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Fear and Loathing in Lighting: Putting Anxieties Back into Context

A BRIEF ON THE RECENT CONTROVERSY OVER PERCEIVED HEALTH EFFECTS OF LED STREET LIGHTING

This white paper provides a high-level overview of the research on LED street lighting's effect on human health and puts it into context. Some considerations for product selection, public consultation and the design process are also provided.

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WHITE PAPER LED STREETLIGHTS AND HUMAN HEALTH

After a brief honeymoon, LED street lighting has been the recipient of some bad press lately. The focus of most of this negative attention has been the potential for increased blue wavelength content in the night sky resulting from the ongoing conversion of high-pressure sodium street lighting to LED, owing largely to a June 2016 public release by the American Medical Association (AMA). The AMA document and its recommendations for "high intensity" street lighting raised a number of important issues as well as some others that have been taken out of context by certain media overly focused on sensational sound bites.

RealTerm Energy is a firm believer in the many benefits of LED street lighting. LED streetlights dramatically improve the quality of light offered to citizens and enhance the natural environment by consuming less energy and avoiding light trespass. LED street lighting produces considerable cost savings for local governments, utilities and their citizens to enjoy. Converting to LED streetlights is one of the most meaningful energy efficiency projects a community can undertake – and thus a key action in the battle against climate change. In this white paper, we have endeavored to compile as much information as possible from independent, credible sources and offer this modest contribution to the ongoing dialogue on a vitally important topic.

The American Medical Association's recent report, *Human and Environmental Effects of Light Emitting Diode (LED) Community Lighting* (CSAPH Report 2-A-16), raises some very valid concerns about glare and lighting design. Concerns raised about blue wavelength content and health concerns are also important, but it is also true that they are complex and not yet entirely understood by the respective scientific communities working on them. While the AMA focuses on LEDs, it is important to note that these issues are neither new nor restricted to LED technology. Blue light is emitted by all lights regardless of source type. Further, the proposed remedy – opt for a lower correlated color temperature (CCT) light – is overly simplistic from both a public health and a public lighting point of view.

GETTING TO KNOW BLUE LIGHT

Blue light is all around us from sources such as the sun, digital screens (TVs, computers, laptops, tablets and smartphones) and electronic devices as well as from both fluorescent and LED lighting.

Light from the sun travels through the atmosphere and shorter, high-energy blue wavelengths collide with the air molecules causing blue light to scatter everywhere. This is what makes the sky look blue, as the light reflects off of the high nitrogen content of the atmosphere. Your body uses blue light from the sun to regulate your natural sleep and wake cycles, known as circadian rhythms. Blue light also helps boost alertness, heighten reaction times and elevate moods. This is why light therapy is used to treat depression, eating disorders and other ailments.

Advancements in both lighting and digital screen technology mean that most light fixtures and almost all electronic devices emit blue light waves. Because of their widespread use and increasing popularity, we are gradually being exposed to more blue light, and for longer periods of time. The human circadian system ignores long-wavelength radiation (>600 nm), but is sensitive to short-wavelength radiation (400-500 nm). Circadian rhythms refer to the human ability to time sleepiness, hunger and alertness according primarily to the amount of ambient light present at a given time.

Similar to many other phenomena, the amount and duration of exposure to blue light is key to evaluating its effects on circadian rhythms and other biological functions.

BLUE LIGHT CONTENT OF DIFFERENT LIGHTING SOURCES

All artificial light, including LEDs, fluorescent bulbs and incandescent bulbs, emits blue light. As Table 1 below reveals (MSSLC Light Postings, July 2016), all incumbent outdoor lighting contains a certain percentage of blue light (determined by the *LSPDD: Light Spectral Power Distribution Database*).

Correlated color temperature (CCT) is a shorthand but imperfect way of measuring the light source color appearance, where higher numbers denote "coolness" and lower numbers "warmth." CCT does not tell you anything about the color rendering ability of the light source, and as the table below shows, is only loosely correlated to the amount of blue light in a given light source.

What has been lost in most media coverage is that there is nothing inherently different about the blue light emitted by LEDs. At the same power and wavelength, electromagnetic energy is the same, regardless of source type. In other words, LEDs emit the same radiant energy as any other type of light. And "as the potential for undesirable effects from exposure to light at night emerges from evolving research, the implications apply to all light sources – including, but by no means limited to, LEDs" (Department of Energy (DOE), Solid-State Lighting Postings, June 2016).

Table 1. **SELECTED BLUE LIGHT CHARACTERISTICS OF VARIOUS OUTDOOR LIGHTING SOURCES AT EQUIVALENT LUMEN OUTPUT**

Row	Light Source	CCT (K)	% Blue	Luminous Lux (lm)	Scotopic content Relative to HPS	Melanopic Content Relative to HPS
A	PC white LED	2700	17% - 20%	1000	1.77 - 1.82	1.90 - 2.06
B	PC white LED	3000	18% - 25%	1000	1.89 - 2.13	2.10 - 2.51
C	PC white LED	3500	22% - 27%	1000	2.04 - 2.37	2.34 - 2.97
D	PC white LED	4000	27% - 32%	1000	2.10 - 2.65	2.35 - 3.40
E	PC white LED	4500	31% - 35%	1000	2.35 - 2.85	2.75 - 3.81
F	PC white LED	5000	34% - 39%	1000	2.60 - 2.89	3.18 - 3.74
G	PC white LED	5700	39% - 43%	1000	2.77 - 3.31	3.44 - 4.52
H	PC white LED	6500	43% - 48%	1000	3.27 - 3.96	4.38 - 5.84
I	Narrowband amber LED	1606	0%	1000	0.36	0.12
J	Low-pressure sodium	1719	0%	1000	0.35	0.10
K	PC amber LED	1872	1%	1000	0.70	0.42
L	High-pressure sodium	1959	9%	1000	0.89	0.86
M	**High-pressure sodium**	**2041**	**10%**	**1000**	**1.00**	**1.00**
N	Incandescent	2851	12%	1000	2.26	2.79
O	Halogen	2934	13%	1000	2.28	2.81
P	F32T8/830 fluorescent	2940	20%	1000	2.02	2.29
Q	Metal halide	3145	24%	1000	2.16	2.56
R	F32T8/835 fluorescent	3480	26%	1000	2.37	2.87
S	F32T8/841 fluorescent	3969	30%	1000	2.58	3.18
T	Metal halide	4002	33%	1000	2.53	3.16
U	Metal halide	4041	35%	1000	2.84	3.75

POTENTIAL EFFECTS ON HUMAN HEALTH

The AMA report raised concerns about blue light and its potential to cause glare, melatonin suppression and circadian disruption. The AMA has also recommended selecting 3000K fixtures to lower the amount of blue light present in outdoor lighting applications.

Melatonin is present at low levels during the day, begins being released a few hours before bedtime and peaks in the middle of the night. Any artificial light suppresses melatonin because it tricks the body into thinking it is still daytime, leading to circadian delay. While not entirely conclusive, most research also suggests that light higher in a certain spectrum of blue light has an enhanced effect on melatonin suppression. It has been suggested by a number of studies (mostly focused on indoor environments for night-shift workers) that chronic exposure to blue light at night can lower the production of melatonin, the hormone that regulates sleep.

The science of photobiology is still in its infancy and there is need for more research in this area. A major limitation of most reports to date, for example, is that they have focused on one particular parameter and not all of the parameters related to exposure. A complete analysis would have to examine the "temporal-spatial-spectral distribution of optical radiation" and not just relative spectral content of a light source (Rea et al., page 4). This would include duration, timing, history (exposure to light during the day helps), quantity, spatial distribution (where light hits the eye) and spectral content (wavelength issues). Focusing on only the spectral content also ignores the simple math of converting from incumbent technology to LED.

LED streetlight conversions generally deploy LED fixtures that emit 50% or less of the light output of the replaced incumbent fixtures. So even if the LED fixture has a melanopic content twice that of the incumbent, converting to LED would produce the same or lower melanopic output. The situation improves further when LEDs are fitted with adaptive controls to allow them to be dimmed at specific times, a technology that cannot be applied to regular HPS or MH streetlights. A second limitation is that the causal relationship between melatonin suppression and circadian disruption is not proven nor simple. While we know that staying awake all night is bad for us, much less is known about how light, regardless of color, factors into the equation. Moreover, stimulation of the circadian system is not synonymous with health risk. A third limitation is that most studies have focused on only the stimulus (i.e., the light) and not the response – but it is impossible to predict health consequences without studying the biological response.

Some media reports have suggested a link between melatonin suppression and cancer proliferation, but caution must be exercised here as no human studies have verified this link, and mice (the subjects of these studies) are 3,000-10,000 times more sensitive to light than humans (Rea & Figueiro, 2016).

A critical factor lost in most media coverage is that the AMA report does not cite any evidence that the intensity and duration of light exposure typically experienced from street lighting is sufficient to have any melatonin-suppressing effect.

Finally, LED lights should not be isolated either as the only or likely culprit: "the complexity and remaining uncertainties in the science of non-visual responses apply to any artificial lighting, so it would be wrong for LEDs alone to be associated with these far-reaching effects" (Public Health England, 2016).

EFFECTS ON WILDLIFE

The effects of blue light on wildlife are not well researched at this point. However, all living systems benefit from a 24-hour light and dark cycle. As all sources of artificial light introduce an unnatural impact onto flora and fauna, it is suggested that this be balanced with safety concerns in areas of natural and scientific interests.

It is critical to note that **the AMA supports moving to LED street lighting because "the inherent energy efficiency and longer lamp life of LED lighting [lead] to savings in energy use and reduced operating costs, including taxes and maintenance, as well as a lower air pollution burden from reduced reliance on fossil-based carbon fuels."** This conclusion confirms that of the Department of Energy and others that the benefits of LED lighting far outweigh the costs. In summary, while there's nothing inherently dangerous about LED lighting, it should be used with the same prudence with which we use any other technology.

STREET LIGHTING IN CONTEXT

Our current media culture is predisposed towards the sensational, which means that the bulk of daily coverage focuses on negative issues such as fear, risk or scandal. The 24-hour news cycle also means that in-depth investigations that look at issues from different sides are becoming increasingly rare. As a result, lost in the media coverage around LED streetlights has been any discussion of how much exposure would be unsafe and what constitutes exposure as well as any attempt to put the perceived risk into context of other lighting or similar public health concerns.

Basic common sense tells us that individuals have far less exposure to streetlights than to other types of lighting. The vast majority of the population (long distance truckers may be an exception) have far more exposure to interior lighting and digital screens than to streetlights. The location and proximity of the risk, in this case the streetlight, is vital from a public health perspective if a valid risk assessment is to be conducted. Public Health England's examination of over 100 LED fixtures concluded that "at a distance of 2 m, reaching the exposure limit values for the Blue Light Hazard would require steady fixation for over 2½ hours, based on conservative calculations" (April 2016). Ask yourself: who spends more than 2½ hours approximately 2 meters away from a streetlight? Let's assume for the sake of argument that some streetlights are approximately 2 meters away from residential windows. Would these people be at risk? Department of Energy (DOE) staff set out to see how much light from different sources was present in a small sample of residential rooms. When the DOE staff conducted light meter readings on various sources of light within the home, results revealed that portable tablet devices generated 150-450 times and bedside lamps 350-3,500 times more lux than street lighting (Kinzey 2016). Further, simply closing the blinds on a window reduced the lux reading to zero.

Combined subset* of readings taken by Naomi Miller, Bruce Kinzey, Rita Koltai, Terry McGowan, Derry Berrigan (*Note: Not all participants provided readings in every category; not all categories listed.)	Reading (lux)
VERTICAL ILLUMINANCE FROM WINDOW FACING STREETLIGHT, IF AVAIL., INTERIOR LIGHTS OFF	
· Blinds open	≤0.1
· Blinds closed	0
Vertical illuminance from window not facing streetlight	0-1
Kitchen	30-340
TV from 10 feet away, room light off	0-10
TV from 10 feet away, room light on	2-30
Phone/tablet at reading distance, other room lighting off	0-5
Phone/tablet at reading distance, room lighting on	15-45
Bedside lamp(s) reflecting on magazine/book page	35-350
Max. horizontal illuminance at streetlight nadir – no vegetation interference	5-10
Max. horizontal illuminance at streetlight nadir – some interference	0-5

The DOE also stated that it is important to note that certain natural light, such as light resulting from moonlight, has a blue-rich content at a 4100K correlated color temperature (CCT). Moonlight is thus often brighter and whiter (i.e., more blue light) than a 4000K LED streetlight.

In addition to natural light, there is also a wide range of artificial light types and sources in the nighttime environment besides streetlights. Uncontrolled uplight comes from other sources of outdoor lighting: billboards, signage, vehicles, plus the significant amount of interior lighting in dense urban areas that simply spills outside. A singular focus on streetlight ignores the effects of these other types of lighting and also ignores any risk-reward analysis associated with all of these types of lighting.

Darkness brings increased hazards to pedestrians, cyclists and drivers because it reduces the distance they can see. Streetlights assist all three groups by providing visibility adequate to detect obstacles, read signs, see boundaries and assist in other visual search tasks as well as contributing to feelings of safety.

In addition to enhanced road safety, LED streetlights have a number of distinct health-related advantages over the incumbents. Remarkably more efficient, LED streetlights provide an indirect benefit to health associated with the reduced carbon emissions of LED lighting relative to current lighting. The dimmability of LEDs allows operators the ability to produce only the level of illumination needed at any specific time. LEDs are also far more directional – meaning they offer a high degree of control over the pattern and evenness of light on the ground compared to the incumbent. These factors allow for dramatically enhanced photometric design over the incumbents (which generally lacked any design). Design is driven by the classification of the particular roadway, the geometric position and frequency of the luminaires with respect to the roadway, and the unique distribution pattern of a prospective fixture. Good lighting for both roadways and local streets means reducing backlight and uplight while delivering the required light to the targeted surfaces. In addition to design, a final benefit of LEDs is that their spectral content can be tailored to minimize blue wavelengths.

While there's nothing inherently dangerous about LED lighting, it should be used with the same prudence with which we use any other technology. LED lighting should be selected, designed and installed in a way that maximizes energy efficiency while minimizing glare, wasted light and blue wavelength content. The AMA is right to point out that the visual components of the driving task issues can be greatly minimized by proper lighting design and engineering. Proper lighting design and installation are crucially important elements of a robust selection process required for a successful streetlight conversion project.

PURPOSE OF ROADWAY AND STREET LIGHTING

(from IES RP-8-14 Roadway Lighting guide)

The principal purpose of roadway and street lighting is to allow accurate and comfortable visibility at night of possible hazards in sufficient time to allow appropriate action. Good lighting has been shown to significantly reduce the night proportion of accidents; especially on urban freeways and major streets. For most streets and sidewalks, good lighting has been reported to increase the feeling of personal security of pedestrians. Lighting is good when it is economical in equipment, energy and maintenance costs, and meets a proven or reasonably predictable need, with a minimum of adverse effects.

ROBUST SELECTION PROCESS REQUIRED

Given the financial savings and a growing body of evidence supporting enhanced performance and energy savings, a large number of municipalities and utilities are considering converting their streetlight network to LED. For many staff first considering an upgrade to LED, the many technical, financial and social aspects to consider can be overwhelming. Fortunately, the DOE and several others (Efficiency Vermont, MAPC, Leotek, Lightsavers) now have case studies, how-to guides and other great resources to help.

The brief discussion that follows will highlight three components of a robust selection process that relate to the potential health impacts of glare and color temperature – fixture selection, design and installation.

Those considering an upgrade should develop a model specification to ensure they obtain the characteristics required to meet or exceed reliability and performance concerns. These include physical and durability features of the luminaire such as the required level of ingress protection, corrosion resistance and electrical protection, plus performance properties like light distribution (e.g., backlight, uplight and glare characteristics), efficacy (lumens per watt), desired color temperature and compatibility with adaptive controls. Thus, outdoor lighting design requires a complex analysis of many criteria. Outdoor lighting systems will vary depending on the application and local conditions. Tradeoffs in the considerations of visibility, environmental impacts, energy efficiency, cost, personal safety and security need to be optimized. Therefore, simply suggesting that everyone opt for 3000K fixtures is a gross oversimplification. Correlated color temperature (CCT) is a simplified metric designed to represent how people see the tint of illumination from a light source, but, as noted above, it ignores almost all of the critical factors associated with light exposure (amount, duration, timing) and is only relevant to a single biological response. As the Municipal Solid-State Street Lighting Consortium (MSSLC) has demonstrated, lower CCT fixtures sometimes have higher concentrations of blue light than comparable higher CCT fixtures. While low CCTs may be more aesthetically pleasing to some (largely because they appear closer to the incumbent, yellow/orange HID technology that we're all simply used to), they may also reduce the effectiveness of the lighting. This reduction would mean more lumens would be required, which would potentially negate the effects of reducing the relative amount of blue emission.

In addition to the range of safety considerations, good design results from using the right type of fixtures (including wattages, color temperatures and distribution patterns) for the correct applications. Improper design results in uniformity and glare issues, which lead to citizen complaints. Good design requires a thorough analysis of the photometric performance of fixtures (quality fixtures have all been measured, verified and published by a third-party laboratory) in the form of luminous intensity tables that can be fed into a photometric calculation by means of an .ies file. Good design also means addressing areas that are under or overlit. Good design means moving beyond a simple one-for-one fixture replacement to one tailored to the local infrastructure – which means separate designs for each unique street. Finally, diligence in product selection and design can all be undermined by shoddy installation. For example, a common mistake in poor installations is a failure to level set the new LED fixtures (usually because incumbent fixtures were tilted to cast the globe of light further), which results in glare issues that can be especially troubling in hilly areas.

SPECIAL CARE REQUIRED FOR OBSERVATORIES

While properly selected and designed LED streetlights will dramatically reduce uplight, there can be issues with radiant skyglow (related to the diffusion of blue light) that erode the effectiveness of astronomical facilities.

The City of Flagstaff, Arizona, recently conducted an extensive study using illuminating engineering to design an approach that maintains or reduces the skyglow caused by street lighting. The innovative solution consists of spectral control, high fitted target efficacy, lighting controls and the application of IES RP-8-14. Advanced aerial testing of before-and-after skyglow conditions were used to confirm success. The process included an in-depth understanding of the needs of modern day astronomy and how they differ from the largely environmental demands of other demanding locations.

Observatories represent a unique land use for their host communities and not surprisingly require a somewhat unique approach to planning a streetlight upgrade that puts a higher premium on spectral control (and therefore a higher cost) than average community needs.

REALTERM ENERGY'S CLIENT-DRIVEN DESIGN

RealTerm Energy acts as an informed but impartial advisor to our clients. Our sales and engineering teams work with municipal and/or utility staff to source the best equipment that meets or exceeds specifications and offers the best overall value. Its design team optimizes the photometric design to address local standards and preferences in terms of safety, energy efficiency and aesthetic. Our installation team works with local labor to ensure fixtures are installed properly and glare is eliminated or minimized to the fullest extent possible.

White papers on photometric design and installation best practices are now available on the RealTerm Energy website.

RECOMMENDED SOURCES

A WORD ON SOURCES

Not all information is created equal. Readers should consider the following questions to evaluate a source:
Who published the source? Is it a university press, government agency or a large reputable publisher?

Does the information appear to be valid and well-researched or is it questionable and unsupported by evidence? Is there a list of references or works cited? What is the quality of these references?

When was the source published? Is the source current or out of date for your topic?

Who is the author? What are the author's credentials (educational background, past writing, experience) in this area? What is the author's intention? Is the author's point of view objective and impartial? Is the language free of emotion-rousing words or bias?

With this in mind we would like to present a listing of resources on this topic that prioritizes content by trustworthy entities such as the Department of Energy and other government or research-based institutions.

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