Aging Properties of Select UV-Blocking Window Films

Introduction

The need to remove damaging ultraviolet radiation from the natural daylight currently popular in exhibition spaces requires placement of UV-blocking films on windows and glass doors and ceilings in galleries. The film properties desired for museum use are different from those by which manufacturers rate their products (1-4). In a previous study (5), we characterized the UV absorption, visible transmission, and colorimetric properties of a large number of transparent UV-blocking window films, applying criteria suitable for museum consideration.

Manufacturers guarantee their commercial film products will last without significant change for several, typically ten, years. Their criteria - again – can be different from those important to museums. An essential part of our investigation has thus been to characterize optical changes which may occur upon aging of the potentially useful UV-blocking films.

Samples of all the films that were observed to have acceptable optical properties in the earlier experiments (5) have now been artificially photoaged. Absorption of UV radiation and transmission of visible light by the samples were monitored during the aging process. This paper reports the changes observed in the films as the samples underwent aging. Again the suitability of the films for use on windows in exhibition spaces has been evaluated with criteria we have identified as appropriate for consideration by museums and galleries. It must be emphasized that this investigation has characterized only the changes in optical properties of the films. Other properties, such as physical deterioration of the films and adhesives, delamination, and ease of removal (3,7), have not been directly addressed by these experiments. Consideration of any or all of these additional properties may be as least as important in the overall process of choosing appropriate films.

Film Selection

Samples of all films that met the criteria for UV-blocking used in the previous study, absorption of $\geq$95% UV radiation between 300 and 400 nm (5), were included in the artificial aging phase of the investigation. This group included films which did not meet the requirements for color neutrality employed in the earlier experiments. Subtle color effects may be desirable in some display applications, and aesthetic choices will vary among curators and exhibition designers.

Experimental Procedure

Film Preparation

Each film sample was individually mounted on 1 cm x 4 cm pieces of window glass as previously described (5). Triplicate samples of the films were used in the investigation. UV-visible transmission spectra of these mounted samples were obtained with an Ocean Optics DT 1000 CE UV/Vis light source and an Ocean Optics ADC1000-USB detector calibrated in the 200-850 nm range according to the same procedure used in the previous study. The results presented below are all averages of the data for the three samples of each film.

Film Aging and Characterization

Artificial photoaging was conducted with an Atlas Ci4000 Weather-O-M eter fitted with a xenon lamp, a CIRA inner filter, and a soda-lime glass outer filter to simulate natural daylight. Each film sample was attached at one end only to the sample holders with a binder clip, with the film side facing away from the light source (Figure 1). The sample holders were placed on the middle level of the rotating rack so they were vertical (Figure 2). The power setting was 0.5 watts/m^2 at 340 nm. At this setting the total near UV plus visible power delivered to the samples was approximately 495 W/m^2, calculated from data provided in the instrument handbook. The relative humidity in the exposure chamber was 50±10% throughout the experiment.

Figure 1: Films on the sample holder

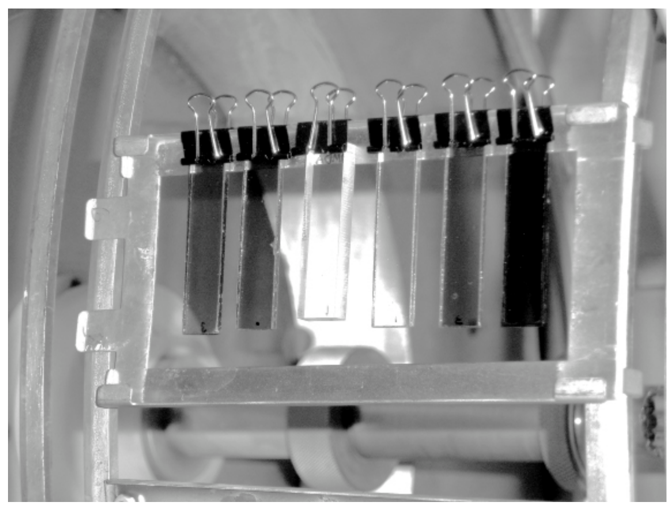
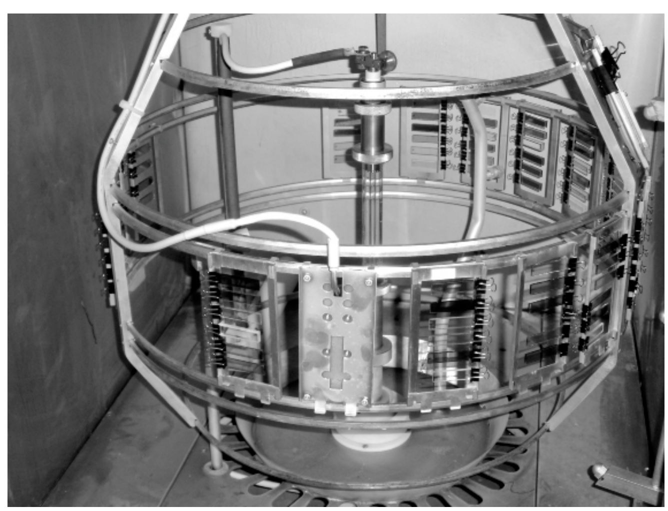


Figure 2: Films in the Weather-O-Meter



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The films were exposed for 6 to 15 day periods over the course of several months, for a total exposure energy (equal to power x time) of about 5840 MJ/m^2. This is equivalent to roughly 6.7 years of exposure at a north-facing window in Los Angeles, California. See endnote (6) for additional information on exposure equivalents.

The transmission spectra of all samples were recorded as described above after each of the fifteen exposure periods. In between exposures, the samples were kept in the dark at room temperature and stable humidity in the Conservation Center. Between the sixth and seventh measurements, a machine malfunction resulted in water spraying on some of the films and leaving mineral deposits; however, this did not appear to have a significant effect on the results.

Results and Discussion

Figure 3 shows several aged samples with varying extents of change in transmission of visible light. The labeled end of the film, which was protected by the opaque sample holder and binder clip, indicates the original appearance.

The visible transmission of the films on the left decreased, i.e., the aged film transmits less light, the one in the center shows no change, and those on the right increased, i.e., the aged film transmits more light. Some delamination can be seen in a few samples.

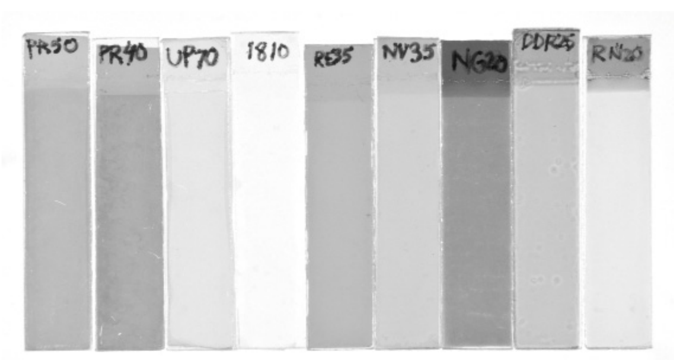

Figure 3: Several films after aging. L to R: Change in visible transmission approx. -25%, -20%, -10%, -5%, 0%, 5%, 10%, 15%, 40%

Spectral transmission data were evaluated in several ways. As an example, the results for a film that underwent significant change in its optical properties, 3M Night Vision 35, are shown. The transmission spectra of the film after each exposure period are plotted in Figure 4. The data for wavelengths between 655-657 nm were corrupted by a detector artifact and have been omitted from all spectra.

The film transmits about 5% more light after 5840 MJ/m^2 of exposure. More importantly, it loses a large fraction of its UV absorption in the 340-400 nm range. This behavior suggests the film may have at least two UV blockers: a UVA blocker that is degraded by light exposure and a UVB blocker that is not significantly changed after this cumulative light exposure.

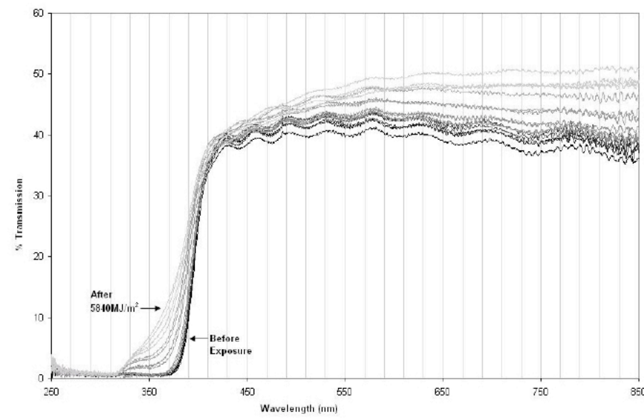

Figure 4: Spectra of Night Vision 35 over time (lighter shades are later weeks

Figure 5 shows the changes in UV absorption and visible transmission of Night Vision 35 as a function of light energy exposure. Little change occurs during the first 2500 MJ/m^2, after which the film begins transmitting both more UV and more visible radiation. UV absorption decreases and visible transmission rises.

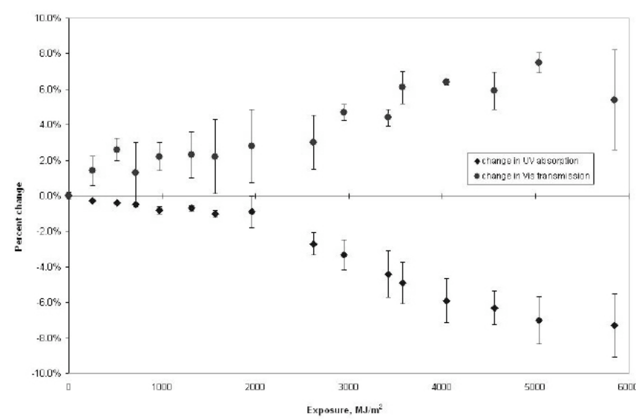

Figure 5: Change in visible transmission and UV absorption of Night Vision 35

At the end of the experiment, the aged film transmits about 5% more visible light and 7% more UV radiation. The former is noticeable with the naked eye, but may be acceptable, depending on the sensitivity of the objects on display and the aesthetic requirements of the museum staff. However, the increase in transmission of UV fails to meet our criterion of 95% absorption up to 400 nm (See below).

Table 1 summarizes the photoaging results for all films. The second column lists the final UV absorption at the end of the study, equivalent to about 6.7 years of north-facing exposure (6), with the initial value shown for comparison.

The third column shows how many equivalent years of north exposure it took for the film to fall below 95% UV absorption, the criterion used in the previous study for determining acceptable film performance (5). A value in parentheses is an extrapolation based on the aging rate at the latest stage of the aging process; this number should be regarded as a very rough estimate. An empty cell indicates that UV absorption is not predicted to fall below 95% on the basis of the behavior observed in this experiment.

The fourth column lists the equivalent years of exposure it took for the film to show a significant colorimetric change (defined as a ΔE of 5 or greater); an empty cell indicates that this extent of change was not observed during the investigation.

The fifth column shows the initial visible transmission, final transmission, and change in visible transmission of each film.

Conclusions

Table 2 summarizes our evaluation of the effects of photochemical aging on the optical properties of the films. The acceptability of film durability during this exposure was assessed using three criteria. The most important of these is the ability to maintain a high level of absorption of UV radiation between 300 and 400 nm. In the previous study, a minimum of 95% UV-absorption was set as the cutoff (5). In this study we have continued to apply this criterion. Absolute UV absorption is a better measure than change in UV absorption; for example, if a film with 96% absorption initially drops by 3%, it is no longer acceptable, but a film with 99% absorption can drop 3% and still meet this requirement. 3M Neutral 20 is a borderline case; although its UV absorption was above 95% at the end of the experimental exposure, UV absorption is predicted to fall below this cut-off within a few more year equivalents of aging (see Table 1, column 3). The second criterion, how closely the films maintained

Table 1: Overall Aging Results

Film	Initial/Final UV Absorption (absolute %)	Years* to <95% absorption	Years* to ΔE = 5	Initial/Final/ Change in Visible Transmission (absolute %)
3M Night Vision 15	98.6 / 97.1	(19)		17.8 / 20.9 / 3.1
3M Night Vision 35	97.2 / 89.9	3.0	4.5	39.2 / 44.6 / 5.4
3M Prestige 40	98.5 / 99.3		3.0	38.9 / 21.2 / -17.7
3M Prestige 50	98.3 / 99.4		4.0	47.1 / 22.4 / -24.7
3M Prestige 70	97.3 / 98.0		3.0	66.3 / 52.9 / -13.4
3M Ultra Prestige 70	98.4 / 98.8		1.5	65.4 / 52.5 / -12.9
3M Neutral 20	98.8 / 95.5	(8)		14.7 / 15.2 / 0.5
3M Neutral 35	97.2 / 91.2	4.0		35.4 / 35.9 / 0.5
LlumarN1020	97.8 / 98.2			23.1 / 21.6 / -1.5
LlumarNUV65	98.0 / 98.1			70.1 / 73.1 / 3.0
LlumarUVCL SRPS	97.2 / 97.1			85.9 / 82.3 / -3.6
Vista Soft Horizons V33	98.2 / 98.7			34.0 / 32.8 / -1.2
GAM 1810	95.5 / 93.6	2.0		82.8 / 78.3 / -4.5
GWF Delta Dual Reflective 25	95.9 / 93.6	4.0	1.0	28.8 / 43.6 / 14.8
GWF Residential Neutral 20	97.7 / 90.3	3.5	0.5	22.1 / 65.5 / 43.4
Hanita Tek Cold Steel 70	97.2 / 96.6	(28)		67.1 / 69.5 / 2.4
Hanita TekOptitune 15	99.0 / 98.6			12.4 / 15.7 / 3.3
Hanita TekUV Filter Film	97.9 / 97.9			81.3 / 79.7 / -1.6
Madico Advanced Ceramic 3000	97.3 / 94.0	5.0		36.4 / 35.2 / -1.2
Madico Advanced Ceramic 6000	95.0 / 95.7			61.5 / 58.6 / -2.9
Madico CLS-200-X	98.5 / 98.2			79.1 / 71.8 / -7.3
Madico NG -20	99.2 / 97.8	(22)	1.5	10.8 / 21.3 / 10.5
V-Kool VK 40	98.2 / 98.1			39.4 / 41.3 / 1.9
V-Kool VK 70	97.1 / 97.1			62.2 / 62.3 / 0.1

*Equivalent North light exposure in Los Angeles their initial visible light transmission properties, may be influenced more by individual exhibition needs and subjective judgments. Although a small change in visible transmission may be easily noticed, depending on the initial transparency of the film, it need not in all cases be as detrimental as a loss of UV absorption. Also, both increases and decreases in visible transmission were observed in the investigation. Under these circumstances, the relative change in visible transmission is a more useful criterion to apply. For example, a highly transmitting film placed on a window where interior visible light levels need not be very low could drop from 90% to 85%T without causing problems, but for a dark film in a very light-sensitive setting, a change of a few percent might be a major failure. In consideration of the range of needs for visible %T of the films, the more generous criterion of a relative change of 10% or greater was designated to be unacceptable. Absolute and relative changes in visible transmission are both listed in

Table 2: Acceptability of UV-Blocking Window Films, Based on Aging Results

Film	UV Absorption after 5840 MJ/m2 (absolute %, with standard deviation)	Change in Visible Transmission (absolute %)	Change in Visible Transmission (relative %)	Change in color (ΔE)
3M Prestige 50	99.4% ± 0.08%	-24.7%	-52.4% x	25.1 x
3M Prestige 40	99.3% ± 0.16%	-17.70%	-45.4% x	21.8 x
3M Ultra Prestige 70	98.8% ± 0.28%	-12.9%	-19.8% x	10.3 x
Vista Soft Horizons V33	98.7% ± 0.02%	-1.2%	-3.4%	2.4
HanitaTek Optitune 15	98.6% ± 0.12%	3.3%	26.5% x	4.8
Madico CLS-200-X	98.2% ± 0.17%	-7.3%	-9.2%	4.8
Llumar N1020	98.2% ± 0.08%	-1.5%	-6.7%	2.0
Llumar NUV65	98.1% ± 0.09%	3.0%	4.2%	3.1
V-Kool VK 40	98.1% ± 0.04%	1.9%	4.9%	1.4
3M Prestige 70	98.0% ± 0.24%	-13.4%	-20.3% x	11.3 x
HanitaTek UV Filter Film	97.9% ± 0.13%	-1.6%	-2.0%	1.5
Madico NG-20	97.8% ± 0.07%	10.5%	97.1% x	19.7 x
Llumar UVCL SRPS	97.1% ± 0.41%	-3.6%	-4.2%	1.5
V-Kool VK 70	97.1% ± 0.16%	0.1%	0.2%	0.7
3M Night Vision 15	97.1% ± 0.14%	3.10%	17.7% x	4.2
HanitaTek Cold Steel 70	96.6% ± 0.16%	2.4%	3.6%	3.3
Madico Advanced Ceramic 6000	95.7% ± 0.19%	-2.9%	-4.7%	3.1
3M Neutral 20	95.5% ± 0.31% *	0.5%	3.4%	1.4
Madico Advanced Ceramic 3000	94.0% ± 0.60% x	-1.2%	-3.2%	2.0
GWF Delta Dual Reflective 25	93.6% ± 0.13% x	14.8%	51.5% x	11.8 x
GAM 1810	93.6% ± 0.05% x	-4.5%	-5.4%	2.5
3M Neutral 35	91.2% ± 0.08% x	0.5%	1.5%	1.2
GWF Residential Neutral 20	90.3% ± 0.34% x	43.4%	196.5% x	34.1 x
3M Night Vision 35	89.9% ± 1.78% x	5.40%	13.8% x	5.5 x

* See text.
x Does not meet the criteria described in text.

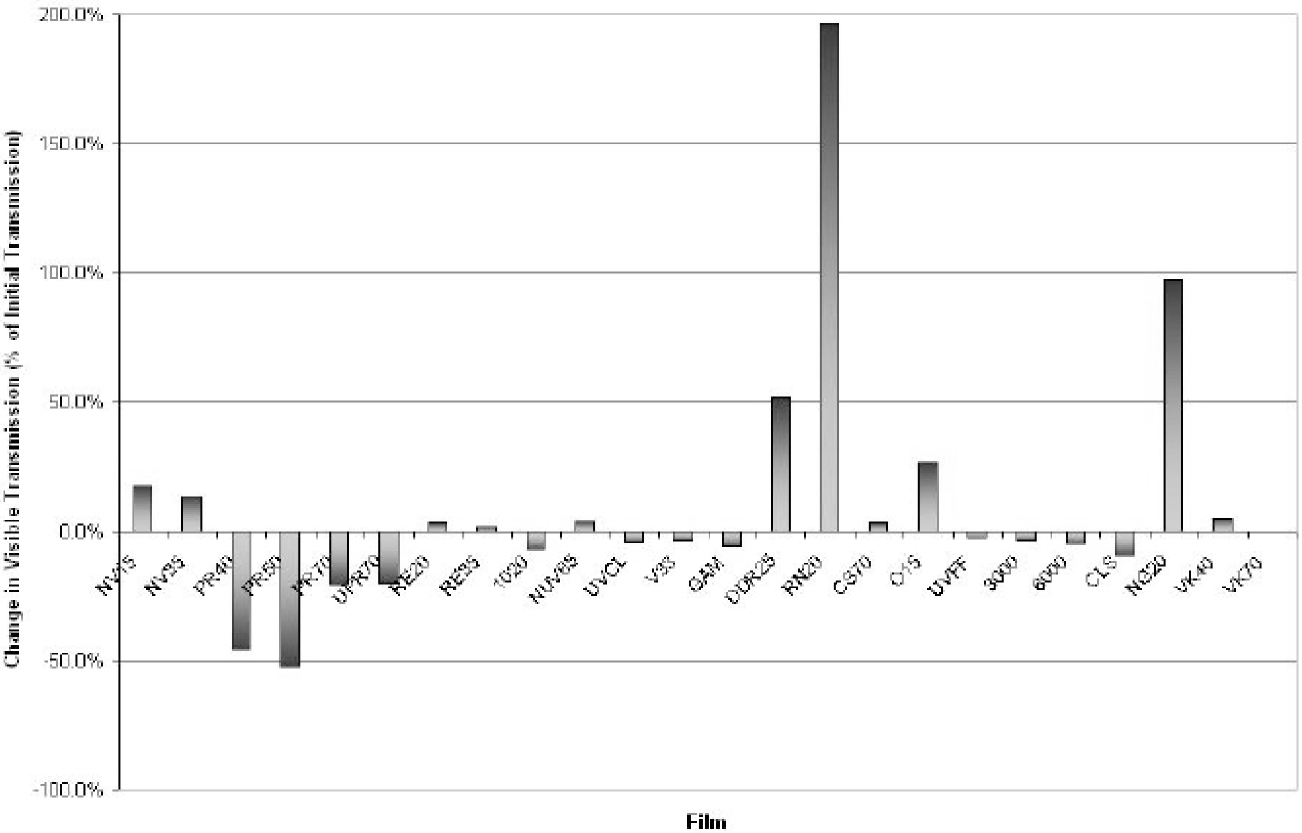

Figure 6: Relative change in visible light transmission of UV-blocking films

Table 2 for comparison. Relative percent change in visible transmission is also shown in Figure 6.

The third important criterion for optical performance is color. In the previous study we measured the CIE L*a*b* values of all films. In this experiment we have characterized the appearance changes ($\Delta E = \text{sqrt}[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]$) of all films during the accelerated aging process. These changes are given in Table 1, column 5. A ΔE of more than 5 may be unacceptable, but again this is a subjective judgment; different institutions/individuals may have different needs. Because the calculation weights changes in lightness or darkness (ΔL^*) and changes in the two different color measures (Δa^* and Δb^*) equally, the resulting ΔE can be dominated by a large value for any one of these three changes. Thus the films that darkened or lightened significantly without a color shift had large ΔEs. No film in this study changed color significantly without changing overall percent visible transmission sufficiently to be rejected solely by the former criterion.

All the 3M films performed well in the previous study and were recommended. However, in this study the UV absorption of the Night Vision and Neutral lines dropped rapidly (see Figures 4 and 5); some of these films had less than 95% UV absorption by the end of the aging regimen. The spectra of those that did not fall below this cut-off did nonetheless show significant loss of UVA absorption. The Night Vision line also underwent large changes in visible transmission. In contrast, the 3M Prestige films became more opaque, losing as much as 40% visible transmission. As a result of significantly increased opacity, they actually showed marginal increases in UV absorption. A similar phenomenon had been reported previously for a Scotchtint 3M film (4). The Prestige samples also appeared cloudy to the eye. Due to the variety of undesirable changes observed upon aging of these samples, the 3M films tested in this investigation can no longer be recommended for other than very short term use.

The UV-blocking properties of the three HanitaTek films tested remained well above our cut-off criterion, although the highly tinted Optitune 15 showed a large change in relative visible transmission. Other Hanita Tek films had not met our requirements to be included in the photoaging study.

Madico films performed well in this investigation: only the Advanced Ceramic 3000 fell below 95% UV absorbance. The Advanced Ceramics films showed very little visible change. However, Madico NG20 showed a major change in visible transmission. The acceptability of these films will depend on the discretion of the museum personnel. CPFilms (Llumar and Vista) performed well according to all criteria used. None of the films tested showed a significant change in UV absorbance, all staying above 97%, and none had more than 4% transmission change in the visible range. Because this brand easily met all our criteria, it can be strongly recommended with regard to optical performance.

The Global Window Films samples included in this phase of the study rapidly lost UV-blocking properties and showed significant changes in visible light transmission. GAM 1810, which barely met the original performance criteria, with 95.5% UV absorbance, fell significantly below this during aging. None of these films met the criteria of the aging study.

The two V-Kool films tested showed virtually no change in either their visible or their UV properties and are therefore acceptable, but curators should bear in mind their noticeable green tint.

The accelerated photoaging used in this investigation was the equivalent of less than seven years of light exposure for a north-facing window in the Los Angeles region, and slightly less than 3 years of direct sunlight exposure on a south-facing window. During this time the UV absorption properties of roughly one-fourth of the films studied fell below the level deemed acceptable for use in exhibition spaces. Almost one-third of the films underwent a large change in visible transmission, due to significant lightening or darkening, sometimes accompanied by change in color.

The other films in this study met or exceeded our optical criteria after this aging equivalent. These particular films can be recommended on the basis of the stability of their optical properties. However, we did not test the films for deterioration of other physical properties such as cracking or crazing, adhesive cross-linking, or delamination. The absence of these changes is also essential to acceptable film performance in a museum setting. Ease of removal without damage to the glazing is particularly important if films are installed on historic glass (3,7).

Formulations of commercial UV-blocking window films may be expected to evolve over time. When a museum or gallery is considering the installation of these films, measurement of the initial optical properties of each product under consideration is strongly encouraged (1,8).

The results reported above underscore the importance of characterizing both the UV and visible properties of the films. Also, the optical performance of the film should be measured immediately after installation and on a regular schedule thereafter, using the same calibrated light meter when possible, at the same location and time of year under similar weather conditions. In addition, because chemical changes in the adhesive, e.g., cross-linking, might make the film intractable, it is recommended that no UV-blocking film is left on museum windows for more than five to seven years whether or not the optical properties have changed.

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Suppliers

Aladdin Glass (supplier of glass blanks)
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Canoga Park, CA 91304
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www.aladdinglass.com

CPFilms (distributor of Llumar and Vista)
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13805 West Road, Suite 400
Houston, TX 77041
800.786.2468
www.v-kool-usa.com

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

Aging Properties of Select UV-Blocking Window Films, continued

Appendix

Btu/sq.ft./day were converted into J/m^2/day using the factor 11,356.5 (9), and multiplied by 365 for an approximate annual exposure. But these values include heat radiation. Several sources indicate that approximately one-half of the total solar energy is heat energy (e.g., 10, 11). So the J/m^2/yr. were divided by 2 to give approximate solar energy/area/year due to ultraviolet and visible radiation striking vertical surfaces in the Los Angeles area. The values are (in MJ/m^2/yr):

North, 870; East, 1680; South, 2280; West, 1930.

The total Weather-O-Meter dose of 5840MJ/m^2 is thus equivalent to approximately the following years of exposure in Los Angeles:

North, 6.7; East, 3.5; South, 2.6; West, 3.0.

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