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Climatic Compatibility of Courtyard Houses, Based on Shading- sunlit Index; Case Studies: Traditional Houses in Kashan & Ardabil Cities

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ABSTRACT: Today, access to sustainable environment for more presence of humans in open space should improve the quality of open spaces and human thermal comfort. Hence, the courtyard as an open space is an important element in solar radiation absorption and providing thermal comfort. The aim of this paper is to investigate the climatic performance of traditional courtyard houses, according to shading and sunlit in two cities with different climates: Kashan city (hot-arid climate) and Ardabil city (cold climate). In order to carry out this research, firstly ten types of traditional houses in Kashan and Ardabil were chosen. , thereafter, the shadow and sunlit in almost all floors and walls of courtyards were calculated and analyzed in June and December using Ecotect software simulations. In order to assess the compatibility level of the selected historical samples of each city with the region's climate, the average of a composite indexes (shading-sunlit index of walls and floor) of the selected houses in two cities have been compared. The average shading-sunlit index for the houses in Kashan is 0.43 and for the selected houses in Ardabil is 0.40; meaning that in both cities, the houses are relatively compatible with the region's climate and the cases in Kashan city show more compatible to some extent. Also the results of studies demonstrate that in case studies in both cities, the amount of shaded surfaces have appropriate climate compatibility in warm months; while, in terms of sunlit, they do not have an appropriate climate compatibility in cold months.

Keywords: Climatic Compatibility, Shading-sunlit Index, Traditional House, Courtyard, Kashan and Ardabil City.

INTRODUCTION

According to the architectural background of traditional houses, the concept of vernacular architectures is based on climate properties such as sunlit, wind blowing direction and other related factors that provide a method for determining the house orientation in different climatic conditions in Iran (Pirnia, 2005). Regarding the effect of sun movement on various surfaces, house builders have allocated each surface to a specific season and hour (Memarian, 2008). Traditional Iranian architects usually tried to create a space in which they could relax and rest. Therefore, they needed to employ natural factors to create these kinds of spaces and they also believed that architectural sustainability is merged with and parallel to nature attributes. According to four different climates in Iran, courtyards are built in different dimensions and sizes. Spaces around the yard are also distinct in compliance with various climates. In order to achieve climate sustainability in designing traditional houses with cenral courtyards, optimum usage of natural factors like wind, sunlight, water and plantings is enabled by using passive systems. Courtyards as the open spaces of houses, play the most critical and effective role in absorbing solar energy, so controlling sunshade -due to thermal comfort necessity- is really important in architectural system of buildings. Obviously, one of the design goals in tropical regions is to prevent sunlight radiation and provide shadow on building surfaces and walls, whereas in cool regions, preventing the creation of shadow on surfaces is more crucial. Proportions, placement directions, materials and courtyard form play the major role in

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determining the solar energy amount on various surfaces of yard and providing visual and thermal comfort for residents. The purpose of this research is to investigate the climatic performance of few traditional houses with central courtyards based on shading percentage and sunlit reception rate. The main question is "how the adaptability rate of houses (with central courtyard pattern) to the climate is determined based on shading-sunlit index?". In order to determine the rate of climate compatibility of traditional houses, different case studies dating back to Qajar period in two different climates of hot-dry (Kashan city) and cold (Ardabil city) were chosen to be investigated. Thereafter, the shaded and sunlit horizontal surfaces (courtyard floor) and vertical surfaces facing the courtyard (north, south, east and west facades) were calculated by using numerical methods and simulations in 22 June and 22 December. At last, the adaptation rate of the case studies were scrutinized and analyzed.

RESEARCH BACKGROUND

By comparing the shading percentage of different case studies in different seasons, Taban et al. in a paper entitled "Determining optimum courtyard pattern in Dezful traditional houses by relying on shading analysis" showed that in courtyards length to width proportion of 1 to 1. 4 (in square form house) and also the length to height proportion of 1.1 to 1.2 (average depth), the most suitable shading percentage in warm seasons on the floor and the wall is achieved (Taban et al., 2013a). Also in the paper "Climate Impact on Architectural Ornament Analyzing Shadow of Khavoon in Dezful Historical Context Using Image Processing",it was shown that brick templates in different angles increase the shading percentage up to 2.5-4.5 times more than before according to sunlit hours calculation on surfaces (Taban et al., 2013b). In paper "Determining the most appropriate measures of radiation in the central courtyard of Yazd houses" results show that the best direction of courtyards in this climate is 37degrees southwest (Hoseinizadeh Mehrjerdi, 2012). In the paper "A comparative analysis of the outdoor thermal environment of the urban vernacular and the contemporary development" outputs illustrate that summer daily temperature in streets with a height to width proportion of 1 to 1, is 4 degrees more than streets with a height to width proportion of 3 to 1 (Shabbier, 1994). In paper "Shading simulation of the courtyard form in different climatic regions" despite modeling the shadow pattern in a sample central courtyard in four different areas with dissimilar climates, results display that the model and location of the courtyard is the most important fact in shading (Muhaisen, 2006a). The study "Effect of courtyard proportions on solar heat gain and energy requirement in the temperate climate of Rome" emphasizes on protecting the yard surfaces from excessive radiation and to avoid disturbing winds with regard to the proportions and surrounded degree (Muhaisen and Gadi, 2006). The article "The impact of shading design and control on building cooling & lighting demand" indicates that shading and radiation control will make energy usage decrease up to 31 percent in building (Tzempelikos et al., 2007). The paper "Seasonal effects of urban street shading on long-term outdoor thermal comfort" demonstrates that shady places usually in hot summer seasons, especially at noon, make people feel satisfied about the environment, and reduces satisfaction in winter (Hwang et al., 2010). In the paper "Investigation of Iranian traditional courtyard as passive cooling strategy" the study of three significant factors in designing the courtyard like orientation, dimensions and proportions in 20 traditional houses in seven traditional cities of Iran resulted in a physical environmental design for courtyard as a design proposal (Soflaei et al., 2016). Also, Soflaei et al. (2017) in the paper "The impact of courtyard design variants on shading performance in hot- arid climates of Iran" have introduced the most suitable courtyards in terms of dimensions and the angle of deviation from the North as for shading index based on thermal comfort by studying and analyzing the shading patterns of 10 case studies of Kerman traditional houses.

RESEARCH PROCESS

In this paper, the analytical-descriptive method has been used. In order to determine the adaptability of traditional houses with their climate, firstly 10 examples of traditional courtyard houses which date back to Qajar period which were located in both hot-dry (Kashan city) and cold (Ardabil city) climates were selected. In the next step, the shading and sunlit index on floors and walls (North, South, East and West) in the first days of June and December (9 A.M., 12 P.M., 3 P.M.) were calculated by simulation in Ecotect software, and categorized by excel software, so that obtained data of shaded and sunlit were shown in charts. According to the monthly and three hours temperature of Kashan and Ardabil, the shading in June and sunlit in December are required in both cities based on comfort temperature zone (22 degrees). In this paper, the number of walls (1.2.3.4) respectively represent South, East, North and West orientation. Also calculating the vegetation shading in the open spaces of courtyard and the latter yards (especially samples of Esfahanian and Bakuchi) are ignored.

FIELD STUDY: Environmental- geometric and Physical Analysis of Traditional Courtyards of Kashan and Ardabil, Iran

Kashan city is located in 33 degrees- 59 minutes of northern latitude and 51 degrees- 27 minutes of eastern longitude in approximately altitude of 982 meters above the sea level. Kashan is located in hot-arid region. On the other hand, Ardabil city is located at 38 degrees-15 minutes of northern latitude and 48 degrees- 17 minutes of eastern longitude in average altitude of 1332 meters above the sea. Ardabil is located in cold region.

The monthly average, minimum and maximum temperature of Kashan and Ardabil cities are shown in Tables 1 & 2.

Table 1. Minimum and Maximum of Monthly Average Temperature of Kashan and Ardabil Cities in December and June

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kashan (1966-2005)	Min	-0.3	1.5	6.3	12.1	16.9	21.9	24.8	23.3	18.4	12	6.2	1.5
	Max	10.2	13.4	19	26.3	31.8	38.2	40.8	39.9	35.3	27.6	18.9	12.1
	Average	5	7.7	13.2	20	25.4	31.4	34	32.6	27.8	20.6	12.8	6.8
Ardabil (1977-2005)	Min	-7.8	-5.8	-2	2.9	6.2	9.2	11.7	11.7	8.9	5.1	0.3	-4.5
	Max	3	4.9	9.8	16.6	19.9	23.4	25.1	25.1	22.7	17.7	11.6	5.9
	Average	-2.4	-0.5	3.9	9.7	13.1	16.3	18.4	18.4	15.8	11.4	5.9	0.7

Table 2. Three Hours Average Temperature of Kashan and Ardabil Cities in December and June

	Time	00:00	03:00	06:00	09:00	12:00	15:00	18:00	21:00
Kashan	22 December	1.97	2.96	5.27	9.55	11.3	7.94	5.28	3.35
	22 June	28.6	27.2	33.3	37.8	40.6	39.36	34.9	31.7
Ardabil	22 December	-0.97	-1.6	1.11	3.64	4.2	1.08	0.25	-0.64
	22 June	14.02	14.7	21.47	24.95	24.62	21.02	17.9	16.2

Tables 3 and 4 conclude physical specification of the species studied, include the orientation of the building, horizontal surfaces (floor and wall) and vertical surfaces (north, south, east and west facades) facing the courtyard and 3d form of the house.

Table 3. Geometric– physical Analysis of Traditional Courtyards in Hot-dry Climate of Kashan City

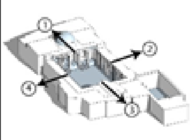
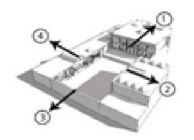
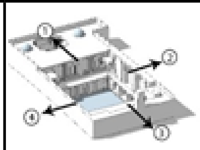
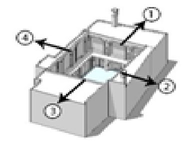
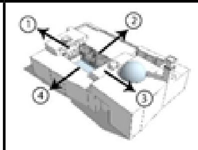
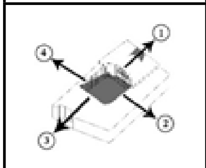
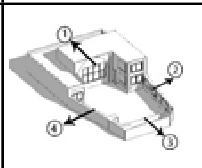
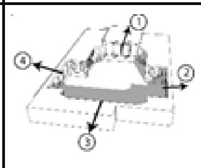
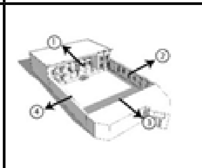
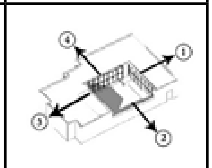
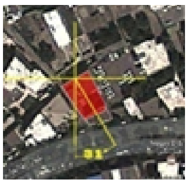
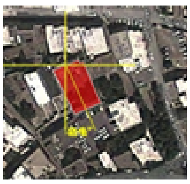
	Esfahanian	Al Yasin	Bakuchi	Tahami	Jahanarayi
Kashan Houses					
Orientation and Deviation Angle from the South					
	12.0˚	45.0˚	28.0˚	15.0˚	10.0˚
Roof (m^2)	1304.45	1048.33	560.66	473.64	562.19
Floor (m^2)	747.29	647.75	174.45	234.31	103.18
Wall 1 (m^2)	457.55	159.46	175.18	167.97	84.35
Wall 2 (m^2)	385.75	490.11	279.78	304.87	152.82
Wall 3 (m^2)	353.62	97.65	165.16	164.54	71.71
Wall 4 (m^2)	350.98	232.84	174.65	205.51	172.73

Table 4. Geometric– physical Analysis of Traditional Courtyards in Cold Climate of Ardabil City

	Ershadi	Taghavi	Khalilzadeh	Rezazadeh	Vakil
Ardabil Houses					
Orientation and Deviation Angle from the South					
	62°	31°	24°	55°	54°
Roof (m^2)	213.13	287.2	325.13	439.21	494.57
Floor (m^2)	61.66	248.33	270.18	422.21	192.3
Wall 1 (m^2)	27.61	82.58	114.17	250.84	73.69
Wall 2 (m^2)	33.15	66.46	30.2	81.86	44.24
Wall 3 (m^2)	27.27	25.13	83.7	105.51	196.99
Wall 4 (m^2)	48.13	43.44	30.4	81.1	69.35

VALIDATION

The shadow pattern and percentage are measured from 9 A.M. to 2 P.M. and on January 31, 2 and 3 February on the western façades in two cities. The amount of shadow is measured and installed on the tripod of 1.5 meters height by using camera pictures and laser distance meter (Fig. 1).The shading is at maximum points for both graph after 2 P.M., but differs about 2% at this point, and the average difference is 0.8% (Fig. 2). Comparison of collected information with the simulated model results is analysed by Excel software. Based on the results obtained, the correlation between the measured data and simulation is 0.99 which indicates high consistency (Fig. 2).

Fig. 1. Data Logger, A View of the Measured Courtyard (Left), and the Location of the Traditional Courtyard House (Right)

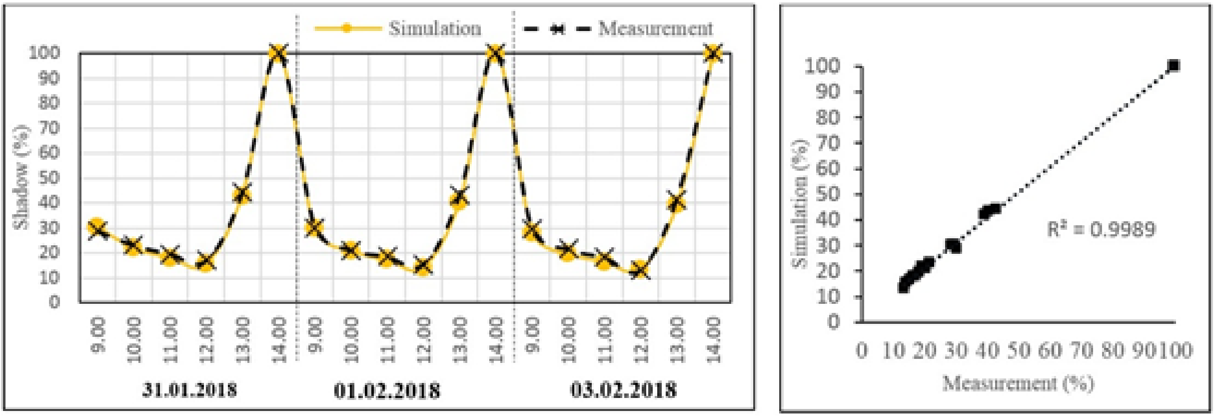
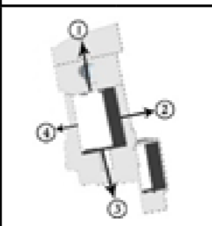
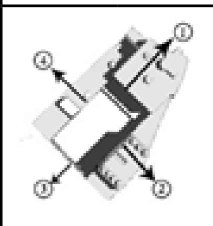
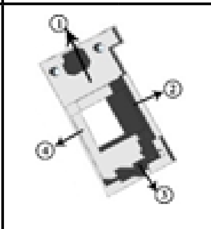
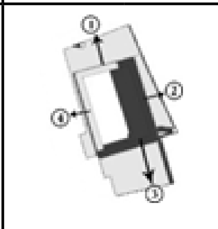
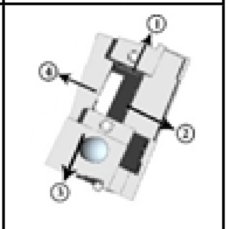
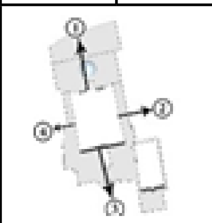
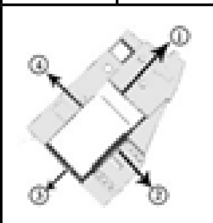
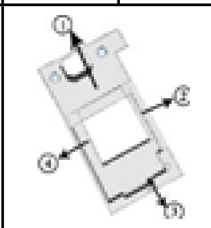
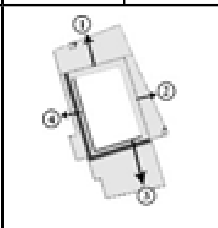
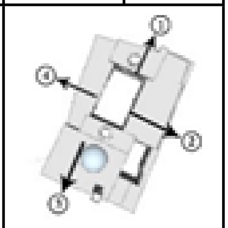


Fig. 2. A Comparison of the Shading Percentage between Simulation Results and the Measurements on January 31, 2 and 3 February (Left). The Comparison of the Shading Percentage in a Scattered Graph (Right)

The tables 5 to 8 demonstrates the shading percentage on floors and walls of the Kashan and Ardabil houses at 9 A.M., 12 and 15 P.M. on the first days of June and December.

Table 5. Shading Percentage in Kashan Houses in 22 June

Date	Esfahanian		Al Yasin		Bakuchi		Tahami		Jahanarayi	
22 June (9 am)										
	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)
Floor (m^2)	255.52	34.19	261.44	40.36	91.26	52.31	116.56	49.74	63.08	61.13
Walls (m^2)	1397.63	90.29	754.14	76.94	564.24	70.99	590	70	313.28	65.04
Total	1653.16	72.02	1015.58	62.38	655.5	67.63	706.56	65.59	376.36	64.35
22 June (12 pm)										
	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)
Floor (m^2)	274.04	36.67	49.38	7.62	20.51	11.75	34.42	14.68	10.75	10.41
Walls (m^2)	1298.77	83.90	912.77	93.13	521.43	65.60	662.17	78.55	453.68	94.20
Total	1572.81	68.52	962.15	59.10	541.94	55.91	696.59	64.66	464.43	79.41

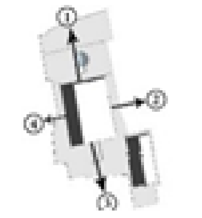
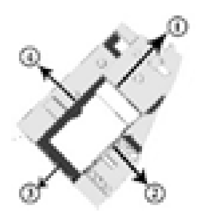
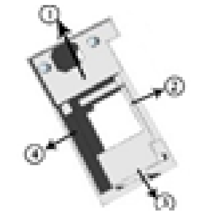
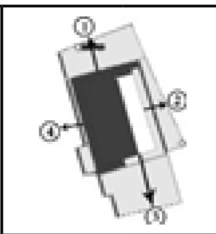
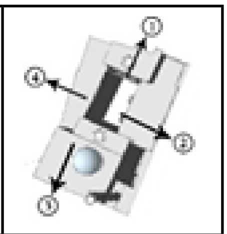
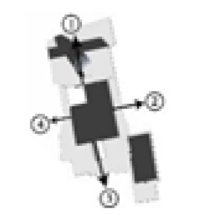
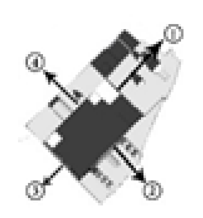
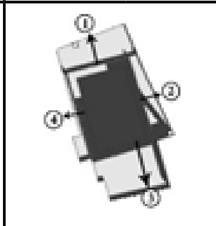
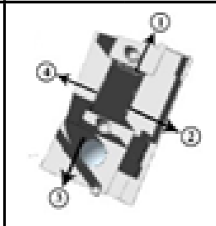
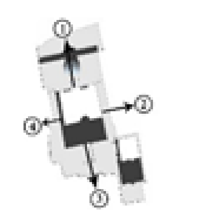
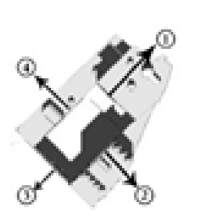
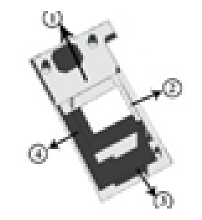
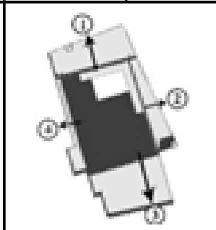
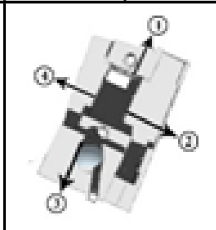
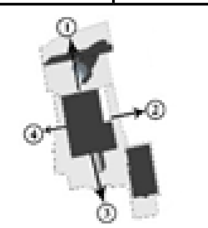
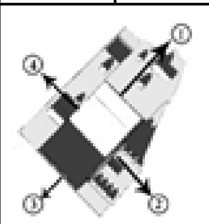
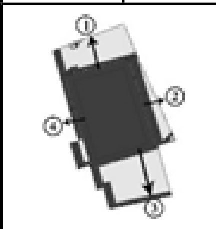
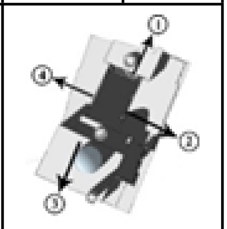
22 June (15 P.M.)										
	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)
Floor (m^2)	406.58	54.40	201.26	31.07	52.28	29.96	173.61	74.09	55.37	53.66
Walls (m^2)	1429.62	92.35	668.59	68.27	529.73	66.65	522.24	61.95	418.54	86.90
Total	1838.2	80.08	869.85	53.43	582.01	60.04	695.85	64.59	473.91	81.03

Table 6. Shading Percentage in Kashan Houses in 22 December

Date	Esfahanian		Al Yasin		Bakuchi		Tahami		Jahanarayi	
22 December (9 A.M.)										
	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)
Floor (m^2)	685.61	91.74	562.61	86.85	174.45	100	234.31	100	103.18	100
Walls (m^2)	1428.74	92.30	830.06	84.69	614.38	77.30	657	77.94	423	87.83
Total	2112.35	92.03	1392.67	85.55	788.76	81.38	891.31	82.74	526.18	89.97
22 December (12 P.M.)										
	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)
Floor (m^2)	456.26	61.05	350.85	54.16	89.81	51.48	193.84	82.72	77.28	74.89
Walls (m^2)	1394.5	90.08	766.91	78.25	511.21	64.32	623.18	73.93	409.19	84.96
Total	1850.76	80	1117.76	68.66	601.02	62.01	816.02	75.75	486.74	83.23
22 December (15 P.M.)										
	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)

Floor (m^2)	701.51	93.87	288.46	44.53	174.45	100	234.31	100	103.18	100
Walls (m^2)	1344.06	86.83	916.39	93.50	513.18	64.69	813.69	96.53	418.47	86.88
Total	2045.57	89.12	1204.85	74.01	687.63	70.94	1048	97.28	521.65	89.20

Table 7. Shading Percentage in Ardabil Houses in 22 June

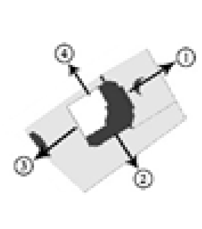
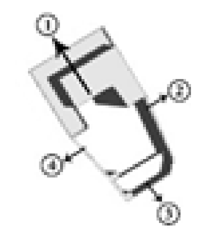
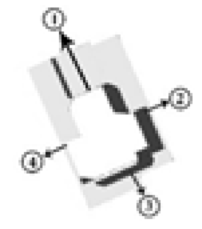
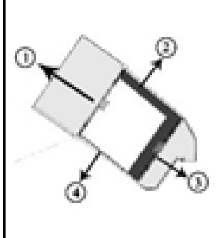
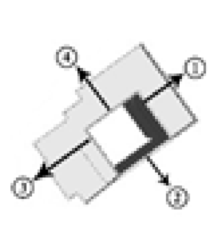
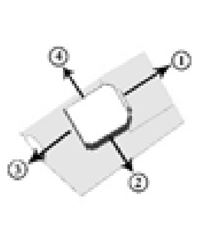
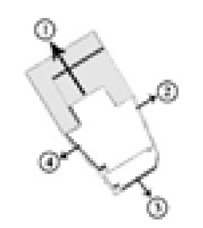
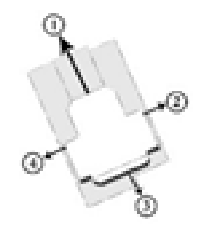
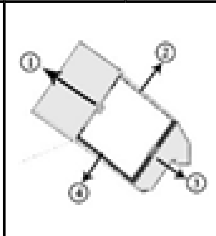
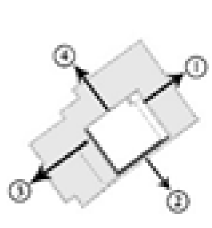
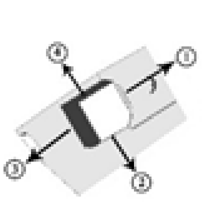
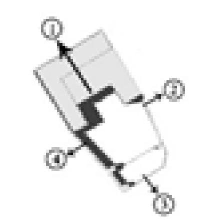
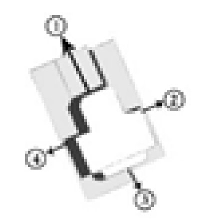
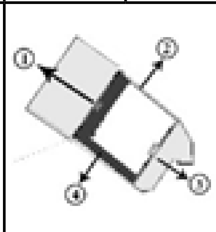
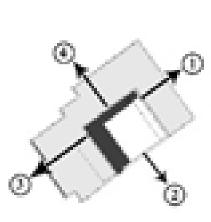
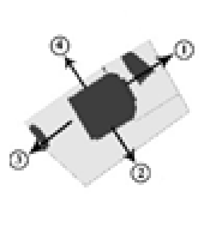
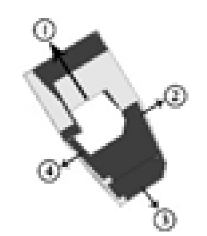
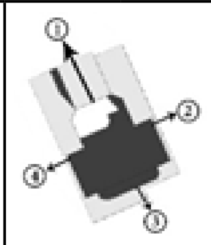
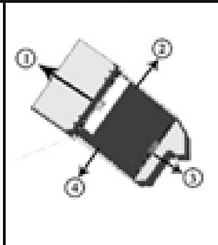
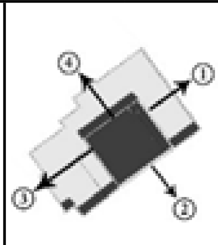
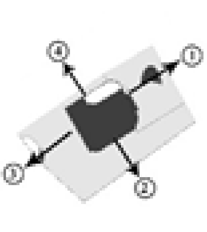
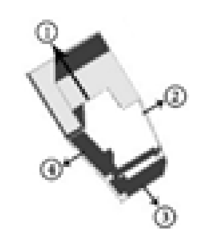
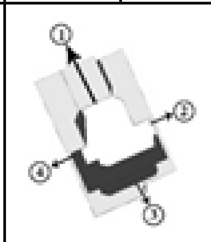
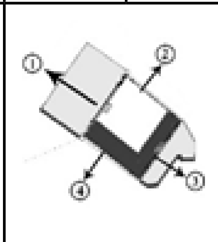
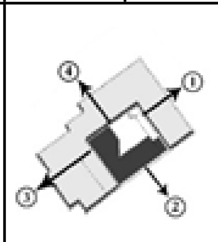
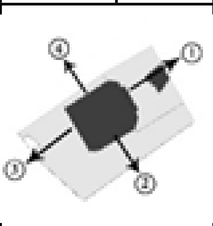
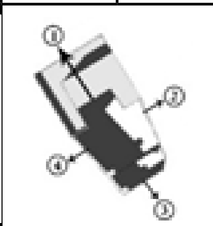
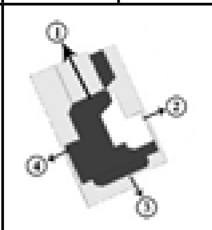
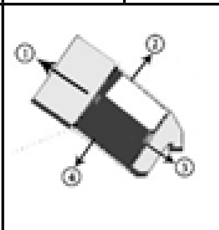
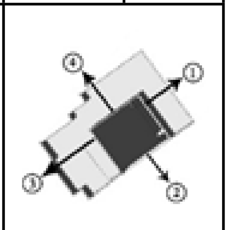
Date	**Ershadi**		**Taghavi**		**Khalilzadeh**		**Rezazadeh**		**Vakil**	
22 June (9 A.M.)										
	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)
Floor (m^2)	33.24	53.90	59	23.75	72.84	26.95	103.22	24.44	94.88	49.33
Walls (m^2)	91.06	66.87	157.55	72.40	156.17	60.42	315.48	60.74	261.56	68.06
Total	124.3	62.83	216.55	46.47	229	43.31	418.7	25.06	356.44	61.82
22 June (12 P.M.)										
	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)
Floor (m^2)	7.94	12.88	14.87	5.98	19.29	7.13	26.11	6.18	20.47	10.64
Walls (m^2)	79.06	58.06	122.35	56.22	195.77	75.74	376.74	72.54	344.44	89.63
Total	87	43.97	137.22	29.45	215.06	40.68	402.85	24.11	364.91	63.28
22 June (15 P.M.)										
	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)
Floor (m^2)	24.6	39.89	52.35	18.22	54.4	20.13	112.87	26.73	75.8	39.41
Walls (m^2)	100.83	74.05	136.2	62.58	161.3	62.40	381.69	73.49	294.86	76.73
Total	125.43	63.40	188.54	40.46	215.7	40.80	494.56	29.60	370.66	64.28

Table 8. Shading Percentage in Ardabil Houses in 22 December

Date	**Ershadi**		**Taghavi**		**Khalilzadeh**		**Rezazadeh**		**Vakil**	
22 December (9 A.M.)										
	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)
Floor (m^2)	61.66	100	167.85	67.57	227.16	84.07	356.17	84.35	192.3	100
Walls (m^2)	112.44	82.57	179.51	82.49	180	69.64	310.55	59.80	312.56	81.33
Total	174.1	88.00	347.32	74.53	407.16	77.01	666.72	39.91	504.86	87.56
22 December (12 P.M.)										
	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)
Floor (m^2)	45.05	73.06	95.28	38.36	123.79	45.81	181.05	42.88	126.4	65.73
Walls (m^2)	86.08	63.22	115.31	52.98	163.16	63.12	333.28	64.17	279.83	72.82
Total	131.13	66.28	210.59	45.19	286.95	54.27	514.33	30.78	406.23	70.45
22 December (15 P.M.)										
	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)	Shading Area (m^2)	Shading (%)
Floor (m^2)	61.66	100	175.41	70.63	200.61	74.25	276.26	65.43	178.35	92.74
Walls (m^2)	102.75	75.46	130.51	59.97	180.08	69.67	408.61	78.68	318.45	82.87
Total	167.44	84.64	305.92	65.65	380.69	72.01	684.87	41	496.8	86.16

Figs. 3. and 4 Display the Shading and the Sunlit Percentage of Courtyard Walls on the First Days of June and December.

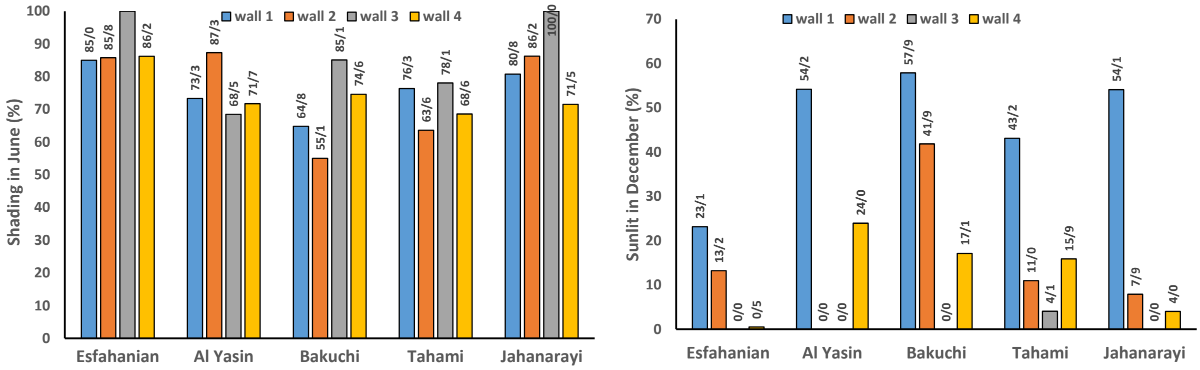


Fig. 3. Sunlit Percentage in December (Right) and Shading Percentage in June (Left) of the Wall of Houses in Kashan (at 9, 12 A.M. and 15 P.M.)

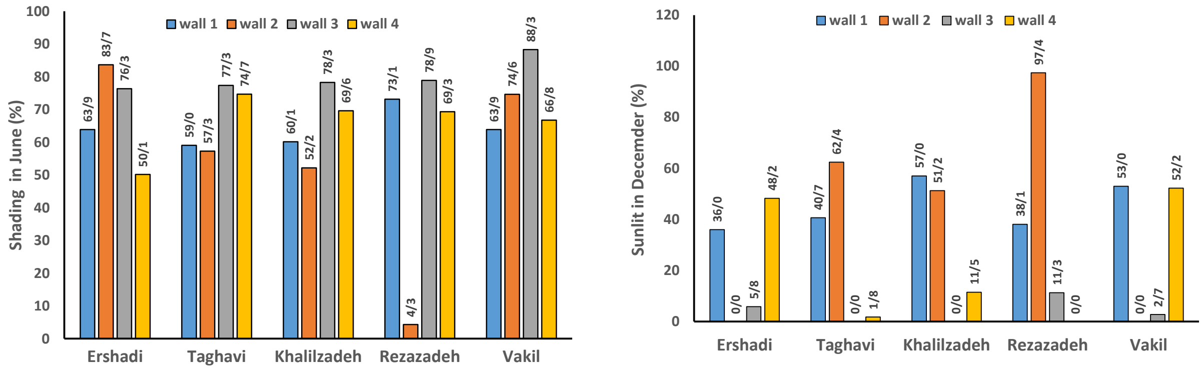


Fig. 4. Sunlit Percentage in December (Right) and Shading Percentage in June (Left) of the Wall of Houses in Ardabil (at 9, 12 A.M. and 15 P.M.)

RESULTS AND DISCUSSION

The shading percentage of walls of Esfahanian, Al Yasin, Bakuchi, Tahami and Jahanarayi houses in June based on Figs. 3 and 4, are respectively 88.9, 79.43, 67.75, 70.17, 82.05 and the sunlit percentage in December are respectively 10.26, 14.52, 31.27, 17.23, and 13.44. Also the percentage of shading on walls in the Ershadi, Taghavi, Khalilzade, Rezazadeh and Vakil houses in June are 66.33, 63.74, 66.19, 68.93, 78.14 respectively and the sunlit percentage in December are 25.5, 34.85, 32.52, 32.45 and 20.99. Al Yasin and Vakil houses have the highest total of shading in the warm months, and Tahami and Taghavi houses have the highest total of sunlit on the walls facing the courtyard in cold months. In the whole sample houses, the major part of summer shading is for wall 3 and the most winter sunlit percentage is for wall 1. Figs. 5 and 6, illustrate the shading and the sunlit percentage of the walls and floors of the courtyard in traditional houses of Kashan and Ardabil, at 9, 12 A.M. and 15 P.M. on the first days of June and December.

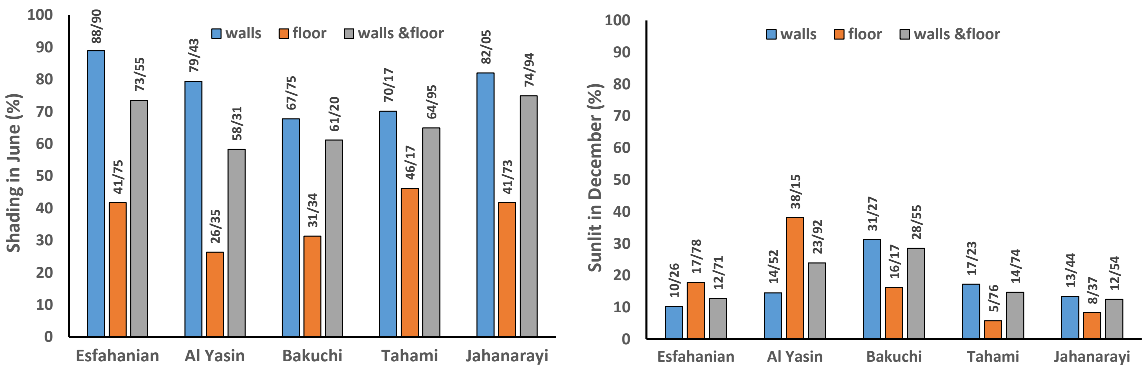


Fig. 5. Average Shading in June (Left) and Average Sunlit in December (Right) for Horizontal and Vertical Surfaces of Kashan Houses (at 9:00, 12:00 A.M. and 15:00 P.M.)

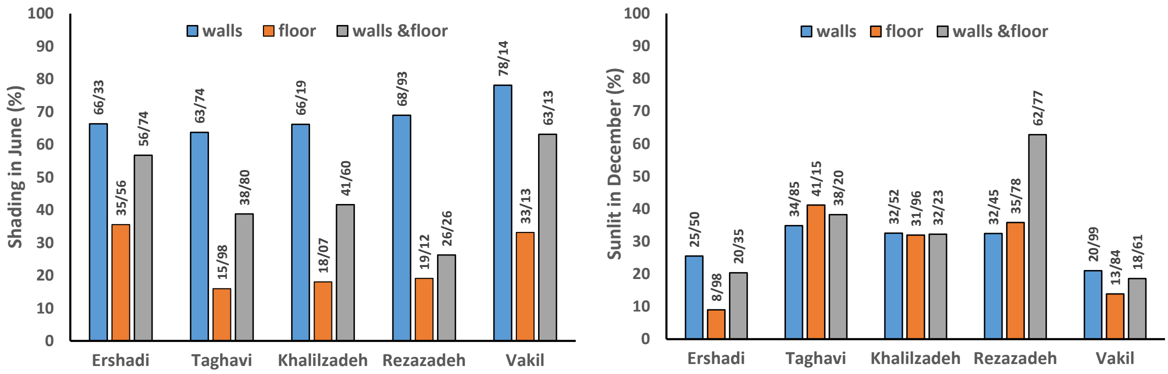


Fig. 6. Average Shading in June (Left) and Average Sunlit in December (Right) for Horizontal and Vertical Surfaces of Ardabil Houses (at 9:00, 12:00 A.M. and 15:00 P.M.)

According to Figs. 5 and 6, the average shading percentage of the overall surfaces for Esfahanian, Al Yasin, Bakuchi, Tahami and Jahanarayi houses in June are 73.55, 58.31, 61.2, 64.95, 7494 respectively, and the sunlit percentage in December are 12.71, 23.92, 28.55, 14.74, and 12.54 in respective order. The shading percentage of overall surfaces for Ershadi, Taghavi, Khalilzadeh, Rezazadeh and Vakil are 56.74, 38.8, 41.6, 26.26, 63.13 and the sunlit percentages are 20.35, 38.2, 32.23, 62.77 and 18.61 respectively. Vakil and Jahanarayi houses include the highest total shading percentage in June; on the other hand, Rezazadeh and Bakuchi houses also have the highest rate of sunlit in December. Also, Tahami and Ershadi houses have the highest shading coverage in hot months, and Al Yasin and Taghavi houses have the highest amount of sunlit in the yard's surfaces in cold months. So, according to the hot and dry climate of Kashan and cold climate of Ardabil, the mentioned houses have suitable shading percentage in compliance with the region's climate in the hot months, but they do not have proper sunlit receiving in compliance with region's climate in cold months over the year.

Table 9 Shows shading index and Table 10 represents climate compatibility of walls and floors in traditional central courtyard houses of Ardabil and Kashan.

Table 9. Shading-sunlit Index of the Cases in Ardabil and Kashan

Central Courtyard Houses	Kashan					Ardabil				
	Esfahanian	Al Yasin	Bakuchi	Tahami	Jahanarayi	Ershadi	Taghavi	Khalilzadeh	Rezazadeh	vakil
Shading-sunlit Index of Wall	0.50	0.47	0.50	0.44	0.48	0.46	0.49	0.49	0.51	0.50
Shading-sunlit Index of Floor	0.30	0.32	0.24	0.26	0.25	0.28	0.27	0.25	0.41	0.26

Table 10. Climate Compatibility of Surfaces Based on Summer Shading and Winter Sunlit (0-25 Inappropriate, 25-50 Relatively Appropriate, 50-75 Appropriate, 75-100 Completely Appropriate)

Alignment Condition with the Climate		Shading Percentage in June					Sunlit Percentage in December				
		Floor	Wall 1	Wall 2	Wall 3	Wall 4	Floor	Wall 1	Wall 2	Wall 3	Wall 4
Kashan	Esfahanian	41.75	85	85.8	100	86.2	17.87	23.1	13.2	0.0	0.5
	Al Yasin	26.35	73.3	87.3	68.5	71.7	38.15	54.2	0.0	0.0	24
	Bakuchi	31.34	64.8	55.1	85.1	74.6	16.17	57.9	41.9	0.0	17.1
	Tahami	46.17	76.3	63.6	78.1	68.6	5.76	43.2	11	4.1	15.9
	Jahan Ara	41.73	80.8	86.2	100	71.5	8.37	54.1	7.9	0.0	4
Ardabil	Ershadi	35.56	50.1	63.9	83.7	76.3	8.98	48.2	36	0.0	5.8
	Taghavi	15.98	59	57.3	77.3	74.7	41.15	40.7	62.4	0.0	1.8
	Khalilzadeh	18.07	60.1	52.2	78.3	69.6	31.96	57	51.2	0.0	11.5
	Rezazadeh	19.12	73.1	42.9	78.9	69.3	35.78	38.1	74.6	11.3	0.0
	vakil	13.33	66.8	63.9	74.6	88.3	13.84	52.2	53	0.0	2.7

The shading-sunlit index is the proportion of shading percentage and sunlit of walls and floors to the overall surface in June and December. Based on the shading-sunlit index of all surfaces (walls and floor), Bakuchi and Rezazadeh houses are the most compatible houses with the climate of Kashan and Ardebil. The results in this table display that Kashan and Ardabil traditional houses have almost adequate adaptation to the climatic condition of the region. According to Table 8, the courtyard surfaces of all Kashan houses are in relatively appropriate situation based on summer shading. Also Ardabil houses except Ershadi have inappropriate situation. Moreover, all houses except Taghavi, Khalilzadeh, Rezazadeh do not have appropriate situations in terms of sunlit. Furthermore, almost all walls of traditional houses in terms of summer shading have appropriate and very suitable condition and in terms of winter sunlit, the walls 1-2 and 3-4 in order, have appropriate and inappropriate condition.

Table 11. Geometrical Properties and Shading-sunlit Index of Case Studies

City	Case Study	Orientation and Rotation Angle From the South	Length / Width	Length / Height	Width / Height	$I_{sh\text{-}sl}$
Kashan	Esfahanian	12.0°	1.33	3.62	2.6	0.435
	Al Yasin	45.0°	1.25	4.71	2.71	0.413
	Bakuchi	28.0°	1.43	2.92	2.0	0.456
	Tahami	15.0°	1.23	2.26	1.6	0.401
	Jahanarayi	10.0°	1.36	2.15	1.35	0.447
Ardabil	Ershadi	62.0°	1.19	1.87	1.8	0.393
	Taghavi	31.0°	1.16	4.62	4.37	0.386
	Khalilzadeh	24.0°	1.13	5.55	4.16	0.372
	Rezazadeh	55.0°	1.41	4.2	4.0	0.451
	Vakil	54.0°	1.27	2.41	2.25	0.418

The geometric properties of courtyards and also shading-sunlit index is calculated for each house in Table 11. The lowest index is for Khalilzadeh house (in Ardebil) with value of $I_{sh\text{-}sl} = 0.372$ and highest shading-sunlit index is for Bakuchi house (in Kashan) with value of $I_{sh\text{-}sl} = 0.456$ among ten studied cases. In general, the radiation index-shading in the selected houses of Kashan has a higher average than that of Ardabil houses. The range of this index is from 0.37 to 0.45 in a relatively reasonable range in terms of the quality of adaptation to the climate.

CONCLUSION

Due to having four different climates in Iran, the courtyards are in various dimensions and sizes with distinct surrounded spaces. Proportions, direction, materials and form of the courtyard play a critical role in determining the shading percentage and sunlit amount in different surfaces of the courtyard. In order to investigate the compatibility and sustainability of traditional houses according to their climate, 10 traditional central courtyard houses from Qajar period located in two different hot-dry (Kashan city) and cold (Ardabil city) climates were selected. In the next stage, the amount of shading and sunlit on walls and floors in June and December are calculated and analyzed. The results and the analysis of shaded surfaces in both cities shows that all cases have suitable climate compatibility in warm months; while, in terms of sunlit, they do not have an appropriate climate compatibility in cold months. The average calculated shading-sunlit index for walls in Ardebil and Kashan is relatively appropriate and for the houses studied in Ardebil, the walls have more compatibility with the climate (Ardebil index is 0.49 and Kashan index is 0.48). Regarding the average of shading-sunlit index for the floor, the houses in both cities are in a relatively appropriate position, but the compatibility of the floor is less than the walls in both cities (above mentioned index in Ardabil: 0.29, Kashan: 0.27). The average composite index of walls and floor for selected houses in both cities is also relatively appropriate and in the selected houses of Ardabil, is more compatible with the climate, than the case studies of Kashan (0.43 vs. 0.4). Calculating the shading-sunlit index of walls and floor, among the case studies shows that in hot –arid climate of Kashan, Bakuchi house with 28 degrees deviation from North and with the length to width ration of 1.33 is the most compatible case with the climate. On the other hand, in cold climate of Ardebil, Rezazadeh house, with a deviation of 55 degrees from the South and the length to width ratio of 1.41, is the most compatible with climatic conditions rather than other examples.

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