Outdoor Advertising Association of America

OAAA Blue LED Light Guidance: Q & A

Abstract - In 2016, the American Medical Association (AMA) published guidance regarding the level of exposure to blue light from Light Emitting Diodes (LEDs) used in street lighting fixtures. The guidance warned that too much blue light can cause excessive nighttime glare and can suppress melatonin production.

This document addresses several points raised by the AMA guidelines indicating that LED signage does not come close to reaching the exposure levels needed to cause either a health risk or harmful conditions.

Background

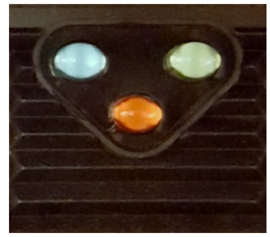
LED's have long lifetime, good power efficiency and great reliability. These and other benefits has made this technology very commonplace. As a result, there are wide ranges of applications that leverage LED (light emitting diode) technology in the lighting industry.

Two of the more common light emitting diodes in the lighting industry use either "White LEDs", used in applications such as street lighting, LED backlit phones, and computer tablets, or RGB LED's (red, green, and blue diodes) used in applications such as scoreboards and outdoor sign displays. One of many differences between these lighting methods is the manner in which each generates a white light. White LED's begin with pure blue diodes and then cover them with phosphorous coating to generate white light. RGB LED's consist of three separate diodes that are combined to generate white light.

Recent health and public safety concerns regarding the "blue light" contribution in White LED applications are more concerned with "White LEDs". The 2016 American Medical Association recommendations are based upon research of street lighting using White LEDs. However, these concerns should not be directly applied to "RGB LEDs, such as those used in the OOH Media industry (digital billboards).

Digital billboards used in the OOH Media industry do not use "White LED" technology.

White LED used in lighting industry



RGB LED Pixel used in OOH Media

In essence, digital billboards employing RGB LED technology do not deliver the same constant "blue rich" wavelength of white light as White LED technology used in street lighting, which are the subject of the (American Medical Association (AMA) report issued in 2016[1]) and should not be subject to the same regulatory scrutiny.

A Question & Answer (Q & A) document follows, which provides guidance to OOH media interests and others.

1. Can you put digital billboards in perspective to street lighting?

The number of digital billboards in the United States is dwarfed compared to street lights. For example, in the United States alone there are over 26 million street lights[2]. The Outdoor Advertising Association of America (OAAA) reports that as of September 1, 2016, there are a total of 6,700[3] digital billboards in the USA. This equates to one digital billboard for every 3,880 street lights.

The comparisons reveal a similar disparity with conventional billboards. According to OAAA, digital billboards are less than 2 percent of the nearly 400,000[4] billboards installed in 46 of the 50 states, Puerto Rico, and the District of Columbia. Digital billboards are not as commonplace as street lights or traditional billboards.

2. How much glare is too much?

LED lighting intensity must be at a level in excess of 10,000 candelas/square meters (nits) to be considered a risk to a person's retina[5]. This level is not applicable to digital billboards. Although some LED digital billboards have a maximum daytime capacity near this number, off-premise digital billboards owned by OAAA member companies are not operated at this level[6]. During nighttime

[1] Human and Environmental Effects of Light Emitting Diode (LED) Community Lighting, Presented by: Louis J. Kraus, MD, Chair, American Medical Association http://darksky.org/wp-content/uploads/bsk-pdf-manager/AMA_Report_2016_60.pdf

[2] Streetlights: Changing our night sky, one lamppost at a time, The Boston Globe, By Edward Smalley, August 2, 2012, https://www.bostonglobe.com/opinion/2012/08/02/podiumstreetlight/9qVaAubIxU0j27bcavREaK/story.html

[3] OAAA, September 6, 2016

[4] OAAA, September 6, 2016

[5] IESNA 1966a, Recommended Practice for Photo biological Safety for Lams and Lamp Systems: General requirements. ANSI/IESNA RP-27.1-96 New York, Illuminating Engineering Society of North America

[6] Operating LED signage at this high level is unnecessary for the display to be viewable in daytime conditions

hours, which the AMA is contemplating, light intensity output from a digital billboard is only in the hundreds of nits, which is well below the 10,000 candela/square meter limit. Thus, there are not enough blue light elements included in a digital billboard to cause any impact to humans which can be considered a health risk.

3. What about sleep patterns?

With everyday usage, digital billboard exposure will not meet a minimum nuisance threshold of exposure to blue LED.

For example, a minimum of 60-90 minutes[7] of constant exposure to the blue light spectrum is necessary to show statistically significant melatonin suppression[8]. This does not occur with digital billboards. For digital billboards, the Federal Highway Administration (FHWA) recommends in its 2007 digital billboard policy guidance that display times can range from 4-10 seconds[9] with an average of six seconds throughout the nation.

Further, FHWA research shows a maximum two second threshold of glance periods from drivers has already been established[10]. Even if a driver and a digital billboard were located at the same traffic light, exposure levels would reach a maximum of around 90 seconds. This exposure is likely too high since this ignores the high probability that drivers spend considerable time glancing elsewhere and not entirely at the digital billboard. Thus, in normal circumstances, there is not enough blue light exposure time with digital billboards to cause any impact to humans which can be considered harmful.

In addition, the physical distance of the digital billboard from viewers probably further diminishes any blue light impact. Research shows people spending hours focused on television can have an increased melatonin suppression based on proximity to the eyes. As the physical distance from a source increases, the impact of blue rich light exposure diminishes[11].

4. How do digital billboards work compared to street lights?

The technology used in LED digital billboards differs from the type analyzed by the AMA report.

Digital billboards leveraging red, green, and blue LED technology are fundamentally different than applications that leverage a "white" light as a light source. The percentage of blue light in the white spectrum on a digital billboard is significantly lower than white LED street lighting applications

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[7] Figuerio et al: Implications of controlled short-wavelength light exposure for sleep in older adults, BMC Research Notes 2011, 4:334

[8] Stokes: Study of Potential for Melatonin Suppression from LED signage – Memo #1 V$ - October 15, 2016 (Article in appendix A)

[9] USDOT Federal Highway Administration Memorandum, Subject: Information: Guidance on Off-Premise Changeable Message Signs, dated September 25, 2007

[10] According to the National Highway Traffic Safety Administration (NHTSA), safety concerns arise when a driver's eyes are diverted from the roadway by glances that continue for more than 2.0 seconds.

[11] Figuerio et al: /Impact of watching television on evening melatonin, Journal of the SID 21/10, 2014

currently accepted at 3000K. (This nomenclature (Kelvin scale) reflects the equivalent color of a heated metal object to that temperature. The LEDs are cool to the touch and the nomenclature has nothing to do with the operating temperature of the LED itself[12].)

Unlike lighting applications, digital billboards do not display a solid white image continuously. Almost any digital signage image, other than a solid white background, further reduces the observed blue light spectrum.

A picture of a typical digital billboard module displaying the array of red, green, and blue diodes that can be combined to create a white image is shown below. These RGB LEDs can produce billions of color variations. This can be contrasted with the image of the White LEDs used in most street lighting applications. These LEDs produce one color: white.

Digital billboard module

LED Street light fixture

As noted earlier, the blue light content of digital displays is well below that of street lights. Typical LED street lighting fixtures create white light using a high energy blue LED combined with a phosphor coating that together blend to create white light. Digital Billboards use a combination of three separate LEDs (red, green, and blue) to create white light. Typically the percentage of blue light in an "RGB LED" white image is less than 12 percent.

[12] AMA report of the council on Science and Public Heath: Human and Environmental Effects of light Emitting Diode (LED) Community Lighting, CSAPH Report 2-A-16

Conclusion

The 2016 AMA recommendations are intended to provide guidance to reduce the potential for harmful human and environmental effects of bright lights at night. In particular, the guidance focuses on street lighting and the level of blue light spectrum in LED lamps. However, the AMA is not against LEDs. In fact the AMA supports the conversion of street lamps to the energy saving LED lighting. It offers its support with two provisions: 1) Minimize and control the amount of blue rich lighting; and, 2) Tailor the spectral content of outdoor lighting applications to be at or below 3000K, which represents a lower level of blue lighting.

According to several lighting experts, the harmful human and environmental concerns addressed by the AMA require the presence of very bright lights or long exposure durations or both. Digital billboards in the OOH media industry do not operate displays in a manner approaching these limits.

- In terms of brightness, blue LED lighting can be a concern to retinal damage if the lighting level exceeds 10,000 candelas/square meters at night. Digital billboards operate around 300 to 500 candelas/square meter at night. Even during the brightest time of the day, digital billboards rarely exceed 8.500 candelas/square meters.
- In terms of exposure time, blue LED lighting can suppress the generation of melatonin after a constant exposure of 60 to 90 minutes. Digital billboards do not have this type of exposure time. Digital billboards are usually exposed to viewers for seconds (4-10 secs.), with the longest conceivable exposure time of no more than 90 seconds.
- In terms of technology, the blue light spectrum is more significant in "White" LEDS, which consist of a high energy blue LED combined with a phosphor coating. Digital Billboards rely on a cluster of three separate LEDs (red, green, and blue) to present all the various colors needed in image generation. This three LED pixel generates a smaller amount of blue light spectrum than LED street lighting.

The AMA agrees there is nothing inherently dangerous about LED lighting. Its only concern is the manner in which this lighting technology is deployed. The OOH media industry operates LED displays via digital billboards in a manner that accommodates all concerns of excessive blue rich lighting.

Appendix A

Study of potential for melatonin suppression from LED signage by Ed Stokes, professor of Electrical and Computer Engineering at the University of North Carolina at Charlotte.

– Memo #1 V4 – October 15, 2016

Evaluation of the potential for melatonin suppression from LED signage

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Abstract

To evaluate the potential for nighttime melatonin suppression from LED billboards, light levels at nominal billboard conditions are compared with light levels of other nighttime sources such as televisions, computer screens, and mobile devices. Light levels in the literature for these other devices were considered in various ways such as: (1) illuminance (in lux) for white light, and (2) light intensity (in $\mu W/cm^2$) and (3) photon flux (in $photons/cm^2 sec$) for blue light (at 460-480nm). For a typical billboard (14 feet x 48 feet) at typical "white" nighttime brightness levels (300 nits) and a worst case viewing distance of 100 feet, the eyes of an observer are subjected to "white" illuminance of about 20 lux, which includes blue (470nm) light intensity of about 4 $\mu w/cm^2$. [1] For blue light of this intensity, melatonin suppression is not observed at all for short times (5-10 minutes), and is less than 10% for times less than 20 minutes. Longer exposure times (an hour or more) to blue light of this level is expected to result in melatonin suppression more than 10%. The "white" illuminance from a billboard is about the same as an I-Pad®, but about 3x more than a television or computer monitor. For televisions, computer screens, and mobile devices emitting broad spectrum "white" light, melatonin suppression of order 10% is observed for viewing times of roughly an hour or more. Based on these calculations and a review of the existing scientific literature, it therefore seems unlikely that exposure to a typical LED billboard for times of order a few seconds to a few minutes will result in any measurable levels of melatonin suppression.

Introduction

Digital billboard manufacturers are concerned with the potential for melatonin suppression due to human exposure to their outdoor LED signage products. Typical billboards are nominally 14 feet x 48 feet in size and contain a large number of RGB LED sources. The signs are capable of displaying multicolor images, so the brightness varies with color. The analysis below assumes that the color is uniformly "white" (D65, 6500K). While the daytime luminance of a white sign is 7500 nits, the nighttime luminance is only 300 nits, so 300 nits is used in the following calculations. The luminance distribution of the light is understood to be 25% red (621 nm), 65% green (527 nm), and 10% blue (470 nm). These levels are approximately the same as other nighttime signage that drivers commonly encounter. The beam angles of commercial signage can vary from sign to sign and manufacturer to manufacturer. Sometimes a tight distribution of 90/45 might be used, and other times a broader distribution like 110/60. For this analysis, a tight distribution of 90/45 is assumed, which is a worst case scenario for brightness and illuminance. (Note: "90/45" implies 50% intensity at +/- 45 degree viewing angle horizontally and +/- 22.5 degree viewing angle vertically.)

Krause[2], Brainard[3], and others have reported that exposure to blue light, particularly at night, can suppress melatonin levels in humans, potentially causing sleep disruption and other health issues. Since melatonin levels are normally low in daylight hours, this effect is generally a problem only at night. Various studies have been conducted to demonstrate the magnitude of this effect with computer screens[4], televisions[5], blue light[6], and mobile devices[7]. A systematic study specifically on LED signage has not been identified, but might warrant a future literature search.

As an aside, extremely bright blue light can also cause physical damage to retina tissue, which is an entirely different problem, and has nothing to do with melatonin suppression. It has been reported that light sources with luminance less than 10,000 candelas per square meter (cd/m^2) are not a cause for concern for retinal damage.[8] Due to the relatively low luminance of signage, this report is focused on melatonin suppression and not retina damage.

The goal of the following calculations is to use the 300 nit nighttime luminance to estimate human exposure to light levels from LED signage. These results will then be compared to existing scientific literature for other light sources such as arc lamps, computer monitors, blue LED goggles, mobile devices, and televisions, and finally the potential risk of nighttime melatonin suppression from LED signage will be evaluated.

For this initial evaluation, it is assumed that a person ("the observer") stares at a typical LED sign at a worst case distance of 100 feet away. This situation is equivalent for example to a driver being stopped at a traffic signal at night across the street from an LED sign. Note that typical viewing distances for drivers are likely to be larger, in the range of 300-1000 feet or more. A worst case emission scenario is also assumed, that the light of the entire sign is emitted from a single point closest to the observer. For simplicity, the "color" of the point source is assumed to be white (D65, 6500K), which corresponds to the maximum luminance of 300 nits, and therefore also the maximum possible brightness, since non-white colors are formed in a subtractive manner by removing wavelengths from the white spectrum. For example, blue is formed by turning off red and green, and therefore the luminance of a blue sign at night would be 30 nits (10% of 300). Note that signs with multicolor images are therefore running at reduced luminance and are typically measured at 75-105 nits with a "nit gun".

Assume the luminance of the uniformly white (D65, 6500K) sign is 300 nits:

$$L_v = 300\,nit = 300\,cd/m^2 \tag{1}$$

This luminance is partitioned into 10% blue, 65% green, and 25% red, so the maximum luminance of the blue, red, and green components is:

$$L_{vB} = 30\,nit = 30\,cd/m^2 \tag{2}$$

$$L_{vG} = 195\,nit = 195\,cd/m^2 \tag{3}$$

$$L_{vR} = 75\,nit = 75\,cd/m^2 \tag{4}$$

The area of the sign is:

$$A = (14\,ft)(48\,ft)\left[\left(12\,\frac{in}{ft}\right)\left(2.54\,\frac{cm}{in}\right)\left(1\,\frac{m}{100\,cm}\right)\right]^2 = 62.4\,m^2 \tag{5}$$

The total luminous intensities of the sign (white light) and of the blue, green, and red components are:

$$I_v = L_v A = 18.7 \times 10^3\,cd \tag{6}$$

$$I_{vB} = L_{vB} A = 1.87 \times 10^3\,cd \tag{7}$$

$$I_{vG} = L_{vG}A = 12.2 \times 10^{3} cd \quad (8)$$

$$I_{vR} = L_{vR}A = 4.68 \times 10^{3} cd \quad (9)$$

Assume that the light is uniformly distributed over a solid angle Ω defined by the 90/45 beam angle of the LEDs:

$$\Omega = \int_{-\pi/4}^{+\pi/4}\int_{3\pi/8}^{5\pi/8} (\sin\theta) d\theta d\phi = 1.20 sr \quad (10)$$

Then the total "white" luminous flux of the sign, and the total luminous flux of the blue, red, and green components are:

$$\phi_{v} = I_{v}\Omega = 22.4 \times 10^{3} lm \quad (11)$$

$$\phi_{vB} = I_{v}\Omega = 2.24 \times 10^{3} lm \quad (12)$$

$$\phi_{vG} = I_{v}\Omega = 14.6 \times 10^{3} lm \quad (13)$$

$$\phi_{vR} = I_{v}\Omega = 5.62 \times 10^{3} lm \quad (14)$$

The peak wavelengths of the blue, green, and red LEDs in a sign are assumed to be 470, 527, and 621nm respectively. The luminous efficacies of blue, green, and red sources are determined from the CIE eye sensitivity function, as a fraction of the peak sensitivity of 683 lumens per watt at a wavelength of 555 nm. Assuming the total 300 nits of the sign, as measured with a candela meter (or "nit gun"), correspond to the eye sensitivity function for the photopic vision regime (as used by the "nit gun"), those fractions are 0.0910, 0.816, and 0.369, and the luminous efficacies for blue, green, and red sources are therefore 62.1, 557, and 252 lumens/watt respectively.[9] So the optical power contained in each color is:

$$P_{B} = \frac{2.24 \times 10^{3} lm}{62.1 lm/W} = 36.1W \quad (15)$$

$$P_{G} = \frac{14.6 \times 10^{3} lm}{557 lm/W} = 26.2W \quad (16)$$

$$P_{R} = \frac{5.62 \times 10^{3} lm}{252 lm/W} = 22.3W \quad (17)$$

And the sum of red, green, and blue power gives the total optical power emitted from the white sign.

$$P_{W} = P_{B} + P_{G} + P_{R} = 84.6W \quad (18)$$

A distance of 100 feet is equivalent to a distance of 30.5 meters. Therefore, the intensity of white light and blue light at the position of the observer are:

$$I_W = \frac{84.6W}{1.20sr \times (30.5m)^2} = 0.0758\,\frac{W}{m^2} = 7.58\,\frac{\mu W}{cm^2} \approx 8\,\frac{\mu W}{cm^2} \tag{19}$$

$$I_B = \frac{36.1W}{1.20sr \times (30.5m)^2} = 0.0323\,\frac{W}{m^2} = 3.23\,\frac{\mu W}{cm^2} \approx 4\,\frac{\mu W}{cm^2} \tag{20}$$

The total white illuminance of the sign is:

$$M_v = \frac{22.4 \times 10^3\, lm}{1.20sr \times (30.5m)^2} = 20.1\frac{lm}{m^2} = 20.1lx \approx 20lx \tag{21}$$

Note therefore that ~20 lx of white light corresponds to about ~8μW/cm^2 for these conditions.[10]

Finally, the energy of one 470nm photon is:

$$E_{470} = \frac{hc}{\lambda} = \frac{\left(6.63 \times 10^{-34}\, J \sec\right)\left(3.00 \times 10^8\, \frac{m}{\sec}\right)}{470 \times 10^{-9}\, m} = 4.22 \times 10^{-19}\, J \tag{22}$$

And therefore the number of blue photons per area per second incident on the observer is:

$$\phi = \frac{I_{obs}}{E_{470}} = \frac{3.23 \times 10^{-6}\, \frac{J}{s \times cm^2}}{4.22 \times 10^{-19}\, \frac{J}{photon}} = 7.65 \times 10^{12}\, \frac{photons}{s \times cm^2} \approx 8 \times 10^{12}\, \frac{photons}{s \times cm^2} \tag{23}$$

Discussion

Results on melatonin suppression from the literature are summarized in the table and discussion below:

Study	Light source	Color	Light level	Duration	Melatonin suppression	Comparable LED sign light level
Figueira 2011a (ref 6)	Blue LED goggles	Blue (470nm)	6 μW/cm^2 and others	5 to 90 minutes	Nothing at 5 minutes; Less than 10% for less than 20 minutes	4 μW/cm^2 (roughly same as to the study)
Brainard 2001 (ref 3)	Arc lamp with monochromator	Blue (460nm & 470nm) and others	8x10^{12} photons/cm^{2}sec and others	90 minutes	~40% for 460nm and ~35% for 470nm	8x10^{12} blue photons/cm^{2}sec (roughly same as the study)
Figueira 2011b (ref 4)	Computer monitor	Broad spectrum	7 lux	120 minutes	11% (not statistically significant)	20 lux (~3x higher than the study)
Figueira 2011b (ref 4)	Blue LED goggles plus computer monitor	Blue (470nm)	40 μW/cm^2	120 minutes	30%	4 μW/cm^2 (10x smaller than the study)
Figueira 2014 (ref 5)	Television	Broad spectrum	5 to 10 lux	90 minutes	None (small increase reported)	20 lux (~2-4x higher than the study)
Wood 2013 (ref 7)	I-Pad®	Broad spectrum	18 lux -------------- 16 lux	1 hour ---------- 2 hours	7% --------------- 23%	20 lux (roughly same as the study.

Blue light results:

Reference 6 uses a number of different blue intensity levels, including one intensity level directly comparable to the LED sign, and reports measured levels of melatonin suppression over a range of exposure times. Eleven adults between 52 and 61 years of age were exposed to intensity levels of 470nm light from 0.7 to 72 μW/cm^2 by wearing previously developed "blue light goggles". Melatonin levels were measured at various times from 5 minutes to 90 minutes. See figure 1 in the reference. ***For 6.0 μW/cm^2 (almost twice as much as the LED sign at 100 feet away) the measured melatonin suppression was negligible at 5 minutes, and less than 10% for exposure times less than 20 minutes.***

Reference 3 uses a number of different blue photon flux levels generated by a xenon arc lamp and a monochromator, including the level directly comparable to the LED sign. Subjects were exposed to a variety of wavelengths of light for 90 minutes at various photon flux levels. See figure 3 in the reference. ***At a blue photon flux equivalent to the LED sign observed from 100 feet away (7x10^{12} photons/cm^{2}sec, from equation 14 above), the reported melatonin suppression is 40% for an exposure of 90 minutes.*** The data in the paper does not allow conclusions to be drawn for shorter time periods.

In reference 4, twenty-one subjects were exposed to 40 $\mu W/cm^2$ of blue light (470 nm) from blue LED goggles along with broad spectrum light from a computer monitor for two hours. A statistically significant median melatonin suppression of 30% was observed. ***This blue light is more than 10 times larger than that of the LED sign (3.3 $\mu W/cm^2$) observed at 100 feet away.***

Broad spectrum results

The LED sign's broad spectrum illuminance is estimated to be 20 lux; see equation 21 above.

In reference 7, thirteen subjects were exposed to light from an Apple I-Pad® mobile device set at full brightness and melatonin levels were measured twice, after 60 and 120 minutes. See table 1 in the reference.

- The average illuminance of the I-Pad® over 60 minutes was 18 lux and resulted in melatonin suppression of 7%.
- The average illuminance of the I-Pad® over 120 minutes was 16 lux and resulted in melatonin suppression of 23%.

These illuminance levels are comparable to the 20 lux illuminance of the LED sign observed at 100 feet away. This suggests that staring at an LED sign for an hour or more from 100 feet away would be expected to result in some melatonin suppression.

In references 4 and 5, lower illuminance levels were used, ranging from 5 to 9 lux, and no statistically significant melatonin suppression was observed.

- In reference 4, twenty-one subjects were exposed to 7 lux of broad spectrum light from a computer monitor for 120 minutes and median melatonin suppression of 11% was observed, but this suppression was not statistically significant.
- In reference 5, sixteen test subjects were exposed to broad spectrum light from watching a movie on a television adjusted to various CCTs (corrected color temperature), including 6500K. Two different distances from subject to screen were used (6 feet and 9 feet), for which the average illuminance was 9.65 lux (~10) and 5.53 lux (~6) respectively. After 90 minutes for 6500K CCT, the average melatonin levels were not suppressed, but actually increased 4.4% for 10 lux and 5.3% for 6 lux. See table 2, figure 3, and the discussion in the reference.

Note: These illuminance levels (references 4 and 5) are 2-4 times lower than the LED sign observed at 100 feet away. This suggests that if the broad spectrum sign illuminance was reduced by a factor of somewhere between 2 and 4, there would be no issue with melatonin suppression, even for exposure times of an hour or more.

Summary

A uniformly white (D65, 6500K) LED sign observed from 100 feet away is estimated to expose the observer to:

(1) white illuminance of about 20 lux, including:
(2) blue light (peak wavelength 470 nm) with intensity of about 4 $\mu W/cm^2$, which corresponds to a blue photon flux of $8x10^{12}$ photons/cm^2sec.

Numerous peer reviewed studies (references 1 through 6) have demonstrated that measurable melatonin suppression can be caused by nighttime exposure to sufficiently high light intensity for sufficiently long times. Both blue light around 470 nm (references 2, 3, and 5) and broad spectrum light (references 3, 4, and 6) were investigated.

The blue light studies for intensity/flux levels equivalent to that of the LED sign observed from 100 feet away show no measurable melatonin suppression for short exposure times (less than 5 minutes). Longer exposure times of an hour or more would be expected to result in measurable levels of melatonin suppression.

The white light studies show measurable melatonin suppression for long exposure times of an hour or more for white light illuminance levels roughly equivalent to that of the LED sign from 100 feet away. For 2-4x lower illuminance levels, no significant melatonin suppression was observed at any exposure time.

Conclusions

(1) An LED sign of typical nighttime brightness observed from 100 feet away is unlikely to result in measurable melatonin suppression for observation times of five minutes or less.
(2) Staring at an LED sign for an hour or more would be expected to result in measurable melatonin suppression of 10% or more.
(3) The threshold exposure time for melatonin suppression, somewhere between 5 minutes and 60 minutes, cannot be reliably discerned from the available studies.
(4) Reducing the overall broad spectrum LED illuminance by a factor somewhere between 2 and 4 would significantly mitigate the risk for melatonin suppression for longer exposure times of an hour or more.

Biography

Ed Stokes is a professor of Electrical and Computer Engineering at the University of North Carolina at Charlotte. From 1986 until 2002, he was a Staff Scientist at the General Electric Global Research Center in Schenectady, NY. He holds a Ph.D. in Physics from Rensselaer Polytechnic Institute (RPI) in Troy, NY. Dr. Stokes has been actively involved in LED (and other) lighting research for most of his career. He frequently participates in technical panels and workshops for the Department of Energy's Solid State Lighting research programs. Dr. Stokes was a co-founder of Dot Metrics Technologies, an early developer of disinfection systems using ultraviolet LEDs. He is the co-author of more than 50 scientific papers and is listed as co-inventor on more than 20 U.S. patents, many of them related to LED technology. Dr. Stokes' research group at UNC Charlotte is currently developing semiconductor epitaxial crystal growth methods to support the next generation of LED lighting.

References

[1] See the subsequent calculations. This level of “white” illuminance includes a “blue” photon flux of approximately $7x10^{12}/(cm^2*sec)$, which corresponds to a “blue” intensity of 3.3 $\mu W/cm^2$. The exact values of “blue” photon flux and “blue” intensity depend on the CCT of the “white” light, which is assumed here to be 6500K.

[2] Krause, Louis J., “Human and Environmental Effects of Light Emitting Diode (LED) Community Lighting”, AMA Council on Science and Public Health report # 2-A-16 (2016).

[3] Brainard et al., “Action Spectrum for Melatonin Regulation in Humans: Evidence for a Novel Circadian Photoreceptor”, The Journal of Neuroscience, 21(16):6405–6412 (2001)

[4] Figueiro et al., “The impact of light from computer monitors on melatonin levels in college students”, Neuroendocrinology Letters, 32(2): 158-163 (2011)

[5] Figueiro et al., “The impact of watching television on evening melatonin levels”, Journal of the SID, 21(10): 417-421 (2014).

[6] Figueiro et al., “Implications of controlled short-wavelength light exposure for sleep in older adults”, BMC Research Notes, 4:334, (2011).

[7] Wood et al., “Light level and duration of exposure determine the impact of self-luminous tablets on melatonin suppression”, Applied Ergonomics 44: 237-240 (2013).

[8] Bullough, “The blue light hazard: A review”, Journal of the Illuminating Engineering Society, pp. 6-14, Summer 2000.

[9] http://hyperphysics.phy-astr.gsu.edu/hbase/vision/efficacy.html

[10] Note that reference 3 makes the statement: “*Specifically, subjects … were exposed to 40 lux (40 µW/cm2) of short-wavelength … light at each cornea …*”.) This statement seems to imply that lux and $\mu w/cm^2$ are numerically equivalent. This may be true for certain experimental conditions, but it is not generally true.