Colour and environmental quality: second-level parameters

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ABSTRACT

Illuminance level and discomfort glare, first-level parameters for comfort evaluation in indoor spaces, are now often supported by second-level parameters for an improvement of environmental quality. Colorimetric quantities in their spatial distribution represent an example of second-level parameter supporting the usual Colour Rendering Index (CRI) and the Correlated Colour Temperature (CCT) of light sources.

The present work is oriented to the study of chromatic aspects in terms of spatial distribution in spaces with Multi-Type Lamp Systems (MTLS). The aim is to integrate the information provided by commercial software in terms of illuminance distribution with the knowledge of the spatial variation of CRI by taking into account the arrangement of lamps and their photometric properties, and employing this data for computing a composite CRI. This will allow the optimisation of positions and types of lamps for minimizing the spatial variation of chromatic aspects in the frame of feasibility in energetic and environmental terms.

INDEX TERMS

Chromatic aspects; Environment; Multi-type lamp systems; Quality; Composite CRI

INTRODUCTION

The rising demand for an increasingly comfortable environment, the growing functional complexity of spaces, the adoption of new materials and technologies for environmental control have been in these last years, together with improved economic level, the elements that fostered studies and research in design techniques to improve environmental comfort. Illuminance level and discomfort glare, constituting first-level or general design parameters for comfort evaluation, are now often supported by second-level parameters for a further improvement of environmental quality. Spatial distribution of colorimetric quantities represents an example of second-level parameters.

Quantifying the appearance of objects under different light sources has been of interest over the years; this leads to several tools, among which the most widely used by lighting engineers, interior designers and architects, is the Colour Rendering Index, CRI (CIE, 1995). Many other tools have been developed to provide for CRI shortcomings: the Colour Preference Index (Judd, 1967), graphical methods, etc. Anyway, implicit in each of the above tools is that consider only one type of light source at a time: generally however different types of light sources are used together in the same lighting system to fulfil aesthetic, visual or technical needs. Multi-Type Lamp Systems (MTLS) can be considered as an alternative to Single-Type Lighting Systems (STLS) to reduce electrical consumption, to improve or keep in a prefixed range the colour aspect of objects and internal spaces, to minimize visual effects due to the starting and restarting time of lamps, to adequate engineering and architectural needs and to contain system costs. This means that it is necessary to extend and generalize one of the existing criteria for multiple light sources. The problem has been studied, among others, by Embrechts (1992), Begemann *et al.* (1994) and Gugliermetti *et al.* (1995) in spaces provided with artificial lighting systems employed for integrating daylight, by Gugliermetti *et al.*

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(1996a,b) and Houser and Gibbons (1999) for MTLS, in the first case considering only perfect mixing, in the second without energy considerations.

The present work is oriented to the study of chromatic aspects, in terms of spatial distribution, for spaces provided with different types of lamps. The aim of the paper is to integrate information generally provided by commercial software (Litestar®) in terms of illuminance distribution on the working surface with the knowledge of the spatial variation of CRI, by taking into account the arrangement of lamps and their photometric properties, and employing this data for computing a proper CRI. This will allow the optimization of geometry and type of lamps for minimizing the spatial variation of chromatic aspects in the frame of feasibility in energy efficiency and environmental terms. Only two kinds of lamps with different beam spreads are analysed, as the aim in this paper is to show problems and possible solutions rather than performing a systematic analysis of MTLS; two environments with completely different visual tasks, an open space office and an industrial space, are considered.

BACKGROUND AND METHOD

Human eye is not able to sort out individual colour frequencies; the perceived colour of light sources mainly depends on their Spectral Power Distribution (SPD) and an object colour depends on the SPD of the sources and on the spectral reflectance of surfaces. Large changes in SPD generally do not involve variations in the eye perception of colours; as a consequence the experience with types of illuminance appears more important than its own physical nature. A great deal of semi-empirical formulas and mathematical models has been produced to evaluate colour differences and colour rendering, observer's sensation varying with condition of observation and specific kind of stimulus. Artificial lighting of interiors shows really peculiar aspects, making different the approach to colour evaluation in respect to industrial situation: this is mainly due to chromatic adaptation phenomena and to the fact that eye judgements are greatly influenced by eye perception of the whole lit environment (walls, furniture, etc.). Nowadays, C.I.E./T.C.-3.2 Test Colour Method is still regarded as the fundamental method for colour rendering appraisal. Many experimental works on lighting systems requirements have been done using Correlated Colour Temperature (CCT) and CRI as main parameters to characterize colour aspects for interiors, as it is possible to identify values of CCT and CRI, depending on the considered task, to guarantee good or acceptable colorimetric comfort (CIE, 1986). Experience has also proved that systems with a high R_a are to be preferred in critical situations, regardless their own R_i; for typical situations R_a indicates colour rendering mean deviation, and this does not guarantee the same R_i for sources with the same R_a; still, differences of about 5 units are necessary to perceive visual colour difference under the best conditions. CRI presents some limits: the real point of interest is not the behaviour of a light source in respect to its reference illuminant, but whether a source is acceptable to any specific purpose, after chromatic adaptation.

Colour qualities for MTLS are expressed by colour appearance of light sources and by colour rendering of light, respectively through CCT, computed using Robertson's (1979) interpolation method, and CRI (R_i and R_a), calculated following the method reported in CIE/13.2 (1974). These parameters can be evaluated basing on the SPD of the considered light source. SPD on the workplane is made of each spectrally different light coming from each considered lamp contributing to the total power in a way that depends on their luminous flux distribution, on lamps position, on the spatial characteristics of luminaries, on the colour of walls, ceiling, floor; the latter aspect has not been considered. SPDs for different composition of a halogen and a high pressure (HP) sodium lamp in the range 380–780 nm with a 5 nm division are reported in Figure 1.

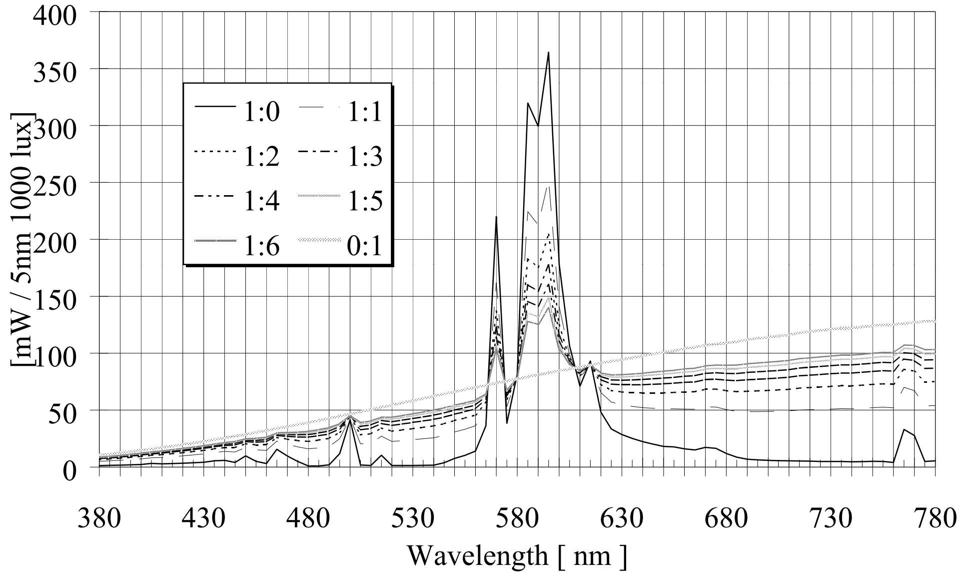

Figure 1 SPD for several ratios: 50 W HP sodium/100 W halogen lamps: experimental data.

PRELIMINARY CONSIDERATIONS

The most natural solution designing a lighting system would be to utilize a lamp with both good luminous efficiency and colour rendering; unluckily, increasing energy efficiencies corresponds to decreasing colour performance, and it seems not possible to balance these two requirements, especially in environments where high values of both are required. An STLS using incandescent lamps shows a high R_a and a scarce luminous efficiency; it is reasonable then to think to save energy by combining incandescent lamps together with other light sources characterized by good luminous efficiency and lower R_a: an increase in the ratio high efficiency lamps/high R_a lamps surely causes a worsening of colour performances. This increasing process must then be stopped when MTLS colour quality becomes lower than standard values related to space use destination.

In the hypothesis of perfect mixing, SPD on the working plane being the sum of the spectral power of each lamp, regardless of the light source geometry and distribution, a theoretical solution of the problem can be considered i.e. the one showed in Table 1, where only HP sodium lamps and halogen lamps have been considered. The optimum ratio will be a function of the specific application, as it is generally possible to identify preferable CCT and R_a values depending on the type of interior task or activity. Energy aspects are only characterized by the total luminous efficiency, while starter and ballast electrical consumptions have not been considered. A better energy efficiency result to the detriment of colour performance can be achieved with mercury fluorescent lamps, while the use of metal halide lamps can limit colour depreciation in respect to the previous case and assure good energy savings. Anyway, as each rendering and colour group can be linked to a specific type of interior, task or activity, the problem of interchangeablility of different solutions can become important. Such problems are not always theoretically soluble and misunderstandings can arise using only the CRI method: lamps can be considered as practically interchangeable only if they present a small CCT difference and their R_a differ by about a maximum of 5 units, being it the threshold for perceptible colour differences; besides, a more accurate way to verify the possibility of interchangeability is the comparison among all the general colour indexes R_i. Anyway, Table 1 cannot be used to evaluate colour qualities on the working plane as it refers only to a perfect mixing situations. An applicatory investigation is then required.

Table 1 Energy efficiency and colour aspects for several ratios: 50W HP sodium lamps/100W halogen lamps

HP sodium/halogen	Colour qualities				Efficiency	Flux
(No./No.)	Appearance	T_c	Rendering	R_a	η	ϕ_v
–	group	(K)	group	–	(lm/W)	(lm)
1:0	n.c.	n.c.	n.c.	n.c.	70.0	3500
1:1	1	2237	3	43	38.7	5800
1:2	1	2453	2B	60	32.4	8100
1:3	1	2589	2A	70	29.7	10 400
1:4	1	2684	2A	75	28.2	12 700
1:5	1	2752	2A	79	27.3	15 000
1:6	1	2804	1B	82	26.6	17 300
0:1	1	3187	1A	100	23.0	2300

PROPOSED APPROACH AND RESULTS

Two rectangular shaped environments with completely different visual tasks have been considered: an open space office (space 1), dimensions 15 × 10 × 4 m, and a machine shop (space 2), dimensions 15 × 10 × 12 m. Lighting design has been developed by a commercial software, fixing as required by Standards (CIE, 1986) 500 lx on the working plane, placed at 0.8 m, for both spaces, and R_a, respectively, more than 80 and in the range 40–60 (groups 1B and 3, CIE classification). No windows have been considered to study the effect of mixing different lamps only. Room visible lambertian reflectances are: walls, 50%; floor, 30%; ceiling, 70%. Two symmetrical luminous intensity distributions with different beam spreads, obtained with specific luminaries, have been considered: (a) narrow beam, <20°; (b) wide beam, >40°; the beam angle is the angle over which the luminous intensity drops to 50% of its peak value. Forty-eight equally distributed 100 W halogen lamps were used for combination space-beam 1-b) and for 2-a) reference cases; a different number of lamps with consequentially variable steps have been obtained for the other analysed cases: specifically, combination 1-b) and combination 2-a) cases present a 1:1 ratio with 40 lamps, and a 1:2 ratio with 15 sodium and 30 halogen lamps, while the 2-b) requires a 1:1 ratio with totally 96 lamps, and a 1:2 ratio with 34 sodium and 70 halogen lamps to assure the minimum illuminance value and R_a. Simple considerations lead to the conclusion that the case 1-a) cannot assure mixing, and so it will not be studied, while all b) cases will guarantee a better mixing of different lamps, apart from the considered space, Figure 2. Results referred to the working plane considered from visual comfort, alteration of CRI, work performance points of view are presented in Figure 3, combination 1-b), and Figure 4 combination 2-a).

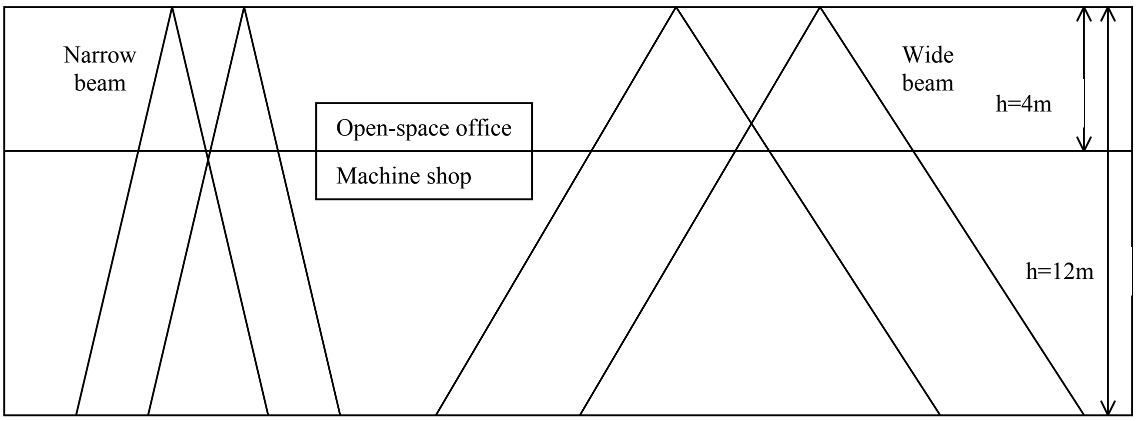

Figure 2 Presented cases and 'perfect mixing'.

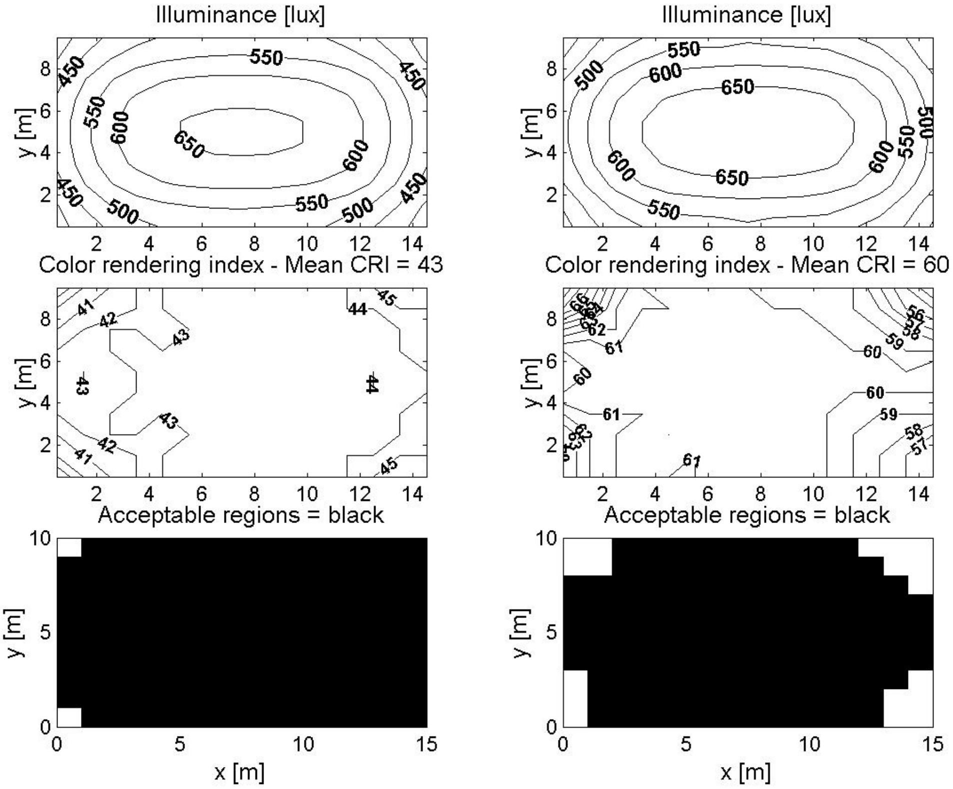

Figure 3 Illuminance, CRI distribution, work performance for open-space office 1:1 (left) and 1:2 (right) ratio.

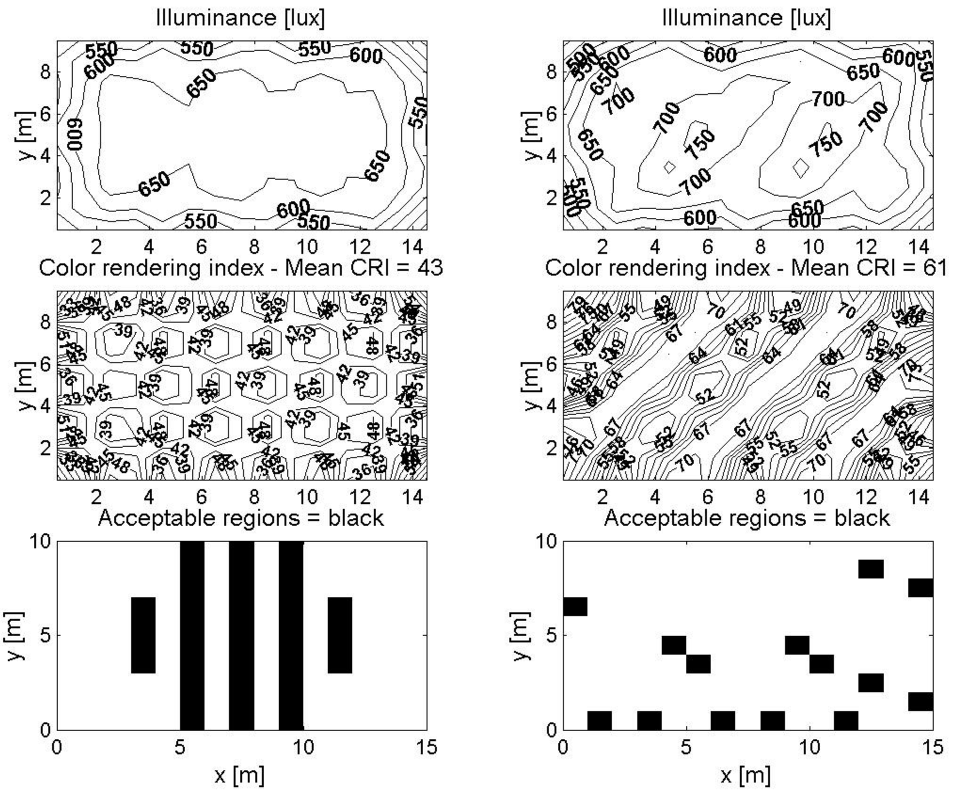

Figure 4 Illuminance, CRI distribution, work performance for machine shop 1:1 (left) and 1:2 (right) ratio.

Illuminance is always assured on the working plane; mean CRI satisfies CIE Standard, but while b) beam spread assures good working conditions (not reported here as it presents requested CRI everywhere on the work plane), a) beam spread present an acceptable behaviour neither in the 1:1 nor in the 1:2 ratio configurations, in which good work performances cannot be reached from colorimetric point of view, as evidenced by white regions, while in the black ones show the acceptable regions, where R_a fluctuations around the R_a mean value are less than ±2.5. Considering the open space office situation instead, only the reference case can guarantee standard values on the working plane: no mixing conditions can be accepted due to the high R_a requested. From an energy efficiency point of view, conclusive considerations cannot be done, as other kinds of lamp/mixing must be considered, and still other geometries. This is quite evident for the office case, where no alternatives have been found, while it results reasonable for the machine shop case, where the 1:1 ratio is to be preferred to the 1:2 one (efficiency up to 38.67 versus 32.24), but where other kinds of lamps can produce similar chromatic and illuminance performances with higher efficiencies.

CONCLUSIONS

An investigation on MTLS based on second-level parameters concerning spatial chromatic aspects and visual quality has been proposed, starting from heuristic and theoretical considerations. MTLS can be a good design for energy saving solution; but using different type of lamps requires some considerations. The problem is to realize a good and uniform integration among luminous fluxes of different SPD light sources placed in different points of the room. This can be achieved by following two strategies: using different low power light sources in regular arrays, or using high power sources, to realize indirect or diffuse lighting, and low power lamps, still in regular arrays, to integrate illuminance. With the first choice the problem of different colour spots in the human viewing zone, due to CCT differences, arises, while it is quite easy to achieve a good integration of fluxes; more, colour aspects are not influenced by walls colour (using ceiling mounted recessed luminaries). The second solution shows difficulties linked to the choice of luminary types and positions to achieve a uniform illuminance and to the influence of ceiling and walls on light colour. Simple geometric configurations have been here analysed by energy efficiency and chromatic view points, although no optimal solutions have still been found. Two main problems exist: a tool to help designers in choosing the best MTLS solution, and an optimization of geometry distribution of lamps to assure illuminance performances, energy savings and negligible R_a fluctuations. Authors are investigating both these aspects to develop a design tool using an innovative method based on genetic algorithms to optimize environmental and efficiency conditions.

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