PHILIPS

White paper

The impact of blue light in outdoor lighting

An industry insight into the effects of blue LED light on eye health, circadian rhythm and sky glow

Introduction

Blue light is an essential component of white light emitting diodes (LEDs) and is the specific part of the light spectrum that enables us to see the color blue. However, it is not a phenomenon that has occurred since the introduction of LED technology. First and foremost blue light arises naturally from the sun, which radiates a lot of blue light. But for many years exposure to blue light has become increasingly common from a wide range of other sources.

The sun remains the most extreme light source, and in some respects the most dangerous by far, and for additional reasons to those related to blue light. But does blue LED light have a dark side? Despite evidence to the contrary, some still claim that blue light has a negative effect on eye health, sleep and the circadian rhythm. Or that blue light is inextricably linked to light pollution and the unwanted effects of sky glow.

In this white paper, we examine each of these important topics in turn, explaining the reported risks (and myths) of the effects of blue light with a particular focus on outdoor lighting.

What is blue light?

Blue light is at the lower part of the light spectrum that is visible to humans, which ranges from about 380 to 780 nanometers (nm), as shown in Figure 1. That means it can have a very potent effect on our biological clock and, used correctly, can be very beneficial to health, well-being and the circadian rhythm. However, the underlying mechanisms, effects and spectral parameters of blue light on each of these sensitivities are completely different. It is also important that the spectral distribution, intensity and duration of observation of blue light is taken into account when considering any negative impacts.

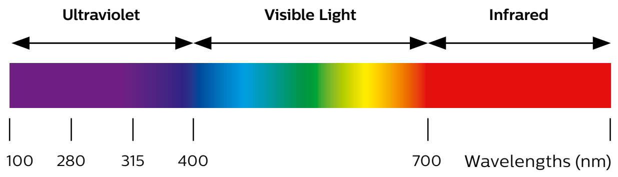


Figure 1: Wavelengths (nm) of light

Blue light and eye safety

To protect against retinal damage by high-energy radiation and light, photobiological safety standards are in place. These relate to the risks of the human eyes and skin being exposed to ultraviolet, blue, infrared and thermal sources. One of these standards, blue light hazard (BLH), relates specifically to the risk of retinal injury from high-energetic violet-blue light with a wavelength range of 400 to 500 nm. For context, it is important to note that the most dangerous blue light source remains the sun, depending on the season, geographical location, and weather conditions.

The highest sensitivity for injury is at 435 to 440 nm, which is within the violet wavelength range. The presence of high-energetic blue light, coupled with high concentrations of oxygen in the eye, can cause the formation of toxic reactive oxygen species. This has the potential to induce photochemical damage, which in turn can permanently damage the retinal epithelium (RPE).

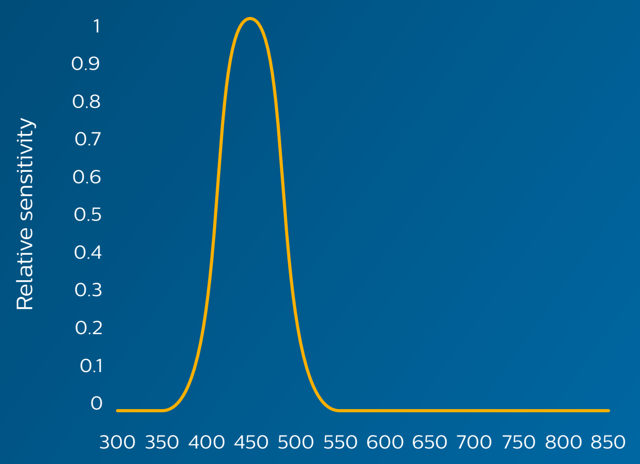


Figure 2: 740 : How effective light of various wavelengths is at damaging the retina (at equal power)

That's important to safeguard against because the RPE nourishes retinal visual cells and ensures the photoreceptors are functioning well. However, RPE cells have the potential to cope with oxidative stress and can even repair visual function. It is only when irreparable damage has taken place that damaged RPE cells can result in loss of sight.

The International Electrotechnical Commission (IEC) is an organization that prepares and publishes international standards for all electrical, electronic and related technologies.

The IEC's latest edition of the IEC TR 62778 assesses whether or not LED modules or luminaires exceed the blue light hazard limits (safety) and the standard EN 62471 defines the measurement conditions and provides the risk group classification. This is determined by taking into account luminance, exposure time, exposure distance and of course the spectrum, weighted by the blue light hazard spectral weighting function (see Figure 2).

There are photobiological risk groups, from Risk Group Exempt up to High, which define the levels of precaution that are required when using LED sources, depending on their application, exposure time and measurement distance (see Table). These included shift workers, children whose eyes cannot filter blue light, and people who have had cataract surgery.

In practice, and according to the applicable standards, LED sources or luminaires can be classified as any of the aforementioned risk groups, taking into account that:

- Risk Group "X" Unlimited (i.e. Risk Group 1 Unlimited) corresponds when measurements are performed at a 20 cm distance, meaning the LED source or luminaire is considered safe at any distance.
- For general lighting applications, and if not measured at 20 cm distance, LED modules or luminaires are considered safe when risk group classification is accompanied by the measurement distance. For example, for a Road and Street or Urban luminaire can be classified as Risk Group 0 at a measured distance of 1.5 meters.

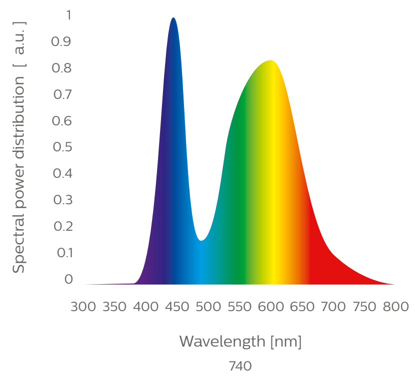
In addition to the measurement distance, the exposure time as indicated in Table 1 must also be considered.

Many critics suggest that blue light hazards for the eyes are not based on realistic scenarios. Normal observers will naturally look away from sources of bright light or shield their eyes, whereas the blue light hazard in the risk group is calculated on the premise that people will stare into a bright light for more than 100 seconds.

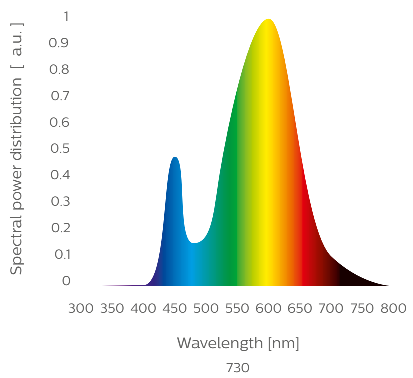
Risk group	Risk	Safety message	Exposure periods to determinate (emission limits)	
			Retinal photochemical hazard	Retinal thermal hazard
Group 0	Exempt	No photobiological hazard	10,000 s	10 s
Group 1	Low	No hazard due to normal behavioral limitations on exposure	100 s	10 s
Group 2	Moderate	No hazard due to the aversion response to very bright light sources or due to thermal discomfort	0.25 s	0.25 s
Group 3	High	Hazardous even for momentary exposure	<0.25 s	<0.25 s

Table 1: Possible IEC TR 62778 assessment results of luminaires

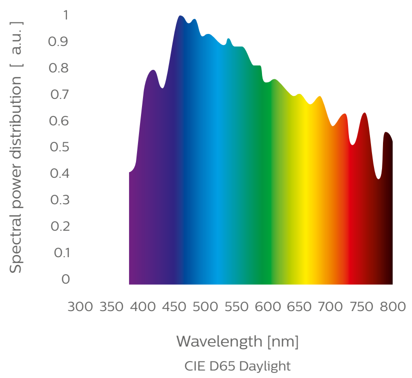
This means the risk of retinal damage would require exposure at much higher intensities and for far longer than motorists, pedestrians and cyclists would typically encounter under normal outdoor street lighting conditions. Lighting professionals who work with street lighting should be trained and equipped to carry out their operations safely, with protective measures including goggles that attenuate blue light, as they can be exposed to much higher levels at shorter distances in their jobs. It is important to note that this does not just apply to LED luminaires and has always been a requirement when working with conventional high-intensity outdoor luminaires.



Spectrum 1: Neutral white 740 LED spectrum



Spectrum 2: Warm white 730 LED spectrum



Spectrum 3: Natural daylight

Figure 3: A comparison of the blue light proportions within the spectra of different light sources

High energetic blue light can create damage on the retina. Taking into account the risk group of lighting products is a good reference to know if the solution is without risk for the safety of eyes. But light sources for outdoor lighting, just like any light source encountered by the general public, are all safe for their intended use.

Blue light and circadian rhythm

The effect of light on the circadian rhythm is determined by the spectral power distribution of a light source, its intensity and the duration of exposure. In this case, it is associated with wavelengths in the range of 400 to 580 nm (violet 400 - 450 nm, blue 450 - 490 nm). The circadian body clock is sensitive to all light in the visible spectrum, but spectral sensitivity peaks at around 490 nm.

Light is an important regulator of our biological clock, which balances many biological functions of the body such as the liver, lungs and sleep. This includes the production of the hormone melatonin, which reaches peak levels at night to regulate the sleep-wake cycle. Academic research has proven, for two key reasons, that exposure to low levels of light after dusk, such as that produced by road and street lighting, does not shift the body clock away from our natural sleep-wake cycle.

CCT and spectral power distribution

Firstly, although a light source may appear to be white, that does not necessarily mean that it will disrupt the sleep-wake cycle. Correlated Color Temperature (CCT) is commonly used as an indicator of blue light content and a higher CCT is usually associated with more blue light. However this is not always the case. As Figure 4 demonstrates, it is possible to make the same CCT by mixing different combinations of primary colors and this will result in very different levels of blue light content.

For example, white can be made by mixing pure blue with yellow, but also by mixing cyan with red. These two combinations have a completely different spectral power distribution, but will appear as the same color.

The spectral power distribution, or the radiant power at different wavelengths, offers a more accurate picture of the amount of blue light in a source. If this is taken into account, it is clear that at the same CCT, fluorescent technologies would suppress melatonin just as well as a typical LED.

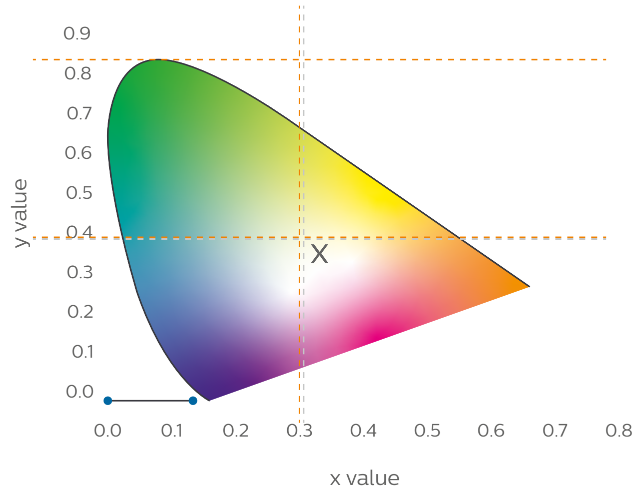


Figure 4: Correlated Color Temperature

Light sources with lower CCT generally contain less blue light. But when sleeping at night, the body clock is not impacted by the typical low levels of light emitted by road and street lighting.

Light and closed eyes

There is a second reason that exposure to low levels of light after dusk, such as that produced by road and street lighting, does not shift the body clock away from our natural sleep-wake cycle. Investigations into melatonin suppression in people with closed eyelids found that high intensities of more than 17000 lux (up to 50000 lux) were required to suppress melatonin[1]. In studies that have suggested a human melatonin response to light at night, significant differences have been reported in the levels of suppression between subjects and studies, casting doubt on what this means in daily practice. The reason for this could largely be due to the very different protocols involved in each study. Only studies with standard protocols will produce the consistent results that are needed to analyze the effect of light on melatonin suppression with confidence. These include maintaining subjects in dim light during the daytime, keeping them awake for all or part of the night, and exposing them to high light levels during the night while they are awake and sitting up with their eyes open. Because as long as the eyes remain closed, melatonin will never be suppressed enough to keep people awake at night under normal light levels as the eyelids will block out at least 95% of the light.

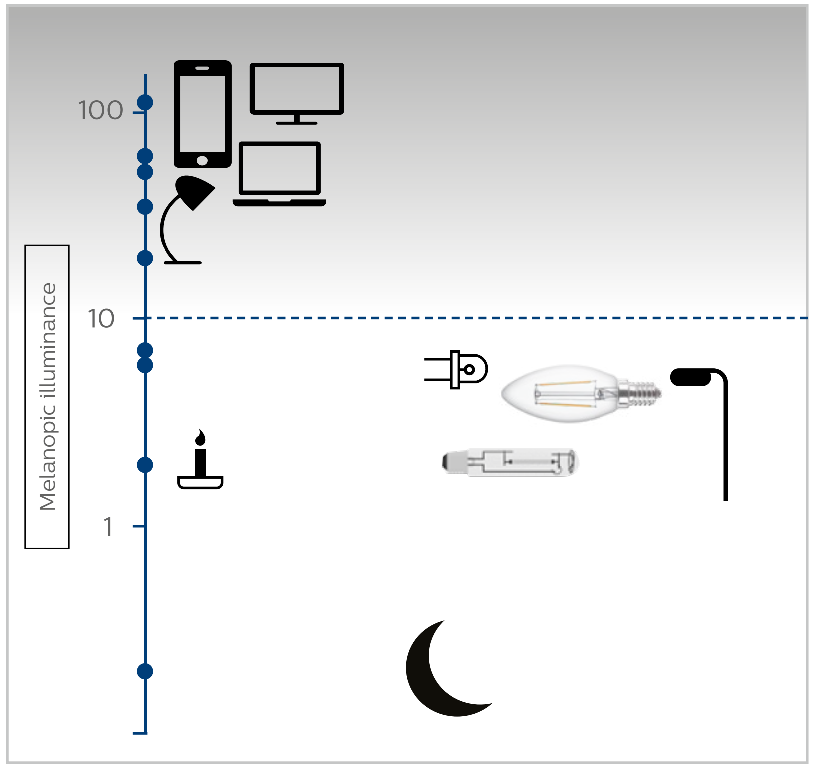
The latest research has shown that sensitivity differs across the population. The onset of melatonin suppression starts at a threshold of 6 lux in the most sensitive individuals, when the eyes are open. For closed eyes, that threshold illuminance would equate to 100 - 120 lux on the eye[3].

Given their low intensity, and the relatively short duration of exposure in typical urban environments and at property boundaries, the potential for LED streetlights to shine into bedrooms and suppress melatonin is too low to cause significant circadian problems. And of course this is reduced even further when curtains and eyes are closed.

Self-luminous devices

So why all the scaremongering about blue light and its effect on the body clock in the first place? The truth is that many articles and discussions on the negative impact of light exposure at night are driven by concerns about people working night shifts and evening exposure to interior lights levels. There is also great concern about the screens of self-luminous devices such as computers, tablets and smartphone when used at night, all of which have a greater melanopic illuminance[2] than outdoor lighting (see Figure 5). Furthermore, users of such devices are exposed to more intense light and for longer than they would experience from any outdoor lighting system.

It has been demonstrated that exposure to such light sources and displays in the evening can suppress the normal increase in melatonin levels and may therefore delay sleep onset. But what is also key is the amount of light that a subject is exposed to during the day because this has a direct influence on how effective light will be in suppressing melatonin during the evening or night. Indeed, a healthy lighting lifestyle with sufficient exposure to sufficient light during the day, will ensure people are less sensitive to any light at night.



Melanopic illuminance levels at which blue light can have a negative impact when users are exposed to it at night.

Figure 5: A comparison of the melanopic illuminance values of self-luminous devices and lighting

Exposure to the blue light of self-luminous devices at night can result, depending on exposure to light during the day, in melanopic illuminance levels that will have a negative impact on sleep onset. Outdoor lighting levels are far below such levels.

Do we need more research?

Some industry players such as the National Electrical Manufacturers Association (NEMA)[4] suggest more scientific study and additional research is required before reaching any firm conclusions on blue light and circadian disruption. The America Medical Association has also expressed concerns regarding the impact of LED street lighting on disruption to the human circadian system[5]. However, many academic and industry responses have been critical of these arguments.

An independent review carried out by Dr Stephen Lockley (Harvard Medical School, Division of Sleep and Circadian Disorders) supports our assertion that light levels from LED and conventional streetlights are simply too low to cause significant negative circadian rhythm related health problems[6]. He also concludes the health concerns about indoor light sources easily override any effects of street lighting. Therefore, measures to reduce the impact of light sources that are used at home in the evening and having enough light exposure during daytime, should be of far greater concern than the much lower levels of light emitted by LED street lights.

Recent research on mice has shown that during dusk, green/yellow light is more effective in suppressing melatonin than blue light. As the sun sets, its blue light content increases, making it an unreliable indicator for day length. Therefore, in the evening, the L cone signal is also taken into account. This might explain earlier research results, which showed the same shift in spectral sensitivity in humans. Scientists warn that shifting display color to higher color temperatures, or decreasing the color temperature of lighting, may have an adverse effect[7].

While the scientific focus is on investigating the long-term effects of devices that emit blue light, the impact of outdoor light sources on health and wellbeing has less relevance to researchers.

Blue light and sky glow

The effect of blue light on dark skies is another topic that attracts attention. Concerns have been raised that because shorter wavelengths scatter more readily in the Earth's atmosphere, LEDs that include violet, blue and cyan components will reduce night-sky visibility due to greater levels of scattered light. But while increasing the short wavelength content on LED street lighting will increase the potential for sky glow, this can be offset by other characteristics including spectral power distribution, total lumen output and the distribution of light from luminaires, particularly light that is directed upwards.

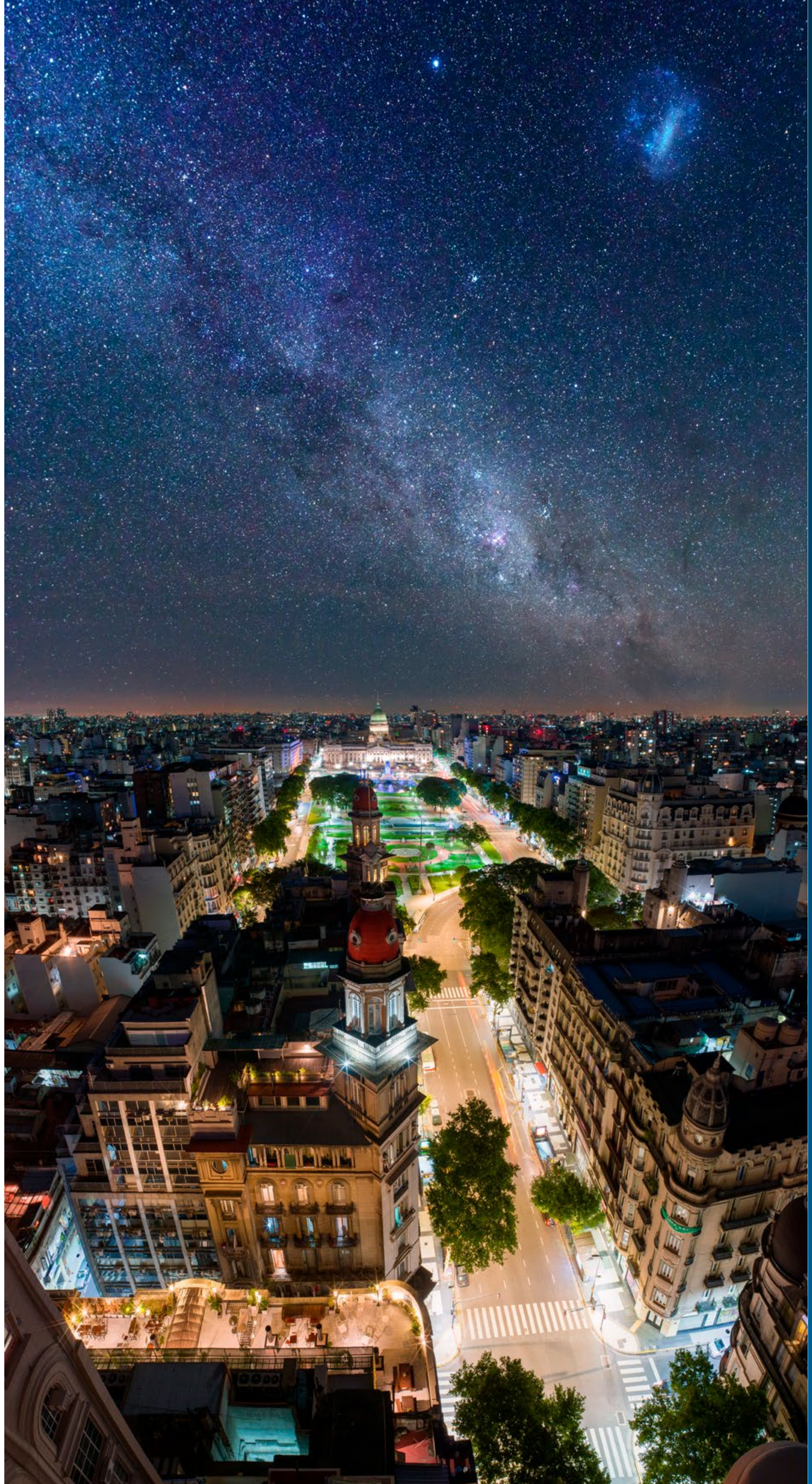
The SkyGlow Simulator developed by Miroslav Kocifaj, a senior researcher at the ICA Institute of the Slovak Academy of Sciences, was used to model the impact of LED street lighting on sky glow by the US Department of Energy[8]. The study found that although light sources with higher short wavelength energy experience more scatter in the atmosphere, longer wavelengths tend to travel further and will have a greater impact on sky glow when viewed from a distance.

The study also found a linear relationship between light output and sky glow. Any increase or decrease in lumen levels from a lighting system will have the same positive or negative contribution to sky glow. Therefore, techniques such as dimming LED street lighting during the evening and limiting the amount of light that is directed upwards by choosing the right luminaires, can be a powerful way to address any concerns about sky glow.

A much more important factor is the light distribution. Eliminating light above the horizontal plane from 2 to 0 % will significantly reduce sky glow by at least 95% for the distant observer*. What's more, the combined effect of a 50% reduction in lumen output by upgrading installations with LED and the elimination of any uplight will significantly reduce sky glow (by up to a factor of 50, not taking dimming into account) for near observers compared to high pressure sodium systems with 2% uplight.

*In terms of the all-sky horizontal irradiance (W/m^2) metric selected for the investigation.

Blue and violet wavelengths scatter more in the atmosphere, but these longer wavelengths have more impact on sky glow the further they travel. Choosing the most appropriate product with the right light distribution and applying dimming scenarios will have a far more significant impact on reducing light to the ground, and proportionally the indirect light reflected to the sky.



Conclusion

While some scaremongering about blue LED light will inevitably come to the attention of the lighting industry, we now have the scientific evidence that outdoor LED lighting has no impact on eye health, circadian rhythm or sky glow. Furthermore, if properly designed and applied, LED street lighting provides many advantages, including a reduction in light pollution and increases in the safety and security for pedestrians, cyclists and motorists.

All our light sources are completely safe for use and comply fully with all EU and US regulations and measures for outdoor lighting. Our solutions are also tailor-made, delivering precisely the right levels of light for every application from roads and tunnels to city centers and parks. We also use lighting controls, dusk-to-dawn sensors and shields to minimize uplight, sidelight and glare.

So when it comes to blue light from outdoor LED lighting from Signify, we're confident you can give it the green light.

References

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