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Investigating the Effect of Different Proportions of Iwan and Window Area of Adjacent Room on Cooling/Heating Load and Energy Consumption in Central Courtyard Model in Yazd

A. Kamyab[1], M. Mahmoodi Zarandi[1]*, M. Nikpour[2]

[1] *Architecture Department, North Tehran Branch, Islamic Azad University, Tehran, Iran*
[2] *Architecture Department, Bam Branch, Islamic Azad University, Bam, Iran*

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A B S T R A C T

The city of Yazd has a large number of traditional houses. Houses with central courtyards and an Iwan were suitable for establishing thermal comfort conditions. In this research, the effect of Iwan's depth and the ratio of the adjacent room's openings on the comfort condition in the residential courtyard buildings in Yazd city were evaluated. The current research aims to provide an optimal model of the Iwan to increase sustainable development and use such models as the Iwan in contemporary housing in the hot and dry climate of Yazd. In order to investigate the effect of parameters, samples from the north-facing room and south-facing room in a central courtyard model with different proportions of the Iwan and different sizes of the window were simulated in Design Builder software. The results showed that the depth of Iwan and window to wall ratio's (WWR) of the adjacent room's window significantly affects the comfort (according to cooling load, heating load, and energy consumption) in this room. The results obtained in this research will be a new window to recover the concepts of old patterns and help to solve climate problems.

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INTRODUCTION

Yazd is a traditional city where the development of domestic architecture from the Islamic Middle Ages to subsequent times is observed [1]. The province of Yazd includes the city of Yazd, which is situated in Iran's central region; it is referred to as the desert's capital [2]. This city is entirely locked off and has a very thick skin. All the areas are adequately shielded from wind-borne dust and are designed to take advantage of the summer's cool breeze and the winter's sunlight [3].

In hot-arid parts of Iran, traditional architecture, particularly dwelling designs, has discovered answers to climate-related issues [4]. Most of the old architecture is introverted, with all the rooms organized around a rectangular, open courtyard that served as the connection between the different rooms. This geometry imposes a hierarchy on its many spaces [2]. In Iran, courtyard houses are the most common style of traditional dwelling [5]. Courtyards are one of the most notable instances of this architecture's resistance to climatic conditions [6–8]. In the past, constructing courtyards was almost done for cooling in hot regions and access to proper light [9, 10]. The idea behind the traditional design in terms of climate is to use the least amount of energy possible to turn unpleasant outside circumstances into a balanced and attractive place [1].

There is a significant component in courtyards like Iwan; in addition to affecting how the building's façade looks, may also affect how comfortable the surrounding rooms' heating is.

Prior studies have mainly concentrated on a single form of shading-overhang, side fan, Venetian blind, self-adaptive, etc. and how it affects a building's energy use. Additionally, architectural openings are typically the center of the shadings span [11–16].

*Corresponding Author Email: *Mahnazmahmoodyz@gmail.com*
(M. Mahmoodi Zarandi)

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Foruzanmehr [17] also looked at the loss of iwan in contemporary architectural styles. In order to re-incorporate the vernacular iwans of Yazd into modern dwellings, he looked into numerous iwan characteristics, including social, cultural, and aesthetical factors.

According to Kalantari et al. [18] Iwan was solely used as a symbolic feature in the architecture of traditional buildings in Tabriz city, and its climatic function was seldom taken into account while these buildings were being designed. The findings of Nejadriahi [19] on the other hand, highlighted the significance of Iwan as one of the sustainable components in traditional Iranian homes by "offering more comfort with less energy usage"

The Iwan's orientation can influence how much energy is used in four distinct climatic zones. The best weather for building an Iwan and maximizing energy is hot and humid weather, followed by moderate and humid weather, hot and dry weather, and finally, cold and mountainous weather, according to some Energy Plus software research. The south view is also the best orientation for using the Iwan [20].

Iwan in traditional architecture

IWAN, also EYVAN and occasionally in spoken Arabic LIWAN, is a Persian word acquired by the Turkish, Kurdish, and Arabic languages, and later by western travelers, archaeologists, and art historians to refer to particular characteristics of Near Eastern and Islamic architecture [21]. Iwan, or semi-open areas, are utilized to produce daytime shade and comfortable living spaces.

The Iwan, which has a closed corridor in front of the rooms, allows for a communal living (an open living room inside the house). They are often orientated to the south. Iwans facing south and east are very pleasant and provide shaded areas during the warm afternoons [22]. Iwan is a semi-open area that serves a variety of functions in structures. It may be a transitional area connecting a building's yard or garden with its rooms. It also serves as a place to rest [23].

Middle Eastern architecture and Iwan are frequently associated. It is a rectangular hall or area often roofed and walled on three sides. The fourth side is completely open through a portico into a yard or partially through a portico [24]. Iwan comes from Persian word for portico, open gallery, or porch. Walls enclose the semi-open area on three sides, are open in front and have a flat or domed roof [25].

Woolley [26] believed that the arched entrances in front of the broad and shallow rooms located in one wing of the courtyards of huge homes from the Ur III era in the city of Ur can be regarded as the ancestors of the iwan. After that, the iwan appears in the architecture of the Parthians and Sassanids [26]. In Hatra, dating back to the second century B.C., the iwan was an integral part of the layouts of temples, palaces, and residences [27].

Iwan, a component of Sassanian architecture that originated in Mesopotamia, became an element of Islamic and Middle Eastern architecture during the Seljuks' reign in the 10th century [24]. In the Parthian palace dating to the second century B.C. in Assyria, iwans are located on the four wings of the courtyard, in the side chambers, and in other areas [28]. In Sassanid architecture, the king's audience hall provides an additional early example of the iwan [25]. The palace of Tak-i Kisra dates back to 550 B.C. Located in Ctesiphon, the throne room features a 43.50-meter-deep iwan and 25.50m wide. It is constructed of brick and vaulted, giving a striking impact in its own right [28]. The iwan was initially utilized in Parthian household construction. In the primary living quarters of Parthian-era homes, iwan-room and room-iwan-room formations were prevalent. During the Parthian era in Assyria, every courtyard had at least one iwan on the southern side [28].

Iwan is a sort of exterior shading system that enhances the energy efficiency of buildings. It has been regarded as one of the primary shading components and passive cooling mechanisms in the architecture of the Middle East and North Africa [29]. Consequently, the inside areas adjusted to the iwan will remain cool. Iwan also plays climatic functions by giving protection from the summer's intense heat and by generating shade from winter's rain, snow, and wind [30, 31].

Iwans are important because of their size, shape, and ornamentation. Northern Iwans provide a flow of cool wind under them toward interior areas because they get cold in hot weather. Both the heating and cooling seasons of the year use southern Iwans (facing the sun). Southern Iwans lessen the penetration of solar beams into interior areas with regard to slanted sunlight [32].

In traditional buildings, shading components minimize the amount of solar radiation that enters a structure. Iwan is one of these classic building shading features that play a vital function. In a typical residence, Iwan combines and unites many rooms [33].

Energy consumption

Today, the primary cause of climate change is the excessive carbon emissions caused by fuel usage in buildings [34]. As a result, cutting back on energy exports may be the best alternative for enhancing Iran's economic and energy security [35]. As part of the principles and practices of sustainable architecture, designers are required to identify the architectural demands of the project based on climate conditions, the preservation of the environment, and a reduction in the amount of energy that is used. The thermal performance and lighting of structures can be affected, to varying degrees, by natural energy sources such as the sun, depending on the characteristics of the building façade [36]. The demands for energy can be satisfied with renewable energy. Additionally, solar energy plays a significant part in supplying energy demands as one of the renewable energy sources [37, 38]. Energy conservation in residential buildings is one of the Iranian government's primary initiatives [39]. It has been observed that the building of spaces lost their quality due to the result of the enormous expansion of housing, such as apartments, in the vertical direction and the scarcity of suitable land. Modern architecture has become more distinct from traditional architecture as a result of the elimination of original areas like yards and Iwans and the substitution of unsuitable terraces [3]. On the other hand, the immoral and unconventional way that buildings are built results in a significant loss of fossil fuel energy that must be utilized for heating and cooling, polluting the environment and wasting energy [40].

Traditional Iranian architecture is a highly potent style form based on climatic concerns; however, due to advancements in construction technology as well as changes in people's lifestyles and cultures, the traditional forms of structures have been lost. This is despite the fact that traditional Iranian architecture is a form that has existed for centuries [41]. Houses are the most significant structures in traditional Iranian architecture, which is exceedingly intricate in response to climatic circumstances [42]. Iranian traditional architecture reflects their wants, requirements, and methods for meeting those needs [6].

This study aims to estimate the proportion of Iwans on two sides of the courtyard that can affect the cooling/heating load and energy consumption of residential buildings. An efficient Iwan and environmentally friendly model can improve optimization at the start of the architectural design of residential structures in Yazd. The results of the analysis and typology of the Iwan can be used to obtain optimal iwan models in Yazd residential buildings.

MATERIAL AND METHODS

Methodical consideration

Simulation software has been the method that has been used the most frequently. Computer simulation has developed as one of the most potent techniques for studying the operational efficiency of buildings [43]. By utilizing building energy modeling systems, one is able to provide an accurate estimate of the performance of a building [44–47].

Previous research has demonstrated that a number of simulators have been developed to model a variety of energy-saving strategies [48]. There are certain methods available now that can examine the energy usage and thermal characteristics of buildings [49]. The Design Builder software is one of the most specialized applications available for modeling the energy consumption of buildings. Evaluation of a building's functionality may be accomplished through the use of a variety of simulation techniques [50]. The most popular simulation method produces trustworthy and precise findings at reasonable prices, and it helps speed up the research process.

To begin, it is essential to be aware that it is possible to utilize simulation software as a foundation simulation for energy calculations in buildings. These calculations might include the efficiency of shading and the amount of energy that is used. As is well known, Energy Plus has been utilized in a large number of studies throughout the globe for shading design in buildings and for extracting data on temperature, humidity, energy use, and other variables [9, 51–54]. In the majority of instances, computer simulation is a cost- and time-efficient method for achieving acceptable outcomes [54].

The Design Builder program is one of the comprehensive user interfaces offered by Energy Plus for the purpose of energy modeling. A fundamental understanding of Design Builder includes categories such as template components, the material database, heating, ventilation, and air conditioning (HVAC), as well as other topics. In general, Energy Plus is a stand-alone simulation application that does not include a graphical user interface that is considered to be "user-friendly." The user-friendly graphical interface that Design Builder offers has recently been included into the calculating model of the Energy Plus program. The simulation that Design Builder makes use of is the most precise simulation available, with dynamic parameters that include all of the energy calculations [55, 56].

In prior studiesconducted by Tayari and Nikpour [50] a, Bergero and Chiarind [57] the validity of the Design Builder and energy plus software was demonstrated. Design Builder was used by Taleghani et al. [58] to simulate their models in order to calculate heating and cooling in buildings that have courtyards. Tabesh and Sertyesilisik [59] utilized Design Builder to measure the amount of energy consumed in courtyard structures as well. Eskandari et al [60] used software simulation to investigate 22 traditional houses' Iwan in four different climatic regions and four different orientations in Iran. As a result, the Design Builder program was employed as an energy simulator in this paper. In this research, the analysis relies on computer simulation to measure the effect of different proportions of Iwan on energy consumption and the amount of cooling load and heating load in the Yazd city climate conditions.

Simulation

Design builder simulation software was chosen to simulate 128 models in this research. According to Figure 1 the selected models of Iwans have a room behind them with 3-meter width, 4-meter length, and 3.5-meter height. The depth of Iwan in each simulation changes from 0.5 meters to 4 meters. The room behind the Iwan has a window in which the amount of WWR changes from 10 percent to 80 percent of the wall’s area. The main features

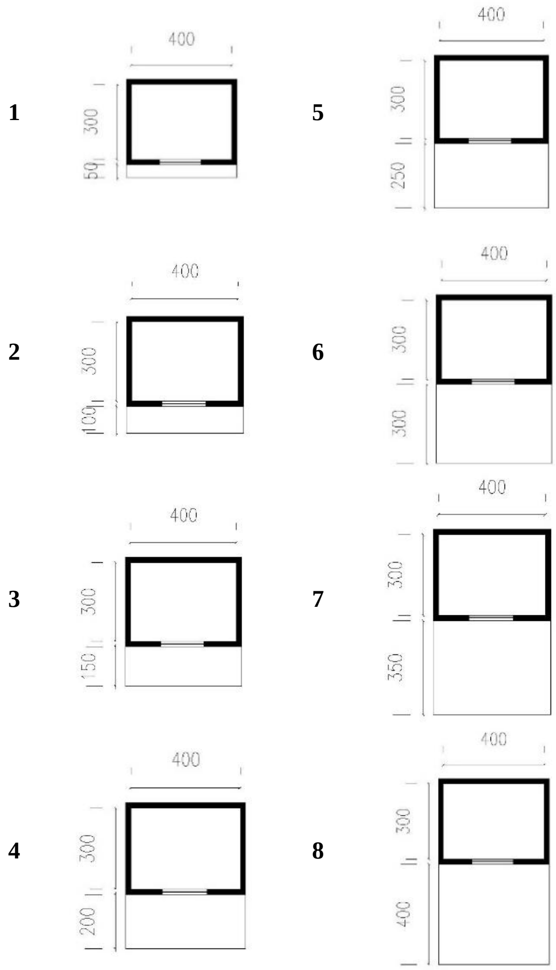

Figure 1. Proportions of Iwan and the size of the adjacent room

for simulation were the depth of Iwan and the WWR of the adjacent room’s window. Half of the models were located faced to the north, which in the traditional architecture of Iran, the rooms at the end of courtyards called Tabestan Neshin, and the other half faced to the south, called Zemestan Neshin. Tabestan Neshin means a room that is suitable for summer conditions, and Zemestan Neshin is a room whose condition is comfortable for winter according to their solar gains.

The simulated model in Design Builder is shiwn in Figure 2. The climate information for the city of Yazd, which is located in a hot and dry part of Iran at a latitude of 31.89 and a longitude of 54.35, was used for energy analysis in Design-Builder. This set of meteorological information contained dry bulb temperature and wet temperature readings, as well as humidity and solar heat gain, among other things.

All of the models' construction features for the walls, roofs, and flooring are based on typical materials that have been utilized in the construction of homes in climates that are hot and dry. Table 1 summarized the construction details of the models.

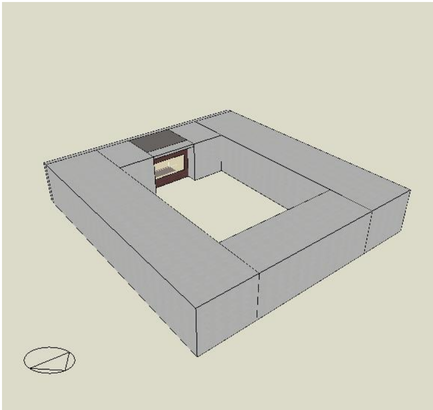

Figure 2. Simulated model in Design Builder

DISCUSSION OF RESULTS

The results presented in this research are derived through computer simulations in order to ensure accuracy. The numerical results of this study were calculated by using the software for energy modeling known as Design Builder. The examination of different proportions of Iwan in residential structures in terms of features of the consumed cooling load, heating load, and energy consumption has been studied. These aspects include: cooling load, heating load, and energy consumption. According to the findings, the depth of Iwan has a direct influence on the amount of energy that is consumed as well as the cooling and heating loads. Figures 3 to 5 show the results for models facing north (Tabestan Neshin). As a result of cooling loads, it can be seen that with increasing depth of Iwan, the cooling load decreases. Also, the WWR affects the cooling loads by increasing the percentage of WWR. The lowest amount belongs to the model with a 4meter depth Iwan and 10 % WWR, and the highest cooling load belongs to the model with a 0.5meter depth and 80% WWR. The cooling and heating loads in rooms faced north are reported in Tables 2 and 3, respectively. Table 4 summarized energy consumption in room faced north.

The heating load results are vice versa; by increasing the depth of Iwan heating load increases too. Also, by increasing the area of window heating load of the room decreases. The highest heating load belongs to the model with a 4meter depth and 10% WWR and the lowest to the model with 0.5meter depth and 80% WWR.

Table 1. Construction details of models

Construction	Thickness	U-value surface to surface	R-value	U-value
Floor	0.2	2.112	0.684	1.463
Wall	0.34	0.926	1.25	0.8
Roof	0.22	2.946	0.479	2.086

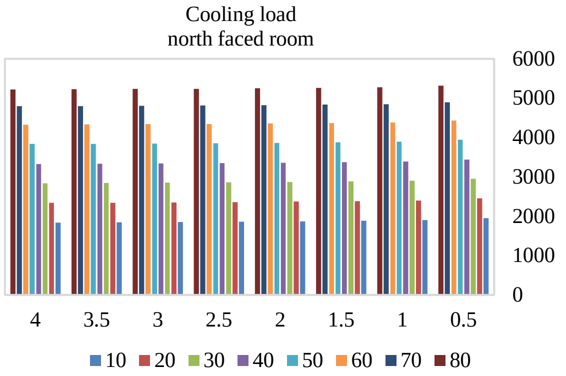

Figure 3. Measured cooling load in the room faced north with different proportions of Iwan

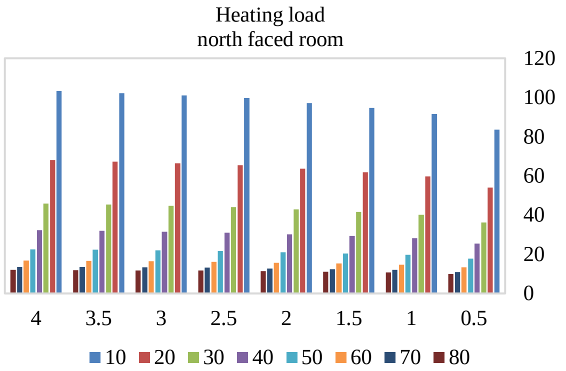

Figure 4. Measured heating load in the room faced north with different proportions of Iwan

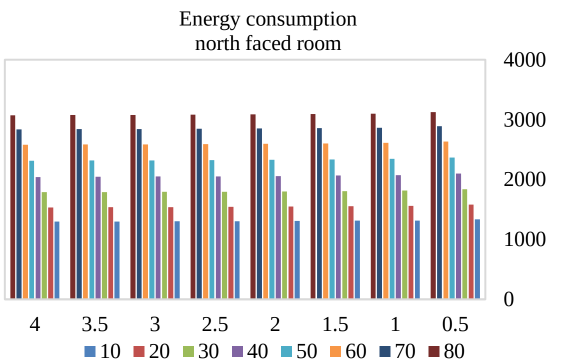

Figure 5. Measured energy consumption in the room faced north with different proportions of Iwan

In Figure 5, the most influential factor is WWR. The area of the window affects energy consumption more than the depth of Iwan. Nevertheless, it should be considered that increasing the depth of Iwan also decreases the amount of energy consumption.

In models faced to the south, the changes are more prominent. The depth of Iwan is more effective compared to the results of models that faced the north. The cooling load decreases more, and it can be related to the direct solar gain in the external wall and window of the room

Table 2. Measured cooling load in room faced north

Depth	Cooling load in room faced north							
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**
0.5	1950	2452	2953	3440	3945	4435	4898	5323
1	1899	2400	2901	3389	3894	4386	4851	5277
1.5	1884	2384	2885	3373	3879	4370	4836	5263
2	1872	2371	2872	3360	3867	4358	4825	5252
2.5	1859	2358	2858	3347	3853	4346	4812	5241
3	1853	2351	2852	3340	3846	4339	4806	5234
3.5	1847	2345	2845	3334	3841	4333	4800	5229
4	1841	2339	2839	3328	3834	4327	4794	5223

Table 3. Measured heating load in room faced north

Depth	Heating load in room faced north							
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**
0.5	83.5	54	36.1	25.3	17.6	13.2	10.9	9.94
1	91.5	59.6	40.0	28.1	19.6	14.7	12.0	10.7
1.5	94.6	61.8	41.6	29.3	20.4	15.2	12.4	11.1
2	97.1	63.6	42.8	30.1	21.0	15.6	12.7	11.3
2.5	99.6	65.4	44.1	31.0	21.6	16.1	13.1	11.6
3	101	66.4	44.7	31.5	22.0	16.3	13.3	11.8
3.5	102.1	67.2	45.3	31.9	22.3	16.5	13.4	11.9
4	103.2	68	45.8	32.3	22.5	16.7	13.5	12.0

Table 4. Measured energy consumption in room faced north

Depth	Energy consumption in room faced north							
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**
0.5	1336	1581	1840	2098	2370	2637	2891	3126
1	1317	1559	1815	2073	2344	2611	2866	3102
1.5	1312	1553	1808	2065	2336	2603	2859	3094
2	1308	1548	1802	2059	2330	2597	2853	3088
2.5	1304	1543	1796	2053	2324	2591	2846	3082
3	1302	1540	1793	2050	2320	2587	2843	3079
3.5	1300	1537	1790	2047	2317	2584	2840	3076
4	1298	1535	1788	2044	2314	2581	2837	3073

that Iwan can block out. Also, like models face to the north, the lowest amount belongs to the model with a 4meter depth Iwan and 10 % WWR, and the highest cooling load belongs to the model with a 0.5meter depth and 80% WWR. However, the amounts are lower than those models. The cooling and heating loads in room faced south are summarized in Tables 5 and 6, respectively.

Table 5. Measured cooling load in room faced south

Depth	cooling load in room faced south							
	10	20	30	40	50	60	70	80
0.5	2558	3110	3639	4143	4657	5146	5605	6023
1	2276	2827	3359	3869	4388	4884	5349	5772
1.5	2014	2555	3085	3596	4119	4620	5089	5518
2	1857	2376	2895	3401	3920	4421	4893	5324
2.5	1802	2300	2805	3300	3814	4310	4780	5211
3	1781	2272	2767	3254	3760	4252	4720	5150
3.5	1775	2263	2756	3240	3741	4230	4695	5124
4	1768	2257	2749	3233	3734	4221	4687	5115

Table 6. Measured heating load in room faced south

Depth	Heating load in room faced south							
	10	20	30	40	50	60	70	80
0.5	9.8	7.8	6.2	5.1	4.2	3.7	3.6	3.6
1	11.6	9.1	7.2	5.9	4.8	4.2	4.0	4.0
1.5	16.7	11.6	8.9	7.2	5.8	5.0	4.7	4.6
2	33.2	21.6	15.4	11.7	8.9	7.4	6.7	6.4
2.5	65.3	42.1	29.0	21.1	15.4	12.0	10.2	9.4
3	105.6	69.7	47.6	34.2	24.4	18.4	15.1	13.3
3.5	134.5	91.1	62.7	44.5	31.6	23.4	18.8	16.4
4	141.9	97.1	67.2	47.7	33.7	25.0	20.0	17.3

The cooling and heating loads in room faced south with different proportions of Iwan are shown in Figures 6 and 7, respectively.

In models facing the south, the heating load is much lower. The highest heating load belongs to the model with a 4meter depth and 10% WWR and the lowest to the model with 0.5meter depth and 80% WWR.

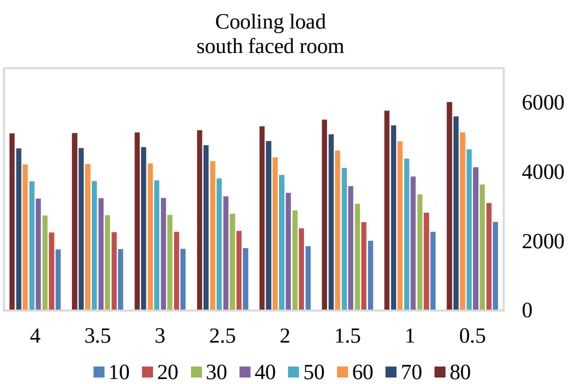

Figure 6. Measured cooling load in the room faced south with different proportions of Iwan

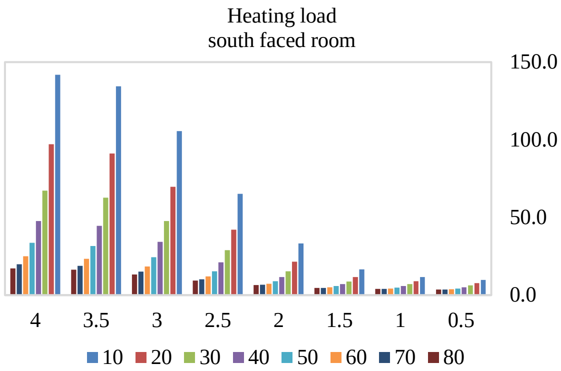

Figure 7. Measured heating load in the room faced south with different proportions of Iwan

Energy consumption in room faced south with different proportions of Iwan is shown in Table 7 and Figure 8. Energy consumption in models that faced the south is more than in models that faced the north. The minimum amount of energy usage to the model with a 2meter depth of Iwan and 10% WWR, and the highest amount belongs to the model with a 0.5meter depth and 80% WWR.

Table 7. Measured energy consumption in room faced south

Depth	Energy consumption in room faced south							
	10	20	30	40	50	60	70	80
0.5	1583	1889	2183	2463	2748	3020	3274	3507
1	1428	1733	2028	2311	2599	2874	3132	3368
1.5	1288	1585	1878	2161	2451	2729	2989	3227
2	1222	1498	1780	2058	2344	2621	2883	3122
2.5	1231	1482	1748	2014	2294	2566	2825	3063
3	1268	1499	1749	2005	2275	2542	2797	3034
3.5	1298	1520	1762	2010	2274	2536	2788	3023
4	1304	1524	1763	2010	2272	2533	2785	3020

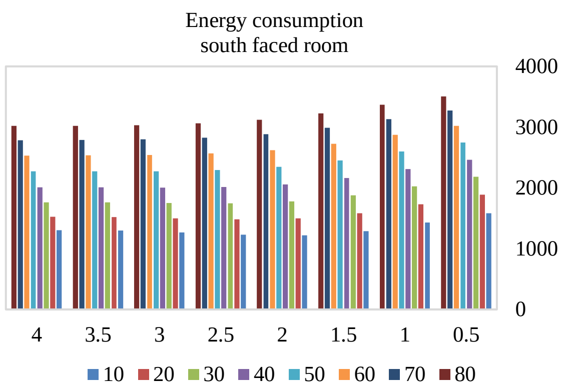

Figure 8. Measured energy consumption in the room faced south with different proportions of Iwan

CONCLUSION

The findings of this study shown that altering the proportions of Iwans in courtyard buildings with Iwans in the south or north of the yard might alter the amount of cooling load, heating load, and energy consumption. Although all the parameter above measured under effect of changing WWR (window wall ratio) in each model.

The simulation results in this research were carried out and divided by the orientation of two different rooms in the courtyard (Zemestan neshin and Tabestan neshin). According to the principles of traditional architecture and houses with a central courtyard in this area, most of the rooms on the south side of the building and facing north are used for living during the warm seasons, while the rooms on the north side of the building and facing south have been selected as living space during the winter. Results revealed that by increasing the depth of Iwan in models facing north and south, the cooling load and energy consumption decreased, and the heating load increased. By changing WWR from 10% to 80%, the cooling load and energy consumption increased, and the heating load decreased. It should be considered that although the increasing and decreasing data in the two orientation was the same, the amounts of loads and energy consumption were different.

The findings of the Iwan optimal proportion allow architects have a broad view to produce more efficient building designs. There may be more Iwan building features that may be considered as efficient criteria for cooling/heating load and energy usage.

CONFLICT OF INTEREST

There is no conflict of interest.

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Persian Abstract

چکیده

شهر یزد دارای خانه سنتی متعددیست. خانه‌هایی با حیاط مرکزی و ایوان در گذشته برای ایجاد شرایط آسایش حرارتی مناسب بودند. در این تحقیق تأثیر عمق ایوان و نسبت دهانه‌های پنجره در اتاق مجاور ایوان بر وضعیت آسایش این فضا در ساختمان‌های حیاط مرکزی و مسکونی شهر یزد مورد بررسی قرار گرفت. هدف پژوهش حاضر ارائه مدلی بهینه از ایوان برای افزایش توسعه پایدار و استفاده از مدل‌هایی مانند ایوان در مسکن معاصر در اقلیم گرم و خشک یزد است. به منظور بررسی تاثیر پارامترها، نمونه‌هایی از اتاق مجاور ایوان با بازشو رو به شمال و جنوب در مدل حیاط مرکزی با نسبت‌های مختلف ایوان و اندازه‌های مختلف پنجره در نرم‌افزار دیزاین بیلدر شبیه‌سازی شد. نتایج نشان داد که عمق ایوان و WWR پنجره اتاق مجاور به طور قابل توجهی بر راحتی (با توجه به بار سرمایشی، بار گرمایشی و مصرف انرژی) در اتاق مجاور ایوان تأثیر می‌گذارد. نتایج به‌دست‌آمده در این تحقیق دریچه جدیدی برای بازیابی مفاهیم الگوهای قدیمی و کمک به حل مشکلات اقلیمی خواهد بود.