Specific Lighting Applications: Is R_a Enough?

J. Sandoval, E. Colombo, and S. Gor
Departamento de Luminotecnia, Luz y Visión, Facultad de Ciencias Exactas y Tecnología,
Universidad Nacional de Tucumán
4000-Tucumán (ARGENTINA)
Corresponding author: J. Sandoval (jsandoval@herrera.unt.edu.ar)

ABSTRACT

In the present work we analyse the significance and constraints of R_a to proper solve some questions that raise at the time of the source selection in a lighting project. We measured and analysed the spectral power distribution (SPD) of several source commonly used in lighting practice, including metal halide, compact fluorescent, high pressure sodium and induction lamps. From SPDs, we determine not only general colour rendering index R_a but values for all fourteen special colour rendering indices R_i. Analysing results and comparing them, it becomes clear the limitations of the general R_a to indicate the colour aspects of the lighting quality: considering lamps with identical (and relatively high, like is strongly recommended in lighting practice when color aspects are of importance) R_a, it can be seen that the behaviour of the lamp could be extremely inadequate depending on the specific application and colour characteristics and dominance of the scene to be lighted. Inversely, lamps that should be discarded from its R_a value, could still be useful for certain applications, lighting objects for which "representative" colour that lamp have a high value for R_i.

Our results emphasise the convenience of having complete and precise information of the spectral quality of sources at the time to select the most adequate to the actual project and the need to analyse such characteristics in concordance with the specific requirements of the project.

1. INTRODUCTION

A major aspect of lighting quality is the resultant ability to see colours properly. In that sense, the properties of the light sources employed and their ability to accurately resemble the "true" colours of people and objects are among their main characteristics.

The tools available for lighting designers, to manage problems related with this issue and solve them, include the correlated colour temperature (CCT) and, specifically, the colour rendering index (R_a or CRI). The colour rendering index is used to compare the effect of light sources on the colour appearance of objects and their surroundings in comparison with their appearance under a proper reference source [1].

The R_a is a relative scale ranging from 0 to 100 that indicates how perceived colours match "actual" colours: it quantify the degree in which perceived colours of objects, under lighting provided by a considered source, conform to the colours of the same objects when illuminated by a reference standard light source under well specified conditions.

To determine the values of R_a corresponding to lamps to be used to satisfy requirements assessed in a given project, it is necessary to have accurate and precise spectroradiometric measurements of those sources.

Wyszecki and Stiles [2] present a summary of the CIE method to calculate a colour rendering index. Briefly, they state the procedure in six steps that include the selection of a reference illuminant; the specification of a set of test-colour samples in terms of spectral radiance factors; the determination of two sets of CIE 1931 tristimulus values of the test-colour samples: one illuminated by the reference illuminant and the other illuminated by the source to be tested; the determination of the resultant colour shift; the calculation of the set of CIE Special Color Rendering Indices; and the calculation of the CIE General Colour Rendering Index, which is defined as the arithmetic mean of the Special Indices R_1 to R_8:

$$R_a = \frac{1}{8}\sum_{i=1}^{8} R_i \tag{1}$$

2. METHOD

The calculations made to determine values for R_i were performed from the spectra measured with a LabSphere spectroradiometric system. The measuring range was from 350 nm to 1050 nm.

The set of lamps tested consist of 14 metal halide lamps (MHL) of different wattages (6 of 250 W; 2 of 35 W; 2 of 70 W; 2 of 150 W; 1 of 400 W and 1 of 1000 W) plus 11 high pressure sodium lamps (4 of 70 W; 1 of 100 W; 2 of 150 W; 2 opf 250 W and 2 of 400 W). As a control, we measured as well two tungsten halogen lamps rated 100 and 150 W.

For each lamp the spectrum was determined by means of the spectroradiometer, performing at least three scans. Figure 1 shows, as an example, the spectrum for a 70 W metal halide lamp.

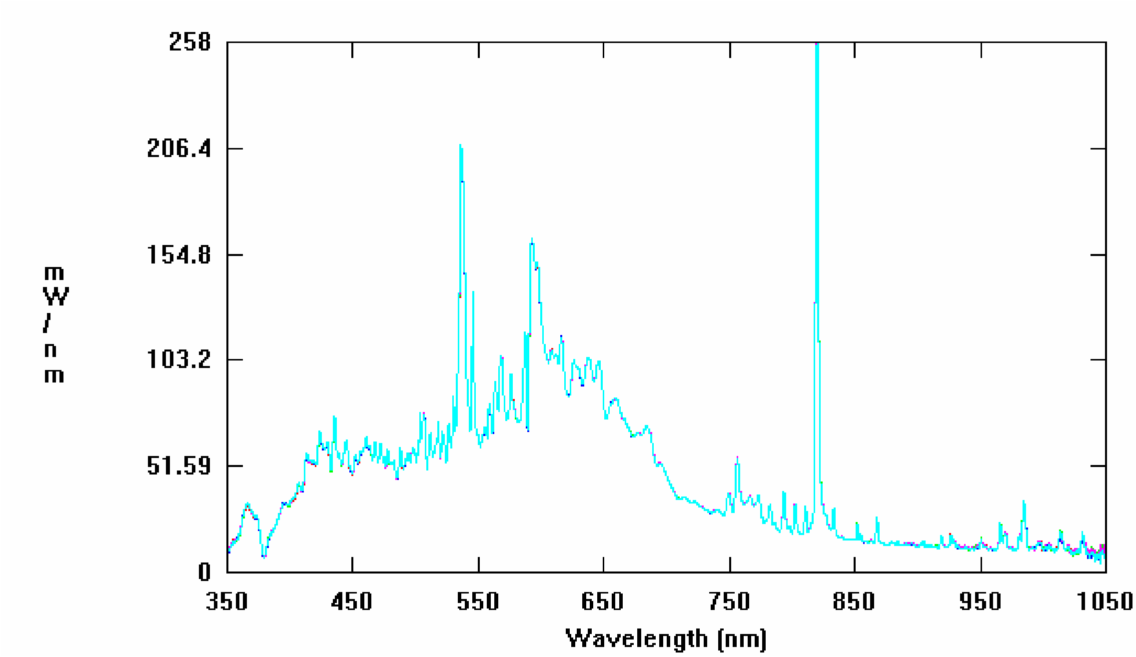

Figure 1: Spectral Power Distribution for a 70 W metal halide lamp. It shows scan 1 of five taken.

Resolution in the determination of colour temperature of the planckian reference was 25 K. From the spectra, the equipment give us all the 14 values for R_i, the resulting value for R_a, the employed reference illuminant in each case, and the corresponding correlation coefficients.

3. RESULTS

Table I shows the result obtained for the computation of colour rendering indices for the 14 metal halide lamps measured. Values for R_1 to R_{14} are given, together with the corresponding value for R_a for all the lamps. In the same way, Table II shows values for sodium, fluorescent and incandescent lamps as well.

Table I: Values of colour rendering indices R1 to R14 for the metal halide lamps measured. Value of R_a is also showed.

	R_a	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14
mh 10 250 w	**65.1**	68.3	81.6	76	71.3	66.2	73.3	66.6	17.4	-129	42	73.3	33.7	77	85.3
mh 11 250 w	**67.8**	75.9	78.4	59	75.7	70.6	66.8	75	41.6	-87	28.7	74.5	22	80.6	75.1
mh 13 70 w	**94.3**	97.6	97.3	92	95.3	96.6	96.7	93.4	85.5	61	89.3	95.9	92.6	98.1	94.7
mh 15	**82.3**	89.4	92.2	81.1	90	86.2	90.2	81.2	48.5	-36	68.8	91.3	69.5	93.6	87.7

35 w															
mh 16 35 w	**83.6**	91.6	93.5	80.8	90.6	88.3	92.1	81.6	50.3	-31	71	91.5	71.8	95.7	87.2
mh 1 250 w	**56.1**	59	67.9	55.8	63.3	57.4	54	67.5	23.8	-168	7.1	60.8	11.9	65.3	74.5
mh 2 150 w	**91.3**	96.8	97.6	90.2	94.5	94.8	97.5	88	70.9	29.5	86.8	94.9	89.4	98.4	92.9
mh 3 250 w	**54.8**	57.4	65.1	52.2	60.9	55.6	51.2	68.7	27.5	-166	0.6	56	8.4	62.7	72.6
mh 4 250 w	**57.3**	57	79.4	80	57	57.4	73.9	54.6	-0.9	-163	42.8	58.2	41.8	67.4	89.1
mh 5 150 w	**84**	89.3	93.2	85.4	90.5	86.9	91.8	82.1	52.5	-21	73.4	91.9	74	93.2	90.3
mh 6 70 w	**77.9**	82.1	89.2	84.2	85.1	80.1	86.4	77.4	38.8	-60	63.8	86.7	64.9	87.1	89.9
mh 7 400 w	**81.1**	79.5	81.7	79.7	83.1	78.7	76.3	90.2	79.4	25.4	53.6	77.4	63.6	79.1	88.5
mh 8 100 w	**69.5**	63.2	70.8	72.7	68.7	64.4	63.1	85.6	67.9	-22	28.3	57.5	46.2	63.4	84.3
mh 9 250 w	**55.8**	58.8	66.2	53.4	62.3	56.7	52.7	69.1	27.4	-164	3.3	57.7	9.6	64.2	73.3

Table II: Values of colour rendering indices R1 to R14 for tungsten halogen, compact fluorescent and high pressure sodium lamps measured. Value of R_a is also showed.

	R_a	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14
th 2 100 w	**99.6**	99.9	99.7	99.4	99.8	99.8	99.4	99.6	99.6	99.4	99.2	99.8	98.7	99.8	99.7
th 3 150 w	**99.6**	99.6	99.8	99.8	99.4	99.6	99.7	99.8	99.4	99	99.6	99.3	99.4	99.6	99.8
cf 1 9 w	**81.6**	98.3	93.4	48.4	90.8	87	79.7	89.9	65.7	-9.4	46.3	81.2	40.1	96.1	64.9
cf 2 20 w	**80.7**	98.1	93.3	50.1	87.7	86.4	80.4	86.7	62.8	-12.3	47.6	79.6	40.5	96.5	66
hps 1 70 w	**-6.6**	-22.4	53.5	36.5	-47.8	-24.3	37.1	12.2	-97.4	-320	27	-78	-4.3	-7.7	57.5

The set of test-colour samples employed to calculate the indices are specified in terms of their spectral reflectance and radiance factors. Their approximate Munsell notations and colour appearance under daylight are as follows [2]:

Sample Nº	Approximate Munsell Notation	Colour Appearance Under Daylight
1	**7.5 R 6 / 4**	Light grayish red
2	**5 Y 6 / 4**	Dark grayish yellow
3	**5 GY 6 / 8**	Strong yellow-green
4	**2.5 G 6 / 6**	Moderate yellowish green
5	**10 BG 6 / 4**	Light bluish green
6	**5 PB 6 / 8**	Light blue
7	**2.5 P 6 / 8**	Light violet
8	**10 P 6 / 8**	Light reddish purple

These eight samples take part in determining the general colour rendering index R_a. In addition, the following six test-colour samples are used:

Sample Nº	Approximate Munsell Notation	Colour Appearance Under Daylight
9	**4.5 R 4 / 13**	Strong red
10	**5 Y 8 / 10**	Strong yellow
11	**4.5 G 5 / 8**	Strong green
12	**3 PB 3 / 11**	Strong blue
13	**5 YR 8 / 4**	Light yellowish pink (Caucasian completion)
14	**5 GY 4 / 4**	Moderate olive green (leaf green)

4. DISCUSSION AND CONCLUSIONS

From the results showed in Table II, it can be clearly seen that the method employed to determine values for the colour rendering indices was precise and accurate. Values obtained for incandescent lamps, labelled **th2 100w** and **th3 150w**, are very high as would be expected: $R_a = 99.6$ in both cases, with the indices R_i varying between 98.7 and 99.9.

It can also be seen from the Table the extremely poor chromatic quality of the high pressure sodium lamp tested: none of the indices is higher than 53.5. Furthermore, several values are negative which in fact do not make physical sense. Colour rendering is very bad, specially in the cases of R_1, R_4, R_8, R_9 and R_{11}. This feature of the high pressure sodium lamp is well predicted by R_a.

Regarding the values showed in the Table I, we can notice some features that distinguish metal halide lamps from the rest with respect to the colour rendering.

Taking into account that the perceived colour of an object is affected by the colour rendering properties of the lamp used, if we have to illuminate an office in which the colour discrimination is an important part of the work (advertising agency, tourist information office), a source with a R_a of 90 or higher should be employed [3].

The sources that accomplish this requirement are those labelled **mh13 70w** and **mh2 150w** having 94.3 and 91.3 respectively. In general they render colours fairly well but problems would rise if the office to be lighted has dominance of saturated red: the value for R9 is as low as 61 for the first lamp (70 W) and unacceptable for the last (150 W). This is a piece of information that in general is not available for the designers. On the other hand, lamps that show a rather low value for R_a, like those labelled **mh3**, **mh4** and **mh9** (all of 250 W) having 54.8, 57.3 and 55.8 respectively, show behaviour not too bad in some situations: mh4 is acceptably good for light scenes with trees, vegetals, flowers, etc.

Still more figures and comparisons would be extract from the Tables I and II, all of them ponting in the same direction: in some occasions, the general colour rendering index R_a is not enough. When the colour rendering is an important aspect of the project, the whole information needed to proper solve the problem of selecting the adequate source is given by the emission spectrum of the source. Having the spectrum, all the indices and figures needed could be obtained. This would permit the designers to choice the lamp that best accomplish the requirements stated by the particular application.

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