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Discomfort glare perception of non-uniform light sources in an office setting

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ABSTRACT

For indoor lighting the glare assessment by Unified Glare Rating (UGR) is widely adopted. However, disagreement exists on how to evaluate glare of non-uniform sources. This recently gained attention with the introduction of small and bright LEDs in general lighting. Earlier studies in a laboratory set-up showed that with equivalent average luminance, discomfort glare from a non-uniform stimulus seems to be greater than that of a uniform stimulus. We investigate the relation between discomfort glare perception of office employees and a set of parameters that is typical for LED luminaires, in a representative office environment. The offered light settings varied in luminance pattern, beam shape and illuminance on the work plane. In agreement with earlier work it can be concluded that point array LED luminaires provoke more discomfort glare in open plan offices than uniform sources and that the currently used UGR is not a good predictor in these cases. The luminance characteristics in the exit window (peak luminance, luminance contrasts, and spatial luminance distribution) play an important role in the design of comfortable (LED) office luminaires. A better understanding of these characteristics and their effects on glare perception, as well as a redefinition of a glare index are essential for a reliable prediction of glare perception.

1. Introduction

Good lighting quality requires a balance between the needs of occupants, economic needs, integration with the architecture and energy efficiency aspects (e.g. Veitch, 2006). Therefore, good-quality lighting demands simultaneously satisfying sometimes conflicting requirements. Literature supports arguments that high quality lighting in offices can contribute to environmental satisfaction and individual performance, making the higher costs of investment in quality lighting worthwhile (e.g. Boyce et al., 2006; Newsham & Veitch, 2001; Veitch, 2006; Veitch & Newsham, 1998; Veitch, Newsham, Boyce, & Jones, 2007).

Visual comfort is considered as one of the quality measures to be relevant for indoor functional lighting with LED lighting systems (Knoop, 2011). One aspect of visual comfort is discomfort glare, which is the type of glare that occurs when people complain about visual discomfort from bright light sources, even when the brightness is not impairing vision. In contrast with so-called disability glare, which is caused by light scattering in the eye, the mechanism for discomfort glare is not well understood and can only be measured with subjective evaluation questionnaires. Still, several empirical formulae based on subjective glare evaluations have been proposed over the past 60 years to predict the degree of discomfort for various types of light sources (e.g. artificial lighting or daylight) and for various applications (e.g. indoor lighting or outdoor lighting) (Boyce 2003).

For indoor lighting, the assessment of discomfort glare based on the Unified Glare Rating (UGR) is widely adopted (CIE, 1983, 1995). This rating is a function of the average luminance of the apparent surfaces of the luminaires, seen from the position of the observer, and the background luminance. The predictions for discomfort glare experiences based on UGR calculations are found to be quite satisfactory for normal-sized luminaires with a reasonably uniform exit window luminance. However, there is a lot of disagreement on how to evaluate glare produced by very large sources, very small sources, or non-uniform sources. In the CIE Report on glare (2002), small-source and large-source adaptations for UGR are proposed. The applicability of these and other glare ratings for non-uniform light sources has been studied recently by Cai and Chung (2012). They conclude that all formulae are inappropriate to evaluate glare

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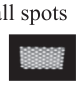
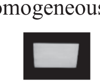
from non-uniform light sources. Xia et al. (2011) showed that the standard UGR approach (using the average luminance of the exit window) yields values that are too low, while predicted glare is overestimated in case the individual sources of a complex luminaire are taken into account. A recent review by Clear (2012) describes the issues with glare ratings like UGR with regard to small sources, large sources, and complex luminance distributions. It concluded that “evaluating glare in complex scenes may require fundamental changes to the form of the glare models”.

The introduction of efficient light emitting diodes (LEDs) in general lighting systems has added relevance to the discussion on glare from small and from non-uniform light sources. The small size and high brightness of LEDs compared to conventional fluorescent tubes enable lighting fixtures with much higher peak luminances and luminance contrasts than before. With equivalent average luminance, discomfort glare from a non-uniform stimulus seems to be greater than that of a uniform stimulus (Kasahara et al., 2006; Lee, Kim, & Choi, 2007; Takahashi, Kobayashi, Onda, & Irikura, 2007; Takahashi, Irikura, Moriyama, Toda, & Iwamoto, 2007; Tashiro, Kimura-Minoda, Kohko, Ishikawa, & Ayama, 2011; Xia et al., 2011). Kasahara et al. (2006) studied the effect of arrangement and number of LEDs on glare perception with a simulated light source in a laboratory set-up. They found that the glare perception decreased when the luminance contrast (peripheral area/LED source) was smaller, and that increasing the number of LEDs within the same area reduced glare perception. Moreover, they found that glare perception decreased as the light source was positioned more directly above the line of sight. Takahashi, Kobayashi et al. (2007) also found that a matrix light source causes more discomfort glare than a uniform light source. However, they found no difference between uniform and matrix light sources for a position above the line of sight. Eble-Hankin (2008) studied non-uniform stimuli with linear patterns and showed that with increasing spatial frequency, discomfort increases. But in contrast with the above mentioned studies, she found that a non-uniform stimulus is considered less discomforting than a uniform one.

Most of the above mentioned studies were done in a laboratory set-up where a bright light source is positioned directly in the line of sight or positioned at a single viewing angle (Kasahara et al., 2006; Lee et al., 2007; Osterhaus & Bailey, 1992; Takahashi, Kobayashi et al., 2007; Takahashi, Irikura et al., 2007). In a realistic situation however, several light sources are mounted in the ceiling, resulting in many different angles of view of the luminaire, but none directly in the line of sight. Furthermore, in commercially available LED office luminaires, the individual LEDs are not always visible as a matrix of bright spots, but the light is often concentrated in one or two small bright areas, surrounded by a low-brightness edge. Finally, since discomfort glare can only be evaluated subjectively, the setting of the test (both the type of room and the activity of the test person) is expected to influence the glare rating. It is therefore the aim of this study to examine the relation between glare perception and a set of typical luminaire design parameters in a representative office environment.

Table 1
Overview of variables and settings as used in both studies.

Variable	***Peak Brightness***	***Balanced Brightness***	
	(3x3x2)	(5x2x1)	(2x2x1)
Luminance pattern	L_{center} = small spots (L_{rim} = 0) 	L_{rim} = 0  L_{center} = homogeneous	L_{rim} = 0  L_{center} = homogeneous
	L_{center} = larger spots (L_{rim} = 0) 	L_{rim} = minimal  L_{center} = homogeneous	L_{rim} = minimal  L_{center} = homogeneous
	L_{center} = homogeneous (L_{rim} = 0) 	L_{rim} = middle  L_{center} = homogeneous	/
		L_{rim} = L_{center}  L_{center} = homogeneous	/
		L_{rim} = 0  L_{center} = small spots	/
E_{hor} at desk	350 lux	/	/
	500 lux	500 lux	500 lux
	700 lux	700 lux	700 lux
Beam Shape	Lambertian	Lambertian	/
	Cut-off	/	Cut-off