energy received by the vertical surfaces of square and rectangle forms with different aspect ratios is calculated in terms of cold and hot periods and presented in tables 7 and 8. According to the amount of received energy and based on differences between the amount of received energy in cold and hot periods, the optimal forms which are compatible with the climate of the region, are determined.

Table 7: The amount of energy received by the studied forms in Ardabil and Rasht (BTU/H/FT2)

Aspect ratios		Ardabil						Rasht					
		Period				%	.Dif	Period				%	.Dif
		Total	Cold	%	Hot			Total	Cold	%	Hot		
Square		4162.9	2699.6	64.9	1463.3	35.1	1236.4	2693.4	1535.7	57	1157.7	43	378.1
EW rectangle	1:1.2	4112.4	2698.2	65.6	1414.3	34.4	1283.9	2653.4	1539.4	58	1114	42	425.4
	1:1.4	4070.7	2697	66.3	1373.7	33.7	1323.2	2620.2	1542.4	58.9	1077.8	41.1	464.6
	1:1.6	4035	2695.9	66.8	1339.1	33.2	1356.8	2591.9	1545	59.6	1046.9	40.4	498.1
	1:1.6	4004.8	2695	67.3	1309.8	32.7	1385.3	2567.9	1547.2	60.2	1020.8	39.8	526.4
	1:2	3978.5	2694.3	67.7	1284.2	32.3	1410.1	2547	1549.1	60.8	998	39.2	551.1
	1:2.2	3955.5	2693.6	68.1	1261.9	31.9	1431.7	2528.8	1550.7	61.3	978.1	38.7	572.6
	1:2.4	3934.8	2693	68.4	1241.8	31.6	1451.2	2512.3	1552.2	61.8	960.1	38.2	592.1
	1:2.6	3917	2692.5	68.7	1224.5	31.3	1468	2498.2	1553.5	62.2	944.7	37.8	608.8
	1:2.8	3900.6	2692	69	1208.6	31	1483.4	2485.2	1554.7	62.6	930.6	37.4	624.1
	1:3	3886.4	2691.6	69.3	1194.8	30.7	1496.8	2473.9	1555.7	62.9	918.2	37.1	637.5

	Aspect ratios	Ardabil						Rasht					
		Period						Period					
		Total	Cold	%	Hot	%	.Dif	Total	Cold	%	Hot	%	.Dif
NS rectangle	**1:1.2**	4213.4	2701.1	64.1	1512.2	35.9	1188.9	2733.5	1532.1	56	1201.4	44	330.7
	1:1.4	4255.1	2702.3	63.5	1552.8	36.5	1149.5	2766.6	1529.1	55.3	1237.5	44.7	291.5
	1:1.6	4290.8	2703.4	63	1587.4	37	1115.9	2794.9	1526.5	54.6	1268.4	45.4	258.1
	1:1.6	4321	2704.2	62.6	1616.7	37.4	1087.5	2818.9	1524.3	54.1	1294.6	45.9	229.7
	1:2	4347.3	2705	62.2	1642.3	37.8	1062.7	2839.8	1522.4	53.6	1317.4	46.4	205
	1:2.2	4370.3	2705.7	61.9	1664.6	38.1	1041.1	2858	1520.8	53.2	1337.3	46.8	183.5
	1:2.4	4391	2706.3	61.6	1684.7	38.4	1021.5	2874.5	1519.3	52.9	1355.2	47.1	164
	1:2.6	4408.8	2706.8	61.4	1702	38.6	1004.8	2888.6	1518	52.6	1370.7	47.4	147.3
	1:2.8	4425.2	2707.3	61.2	1717.9	38.8	989.4	2901.6	1516.8	52.3	1384.8	47.7	132
	1:3	4439.4	2707.7	61	1731.7	39	976	2912.9	1515.8	52	1397.2	48	118.6

Table 8: The amount of energy received by the studied forms in Kerman and Bushehr (BTU/H/FT2)

	Aspect ratios	Kerman						Bushehr					
		Period						Period					
		Total	Cold	%	Hot	%	.Dif	Total	Cold	%	Hot	%	.Dif
	Square	5271.3	2611.5	49.5	2659.8	50.5	-48.4	5103.5	1281	25.1	3822.5	74.9	-2541.6
EW rectangle	**1:1.2**	5179.1	2620.8	50.6	2558.3	49.4	62.5	5002.4	1291.3	25.8	3711.1	74.2	-2419.8
	1:1.4	5102.7	2628.5	51.5	2474.2	48.5	154.2	4918.8	1299.8	26.4	3618.9	73.6	-2319.1
	1:1.6	5037.5	2635	52.3	2402.4	47.7	232.6	4847.3	1307.1	27	3540.2	73	-2233
	1:1.6	4982.3	2640.6	53	2341.7	47	298.9	4786.8	1313.3	27.4	3473.5	72.6	-2160.2
	1:2	4934.1	2645.5	53.6	2288.6	46.4	356.8	4734.1	1318.7	27.9	3415.3	72.1	-2096.6
	1:2.2	4892.2	2649.7	54.2	2242.5	45.8	407.2	4688.1	1323.4	28.2	3364.7	71.8	-2041.3
	1:2.4	4854.2	2653.5	54.7	2200.7	45.3	452.8	4646.5	1327.7	28.6	3318.9	71.4	-1991.2
	1:2.6	4821.7	2656.8	55.1	2164.9	44.9	491.9	4610.9	1331.3	28.9	3279.6	71.1	-1948.3
	1:2.8	4791.8	2659.8	55.5	2132	44.5	527.8	4578.2	1334.7	29.2	3243.5	70.8	-1908.8
	1:3	4765.7	2662.5	55.9	2103.3	44.1	559.2	4549.6	1337.6	29.4	3212	70.6	-1874.4
NS rectangle	**1:1.2**	5363.5	2602.2	48.5	2761.4	51.5	-159.2	5204.5	1270.6	24.4	3933.9	75.6	-2663.3
	1:1.4	5439.9	2594.5	47.7	2845.4	52.3	-250.9	5288.2	1262.1	23.9	4026.1	76.1	-2764
	1:1.6	5505.1	2587.9	47	2917.2	53	-329.3	5359.6	1254.8	23.4	4104.9	76.6	-2850.1
	1:1.6	5560.3	2582.3	46.4	2978	53.6	-395.7	5420.1	1248.6	23	4171.5	77	-2922.9
	1:2	5608.5	2577.5	46	3031	54	-453.5	5472.9	1243.2	22.7	4229.7	77.3	-2986.5
	1:2.2	5650.4	2573.2	45.5	3077.1	54.5	-503.9	5518.8	1238.5	22.4	4280.3	77.6	-3041.8
	1:2.4	5688.4	2569.4	45.2	3118.9	54.8	-549.5	5560.4	1234.3	22.2	4326.2	77.8	-3091.9
	1:2.6	5720.9	2566.1	44.9	3154.7	55.1	-588.6	5596	1230.6	22	4365.4	78	-3134.8
	1:2.8	5750.8	2563.1	44.6	3187.7	55.4	-624.5	5628.8	1227.3	21.8	4401.5	78.2	-3174.3
	1:3	5776.8	2560.5	44.3	3216.4	55.7	-655.9	5657.4	1224.3	21.6	4433	78.4	-3208.7

According to the results of tables 7 and 8, the maximum amount of energy received by vertical surfaces is related to the rectangular form with North-South orientation and the minimum amount 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 the other forms but, these forms have different performance due to the shift of angles of surfaces in relation to receiving solar energy in cold and hot weather. Due to the climate of the studied cities, the best form of building is determined, based on the maximum amount of differences between received energy, in cold and hot periods of the years or the maximum amount of received sunlight energy in the cold period. The highest amount of energy in cold period in the studied cities is related to the rectangular form with East-West orientation and the lowest amount of energy in the cold period is related to the rectangular form with the North- South orientation. Therefore, according to the established criteria, the best form of building in the studied cities, is the rectangle 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, as well. The form's optimal aspect ratio, is a relation in 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 1:3, in relation to the square, are 1.004, 1.014, 1.027, 1.043, 1.06, 1.078, 1.097, 1.116, 1.135 and 1.153 percent, and the maximum absorbed energy in hot period are 0.996, 0.986, 0.973, 0.957, 0.94, 0.922, 0.903, 0.884, 0.865 and 0.847 percent, respectively. Table 9 shows the amount of the ratio of energy received by rectangle to square forms in during cold and hot periods in percent.

Table 9: The ratio of energy received by rectangle to square forms in during cold and hot periods (%)

Form	Period	City	1:1.2	1:1.4	1:1.6	1:1.8	1:2	1:2.2	1:2.4	1:2.6	1:2.8	1:3
EW rectangle	Cold	Ardabil	0.999	0.999	0.999	0.998	0.998	0.998	0.998	0.997	0.997	0.997
		Rasht	1.002	1.004	1.006	1.007	1.009	1.010	1.011	1.012	1.012	1.013
		Kerman	1.004	1.006	1.009	1.011	1.013	1.015	1.016	1.017	1.019	1.02
		Bushehr	1.008	1.015	1.02	1.025	1.029	1.033	1.036	1.039	1.042	1.044
	Hot	Ardabil	0.966	0.939	0.915	0.895	0.878	0.862	0.849	0.837	0.826	0.816
		Rasht	0.962	0.931	0.904	0.882	0.862	0.845	0.829	0.816	0.804	0.793
		Kerman	0.962	0.93	0.903	0.88	0.86	0.843	0.827	0.814	0.802	0.791
		Bushehr	0.971	0.947	0.926	0.909	0.893	0.88	0.868	0.858	0.849	0.84
NS rectangle	Cold	Ardabil	1.001	1.001	1.001	1.002	1.002	1.002	1.002	1.003	1.003	1.003
		Rasht	0.998	0.996	0.994	0.993	0.991	0.99	0.989	0.988	0.988	0.987
		Kerman	0.996	0.993	0.991	0.989	0.987	0.985	0.984	0.983	0.981	0.98
		Bushehr	0.992	0.985	0.98	0.975	0.97	0.967	0.964	0.961	0.958	0.956
	Hot	Ardabil	1.033	1.061	1.085	1.105	1.122	1.138	1.151	1.163	1.174	1.183
		Rasht	1.038	1.069	1.096	1.118	1.138	1.155	1.171	1.184	1.196	1.207
		Kerman	1.038	1.07	1.097	1.12	1.14	1.157	1.173	1.186	1.198	1.209
		Bushehr	1.029	1.053	1.074	1.091	1.107	1.12	1.132	1.142	1.151	1.16

The amount of energy performance for the aspect ratios of forms is calculated according to the equation 9.

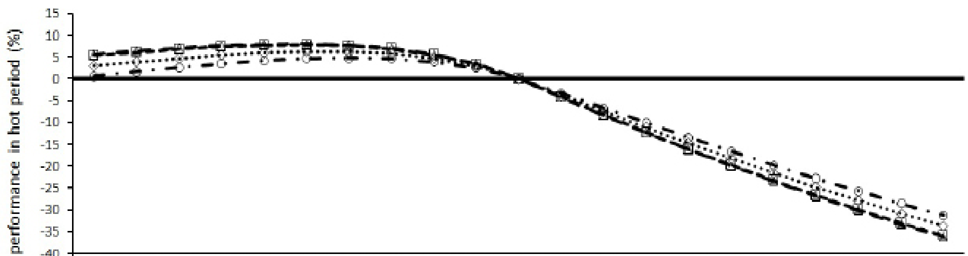
$$[(E_{Max.\ Required} - E_{Received}) \times \text{Hot period } (\%)] + [(E_{Min.\ Required} - E_{Received}) \times \text{Cold period } (\%)] \qquad (9)$$

Where, "E" is the reguired and received energy in hot and cold periods (BTU/H/FT2).

Figs. 1 to 3 show the performance of different aspect ratios of rectangle form compared to the square form in receiving energy. Considering the amount of energy lost and gained in the cold period, the optimal aspect ratio in that period in Ardabi, Rasht, Kerman and Bushehr cities is 1:1.2. Also, regarding the minimum heat energy received in hot period, the optimal aspect ratio in that period in Ardabil, Rasht and Kerman cities is 1:2 and in Bushehr cities is 1:1.8. Based on the equation 9, the best aspect ratio for EW rectangle in Ardabil is 1:1.2, in Rasht is 1:1.4 and in the Kerman and Bushehr cities is 1:1.6.

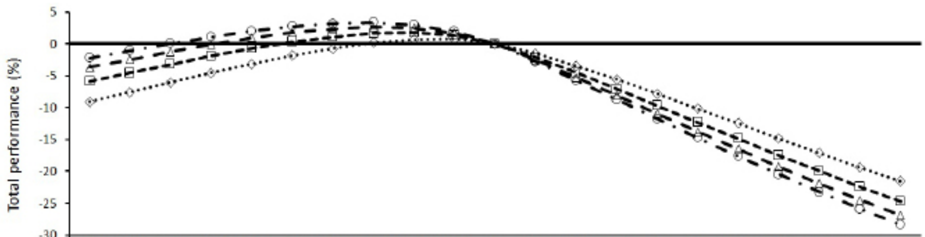
	1:3	1:2.8	1:2.6	1:2.4	1:2.2	1:2	1:1.8	1:1.6	1:1.4	1:1.2	1:1	1:1.2	1:1.4	1:1.6	1:1.8	1:2	1:2.2	1:2.4	1:2.6	1:2.8	1:3
	Rectangle (EW)										Square	Rectangle (NS)									
Ardabil	-15.6	-13.7	-11.8	-9.94	-8.02	-6.20	-4.47	-2.84	-1.50	-0.45	0.00	-0.34	-1.30	-2.56	-4.13	-5.80	-7.57	-9.45	-11.3	-13.2	-15.0
Rasht	-14.0	-12.2	-10.4	-8.62	-6.82	-5.13	-3.55	-2.10	-0.96	-0.16	0.00	-0.63	-1.83	-3.30	-5.04	-6.86	-8.77	-10.7	-12.7	-14.7	-16.6
Kerman	-13.3	-11.6	-9.87	-8.09	-6.34	-4.70	-3.19	-1.80	-0.75	-0.04	0.00	-0.76	-2.05	-3.60	-5.42	-7.30	-9.26	-11.3	-13.3	-15.3	-17.2
Bushehr	-10.8	-9.31	-7.67	-6.06	-4.49	-3.06	-1.78	-0.66	0.07	0.40	0.00	-1.21	-2.88	-4.75	-6.83	-8.95	-11.1	-13.3	-15.5	-17.7	-19.7

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



	1:3	1:2.8	1:2.6	1:2.4	1:2.2	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	1:2.2	1:2.4	1:2.6	1:2.8	1:3
	Rectangle (EW)										Square	Rectangle (NS)									
Ardabil	3.05	3.91	4.72	5.44	5.96	6.24	6.19	5.79	4.72	2.95	0.00	-3.74	-7.52	-11.1	-14.7	-18.2	-21.5	-24.8	-27.9	-30.9	-33.6
Rasht	5.39	6.12	6.80	7.37	7.71	7.80	7.53	6.87	5.50	3.38	0.00	-4.17	-8.30	-12.2	-16.1	-19.8	-23.3	-26.7	-29.9	-33.1	-35.9
Kerman	5.62	6.34	7.01	7.56	7.89	7.95	7.66	6.98	5.58	3.42	0.00	-4.22	-8.38	-12.3	-16.2	-19.9	-23.4	-26.9	-30.2	-33.3	-36.2
Bushehr	0.67	1.65	2.60	3.48	4.18	4.65	4.83	4.69	3.93	2.51	0.00	-3.31	-6.73	-10.0	-13.4	-16.6	-19.7	-22.8	-25.8	-28.6	-31.2

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



	1:3	1:2.8	1:2.6	1:2.4	1:2.2	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	1:2.2	1:2.4	1:2.6	1:2.8	1:3
	Rectangle (EW)										Square	Rectangle (NS)									
Ardabil	-9.07	-7.59	-6.06	-4.56	-3.13	-1.84	-0.74	0.18	0.68	0.74	0.00	-1.53	-3.47	-5.58	-7.86	-10.1	-12.4	-14.8	-17.1	-19.4	-21.5
Rasht	-5.86	-4.54	-3.20	-1.91	-0.72	0.30	1.10	1.67	1.75	1.32	0.00	-2.12	-4.55	-7.06	-9.70	-12.3	-14.8	-17.4	-19.9	-22.4	-24.7
Kerman	-3.67	-2.47	-1.26	-0.11	0.92	1.75	2.35	2.68	2.48	1.72	0.00	-2.52	-5.28	-8.08	-10.9	-13.7	-16.5	-19.2	-21.9	-24.5	-26.9
Bushehr	-2.22	-1.09	0.03	1.09	2.01	2.72	3.18	3.35	2.96	1.99	0.00	-2.79	-5.76	-8.75	-11.7	-14.7	-17.6	-20.4	-23.2	-25.9	-28.3

Fig. 3. Total energy performance in rectangle and square forms (%)

Table 10: shows the amount of energy received by optimal aspect ratios, in different orientations in studied cities.

			Southwest						Southeast				
			-105°	**-120°**	**-135°**	**-150°**	**-165°**	**180°**	**+165°**	**+150°**	**+135°**	**+120°**	**+105°**
Ardabil (A.R= 1:1.2)	Total		4261.6	4275.9	4255.3	4229.4	4175.1	4112.6	4175.1	4229.4	4255.3	4275.9	4261.6
	period	Cold	2749.7	2713.8	2689.3	2702.5	2702.9	2698.2	2752.2	2719.6	2694.6	2708.6	2709.6
		%	64.5	63.5	63.2	63.9	64.7	65.6	65.9	64.3	63.3	63.3	63.6
		Hot	1511.9	1562.1	1566	1526.9	1472.2	1414.4	1422.9	1509.8	1560.8	1567.2	1552
		%	35.5	36.5	36.8	36.1	35.3	34.4	34.1	35.7	36.7	36.7	36.4
	Difference		1237.8	1151.7	1123.3	1175.6	1230.7	1283.8	1329.3	1209.8	1133.8	1141.4	1157.6

City	A.R			Southwest						Southeast				
				-105°	-120°	-135°	-150°	-165°	180°	+165°	+150°	+135°	+120°	+105°
Rasht	(A.R= 1:1.4)		Total	2799.1	2803.3	2773.4	2735.8	2673.9	2620.2	2673.9	2735.8	2773.4	2803.3	2799.1
		period	Cold	1550.3	1531	1520.2	1534	1554.9	1542.4	1562.3	1539.8	1520.8	1529.2	1544.9
			%	55.4	54.6	54.8	56.1	58.2	58.9	58.4	56.3	54.8	54.6	55.2
			Hot	1248.7	1272.3	1253.2	1201.8	1119	1077.8	1111.6	1196	1252.6	1274.1	1254.2
			%	44.6	45.4	45.2	43.9	41.8	41.1	41.6	43.7	45.2	45.4	44.8
			Difference	301.6	258.8	267	332.2	436	464.6	450.8	343.8	268.1	255.1	290.7
Kerman	(A.R= 1:1.6)		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	2536.7	2528.1	2632.1	2635	2652.5	2588.4	2607.3	2549	2619.4
			%	47	46.1	46.8	47.7	51.2	52.3	51.6	48.8	48.1	46.2	47.2
			Hot	2938	2979.1	2886.2	2771.2	2509.2	2402.9	2488.8	2710.8	2815.5	2974.2	2927.6
			%	53	53.9	53.2	52.3	48.8	47.7	48.4	51.2	51.9	53.8	52.8
			Difference	-329	-435	-349.5	-243.1	122.9	232.2	163.6	-122.4	-208.2	-425.2	-308.2
Bushehr	(A.R= 1:1.6)		Total	5404.6	5383.6	5275.9	5139.7	4962.2	4847.7	4962.2	5139.7	5275.9	5383.6	5404.6
		period	Cold	1246.2	1171.9	1147.3	1210.6	1302.7	1307.1	1307.6	1225.9	1186.3	1234.1	1290.1
			%	23.1	21.8	21.7	23.6	26.3	27	26.4	23.9	22.5	22.9	23.9
			Hot	4158.4	4211.7	4128.5	3929.1	3659.5	3540.6	3654.6	3913.8	4089.6	4149.4	4114.5
			%	76.9	78.2	78.3	76.4	73.7	73	73.6	76.1	77.5	77.1	76.1
			Difference	-2912.3	-3039.7	-2981.2	-2718.5	-2356.8	-2233.5	-2347	-2687.8	-2903.3	-2915.3	-2824.3

According to the results of Table 10, in surveyed aspect ratios, the maximum amount of energy received by vertical surfaces is related to the orientation of 120º and 105º Southeast and southwest and the minimum amount relates to the South orientation. As the form rotates toward East and 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 Southeast and Southwest in Ardebil, Rasht, Kerman and Bushehr are about 10%, 16%, 21% and 16% higher than the South direction, respectively. Considering the climate of the studied cities, the best building orientation is determined due to the receiving minimum energy in hot period and maximum energy in cold period. Therefore, according to the established criteria, the best orientation for the selected aspect ratios in the city of Ardabil is 165º SE, and then it is 180º south and in Rasht, Kerman and Bushehr cities, is 180º South and then it is 165º SE. Fig. 4 shows the orientation prioritization for buildings in the studied cities.

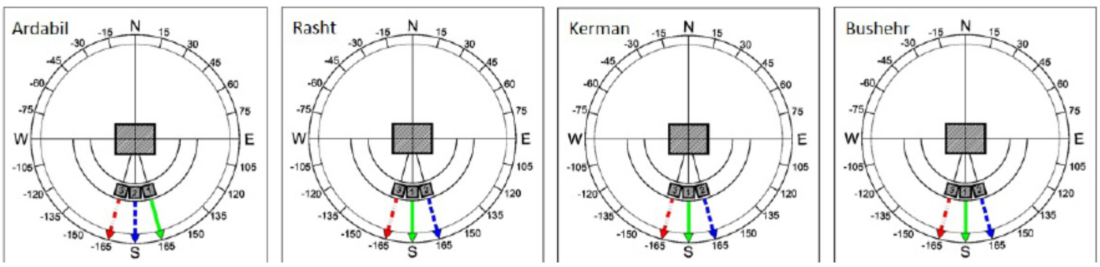


Fig.4. Orientation prioritization for buildings in the studied cities; (Green line: first priority; Blue line: second priority; Red line: third priority)

5. CONCLUSION

This research investigated the optimal aspect ratio and orientation of the buildings based on energy receiving in the cities of Ardabil, Rasht, Kerman and Bushehr. The square and rectangular forms with North-South and East-West orientation were studied. The aspect ratios of the rectangular form were 1:1.2 to 1:3 (by step 0.2). The amount of received radiation energy on vertical surfaces was calculated using the "Law of cosines" computational method. The results showed that the highest amount of energy received by vertical surfaces is related to the rectangular form with the North-South orientation and the minimum amount is related to the rectangular form with East-West orientation. In order to get optimum amount of solar energy, the best form of buildings in the studied cities is the rectangular with East-West orientation. The most appropriate aspect ratio for the rectangle with East-West orientation in Ardabil is 1:1.2, in Rasht is 1:1.4 and in Kerman and Bushehr, is 1:1.6. The most suitable orientation for the selected aspect ratios in Ardabil is 165º SE and in Rasht, Kerman and Bushehr cities, is 180º South.

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HOW TO CITE THIS ARTICLE

Akbari, H., Hosseini Nezhad. F., H. (2021). Optimal Aspect Ratio and Orientation of the Building, Based on Solar Energy Receiving in Different Climates, Iran. Armanshahr Architecture & Urban Development Journal. 14(36), 267-278.

DOI: 10.22034/AAUD.2020.222272.2147
URL: http://www.armanshahrjournal.com/article_142360.html?lang=en