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Iranian (Iranica) Journal of Energy & Environment
Journal Homepage: www.ijee.net
IJEE an official peer review journal of Babol Noshirvani University of Technology, ISSN:2079-2115

Investigation on Daylight Quality of Central Courtyard's Adjacent Rooms in Traditional Houses in Hot Dry Region of Iran: A Case Study Yazdanpanah House

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P A P E R I N F O

Paper history:
Received 29 April 2022
Accepted in revised form 30 May 2022

Keywords:
Courtyard house
Hot-dry climate
Kerman climate
Uniformity
Work plane illuminance

A B S T R A C T

Most of the spaces in contemporary houses in Iran cannot achieve enough daylight during daytime. Daylight utilization has a significant impact on decreasing energy consumption in residential buildings. Residents are deprived of natural daylight when there is no attention to the design based on daylight. Iranian traditional architects use practical and straightforward methods in constructing courtyards houses to provide comfort conditions in unique rooms in courtyard houses in terms of daylight quality. In this research, the daylight quality of five separate rooms around the courtyard of Yazdanpanah's house was investigated through an experimental method. Average work plane illuminance and uniformity ratio were calculated in these rooms of the house in Kerman city, located in Iran's hot and dry climate. Findings of this research demonstrated that all rooms surrounding the courtyard of traditional houses have the ability to achieve work plane illuminance of more than acceptable value. Among all rooms around the central courtyard, one room facing the south direction achieves more than 500 Lux work plane illuminance. The amount of uniformity in this room is acceptable with more than 0.5 on most of the days in a year. The findings of this research could be used to design more comfortable rooms in contemporary houses in terms of daylight quality by creating central courtyards.

***doi**: 10.5829/ijee.2022.13.04.01*

INTRODUCTION

Daylight is a valuable parameter for providing visual comfort in buildings. It makes the indoor environment more pleasant for occupants [1, 2]. Due to the harsh weather conditions in desert areas, many solutions have been used to deal with these conditions. In the hot and dry region of Iran, cities have dense textures, and in all these cities, traditional houses are built in the shape of a central courtyard and are similar to each other.

Cultural needs and occupants' requirements always shaped the traditional Iranian houses and added different physical features to the buildings [3, 4]. The adaption of these houses is an excellent aspect of the hot-dry climate that covers most parts of Iran [5]. A wide range of temperatures between day and night, lack of clouds, and less humidity are the conditions of Iran's hot-dry region [6, 7].

The sun is used as an energy source for 4.5 million years [8]. Daylight (Sunny) is a natural resource and plays an essential role in designing a passive solar building. An appropriate and proper design by daylight considers surroundings, provides adequate illuminance level with high uniformity and saves energy. An illuminated environment can send essential information to the human brain to shape and help human moods and psychological well-being [9].

Hot and dry weather is challenging weather to consider when working with daylight. Light is only part of the solar radiation spectrum, and there is also heat in the radiation spectrum that enters the building whenever direct sunlight enters. At the very least, creating

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Please cite this article as: N. Tayari, M. Nikpour, 2022. Investigation on Daylight Quality of Central Courtyard's Adjacent Rooms in Traditional Houses in Hot Dry Region of Iran: A Case Study Yazdanpanah House, Iranian (Iranica) Journal of Energy and Environment, 13(4), pp. 320-332. Doi: 10.5829/ijee.2022.13.04.01

openings in buildings can also bring in heat from the environment. They must be used the best way when creating openings, allowing light to enter to the building and ventilation. One of the biggest problems is glare when studying how to get daylight in hot-dry climates [10, 11].

Most traditional houses of Iran were designed based on principles and climate demands. All of them were built to fulfill people's requirements [5]. Compact forms with less area and fewer openings are chosen to reduce the effect of solar radiation on the envelope of houses [4]. Different courtyard forms depend on the proportion of the courtyard (length, width, perimeter, height) and the amount of courtyard's walls area receive different amounts of daylight [13]. Further analysis like field surveys shows that daylighting can save energy from 30 to 70 percent of electrical light consumption [12]. Therefore, according to artificial light, daylighting has better advantages like behavioral influences that help improve people's productivity [14].

Baboli et al. [15] studied thirty-four courtyard houses in the north of Iran (moderate climate). The results revealed that all the houses were built to occupants' needs, and occupants often use different spaces during the year. When the sustainable design of traditional architecture in Iran is under exploration, it is possible to detect how traditional buildings in this region were designed according to the regional cultural and climatic conditions and how their format and construction combine with today's design techniques.

One of the most vital design parameters in traditional hoses is the envelope of the buildings and the area of the openings in the outer envelope and the envelope of the courtyard. This parameter can control the lighting and thermal conductions [16]. Windows have a significant influence on the thermal performance [17]. Evaluating the amount of daylight entering a building is elemental to reduce electric lighting consumption and its impact on visual comfort situations, user tempers, solar gains, and qualitative factors of the illuminated space[18]. Guedouh and Zemmouri [19] investigated obn five houses with different central courtyards and found that sunlight in winter and summer behaves differently in each of the courtyards. In most cases, the number of illuminations increases outside the courtyard's center.
Daylight is a good source of light for residents, even with variations in luminosity [20]. Daylight quality is essential in spaces, and Work plane illuminance and uniformity are indicators for checking that quality.

According to Dubois et al. [20] places with different activities require different work plane illuminance (WPI). Work plane illuminance is calculated in minimum, average and maximum. WPI ratio (WPI minimum/WPI average) acceptable is less than 0.8.

The daylight investigation from the mid-twentieth century only considered unchanging sky conditions, which meant only diffuse illumination conditions, and did not consider illumination variability [21]. In this research, two quantitative parameters, WPI and Uniformity, are used to determine the quality of light in spaces.

According to Table 1, the uniformity (U0) of the work plane defines as the minimum illuminance (E min) on the work plane of a room to the average illuminance (E max) of it in a given moment. The uniformity of illuminance is essential for lighting inside a room environment. It can be acceptable or preferable depending on the environment and the activity type.

Experimental measurement in different rooms with different orientations in traditional houses in the hot and dry climate of kerman has not been investigated in terms of work plane illuminance and uniformity ratio in different hours of 4 critical days (Equinox and Solstice) in a year.

This paper aims to examine and measure the amount of daylight in the rooms around the central courtyard of a traditional house in Kerman. The use of daylight reduces energy demands in buildings, and a high-efficiency building should have good conditions in terms of energy consumption and residents' comfort.

MATERIAL AND METHODS

Case study

The hot and dry region is the widest climate in Iran. Many regions of Iran are desert and Kerman province, located in the southeast of Iran, is also in the desert region. According to the Kerman's location, latitude 30.29 and longitude 57.06, there is much solar radiation the whole year. The main direction for buildings in Kerman is Kiblah. The Yazdanpanah's House is one of the old houses in Kerman, which is almost 150 years old. This house is built as a central courtyard, and its orientation is in the direction of Kiblah. The rooms of this house are primarily with three doors overlooking the courtyard. All the rooms are located on three sides of the courtyard.

In order to experimentally investigate the work plane illuminance and work plane illuminance ratio (uniformity) in the rooms overlooking a central courtyard, Yazdanpanah House in Kerman was randomly selected among traditional houses that were renovated and restored the same as the past conditions.

Table 1. Daylight illuminance uniformity indicator for buildings (British Standard Institution)

	Illuminance Uniformity on the Work plane	
Uniformity	$U_0 \frac{E_{min}}{E_{max}} [Ix]>0.5$	Acceptable
	$U_0 \frac{E_{min}}{E_{max}} [Ix]>0.7$	Preferable

This house is located northeast of Kerman and in an old texture of town (Figure 1). This house is one of the few old houses in Kerman that has been completely renovated and has the exact features of old houses. This house belongs to the Qajar period. The house has five rooms around the courtyard in three directions which can access direct daylight (Figures 2-7).

Figure 1. Location of Yazdanpanah house (Google map)

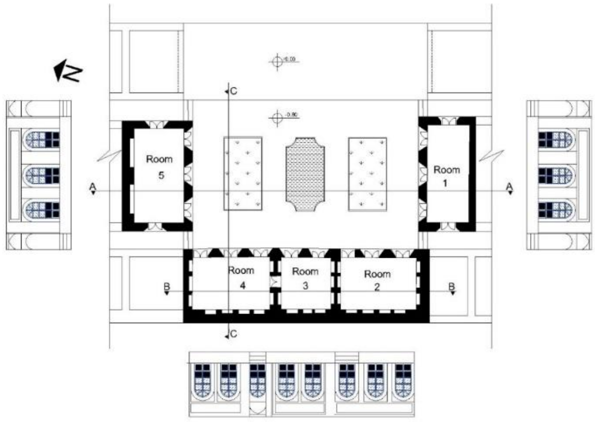

Figure 2. Position of the rooms around the courtyard and elevations

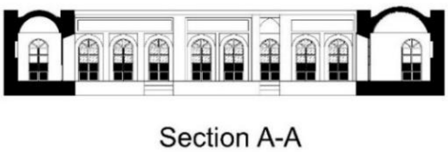

Figure 3. Section A-A from Yazdanpanah house

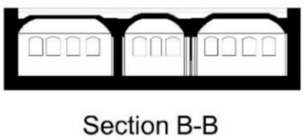

Figure 4. Section B-B from Yazdanpanah house

Figure 5. Section C-C from Yazdanpanah house

Figure 6: Panorama view of Yazdanpanah's courtyard

Figure 7. Panorama view of Yazdanpanah's courtyard

At first, the physical characteristics of each room, including length and width and height, window area, and orientation, were measured (Figure 8). Then the room index value was calculated to measure WPI. The physical aspects of Yazdanpanah's house are summarized in Table 2.

The studied house had single-glazed windows, oriented North, West, and South. Figures 2 to 7 show the studied house and the location of the rooms. The indoor illuminance was recorded in 30 minutes intervals using 5 Lux meters. The Lux meters were located at work plane height (0.80 m from the floor) at the specified point in each room. All the information was collected on 21 March, 22 June, 23 September, and 22 December of 2021 (Equinox and Solstice) under clear sky conditions.

The room index is required to know the minimum number of measuring positions.

$$\text{Room index} = \frac{(\text{length} \times \text{width})}{[\text{Mounting height} \times (\text{length} + \text{width})]} \quad (1)$$

According to the room index concern in Table 3, all the rooms were divided into four even rectangular areas (2 times 2). The illuminance sensor was placed at the center of the divided area, at the height of the work plane (0.80 m), then the WPI was recorded for each point simultaneously.

Work plane illuminance for each room was recorded at different times of day, 9:30 a.m. to 2:00 p.m., with just 30 minutes intervals to determine daylight quality at different times of the day.

Table 2. Specifications and details of each room

Room	Orientation faced	ORI*	X	Y	Z	Room Area (m^2)	Window Area (m^2)	WWR
1	north	17°	3	6.7	4.2	20.1	4.08	**14.49**
2	east	73°	3.5	5	4.2	18.5	4.08	**22.85**
3	east	73°	3.5	3.5	4.2	12.1	2.72	**18.5**
4	east	73°	3.5	5.3	4.2	18.8	4.08	**18.3**
5	south	163°	3.4	6.5	4.2	22.2	4.08	**14.94**

*****ORI: The angle which is made between a line that is perpendicular to the opening surface and the north direction

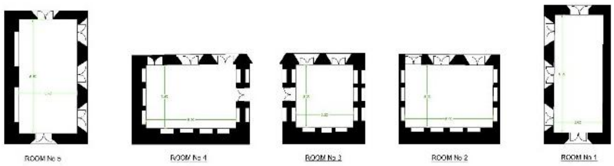

Figure 8. Five examined room's plans

Table 3. Room index, measurement requirement

Room index	Minimum number of measuring positions
Less than 1	4
1 to below 2	9
2 to below 3	16
3 or greater	25

Experimental tools

Illumination is the amount of light that reaches surfaces before reflection. The unit of illuminance is lux for measuring different parameters such as WPI, surface luminance, and reflectance in rooms of the chosen traditional house. The following materials and methods were used.

- Two Lux meters model of TES 1339R and three lux meters model of TES 1335 (Figure 9)

Before measuring the illuminance of the chosen house, a calibration test was carried out to check the accuracy of the equipment. As much as possible, two different model Lux meters were located near each other, and in the 5-minute intervals, the amount of illuminance was noted.

Calibration test

By each light meter, almost 100 steps of light were measured. All the results were assessed with the Pearson correlation test using the SPSS software. The result (Table 4) showed a solid and positive significant correlation between the two pieces of equipment data. The accuracy of these light meters has been approved by this correlation test.

Table 4. SPSS correlation tes

Correlations			
		1335	1339R
1335	Pearson Correlation	1	1.000**
	Sig. (2-tailed)		.000
	Sum of Squares and Cross-products	1992693.790	2002280.050
	Covariance	20128.220	20225.051
	N	100	100
1339R	Pearson Correlation	1.000**	1
	Sig. (2-tailed)	.000	
	Sum of Squares and Cross-products	2002280.050	2012766.750
	Covariance	20225.051	20330.977
	N	100	100

**Correlation is significant at the 0.01 level (2-tailed)

Figure 9. Lux meters model

FINDING AND DISCUSSION

The amount of WPI and WPI Ratio in 5 different rooms in Yazdanpanah's House in different hours on 21 March, 22 June, 23 September of 2021, and 22 December of

2022, under clear sky conditions, were measured and tabulated in Tables 5 to 9.

Room No. 1 (Figure 10), with 3-meter width, 6.7-meter length, and 14.49 WWR, faces north. In traditional architecture, this type of room with this orientation is used for the summer season and warm months of the year.

Table 5. WPI and uniformity in different hours in room No. 1

				Room 1			
				ORI 17			
		Azimuth	**Altitude**	**HSA**	**VSA**	**E_{Av} (Lux)**	**u0**
09:30	21-Mar	126.1	45	143.1	_	495	**0.71**
	22-Jun	94.7	59.5	111.7	77.71	587	**0.49**
	23-Sep	115.2	37.1	132.2	_	505	**0.77**
	22-Dec	134	19.4	151	_	399	**0.55**
10:00	21-Mar	134.5	50	151.5	_	481	**0.7**
	22-Jun	100.1	65.9	117.1	78.48	627	**0.54**
	23-Sep	121.5	42.8	138.5	_	498	**0.82**
	22-Dec	139.6	23.9	156.6	_	418	**0.62**
10:30	21-Mar	144.6	54.2	161.6	_	466	**0.68**
	22-Jun	107.9	72.2	124.9	79.59	640	**0.49**
	23-Sep	129.1	48.1	146.1	_	503	**0.82**
	22-Dec	145.9	27.8	162.9	_	443	**0.56**
11:00	21-Mar	156.7	57.4	173.7	_	446	**0.67**
	22-Jun	122.1	78.1	139.1	_	652	**0.49**
	23-Sep	138.4	52.8	155.4	_	508	**0.81**
	22-Dec	152.8	31.1	169.8	_	441	**0.57**
11:30	21-Mar	170.6	59.2	187.6	_	446	**0.68**
	22-Jun	154.7	82.6	171.7	_	670	**0.54**
	23-Sep	149.6	56.6	166.6	_	486	**0.78**
	22-Dec	160.4	33.7	177.4	_	421	**0.5**
12:00	21-Mar	185.3	59.4	202.3	_	464	**0.69**
	22-Jun	209.1	82.3	226.1	_	693	**0.52**
	23-Sep	162.8	59.3	179.8	_	512	**0.82**
	22-Dec	168.5	35.4	185.5	_	396	**0.51**
12:30	21-Mar	199.5	58	216.5	_	487	**0.7**
	22-Jun	239.5	77.7	256.5	_	685	**0.56**
	23-Sep	177.6	60.4	194.6	_	531	**0.76**
	22-Dec	176.9	36.3	193.9	_	355	**0.47**
13:00	21-Mar	212.2	55.2	229.2	_	505	**0.7**
	22-Jun	252.8	71.7	269.8	_	693	**0.52**
	23-Sep	192.6	59.8	209.6	_	589	**0.73**
	22-Dec	185.4	36.1	202.4	_	338	**0.45**
13:30	21-Mar	222.9	51.2	239.9	_	522	**0.71**
	22-Jun	260.4	65.4	277.4	_	680	**0.46**
	23-Sep	206.5	57.6	223.5	_	577	**0.72**
	22-Dec	193.8	35	210.8	_	320	**0.43**
14:00	21-Mar	231.7	46.5	248.7	_	533	**0.71**
	22-Jun	265.7	59	282.7	_	681	**0.41**
	23-Sep	218.3	54.1	235.3	_	590	**0.7**
	22-Dec	201.7	33.1	218.7	_	300	**0.4**

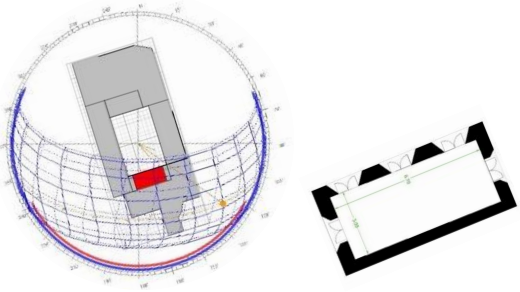

Figure 10. Position of the room No. 1 in house and room dimensions

Table 5 shows the amount of WPI and WPI Ratio in room 1, facing the North on measuring days. As shown in Table 5, WPI in different hours on March 21 from 9:30 AM to 2:00 PM is between 464 to 533 Lux. According to the solar path diagram for Kerman city and the position of room 1, it is evident that this room does not receive direct solar radiation during the daytime; hence there are no significant differences in WPI values at different hours. The amount of standard deviation of the WPI indicates a suitable condition in terms of daylight distribution in this room. According to Dubois et al. [20] the work plane illuminance ratio of more than 0.5 may be acceptable when calculated by dividing the minimum WPI by the maximum WPI simultaneously within the room and the uniformity larger than 0.7 is considered preferable. As shown in Table 5, most of the time, on March 21, the value of the uniformity ratio is more excellent than 0.7; therefore, the condition of this room in terms of work plane illuminance ratio is considered preferable.

On the same day, WPI decreases from 9:30 AM to 11:30 AM in room No. 1, which has three fenestrations to the North; it is justifiable concerning the sun path diagram and the North facing of this room. Furthermore, the value of WPI increases from 11:30 AM to 2:00 PM in room No. 1 from 446 Lux to 533 Lux. The lowest WPI is measured at 11:30 AM, which this time, the sun is located opposite of facing this room. Regarding table 5, there are no significant differences in uniformity Ratio in different hours on the March 21's measurement in room No. 1.

WPI and the Uniformity of room No. 1 were measured for the second time on June 22. The range of WPI Avg was between 587 and 693 compared to March 21 WPI Avg increased, and the amount of uniformity was reduced to around 1/2 of the previous daylight measurement on March 21. The cause of this reduction can be related to the different sun paths.

On the third measurement day, the average illuminance was between 486 and 590 on September 23, when the sun's angle was between 42 degrees and 60 degrees. The amount of WPI is close to the first day of measurements on March 21. The uniformity was between 0.7 to 0.82, which is a more appropriate amount than June 22. The last light measurement in Room 1 on December 22 shows WPI between 300 and 443. The uniformity rate is between 0.4 and 0.62.

Figure 11 shows the difference between the WPI Avg in room No. 1 on four days of light measuring. On June 22, the amount of WPI increased in room No. 1. The reason behind this increase is the altitude of more than 60 degrees. However, on March 21 and September 23, the altitude angle was lower than 60 degrees. On December 22, Room 1 received the least amount of light, especially in the final hours of measurements. Therefore, most of the light enters the room in June. The higher altitude can cause lower uniformity and a higher WPI Avg.

Room 2 (Figure 12) faces East, with a 3.5-meter width, 5-meter length, and 22.85 WWR. Table 6 also shows the amount of WPI Ratio and uniformity in room 2 on the measurement days.

WPI in different hours in this room on March 21, from 9:30 AM to 2:00 PM, is between 352 to 425 Lux. Regarding Table 6, same as room No. 1, there are no significant differences in the uniformity ratio of rooms during the measurement on March 21; also, the WPI Avg rate is less than room No. 1.

The highest level of uniformity was recorded in room No. 2 on September 23 and the lowest on December 22. The highest amount of WPI was recorded

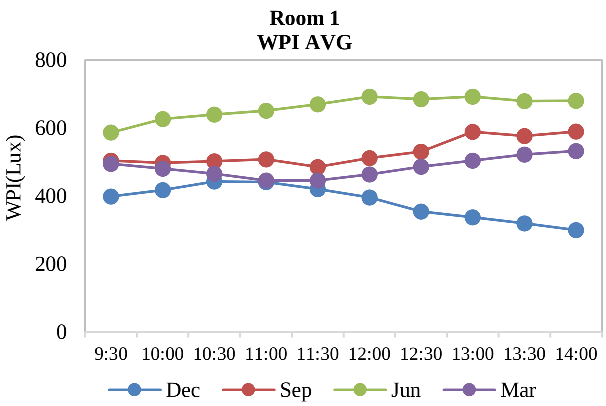

Figure 11. Amount of WPI according to different hours in room No. 1

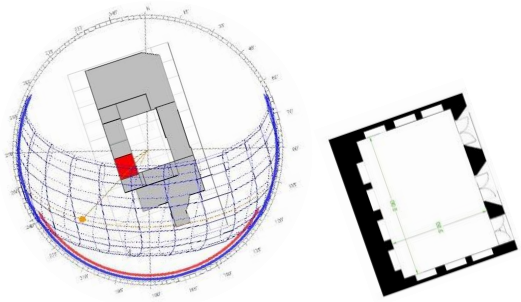

Figure 12. Position of the room No. 2 in house and room dimentions

Table 6. WPI Ratio and Uniformity in different hours in room No. 2

Room 2 ORI 73							
		Azimuth	**Altitude**	**HSA**	**VSA**	**EAv (Lux)**	**u0**
09:30	21-Mar	126.1	45	53.1	59	425	**0.68**
	22-Jun	94.7	59.5	21.7	61.3	1366	**0.37**
	23-Sep	115.2	37.1	42.2	45.6	710	**0.76**
	22-Dec	134	19.4	61	36	365	**0.28**
10:00	21-Mar	134.5	50	61.5	68.2	419	**0.68**
	22-Jun	100.1	65.9	27.1	68.3	1291	**0.37**
	23-Sep	121.5	42.8	48.5	54.4	659	**0.76**
	22-Dec	139.6	23.9	66.6	48.1	340	**0.29**
10:30	21-Mar	144.6	54.2	71.6	77.2	413	**0.68**
	22-Jun	107.9	72.2	34.9	75.2	1053	**0.31**
	23-Sep	129.1	48.1	56.1	63.4	555	**0.8**
	22-Dec	145.9	27.8	72.9	60.9	310	**0.33**
11:00	21-Mar	156.7	57.4	83.7	86	405	**0.68**
	22-Jun	122.1	78.1	49.1	82.1	852	**0.38**
	23-Sep	138.4	52.8	65.4	72.5	540	**0.8**
	22-Dec	152.8	31.1	79.8	73.6	281	**0.38**
11:30	21-Mar	170.6	59.2	97.6	_	396	**0.68**
	22-Jun	154.7	82.6	81.7	88.9	767	**0.46**
	23-Sep	149.6	56.6	76.6	81.3	493	**0.81**
	22-Dec	160.4	33.7	87.4	86.1	268	**0.37**
12:00	21-Mar	185.3	59.4	112	_	386	**0.67**
	22-Jun	209.1	82.3	136	_	725	**0.49**
	23-Sep	162.8	59.3	89.8	89.9	507	**0.82**
	22-Dec	168.5	35.4	95.5	_	254	**0.35**
12:30	21-Mar	199.5	58	127	_	376	**0.66**
	22-Jun	239.5	77.7	167	_	693	**0.5**

	23-Sep	177.6	60.4	105	_	479	**0.83**
	22-Dec	176.9	36.3	104	_	243	**0.39**
13:00	21-Mar	212.2	55.2	139	_	370	**0.65**
	22-Jun	252.8	71.7	180	_	665	**0.52**
	23-Sep	192.6	59.8	120	_	436	**0.79**
	22-Dec	185.4	36.1	112	_	234	**0.4**
13:30	21-Mar	222.9	51.2	150	_	361	**0.65**
	22-Jun	260.4	65.4	187	_	601	**0.55**
	23-Sep	206.5	57.6	134	_	409	**0.75**
	22-Dec	193.8	35	121	_	226	**0.39**
14:00	21-Mar	231.7	46.5	159	_	352	**0.62**
	22-Jun	265.7	59	193	_	562	**0.59**
	23-Sep	218.3	54.1	145	_	381	**0.7**
	22-Dec	201.7	33.1	129	_	219	**0.39**

on June 22, then September after March, and the lowest in December. However, in Table 6, it can be seen that the amount of uniformity in June and December is less than in March and September, but in the final hours of measurement, the amount of light in the room is minor and similar. The room's illumination shows many changes that range between 1987 and 219. Measurement of light in December shows less light than on previous days, and the illuminance averages inside the room are between 365 and 219.

Figure 13 shows the difference in WPI on the days of light measurement in room No. 2. This figure shows that the highest amounts of light are received in the room on June 22, and the lowest part is in December. In general, the amount of light in room No. 2 is much higher than in room No. 1. This difference in light reception indicates that room No. 1 has more suitable conditions to establish comfort conditions in the year's warm seasons.

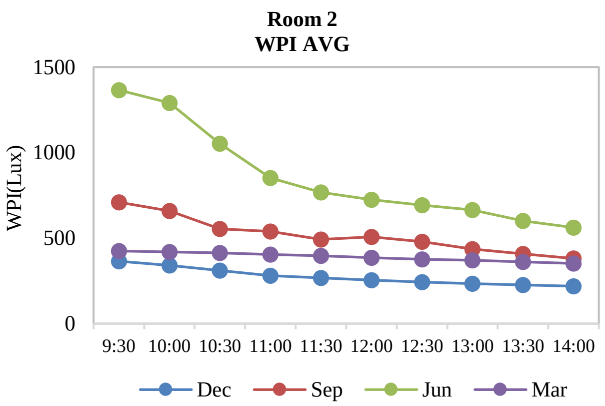

Figure 13. Amount of WPI according to different hours in room No. 2

Room 3 (Figure 14) faces East, with a 3.5-meter width, 3.5-meter length, and 18.5 WWR. The amount of WPI and WPI ratio in room 3 is tabulated in Table 7.

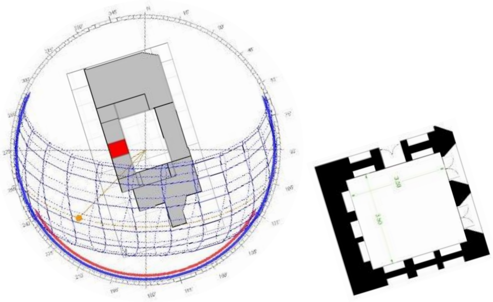

Figure 14. Position of the room No. 3 in plan and room index

Table 7. WPI and WPI Ratio in different hours in room No. 3

Room 3 ORI 73							
		Azimuth	**Altitude**	**HSA**	**VSA**	**E_{Av} (lux)**	**u0**
09:30	21-Mar	126.1	45	53.1	59	804	**0.45**
	22-Jun	94.7	59.5	21.7	61.3	1684	**0.28**
	23-Sep	115.2	37.1	42.2	45.6	1055	**0.68**
	22-Dec	134	19.4	61	36	484	**0.43**
10:00	21-Mar	134.5	50	61.5	68.2	809	**0.46**
	22-Jun	100.1	65.9	27.1	68.3	1407	**0.23**
	23-Sep	121.5	42.8	48.5	54.4	931	**0.66**
	22-Dec	139.6	23.9	66.6	48.1	468	**0.47**
10:30	21-Mar	144.6	54.2	71.6	77.2	815	**0.48**
	22-Jun	107.9	72.2	34.9	75.2	1139	**0.25**
	23-Sep	129.1	48.1	56.1	63.4	860	**0.73**
	22-Dec	145.9	27.8	72.9	60.9	453	**0.48**
11:00	21-Mar	156.7	57.4	83.7	86	804	**0.47**
	22-Jun	122.1	78.1	49.1	82.1	879	**0.47**
	23-Sep	138.4	52.8	65.4	72.5	752	**0.75**
	22-Dec	152.8	31.1	79.8	73.6	439	**0.52**
11:30	21-Mar	170.6	59.2	97.6	_	795	**0.47**
	22-Jun	154.7	82.6	81.7	88.9	820	**0.56**
	23-Sep	149.6	56.6	76.6	81.3	715	**0.8**
	22-Dec	160.4	33.7	87.4	86.1	426	**0.54**
12:00	21-Mar	185.3	59.4	112	_	739	**0.44**
	22-Jun	209.1	82.3	136	_	759	**0.59**
	23-Sep	162.8	59.3	89.8	89.9	670	**0.72**
	22-Dec	168.5	35.4	95.5	_	399	**0.52**

12:30	21-Mar	199.5	58	127	_	698	**0.45**
	22-Jun	239.5	77.7	167	_	703	**0.63**
	23-Sep	177.6	60.4	105	_	621	**0.73**
	22-Dec	176.9	36.3	104	_	394	**0.65**
13:00	21-Mar	212.2	55.2	139	_	652	**0.44**
	22-Jun	252.8	71.7	180	_	663	**0.58**
	23-Sep	192.6	59.8	120	_	635	**0.58**
	22-Dec	185.4	36.1	112	_	374	**0.55**
13:30	21-Mar	222.9	51.2	150	_	617	**0.41**
	22-Jun	260.4	65.4	187	_	586	**0.54**
	23-Sep	206.5	57.6	134	_	547	**0.74**
	22-Dec	193.8	35	121	_	366	**0.61**
14:00	21-Mar	231.7	46.5	159	_	552	**0.49**
	22-Jun	265.7	59	193	_	522	**0.5**
	23-Sep	218.3	54.1	145	_	501	**0.7**
	22-Dec	201.7	33.1	129	_	342	**0.67**

On March 21, WPI in different hours in this room, from 9:30 AM to 2:00 PM, is between 552 to 815 Lux. Regarding Table 7, there are no significant differences in the uniformity ratio of rooms during the measurement, but the amount of uniformity decries according to rooms 1 and 2.

In the early hours of June 22, the WPI is higher, but the values are closer together in the final hours. So, the amount of uniformity at the beginning of the measurement hour was much less than half due to the end of the measurement hours. Table 7 shows Room 3's WPI specifications and amount on September 23. The WPI in September varies between 1055 and 501, and the uniformity is within acceptable limits. In December, WPI is in the lowest range of the year (342-484), but uniformity is between 0.43 to 0.67 and in the acceptable range.

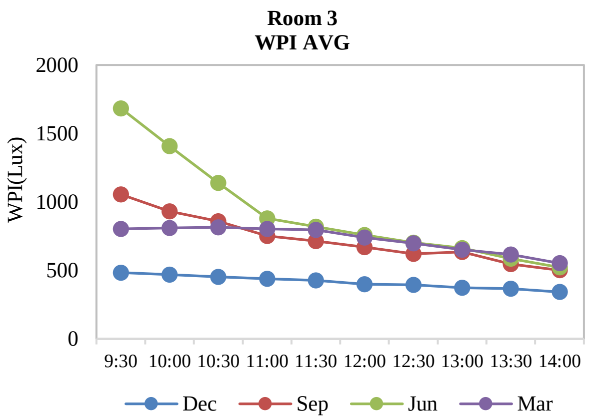

Figure 15. Amount of WPI according to different hours in room No. 3

Figure 15 shows that in the final hours of the measurement, the WPI levels are very similar every three days, but the levels are different in the early hours, between 9:30 and 11. This similarity can be attributed to the shading of the adjacent spaces in this room during these hours. On 22 December, according to the previous days, WPI decreased.

Room 4 (Figure 16) faces East, with a 3.5-meter width, 5.3-meter length, and 18.3 WWR. The amount of WPI and Uniformity in room 3 is tabulated in Table 8.

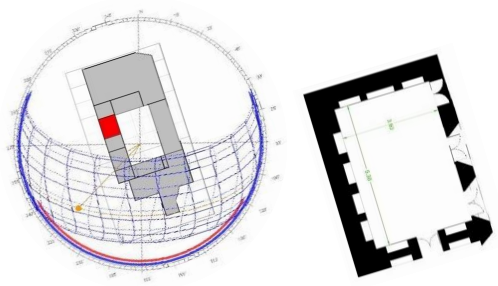

Figure 16. Position of the room No. 4 in plan and room index

Table 8. WPI Ratio and Uniformity in different hours in room No. 4

Room 4 ORI 73							
		Azimuth	**Altitude**	**HSA**	**VSA**	**E_{Av} (lux)**	**u0**
09:30	21-Mar	126.1	45	53.1	59	808	**0.55**
	22-Jun	94.7	59.5	21.7	61.3	1458	**0.2**
	23-Sep	115.2	37.1	42.2	45.6	974	**0.67**
	22-Dec	134	19.4	61	36	678	**0.31**
10:00	21-Mar	134.5	50	61.5	68.2	820	**0.56**
	22-Jun	100.1	65.9	27.1	68.3	1171	**0.28**
	23-Sep	121.5	42.8	48.5	54.4	902	**0.64**
	22-Dec	139.6	23.9	66.6	48.1	650	**0.31**
10:30	21-Mar	144.6	54.2	71.6	77.2	786	**0.54**
	22-Jun	107.9	72.2	34.9	75.2	898	**0.44**
	23-Sep	129.1	48.1	56.1	63.4	807	**0.72**
	22-Dec	145.9	27.8	72.9	60.9	617	**0.32**
11:00	21-Mar	156.7	57.4	83.7	86	766	**0.53**
	22-Jun	122.1	78.1	49.1	82.1	740	**0.46**
	23-Sep	138.4	52.8	65.4	72.5	720	**0.72**
	22-Dec	152.8	31.1	79.8	73.6	588	**0.3**

11:30	21-Mar	170.6	59.2	97.6	_	742	**0.51**
	22-Jun	154.7	82.6	81.7	88.9	683	**0.44**
	23-Sep	149.6	56.6	76.6	81.3	680	**0.78**
	22-Dec	160.4	33.7	87.4	86.1	558	**0.31**
12:00	21-Mar	185.3	59.4	112	_	726	**0.47**
	22-Jun	209.1	82.3	136	_	869	**0.47**
	23-Sep	162.8	59.3	89.8	89.9	598	**0.75**
	22-Dec	168.5	35.4	95.5	_	538	**0.3**
12:30	21-Mar	199.5	58	127	_	658	**0.52**
	22-Jun	239.5	77.7	167	_	613	**0.49**
	23-Sep	177.6	60.4	105	_	562	**0.7**
	22-Dec	176.9	36.3	104	_	535	**0.35**
13:00	21-Mar	212.2	55.2	139	_	633	**0.48**
	22-Jun	252.8	71.7	180	_	552	**0.5**
	23-Sep	192.6	59.8	120	_	528	**0.52**
	22-Dec	185.4	36.1	112	_	533	**0.4**
13:30	21-Mar	222.9	51.2	150	_	591	**0.45**
	22-Jun	260.4	65.4	187	_	469	**0.47**
	23-Sep	206.5	57.6	134	_	438	**0.64**
	22-Dec	193.8	35	121	_	505	**0.41**
14:00	21-Mar	231.7	46.5	159	_	537	**0.54**
	22-Jun	265.7	59	193	_	395	**0.44**
	23-Sep	218.3	54.1	145	_	376	**0.59**
	22-Dec	201.7	33.1	129	_	472	**0.35**

WPI variations in this room range from 1458 to 376 lux. The uniformity values are very similar in March and September. This uniform distribution of light in the room can be due to small changes in WPI and the sun's angle. In June and December, decreasing in uniformity is observed. On September 23, the uniformity level reached an acceptable level, and the WPI varied between 974 and 376. Due to the solar path diagram for Kerman city in March and the position of rooms, it is evident that rooms 2,3, and 4 do not receive direct solar radiation during the daytime like room 1. As shown in Table 8, most of the time in the day, the value of the Uniformity ratio in room 2 is higher than 0.6. Therefore, the condition of this room in terms of Work Plane Illuminance Ratio is considered preferable. In rooms 3 and 4, the Uniformity ratios are around 0.5 and 0.4. The amount of WPI decreases from 9:30 A.M to 2:00 P.M in these three rooms, which is justifiable concerning the sun path diagram and the East facing of these rooms.

Room 4's exposure to sunlight throughout the year is unpredictable and varied, while in other rooms, the amount of light in each season has decreased or increased by a certain amount. In Figure 17, it can be seen that in each season and at different hours, the amount of light received in room No. 4 has unexpected changes.

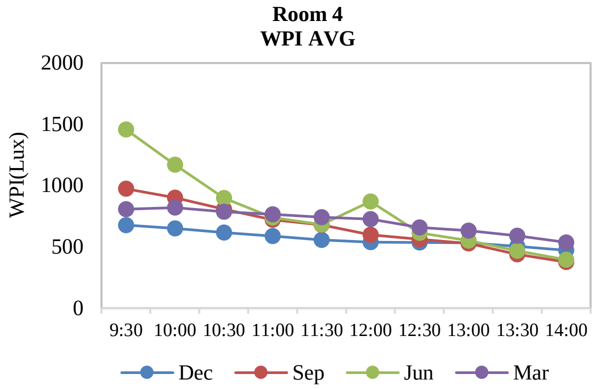

Figure 17. Amount of WPI according to different hours in room No. 5

Overall, in June, the results show that the amount of light in these three rooms has increased compared to March. However, this increase is more seen in rooms number 2 and 3, and 4; this increase occurred only in the early hours of the day. Another noticeable difference that can be mentioned is the size of the uniform. The amount of uniformity in these rooms is inversely related to the increase in the average illuminance on June 22. These three rooms showed that they could provide the light they needed, and their uniformity was in the standard range. Sometimes it is with a minimal difference in these amounts.

The last room measured was room No. 5 (Figure 18), with 3.4-meter width, 6.5-meter length, and 14.93 WWR, facing the South. The amount of WPI and uniformity in room 3, the same as in other rooms, are tabulated in Table 9.

In Table 9 it can be seen that, the amount of light received in room No. 5 is higher than in other rooms. Due to the orientation of this room and its south-facing windows, it was expected that the amount of light would be higher. The amount of uniformity is also acceptable in this room. light received in room 5 on June 22 has

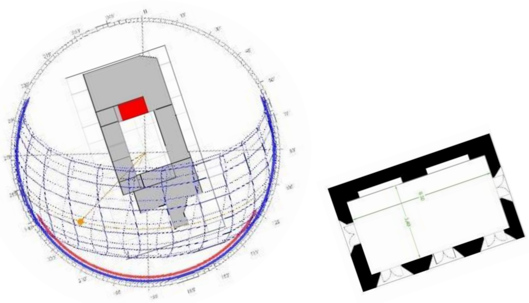

Figure 18. Position of the room No. 5 in plan and room index

Table 9. WPI and uniformity in different hours in room No. 5

Room 5 ORI 163							
		Azimuth	**Altitude**	**HSA**	**VSA**	**E_{Av} (lux)**	**u0**
09:30	21-Mar	126.1	45	-36.9	51.4	1468	**0.75**
	22-Jun	94.7	59.5	-68.3	77.7	768	**0.52**
	23-Sep	115.2	37.1	-47.8	48.4	2207	**0.6**
	22-Dec	134	19.4	-29	21.9	3122	**0.39**
10:00	21-Mar	134.5	50	-28.5	53.6	1402	**0.75**
	22-Jun	100.1	65.9	-62.9	78.5	813	**0.61**
	23-Sep	121.5	42.8	-41.5	51	2097	**0.61**
	22-Dec	139.6	23.9	-23.4	25.8	3233	**0.42**
10:30	21-Mar	144.6	54.2	-18.4	55.6	1354	**0.77**
	22-Jun	107.9	72.2	-55.1	79.6	838	**0.58**
	23-Sep	129.1	48.1	-33.9	53.3	1976	**0.61**
	22-Dec	145.9	27.8	-17.1	29.8	3594	**0.47**
11:00	21-Mar	156.7	57.4	-6.3	57.6	1293	**0.73**
	22-Jun	122.1	78.1	-40.9	80.9	828	**0.6**
	23-Sep	138.4	52.8	-24.6	55.4	1945	**0.6**
	22-Dec	152.8	31.1	-10.2	31.5	3503	**0.29**
11:30	21-Mar	170.6	59.2	7.6	59.4	1232	**0.7**
	22-Jun	154.7	82.6	-8.3	82.7	814	**0.53**
	23-Sep	149.6	56.6	-13.4	57.3	1855	**0.62**
	22-Dec	160.4	33.7	-2.6	33.7	3532	**0.4**
12:00	21-Mar	185.3	59.4	22.3	61.3	1176	**0.68**
	22-Jun	209.1	82.3	46.1	84.6	800	**0.5**
	23-Sep	162.8	59.3	-0.2	59.3	1718	**0.61**
	22-Dec	168.5	35.4	5.5	35.5	2894	**0.35**
12:30	21-Mar	199.5	58	36.5	63.3	1109	**0.69**
	22-Jun	239.5	77.7	76.5	87.1	783	**0.56**
	23-Sep	177.6	60.4	14.6	61.2	1511	**0.56**
	22-Dec	176.9	36.3	13.9	37.1	2692	**0.35**
13:00	21-Mar	212.2	55.2	49.2	65.6	1031	**0.7**
	22-Jun	252.8	71.7	89.8	89.9	795	**0.6**
	23-Sep	192.6	59.8	29.6	63.2	1397	**0.56**
	22-Dec	185.4	36.1	22.4	38.3	2439	**0.3**
13:30	21-Mar	222.9	51.2	59.9	68	1072	**0.64**
	22-Jun	260.4	65.4	97.4	_	699	**0.63**
	23-Sep	206.5	57.6	43.5	62.3	1285	**0.57**
	22-Dec	193.8	35	30.8	39.2	2175	**0.25**
14:00	21-Mar	231.7	46.5	68.7	71	1139	**0.65**
	22-Jun	265.7	59	103	_	675	**0.64**
	23-Sep	218.3	54.1	55.3	67.6	1178	**0.56**
	22-Dec	201.7	33.1	38.7	39.9	1943	**0.21**

decreased compared to March 21, but the light and uniformity is still acceptable. On the third day of the light measurements, September 23, we can see the increase in sunlight in room No. 5. This amount is higher than on March 21, and it still receives more light than other rooms. On December 22, room 5 received the highest amount of light of the year. However, the uniformity is not at its highest peak of it.

WPI ratio in room 5 can be seen in Figure 19. The most received light is in December, and the lowest amount of light is received in June.

Figure 20 compares the light that enters the examined rooms and how each room behaves differently depending on the angle of sunlight in each season. The most changes in the amount of light received belong to rooms number 1 and 5.

Evaluation of different rooms with different orientations in central courtyard houses

The room facing north

Fluctuations in the amount of light in the room facing north are less than in other rooms with south and east directions. The room facing north, because it receives less direct sunlight and due to the shallow depth of the room, is able to receive a sufficient amount of light, and most of the time in a day, has acceptable uniform light throughout all four critical days of the year.

The room facing south

The room facing south receives less daylight on June 22 than on other days of the year, which can be justified by

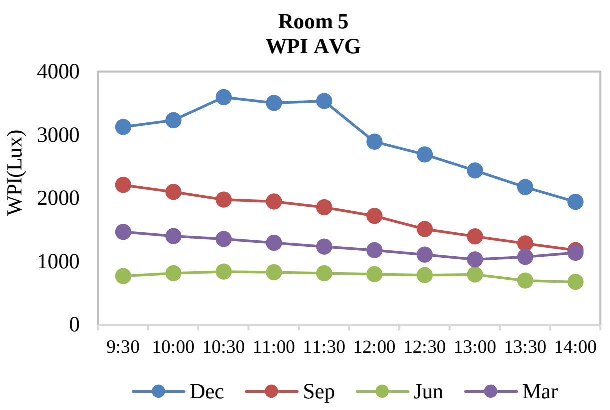

Figure 19. Amount of WPI according to different hours in room No. 5

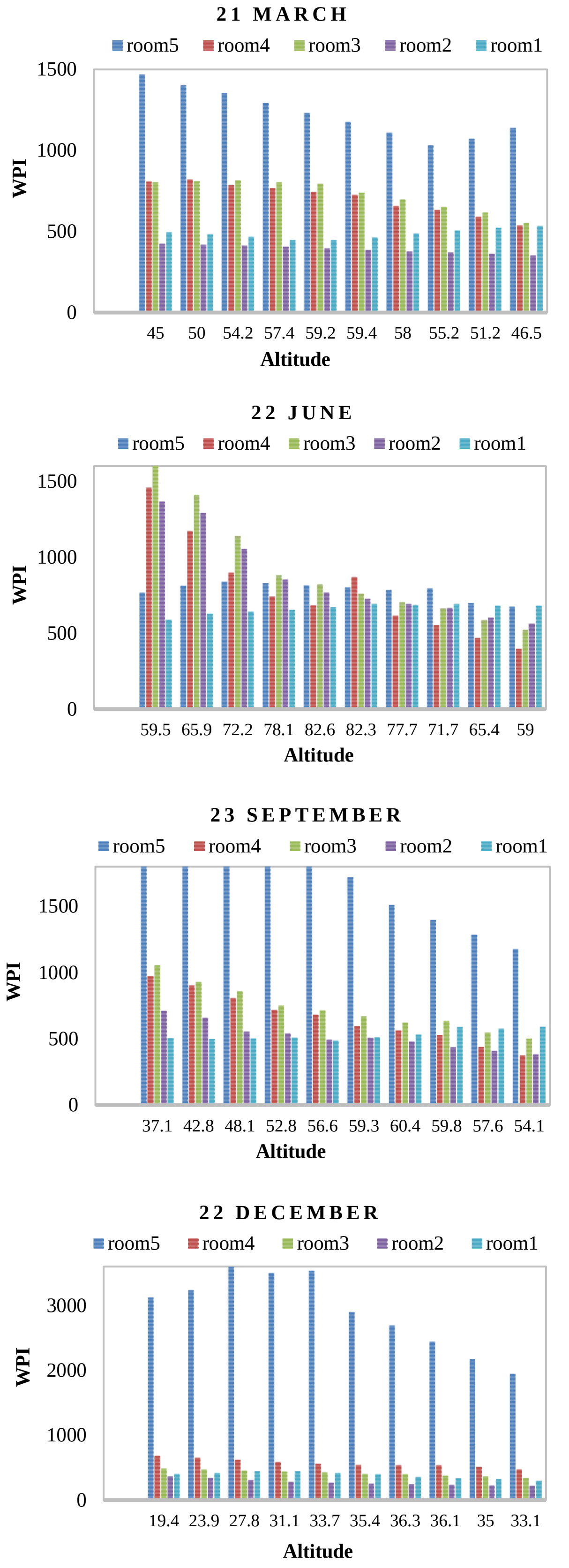

Figure 20. Comparing the amount of light in the rooms based on months

the angle of the sun and the location of the opening at depth. But the amount of light received is too much in September, March, and December due to the sun's low angle in these seasons. The amount of light uniformity is acceptable in this room except in winter.

The rooms facing east

East-facing rooms generally receive more light in the early hours of the day than at other times of the year. The amount of light received in the rooms facing east, despite the need for a lot of light in summer. And due to the greater demand in winter, they receive the least amount of light in winter. Also, it is challenging to provide light uniformity in rooms facing east in summer and winter.

CONCLUSION

The results show that the rooms located around the central courtyard behave differently at different times of the day and year. Because rooms are located in three different directions, they have different behaviors in receiving light. In room No. 1, which faces north, light is found to have the same trend throughout the day, and the amount received during the day changes only by changing seasons.

In traditional Iranian architecture, most of the rooms on the south side of the building and facing north are used for living in the warm seasons. The results obtained in this study show that room 1 which faces north, receives less light than other rooms, that can create a sustainable atmosphere and make this room comfort visualy for living in summer.

Rooms 2, 3, and 4 that are facing east, usually receive the most daylight in the early morning hours compared to each other. However, the change of seasons also affects the amount of light entering these rooms. In rooms 2 and 3, the amount of light they receive is proportionally reduced or increased with the change of seasons. In room 4, these changes do not follow a specific algorithm. This behavior can be due to changes in the angle of radiation and shading of parts of the building on the openings of this room.

Room 5 which face south receives the highest amount of sunlight among the surveyed rooms. According to the principles of traditional architecture and houses with a central courtyard in this area, the rooms located on the north and facing south have been selected as living space in winter. This study confirmed that this room and similar rooms that located in the north part of central courtyards have the potential to establish comfort for residents in cold seasons. Because while providing sufficient light, they also benefit from the heat of solar radiation. The uniformity is also recorded in all rooms in an acceptable amount. In the end, it can be concluded that not only the rooms around the central courtyard are successful in providing the required light, but also, due to the amount of light received in the rooms in traditional architecture, they were used in each season correctly. The design of a courtyard is possible even in residential apartments; therefore, this strategy would be helpful for creating more efficient spaces in the apartment.

CONFLICT OF INTEREST

There is no conflict of interest.

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Persian Abstract

چکیده

امروزه اکثر فضاها در خانه‌های معاصر ایران قادر به تامین نور کافی در روز نمی‌باشند. استفاده از نور روز تاثیر بسزایی در کاهش مصرف انرژی در ساختمان‌های مسکونی دارد. زمانی که به طراحی مبتنی بر نور روز توجهی نشود ساکنان از نور طبیعی روز محروم می‌شوند. معماران گذشته معماری سنتی ایرانی در ساخت خانه‌ها از روش‌های کاربردی استفاده می‌کنند تا شرایط آسایش در اتاق‌های اطراف خانه‌های حیاط مرکزی را از نظر کیفیت نور روز فراهم کنند. در این تحقیق کیفیت نور روز پنج اتاق در اطراف حیاط خانه یزدانپناه به روش تجربی مورد بررسی قرار گرفت. در اتاق‌های این خانه که در شهر کرمان و اقلیم گرم و خشک ایران واقع است، میزان WPI و نسبت یکنواختی محاسبه شد. یافته‌های این تحقیق نشان داد که این اتاق‌ها در خانه‌های سنتی توانایی دستیابی به روشنایی بیش از حد قابل قبول را دارند. در میان تمام اتاق‌های اطراف حیاط مرکزی، اتاق رو به سمت جنوب بیش از ۵۰۰ لوکس WPI دریافت می کند. میزان یکنواختی نور در این اتاق در اکثر روزهای سال بیش از ۰/۵ می‌باشد که میزان قابل قبولی است. از یافته‌های این تحقیق می‌توان در ایجاد فضاهای مرغوبتر از نظر کیفیت نور روز در خانه‌های معاصر استفاده کرد.