SYSTEMS FOR LIGHT DIFFUSION THROUGH TRANSPARENT MATERIALS: PERFORMANCE INDEXES RELATED TO THE CONTAINMENT OF LUMINANCE AND TO THE REMOVAL OF THE UV COMPONENT.

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1. Introduction

This article relates the results of some research, the first phase of which has been presented in a CIE Convention in 2002. The subject of the research is the study of the materials usually employed for light diffusion, in particular the commercial and exhibition applications. In both cases, the role these materials have in the removal of the most damaging component of light, that is the power issued in UV fields, is pivotal. Altogether, the research involved different types of glass, micro-drilled metal plates, plastic materials and films.

2. Working procedure

The screens have been tested in relation to their performance, in terms of:

- Distribution of surface luminance
- Energetic power in the visible field
- Removal of energy in the UV field

The aim of the study is the identification of materials that guarantee a proper distribution of light on the surface, a high performance in the transmission of the light flow and a strong UV removal.
The luminance distribution on the surface has been the subject of the study, as it represents the performance of the diffusing system of the light flow and in particular of the control level which is obtained on the dazzlement phenomenon. The average lighting of a sample surface beyond the screen has been taken as the parameter of the energy performance of the system. The UV content per light flow unit transmitted, finally, has been monitored as a parameter linked to the conservation of materials. The relationship between the luminance on a surface with and without the screen does not represent a real energetic performance of the system, because it does not take into account the variation of the widening of the light beam; however, if the observation field is limited to the useful light flow, that is to that flow which reaches a sample reference surface, then this relationship might as well be considered as representative of the energetic performance of the system. The UV measurements we are interested in, is the proportion of UV ($0,315 < \lambda < 0,400$ μm) expressed as microwatt per lumen, which shows directly if the behaviour of the diffuser is selective, by comparing visible energy to ultraviolet energy.
The measurement device is made of a camera obscura (4000 x 4000 x 3000 mm); a projector equipped with an halogen lamp of 50 W and widening of the light beam at 24°, a mobile support which allows the modification of the position of the illumination device, in comparison with the diffusing screens; a set of diffusing transparent materials, with sizes equal to 1 x 1 m, to minimize the effects of the borders.
A multifunction tool for the measurement of light and UV Elsec 764 (measurement accuracy: +/-5%) and a luminance measurement device Minolta LS 100 (measurement accuracy: +/- 2%; opening angle: 1°) have been used. The absorption coefficient of the walls of the room is in reality lower than 1, thus part of the energy which invests the measurement surface does not come from the diffuser but from multiple reflexes of the flow not intercepted by the screen. To evaluate the width of this variable, some sample measures have been repeated outdoor on a cloudy starless and moonless night and the results have been compared to the ones measured in the sample room: a maximum error of 6%, due to the reflexes, was identified. Such an error has been considered acceptable in relation to the aims of the study.
The work has been finalized with a comparison summary table between the various materials and the related performance indexes mentioned above. For space reasons, the single reports of measurement on the various materials are not related here.

3. Diffusers

The materials most commonly used in architecture to diffuse light exploit the diffraction phenomena that can be monitored through three levels of intervention: the structure of the materials; the elaborations of the border layers of the materials and the installation of special films on one or both the border layers. Inside the previous typologies, the materials subject of the study are the following:

Polycarbonate.The polycarbonate “Lexan” is a thermo-plastic techno-polymer which contains a series of high performance mechanical, optical, technical and electrical features. Extruded as a plate, the material presents special optical and collision proof features. The four tested plates have a 10 mm thickness and different types of finishing.

Polymethylmethacrylate.The flat plated Polymethylmethacrylate (PMMA) is a thermoplastic material, similar to glass, rigid, transparent, resistant to bad weather and to chemical agents. It has an excellent mechanical workability and an easy transformability, brightness, color variability, lightness and resilience, and a high resistance to light and ageing. The eight tested plates have a 5-10 mm thickness and different types of finishing.

Drilled plates. Drilled plates are manufactured by piercing a metal plate: the hole can have different shapes and dimensions: the most common is the circular shape with a small diameter. In this work we will study the drilled plate with diameters ranging from 1 to 4.

Glass diffuser.Glass is an inorganic product of fusion which has been cooled to a rigid condition without crystallizing: different physical and optic proprieties can be obtained by varying the composition, heat treatment and surface finish. The surfaces may be altered by chemical etching, sandblasting or shot blasting, polishing staining and coating. Composition and surfaces alterations produce effects on transparency and refraction; in order to consider the main category of glass available on the market [4], 5 kinds of monolayer glass and 3 composite structures (2 glasses + tissue paper or anti-UV film) have been tested.

4. Experimental results

The luminance and UV measures have been made on a 200 x 200 mm grid on a surface perpendicular to the luminaire axis positioned at 1000 mm from the light source and centred on the axis of the luminaire.

With the average value of light on the measurement surface without the diffusing screen set as equal to 1, the values with the screen range from 0,01 to 0,70 in the polycarbonate case and from 0,04 to 0,82 in the case of polymethylmethacrylate. With the average value of UV on the measurement surface without the diffusing screen set as equal to 1, the values with the screen range from 0,96 to 0,70 in the polycarbonate case, and from 0,021 to 0,96 in the case of polymethylmethacrylate. A sharply selective behavior advantageous to the visible field with respect to the UV has been identified in some plates of polymethylmethacrylate (particularly repsol 0180 and repsol 0360). The greater part of these materials, however, has an extremely low diffusing power. On average, the polymethylmethacrylate is the most efficient under an energetic point of view compared to polycarbonate: one exception is the “solar control” polycarbonate, which has a 70% visible wavelength transparency, together with an excellent diffusing power.

The last column of the table relates a complex parameter, which tries to summarize the mentioned performance features of the diffusing screens. Such a parameter, L_n/E_n, represents the relationship between the reduction of luminance and the reduction of lighting on the sample surface. A low value of this parameter indicates a combination between the low value of luminance and a high values of lighting; in other words, the high diffusing power and high energetic performance of the screen. Two polycarbonate plates, *opal* and *solar control* and three polymethylmethacrylate plates have, on the other hand, values that are sharply lower compared to other materials and thus can be considered as reference materials. Among them, two (the *solar control* polycarbinate and the *Repsol 180* polymethylmethacrylate) have a particularly high energetic performance, two (the *opal* polycarbonate and the *satinized Repsol* polymethylmethacrylate) stand out for a very high reduction of the luminance and one (*Repsol 360* polymethylmethacrylate*),* for a balance between the two features.

As far as luminance is concerned in glass diffusers, the best performances (low loss) have been obtained with the highest transparency glasses, as dot etched and printout glass; because of the transparency, loss of luminance is not very high (40-60%) and so the efficiency parameter Ln/En has a middle value (0.43, 0.67 respectively in 0.03 -1.29 range).

As regards UV the best performances (high loss) have been obtained with custom structures, composed by one 3 mm glasses and an anti-UV film, which show also good values in the efficiency parameter (0.35 for grey film, 0.25 for white film in 0.03 -1.29 range). In drilled plates UV/lm is always close to 1 because energy transmission in the holes is not selective. The small differences are due to diffraction phenomena on the edge of the holes: as a matter of fact this aspect is more evident in small hole plates.

The transparency and the refraction features of a material are influenced by the wavelength of the angle of incidence of radiation. The luminance perceived by the observer also depends on his/her position with respect to the observed point, especially on the angle. Three measurement points have been identified on a quarter of circumference with a radium equal to 2 meters placed on a horizontal plane and centered on a measurement point. These points represent three observation angles in relation to the ordinary: 0°, 7,5°, 15°, identified in relation to the widening angle of the device, equal to 24°. The measurement worksheet and the sizes of the diffusers have been chosen so that the measures are not influenced by the effect of the borders. Since the widening angle of the luminance measurement device is equal to 1°, the measurement area is then equal to 28,8 mm. Being the luminance value on the axis of the device without the diffusing screen equal to 1, the luminance values with the screen range from 0,027 to 0,96 in the case of polycarbonate and from 0,021 to 0,96 in the case of polymethylmethacrylate.

5. Conclusions

As far as plastic materials are concerned, it is clear that the quality of the polycarbonates and of the PMMA is, in total, equivalent, and the differences are found especially in the way the plate is treated. The energetic performance of the glass and plastic material diffusers, with the proper treatments, is comparable. Plastic materials are generally more efficient in removing the UV radiation, while the luminance removal depends exclusively on the treatment the material undergoes, and not on its natural features.

In general drilled plates have shown an high loss of luminance, a good diffusive behaviour for little holes (□= 1 mm) and altogether the worst values for the efficiency parameter Ln/En.

As regards Luminance in glass diffusers, the best performances (high loss) have been obtained with diffuser glass and with a custom structure, composed by two 3 mm glasses and tissue paper, which show the best value of the efficiency parameter (0.04, 0.03 respectively in 0.03 -1.29 range).

Considering as inefficacious the diffusing material which does not reduce the maximum luminance by at least 50% , six of the 24 tested materials could not be classified as diffusing materials.

Drilled plate represent a good alternative if the piercing characteristics are worth for the usual distances and view angles of the observers and when the object to be lighted has not problems of conservation.

Every solution has to be studied also referring to the installation, maintenance, budget conditions. Diffuser glass, for example, costs 6-7 times more than printout or sandblasted glass.

As far as the conservation topics and thus the removal of the UV radiation are concerned, it can be said that polymethylmethacrylate has shown a better behavior compared to polycarbonate, even though the cases vary according to the treatments these materials undergo. One could then propose, after having considered all that was stated above, some corrections parameters of the maximum values of exposure envisaged by Rule UNI 10829 “Environmental Conservation Conditions. Measurement and Analysis”, variable according to the kind of screen employed, other than, obviously, the type of source.

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Diffuser	$E_n = E / E_{without\ diffuser}$ (average values)	$UV_n = UV / UV_{without\ diffuser}$ (average values)	$L_n = L_{max} / L_{max\ without\ diffuser}$ $\alpha = 0°, d = 150$ mm	L_n / E_n
None	1,00	1,00	1,00	1,00
alveolar polycarbonate *thermoclear* –opal (A1)	0,10	0,18	**0,027**	**0,27**
polycarbonate ge “Lexan” -exell d st embossed (A2)	0,04	0,34	0,28	7,00
alveolar polycarbonate *thermoclear* -solar control (A3)	**0.70**	0,90	0,15	**0,21**
polycarbonate ge “Lexan” -exell sg305 (A4)	0,01	**0,02**	0,96	96,0
polymethylmethacrylate *“refined pmma”* repsol -0000r (A5)	0,22	0,19	0,86	3,91
polymethymethacrylate *“refined pmma”* repsol 0360 (A6)	0,43	**0,07**	**0,030**	**0,07**
polymethylmethacrylate *“refined pmma”* repsol 0180 (A7)	**0,82**	**0,03**	0,21	**0,26**
polymethylmethacrylate *“refined pmma”* repsol 8750 (A8)	0,21	**0,09**	0,60	2,86
polymethylmethacrylate *“refined pmma”* repsol opalino (A9)	**0,62**	0,26	0,60	0,97
polymethylmethacrylate *“refined pmma”* repsol traslucido (A10)	0,04	0,33	**0,021**	0,52
polymethylmethacrylate *“refined pmma”* repsol antiriflesso (A11)	**0,74**	0,88	0,74	1,00
polymethylmethacrylate *“refined pmma”* repsol satinato (A12)	0,22	**0,08**	**0,039**	**0,18**
Drilled plate Φ 1mm	0.20	0.90	0.24	1.20
Drilled plate Φ 2mm	0.28	0.93	0.36	1.29
Drilled plate Φ 3mm	0.36	0.95	0.38	1.05
Drilled plate Φ 4mm	0.42	0.99	0.49	1.17
Dot etched glass	**0.90**	0.90	0.60	0.67
Butter finished glass	0.73	0.90	0.10	0.13
Sandblasted Glass	0.73	0.87	0.13	0.18
Printout glass	**0.92**	0.87	0.40	0.43
Diffuser glass	0.53	0.70	**0.02**	**0.04**
Double glass + tissue paper	0.62	0.80	**0.02**	**0.03**
Glass + anti-UV gray film	0.31	**0.10**	0.11	0.35
Glass + anti-UV white film	0.67	**0.07**	0.17	0.25

Tab.1 Material proprieties: measurements results and complex parameters