PART 14

ADVERSE EFFECTS OF LIGHTING

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Part 14 Adverse Effects of Lighting		
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BUREAU OF INDIAN STANDARDS

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Draft NATIONAL LIGHTING CODE OF INDIA

PART 14 Adverse Effects of Lighting

[First Revision of SP 72 (Part 14)]

Illumination Engineering and Luminaries Sectional Committee, ETD 49	**Last Date for Comments: 23 August 2024**

FOREWORD

Artificial light is essential in all aspects of human activity. However, artificial electric light can sometimes impair vision and pose health risks. These negative effects are crucial considerations when using and managing lighting products or systems. This chapter addresses the inherent characteristics of light that may arise from the lighting spectrum, products, or their accessories, and their potential impact on vision and health.

Primarily, there are 4 types of adverse effects:

a) Visual disturbances in visual performance on account of Glare phenomenon.
b) Adverse effects due to light modulation over time and frequency. These can cause serious neurological and physiological issues
c) Photo-biological effects of light, also known as optical radiation hazards
d) Light pollution i.e. unwanted light and bright light at night.

1 SCOPE

The aim of this chapter is to understand the quality aspects of lighting to make the best selection and minimize adverse effects in real-life installations. It covers two critical subjects in detail: Flickers and Photobiological Safety. This chapter includes definitions, characteristics, and the main causes of these effects.

2 NORMATIVE REFERENCES

IS Standard / International Standard	*Title*
IS 16108: 2012	Photobiological Safety of Lamps and Lamp Systems
IEC 62778	Application of IEC 62471 for the assessment of blue light hazard to light sources and luminaires
IEEE 1789 (2015)	Recommended Practices for Modulating Current in High Brightness LEDs for Mitigating Health Risks to viewers

3 MODULATION EFFECT

3.1 Flicker

Flicker is defined as the regular fluctuation of brightness within our line of sight. It involves a continuous change in light intensity at a specific frequency. When the eye is exposed to rapidly changing brightness levels within certain frequency ranges, it can be very irritating for the observer. Even subconsciously perceived flicker can cause symptoms. In this context, both the object and the observer are static.

3.2 Intermittent Flicker

Flicker occurs when light turns on and off at short, irregular intervals. This phenomenon is often observed with electromagnetic fluorescent tube lights when they are switched on or with high-pressure sodium vapor (HPSV) lamps nearing the end of their lifespan. Fortunately, these issues are typically short-lived and easily addressed. For fluorescent lamps, using a high-frequency electronic driver can resolve the flicker, while replacing the lamp can fix the problem in HPSV lamps. However, it is important to note that high-frequency operation can introduce its own modulation issues, potentially leading to other adverse effects.

3.3 Stroboscopic Effect

Another adverse effect is the stroboscopic effect. This phenomenon can alter the perception of movement in rotating or reciprocating machine parts, making them appear stationary to a static observer in a dynamic environment. The frequency range of this effect is from 80 to 2000 Hz. For example, in a factory, a rapidly rotating machine can pose an increased risk of injury because the eye is led to believe that the machine is at a standstill. This occurs due to the synchronization or matching of the light's frequency with that of the rotating parts, causing the moving object to appear static to the observer.

3.4 Phantom or Ghosting Effect

Ghosting effect or phantom array effect is the opposite of the stroboscopic effect. In this case, the eye moves while the lighted objects remain fixed and time-modulated. This results in the appearance of non-existing phantom or ghost lights in addition to the real lights, causing a change in the perceived shape or spatial layout of objects. This effect is often observed while driving behind a car with poorly modulated rear lamps. It occurs when there is a very high contrast between the light source and its background, with a frequency range of 80 Hz to 2500 Hz. Here, the observer is in motion while the object remains static.

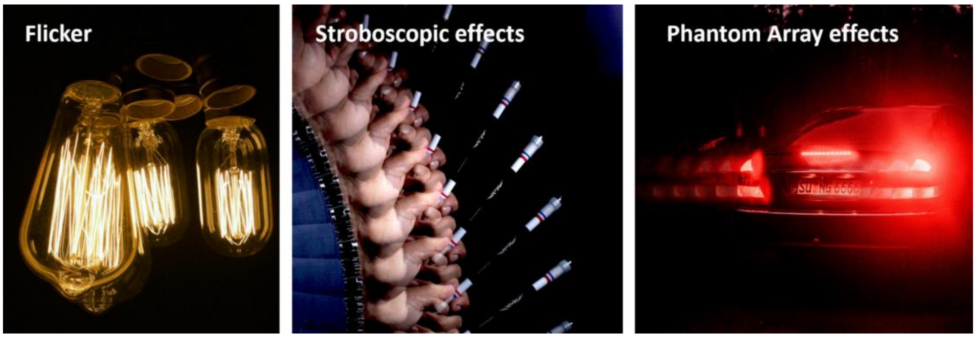


Fig. 1 Examples of Modulation Effect

Out of the four, flicker is most important phenomena in the era of LED lighting and dynamics of intelligent lighting where dimming is involved

4 FLICKER

4.1 Flicker is a perception of visual unsteadiness for a static observer in a static environment. It depends on frequency range (3 Hz- 80Hz) and the modulation amplitude.

Flicker is divided into three categories:

a) Visible flicker 100% modulation (*see* Fig. 2)

Visible flicker which is perceived by 75% people and regarded as irritating. In this area the signal with 100Hz &100% modulation.

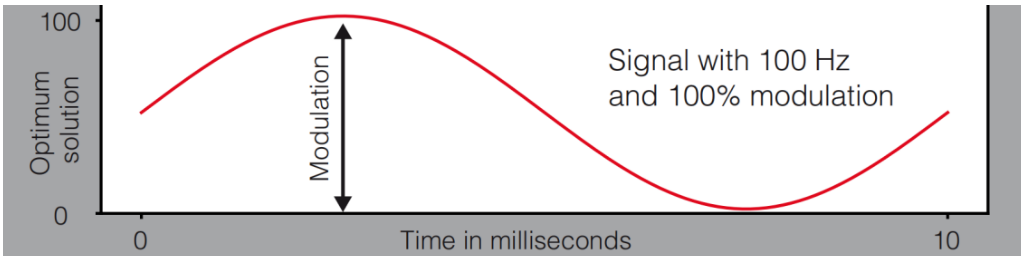


Fig. 2 Visible flicker 100% Modulation

b) Visible flicker 20% modulation (*see* Fig. 3)

Second one is hardly perceptible flicker means in general no flicker is perceived but still flicker can cause headache in sensitive people. Here signal is 300Hz & 20% modulation.

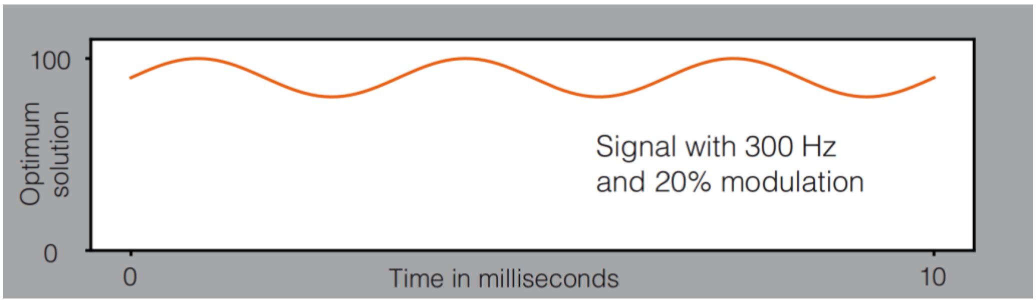


Fig. 3 Visible Flicker 20% Modulation

c) Flicker modulation 10% (*see* Fig. 4)

Third one is flicker free signal with 500Hz and 10% modulation. This is the best solution in practice.

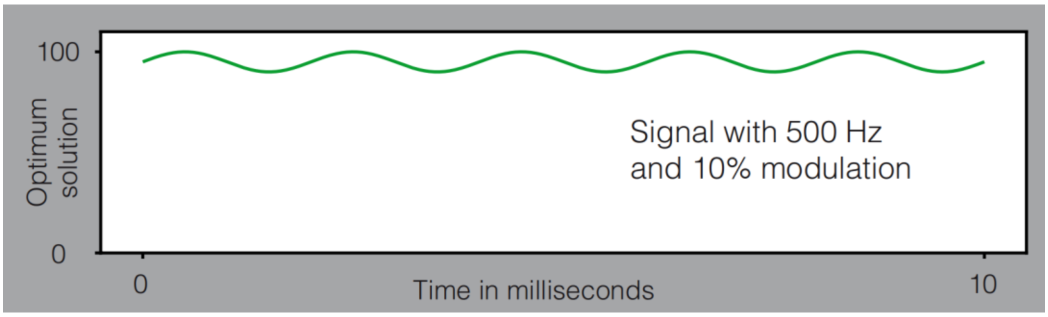


Fig 4 Flicker Modulation 10%

4.2 Fig. 5 shows the graphical version of flicker as per IEEE 1789.

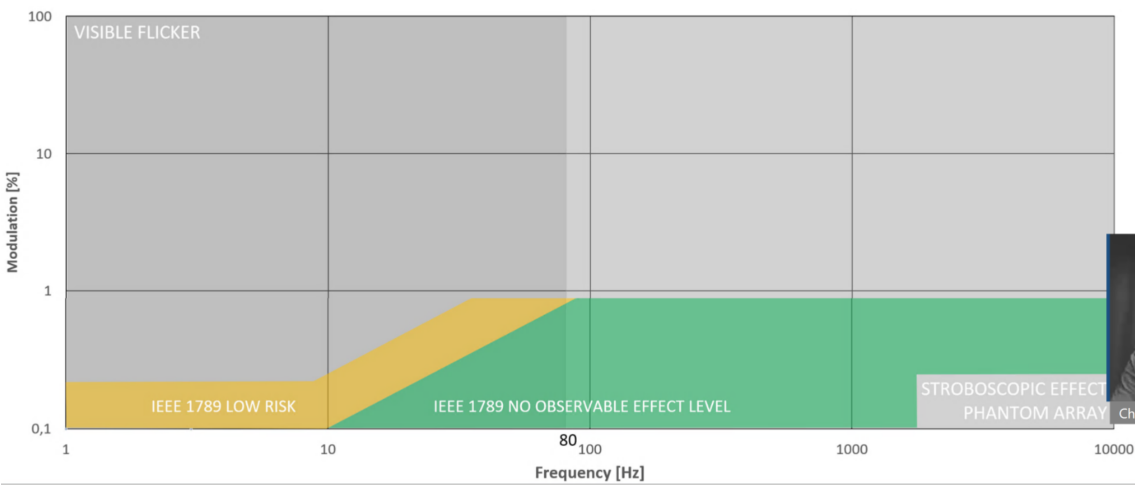


Fig. 5 Graphical Version of Flicker

The adverse effect of lamp flicker is referred as TLA (Temporal Light Artifact). TLA is an undesired change in visual perception induced by a light stimulus (Temporal light modulation, TLM) whose luminance or spectral distribution fluctuates with time.

4.2.1 *TLA & Its Value*

TLA can be due to the following main reasons:

a) Light source technology and drivers .

b) Dimming technology and dimming level

c) Mains voltage fluctuation

Note- the resulting fluctuation may be periodic or non-periodic.

4.2.2 The followings factors determines the visibility:

a) Frequency and relative magnitude of modulation

b) The shape of the waveform (Square, sinusoidal, duty cycle)

c) The lighting level

d) The illuminated/observed object and its speed of movement

e) The sensitivity of the observer, viewing angel etc

f) Contrast and background light level within the environment

4.2.3 In the case of fluorescent tube lights, they now operate using electronic high-frequency (HF) drivers with frequencies ranging from 20,000 kHz to 40,000 kHz. These frequencies are sufficiently high to minimize the flickering effect typically associated with fluorescent lighting.

For solid-state lighting, such as LEDs, they operate on low-voltage DC through their drivers. These drivers rectify the main voltage supply to a lower voltage and convert it to direct current to power the LEDs. Typically, an LED driver (refer to Fig. 6) is essentially a rectifier bridge without additional electronic circuits to suppress modulation, potentially leading to noticeable flickering effects. This means that the 50 Hz mains supply is modulated at 100 Hz, which can result in undesirable flickering effects.

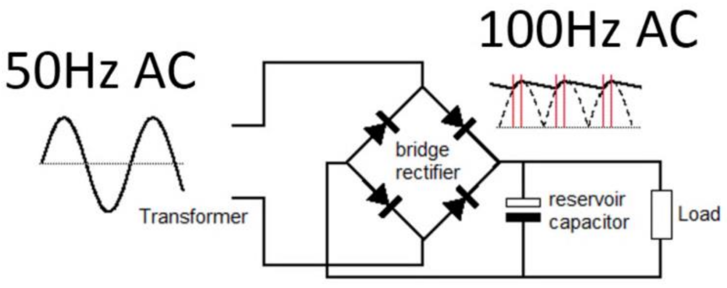


Fig. 6 Typical Circuit of LED Driver

Therefore meticulous driver design is crucial in preventing flickering in LED lighting systems. A high-quality, compatible LED driver can effectively eliminate flicker from the light source, ensuring performance comparable to incandescent lamps. Further details on driver design are elaborated in the Part 3/ Sec 2 of this code.

There are various dimming techniques that can also contribute to flickering. Fig. 7 illustrates the necessary steps and considerations for effectively minimizing flicker with different dimming drivers.

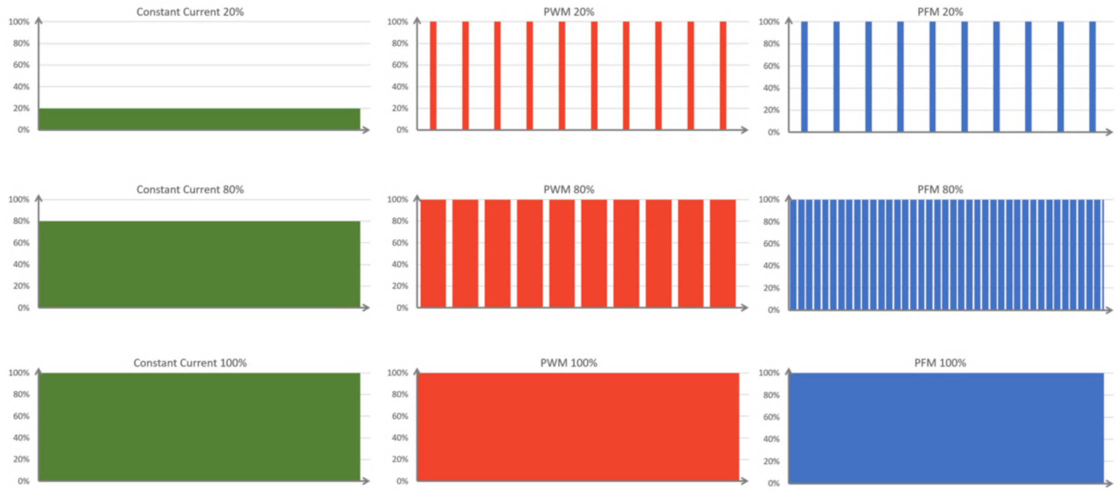


Fig. 7 Different Types of Dimming

4.2.4 When employing Pulse Width Modulation (PWM) dimming for LED products, it is recommended to use higher frequencies for turning on and off to minimize flickering

Voltage fluctuations caused by household appliances such as geysers, irons, heaters, washing machines, etc., introduce square waves into the power line, which can lead to flickering issues, especially in LED systems.

Flicker measurement involves plotting graphs over time to analyze sequences of repetitive modulations along with frequency characteristics of the time-modulated light output. Two commonly used metrics for evaluating flicker are Percent Flicker and Flicker Index, as illustrated in Fig. 8.

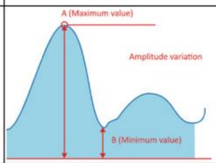
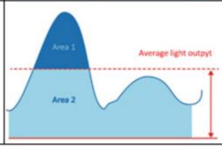
Index	Defined By	Definition Point	Formula	Index Range
Frequency	Universal	Time component of flicker	Main pulse per second	1 to ∞ Hz (in practice 50-2000 Hz)
Percent Flicker	Illuminating Engineering Society (IES)	A relative measure of the cyclic variation in the amplitude of a light.	 Percent Flicker = $\frac{A - B}{A + B} * 100\%$	0% to 100% The lower the percent flicker, the less substantial the flicker
Flicker Index	Illuminating Engineering Society (IES)	A measure of the cyclic variation taking into account the shape of the waveform.	 Flicker Index = $\frac{\text{Area 1}}{\text{Area 1} + \text{Area 2}}$	0 to 1 The lower the flicker index, less substantial the flicker.

Fig. 8 Unit of Flickers TLA Measurement

4.2.5 Percent Flicker: Amplitude Modulation Depth

Flicker frequency should be specified along with flicker percent or flicker index. Modern luminance and spectrometers can measure both the frequency of flicker and percent flicker, as well as the flicker index. While these measurements are relative, they do not directly indicate the impact on perception and health when using the lamp. However, both sets of data can be used to compare the adverse effects of lamps used in similar applications.

For example, relative flicker measurements are shown in Fig. 9, comparing flicker across various gadgets and drivers, while Fig. 10 compares flicker in different lighting products.

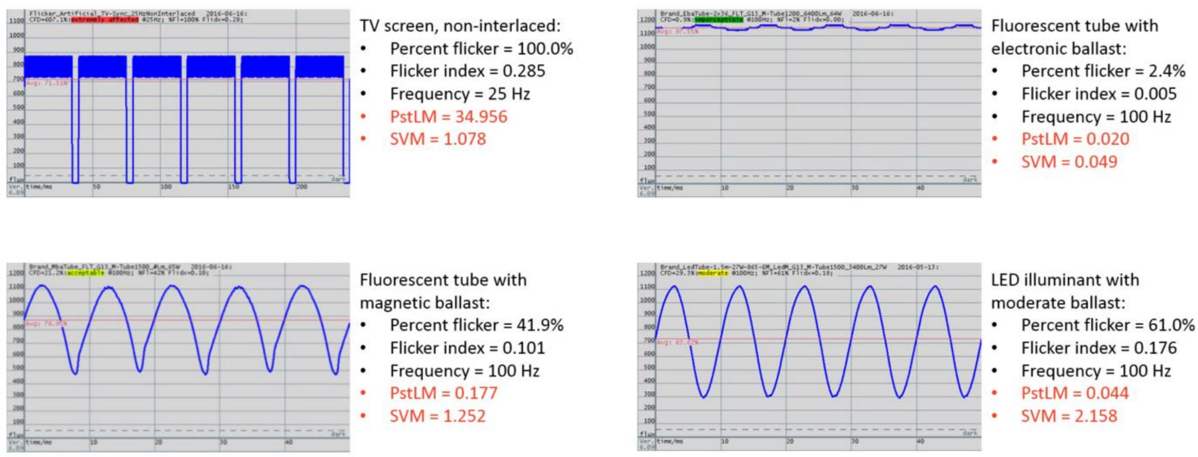


Fig. 9 Comparison Flicker in Different Gadgets and Drivers

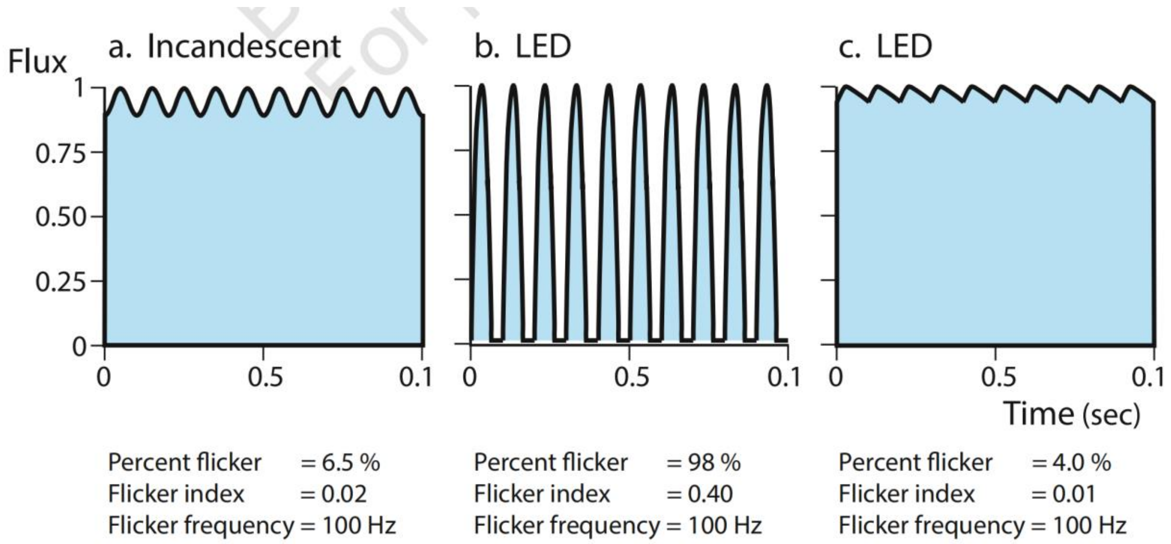


Fig. 10 Comparison of Flicker in Lighting Products

4.3 Flicker Sensitivity

For more detailed information and measurement of the visible flicker effect on perception and health, consider the visible flicker sensitivity curve, which relates to the eye-brain response varying with the frequency of modulated light and the average luminance of the flickering source. A flicker sensitivity value of 1 indicates that no visible flicker is perceived. Refer to Fig. 11 for the flicker sensitivity curve.

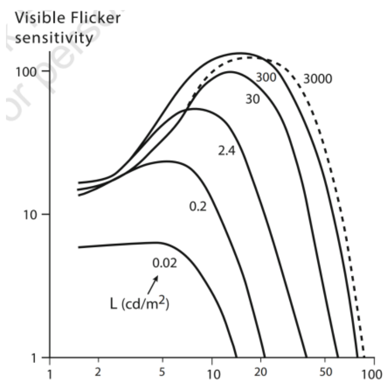


Fig. 11 Visible Flicker Sensitivity as a Function of Flicker Frequency for Different Average Luminance

4.4 Flicker Measurement Tools

In addition to measuring flicker index, flicker percent, and frequency using high-quality spectrometers and luminance meters, the IEC standards provide functional and design specifications for flicker measuring apparatus.

Fig. 12 below illustrates a typical flicker testing layout."

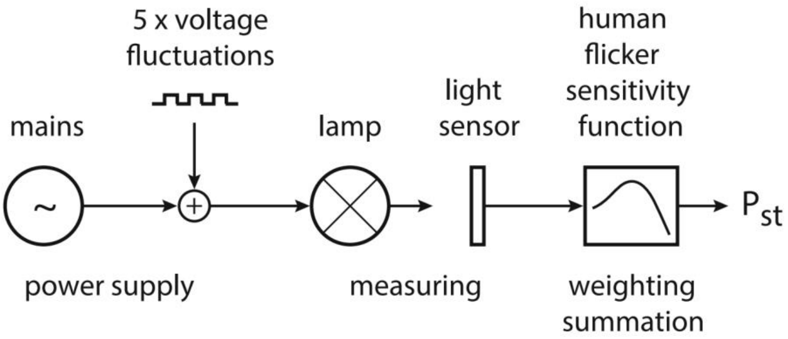


Fig. 12 IEC Flicker Testing Layout

Short-term flicker sensitivity measurement schematic principle of the IEC flicker meter involves assessing lamp flicker through five intervals of rectangular voltage fluctuations over minutes

It's important to note that even in the absence of visible flicker, stroboscopic effects may still occur, particularly at frequencies above 80 Hz, with the peak sensitivity occurring around 75 Hz. In practical situations, this issue often arises due to poorly designed drivers that generate square waves or other complex waveforms in LED systems.

5 PHOTOBIOLOGICAL SAFETY

5.1 Various Effect of Photobiological Hazards

Light in the visible spectrum of electromagnetic radiation can induce two types of effects on human health known as Photobiological Hazards:

a) Photochemical Interactions — Predominantly in the short wavelength range (UV region). The wavelength (energy) can excite electrons in cellular molecules, potentially leading to the breaking of chemical bonds. This can directly result in DNA damage or affect cells such as retinal photoreceptors.

b) Thermal Interactions — Predominantly in the long wavelength range (IR region). Absorption of light can cause an increase in temperature, which may lead to protein denaturation and cellular damage.

Various effects on the skin and eyes are explained in detail in Fig. 13.

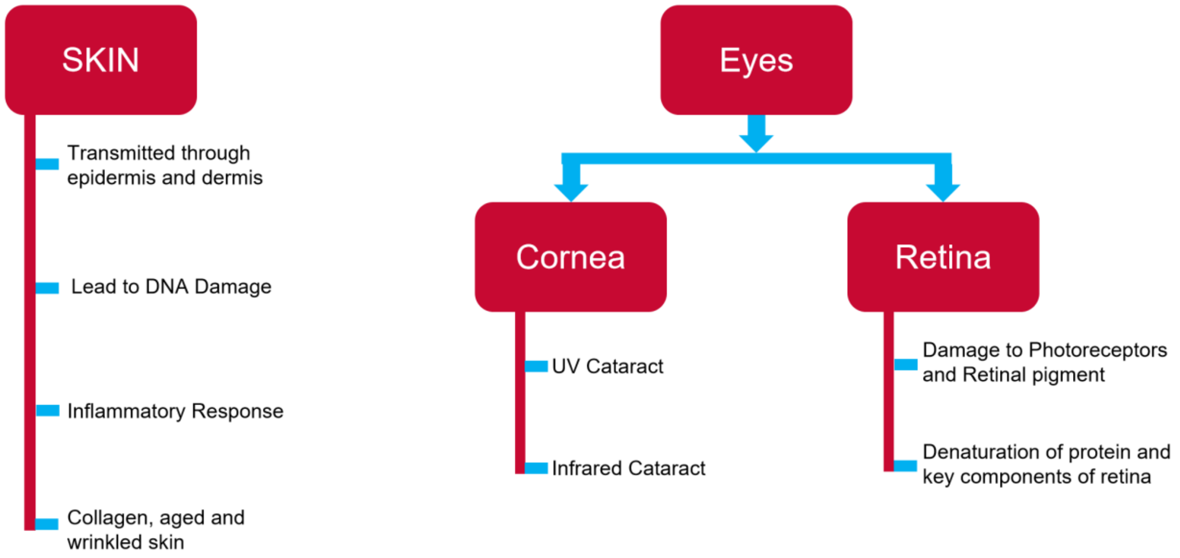


Fig.13 Radiation Effect on Human Body and Eye

5.2 Study of Radiation Spectrum and Blue Light

While studying the radiation spectrum and its interaction with living organisms, significant research was initially conducted on monkeys to examine the effects of radiation by Ham et al. in 1976 and 1978.

The chart in Fig. 14 below illustrates that light sources can produce a wide range of spectra spanning visible, IR, and UV ranges. UV and IR are further categorized based on their specific wavelengths

Let's now examine and analyze the real-life scenario of general lighting sources and their impact on IR and UV spectra.

LEDs used for general lighting typically emit light through blue phosphors or RGB combinations, which generate no UV radiation and minimal IR. Glass coatings in GLS bulbs and low-pressure discharge lamps (FL or CFL) effectively block UVC, UVB, and UVA wavelengths. Halogen and discharge lamps employ filters to block IR radiation, while UV quartz filters are used to block UV radiation. In LEDs and fluorescent lamps (FL), the IR emission is minimal; even at a distance of 20 cm, the IR strength is significantly reduced.

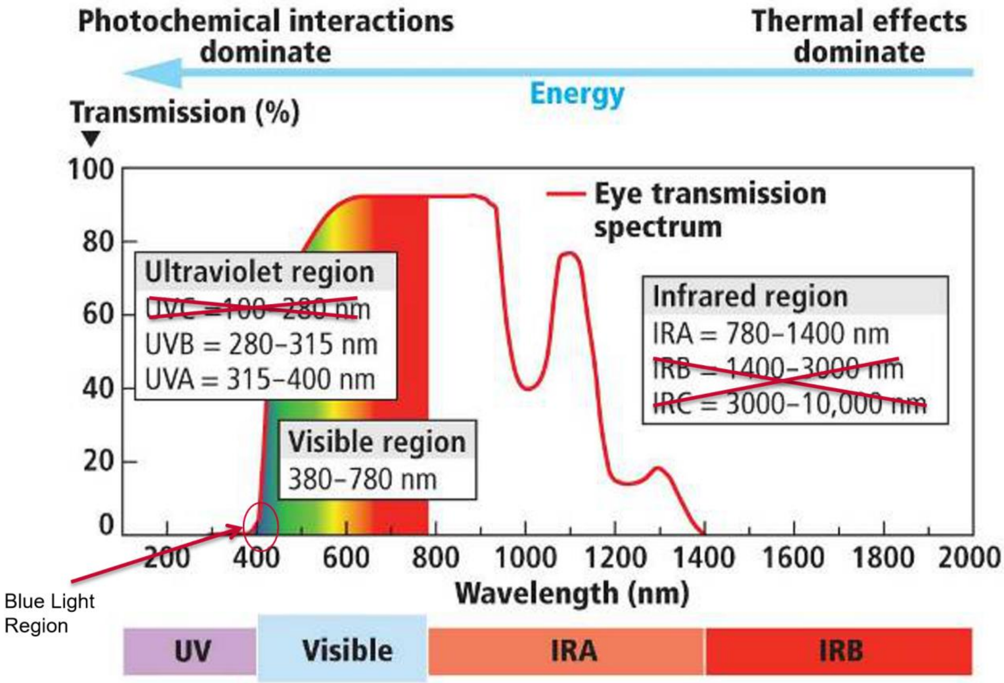


Fig. 14 Visible Spectrum Analysis

However, the wavelength range of 400 to 500 nm in visible light is associated with a relatively strong photochemical effect on retinal tissue, known as Blue Light Hazard, with its spectrum referred to as the action spectrum. Retinal damage, including to the fovea, can potentially be permanent. Blue light hazard is a concern specifically related to LED light sources and luminaires, as highlighted by studies from ICNIRP. Among these wavelengths, 440 nm is identified as posing the highest risk for retinal damage.

Several factors contribute significantly to blue light hazards, including the radiation power of the light source, duration of exposure, size and angle of the light source, viewing distance, eye movements, the action spectrum, and the eye's pupillary reflex

5.3 Standards

"It is evident that regardless of the visible light generation technology used in general lighting systems, ensuring safety for human beings is paramount, especially considering the blue light action spectrum falls within the visible region. Therefore, establishing standards for photobiological safety is crucial. (*See* IS 16108)

5.4 Risk Group

Measurement methods and limit values for radiance or irradiance are established for all types of hazards. Light sources and luminaires are categorized into risk groups (RGs) ranging from level 0 to 3. The information provided in Fig. 15 clarifies the risk group classification, their respective values, and details regarding their effects and exposure

RISK EVALUATION

HAZARDs	Symbol	Exposure Limits			Units
		Exempt	Low Risk	Mod Risk	
Actinic UV Skin and Eye	E_s	0.001	0.003	0.03	W/ sq. m
UVA Eye	E_{UVA}	10	33	100	W/ sq. m
Retinal Blue Eye	L_B	100	10000	4000000	W/sq. m/sr
Retinal Blue Eye, small source	E_B	1.0*	1.0	400	W/ sq. m
Retinal Thermal	L_R	28000/α	28000/α	71000/α	W/sq. m/sr
Retinal Thermal, weak visual stimulus**	L_{IR}	6000/α	6000/α	6000/α	W/sq. m/sr
Infrared radiation Eye	E_{IR}	100	570	3200	W/ sq. m

* Small source is defined as one with α <0.011 radian.
** Involve evaluation of non-GLS source

Risk Group	Philosophical Basis	Exposure Limits
Exempt (RG0)	No Photobiological Hazard	<Exempt
RG1	No photobiological hazard under normal behavioral limitation	Between Exempt to Low Risk
RG2	Does not pose a hazard due to aversion response to bright light or thermal discomfort	Between Low Risk to Mod Risk
RG3	Hazardous even for momentary exposure	Greater than Mod Risk

Fig. 15 Risk Group Classification with Exposure Limit

Once a product is tested according to the standard, it is classified into a risk group based on the results, as shown in the chart above.

a) RG0 - No Risk: There is no limit to exposure, meaning one can look directly at the light source for an unlimited time without any risk. No risk assessment or labeling is required for these light sources or systems.

b) RG1 - Low Risk: There is limited risk when exposed to the light source. Looking directly at the light source does not cause damage to the eyes.

c) RG2 - Moderate Risk: Exposure to the light source may potentially damage the eyes, but our natural aversion reaction prevents immediate harm. The exposure is generally pleasant, and the eye-brain combination naturally protects itself. This exposure is typically short-term. Labelling with a symbol (*see* to Fig. 16) on the packaging is mandatory for these products

Fig. 16Mandatory Symbol on the Packing for RG2 Products

d) RG3 - High Risk: Even a brief glance into the light source can cause damage to the eyes. Therefore, luminaires classified under RG3 are not permitted according to safety standards.

The data presented in Fig. 17 illustrates the relationship between risk groups and exposure time in seconds versus the radiance power of the light source.

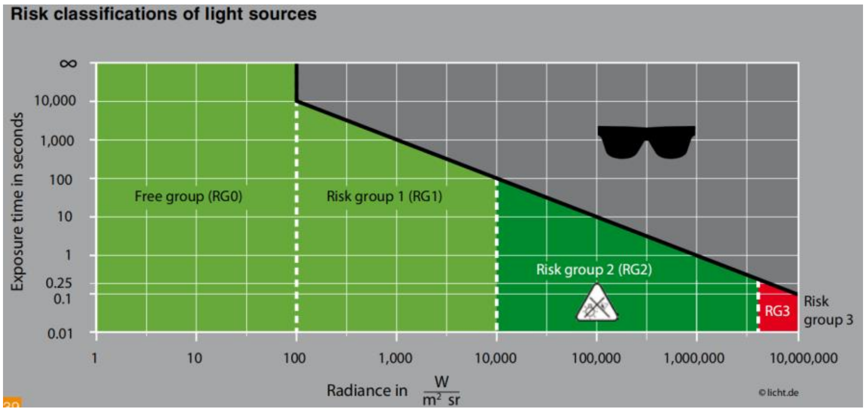


Fig. 17 Risk Group with Exposure Time

5.5 Survey of Light Source Wise Risk Group

The risk classification of general lighting systems is determined through rigorous testing and evaluation of properly designed and manufactured products or systems.

a) LED Chips— LED chips must undergo measurement and testing to determine their risk group classification. Classification declaration is required according to safety standards. Good quality LED chips used for general lighting typically fall into RG0 or RG1. If classified as RG0 or RG1, labeling is not required.

b) LED Lamps, LED Retrofit and Non-Retrofit Lamps— These products must undergo classification after valid safety testing. Generally, these products fall into RG0 or RG1 groups. Therefore, according to standards, labeling is not required.

c**)** LED Modules— LED modules consist of various combinations with different optics, necessitating testing prior to use. If they fall into RG0 or RG1, labeling is not required as per standards.

d) Incandescent Lamps (GLS Bulb), Tungsten Halogen Lamps, Fluorescent Lamps, CFL Retrofit and Non-Retrofit Lamp, Induction Lamp, Coated High Pressure Mercury

Vapor, Coated Metal Halide (Halogen Based), Low and High Pressure Sodium Lamps — These lamps typically pose no risk and fall under RG0. Therefore, labeling is not required. However, lamps containing mercury must comply with environmental safety norms for disposal.

e) Clear Metal Halide & Mercury Vapor Lamps— These lamps have a risk group and require testing to classify them. They generally fall under RG2, necessitating labeling according to standards.

f) Dichroic Halogen Lamps, Special Halogen for Projection, Photography, Stage Lighting & any Other Special Lighting— Testing is essential to classify these lamps. They are often categorized under RG2, requiring labeling as per standards.

5.6 Test and Measurement

Spectral radiometric measurements are essential for determining the risk group of light sources or products. Laboratories must utilize high-quality instruments to conduct these tests. Radiometric measurements are expressed in terms of Radiance (R) and Irradiance.

Radiance (R) (*see* Fig. 18) of a source emitting from area (A) is defined as the radiation power (P) emitted from A and propagating in solid angle Ω, divided by the product of area A and solid angle Ω: $R = P / (A \times \Omega)$. The SI unit for radiance is $W / (m^2 \cdot sr)$.

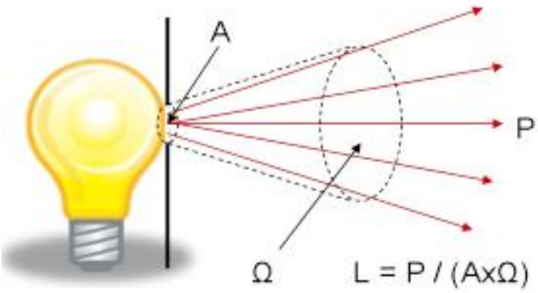


Fig. 18 Radiance

Steradian (sr) is the SI unit for measuring solid angles, defined by the solid angle (Ω) that projects onto the surface of a sphere with a radius (r), where the area (A) equals r^2. It is independent of distance and defined at every point on the emitting surface, accounting for position and angle of observation.

Irradiance (E) (*see* Fig. 21) is defined as the power per unit area of electromagnetic radiation incident on a surface. The SI unit for irradiance is W/m^2."

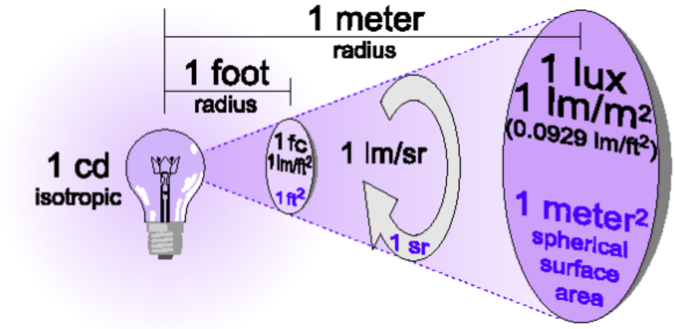


Fig 19 Irradiance

Irradiance decreases in proportion to the square of the distance from the source for uniform radiation. When comparing irradiance levels from different sources, the distance from the source must be considered. A standard distance of 50 cm is often used for such measurements. Irradiance is independent of solid angles, allowing multiple sources to be combined to achieve a desired power output per square meter.

Photo-biological testing instruments typically include components such as a Spectroradiometer, Retina Radiance Meter, Optical Rail, Power Supply/Power Meter, etc. For detailed test procedures, refer to IEC 62778.

Figure 20 depicts the setup for photobiology testing, Figure 21 shows a detector, Figure 22 illustrates a spectroradiometer, and Figure 23 displays a power supply unit.

Fig. 20 Photobiology Set Up

Fig. 21 Detector

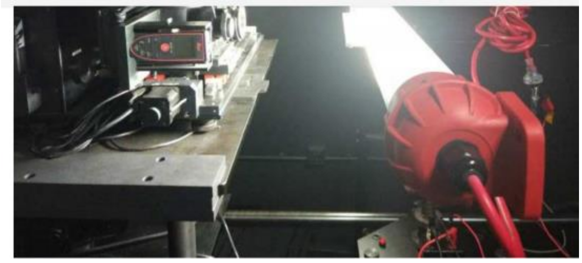


Fig 22 Spectroradiometer

Fig 23 Power Supply Unit

For lighting installations, a simplified method has been proposed in the technical report based on various measurement statistics in IEC TR 62471.