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COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

REVIEW OF LIGHTING QUALITY MEASURES FOR INTERIOR LIGHTING WITH LED LIGHTING SYSTEMS

CIE 205:2013

UDC: 628.931
628.972
628.987

Descriptor: Electrical lighting design
Interior lighting
Evaluation of lighting installations

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3. De donner des directives pour l'application des principes et des méthodes d'élaboration de normes internationales et nationales dans les domaines de la lumière et de l'éclairage.
4. De préparer et publier des normes, rapports et autres textes, concernant toutes matières relatives à la science, la technologie et l'art dans les domaines de la lumière et de l'éclairage.
5. De maintenir une liaison et une collaboration technique avec les autres organisations internationales concernées par des sujets relatifs à la science, la technologie, la normalisation et l'art dans les domaines de la lumière et de l'éclairage.

Les travaux de la CIE sont effectués par 7 Divisions, ayant chacune environ 20 Comités Techniques. Les sujets d'études s'étendent des questions fondamentales, à tous les types d'applications de l'éclairage. Les normes et les rapports techniques élaborés par ces Divisions Internationales de la CIE sont reconnus dans le monde entier.

Tous les quatre ans, une Session plénière passe en revue le travail des Divisions et des Comités Techniques, en fait rapport et établit les projets de travaux pour l'avenir. La CIE est reconnue comme la plus haute autorité en ce qui concerne tous les aspects de la lumière et de l'éclairage. Elle occupe comme telle une position importante parmi les organisations internationales.

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Die Ziele der CIE sind :

1. Ein internationaler Mittelpunkt für Diskussionen aller Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik und für den Informationsaustausch auf diesen Gebieten zwischen den einzelnen Ländern zu sein.
2. Grundnormen und Verfahren der Messtechnik auf dem Gebiet der Lichttechnik zu entwickeln.
3. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
4. Normen, Berichte und andere Publikationen zu erstellen und zu veröffentlichen, die alle Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik betreffen.
5. Liaison und technische Zusammenarbeit mit anderen internationalen Organisationen zu unterhalten, die mit Fragen der Wissenschaft, Technik, Normung und Kunst auf dem Gebiet der Lichttechnik zu tun haben.

Die Arbeit der CIE wird in 7 Divisionen, jede mit etwa 20 Technischen Komitees, geleistet. Diese Arbeit betrifft Gebiete mit grundlegendem Inhalt bis zu allen Arten der Lichtanwendung. Die Normen und Technischen Berichte, die von diesen international zusammengesetzten Divisionen ausgearbeitet werden, sind auf der ganzen Welt anerkannt.

Alle vier Jahre findet eine Session statt, in der die Arbeiten der Divisionen überprüft, berichtet und neue Pläne für die Zukunft ausgearbeitet werden. Die CIE wird als höchste Autorität für alle Aspekte des Lichtes und der Beleuchtung angesehen. Auf diese Weise unterhält sie eine bedeutende Stellung unter den internationalen Organisationen.

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This Technical Report has been prepared by CIE Technical Committee 3-50 of Division 3 "Interior Environment and Lighting Design" and has been approved by the Board of Administration as well as by Division 3 of the Commission Internationale de l'Eclairage. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory.

Ce rapport technique a été élaboré par le Comité Technique CIE 3-50 de la Division 3 "Environnement intérieur et étude de l'éclairage" et a été approuvé par le Bureau et Division 3 de la Commission Internationale de l'Eclairage. Le document expose les connaissances et l'expérience actuelles dans le domaine particulier de la lumière et de l'éclairage décrit ici. Il est destiné à être utilisé par les membres de la CIE et par tous les intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire.

Dieser Technische Bericht ist vom Technischen Komitee CIE 3-50 der Division 3 "Innenraum und Beleuchtungsentwurf" ausgearbeitet und vom Vorstand sowie Division 3 der Commission Internationale de l'Eclairage gebilligt worden. Das Dokument berichtet über den derzeitigen Stand des Wissens und Erfahrung in dem behandelten Gebiet von Licht und Beleuchtung; es ist zur Verwendung durch CIE-Mitglieder und durch andere Interessierte bestimmt. Es sollte jedoch beachtet werden, dass das Dokument eine Empfehlung und keine Vorschrift ist.

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REVIEW OF LIGHTING QUALITY MEASURES FOR INTERIOR LIGHTING WITH LED LIGHTING SYSTEMS

Summary

With recent increases in luminous flux and efficacy, LEDs have started to compete with conventional light sources in luminaires for general lighting. Typical LED characteristics, such as directional light, small size and high brightness are as such not new light source characteristics; nonetheless they are (alone or as combination) new characteristics in some areas of functional interior lighting, such as offices, class rooms, meeting rooms or patient rooms. Most existing quality measures for those applications are derived from research with and referring to the use of diffuse fluorescent lighting. This report provides information on the suitability of existing lighting quality measures when applied to (commercial) interior LED lighting systems. It identifies the gaps and weaknesses in existing quality measures, recommends new quality measures and includes suggestions for required research.

REVUE CRITIQUE DES MESURES DE LA QUALITÉ DE L'ÉCLAIRAGE DES AMBIANCES INTÉRIEURES RÉALISÉES PAR LES SYSTÈMES D'ÉCLAIRAGE LED

Resume

De par leurs récentes améliorations tant au niveau de leur flux lumineux et de leur efficacité, les LEDs concurrencent maintenant les sources conventionnelles pour luminaires à destination de l'éclairage fonctionnel. Les caractéristiques typiques des LEDs telles que la directionnalité de la lumière, leur faible dimension et leur brillance élevée ne sont en soi pas de nouvelles caractéristiques. Il existe cependant de nouvelles caractéristiques (à traiter indépendamment ou en combinaison avec les caractéristiques existantes) applicables à certains domaines de l'éclairage intérieur fonctionnel, comme les bureaux, les salles de cours, les salles de réunions ou d'examen. La plupart des mesures de qualité de ces applications sont issues de recherches réalisées au moyen d'éclairage fluorescent diffus et qui réfèrent à sa mise en œuvre. Ce rapport fournit des informations sur la pertinence des mesures de qualité de l'éclairage appliquées aux systèmes (commerciaux) d'éclairage LED intérieur. Il identifie les lacunes et faiblesses des mesures de qualité existantes, recommande de nouvelles mesures de qualité et inclut des suggestions pour les recherches nécessaires.

BEWERTUNG LICHTTECHNISCHER GÜTEMERKMALE FÜR DIE INNENRAUMBELEUCHTUNG MIT LED-BELEUCHTUNGSSYSTEMEN

Zusammenfassung

Durch die in jüngster Zeit erfolgte Steigerung von Lichtstrom und Lichtausbeute sind Leuchtdioden (LEDs) in den Wettbewerb mit konventionellen Lichtquellen in Leuchten für die Allgemeinbeleuchtung getreten. Typische LED-Eigenschaften wie gerichtetes Licht, kleine Abmessungen und große Helligkeit sind an sich keine neuen Eigenschaften von Lichtquellen; dennoch sind sie (einzeln oder als Kombination) neue Eigenschaften in Hinsicht auf einige Gebiete funktioneller Innenraumbeleuchtung, wie z.B. Büros, Klassenräume, Besprechungsräume oder Krankenzimmer. Die meisten existierenden Gütekriterien für diese Anwendungen werden aus Forschungsergebnissen mit und in Bezug auf die Nutzung von diffusem Leuchtstofflampenlicht hergeleitet. Dieser Bericht liefert Informationen zur Eignung bestehender Beleuchtungs-Gütekriterien bei Anwendung auf (kommerzielle) LED-Innenraumbeleuchtungssysteme. Die Lücken und Schwächen existierender Gütekriterien werden aufgedeckt, neue Gütekriterien werden empfohlen und Vorschläge für erforderliche Forschung gemacht.

1 Introduction

In the last decade light emitting diodes (LEDs) have shown a rapid evolution. Luminous flux, luminous efficacy, colour quality and power per LED have strongly increased and this development is ongoing. The unique properties of LEDs such as their small size and the availability of saturated colours ranging from red, green, blue to different tones of white offer tremendous new possibilities in application. At first LEDs were used in “luminance driven” applications such as signage, markers, decorative lighting, cove lighting etc. These are applications where the LED lighting systems are used to generate a bright (coloured) plane, line, or architectural shape, in other words systems that are luminous objects or lighted surfaces, rather than illuminating objects or surfaces. With recent increases in luminous flux and efficacy, LEDs have started to compete with conventional light sources such as halogen, linear and compact fluorescent, and high intensity discharge lamps in luminaires for general lighting and for accent lighting.

Typical LED characteristics, such as small size and high brightness can be very advantageous in specific applications such as accent lighting. In general lighting applications for offices, public buildings or retail, these LED characteristics can lead to problems with respect to the quality aspects. Lighting characteristics such as directional light, small size and high brightness are as such not new light source characteristics; nonetheless they are (alone or as combination) new characteristics in some areas of functional interior lighting, such as offices, class rooms, meeting rooms or patient rooms. As most existing quality measures for those applications are derived from research with and referring to the use of diffuse fluorescent lighting, the question arises whether these measures are suitable for evaluating indoor lighting with LED lighting systems. Or do we need additional metrics, recommendations, and criteria?

2 Terms of Reference

In June 2010 a proposal for a new Technical Committee (TC) *Lighting Quality Measures for Interior Lighting with LED Lighting Systems* was approved with the following terms of reference:

- To review relevant CIE publications and standards to evaluate the suitability of existing lighting quality measures when applied to (commercial) interior light-emitting diode (LED) lighting systems.
- To identify the gaps and weaknesses in existing quality measures, exhibited in one of two ways: either the criterion is valid, but the evaluation method is not (e.g. colour rendering) or a new criterion needs to be taken into consideration (e.g. overhead glare, binning).
- To prepare a Technical Report which will include the findings of the review and recommendations for new lighting quality measures and evaluation methods, as well as suggestions for new research, if appropriate quality measures and evaluation methods are missing.

3 Scope

The work of the Technical Committee has focused on the application of commercial interior LED lighting systems. Therefore, the quality of the lighting solution is considered, not the intrinsic quality of the product.

Lighting practice and the majority of existing lighting quality measures focus on visual performance and avoiding visual discomfort. Nonetheless, a high quality lighting installation goes beyond visibility of the task and includes visual appearance of the space (e.g. Veitch et al. 2007 and work done within TC 3-34 *Protocols for Describing Lighting* and TC 3-45 *Luminance Based Design Approach*). As the use of LED lighting systems can have a

significant effect on the appearance of the room, this aspect has also been included in the Technical Committee's work.

The work of this Technical Committee did not include the review of photobiological safety requirements for LED lighting solutions. Although the committee is aware of the fact that LEDs, being bright, point-like sources, pose a potential risk for eye injury from excessive irradiation, this topic is addressed in IEC 62471/CIE S 009/E:2002 (IEC 2002) and TC 6-55 *Photobiological Safety of LEDs*.

4 LED Characteristics

There are a number of LED characteristics that are either new for light sources or new for general lighting applications. These characteristics are long life time, high (anticipated) luminous efficacy, directed light, small size, high brightness, the availability of saturated colours ranging across the colour spectrum, tunable spectral output and different tones of white. LEDs may vary in luminous flux and light colour due to production differences and changes over the LED's lifetime. It is often the combination of characteristics that is of interest. For example, high brightness in combination with small size affects glare perception, or the combination of small size and colour differences affects colour consistency within lighting systems.

5 Quality Measures

5.1 Way of Working

The quality measures the Technical Committee examined were derived from existing building codes, standards and recommendations¹, taking into consideration that good lighting quality is contextual and related to the needs of occupants, the economic needs of the clients, the integration with the architecture and the protection of the environment (e.g. Veitch 2006, IESNA 2008).

The majority of existing lighting quality criteria focus on visual performance and avoiding visual discomfort, but additional issues are addressed as well. A categorization of quality measures has been made:

- quality criteria, to ensure performance and safety and
- quality recommendations, to achieve higher lighting quality, or to benefit human health and well-being

Resulting, the following distinction can be made in quality measures:

- A quality criterion is available, and is applicable for LED lighting solutions.
- A quality criterion is available, but is possibly not applicable or should be adjusted for LED lighting solutions.
- No quality criterion is available, but a criterion is required, as the aspect is essential for good visual performance or visual comfort, or other aspects of well-being.
- Recommendations to improve lighting quality are available, but they possibly need to be adjusted or emphasized for LED lighting solutions. Typically these recommendations give descriptive design guidance or minimum requirements to improve lighting quality.
- No recommendations are available, but addressing the topic could improve lighting quality.

The Technical Committee reviewed relevant publications and standards to evaluate the suitability of the existing lighting quality measures.

¹ e.g. CIE 1998, CIE 2002a, CIE 2002b, CEN 2011, IESNA 2000, IESNA 2004, IESNA 2008, McGowan 2009

5.2 Relevant Quality Measures

The following quality measures were considered by the Technical Committee for relevance to indoor functional lighting with LED lighting systems:

- Task visibility: uniformity of task illumination, reflected glare, veiling reflections and shadows
- Visual comfort: discomfort glare, overhead glare, luminance ratios, visual fatigue and eyestrain
- Flicker and stroboscopic effects
- Modelling of faces and objects
- Colour rendering, light colour preference, object colour appearance
- Consistency of colour and luminous flux over time and space
- Appearance of spaces: room surface brightness, distribution of light on surfaces
- Appearance of the light source and luminaire: style, integration into architecture, appropriateness of appearance, size, etc.

Except for colour and luminous flux consistency, all measures are already recognized as relevant parameters for functional indoor lighting. Although colour and luminous flux consistency, both directly after production and over lifetime, are typically product related quality measures, they can become lighting quality aspects for indoor lighting with LED lighting systems. The combination of inconsistency and small light source size can lead to conspicuous differences, which will affect the perceived quality of the LED lighting solution.

Based on experience in the field, it seems that the appearance of LED luminaires can in itself induce a feeling of restlessness, especially when the light source visibly consists of a large number of high brightness sources. This might impact well-being, visual fatigue as well as performance. Up until today, the Technical Committee is not aware of research dealing with this topic. Therefore it will only be addressed in the recommendations at the end of this report.

Note that the importance of these quality criteria, or the priority in the design process, and the minimum requirements will differ from application to application and region to region as a result of, for example, cultural differences and norms, economic requirements, code limitations, user populations, owner preferences and priorities, etc.

6 Quality Criteria

To ensure performance and safety, the quality criteria reviewed in this section focus on visual performance and avoiding visual discomfort. These quality measures are typically included in guidelines and standards, to ensure that the user in the application is able to comfortably perform basic visual work.

6.1 Light Distribution

Uniformity of task illumination and luminance ratios on surfaces were not considered to differ in the design approach or the assessment of quality of LED lighting solutions. Recommendations for minimum ratios of minimum and average illuminance (uniformity) and luminance ratio limits are available (IESNA 2004, CEN 2011), and are applicable for LED lighting solutions.