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Analysis of the Quality of Light Obtained from the Stained Glass Windows of Traditional Iranian Architecture based on the Color Temperature Curve (CIE)

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ABSTRACT: The color temperature of light is one of the important indicators in lighting that should be considered. Because people experience and feel their surroundings not only with brightness and darkness, light and shadow but also through colors, the feeling that the color of the light creates in the space affects human perception and health through the warmth and coldness of the light. The color receptivity and color temperature chart is a tool that determines how the human eye feels when faced with a spectrum of light. Since the purpose of this research is to analyze the light quality of the stained glass windows of traditional Iranian architecture, calculating the color temperature will be a suitable criterion for judgment, that is, if the color temperature of the light from the stained glass windows is calculated, the experience of people in facing the light can be calculated quantitatively. Comparative methods were used to analyze the quality of light based on the color temperature curve with calculation tristimulus values XYZ from spectral data and calculation xyz chromaticity values. Investigations showed that the light color temperature of 65% of the windows is 3000 to 4600 K, and 35% is. In these windows with this combination model and area percentage of four colors, red, green, blue, and yellow, the quality of light has not decreased based on the color temperature curve.

Keywords: *Iranian architecture, Lighting, Stained glass, Color temperature curve.*

INTRODUCTION

One of the important indicators in the lighting of an environment is the color temperature of the light. Because people experience and feel their surroundings not only through light and darkness, light and shadow but also through light color, the feeling that the color of light creates in the space affects human perception and health. For this reason, choosing light with the right color temperature is important for every space. The International Commission on Illumination (CIE) introduces the color temperature curve as an important tool for determining how the human eye experiences a light spectrum. In this research, the color temperature curve calculates the color temperature of light passing through stained windows. Stained glasses reduce the intensity of sunlight. The main research question is that despite the reduction of light intensity by stained glasses, how is the quality of light passing through these glasses based on the color temperature curve? In other words, in what range is the color temperature of the light obtained from stained glass windows in Iranian architecture, and is this color temperature, according to the CIE standard, suitable for human health and the use of these spaces?

The brilliant point of this research is calculating the color temperature of the light obtained from the stained glass windows of Iranian architecture, which has not been calculated so far. In this way, the perceptual parameters of light quality can be judged by converting them into quantitative parameters.

Among all the visual cells of the human eye, nearly 123 million of them are of the cylindrical type, sensitive to the brightness of the light source, and it can almost be stated that they have no sensitivity to the color of the light. Therefore, these cells are most sensitive when the ambient light is low

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(night light). About 7 million cells sensitive to the color of light in the human eye are responsible for recognizing colors; the brightness of the environment must be higher than a certain level for them to be activated. Upon receiving light, the human eye cells are stimulated and send appropriate orders to the body's internal glands, each of which has a different effect on the human body that must be considered in lighting design. For example, the hormone that regulates the level of alertness in the human body is called melatonin, the secretion of the melatonin hormone in the human body, which follows the body's internal clock and the hours of the day, causes a decrease in the level of consciousness and conversely, a decrease in the level of melatonin in the blood increases human consciousness. Light color is one of the main factors of melatonin secretion in the human body. Ambient light affects melatonin secretion in the human body and, as a result, regulates the circadian rhythm (Kalhor, 2009).

CIE 1931 color space: CIE 1931 color spaces are the first quantitatively defined links between wavelength distribution in the visible electromagnetic spectrum and physiologically perceived colors in human color vision. The mathematical relationships that define these color spaces are fundamental tools for color management. The CIE 1931 RGB color space and the CIE 1931 XYZ color space were created by the International Commission on Illumination (CIE) in 1931. They resulted from a series of experiments conducted in the late 1920s by William David Wright using ten observers (Wright, 1928), and John Guild conducted it using seven observers (Guild, 1931). The experimental results were combined into the CIE RGB color space specification from which the CIE XYZ color space was derived.

The CIE XYZ color space includes all color sensations visible to a person with average vision. This is why CIE XYZ (with tristimulus values) is a fixed device of color representation and serves as a standard reference based on which many other color spaces are defined. Most wavelengths stimulate two or all three types of cone cells because the spectral sensitivity curves of these three types overlap. The CIE 1931 color space defines tristimulus values and represents them as X, Y, and Z.

Since the human eye has three types of color sensors that respond to different wavelengths, a complete projection of all visible colors is a three-dimensional figure. However, the concept of color can be divided into luminance and chromaticity. For example, white is a light color, while gray is considered a less light version of white. In other words, white and gray are the same color, while their brightness is different.

The CIE XYZ color space is intentionally designed so that the Y parameter measures a color's luminance. Then the color (chromaticity) is determined by two derived parameters, X and Y, which are two of the three stimulus values X, Y, and Z (Poynton, 2012, 275).

Color temperature: A black body is an element like platinum that does not reflect any light and absorbs all the light that shines on it. The color temperature is defined based on the color emitted from the black body at a certain temperature and is expressed in degrees, Kelvin. The meaning of color here is not the absolute colors but the heat spectrum of the color. The range of color temperature in practice is between 1000 and 10000 degrees Kelvin, and it starts from red and yellow at lower temperatures and reaches blue at higher temperatures (Fig.1).

Fig.1 shows that a color temperature below 2000 degrees Kelvin has a faint glow of light, similar to that perceived by candlelight. Candlelight has a color temperature of 1500 degrees Kelvin. Table 1 shows that 2000-3000 degrees Kelvin gives a soft glow to the white color, often yellow. It is best for living, dining, bedroom, and outdoor spaces. 3000-4600 degrees Kelvin emits a bright white light. The best option for kitchens, offices, workspaces, and washrooms where lighting is needed. 4600-6500 degrees Kelvin gives a bright blue-white light, similar to daylight which is best for exhibition areas and work environments where much light is needed. Six thousand five hundred degrees Kelvin and more give a bright bluish color of light often found in commercial settings (Al Bahadly & Berndt, 2010).

Fig. 2 illustrates the effect of light color temperature on the environment.

Literature Review

Haji Seyed Javadi & Pourdihemi (2008) investigated the

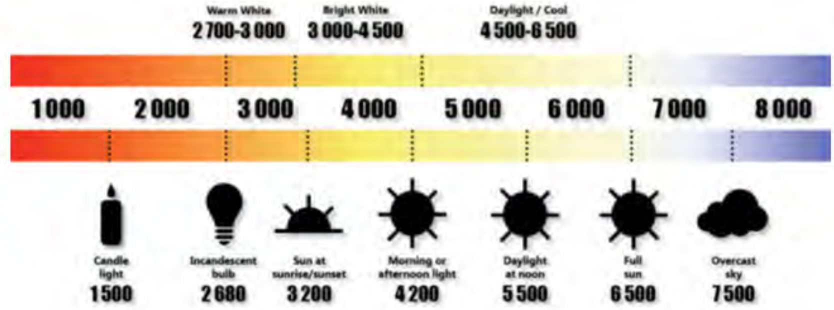


Fig. 1: Color temperature range (Standardpro, 2023)

Table 1: Light suitable for different environments according to light color temperature based on CIE standard

Color temperature (Kelvin)	D Kelvin 3000 – 2000	D Kelvin 4600 – 3000	D Kelvin 6500 – 4600
Light Appearance	Warm white It varies in appearance from orange to yellow-white.	Bright white – natural white Middle light or natural and living light. It emits a more neutral white light and may have a slight blue tint.	daylight – cool white The light is bluish-white in appearance.
Environment	Warm and intimate inducing a gentle, relaxing feeling creates an inviting and welcoming feeling.	It makes the surrounding space bright and attractive. It is brighter and more lively.	It cools the surrounding environment and makes it concentrate and invigorate. It imitates daylight.
Suitable for	Living environment or rest environment, bedroom and living room, patient room in hospital and hotel rooms.	Schools, offices, kitchens, corridors, public areas, hospitals, and dormitories.	Best for outdoor lighting, security lighting, and commercial or retail spaces. Exhibition spaces, lathe workshop, press, cutting, needlework, drawing, and similar jobs

Fig. 2: The effect of light color temperature on the environment (Westinghouselighting,2023)

effect of daylight on humans and the perceptive and biological-psychological processes of daylight. Mirgholami & Pishbin (2013) briefly studied the effect of light and color in residential interior spaces of Islamic Iranian architecture. Jazdareh & Zia Bakhsh (2014) used a questionnaire to ask the opinion of users to understand their feelings towards the surrounding environment and, based on that, provided solutions for adjusting the light in dark and bright spaces. Dashti Shafiei et al. (2014) used the correlation research method to discover the relationships between phenomena and the effect of natural light on humans' quality of life and mental health. In their research, Tahbaz et al. (2013) investigated natural lighting in traditional Kashan houses. By using field measurements and computer simulation, they tried to show the way of light distribution and its amount in different types of spaces and old skylights. In their research, Haqshanas & Qayabaklou (2008) investigated the effect of stained glass on the amount of light and energy transmitted in the visible range. In another study, Hagh Shenas et al. (2016), by examining the sashes of several traditional houses in Isfahan, concluded that the type of glass in the sashes was selected in such a way that, in addition to reducing the transmission of visible light or radiant energy, the passage of wavelengths harmful for skin and other materials in the main space of the building is reduced. Bani Hashem & Latifi (2014), by collecting information through library-field and observational methods, tried to state the identity and place of light in Iran culture by representing the role of light in traditional architecture as a cultural foundation, as well as the relationship between light and human states of mind and spirit and the effect of light on human physical health. Alipour (2011) studied the design of Qajar palace sashes and examined the main motifs and their comparison with other arts in the Qajar period. Vahdat Talab & Nik Meram (2017) investigated the importance and abundance of red in the sashes of Qajar houses. Bellia & Fragliasso (2021) investigated the role of architecture in determining the non-visual effects of light, including influencing the process of melatonin secretion and, as a result, the sleep-wake cycle. Houser et al. (2020) have studied human-centered lighting and stated that considering visual comfort, which is important in lighting design, a new responsibility regarding how light affects non-visual human responses is also considered. Mostafavi et al. (2023) stated that investigating human responses to light can reveal important information that can potentially improve environmental design, circadian health, cognitive performance, and overall well-being. In their study, the researchers used V.R. immersion, EEG, and a machine-learning approach to understand better the relationship between brain activity and two important lighting properties - the illumination level and the correlated color temperature (CCT). Zeng et al. (2022) investigated the effect of a correlated color temperature of office light on subjective perception, mood, and task performance. Their research has shown multiple light-correlated color temperature (CCT) effects on office staff. These findings highlight that the optimal CCT level varies for different demands such as comfort, positive mood, alertness, and task performance, so the selection of office light CCT should be weighed according to the scenario demands. Tofel et al. (2004) investigated color in healthcare environments and classified experts' opinions about the effects of colors at different times. Edwards & Torocellini (2002) reviewed the relevant literature on the effects of natural light on building users. Dai et al. (2018), while introducing a new lighting design method based on health benefits, analyzed four combined lights and used the color temperature curve for this purpose. Salonen & Morawska (2013) examined the physical characteristics of the interior space that affect health and well-being in healthcare spaces. Bosch & Gresham (2012) studied the use of color in healthcare spaces. Samuels (1990) stated that due to the impact of light on the retina and its transmission to the hypothalamus, human circadian cycles are controlled, and the body's internal clock is synchronized with different 24-hour times. Terman et al. (1986) stated that individuals subjected to isolated laboratory conditions would have a circadian cycle of more than 24 hours. This fact illustrates the ability of light to correct the body's internal clock daily. In the absence of light, the synchronization of the body with the outside world is deviated. Franta & Anstead (1994) designed a fun and healing environment for people with mental health conditions in a psychiatric treatment center in Maryland. The design of this center was based on the use of daylight in different parts of the building. Benedetti et al. (2001) emphasized the advantages and effects of bright artificial light on non-seasonal depression in people with mental health conditions. In this research, it has been concluded that natural light is not very effective in treating bipolar depression because it cannot be controlled. Sharma (2016) explored different types of lighting designs in different cultures. Among these, the illumination of Iranian sashes is mentioned.

As it is observed, until now, the light quality of Iran's stained windows has not been investigated based on the color temperature curve, and this research is important from this point of view.

MATERIALS AND METHOD

Research Method

This research has been conducted as a case study and research on specific samples. A descriptive-analytical method is used to classify the extracted data. Comparative methods are used to analyze the quality of colored light based on the color

Table 2: The area percentage of each stained glass (yellow, green, blue, red)

#	Location of window	Yellow	Green	Blue	Red
1	Karim Khan Citadel 1, Shiraz	41.77%	15.39%	19.01%	23.83%
2	Karim Khan Citadel 2, Shiraz	45.77%	12.86%	22.16%	19.21%
3	Dowlat Abad Garden Monument, Yazd	31.29%	30.68%	14.74%	23.29%
4	Tekye Moavenolmolk, Kermanshah	36.02%	23.30%	14.62%	27.06%
5	Rezazadeh Historical House, Ardebil	21.67%	25.34%	26.67%	26.32%
6	Emamzadeh Zanjiri, Shiraz	25.90%	25.82%	21.78%	26.50%
7	Nasir al-Mulk Mosque Shabistan 1, Shiraz	25.35%	22.63%	24.68%	27.34%
8	Nasir al-Mulk Mosque Shabistan 2, Shiraz	27.64%	21.72%	23.93%	26.71%
9	Nasir al-Mulk Mosque Shabistan 3, Shiraz	21.88%	30.40%	23.65%	24.07%
10	Akhavan Historical House, main sash, Isfahan	12.12%	33.34%	11.11%	33.33%
11	Akhavan Historical House, eastern sash, Isfahan	37.50%	12.50%	12.50%	37.50%
12	Sheikh ol-Islam Historical House, Isfahan	14.28%	42.86%	0	42.86%
13	Sadr Historical House, Isfahan	28.57%	14.28%	14.29%	42.86%

Continiue of Table 2: The area percentage of each stained glass (yellow, green, blue, red)

#	Location of window	Yellow	Green	Blue	Red
14	Baghaee Historical House, Isfahan	33.34%	11.11%	33.33%	22.22%
15	Bozorgzad Historical House, Isfahan	12.50%	37.50%	12.50%	37.50%
16	Rangrazha Historical House 1, Isfahan	23.53%	35.29%	11.76%	29.42%
17	Rangrazha Historical House 2, Isfahan	28.57%	14.29%	14.29%	42.85%
18	Taghavi Historical House, Isfahan	33.33%	11.12%	33.33%	22.22%
19	Zavolian Historical House, Isfahan	5.88%	47.06%	11.76%	35.30%
20	Petrus Historical House, Isfahan	6.66%	40%	13.34%	40%

temperature curve.

To analyze the quality of light obtained from stained windows in Iranian architecture, 20 stained windows were first selected. Then, the area percentage of each stained glass is calculated, as given in Table 2.

Relations for Calculating Color Temperature: This section describes the method of calculating the color temperature of light passing through stained glass and their relations. Before starting this section, it is to mention the fact that the parameters XYZ (tristimulus values) and XYZ (chromaticity values) and $\bar{x}$ $\bar{y}$ $\bar{z}$ (color matching functions) discussed in the following are different from each other. More precisely, first, by using $\bar{x}$ $\bar{y}$ $\bar{z}$ (color matching functions), the values of XYZ parameters (tristimulus values) are calculated. Then, using the calculated XYZ parameters, XYZ values (chromaticity values) are obtained. Finally, the color temperature can be extracted by two chromaticity values, i.e., xy. The detailed relations and steps for performing these calculations are given below.

Calculating tristimulus values XYZ from spectral data: The concept of tristimulus values (X, Y, and Z) was explained in the previous sections. In this section, how to calculate them is discussed. These values for color are obtained from the following relations:

$$X = \frac{K}{N}\int_{\lambda_1}^{\lambda_2} S(\lambda), I(\lambda), \bar{x}(\lambda), d\lambda \qquad \text{(Equation 1)}$$

$$Y = \frac{K}{N}\int_{\lambda_1}^{\lambda_2} S(\lambda), I(\lambda), \bar{y}(\lambda), d\lambda \qquad \text{(Equation 2)}$$

$$Z = \frac{K}{N}\int_{\lambda_1}^{\lambda_2} S(\lambda), I(\lambda), \bar{z}(\lambda), d\lambda \qquad \text{(Equation 3)}$$

The value of N is obtained from the following equation:

$$N = \int_{\lambda_1}^{\lambda_2} I(\lambda), \bar{y}(\lambda), d\lambda \qquad \text{(Equation 4)}$$

In the above relations:

λ: wavelength of colored lights (from 380 nm to 780 nm);

K: scaling factor (zero to one, completely dark to completely light);

S(λ): spectral transmissivity coefficient of the engineering object;

I(λ): spectral emissive power of the black body;

$\bar{x}(\lambda)$: red color matching function in CIE standard (Fig. 3).

$\bar{y}(\lambda)$: green color matching function in CIE standard (Fig. 3).

$\bar{z}(\lambda)$: blue color matching function in CIE standard (Fig. 3).

Color matching functions in the CIE standard, i.e., parameters $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$ These are the numerical descriptions of the chromaticity response by an observer. These curves represent the spectral sensitivity of the three main lights, leading to the calculation of tristimulus values (X, Y, and Z) in the CIE standard.

The values $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$ A computer code calculates using the above chart and considers the area share of the red, green, and blue glasses in the windows in question. Since yellow is a combination of red and green colors, its area was equally distributed between red and green colors if the yellow color was used in the window in question.

In calculating the integrals of equations 1 to 4 to simulate the amount of illumination at different day hours, the value of the scaling factor (K) was placed in three different modes: 0.25, 0.5, and 1. It is notable that although the value of K is effective in the calculation of tristimulus values (X, Y, and Z), it will be observed in the next section that the value of K will lose its effect in the calculation of chromaticity values (x, y, and z). Therefore, since the subsequent analysis of this research is focused on x, y, and z values, the approximate choice of K will not affect the research results.

Based on the information available in the relevant references, the value of stained glass's transmission coefficient was considered 0.79. Due to the variability of the I(λ) function, the method of spectral bands was used to calculate the integrals accurately. It is a common method for calculating radiation at limited (spectral) wavelengths (Incropera & DE Witt, 1996). It is to explain that in this method, instead of considering λ1 and λ2 as the lower and upper limits of the integrals, the parameters λ1.T and λ2.T are used. Consequently, the value of the integrals is calculated with the help of tables in which T is the temperature of engineering surfaces approximated by the black body. Based on the information in the related references, the value of T=5800 degrees Kelvin was considered (Incropera & DE Witt, 1996). In this way, the limits of the integral are calculated as follows:

$$\lambda_1 = 380\ \eta m \Rightarrow \lambda_1, T = 2204\ \mu m, \qquad \text{(Equation 5)}$$

$$\lambda_1 = 780\, \eta m \Rightarrow \lambda_1 T = 4524\, \mu m, K$$ (Equation 6)

Taking into account the above values and using the reference tables, the fractions of radiation up to the desired wavelength (F) are obtained:

$$F(0 \rightarrow \lambda_1) = 0{,}101675$$ (Equation 7)

$$F(0 \rightarrow \lambda_2) = 0{,}567696$$ (Equation 8)

And finally, to facilitate the calculation of integrals, the fraction of spectral radiation from 380 nm to 780 nm, F(λ1-λ2), is obtained as follows:

$$F(\lambda_1 - \lambda_2) = F(0 \rightarrow \lambda_2) - F(0 \rightarrow \lambda_1) = 0{,}46602$$ (Equation 9)

By placing the values and relations mentioned in equations 1 to 3, X, Y, and Z values can be easily calculated. This section explains the equations and relations for calculating the tristimulus values (X, Y and Z) of stained glass windows. This article aims to calculate the color temperature of these windows. For this purpose, chromaticity parameters (x, y, and z) must be calculated, which will be explained below.

Calculating xyz chromaticity values: after calculating the XYZ values, the normalized chromaticity values (x, y, and z) should be calculated. The concept of chromaticity values (x, y, and z) has been described in the previous sections. In this section, how to calculate them is discussed. The normalized chromaticity values are obtained from the following relations:

$$x = \frac{X}{X+Y+Z}$$ (Equation 10)

$$y = \frac{Y}{X+Y+Z}$$ (Equation 11)

$$z = \frac{Z}{X+Y+Z} = 1 - x - y$$ (Equation 12)

As observed, the parameter z does not have an independent value mathematically and can be written in terms of x and y. Therefore, chromaticity can be extracted by the abovementioned normalized parameters x and y. It is clear from the above relations that these two normalized values are functions of all tristimulus values (X, Y, and Z).

Calculating the color temperature: The color temperature can be calculated by having x and y values. Since the human eye has three types of sensors that cover different ranges of wavelengths, the complete diagram of visible colors will be three-dimensional. However, the concept of color is divided into luminance and chromaticity. For example, white is a bright color, while gray is the non-bright version of the white color. In other words, the chromaticity of white and gray are the same, but their brightness is different. Fig 4 illustrates chromaticity and color temperature in the range of visible radiation (from 380 nm to 780 nm). It is emphasized that the chromaticity chart does not specify the apparent color of the object (the apparent color depends on the characteristics of the object. As stated in the relations, the degree of chromaticity depends on the light source in addition to the characteristics of the object). In other words, the chart of chromaticity and color temperature is a tool that determines what the human eye experiences when faced with a spectrum of light.

RESULTS AND DISCUSSION

Data Analysis

Since this research aims to analyze the performance of traditional Iranian windows, calculating the color temperature of the windows will be a suitable criterion for judgment. That is, if the color temperature of the stained windows of traditional Iranian architecture is calculated, the experience of people facing the sunlight passing through these windows can be quantitatively expressed.

In this research, according to the described relations, the exact

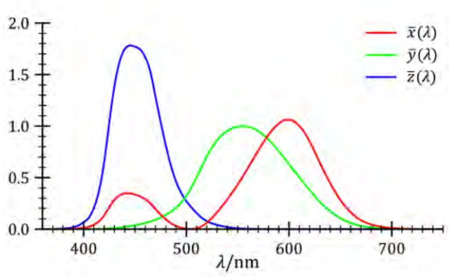


Fig. 7: Comparision between single-glazed glass and double-glazed glass in cooling

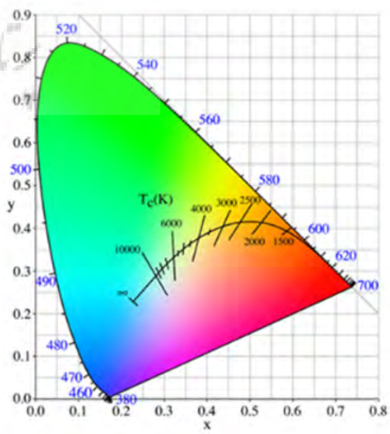


Fig. 4: Color Temperature curve (International Illumination Commission, CIE 1932).

values of x and y chromaticity values of each of the windows in question are calculated (Table 3). Then, the color temperature value of each window will be extracted by locating the x and y values on the chromaticity and color temperature diagram. Of course, some sites provide services in this field to facilitate it. That is, instead of finding approximate points on the diagram, the user can get the color temperature value by entering the calculated x and y values (Table 4).

As observed, all windows are in these two ranges, so 65% are in the range of 3000 to 4600, categorized in the natural white lights category, and 35% are in the range of 2000 to 3000, in the warm white lights category (Fig 5). Therefore, even though the color temperature of the sunlight changes during the day, the stained windows under study keep the color temperature of the ambient light constant in these two ranges. In other words, even though the stained windows reduce the intensity of the sunlight, the feeling they create in the space is in the following two categories (Table 1):

• Warm and friendly with a soft and relaxing feeling and an inviting and welcoming feeling;

• The feeling of a bright, attractive, and lively space.

It is noted that the color temperature range of 2000-3000 degrees Kelvin is called sunny, and its color is warm and yellowish. This light color will make the surrounding space warm and comfortable. The light color temperature range of 3000 to 4600 degrees Kelvin is called natural, and its color is close to the sunlight during the day and combines two colors of natural light and moonlight. This light color will make the surrounding space bright and attractive. The light color temperature range of 4600 to 6500 degrees Kelvin is called moonlight. Light cools the surrounding space by using this color, creating concentration and invigoration. Therefore, it can be concluded that in all samples of studied windows, the temperature of the transmitting color is in a range that psychologically induces a favorable feeling in humans.

CONCLUSION

Incorrect architecture and other harmful factors can cause stress, fatigue, psychological symptoms, and even physical discomfort. Generally, these effects are not obvious immediately but often appear after several months or years. This conclusion also proves that the spaces can promote healing and health processes with the reverse function. It has been proven that humans are under the influence of different spectrums of light, both psychologically and physiologically. These effects have been less measured or easily ignored in architecture.

Table 3: Calculation of the color temperature of the windows from the color temperature curve

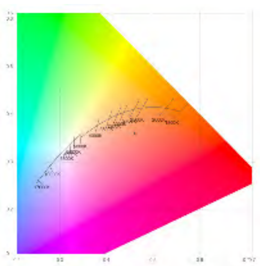
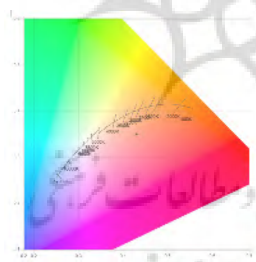
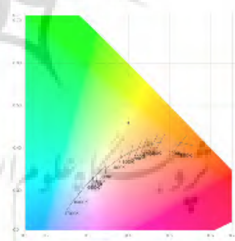
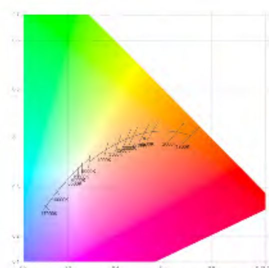
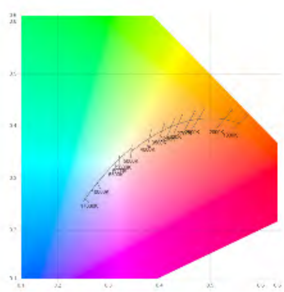
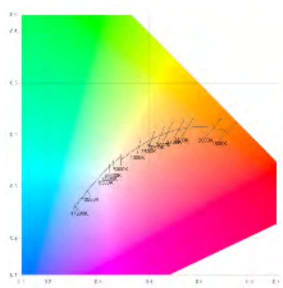
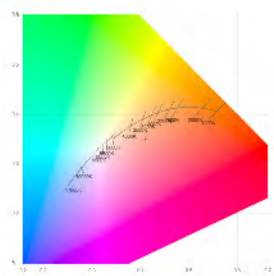
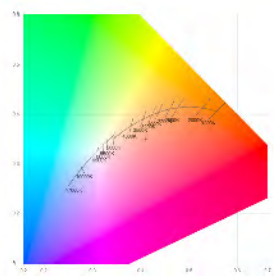
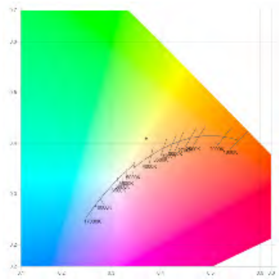
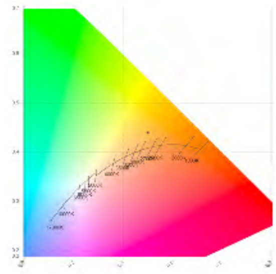
Karim Khan Citadel 1, ShiraZ	Karim Khan Citadel 2, Shiraz	Dowlat Abad Garden Monument, Yazd	Tekye Moavenolmolk, Kerman-shah
			
Rezazadeh Historical House, Ardebil	Emamzadeh Zanjiri, Shiraz	Nasir al-Mulk Mosque Shabistan 1, Shiraz	Nasir al-Mulk Mosque Shabistan 2, Shiraz
			
Nasir al-Mulk Mosque Shabistan 3, Shiraz	Akhavan Historical House, main ,sash	Akhavan Historical House, ,eastern sash	Sheikh ol-Islam Historical House, Isfahan

Fig. 7: Comparision between single-glazed glass and double-glazed glass in cooling


Sadr Historical House, Isfahan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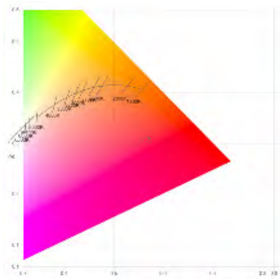
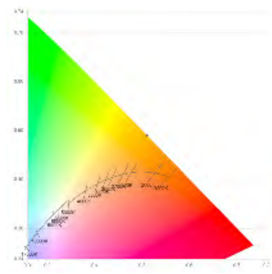
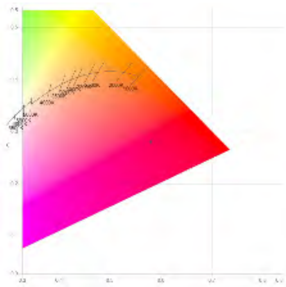
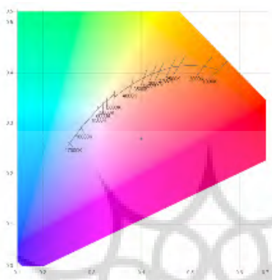
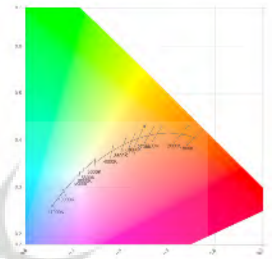
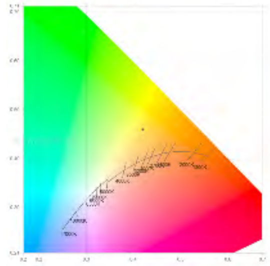

Bozorgzad Historical House, Isfahan

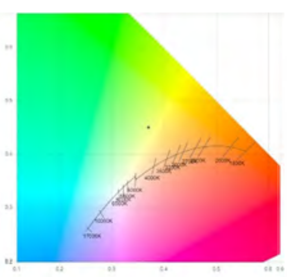

Rangrazha Historical House 1, Isfahan

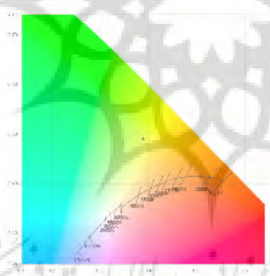

Taghavi Historical House, Isfahan

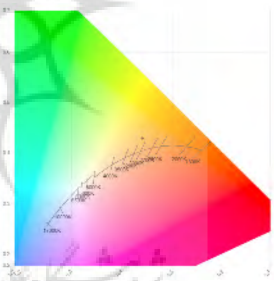

Zavolian Historical House, Isfahan


Petrus Historical House, Isfahan


Rangrazha Historical House 2, Isfahan







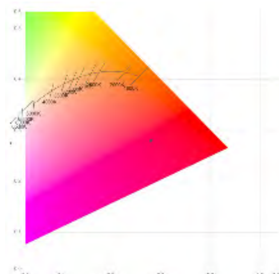


Table 4: Conversion of x and y to color temperature in degrees Kelvin

#	Location of window	x	y	Color temperature
1	Karim Khan Citadel 1, Shiraz	0.46	0.36	2246
2	Karim Khan Citadel 2, Shiraz	0.43	0.35	2612
3	Dowlat Abad Garden Monument, Yazd	0.40	0.46	4030
4	Tekye Moavenolmolk, Kermanshah	0.46	0.40	2610
5	Rezazadeh Historical House, Ardebil	0.38	0.36	3891
6	Emamzadeh Zanjiri, Shiraz	0.40	0.38	3537
7	Nasir al-Mulk Mosque Shabistan 1, Shiraz	0.41	0.35	3024
8	Nasir al-Mulk Mosque Shabistan 2, Shiraz	0.41	0.35	3024
9	Nasir al-Mulk Mosque Shabistan 3, Shiraz	0.37	0.41	4455
10	Akhavan Historical House, main sash, Isfahan	0.45	0.44	3064
11	Akhavan Historical House, eastern sash, Isfahan	0.57	0.31	2518
12	Sheikh ol-Islam Historical House, Isfahan	0.51	0.49	2648
13	Sadr Historical House, Isfahan	0.58	0.28	4439

Continiue of Table 4: Conversion of x and y to color temperature in degrees Kelvin

#	Location of window	x	y	Color temperature
14	Baghaee Historical House, Isfahan	0.40	0.27	2095
15	Bozorgzad Historical House, Isfahan	0.45	0.43	2993
16	Rangrazha Historical House 1, Isfahan	0.42	0.46	3672
17	Taghavi Historical House, Isfahan	0.37	0.45	4600
18	Zavolian Historical House, Isfahan	0.39	0.49	4337
19	Petrus Historical House, Isfahan	0.44	0.43	3149
20	Rangrazha Historical House 2, Isfahan	0.58	0.28	4439

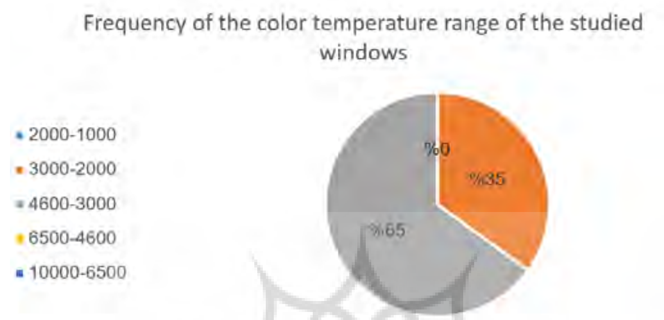


Fig.5: Frequency of the color temperature range of the studied windows

In this research, the color temperature of the light obtained from twenty stained windows of Iranian architecture was calculated based on the CIE color temperature curve to determine the quality of the light obtained from these windows based on the standards. Investigations affirmed that the light color temperature of 65% of the windows is in the range of 3000 to 4600 degrees Kelvin, categorized in the natural white light group, and 35% are in the range of 2000 to 3000, in the warm white light category; so despite that the stained glasses reduce the intensity of sunlight, but the color temperature of the light they create is either equivalent to natural light or equivalent to warm white light. Therefore, the use of stained glass with this model (a combination of four colors, red, green, blue, and yellow, and the area percentage that is used in each stained window) affirms that despite the decrease in light intensity, that seems essential in most regions of Iran, the light quality is not reduced based on the color temperature curve.

It is to mention that the concept of color is divided into two parts, brightness and chromaticity (color temperature). Despite the day's brightness change based on the sun's radiation throughout the day, the stained glasses of the studied windows always keep the color temperature of the light constant.

AUTHOR CONTRIBUTIONS

F. Barzegari Naeini performed the literature review and experimental design, analyzed and interpreted the data, and prepared the manuscript text and edition. H. Soltanzadeh performed the literature review and helped with the methodology. S. Mirshahzadeh helped with the literature review and methodology. S.Z. Moosavi Mohammadi performed some of the remaining experiments, helped with the research method and data analysis, and helped prepare the manuscript text.

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CONFLICT OF INTERESt

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication or falsification, double publication and, or submission, and redundancy, have been completely witnessed by the authors.

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