DOMOTICWARE
Smart Environments

WHITE PAPER

CONTROLLING LIGHT DAMAGE ON MUSEUM ART USING SMART GLASS

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1 Executive Summary

This paper is the result of interviews carried out with several large museums in Europe during February 2010 and on independent research based on the international standard for control of light damage to museum objects (CIE 157:2004, ref [2]).

The current document tries to model the optimum light transmission that a museum vitrine must offer in order to accurately display works of art but at the same time minimising the deterioration resulting from incident light.

It is found that the optimum light levels depend on factors such as the reflectance of the artwork, the light transmission properties of the display case glass and the illuminance of the light sources in the museum.

Several solution models are presented based on CIE recommended illuminance figures and grouped by the CIE categories of light sensitive objects.

2 Light in Museums

2.1 Display Case Model

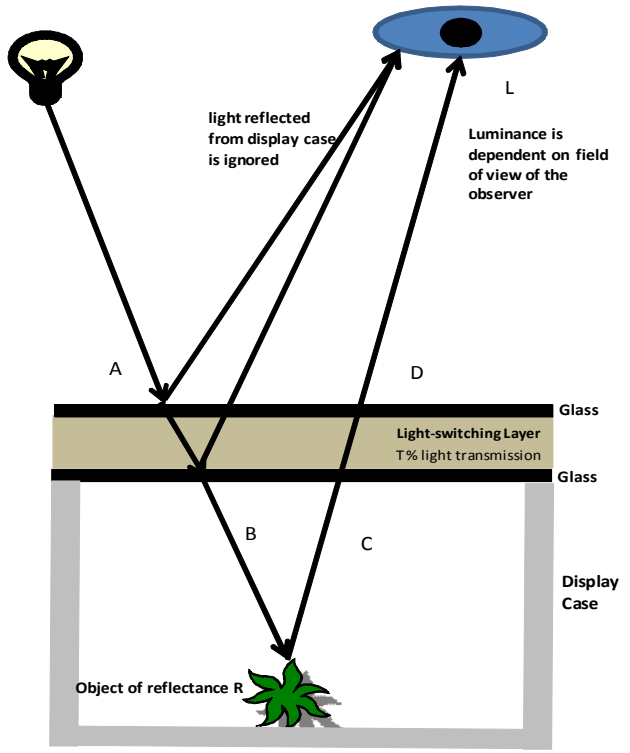

Fig 1 Museum Display Case housing a light-sensitive specimen

Fig. 1 on the left shows a museum display case housing a light-sensitive object and illuminated by a light source.

The light source is assumed to have a Correlated Colour Temperature (CCT) of between 2900K and 4200 K and a Colour Rendering Index, CRI >= 85.

The display case glass is assumed to be a 'clear' glass according to IWA 8:2009 (E) [see Ref 5, sect 2.3], such that:

- Lightness, L* >= 98.0
- Chroma C* <= 0.5
- Iron oxide content <= 200 mg / kg
- 10mm thick glass
- Observer at 10° (see ISO 11664-1)
- Temp: 22ºC +/- 2 [see Ref 5, sect A.3.1]

An observer may perceive light reflected from the object; this appears as a field-of-view dependent luminance, L.

The display case glass may change its transparency, which is modelled as T.

The illuminance incident on the display case is marked as A, of which T% is transmitted by the glass into the display case. This results in B Lux entering the display case and illuminating the object.

The object reflects a fraction R of the light to give off C Lux, of which T% is transmitted by the glass and exits the display case as D lumens / m2.

Assumption [see Ref 1]: as long as D is above 10 lumens / m2, the observer can be assumed to receive a luminance L of 3 cd / m2 in the field of view, sufficient to allow photopic (i.e. colour) vision.

Table 1 – Light control in Museums (see [Ref 2], p26)

Max Material Responsiveness	1. Irresponsive	2. Low responsivity	3. Medium responsivity	4. High responsivity
Daylight Admission	Yes		No	
Sunlight Admission	Yes	No		
Exposure Limit (lux h / y)	No limit	600,000	150,000	15,000
Illuminance Limit (lux)	No limit	200	50	
UV Control	No	Yes		
IR Control	No		Yes	

Table 1 shows light exposure (i.e. dosage) and illuminance limits as a function of the CIE categories of light-sensitive objects, which are described further in Table 2.

Table 2 – CIE Light-Sensitive Object Categories, from [Ref 2, Table 3.4, p26]

CIE Category	Description	Example materials
1	Irresponsive	Most metals, glass and minerals; All stone, genuine ceramic, enamel
2	Low responsivity	Oil, tempera painting, fresco, undyed leather and wood, horn, bone, ivory, lacquer, some plastics
3	Medium responsivity	Costumes, watercolours, pastels, tapestries, prints, drawings, manuscripts, miniatures, wallpaper, gouache, dyed leather, most natural history objects, botanical specimens, fur, feathers
4	High responsivity	Silk, fugitive colourants, newspaper

2.2 Solution Models

This section attempts to create models of possible solutions to estimate optimum luminance at the observer but ensuring minimal light damage on the light-sensitive object. The reader is referred to Fig.1 for variables mentioned in this section.

The sections below show how the CIE recommended illuminance and exposure figures from Table 1 affect the light entering and exiting a display case.

2.2.1 Control Case: Non Switchable Glass of 95% Transmission

Table 3 – Normal non-switching glass

Variable (see Fig.1)		CIE 4: High responsivity	CIE 3: Moderate responsivity	CIE 2: Medium responsivity	CIE 1: Not responsive	Notes
Illuminance (lux)	A	50	50	200	no limit	Recommended illuminance, see [2]
Exposure Limit (lux h / y)	P	15,000	150,000	600,000	no limit	See [2]
Transmission of glass (%)	T	95.0				
Light transmitted into display case (lux)	B	48	48	190		A * T %
Displayed (hrs) per year	J	3000	3000	3000	3000	approx 8 hrs x 7 days x 52 weeks
% of display time transmitting light	Y	100	100	100	100	switching display glass
Displayed hours transmitting light	S	3000	3000	3000	3000	J * Y %
Total Exposure (lux h / y)	X	142,500	142,500	570,000	no limit	B * S
Within exposure limits?		No	Yes	Yes	Yes	X < P ?
Reflectance of object	R	0.6				example reflectance
Light reflected from object (lux)	C	29	29	114		B * R
Exitance from display (lm/m2)	D	27	27	108		C * T %
Luminance > 3 cd / m2?	L	Yes	Yes	Yes	Yes	(D > 10) implies Luminance>3)

Table 3 shows the control case for a normal (non-switching) vitrine where the objects are on display in a museum for J = 3000 hours per year and the glass transmits light during Y = 100% of that time at T = 95% transmission (for a typical museum display case glass). Y is called the Duty Cycle and assumes a non-switchable glass (i.e. it is transparent for 100% of the time).

A representative object reflectance R of 0.6 is assumed but this will of course be different for each work of art.

It can be seen in this case that observers would receive enough light, L (> 3 cd / m2) to be in photopic vision but that objects of type CIE category 4 would be exposed to light above their maximum recommended exposure levels (for CIE 4 objects which are highly responsive, the total exposure X = 142,500 Lux hours / year when the CIE exposure limit P = 15,000 Lux hours / year).

2.2.2 Switchable Display Glass with 50% Light Transmission

Table 4 – Display glass of 50% light transmission

Variable (see Fig.1)		CIE 4: High responsivity	CIE 3: Moderate responsivity	CIE 2: Medium responsivity	CIE 1: Not responsive	Notes
Illuminance (lux)	A	50	50	200	no limit	Recommended illuminance, see [2]
Exposure Limit (lux h / y)	P	15,000	150,000	600,000	no limit	See [2]
Transmission of glass (%)	T	50.0				
Light transmitted into display case (lux)	B	25	25	100		A * T %
Displayed (hrs) per year	J	1200	3000	3000	3000	3000 hrs= 8 x 7 days x 52 wks
% of display time transmitting light	Y	50	50	50	50	switching display glass
Displayed hours transmitting light	S	600	1500	1500	1500	J * Y %
Total Exposure (lux h / y)	X	15,000	37,500	150,000	no limit	B * S
Within exposure limits?		Yes	Yes	Yes	Yes	X < P ?
Reflectance of object	R	0.6				example reflectance
Light reflected from object (lux)	C	15	15	60		B * R
Exitance from display (lm/m2)	D	8	8	30		C * T %
Luminance > 3 cd / m2?	L	No	No	Yes	Yes	(D > 10) implies Luminance>3)

In Table 4, the display case uses a glass which can alter its transmission of light by application of an electrical signal (smart glass) and the Duty Cycle Y indicates that it is transparent (i.e. powered) for 50% of the time on display.

For CIE 4 objects, the exposure time would need to be reduced to J = 1200 hours per year in order that the object receive light within the maximum exposure limits of P = 15,000 Lux hours / year.

However in the case of CIE 4 and CIE 3 type objects (high or moderate responsivity), the exitance D from the display case is only 8 lm / m2, which is not enough to produce the luminance L of 3 cd / m2, necessary to allow photopic vision at the observer.

The Duty Cycle (Y = 50%) whilst on display for J = 1200 hours per year corresponds to a typical energy consumption of:-
5W / m2 x 600 hours = 3000 Watt.Hours / m2 / year

The glass could be activated for example by a proximity sensor when visitors approach the display case. However, it may not be satisfactory for any museum to have to restrict the number of displayed hours to only 1200 per year.

2.2.3 Switchable Display Glass with 58% Light Transmission

Table 5 – Display glass of 58% light transmission, reduced display time for CIE-4 Objects

Variable (see Fig.1)		CIE 4: High responsivity	CIE 3: Moderate responsivity	CIE 2: Medium responsivity	CIE 1: Not responsive	Notes
Illuminance (lux)	A	50	50	200	no limit	Recommended illuminance, see [2]
Exposure Limit (lux h / y)	P	15,000	150,000	600,000	no limit	See [2]
Transmission of glass (%)	T	58.0				
Light transmitted into display case (lux)	B	29	29	116		A * T %
Displayed (hrs) per year	J	1025	3000	3000	3000	3000 hrs= 8 x 7 days x 52 wks
% of display time transmitting light	Y	50	50	50	50	switching display glass
Displayed hours transmitting light	S	513	1500	1500	1500	J * Y %
Total Exposure (lux h / y)	X	14,863	43,500	174,000	no limit	B * S
Within exposure limits?		Yes	Yes	Yes	Yes	X < P ?
Reflectance of object	R	0.6				example reflectance
Light reflected from object (lux)	C	17	17	70		B * R
Exitance from display (lm/m2)	D	10	10	40		C * T %
Luminance > 3 cd / m2?	L	Yes	Yes	Yes	Yes	(D > 10) implies Luminance>3)

Table 5 shows a possible solution in which the glass transmission has been increased to T = 58% and so will transmit more light into the display case when it is activated.

CIE 4 highly responsive objects may only be displayed for J = 1025 hours per year and the glass Duty Cycle Y must not exceed 50% for all object categories.

The Duty Cycle of Y = 50% whilst on display for 1025 hours per year corresponds to an energy consumption of:-
5W / m2 x 513 hours = 2565 Watt.Hours / m2 / year

This solution gives a total light exposure (X) within the limits (P) of all CIE object categories as well as giving sufficient luminance (L) so that observers may view museum pieces with photopic vision.

2.2.4 Switchable Display Glass with 65% Light Transmission (reduced Duty Cycle)

Table 6 – 65% light transmission, 15% glass switching duty cycle for CIE-4 Objects

Variable (see Fig.1)		CIE 4: High responsivity	CIE 3: Moderate responsivity	CIE 2: Medium responsivity	CIE 1: Not responsive	Notes
Illuminance (lux)	A	50	50	200	no limit	Recommended illuminance, see [2]
Exposure Limit (lux h / y)	P	15,000	150,000	600,000	no limit	See [2]
Transmission of glass (%)	T	65.0				
Light transmitted into display case (lux)	B	33	33	130		A * T %
Displayed (hrs) per year	J	3000	3000	3000	3000	3000 hrs= 8 x 7 days x 52 wks
% of display time transmitting light	Y	15	50	50	50	switching display glass
Displayed hours transmitting light	S	450	1500	1500	1500	J * Y %
Total Exposure (lux h / y)	X	14,625	48,750	195,000	no limit	B * S
Within exposure limits?		Yes	Yes	Yes	Yes	X < P ?
Reflectance of object	R	0.6				example reflectance
Light reflected from object (lux)	C	20	20	78		B * R
Exitance from display (lm/m2)	D	13	13	51		C * T %
Luminance > 3 cd / m2?	L	Yes	Yes	Yes	Yes	(D > 10) implies Luminance>3)

Table 6 shows another possibility using a glass with T = 65% transmission but where the Duty Cycle Y is reduced to 15% (this could be achieved by time-controlled switching).

This corresponds to an energy consumption of:- 5W / m2 x 450 hours = 2250 Watt.Hours / m2 / year

This solution allows the museum to display all objects within CIE exposure limits (P) and for 3000 hours per year and permits photopic observation for all CIE object categories.

2.2.5 Conclusion

Depending on various factors such as the object reflectance, advances in transmission of switchable glass, optimum energy consumption levels and exposure limits per object category, there are many possible solutions available which achieve both an optimum luminance at the observer as well as minimal light damage on the work of art.

These models are available for further inspection on request and we can provide further analyses based on concrete values for your specific display requirements.

3 References

Ref	Description
1	"Light for Art's Sake: Lighting for Artworks and Museum Displays", Christopher Cuttle, ISBN: 978-0-7506-6430-1
2	"Control of Damage to Museum Objects by Optical Radiation", International Commission on Illumination [CIE 157:2004], ISBN-978-3-901906-27-5
3	UK Chartered Institute of Building Services Engineers (CIBSE), Society of Light and Lighting (SLL) Lighting Handbook, ISBN-978-1-9068-4602-2 (Chap 13 – Lighting for Museums and Art Galleries)
4	Northeast Document Conservation Centre, Preservation Leaflets, Sect 2.4 "Protection from Light Damage": http://www.nedcc.org/resources/leaflets/2The_Environment/04ProtectionFromLight.php
5	ISO International Workshop Agreement, IWA 8:2009 (E). "Tableware, giftware, jewellery, luminaries -- Glass clarity -- Classification and test method"