Evaluating the visual comfort of Orosi windows in hot and semi-arid climates through climate-based daylight metrics: a quantitative study

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ABSTRACT

Proper design and appropriate configuration of daylight systems, as the primary means of controlling and distributing daylight, greatly improve the visual comfort and reduce energy consumption. Daylight systems are widely used around the world, controlling the light distribution in interior spaces; in residential buildings, vertical windows are the most common ones. Iranian architecture has been using a traditional daylight system for over centuries: the Orosi window. This research investigates how the Orosi elements affect visual comfort, based on climate-based daylight metrics. Results show that the tinted glasses have the potential to control the quality of the light that is transmitted into the interior space. Besides, frames have the potential to increase the UDI while keeping the overall illuminance of the space within the specific range. Furthermore, glass shapes, and consequently frame shapes, and the way they are scattered on the surface have the potential to control the way that light enters the interior space; therefore, they homogenize it by decreasing the illuminance differences between central, frontal, and side zones of the space.

1. Introduction

Daylighting is one of the most important design strategies in architecture, which effectively facilitates the use of daylight that is transmitted into space through the openings. Daylighting affords more visual comfort in interior and less consumption of energy in the building (Apian-Bennewitz et al. 1998). The act of controlling and distributing the natural light, by ignoring or accepting it, is provided by the daylight systems (Baker and Steemers 2002). Estimations show that the optimization of daylight systems, improving the natural light distribution, results in saving at least 9% of consumed energy, mechanical and electrical, by buildings (Urbana Gutierrez et al. 2019).

Accordingly, as one of the leading parts of the optimum natural light distribution, daylight systems on façades are strategically important. Transmitting daylight into buildings needs carefully considered factors on its façade such as window parameters (Mardaljevic, Heschong, and Lee 2009; Rockcastle and Andersen 2014). Vertical windows, the most common (Ander 2003), are a subset of the main category of daylight systems called side-lightings. They are the most-used components in every kind of buildings to provide daylight. Unguarded windows create two situations: Leading excessive daylight into buildings that cause glare in an over-lit space and lack of sufficient daylight in some areas that cause more use of artificial lighting. Visual comfort cannot take place in this so-called situation; therefore, using a proper daylight system would bring a desirable uniformity, based on natural light, to interior spaces.

Applying daylight systems is based on some factors such as building function and climate conditions. Some researchers worked on daylight systems, as dynamic and static solutions for vertical windows, apart from their element configurations. In this regard, designing daylight systems, particularly vertical windows, is studied using different methods. Related to glazing, Ochoa et al. (2012) showed that adequate glazing, besides shading devices, should be considered from the early stages of design to reach visual comfort; however, windows optimized exclusively for visual comfort increase energy consumption. Further, Vossen, Aarts, and Debie (2016) concluded that people, in office spaces, prefer a higher percentage of colored luminescent solar concentrator glasses when they know they have sustainable benefits – 50% of glazing is accepted to be colored. In the same way, Chen, Zhang, and Du (2019) studied colored windows of an office room in China – clear, blue, bronze, grey, green, dark blue, and red. There was no artificial lighting allowed, and it was expressed that all colors, except dark blue, effectively reduced sleepiness and increased vitality and alertness in participants. In a distinct but similar research on colored glazing, Haghshenas, Bemanian, and Ghiabaklou (2015) worked on the CIE damage factor of some traditional Iranian windows, called Orosi, and found that the glass colors have the most important role in the brightness of the space and the so-called factor as well. They also depicted that the red color has a minimum, almost zero, CIE and skin damage factor. Two deeper
researches (Hosseni et al. 2020, 2018) on colored glazing of the so-called Orosi windows are recently done. In the first research, Hosseni et al. (2020) worked on a kinetic facade that uses colorful glasses based on the Orosi windows. They employed colored glasses of a passive system in an office space (located in Yazd city of Iran with hot and semi-arid climate) with a dynamic window to improve its daylight performance. This paper showed that blue, red, and mixed colors improve daylight performance by preventing glare and overloading light (illuminance >2000 lx), while yellow, green, and colorless admit daylight to interior space as much as possible. In the second one, Hosseni et al. (2018) depicted that colored glasses in the Iranian traditional Orosi windows have the light controlling ability as well as the aesthetic aspect. They divided the Orosi into three individual elements including Iranian-Islamic patterns, grid frames, and wooden cover. They concluded that blue color has the most significant effects on climatic-luminance-based metrics. Finally, they inferred that applying colored glass approximately decreases the daylight glare probability (DGP) to the optimal range for visual comfort in the most scheduled time. It also provides visual comfort near the window by preventing excessive useful daylight illuminance (UDI), while it does not have the capability to transmit sufficient light for the distant layers of the space.

As daylighting is of great importance for occupants of spaces, especially residential ones, there are a significant number of daylight systems that are used around the world, locally or globally, for enhancing the visual and thermal performances of various types of buildings. As mentioned above in some researches, Iranian architecture has been using a traditional daylight system over centuries called Orosi (Figure 1). Orosi is an Iranian latticed window, which opens vertically, with colorful glazing pieces that are located inside wooden patterns. These windows were emerged in about 1501 to 1722 in Iran, especially in the central zone with hot and semi-arid climate (Badiee 2016). They were used as decorative self-guarded elements in houses, schools, mosques, and other types of buildings, mostly in northern residential courtyards that receive the most amount of sunlight. Almost all researches on Orosi windows concern qualitative aspects of them, including aesthetics, manufacturing, privacy, psychological effects, and quality of the interior space created by the large glazed surfaces of the Orosi, splashing colorful lights on the interior surfaces including Persian rugs and carpets (Badiee 2016; Hazratzadeh and Khazaie 2015; Amrayi 2004; Ahani 2011; Foruzanmehrz 2015; Pirnia 2011; Azhdari 2017; Jalli and Nazari Poorgol Sefidi 2016; Habib, Alborzi, and Etessam 2013; Arjmandi et al. 2011; Makani, Khorram, and Ahmadipour 2012; Nabavi, Ahmad, and Goh 2012; Nabavi, Ahmad, and Tee Goh 2013; Javani, Javani, and Moshkforoush 2010; Mehrizi and Marasy 2017; Azarian Sadabad, Amirdastmalchi, and Haj Ostad Nourani 2014; Feridonzadeh and Cyrus Sabri 2014) although quantitative researches on Orosi windows are rare (Haghshenas, Bemanian, and Ghiabaklou 2015; Hosseni et al. 2020, 2018).

Orosi windows were used as one of the solutions, visual and thermal, for controlling the incoming sunlight in the hot and semi-arid climate of Iran (Haghshenas, Bemanian, and Ghiabaklou 2015; Hosseni et al. 2018); therefore, their characteristics and configurations, by some small changes in shape and color, were almost the same (Badiee 2016). As with any other windows, Orosi has main elements that could be considered for further evaluations: glass color, frames with depth, and glass shape. Table 1 shows all types of researches on the Orosi windows simultaneously.

Regarding the importance of studying residential visual performance, Dogan and Park (2019) presented that residential buildings have the largest construction sector. However, there is only 27% of climate-based researches related to them. Recent related studies on visual comfort are mostly conducted in office spaces (Vossen, Aarts, and Debije 2016; Nasrollahi and Shokri 2016; Pandharipande and Caicedo 2015) and few cases in residential ones (Cho, Yoo, and Kim 2014; Xue, Mak, and Huang 2016; Acosta, Campano, and Molina 2016; Toutou, 2019).

Figure 1. Some samples of Orosi windows.
Table 1. Researches on Iranian traditional Orosi.

| Research | Qualitative | Glass color | Frame depth | Glass shape | Residential oriented |
|----------|-------------|-------------|-------------|-------------|---------------------|
| (Haghighat et al.) 2015 | ● | ● | - | - | - |
| (Hosseni et al.) 2016 | ● | ● | - | - | - |
| (Haghighat and Khazaei 2015) | ● | ● | - | - | - |
| (Amrani 2010) | ● | ● | - | - | - |
| (Fonuzamneh 2015) | ● | ● | - | - | - |
| (Pirnia 2011) | ● | ● | - | - | - |
| (Ashdari 2017) | ● | ● | - | - | - |
| (Jalili and Nazari Poorgol and Etemam 2013) | ● | ● | - | - | - |
| (Arjmandi et al. 2011) | ● | ● | - | - | - |
| (Mehrizi and Marasy 2017) | ● | ● | - | - | - |
| (Nabavi, Ahmadi and Goh 2013) | ● | ● | - | - | - |
| (Nabavi, Khonam, and Ahmadipour 2012) | ● | ● | - | - | - |
| (Nabavi, Ahmad, and Mohbiforoush 2010) | ● | ● | - | - | - |
| (Mehrizi and Maray 2017) | ● | ● | - | - | - |
| (Makani, Khorram, and Ahmadi 2012) | ● | ● | - | - | - |
| (Hosseini et al. 2020) | ● | ● | - | - | - |
| (Badiei 2016) | ● | ● | - | - | - |
| (Hosseni et al. 2018) | ● | ● | - | - | - |
| (Jalili and Nazari Poorgol and Etemam 2013) | ● | ● | - | - | - |
| (Habib, Alborzi, and Etessam 2013) | ● | ● | - | - | - |
| Total | 85% | 65% | 5% | 30% | 55% |
Fikry, and Mohamed 2018), which is highly needed (Mardaljevic et al. 2011a). Besides, based on the aforementioned researches, Orosi has features to improve thermal and visual comfort of space; however, there is a lack of comprehensive residential quantitative study. In other words, there is no simultaneous study on all three Orosi elements (glass color, frames with depth, and glass shape). This research is framed by the following question: How the Orosi elements affect the visual comfort based on climate-based daylight metrics? In particular, this research aims to find the relationship between each Orosi element on each selected daylight metric.

2. Methodology

Based on scopes and objectives of the research, the Orosi window of the Isfahan Constitution House (Figure 2), located in the hot and semi-arid climate of Iran (latitude: 32.6°N/longitude: 51.6°E), is selected. This place was scheduled for a long stay where a family, or more, were living together. The north courtyard of this residential (Figure 3) has a five-part Orosi window facing south (Figure 4), which occupies 42 square meters of space. It is worth noting that this Orosi window is only a selected thorough sample among many other Orosi windows located in this climate, which are approximately similar to this selected Orosi in all elements.

As mentioned in Section 1, the selected window is divided into three main elements: glass color, frames with depth, and glass shape. In order to find the relationship between each Orosi elements on each selected daylight metrics, five alternatives are made by ignoring one, two, or all three Orosi elements. In the as-built model (Alt. 00), the selected daylight system is simulated as the original form to determine the visual comfort of the interior space. In the first alternative (no frame), the whole depth of the frames, and consequently their shading, is ignored to determine its possible impact on the visual comfort. In the second alternative (no color), glasses are assumed to be colorless to evaluate the influence of the tinted glasses. In the third alternative (no frame/color), the frame depth and the colors of the glasses are ignored.
simultaneously, allowing the accurate summary of the combined effects of these two components. In the fourth alternative (no shape), the isochromatic glasses are merged to appraise the impact of the shape positions and distribution of the glasses. In the fifth alternative (ordinary window), the whole Orosi is replaced with a simple five-part window to evaluate the simultaneous impact of the shape, frame, and color – the three main elements of the daylight system (the Orosi). Table 2 lists the Orosi and the five alternatives with their specifications.

Climate information of the region, which affects the light transmittance of the Orosi window, is derived from the Energy Plus database (energylplus n.d.). Besides, the space of the Orosi is surveyed by the authors (Figure 11). The frames are made of walnut wood, and its glasses are light green, green, blue, red, yellow, and white. The total area of tinted glasses plus the frames is 24 square meters, including 62.06% of the total glasses and 37.94% of the wooden frames. Additionally, the depths of the mainframes are 10–20 cm, and the secondary frames are 2–5 cm. The dimensions and specifications of the Orosi are fully described in Table 3. Moreover, the materials for the ceiling, wall, and floor are, respectively, white plaster, white-brown plaster, and the carmine red Iranian carpet. Finally, in conjunction with the simulated model, Table 4 shows the light transmission value of tinted glasses, and Table 5 shows the coefficient of the reflection of the opaque materials (Haghshenas, Bemanian, and Ghiabaklou 2015).

**Table 2.** Specifications of the Orosi and the alternatives.

| Alt  | Name      | Type       | Description                              | Image          |
|------|-----------|------------|------------------------------------------|----------------|
| 00   | As Built  | -          | -                                        | Figure 5       |
| 01   | No Frame  | Modified   | Frame depth ignored                      | Figure 6       |
| 02   | No Color  | Modified   | Glass color ignored                      | Figure 7       |
| 03   | No Frame/Color | Modified | Frame depth and glass color ignored | Figure 8       |
| 04   | No Shape  | Modified   | Glass shape ignored                      | Figure 9       |
| 05   | Ordinary  | Replaced   | Frame depth, glass color, and glass shape ignored | Figure 10       |

![Figure 5. As-built alternative (Alt. 00).](image)

![Figure 6. No frame alternative (Alt. 01).](image)

![Figure 7. No color alternative (Alt. 02).](image)

![Figure 8. No frame/color alternative (Alt. 03).](image)

![Figure 9. No shape alternative (Alt. 04).](image)

![Figure 10. Ordinary window alternative (Alt. 05).](image)

**2.1. Computational model**

Daylight systems, in general, are evaluated via four main methods – containing approximately 50 different parameters: scale models, mathematical models, full-scale models, and computer simulations (Wong 2017).

In this research, the computer simulation method is selected for analyzing the aforementioned alternatives because of its high speed and accuracy (Reinhart...
Besides, the simulation path is checked via Reinhart (Wienold 2009) study. To simulate the 3D model of the selected daylight system, the Rhino 6 software and the Grasshopper 1 plug-in are applied to modify the geometric parameters. In the following, the HoneyBee and LadyBug plug-ins are employed to add the required features of the daylighting model and link it to the main daylight analysis software.

Analysis periods of all simulations are annual. Therefore, DAYSIM software is used as the main simulation engine. DAYSIM is a validated, RADIANCE-based daylighting analysis software that models the annual amount of daylight in and around buildings (Reinhart and Selkowitz 2006). Besides, dimensions of the studied grids are considered as 0.1 m due to dimensions of the glazing elements of the Orosi to fully assess the effect of the passing beams on the space floor (Figure 12). Additionally, grid heights are also considered 0.85 m due to the space function. DAYSIM settings, based on a previous study (Reinhart and Weissman 2012), are shown in Table 6. However, due to the complexity of the form and glazing surfaces of the Orosi window, the value of the ambient bounce parameter is considered seven. This change in numbers is because of massive sequential reflections of the beams, which collide with the glasses and their entry into the space. In addition, higher values of the ambient bounce are not considered, due to the high amount of calculations. A PC with an 8.00 GB RAM and a Core i7 CPU with a 4.00 GHz processor, over 29 days, is performed all calculations, assessments, and modeling. The EVALGLARE software measures the amount of daylight glare, which is also capable of measuring the brightness average and the main source of the light (Daysim n.d.). A camera with an image that is 800 by 800 pixels is determined to analyze the glare

Figure 11. 3D model of the Orosi and the interior space.

| Table 3. The Orosi window specifications. |
|-------------------------------------------|
| Elements | Area [m²] | Sum area [m²] | Total area percentage |
| Glazing tiles | Light green tiles | 1.02 | 12.92 | 62.06% |
| | Green tiles | 1.12 |  |
| | Blue tile | 1.40 |  |
| | Red tiles | 2.31 |  |
| | Yellow tiles | 0.50 |  |
| | White tiles | 6.57 |  |
| Wooden frames | Sub frames | 2.20 | 11.08 | 37.94% |
| | Main frames | 8.88 |  |
| Total (window to wall ratio) | 24.00 | 100% |  |

| Table 4. Visible transmittance of tinted glasses. |
|-----------------------------------------------|
| Tile color | Blue wavelength (415 nm) | Green wavelength (532 nm) | Red wavelength (685 nm) |
| Dark | green | 0.01 | 0.45 |
| 0.01 |  |
| Green | 0.02 | 0.47 | 0.03 |
| Blue | 0.83 | 0.09 | 0.08 |
| Red | 0.00 | 0.00 | 0.72 |
| Yellow | 0.03 | 0.40 | 0.76 |
| White | 0.80 | 0.80 | 0.80 |

| Table 5. Reflectance of the materials. |
|----------------------------------------|
| Space elements | Material | Reflection coefficient |
| Orosi (Southern Wall) | Wood | 0.5 |
| Wall | White & brown gypsum | 0.6 |
| Ceiling | White gypsum | 0.7 |
| Floor | Persian carpet | 0.2 |

Figure 12. Grid point numbers and camera position of the space.
This analysis is based upon one of the possible moments when the glare occurs (worst situation): At noon (12 pm) of December 21.

### 2.2. Climate-based daylight metrics

Visual comfort of any space is linked to four parameters: light quality, light distribution, light quantity, and glare (Carlucci et al. 2015). In recent years, various metrics have been developed (Carlucci et al. 2015; Alrubaih et al. 2013; Galatioto and Beccali 2016) to evaluate these four parameters; nevertheless, none of them is capable of evaluating the visual comfort alone. Annual illuminance average is the first selected metric that indicates the amount of daylight received by the space and shows uniformity of illuminance on a given task area (Carlucci et al. 2015). A useful daylight illuminance (UDI) metric is chosen to calculate the annual daylight distribution. UDI is a percentage of time within a year where the horizontal irradiance in a specific point locates within a certain range, having the optimum being between 100 and 3000 lx (Mardaljevic et al. 2011b). Spatial Daylight Autonomy (sDA), which is picked as an ancillary metric, is an annual criterion that measures the amount of ambient daylight in the interior space. This metric shows the percentage of the surfaces, which have the minimum threshold of daylight illuminance within a specified fraction of hours occupied by users in one year (IES, Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE) 2012). To apply the sDA metric, the selected model has to be reticulated spatially, and the natural light of each grid must be within the sDA300/50% range. This means that at least in 50% of the times that space has users, the horizontal illuminance has to reach the amount of 300 lx. LEED version 4 has set these three benchmark values for sDA metric: sDA300,50% >40% is minimum, sDA300,50% >55% is acceptable, and sDA300,50% >75% is optimal (LEED v4 n.d.). In addition, glare occurs when the daylight is not in control and the amount of illuminance is increasing. Therefore, there would be serious consequences for visual comfort (Acosta, Campano, and Molina 2016). The most valid metric for glare is the daylight glare probability (DGP) since all the previous glare metrics were focused solely on the ratio of the average background illuminance to the glare source (Wienold and Christoffersen 2006). DGP ranges are shown in Table 6. In addition to the metrics related to the glare, the illuminance ratio is selected, presenting the illuminance ratio of the user’s position to his/her surrounding environment (Carlucci et al. 2015). As illustrated in Figure 12, in all the forthcoming analyses, space is divided into three main zones: center, front, and sides. All the results are presented after the analysis of each part. All the visual comfort metrics that are used in this study are listed in Table 7.

### 3. Results and discussion

All evaluations are categorized according to different positions of various points of the space. Two sides of the Orosi are entrances to the space, which are less important than the central and frontal zones. The weighted average of these two zones (center and front) would be the criterion for the final evaluation of different alternatives.

Figure 13 shows the annual results of daylight illuminance in different alternatives. According to the aforementioned descriptions, Figure 14 depicts the average amount of each zone of the space separately. Average daylight illuminance of the main zones (center and front) of the Alt. 03 and Alt.05 are, respectively, 2405 and 2384 lx, which are the highest amounts among all the alternatives, as shown in Table 7. Other

### Table 6. DASIM simulation settings.

| Ambient bounces | Ambient division | Ambient sampling | Ambient accuracy | Ambient resolution | Direct threshold |
|-----------------|------------------|------------------|------------------|--------------------|------------------|
| Ambient bounces | Ambient division | Ambient sampling | Ambient accuracy | Ambient resolution | Direct threshold |
| 7 | 1500 | 100 | 0.05 | 300 | 0 |

### Table 7. Summary of applied daylighting metrics.

| Daylighting metrics | Scope of index | Calculation | Benchmark values | Benchmark reference |
|---------------------|----------------|-------------|-------------------|---------------------|
| Spatial daylight autonomy (sDA) | Amount of light | Annual | sDA300,50% > 40% | Minimum |
| Useful daylight illuminance (UDI) | Amount of light | Annual | sDA300,50% > 55% | Acceptable |
| | | | UDI < 100 lux | Optimal |
| | | | 100 lux < UDI < 500 lux | Fell-short |
| | | | 300 lux < UDI < 3000 lux | Supplementary |
| | | | 100 lux < UDI < 3000 lux | Autonomous |
| | | | UDI > 3000 lux | Combined |
| Illuminance ratio | Glare | Annual | Exceeded | For the visual task and any other surfaces in the field of view |
| Daylight glare probability (DGP) | Glare | In time | Imperceptible | (Osterhaus 2009) |
| | | | Perceptible | (IES, 2011b) |
| | | | Disturbing | (Carlucci et al. 2015) |
| | | | Intolerable | (CIBSE 1999) |
alternatives are in the permissible useful range, knowing the fact that their significant illuminance changes are well distinguished, Figure 14, by the differences applied to each alternative.

The percentage of space grids having illuminance over 300 lx are assessed regarding daylight availability. sDA values of alternatives are resulted as follows: Alt. 00 with amount of 17% is far below than minimum threshold. Alt. 02 with amount of 72.5% is in acceptable range. The rest of the alternatives are in the optimal range.

After calculating the illuminance of the space during all hours of a year, the frequency of each spot placement in the UDI interval is calculated. Figure 15 shows the results of UDI of the space in different alternatives, as well as Figure 16 illustrates the UDI separately in the specified zones. According to the results, the Alt. 02, as well as the as-built alternative with 96.5% and 93%, shows the best UDI performance in the frontal and central zones (main zones). It is worth noting that the Alt. 02 with 94% of UDI has the best performance in the whole space (Figure 16). As expected, the Alt.03 and Alt. 05 that receive excessive illuminance have the lowest performance of UDI with 78%. Finally, to determine the most proper alternative, the percentage of points in the space grid, which has the UDI more than 75%, are also calculated that almost confirms the same previous assessment (Figure 17). The results of all the UDIs are shown in Figure 18.

To evaluate the illuminance ratio of the space, two phases are considered. In the first phase, the ratio of maximum and minimum illuminance, received by each

Figure 13. Annual daylight illuminance.
point during the year, is calculated (Figures 19 and Figure 20), and in the second phase, the ratio of maximum and minimum illuminance of the space points per hour is calculated to determine the critical hours of the year. Based on the first-phase results of the illuminance ratio, the least changes occurred in the center, and the most changes occurred in the front of the space in all alternatives. To compare the integrity of light distribution in each alternative, the illuminance ratio of the front zone is divided into the illuminance ratio of the center zone. According to Table 8, Alt. 05 has the highest ratio with the amount of 7, which has the poorest distribution performance among all alternatives. Based on the results of phase 2, Figure 22 shows the changes of annual illuminance ratio in the as-built alternative, and the critical times are recognizable as well.

After generating the fish-eye images, the glare in each alternative is shown in Figure 23 along with its range. This analysis is based upon the worst situation: At noon (12 pm) of December 21. The Alt. 00, with the amount of 0.356 and positioning in the perceptible range, performed well in glare metric. The Alt.01, Alt. 03, and Alt. 05 have the worst performance with the
amounts of 0.452, 0.621, and 0.569, respectively, placing in the intolerable range of glare. Alt. 02 and Alt. 04 are placed in disturbing range with amounts of 0.432 and 0.402, respectively.

All the assessment results are shown in Table 8.

According to the results of the glare, the Alt. 00 with 35.6% of DGP has the lowest amount of glare, which is much better than Alt. 02 (which has all as-built features except color) with 43.2% of DGP. By ignoring the shape and the distribution algorithm of the glasses and frames, the Alt. 04 with 40.2% of DGP still has a fine glare performance compared to all the colorless alternatives (Alt. 02 with 43.2%, Alt. 03 with 62.1%, and the Alt. 05 with 56.9% of DGP). It is evident that when glasses turn into tinted ones, therefore, the glare decreases significantly.

The difference of illuminance average between the Alt.01 (which has all as-built features except frames) and the Alt. 00 is approximately 830 lx, which is a sudden increase in indoor illumination. Ignoring the frames increased the illuminance of the space and caused a 15% reduction of UDI in the frontal zone, which is substantially out of the range. However, the illuminance average difference between the Alt. 00 and the Alt. 02 is approximately 225 lx. However, in the same situation, the glare is not increased significantly (2% of difference), and according to the glare status in alt. 04, as explained, it shows that frames have not affected the glare as much as the UDI. So, based on the above results, it appears that frames have the most effective role in controlling and balancing the amount of light transmitted into space.

Figure 16. Useful daylight illuminance (UDI).
The aforementioned results are confirmed by the analysis of the Alt. 03, which has neither tinted glasses nor frames. In this alternative, both the quality and the quantity amount of light are greatly reduced compared to other alternatives (27% decrease in glare and 15% decrease in UDI average of the main zones compared to the as-built alternative). The Alt. 05 is created by ignoring the shape of the selected daylight system, as the last remaining feature of it, which has none of the numerous features that other alternatives have. In the other words, the Alt. 05 is just a simple window. The DGP and UDI of this alternative are, respectively, 56.9% and 78%, which are far worse than the same results of the other alternatives, especially the Alt. 00. Finally, comparing the illuminance ratio of the front-to-center zone in each alternative shows that Alt. 04, which its glass shapes do not allow frames to be scattered enough, has one of the highest amounts of ratio compared to the other alternatives. This means that by editing the glass and frame shapes, the daylight distribution of the space becomes worse. Figure 24 compares all the alternatives cumulatively.

Figure 17. UDI in different space zones.

Figure 18. Results of UDI.

Figure 24. A. Omid ET al.
Some metrics are weighted regarding the better understanding of the relationships between them.

Based on the research question, in order to analyze the role of Orosi elements in providing visual comfort, Table 9 shows the ranking of Orosi elements from the highest to the lowest level of performance regarding each metric. Ordinary window, as a replacement of the Orosi window, is considered as the reference value for final comparison because there are no Orosi elements located inside the ordinary window. This analysis would be able to simplify the differences of values based on each applied metric. Figure 21

As Table 9 shows, the best performance is the combination of color and frame. However, in other combinations, based on the function and design priorities, even the lowest percentages could still be within the acceptable ranges.

To analyse the efficiency of the Orosi, it is compared with the Ordinary Window alternative. According to Figure 15, the presence of the Orosi prevents intense sunlight in front of the window (5,241 lx. in Ordinary Window), bringing it to the acceptable 639 lx. In addition, the comparison of the UDI numbers of the main zones of the space (CF UDI average) shows a 14% increase, which is quite significant. Finally, a review of the DPG results in Figure 23 shows that it has caused
a 21% reduction, improving it from the intolerable glare in the Ordinary Window to a perceptible glare, which is the ideal state of the glare of the space.

4. Conclusion
This paper discusses a traditional daylight system that has been used in the hot and semi-arid climate of Iran, called Orosi. These colorful and latticed windows have three important elements, which worth noting. Orosi elements are evaluated based on the climate-based daylight metrics in five different types of Orosi-derived windows, called Alternatives in the paper. The research culminated in some useful data derived from different combinations of Orosi elements in order to assess the impacts of them on the so-called metrics.

Based on the assessments, this fact is concluded that the tinted glasses have the potential to reduce the amount of possible glare and control the quality of the light that is transmitted into space. However, it may increase the demand for lighting energy. Frames also play the role of multiple shades that are positioned on the light-transmitting surfaces. They have the potential of controlling the amount of incoming light, increasing the useful daylight illuminance, and keeping the overall illuminance of the space within a specific range. In the following, the shape of the glasses and
Table 8. Assessment results of each alternative.

| Type            | Zone          | As-built Alt. 00 | No frame Alt. 01 | No color Alt. 02 | No frame/color Alt. 03 | No shape Alt. 04 | Ordinary window Alt. 05 |
|-----------------|---------------|------------------|------------------|------------------|-------------------------|------------------|-------------------------|
| Illuminance     | Centre (C)    | 249              | 649              | 445              | 1191                    | 558              | 965                     |
|                 | Front (F)     | 639              | 2958             | 970              | 4834                    | 2517             | 5241                    |
|                 | Left          | 210              | 468              | 346              | 826                     | 410              | 509                     |
|                 | Right         | 195              | 483              | 350              | 868                     | 426              | 542                     |
| CF illuminance average | 379          | 1418.7           | 620              | 2405.3           | 1211                    | 2384.3           |                         |
| Illuminance average | 330.9       | 1161.1           | 546.2            | 1980.2           | 994.3                   | 1877.5           |                         |
| Front/side illuminance | 2.57        | 4.56             | 2.18             | 4.06             | 4.51                    | 5.43             |                         |
| Front/side illuminance | 3.16        | 6.29             | 2.79             | 5.71             | 6.05                    | 9.96             |                         |
| UDI             | Centre (C)    | 95               | 97.8             | 985              | 918                     | 97.7             | 94.7                    |
|                 | Front (F)     | 88.6             | 73.6             | 92.5             | 51.2                    | 76.4             | 45.7                    |
|                 | Left          | 61.3             | 92.7             | 88.3             | 96.8                    | 90.6             | 97.3                    |
|                 | Right         | 62               | 92.5             | 88.1             | 96.2                    | 90.5             | 96.9                    |
| CF UDI average  | 92.9          | 89.7             | 96.5             | 78.3             | 90.6                    | 78.4             |                         |
| UDI average     | 84.6          | 90.6             | 94.3             | 83               | 90.7                    | 83.5             |                         |
| UDI >75%        | 80.2          | 85.7             | 94.3             | 72.5             | 86.4                    | 73.1             |                         |
| sDA (300)       | 17             | 92.5             | 72.5             | 97.4             | 80.9                    | 96.3             |                         |
| Illuminance ratio | Centre (C)   | 9.8              | 10.7             | 9.5              | 9.5                     | 12.1             | 5.1                     |
|                 | Front (F)     | 46.4             | 49               | 40.2             | 42.1                    | 38.8             | 35.7                    |
|                 | Left          | 34.2             | 21.8             | 25               | 17.8                    | 24.4             | 5.6                     |
|                 | Right         | 25.7             | 21.6             | 24.6             | 18.3                    | 24.6             | 7.3                     |
| CF illuminance ratio average | 22         | 23.5             | 19.7             | 20.4             | 21                      | 15.3             |                         |
| Illuminance ratio average | 29         | 25.8             | 24.8             | 21.9             | 25                      | 13.4             |                         |
| Front/center ill. ratio | 4.7       | 4.6              | 4.2              | 4.4              | 3.2                     | 7                |                         |
| DGP             | 0.356         | 0.452            | 0.432            | 0.621            | 0.402                   | 0.569            |                         |

Figure 22. Illuminance ratio changes during a year in the Alt.00.

Consequently the shape of the frames and, also, the way they are scattered on the surface have the potential to control the way that light enters the interior space; therefore, they homogenize it by decreasing the illuminance differences between central, frontal, and side zones. In summary, by conducting quantitative analysis on the Orosi elements regarding climate-based daylighting metrics in order to increase the visual comfort, this is concluded that among all three Orosi elements, the glass color plays the most effective and, in contrast, the glass shapes play the least effective role.

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Figure 23. DGP results of each alternative.

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Figure 24. Cumulative comparison between all the alternatives.

Table 9. Ranking of the highest and lowest performances of the combination of the Orosi elements in each metric based on the reference values of the ordinary window.

| Element combinations | Differences by percentage | Referenced values |
|-----------------------|---------------------------|-------------------|
| Metrics               | Color + frame + shape     | Color + shape     | Shape + frame | Color + frame | No color & no frame & no shape |
| Center and front illumination average | –84.1 | –40.5 | –74.0 | +0.9 | –49.2 | 2384.3 |
| Center and front UDI average | +14.5 | +11.4 | +18.1 | –0.1 | –12.2 | 78.4 |
| dDA | –79.3 | –3.8 | –23.8 | +1.1 | –15.4 | 96.3 |
| Front to center illumination ratio | –32.4 | –34.6 | –39.5 | –36.7 | –54.2 | 7.0 |
| DGP | –37.5 | –19.6 | –23.2 | +10.7 | –28.6 | 0.56 |
| Range | Highest performance | No color & no frame & no shape | Lowest performance |

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