Arkansas Natural Sky Association

LED Lighting - The Risks of Over Illumination

Everyone knows that LED fixtures are more efficient than Legacy (HID) technologies and hence you need fewer watts. But, many don't know that you typically need fewer lumens as well. The reason is, LEDs are more efficient at delivering light to the target and often in a spectrum more efficiently perceived by the eye under outdoor lighting conditions. If you don't account for all this, you will end up over-lighting, and too much light in the outdoor nighttime environment is bad lighting.

Why over-lighting is bad.

Over-light wastes energy, which means unnecessary pollutants to include greenhouse gas emissions.[1] Energy savings was the principal driver in promoting the development of solid-state (LED) lighting technology. But, Instead of saving energy, LED lighting is often used to generate more light.[2] Not wasting light is one of the easiest ways we can reduce carbon emission.

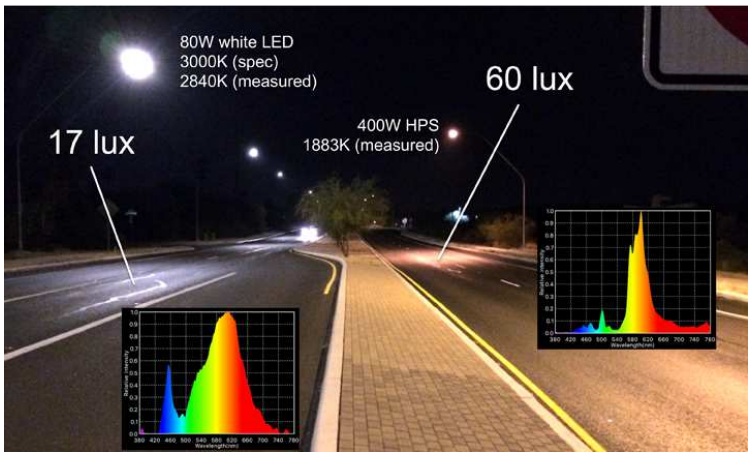

Figure 1: Tucson LED streetlighting transition

Over-lighting adds to sky glow, light trespass, glare and light pollution. Light pollution possess risks to human health, wildlife and detracts from the esthetics of our communities. Not using more light than necessary is critical to reducing light pollution.[3]

Finally, over-lighting is not good lighting because it actually reduces visibility, something the public does not often appreciate. The Illumination Engineering Society of North America (IESNA) Recommended Practices Manual on Exterior Lighting RP-33-14, section 4.6.1 notes:

> Too often, people associate brighter light and glare with “safer” surroundings. In reality, more light and glare do not necessarily equate to better lighting. It can be easily demonstrated that too much light, or poorly directed light, actually causes a loss of visibility.

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[1] A 100-watt coal fired incandescent bulb left on all night for a year generates almost a half a ton of carbon dioxide.

[2] Artificially lit surface of Earth at night increasing in radiance and extent, Science Advances, 22 Nov 2017: Vol. 3, no. 11

[3] It has been estimated that converting all legacy lighting to 4000K CCT LED fixtures will make skyglow two and a half times worse. The U.S. Dept of Energy Solid-State Lighting Division, modeled comparative sky glow of LED and HID fixtures to show that this effect could be countered by improved shielding and cutting LED lumens in half. https://www.energy.gov/sites/prod/files/2017/05/f34/2017_led-impact-sky-glow.pdf

The manual goes on to explain that too much light can reduce visibility in surrounding darker areas by impacting the observer's dark adaption and causing blinding "disability" glare. Hence, just adequate well-directed light is optimum.

Why LED lights need fewer lumens

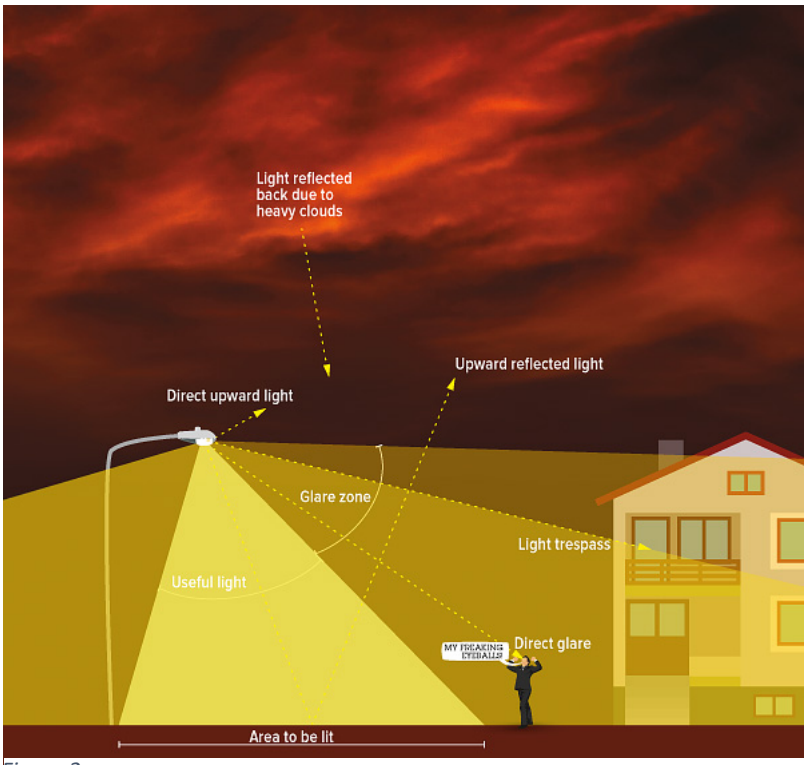

Figure 2

Legacy (HID) luminaires all depend on a lamp mounted in a fixture that uses a reflector to capture, reflect and direct generated light. In this process some is unavoidably lost or misdirected.[4] Because, LEDs emit rather than reflect light they don't lose light in this manner.

In addition, light emitted above sixty degrees is generally considered wasted light. In fact is it harmful, as it is either ends up in the "glare zone" or as up-light contributing to sky-glow, as illustrated in *figure 2*. Because of the inherent directional nature of LED less light falls outside the useful zone. These efficiency differences are not considered in a fixture's lumen rating and hence ratings of LED and HID fixtures are not comparable. [5]

A great example of this is the classic NEMA-head "yard light", which seems optimally designed to waste light. *Figure 3* is a table showing the distribution of light from such a fixture broken down into the "BUG" rating format developed to encourage improved fixture design and highlight undesirable lighting characteristics.[6] Under the BUG scheme illumination above 60 degrees (high and very high) and "up-light" emitted above

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[4] The Luminaire Efficiency Ratio (LER) describes the efficiency of the fixture in emitting the light generated and lumen ratings of HID fixtures are relative in nature to account for the variations in performance between designs.

[5] How effectively a fixture delivers light (Delivered Lumens) is referred to as the coefficient of utilization (CU).
http://www.lightnowblog.com/2010/03/what-is-luminaire-efficiency/
http://www.premierltg.com/total-lumens-vs-delivered-lumens/

[6] https://blog.1000bulbs.com/home/how-is-a-bug-rating-calculated

90 degrees, highlights wasted light contributing to glare, light trespass and sky-glow. In the case of this very common fixture, only 27% of the generated light escapes the fixture and falls in the useful lighting zones below 60 degrees; the lumen rating on this fixture is grossly misleading.

But as they say on late night TV, there is more. LED fixtures, as shown in *figure 1* and illustrated in *figure 4*, provide a more even distribution of light. Using legacy fixtures, it is necessary to over-light in some locations to achieve the desired average illumination. Finally, as shown in the illustration, LED lighting can be targeted reducing "spill light" typical of traditional lighting technologies.

LCS TABLE		
BUG RATING	**B4 - UX - G4**	
FORWARD LIGHT	LUMENS	LUMENS %
LOW(0-30):	404.0	2.5%
MEDIUM(30-60):	1,759.4	11%
HIGH(60-80):	3,098.9	19.4%
VERY HIGH(80-90):	737.1	4.6%
BACK LIGHT		
LOW(0-30):	404.0	2.5%
MEDIUM(30-60):	1,759.4	11%
HIGH(60-80):	3,098.9	19.4%
VERY HIGH(80-90):	737.1	4.6%
TRAPPED LIGHT:	4,001.1	25%

Figure 3

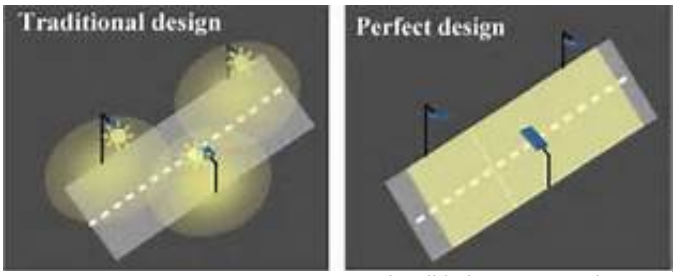
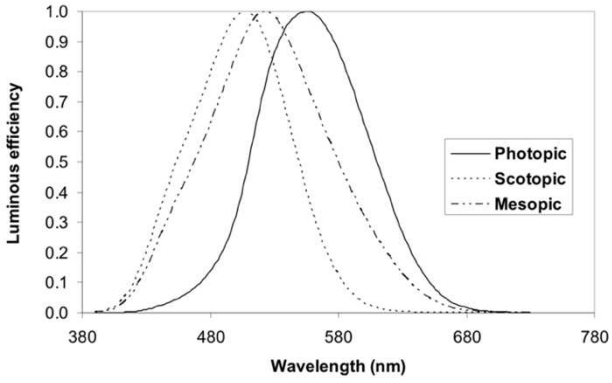


Figure 4 – Optics Express. Hot spots and spill light are wasted.

In an outdoor nighttime setting, there is yet another reason one needs fewer lumens with LED lighting.

The sensitivity of the eye varies with the color (spectrum) and intensity of light. The lumen rating of a commercial fixture is based on the spectral sensitivity of the eye under brightly illuminated (photopic) conditions where vision involves the cone receptors in the eye. This makes sense for indoor luminaires. However, under low light conditions (scotopic vision) the eye's rod receptors take over, and rods are more responsive to shorter-wavelength light than cones. Outdoor fixtures tend to operate in what are known as mesopic conditions, which lies between scotopic and photopic conditions, where both the rods and the cones are utilized. The sensitivity of the eye in mesopic conditions more resembles scotopic than photopic.



Credit: Alliance for Solid-State Illumination Systems and Technologies (ASSIST), fig. 5

In consequence, a photopic lumen rating does not accurately reflect its "visual efficiency" in the outdoor nighttime lighting environment.[7]

This brings us to the so-called S/P ratio (scoptic/photopic), which effectively cranks in the color of the light to convert the nominal photopic lumen rating to approximate performance under mesopic conditions, or what is called "visually useful light" stated in "visual lumens".[8] The S/P ratio for a high-pressure sodium fixture (HPS), one of the most common HID technologies in use today in the outdoor environment, is very poor at about .62, meaning it is ~38% less efficient in mesopic conditions than its photopic lumen rating implies. Conversely, a warm white LED, with a color temperature of 3000K CCT, has an S/P ratio of about 1.21, meaning it is ~21% more efficient than its lumen rating implies under mesopic conditions. Net result, you need half the lumens in the target area from the LED fixture, in a nighttime outdoor lighting environment, to achieve the same effective illumination.

To illustrate all this, let's take a typical 100-watt HPS yard light fixture as described in figure 3 above.[9] The lamp will have a mid-life rating of about 8500 lumens. However, as we have seen, only about 27% of that will be placed where it might be useful – below 60 degrees. So we are down to about 2300 useful lumens and that ignores the potential for any loss due to spill light off target. As noted above, the warm color temperature of HPS is very inefficient under mesopic conditions. Adjusting for this takes us down to 1400 visually useful lumens.

A 70-watt LED may have an Absolute Lumen rating of 9800.[10] Not so far from the 8500 lumen rating of the 100-watt HID fixture to be replaced. However, from the BUG rating we see that over 72% of its light is in the useful lighting zone - the inverse of the yard light - yielding 7100 lumens of useful light less of which is likely to be spilled off target. Adjust this for color and we end up with 8600 visually useful lumens! The 30-watt version of that same LED fixture, is rated at 4346 lumens and will provide approximately 3800 lumens of visually useful light – nearly three times that of the old 100-watt HPS yard light with a third of the energy.

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[7] https://www.thelia.org.uk/sites/default/files/resources/LIA%20TS24%20-%20SP%20Ratios%20and%20Mesopic%20Vision.pdf

[8] https://www.accessfixtures.com/how-to-select-led-equivalent-wall-pack-replace-hps-wall-pack/
https://www.lrc.rpi.edu/programs/solidstate/assist/pdf/AR-VisualEfficacy-Jan2009.pdf

[9] The lumen levels in figure 2 are with a 150-watt bulb. A 100-watt is more typical of a residential "security light" and better illustrates the extreme range of nominally "suitable" lighting. This distribution should be the same.

[10] The manufacturer also says its 30, 40 and 55 watt units are suitable. Go figure.

Granted, the NEMA head HPS fixture is an extreme case. Its CU is little better than a bare bulb, and HPS has one of the poorest S/P ratio ratings of commonly used technologies. But even with higher quality fixtures, one frequently finds, as the DoE study referenced in footnote 3 suggests, that you can at least cut lumens by 50% when transitioning from HPS area lighting to white light LEDs for outdoor night time applications. Doing so saves more energy, in this case a 70% reduction, provides better illumination and saves money.

In summary

In conclusion, it should be noted that most of the above has little or no application to indoor lighting. The average homeowner, replacing a conventional light with an LED source for indoor use, can rely upon the lumen rating, or manufacturer's statement of equivalence to select a proper luminary. In the outdoor setting, reducing lumens by half, or two thirds if replacing a high pressure sodium source, will normally yield satisfactory results for a homeowner's purposes. However, larger scale lighting projects should employ the services of lighting specialist. It is possible to model lighting based upon the photometric characteristic of fixtures documented by the manufacturers. When doing so a specialist should target minimum lighting levels recommended by IES and make adjustments for color. Better still, if possible, test fixtures and consider taking advantage of dimming, often available in LED fixtures, to get the minimum level needed to serve the purpose.

While some manufacturers of outdoor LED fixtures provide equivalence statements, a process for determining equivalence has not been standardized and due to the wide range of efficiency variance in the universe of HID fixtures discussed above, to include the lack of any consideration of spectrum efficiency, such statement can be very misleading. Both the 30 and 70 watt LED's were listed by the manufacturer as equivalent to a 100 watt HID when in fact both are many times brighter in actual application to the 100 watt fixture used in the illustration discussed above.

A note of thanks to Bruce Kinzey of the DoE's Pacific Northwest Laboratory for his patient help with the issues addressed here and John Reed, EE.