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Investigating on Evolution of Windows from Qajar to Pahlavi Era in Tabriz's Ganjei-Zade House with Heat Dissipation Approach

S. Abdoli Naser[1], F. Haghparast[2]*, M. Singery[3], H. Sattari Sarbangholi[3]

[1] *Department of Architecture, Tabriz Branch, Islamic Azad University, Tabriz, Iran*
[2] *Faculty of Architecture and Urbanism, Tabriz Islamic Art University, Tabriz, Iran*
[3] *Department of Architecture and Urbanism, Tabriz Branch, Islamic Azad University, Tabriz, Iran*

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A B S T R A C T

Iranian vernacular architecture has rich experiences in terms of coordinating with its surroundings. although, high energy consumption was one of the major concerns in the past decades. According to statistics presented by Iranian Statistics Center, 40% of the country's energy consumption is relevant to the construction industry. However, about 70% of consumption is used solely for space heating and cooling. In the meantime, windows have a significant influence on the thermal performance. Ganjei-Zade House in Tabriz is one of the monuments and includes two parts. The north side of Qajar era and the western side was added to the former building in Pahlavi era. The present article deals with the study of the evolution of windows from Qajar to Pahlavi in Ganjei-zade house and the amount of heat dissipation from windows. These evaluations has been carried out by simulating Ganjei-zade house in the DesignBuilder software. The research related to this article was conducted based on analytic and comparative method and the purpose is to provide the important criteria for windows in residential buildings in the cold climate of Tabriz considering native architecture solutions in order to reduce heat dissipation. The conducted calculations confirm that the amount of heat losses from windows from Qajar to Pahlavi era, has been reduced by 22.2% and the amount of heat dissipation per square meter of windows from Qajar period to Pahlavi was decreased by 58.33%.

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NOMENCLATURE

WWR	Window-to-wall-ratio	SHGC	Solar heat gain coefficient
HVAC	Heating-ventilation-air conditioning	Tv	Visible transmittance

INTRODUCTION

Residential energy consumption shows more than a quarter of the total energy usage in most countries and plays a considerable role in discounting global climate change [1]. Residential buildings consume about 40% of the world's energy and windows in the buildings are responsible for heat dissipation because glazing of windows are poor insulators [2]. A significant relationship can be found between these crises and the widespread use of fossil fuels on one hand, and the disregard for indigenous architecture and passive solutions to create a state of thermal comfort in the buildings, on the other hand. Accordingly, studying the solutions used and examining the evolution of windows can be an approach to overcome these crises. Quantitative researches have been conducted on the evolution of the design and implementation of translucent walls (windows) from Qajar to Pahlavi periods in the cold and mountainous climate of Tabriz, which is presented in

*Corresponding Author Email: *f.haghparast@tabriziau.ac.ir* (F. Haghparast)

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terms of historical sequence. Chou et al. [3] assessed on double skin facades. They have concluded the window-to-wall-ratio (WWR) of 0.3 in the buildings heat transfer will be reduced by 45%.

Eiraji and Akbari-Namdar [4] concentrated on traditional architecture in Iran. They showed that the purpose of sustainable design in traditional homes built in cold areas is to take advantages of sunlight and natural heat.

Ramli [5] studied on traditional houses. Their outcomes represented that: the perfect fenestration design with hollow wood curving will let more natural ventilation flow to internal spaces. Soleymanpour et al. [6] investigated on Iranian vernacular and contemporary houses. They have come to the conclusion that in traditional houses in cold and dry climates, most openings are designed on the south side of the building.

Saljoughinejad and Rashidi Sharifabad [7] studied on vernacular residences in Iran. Their findings indicate that in Iranian native houses, the openings are designed to direct sunlight into the interior in winter.

Biabani MoghadamBaboli et al. [8] centralized on courtyard of traditional houses. Their outcomes represented that because of deficiency of energy resources, vernacular architecture provides an important source of architectural knowledge in respond to climate and culture without reliance on energy-guzzling active systems. Vahdattalab and Nikmaram [9] concentrated on stained glass windows of Qajar traditional houses of Tabriz. Their results showed that the placement of colors on the light transient surfaces is not accidental and has a mysterious order; an order that creates a kind of universal beauty on the way the colored glass is arranged in the sash.

Soflaei et al. [10] studied on traditional courtyards in Iran. As conclusion, some socio-environmental design principles were extracted, which can be thought-out in designing of contemporary sustainable residential buildings in Iran. These design patterns, can be generalized to all cases with similar climatic conditions, in order to reduce energy consumption as well as enhancing social values as mentioned.

Hasan et al. [11] focused on building simulation. They came to the conclusion that WWR shoud be determined based on to its floor area. Tayari and Burman [12] investigated on electrical energy consumption analysis of a building. Their outcomes indicated that windows with single glazed-glazing have more heat losses.

Ghasemi et al. [13] assessed the rules of settlements. Results prove that it is feasible to find ways to make the environment to be responsive to the current needs while it keeps its continuity with the historical manufacture.

Yaran et al. [14] studied on historical homes of Tabriz and in the case of windows, they refer to the following points: The physical concept of protrusion by placing openings in the wall and all different elements of protrusion create architecture. This is a variety of quality proximal elements. Other visuals such as composition, order, complexity, proportion, etc. are connected to the outer wall.

Mirshojaeian Hosseini et al. [15] stated their opinion about old buildings and houses in different climates of Iran would not be recognized regardless of adaptation with their environmental context; but now utilizing these buildings are dependent on energies that are limited and have conditional applications.

Tahsildoost and Zomorodian [16] investigated on housing in different climates. Results indicate low energy reduction due to increase in the WWR in Tabriz.

Therefore, the purpose of this study is to provide the design criteria and implementation of windows in residential buildings in cold and mountainous climate of Tabriz, considering the evolution of design and implementation of windows in Qajar and Pahlavi periods, to decrease heat losses. Accordingly, The main contribution of this study is focused on the amount of heat losses from windows in different sides of Ganjei-Zade house, which was built in different historical periods.

The rest of the paper is organized as follows. After current introduction and dataset gathering; we are concerned with research methodology. The next section introduces the case study house. After introducing simulated house, the following section, elaborates on simulation results in terms of total heat losses, total energy consumption, heat losses from windows on different fronts of the building, heat losses from different parts of the building according to the construction ear, annual solar gain exterior windows, annual natural ventilation and heat losses per square meter from windows from different parts of the building according to the construction era. Finally, a conclusion will wrap up the study opening windows to future works.

MATERIAL AND METHODS

In this study, the research structure is in the field of architecture and energy. The research type is quantitative and its inference requires analysis. In order to collect information, scientific-research articles as well as articles of the world's leading scientific publishers are investigated. In addition, for obtaining the desired result and provide appropriate answers to research questions, DesignBuilder software (EnergyPlus simulator) has been used .

The most important question that may be asked about the use of software is the validation and accuracy of this software in calculating energy consumption compared to its actual amount. Numerous studies have been conducted in this area, including recent studies: A study conducted by Skin and Turkmen [17] compared the amount of heating and cooling loads by EnergyPlus software with its actual amount in a 24-hour period. It is witnessed that the amount of this difference is very insignificant at the level of 3% and 5% for heating and cooling loads, respectively.

Climatic data of Tabriz city were collected from Tabriz Meteorological Department and building physical data such as plan, mechanical and electrical equipment, building facade were collected by field survey in the building. The procedure of simulation in EnergyPlus engine and gaining results in the DesignBuilder software is as follows: 1. Entering the climatic data of Tabriz (The average climate of 11 years); 2. Drawing a 3-D model of the building; 3. Specifying the building is intended for residential use; 4. Enter fixed specifications of building (executive details, windows specifications, Heating- Ventilation-Air Conditioning system (HVAC system). Finally, the simulation is performed by the DesignBuilder software and important results will be presented.

Ganjei-Zade house

The simulated house is Ganjei-Zade house located in the historical neighborhood of Maghsoudiyeh in Tabriz. This building consists of two parts. The eastern part was built during Qajar period and the western part was added to the previous building during Pahlavi period. The total area of the building is 4142 square meter (m^2) and the total area of the infrastructure is about 729 m^2. Figure 1 shows (a) an aerial photo, (b) Pahlavi era and (c) Qajar period of Ganjei-Zade house in Tabriz. The construction periods of the building are shown separately. Figure 2 shows different views of different parts of Ganjei-Zade house which was built in Qajar and Pahlavi periods. Figure (2a) is a part of the building which was built in Qajar period and Figures (2b-d) are a part of the building which was built in Pahlavi period.

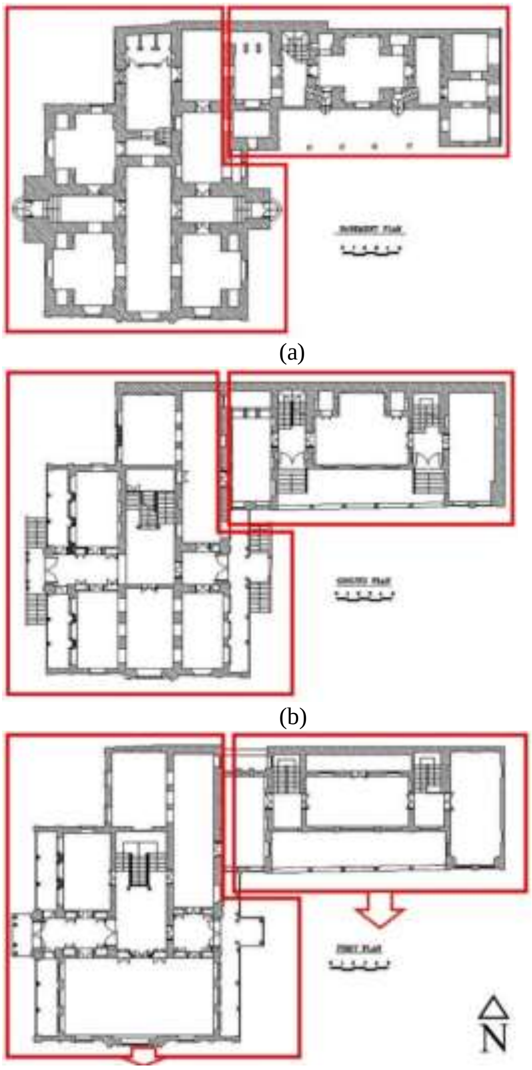
Figure 3 shows (a) basement, (b) ground floor and (c) first floor plan of Ganjei-Zade house, respectively. A red box has been used to determine the construction period of the building.

Important details related to the Elevations and windows of Ganjeh Zadeh House are presented in Tables 1, 2 and 3. The view profile of Ganjei-Zade house is summarized in Table 1. Table 2 presents windows specifications and solar heat gain coefficient (SHGC), visible Transmittance (T_v), Thermal transmittance (U-

(a) (b) (c)

Figure 1. (a) Aerial photo (Source: Google Earth, 2020), Panoramic image of Ganjei-Zade house and construction period (b) Pahlavi era, (c) Qajar era (Source: Authors)

Figure 2. Images of Ganjei-Zade house and construction period, (a) Qajar era, (b), (c) and (d) Pahlavi era (Source: Authors)



(c)

Pahlavi era Qajar era

Figure 3. (a) Basement, (b) Ground and (c) First Floor Plan (Source: Cultural Heritage, Handicrafts and Tourism Organization of East Azerbaijan Province, 2020)

Table 1. View profile of Ganjei-Zade house*

Building parts	View	Area (m^2)	Total area of windows (m^2)	WWR (%)
North side of the building (Qajar)	South	182.927	41.8793	22.89
	North	182.927	-	-
	East	81.68	3.79	4.6
	West	81.68	-	-
West side of the building (Pahlavi)	South	148.122	23.43	15.8
	North	115.83	4.84	4.1
	East	114.31	18.73	16.4
	West	193.56	31.73	16.4

* Source: Authors

Table 2. Specifications of windows*

Building Parts	Window specifications		coefficient of performance		
North side of the building (Qajar)	Sill		Height	Distance	0.8 m
	Type of glazing		Clear single glazed (1-window)	Thickness	6 mm
				U-Value	5.778 W/m^2K
				T_v	0.881
				SHGC	0.819
	Frames		Wooden (painted)	Thickness	0.1 m
				U-Value	1.857 W/m^2K
				R-Value	0.538 m^2K/W
	Dividers		Width	Distance	0.05 m
West side of the building (Pahlavi)	Sill		Height	Distance	0.8 m
	Placing two windows at a distance of 10 cm from each other	Type of glazing	Clear double glazed (2-windows)	Thickness	22 mm
				U-Value	2.764 W/m^2K
				T_v	0.781
				SHGC	0.702
		Frames	Two wooden frames (painted)	Thickness	0.1 m
				U-Value	0.887 W/m^2K
				R-Value	1.127 m^2K/W
	Dividers		Width	Distance	0.05 m

* Source: Authors, DesignBuilder software, 2020

Value) and thermal resistance (R-Value). The Ganjei-Zade house characteristics are summarized in Table 3. Details of section and construction periods are presented as follows.

Opaque walls

- Exterior walls: [Qajar: Brick-aerated 0.11 meter (m) + cement/plaster/mortar-cement mortar 0.02 m + brick-mud, at 50C degrees 0.15 m + gypsum plastering 0.02 m], [Pahlavi: Brick-aerated 0.11 m + cement/plaster/mortar-cement mortar 0.02 m + brick-mud, at 50C degrees 0.35 m + gypsum plastering 0.02 m]
- Interior walls: [Qajar: Gypsum plastering 0.02 m + brick-mud, at 50C degrees 0.59 m + gypsum plastering 0.02 m], [Pahlavi: Gypsum plastering 0.02 m + brick-mud, at 50C degrees 0.51 m + gypsum plastering 0.02 m]

Floor

- Ground floor: [Qajar and Pahlavi: Brick-tile, at 50C degrees 0.06 m + loose fill/powders sand 0.1 m + cast concrete (dense) 0.215 m]
- Internal floor: [Qajar and Pahlavi: Brick-tile, at 50C degrees 0.06 m + loose fill/powders sand 0.05 m + gypsum plastering 0.02 m + wood, hard, 25 millmeter (mm), 1 in (WD12) 0.025 m+ wood-timber, at 50C degrees 0.14 m + metal-iron 0.015 m + gypsum plastering 0.02 m]

Roof

- [Qajar: Bitumen/felt layers 0.03 m + loose fill/powders sand 0.05 m + gypsum plastering 0.02 m + wood, hard, 25 mm, 1 in (WD12) 0.025 m + wood-timber, at 50C degrees 0.14 m + metal-iron 0.015 m + gypsum plastering 0.02 m], [Pahlavi: Wood, hard, 25 mm, 1 in (WD12) 0.025 m + air gap (R=0.18 m2k/w) 0.835 m + Bitumen/felt layers 0.03 m + loose fill/powders sand 0.05 m + gypsum plastering 0.02 + Wood, hard, 25 mm, 1 in (WD12) 0.025 m + wood-timber, at 50C degrees 0.14 m + metal-iron 0.015 m + gypsum plastering 0.02 m].

The physical characteristics of construction sections of Ganjei-Zade house are presented in Table 3.

Figure 4 shows windows of Ganjei-Zade house which were built in Pahlavi period. Figure (4a) demonstrates the exterior of the windows of Ganjei-Zade house, Figure (4b) shows the view of the window from the interior (closed window mode) and Figure (4c) shows the view of the window from the interior (Open window mode).

Figure 5 shows simulated perspectives of Ganjei-Zade house in DesignBuilder software. Figure (5a) is a view of southeast front, Figure (5b) is a view of southwest front, Figure (5c) is a view of northwest front and Figure (5d) is a view of northeast front.

Table 3. Ganjei-Zade house characteristics*

Specifications (Input data)		Performance coefficient		
Section	**Construction time**	**U-Value surface to surface (W/m^2K)**	**U-Value (W/m^2K)**	**R-Value (m^2K/W)**
Exterior walls	Qajar	1.552	1.228	0.814
	Pahlavi	1.098	0.925	1.081
Interior walls	Qajar	1.128	0.872	1.147
	Pahlavi	1.282	0.962	1.04
Ground floor	Qajar & Pahlavi	3.496	2.016	0.496
Internal floor	Qajar & Pahlavi	0.745	0.62	1.613
Roof	Qajar	0.648	0.594	1.682
	Pahlavi	0.607	0.56	1.787

* Source: Authors, DesignBuilder software, 2020

RESULTS AND DISCUSSION

On the basis of the above-mentioned research methodology, in this section simulation results are presented for heat losses, energy consumption, heat losses from windows based on construction era, solar gain exterior windows, the amount of natural ventilation and heat losses per square meter from windows from different parts of the building according to the construction era.

Total heat loss

Findings that include the amount of heat losses in the form of convection from different parts of the building are presented in the Figure 6 and shows the fact that 21% of total heat dissipation in the building (Qajar + Pahlavi) is from windows, 66% is from external walls, 12% is from roofs and a little amount of heat loss (1%) is from floor of Ganjei-Zade house. Figure 6 illustrates heat losses from different part of buildings' heat transfer area.

(a) (b) (c)

Figure 4. Windows of Ganjei-Zade house in Pahlavi period - (a, b, c): Pahlavi era windows (Two windows at a distance of 10 cm from each other) (Source: Authors), (b): Closed window mode-(c): Open window mode [18]

Total energy consumption

Figure 7 shows the annual energy (gas, electricity, domestic hot water (DHW)) consumption and indicates that 82.64% of the annual total energy consumption in Ganjei-Zade house is allocated to natural gas for heating spaces.

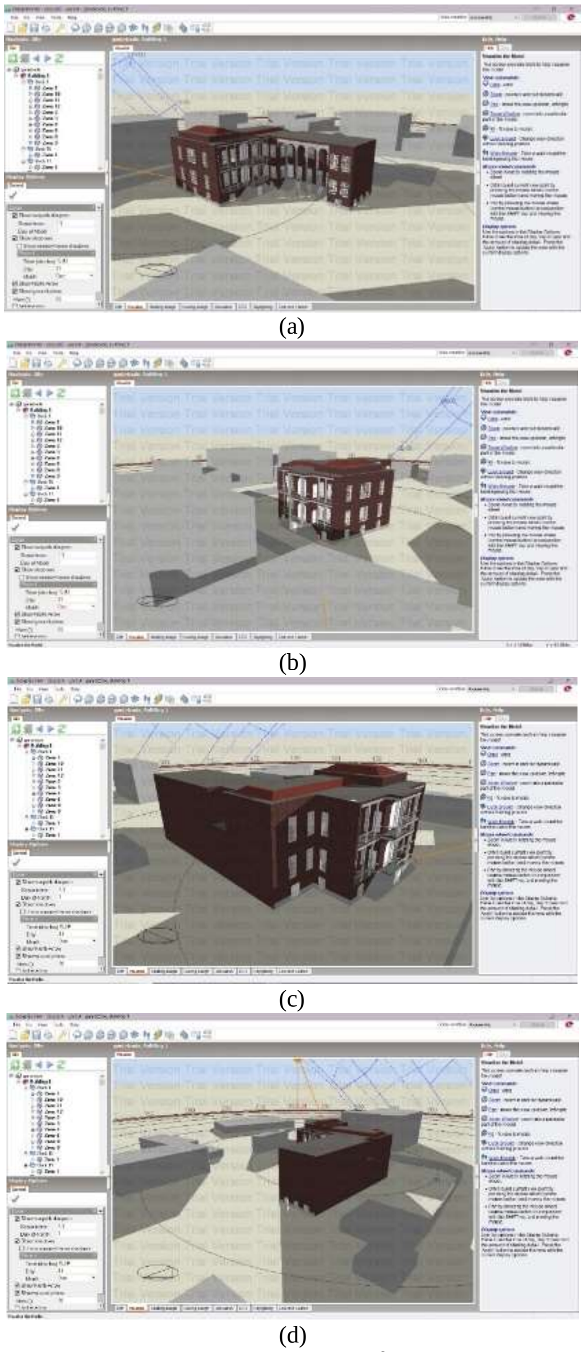


Figure 5. Simulated perspectives of Ganjei-Zade house (Source: Authors, DesignBuilder software, 2020)

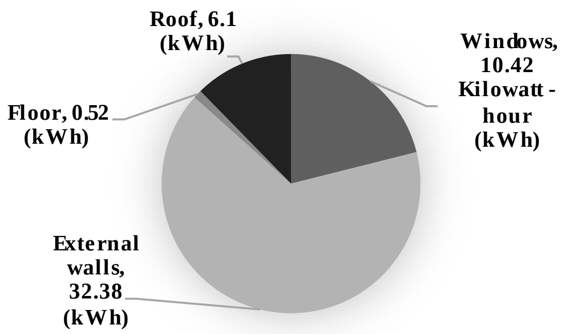


Figure 6. Heat losses from different sections (Source: Authors, DesignBuilder software, 2020)

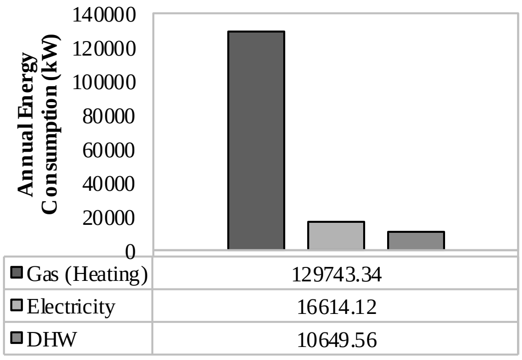


Figure 7. Annual total energy consumption (gas, electricity, domestic hot water (DHW)) of the building (Source: Authors, DesignBuilder software, 2020)

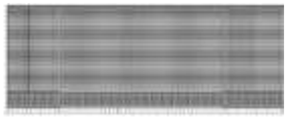
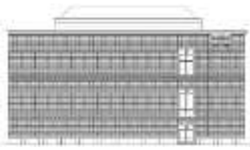
Simulation results according to the construction era (Qajar, Pahlavi)

Table 4 indicates the amount of heat dissipation from the windows of Ganjei-Zade house from different fronts (Qajar and Pahlavi periods). Results show more heat losses from windows in the section built during Qajar era.

Table 5 summarized heat losses from different sections of Ganjei-Zade house, the greater heat loss from the windows in the section built in the Qajar period.

Figure 8 illutrates annual solar heat gained and natural ventilation from exterior windows of Ganjei Zade's house by building construction time (Qajar, Pahlavi). In addition, it shows the improvement of thermal and ventilation performance of windows in the section made in Pahlavi period. From this result, it is inferred that the amount of heat losses from the windows in Ganjei-Zade house has decreased from Qajar period to the Pahlavi period. The amount of heat loss per square meter of windows in Qajar era is 0.12 kWh and in Pahlavi era is 0.05 kWh. Figure 9 shows the fact that the amount of heat loss per square meter of windows from the Qajar period to the Pahlavi is reduced by 58.33%.

Table 4. Heat loss from windows on different fronts of the building (Qajar era)*

Construction time		Studied view	Heat loss (kWh)
Qajar era	North elevation		-
	South elevation		5.02
	East elevation		0.45
	West elevation	-	-
Pahlavi era	North elevation		0.24
	South elevation		1.17
	East elevation		0.93
	West elevation		1.58

* Source: Authors

Table 5. Heat losses from different parts of the building according to the construction era*

Sections of the building	Heat losses (kWh) Heat loss of different parts of the building	
	Qajar	Pahlavi
Windows	5.86	4.56
External walls	16.87	15.51
Floor	0.28	0.24
Roof	2.42	3.86

* Source: Authors, DesignBuilder software, 2020

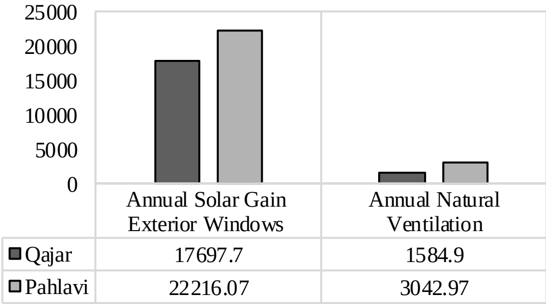


Figure 8. Annual solar gain & natural ventilation from exterior windows (Source: Authors, DesignBuilder software, 2020)

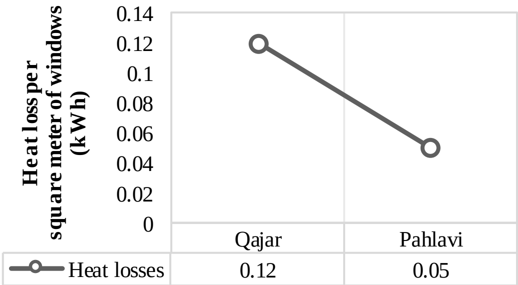


Figure 9. Heat loss per square meter from windows from different parts of the building according to the construction era (Qajar, Pahlavi), (Source: Authors, DesignBuilder software, 2020)

CONCLUSION

The form of architecture in the cold and dry climate of Tabriz, where the length of the cold winter is much longer than the hot summer; should be defined in such a way that in addition to creating comfort and convenience for individuals, energy consumption for heating the building is also reduced. In this study, the evolution of windows from the Qajar era to the Pahlavi in Ganjei-Zade house in the cold and dry climate of Tabriz has been studied and analyzed. The results confirm that the window-to-wall-ratio (WWR) in the southern facade of the house in the northern part (built in the Qajar period) is 22.89% and in the western part of the building (built in the Pahlavi period) is 15.8%. The openings, in the section built in the Qajar era consists of one window and in the section built in the Pahlavi era consists of two windows, which open the inner window facing inward and the outer window facing outward.

The simulation shows that the amount of heat loss per square meter of windows by changing from one-window to two-windows, was decreased by 58.33% and the amount of heat loss from windows in the whole building from Qajar to Pahlavi era was reduced by 22.19%. These cases indicate an increase in attention to the design and implementation of building windows in order to reduce heat loss from Qajar era to Pahlavi.

Therefore, in order to reconsider the design and implementation of windows of residential buildings and reduce heat loss (from windows) in winter, the following suggestions are presented in the design of the building's exterior shell:

- By minimizing the area of the openings (WWR), the amount of heat transfer during the cold winter of Tabriz is reduced.
- Construction of windows in the form of double windows (two windows - open the inner window facing the room and the outer window facing the outside (In fact, the two windows should be separated by a middle cavity). The middle cavity acts as a thermal insulator to reduce heat dissipation of the building. In this way, that radiant solar energy is stored in this cavity and its temperature is equal to the temperature inside the building. This reduces the heat exchange of the indoor space with outdoor.

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Persian Abstract

چکیده

معماری بومی ایران در زمینه هماهنگی با محیط پیرامون خود دارای تجارب غنی می‌باشد. از طرف دیگر، مصرف بالای انرژی یکی از دغدغه‌های مهم در دهه‌های گذشته بوده است. طبق آمار ارائه شده از طرف مرکز آمار ایران، ۴۰٪ از مصرف انرژی کشور مربوط به صنعت ساختمان است. از این میزان در حدود ۷۰٪ از مصرف صرفا به منظور گرمایش و سرمایش فضاها استفاده می‌شود. در این میان پنجره‌ها، تاثیر قابل ملاحظه‌ای بر عملکرد حرارتی دارند. خانه گنجه‌ای‌زاده تبریز یکی از بناهای تاریخی و دربرگیرنده دو بخش است. ضلع شمالی آن در دوره قاجار و ضلع غربی که در دوره پهلوی به ساختمان پیشین افزوده شده است. مقاله حاضر به ارزیابی سیر تحول پنجره‌ها از دوره قاجار به پهلوی در خانه گنجه‌ای‌زاده تبریز و میزان اتلاف حرارت از آن می‌پردازد. این محاسبات با شبیه‌سازی خانه گنجه‌ای‌زاده در نرم‌افزار دیزاین بیلدر صورت گرفته است. پژوهش مربوط به این مقاله با تکیه بر روش تحلیلی ـ مقایسه‌ای انجام شده و هدف از آن ارائه معیارهای مهم برای جداره‌های نورگذر در ساختمان‌های مسکونی در اقلیم سرد شهر تبریز با توجه به بررسی راهکارهای معماری بومی، در راستای کاهش اتلاف حرارت می‌باشد. محاسبات انجام شده موید این مطلب است که میزان اتلاف حرارت از پنجره‌ها در کل بنا از دوره قاجار به پهلوی به میزان ۲۲/۱۹٪ و میزان اتلاف حرارت در هر مترمربع از پنجره‌ها از دوره قاجار به دوره پهلوی، به میزان ۵۸/۳۳٪ کاهش یافته است.