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The Impact of External Shading Design on the Building Energy Consumption

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Abstract

In this paper, the effect of an exterior shading element (Iwan) on energy consumption in four different climatic regions, and for different geographical directions, has been investigated numerically and experimentally. By applying different materials and techniques and creating various elements and spaces, architects make hard climatic conditions more tolerable for residents. Iwan is one of the cooling elements which is used in different forms and dimensions in the Islamic architecture. In the present research, Iwan has been introduced as a climatic element in traditional and contemporary architectures and its role in reducing the energy consumption in buildings has ben studied. In this respect, first, the thermal loads of a building without Iwan are computed by means of EnergyPlus software. Then, four different forms of Iwan are added to the abovementioned structure along the four principal geographical directions, and the effect of Iwan on the reduction of thermal loads is analyzed for four different climates. Finally, the design parameters of Iwan, in terms of depth and form, that can help reduce the thermal loads in different climatic conditions are presented. The results show that the best position for using an Iwan is the south direction and the use of Iwan in temperate & humid, hot & humid, cold & mountainous and hot & dry climates could reduce the energy consumption in buildings by 32%, 26%, 14%, and 29%, respectively.

Keywords: shadings; thermal performance; Iwan; experimental; EnergyPlus

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1. Introduction

Buildings in the world require large amounts of energy for cooling and heating, while the cost of electrical energy is continuously increasing [1-5]. The amount of energy required for providing comfortable living conditions inside the buildings in a particular region depends on the weather conditions prevalent in that region [6-13].

An architectural element such as a shading device could be an important tool for reducing the energy consumption of a building, especially in hot climates. In summer, shading can protect the windows from intense solar radiation; while it allows maximum solar radiation in the wintertime. Shading devices have been used in different buildings [14-16]. There are different types of shading devices which improve the energy performance of buildings, such as external shadings [17], internal shadings [18], overhangs [19], venetian blinds [20] and canopies [21].

One of the best energy saving strategies in buildings is the use of passive solar energy in buildings [22]. Iranian traditional architecture has offered appropriate solutions for the optimal use of passive solar energy [23]. These schemes can be found in building elements like Windcatchers [24], Shovadans [25], Courtyards [26] and Domed roofs [27] as well as in spaces like cisterns [28] and ice-pits [29]; most of which have been used for cooling purposes in hot-arid regions [30]. Shading against solar rays plays a significant role in reducing the cooling loads of a building [31, 32]. The thermal performance of a building with a shading model developed for its windows was studied in [33].

The shading device selected for this study was externally fixed horizontal louvers with various slat lengths, and the research was carried out in four different Italian cities. These researchers found the proper shading device that improved the thermal performance of buildings in each of the considered cities. By varying the depth and design of horizontal shading devices, Mehrotra [34] simulated the simultaneous parameters of a building's thermal performance and luminance levels. The effects of various shading devices (internal,

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external, and overhangs) on the thermal performance of buildings in four different locations in Italy were simulated by TRNSYS software in order to obtain the best shading device for each location [35, 36]. Some studies have shown that for energy-efficient buildings, the effect of external shading on thermal improvement is greater than that of internal shading [37, 38]. The effects of vertical and horizontal shading devices on the quality of daylight in buildings and the associated energy saving were examined by Hussain et al. [39]. Yu Huang et al. [40] analyzed the thermal performance and the daylight quality provided by glazing and shading designs in office building located in dominantly cool climates. They found out that, with the increase of latitude, shading designs on the south windows perform better. The relationship between the use of exterior shading devices and the availability of natural light was investigated by Kim et al. [41]. They suggested that optimal shading systems should increase daylight levels while controlling the amount of excessive sunlight. The feasibility of using external shading for different exposures and at different latitudes was studied by El-Refaie et al. [42]. They concluded that shading devices are required for saving energy and reducing the cooling load of buildings. An experimental investigation of energy distribution and energy efficiency, with regards to the effect of shading on each zone of a solar pond, was presented by Karakilcik et al. [43]. The effects of adjacent shading on the thermal performance of residential buildings in a subtropical region were investigated by Chan [44]. The results showed that the use of shading could practically reduce the cooling load of a building by up to 18.3%.

The impacts of variable exterior climatic conditions and different glazing and shading schemes on indoor thermal comfort level and on the heating demand of spaces exposed to solar radiation were studied by Tzempelikos et al. [45]. They found that facades with insulating and low-transmittance glass create more comfortable and stable conditions. Also, using different types of shading devices, they studied experimentally the indoor thermal environment near a full-scale glass facade under varying climatic conditions in winter [46]. The most significant reason for using a shading device is to prevent the penetration of direct

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sunlight into a building during the cool seasons, while allowing the wanted solar radiation gains during the hot seasons [47].

Iwan is a type of external shading device for improving the energy performance of buildings. It has been considered as one of the main shading elements and passive cooling devices in the Middle Eastern and North African architectures. [48]. Its difference from overhangs and balconies is that the thermal effect of Iwan often covers the whole surfaces of walls and openings.

In this research, Iwan is explored as a semi-open space in architecture, and its structural characteristics and specially its various types are investigated for different climatic conditions. Unlike most shading devices for buildings, which are usually used in one direction only (vertically, horizontally, or obliquely), Iwan, as an external shading element, is an integration of vertical and horizontal shading devices. Moreover, contrary to previous studies on the thermal performance of shading devices, which focus more on solar gains through exterior openings, Iwan, in addition to providing shading for exterior openings, can also reduce the absorption of solar radiation through building walls. Although a review of the literature published on the energy performance of buildings indicates the use of several different shading mechanisms to improve the thermal efficiency of buildings, the effect of Iwan on energy efficiency has not been investigated yet.

Therefore, in this paper, the performance of Iwan in terms of cooling and heating improvements and its effect on the comfort and convenience of building residents are analyzed through experiment and simulation. The effects of different geographic directions and various models and dimensions of Iwan are investigated and analyzed for four different climates. Using an Iwan with the right depth and at proper geographical direction could be very effective in reducing the energy consumption of buildings. So, the optimal depth and geometrical form of Iwan as well as its best geographical direction that can improve the energy performance are explored in this research. The results of this study can be used by contemporary architects to estimate the energy efficiency of traditional buildings.

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2. Traditional shading elements (Iwan)

In traditional architecture, shading elements reduce the incident solar rays into buildings. Iwan is one of these traditional shading elements which play an important role in buildings. In a traditional house, Iwan integrates and connects the other spaces of the building. [49]. In terms of form, dimension, and installed location, Iwans have various functions. Many spaces could be located around an Iwan . In many houses remaining from the Safavid and Qajar periods, Iwans are used as the main elements in one or more views (Fig. 1).

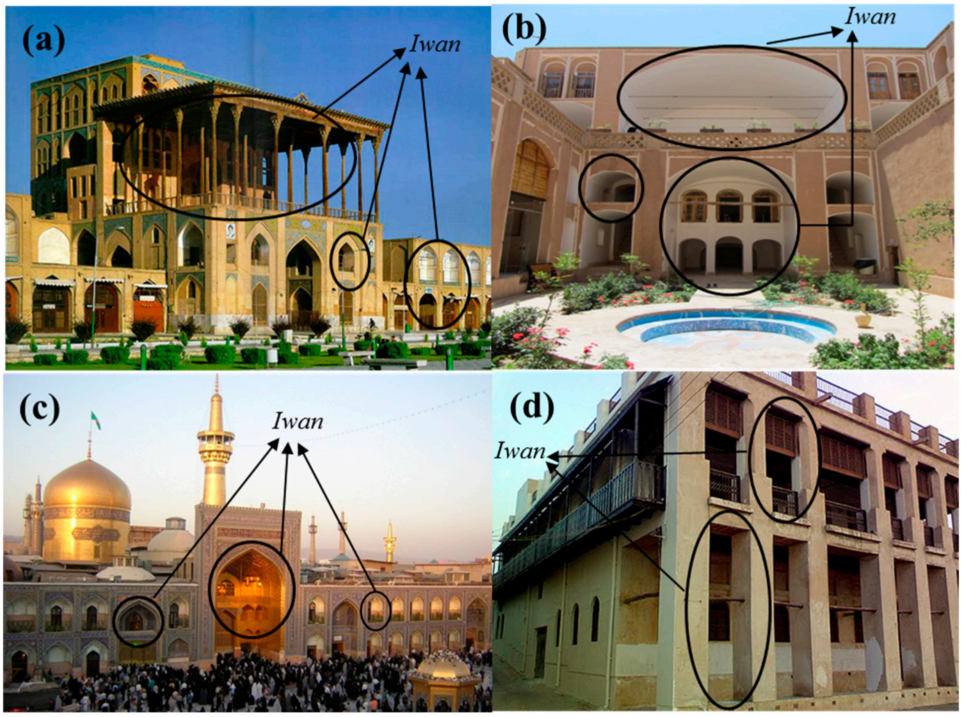

Fig. 1. Different forms of Iwan. (a) Ali Qapu palace (Isfahan); (b) Ooomiha House (Yazd); (c) Imam Reza Shrine (Mashhad); (d) Amiriye Mansion (Bushehr)

Iwans are valuable elements in terms of size, form, and even decorations. Northern Iwans are cold at hot weathers and create a flow of cold breeze under them toward interior spaces.

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Southern Iwans (facing the sun) are used in both the hot and the cold seasons of the year. With respect to skewed sunlight, southern Iwans reduce the penetration of solar rays into interior spaces [47, 50]. In terms of climatic conditions, Iwans are divided into four categories (Table 1). The characteristics of the four different climatic regions have been listed in Table 2.

Table 1. Comparing Iwan application at different climates

Climate	Climatic explanation of Iwan	Iwan figure
Cold and Mountainous climate	Shading during summer & increasing house beauty preventing direct sunlight into rooms at summer and preventing rainfall and snow at winter.	
Hot and Dry climate	Because of special climatic conditions, semi-open spaces are common in these climates and used half of the year protect spaces from sunlight and create air flow simultaneously.	
Temperate and Humid climate	several steps inserted which commonly are at the corner of the Iwan, preventing rain entering the residential space creating two-way airflow & increasing welfare temperature	

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Hot and Humid climate	For more use of sea breezes and support natural ventilation, as temporary seasonal living space particularly in night preventing direct sunlight into space at summer.	

Table 2. Classification of climates of four different regions

Site: Location	Yazd - IRN	Bandar Abass - IRN	Tabriz - IRN	Sari - IRN
Latitude	{N 31° 52'}	{N 27° 7'}	{N 38° 2'}	{N 36° 33'}
Longitude	{E 54° 16'}	{E 56° 13'}	{E 46° 10'}	{E 53° 0'}
Elevation (m) above sea level	1237	10	1361	23
Standard Pressure at Elevation	87321 Pa	101207 Pa	86008 Pa	101600 pa
WMO Station	408210	408750	407060	407590
Maximum Dry Bulb Temperature (ºC)	42.3	43.6	37.0	32.5
Maximum Dry Bulb Occurs on	Aug 16	May 30	Jul 14	Jul 19
Minimum Dry Bulb Temperature (ºC)	-7.0	5.7	-15.0	3.2
Minimum Dry Bulb Occurs on	Jan 3	Dec 29	Jan 25	Feb12
Maximum Dew Point Temperature (ºC)	15.0	30.6	18.6	18.5

Minimum Dew Point Temperature (ºC)	-17.0	-17.0	-25.0	-20.0
Köppen Classification	BWh	BSh	BSk	Csa
ASHRAE Climate Zone	2B	1A	4B	4A
ASHRAE Description	Hot-Dry	Very Hot-Humid	Mixed-Dry	Mixed-Humid

3. Material and building details

Iwans have been used in every climatic region of the Middle East; although the form, depth, and the placement direction of Iwans vary from place to place. Iwan forms depend on building plans. Usually, Iwans are enclosed from one, two or three sides. To measure the thermal efficiency of an Iwan, a 4×4 m room with 3 m height was considered (Fig. 2 and Table. 3). The components of the whole room, except a wall with a window opening, was assumed to be adiabatic. A window opening of 2×1 m dimensions was placed at a height of 1 m from the room floor. The specifications of wall materials have been given in Tables 3, 4 and 5.

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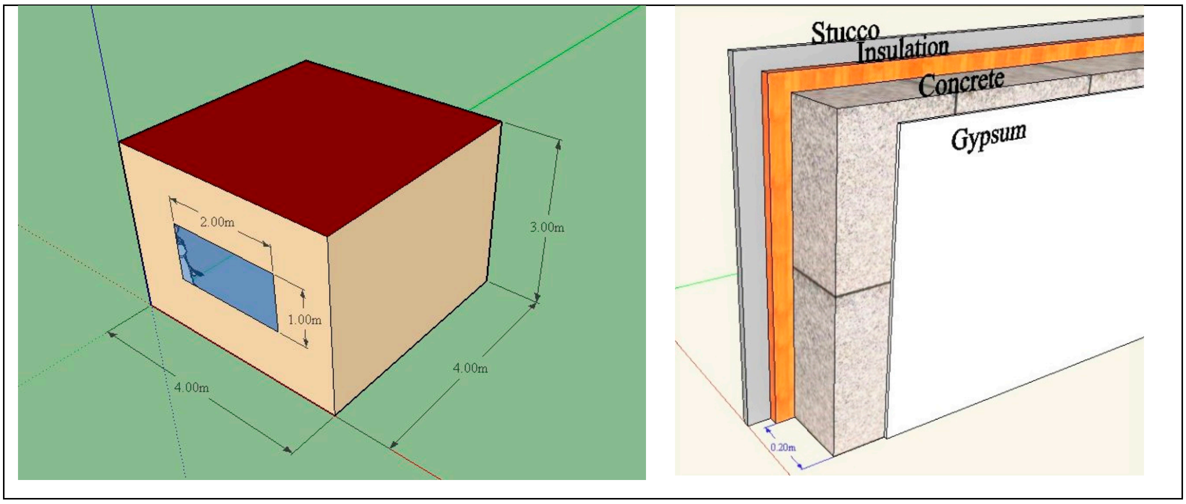

Fig. 2. The building geometry and materials

Table 3. The basic information for building geometry

Parameter	Building Model
Total building floor area [m^2]	16 m^2 (4m ×4m)
Window area (% floor area)	12.5% (% floor area)
Window area (window to wall ratio)	16.6
Window size	2 m × 1 m
Occupancy density: zone floor area per person [m^2/person]	0.06
Activity	Light manual work
Metabolic rate per person(W/Person)	180
Clothing(clo)	0.75
Infiltration rate (ach)	0.6
Fresh Air (I/S-person)	10
Illuminance set-point [lx]	200

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Table 4. The thermal characteristics of wall

Wall	Construction	Reflectance	U-Factor with Film [W/m2-K]	U-Factor no Film [W/m2-K]	Gross Area [m^2]	Thickness {m}
Iwan connected walls	Layer 1: 2.4cm Stucco, Outside Layer 2: 3cm Wall Insulation 40, Layer 3: 20cm Concrete H, Layer 4: 1cm Gypsum, Indoor	0.08	0.450	0.483	12.00	0.264

Table 5. The thermal characteristics of window

Window	Construction	Properties	Thickness {m}	Solar Transmittance at Normal Incidence	Front Side Solar Reflectance at Normal Incidence	Conductivity {W/m-K}
Iwan connected windows	Clear .3cm, Outside Layer Air .6cm, Layer 2 Clear .3cm, Layer 3	U=3.122 SHGC=0.762 TSOL=0.705 TVIS=0.812	0.012	0.63	0.22	0.9

4. Governing equations and the solution method

This study has been performed by using the EnergyPlus (v. 8) software [51], developed by the U.S. department of energy; which simulates the whole energy utilization of a building. Fig. 3 shows the energy balance between the exterior and interior of a building wall.

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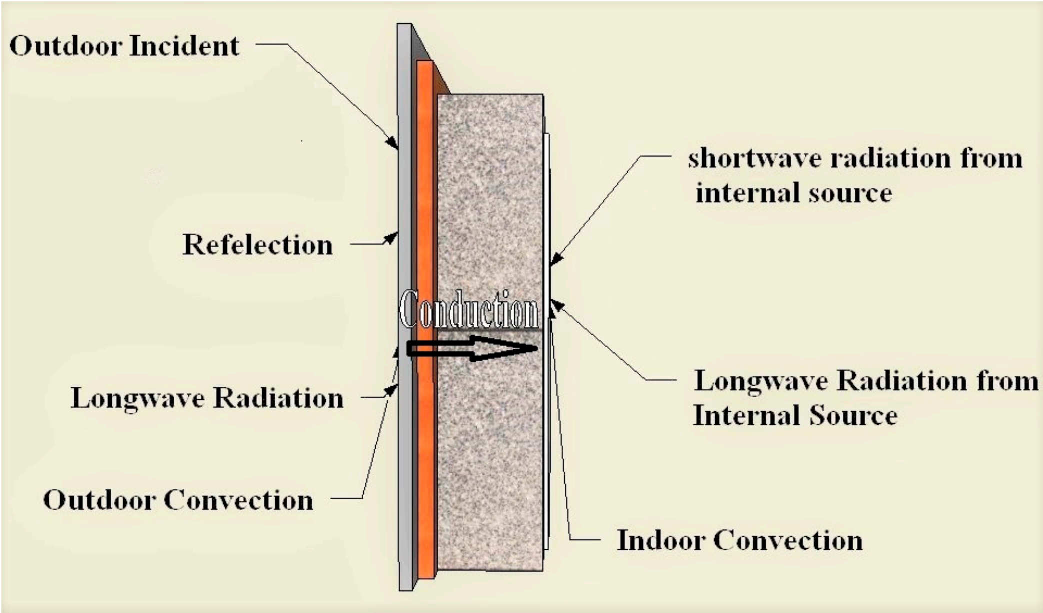

Fig 3. Inside and outside the energy balance control volume

The energy balance equations for zone air and surface heat transfer are two essential equations that an energy program should solve. The energy balance equation for room air is written as:

$$\sum_{i=1}^{N} q_{i,c} A_i + Q_{other} - Q_{extraction} = 0 \quad (1)$$

where $\sum_{i=1}^{N} q_{i,c} A_i$ is convective heat transfer from enclosure surfaces to room air, $q_{i,c}$ is convective flux from surface i, N is the number of enclosure surfaces, A_i is the area of surface i, Q_{other} is the heat gains from lights, people, appliances, infiltration, etc., and $Q_{extraction}$ is the heat extraction rate of the room. The heat extraction rate is the same as the cooling/heating load when the room air temperature is kept constant ($\Delta T = 0$). The convective heat fluxes are determined from the energy balance equations for the corresponding surfaces, as shown in

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Figure 2. A similar energy balance is performed for each window. The surface energy balance equation can be written as:

$$q''_{i} + q''_{ir} = \sum_{k=1}^{N} q''_{ik} + q''_{i,c} \qquad (2)$$

where q''_i is the conductive heat flux from surface i and q''_{ir} is the radiative heat flux from internal heat sources and solar radiation. The radiative heat flux is:

$$q''_{ik} = h_{ik,r}(T_i - T_k) \qquad (3)$$

Where $h_{ik.r}$ is the coefficient of linearized radiative heat transfer between surfaces i and k, T_i is the temperature of interior surface i and T_k is the temperature of interior surface k.

$$q''_{i,c} = h_c(T_i - T_{room}) \qquad (4)$$

h_c is the convective heat transfer coefficient and T_{room} is the room air temperature. The heat balance on the outside face is:

$$q''_{sol} + q''_{LWR} + q''_{conv} = q''_{cond} \qquad (5)$$

$q''_{\alpha sol}$ is the absorbed direct/diffuse solar radiation (short wavelength) heat flux and it is calculated using the procedures presented elsewhere for both the direct and diffuse incident solar radiation absorbed by a surface. The amount of solar radiation absorbed by a surface is influenced by location, surface tilt angle, use of shading surfaces, surface material properties, weather conditions, etc. A baffle blocks all shortwave radiation from reaching an underlying surface. q''_{LWR} is the net long wavelength (thermal) radiation heat flux exchanged with the surrounding air, q''_{conv} is the convective heat flux exchanged with the outside air and q''_{cond} is the conducted heat flux (q/A) into the wall. Consider an enclosure consisting of the exterior

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surfaces of a building, the ground surface under the building, and the sky. The total long wave radiative heat flux is the sum of components due to radiation exchange with the ground, sky, and air.

$$q''_{LWR} = q''_{ground} + q''_{sky} + q''_{air} \tag{6}$$

Applying the Stefan-Boltzmann Law to each component yields:

$$q''_{LWR} = h_{r,ground}(T_{ground} - T_{surf}) + h_{r,sky}(T_{sky} - T_{surf}) + h_{r,air}(T_{air} - T_{surf}) \tag{8}$$

Where

$$h_{r,ground} = \frac{\varepsilon\sigma F_{ground}(T_{surf}^4 - T_{ground}^4)}{T_{surf} - T_{ground}} \tag{9}$$

$$h_{r,sky} = \frac{\varepsilon\sigma F_{sky}\beta(T_{surf}^4 - T_{sky}^4)}{T_{surf} - T_{sky}} \tag{10}$$

$$h_{r,air} = \frac{\varepsilon\sigma F_{sky}(1-\beta)(T_{surf}^4 - T_{air}^4)}{T_{surf} - T_{air}} \tag{11}$$

The longwave view factors to ground and sky are calculated with the following expressions[46]:

$$F_{ground} = 0.5(1 - \cos\phi) \tag{12}$$

$$F_{sky} = 0.5(1 + \cos\phi) \tag{13}$$

$$\beta = \sqrt{0.5(1 + \cos\phi)} \tag{14}$$

Also, outside heat transfer from surface convection is modeled using the classical formulation:

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$$Q_{conv} = h_{c,ext} A(T_{surf} - T_{air}) \tag{15}$$

Q_{conv} is a rate of exterior convective heat transfer, $h_{c,ext}$ is an exterior convection coefficient, A is a surface area , T_{surf} Surface temperature and T_{air} is an outdoor air temperature. These equations are solved by Finite Difference methods.

5. Result and discussions

The results obtained in this paper are based on computer simulations and experimental measurements. An experimental building with specifications given in Fig.1 and Table 1 was used to validate the computer model in hot and dry climate. Instruments such as thermometer and Hygrometer were employed in experimental testing (Fig. 4). The accuracy and adequacy of the simulation method is confirmed by achieving an error of about 6-7% between the experimental and simulation results. For validation purposes, the temperatures and light intensities at several different points are compared in Table 6. The precisions of the measuring instruments used in the experiments (thermometer, moisture meter, lux meter and speedometer) are ± 0.5 °C, 3%, 0.05 m/s, and 0.01 lux meters, respectively.

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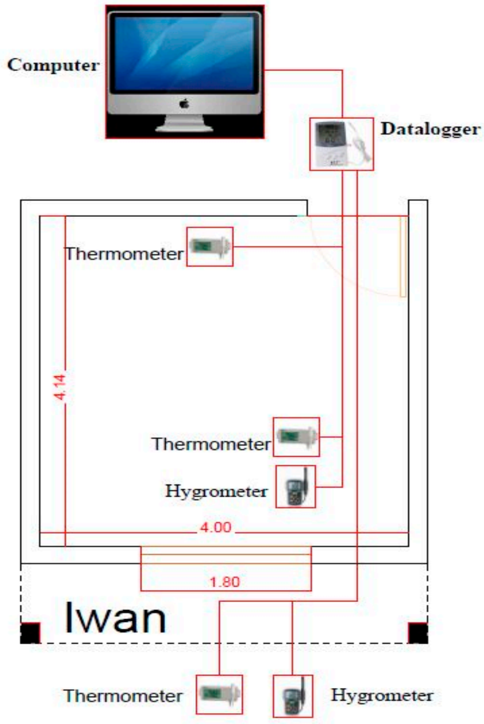

Fig. 4. Schematic of experimental testing

Table 6. The comparison of the experimental results and simulation model

Climate	Minimum Temperature (°C)		Maximum Temperature (°C)		Light Meter (Lux)	
	Experimental	Numerical	Experimental	Numerical	Experimental	Numerical
Hot and dry	- 6.6	-7	41.5	42.3	2050	2192
	- 3.1	-2.8	38	37.1	1378	1450

5.1. Simulation results

In the present study, the effect of Iwan on energy consumption rate in a building has been investigated and the general guidelines for the design of Iwan for different climates have been obtained. An ideal air load has been defined for the considered building in order to calculate the cooling and heating loads. The thermal zones are controlled by means of a thermostat,

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with its low and high temperatures being +18 ºC and +24 ºC, respectively. Based on this, the software program analyzes the cooling and heating loads of the building. At first, the abovementioned building is simulated without an Iwan, for the four major climates mentioned. For this purpose, the weather information of the following four regions is used: hot & dry climate (City of Yazd), hot & humid climate (City of Bandar Abbas), temperate & humid climate (City of Sari), and cold & mountainous climate (City of Tabriz).

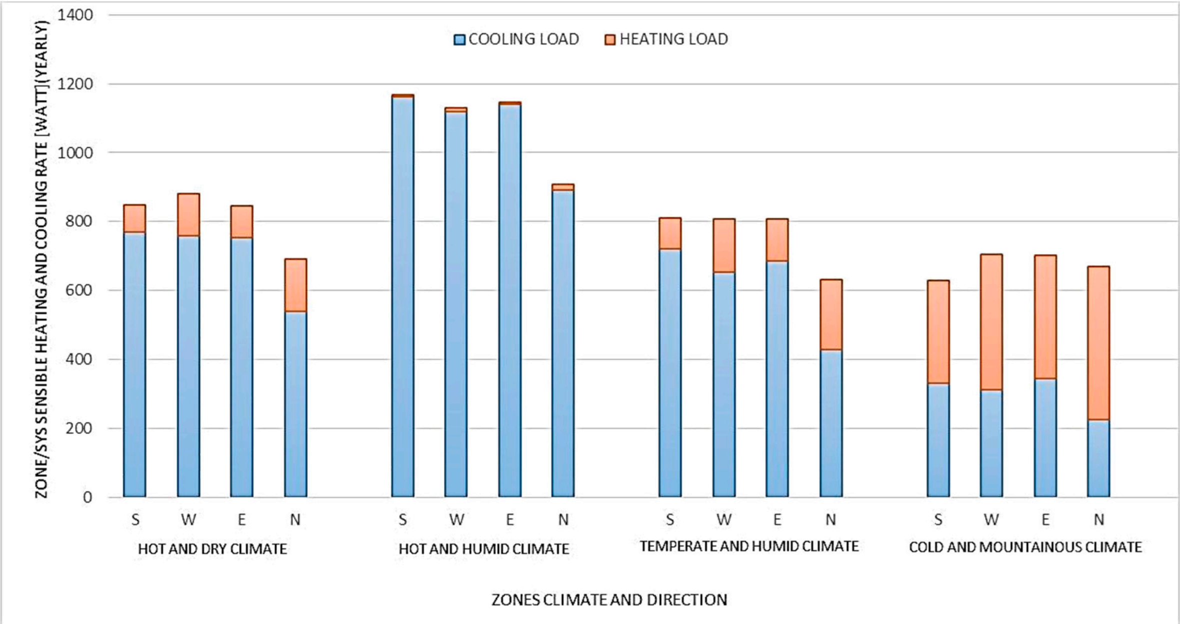

Fig. 5. Thermal load of zones without Iwan (in 4 major directions and 4 major climates)

In the Figure 5, the examined building has its maximum thermal load in the hot & humid climate, followed by the hot & dry, temperate & humid, and cold & mountainous climates. In addition, the maximum cooling load is obtained in the hot & humid climate, followed by the hot & dry, and temperate & humid climates. The maximum and the minimum heating loads are obtained in the cold & mountainous and hot & humid climates, respectively. The maximum and the minimum heating loads are required on the north side and south side,

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respectively. On the other hand, as Fig. 5 shows, the cooling load is several time higher than the heating load in three climates, except the cold & mountainous climate, in which the heating loads of buildings are slightly higher than the cooling loads. For example, the cooling load is 100 times the heating load in a hot & humid climate. Therefore, it is essential to reduce the cooling loads of buildings. One solution for reducing a building's cooling load is to construct an Iwan over the warm side of the building, and to use various Iwan forms and dimensions based on a particular climate. Commonly, the height of an Iwan equals the height of a building roof and it has a depth of 1-2 meters. Also, in terms of form, Iwans are usually enclosed from one, two or three sides. So, in order to study the effect of Iwan on the cooling load, an Iwan was added to the considered building over each of its four sides. First, an Iwan in the form of an overhang was added in each of the four directions of building. In the next step, in each of the four directions, a side fan, as wide as Iwan depth, was added to the right side of Iwan. Then, the location of the fan was changed from the right to the left side. At the final step, two fans were added together from the right and left sides of Iwan in each of the four existing directions (Table 7).

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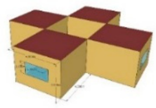
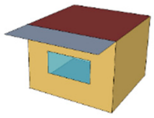
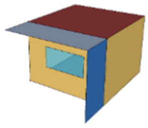
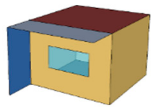
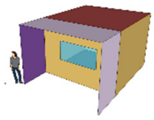
Table 7. Steps of Iwan forms placement

Steps	Explanations	Figures
0	Building placed in four geographic directions with rooms of 4*4 dimensions, three meters height and openings of 1*2 in four climates	
1	An overhang with 1.5 meter depths added to the top of openings to all zones	
2	Overhang placed at the top section and a side fan with 1.5 meter depth added to the right side of opening	
3	Overhang placed at the top section and a side fan with 1.5 meter depth added to the left side of opening	
4	All above-mentioned steps used synthetically and then, with 1.5 meter depth designing plan continues	

The numerical simulations investigated a different Iwan mode for each of the four directions. The simulations were performed for four different climatic regions, and the heating and cooling loads of the building were calculated. Also, the effects of geographical directions on the energy optimization achieved by all Iwan forms were investigated. First, the building was modeled with no Iwan installed in any of the four geographical directions, and then the simulations were performed for four forms of Iwan. Six different Iwan depths were studied. So in total, 120 different cases have been simulated. The building and all the

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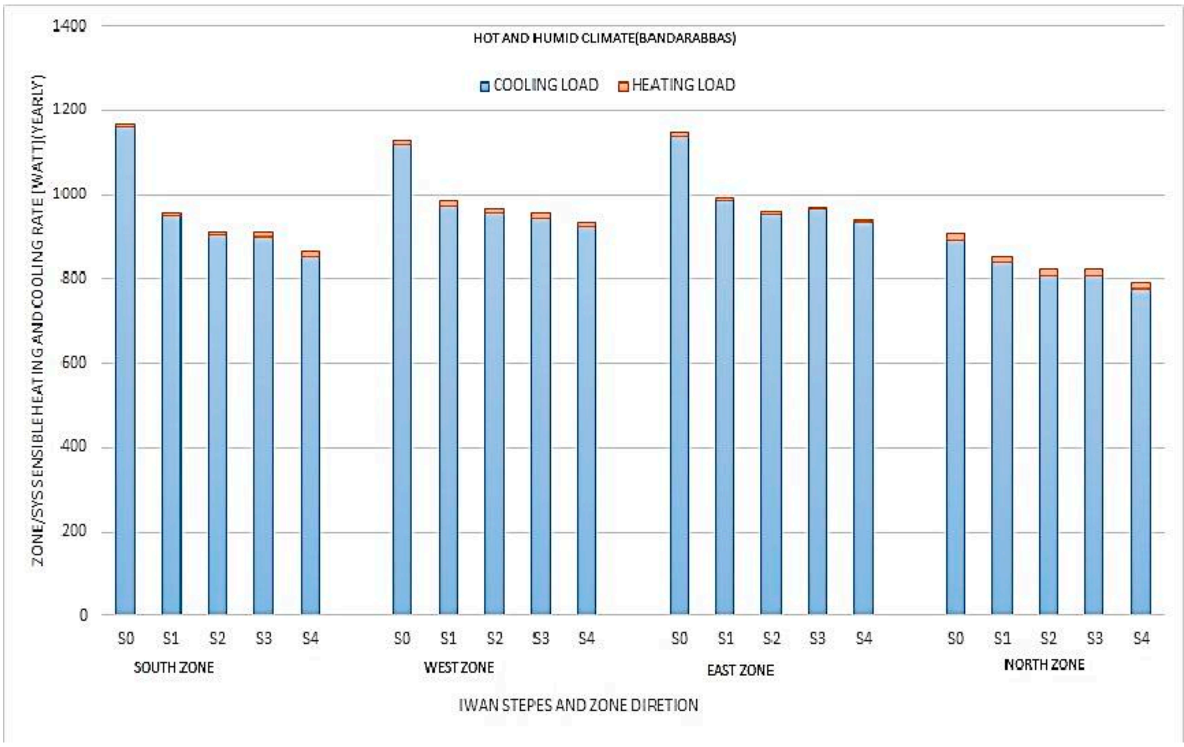
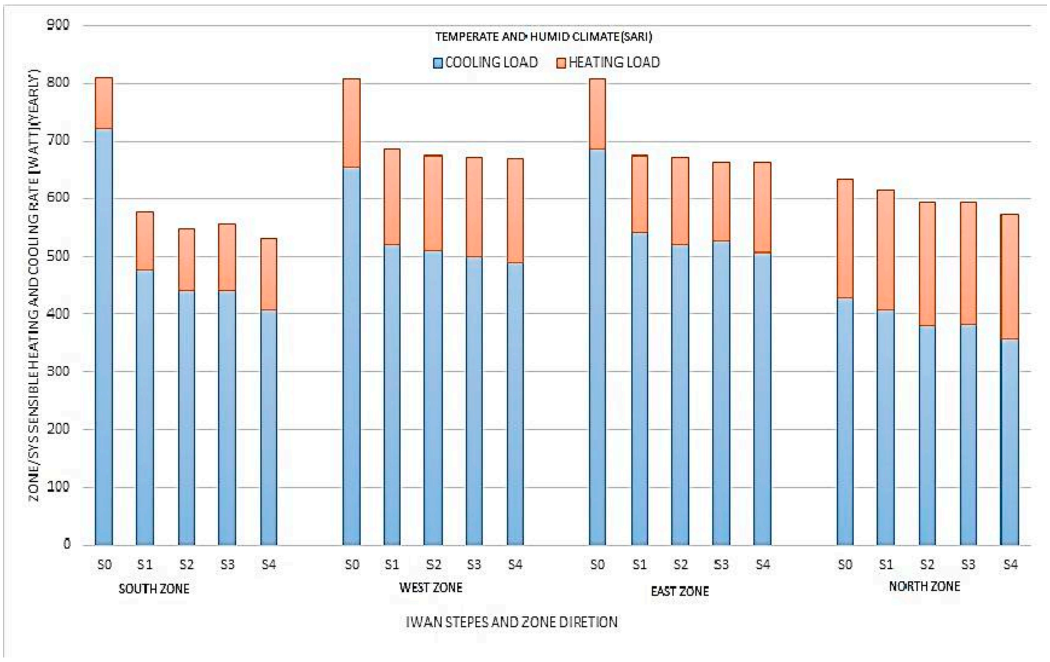
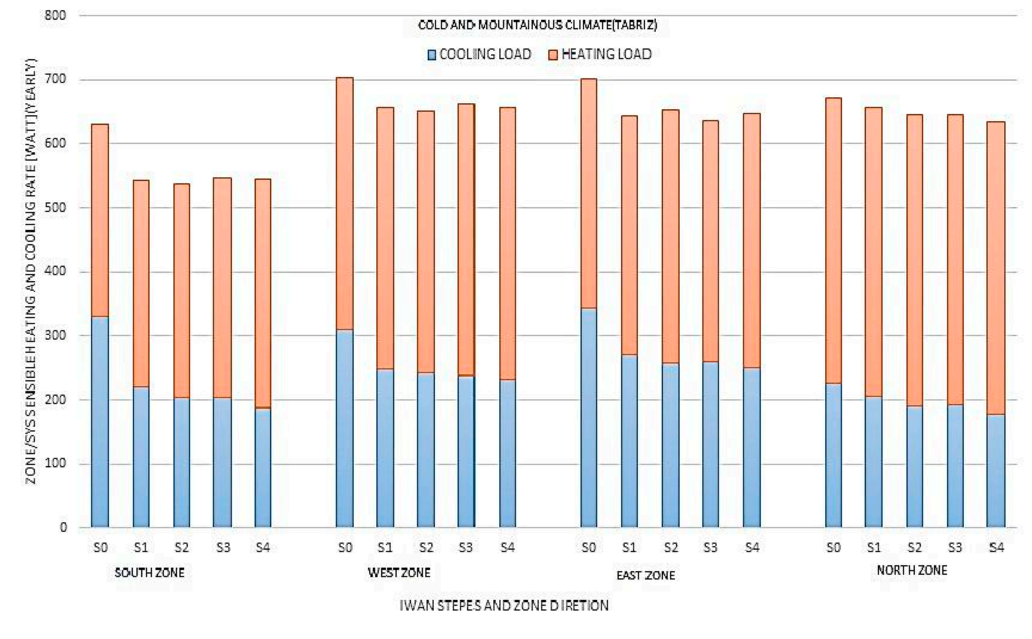
above cases of Iwan have been modeled for four different climates, and the results for the cooling and heating loads of the building have been illustrated in the following diagrams (Fig. 6 and Table 8).



(a)


TEMPERATE AND HUMID CLIMATE(SARI)
COOLING LOAD
HEATING LOAD
ZONE/SYS SENSIBLE HEATING AND COOLING RATE [WATT](YEARLY)
900
800
700
600
500
400
300
200
100
0
S0
S1
S2
S3
S4
SOUTH ZONE
WEST ZONE
EAST ZONE
NORTH ZONE
IWAN STEPES AND ZONE DIRETION

(b)


COLD AND MOUNTAINOUS CLIMATE(TABRIZ)
COOLING LOAD
HEATING LOAD
ZONE/SYS SENSIBLE HEATING AND COOLING RATE [WATT](YEARLY)
800
700
600
500
400
300
200
100
0
S0
S1
S2
S3
S4
SOUTH ZONE
WEST ZONE
EAST ZONE
NORTH ZONE
IWAN STEPES AND ZONE DIRETION

(c)

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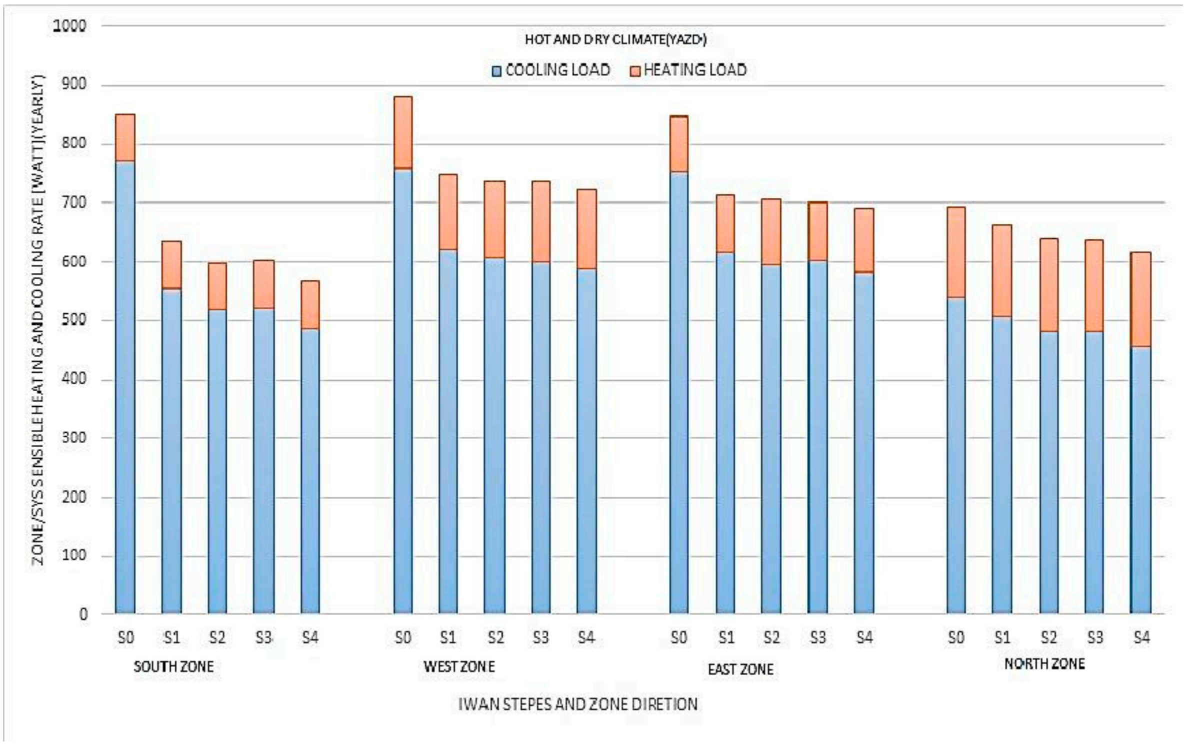

(d)

Fig.6. Thermal loads of Iwan's various steps form in major climates (a) Hot and Humid (Bandar Abbas); (b) Temperate and Humid (Sari); (c) Cold and Mountainous (Tabriz); (d) Hot and Dry (Yazd)

Table 3. Thermal load analysis after Iwan insertion

Climate	Temperate & humid				Hot & humid				Cold & mountainous				Hot & dry			
Zones Direction	N	E	W	S	N	E	W	S	N	E	W	S	N	E	W	S
Max decrease rate of cooling load				*				*				*				*
Min decrease rate of cooling load	*				*				*				*			
Max increase rate of heating load				*				*				*				*
Min increase rate of heating load	*				*				*				*			
Difference between max cooling and heating(W)	470				1125				114				611			

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Regarding the above diagram (Table 8, Fig. 6), we can see that after applying an Iwan, the heating loads increase and the cooling loads diminish. Therefore, it can be said that in this case an Iwan acts as a cooler for the building and, consequently, it decreases the cooling load and increases the heating load in all climatic conditions. Another point is that for all climates, the maximum reduction of cooling load occurs on the south side of the building, and that Iwan Form S4 is the best form among all Iwan forms, because the reduction of building's thermal load is achieved by using this form. The results did not change much by using Iwan Forms S2 and S3, and the maximum change in the results occurred by using Iwan Form S1. Therefore, we can say that the key element in the design of an Iwan is its roof, because it can result in a tangible reduction of temperature. An ideal direction in which an Iwan can be used is the front that provides a maximum rate of thermal load (cooling and heating) before using an Iwan and a max rate of thermal load reduction after applying an Iwan. According to diagrams and calculations, the south side of a building is the ideal front to use an Iwan in all climates.

5.2. Studying the southern zone

Now that we know the south side is the ideal front for installing an Iwan in all climates, we try to find the best Iwan depth that can reduce the thermal load.

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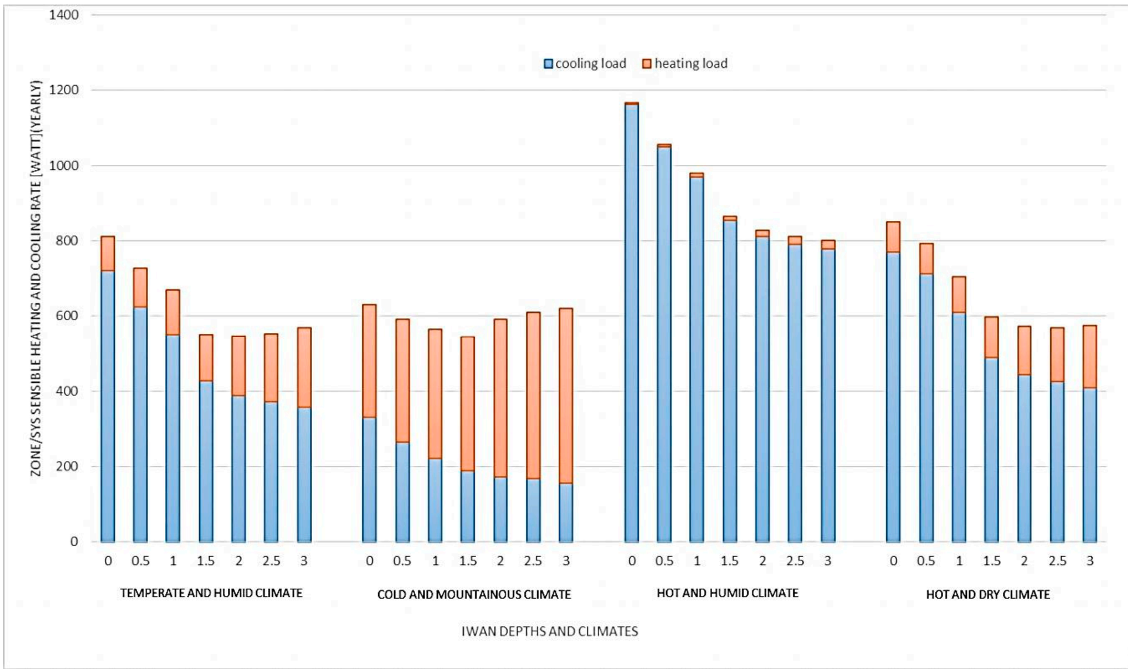

Fig. 6. Thermal loads of southern zone based on the Iwan depth

In a cooling load analysis (Fig. 7), an Iwan with a depth of 1.5 m achieves tangible and gradual reduction in the cooling load; however, above the depth of 1.5 m, the differences in the results are negligible. Therefore, the best way of reducing the cooling load is to use Iwans with a depth of 1.5 m. In this respect, the minimum and the maximum cooling load reduction is achieved in the cities of Tabriz and Bandar Abbas, respectively. However, by increasing the Iwan depth, and thus increasing the shading, the heating load increases in all climates. As for the thermal load of a building, we can say that in temperate & humid and in dry & hot climates, the lowest thermal load is achieved by Iwans of 1.5 m depth, and that in cold & mountainous regions, the thermal load is reduced slightly by using Iwans with 0-1.5 m depth, and it is increased by using Iwans of larger depths. In hot & humid climates, the lowest thermal load is achieved by Iwans with a depth of 3 m; but there is no significant difference between the thermal loads when using Iwans with a depths of 1.5-3 m. Also, a gradual increase in thermal load is observed when using Iwans with a depth of less than 1.5 m.

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Generally, we can say that the best depth for Iwans, in all climates, is 1.5 m. Table 9 shows the thermal performances of various Iwans with respect to their depth.

Table 4. General analysis of thermal performance in different depth of Iwan in buildings

Climates	Iwan depth (southern)					
	0.5 m	1 m	1.5 m	2 m	2.5 m	3 m
Hot and dry climate	☑	☑☑	☑☑	☐	☒	☒
Hot and humid climate	☑☑	☑☑	☑☑	☑	☐	☐
Temperate and humid climate	☑☑	☑☑	☑☑	☒	☒	☒
Cold and mountainous climate	☑	☑	☑☑	☒	☒	☒

☑☑ = Excellent
☑ = Good
☐ = Medium
☒ = Weak

6. Conclusion

In this paper, the effects of Iwan, as an exterior shading element, on the reduction of energy utilization in a building and on the thermal comfort level of the building's residents were evaluated by modeling various forms of Iwan for different climates and different geographical directions. The obtained results indicate that the most important element in the

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design of Iwan is the overhang. By using overhangs, the annual thermal load of a building in hot & humid, cold & mountainous, temperate & humid, and dry & hot climates is reduced by 18, 14, 28 and 24%, respectively. A maximum reduction of thermal and cooling loads is achieved by applying an Iwan over the south side of a building. Therefore, the ideal geographical direction for using an Iwan is the south front, and the best climate is the hot & humid climate, followed by temperate & humid, hot & dry, and finally cold & mountainous climates. Experimental and numerical results show that, from the perspective of energy efficiency and the reduction of a building's thermal load, using Iwans (especially with depths larger than 1 m) in a cold & mountainous climate is not economical. The best depth for Iwans on the south side is 1.5 m; and by using a 1.5 m deep Iwan in the south direction, a thermal load reduction of 32, 26, 29 and 14% is generally achieved in temperate & humid, hot & humid, dry & hot and cold & mountainous climates, respectively. The conclusions of this research paper are summarized as follows:

1. The best possible geographical position for using an Iwan is the south direction.
2. The most optimal Iwan depth is 1.5 m.
3. The best Iwan form is S1.
4. By using an Iwan in the south direction, the energy consumption of buildings in temperate & humid, hot & humid, dry & hot, and cold & mountainous climatic regions is reduced by 32, 26, 29 and 14%, respectively.

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