PHOTOPROTECTION BY WINDOW GLASS, AUTOMOBILE GLASS AND SUNGLASSES

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Abstract

In daily activity, much time is spent indoors and in vehicles. Although the adverse effect of UV radiation is now well recognized and a significant public education program has been undertaken regarding photoprotection, the role of window glass in photoprotection has been rarely addressed. It has been known for some time that window glass filters out UVB, but UVA and visible light are transmitted. Factors affecting UV protective properties of glass are glass type, glass color, interleave between glass, and glass coating. Recent developments in the glass industry have resulted in window glass that provides broad UV protection without the historically associated loss of visible light transmission. In this article, photoprotection by window glass, automobile glass and sunglasses is reviewed.

Introduction

Electromagnetic radiation is broadly divided into infrared radiation, visible light, and ultraviolet radiation (UVR) (Fig. 1). Heat is part of infrared radiation, which is not visible to the human eye. Visible light is the wavelength range of general illumination. UVR is divided into three distinct bands in order of decreasing wavelength and increasing energy: UVA (320-400 nm), UVB (290-320 nm) and UVC (200-290 nm). Different wavelengths and energy associated with UV subdivision corresponds to distinctly different effects on living tissue. UVC, although it possesses the highest energy and has the greatest potential for biological damage, is effectively filtered by the ozone layer and is therefore not considered to be a factor in solar exposure of human beings. During a summer day, the ultraviolet spectrum that reaches the earth's surface consists of 3.5% UVB and 96.5% UVA.[1] UVB is primarily associated with erythema and sunburn. It can cause immunosuppression and photocarcinogenesis. UVA penetrates deeper into the skin. In contrast to UVB, it is more efficient in inducing immediate and delayed pigment darkening and delayed tanning than in producing erythema. UVA is known to have significant adverse effects including immunosuppression, photoaging, ocular damage, and skin cancer [2-6].

More than one million new cases of skin cancer are diagnosed annually in the United States, with sun-induced carcinomas as the most common form. In the U.S., one person in five will develop skin cancer at some point in their lifetime.[7]

Eighty percent of the average day of Americans is spent indoors.[8] Although not as high as the outdoor workers, it has been estimated that individuals who work indoors receive between 7 to 10 standard erythema dose (SED) per day of UV radiation in spring and 2 or more in winter and on cloudy summer days[9] (1 SED is equivalent to an erythemal effective radiant exposure of 100 J/m^2). Contemporary residential and commercial architectural design increasingly incorporates more and larger window areas (Fig. 2). This design trend is supported by the evolution of energy efficient glazings. The most effective of these glazings are capable of dramatically reducing heat gain and heat loss through windows. Many of these energy efficient glazing options also provide some measure of UV protection, however only a very small percentage of architectural glazing provides full UV protection.

In studies of UV exposure in cars, it was concluded that the parts of the driver's or passengers' bodies closest to a non-laminated or tinted window showed the most exposure to UV radiation.[10-12] Extending this conclusion to people that spend significant indoor time near windows, it is reasonable to conclude that exposure to UV through architectural window glass is a topic that should be addressed.

The hazardous effect of UV radiation is now well recognized; public education regarding the use of sunscreen, sunglasses, protective clothing, seeking shade and sun avoidance during peak exposure periods is ongoing. [13-19] However the topic of UV exposure risk through window glass has been rarely addressed. In a study reported in 2003 on UV protection in shade structures, the authors concluded that shade structures did not effectively protect against the skin and eye danger presented by the exposure to diffuse UV radiation.[17] The interior of motor vehicles and any residential or commercial space in proximity to open or closed glass windows must also be included in the definition of a shade structure.

It has been well recognized that standard glass filters out UVB, but UVA, visible light and infrared radiation are still transmitted. With recent developments in the glass industry, additional filters for UVA and infrared radiation can now be incorporated. Most of these glasses are indistinguishable to the human eye but provide different degrees of UV and infrared protection. This article was written to provide an update on the role of window glass, automobile glass and sunglasses in photoprotection.

Window glass and photoprotection

I. What is glass?

Glass is a mixture of sand: very high-quality silica sand added with other materials such as salt cake, limestone, dolomite, feldspar, soda ash and cullet. The resulting mixture is called a batch (Fig.3). Glass is made through the melting and cooling of the batch. As the batch cools, it becomes a solid without forming crystals, thereby making glass transparent.

Float glass refers to glass made by pouring the molten batch from a furnace into a chamber that contains a bed of molten tin. The atmosphere inside the chamber is carefully controlled. The glass floats on the tin and forms itself in the shape of the container. This process produces a long ribbon of high-quality flat glass that will be later cut into smaller pieces for fabrication.

II. Configurations of architectural glass

In ancient times, holes were strategically placed in structures to provide light and a view of the outdoors. The word we now know as “window” was first associated with these wall holes in the 11th Century, deriving from an Old Norse expression that can be translated as the combination of the words “wind” and “eye”. Unfortunately, as this translation suggests, these holes provided a view (“eye”), but they also subjected occupants to the elements (“wind”, not to mention rain, heat, cold, etc.). With the discovery and production of glass it became possible to shield building occupants from the negative effects, while maintaining the desired effects, of windows. Although the use of monolithic window glass (i.e., window glass with a single pane of glass) was an improvement over a simple hole in the wall, windows were still the least insulating of all exterior building components. The use of more and larger windows in all forms of architecture steadily increased until the cost of heating and cooling buildings with more and more windows and less and less wall exceeded the aesthetic value of the windows. In order to reduce the energy liability of monolithic window glass, insulating glass units were introduced. Insulating glass units (IGUs) are comprised of two or more monolithic pieces of glass, separated by a perimeter spacer to keep the pieces of glass apart, and sealed with curable adhesive material that holds all the pieces together. There was one other important innovation associated with the use of insulating glass; it was now possible to consider the use of heat reflecting coatings on the protected surfaces of the IGU. Until this time, glass coatings were limited to the use of materials that had chemical and mechanical durability characteristics that were at least comparable to uncoated glass. With the advent of insulating glass it became possible to use materials that were less durable than glass, yet provided heat-reflecting characteristics that dramatically improved the insulating value of windows. Today, insulating glass units are included in over 95% of all windows sold in the United States, and although still a small percentage of total window sales, triple glaze IGUs (three pieces of glass) are growing in popularity.

III. Types of glass

Common types of glass used in residential and commercial buildings are summarized in Table 1, and discussed in the following paragraphs.

Clear glass

Clear glass is generally described as transparent and nearly colorless. The primary characteristic of glass in architectural applications is to provide protection from the outside elements, while providing a view and enabling visible light transmittance to the interior. Depending upon its thickness, clear glass allows up to 90% of the visible light, up to 72% of UV (300-400 nm), and up to 83% of solar heat to pass through.

Tinted or heat-absorbing glass

This type of glass contains special color components. The tint is typically specified for its aesthetic properties and for its ability to reduce unwanted solar heat transmission. Commonly used tinted glass may absorb 40%-50% of incoming solar energy, reducing unwanted heat gain. Solar radiation is reflected, transmitted and absorbed by glass. Most of the absorbed radiation is emitted as heat in both directions; some of the absorbed, however, passes through the window by conduction and re-radiation. Tinted glass also has less UV and visible light transmission in comparison to clear glass.

Reflective glass

This type of glass is designed to reflect light and heat, through the use of metal oxide coatings that typically give the glass a mirror-like appearance. This type of coated glass minimizes unwanted solar heat gain and reduces UV transmission, although visible light transmission is also typically reduced quite significantly. Reflective glass is often specified for commercial buildings. The most commonly used reflective glass in commercial applications will virtually eliminate the ability to see the interior of a building from the outside; an observer will only see their own refection during daylight hours, although exterior views are unimpeded from the building interior. At night however, due to the higher light intensity inside than the outside, the mirroring effect is reversed. An outside observer may see in, but an interior observer may only see his or her own image.

Low-emissivity (low-E) glass

This type of glass has a special surface coating comprised of microscopically thin, optically transparent layers of silver sandwiched between layers of antireflective metal oxide coatings. Low-E glass provides a unique combination of performance attributes, which have led to broad use in residential and commercial architectural applications. Most low-E coated glass will significantly reduce the loss of generated heat. The most common low-E products also minimize undesirable solar heat gain through a window without the loss of color neutrality and visible light transmission. These coatings reflect from 40% to 70% of the solar heat that is normally transmitted through clear glass, while allowing the full amount of visible light to pass through. Different types of low-E coatings have been designed to allow for high, moderate or low solar gain applications, so attention to product-specific performance attributes is necessary to achieve the desired effect. UV transmission may also be reduced from approximately 60% down to 20% when comparing a window with standard clear glass to a window containing the most common low-E coated glass. While this is a sizeable reduction in total UV transmission, the majority of the UV radiation being reflected by the low-E coating falls in the UVB range; UVA is largely unimpeded by these otherwise advanced coatings.

Laminated glass

Laminated glass is produced by permanently bonding two pieces of glass together with a tough plastic interlayer (polyvinyl butyral, PVB) under heat and pressure. Once bonded together, the glass sandwich acts as a single unit and generally appears very similar to standard clear glass. The interlayer is virtually invisible when viewed in transmission with glass on either side. The benefit of laminated glass is that if broken, glass fragments will adhere to the PVB interlayer rather than falling free, thereby reducing the risk of physical injury and property damage. PVB also has properties that effectively filter over 99% of UV up to approximately 375 nm without sacrificing visible light transmission, although with new developments, laminated glass is increasingly more transparent to wavelengths above 380 nm. It also reduces transmission of sound. Laminated glass is commonly used in automobiles (for windshields), airports, museums, sound studios, schools, greenhouses, and large public spaces.

UV-blocking coated glass

This new type of glass has a very thin, virtually invisible surface coating that makes it nearly indistinguishable from standard clear glass. In monolithic form (i.e., a window composed of a single pane of glass), this unique coating blocks more than 98% of UV radiation while transmitting all the visible light. This product is designed for use in an insulating glass unit (IGU, comprising two or more panes of glass) (Fig. 4); therefore it can be combined with a variety of other glass products depending on the overall performance and aesthetic application requirements, often resulting in nearly complete UV blockage.

Spectrally selective & UV-blocking insulating glass

This special glass package provides the combined performance benefit of spectrally selective low-E with nearly complete UV protection. It is made of one piece of UV-blocking coated glass and one piece of spectrally selective low-E coated glass. It blocks more than 99% of UV transmission, nearly 70% of unwanted solar heat gain, while maintaining approximately 70% visible light transmission with aesthetic properties that are very close to standard clear glass.

The properties of solar, visible light and UV transmission through a number of different types of glass are demonstrated in Table 2, Table 3, Fig.5 and Fig.6. It should be noted the glass performance data referenced throughout this document has been generated by Guardian Industries Corp. (Auburn Hills, Michigan) by using the Lawrence Berkeley National Laboratory (LBNL) Window 5 software program. Spectral performance data contained in the Window 5 program has been submitted by the individual product manufacturers and verified by LBNL staff and a peer review process.

IV. Thickness of glass

Float glass is commonly produced in a wide range of thickness depending on the application requirements. Examples of common glass thickness and the associated application are demonstrated in Table 4. Thickness of glass has limited effect on the properties of solar, visible light and UV transmission. (Tables 2, 3).

V. Color of glass

Glass is produced in a wide range of color depending on the application requirements. Examples of common glass colors and the associated applications are demonstrated in Table 5. Effect of glass colors on the properties of solar, visible light and UV transmission is depicted in Figure 7.

VI. Test methods for quantitative assessment of UV protection of glass

Various components affect UV protection factor of a finished window glass. Some of the main factors are glass type, glass color, interleave between glass, and coating on glass. Thickness of glass has little effect on UV transmission. Spectrometry is a method used in determining UV protection factor and transparency factor of windows. The tested glass sample is placed in a specimen holder of spectrophotometer in alignment to illuminating beam. The wavelength range will be scanned from 280 nm to 780 nm with 5 nm intervals. The relative transmission in the range of 300 nm to 400 nm is used to calculate transmission of UV (Tuv, %). The relative transmission in the range of 400 nm to 780 nm is used to calculate transmission of visible light (Tvis, %).

Automobile glass and photoprotection

Overview

Although glass effectively blocks all of UVB radiation, UVA, especially the longer spectrum of UVA (UVA1) can still be transmitted. Photosensitive patients can experience exacerbations of their disease while driving or traveling by car. Transmission of UVR through automobile glass depends on type and tint of glass. For safety reasons, all windshields are made from laminated glass, which can filter most of UVA. However, side and rear windows are usually made from non-laminated glass; therefore, a significant level of UVA can pass through. Individuals traveling by car can be exposed to considerable amount of UVA through side and rear windows. Percent of UV and visible light transmission through different types of automobile glass is shown in Table 6. It should be noted that as the UV transmission decreases, it is the long wave UV, predominantly UVA1 that continues to be transmitted.

In a study of automobile window glass, it was demonstrated that tinted window glass removed a significant amount of UVA; it allowed for 3.8 times less UVA to be transmitted compared to untinted window glass.[20] Parts of the drivers or passengers' bodies closest to a non-laminated or tinted window received the most irradiation. The shoulder, arm, and hand of the driver are the body parts that received the highest UV exposure. UV exposure was two to three times greater in a smaller car compared to a larger car.[12]

A study was conducted on UV transmission through samples of windshields, side windows, rear windows and sunroofs of Mercedes-Benz cars. Windshields were found to effectively block UV of wavelengths shorter than 375-385 nm. Back and side windows were similar in UV protection and were less effective in filtering UV than the windshield. Average UVA transmission through side windows and back windows range from 0.8%- 17.5% and 0-25.7%, respectively. Sunroof glass filters UV shorter than 335 nm. In this study, simulated UV exposure during driving was done by placing dummies with attached dosimeters in the car. On the arm, the averages of UVA exposure when the windows were shut and opened were 3%-4% and 25%-31% of ambient radiation, respectively. In an open convertible car, the relative personal dose reached 62% of ambient radiation.[11]

In a 2004 study, transmission of UVA through a range of automobile glass types was assessed by measuring UV transmission of laminated and non-laminated glass, each with different color tints[21]. Clear non-laminated glass was found to have the lowest UVA protection, followed by non-laminated light green, non-laminated dark green and laminated clear glass. Grey tinted laminated glass provided the highest UV protection. Only 0.9% of UVA was transmitted through gray tinted laminated glass compared to 62.8% by non-laminated clear glass. UVA exposure in automobiles is also influenced by non-glass related factors such as position of the individual in a vehicle, direction of travel with respect to the sun and time of the day. Clinical relevance of UV exposure in automobiles of the photosensitive patients was also assessed. A 5 J/cm^2 dose of UVA, which is sufficient to induce cutaneous eruption in patients with severe photosensitivity, could be obtained when the arm is placed near a non-laminated clear window for 30 minutes. If a laminated gray window was used as a substitute, at least 50 hours of UV exposure would be required to produce skin lesions in those patients.[21]

Enhanced photoprotection through the use of window film

It is now possible for automobile owners to further darken the tint on side and rear windows. This process, by reduction of the transmission of visible light and infrared radiation, permits reduced interior heat gain and minimizes the fading of interior components. Aftermarket tinting of side and rear vehicle windows has become popular due to the availability of a broad range of colors and tints, and the general ease of installation. In the United States, aftermarket tints are not allowed to reduce the federally-mandated 70% minimum visible light transmittance of automobile windshields, except for the top 4 inches of the windshield.[22] Minimum allowable visible light transmission levels for side and rear windows are determined by each State. Most States in the U.S. do not allow plastic films with less than 35% visible light transmittance.[22] It has been reported that plastic film with 35% and 20% visible light transmittance filtered UVA below 370 and 380 nm respectively.[23]

Eyeglasses and photoprotection

Introduction

One of the most common questions about sunglasses is how should one pick suitable sunglasses. To properly advise patients, one must understand the main purpose of sunglasses, which is protection against sun glare and harmful radiation. Current available knowledge shows that electromagnetic radiation; especially UV radiation, is potentially hazardous to the structure of the eyes, particularly the cornea, lens and retina.[24-25] Therefore to adequately protect the eyes by sunglass, a sunglasses standard is required. The first sunglasses standard was published in 1971 in Australia. Since then, the United States and European countries have also established their standards.[26, 27]

Sunlight and the eye

There are several eye disorders related to sun exposure. Among them, cataracts and age-related macular degeneration is of the greatest concern to the ophthalmologist. Pterygium and keratitis are also commonly found in people who predominantly work outdoors. Although solar radiation is comprised of a wide range of wavelength radiation, all of the eye disorders mentioned above are related to UV and short wavelength visible light.[28, 29] The ozone layer in the earth's atmosphere filters out the most potentially damaging UV radiation to the eyes, namely UVC. Similar to cutaneous erythema, the longer the wavelength, the longer the duration of exposure required producing the same degree of ocular damage.

Due to the filtration effect of ocular structures, different wavelengths within the UV and visible light ranges penetrate through different parts of the eye (cornea, lens and retina). The cornea substantially absorbs wavelengths shorter than 295 nm. Excessive UVB exposure can cause conjunctiva and permanent damage to the cornea. Wavelengths between 295-400 nm penetrate more deeply and can cause damage to the crystalline lens.[30] Visible light and infrared transmit to the retina.

UV-induced ocular damage is divided into acute and chronic effects. Examples of acute effects include photokeratiitis (also known as welder's flash or snow blindness) from UVC and UVB radiation, and solar retinitis (also called blue light retinitis or eclipse blindness) from unprotected exposure to intense sunlight such as viewing of solar eclipse.[27] Short-wavelength visible light (blue-violet) can cause a retinal photochemical burn, whereas longer wavelengths and short pulses of intense visible light appear to be capable of inducing retinal thermal damage. Wavelengths between 400 and 1,400 nm may reach the retina in the normal eye, and at sufficient irradiance levels can cause a retinal burn.[31] Chronic effects of UV radiation associated with long-term exposure to sunlight include cataracts, pterygium and age-related macular degeneration. Adverse effects of different wavelengths of the electromagnetic spectrum on different parts of the eye are summarized in Fig. 8.

Sunglasses standard

Australia has led the world in sunglass standards, developing the world's first national standard for sunglasses for general use in 1971.[26,27] This standard contained requirements for both sunglass lenses and assembled sunglasses. The Australian sunglass standard AS1067 was reissued in an extensively revised form in 1983 and was further revised in 1990. The current draft Australia standard has been modified to reflect the current European standard (EN 1836-1997). Committee work on the sunglass standard in the USA began on 7 Jan 1971. The USA sunglass standard was first published in 1972 by American National Standards Institute (ANSI Z80.3-1972); its most recent version was published in 2001. This standard (ANSI Z80.3) is voluntary and is not followed by all manufacturers.[32] Although the International Standardization Organization (ISO) has been working on an international standard for sunglasses, it was not published at the time of this writing.[27]

Three types of sunglasses have been classified: 1) cosmetic sunglasses (worn as fashion accessories and providing minimal UV protection), 2) general purpose sunglasses (for reducing glare in bright light or in circumstances such as driving in daylight), and 3) special purpose sunglasses (for activities such as skiing, going to the beach) (Table 7). ANSI Z80.3 requires less than 1% of the wavelengths below 310 nm to be transmitted.[32] Based on the ANSI standard, lenses are classified according to intended function (special, dark, general purpose, and cosmetic tint) (Table 7). Lenses should be strong enough so that they will not break into several pieces, and sunglass material should not be flammable. Polarizing lenses are helpful in minimizing glare; however, they do not provide added UV blocking properties. Scratched lenses will scatter the incoming UV and visible light and could cause glare around the area of the scratch. There is no regulation regarding lens color; however, the effect of the color should not interfere with the ability to see color-coded signals, particularly red and green traffic signals. Neutral gray and amber brown are two popular colors that give true color rendition. Dark tint lens may cause papillary dilation, allowing the oblique peripheral ray of light to transmit to the eye if the sunglasses are not designed to wrap around the temporal area. Because UVR can cause eye damage and skin cancer of the eyelids,[33,34] the ideal sunglass should be designed to wrap around the eyes , thereby maximizing eye and eyelid protection.

Only visible light, not UV, is required for human vision. Therefore, the ideal sunglasses should substantially reduce UV to cornea and lens, including that from lateral directions. The lens should not be too small because a significant amount of UV can reach unprotected eyes. Only the Australian standard AS1067 addressed this issue by setting requirements for the minimal lens dimension.[27] Eyeglasses should reduce visible light sufficiently to diminish discomfort associated with glare, but should transmit sufficient visible light with wavelengths that allow for good color discrimination such as red and green of traffic lights. Short wavelengths e.g., blue light, is considered to be hazardous to the retina;[35-36] this has led to development of "blue-blocking lenses" that absorb visible light between 400-500 nm. Blue-blocker sunglasses that transmit sufficient blue signal are able to pass the European Standard (EN-1836), although they failed to meet the Australian AS1067 and U.S. ANSI Z80.3 standards.[27]

Expensive sunglasses do not necessarily provide better UV protection.[37] Looking for sunglasses that meet sunglass standards for a safe level of UV protection is a good start. Consulting an ophthalmologist or eye-care specialist when selecting eyeglasses is helpful.[38] For even better photoprotection, wearing a broad-brimmed hat helps tremendously in reducing the level of UV radiation reaching the eyes and surrounding tissue.

Conclusion

The degree to which glass products provide UV protection depends on the glass type, glass color, the presence of an interleave between pieces of glass, or the presence of a coating on the glass. Window glass is generally known to filter UVB. Dark tinted and reflective window glass commonly used in commercial buildings has historically provided occupants of these buildings greater UV protection than occupants of residential structures, in which highly transmitting glass is predominant.

Recent developments in the glass industry have resulted in the introduction of additional filters for UVA and infrared radiation. This UVA filtering technology can now be incorporated into a glass coating, providing more comprehensive photoprotection.

Automobile glass provides different properties of UV protection. Although windshields are made from laminated glass, which can block a large amount of UVA, most side and rear windows are tinted, but not laminated glass, therefore UVA1 can still reach vehicle occupants. Enhanced photoprotection can be achieved in automobiles through more comprehensive use of laminated glass, through the incorporation of glass coatings, or by tinting or applying window film to non-laminated rear and side windows. Patients with severe photosensitivity are advised to choose vehicles with complete laminated window glass packages or apply plastic film to non-laminated rear and side windows. Of course it is also advisable to keep vehicle windows closed, wear protective long-sleeved clothing, and apply broad-spectrum sunscreen when driving or traveling by cars.

In order to select sunglasses that will maximize UV protection, one should look for sunglasses fulfilling one of the comprehensive sunglass standards. Attention should be paid to the entire frame, not just the lens itself; sunglasses with wraparound, side shields or overhead protection provide better UV protection to the eyes and surrounding areas. In the U.S., because compliance with the sunglass standards is voluntary, most but not all sunglasses that have good UV protection carry an identifying label. It should be noted that expensive or dark-tinted sunglasses might not provide the most comprehensive UV protection. Dark-tinted sunglasses can make pupils dilate and increase lid opening, thereby resulting in increased UV exposure to the lens of the eye.

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Table 1. Common types of glass used in residential and commercial buildings

Glass Types
Clear Glass
Tinted (Heat Absorbing) Glass
Reflective Glass
Low-Emissivity (Low-E) Glass
Laminated Glass
UV-blocking Coated Glass
Insulating Glass

Table 2. Typical residential architectural window glass configurations with properties of solar, visible light and ultraviolet transmission[a]

Type of glass	Thickness (mm)	Tsol[b] (%)	Tvis[b] (%)	Tuv[b] (%)
Monolithic[c] clear glass	3.0 mm	83%	90%	72%
Monolithic tint glass	3.0 mm	61%	62%	40%
Monolithic laminated glass	6.0 mm	74%	88%	0.6%
Double glazed[d] clear glass	3.0 mm / 3.0 mm IGU[e]	72%	82%	57%
Double glazed tint glass	3.0 mm / 3.0 mm IGU	52%	56%	33%
Double glazed spectrally selective low-E glass	3.0 mm / 3.0 mm IGU	36%	71%	20%
Double glazed laminated glass	6.0 mm / 3.0 mm IGU	63%	80%	0.5%
Double glazed spectrally selective UV-blocking glass	3.0 mm / 3.0 mm IGU	34%	69%	0.1%

a Data provided by Guardian Industries Corp. (Auburn Hills, Michigan, USA).

b Tsol: transmission of solar radiation, Tvis: transmission of visible light, Tuv: transmission of ultraviolet radiation.

c Monolithic glass: a single pane of uncoated glass.

d Double glazed: an insulating glass unit formed using two layers of glass separated by a sealed airspace.

e IGU: Insulating glass unit

Table 3. Typical commercial architectural window glass configurations with properties of solar, visible light, and UV transmission [a]

Type of glass	**Thickness (mm)**	**Tsol[b] (%)**	**Tvis[b] (%)**	**Tuv[b] (%)**
Double glazed tint glass	6.0 mm / 6.0mm IGU	35%	40%	20%
Double glazed spectrally selective low-E glass	6.0 mm / 6.0 mm IGU	32%	68%	28%
Double glazed reflective glass	6.0 mm / 6.0 mm	13%	19%	17%
Double glazed spectrally selective reflective glass	6.0 mm / 6.0 mm	24%	43%	25%
Double glazed laminated glass	6.0 mm / 6.0 mm IGU	58%	79%	0.5%
Double glazed spectrally selective UV-blocking glass	6.0 mm / 6.0 mm IGU	32%	67%	0.2%

a Data from Guardian Industries Corp. (Auburn Hills, Michigan, USA)

b Tsol: transmission of solar radiation, Tvis: transmission of visible light, Tuv: transmission of ultraviolet radiation.

Table 4. Common architectural and automotive glass thickness and applications[a]

Application	**Monolithic glass thickness**	**Application configurations**
Residential architecture	2.3mm, 3.0mm, 4.0mm, 5.0mm, 6.0mm	Insulating glass unit comprised of two pieces of equal thickness glass
Commercial architecture	5.0mm, 6.0mm, 8.0mm, 10.0mm	Insulating glass unit typically comprised of two pieces of equal thickness glass
Automotive (monolithic tempered glass)	3.1mm, 4.0mm, 5.0mm	Monolithic tempered glass used primarily for side and rear windows in passenger vehicles
Automotive (laminated glass)	4.0mm, 5.0mm, 6.0mm	Laminated glass used primarily for front windshield and some side windows.

a Data provided by Guardian Industries Corp. (Auburn Hills, Michigan, USA)

Table 5. Common architectural and automotive glass colors and types and their applications[a]

Application	**Glass types**
Residential architecture	Clear, Bronze, Gray, Spectrally selective low-E, Spectrally selective UV-blocking low-E, Laminated glass
Commercial architecture	Clear, Low iron Clear, Bronze, Gray, Green, Blue green, Reflective, Spectrally selective low-E, Spectrally selective reflective low-E, Laminated glass
Automotive (monolithic tempered and laminated)	Solar green, Solar gray, Solar control coated glass

a Data from Guardian Industries Corp. (Auburn Hills, Michigan, USA)

Table 6. Percent of UV and visible light transmission through different types of automobile glass[a]

Application	Glass Type	Tvis[b] (%)	Tuv[b] (%)
Vision Glass			
Windshield	Standard green tint laminated glass	75%	3%
Windshield	Solar management laminated glass	71%	2%
Tempered side window	Standard green tint	79%	48%
Tempered side window	Solar management glass[c]	73%	33%
Tempered rear window	Standard green tint	79%	48%
Tempered rear window	Solar management glass	73%	33%
Privacy Glass			
Tempered side window	Gray privacy glass[d]	18%	8%
Tempered rear window	Gray privacy glass	18%	8%
Moon or Sun Roof	Laminated, dark gray privacy glass	6%	2%

a Data provided by Guardian Industries Corp. (Auburn Hills, Michigan, USA)

b Tvis: transmission of visible light, Tuv: transmission of ultraviolet light

c Solar management glass: tinted glass with enhanced solar control characteristics that is designed to block infrared radiation, thereby reducing the solar heat transmitted into the car.

d Privacy glass: monolithic, tempered tinted glass with enhanced solar control characteristics and very low visible light transmission, thereby significantly reducing solar heat transmission and visibility through the glass.

Table 7. Classification of Sunglasses and Lenses

Type of sunglasses
Cosmetic
General purpose
Special purpose
Type of lenses
Special
Basic
General purpose
Cosmetic tint

Figure 1. The electromagnetic spectrum emitted by the sun

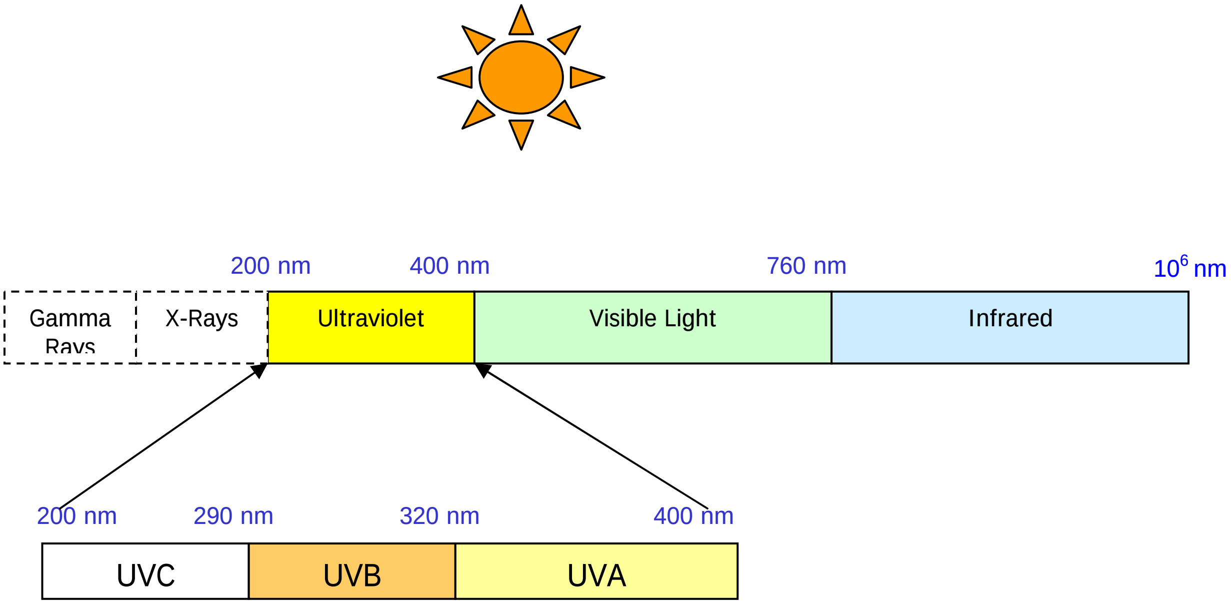


Figure 2. A common residential window configuration is likely to have substantial UV exposure

Figure 3. “Batch” is a mixture of very high quality silica sand and other materials such as salt cake, limestone, dolomite, feldspar, soda ash and powdered cullet. Glass is made from melting and cooling the batch.

Figure 4. An insulating glass unit (IGU) is a combination of two or more panes of glass with a sealed airspace between panes. Inert gas, e.g. argon or krypton, is commonly filled between panes of glass in IGUs to enhance insulation. These gases are less heat conductive than air. The UV-blocking coated glass is designed for use in an IGU configuration.

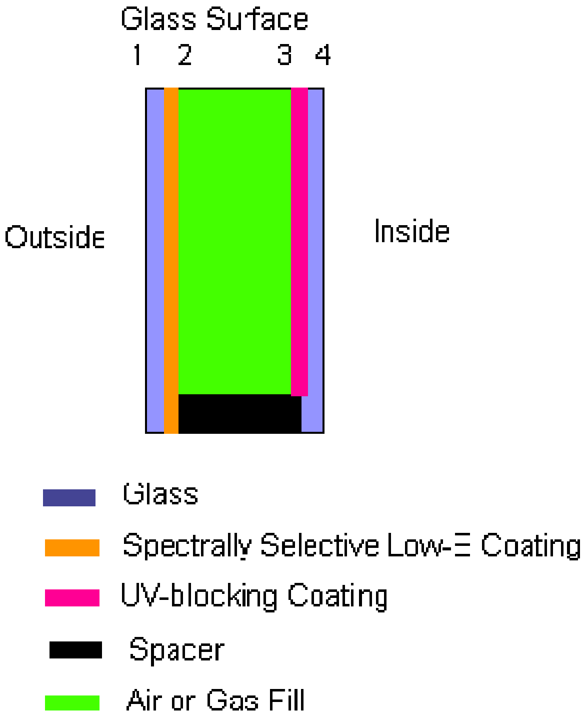
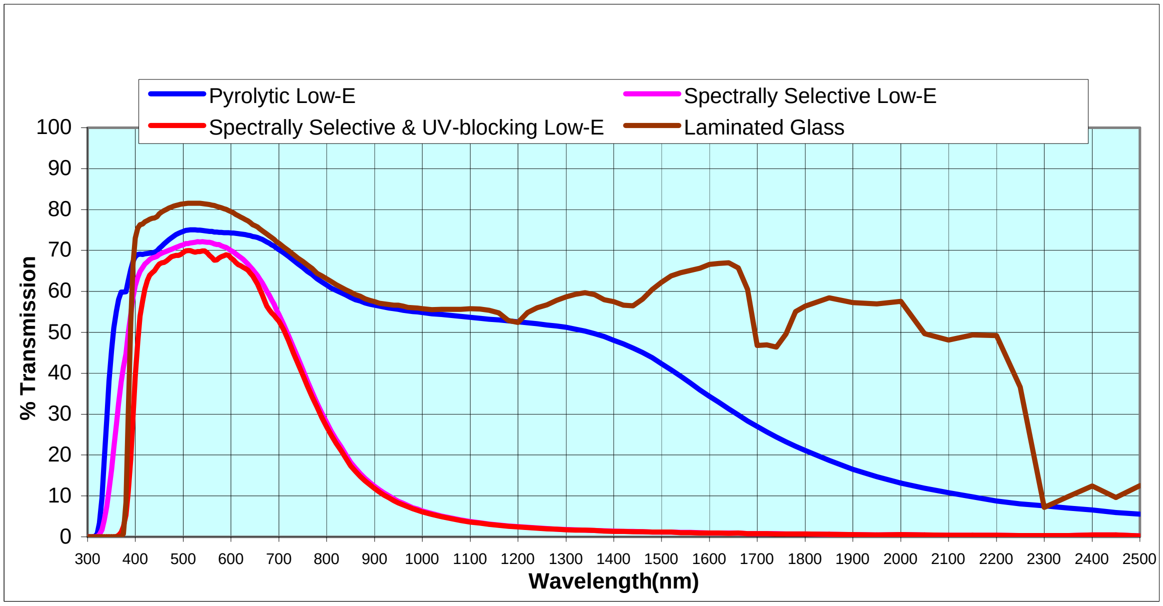


Figure 5. A. UV, visible, and near infrared transmittance (300-2,500 nm) of different types of residential architectural glass. **B.** UV and short-wavelength visible light transmittance (300-550 nm) of different types of residential architectural glass.

A.



B.

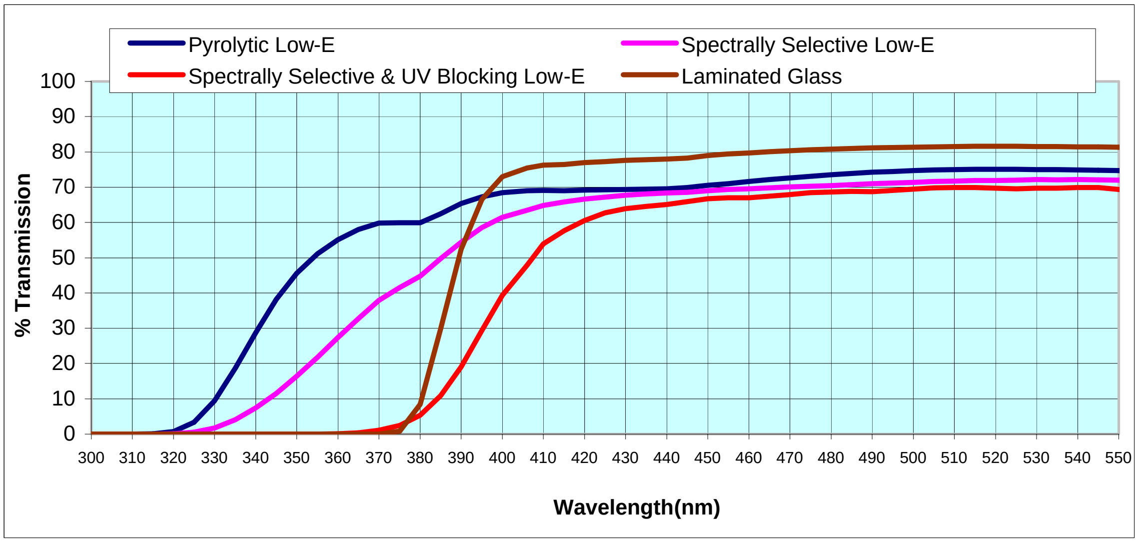
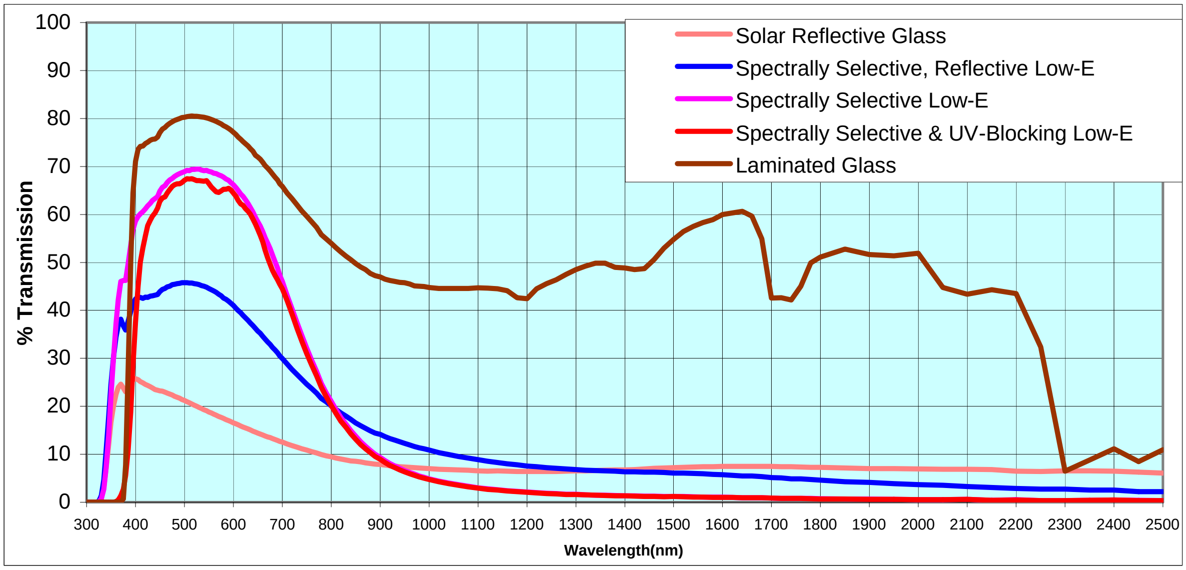


Figure 6. A. UV, visible light, and near infrared transmittance (300-2,500 nm) of different types of commercial architectural glass. **B.** UV and short-wavelength visible light transmittance (300-550 nm) of different types of commercial architectural glass.

A.



B.

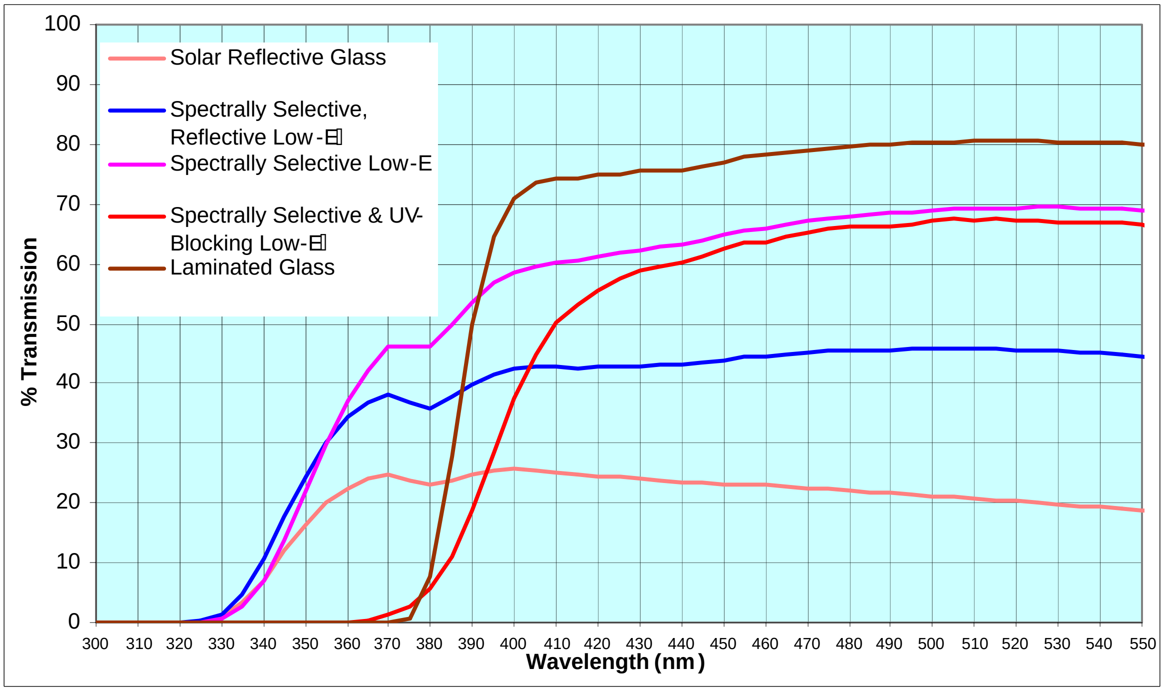
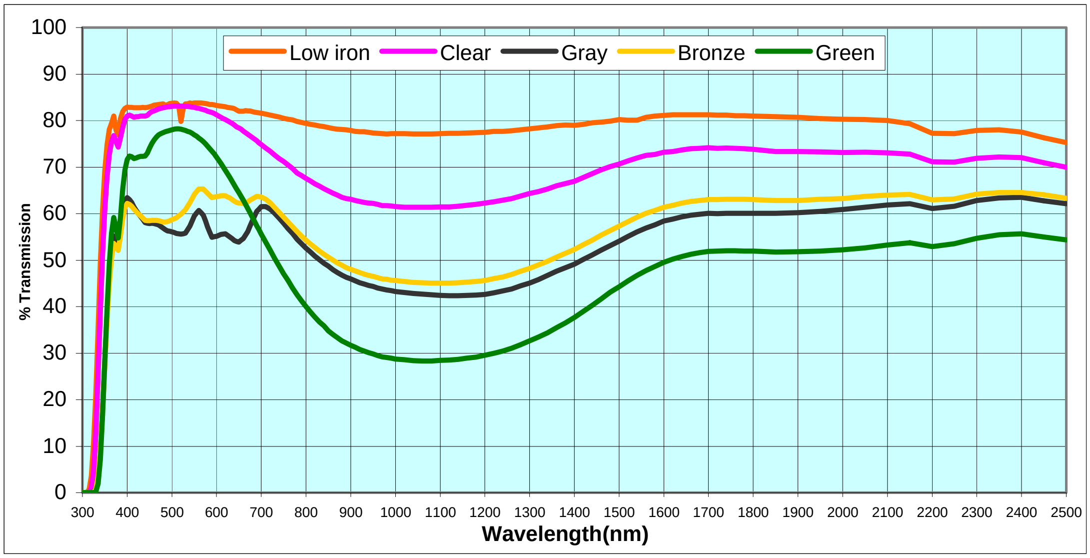


Figure 7. A. UV, visible, and near infrared transmittance (300-2,500 nm) of common glass with different colors used in architectural applications. **B.** UV and short wavelength visible light transmittance (300-550 nm) of common glass with different colors.

A.



B.

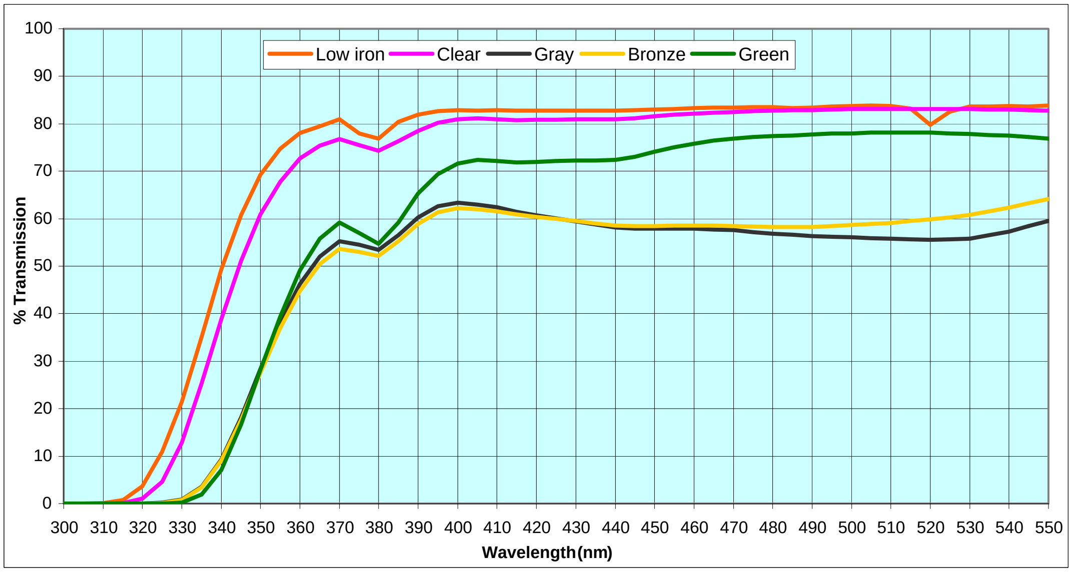


Figure 8. Adverse effects to eyes, resulting from exposure to different wavelengths of the electromagnetic spectrum