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EyeComfort white paper[1]

Nowadays, light quality is a key differentiator in lighting. In general, quality of light refers to the visual aspects of light and its dependencies on and interaction with people and the environment. LEDification gives us endless possibilities to differentiate in spatial, spectral, and temporal light quality. It forces us to revise our traditional way of evaluating light quality. Signify continuously optimizes its products by bringing together in-depth understanding of user needs, lighting application knowledge, and scientific insights. Signify, the global leader in lighting, brings its LED lamps and LED luminaires to the market under the well-known Philips brand.

Signify has created the EyeComfort trademark based on the following selected criteria: Flicker, Stroboscopic effect, Photobiological safety, Glare, Dimming, Tunable, Color rendering, and Audible noise.

Our LED lamps and LED luminaires product portfolio is evaluated using these criteria. This white paper explains these criteria and, accordingly the importance of optimizing lighting.

Scientific Background

Philips branded EyeComfort LED of Signify incorporates the above-mentioned criteria:

1. Flicker and Stroboscopic effect

Flicker and Stroboscopic effect are Temporal Light Artifacts ("TLAs"). TLAs are defined as change in visual perception, induced by a light stimulus, the luminance or spectral distribution, which fluctuates with time for a human observer in a specified environment. Flicker is the perception of visual unsteadiness induced by a light stimulus, the luminance or spectral distribution, which fluctuates with time, for a static observer in a static environment. In other words, it is a disturbing rapid fluctuation of the light in the room.

The stroboscopic effect is different than flicker and is defined as the change in motion perception, induced by a light stimulus, the luminance or spectral distribution, which fluctuates with time, for a static observer in a non-static environment. In other words, the stroboscopic effect results in an unnatural break-up of a continuous motion.

A property of LEDs is the rapid response to variations in the input signal. Therefore, they faithfully reproduce those fluctuations in the light output, potentially leading to TLAs for individuals in the lit space. The fluctuations may come from various sources, including: disturbances on the mains, interactions with controls (e.g. dimmers), disturbance on the input signal from external sources (e.g. microwave), and designed-in fluctuations from the electronic driver. Methods to suppress fluctuations in the light output of LEDs and, at the same time, lower the visibility of unwanted TLAs are known. These methods, however, require compromise on cost and efficiency and require more physical space, while lowering the lifetime of LED products with any architecture.

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

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Until recently, several measures like Flicker Index (FI) and Modulation depth were used to assess the visibility of flicker and the stroboscopic effect. None of these measures are suitable to predict what people actually perceive or experience. Flicker and stroboscopic effect visibility are impacted by modulation depth, frequency, wave shape and duty cycle, and these measures do not take into account all these parameters. Therefore, scientific models have been developed based on the Human Visual System, referring to the visual perception of humans, which is the part of the nervous system that allows us to see. 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. Continuous improvements on TLA measures are currently investigated.

The usual definition of the absolute visibility threshold is the point where the observer can detect the percept 50% of the time [2]. This means that a person is not sure whether or not he/she sees the flicker effect and chooses to respond with “I see in 50% of the time”. It is not that the observer will have a clear idea of seeing flicker 50% of the time and clear idea of not seeing the other 50%. Rather instead, the 50% level is the level where the decision of whether or not to see is at chance.
Given the above, the requirement for no visible flicker is defined as $P_{st}^{LM} \leq 1,0$ and is based on IEC 61000-4-15 [53] and NEMA 77-2017 [54]. Measurement of P_{st}^{LM} 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 as lower quality lighting [5-14]. TLAs are not only annoying for people but also have impact on the comfort of the eye, general comfort and visual performance. More specifically, visible TLAs can decrease visual task performance, cause eye discomfort (tired eyes), increase headache occurrence, eyestrain, and cause annoyance. Studies show that visible flicker can trigger epileptic seizures in certain cases [5-14]. With this in mind, Philips branded EyeComfort LED products of Signify have been designed to minimize visible flicker and stroboscopic effect.

2. Photobiological safety

Blue light hazard

The blue light hazard is a photochemical damage of the retina and 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]. The sources are classified in 4 risk groups (0 = no risk, 3 = high risk).

Risk Group 0: The lamp poses no photobiological hazard
Risk Group 1: No photobiological hazard under normal behavioral limitations
Risk Group 2: Does not pose a hazard due to aversion response to bright light or thermal discomfort
Risk Group 3: Hazardous even for momentary 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 cause blue light hazard. This has been researched and measured thoroughly by the Global Lighting Association, comparing spectral content of different lighting technologies and the above-mentioned standard, together with the input of many scientists [15].

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. The portion of blue in LED lighting is not different from the portion in other technologies at 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 within the uncritical 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.

Ultraviolet

LED based light sources for consumer use do not contain any energy in the UV part of the spectrum and are therefore not harmful to people with a higher sensitivity to UV light.

Infrared

In contrast with incandescent and halogen, LEDs hardly emit any infrared (IR). For consumer LED light sources there is no risk, because the IR radiation is not powerful enough.

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 behavioral limitations, or the lamp poses no photobiological hazard.

3. Glare

Glare is one of the most significant dissatisfiers in relation to comfortable lighting. Glare can be divided into disability glare and discomfort glare. Disability glare refers to the reduction of visual performance caused by a glare source in the field of view. Discomfort glare is defined as the sensation of discomfort caused by bright light sources. The sensation of discomfort depends on many parameters like the source luminance, source area, source position in the field of view, background light conditions, type of activity and duration of exposure to a bright source. For years, researchers have tried to quantify the amount of visual discomfort. The assessment of glare for indoor workplaces (professional environment) is usually done using the UGR measure (Unified Glare Rating). This measure is based on average luminance levels calculated from a far field intensity distribution. In LED lighting solutions often see non-uniform or pixelated exit windows with high luminance contrasts are seen. Studies have shown that pixelated exit windows having the same average luminance as uniform exit windows (and thus the same UGR value) result in higher discomfort glare [19-35]. This means that the current UGR is not always appropriate for use with non-uniform exit windows.

Investigating the applicability or improvement of the current UGR and exploring alternative ways to predict discomfort glare is a considerable topic of research. Improvements to the current UGR are mainly aimed at correction of the position index in the UGR formula to take the viewing-angle-dependency into account, correction of the average luminance, a correction of the observed luminous surface, and general correction by adding an additional intercept to express the luminance contrast within the glare source [36-44]. Suggestions for alternative methods of describing glare are based on modeling the retinal receptive fields of the Human Visual System (HVS) and applying this model on luminance maps of the room to assess discomfort glare [34]. The last approach is identical to the TLA measures which are also based on modelling of the human visual system.

For consumer lamps there is currently no glare measure available to quantify glare. Moreover, the perceived glare of a light bulb will also depend on the application. A naked bulb above the table close to the observer, and at eye height, will be more glary than the same bulb in a lampshade in the corner of the room. In general, glare is caused by a combination of high luminance, high contrast, and source size. Anti-glare measures should at least address one of those causes: lower the luminance, reduce the contrast, or reduce 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 contains diffusing materials and/or a pixelated lace on top of the bulb and is perceived as less glary compared to lamps without any glare control at same flux and same background adaptation. A good glare measure for bulbs is currently not available and is a topic of research for the future.

4. *Dimming*

The dimming feature of LED products is defined as the possibility to change the intensity of the light according to your own preference. The dimming feature of LED products enables you to create the perfect ambiance or task lighting in every environment. People want to dim artificial lighting for several reasons. First, they want the ability to change the ambiance of the environment (dim and cosy, bright and energizing). Secondly, the dimming feature can provide different flux levels over the day, based on different activities or dependent on the outdoor light levels. For instance, in the evening you might like to dim the light levels to reduce the contrast between the dark environment and the LED light, in order to reduce potential glare. Finally, the dimming feature is used for energy saving.

Poor implementation of the dimming feature can introduce some discomfort or unwanted effects like visible flicker at deep dimming levels, unsteady transitions, high minimum light levels. These problems originate from the LED driver circuit, variations in mains voltage amplitude, mains connected loads, and dimmer interaction. Smart electronics design solves the deep dimming issue that suppresses repetitive and/or irregular visible variations in light level.

The dimmable products of the Philips branded EyeComfort LED range of Signify provide step wise dimming in presets (SceneSwitch) or continuously over the whole intensity range.

5. *Tunable*

Tunable LED lighting can be defined in three categories:

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

Dimming of an incandescent bulb gives a different light experience than dimming of regular white LED lights. Due to the technology used, an incandescent spiral becomes less hot during dimming and will therefore emit more reddish white light (lower color temperature). In contrast, the color of the LED-die does not change during dimming. So, the incandescent bulb gives you both an intensity and color temperature variation, while LED only provides an intensity variation and the color temperature will remain the same.

People appreciate the warm setting at low light levels for creating nice and cozy ambiances [45], but this can be different per region. Some Philips branded 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 settings and smooth WarmGlow dimming over the whole range. (2700K-2200K).

Next to the ambiance effect, a dimming feature combined with a CCT change also has advantages regarding the circadian rhythm of people. Our biological clock tells us when to wake up and when to fall asleep. The intensity and action spectrum of light is one of the parameters controlling those responses [46]. High intensity light that contains a lot of blue makes us feel awake and alert, while low intensity light with low quantity of blue triggers the release of the sleep hormone melatonin, which makes us sleepy. Research has showed that bright lighting with a strong blue component is advised in the morning to support waking up and should be avoided in the evening, because it suppresses the melatonin production and makes it harder to fall asleep. Dimmed and warm CCT environments in the evening are ideal 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.

6. *Color rendering*

Color quality relates to the preference and appreciation of users' perception of lighting in a given application. 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. 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 white 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 test source is equal compared to the rendering of colors under the reference source (reference being incandescent for CCTs <5000K)

The preference of users is not always coupled directly to the CRI value. A higher CRI source is not always more preferred. Color saturation (vividness), especially red saturation, 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, also between cultures.

It is important to find the right balance between color fidelity (CRI) and color saturation for a specific application. Philips branded EyeComfort LED of Signify aims to improve color differentiation and enhance aesthetics through the use of LEDs with good color quality properties.

7. Noise

LEDs can suffer from audible noise, specifically when used at deep dimming levels. The voltages and current which are produced, can create mechanical resonance in the components. This noise can be perceived as very annoying and uncomfortable. This is the reason why Energy Star has put requirements in to place for audible noise levels.

According to the Energy Star requirements for audible noise, lamps shall not emit noise above 24 dBA @ 1 meter distance [51]. This threshold is not strict enough for lamps in a completely silent living room (around 20 dBA), or lamps located close to the people (reading light, bedside lamp). All Philips branded EyeComfort LED products of Signify take the published regulations into account.

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