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Effect of Window Area and Proportions of Iwan on Daylight in Adjacent Room: An Investigation in Yazd City

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A B S T R A C T

Yazd is located in a hot-dry region with harsh weather conditions. Houses with an iwan were suitable for establishing comfort conditions in the past. An evaluation of the visual comfort conditions in residential courtyard buildings in Yazd city was carried out by investigating the effects of the depth of the iwan and the ratio of the adjacent rooms' openings. Research is currently being conducted on an optimal model of the iwan in an effort to facilitate sustainable development and increase the use of such a model in contemporary housing. The effect of the parameters was investigated by simulating models containing different proportions of the iwan and sizes of the window in the Design Builder software. The results indicate that the proportion of the iwan and Window Wall Ratio of the adjacent room's window significantly affects the daylight that penetrates into the rooms. For the purposes of this study, climate-based daylight metrics (CBDMs), such as Useful Daylight Illuminances (UDI) with thresholds of 100–3000 lux and Spatial Daylight Autonomy (sDA) over 300 lux. In models with an iwan depth of 1.5 and above, windows from 20% to 60% WWR have the ability to bring a suitable amount of light into the room. This means that by using the iwan, wider windows can be designed without having glare and adding extra thermal load to the building. Results obtained from this research will provide new insight into the concepts of iwan. Furthermore, findings of this research help architect to design spaces with the utilization of daylight.

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INTRODUCTION

The architect always faces a complex problem, including balancing the size and location of daylight sources with the surface geometry in designing buildings that use natural daylight to produce balanced light as well as uniform daylighting [1].

Renewable sources of energy, such as natural light, are a crucial factor to reduce the artificial lighting needs in designing energy-efficient buildings [2]. However, there is another advantage to using natural daylight the use of electricity for artificial lighting can be reduced by using natural daylight [3]. In order to improve the health and well-being of occupants, bringing daylight into the building is a crucial issue [4].

Furthermore, Yazd weather data used for the simulation process are available from the Energy Plus website and arranged by the World Meteorological Organization region and Country (EnergyPlus., 2019) [1].

Yazd is one of Iran's traditional cities, where the evolution of vernacular architecture from the past to the present can be observed [5]. The city of Yazd is located in Yazd province, which is the desert region of Iran [6].

The geographical range of this climatic zone in Iran, is mainly spread in the central parts. The climatical characteristic of these areas is an arid and dry climate due to few rainfalls throughout the year. The wind is another factor that blows in dry areas and decreases humidity [7].

The arid and dry climate of Yazd has had a great impact on the principles governing the residential architecture of the region. Among the various climatic factors, the sun has always played an important role in creating the thermal comfort of the residents, and for this reason, architects in different eras try to have the best

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[1] https://energyplus.net/weather-location/asia_wmo_region_2/IRN/IRN_Yazd.408210_ITMY

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interaction with this energy source by using different methods. Because the architecture of the buildings should be designed in such a way that to create thermal comfort during the day [8].

In general, the features and characteristics of the hot and dry climate can be described as follows: the sky is cloudless most of the year, the reflected radiation from the bare surfaces of the land is very high, and storms and dust occur in the afternoons. Rainfall is very low; humidity is low and the air is very dry. This climate has high day and night temperatures fluctuation [7-9].

There have been a number of solutions used to deal with the harsh conditions that are encountered in desert areas in terms of the design of buildings to deal with these harsh conditions. The majority of Yazd's traditional houses have central courtyard and iwan [5]. The amount of solar radiation in Yazd region has made it an important issue in building climate design, which has a great impact on the formation of residential architecture [10]. There are a number of principles that an architect chooses to utilize and to maximize the use of sunlight, such as orienting the building in order to receive light according to the desired thermal, health and psychological conditions. The amount of solar radiation that will be absorbed by a building can be determined by such principle [10]. Traditional architecture, particularly home designs, has found solutions to climate-related issues in Iran's arid regions [11]. Traditional Iranian architecture aims to integrate as many natural elements as possible into residential spaces, such as water, soil, wind, and light. This is done by designing central courtyards in residences [6, 12]. Courtyards are among the most notable instances of weather resistance in this architecture [13-15].

Iranian architects have employed numerous strategies to create appealing areas in Iranian dwellings by using the passive solar strategy, the study identified traditional Iranian architects as being adept at designing energy-efficient buildings based on the principles of passive solar design [5, 16, 17]. In order to make better use of daylight, different strategies are suggested. There have been suggestions that a self-shading strategy, such as a courtyard form, could eliminate the direct impact of direct solar radiation, thus minimizing the energy needed for cooling [18-20]. Another key architectural feature of houses in the central courtyard is the iwan; an area that was closed on three sides and opened into the courtyard was the most unique feature of traditional houses [21]. Throughout Persian history, the iwan describes porticos, open galleries, or porches. Three sides of the semi-open area are enclosed by walls, the front is open, and the roof is flat or domed. The size, shape, and ornamentation of iwans make them extremely valuable. During hot weather, northern iwans blow cool air under themselves toward interior areas. A southern iwan (facing the sun) is used in both the heating season and the cooling season of the year. With regard to slanted sunlight, southern iwans reduce solar beam penetration into interior areas [22].

The purpose of shading components in traditional buildings is to minimize the amount of solar radiation entering a structure. Iwan is one of the classic features of building shading that is vital for the proper function of the building. It is common for iwan to combine and unite many rooms in a typical residence [23]. The functioning of rooms on two or three sides of iwan maintained continuity in the iwan space as well. That is why this type of house is also called the "house with iwan". A simple traditional courtyard-iwan consists of one or more iwan surrounded by one or more rooms on one or both sides of the courtyard. The iwan can be located on the ground floor or the first floor[17, 24-29].

Iwans are spaces within the structure, one side of which is exposed to the exterior; this open side of the semi-closed rooms enables light to penetrate the iwan and the areas surrounding it [30]. An iwan is usually located on the south side of a courtyard, whereas the open parts of the space are usually located on the north side [31]. This strategy enables the iwan to utilize indirect light from the northern sky without exposure to direct radiation. (Figure 1) [12, 32].

Evaluating how much natural light comes into a structure is required to cut down on the amount of energy used for artificial lighting. This in turn has an impact on aspects such as visual comfort, user mood, solar advantages, and the quality of the elements that make up the illuminated area [33]. There are many benefits associated with using daylight in buildings, including reducing electricity consumption for lighting and creating an indoor environment that is more aesthetically pleasing [34].

The use of daylight in buildings has become increasingly popular in order to conserve energy [35]. Windows let in sunshine and sunlight, as well as provide air and vistas. The windows must be designed in a manner that is appropriate for their function [6, 32]. There is an

Figure 1. Iwans in courtyard buildings [32] obvious difference between the modern houses of Yazd and traditional houses of Yazd, which provide the users with a variety of daylight and shadow quality that is based on their activities and time. But there is no innovation in managing daylight and shadow in designing modern Yazd houses [17]. The level of concern regarding energy consumption and its effects on the environment has been steadily increasing as time passes. It is critical for designers to take into account issues such as energy, construction, the environment, and sustainable development [36]. In order to create desirable spaces in Iranian cities, Iranian architects have used a variety of techniques.

Traditional Iranian architects have designed buildings considering solar and passive strategies that reduce energy consumption. Through a simple organization method, Iranian architecture has reduced energy consumption and created sustainable architecture [37]. A study by Guedouh and Zemmouri [38] examined five houses with different central courtyards and found that sunlight behaved differently in each courtyard during winter and summer. It is generally accepted that the number of illuminations increases outside the courtyard's center as time passes. Even though the brightness of the sun varies throughout the day, daylight can provide suitable lighting for residents [39].

According to Dubois et al. [39], Guedouh and Zemmouri [38] acceptable levels of different indicators of daylight such as Illuminance, uniformity and DF have been determined. Tayari and Nikpour [20] indicated that by changing the proportions of the courtyard models, the amount of energy consumed by courtyard buildings was reduced. In current study the effect of iwan's depth on the amount of penetrate daylight in adjacent room of iwan was carried out.

MATERIAL AND METHODS

Methodical consideration

Today, simulation software is very important in building design and climate interaction. There are many advantages to utilizing these standards, including saving time and reducing design costs. The use of these factors can lead to the creation of a design that is best suited to the climate of the region in which it is situated. The most ideal conditions are provided at the lowest cost by utilizing each climate's capacities appropriately [40]. Simulator software is one of the tools that can be used to investigate the interaction of architecture with the climate of the region under study. By creating a virtual environment, this software provides the possibility to predict the performance of the building as close to reality as possible [41-43]. Building simulation should be validated in order to be used in building simulation tools [19, 44]. Several simulation tools are available for analyzing how well a building performs in terms of different factors such as daylighting, heat gain, or energy consumption in order to determine its overall performance [45, 46].

Previous research has demonstrated the simulation of energy-saving strategies [47]. There are few applications as specialized as Design Builder. To assess a building's functional capabilities, various simulation techniques may be used [48]. Design Builder software is designed for climate simulation and analysis of different spaces. The radiation engine used in this software has been measured in valid tests and scientific articles [49-51]. Validation of this software is available on the Energy Plus website also. Several studies have used Design Builder in building shading design and to extract temperature, humidity, energy use, and other variables [20, 52-54]. Generally, computer simulation has proven to be an efficient and cost-effective method of achieving good results [55].

Software validation

Comparative validation

At this stage of the research, to evaluate the validity of the Design-Builder simulator, comparative validation was used. Therefore, a model with similar characteristics was modeled both in Design Builder and in Ecotect software. The model used in this part was a room with 3-meter width and a 4-meter length. The window materials are also listed in Table 5.

It is evident from Table 1 that both software produces similar amounts of illuminance. And the difference between them is less than 10%. Therefore, it can be inferred that Design Builder software has sufficient validity to calculate the amount of daylight in this model with the weather data of Yazd city which is applied. In addition, a lot of research has been done about the Design-Builder validation in terms of different daylight indicators [43].

Empirical validation

For the empirical validation, 3 main spaces in Lariha's house in Yazd city were selected for field measurement. For collecting data in terms of Average Illuminance, Room index equation should be used to find at least the number of illuminance sensors to be installed in each

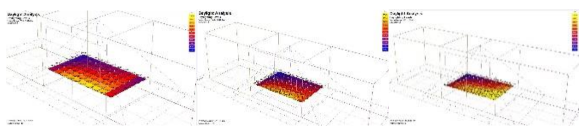

Figure 2. Ecotect illuminance modeling

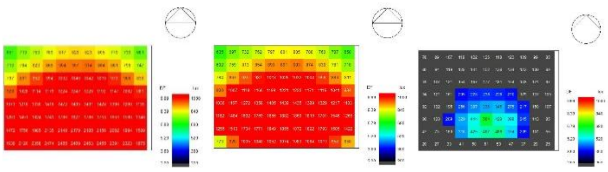

Figure 3. Design Builder illuminance modeling

room. Respect to the dimensions of the rooms and room index equation (Equation (1)), at least, 4 luxmeter should be installed in each room, in 31st of May 2023, from 7 a.m. to 7 p.m. with 1 hour interval, the amount of illuminance which has been captured through each luxmeter were recorded then the average of 4 number of illuminances has been calculated.

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

In the second step of validation of design builder software, the 3 rooms identified in Lariha's house in Yazd, were modeled in design builder as similar to the actual model. The results of experimental measurement and simulation for 3 rooms are presented in Table 3.

In the final step, two groups of variables, simulation and experiment results were imported into SPSS software. This was done to test the correlation between two groups of variables. The Pearson correlation results show a significant correlation between two categories of data at the 0.01 level.

Table 1. Comparison of simulation results between Ecotect and Design Builder

Ecotect Avg. illuminance (lux)	Design Builder Avg. illuminance (lux)	WWR (%)
513.82	292.7	10
657.61	478.35	20
764.93	635.65	30
976.77	757.5	40
1026.69	901.05	50
1223.39	1258.65	60
1320.7	1563.15	70
1541.48	1627.8	80
1003.17	939.35	AVG
63.8	Difference	
6.36	Percentage	

Table 2. 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

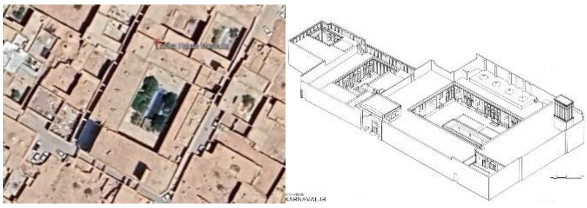

Figure 4. Location and perspective of Lariha's house in Yazd city

Figure 5. Plan and photo of room 1 in lariha's house

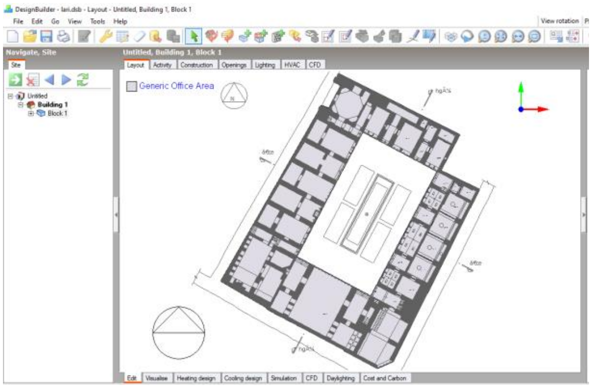

Figure 6. Modeling 3 rooms in Lariha's house in Design Builder software

Table 3. Comparison of field measurement and Design builder's results

Hours	Room 1	Room 2	Room 3	Room 1	Room 2	Room 3
	Software simulation Avg. illuminance (lux)			Field mesearment Avg. illuminance (lux)		
7	373	393	436	413	430	488
8	467	504	545	515	543	605
9	467	533	529	524	570	569
10	407	454	457	451	505	506
11	338	400	386	393	447	427
12	402	470	444	454	531	490
13	657	769	666	706	820	731
14	3984	4049	4029	4334	4450	4434
15	4393	4535	4488	4823	4835	4939
16	3683	3897	3779	4033	4276	4147
17	2371	2452	2499	2611	2708	2744
18	510	548	544	561	604	601
19	49	59	56	52	66	60

Table 4. Correlation table of SPSS software

		VAR00001	VAR00002
VAR00001	Pearson Correlation	1	1.000**
	Sig. (2-tailed)		.000
	N	39	39
VAR00002	Pearson Correlation	1.000**	1
	Sig. (2-tailed)	.000	
	N	39	39

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

Therefore, empirical validation also approved Design Builder simulation in terms of calculating average illuminance under weather data of Yazd city.

Simulation

In this research, 144 models were simulated using Design Builder simulation software. As shown in Figure 6, the selected models of iwans are surrounded by rooms. The adjacent room measures 3 meters width, 4 meters length, and 3 meters height. The idea of the models used in this research is taken from another research conducted by Kamyab et al. [56] (see Figure 4). During each simulation, Iwan's depth varies between 0 meters and 4 meters. Window to Wall Ratio (WWR) changes from 10 percent to 80 percent of the wall's area in the room behind the iwan. In the simulation, iwan's depth and the window's WWR were the most important features (see Figures 4-6).

Additionally, Yazd city weather data was used for the simulation, which is available on EnergyPlus website and validated by national and regional meteorological organizations. There was also information about humidity, solar heat gain, and dry bulb temperature in this set of meteorological data. In order to be able to use the results obtained in today's architecture, the materials chosen for the models were based on today's materials. All of the walls, roofs, floors and windows of the models are made from materials typically used in homes built in hot and dry climates. Since the amount of light entering the space is influenced by the type of glass, the materials used in the windows are summarized in Table 5.

This paper investigates the effect of different depths of iwan and the area of the window on the Daylight Factor, Illuminance, UDI, and SDA of adjacent rooms of iwan using Design Builder.

Daylight Factor (DF) refers to the ratio of the indoor daylight illuminance (Ei) at a specific point within the space in comparison to the outdoor illuminance (Eo) at that point under the same open overcast sky, calculated in percentage [57] (Equation (2)).

$$DF\ (\%) = (E_i/E_o) \times 100 \quad (2)$$

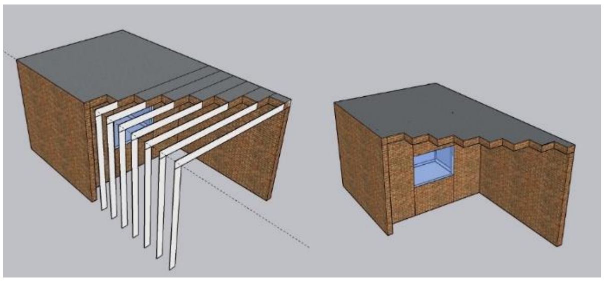

Figure 7. Steps of modeling iwan with different depth

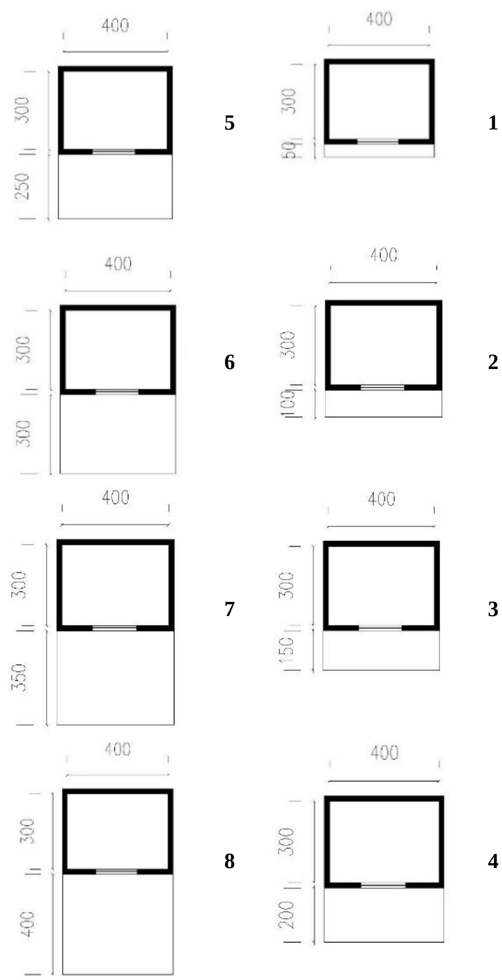

Figure 8. Iwan models with different depth [56]

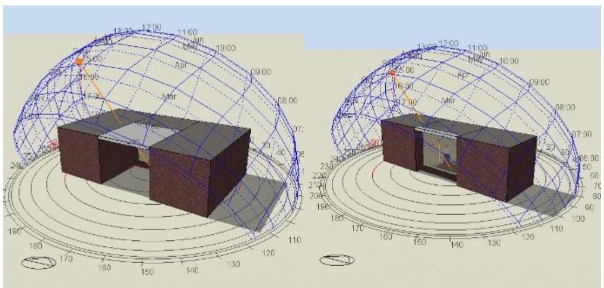

Figure 9. Simulated model in Design Builder

The illuminance of daylight is the sum of direct light from the sky in lux (SC), externally reflected component (ERC) and internally reflected components of solar radiation (IRC) [54]. (Equation (3)).

$$\text{Illuminance} = SC + ERC + IRC \quad (3)$$

Useful daylight illuminance (UDI)

The Useful Daylight Illuminance stands for the amount of light that falls in a given area during the course of the year as a distribution to reach a predetermined illumination goal in the range of 100-3000 lux [58].

Spatial daylight autonomy (sDA)

In order to test the sufficiency of daylight illuminance in an area, a method known as Spatial Daylight Autonomy has been developed. It is calculated using a percentage of floor space that meets a certain level of illuminance for a specific amount of annual hours to calculate the results. For example, sDA (300, 50%) represents the percentage of space in which the illuminance level is greater than 300 lux for 50% of the time [58].

Table 5. Construction details of windows

Parameter	Details/value
Construction	Glass
Thickness (mm)	0.4
Direct solar tarnsmission	0.624
SHGC	0.691
Light transmission	0.744
U-value W/m^2k	1.96
Double-glazed window with 13 mm air gap	

Table 6. Daylight Factor and illuminance standards [59]

Daylight Factor	Interpretation
<1%	Unacceptable
1-2%	Acceptable
2-5%	Preferable
>5%	Ideal for paper work/ too bright for computer work
Avg. Illuminance	
<100 lx	Too dark for computer and paper work
100-300 lx	Too dark for paper work/ acceptable for computer work
300-500 lx	Acceptable for paper work/ ideal for computer work
>500 lx	Ideal for paper work/ too bright for computer work

Table 7. Daylight classification based on UDI [60]

Daylight level	Definition
Non-daylight	UDI<150 lux≥50% of occupancy time
Partially daylight	UDI 150-300 lux≥5%of occupancy time
Full daylight	UDI 300-3000 lux≥50%+UDI 3000, <5% of occupancy time
Overlit	UDI> 3000 lux ≥5% of occupancy time

DISCUSSIONS

To determine daylight indicators of residential structures, various depths of iwan were examined. Tables 8 to 16 show simulation results. In each table, the amount of Daylight Factor, illuminance and the amount of UDI and sDA entered in the room adjacent to the iwan in both north and south directions are given. Table 6 shows the amount of Daylight Factor required for each model space is between 2 and 5%. The amount of Average Illuminance required is between 300 and 500 lux. In each table, the appropriate amount of light is marked with green color. The blue color indicates the level lower than normal and the red color shows the level higher than the required level. In Table 8 the amount of daylight and illuminance that entered the examined room without iwan can be seen. In this table, it can be seen that regardless of using iwan

Table 8. Measured daylight in models without iwan

	UDI area in range (%)	sDA area in range (%)	Avg. illuminance	Average daylight factor (%)	WWR
Without Iwan			**South**		
	96.59	70.45	292.7	1.649	10
	77.27	98.86	478.35	3.574	20
	59.09	100	635.65	5.275	30
	28.41	100	757.5	7.321	40
	10.23	100	901.05	8.982	50
	0	100	1258.65	11.49	60
	0	100	1563.15	13.579	70
	0	100	1627.8	14.42	80
			North		
	93.18	31.82	275.35	1.71	10
	100	87.5	441.25	3.616	20
	100	100	618.2	5.303	30
	100	100	864.8	7.431	40
	96.59	100	889.05	8.931	50
	70.45	100	1267.85	11.561	60
	54.55	100	1561.35	13.295	70
	45.45	100	1612.05	14.052	80

only the room with 20% WWR provides adequate light. On the other hand, the rest of the windows provide more daylight than needed. Based on UDI and according to Table 8 in the south-faced models, fewer models are fully daylighted compared to the north-faced models. In south-facing models more than half of the models are overlited.

In Table 9, the amount of light received in the room next to the iwan is measured while the depth of the iwan was 0.5 meter. In this case, if the window area is 20% of the external wall area, adequate light penetrates into the space. Except in the north direction when the window area is 10%, the sDA amounts do not receive sufficient daylight annually because the sDA of this model is just 31.82%. Which means it does not provide daylight autonomy. All models with windows faced to the south direction UDI indicator shows overlit condition when window to wall ratio (WWR) is more than 40. However, only one model in the north direction with 80% WWR is in the overlit condition due to penetration of diffuse light in the north direction.

Tables 10 to 16 show the amount of light received in the room next to the iwan. In each model, half a meter has been added to iwan's depth. This means that in Table 16, the iwan depth has reached 4 meters.

In Table 7, as the depth of the iwan increases to 1 meter, therefore light distribution has become more favorable. This is why the room with windows of 20 to 30 percent of the external wall provide sufficient light in terms of DF and Work Plane Illuminance (WPI), both from the south and north directions. In terms of sDA indicator, it can be inferred all models with more than 20% WWR, have the ability to reach perfect daylight autonomy with 100% in both south and north direction; however, in terms of UDI, in the south direction, Models with 40% WWR and more than 40% are considered as overlit with UDI less than 50% but in the north direction even though when 80% WWR is applied the amount of UDI remains under 50%.

In Table 11, with the increase in the iwan depth to 1.5 meters, the number of models that provide visual comfort has increased. In this table, models with window areas from 20 to 50% WWR let in the appropriate amount of light into the space in terms of DF and WPI indicators both south and north facing. It has been demonstrated that increasing the depth of the iwan at this stage has helped distribute the light and ensure uniformity when 1.5 meters of iwan is applied.

Table 9. Measured daylight in room adjacent to iwan with 0.5-meter depth

	UDI area in range (%)	sDA area in range (%)	Avg. illuminance	Average daylight factor (%)	WWR
			South		
Iwan with 0.5-meter depth	96.59	69.32	244	1.622	10
	78.41	98.86	408.3	3.507	20
	57.95	100	522.85	5.139	30
	28.41	100	666.5	6.757	40
	14.77	100	702.65	7.556	50
	1.14	100	1068.3	9.617	60
	0	100	1383.8	11.779	70
	0	100	1390.4	11.952	80
			North		
	93.18	30.68	281.3	1.709	10
	100	87.5	438.55	3.584	20
	100	100	551.6	5.295	30
	100	100	732.1	7.064	40
	100	100	714.8	7.523	50
	79.55	100	1074.8	9.727	60
	63.64	100	1365.75	11.542	70
	59.09	100	1388.2	11.767	80

Table 10. Measured Daylight in room adjacent to iwan with 1 meter depth

	UDI area in range (%)	sDA area in range (%)	Avg. illuminance	Average daylight factor (%)	WWR
			South		
Iwan with 1 meter depth	98.86	60.23	155.8	1.224	10
	86.36	98.86	377.6	3.238	20
	63.64	100	464.75	4.642	30
	43.18	100	522.2	5.53	40
	29.55	100	546.25	5.939	50
	18.18	100	796.35	7.589	60
	1.14	100	1182	9.838	70
	1.14	100	1181.75	9.887	80
			North		
	90.91	28.41	252.05	1.48	10
	100	87.5	390.5	3.305	20
	100	100	479.45	4.779	30
	100	100	567	5.572	40
	100	100	605.65	6.054	50
	97.73	100	837.75	7.585	60
	71.59	100	1144.95	9.585	70
	69.32	100	1169.25	9.733	80

All models with 30% WWR and more can reach 100% sDA in both the south and north direction. Although all models meet acceptable UDI levels, in the North direction in terms of UDI, Models with a 60% to 80% Window area in the south direction cannot achieve an acceptable UDI Level with the overlit condition when 1.5 meters depth for iwan was applied.

Table 12 demonstrated that when 2 meters of depth is applied, models with 20 % to 50% WWR have sufficient daylight quality in terms of DF and WPI. All models with 20% WWR and more can reach 100% as sDA which means these models have daylight autonomy. Except for models with 60% to 80% WWR in the south direction are overlit, other models have acceptable UDI levels.

Table 13, shows the amount of daylight in the adjacent room when 2.5 meters depth is applied. The models with WWR between 30 and 60% have received enough daylight in terms of DF and WPI. In terms of sDA, all models oriented to the south with a window area of more than 20% can achieve daylight autonomy for a whole year. However, all models facing north with a window area of more than 30% can achieve daylight autonomy. From the UDI point of view, all models are considered as full daylight spaces except models with 70 and 80% facing the south when 2.5 meters depth of iwan is applied.

Table 14 presents the amount of daylight in different models when 3 meters of depth is applied. All models with 30% to 60% in both the south and north direction can achieve an acceptable level in terms of WPI and DF when 3 meters depth of iwan is applied. In terms of sDA, only models with 10% and 20% in the south direction and Models with windows less than 40% cannot achieve 100%. Furthermore, only models facing to the north with 70 and 80% are considered as overlit spaces with less than 50% as UDI. According to UDI indicators, other models have reached full daylight quality.

The models in Table 15 show the results of different models with different WWR in the south and north direction when 3.5 meters depth of iwan is applied. With regard to WPI and DF indicators, iwan models with 3 meters depth have similar results. Only models with 10 and 20% of WWR, cannot reach 100% sDA both in the south and north directions. UDI indicators indicate that models with 70% and 80% window area in the south direction are overlit.

In Table 16, daylight quality in the adjacent room of

Table 11. Measured Daylight in room adjacent to iwan with 1.5-meter depth

	UDI area in range (%)	sDA area in range (%)	Avg. illuminance	Average daylight factor (%)	WWR
Iwan with 1.5 meter depth			South		
	98.86	59.09	155.8	1.224	10
	97.73	98.86	279.2	2.659	20
	75	100	367.45	3.816	30
	61.36	100	415.05	4.462	40
	55.68	100	442.55	4.779	50
	31.82	100	679.55	6.344	60
	5.68	100	999.25	8.274	70
	5.68	100	1012.35	8.389	80
			North		
	90.91	26.14	171.75	1.256	10
	100	86.36	296.25	2.685	20
	100	100	380.8	3.967	30
	100	100	430.4	4.48	40
	100	100	458.7	4.916	50
	100	100	668.45	6.272	60
	80.68	100	989.4	8.156	70
	77.27	100	989.75	8.248	80

Table 12. Measured Daylight in room adjacent to iwan with 2-meter depth

	UDI area in range (%)	sDA area in range (%)	Avg illuminance	Average daylight factor (%)	WWR
Iwan with 2 meter depth			South		
	98.86	51.14	114.25	0.978	10
	100	97.73	224.6	2.172	20
	89.77	100	312.15	3.223	30
	80.68	100	390.45	3.759	40
	75	100	404.4	4.05	50
	45.45	100	602.2	5.473	60
	18.18	100	891.4	7.295	70
	14.77	100	894.7	7.36	80
			North		
	89.77	13.64	122.95	1.014	10
	100	86.36	230.1	2.207	20
	100	98.86	308.5	3.301	30
	100	100	387.1	3.838	40
	100	100	409.25	4.125	50
	100	100	571.6	5.566	60
	84.09	100	867.7	7.13	70
	84.09	100	878.55	7.216	80

Table 13. Measured Daylight in room adjacent to iwan with 2.5-meter depth

	UDI area in range (%)	sDA area in range (%)	Avg illuminance	Average daylight factor (%)	WWR
			South		
Iwan with 2.5 meter depth	96.59	42.05	82.6	0.82	10
	100	96.59	178.7	1.869	20
	96.59	100	282.15	2.829	30
	92.05	100	315.95	3.286	40
	84.09	100	345.9	3.574	50
	59.09	100	524.9	4.841	60
	31.82	100	805.45	6.573	70
	20.45	100	812.3	6.762	80
			North		
	89.77	3.41	94.8	0.877	10
	100	86.36	196.2	1.901	20
	100	98.86	285.95	2.85	30
	100	100	319.75	3.36	40
	100	100	344.9	3.598	50
	100	100	523.4	4.919	60
	85.23	100	781.25	6.437	70
	84.09	100	792.5	6.622	80

Table 14. Measured Daylight in room adjacent to iwan with 3-meter depth

	UDI area in range (%)	sDA area in range (%)	Avg illuminance	Average daylight factor (%)	WWR
			South		
Iwan with 3 meter depth	97.73	23.86	62.8	0.698	10
	100	96.59	139.25	1.59	20
	100	100	217.75	2.459	30
	100	100	257.1	2.887	40
	100	100	290.95	3.167	50
	65.91	100	450.25	4.448	60
	39.77	100	728.65	6.026	70
	36.36	100	736.3	6.131	80
			North		
	89.77	0	67.5	0.751	10
	100	85.23	175.6	1.687	20
	100	98.86	250.6	2.591	30
	100	100	288.8	3.038	40
	100	100	323.45	3.352	50
	100	100	476.85	4.5	60
	90.91	100	720.4	5.935	70
	89.77	100	728.35	6.025	80

Table 15. Measured Daylight in room adjacent to iwan with 3.5-meter depth

	UDI area in range (%)	sDA area in range (%)	Avg illuminance	Average daylight factor (%)	WWR
			South		
Iwan with 3.5 meter depth	97.73	7.95	53.15	0.608	10
	100	94.32	127.3	1.463	20
	100	100	218.5	2.304	30
	100	100	254.75	2.733	40
	100	100	290.05	3.011	50
	53.41	100	473.2	4.425	60
	47.73	100	689.5	5.692	70
	40.91	100	699.65	5.75	80
			North		
	89.77	0	56.45	0.672	10
	100	86.36	166.65	1.546	20
	100	100	249.3	2.426	30
	100	100	272.45	2.827	40
	100	100	302.3	3.136	50
	92.05	100	468.25	4.332	60
	90.91	100	678.7	5.576	70
	90.91	100	683.85	5.666	80

Table 16. Measured Daylight in room adjacent to iwan 4-meter depth

	UDI area in range (%)	sDA area in range (%)	Avg illuminance	Average daylight factor (%)	WWR
			South		
North Iwan with 4-meter depth	96.59	3.41	46.35	0.576	10
	100	94.32	128.8	1.382	20
	100	100	208.75	2.183	30
	100	100	257.45	2.643	40
	100	100	289	2.899	50
	100	100	280.3	2.953	60
	53.41	100	664	5.415	70
	50	100	668.05	5.513	80
			North		
	89.77	0	50.45	0.608	10
	100	85.23	136.75	1.425	20
	100	96.59	239.75	2.302	30
	100	100	258.75	2.66	40
	100	100	282.45	2.926	50
	100	100	294.45	3.043	60
	92.05	100	653.9	5.301	70
	90.91	100	653.15	5.373	80

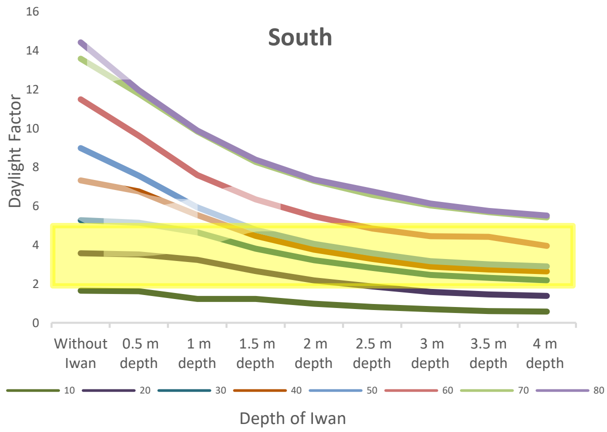

Figure 10. Measured daylight factor in all models faced to the south

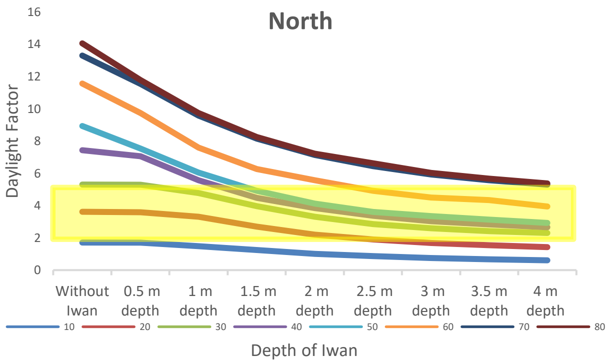

Figure 11. Measured daylight factor in all models faced to the north

iwan is shown when the depth of iwan is taken into account at 4 meters. In terms of WPI and DF indicators, there is a similarity with models with 3 or 3.5 meters iwan depth. The models with a window area of more than 20% in the south direction and models with a 30% window area in the north direction can reach 100% in terms of sDA even though all models in both directions south and north can achieve the quality of space entitled full daylight with UDI>50%.

Figures 10 and 11 show that when a larger iwan depth is applied, the number of models that can achieve acceptable daylight quality increases.

CONCLUSION

Study findings indicate that south or north-facing courtyard buildings could receive daylight depending on their proportion of iwans and the area of windows. As the window wall ratio (WWR) changed in each model, daylight parameters were measured. Two different courtyard rooms (Zemestan Neshin and Tabestan Neshin) were simulated and the results were divided according to their orientation (north and south). A decrease in the Daylight Factor was observed when the depth of iwan was increased in models facing north and south. Additionally, it increased when WWR was increased from 10% to 80%. In spite of the fact that the increasing and decreasing data for the two orientations were the same, the amount of daylight was different in the two orientations.

Although the presence of an iwan in any model can reduce the amount of light entering the room, at the same time, it can prevent direct sunlight and only bring its brightness into the space. This causes less glare in the room and also reduces the amount of heat received while providing adequate light.

The amount of light entering the space is increased due to the increase in the window area compared to the external wall. Also, the amount of light received in the direction of north and south is different from each other. According to Tables 8 to 16, the amounts of light entering space it has a direct relationship with the depth of the iwan, and the iwan plays a very critical role in the distribution of light and its uniformity. In this way, the iwan can be used to increase the surface area of windows. Wider windows can provide an acceptable view while providing adequate light. Additionally, the iwan acts as a shade to prevent direct sunlight from entering. which can be effective in reducing the thermal load entered into the building. The effect of iwan on daylight quality in adjacent rooms is considered significant. Daylight Autonomy (DA) in most models with different window areas shows iwan's positive effect on providing enough daylight. Furthermore, with an increase in iwan depth, the diversity in window design will increase.

A broader view of building design can be achieved through the application of the iwan optimal proportion. It is anticipated that more aspects of buildings will be considered in future research, based on discussion of buildings with Iwans.

CONFLICT OF INTEREST

There is no conflict of interest.

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Persian Abstract

چکیده

یزد در منطقه ای گرم و خشک با شرایط آب و هوایی سخت قرار دارد. خانه های دارای حیاط مرکزی و ایوان در گذشته به منظور ایجاد شرایط آسایش مناسب بودند. در تحقیق پیش رو ارزیابی شرایط آسایش بصری در ساختمان‌های حیاط مسکونی شهر یزد با بررسی تأثیرات عمق ایوان و نسبت دهانه‌های اتاق‌های مجاور انجام شد. هدف این تحقیق یافتن مدل بهینه ایوان به منظور تسهیل توسعه پایدار و افزایش استفاده از چنین مدلی در مسکن معاصر در اقلیم گرم و خشک یزد صورت گرفته است. به همین منظور تأثیر پارامترهای عنوان شده با استفاده شبیه‌سازی مدل‌هایی از اتاق دارای ایوان با نسبت‌های مختلف از ایوان و اندازه‌های مختلف پنجره در نرم‌افزار Design Builder بررسی شد. نتایج نشان می دهد که نسبت ایوان و نسبت سطح پنجره اتاق مجاور به طور قابل توجهی بر میزان نور روز که به اتاق ها نفوذ می کند تأثیر می گذارد. برای اهداف این مطالعه، معیارهای نور روز مبتنی بر آب و هوا (CBDMs) با آستانه‌های بالاتر از ۳۰۰ لوکس، مانند روشنایی مفید نور روز100-3000 (UDI) لوکس و استقلال نوری فضا در روز (sDA) بیش از ۳۰۰ لوکس، غیرقابل اجرا هستند. در مدل‌های ایوان با عمق ۱.۵ متر و بالاتر، پنجره‌های دارای ۲۰٪ تا ۶۰٪ سطح دیوار خارجی این قابلیت را دارند که مقدار مناسبی از نور را به اتاق وارد کنند. به این معنی که با استفاده از ایوان می توان پنجره های عریض تری را بدون وجود خیرگی و افزودن بار حرارتی اضافی به ساختمان طراحی کرد. نتایج به‌دست‌آمده از این تحقیق بینش جدیدی را در مورد مفاهیم الگوهای قدیمی مانند ایوان ارائه و همچنین به یافتن راه‌حل‌هایی در پاسخ به تغییرات اقلیمی کمک می‌کند.پنجره اتاق مجاور به طور قابل توجهی بر راحتی (با توجه به بار سرمایشی، بار گرمایشی و مصرف انرژی) در اتاق مجاور ایوان تأثیر می گذارد. نتایج به‌دست‌آمده در این تحقیق دریچه جدیدی برای بازیابی مفاهیم الگوهای قدیمی و کمکی به طراحی فضاهای مناسب از نقطه نظر کیفیت نور خواهد بود.