IS STREET LIGHTING DAMAGING OUR HEALTH?

LEDs are efficient at lighting our roads yet people complain of discomfort.

As LED technology improves, can we keep all the benefits that come from using LEDs ***and*** increase visual comfort?

WHITEPAPER

CREE LIGHTING

ABOUT THIS PAPER

This paper supports the need for a new glare model for assessing discomfort glare caused by LED luminaires and to improve the understanding, calculation and criteria for the evaluation of discomfort glare.

INTRODUCTION

LED light sources continue to evolve into gentler, more user-friendly forms. This technology will play a huge part in our future, however, the shift to a kinder LED luminaire needs to increase rapidly if we are to prevent further, sometimes unrecognised, harm to ourselves and the planet. A shift can be accelerated if we review and update the calculations that are used to determine street lighting standards, such as the volume of acceptable glare.

Originally developed back in the 1970s, before LEDs were commonplace, the current calculations do not justify the specification of the best quality lighting option - and we'd argue, they do not ensure the safest or healthiest option either.

We are calling for a change to the method of calculation to take into account the opportunities of using the very latest LED and optical technology. This will ensure more human and nature-centric street lighting is specified across the world. This paper explains more.

CONTENTS

A SHORT HISTORY OF LED AND STREET LIGHTING STANDARDS

2006

Before 2006, LED lights were considered under the same legislation as lasers because historically, LEDs were used as marker lights rather than for illuminating wide areas. As LEDs were considered not suitable for general lighting, there were no product or street lighting standards compatible with LED products.

As the push for energy savings increased, so did the call for a more widespread use of energy efficient LEDs.

2008

In 2008, the IEC General Lighting Standards were updated to include LED lighting. Great for energy savings and a low lux level, however, the previous calculation methods were simply transferred over to the new standards.

2013

After ongoing complaints from the public and concerns from experts and environmental groups, the lighting standards were revised in **2013**. Unfortunately, the research used to update the legislation did not consider the luminance differences introduced by using LED technology.

For the past seven years, the specification of street lighting has been based on the 2013 standards. Scientific evidence has proved that the colour spectrum and luminance of LEDs has and still is causing impacts on health, safety, quality of life, and the environment. A further review of luminaire standards conducted by CIE in 2020 may go some way towards resolving issues, however, there is mounting evidence that we need to act further by updating metrics related to LED light sources in application to prevent further harm to our environment caused by ongoing glare issues, setting aside financial concerns and choosing the best option, rather than the cheapest.

2021 A NEW ERA BEGINS.

A SHORT HISTORY OF GLARE METRICS

Not one of the existing metrics takes into account the non-uniform emitting surface of a LED luminaire.

GLARE METRIC DEVELOPMENT

GLARE MEASURES FOR INDOOR ELECTRIC LIGHTING 1920-1983

- **British** Glare Index
- **USA**: Visual comfort probability
- **Czechoslovakia** glare index
- **USSR** glare index
- **Germany**: Söllner curves

1983 CIE GLARE INDEX (SOUTH AFRICA)

1995 - UNIFIED GLARE RATING CIE 117 – UGR GENERAL FORMULA

2010 CIE 190 UGR TABULAR METHOD

2019 - CIE 232 – CORRECTION FOR NONUNIFORM SOURCES

GLARE MEASURES: SEVERAL COMPETING DAYLIGHT GLARE MODELS

- Daylight glare index
- Predicted glare sensation vote
- Daylight glare probability

2021-??? CIE TC 3-57 A GENERIC DISCOMFORT GLARE SENSATION MODEL





1920 - 1980's | 1990's | 2000 - 2010 | 2010 - 2020 | 2021




LED DEVELOPMENT

1979 SHUJI NAKAMURA DEVELOPS FIRST BLUE LED

1990's LED ADOPTION BECAME WIDESPREAD

1995 FIRST COMMERCIAL WHITE LED

2007 1ST COMMERCIALLLY VIABLE STREETLIGHT INTRODUCED

2016 FIRST COMMERCIALLY AVAILABLE WAVE GUIDE ADDRESSES LED GLARE ISSUES

GLARE MEASURES: MANY COMPETING OUTDOOR LIGHTING GLARE MODELS

- **Road Lighting**
  CIE Glare Control Mark, IESNA Cumulative, Brightness Evaluation, Vos' Glare index, Bullough glare rating
- **Car headlights**
  Schmidt-Clausen & Bindels, Alferdinck, Völker
- **Sport Lighting**

LEDs -
UNINTENDED CONSEQUENCES OF USE

The development of LED lamps was considered to be a huge technological breakthrough due to their low energy consumption, smaller size, longer lifetime, and faster switching when compared to all other light sources. A type of solid-state lighting, LEDs use a semiconductor to convert electricity into light and emit it in a specific direction, reducing the need for reflectors and diffusers that can trap light.

- A research of Global LED & Smart Street Lighting Market (2016-2026) states that **"there are 315mln streetlights in the world, growing to 359mln by 2026."** Furthermore, **"LED streetlights are projected to reach 89% of the total streetlight market by 2026.[1]"**
- Studies estimate that around 70% of UK street lights have undergone or are contracted for LED adoption[2].

The difficulty with using LEDs is there are often unintended, undesirable side effects: harshness, glare, uneven illumination, and sharp shadows. These are not trivial concerns. Many campaigners have cited how these side effects influence mood, productivity, alertness, safety, comfort, spatial awareness and perception of depth. Whilst others go further and suggest that on a deeper level, our circadian rhythm and sense of well-being are negatively impacted. These concerns are ubiquitous and may be easily researched by readers interested in obtaining a greater understanding.

Is there a reason for these unintended consequences?

Simply, we retained the metrics to determine comfortable lighting levels for drivers and comfortable brightness, or luminance, for pedestrians as we moved away from luminaires providing a large, single source of uniform luminance. This is despite the fact that today's luminaires contain multiple small, high intensity light sources.

1 https://www.prnewswire.com/news-releases/global-led-and-smart-street-lighting-market-forecast-2016-2026-street-lights-numbers-to-increase-from-315-million-in-2016-to-359-million-by-2026---research-and-markets-300392637.html
2 LIA (Lighting Industry Association Ltd)

Manufacturers claim LEDs are up to 50% more energy-efficient than traditional yellow sodium lights and last for up 20 years, instead of two to five years.

THE ISSUE WITH GLARE

Glare is a very complex phenomenon caused by the contrast between bright and dark areas in the field of view. It causes a physical and neural response from the human eye which ranges from discomfort to disability, and it is exacerbated when the eye can see the source of the light, for example, the bulb within a luminaire.

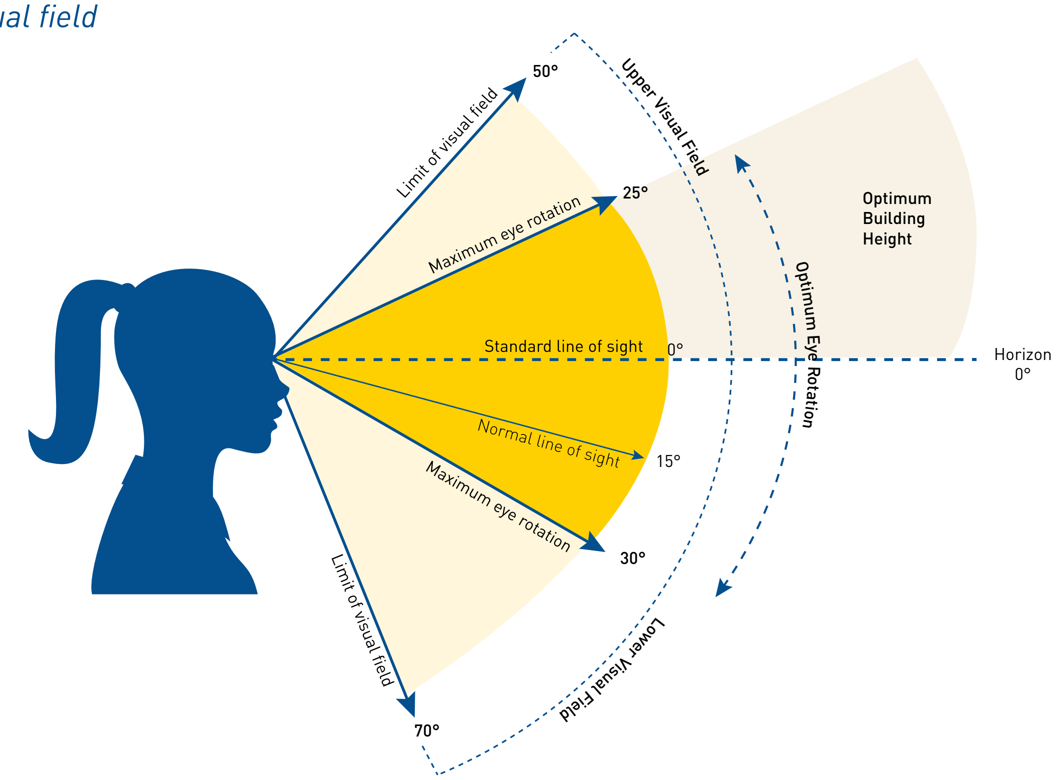
Glare occurs because some intense light in the peripheral scatters when it enters the eye, which, in turn, reduces the sharpness of vision and raises the differential light threshold of the object you are trying to view. **When glare interferes with or blocks vision, it is known as disability or veiling glare**.

Disability glare tends to become more problematic as we age, as the transparency of the crystalline lens decreases. Whilst the issue of a driver being temporarily blinded by glare is obvious, less understood is the uncomfortable psychological response that they or others experience, for example, passengers in the car or pedestrians.

> ***Their eyes and brain are working continuously to decode light and dark.***

Having excessively bright elements within their view may cause discomfort rather than an inability to see, and over time may cause eyestrain and fatigue, often revealed as headaches or migraines or in the longer term, stress.

Figure 1: *Visual field*



DISCOMFORT GLARE

Discomfort glare is defined as "glare that causes discomfort without necessarily impairing the vision of objects" by the Commission Internationale de l'Eclairage (CIE). In general, the brighter or larger the glare source or the darker the background - compare the amount of light in a city compared to in a forest - the more discomfort glare observers will report, while the darker the background or the smaller the angle of the glare source from the line of sight, the greater the discomfort glare will be. The eye responds to discomfort glare by constricting the pupil and it is natural for the affected individual to squint and shield the eyes.

Interestingly, there is no widely accepted theory about why humans experience discomfort nor is there a fully satisfactory index for quantifying it.[3] As it does not directly impact safety, discomfort-causing glare is often labeled 'subjective'.

3 CIE International Commission on Illumination

PIXELATION

We have the tools to take the measurements - we now need to agree on what that measurement, and its parameters, should be.

Pixelation is a negative phenomenon for the human eye and one of the physical causes of discomfort. To resolve the issue, there is a clear need to accurately quantify what the eye experiences in a real-world scenario.

Firstly, the effects of the discrete LED sources on the lighting of the scene. We are aware of pixelation on computer screens, when images break down into their individual colour pixels, and it's the same phenomenon in street lighting. It occurs because of the ratio of contrast between the high intensity emitting source, the LED-housing luminaire, and the surrounding area, which tends to be at a lower intensity.

Secondly, the inadequacy of the photometric measurements that assumes the source is a single point. Instead, it is an array of closely spaced sources: very small high luminance zones separated by low luminance zones.

The current photometrics for glare assumes a single source of luminance and so requires only a snippet of information - a measurement taken from one spot facing this single point source. Of course, a LED luminaire contains multiple light sources within that single luminaire, so it's obvious that new metrics are needed to take account of this. As our technology advances and new tools are available, such as high-resolution digital cameras, we can utilise radiant imaging to measure every single point on the screen and quantify what people actually experience.

We can take this further when we compare the eye to a camera sensor. In raw terms, the human brain uses the eye to take many HDR-style images in very quick succession, stitching them together into a constantly updated image. This is better than existing cameras.

A photometric measure uses a light sensor to collect the light from multiple LED sources as if the light has been emitted from a point source of light where distance is irrelevant. In other words, the photometry cuts down the luminaire's details to one pixel of information. In glare calculations then we are comparing a very small number of pixels (one per luminaire) to the background (this gives us contrast) and relating that to user experience.

Users on the other hand experience glare and see every single nuance of intensity change within the luminaire optic against a super detailed intensity map of the background.

This is why the photometry used for light calculation causes problems for real human beings and why research into more relevant measures is needed.

We have the tools to take the measurements - we now need to agree on what that measurement, and its parameters, should be.

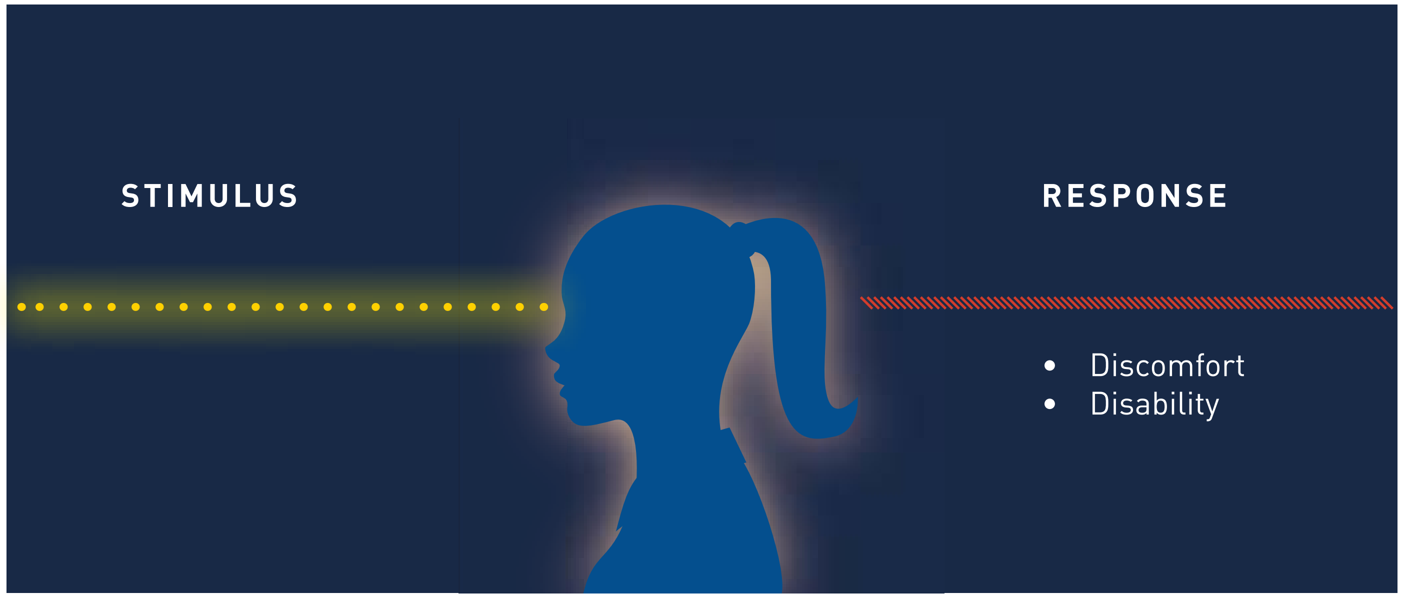
"Humans, on the other hand, are using a HDR camera - the human eye - to experience glare. They see every nuance from changes in intensity within the luminaire optic contrasted against the super-detailed intensity map formed by the background.

Iain Macrae, Iain Macrae Limited

IT'S A PHYSICAL (AND NEURAL) REACTION

Glare is the loss of visual performance or discomfort produced by an intensity of light in the visual field greater than the intensity of light to which the eyes are adapted. Simply put, glare occurs when too much light enters your eye and interferes with your brain's ability to manage it. This means that the glare source - in this case, the LED streetlight - appears excessively bright when compared with its surroundings, leading to visual impairment and/or visual discomfort.

***Figure 2:** Stimulus & Response*



There are numerous instruments available to objectively measure the luminance of street lighting based on defined calculations. However, there are two issues with this.

1. **The calculations were originally developed for older technology, favouring certain lamp types over others. These methods do not work well for the vast majority of LED luminaires, the prevalent light source used in street lighting.**

2. **A street light installation may meet the current criteria for glare but the user still experiences glare. This is because the impact assessment does not take into account how the human eye and brain work together.**

The main physical parameters that influence discomfort glare include the luminous flux (lumens) of the glare source, its size, the background surrounding the glare source, and its position within the field of view. Let's consider this in more detail using the photometry element of street lighting as an example.

The metrics for determining an even spread of light along a street uses calculations based on there being one large light source on a post evenly spaced along a road. To calculate the angle of light distribution, the measurement has to be taken from at least 8 x the distance from the light source to be valid. Today's LED street lighting uses modern lenses and multiple, smaller light sources - yet the metrics have not changed. It is obvious that LEDs, made up of multiple points of light, and the angles between the luminaires would provide a different experience when compared to older technologies.

The eye starts to see direct light at 65° from the nadir of a streetlight yet the luminaire visual comfort level - the glare - is evaluated at 70°.

Think about the equipment used to measure the even spread of light - one high-definition camera using centre line integrity, measuring the average luminance over a specified area. There are a number of issues with this, including:

- **The equipment uses standard calculations that do not take into account the interdependency of the luminaire with the environment - bright city backgrounds or darker countryside.** Compare this to the human eye which picks up lots of fine detail: every rod and cone within the eye reacting to every single photon.

- **The photometry sensor measures a horizontal line running perpendicular at a fixed height. Yet the human eye is rarely if ever static.** Humans not only have a wide field of vision, they move around to take in a wider perspective. Models may be applied to mimic the human eye, some at a cone of 2°, 5°, 10° and others map the wider peripheral vision at 25° up and 30° down and as wide as 110° either side, yet a metric that is relying on a static and restricted vision model will never truly predict human experience. It also does not take into account that the human may be offset from the luminaire, viewing the light from an angle rather than straight on.

- **The eye starts to see direct light at 65° from the nadir of a streetlight yet the luminaire visual comfort level - the glare - is evaluated at 70°,** which is normally most of the roadway optic peak intensity. It is now possible to directly assess the volume and impact of light scatter on the human eye, which should be used when understanding the human visual system in relation to glare.[4]

4 Street Lighting Glare: An Investigation using Light Scattering and fMRI Brain Imaging Track Record City University and Royal Holloway University 2013

THE ISSUE WITH STREET LIGHTING METRICS

The issue with existing street lighting is that there is a clear mismatch between LED lighting technology, people's experiences, and the current metrics. Calculations to determine the positioning and efficacy of a LED luminaire may deliver as per the metrics on paper, however, when humans are reporting concerns, and we know that the metrics are based on historical technology, then it is a fair assumption that the metrics and the supporting calculations need to be updated. In addition, most lighting standards do not specify design targets for discomfort glare and those that do are not used universally, and they tend to be based on subjective ratings, which favour older technologies.

Three methods currently exist in the main for predicting and controlling glare of street lighting applications within European standards EN 13201.

- TI (Threshold Increment)
- G* Luminous intensity classes
- D* Disability Glare Index

In addition, there is also

- CIE 112 Glare Rating Index - GR is also adopted for other outdoor purposes
- IES TM-155 G rating is one of the most commonly used methods to measure glare for outdoor lighting

As discussed, each presents a problem for modern technologies given that the calculation was based on research long before LED existed as a light source.

THRESHOLD INCREMENT (TI)

TI represents the percentage by which the road surface luminance would have to be raised to compensate for the reduced visibility due to the glare. Discomfort glare is generally considered to be less important in road lighting as it is thought that the strict limits on TI in main road lighting provide adequate control of discomfort glare. However:

- The calculation relies on an interpretation of the Luminance Intensity from the photometry, averaging the luminance of the luminaire rather than the highest value. It assumes point source optics.
- It does not represent user experience for high luminance, non-uniform, and multi-point luminance luminaires

G* LUMINOUS INTENSITY CLASSES

The issues are that

- The calculation is based on the maximum luminous intensity at >70°, >80° and >90°.
- The vision cone of the human eye above the horizon is limited to 50°. Therefore, the luminance delivered at the metric's reference angles only partially affect the human visual field and then only when the users are far enough away from the luminaire. This renders the metric ineffectual.

D* DISABILITY GLARE

It is based on luminance at 65° only, dividing maximum luminous intensity by the area of the luminaire (flashed area).

The first problem is that the maximum intensity is not necessarily at 65°. The second, the apparent flashed area is simplified to that of the optical surface but non uniformity and intensity of LED sources make this metric ineffective.

CIE 112 GR

CIE 112 GR evaluates the average luminance over luminaire aperture. This is a highly inaccurate assumption now that we have luminaires with visible arrays of LEDs. It misstates the area and the luminance.

IES TM-155

IES TM-155 - G rating scale is based on an absolute value in lumens depending on the zonal lumens of the distribution. Again, this is an incomplete calculation because it is based only on luminous flux and does not consider true luminaire luminance. Moreover, it does not consider the other factors affecting glare directly, such as luminaire uniformity and size of luminance opening.

There are ongoing studies into creating standard, LED-appropriate metrics that consider glare in a contemporary manner. Notice must be taken of the initial studies by the CIE Technical Committee and by the DGONE[5] Committee to create a generic discomfort glare sensation model.

A change in standards will encourage the specification of sustainable lighting products that make living with LEDs more aesthetically pleasing and more comfortable. **There may be an initial small cost implication, but councils will continue to enjoy ongoing energy saving as well as realizing myriad health and environmental benefits.**

5 Discomfort Glare in Outdoor Nighttime Environments

> ***"There is a clear opportunity and urgent need to reduce the methods by which we calculate glare. To do this we need to update and replace the multiple outdated and competing metrics currently in use."***

Nick Farraway, Cree Lighting

THE URGENT NEED TO REASSESS STREET LIGHTING STANDARDS

LED street lighting may be cost effective to run but using the current technology under existing metrics means that there is a negative price to pay by humans and wildlife. By changing the metrics and associated specifying calculations for street lighting, we can not only improve human comfort and increase pedestrian and driver safety, we can continue with the work to reduce light pollution, increase efficiencies and reinstate the natural environment for flora and fauna.

The desire to reassess lighting standards is not new; neither is the need to improve comfort levels, remove unhealthy glare and unwanted light. An ever-growing body of experts - including lighting engineers, The Dark Skies movement, wildlife experts and medical professionals - are calling for a change and demand is building. As we increasingly consider sustainability as important as the mental and physical comfort of humans and the environment around us, we are amplifying this call.

We also bring a call for urgency to this work. Without a speedy agreement on metrics for measuring LED intensity, spectrum, photometry and LED spacing, we will be installing millions of LED luminaires for street lighting purposes that are not suitable for use, could even be described as dangerous, and that will be costly to replace.

We hope that a holistic approach to street lighting encourages the specification of the best quality lighting, rather than that which is cheapest to install, will ultimately mean that we use the healthiest, safest and most environmentally friendly street lighting available.

CREDITS

ABOUT CREE LIGHTING

Cree Lighting is a market-leading innovator of indoor and outdoor LED lighting. We are uniquely positioned to innovate new ways in which lighting will serve as a platform for emerging technologies and capabilities that will enrich lives, improve society and safeguard our planet.

ABOUT THIS PAPER

This accessible paper has been written with input from some of the world's leading lighting experts and with reference to international publications and papers.

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