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BOOK OF PROCEEDINGS VOL 1 ONLINE SESSIONS

An initial approach to the impact of roller screen curtains on colour rendition of transmitted daylight

Experimental measures in real space

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ABSTRACT: Several studies on roller screen shades performance have been conducted focusing on glare, outdoor vision, daylight availability and energy performance. However, other properties—such as chromaticity and colour rendition—of daylight transmitted through this type of shading system have hardly been addressed. Against this background, the present study focuses on the impact of woven shade fabrics on daylight conditions in indoor spaces, targeting variations in colour rendition properties. The hypothesis of this work is that the fibre colour and the openness factor of woven shade fabrics, as well as, the solar incidence position affect the colour rendition properties of the transmitted daylight. Seven screen fabrics were evaluated in a test room, where the CRI and the spectral power distribution (SPD) were measured, at two distinct times of the day. Based on the SPD the Fidelity Index, the Gamut Index and the red Local Chroma Shift were calculated. Results show that the daylight passing through the fabrics has good or excellent colour rendition capacity for the tested samples and the testing conditions. And that the solar position impacts on the studied colour rendition metrics, whereas the openness factor and the colour of the fabric do not.
KEYWORDS: Daylight, Colour Rendition, Woven Shade Fabrics

1. INTRODUCTION

Roller shades are dynamic shading systems widely used globally, as they combine solar and visual protection with an aesthetically appealing presence at a relatively low price. Their properties can improve visual comfort by reducing glare and energy consumption. They consist of different fabric materials produced with varying degrees of openness and transmission characteristics (type of weave, colour, etc.). Several studies have analysed the performance of roller blinds, focusing on the following aspects: glare, outdoor vision, daylight availability and energy performance.

While these are the parameters on which most studies have focused, other measures of lighting quality, such as the spectral transmittance of woven shades and its impact on chromaticity and colour rendering, have not been studied as extensively. The spectral transmittance of glazing and solar shading devices may have an impact on correlated colour temperature (CCT) and colour rendition properties (colour rendering index (CRI), colour fidelity (R_f), gamut index (R_g)). For many years CCT and CRI were the two major components used to understand the spectral power distribution (SPD) of transmitted light. Other parameters used to analyse the colour rendition of light are currently emerging. Some of them are overall average properties (R_f, R_g) and some are hue-specific properties (chroma shift, hue shift) of a light source [1].

Within this framework, this study seeks to analyse the impact of roller screen woven shades on daylight conditions in indoor spaces, targeting variations in colour rendering properties. Colour rendition refers to the effect of the light source SPD on the colour appearance of objects [2]. Moreover, it is relevant to highlight that the impact of woven shades fabric on this parameter has scarcely been explored so far. The hypothesis of this work is that the fibre colour and the openness factor of woven shade fabrics, as well as, the solar incidence position (altitude and azimuth) have an effect on the colour rendition properties of the transmitted daylight.

2. METHOD

2.1 Study case

Seven woven shade fabrics were tested. The fabric selection criterion is based on the colour and openness factor of the fabrics. Woven fabrics with white and grey fibres and their combinations were selected. Furthermore, fabrics with an openness factor of 3 and 5 were chosen. Considering the previously mentioned criteria, the most frequently sold screen fabrics in the local market were selected. Table 1 shows the properties of the selected fabrics. The woven shades tested in this study are only for indoor use.

Table 1:
Properties of selected screen fabrics: fibre colour and openness factor (OF).

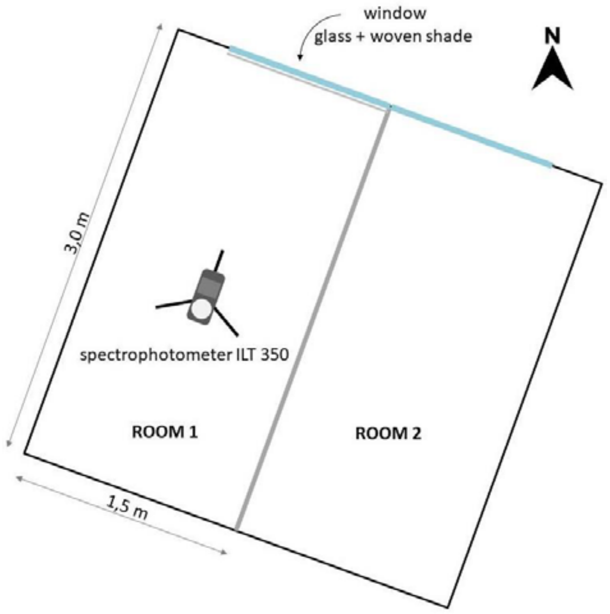
Code	Image	Fibre colour	OF
4301		white/white	3
9801		white/white	5
4001		white/white	5
4308		grey/white	3
4008		grey/white	5
2007		grey/white	5
9808		grey/grey	5

2.2 Experimental measures

Fabrics were analysed under daylight conditions in a test room (Figure 1). The left room (Figure 2) of the lighting research laboratory was used for this study. The room has an opening of 1.00 m x 1.00 m, where the samples were placed. The tests mentioned below were first performed on a setting with no sun protection on its opening, used as the base case. The base case features in the window a 6 mm clear glass. CRI and the spectral power distribution were measured with an ILT 350 Chroma Meter Spectrophotometer (spectral wavelength range: 380 - 780 nm; wavelength accuracy: ± 3 nm; spectral bandwidth: approx. 2.5 nm (half bandwidth); and total uncertainty: ± 7.5%), placed in a horizontal position (1 m in height) on a tripod in the centre of the room. Readings were taken at 11:00 (average altitude: 31.90°, SD 3.87; average azimuth: 26.37°, SD 4.47) and 16:00 (average altitude: 33.35°, SD 4.72; average azimuth: 84.04°, SD 3.17), between April and May. All assessments were conducted under clear sky conditions. A more detailed description of the measurement methodology is presented in Villalba et al.[3].

Figure 1:
Outside view of the lighting research laboratory.

Figure 2:
Top view of the measurement setting. Left: room 1; right: room 2.



Although the effect of woven shade fabrics on colour rendition metrics could be determined from the spectral transmittance data measured in a bench-top spectrophotometer [4], in this study, they were measured in a test room at two different times of the day. This approach allows analysis of the impact of the solar incidence angle on the colour rendition parameters.

2.3 Analysed parameters

The colour rendering index (CRI) is a measure of the degree to which the psychophysical colour of an object illuminated by the test illuminant conforms to that of the same object illuminated by the reference illuminant, suitable allowance having been made for the state of chromatic adaptation [5]. CRI values go from 0 to 100 [6] where values between 80 and 90 are acceptable (neutral) for most applications. Due to the shortcomings of the CRI related to colour space, sample set and reference illuminant [2,7], this index is now being replaced by the Colour Fidelity Index (R_f), which is a more accurate measure of average colour fidelity.

Currently, several experts [7,8] suggest that the colour rendition properties of a light source should be defined by more than one metric. According to this approach, the method proposed by the ANSI/IES TM-30-20 [1] entails the determination of both overall average properties (colour fidelity, gamut area) and hue-specific properties (chroma shift, hue shift) of a light source.

As the ANSI/IES TM-30-20 focuses only on describing the objective aspects of colour rendition [2] characterization techniques, and it does not relate values to a subjective evaluation, in this study, the colour preference specification criteria determined by Royer et al. [9] will be used. Royer developed these criteria according to results obtained in several psychophysical experiments [9–11]. These criteria are based on the R_f, the Colour Gamut Area Index (R_g) and the red Local Chroma Shift ($R_{cs,h1}$). Royer et al. [9] set three tiers with different levels of stringency:

-Best: Tier A: $R_f \geq 78$, $R_g \geq 95$, $-1\% \leq R_{ch,h1} \leq 15\%$;
-Good: Tier B: $R_f \geq 74$, $R_g \geq 92$, $-7\% \leq R_{ch,h1} \leq 19\%$;
-Acceptable: Tier C: $R_f \geq 70$, $R_g \geq 89$, $-12\% \leq R_{ch,h1} \leq 23\%$.

The R_f represents how similar the colour appearances of 99 test-colour samples are rendered on average by a test light compared to those under a reference illuminant [12]. R_f ranges from 0 to 100, with higher numbers indicating more similarity to the reference [1].

The R_g is the ratio of the area spanned by the average coordinates (a',b') of the colour evaluation samples in each hue-angle bin illuminated by the test source and by the reference illuminant [1,2]. In this manner, it measures an increase or decrease in saturation. Values close to 100 mean that the test source on average does not modify the chroma compared to the reference illuminant. Values above 100 indicate an overall average increase in saturation, while values below 100 show an overall average decrease in saturation.

The $R_{cs,h1}$ represents the relative average chroma shift for hue-angle bin 1 (red). A negative value indicates a decrease in chroma, whereas a positive value indicates an increase in chroma for the averaged samples within the red hue-angle bin [1]. The values of $R_{cs,hj}$ are given in per cent. The reason for the selection of $R_{cs,h1}$ is that red plays a more substantial role in human preferences than other hues [9–11].

The R_f, the R_g and the $R_{cs,h1}$ were calculated based on the SPD measured in the test room, according to ANSI/IES TM-30-20.

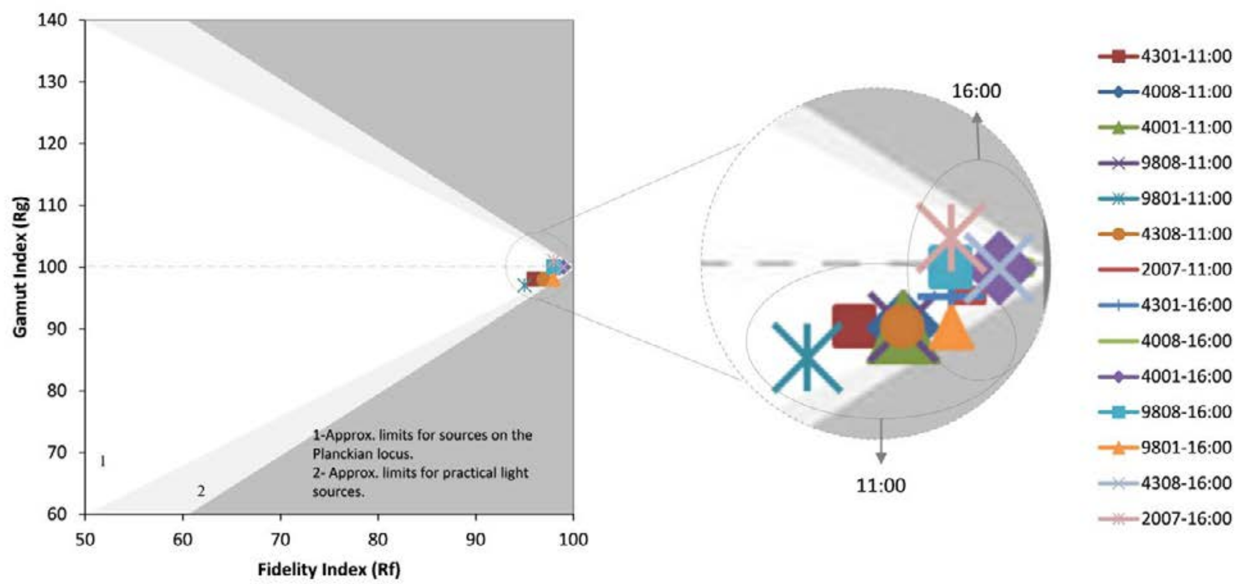
3. RESULTS

Concerning the CRI, it is observed that (Table 2), all the scenarios with roller fabrics at both hours analysed show values ≥95. These values are lower than those of the clear glass base scenario (99). This suggests very good conditions in terms of colour perception according to EN 12464-1:2011 [13]. R_f scores also approach 100, and in all cases, are ≥95. This suggests a high similarity to the reference source. Both indexes show a slightly higher value in the afternoon, when the incidence of direct sunlight on the window is weaker and the angle of azimuth exceeds the cut-off angle of this type of woven shade fabric (65° and 75°) [14]. A correlation analysis (Pearson coefficient) was conducted between these indexes and the solar incidence angle according to the time of day (11:00 or 16:00) in order to check for collinearity. The azimuth and altitude at which each measurement was taken were selected as variables to represent the solar position. No correlation was detected between either of these two metrics and solar altitude. Significant positive collinearity of both CRI and R_f with azimuth angle was detected (CRI/azimuth 0.5530, p-value 0.0402; R_f/azimuth 0.6829, p-value 0.0071). However, the average difference of CRI and R_f between the two analysis settings is less than two (CRI 1.14/ R_f 1.57).

Table 2:
CRI, R_f, R_g and $R_{ch,h1}$ values for the scenario with clear glass and the scenarios with roller screen shades at 11:00 and at 16:00.

	11:00				16:00			
Code	CRI	R_f	R_g	$R_{ch,h1}$	CRI	R_f	R_g	$R_{ch,h1}$
clear glass	99	99	99	-1%	99	99	100	0 %
4001	98	97	98	-1%	99	99	100	0%
4301	97	96	98	-1%	98	98	99	-1%
9801	95	95	97	-2%	97	98	98	-2%
2007	97	99	99	-1%	99	98	101	-1%
4008	98	97	98	-1%	99	99	100	-1%
4308	98	97	98	-1%	99	99	100	0%
9808	97	97	98	-2%	98	98	99	-2%

Figure 3
Left: R_g versus R_f plot. Right: Detail showing how the different woven shades are distributed in the plot at 11:00 and 16:00.



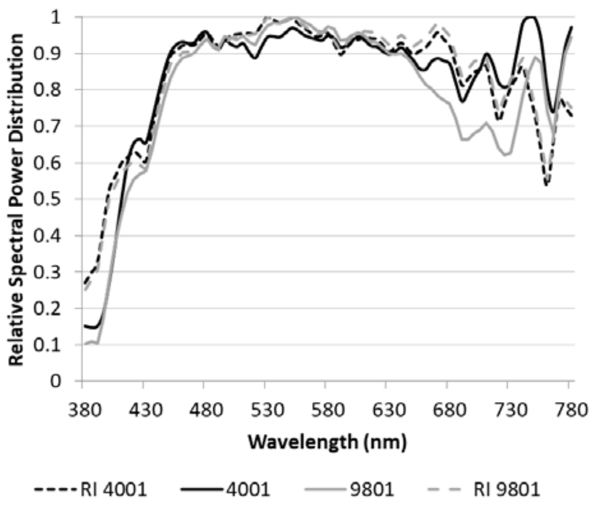
Regarding the R_g values, it was observed that at 11:00 the values were slightly under 100 in all settings, which indicates a slight average reduction in chroma (Table 2). In the afternoon hours, this situation is less uniform. Fabrics 4001, 4008, and 4308 have an R_g value of 100 which means that the transmitted light does not increase or decrease chroma compared to the reference illuminant. Woven shade fabric 2007 slightly increases the saturation (R_g 101) while fabrics 4301, 9801, and 9808 slightly reduce the R_g value, indicating an overall average decrease in chroma compared to the test illuminant. Significant positive collinearity between R_g and the azimuth angle was also found (R_g/azimuth 0.7301, p-value 0.0030). Similar to the R_f values, the average difference in R_g for the two schedules is low (1.57 points). This can be clearly seen in Figure 3, R_g versus R_f plot, where textiles have lower R_f and R_g values in the morning than at 16:00. At 16:00, both parameters are closer to 100. Collinearity between solar altitude and R_g was not observed.

The absence of a significant correlation between altitude and the studied colour rendition metrics was probably due to the fact that the analysed range of this variable was between 26.89° and 38.24°. Considering that the cut-off angle (angle from which the direct transmission is reduced to zero) of this type of fabric is between 65° and 75° [14], the altitude did not reach these values at any time, while the azimuth (20.74° to 87.31°) exceeded 65° in some periods. This possibly explains why the influence of altitude on CRI, R_f, and R_g was not statistically significant.

The analysis of $R_{ch,h1}$ shows that during the hours when direct sunlight is most intense (11:00), the transmitted light decreases by 1 to 2% in saturation for this hue angle bin (red) in all analysed settings. While at 16:00 settings 4001 and 4308 do not modify the saturation of the transmitted light with respect to the reference illuminant and the other textiles maintain the same behaviour as at 11:00. The textiles 9801 and 9808 are those with lower values of $R_{ch,h1}$ (-2). Figure 4 shows the SPD curves of fabrics 9801 and 4001 at 16:00 and those of their respective reference illuminants.

The differences in the SPD functions explain the variation in the colour rendering performance of the transmitted light in each of these settings. This difference in spectral transmittance at wavelengths 640 nm-750 nm of these two fabrics with similar properties (OF 5 and colour "white-white") could be due to the materials used: 9801 PVC-coated fiberglass and 4001 PVC-coated polyester. This was previously identified by the authors in spectrophotometer laboratory measurements [4].

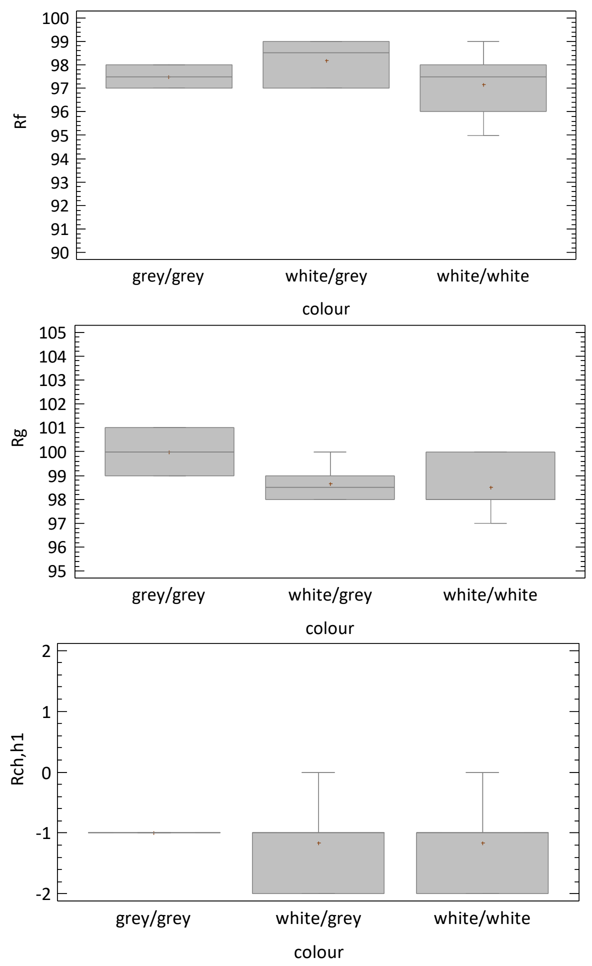
Figure 4:
Relative spectral power distribution for woven shades 4001 and 9801 settings at 16:00 o´clock and their reference illuminants.



According to the criteria proposed by Royer et al. [9], most of the roller shade scenarios would qualify as "Best: Tier A" (Table 2). Fabrics 9808 and 9801 present $R_{ch,h1}$ values outside the acceptable range for this class in the two schedules analysed and therefore correspond to "Good: Tier B". Therefore, in most settings, the light that passes through the fabrics has excellent colour rendition.

Finally, for the tested sample, no specific effect of colour or openness factor on the colour rendering capacity of the light passing through the screen fabrics was observed. Collinearity between OF and rendition properties (CRI, R_f and R_g) was checked by means of a correlation analysis (Pearson coefficient). All the Pearson's correlations calculated were low, and in all cases, they were not statistically significant. As fibre colour is a categorical variable, an analysis using box plots was performed to check its association with the analysed colour rendition metrics (Figure 5). From the observation of the graphs, it is assumed that R_f, R_g and $R_{ch,h1}$ are not associated with fibre colour as the distributions of these variables do not show an appreciable variation across fibre colour categories.

Figure 5:
Boxplot of fibre colour and R_f (top). Boxplot of fibre colour and R_g (middle). Boxplot of fibre colour and $R_{ch,h1}$ (bottom).



4. CONCLUSION

Firstly, it is important to stress that this study also shows the need to use more than one colour rendition metric to analyse the colour performance of light. If only the CRI is considered, it is observed that all the fabrics in both analysis settings show excellent colour rendering capability. However, if a set of metrics, such as colour fidelity (R_f) and colour gamut area measures (R_g and $R_{ch,h1}$), are considered, a more comprehensive and accurate classification of the colour preference of light is achieved. Including updated colour rendition metrics in shading system assessments, in addition to those traditionally used (glare, view clarity, visibility), becomes crucial if we want to achieve daylit spaces that truly consider the needs and preferences of the users.

Secondly, analysing the colour rendition properties of daylight transmitted through woven shade fabrics in real contexts -test room- enables analysing the impact of environmental variables (for example, solar position) on sunlight, in addition to the impact of opto-physical properties of the material, which can be analysed through bench-top spectrophotometer measurements.

Finally, it is necessary to emphasize that this is an initial study, and therefore the results obtained are preliminary. In order to further advance on definitive results regarding the influence of these properties on the colour rendition of transmitted daylight, it is necessary to extend the sample. It is also important to extend the analysis to different times of the day, seasons of the year, and different facade orientations. As the SPD of daylight strongly depends not only on the latitude but also on the façade orientation [15].

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