PHILIPS

LED

Whitepaper
Philips EyeComfort LED

EyeComfort*

* EyeComfort white paper may be amended by Signify as (additional) information becomes available to us in various areas, including Product Development, Research, Standards & Regulations.

Introduction

Nowadays, light quality is a key differentiator in lighting. In general, the quality of light refers to the visual aspects of light and its dependencies on and interaction with people and the environment.

LEDification allows us to make the customer aware of the spatial, spectral, and temporal qualities of our lights so that they can make informed choices. Signify, the global leader in lighting, continuously optimizes its products by bringing together in-depth understanding of user needs, lighting application knowledge, and scientific insights.

Signify has created a trademark called "EyeComfort" to be used for certain LED lamps and LED luminaires if certain selected criteria are met in the following areas:

Flicker

Dimming

Stroboscopic effect

Tunable

Photobiological safety

Color rendering

Glare

Noise

This whitepaper sets forth these criteria and, accordingly the importance of optimizing lighting.

"Choosing the right lighting is ***very important.****"*

"The type of lighting we use day to day can have an impact on our quality of life. For instance, controlling the colour and intensity of lighting over the course of the day can improve our sleep patterns, which can be critical to well-being and health. By contrast, poor artificial lighting can have deleterious effects on the quality of life and lead to disturbed sleep patterns, eye discomfort, and even headaches. Choosing the right lighting is important."

Andrew Stockman, Professor at UCL Institute of Ophthalmology

Contents

Philips LED EyeComfort Criteria and Scientific Background

Global market research carried out by Signify in 2019 shows that the importance of eyesight increases with age*. However, when it comes to maintaining personal well-being, 66.6% don't take care of their eyes or get regular eye tests.

Philips LED lights that conform to the EyeComfort criteria are measured according to a set of comfort-related criteria: flicker, glare, stroboscopic effect, photobiological safety, dimmability, tuning and color rendering. These criteria can have an impact on the comfort of your eyes. It is as simple as changing your light bulb.

* Result from a study conducted by YouGov on behalf of Signify in May 2019 amongst 1000+ adults each in US, Czech Republic, Argentina, Poland, China, Mexico, Indonesia, Germany.

Flicker and Stroboscopic effect

Flicker and Stroboscopic effect are **Temporal Light Artifacts (TLAs).** TLAs are unwanted changes in visual perception induced by temporal variations in the luminance or spectrum produced by the light source. **Flicker is the perception of visual fluctuations even when the observer is static.** In other words, flicker is a disturbing temporal fluctuation of light in the room.

The stroboscopic effect is also caused by temporal variations in the light source. Since the stroboscopic effect discontinuously illuminates objects moving in the environment, it results in an unnatural break-up of a continuous motion.

> *“Flicker is a disturbing rapid fluctuation of the light in the room and the stroboscopic effect is the unnatural break-up of continuous motion.” [Signify EyeComfort Whitepaper 2018]*

The fluctuations may come from various sources including:

- Disturbances on the mains
- Interactions with controls (e.g. dimmers)
- Disturbance on the input signal caused by
- external sources (e.g. microwave)
- Designed-in fluctuations from the electronic driver.

There are known methods to suppress fluctuations in the light output of LEDs and thus, lower the visibility of unwanted TLAs. These methods, however, affect costs and efficiency and require more physical space, while potentially lowering the lifetime of LED products [2].

Until recently, several measures like Flicker Index (FI) and Modulation depth were used to assess the visibility of flicker and the stroboscopic effect. However, these measures can be poor predictors of what people actually perceive or experience [1,2,3].

The visibility of flicker and stroboscopic effects are affected by modulation depth, frequency, wave shape and duty cycle. Therefore, scientific models have been developed based on our knowledge of how the Human Visual System (HVS) processes visual signals. The HVS is the part of the nervous system from eye to brain that allows us to perceive the world.

A more robust TLA measure for flicker is P_{st}^{LM}, and for the stroboscopic effect SVM [1,2]. These measures are supported by Lighting Europe [3] and NEMA [4] and are used in the assessment of Philips branded EyeComfort LED lighting of Signify. Improvements in TLA measures are currently being investigated.

Flicker and Stroboscopic effect

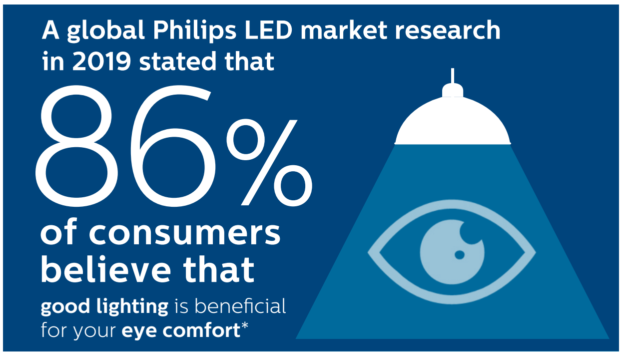
A common definition of the visibility threshold is the point where the observer can detect some percept 50% of the time [2]. This is the point at which a person sees a visual phenomenon, such as flicker, 50% of the time but does not see it the other 50%. Thus, visibility is at chance. Given the above, the requirement for imperceptible visible flicker is defined as P LM≤1,0 and is based on IEC 61000-4-15 [53] and NEMA 77-2017 [54]. Measurement of PstLM is done according to IEC TR 61547-1, edition 2 [52].

Why should we care about Flicker and the Stroboscopic effect?

Lighting products which exhibit flicker or the stroboscopic effect are considered lower quality lighting [5-14]. TLAs are not just irritating for people but also have an impact on general comfort and visual performance. More specifically, visible TLAs can:

- Decrease visual task performance
- Cause eye discomfort (tired eyes)
- Increase the occurrence of headache
- Increase eyestrain
- Cause annoyance

Studies also show that in certain cases visible flicker can trigger epileptic seizures [5-14]. Philips branded EyeComfort LED products of Signify have been designed to minimize visible flicker and stroboscopic effect.



*Result from a study conducted by YouGov on behalf of Signify in May 2019 amongst 1000+ adults each in US, Czech Republic, Argentina, Poland, China, Mexico, Indonesia, Germany.

Photobiological safety

Blue light hazard

The blue light hazard is the potential for photochemical damage of the retina that depends on the spectral composition, intensity and time of exposure to the eye. The International Electrotechnical Commission (IEC) has developed a standard for evaluating Photobiological safety [16].

Light sources are classified in 4 risk groups
(0 = no risk, 3 = high risk) [16]:

Risk Group 0:	The source poses no photobiological hazard
Risk Group 1:	The source poses no photobiological hazard under normal use
Risk Group 2:	The source does not pose a hazard due to the aversion response to very bright light sources or thermal discomfort
Risk Group 3:	The source is hazardous, even for brief exposure

A common misunderstanding in the media is the idea that LED lighting contains higher portions of blue wavelengths and is therefore more likely to have the potential for blue light hazard. This has been researched and measured by the Global Lighting Association, comparing spectral content of different lighting technologies with the above-mentioned standard. Together with the input of many scientists the key scientific findings are [15]:

- With respect to the blue light hazard, LED lamps are no different from conventional technologies, such as incandescent and fluorescent lights of the same color temperature.
- A comparison of LED retrofit products with the conventional products they are intended to replace, reveals that the risk levels are very similar and well outside the critical range.
- LED sources (lamps or systems) and luminaires that fall into Risk Group 0 or 1 as defined by IEC can be used by consumers.

*"Concerning photobiological safety, **Philips LEDs are not different from traditional incandescent bulbs of the same color temperature.** They do not contain higher amounts of short wavelength light which can cause blue light hazard and fall well within safety standards." [15]*

Ultraviolet

LED based light sources for consumer use do not produce energy in the ultraviolet (UV) part of the spectrum and are therefore not harmful in that part of the spectrum.

Infrared

In contrast to incandescent and halogen lights, LEDs emit very little infrared radiation (IR) [16]. For consumer LED light sources there is no risk associated with IR radiation [17]. Optical safety is addressed by international standards and guidelines [16,17]. Philips branded EyeComfort LED products of Signify are all classified in Risk Group 0 or 1 (RG0 / RG1) meaning that the use of these LED products is not a photobiological hazard under normal conditions of use and the lamp poses no photobiological hazard.

Glare

> *"Glare is one of the most significant dissatisfiers in relation to comfortable lighting. Some LED lamps are perceived as glary. This could cause visual discomfort and even headaches."*
>
> **Andrew Stockman, Professor at UCL Institute of Ophthalmology**

Glare can be divided into two types: disability glare and discomfort glare. Disability glare refers to the reduction in visual performance caused by a glare source in an observer's field of view. Discomfort glare refers to the sensation of discomfort caused by bright light sources that results in an instinctive desire to look away from a bright light source or have difficulty seeing a task. The sensation of discomfort depends on many factors including the luminance of the source, source area, and its position in the field of view and background lights, type of activity and duration of exposure to a bright source. For years, researchers have tried quantifying the amount of visual discomfort.

The assessment of glare for indoor workplaces (professional environment) is usually done using the UGR measure (Unified Glare Rating). In LED lighting designs, non-uniform or pixelated light fixtures with high luminance contrasts are often used. Studies have shown that pixelated light fixtures result in higher discomfort glare than uniform light fixtures with the same average luminance (and thus the same UGR value) [19-35]. This means that the current UGR is not always appropriate for use with non-uniform lights.

Investigating the applicability of the current UGR and finding better ways of predicting discomfort glare is an important topic of research. Potential alternative methods of describing glare are based on modeling the retinal receptive fields of the Human Visual System (HVS) and applying this model to luminance maps of the room to assess discomfort glare [34]. This approach is comparable to the TLA measures, which are also based on modeling of the human visual system.

Global Philips LED research in 2019 found that over 50% of people spend more than

8 hours a day (58%)

under artificial light*

For consumer lamps, there is currently no measure available to quantify glare. Moreover, the perceived glare of a light bulb depends on the application. A naked bulb above the table close to the observer, and at eye level, will be more glary than the same bulb in a lampshade in the corner of the room.

*Result from a study conducted by YouGov on behalf of Signify in May 2019 amongst 1000+ adults each in US, Czech Republic, Argentina, Poland, China, Mexico, Indonesia, Germany.

Glare

In general, glare is caused by a combination of high luminance, high contrast, and source size. Anti-glare measures should address these causes: lowering the luminance, reducing the contrast, or reducing the source size.

In the Philips branded LED lighting portfolio of Signify, lamps with and without glare control are distinguished. A lamp with glare control, such as diffusing materials and/or a pixelated lace on top of the bulb, is perceived as producing less glare than a lamp without any glare control at the same flux and in a similar environment. A good glare measure for bulbs is currently not available and is a topic for future research.

Dimming

The dimming feature of LED products is defined as **the ability to change the intensity of the light to suit your own preference.**

> *"The dimming feature of LED products enables you to optimize the ambiance or task lighting for every environment."*
>
> **Andrew Stockman, Professor at UCL Institute of Ophthalmology**

People tend to dim artificial lighting for several reasons:

- First, they want to change the ambiance of the environment (for example, from dim and cozy to bright and energizing).
- Secondly, they want to adjust light levels over the day, depending on different activities or on the outdoor light levels.

For instance, in the evening the light levels might be dimmed to reduce the contrast between the dark environment and the LED light, and thus reduce glare. The dimming feature is also useful for energy saving.

Poor implementation of the dimming feature can introduce discomfort or unwanted effects such as visible flicker at low dimming levels, unsteady transitions and minimum light levels that are too high [2].

These problems originate from the LED driver circuits, variations in mains voltage, other mains connected loads, and dimmer interactions. Smart electronics designs, as used by Philips EyeComfort LEDs, solve the deep dimming issue and suppress repetitive and/or irregular visible variations in light level.

The dimmable products of the Philips branded EyeComfort LED range of Signify provide preset stepwise dimming (SceneSwitch) or continuous dimming over the whole intensity range.

Global research carried out in 2019 by Philips LED showed the following:

77%

of consumers

believe that good lighting in the home improves **daily productivity***

*Result from a study conducted by YouGov on behalf of Signify in May 2019 amongst 1000+ adults each in US, Czech Republic, Argentina, Poland, China, Mexico, Indonesia, Germany.

Tunable

Tunable lighting is controlled in color and intensity. Tunable LED lighting can be classified into three categories:

- **Warm dimming**: designed to mimic incandescent dimming behavior (e.g. CCT drops from 2700K to 2200K while dimming)
- **Tunable white:** ability to change the warmth of a white light (e.g. 2700K to 6500K)
- **Tunable color:** ability to change the color of the lighting (RGB)

Dimming an incandescent bulb produces a different light experience than dimming conventional white LED lights. Dimming an incandescent filament reduces its temperature so that it emits a more reddish white light (lower color temperature). In contrast, the color temperature of the LED-die does not change significantly during dimming. **Thus, an incandescent bulb varies in both intensity and color temperature, whereas dimming an LED only varies in intensity.**

People generally appreciate the warmer setting at low light levels since it creates nice and cozy ambiances [45], but this can be different per region. Some Philips EyeComfort LEDs of Signify provide the WarmGlow dimming feature. By combining two different LEDs (2200K and 2700K), an incandescent dimming behavior can be mimicked. The WarmGlow feature comes in two variations: SceneSwitch with fixed color temperature settings and smooth WarmGlow that changes the color temperature continuously as it is dimmed over the whole range (2700K-2200K).

As well as the ambiance effect, a dimming feature combined with a correlated color temperature (CCT) change also has some advantages in supporting the circadian rhythm of people. Our biological clock tells us when to wake up and when to fall asleep. The intensity and spectrum of light are two of the parameters regulating those responses [46]. A guiding principle is that lighting should mimic natural variations in the environment.

High intensity light that contains a lot of blue/cyan light makes us feel awake and alert, while low intensity light with less blue light triggers the release of the hormone melatonin, which makes us sleepy [46]. Research has shown that bright lighting with a strong blue component is preferable in the morning to support waking up but should be avoided in the evening, because it suppresses melatonin production and makes it harder to fall asleep. Dimmed and warm CCT environments in the evening are better for an undisturbed biological rhythm [46].

Philips branded EyeComfort LEDs of Signify with WarmGlow dimming feature support both the ambiance function and the circadian rhythm of people.

> *"Good lighting mimics natural daylight with a similarly continuous spectrum that excites the different photoreceptors in a comparable way to natural daylight. This can be achieved by using lights that vary in colour temperature and intensity."*
>
> **Andrew Stockman,**
> **Professor at UCL Institute of Ophthalmology**

Color rendering

Color quality relates to the subjective preference and appreciation of users of colors in a given application. The color quality of white light sources impacts space, objects and human appearance.

Poor color quality can reduce visual discrimination and the accurate rendering of illuminated spaces, objects, or people [50]. For instance, human skin tones, plants, and foods may appear dull or undersaturated under lighting with low color rendering and/or low color saturation.

> *"Color rendering of a white light source is defined as the effect of an illuminant on the color appearance of objects, by conscious or subconscious comparison with their color appearance under a reference illuminant." [47]*

The general color rendering index (CRI-Ra) is used to measure and specify the color rendering ability of a light source, based on a set of eight specific CIE 1974, moderately saturated, test-color samples (TCS). A CRI of 100 means that the rendering of colors under the light source is equal to their rendering under a reference source (an incandescent source with a CCT<5000K)

User preference is not always coupled with higher CRI values. A source with a higher CRI is not always more preferred. Color saturation (vividness), especially saturation in the red also plays an important role in preference [48,49,50]. Some over-saturation is in general preferred by people, because objects look more colorful. The preference for skin tone appearance is different, but also differs between cultures.

It is important to find the right balance between color fidelity (CRI) and color saturation for a specific application.

Philips EyeComfort LEDs aim to improve color differentiation and enhance aesthetics through the use of LEDs with good color quality properties by means of a high Color Rendering Index, meaning that for example a home's furnishings appear in high definition and true color.

Noise

LEDs can suffer from audible noise – an irritating hum, especially when used at deep dimming levels. The voltages and current that are produced can create mechanical resonance in the components. This noise can be annoying and uncomfortable. For this reason, Energy Star, a program run by the U.S. Environmental Protection Agency and U.S. Department of Energy which promotes energy efficiency, has put requirements in place for audible noise levels.

According to the Energy Star requirements for audible noise, **lamps shall not emit noise above 24 dBA at 1 meter distance** [51]. This threshold is not strict enough for lamps in a quiet living room (of around 20 dBA) or for lamps located close to people (reading lights, bedside lamps).

References

[1] Małgorzata Perz, Dragan Sekulovski, Ingrid Vogels & Ingrid Heynderickx (2017): Quantifying the Visibility of Periodic Flicker, LEUKOS, DOI: 10.1080/15502724.2016.1269607

[2] IEC CIE TN 006:2016, Visual Aspects of Time-Modulated Lighting Systems – Definitions and Measurement Models, September 2016: http://files.cie.co.at/883_CIE_TN_006-2016.pdf.

[3] https://www.lightingeurope.org/images/publications/position-papers/LightingEurope_-_position_paper_-_flicker_and_stroboscopic_effect_-_final.pdf

[4] http://www.nema.org/Standards/Pages/Temporal-Light-Artifacts-Flicker-and-Stroboscopic-Effects.aspx?_sm_au_=i5VMrMH4n4J8p7jb

[5] Wilkins, A., Veitch, J., Lehman, B. 2010. LED Lighting Flicker and Potential Health Concerns: IEEE Standard PAR1789 Update. In 2010 IEEE Energy Conversion Congress and Exposition (ECCE), 171–78.

[6] Jaen, M., J. Sandoval, E. Colombo, and T. Troscianko, “Office workers visual performance and temporal modulation of fluorescent lighting,” LEUKOS, vol. 1, pp. 27–46, 2005.

[7] Veitch, J. A., and S. L. McColl, “Modulation of fluorescent light: Flicker rate and light source effects on visual performance and visual comfort,” Lighting Research and Technology, vol. 27, p. 243,1995.

[8] Wilkins, A.J., Nimmo-Smith, I.M., Slater, A. and Bedocs, L. (1989) Fluorescent lighting, headaches and eye-strain. Lighting Research and Technology, 21(1), 11-18.

[9] Arnold Wilkins, Brad Lehman. Biological effects and health hazards from flicker, including flicker that is too rapid to see. 2/15/10, IEEE Standard P1789. http://grouper.ieee.org/groups/1789.

[10] J. D. Bullough, K. S. Hickcox, T. R. Klein and N. Narendran, “Effects of flicker characteristics from solid-state lighting on detection, acceptability and comfort,” Lighting Research and Technology, vol. 43, p. 337–348, 201

[11] Harding, G. F. A., and P. Jeavons, Photosensitive Epilepsy. London: Mac Keith Press, 1994.

[12] Binnie, C. D., R. A. de Korte, and T. Wisman, “Fluorescent lighting and epilepsy,” Epilepsia, vol. 20, pp. 725–727, 1979.

[13] Harding, G. F. A., and P. F. Harding, “Photosensitive epilepsy and image safety,” Applied Ergonomics, 16 Oct. 2008.

[14] Fisher, R. S., G. F. A. Harding, G. Erba, G. L. Barkley, and A. Wilkins, “Photic- and pattern-induced seizures: A review for the Epilepsy Foundation of America working group,” Epilepsia, vol. 46, pp. 1426– 1441, Sep. 2005.

[15] Global Lighting Association: Optical and Photobiological Safety of LED, CFLs and Other High Efficiency General Lighting Sources

[16] IEC 62471:2006, Photobiological safety of lamps and lamp systems

[17] IEC TR 62778, Application of IEC 62471 for the assessment of blue light hazard to light sources

[19] Eberbach, K. (1974). Der Einfluss der Leuchtdichtestruktur von Lichtquellen auf die Blendempfindung. Lichttechnik 6, p. 283–286.

[20] Waters, C.E., Mistrick, R.G., Bernecker, C.A. (1995): Discomfort Glare from Sources of Nonuniform Luminance. In: Journal of the Illuminating Engineering Society 24 (2), p. 73–85.

[21] Kasahara, T., Aizawa, D., Irikura, T., Moriyama, T., Toda, M., Iwamoto, M. (2006): Discomfort Glare Caused by White LED Light Source. In: Journal of Light and Visual Environment 30 (2), p. 49–57.

[22] Takashi, H., Irikura, T., Moriyama, T., Toda, M., Iwamoto, M. (2007): Discomfort glare and annoyance caused by white LED lamps Proceedings of the 26th Session of the CIE, Beijing, China, p. D1- 80–D1-83

References

[23] Lee, CH.-M., Kim, H., Choi, D.-S. (2007): A Study on the Estimation of Discomfort Glare for LED Luminaires. In: CIE (Hg.): Proceedings of the 26th Session of the CIE, Beijing, China, p. D3-33–D3-36

[24] Jung, S.-G., Cho, Y.-I., Kim, H. (2009): A Study of UGR for Non-Uniform Luminance Source. Proceedings of Lux Europa 2009, Istanbul, Turkey, p. 553–558.

[25] Kim, W., Kim, J.T. (2010): The scope of the glare light source of the window with non-uniform luminance distribution, Proceedings of 3rd International Symposium on Sustainable Healthy Buildings, Seoul, Korea, p. 253–271

[26] Tashiro T., Kimura-Minoda, T., Kohko, S., Ishikawa, T., Ayama, M. (2011): Discomfort Glare Evaluation to White LEDs with Different Spatial Arrangement. Proceedings of the 27th Session of the CIE, Sun City, South Africa, p. 583–588.

[27] Bullough, J.D. (2011): Luminance versus luminous intensity as metric for discomfort glare. SAE International, DOI: 10.4271/2011-01-0111.

[28] Bullough, J.D., Sweater Hickcox, K. (2012): Interactions among light source luminance, illuminance and size on discomfort glare. SAE International, DOI: 10.4271/201201-0269

[29] Hara, N., Hasegawa, S. (2012): Study on Discomfort Glare Rating on the Luminaire with LED Array. In: Journal of Illuminating Engineering Institute Japan 96 (2), p. 81–88.

[30] Erdem, L., Trampert, K., Neumann, C. (2012): Evaluation of Discomfort Glare from LED lighting systems. Proceedings of Balkan Light 2012, Belgrade, p. 213–220.

[31] Ayama, M., Tashiro, T., Kawonabe, S., Kimura-Minoda, T., Kohko, S., Ishikawa, T. (2013): Discomfort glare of white LED sources of different spatial arrangements, Proceedings of the CIE Centenary Conference, Paris, France, p. 119–122

[32] Geerdinck, L.M., Van Gheluwe, J.R., Vissenberg, M.C.J.M. (2014): Discomfort glare perception of non-uniform light sources in an office setting, Journal of Environmental Psychology, 39, p. 5–13

[33] Funke, C., Schierz, CH. (2015): Extension of the Unified Glare Rating Formula for NonUniform LED Luminaires. Proceedings of 28th session of the CIE, Manchester, UK, p. 1471– 1480

[34] Donners, M.A.H., Vissenberg, M.C.J.M., Geerdinck, L.M., Van Den Broek-Cools, J.H.F., Buddemeijer-Lock, A. (2015): A psychophysical model of discomfort glare in both outdoor and indoor applications. Proceedings of 28th Session of the CIE, Manchester, UK, p. 1602–1611

[35] Yang, Y., Luo, M.R., Ma, S.N. (2016): Assessing glare. Part 2: Modifying Unified Glare Rating for uniform and non-uniform LED luminaires. Lighting Research & Technology, 2016

[36] Takahashi, H., Kobayashi, Y, Onda, S., Irikura, T. (2007): Position Index for the Matrix Light Source. In: Journal of Light and Visual Environment 31 (3), p. 128–133.

[37] Hara, N. (2016): Visual characteristics for evaluating the discomfort glare – relationship between the position, size, array of the LED chips, and BCD on the discomfort glare. Proceedings of CIE 2016 "Lighting Quality and Energy Efficiency", Melbourne, Australia, p. 704–707.

[38] Yang, Y., Ma, S.N., Lou, M.R., Liu, X.Y. (2015): Discomfort glare by non-uniform white LED matrices. Proceedings of the 28th Session of the CIE, Manchester, UK, p. 393–399.

[39] Chen, M.K, Chou, C.J., Chen H.S. (2016): Assessment of glare rating from non-uniform light sources. Proceedings of CIE 2016 "Lighting Quality and Energy Efficiency", Melbourne, Australia, p. 697– 703.

[40] Tashiro T., Kimura-Minoda, T., Kohko, S., Ishikawa, T., Ayama, M. (2011): Discomfort Glare Evaluation to White LEDs with Different Spatial Arrangement. Proceedings of the 27th Session of the CIE, Sun City, South Africa, p. 583–588. South Africa, p. 583–588.

References

[41] Scheir, G.H., Hanselaer, P., Bracke, P., Deconinck, G., Rykaert, W.R. (2015): Calculation of the Unified Glare Rating based on luminance maps for uniform and non-uniform light sources. Building and Environment 84 (2015), p. 60–67.

[42] Škoda, J., Sumec, S., Baxant, P., Krbal, M., Parma, M. (2015): Measurement of discomfort glare through luminance analyser, Proceedings of the 28th Session of the CIE, Manchester, UK, p. 1373–1381.

[43] Koga, S., Higashi, H., Kotani, T. (2013): The development of evaluation for discomfort glare in LED lighting of indoor work place. The modification of G-classification using luminance distribution of luminous parts, Proceedings of the CIE Centenary Conference, Paris, France, p. 657–662.

[44] Yang, Y., Ma, S.N., Luo, M.R. (2016): Glare model for non-uniform white LED luminaires. Proceedings of CIE 2016 "Lighting Quality and Energy Efficiency", Melbourne, Australia, p. 451–456.

[45] Seuntiens, P.J.H. & Vogels, Ingrid. (2008). Atmosphere creation: The relation between atmosphere and light characteristics. Proceedings from the 6th Conference on Design and Emotion 2008.

[46] Brainard GC, Hanifin JP, Greeson JM, Byrne B, Glickman G, Gerner E, Rollag MD. Action spectrum for melatonin regulation in humans: evidence for a novel circadian photoreceptor. J Neurosci. 2001;21:6405–6412.

[47] CIE 013.3-1995 - Method of Measuring and Specifying Colour Rendering Properties of Light Sources

[48] Teunissen C, van der Heijden FHFW, Poort SHM, de Beer E. Characterising user preference for white LED light sources with CIE color rendering index combined with a relative gamut area index. Lighting Research and Technology 2017; 49: 461–480.

[49] Royer, MP, Wilkerson, A, Wei, M, Houser, K, Davis, R. Human perceptions of color rendition vary with average fidelity, average gamut, and gamut shape. Lighting Research and Technology 2017; 49: 992–1014.

[50] Tang, X & Teunissen, Kees. The appreciation of LED-based white light sources by Dutch and Chinese people in three application areas. Lighting Research & Technology (2018)

[51] Energy Star, Energy Star Program Requirements for Lamps (light bulbs), Eligibility criteria version 1.1.

[52] IEC TR 61547-1:2017, Equipment for general lighting purposes – EMC immunity requirements – Part 1: An objective voltage fluctuation immunity test method, edition 2.

[53] IEC 61000-4-15, Electromagnetic compatibility (EMC). Part 4-15: Testing and measurement techniques. Flickermeter. Functional and design specifications.

[54] NEMA 77-2017, Temporal Light Artifacts: Test Methods and Guidance for Acceptance Criteria

www.lighting.philips.com