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Thermal Performance Evaluation of Low-E Coated Building Glazing Systems

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Abstract

Considering the determinant role of energy efficiency opportunities in the building sector, proposing guidelines and technical solutions in order to improve the thermal performance of glazing systems is in priority in Iran and other countries. In glazing systems, a substantial amount of radiative heat transfer results from absorption and emission. Applying low-E (low emissivity) coatings on the glazing system is a solution for reducing the radiative heat transfer by radiation in glazing systems, without a noticeable decrease of visible light transmittance. By selecting the proper glazing type, in a hot climate, the amount of solar heat gain can be reduced significantly. Vice versa, in cold climate, the heat loss by long wave radiation of inner surfaces can be reduced. In this paper, first, the thermal and optical characteristics of local clear and Low-E glasses have been measured in BHRC (Road, Housing & Urban Development (National) Research Center) laboratory, by the spectrophotometer and then the thermal performance of single and double glazing units, with and without low-E coating, in different orientations (North, South, East and West) are computed, compared and analyzed for cold (Ardebil) and hot (Bandar-Abbas) climates in Iran. The selection of these two cities is based on maximum heating and cooling degree day values obtained respectively for Ardebil and Bandar-Abbas. The simulation results indicate that using double clear glazing unit with low-E coating reduces the energy consumption significantly in very hot climates, using mostly electrical energy for cooling. In cold climates like Ardebil, double glazing with low-E coating has a minor impact on annual heating load, because of the great amount of thermal radiation, even in the cold season, the high cost of low-e coating and the considerable payback time, compared to the building life cycle.

Keywords:Double Glazing, Coating, Low- emissivity-*coatings, Energy Consumption*

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1. Introduction

In recent years, the use of large windows, with low thermal performance, has risen significantly in Iran. While these highly glazed buildings are better appreciated, especially in dense urban agglomerations, alarming environmental issues, such as extra heat gain in summer and extra heat loss in winter create real problems for the quality of life and the thermal comfort of inhabitants. Therefore, the energy cost for operation and maintenance of HVAC (Heating, Ventilation and Air Conditioning) systems, in order to provide thermal comfort inside the buildings increases continuously. Regarding the important role of the building facades glazing areas, proper design and selection of glazing types can help reducing solar heat gain in hot regions, thermal heat losses in cold ones, and also ameliorating the thermal comfort conditions in both cases. Thus, the first priority in designing energy-efficient buildings with large glazing facades should be the simultaneous reduction of energy consumption and control of the amount of light and heat transfer through the facade. This can be achieved, only if the design and selection of building elements is performed by taking into account the thermal properties (emissivity, reflectance, transmittance and absorbtance) of the IGUs (Insulating Glass Units) that can be produced locally. Taking into account the considerable price difference between local and foreign products, the use of local Low-E glass products is considered as a priority. For this purpose, it is necessary to register the specifications of local products in international databases. This can be easily fulfilled, with the help of specialized national laboratories, equipped with guarded hot box and spectrophotometers, for the determination of thermal and radiative performance of glasses and IGUs. This task has been fulfilled by the authors in BHRC laboratory.

Today, energy-saving technologies have the potential to play a major role in the development of glazing products with very low-E coatings, which are very attractive for use in a variety of climates to simultaneously optimize energy savings and visual quality (daylight benefits). Low-E coatings have been developed to minimize the amount of ultraviolet and solar infrared radiation that can pass through the glass without compromising the amount of visible transmitted light.

It is obvious that appropriate solutions for various existing climates in the country depend closely on the façade orientation and also on the variation of temperature and solar radiation during the heating and cooling periods.

Many studies have been conducted to estimate the thermal performance of various window and IGU systems. Considering the complexity of the phenomenon, and the great number of influencing factors, a mobile field test facility (Dual Calorimeter), called MoWiTT was constructed by the LBNL and has been used for measuring fenestration performance under realistic conditions. The conducted research demonstrated that the mentioned facility provides high measurement accuracy and can be used for evaluating and measuring the real behavior of most fenestration systems [1]. In similar studies, the thermal performances of single and double glazing systems were evaluated [2,3].

In a separate investigation, the thermal performance of a low-E glazing was evaluated with the dual calorimeter, in north and south orientations [4]. In this study, the U-value and the heat transfer through the glazing were measured. The facility was limited in measuring very high thermal resistance glazing systems (7 to 10 times higher than values for single glazing) and estimating the corresponding values of solar heat gain coefficient.

In another study [5], U-value measurements of four types of windows with the MoWiTT field test facility and test laboratory were compared with calculations made with the WINDOW program concluding in good agreement for three of the windows. But for the double glazed window with a highly conductive frame, despite a good agreement between the calculations and the MoWiTT measurements, agreement with the test laboratory was only marginal. Today, the approximate multipliers developed by ASHRAE are used for the shading coefficient (SC) [6]. These multipliers are Interior Solar Attenuation Coefficients (IAC). In some studies, conducted SHGC evaluation has led to the proof evaluation of [7, 8, 9] the selected coated glazings [10].

Over the past decade, many simulation studies have been conducted to estimate the energy savings potential of windows for various climates. In one of these studies, the effect of three types of IGUs was evaluated on the annual energy savings in a building [11].

In another study, the heating loads and energy savings of a residential building with different types of windows were obtained by three methods [12]. Firstly, the energy through the window was evaluated considering only the climatic conditions. Secondly, the study was performed taking into account the useful energy for the heating system, considering the climate and the type of building. Finally, the different cases were simulated using TRNSYS and WINDOW. This study was performed for different European climates. Yin and Xu [13] used e-Quest for determining the energy saving due to the window films in two commercial buildings in China.

Unfortunately, in Iran, there is no significant research background in this field and utilizing the Low-E glazings is not widespread. Therefore, the thermal performance evaluation of IGU systems in different climates of the country has to be performed with detailed measurements and simulations on Low-E glazings (heating and cooling load) in appropriate configurations. Due to the various types of climates in Iran, these evaluations should be carried out through different case studies.

In this paper, the thermal performance of single and double glazing units, with and without low-E coating are computed throughout several simulation runs and the results are compared and analyzed for cold (Ardebil) and hot (Bandar-Abbas) climates in Iran.

2. Model set-up

In this paper, the thermal performance of double clear glazing systems and double low-E glazing systems in two extreme climates (cold and hot) are studied, evaluated and compared in four main orientations (North, South, East and West). Ardebil and Bandarabbas are selected for representing, respectively, cities in cold and hot climates. For more detailed analysis, the output results (heating and cooling loads) of the two selected climates are compared with another cold climate having similar average daily temperature, and a lower amount of solar radiation.

2.1. Methodology and simulation tools for window systems

There are various simulation tools for analyzing window system performance, such as RESFEN (Residential Fenestration) and COMFEN (Commercial Fenestration) developed by Lawrence Berkley National Laboratory (LBNL), giving early feedback on the impacts of design variables, for a better design decision making.

RESFEN and COMFEN use either the DOE-2 or EnergyPlus simulation engine, with parameters defined in OPTICS and WINDOW [14]. WINDOW has a complete updated database for different type of glasses, and calculates the total window system's thermal and optical performance indices, such as U-factor, Solar Heat Gain Coefficient, Visible Transmittance and Condensation Resistance.

RESFEN helps residential consumers in the decision making process, for the selection of appropriate window systems, after the calculation of heating and cooling energy use (annual energy simulations). The software associates costs, peak heating demand, and peak cooling demand for defined window products. These defined window products can either be the default generic set that is provided with the program, or the user customized products, by assigning specific thermal and physical properties. The thermal properties required by this tool are: U-factor, solar heat gain coefficient, and air leakage rate.

COMFEN design tool provides a graphical interface to create and simulate an EnergyPlus simplified small office building model. In this tool, libraries of glazing and various other material definitions are provided to define input data. However, because overall input options are restricted, this allows the user to focus on defining relevant parameters enabling them to utilize the EnergyPlus software without the need to define a simulation file from scratch.

Tools such as RESFEN and COMFEN focus on comparative analysis of fenestration alternatives and only certain EnergyPlus simulation input parameters are definable within these two tools, while some of the other tools offer additional user controlled input variables (many other building loads, schedules, HVAC system, complex building form, opaque envelope variations, etc.), and therefore may offer additional singular analysis results.

In the present study, the thermal calculations are performed with EnergyPlus software, which is a validated "whole building energy simulation" program, designed for modeling detailed buildings, with all associated heating, ventilating, and air conditioning equipment. EnergyPlus enables the evaluation of the potential energy savings by using proper glazing types, with very low-E coatings, and reports the energy results as hourly, monthly and annual energy loads, for total heating and cooling energy for a designated space or zone. This program was created, based on the combination of two programs: BLAST and DOE-2. The calculations are based on the heat balance of BLAST, with a generic model of conditioned air, new algorithms of heat transfer and heat flux of air between zones [15].

There are several methods used in EnergyPlus for simulating window systems. One of them is the simplified method based on SHGC and U-factor as input factors. This method is not accurate, since different windows with same SHGC often have different ratios of transmitted to absorbed solar radiation. When the simplified method is used, the dependency of the transmitted solar radiation to the incidence angle is neglected, because SHGC is determined at normal incidence, while angular properties of glazings vary with number of layers and coatings. Therefore, products with the same SHGC can have different angular properties. On the other hand, U-factors vary with the temperature, and can be fundamentally different in winter and summer conditions.

The more accurate and detailed calculation method is based on the transmittance, reflectance and emissivity values for each layer and surface in the window system in visible, solar and thermal wavelength range. In this study, the second method is used for more accurate thermal calculations. For local products, the transmittance, reflectance and emissivity value have been measured in BHRC by the authors, using the spectrophotometer in the range of 250 nm to 2500 nm. Afterwards, the obtained values were entered as the input data in the EnergyPlus software.

The third method which is the most detailed refers to BSDF (Bidirectional Scattering Distribution Function) calculations, which is often used for complex fenestration systems. In this method, a matrix (of incident and outgoing angles) is needed as an input data which can be generated by WINDOW tool. This method is based on the definition of discrete set of incident and outgoing angles, which fully describes optical performance of any simple or complex system.

2.2. Thermal, solar and optical properties of glazing systems

Table 1 presents the thermal, solar and optical properties of glazing systems used in this study for both climates. In double clear glazing systems, the 13mm gap between two glasses is filled with air. The thickness of the outer and inner layer are respectively 6 and 4 mm. In IGU systems with low-E glazing, the gap is usually filled with Argon, improving significantly the thermal performance of the IGU, but with clear glazing, the use of Argon is not recommended.

Since the simulations are performed for hot and cold climates, the location of the coating in the double low-E glazing system must be different for each climate. For cooling dominated climates, the low-E coating should typically be used on the second surface to control the solar radiation and reduce the heat transfer from outside to inside. For heating dominated climates, the low-E coating should typically be used on the third surface to reduce the heat transfer from inside to outside.

Therefore, three types of glazing systems are defined in this study (see Fig 1):

1- Double-clear glazing system
2- Double low-E glazing system with the coating on the second surface
3- Double low-E glazing system with the coating on the third surface

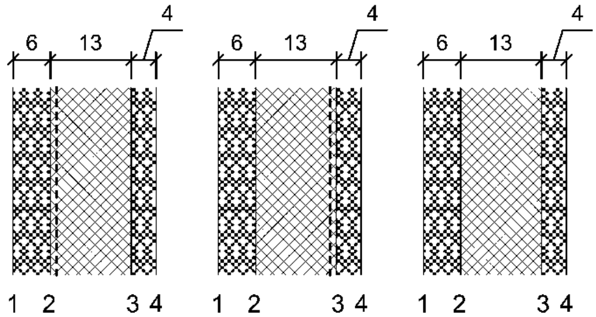

Fig. 1. Types of glazing systems

For a proof evaluation of the coatings effectiveness, two types of low-E glazing systems (type 1 and type 2) are studied. The thermal, solar and optical properties of glazing systems with and without low-E coatings are presented in table 1.

The first type of low-E glazing system is selected among the local products. For the moment, the homologation of local low-E products is not performed, and the technical data are not available in international databases (such as LBNL IGBD). For the above mentioned reasons, the thermal and optical characteristics of local Low-E glasses have been measured in BHRC, by the spectrophotometer in the range of 250nm to 2500nm. The transmittance and reflectance of the studied low-E glazing system (type 1) is introduced in Fig 2. In order to compare the thermal performance of the selected local product with common foreign ones, a second type of low-E glass, with similar visible transmittance and a very low emissivity value is selected. Afterwards, the comparison of the thermal performance of the selected glasses in IGU systems is performed in similar conditions. The solar transmittance of type 1 glass is lower than type 2, and the solar and visible reflectance is higher. The main difference of characteristics between these two types lies in the lower emissivity value of the type 2 glass.

Table 1. Thermal and optical properties (%) of glazing systems with/without low-emissivity coatings

Glazing system type	Visible Transmittance	Solar Transmittance	Visible Reflectance		Solar Reflectance		Emissivity	
			Front	Back	Front	Back	Front	Back
Clear	89.8	83.7	8.1	10.0	7.5	7.5	84	84
Low-E (type 1)	78.5	41.4	7.8	10.4	35.5	25.1	24	84
Low-E (type 2)	78.5	58.9	4.3	5.3	28.8	22.9	6.6	84

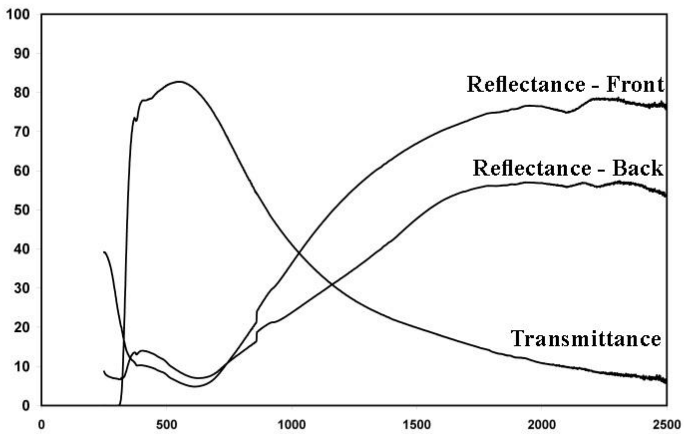

Fig. 2. Transmittance and Reflectance (front & back) of Low-E (type 1) in the solar range (%) measured in BHRC

2.3. Model properties

In this study, four independent thermal zones are defined, for the evaluation of the orientation effect. The dimensions of each zone is 5*5m with 3 meter high. In each thermal zone, a window is considered with 2.5m width, 2m height and 0.9m sill height, facing the main orientations (Fig 3). In each zone, the window to wall ratio is 30%. The thickness of all the opaque surfaces is 25 cm, including two layers: 15 cm of concrete and 10 cm of thermal insulation with a very low thermal conductivity value. The rendering layers are neglected. The material properties are defined in table 2.

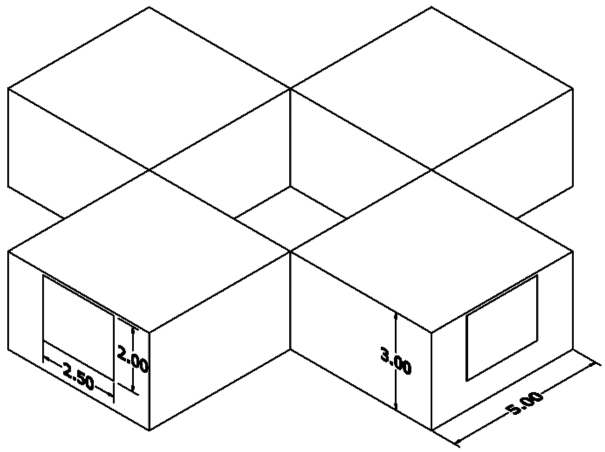

Fig. 3. Model Geometry

Table 2. Material properties for the opaque surfaces

Material	Thickness [m]	Thermal conductivity [W/m.K]	Density [kg/m^3]	Specific Heat [J/kg.K]
Concrete	0.15	2.30	2240	900
Thermal Insulation	0.10	0.0001	16	1210

In each thermal zone, the window is assumed to be fixed, without any frame, making possible the evaluation of the disaggregated effect of the glazing system. In the simulation process, the optical and thermal properties of each glazing system presented in table 1 are taken into consideration for each glazing system in the model and the thermal simulation of each glazing system is carried out separately for the four above mentioned orientations.

In order to determine the heating and cooling periods of the selected hot and cold climates, free running simulations without heating and cooling set points have been performed, and the transition period has been determined, taking 20 and 24 ºC as temperature limits for the daily zone mean radiant temperatures.

3. Energy Analysis

The glazing loads (heating and cooling) include glazing conduction load and solar radiation (direct and diffuse) loads through the glazing. The heat transfer through the glazing by convection and conduction, depends on the temperature difference, and can occur from interior to exterior or vice versa. For each square meter, heat gain or loss by conduction is calculated through this equation:

$$Q_C = \Sigma U^* \Delta T^* \Delta t$$

To better understand the effect of low emissivity coatings on glazing systems, a detailed analysis on window conduction and solar radiation through the windows is conducted, with and without low emissivity coatings in two critical (cold and hot) climates in Iran. These analysis are performed for four main orientations, in both climates. The heat gain and loss values are differentiated by the sign (respectively positive and negative values).

One of the most influencing actions for improving the glazing thermal performance in hot climates is reducing the solar energy transmittance in the near infrared range (from 760nm to 2500nm), allowing simultanously the visible light entering the space. This can be achieved by using appropriate IGUs with low emissivity glasses.

Tables 3 and 4 present the detailed comparison results of the building disaggregated cooling and heating loads for different types of IGU system with and without low- emissivity coatings.

Table 3 Disaggregated building cooling loads from windows in hot climate (Bandarabbas) for four orientations

Glazing system	Orientation	Solar radiation			Conduction [kWh/m^2]	Cooling Load [kWh/m^2]
		Direct solar radiation [kWh/m^2]	Diffuse solar radiation [kWh/m^2]	Total solar radiation [kWh/m^2]		
Double-Clear Glazing	South	164.1	314.3	478.4	92.9	571.3
	North	5.3	258.8	264.2	70.6	334.8
	East	213.4	354.5	567.9	96.2	664.1
	West	153.8	306.4	460.2	86.8	547.0
Double-Low-E Glazing	South	79.1	153.7	232.8	112.6	345.4
	North	2.5	126.5	129.1	78.2	207.3
	East	104.5	173.3	277.8	121.5	399.3
	West	75.0	149.8	224.8	106.0	330.8

Table 4. Disaggregated building heating loads from windows in cold climate (Ardebil) for four orientations

Glazing system	Orientation	Solar radiation			Conduction [kWh/m^2]	Heating Load [kWh/m^2]
		Direct solar radiation [kWh/m^2]	Diffuse solar radiation [kWh/m^2]	Total solar radiation [kWh/m^2]		
Double-Clear Glazing	South	264.2	198.9	463.1	-470.4	-7.3
	North	1.1	135.0	136.1	-205.5	-69.4
	East	155.9	178.0	333.9	-354.5	-20.6
	West	110.9	160.6	271.5	-295.7	-24.2
Double-Low-E Glazing	South	128.5	97.2	225.7	-228.6	-2.9
	North	0.5	66.0	66.5	-106.2	-39.7
	East	76.4	87.0	163.4	-175.1	-11.7
	West	54.1	78.5	132.6	-146.8	-14.2

Fig. 4. illustrates the disaggregated load issued from solar radiation and conduction through the windows in the hot climate, during the cooling period.

During the heating period, the disaggregated heating load issued from conduction through the window is much higher than the solar radiation part.

By using the low- emissivity coating on the second layer of the glazing in this climate, the cooling load decreases significantly in all the four orientations.

Table 3 and Fig 4. show that in Bandarabbas, during the cooling period, with the diminution of the heat gain from solar radiation through the windows by using the low-emissivity glazings, the minimum cooling load is obtained for the northern windows. The reduction of the cooling load is more important in windows oriented respectively to the west, south and east.

In the hot period in Bandarabbas, the cooling load related to glazing systems with low emissivity coatings on the second layer, decreases 41% compared to that of the double clear glazing system.

Fig 4. shows the simulation results for cooling load of the windows for all types of glazing systems, with and without low emissivity coatings. The glazing systems are clear single glazed, clear double glazed, and low emissivity double glazed (type 1 & 2).

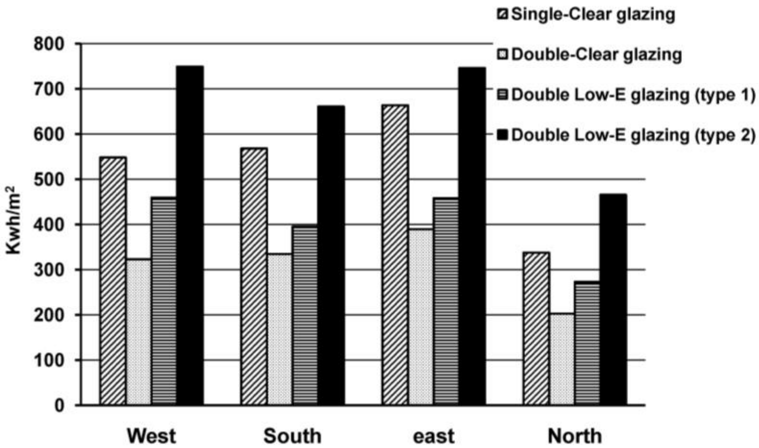

Fig. 4. cooling load of four types of glazing systems in bandarabbas during the hot period in four orientations

Fig 4.shows that even though the emissivity coefficient of the double low-E glazing system (type 2) is lower than the double low-E glazing system (type 1), the average cooling load of the first type is higher. This different behavior originates from the higher solar transmittance and lower solar reflectance of the type 1 glazing.

In the cold climate (Ardebil), during the heating period, the heat transfer through the northern windows is the highest, compared to the other orientations. In addition, the thermal performance of clear double glazing system and low emissivity double glazing system is significantly improved, comparing to the simple glazing system. This advantageous thermal performance decreases considerably in the south orientation, due to the higher heat gain through the glazing system in the heating period. The heating loads related to the east and west orientations are between the values obtained for the two above mentioned orientations.

Table 4 and Fig 5. show clearly that using low emissivity double glazing system (type 1) instead of clear double glazing system reduces the heating load up to 40%, but according to the low heating load of the cold period of the year, due to the high heat gain originating from the high solar radiation, no noticeable difference occurs for the building heating load. In Fig7.,the results obtained for the heating load of the windows with clear single glazed, clear double glazed, low emissivity double glazed (type 1&2) systems are presented. Taking into consideration these results, we can conclude that in the selected cold climate, the clear double glazing system can work effectively.

This graph illustrates that the reduction of the heating load for the double clear glazing system is significant, compared to the single clear glazing system, approaching 70% in the west, east and south and 56% in the north orientation. But, by considering only the absolute value reduction in heating load, the double low-E glazing system has a better performance in the western and especially in the northern orientation.

These results make clear that in a cold climate having high percentage of clear sky days, like Ardebil, the use of low-E glasses has a double opposite effect: reduction of the heat loss by convection and conduction, especially in night time, during the cold period, and also reduction of the heat gain during the day. The consequence is a weak incentive for using IGUs with low-E glasses in this climate. The only exception is the north orientation, where the heat gain from solar radiation is the lowest.

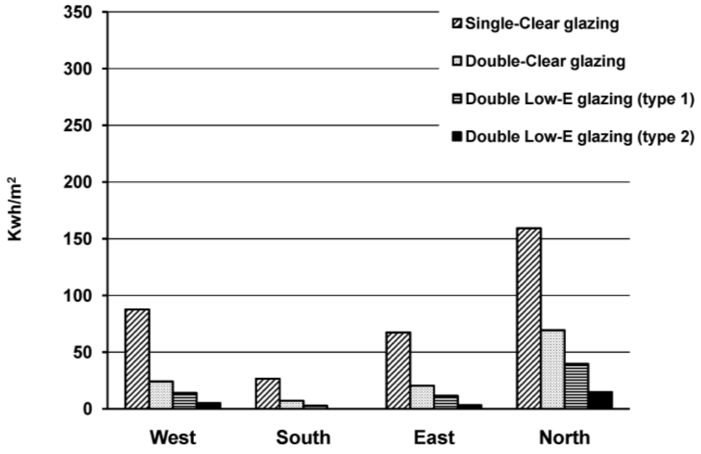

Fig. 5. Heating load of four types of glazing systems in Ardebil during the Cold period in four orientations

On the other hand, using double clear glazing systems in Ardebil can cause overheating during summer. In Fig 6.and Fig 7., the outside and inside dry bulb temperatures are represented for four orientations. The results show clearly that by replacing clear glass with double clear glazing system, the interior temperature increases approximately 10 degrees for all four orientations. This problem can be easily solved by using appropriate types of shades and natural ventilation, especially during the night.

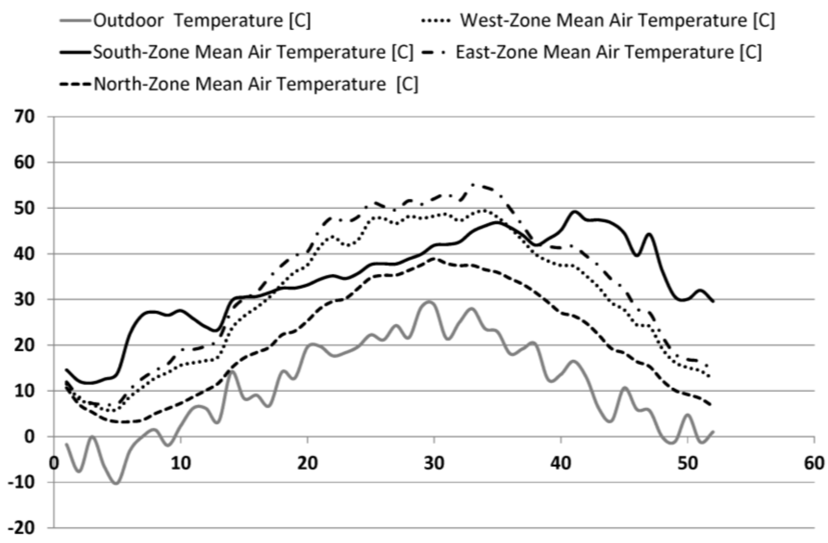

Fig. 6.Outside and inside average weekly dry bulb temperatures for four orientations-Single clear glazing

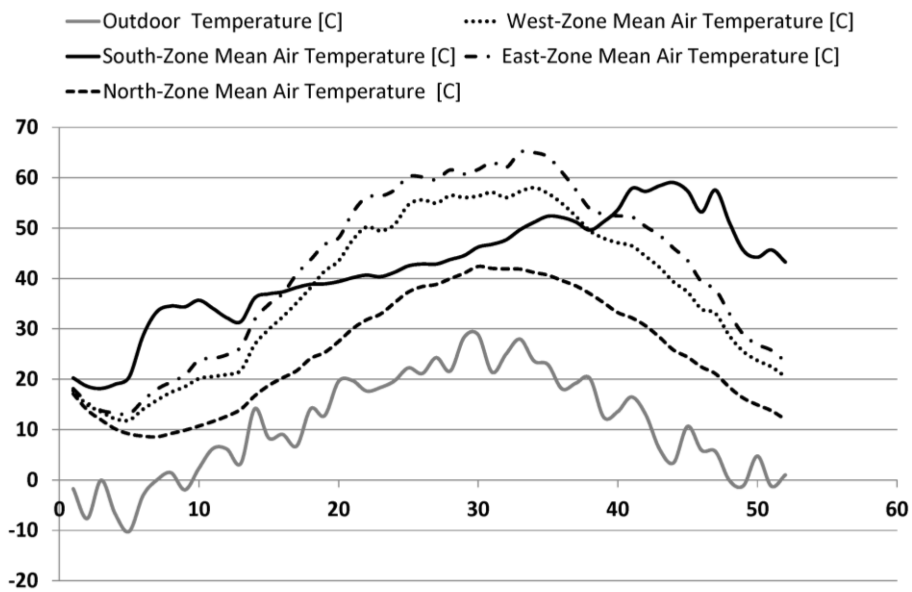

Fig. 7. Outside and inside average weekly dry bulb temperatures for four orientations-Double clear glazing

In order to analyze these results more accurately, complementary calculations are performed for another cold climate, Stockholm in Sweden. The two cold climates have approximately the same heating degree day values, but Stockholm is cloudy during the major part of the cold period. The results make clear that due to the low solar radiation in this city (Fig 8.), the heating load of the glazing systems increases significantly, comparing to Ardebil. In this cold climate, utilizing the low-E glazing systems decrease significantly the heating load (Fig 9.).

In table 5, the energy savings related to double clear and low-E glazing systems instead of single clear glass are presented for four orientations.

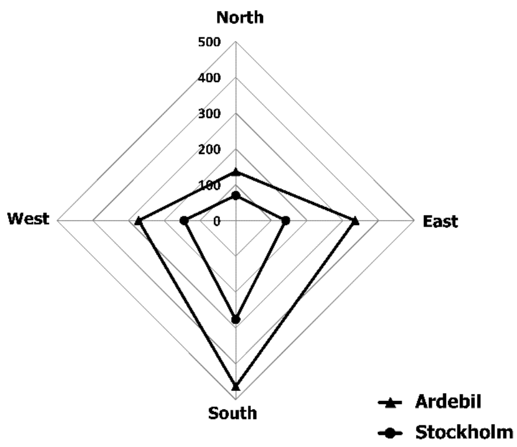

Fig. 8. Comparison of the transmitted solar radiation rate through clear Double glazing, during heating period, for four orientations,

in Ardebil and Stockholm (kWh/m2)

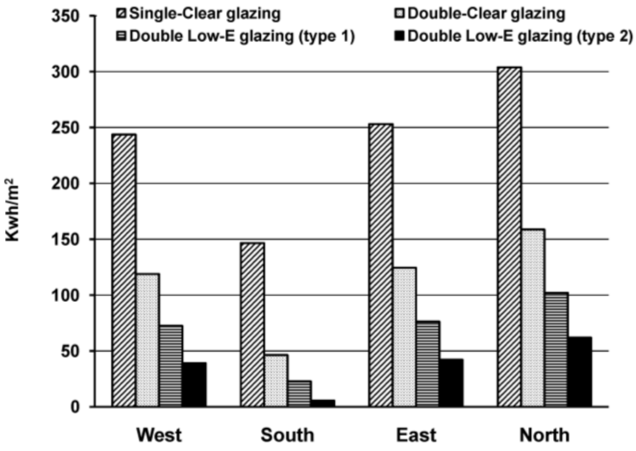

Fig. 9. Heating load of four types of glazing systems in Stockholm during the Cold period in four orientations

Table 5 Energy Saving related to double-clear glazing system and Double Low-E glazing during heating period in Stockholm

Glazing type	West	South	East	North
Double-clear glazing (compare to Single-clear glazing)	51%	68%	51%	48%
Double Low-E glazing (type 1) (compare to Double-clear glazing)	39%	51%	39%	36%
Double Low-E glazing (type 2) (compare to Double-clear glazing)	67%	88%	66%	61%

4. Conclusion

The effectiveness of low-E coated glasses in IGU systems, in two Iranian cold and hot climates, are fundamentally different.

Through analyzing the thermal and optical performance of IGU systems, with and without low-E coatings, double low-E glazing system is found to be more efficient in very hot climates, by reducing the annual cooling load due to the reduction of the emissivity and the near infrared transmittance of the glazing.

In cold climates, like Ardebil, due to the high amount of solar radiation rate, IGUs with low-E coating glasses have minor impact on annual heating load, and the use of IGUs with clear glasses is financially more attractive. But in other cold climates with lower solar radiation, like Stockholm, the annual heating load of the glazing systems can be reduced significantly, by using double low-E glazing systems.

The simulation results show that in hot climates like BandarAbbas, by using low-E glazing systems, the average solar radiation and the cooling load of the north oriented windows have the lowest values, compared to other orientations. Cooling loads through the double low-E glazing systems decreases by 41% compared to the double clear glazing system.

Therefore, low-E coatings on glazing systems could reduce the annual cooling load in hot climates and has minor impact on the heating load in cold climates of Iran.

Future work should emphasize the cost effectiveness of low-E coated glasses used in IGUs, and the payback time, compared to the building life cycle.

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