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Optimization of Thermal Performance of Windows in Intermediate Housing in Cold and Dry Climate of Tabriz

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P A P E R I N F O

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A B S T R A C T

Windows in the building are the biggest elements of heat loss through convective heat transfer. The purpose of study is to select appropriate dimensions for windows relative to shell and appropriate glazing for windows, in order to achieve optimal pattern to reduce energy consumption. The research method is based on the simulation and research tool is DesignBuilder software. Therefore, amount of natural gas consumed annually in the studied building was received from the National Iranian Gas Company and then the basic research was modeled by software and after converting unit from kWh to m^3 and validating simulation results. In the next step, the range of 20% to 80% of window-to-wall-ratio, types of glazing and window height is considered and through parametric optimization, all conditions in the windows are simulated and analyzed for sensitivity index. The calculations confirm that in an intermediate residential building with a rotation of 12 degrees to the southeast in Tabriz, by reducing window-to-wall-ratio from 50% to 20% and replacing triples-glazed-glazing with a low-emission coating filled with argon gas with a transparent single-glazed glazing and UPVC frame and a canopy with a depth of 48cm and windows height of 1.5m, the heat losses were reduced by 60.34% and 75.24%, respectively.

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NOMENCLATURE

SHGC	Solar heat gain coefficient	U-value	W/m^2k
UPVC	Unplasticized poly vinyl chloride	R-value	m^2k/W
T_v	Visible transmittance		

INTRODUCTION

Iran is one of the countries relayed on fossil energy sources such as crude oil and natural gas. This issue has also affected the energy structure of Iran. Due to the abundance of this source, 60.35% of the energy demand in Iran is allocated to natural gas [1]. Based on the implemented researches, buildings consume about 40% of the total ultimate energy [2]. Residential energy consumption represents more than a quarter of building energy consumption [3].

Windows have a significant effect on the thermal characteristics of the building shell due to low thermal resistance [4]. There are three very important reasons for the high heat losses from windows: window to wall ratio (WWR); window orientation; and type of window glazing [5]. Due to its low thickness, glazing has the highest heat transfer coefficient among the elements of the building's exterior shell and also the window to wall ratio is one of the most important factors in energy consumption in designing buildings in cold climates [6]. Therefore, the purpose of this study is to present the design criteria and

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implementation of windows in residential buildings in the cold and dry climate of Tabriz in order to reduce energy consumption. So, the latest books and articles published in this field have been reviewed and presented in historical sequence.

Long and Ye [7] pointed out that winter-appropriate glass should be able to transmit long-wavelength radiation of solar energy.

Ibrahim et al. [8] found that adding 1-2 cm of coverage to thermal bridges around windows reduces heat loss by 24-50%.

Sun et al. [9] have concluded the system of slats achieved up to 28% improvement of U-value when compared with a glazing unit without a Venetian blind.

Cuce [10] has reported that multi-functional PV glazing technologies usage in windows compared to single-glazed glazing reduce energy use by 48% in winter.

Daqiqeh Rezaei et al. [11] pointed out that the best type of glass for use in cold and dry climates is aerogel glazing.

Lechowska et al. [12] found that the air gap filling with polyurethane foam in window frames can diminish heat transfer of frames by about 27%.

Potrc Obrecht et al. [13] found that the southern front; with a rotation of 1-24 degrees, was the best front for windows in order to achieve maximum sunlight.

Zhou and Zheng [14] have reported that aerogel glazing is acute for upgrading zero energy residential buildings.

Sadafi et al. [15] evaluated an energy efficient design optimization of a building envelope in a temperate and humid climate and found that large windows increase the building energy demand.

Al-kuhaili et al. [16] discussed about advanced energy saving which is based on coatings transparent heat mirrors by utilization of thin film of nickel oxide (NiO/Ag) multilayer as energy efficient coatings.

Studies confirm that according to the use of the building and the climate of the region, the type of glazing suitable for windows is different. In addition to this, the optimal window proportions in cold and mountainous climates have not been studied.

The presented materials showed the fact that only a small part of the studies have studied the type of the optimal window in the building in the same latitude as the city of Tabriz, which are more focused on public and office buildings. Little research has been done; mainly, in providing the most suitable facade for window placement, and location of the window in the building shell and the material of the frame. The difference and innovation of the present study can be considered in the study of the effect of thickness in double and triple glazed glazing and glazing cover and also window-to-wall-ratio on the amount of heat losses in the windows of residential buildings in cold and dry climates.

RESEARCH METHODOLOGY

The upcoming research is based on the objectives of the research, is the type of "application" and based on the nature, is "simulation". The statistical society is an intermediate residential building in Tabriz and the objective society is the annual gas and electricity consumption for heating, cooling and lighting the building. The autonomous variable of the research will be different window-to-wall-ratio and glazing type and the affiliate variable will be the amount of natural gas and electricity used annually in the building.

The first action in this research procedure is data collection. Climatic data of Tabriz city has been received from Tabriz Meteorological Department and building physics data such as plan, mechanical and electrical equipment, building facade by field survey in the building. The proceeding of simulation in EnergyPlus engine and gaining results in the DesignBuilder software is as follows [17]:

1. Entering the climatic data of Tabriz (Average climate of region-11years, 2009-2020);
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, HVAC system).

After importation the fixed specifications of basic research model and its simulating on EnergyPlus engine, the amount of gas used for heating will be received from the National Iranian Gas Company to Reliability the accuracy of the results obtained from the DesignBuilder software. Then, window-to-wall-ratio, windows proportions and glazing types of windows will be changed and the building simulation will be executed according to the mentioned changes and will be explore optimum condition.

REASONS OF CHOOSING BASIC RESEARCH MODEL

In order to study and test the research variables, it is necessary to simulate the model to measure the impact of variables on it. The basic model of the research is a four-story building. The reasons for choosing this building as a basic research model are:

1. Field surveys and the opinions of the residents of the building are indicative of the low temperature around the windows in winter;
2. Emphasis on only one geographical direction (to the south along with the rotation to the southeast) is because the openings are removed on different fronts:

- In order to prevent the penetration of the prevailing winter wind (which blows from the north and east fronts in Tabriz), it is better to remove the windows on the north and east fronts;
- In order to prevent the penetration of annoying heat in the summer afternoon, it is better to remove the windows

on the west front. Ground floor plan and floor plans of the studied base model are presented in Figure 1.

REASONS OF CHOOSING DESIGNBUILDER SOFTWARE

Various researches have been done to provide comparative criteria of capabilities of existing simulation tools have been implemented. In the report mentioned in the following section, a general comparison between the capabilities of the simulation software. Table 1 shows the various capabilities of Design Builder software and for the above reasons, this software has been selected for simulation.

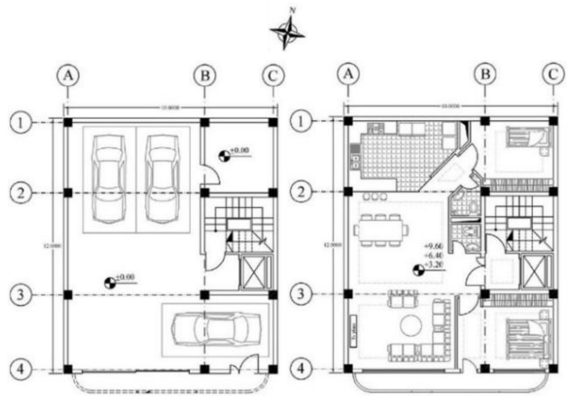

Figure 1. Basement plan and type plans (first, second and third floor)

Table 1. Comparing the capabilities of energy simulation software (Source: Ghiaee et al. [17])

Softwares	**Capabilities of energy simulation software**																			
	Blast	**Bsim**	**Dest**	**Doe-2.1e**	**Ecotech**	**Ener-win**	**Energy exp.**	**Energy 10**	**Energy plus (DesignBuilder)**	**Equest**	**Esp**	**Hap**	**Heed**	**Ida ice**	**Ies**	**Powerdomus**	**Sunrel**	**Tas**	**Trace**	**Transys**
Geometric production of models	*	*	*	*	*	*	*		*	*	*		*	*	*	*	*	*	*	*
Atmospheric analysis		*			*				*		*	*		*	*					*
Energy costing			*	*		*		*	*	*		*			*				*	
Periodic simulation	*	*					*	*	*	*	*			*	*	*	*			*
Automatic production of energy results								*	*		*				*			*		*

SIMULATION

Fixed parameters

The fixed specifications of the building are provided in Table 2 and then the simulation is performed based on the mentioned parameters. Figure 2 shows the basic research model. The simulated perspectives are shown in Figures 3 and 4.

Awning depth

It is desired to use canopies and small deciduous trees at the same time on the south side and in front of the windows. The canopy should be designed with the right depth to shine into the spaces at a 30-degree angle due to the falling leaves of the trees in winter and in summer, shade can be created by canopies against the sunlight with a 75-degree radiation angle.

The minimum depth of the canopy is calculated according to the following formula:

$$D = \frac{h\, Cos\,(Z+N)}{Tan\,\beta} \tag{1}$$

In this regard:

D = canopy depth in meters; h = height of the shadow created by the depth of the canopy on the glass, in meters; Z = direction of radiation; N = angle between the line perpendicular to the window and the true south; β = radiation angle.

According to the above formula, the depth of the canopy for the south side is considered to be 48 cm on the first of July at 12 noon.

$$D = \frac{h\, Cos\,(Z+N)}{Tan\,\beta} = \frac{2*Cos\,(180+12)}{Tan\,76} = 0.48\ m$$

The effect of the designed canopy on the penetration of solar radiation at critical times in winter and summer (at 12:00:00 noon) is shown in Figure 5. The prevention of the penetration of solar radiation in summer with proper design of canopy depth is illustrated in Figure 6.

Table 2. Characteristics of basic research model (input data related to intervention variables) (Source: DesignBuilder software, Nematchoua et al. [18])

Specifications (Input data)			Performance coefficient	
Geometry and dimensions	Plot		Area (m^2)	10 * 19 (190)
	The form of plan		Geometry	Rectangle
	Floors		Area (m^2)	95
Number of residents	4		Activity	Light Activity
			Density of people (m^2 per person)	16
Executive details + thickness	Exterior walls	Brick (0.11 m) + cement mortar (0.02 m) + brick (0.2 m) + gypsum plastering (0.01 m)	U-value (w/m^2k) (Heat transfer coefficient)	1.763
			R-value (m^2k/w) (Heat resistance)	0.567
	Interior walls	Gypsum plastering (0.02 m) + brick (0.1 m) + gypsum plastering (0.02 m)	U-value	1.789
			R-value	0.559
	Flooring (ground floor)	Ceramic (0.03 m) + cement mortar (0.02 m) + light concrete (0.1 m)	U-value	1.857
			R-value	0.538
	Flooring (floors)	Ceramic 0.01 m + cement mortar (0.02 m) + light concrete (0.08 m) + concrete block (0.1 m) + cement mortar (0.02 m) + gypsum plastering (0.005 m)	U-value	0.694
			R-value	1.441
	Flat roof	Asphalt (0.04 m) + gypsum plastering (0.03 m) + cement mortar (0.02 m) + light concrete (0.05 m) + concrete block (0.1 m) + cement mortar (0.02 m) + gypsum plastering (0.01 m)	U-value	0.796
			R-value	1.257
Windows	Height		Distance (m)	1.2
	South elevation		Area (m^2)	128
	Total area of windows		Area (m^2)	64
	Window-to-wall-ratio		%	50
	Sill		Distance (m)	0.8
	Type of glazing (Clear single glazing)		SHGC	0.819
			T_v	0.881
			U-value	5.778
	Frame (Aluminium)		U-value	5.876
			Width (m)	0.08
			Projection (m)	0.02
	Divider		Width (m)	0.05
Heating system	System type	Convection – Central engine	Maximum amount of moisture that can be provided by the system	0.016
	Fuel type	Natural gas		
	Heat distribution units	Radiator	Maximum temperature that can be provided by the system (C)	35
	Fluid type	Hot water		
Lighting	Suspended LED		Radiant fraction	0.42
			Visible fraction	0.18
Cooling	Natural ventilation			

Figure 2. Basic research model

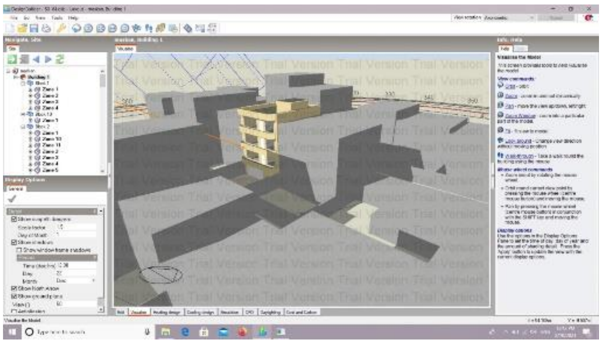

Figure 3. Simulated perspective (Source: DesignBuilder software [18])

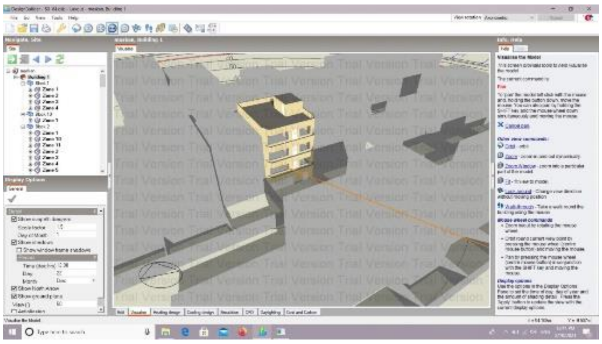

Figure 4. Simulated perspective (Source: DesignBuilder software [18])

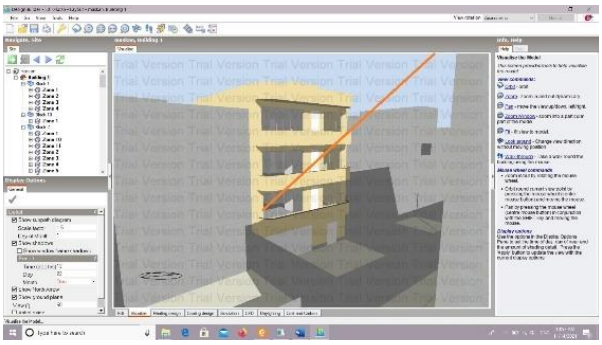

Figure 5. Penetration of solar radiation in winter (December 22nd)

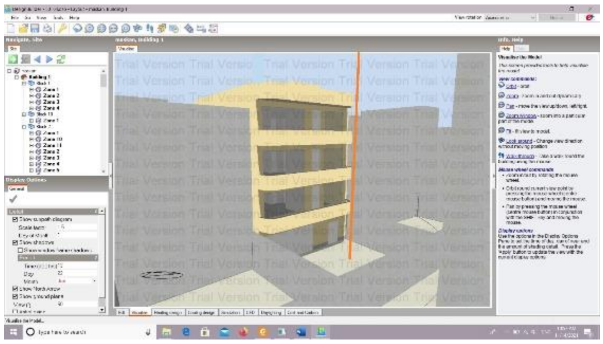

Figure 6. Prevent the penetration of solar radiation in summer with proper design of canopy depth (June 22nd)

RESULTS OBTAINED FROM SIMULATION OF BASIC RESEARCH MODEL IN DESIGNBUILDER SOFTWARE AND VERIFING RESULTS

Table 3 and following figures provided by the National Iranian Gas Company (actual gas consumption of building gas) per m^3 and also the figures obtained from the simulation of the basic research model (window-to-wall-ratio 50% and clear single-glazed glazing with a thickness of 6 mm) per unit indicates kWh.

In order to make sure the exactitude of software results and their reliability, the simulation outputs are converted from kWh to kg and then kg to m^3.

$$1\text{kWh} = (4.0055\ e^{-11})\ \text{kg} \tag{2}$$

$$e = 2.7183$$
$$1\text{kg} = 1.3966\ m^3 \tag{3}$$

At this stage, the figure obtained from the software (annual consumption) is converted from kWh to m^3 according to the formulas provided to verify the figures obtained from the simulation.

$$1\text{kWh} = (4.0055\times (2.7183)^{-11}) = 0.1118\ \text{kg}$$
$$0.1118 \times 1.3966 = 0.156\ m^3$$
$$0.156 \times 84282.27 = 13162\ m^3$$

By reference to the result gained from the conversion of the unit, the actual average of annual building consumption is 12037 m^3 and the amount received by EnergyPlus engine is 13162 m^3. The discrepancy in values is 8.55%. This indicates that, DesignBuilder software computes gas consumption for heating of building with allowable precision.

Table 3. Annual gas consumption in the building

Validation section-m^3 (Source: National Iranian Gas Company, 2020)	**Simulation section-kWh** (Source: DesignBuilder Software [18])
12037	84282.27

PARAMETRIC OPTIMIZATION

Variable parameters

In this paper, window-to-wall-ratio is 50% and the type of glazing is considered clear-single-glazed glazing with the height of 1.2 m, and in the next step, it is compared with other variables. Table 4 summarized variable parameters and the performance coefficient for different type of glazed glazing.

The window-to-wall-ratio is in the range of 20 to 80%. This causes the amount of gas consumed annually with a significant change in the window-to-wall-ratio; clearly marked and the simulation results are compatible.

The variables applied on the glazings are the number of glasses, the type of gas between the glasses and the surface of the glazing. The single, double and triple-glazed glazing are shown in Figure 7.

Table 4. Variable parameters (Source: Authors; DesignBuilder software [18])

Variable parameters		Performance coefficient		
		SHGC	T_V	U-value
Glazing type	1 (Basic research model)	0.819	0.881	5.778
	2	0.703	0.781	2.665
	3	0.704	0.781	2.511
	4	0.568	0.745	1.761
	5	0.564	0.745	1.499
	6	0.579	0.698	1.256
	7	0.579	0.698	1.058
Basic research model	Clear single glazed glazing (1) Window-ta-wall-ratio = 50 % Window height = 1.2 m Canopy depth = 48 cm			
Frame (UPVC)	U-value = 3.476 (W/m^{2}k)			
Window-to-wall-ratio	20 %			
	40 %			
	60 %			
	80 %			
Window height (with fixed total area)	1 m			
	1.5 m			
	1.75 m			

Figure 7. Single, double and triple-glazed glazing

The following glasses have been selected for simulation:

1. Clear single glazed-glazing, (6 mm);
2. Clear double glazed-glazing (6 mm + 13 mm air + 6 mm);
3. Clear double glazed-glazing (6 mm + 13 mm argon + 6 mm);
4. Double glazed-glazing with low emission coating e = 0.1 (6 mm + 13 mm air + 6 mm);
5. Double glazed-glazing with low emission coating e = 0.1 (6 mm + 13 mm argon + 6 mm);
6. Triple glazed-glazing with low emission coating e = 0.1 (3 mm + 13 mm air + 3 mm + 13 mm air + 3 mm);
7. Triple glazed-glazing with low emission coating e = 0.1 (3 mm + 13 mm argon + 3 mm + 13 mm argon + 3 mm)

Specifications for low-emissivity glazing

Low-emissivity glazing was created to minimize the amount of infrared and ultraviolet light that comes glass, without minimizing the amount of light that enters home. Low-E glazing windows have a microscopically thin coating that is transparent and reflects heat. Figure 8 illustrated the low emission glazing mechanism in summer and winter.

The following materials are used on the glazing surface and its specifications are as follows:

NiO/Ag/Silica and Tantalum; T_v: 0.698; Reflection coefficient: 0.88 [16].

It is better that the low-emission coating be placed on the surface shown in Figure 9 in the area with high heat requirements (cold climates).

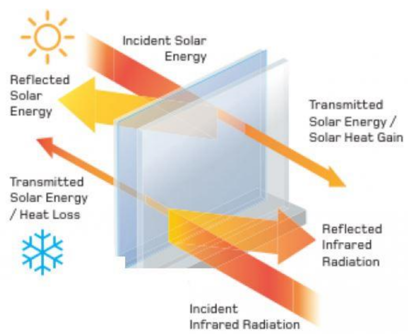

Figure 8. Low emission glazing mechanism in summer and winter

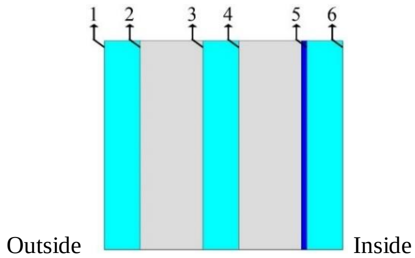

Figure 9. Location of low emission cover in cold and dry climates

RESULTS OBTAINED FROM PARAMETRIC OPTIMIZATION

The simulation results obtained in the software, which have been tested based on the change window-to-wall-ratio and the type of glazing, are presented in Table 5.

Results analysis

Figure 10 illustrates the fact that by changing the type of glazing from clear single-glazed glazing to triple-glazed glazing, the change of gas between the glazing from air to argon gas and also the replacement of clear glazing with low emission glazing; annual gas consumption for heating decreases.

Table 5. Parametric optimization results (Source: Authors, DesignBuilder software [18])

Variable		Heat loss from windows (kWh)	Annual gas consumption (kWh)	Annual solar energy received from windows (kWh)	Annual electricity consumed for lighting spaces (kWh)
Glazing	1	5.17	84282.27	5277.03	5915.75
	2	2.8	81954.81	3932.72	6173.25
	3	2.65	81762.97	3932.72	6173.25
	4	1.89	80882.62	3113.92	6254.33
	5	1.6	80391.81	3113.92	6254.33
	6	1.49	80358.08	2293.32	6310.11
	7	1.28	79961.66	2293.32	6310.11
Basic research model (Table 3)		5.17	84282.27	5277.03	5915.75
Frame (UPVC)		4.12	83115.14	5277.03	5915.75
WWR	20%	2.05	83280.98	2063.63	6324.54
	40%	4.13	83938.38	4208.85	6057.65
	60%	6.09	84313.77	6583.64	5474.12
	80%	8.03	84813.13	8885.36	5026.35
height	1m	6.48	84795.28	5142.28	6154.78
	1.5m	3.25	83254.57	5784.12	5411.32
	1.75m	3.25	83254.57	5784.12	5411.32

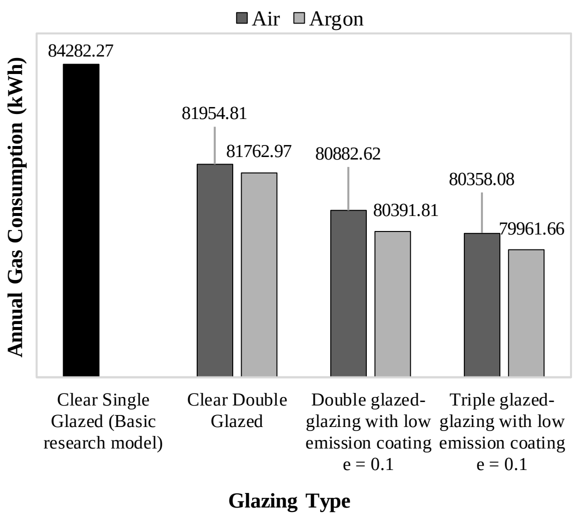

Figure 10. Reduction of annual gas consumption for heating as a result of changing the number of glazing, gas between the glazing and glazing cover

Figure 11 indicates a decrease in the annual gas consumption as a result of changing the material of window frames from aluminum to UPVC.

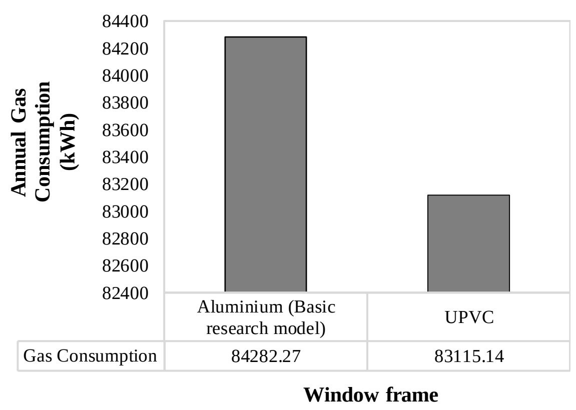

Figure 11. Reduction of energy consumption for heating as a result of changing the material of the window frame

Figure 12 shows that if window-to-wall-ratio decreases from 80 to 20%, the heating demand will reach its lowest level.

Figure 13 illustrates changing in the annual gas consumption as a result of changing the proportions (window height) of the window (with the fixed area).

Results index (sensitivity index)

In order to investigate the effect of the introduced architectural variables using sensitivity analysis, which is the result of dividing the parameter changes into minimum and maximum to maximum ratio, has been used.

$$Index = \frac{Maximum - Minimim}{Maximum} * 100 \quad (4)$$

Table 6 summarized the sensitivity index analysis based on the increase-decrease window-to-wall-ratio, change in the type of glazing and window height for windows compared to the basic research model and shows the fact that by reducing window-to-wall-ratio and the use of triple-glazed glazing with low emission coating, heat loss is significantly reduced and the most suitable height for windows in cold climate is 1.5 to 1.75 meters with UPVC frames.

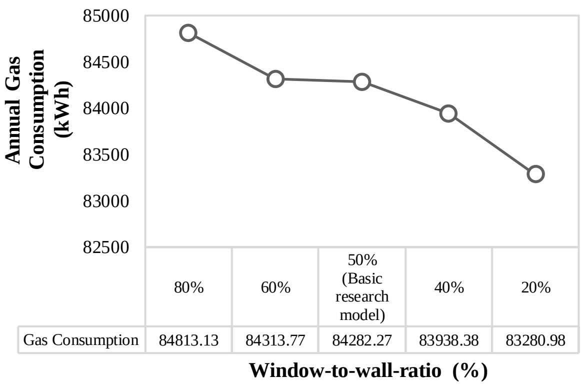

Figure 12. Declining trend in the amount of gas used for heating by reducing the window-to-wall-ratio

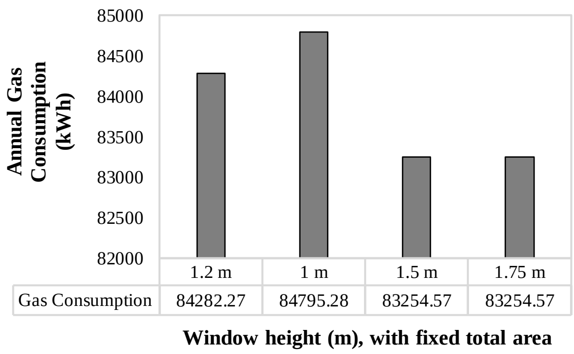

Figure 13. Changing the amount of gas consumed annually by changing the proportions of the window

Table 6. Results index based on variables (%); Percentage decrease (↓) – increase (↑) compared to basic research model)

Variable		Heat loss from windows	Annual solar energy received from windows
Glazing type	2	45.84 % ↓	25.47 % ↓
	3	48.74 % ↓	25.47 % ↓
	4	63.44 % ↓	40.99 % ↓
	5	69.05 % ↓	40.99 % ↓
	6	71.17 % ↓	56.54 % ↓
	7	75.24 % ↓	56.54 % ↓
Basic research model (Table 3)		-	-
Frame (UPVC)		20.31 % ↓	-
WWR	20%	60.34 % ↓	60.89 % ↓
	40%	20.11 % ↓	20.24 % ↓
	60%	15.11 % ↑	19.84 % ↑
	80%	35.61 % ↑	40.61 % ↑
Height	1 m	20.21 % ↑	2.55 % ↓
	1.5 m	37.13 % ↓	8.76 % ↑
	1.75m	37.13 % ↓	8.76 % ↑

CONCLUSIONS

As simulation is considered as one of the new tools to evaluate the energy performance of buildings, the importance of using this tool in decisions in the early stages of architectural design is increasing. In this study, in addition to identifying the optimal variables in the design and implementation of windows in the cold and mountainous climate of Tabriz, the sensitivity index of each variable in a medium-sized residential building is also investigated. For this purpose, using the parametric optimization method, the simulations of middle-level residential buildings in the mentioned variables were investigated. The main findings and limitations for future research are summarized as follows:

- Based on the results of sensitivity index analysis in the parametric optimization method, decreasing the window-to-wall-ratio from 50% to 20% and also from 50% to 40%, reduces heat loss by 60.34% and 20.08% and replacing double and triple-glazed glazing with low emission coating filled with argon gas with clear single-glazed glazing reduces heat loss by 69.05% and 75.24%, respectively.
- Analysis of sensitivity index in the window performance variables (change of glazing type) shows less sensitivity in the amount of electricity consumed annually for lighting (relative to the amount of heat loss) equal to 4.18%, 5.42% and 6.25%, respectively.

- Findings show that in the parametric method, an intermediate residential building with a rectangular shape and orientation of 12 degrees to the southeast with the window-to-wall-ratio of 20% and low-emitting triple-glazed glazing on the outer covering of the inner glaze is filled with argon gas with a heat transfer coefficient of 1.058 W/m^{2}k with a UPVC frame and a canopy depth of 48 cm is suitable in the city of Tabriz.
- In order to improve the thermal performance of windows and increasing solar gain exterior; it is better to design the height of the window between 1.5 to 1.75 meters.

The limitations of this research are as follows:
- Due to the length of the simulation process by the software, in this study only 10 variables were examined and variables such as different heights of residential buildings and other building forms were not examined in this study and should be considered in future research.
- Due to the fact that the parametric optimization method requires powerful computer hardware for simulating to be complete, it is necessary to simplification the modelling, which execute the computational conditions with relatively less accuracy than the fact.

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Persian Abstract

چکیده

پنجره‌ها در ساختمان بزرگترین عناصر اتلاف حرارت از طریق همرفت هستند. هدف از این پژوهش، انتخاب ابعاد مناسب برای پنجره‌ها نسبت به پوسته و شیشه مناسب برای پنجره‌ها جهت دستیابی به الگوی بهینه در راستای کاهش مصرف انرژی است. روش تحقیق بر اساس شبیه‌سازی و ابزار تحقیق نرم‌افزار دیزاین بیلدر است. از این رو، مقدار گاز طبیعی سالانه مصرف شده در ساختمان مورد مطالعه از شرکت ملی گاز ایران دریافت و سپس مدل اولیه تحقیق در نرم‌افزار مدل‌سازی و پس از تبدیل واحد از کیلووات ساعت به مترمکعب و راستی آزمایی نتایج شبیه‌سازی، سپس، محدوده ۲۰ درصد تا ۸۰ درصد نسبت مساحت پنجره به پوسته، انواع شیشه و ارتفاع پنجره در نظر گرفته شده و از طریق بهینه‌سازی پارامتریک،کلیه شرایط در پنجره‌ها شبیه‌سازی و شاخص حساسیت تحلیل می‌شود. محاسبات تایید می‌کند که در یک ساختمان مسکونی میان‌مرتبه با چرخش ۱۲ درجه به جنوب‌شرقی در تبریز، با کاهش نسبت مساحت پنجره به پوسته از ۵۰ درصد به ۲۰ درصد و جایگزینی شیشه سه‌جداره با پوشش کم‌گسیل پرشده با گاز آرگون با شیشه یکجداره شفاف و قاب یو پی وی سی و سایبان با عمق ۴۸ سانتیمتر و پنجره به ارتفاع ۱/۵ متر، اتلاف حرارت بترتیب ۶۰/۳۴ درصد و ۷۵/۲۴ درصد کاهش می‌یابد.