WHITE PAPER

A Comprehensive Approach to Evaluating the Impact of Blue Light on Visual Health and Sleep

eyesafe®

Eyesafe® Display Requirements 3.0:
A Comprehensive Approach to Evaluating the Impact of Blue Light on Visual Health and Sleep

INTRODUCTION

In today's world, digital devices have become deeply woven into nearly every part of daily life—from work and learning, to personal health and entertainment. Our waking hours are filled with screens, as traditionally offline activities, such as fitness, shopping, and social interactions, have increasingly shifted online.

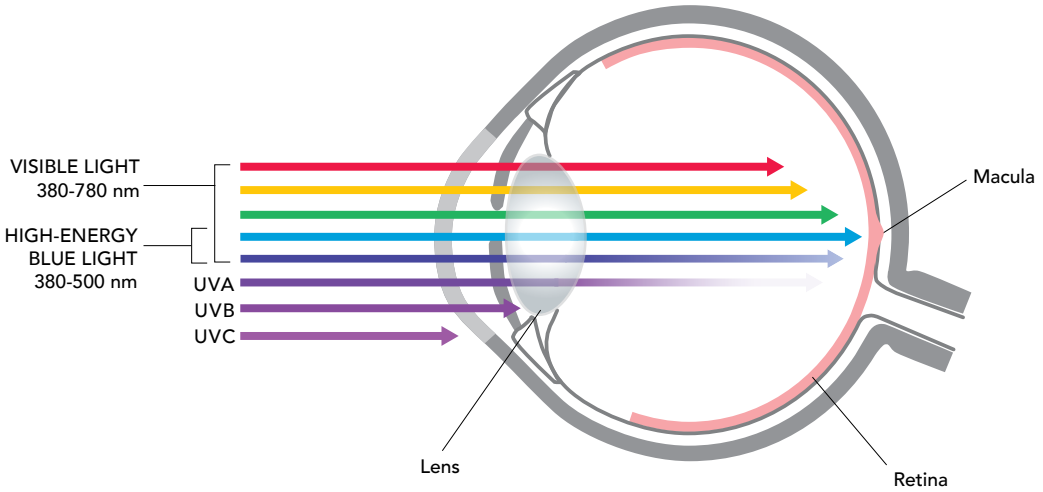
The rapid expansion of digital device use comes with unique challenges. Our digital devices emit high-energy visible (HEV) light, ranging from 380 to 500 nanometers (nm). HEV light, also known as blue light, is a color in the visible light spectrum that can be seen by human eyes. It's a short wavelength, high energy light that our eyes cannot effectively filter, which means it is able to penetrate the cornea, the lens, and on through to the retina.[1] Studies suggest excessive blue light may produce oxidative and phototoxic damage to cells in the cornea and retina of the eye.[2]

The immediate effects of blue light exposure can be felt by users daily, influencing not only visual comfort but also circadian rhythm and sleep quality.[3] As this issue gains prominence, the potential long-term health implications of cumulative blue light exposure is being actively explored.

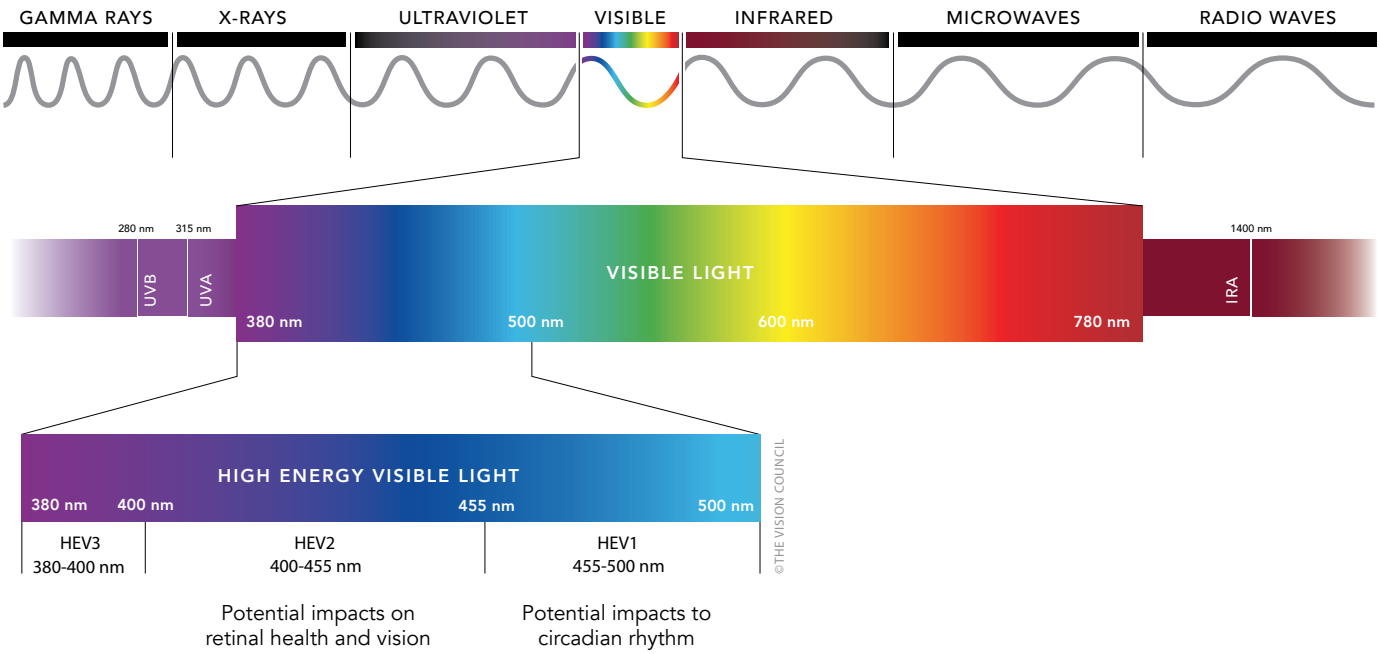
Existing blue light standards and requirements focus primarily on the wavelengths most likely to impact our eyes, but often overlook blue light's effects on circadian rhythms. This narrow scope underscores the need for a more comprehensive set of guidelines that address both visual and sleep impacts.

This paper outlines Eyesafe Display Requirements 3.0: a new approach to measuring blue light emissions associated with potential visual and sleep-related impacts and establishes detailed criteria to elevate the industry standards for consumer electronics.

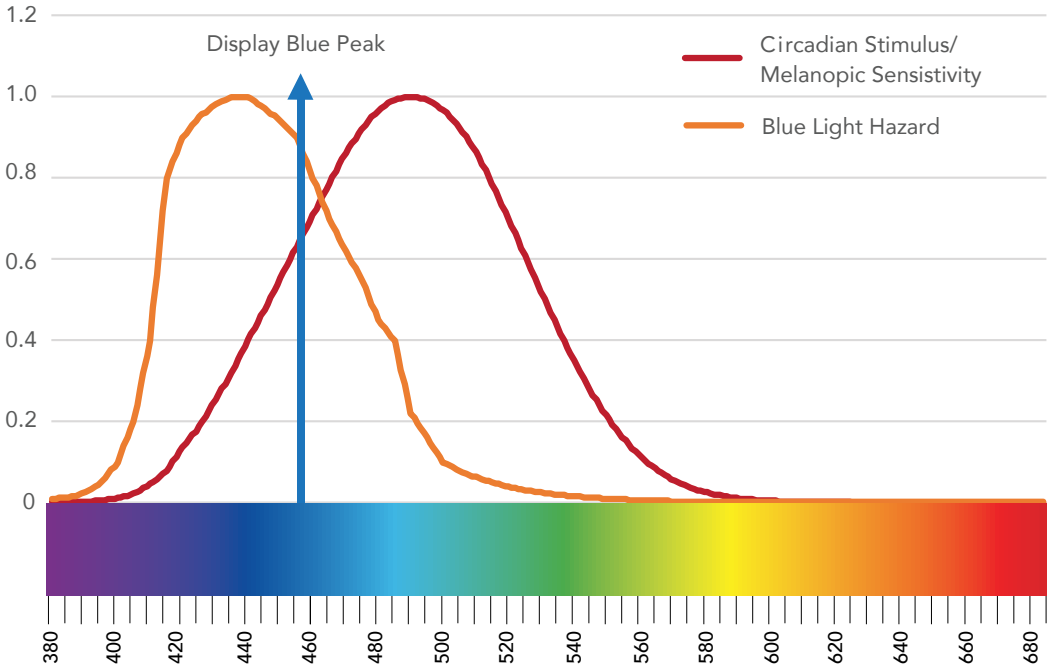
Visible light is transmitted to the retina from natural and artificial light sources between the range of 380-780 nm. The cornea and lens of the adult human eye are effective at limiting UV rays from reaching the light-sensitive retina. HEV blue light is different, passing through the cornea and lens to the retina and macula.



Certain bands of blue light within the visible light spectrum have been linked to health concerns. High-energy visible (HEV) blue light ranges from 380 to 500 nm. The blue light rays that border UV (at 380 nm) have the highest energy.



BLUE LIGHT HAZARD VS CIRCADIAN STIMULUS



Eyesafe Display Requirements are evolving to accommodate both the Blue Light Hazard and the Circadian Stimulus curves shown.

The Effects of Blue Light on Eye Health

Research studies on the effect of light on the ocular system show two main types of potential retinal damage: photothermal and photochemical. The potential damage from blue light is photochemical, involving injury to the eye in the range of 380-550 nanometers (nm). This could potentially arise from exposure to very bright blue-rich artificial light sources (e.g. metal halide, LEDs), hence the naming of these wavelengths as the blue light hazard.[4, 5, 6, 7, 8, 9]

Photochemical damage to the retina is thought to be irreversible and accumulates depending on exposure, duration, and intensity. Variables of exposure may include high intensity within a short time or low intensity over an extended period.

Epidemiologic studies have shown that age-related macular degeneration (AMD), the most common cause of blindness/vision impairment, may potentially be caused by the photooxidative retinal damage from cumulative exposure to natural solar blue light over a long time (years, even decades).[10, 11] With the increased presence of LCD and OLED displays in our environment, studies have only recently begun to evaluate the potential long-term effect of their low-intensity blue light emission, starting with animal studies, and even suggesting a revision of available exposure limit values which have limited scope for addressing high-intensity lighting systems.[12, 13, 14]

The Effects of Blue Light on Circadian Rhythms

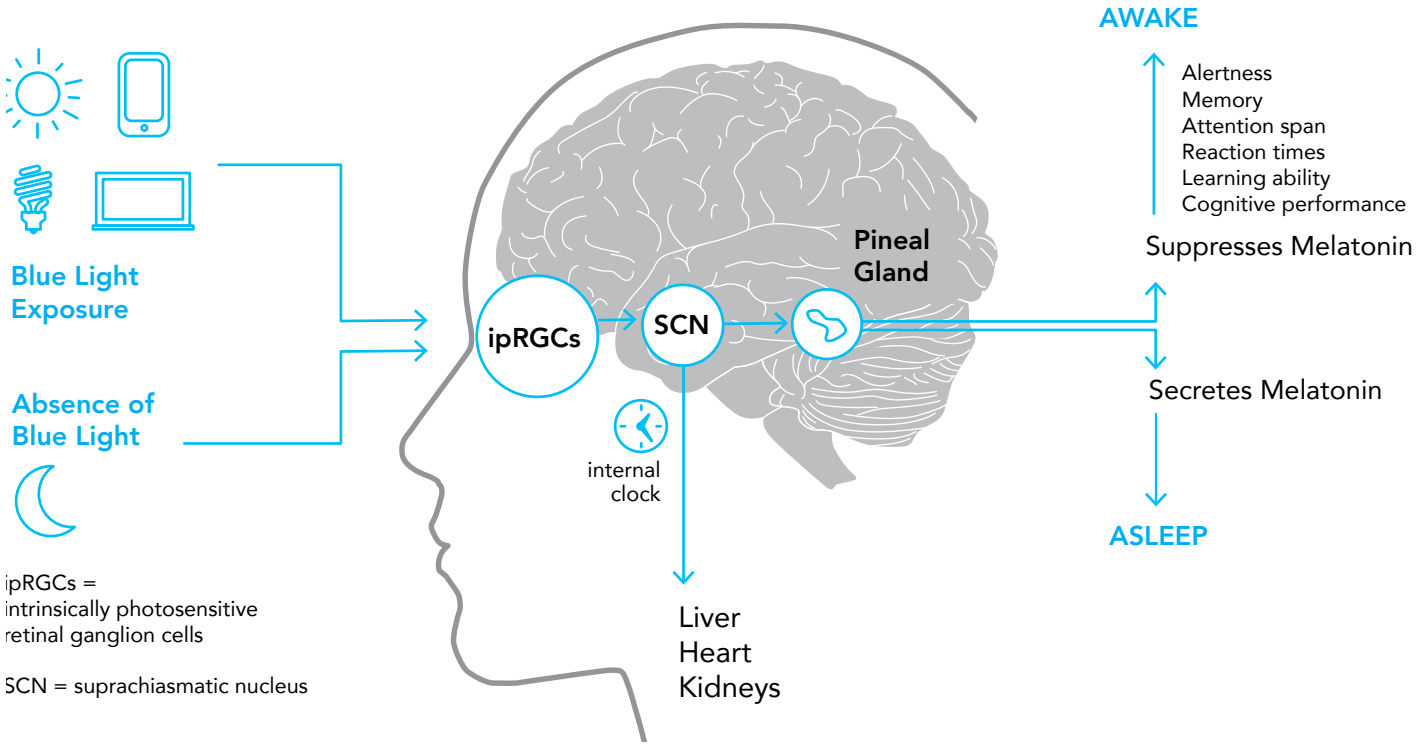
The intricate relationship between light and our biological rhythms is fundamentally mediated by a specialized group of retinal cells known as intrinsically photosensitive retinal ganglion cells (ipRGCs). These cells play a crucial role in regulating circadian rhythms—our body's internal clock that governs various physiological processes over a 24-hour cycle. In nature, ipRGCs are sensitive to the daily cycle of sunrise and sunset, with peak blue light emission at midday, eventually scattering to reduce blue light during sunrise and sunset.

Unlike traditional photoreceptors that primarily contribute to image formation, ipRGCs are sensitive to ambient light levels — including not just daylight, but also artificial lighting and display screens — and communicate directly with the hypothalamus region of the brain, which governs sleep-wake cycles and other related functions.[15]

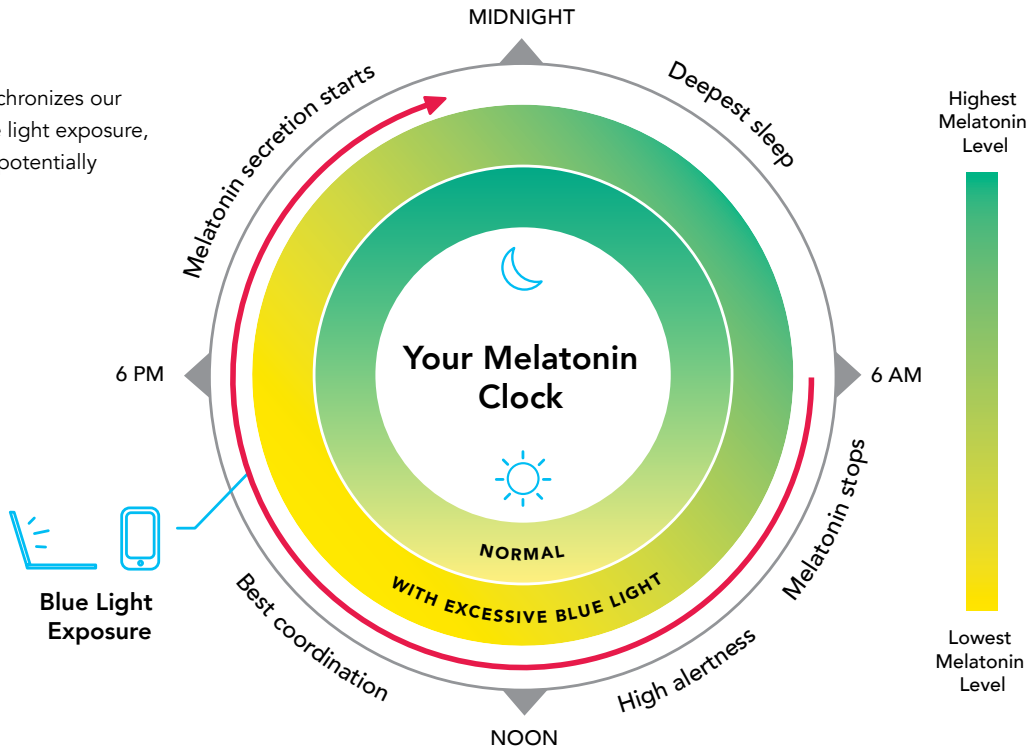
When exposed to light, ipRGCs send signals to the brain, which helps synchronize our biological functions with the external environment. This synchronization influences not just sleep-wake cycles but also a myriad of bodily processes including hormone secretion, metabolism, and cognitive performance. Disruptions in this delicate balance, often exacerbated by artificial lighting and lifestyle factors, can lead to a range of health issues, such as sleep disorders, mood disturbances, and metabolic dysfunctions. Understanding the role of ipRGCs in circadian regulation is essential for developing strategies to optimize health and well-being in an increasingly light-polluted world.[16]

Eyesafe is working to help reduce the amount of light that impacts these circadian rhythms. IpRGCs, like the visual photoceptors in the retina, are sensitive to different wavelengths. When exposed to too much of certain types of light at the wrong time, our bodies lose track of the natural cycles of sunrise and sunset, disrupting melatonin release and sleep-wake cycles. Our goal is to help the world sleep better by regulating or diminishing the wavelengths of light that impact this delicate system. With better sleep, human beings have better digestion, mood, and cognitive ability.[17, 18]

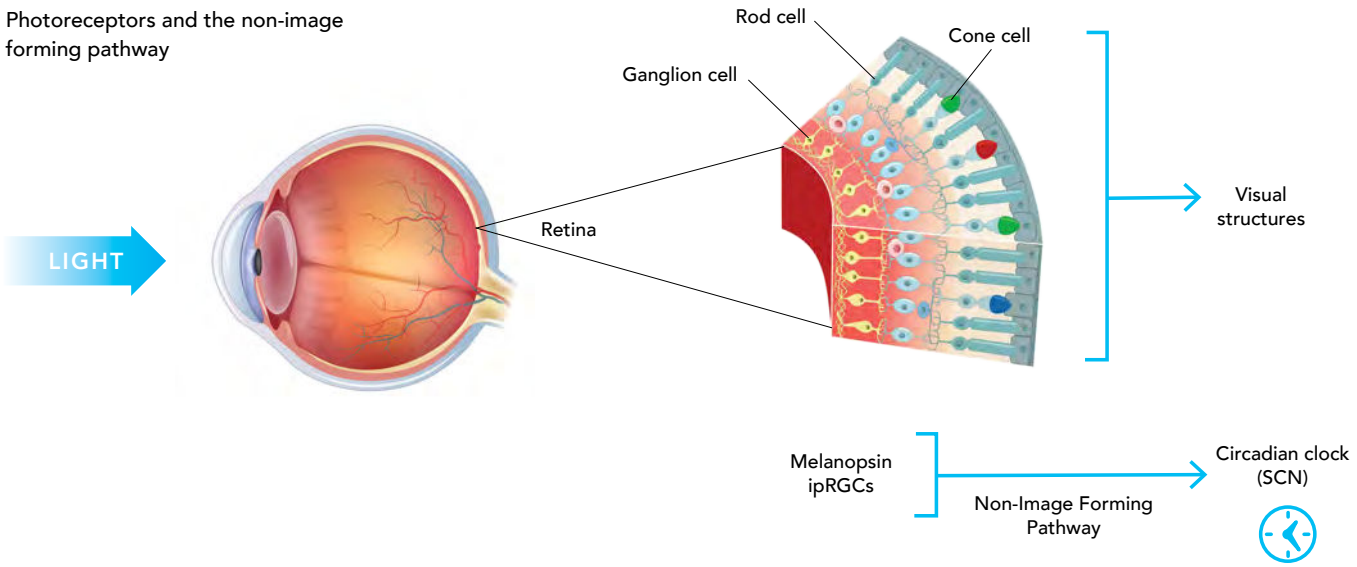
Blue light, through ipRGC pathways, affects sleep cycles by the secretion or suppression of melatonin. Ordinarily the progression of daylight from sunrise to sunset maintains the normal awake to sleep cycle through nonimage brain pathways.



Blue light, and its absence, synchronizes our melatonin clock. Excessive blue light exposure, especially before nightfall, can potentially disrupt the melatonin clock.



Photoreceptors and the non-image forming pathway



The wavelengths between 435-440 nm is considered the peak toxic blue region, posing the most potential risk to our vision. The wavelengths between 480-500 nm represent peak melanopic sensitivity, affecting circadian rhythm and sleep.

	EMISSIONS (nm)	BLUE LIGHT HAZARD FUNCTION*
UV	200-380	0.00
HIGH-ENERGY VISIBLE LIGHT	380	0.01
	385	0.01
	390	0.03
	395	0.05
	400	0.10
	405	0.20
	410	0.40
	415	0.80
	420	0.90
	425	0.95
	430	0.98
	435 Peak	1.00
	440 Peak	1.00
	445	0.97
	450	0.94
	455	0.90
	460	0.80
	465	0.70
	470	0.62
	475	0.55
	480	0.45
	485	0.40
	490	0.22
	495	0.16
	500	0.10

AREAS OF RESEARCH

Ocular Surface Impacts

Cataracts

Retinal Cell Impact

Potential for Age-related Macular Degeneration

*American National Standards Institute (ANSI) Z87.1 Table
International Commission on Non-Ionizing Radiation Protection (ICNIRP) Guidelines, most toxic portions of the blue spectrum*

	EMISSIONS (nm)	CIRCADIAN IMPACT**
UV	200-380	0.00
HIGH-ENERGY VISIBLE LIGHT	380	0.00
	385	0.00
	390	0.00
	395	0.01
	400	0.01
	405	0.02
	410	0.05
	415	0.08
	420	0.14
	425	0.19
	430	0.25
	435	0.32
	440	0.40
	445	0.47
	450	0.55
	455	0.63
	460	0.71
	465	0.79
	470	0.86
	475	0.92
	480 Peak	0.97
	485 Peak	0.99
	490 Peak	1.00
	495 Peak	0.99
	500 Peak	0.97
	505	0.92
	510	0.86
	515	0.79
	520	0.70
	525	0.61
	530	0.52
	535	0.43
	540	0.35
	545	0.28
	550	0.22
	555	0.16
	560	0.12

AREAS OF RESEARCH

Circadian Rhythm Impact

Melatonin Supression

**CIE System For Metrology of Optical Radiation for IPRGC-Influenced Responses to Light, CIE S 026/e:2018*

Eyesafe® Display Requirements 3.0

In 2022, Eyesafe introduced Eyesafe Display Requirements 2.0 to quantify blue light radiation levels and their potential impact to human eyes,[19, 20] using the aforementioned standards' spectral weighting function B(λ) for retinal blue light hazard and overseeing all-optical hazards in the visible spectral range. In tandem, Eyesafe introduced Radiance Protection Factor (RPF®) to help consumers evaluate the level of blue light protection of a given device.

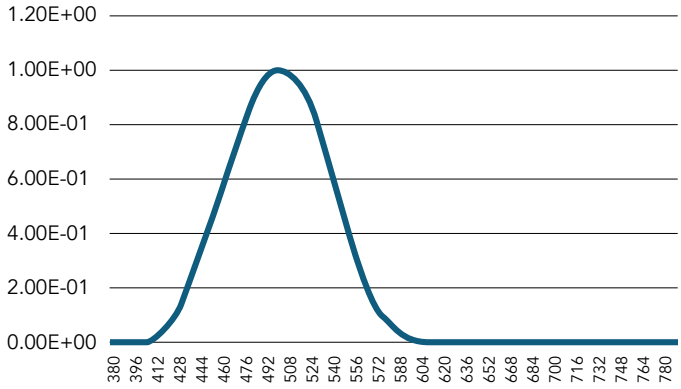
Eyesafe Display Requirements 3.0 measures both RPF and a new optional metric, Circadian Protection Factor (CPF) to evaluate the blue light protection provided by a device in the wavelengths affecting both eye health (peak 435-440 nm) and melatonin/sleep-wake cycles (peak 480-500 nm), providing a more comprehensive measure of blue light on health.

The International Commission on Illumination (CIE) published the universally recognized standard action spectra for melanopic impact that is used by all industries that work with artificial light. The peak sleep-wake impact is at 490 nm, which is between traditional blue and green on RGB displays. Thus, both blue and green display output typically impact the metric. For comparison, the Blue Light Hazard function used to calculate RPF has a peak impact between 435 nm and 440 nm, entirely in the blue spectrum of the backlight or OLED.

It is worth noting that display spectra can be shaped to minimize both hazardous energy and circadian impact. The peak and full width-half max (FWHM) of the blue emission is critical for the hazard and RPF score. Likewise, the separation of blue and green emissions by the display is critical both for expanding the color gamut and avoiding emission at peak melatonin suppression.

Below are the circadian-related action spectra as published by CIE: [21]

CIE ALPHA-OPIC MELANOPIC ACTION SPECTRA



CIE System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light.

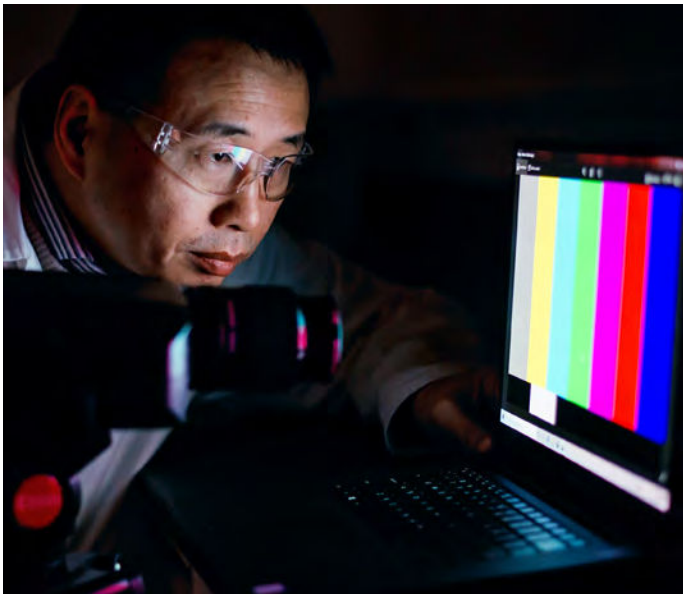
Building on the foundation of the Eyesafe Display Requirements 2.0 released in 2022—which prioritized the RPF metric and color accuracy—the new requirements introduce a significant enhancement. Circadian Protection Factor (CPF) is a new metric to evaluates how effectively a display minimizes blue light exposure, addressing its impact on circadian rhythms and essential biological processes.

Higher RPF and CPF scores indicates better protection against blue light, meaning the device is less likely to interfere with visual comfort and sleep. This is particularly important for smartphones, tablets and computers, which are often used in the evening when our bodies are preparing for sleep.

Both RPF and CPF are based on the spectral output of the display and calibrated to a scale of 0-100, with a 35 the minimum passing level.

The full brightness default mode white screen is measured with a spectroradiometer and then weighted by the CIE melanopic action spectra and a brightness-equivalent factor for ipRGCs. The data is then integrated by wavelength and this result is known as the MEDL, or Melanopic Equivalent Daylight (D65) Luminance, as calculated by CIE standards. Much as luminance defines the brightness of light to human visual photoreceptors, MEDL defines an equivalent brightness value for the non-visual ipRGCs whose signals the brain uses to control circadian rhythms.

The MEDL is adjusted to the Eyesafe CPF scale based on a survey of industry results, with a level of 35 as the minimum to meet passing criteria, and 100 representing an aspirational maximum score.



Eyesafe Display Requirements 3.0 Criteria

Blue light toxicity (RPF), correlated color temperature (CCT) and color gamut requirements are identical to Eyesafe Display Requirements 2.0. This provides a base level of radiance protection and an acceptable level of user experience and color accuracy that many blue light solutions cannot deliver.

If RPF and color performance specifications are met, manufacturers can have their product tested against CPF criteria. CPF is a new, optional requirement, resulting in a CPF score. The minimum passing score for both RPF and CPF is 35. Scores are rounded down after calculation to the next lower value of 35, 40, 50, 60, 70, 80 and 90.

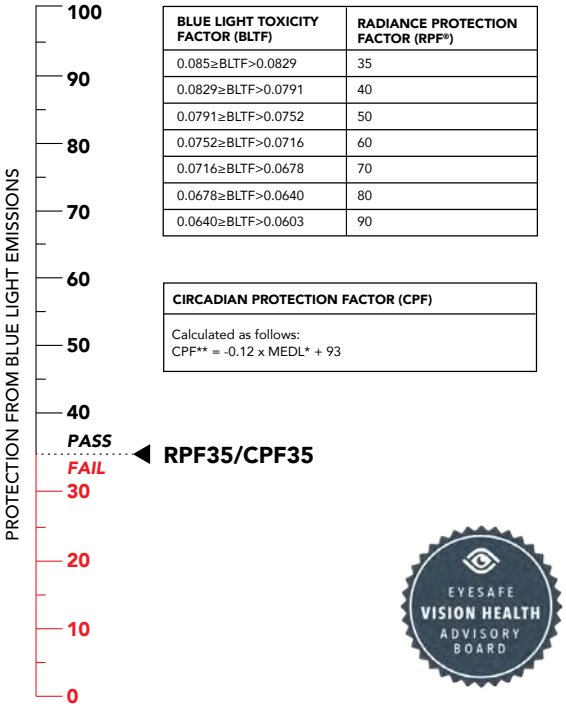
EYESAFE® DISPLAY REQUIREMENTS 3.0		
High Energy Visible Light – Toxicity	Weighted blue light toxicity emissions based on ICNIRP Guidelines	Radiance Protection Factor (RPF®) Pass/Fail of verification will be at RPF35. Measurement of blue light toxicity, based on extensive health research and optical testing. The RPF scale is third-party tested and verified. Higher RPF numbers indicate greater reduction of toxic high-energy blue light emissions.
Color Performance	Color Gamut Coverage %	For sRGB color mode: ≥95% of standard sRGB color space in CIE 1931; 1976 For Adobe RGB color mode: ≥90% of standard Adobe RGB color space in CIE 1931; 1976 For DCI-P3 color mode: ≥90% of standard DCI-P3 color space in CIE 1931; 1976 For NTSC color mode: ≥72% of standard NTSC color space in CIE 1931; 1976* *For battery powered products NTSC color mode : ≥45% of standard NTSC color space in CIE 1931; 1976
Optional: Eyesafe® Circadian Display Requirements		
High Energy Visible Light – Circadian	Emissions based on the CIE System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light	Circadian Protection Factor (CPF) must be CPF35 or higher. CPF is calculated as follows: CPF** = -0.12 x MEDL* + 93 * Melanopic a-opic equivalent daylight (D65) luminance, cd.m 2 as calculated by CIE S 026 alpha-opic Toolbox ** Final CPF rating is rounded down to next lower multiple of 10 (except for 35 <= CPF < 40 which rounds to 35)

RPF
Radiance Protection Factor for Display

RPF designates the level of high-energy blue light reduction in digital displays. Higher RPF numbers indicate greater reduction of toxic high-energy blue light emissions. Grounded in extensive research, validated through third-party testing, and endorsed by key ophthalmologists and optometrists in the eye care community.

CPF
Circadian Protection Factor for Display

CPF designates the level of circadian stimulus reduction in digital displays. The CPF scale measures the effect of blue light emission on circadian rhythm. Higher CPF numbers indicate that a device offers better protection against circadian disruption. Based on research, third-party verified, and supported by leaders in the eye care community.



BLUE LIGHT TOXICITY FACTOR (BLTF)	RADIANCE PROTECTION FACTOR (RPF®)
0.085≥BLTF>0.0829	35
0.0829≥BLTF>0.0791	40
0.0791≥BLTF>0.0752	50
0.0752≥BLTF>0.0716	60
0.0716≥BLTF>0.0678	70
0.0678≥BLTF>0.0640	80
0.0640≥BLTF>0.0603	90

CIRCADIAN PROTECTION FACTOR (CPF)
Calculated as follows: CPF** = -0.12 x MEDL* + 93

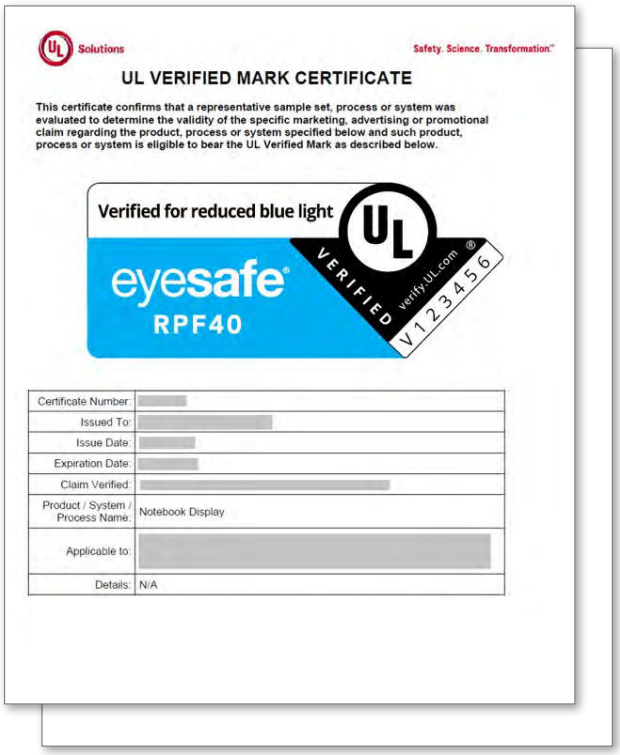
EYESAFE VISION HEALTH ADVISORY BOARD

UL Solutions Verification

Eyesafe Display Requirements 3.0 performance is verified by UL Solutions. UL Solutions tests products using an objective, science-based protocol and evaluates the validity of each marketing claim. Products are sent to UL Solutions for verification. When a product's marketing claim has been Verified, customers receive a UL Solutions / Eyesafe Verified Mark with the Verified claim, a marketing toolkit, a unique identifier and a page on verify.UL.com.

Measurement against RPF, CCT and Color Gamut criteria happens first, and with acceptable results, manufactures may opt to have their product measured against the Circadian Protection Factor (CPF) criteria. While this is optional, it creates an opportunity for OEMs to address the growing consumer need for reduced blue light.

Upon verification, displays are assigned an RPF and CPF (optional) number, which ranges from 35 to 100, with higher numbers indicating greater blue light reduction. The scale was developed by Eyesafe with input from doctors and healthcare leaders to offer a clear, standardized measure of blue light reduction. For more details on the verification process, please visit eyesafe.com/ul-verification.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UL VERIFIED MARK CERTIFICATE

This certificate confirms that a representative sample set, process or system was evaluated to determine the validity of the specific marketing, advertising or promotional claim regarding the product, process or system specified below and such product, process or system is eligible to bear the UL Verified Mark as described below.

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VERIFIED
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Certificate Number:	
Issued To:	
Issue Date:	
Expiration Date:	
Claim Verified:	
Product / System / Process Name:	Notebook Display
Applicable to:	
Details:	N/A

Conclusion

Eyesafe Display Requirements 3.0 represent a pivotal step forward in addressing the multifaceted impacts of blue light on human health. By incorporating comprehensive metrics like RPF and the newly introduced CPF, these requirements set a new benchmark for evaluating and mitigating the effects of blue light emissions on both visual health and circadian rhythms.

As digital device usage continues to grow, the need for meaningful, science-based guidelines has become essential. Eyesafe Display Requirements 3.0 fill an important gap by expanding beyond traditional blue light hazard measurements to also encompass circadian-related effects, offering manufacturers a pathway to innovate and meet the increasing consumer demand for health-conscious technologies.

Through independent testing and verification by UL Solutions, the reliability and credibility of these marketing claims help consumers make informed choices about their devices. Eyesafe Display Requirements 3.0 reflect a meaningful advancement in the measurement of blue light, setting the stage for technology designs that prioritize low blue light emissions.

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FOR MORE INFORMATION

Researchers and eye care providers are increasingly concerned about the potential health impacts of high-energy blue light exposure. Eyesafe Display Requirements have been developed to limit blue light emissions based on the growing body of research.

About Eyesafe

Eyesafe Inc. is the worldwide supplier of advanced blue light mitigating technology, solutions, and standards. With pioneering products and services, in collaboration with healthcare, Eyesafe is shaping the future of consumer electronics designed for human health. Eyesafe® Standards, Eyesafe® technology, and the associated intellectual property portfolio is developed by a world-class team of eye doctors, engineers, and scientists with decades of experience in electronics, display materials, light management, optometry, and ophthalmology. The Eyesafe® brand is trusted by consumers and integrated in millions of digital devices from Dell, HP, Lenovo, ZAGG and others. Eyesafe was recently ranked #5 in the computer hardware category in the Inc. 5000 Fastest-Growing Private Companies in America. Learn more at eyesafe.com

About UL Solutions

A global leader in applied safety science, UL Solutions (NYSE: ULS) transforms safety, security and sustainability challenges into opportunities for customers in more than 110 countries. UL Solutions delivers testing, inspection and certification services, together with software products and advisory offerings, that support our customers' product innovation and business growth. The UL Mark serves as a recognized symbol of trust in our customers' products and reflects an unwavering commitment to advancing our safety mission. We help our customers innovate, launch new products and services, navigate global markets and complex supply chains, and grow sustainably and responsibly into the future. Our science is your advantage.

Developed with Doctors

Developed with the Eyesafe Vision Health Advisory Board, a group of leading optometrists and ophthalmologists from across the globe. These distinguished eye doctors consult with Eyesafe to provide valuable insights that help drive research regarding the effects of blue light on the eyes and brain. They also help guide the development of Eyesafe® technology and industry standards to limit blue light emitted by the displays of electronic devices and other sources. Eyesafe industry-leading low blue light certification is based on optical testing and research.

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