Energy Efficiency (2020) 13:159–176
https://doi.org/10.1007/s12053-019-09831-w

ORIGINAL ARTICLE

Interaction of glazing parameters, climatic condition and interior shadings: performing energy and cost analysis in a residential building in Iran

Fatemeh Yousefi · **Yaghob Gholipour** ·
Yadollah Saboohi · **Wei Yan**

Received: 13 February 2018 / Accepted: 5 November 2019 / Published online: 21 December 2019

Abstract In this paper, the interaction between various window specifications and different climate conditions is investigated. For this purpose, simultaneous effects of several aspects including glazing system, glass type, filling gas, glass thickness, window frame fraction, and interior shading are considered under three different climatic conditions. To evaluate the energy performance of various considered alternatives, the energy simulation of a base case building is evaluated in a computer environment. Using the validated model, the energy analysis is quantitatively performed, and cost-benefit analyses from the viewpoints of both residents and government are carried out based on the domestic and international prices of energy carriers, respectively. Moreover, three levels of energy consumption are considered for the cost-benefit analysis to present a better insight about the effects of occupants' behavior on the results of the financial investigation. Based on the results of the study, argon gas can be recommended to be applied in the window glazing systems in cold-dominated climate zones from both energy and economical points of view. This gas in addition to the Low-e coating is very efficient to be applied in all considered climate zones from the viewpoint of the government. The payback period of using these two items is less than 4.5 years in cold, hot, or semi cold-hot zones for the considered building. The positive effects of Low-e coating on the reduction of thermal energy consumption in cold cities are improved (by 60%) when the windows are covered by interior shadings. The study emphasizes the importance of considering interior shadings in energy simulation analyses because of their significant impacts on the results of the energy evaluation.

Keywords Glazing parameters · Building · Energy consumption · Climate · Cost analysis

Introduction and literature review

Building sector is the most energy consumer in the world (Yang et al. 2014). Based on several reports of the Iran Energy Organization Efficiency of Iran, more than 33% of produced energy between 2006 and 2014 has been consumed by this sector (Iran Energy Efficiency Organization n.d.). Among the various building types, the main part of the energy consumption allots to the residential buildings (Pérez-Lombard et al. 2008). Increment of the energy consumption rate in the world

F. Yousefi
School of Civil Engineering, College of Engineering, University of Tehran, 16th Azar St., Enghelab Sq., Tehran, Iran

Y. Gholipour (✉)
Engineering Optimization Research Gr., College of Engineering, University of Tehran, 16th Azar St., Enghelab Sq., Tehran, Iran
e-mail: ygholipour@ut.ac.ir

Y. Saboohi
Sharif Energy Research Institute, Sharif University of Technology, Tehran, Iran

W. Yan
Department of Architecture, Texas A&M University, College Station, Texas, USA

(Pérez-Lombard et al. 2008) (and in Iran (Iranian National Oil Company 2012)), the dominated number of the residential buildings, and the fossil fuel crises has made the administrators to consider the residential buildings as the main part of the energy-saving plans. Although the residents' behavior plays a very important role in the energy performance of a building (Hoes et al. 2009) , properly designing of a building geometry is the first step generally considered in energy-saving strategies (Smeds and Wall 2007). One of the best solutions for minimizing energy consumption in a new building is employing an energy-efficient envelope (Tsikaloudaki et al. 2015). The building envelope, as the heat exchanging interface between interior and exterior part of a building (Raji et al. 2016), consists of various elements including window and shading devices. Windows can have a big impact on the heat exchange of the buildings even if their area is a small part of the building's façade area. According to Mirhashemi et al. (2010), windows are responsible for 15–20% of heat flow through the new building envelope which may increase to 30% for old buildings.

It should be considered that energy balance of a window and the effect of window properties on the building energy demand are a complex interaction of a large array of parameters (Grynning et al. 2013). Among the ten building envelope parameters studied by Yong et al. (2017) in eight various climates, window insulation and solar heat gain coefficient (SHGC) are presented as the significant parameters responsible for 25 and 43% of the building heating and cooling load variation (respectively) with the design alteration. SHGC can be computed in terms of solar transmittance, solar absorbance, heat transfer coefficient, and surface heat transfer coefficient (Kiran Kumar et al. 2018).

Based on the work by Alaidroos and Krarti (2015), glazing type characterized by low SHGC and U-values will decrease the building energy consumption in hot climate zones. In fact, low SHGC reduces solar heat gain, and low U-value results in reduced cooling load, which therefore are desirable in hot climate zones. The study concludes that about 10% of energy saving can be achieved if the window glazing type changes from single pane clear glazing to argon-filled double pane with tinted selective Low-e glazing characterized by low SHGC and U-values. Bui et al. (2017) confirms that there is a good correlation between window U-value and SHGC with energy saving in a tropical climate like Singapore. This work concluded that using a glass with low SHGC is much more effective than a glass with low U-value for saving cooling energy in a hot climate.

Although low U-value and low solar transmittance can be useful during summer, they may increase energy usage during winter through decreasing the solar gains which can overcome the reduction of thermal losses. Gasparella et al. (2011) showed that low thermal transmittance glazing accompanied by high solar transmittance and selective shading systems are very useful for both winter and summer performances. However, results of a parametric work on a reference room in Coimbra, Portugal (Amaral et al. 2016), indicate that window overhangs do not remarkably improve the room's thermal energy performance but allow bigger window sizes without compromising thermal efficiency.

While there is no correlation between the thickness of the glass pane and U-value of the window (Granzotto et al. 2017), the window's U-value is mainly determined by the number of its glass panes. As the layer of the glass pane increase, the buildings' heat gain decreases (Puttaranga et al. 2017). Karabay and Arıcı (2012) demonstrates through a thermos-economical optimization that the optimal number of panes depends on the climatic zone and the type of used fuel. Arıcı and Kan (2015) presented a correlation for predicting U-value of multi-pane windows considering the number of the glass panes, gap widths between the panes, and emissivity of glass coatings for air and argon gas fillings. The paper shows that the most reasonable gap width between the glass panes are 12 mm in Turkey. Although the window U-value decreases as the gap width increases, the increment is insignificant beyond the gap width of 12 mm. Significant savings in the energy loss can be made if the optimum thickness value is applied based on the climate condition, fuel type, and base temperature (Arıcı and Karabay 2010).

Naturally, the traditional and inexpensive gas for filling the gap between glass panes of the fenestration products is normal air. As air has relatively high U-Value, argon has become in popular use as gas fill in today's window products (Jelle et al. 2012). Krypton with lower U-value than argon is another noble gas that is used in high performance windows, but it is not as widespread as argon because of its higher cost (Jelle et al. 2012).

Applying Low-e coating is another way to improve the energy performance of windows. However, the thermal insulation of windows cannot be guaranteed by the Low-emitting treatments on glasses unless it is accompanied by low heat transfer frame such as PVC (Granzotto et al. 2017). PVC frame has better performance than aluminum and wood frames in terms of thermal insulation (Van Den Bossche et al. 2015) and airtightness (Feijó-muñoz et al. 2019). "Airtightness is of vital importance for thermal insulation performance of windows" (Cuce 2017) and is highly affected by construction features and the window frame length (Sfakianaki et al. 2008). Frame length can be determined by the window size and its frame fraction. Effects of the frame fraction on the window efficiency was studied in a work by Tsikaloudaki et al. (2015). The results show that the cooling energy for windows of the same characteristics decreases as the frame fraction increases in the warm climate of the Mediterranean regions.

Cuce and Riffat (2015) as well as Hee et al. (2015) briefly reviewed many other previous studies and provided an overview on glazing types. From this literature review, it can be concluded that the effectiveness of the glazing types is highly influenced by the building location and the climatic condition (Banihashemi et al. 2015). Most of the studies in this field performed in Iran have focused on the thermal effects of various glazing types in a certain climate condition. For example, a study performed in a three-story residential building in Tehran (Arabzadeh Esfarjani and Kazemzadeh 2006) concluded that employing double-pane glazing instead of single-pane one can reduce the thermal loads and total heat energy consumption up to 11% and 9.4 %, respectively.

Ebrahimpour and Maerefat (2011) showed that the Low-e glazing types are more effective than double-pane clear glazing for a residential building in Tehran. Zomorodian and Tahsildoost (2017) confirmed the conclusion in their study on a classroom in Tehran. The study suggests to use low U-values and low SHGC glazing such as Low-e glazing in both north- and south-faced classrooms. It was discussed that the impact of Low-e glazing is compatible with clear windows and external shadings.

It is shown by Ghafari Jabari et al. (2013) that the residential building's thermal energy demand in Tehran can be decreased by 10% and 16% if double-pane clear and double-pane Low-e glass windows replace the clear pane glass windows, respectively.

Kari et al. (2017) performed energy and cost analysis for using Low-E coating in the windows. The study shows that using Low-e coating in a double glazing system can considerably reduce cooling load in the hot climate; however, using this type of glazing in a cold climate is not economically sensible considering the low price of the energy carriers in Iran.

To conclude the literature review, most of the previous studies in the field of window energy performance have generally considered limited number of glazing parameters or specific climate. Moreover, the simulations employed in these studies are mainly based on the researchers' assumptions without any validation with respect to the real data. The present study has three different perspectives with respect to the previous ones. First, a comprehensive parametric study including the effects of various active factors is considered to evaluate the proper interaction of climate zone, window variables, and interior shading. For this purpose, simultaneous effects of several aspects including the glazing type, filled gas, glass thickness, interior shading, and frame fraction are considered in various climatic conditions. It can be seen that the main focus of the study is on the window glazing parameters (as the most sensitive part of the building envelope in term of thermal insulation (Cuce n.d.)), and frame is treated in a simple way. Second, the analysis is performed by using a validated building simulation model based on the real building data for energy consumption. Third, financial analysis is carried out to understand the cost benefit of the glazing systems using both domestic and export prices of energy carriers. The results of the study may help the early architectural design stage to utilize a better insight about the thermal energy performance of the windows.

The methodology and the building simulation used in this study are explained in the next section. Then, the impact of various window parameters on the building thermal energy consumption is discussed for different climate conditions. Finally, related cost analysis is presented for various glazing systems.

Methodology

In this study, a typical residential building has been selected as the case study for evaluating the energy performance of window parameters.

The residential building selected in this study is an existing multifamily four-story building with two apartments in each floor, as shown in Fig. 1. The geometry and floor plan of this building are a typical example of multifamily apartments constructed in Iran. The total building floor area (including four residential floors and one parking floor) and outdoor gross wall area are 1310 m^2 and 881.6 m^2, respectively. The window-to-wall ratio (WWR) is about 0.42 for north and south directions and about 0.02 for east and west direction. As can be seen in Fig. 1, the building is adjacent with other residential buildings from both east and west sides that are very common in big cities of Iran. The gap between the considered building and each adjacent building is about 0.3 m which prevents any windows to be designed on the main east and west facade.

The main structure of the building is made of concrete frame, EPS block joist ceilings, and concrete block walls with several layers of materials for each element. All windows of the building are composed of double clear glazing system and UPVC frame.

Heating and cooling system of each apartment is electric packaged terminal air conditioner, hot water heating coil, and gas fuel boiler. Since the building is fully occupied, both thermal comfort range (22.5 to 27.5 °C) and occupation behavior were considered to adjust thermostats' set point for each apartment based on (Heidari 2009). Infiltration rate is defined as 1 ac/h based on the estimated infiltration rate proposed by ASHRAE for average houses. Occupancy schedules are also applied in compliance with design flow rate to perform ventilation rate.

Other specifications of this building can be found in the authors' previous study (Yousefi et al. 2017). In (Yousefi et al. 2017), the authors developed an energy model of the above described building for evaluating the effects of building occupant behavior on the energy performance of envelope materials. The geometry of the building and the detached adjacent buildings were designed in Ecotect 3D, and other energy input design factors were directly defined in EnergyPlus. Except considering the shading effects of the adjacent buildings which can be calculated by EnergyPlus, the effects of other surrounding objects are ignored mainly because of their distance from the considered building and the limitation of their height. The authors examined the validity of the energy model based on the real data of energy consumption in the considered building and showed that the internal load intensity can affect the material energy performance. The study emphasises on applying actual (or near actual) occupant data for analyzing energy performance of building materials (Yousefi et al. 2017). It briefly presents the impact of few glazing systems on the building energy consumption too.

In the present study, the most important glazing parameters are deeply studied to understand how they affect the window energy performance from technical and economical viewpoints in Iran. EnergyPlus is selected to perform the building operating energy analysis. It is a well-known open-source whole-building energy simulation tool supported by the US Department of Energy. Validation of this simulation tool that can properly simulate a building very close to the real condition was examined in several studies (Ghafari Jabari et al. 2013) (Henninger et al. 2003) (Zhao et al. 2013).

Among the various algorithms available in EnergyPlus for heat balance, conduction transfer function (CTF) is used to determine heat transfer in the building envelope. For outside and inside surface convection algorithm, DOE-2 and TARP are applied, respectively. The number of time steps for dynamic thermal simulations is set to 6 (equal to 10-min intervals), recommended by EnergyPlus, and 12 average monthly temperatures are defined for the ground temperature. Maximum figures in shadow overlap calculations are

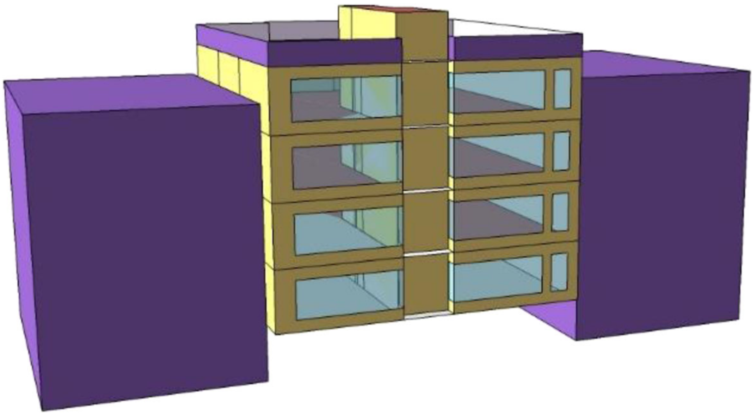

Fig. 1 Rendering for the selected building energy model (northeast aerial view)

also set to 50,000 to have a better control over details of solar, shadings, and daylighting calculation.

The schematic diagram of the problem is shown in Fig. 2. in which one of the apartment located in the 2nd floor of the building is displayed as sample.

The various glazing parameters considered in this study can be seen in this figure. Several glass thicknesses, various glass types, frame fraction, and filling materials for multi-pane windows are investigated separately in this study to classify their influence on the thermal energy consumption of the building. Thermal energy consumption is calculated in Excel by considering heating and cooling energy consumption of the building given by EnergyPlus. Based on the results of the thermal energy analysis, some of the best options for each parameter are chosen for integrated analysis as well as cost-benefit analysis. The analysis is done for hot-humid, cold-dry, and semi cold-hot climatic conditions. Bandar Abbas City that is a semi-desert region placed in the south part of Iran along the Persian Gulf is selected as the representative of hot-humid climate condition. This coastal area is known for long hot and humid summers with moderate winters. On the other hand, Tabriz City located on the northwest mountain region part of Iran is considered for cold-dry climate zone. It experiences very cold long winter and semi-hot dry short summer. Tehran, which is the location of the considered building, is the third city selected for semi cold-hot climate condition. The hottest months of the year in this city are from mid-July to mid-September with the average temperature about 28–30 °C. The most important climatic design parameters of the selected zones are described in Table 1.

Effects of window parameters

In this section, we use the validated model introduced in previous section and detailed in (Yousefi et al. 2017) to investigate the effects of various window parameters on the building energy usage. Three glazing types including triple, double, and single pane glazing, as well as four glass types including clear, tinted, reflective, and Low-e glasses, are considered in analyses for parametric study. Visible transmittance and solar energy in these glasses are ranged from low to high intensity. In reflective glasses, different types of metal cover are considered in the parametric study. These covers can change

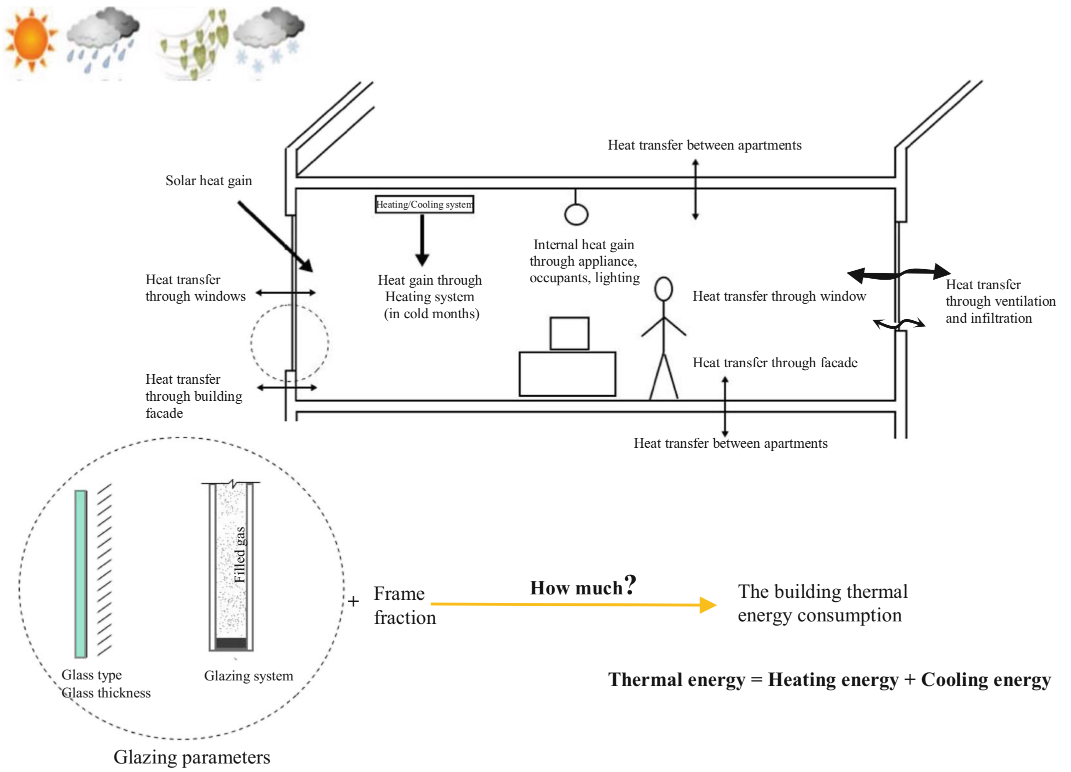

Fig. 2 Schematic diagram of the investigated problem

Table 1 Design day specification for the considered location

City	Climatic condition	Design day type	Maximum dry bulb temp.	Daily dry bulb temp. range	Dew point at max. dry bulb
Bandar Abbas	Hot-humid	Summer	41.8	7	23.7
		Winter	9.3	0	−9.2
Tabriz	Cold-dry	Summer	35.2	12.1	16.6
		Winter	−10.9	0	−17.1
Tehran	Semi cold-hot	Summer	38.5	10.6	19
		Winter	−2.8	0	−13

the ability to transmit light and absorb the heat. Specifications of the various glasses considered here are tabulated in Table 2.

Effects of glass type

To study the effects of glass type on the energy usage of a building, the single pane type is considered for all windows, and constant thickness is applied for glasses. Researchers normally did not consider the interior shading in their analysis of the glazing systems; however, it can affect the results of the study if the interior shading covers the windows in practice. Windows of residential buildings in Iranian big cities are normally covered by thick curtains or blinds and rarely opened by the occupants. Therefore, the effects of these interior shadings are investigated in this study (see Fig. 3). The considered shadings are horizontal blinds with fixed slat angle 45° and slat conductivity 44.9 w/m.k that assumed to be always on. Results of the simulation are compared with the clear glass type in various climates of Iran for two conditions: 1) the windows are not covered, and 2) the windows are covered by interior blind reflecting considerable amount of solar energy during hot months.

Table 2 Glass pane materials' specifications based on the EnergyPlus input requirements (Ernest Orlando Lawrence Berkeleey National Laboratory n.d.)

	Solar transmittance	Solar reflectance at		Visible transmittance	Visible reflectance		Infrared hemispherical emissivity	
		Front	Back		Front	Back	Front	Back
Clear 4 mm	0.816	0.074	0.074	0.892	0.081	0.081	0.84	0.84
Clear 6 mm	0.775	0.071	0.071	0.881	0.08	0.08	0.84	0.84
Gray 4 mm	0.569	0.058	0.058	0.551	0.058	0.058	0.84	0.84
Gray 6 mm	0.455	0.053	0.053	0.431	0.052	0.052	0.84	0.84
Green 4 mm	0.586	0.061	0.061	0.798	0.073	0.073	0.84	0.84
Green 6 mm	0.487	0.056	0.056	0.749	0.07	0.07	0.84	0.84
Bronze 4 mm	0.591	0.059	0.059	0.635	0.062	0.062	0.84	0.84
Bronze 6 mm	0.482	0.054	0.054	0.534	0.057	0.057	0.84	0.84
Low-E clear (Low-e) 4 mm	0.62	0.18	0.22	0.847	0.0556	0.0787	0.84	0.1
Low-E clear (Low-e) 6 mm	0.6	0.17	0.22	0.84	0.055	0.078	0.84	0.1
Low-E clear rev (Low-e R) 4 mm	0.62	0.22	0.18	0.847	0.0787	0.0556	0.1	0.84
Ref A clear HI (RefA) 6 mm (high transmittance stainless steel coating)	0.159	0.22	0.37	0.2	0.25	0.32	0.84	0.57
Ref B clear HI (RefB) 6 mm (high transmittance titanium coating)	0.24	0.16	0.32	0.3	0.16	0.29	0.84	0.6
Ref C clear HI 6 mm (high transmittance pewter coating)	0.2	0.16	0.39	0.22	0.17	0.35	0.84	0.55

The energy analysis shows that interior shadings can significantly increase the thermal energy usage of the building in cold climate or climate with cold winter. The percentage of this increment for the considered building in the cold climatic condition of Tabriz is about 6.5%, 5%, 4.5%, and 4% for clear, tinted, Low-e, and reflective glass type, respectively. However, in hot climate, the interior shading has generally lower effect than cold climate but can decrease the building energy consumption for clear, tinted, and Low-e glass types.

The existence of interior blinds can diminish the change of thermal energy consumption (or the relative thermal energy performance) for all types of considered glass (in the range of 60% to 90) except Low-e one (Fig. 4) which can noticeably affect the strategy of glass type choosing.

As can be seen in both graphs of Fig. 4, all types of tinted and reflective glass have different energy performance in hot and cold climates. The energy performance of this glass in cold climate (Tabriz) is worse than clear glass. Instead, they are more efficient in hot climates (Bandar Abbas) due to their lower absorbing coefficient. As mentioned before, the amount of influence completely depends on the availability of the interior shading in which the energy performance of various glass type in hot-humid climatic condition of Bandar Abbas can reduce from averagely 8 to 2.5%.

In the case of the presence of interior blind, tinted glass has a very low effect on the thermal energy consumption (+0.3% and−0.9% with respect to the clear glass for cold and hot area, respectively). However, if the widows are not covered with interior shading, the change will increase to about 1.7% (for cold climate) and −4.5% (for hot climate). It should be noted that visible transmittance of tinted glasses (0.82 for green, 0.68 for bronze, and 0.61 for grey glass) is also a very important factor for selecting the most effective window. Due to the equal performance of green, grey, and bronze glass in hot climates, the green glass is more recommended because of its higher ability to pass the visible light.

Reflective glasses covering with interior blind can also increase the energy consumption less than 1% depending on the coating type in the cold climate of Tabriz. For hot climate where the optimization of cooling load is important, this type of glass has better performance. They can reduce the energy usage by about 4% (for considered building) through decreasing the solar heat absorption. Between various reflective glasses, those coated with stainless steel (RefA) with lower solar transmittance show better performance (about 40% with respect to titanium coating) in hot climates. If the windows are not covered with blind, reflective glass can reduce the building thermal energy more than 10% in a hot climate zone which is a very considerable value. Using this type of glazing system should also be considered with more attention especially when the windows are not covered with interior shading because they strongly reduce the natural light.

It is interesting to consider the effects of interior shading on the performance of Low-e glass types (Fig. 4). If these glasses are covered with interior shading, their relative energy performance (with respect to clear glass) will be slightly improved in cold climatic conditions. In hot climate, however, interior shading leads to reduce this relative performance.

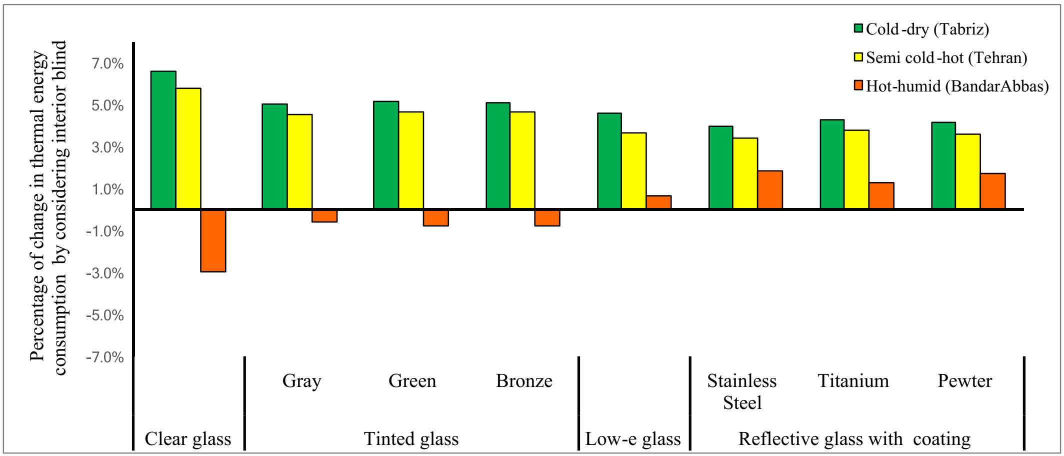

Fig. 3 Thermal effects of the interior shading for various glass types (source energy)

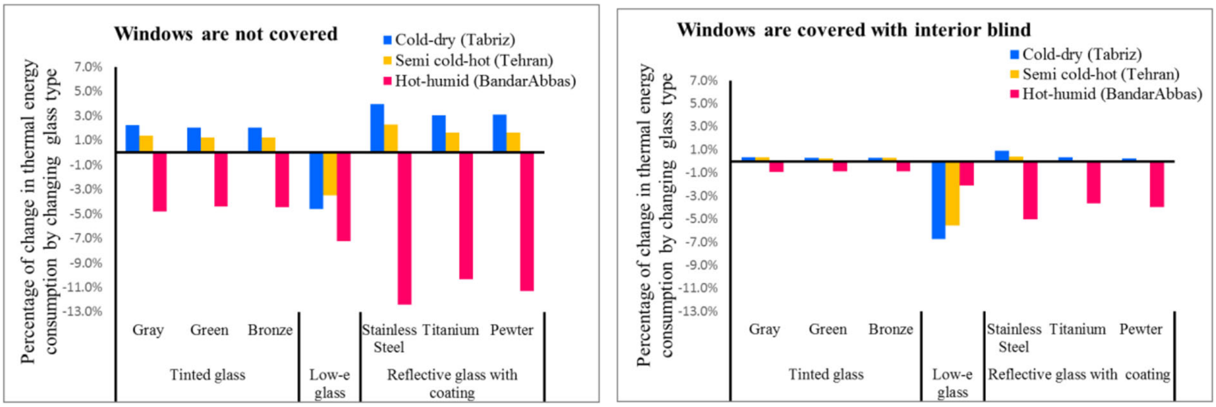

Fig. 4 Simulation results of the various glass types' energy performance (source energy)

Low-e glass, instead of clear and tinted glass, is the only type of glazing that can be recommended for both hot and cold climates to save energy. This is due to its high solar transmittance and low solar reflectance. However, its performance with respect to the reflective glass depends on the climatic condition and availability and properties of the window's interior shading.

Effects of glass thickness

In this section, the effects of glass thickness are investigated by changing it from 4 to 6 mm. The system of all windows is considered to be single-pane glazing. As can be seen in the results presented in Table 3, increasing glass thickness can lead to various amount of change (up to 1%) in the building energy usage depending on the glass type, climatic condition, and window shading. If the windows are not covered with interior shading, thicker glass increases heating usage and decreases cooling usage. Therefore, they can reduce the building source energy consumption in hot climate and increase it in cold one. In addition, this change in hot zone is higher than that of cold climate.

Low-e and clear glass are not as sensitive as tinted glass to the glass thickness especially in cold climate zones. For Low-e glass type, increasing the glass thickness can slightly reduce the building thermal energy consumption (about 0.2%) in hot climate zone and lead to a negligible change in cold climate. However, 6 mm tinted glasses decrease the building thermal energy consumption up to 1% in hot climate zone of Bandar Abbas. Overall, it can be concluded that the higher thickness seems to be more efficient in hot climate especially for tinted glasses rather than clear or Low-e ones.

Again, using the interior blind could considerably reduce the energy performance of both considered glass thicknesses. The relative energy performance of thicker glasses with respect to thinner one is improved in cold

Table 3 Percentage of change in the building thermal energy usage by increasing the glass thickness from 4 to 6 mm

Climate condition	Clear glass	Tinted glass			Low-e glass
		Grey	Green	Bronze	
Windows are not covered					
Cold-dry (Tabriz)	0.0%	0.5%	0.4%	0.5%	0.0%
Semi cold-hot (Tehran)	0.0%	0.5%	0.4%	0.5%	0.0%
Hot-humid (Bandar Abbas)	−0.4%	**−1.0%**	−0.9%	−1.0%	−0.2%
Windows are covered with interior blind					
Cold-dry (Tabriz)	−0.3%	0.0%	0.0%	0.0%	−0.1%
Semi cold-hot (Tehran)	−0.3%	0.3%	0.3%	0.3%	−0.1%
Hot-humid (Bandar Abbas)	−0.1%	−0.2%	−0.1%	−0.1%	−0.1%

climate when the interior shading is present; however, the maximum change of the building energy consumption decreases from 1 to 0.3%.

Effects of filling material

Here, the type of the filling material used between various layers of multi-pane windows is changed from air to argon gas, and the results of numerical simulation for variation of energy consumption are presented in Table 4. As can be seen in the table, using argon gas can reduce the building thermal energy consumption up to 2% (equal to 15 GJ) for the base case model that windows are covered with interior shading. It is also shown that the effect of using argon gas is more noticeable in Low-e glazing (this finding is similar to the results of (Arıcı and Kan 2015)) and is more highlighted in the cold climate rather than hot climate. Replacing air with argon in double-pane Low-e glazing windows will lead to 2% reduction in the building's thermal energy usage in cold-dry climate zone, while substitution of air with argon in other double-pane and triple-pane glazing systems causes lower reduction (up to about 0.8% and 1.4%, respectively, for the considered building). It can be understood from the results that interior shadings do not affect greatly on the energy performance of the filling materials.

Effects of window frame fraction

The buildings' window frame is made of UPVC material and is simulated as single frame in EnergyPlus. In order to study the effect of the frame fraction, several horizontal and vertical UPVC dividers are added to the window structure. Four different frame fractions were investigated including 8% (main frame without any divider), 12% (main frame plus one horizontal and vertical divider), 16% (main frame with two horizontal and vertical dividers as the base case), and 28% (the maximum frame fraction, equal to five vertical and horizontal dividers added to the windows frame). It should be mentioned that for all of the considered cases, the thickness of the windows' main frame remains constant. The simulations were performed for two glazing systems as well as two interior covering conditions.

Results of the analyses separately presented in Fig. 5 show that as the frame fraction increases, the cooling energy decreases (which is compatible with the results of reference (Tsikaloudaki et al. 2015)), and the heating energy increases. Increment of the frame fraction from 12 to 28% in double clear glazing system leads to +1.6% and −2.8% change in the thermal energy usage for Tabriz (cold climate) and Bandar Abbas (hot climate), respectively. It should be noted that the glass type and the presence of interior shading also affect the magnitude of this change.

The effect of the frame fraction when there are interior blinds can be seen in Fig. 5b. The presence of interior shading raises the relative thermal energy usage in the cold climatic condition (up to about two times for the considered case) and slightly lowers the relative energy load in hot climate zone. The same trend would be observed if the higher performance glazing system (Low-e glazing) is applied.

Table 4 Percentage of change in thermal energy usage by changing gas fill from air to argon

Climate condition	Double-pane glazing with various outer layer (inner layer is clear glass)				Triple-pane glazing with various outer layer (inner and middle layer are clear glass)	
	Clear glass	Tinted glass	Low-e glass*	Ref A or B glass	Clear glass	Low-e glass*
Windows are not covered						
Cold-dry (Tabriz)	−0.7%	−0.7%	−1.8%	−0.7%	−0.8%	−1.3%
Semi cold-hot (Tehran)	−0.5%	−0.5%	−1.3%	−0.6%	−0.6%	−1.0%
Hot-humid (Bandar Abbas)	0.0%	−0.2%	−0.2%	−0.4%	0.0%	−0.1%
Windows are covered with interior blind						
Cold-dry (Tabriz)	−0.8%	−0.8%	**−2.0%**	−0.8%	−0.9%	−1.4%
Semi cold-hot (Tehran)	−0.6%	−0.6%	−1.5%	−0.7%	−0.7%	−1.1%
Hot-humid (Bandar Abbas)	0.0%	−0.1%	−0.2%	−0.4%	0.0%	−0.1%

*In cold and semi-cold cities, Low-e coating is applied on the outward face of the inner pane (known in the window industry as surface #3 and #5 in double- and triple-pane glazing system, respectively)

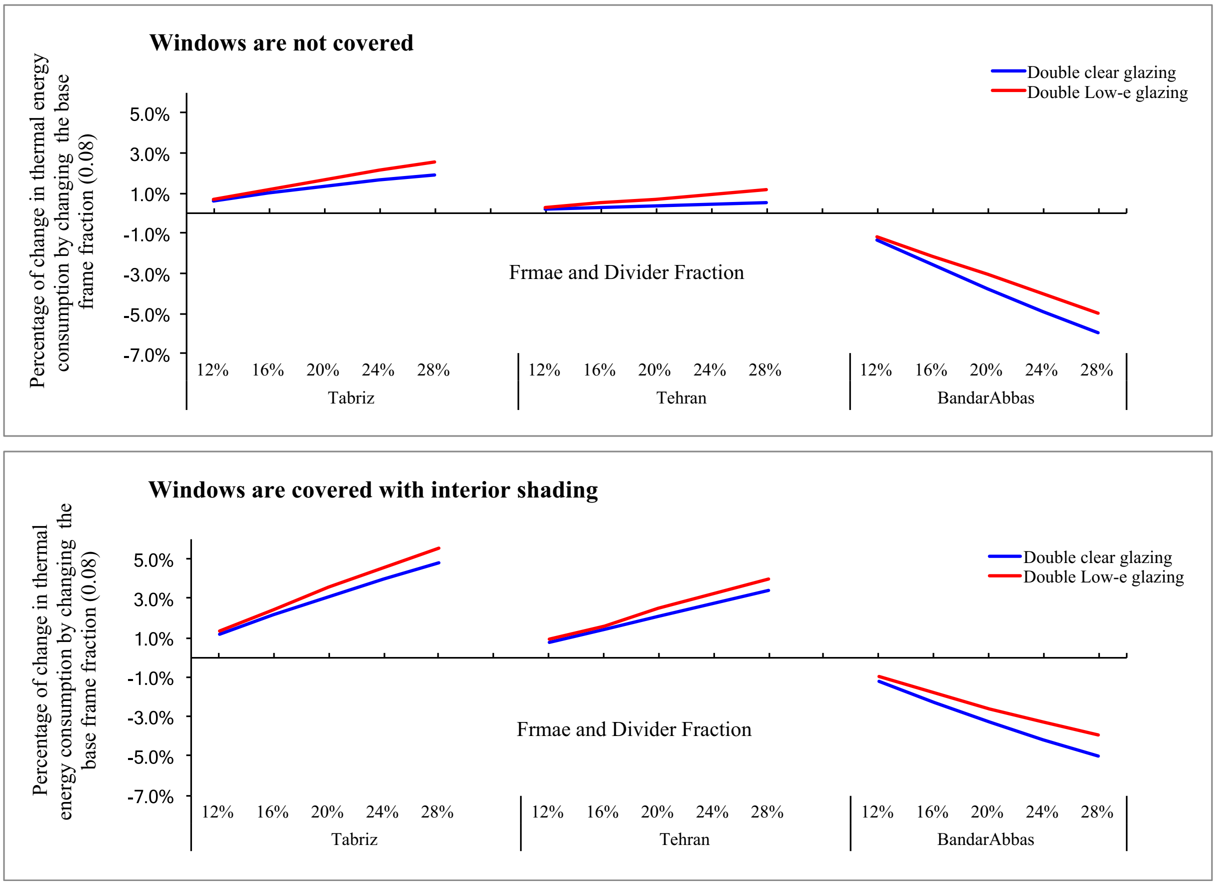

Fig. 5 Simulation results of the various frame fractions (source energy)

Integration of the optimal window design solution

According to the results presented in previous sections, some combined design options (as can be found in Fig. 6) are considered and applied in the base model. Results of the simulation for these various glazing systems are compared with single glass pane window in Fig. 6. It is seen that the double clear glazing which is widely used

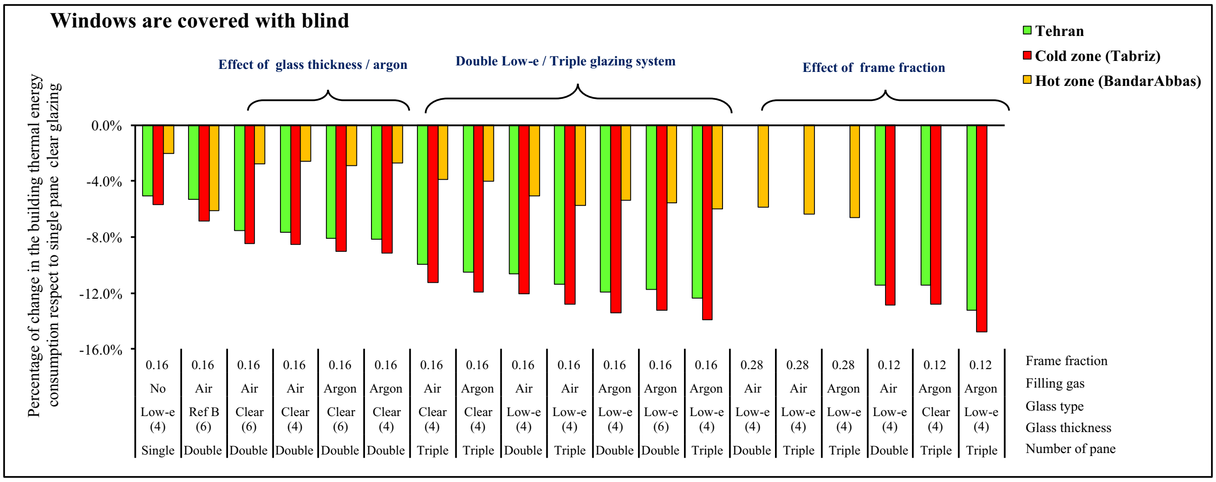

Fig. 6 Energy performance analysis of the various glazing systems

Table 5 Domestic price of energy carriers in terms of gas and electricity

	Gas for heating (\$/m^3)		Electricity for cooling (\$/kwh)	
	Tehran and Tabriz	Bandar Abbas	Tehran and Tabriz	Bandar Abbas
Building with low rate of energy load	0.016	0.01	0.012	0.004
Base case building (moderate demand)	0.036	0.016	0.029	0.005
Building with high rate of energy load	0.082	0.029	0.076	0.035

in residential buildings can reduce thermal energy consumption of the considered building by about 8.5% and 2.5% in cold and hot climates for the considered case, respectively. Covering glass with Low-e coating or adding the number of glazing pane can noticeably increase the window energy performance. Double-pane Low-e and triple layer glazing are more energy-efficient windows in cold climate condition that can reduce the thermal energy consumption by more than 11%. Their performance to reduce the thermal energy usage in hot zone is also acceptable (about 4–6.5%). Moreover, the results show that using reflective glass through double-pane glazing systems can compensate its drawback on energy consumption in the cold climate. Although double reflective glazing is not an efficient option in cold zones, its performance in the hot climate is better than multi-pane Low-e glazing system for saving thermal energy of the buildings. Results of the previous analysis (Fig. 16 of (Yousefi et al. 2017)) show that using single-pane reflective glazing instead of double pane clear one can reduce the thermal energy usage of the considered building by about 3.5%.

The analysis shows that triple-pane Low-e glazing system filled with argon is the best energy-efficient glazing that can be used in all considered climates. It causes about 16, 12.5, and 6% energy reduction for the considered building in cold-dry, semi cold-hot, and hot-humid climate zone, respectively. Low-e coating and argon gas accompanied with multi-layers of the glass and space make this window more effective than others. Although the energy performance of the windows rises by using these options, it should be noted that they increase the cost value of the windows that may affect the material selection strategy.

Table 6 Price of window elements

Item per m^2	Price (\$)
Single-pane glazing	7.84
Double-pane glazing	21.38
Triple clear glazing	32.54
Argon	0.71
Frame (per m)	19.00
Low-e coating	4.75
Double reflective glazing	27.79
Clear (6)–Clear (3)	2.61

To have a better perspective about the efficiency of the various window types, the cost-benefit analysis is also performed for most of the considered features except the frame fraction changing. Regarding to the frame fraction, it should be noticed that for a cold climate zone, the increment of frame area not only reduces the building's energy performance but also increases its construction cost since the price of UPVC frame is higher than glasses. Therefore, it is highly recommended to use the minimum possible frame fraction in cold climatic condition. For hot climate zone, although adding the frame area can improve the building energy performance, the cost of UPVC frame is high enough to compensate the related energy saving cost. So, for considered glazing systems under three climate conditions, frame fraction should be minimized as much as possible to economically optimize the energy performance.

Cost-benefit analysis

To calculate the effectiveness of various window parameters from economical point of view, cost of energy carriers should be determined. Since there is a significant difference between the domestic and export prices of the energy carriers in Iran, and because the energy prices and policies in Iran is very complicated and unstable due to the existence of the economy and politics issues, the cost analysis is performed in two stages. First, monetary saving caused by increasing the glass thickness, using argon gas instead of air, and applying

Table 7 Payback period (years) in the case of replacing air with argon gas

		Double Clear	Triple Clear	Double Low-e	Triple Low-e
Semi cold-hot (Tehran)	Low intensity	76	102	33	36
	Moderate	35	50	16	16
	High intensity	16	25	7	7
Cold-dry (Tabriz)	Low intensity	45	43	20	24
	Moderate	21	20	9	11
	High intensity	9	9	4	5
Hot-humid (Bandar Abbas)	Low intensity	345	NA	97	142
	Moderate	267	NA	78	112
	High intensity	58	NA	15	23

Low-e coating are investigated separately based on the present domestic energy prices for different window types in all considered climate zones. Second, the cost analysis is performed using international prices (export prices) of the energy carriers for various glazing system (those shown in Fig. 6) to understand the potential monetary saving that can be achieved by applying high performance windows.

Cost analysis using domestic energy carrier price

Due to the relation of energy carrier price with the climatic condition and the amount of the energy load consumed by the building's residents in Iran, three levels of energy consumption including low, moderate, and high intensity levels are considered, and the cost of energy carriers is extracted for each level in three climate zones. These values (presented in Table 5) as well as the unit price of windows element (presented in Table 6) are used to calculate the monetary value of the energy saved by various glazing systems in this stage.

The payback period method presented by Eq. 1 (Yousefi 2017) is used for cost-benefit analysis to determine the optimum glazing systems. This method calculates the required period (in years) to pay back the initial investment paid for using a specific window type. Although it is a simple method and does not account the time value of money, payback period is a suitable indicator for energy performance in Iran since the investment is provided only by the private sector and it is not owned by the government (Kari et al. 2017). Kari et al. (2017) emphasize that "in this case, only the lowest payback period provides incentive to save energy."

Table 8 Payback period (years) of Low-e coating over clear glass

		Single —	Double Air*	Triple Air*
Semi Cold-hot (Tehran)	Low intensity	44	64	92
	Moderate	20	29	40
	High intensity	9	12	16
Cold-dry (Tabriz)	Low intensity	30	46	90
	Moderate	14	21	40
	High intensity	6	9	17
Hot-humid (Bandar Abbas)	Low intensity	105	82	107
	Moderate	88	71	94
	High intensity	16	12	15

The results for argon gas are similar but slightly smaller than air

Table 9: Cost-benefit analysis of various glazing system over single pane clear one considering domestic price of energy carriers

Number of glass layer		Single	Double	Double	Double	Double	Double	Triple	Triple	Double	Triple	Double	Double	Triple
Outer Layer glass type*		Low-e	Ref B	Clear	Clear	Clear	Clear	Clear	Clear	Low-e	Low-e	Low-e	Low-e	Low-e
Outer layer glass thickness (mm)		(4)	(6)	(6)	(4)	(6)	(4)	(4)	(4)	(4)	(4)	(4)	(6)	(4)
Filling gas		—	Air	Air	Air	Argon	Argon	Air	Argon	Air	Air	Argon	Argon	Argon
Frame Fraction		0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Payback period (years)	Tehran (semi cold-hot)	20	34	40	34	40	34	45	45	33	44	31	35	43
	Tabriz (cold-dry)	14	34	30	25	29	25	34	33	24	35	23	26	33
	BandarAbbas (hot-humid)	88	119	218	197	220	200	238	237	135	191	131	145	188

*In cold and semi cold cities, Low-e coating is applied on the outward face of the inner pane (known in the windows industry as surface #3 and #5 in double and triple pane glazing system, respectively)

$$n = \frac{\mathrm{A}}{(1.09 \times \mathrm{B} + 0.0013) \times \mathrm{C} + (1.19 \times \mathrm{D}) \times \mathrm{E}} \quad (1)$$

A	The required cost for changing glazing system
B	Domestic price of a unit of electrirty in year 2019
C	Amount of electrisity saving echieved by using new glazing system
D	Domestic price of a unit of gas in year 2019
E	Volume of gas saving achieved by using a new glazing system

*All coefficients and numbers in this equation are computed by applying the value added taxes and charges used for calculating the final cost of the residential building energy usage in year 2019. Final cost is printed in Iranian users' energy bill and should be paid by the building residents. More information about the input data and the method of obtaining this equation can be found in (Yousefi 2017).

Referring to Sect. 3.2, increasing the thickness of the clear glass has always positive effects on saving thermal energy demand in hot climate zones. However, cost-benefit analysis shows that using the thicker glass is not economically recommendable even in hot climate zones from the Iranian residents' point of view.

Regarding the window filling gas, it was concluded in the previous Sect. 3.3 that replacing air with argon is more capable to reduce heating energy than cooling one especially in Low-e glazing system. From an economical point of view, the cost-benefit analysis confirms that using argon in Low-e windows can be economically reasonable in cold climatic condition. Related payback period is about 4.5, 10, and 22 years, respectively, for high, moderate, and low intensity level of energy demand in cold climate of Tabriz (see Table 7). Although payback period of using argon in clear glass windows is around two times longer than Low-e glazing systems, it may be a cost-effective option for using in clear glass windows in the cold region for moderate and high level of energy demand. In contrast, there is no economic justification for replacing air with argon in hot climates, as long as the domestic prices of the energy carriers are at the current level. Economically choosing between air and argon is more challenging in the cities with hot summer and cold winter (as Tehran). In this climate condition, it seems that replacing air with argon can be effective for Low-e windows especially in the buildings with moderate and high intensity of energy demand.

Table 10: Cost-benefit analysis of various glazing systems over double pane clear one (filled by air) considering domestic price of energy carriers

Number of glass layer		Double	Double	Double	Triple	Double	Triple	Triple	Double	Triple	Double
Outer Layer glass type*		Low-e	Low-e	Low-e	Low-e	Ref B	Low-e	Clear	Clear	Clear	Clear
Glass thickness		(4)	(4)	(6)	(4)	(6)	(4)	(4)	(6)	(4)	(6)
Filling gas		Air	Argon	Argon	Argon	Air	Air	Argon	Argon	Air	Air
Frame Fraction		0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Payback period years)	Tehran	29	26	35	53	48	59	68	100	74	209
	Tabriz	21	18	26	45	161	52	52	83	59	486
	Bandar-Abbas	71	72	101	181	91	186	307	411	317	471

These findings are based on the assumption that the performance of filled argon will stay constant during the windows' life span. Considering the polysulfide seal and assuming 1% loss of argon gas per year, it is expected that the filled argon does not lose its performance for 20 years (Schmidt 1997) that is very close to the life spans of the windows in Iran.

The last factor discussed here is Low-e coating. This coating is widely used in practice to produce high performance glazing. However, its monetary benefit is challenging because of low price of the energy in Iran. Appliance of Low-e coating in three types of glazing system is investigated in this part, and based on the driven results (presented in Table 8), Low-e coating is not cost-efficient. Using this coating can be reasonable only when the intensity of energy consumption is too high in a building. The analysis shows that it has generally lower payback period in a cold climate than a hot one. This result is against the finding of (Kari et al. 2017) that suggests using Low-e glazing windows in hot climate condition instead of cold one. This contradiction may have different reasons including the price of the energy carriers and the specification of the used model in two studies. In (Kari et al. 2017) domestic price for year 2001 is used, while in the present study, updated prices of energy carriers are applied. Kari et al. (2017) developed a hypothetical one-story building in the form of + sign, which has a window on each external wall, and its thermal comfort set point ranges are between 20 °C and 24 °C. However, in the present study, a validated model of a real building is used, and near actual occupant behavior besides updated thermostat set point based on (Heidari 2009) is applied. It seems that the results of the present study are more reliable.

The effects of some window parameters are individually discussed in the previous section. In this part, the various combinations of these parameters are economically discussed. Analysis is just performed for the moderate level of energy demand based on the current situation of the considered building. Results of the cost-benefit analysis are presented in Table 9 with the same order of Fig. 6. In some cases, the amount of the cost saving is not in accordance with the energy saving values. For instance, it is shown in Fig. 6 that the double reflective glazing has lower energy performance than the double clear one in Tehran. But cost-benefit analysis shows that the double reflective type is economically more preferable than the clear one even with its higher installation cost. This is due to the different calculation process, various prices for gas and electricity, and potential of reflective glass to decrease the cooling load more than other glass types.

The useful life span of windows in Iran is normally about 15–25 years based on the quality of

Table 11 Export price of the energy carrier

Energy carrier	Destination	Year	Unit	Unit price
Gas	Turkey	2017	m^3	42.5 cents (Eghtesad News 2017)
Electricity	Iraq	2017	kwh	10 cents (Mehr News 2017)

manufacturing and installation. It can be inferred that the glazing types with the payback period longer than 15 years are not economically desirable to be selected by the building owners. As can be seen in Table 9, payback period of all considered double- or triple-pane glazing system are more than 20 years (except single Low-e one) which makes them economically inefficient in all considered zone especially hot zone. However, it seems that there is good potential to save energy and money in a cold temperature-dominated climate if the domestic prices of the energy carriers increase about two times. Using Low-e coating with or without changing the filling gas can decrease the payback period of the double pane windows in all considered climate zones

It should be noticed that in addition to the energy efficiency and cost-effectiveness, there are several other factors that can be first considered for selecting a proper window in many cases. Being soundproof is one of these factors. Double-pane clear glazing filled by air has noise cancelling performance and is widely used by the building's owners and constructors in big-crowded cities. If the single-pane glazing is going to be replaced by double-pane clear windows, the main question is "what is the most cost-effective windows with respect to the double pane clear one?"

Considering Table 10, improving the double-pane clear window to a more energy-efficient system is not economically reasonable for all considered cities especially for hot zones. The minimum payback period in Bandar Abbas (about 71 years) is more than the normal useful life span of the windows in Iran. With the current prices of the energy carrier in Iran, there is no money interest for the building users to choose more energy-efficient glazing system than the double pane clear one.

Cost analysis using export price of the energy carriers

In the previous section, cost-benefit analysis results have been presented from the residents' point of view in which the domestic prices of the energy carriers including the governmental subsidies were considered. In this section, the cost analysis has been considered from the government point of view in which the payback periods are calculated based on the international prices of the energy carriers in the region. Export prices of gas and electricity are considered as the international prices of energy carriers (as shown in Table 11).

The results of cost-benefit analyses from the government viewpoint are presented in Table 12. These values are calculated by the following equation:

$$\textit{Payback period} = \frac{\mathrm{A}}{\mathrm{B}^{*}\times\mathrm{C}+\mathrm{D}^{*}\times\mathrm{E}} \tag{2}$$

A	The required cost for changing window type
B*	export price of a unit of electrirty in year 2017
C	Volume of electrisity saving echieved by using new window type
D*	export price of a unit of gas in year 2017
C	Volume of gas saving achieved by using new window type

As can be seen, the payback periods are reduced to maximum 12 years in all considered climates. From this analysis results, the following conclusion can be made:

1) Using Low-e glazing is recommended for all climate conditions, especially for triple-pane windows in which the payback period become more reasonable.

Table 12: Cost-benefit analysis of various glazing system over double pane window (filled by air) considering export price of energy carriers

Number of glass layer		Double	Double	Double	Triple	Double	Triple	Triple	Double	Triple	Double
Outer Layer glass type*		Low-e	Low-e	Low-e	Low-e	Ref B	Low-e	Clear	Clear	Clear	Clear
Glass thickness		(4)	(4)	(6)	(4)	(6)	(4)	(4)	(6)	(4)	(6)
Filling gas		Air	Argon	Argon	Argon	Air	Air	Argon	Argon	Air	Air
Frame Fraction		0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Payback period (years)	Tehran	3.5	3	4.5	8	NA	9.5	9	19	11	NA
	Tabriz	2	1.5	2.5	5	NA	6	5.5	10	6.5	NA
	Bandar-Abbas	4.5	4.5	6.5	11.5	6	12	19	26	20	32

2) Increasing the glass thickness is not recommended, especially for the cold climate. In the case of using thick glass, it is suggested to use argon and Low-e coating to compensate the effect of increasing the glass thickness if possible.
3) Using argon instead of air does not need considerable investment. Also, its payback period in Low-e glazing system is less than 2 years for Tabriz and Tehran and about 5 years for Bandar Abbas. Therefore, replacing air with argon is strongly recommended in Low-e glazing systems for the buildings similar to the considered building in all climate conditions. It is also advantageous to use argon in the clear glazing system for the cold-dominated climate zones.
4) Triple-pane glazing can be a proper option for all climate if Low-e coating covers its outer or inner pane (based on the climatic condition).

The results of this study can be considered in providing general policy for building construction in big cities. In year 2015, the municipality of Tehran issued many permits for construction of 970, 7688 m^2 of residential buildings in Tehran which is approximately equal to 7410 buildings similar to the one considered in this study. If the government provides the required investment for upcoming residential buildings (about 6720 thousand dollars per year) to upgrade their glazing system (from simple double pane windows to double pane Low-e argon filled glazing), the progressive net income of 2420 thousand dollars can be achieved after 4 years (from the start date of the upgrade program) which is satisfactorily acceptable. In this way, the government will benefit twice of its investment in year 9th.

Conclusion

In this work, a comprehensive parametric study is made to evaluate the energy performance of the glazing variables in various climates. For this purpose, simultaneous effects of several aspects including glazing type, filled gas, glass thickness, interior shading, and frame fraction are investigated in different climatic conditions. The analyses are performed by using a validated building energy simulation model in EnergyPlus. The results of the analysis show that:

- Interior shadings in terms of thick curtains or blinds, which are routinely used in Iranian residential buildings, should be considered in energy simulation analysis. It can significantly affect the thermal energy loads as well as the relative energy performance of the window parameters. For the considered building, the presence of the interior blind increases the building thermal load at about +6% in cold climate of Tabriz for clear glass type.
- Low-e glass is the only glass type that can be recommended for reducing the building thermal energy demand in both hot and cold climates. Using argon gas can also reduce the thermal energy load up to 2% for the considered building. The influence of using argon gas is more highlighted in a cold climate rather than a hot one. It is also more noticeable in Low-e glazing.
- Double clear glazing system can reduce thermal energy consumption of the considered building by about 8.5% and 2.5% in cold and hot climates, respectively, when it is compared with single clear pane. Applying Low-e coating in this glazing system can noticeably increase the window energy performance (up to 11% in cold climate).

To calculate the effectiveness of various window parameters from the economical point of view, monetary saving caused by various features is investigated separately, and the payback period analyses are carried out using both the domestic and international costs of energy.

Based on the domestic prices of the energy carriers, increasing the glass thickness, adding Low-e coating, and using multi-pane glazing are not economically benedictional in all climate zones. However, using argon in Low-e windows can be economically reasonable in cold climatic condition, but it is not the case for hot zones.

Based on the international price of energy carriers, using Low-e glazing is beneficial for all climate conditions, especially for double-pane windows. Also, using argon instead of air is strongly recommended for cold zones. However, increasing the glass thickness is not economically reasonable, mainly for cold cities. In the case of glass layer, the analysis shows that using double and triple glazing system can be cost-efficient options especially if they are accompanied with Low-e coating and argon gas.

Although the economic analysis and politics are very complex in Iran, the present analysis shows that, if the government of Iran provides some investment for upgrading the new buildings' glazing systems (from double pane clear windows to double or triple pane Low-e argon-filled glazing), it can get back progressive net profit after a few years by exporting the saved energy to other countries.

The present study focuses on the glazing parameters by holding some other window's parameter constant. The interaction of the window glazing factors with WWR and building direction can be achieved in the future studies. These two parameters can significantly affect the energy performance of the window system. The thermal energy consumption of the considered building rises at about 40% and 20% by increasing the WWR from 0.15 to 0.75 and changing the building direction from 0° to 120°, respectively. The effects of the window frame materials also need to be further analyzed in the future research to make the window analysis more comprehensive.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict(s) of interest.

References

Alaidroos, A., & Krarti, M. (2015). Optimal design of residential building envelope systems in the Kingdom of Saudi Arabia. *Energy and Buildings, 86*, 104–117.

Amaral, A. R., Rodrigues, E., Gaspar, A. R., & Gomes, Á. (2016). A thermal performance parametric study of window type, orientation, size and shadowing effect. *Sustainable Cities and Society, 26*, 456–465.

Arabzadeh Esfarjani, S., & Kazemzadeh, S. (2006). Energy consumption and conservation in residential buildings in Iran. In 4th Conference on Energy Conservation in Building.

Arıcı, M., & Kan, M. (2015). An investigation of flow and conjugate heat transfer in multiple pane windows with respect to gap width, emissivity and gas filling. *Renewable Energy, 75*, 249–256.

Arıcı, M., & Karabay, H. (2010). Determination of optimum thickness of double-glazed windows for the climatic regions of Turkey. *Energy and Buildings, 42*, 1773–1778.

Banihashemi, S., Golizadeh, H., Reza Hosseini, M., & Shakouri, M. (2015). Climatic, parametric and non-parametric analysis of energy performance of double-glazed windows in different climates. *International Journal of Sustainable Built Environment, 4*(2), 307–322.

Bui, V. P., Liu, H. Z., Low, Y. Y., Tang, T., Zhu, Q., Shah, K. W., Shidoji, E., Lim, Y. M., & Koh, W. S. (2017). Evaluation of building glass performance metrics for the tropical climate. *Energy and Buildings, In Press*, 1–9.

Cuce, E. (2017). Role of airtightness in energy loss from windows: experimental results from in-situ tests. *Energy and Buildings, 139*, 449–455.

Cuce, E. Glazed areas as the most sensitive part of building envelope in terms of thermal insulation performance: Current status and future prospects. In International Conference on Materials Science, Mechanical and Automotive Engineering and Technology in Cappadocia/ TURKEY.

Cuce, E., & Riffat, S. B. (2015). A state-of-the-art review on innovative glazing technologies. *Renewable and Sustainable Energy Reviews, 41*, 695–714.

Ebrahimpour, A., & Maerefat, M. (2011). Application of advanced glazing and overhangs in residential buildings. *Energy Conversion and Management, 52*(1), 212–219.

Eghtesad News (2017, May 27), 13% cut in Iran's natural gas price to Turkey, Eghtesad News. https://www.eghtesadnews.com/fa/tiny/news-169856.

Ernest Orlando Lawrence Berkeley National Laboratory. (n.d.) EnergyPlus Reference Data Set for Window Glass. EnergyPlus 8.4.

Feijó-muñoz, J., González-lezcano, R. A., Poza-casado, I., Padilla-marcos, M. Á., & Meiss, A. (2019). Airtightness of residential buildings in the Continental area of Spain. *Building and Environment, 148*(September), 299–308.

Gasparella, A., Pernigotto, G., Cappelletti, F., Romagnoni, P., & Baggio, P. (2011). Analysis and modeling of window and glazing systems energy performance for a well insulated residential building. *Energy and Buildings, 43*(4), 1030–1037.

Ghafari Jabari, S., Ghafari Jabari, S., & Salehi, E. (2013). Review Strategies for Improving the Design and Construction of Settlements in Tehran. *Energy Policy and Planning Research, 1*, 115–132 http://epprjournal.ir/article-1-26-en.html.

Granzotto, N., Bettarello, F., Ferluga, A., Marsich, L., Schmid, C., Fausti, P., & Caniato, M. (2017). Energy and acoustic performances of windows and their correlation. *Energy and Buildings, 136*, 189–198.

Grynning, S., Gustavsen, A., Time, B., & Jelle, B. P. (2013). Windows in the buildings of tomorrow: Energy losers or energy gainers? *Energy and Buildings, 61*, 185–192.

Hee, W. J., Alghoul, M. A., Bakhtyar, B., OmKalthum Elayeb, M. A., Shameri, M. S. A., & Sopian, K. (2015). The role of window glazing on daylighting and energy saving in buildings. *Renewable and Sustainable Energy Reviews, 42*, 323–343.

Heidari, S. (2009). Thermal comfort temperature for people in Tehran. *Honar Ha Ye Ziba, 38*, 5–14.

Henninger, R. H., Witte, M. J., Crawley, D. B. (2003). Experience testing EnergyPlus with the IEA HVAC BESTEST E100-E200 Series. Proceedings of Building Simulation, the Eighth International IBPSA Conference, Netherlands

Hoes, P., Hensen, J. L. M., Loomans, M. G. L. C., de Vries, B., & Bourgeois, D. (2009). User behavior in whole building simulation. *Energy and Buildings, 41*(3), 295–302.

Iran Energy Efficiency Organization. (n.d.) Yearly "Energy Balances" from 2006 to 2014.

Iranian National Oil Company. (2012). Performance of the Fuel Optimization Company in the building section (2000-2008).

Jelle, B. P., Hynd, A., Gustavsen, A., Arasteh, D., Goudey, H., & Hart, R. (2012). Fenestration of today and tomorrow: a state-of-the-art review and future research opportunities. *Solar Energy Materials and Solar Cells, 96*(7465), 1–28.

Karabay, H., & Arıcı, M. (2012). Multiple pane window applications in various climatic regions of Turkey. *Energy and Buildings, 45*, 67–71.

Kari, B. M., Heidari, S., & Abravesh, M. (2017). Technical and economical evaluation of low-e coated building glazing systems. *Honar Ha Ye Ziba, 21*(4), 5–16.

Kiran Kumar, G., Saboor, S., Kumar, V., Kim, K. H., & Ashok Babu, T. P. (2018). Experimental and theoretical studies of various solar control window glasses for the reduction of cooling and heating loads in buildings across different climatic regions. *Energy and Buildings, 173*, 326–336.

Mehr News (2017, Jan 31), Exporting Electricity is profitable for Iran, Mehr News. http://www.mehrnews.com/news/3892387.

Mirhashemi, S. M., Shapourian, S. M. H., & Ghiabaklou, Z. (2010). A new method of optimzing single glazed windows. *Honar Ha Ye Ziba, 43*, 43–48.

Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. *Energy and Buildings, 40*, 394–398.

Puttaranga, A. B. T. K., Kumar, G., & Saboor, S. (2017). Effects of single, double, triple and quadruple window glazing of various glass materials on heat gain in green energy buildings. *Materials, Energy and Environment Engineering*, 45–50.

Raji, B., Tenpierik, M. J., & Van Den Dobbelsteen, A. (2016). An assessment of energy-saving solutions for the envelope design of high-rise buildings in temperate climates: A case study in the Netherlands. *Energy and Buildings, 124*, 210–221.

Schmidt, G. (1997). Sealants for IG units performance parameters and requirements. Mannheim, Ger., 247–51, 3–15.

Sfakianaki, A., Pavlou, K., Santamouris, M., Livada, I., Assimakopoulos, M.-N., Mantas, P., & Christakopoulos, A. (2008). Air tightness measurements of residential houses in Athens, Greece. *Building and Environment, 43*, 398–405.

Smeds, J., & Wall, M. (2007). Enhanced energy conservation in houses through high performance design. *Energy and Buildings, 39*(3), 273–278.

Tsikaloudaki, K., Laskos, K., Theodosiou, T., & Bikas, D. (2015). The energy performance of windows in Mediterranean regions. *Energy and Buildings, 92*, 180–187.

Van Den Bossche, N., Buffel, L., & Janssens, A. (2015). Thermal optimization of window frames. *Energy Procedia, 78*, 2500–2505.

Yang, L., Yan, H., & Lam, J. C. (2014). Thermal comfort and building energy consumption implications – A review. *Applied Energy, 115*, 164–173.

Yong, S. G., Kim, J. H., Gim, Y., Kim, J., Cho, J., Hong, H., Baik, Y. J., & Koo, J. (2017). Impacts of building envelope design factors upon energy loads and their optimization in US standard climate zones using experimental design. *Energy and Buildings, 141*, 1–15.

Yousefi, F. (2017). Minimization of life cycle energy consumption in Iranian conventional residential building with respect to design and construction parameters (PhD Thesis). University of Tehran, Tehran, Iran.

Yousefi, F., Gholipour, Y., & Yan, W. (2017). A study of the impact of occupant behaviors on energy performance of building envelopes using occupants' data. *Energy and Buildings, 148*, 182–198.

Zhao, J., Lam, K. P., Ydstie, B. E. (2013). EnergyPlus model-based predictive control (EPMPC) by using Matlab/Simulink and MLE+, Proceedings of Building Simulation: 13th International IBPSA Conference, France.

Zomorodian, Z. S., & Tahsildoost, M. (2017). Assessment of window performance in classrooms by long term spatial comfort metrics. *Energy and Buildings, 134*, 80–93.