UV-Blocking Window Films for Use in Museums—Revisited

by Colleen Boye, Frank Preusser, and Terry Schaeffer

Introduction

In naturally lit galleries, the radiation that constitutes daylight can present a hazard to many of the materials found in art and archival collections. Ultraviolet (UV) radiation, in particular, is invisible to the human eye but can fade colorants and damage fibers and polymers. Therefore, institutions generally use window films to block unwanted solar radiation.

Film suppliers have continually expanded their offerings and updated film technology to meet increased demand from commercial, residential, and automotive customers. However, the needs of museums have not been addressed specifically during this expansion of the range of window film products. Museum staff must determine the efficacy of individual films and select those that best meet their requirements for completely blocking UV and reducing visible light to the desired level without altering color values. To this end, the conservation community has been evaluating UV-blocking window films for more than two decades (1-5). They have had a variety of goals and thus have used different types of measurements and performance criteria.

Evaluation of UV-blocking window films has been revisited recently in a survey of the UV and visible light transmitting properties of products from several suppliers (6). After presenting a useful summary of film composition and structure, the author tested the UV transmission of the unmounted film samples without adhesive. A UV meter with response optimized for UVB radiation (280-320 nm) was employed in this initial evaluation. Several films were rejected on the basis of these results. In the second part of the investigation, the transmissions of the remaining films were characterized by absorption spectrophotometry.

After some consideration and discussion of the methodology and results reported, we found that we questioned the appropriateness of some of aspects of the author's initial evaluation process, for the following reasons: in actual use the films are always applied to glass, which absorbs most UVB radiation; the test did not accurately measure transmission of UVA (320-400 nm), which has been shown to damage many materials; adhesives contribute to the performance of some films; and the mixed light sources present during this test were not representative of daylight. Also, absorption spectra have low precision when the absorption level is high, making the spectra difficult to interpret in the particular wavelength regions of interest.

Several 3M films were rejected by the preliminary study. If this were accurate, it would be cause for concern, as 3M products have frequently been used by the museum community for their UV blocking properties. Because of our reservations we undertook our own study using a calibrated light source and UV-visible transmission spectrophotometry. We included several films from 3M and other manufacturers that were tested in the previous study, as well as some new films. All the window films tested incorporated adhesive and were tested both on and off window glass. In this first part of our investigation, transmission spectra of all the samples were obtained and the data used to characterize the UV rejection and color neutrality of the films. The ageing behavior of the films will be examined in a second study.

Film Selection

As it was not the purpose of this study to be comprehensive, we tested only films for which we could readily obtain samples, surveying the different product lines available. We selected samples with high and low visible transmission from each line.

Experimental Procedure

Film Preparation

UV-visible spectra of the films, both unmounted and mounted on window glass, were obtained as follows.

Three samples of each window film were cut to fit into a 1 cm cuvette holder. The samples were cleaned of dust and fingerprints with a Kimwipe and the backing removed. The film samples were placed in the cuvette holder with the adhesive side towards the light source. Transmission was measured at three different locations on each of the triplicate samples.

The films were also mounted to blanks of 1/16" window glass cut to fit into the cuvette holder (figure 1). Three samples of each film were cut slightly larger than the glass blanks, the backing removed, and the film placed adhesive side up on a clean surface. The glass blanks were rinsed with a dilute solution of approximately 0.1 mL semisolid sodium dodecyl sulfate/1 L distilled water and placed while still wet on the film samples, which were trimmed. Bubbles between the film and the glass were removed by rolling the shaft of a fluoropolymer policeman repeatedly over the sample. The samples were allowed to dry for at least one hour (some sources recommend allowing at least one week for films applied to windows to dry (3), but tests showed that, at this small scale, there were no significant spectral differences between films allowed to dry for one hour and films allowed to dry for as long as one month). Transmission was measured at three different locations on each of the triplicate samples. The glass was oriented towards the light source.

Figure 1. Film samples mounted on glass

Transmission Spectroscopy

The transmission properties of the films were evaluated using an OceanOptics DT 1000 CE UV/Vis light source and an OceanOptics ADC1000-USB detector calibrated in the 200-850 nm range. An OceanOptics 1 cm cuvette holder was positioned horizontally with the light path pointing downwards so that films with no backing could lie horizontally and normal to the light path, with the adhesive side up (figure 2).

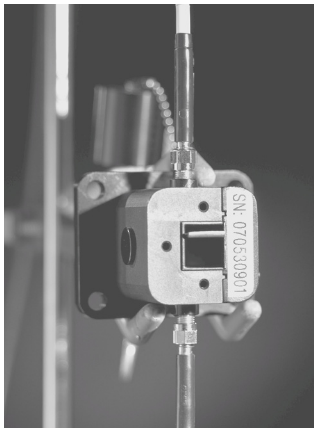


Figure 2. Fiber optic cell

The spectrometer was calibrated to 100% transmission with the cuvette holder empty. A zero light calibration was also performed for every spectroscopy session. Transmission spectra of the films were referenced to air. A new air background was taken between every film sample. Transmission was recorded approximately every 0.3 nm between 200 to 800 nm, integrating over 4 ms and averaging 100 scans. Percent transmission was measured to facilitate direct comparison of the data to the manufacturer's specifications. This approach also precludes the need to perform mathematical operations on the very small signals obtained in the UV range and the resulting uncertainties in the data.

Data Reduction

The three spectra obtained for each sample were averaged and the approximate total area under the averaged curve from 300-400 nm obtained by taking a Riemann sum. This sum was divided by the total possible transmission over that range (100% x 100 nm) to obtain the percent transmission in the near ultraviolet range, which was converted to percent rejection for comparison to manufacturers' values. The same calculation was performed over the 400-700 nm range to obtain the percent visible light transmitted. The values obtained from the three different samples of each film type were averaged to obtain a final UV percent rejected and visible percent transmitted, and standard deviations were calculated.
To evaluate the steepness of the UV cutoff, a linear regression was fit to the curve. The midpoint of the cutoff region of the transmission curve was approximated by defining the lower and upper endpoints as the wavelengths where the extension of the linear regression line crossed the abscissa and the film's average visible transmission (figure 3).

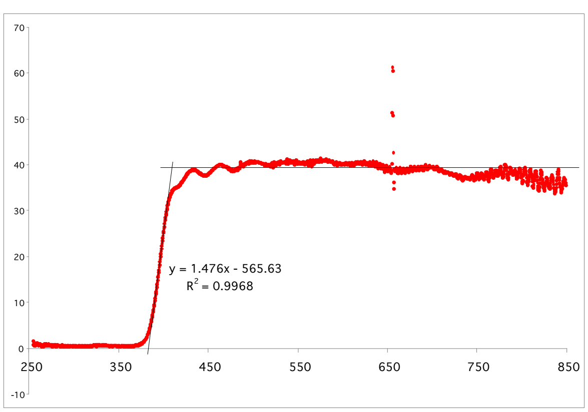


Figure 3. Calculation of slope and midpoint of the cutoff region

Color neutrality is an important factor for films to be used on museum windows. Color neutrality was evaluated in two ways. First, approximate CIE L*a*b* values were calculated from the averaged visible spectra of the three samples of each film not mounted to glass. Second, to characterize the extent to which the films removed blue and red light, the percent transmission at maximum eye sensitivity in the green at 550 nm was compared to the values at 425 nm in the blue and 675 nm in the red.

Results and Discussion

Figures 4-7 show spectra of several window films on glass. These curves are representative of the range of spectra obtained for all the films tested. All block the vast majority of radiation below 380 nm, but the visible transmission, the shape and location of the curve between 380 and 400 nm, and the shape of the curve in the visible range are all highly variable. The spike just above 650 nm is a machine artifact. An ideal spectrum would be as close to vertical as possible at 400 nm in order to cut out all the UV, and then as close to horizontal as possible afterwards in order to have a neutral color (a slight yellow tint is also considered acceptable). Most of the spectra show ringing, which is clearly visible in the Cold Steel 50. This is caused by light passing through films composed of multiple layers with different refractive indices. Additionally, it is clear that the transmission spectra of the films are far from the ideal of vertical at 400 nm and horizontal thereafter. The steepness of the cutoff curve

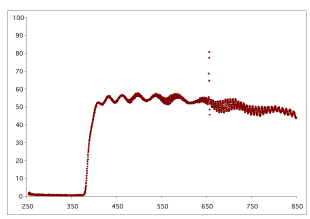


Figure 4. HanitaTek Cold Steel 50

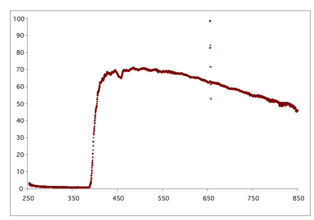


Figure 5. 3M Prestige 70

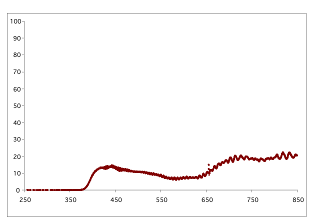


Figure 6. Madico NG-20

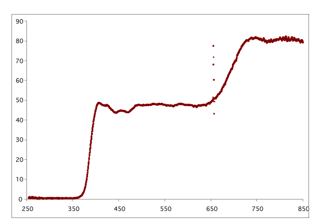


Figure 7. GWF Resid. Neutral 50

can be misleading: one might immediately reject the NG-20 because of its gradual slope between 380 and 400 nm, but due to its overall low transmittance, it has the highest total UV rejection of any film tested. The Cold Steel 50 is neutral colored, but the transmission of the Prestige 70 drops off at high wavelengths so that it appears cyan. The transmission of the NG-20, in contrast, is highest in the low and high wavelengths, but dips in the middle wavelengths and consequently appears violet. Most of the films, particularly the Prestige 70, appear to reduce IR as well as UV and visible light. In contrast, the Residential Neutral 50, like many of the Global Window Films samples, shows a sharp increase in transmittance in the near IR, giving a slightly reddish tint to an otherwise neutral-colored film.

The calculated percent of UV rejected and percent of visible light transmitted for each film are shown in table 1, where they are compared with the manufacturers' values. The data obtained for films on glass are listed; values obtained for unmounted films were usually within 1% of the values for the films on glass. It should be noted that the disparity between

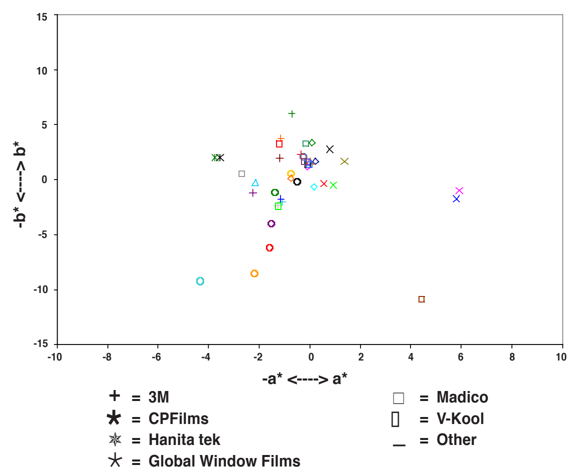
Table 1. Spectral Properties of Various Window Films on Glass

Film	UV Rejection	UV Rejection (Manufacturer's Data)	Visible Transmission	Visible Transmission (Manufacturer's Data)
Window Glass	41.3%	NA	90.2%	NA
3M Night Vision 15	98.6%	99.0%	17.8%	15.0%
3M Night Vision 35	97.2%	99.0%	39.2%	35.0%
3M Prestige 40	98.5%	99.9%	8.9%	39.0%
3M Prestige 50	98.3%	99.9%	47.1%	50.0%
3M Prestige 70	97.3%	99.9%	66.3%	69.0%
3M Ultra Prestige 70	98.4%	99.9%	65.4%	67.0%
3M Neutral 20	98.8%	99.0%	14.7%	16.0%
3M Neutral 35	97.2%	99.0%	35.4%	37.0%
Artscape Energy Film	85.7%	97.0%	79.6%	77.0%
Llumar N1020 SR CDF	97.8%	99.0%	23.1%	24.0%
Llumar N1065 SR CDF	94.9%	99.0%	67.5%	71.0%
Llumar NUV65 SR PS4	98.0%	99.9%	70.1%	63.0%
Llumar UVCL SR PS	97.2%	99.9%	85.9%	88.0%
Vista Soft Horizons V33	98.2%	99.9%	34.0%	33.0%
GAM Color Cinefilter 1810	95.5%	97.0%	82.8%	90.0%
GWF Delta Dual Reflective 25	95.9%	98.0%	28.8%	12.0%
GWF Delta Dual Reflective 45	94.4%	98.0%	41.1%	42.0%
GWF Glare Cut NR 35	94.7%	98.0%	35.5%	35.0%
GWF Glare Cut NR 70	92.6%	98.0%	69.0%	72.0%
GWF Residential Neutral 20	97.7%	98.0%	22.1%	20.0%
GWF Residential Neutral 50	93.2%	98.0%	48.6%	50.0%
HanitaTek Cold Steel 20	96.9%	99.0%	24.2%	19.0%
HanitaTek Cold Steel 50	93.8%	99.0%	54.2%	47.0%
HanitaTek Cold Steel 70	97.2%	99.0%	67.1%	66.0%
HanitaTek Optitune 15	99.0%	99.0%	12.4%	12.0%
HanitaTek Optitune 30	94.6%	99.0%	40.6%	31.0%
HanitaTek Optitune 55	92.8%	99.0%	59.8%	53.0%
HanitaTek Silver 35	94.6%	99.0%	34.9%	31.0%
HanitaTek Silver 70	91.8%	95.0%	51.3%	46.0%
HanitaTek UV Filter Film	97.9%	99.8%	81.3%	87.0%
Madico Advanced Ceramic 3000	97.3%	99.0%	36.4%	33.0%
Madico Advanced Ceramic 6000	95.0%	99.0%	61.5%	61.0%
Madico CLS-200-X	98.5%	99.0%	79.1%	77.0%
Madico CL-200-XSR	94.2%	99.0%	87.4%	85.0%
Madico CL-200-X	94.5%	99.0%	85.5%	85.0%
Madico NG-20	99.2%	99.0%	10.8%	13.0%
Madico Sunscape Satin 550	95.0%	99.0%	54.7%	50.0%
Madico TSG-335	98.7%	99.0%	42.2%	40.0%
V-Kool VK40	98.2%	99.0%	39.4%	43.0%
V-Kool VK70	97.1%	99.0%	62.2%	70.0%

the measured values of UV rejection and the manufacturers' claims do not mean that the latter are erroneous. The industry defines the near UV region at 300-380 nm for their specifications, whereas we have taken the usual museum approach that the cutoff between UV and visible light is at 400 nm.

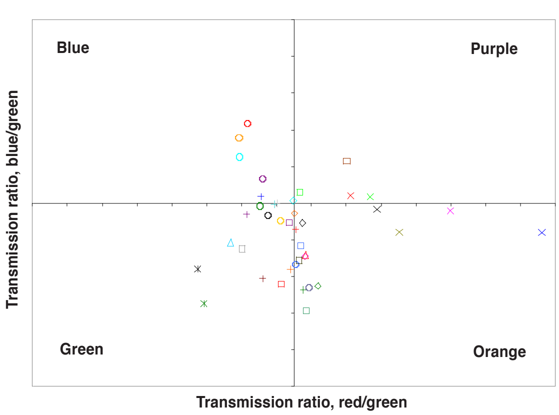
CIE L*a*b* colorimetric data are shown in figure 8. The a* and b* values show several significant outliers, but do not correlate well with visual evaluation of the colors of the samples. This is likely due to the fact that highly transparent samples can have low chroma but still be highly saturated.

Figure 8. Films in CIE L*a*b* space



The transmission of the films at 425 and 675 nm, as compared with 550 nm, are plotted in figure 9. These data are presented in an attempt to quantify the common problems of films cutting out part of the blue along with the UV, and of decreasing transmission in the red. In this representation, the center of the graph is neutral colored, the upper left is blue, the upper right is purple, the lower left is green, and the lower right is orange. This representation correlated more strongly with visual observations, except in the case of the Global Window Films samples. These tend to increase in transmission sharply above 650 nm, which results in their appearing less red to the eye than the calculations suggest, due to the eye's lower sensitivity in that range. It should be borne in mind that no mathematical measure of color is a replacement for human observation.

Figure 9. Change in film transmittance at high and low wavelengths



Conclusions

The most important considerations for a museum when selecting a window film are the overall amount of UV blocked, the steepness and location of the cutoff curve, and the color appearance. Table 2 lists these properties for all the films evaluated. By setting 95% as the minimum acceptable UV rejection level for the 300-400 nm range and 390-410 nm as an acceptable range for the midpoint of the cutoff curve, the list of films suitable for museums can be narrowed down.

In contrast to the findings published previously (6), this study found all of the 3M films to perform well enough for museum use. These films rejected at least 97%, and most more than 98%, of the UV radiation below 400 nm, and the Prestige line had the steepest cutoff curve of any of the films evaluated. The only potentially objectionable trait of these films is their tint: 3M does not produce a highly transparent UV-blocking film and the Night Vision line is mirrored, which may not be appropriate for museums.

The 3M films have their UV absorbers incorporated into the adhesive. Previous studies (2, 6) have indicated that this is less desirable than having a separate UV-blocking layer, leading to worse performance and longevity, but no experimental support has been given for this assertion. Our findings show that the 3M films performed more uniformly well than any other brand, despite having UV blockers in the adhesive; the second part of the study will evaluate their longevity.

Most of the Llumar and Madico films were found to be acceptable, in agreement with the earlier study, but several of these films rejected less than or exactly 95% of the UV light. Films from these manufacturers should be evaluated on a case-by-case basis. CPFilms, Llumar's parent company, also owns Vista. The single Vista film evaluated performed well, but generalizations about the brand cannot be drawn from that one sample.

Few of the Global Window Films were acceptable because the midpoints of the cutoff curves for most of these films were much too short in wavelength. The films also had uneven transmission in the visible range, although visually the films did not appear as highly colored as the colorimetric data would indicate. Only the darkest tinted films were found to reject an adequate amount of UV light. These findings correlated with the findings of the previous study (6).

The tinted HanitaTek films did not perform well according to the criteria used in this study. In particular, the Optitune and Silver lines are highly mirrored and appear slightly blue. While non-neutral color is not necessarily a failing for these films, which are marketed for their aesthetics as well as their utility, it does make them unsuitable for use in a museum setting. UV rejection was also variable.

Of the less widely distributed films, the Artscape Energy Film, a do-it-yourself adhesive-free film, is clearly unsuitable for museum use. The V-Kool films, which are marketed primarily as IR-blocking rather than UV-blocking, perform acceptably but have too much of a green tint.

Some sources have suggested that the ideal UV filter would block all radiation under 400 nm but no visible light (2). This study evaluated several highly transparent UV-blocking films with visible transmissions of 80% or above: Llumar UVCL, GAM #1810, HanitaTek UV Filter Film, and Madico CLS-200-X, CL-200-XSR, and CL-200-X. Only the Madico CL-200-XSR and CL-200-X were found to be unacceptable. Of the others, GAM #1810 was the weakest performer, but the other three blocked greater than 97% of the UV and had good color neutrality, making them all acceptable options.

The present study looked at a small number of representative films from each company. In many cases, other films

Table 2. Overall Performance of Various Window Films (x indicates rejection based on this property)

Film	UV Blocking	Cutoff Midpoint	Tint Color
3M Night Vision 15	98.6%	395 nm	Mirrored Neutral
3M Night Vision 35	97.2%	396 nm	Mirrored Neutral
3M Prestige 40	98.5%	402 nm	Neutral/Yellow
3M Prestige 50	98.3%	400 nm	Neutral/Yellow
3M Prestige 70	97.3%	399 nm	Neutral/Cyan
3M Ultra Prestige 70	98.4%	400 nm	Neutral/Green
3M Neutral 20	98.8%	394 nm	Neutral
3M Neutral 35	97.2%	395 nm	Neutral
Artscape Energy Film	85.7% x	384 nm x	Cyan x
Llumar N1020	97.8%	396 nm	Neutral
Llumar N1065	94.9% x	398 nm	Neutral
Llumar NUV65	98.0%	406 nm	Neutral/Orange
Llumar UVCL SRPS	97.2%	404 nm	Neutral/Yellow
Vista Soft Horizons V33	98.2%	401 nm	Neutral
GAM 1810	95.5%	401 nm	Neutral/Orange
GWF Delta Dual Reflective 25	95.9%	396 nm	Neutral/Orange
GWF Delta Dual Reflective 45	94.4% x	397 nm	Neutral
GWF Glare Cut NR 35	94.7% x	388 nm x	Neutral/Red
GWF Glare Cut NR 70	92.6% x	391 nm	Neutral
GWF Residential Neutral 20	97.7%	392 nm	Orange/Red x
GWF Residential Neutral 50	93.2% x	387 nm x	Neutral
HanitaTek Cold Steel 20	96.9%	388 nm x	Neutral
HanitaTek Cold Steel 50	93.8% x	390 nm	Neutral
HanitaTek Cold Steel 70	97.2%	402 nm	Neutral
HanitaTek Optitune 15	99.0%	393 nm	Mirrored Blue x
HanitaTek Optitune 30	94.6% x	388 nm x	Mirrored Neutral/Blue x
HanitaTek Optitune 55	92.8% x	389 nm x	Mirrored Neutral
HanitaTek Silver 35	94.6% x	386 nm x	Mirrored Blue x
HanitaTek Silver 50	91.8% x	387 nm x	Mirrored Blue x
HanitaTek UV Filter Film	97.9%	408 nm	Neutral/Yellow
Madico Advanced Ceramic 3000	97.3%	396 nm	Neutral/Green
Madico Advanced Ceramic 6000	95.0%	396 nm	Neutral/Yellow
Madico CLS-200-X	98.5%	409 nm	Neutral
Madico CL-200-XSR	94.2% x	397 nm	Neutral
Madico CL-200-X	94.5% x	398 nm	Neutral
Madico NG-20	99.2%	394 nm	Violet x
Madico Sunscape Satin 550	95.0%	394 nm	Neutral
Madico TSG-335	98.7%	402 nm	Neutral
V-Kool VK 40	98.2%	401 nm	Green x
V-Kool VK 70	97.1%	400 nm	Green x

UV-Blocking Window Films for Use in Museums—Revisited, continued

from the same line may be assumed to perform similarly to the ones tested. For example, the commonly used 3M Night Vision 25 was not tested, but because both the Night Vision 15 and 35 reject approximately 98% of UV, the Night Vision 25 may be assumed to do so too. For product lines that demonstrated less consistency, however, the behavior of other films in the same line cannot be predicted. Also, because manufacturers may change the composition of a film at any time, the performance of all UV-blocking films should be verified before installation. While film transmittance can be measured with a light meter, measurement with a spectrometer is recommended to obtain greater accuracy and detail.

Further Research
This paper is the first in an extended investigation of the spectral properties and durability of UV-blocking window films. An accelerated aging study of the films found to be acceptable is currently in progress to determine how their UV rejection and appearance change with time of exposure to simulated sunlight.

Suppliers
Aladdin Glass (supplier of glass blanks)
9007 De Soto Ave
Canoga Park, CA 91304
818.700.7833 aladdinglass.com

Artscape Inc.
3487 NW Yeon Ave
Portland, OR 97210
877.729.0708 artscape-inc.com

CPFilms (distributor of Llumar and Vista)
Western Distribution Center
1849 West Sequoia Ave.
Orange, CA 92868
714.634.0900 cpfilms.com

GAM Products Inc.
4975 West Pico Blvd.
Los Angeles, CA 90019
323.935.4975 gamonline.com

Global Window Films
Global/Express West
330 East Orangethrope Ave
Placentia, CA 92870
800.345.6669 globalwindowfilms.com

HanitaTek
220 Regency Court, Suite 200
Brookfield, WI 53045
800.660.5559 hanitatek.com

Suntech (3M distributor)
18401 Vanowen St
Reseda, CA 91335
818.342.9285 3m.com

V-Kool, Inc.
13805 West Road, Suite 400
Houston, TX 77041
800.786.2468 v-kool-usa.com

Window Tints, Etc. (Madico distributor)
6030 Santa Monica Blvd
Hollywood, CA 90038
323.466.0608 madico.com

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