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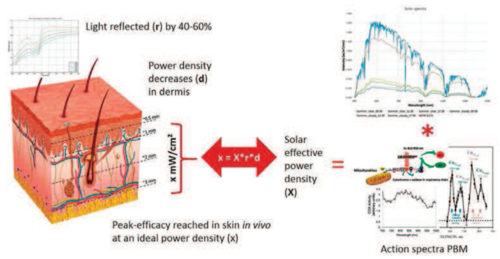

ADVERTISING INDEX

New Directive in Europe: Flicker of LED Lighting

Over the past 10 years LED lighting has gained in importance. It has also been noticed that the alternating proportion of LED light can be very high compared to incandescent lamps. Many institutions from all over the world have thought about algorithms to measure and evaluate light modulation, considering the effect it has on humans. In the meantime, directives have been established in the USA and Europe. But do the directives really have a positive effect on the health of humans and other beings? Peter Erwin, CEO and Design Engineer at Der Lichtpeter provides insight into this question.

FLICKER is still a persistent issue in many LED lights. On 1 October 2019 the European Commission adopted 10 Ecodesign implementing regulations, setting out energy efficiency and other requirements for product groups including LEDs. Evaluation and measurements of optical flicker is now an important new task for electronic developers who provide solutions for LED lighting applications. However, if these regulations really can guarantee a healthier light for humans, how the measurement has to be performed and how the results have to be interpreted are crucial questions. A sound understanding of the topic is required. These points and many more shall be discussed here.

Light Modulation and Its Health Effects

Light modulation

Optical light modulation is defined as fluctuations in the luminance (modulation) of an electrically operated lamp, which is due to the structure and construction of the lamp. The emitted light consists of a desired equable component and an undesirable alternating component [1].

The light of the sun is the ideal model in terms of the color spectrum and the absent modulation. Since time immemorial, people have tried to extend the day with artificial light.

Electric light sources such as incandescent lamps or fluorescent tubes, which are operated directly with the mains AC voltage, generally contain an alternating component at twice the mains frequency. Due to the thermal inertia, the alternating component is less with incandescent lamps than with so-called cold lamps such as fluorescent lamps, compact fluorescent lamps or SSL such as LED lamps. It is not the light-emitting element (filament, fluorescent material, semiconductor, plasma) that is responsible for the degree of the alternating component, but only the power supply that is usually integrated in the lamp base for operating the light-emitting element. It is therefore the task of the control gear to generate a direct current from the AC mains voltage, which is associated with costs and space requirements.

Effect on the organism

It is certain that the alternating component (modulation) has a negative effect on the nervous system of humans and other beings [1] [2]. The alternating component is a stress load for the nervous system; rapid changes in light activate the alarm system subconsciously and can have different effects depending on the frequency.

Main issues of light flicker and stroboscopic effects:

- Photoepilepsy or flashing-light induced seizure at frequencies below ≈ 70 Hz
- Possible human biological effects due to invisible flicker at frequencies above ≈ 70 Hz
- Stroboscopic effect and associated apparent slowing or stoppage of rotating machinery
- Migraine or severe paroxysmal headache often associated with nausea and visual disturbances
- Asthenopia, including eyestrain, fatigue, blurred vision, conventional headache, and decreased performance on sight-related tasks
- Stress on the brain with stroboscopic light because it compensates for the beta-motion of the individual images through higher cognitive processes to a nature-related flowing film

Light Flicker Measuring Methods [3]

The impact on the organism or nervous system was recognized long ago, but since the widespread use of solid-state lighting (SSL) in this century, there have been many complaints from end users. For this reason, various institutions worldwide have made efforts to measure and evaluate the light modulation, preferably according to the sensitivity of humans.

Light modulation varies arbitrarily in its amplitude, fundamental frequency and waveform. Every single criterion affects perceptibility. As a result, inappropriate methods are either those operating in the time domain where no frequencies are taken into account at all, or those operating in the frequency domain, but where the frequency range is insufficient, or those that have non-physiological definition gaps or discontinuities.

Rather unsuitable methods

The methods mentioned below have been analyzed within the process for the new European Eco-Design Directive and for the depicted reasons considered not suitable.

Method according to IES: RP-16-10

The simplest and thus most widespread method according to IES: RP-16-10 with %flicker (pure AC/DC amplitude ratios, also known as Modulation (%), modulation depth, or Michelson contrast) and flicker index (pure area ratios as shown in **Figure** 1) is the least suitable method because two values whose combination is not defined are not communicable and frequencies are not considered at all.

Method according to IEEE 1789 RP1

The recommendation IEEE 1789 Recommended Practice 1 from the USA is often used because frequencies are taken into account depending on the gross dependence of human sensitivity and because there is a classification ('seizure risk', 'low risk', 'no effect'). Nevertheless, the harmonic spectrum and thus the curve shape are not taken into account, because only the fundamental frequency is decisive. In the case of a modulation frequency mix, however, this may not be determinable.

Additionally, the transition from the sensitivity function for frequencies below 90 Hz to the sensitivity function for frequencies above 90 Hz contains physiologically unexplained discontinuities. Thus products with light modulations around 90 Hz due to their design cannot be rated.

The method itself already includes the classification, from which it follows that the light of the European incandescent lamp falls into the 'risky' area, although realistically, people have not at any time complained about TLA from incandescent lamps for over 100 years.

Method according to CEC T24 JA10

The method according to California Energy Commission Title 24, which came into force in January 2017, including the test method "Joint Appendix 10", requires that LED products must have less than 30% modulation at frequencies below 200 Hz (**Figure** 2). This applies to full load as well as in dimmed to 20% state. The disadvantageous fact is the lack of weighting the contained frequencies according to human sensitivity, which is why a highly noticeable flicker at low frequencies is considered "low flicker". This may easily occur with unbalanced rectification of the mains power supply.

Method according to ASSIST

The procedure according to ASSIST performs a frequency analysis, weights the individual frequencies according to a sensitivity curve similar to the Pst^{LM} sensitivity curve shown in IEC / TR 61547-1 and sums up the components again.

With its sensitivity curve this method includes only frequencies up to 70 Hz (**Figure** 2), consequently stroboscopic effects and phantom array effects based on double mains frequency are not considered.

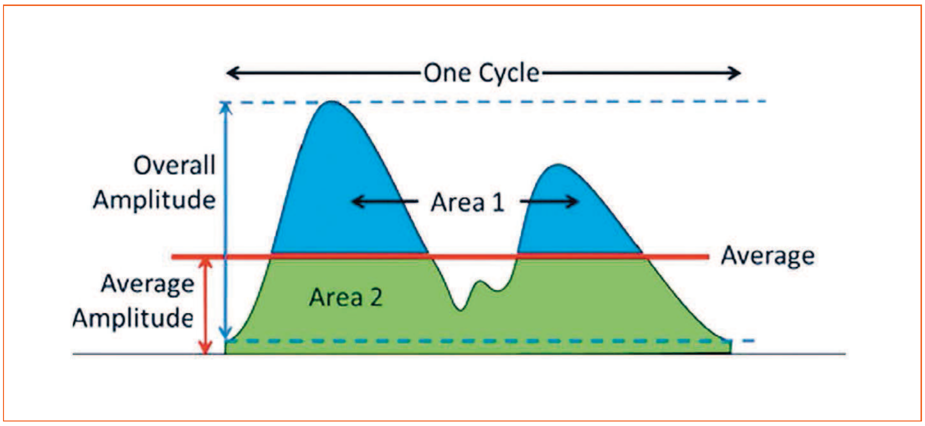

Figure 1: IES-RP-16-10 - Flicker index calculation

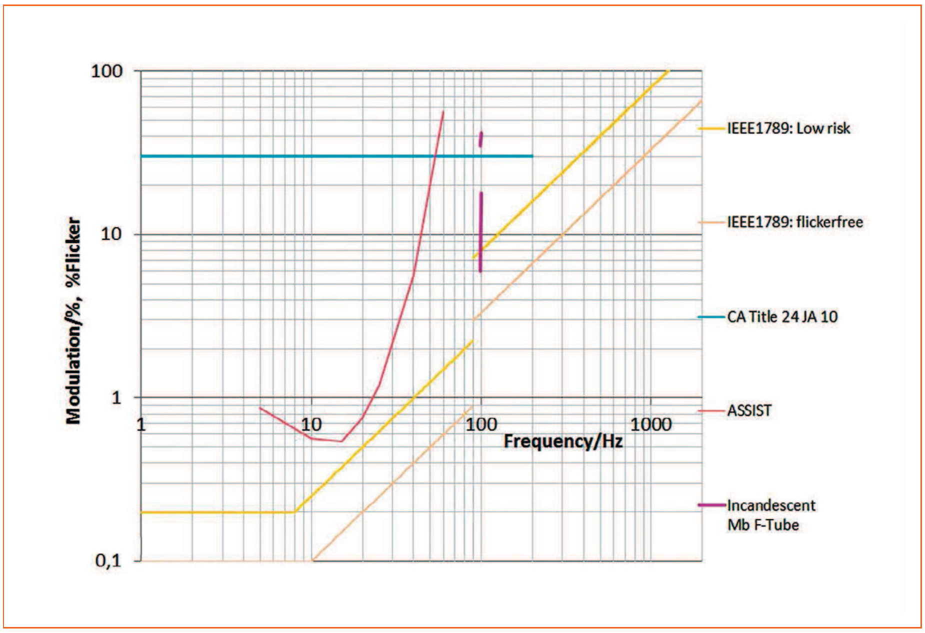

Figure 2: Sensitivity curves according to IEEE 1789 RP1, CEC T24 JA10, ASSIST

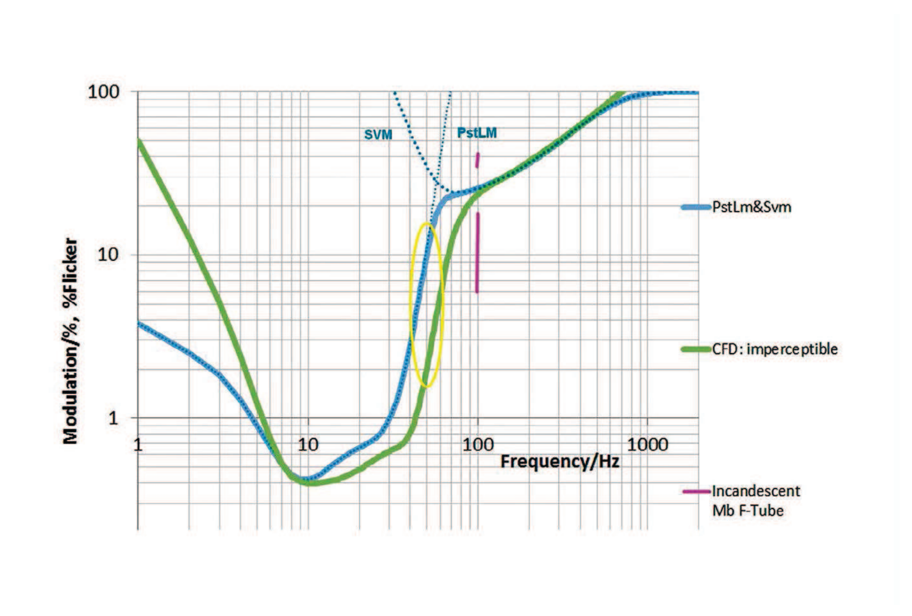

Figure 3: TLA sensitivity curves CIE (PstLM + SVM) and CFD compared

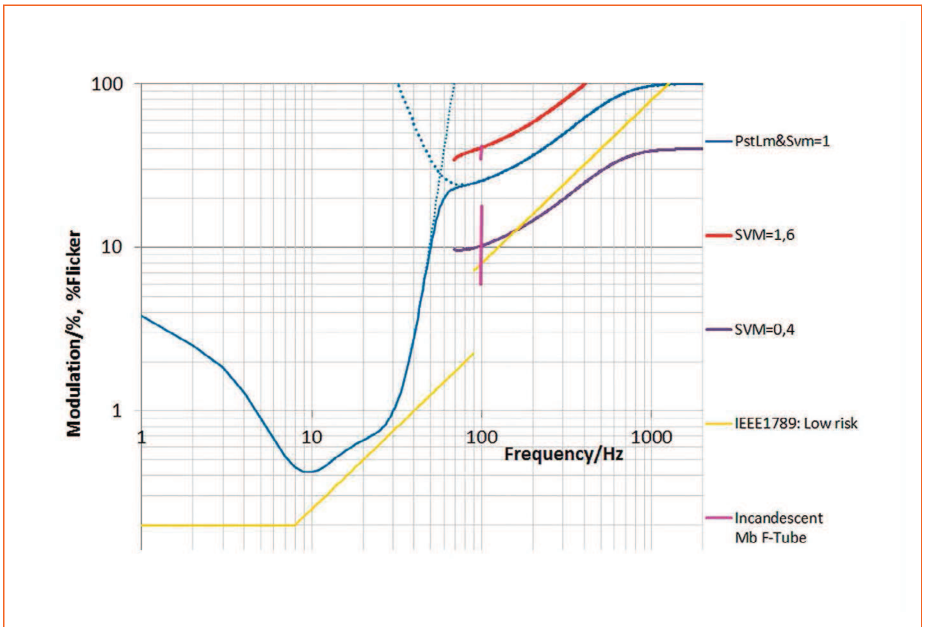

Figure 4: Sensitivity curves with SVM=1.0; 1.6; 0.4

Appropriate methods

Useful measuring methods consider each frequency component up to at least 2 kHz, weighted according to human sensitivity, because humans (and other seeing beings) perceive light modulation depending on the containing frequencies.

To compute this properly, a frequency analysis and thus a powerful CPU is required.

Method according to CIE: TLA (Pst^{LM} + SVM), NEMA 77

The Technical Committee TC 1-83 of the International Commission on Illumination CIE ("Commission Internationale de l'Éclairage") describes light flicker with the term "Temporal Light Artefact" (TLA).

Accordingly Pst^{LM}(Short Term Flicker Indicator based on IEC/TR 61547-1) method is used, where a value of $Pst^{LM} = 1$ means that the average observer has a 50% probability of detecting flicker. This part, though, is not sufficient due to its low cut off frequency at about 70 Hz. The lack is supplemented by the SVM method (stroboscopic visibility measure according to CIE TN 006:2016), where SVM = 1 represents the visibility threshold for an average observer (**Figure** 3).

The resulting two values for the measurement of temporal light artifacts are somewhat complicated with regard to communication and a normative regulation of application-specific limit values. Additionally it might happen that in the transition area a theoretical total actually intended value can be above the limit, even if the individually considered values are considered good.

The NEMA 77 standard has adopted this determination method.

Method according to Der Lichtpeter: CFD

The Compact Flicker Degree (CFD) developed by Der Lichtpeter has been a template for a way to measure, declare and assess temporal light artifacts, because this method provides a single percentage value for the entire frequency range effecting on humans with frequency-dependent weighting and without definition gaps or discontinuities (**Figure** 3).

Comparison:

Both methods, CIE-TLA and CFD, are quite similar in their way of calculation and sensitivity curves (Figure 3). Apart from the fact, that the CFD only needs one value to cover the whole range of human perception, CIE-TLA and CFD differ in several points.

Differences between CIE-TLA and CFD:

- The CIE-TLA calculation is more tolerant towards measure- and calculation uncertainty
- It tends to rate mainly the fundamental frequency and thus neglects the waveform more than the CFD calculation
- At around 50 Hz the CFD curve shows a sensitivity that is 5 times higher

Decision of the EU Commission

Due to the long-term establishment and experience of Pst for light flicker (IEC/TR 61547-1) and the sufficiently wide frequency range for stroboscopic effects, the EU Commission decided for the combination of Pst^{LM} and SVM.

Limit values

On December 5, 2019, the EU Commission published requirements for the design of light sources in the new directive 2019/2020 [4]. It will come into force on September 1st, 2021 and is directly applicable in every member state. Among other things, this regulation also provides measures against temporal light artifacts.

After several public submissions, the EU commissioners voted as limit values $Pst^{LM} \leq 1.0$ and $SVM \leq 0.4$ at full-load for LED and OLED MLS light sources intended for use in indoor applications, where lighting standards require a CRI ≥ 80.

Instead of the original value of $SVM = 1.0$, envisaged by the CIE, which represents the visibility threshold for an average observer, for LED light sources the value of $SVM \leq 0.4$ at full-load is required (**Figure** 4).
This excludes the possibility of stroboscopic effects even with short blanking at double mains frequency.

But on the other hand this leads to the fact, that, similar to IEEE1789, many of the European incandescent lamps are out of the admissible range, which does not matter by considering that this directive only applies to LED light sources.

Oppositions

Based on the NEMA 77 standard, industry associations such as LightingEurope or NEMA are trying to relax the SVM limit to ≤ 1.6 (**Figure** 4) [5]. They assert that customers would be left in the dark because it was not feasible to supply the relevant products before the entry into force.
In particular, the smaller designs with bases such as E14 or G9 would be affected.

In fact, the SVM value of 1.6 is worse than 1.3 with fluorescent tubes under magnetic ballast and enables strobe light as a market example shows (**Figure** 5) [6].

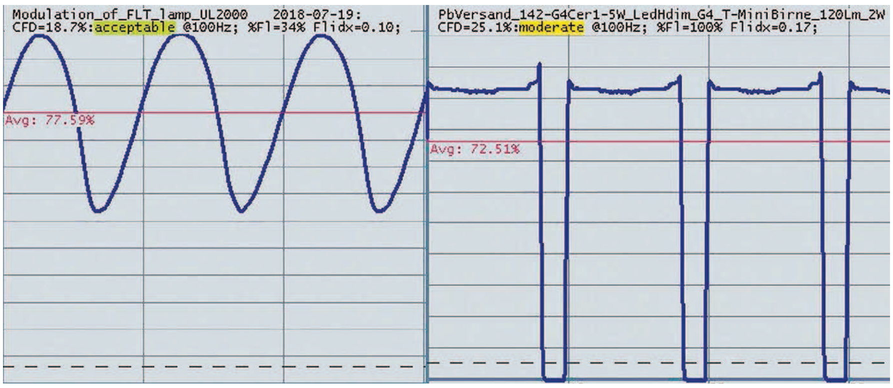

Figure 5: Light emission of a MB-Flt with SVM=1.3 and a strobe light product with SVM=1.6

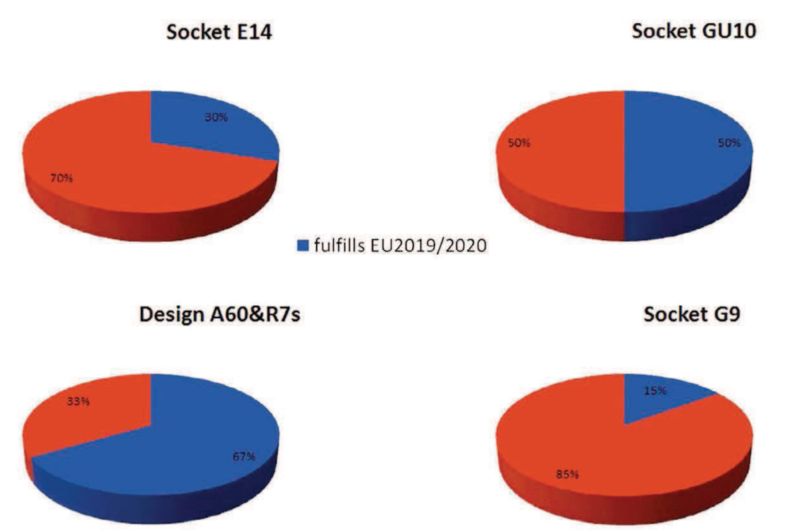

Figure 6: Market availability of LED lamps meeting the EU 2019/2020 requirements in July 2019

Both in a counter notification and in a market overview of over 1200 products, Der Lichtpeter showed in July 2019, that the market was already able to deliver [5].

For example, 30% of the E14 and 15% of the G9 comply with the new limit values (**Figure** 6). Even dimmable versions are available with low flicker values.

Consequently, it is technically feasible at a market price that practically doesn't differ from the low-quality lamps offered.

Does the regulation serve the health of humans and other living creatures?

By looking at the limit values and the associated exceptions, one can see that the regulation in Europe through the directive 2019/2020 applies to LED light sources in indoor living and workplaces. These are certainly the most important and, in terms of diversity, most of the areas. As a result, the applications with which the end user or the average punter is concerned will be covered extensively, and complaints about bad LED light will be massively reduced.

A closer look reveals that this directive does not include the following applications:

- Light sources in dimmed state.
  The dimmed living room light may flicker
- No limit values are set for outdoor lighting (e.g. street lamps): Therefore, stroboscopic light will result in causing suffering to nocturnal beings, or impairment to participants in night traffic
- Illuminations for which a CRI <80 is sufficient. This means that if the color rendering is poor, strobe light is permitted
- Lighting of outdoor sports facilities

It has long been known that different animals react differently to flickering light than humans. For example, chickens are so stressed in flickering light that they stop laying eggs. This was striking when trying to illuminate chicken coops with fluorescent tubes under magnetic ballast. Attention is also paid to low-flickering light for terrariums. Even if this area has not yet been explored, this leads to the conclusion that there are other living things that suffer under flickering light [5].

The lighting industry will try to use cheap control gears such as "driverless AC direct technology" for all applications that are not regulated. In addition to the low price, this technology has the advantage that

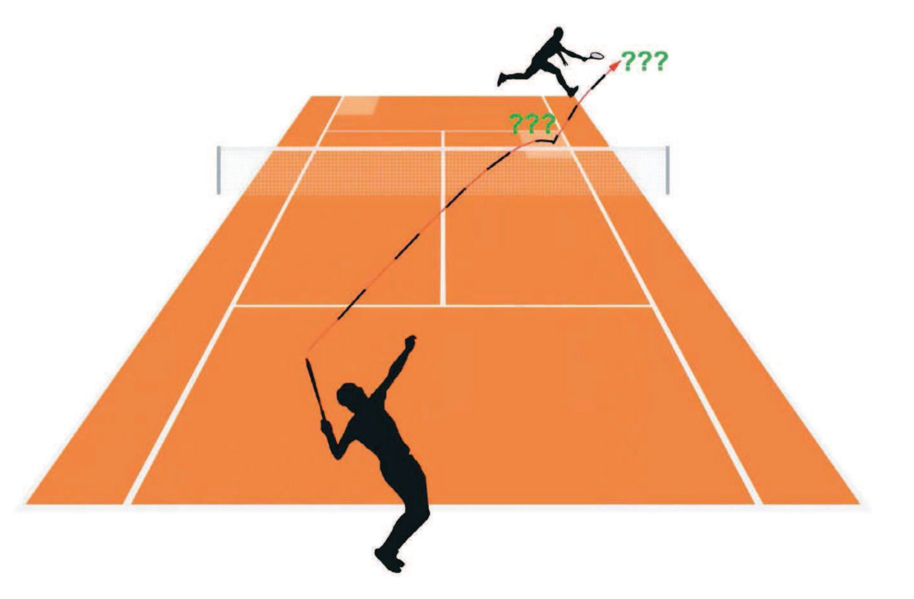

Figure 7: Visibility of a tennis ball when served with stroboscopic light

Figure 8: Self-help via smartphone to make network-dependent flicker visible

it takes up less space due to the lack of electrolytic capacitors and also prospects a longer lifetime. But this comes at the expense of the quality of light, as far as light modulation is concerned. - Accordingly, outdoor floodlights are currently spreading on the market.

Referring to the latest directive EN 12193:2018, temporal irregularity of electrical light sources is not regulated in any sports facility directive. This could have fatal consequences, for example, in tennis courts (**Figure** 7): At a ball speed of 50 m/s, the ball covers 20 inches each alternating between total darkness and visibility. The predictability of the flight direction after hitting the ground or the racket is possibly late, potentially too late and may lead to injuries due to the lack of ability to always determine the position of the ball.

Conclusion

In summary, the question of serving the health of humans can be answered with 'YES', but there is still a lot of potential for further development to offer all-round help. This is also regarding other beings or outdoor applications.

Helpful measures

IEEE 1789 in the USA and the new directive 2019/2020 in Europe work against the most common mains frequency-dependent light flicker, which is definitely a great help.

The measuring method according to California Energy Commission Title 24 JA10 is only useful to rule out strong stroboscopic light at twice the mains frequency. This is because the limit is about 3 times higher than according to IEEE 1789 or EU 2019/2020.

In contrast, the method by IES: RP-16-10: %flicker and flicker index should be prohibited for professional assessment of temporal light artifacts because they believe a judgment that is not present at all.

Until all directives come into force, however, the user can only help themselves with simple methods to detect the majority of the lamps flickering at twice the mains frequency (**Figure** 8).

There is still a lot of potential

In general, it makes no sense to differentiate between limit values for light modulation according to the light source. In principle, the organism (that of humans or other light-sensitive beings) cannot distinguish whether the light modulation of the perceived light comes from an incandescent lamp, an LED or another electrical light source. The decisive factor is the consistency of light with regard to the color spectrum, color temperature and frequency spectrum of the modulated alternating component.

Consequently, the measurement and assessment methods should be designed independently of the light-emitting element, the operating mode (full load, dimmed, also PWM) or the energy source (mains or battery).

In addition, limit values for light modulation should be set in application-specific categories, similar to other parameters such as color rendering [3][6]. Different distinctions should be made.

For example, distinctions should be made between:

- Outdoor applications, such as street lighting or parking lots
- Indoors with less demanding requirements such as consumer home lighting
- Indoor and outdoor facilities with high demands such as offices, educational institutions, machine workplaces and sports facilities, where people work concentrated over long periods of time

Furthermore, mobile lighting would have to be included because it is not evident to what extent such light should act differently than stationary lighting [5].

Stroboscopic LED daytime running lights and rear lights of motor vehicles are particularly irritating. Lighting on bicycles with dynamo driven LED headlights is problematic, because when driving slowly or with the bike pushed, massive stroboscopic flickering is generated in the very photosensitive frequency range.

In this respect, there is a need to further develop the methods and the resulting directives. Various committees are working on this, for example, within the International Commission on Illumination CIE.

One further aspect for healthy light

The ideal light source replaces daytime sunlight in places where people work but who are not getting sunlight.
One example is a shopping mall in which there is no daylight underground or in the small shops. There, the light should come close to sunlight, which also contains an infrared and a UV component. For such locations, no LED light should be used, but rather a heat-generated light with a high color temperature (around 5000 K). Of course, this will consume more energy, but it helps people to stay healthy. There, in the evening and in the dark, for the unnatural extension of the day, the infrared and UV components can be omitted and the color temperature can drop to below 3000 K. With regard to energy saving, LED lamps with 2700 K can be used for this purpose. ■

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ABOUT THE AUTHOR

Peter Erwin: Inventively minded design engineer with 25 years of experience in innovative design and development of MCU controlled hardware and software for customer-friendly, intuitive and easy to use devices and applications.

Since 2010, the topic of lighting with artificial light has been important in Peter Erwin's own interest. The focus of his work lies in the determination of optical light flicker. This unpopular but nevertheless very important technical property of a luminous means needs paying more attention in view of the growth rates of flickering illuminants in the market. For this reason, Der Lichtpeter was founded. Der Lichtpeter works for the benefit of humans and invests some money and about 1000 working hours per year.

In 2018, Peter Erwin has been working together with IEC TC 34 / WG 5 and is a member of the International Commission on Illumination research forum RF-02 to support standards against light flicker.