SLSC STREET LIGHTING | SMART CONTROLS

IPWEA

SLSC BRIEFING

Addressing health concerns about the blue light content in exterior LED public lighting

June 2019

KEY POINTS:

LED lighting is the new technology of choice for all lighting including public lighting due to its dramatic increase in efficiency, flexibility, and longevity with minimised maintenance. However, these benefits also bring complexities in management, including the need to choose the most appropriate colour of the light.

When LEDs were first introduced they had high levels of “blue content” - an unscientific term that described their appearance and corresponded to “Correlated Colour Temperatures” of 4000-6500 Kelvin. This colour range is good to keep humans alert to drive safely, but has been scientifically shown to have negative health impacts for interior lighting. It is therefore important to manage this trade-off through for exterior lighting the use of best practice design and the use of modern technology.

Where traffic volumes are low, or because it is an off-peak period of the night, serious consideration should be given to dimming or switching-off lighting. Where traffic volumes are high and/or traffic speeds are high, blue-rich LED at around 4000K is recommended, but in residential areas where vehicular demands are low and pedestrian and community issues are more important, LED colour temperatures of 3000K or less should be used.

The purpose of this briefing is to inform professionals who are responsible for exterior public lighting, whether they work in the public lighting sector or in the public works engineering and asset management sectors. The paper does not deal with interior lighting other than to contrast the comparative risks that humans face from interior lighting with those faced from exterior lighting. Nor does this paper deal with lighting impacts on wildlife which is dealt with in Briefing Paper 7: “Minimising the impact of public lighting on threatened species”.

From a historical perspective, the potentially positive and negative effects of blue-rich white light[1] have become apparent when LED technology became commercially viable about 6-10 years ago, and with new research, the level of awareness (and concern) about this issue has increased. Before then, the most prevalent public lighting

[1] The International Dark Sky Association (IDA) describes “the term ‘blue-rich light’ will often be used to refer to all types of white light. The term is used in contrast to yellow-rich sources (principally HPS) and includes sources with varying proportions of blue light, generally defined as light with wavelengths shorter than 500nm. The term is not meant to imply that the light would actually appear blue, though some of the sources discussed do have a blue hue. Examples of such blue-rich light sources include fluorescent, white LED (all CCT), induction, and metal halide.” Note that white light of 3000K or less therefore provides a reasonable compromise.

was 70+ year old white Mercury Vapour (MV) lighting technology, 60+ year old yellow High Pressure Sodium (HPS) lighting technology, and 30+ year old white Metal Halide (MH) lighting technology.

It is important to recognise that MH and MV white lighting has greater blue content than even 4000K LEDs, and these two types of lighting represent more than 40% of all street light luminaires currently used in Australia. Thus, LED lighting in these cases represents a resultant decrease in blue-rich white light, even before accounting for the lower lumen requirements of LED design solutions, or from the use of controls. In this wider context, LED lighting has arguably been very unfairly maligned by some of the narrowly-focused critique.

It is important to distinguish between eye damage described in the literature resulting from "blue light hazard" (BLH)[2] from the impact of circadian disruption on human wellbeing. The term "blue light hazard" should only be used when considering the risk to the retinal tissues of the eye and should not be confused with circadian impacts and disruption of the sleep/wake cycle which this paper addresses. Retinal damage from BLH is well understood and is addressed by conformity to the mandatory AS/NZS 60598.1 luminaire safety standard.

In most cases the change to LED lighting reduces energy consumption and maintenance by more than 50% over legacy technologies and so even for economic reasons alone, LED lighting will continue to progressively replace all previous lighting technologies. LED lighting technology is improving at a far greater pace than any of its predecessor lighting technologies, bringing with it many opportunities to maximise the benefits and also to minimise any potential detriments of artificial lighting at night.

LED is a real revolution in lighting, and for asset managers working in exterior public lighting the mass replacements of public lighting, both planned and already underway, creates a need to become familiar with a wide range of new technical, social, and environmental topics associated with LED lighting and smart controls. This disruptive change in technology has surpassed the ability of technical standards covering products, design and application to keep pace. In Australia and New Zealand, there are major gaps in professional and practical knowledge and guidance for the application of the latest lighting and control systems technologies. The IPWEA SLSC Programme is assisting with information on bridging these gaps.

Australia and New Zealand currently have some of the lowest illumination levels for street lighting in the developed world and these levels are much lower than that of the USA or European Union (EU). A typical Australian residential road is lit to as little as 1/5th of the lighting level used on comparable residential roads in North America or Europe[3]. Lighting levels on our main roads, while more comparable to overseas, are at the low end of international norms.

In Australia and New Zealand, the Technical Specification for road lighting luminaires, SA/SNZ TS 1158.6:2015 Amd1:2018, states that the value of nominal Correlated Colour Temperature (CCT) for road lighting should be no greater than 4000K. However, this was drafted in 2014 and this guidance has now been effectively updated by much new research and technology advances.

Currently, only about 15% of Australia's 2.5 million street luminaires have been converted to LEDs and less than 1% of LED luminaires installed in Australia have smart controls. There are around 1 million MV luminaires in Australia that will need to be replaced under the requirements of the Minamata Convention (reduction of mercury) within the next three to four years and this lends urgency to the need for sound guidance in replacement technology choices.

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[2] International Commission on Illumination (CIE) Vienna. CIE Position Statement on the Blue Light Hazard, April, 2019. Free download at: CIE Position Statement on the Blue Light Hazard

[3] IPWEA, 2016, "Street Lighting and Smart Controls (SLSC) Roadmap" Chapter 4, for Department of the Environment and Energy, Australian Government, by Strategic Lighting Partners and Next Energy

Drivers of the positive and negative effects of lighting on humans

In order to determine what is best practice for public lighting, it is important to understand how lighting affects the human population. There are five drivers that need to be understood, specified and managed to ensure best outcomes for human beings. Where the technology allows they may be varied through control of parameters such as lighting intensity and time of day, whereas others need to be specified at time of construction, such as luminaire design and installation orientation. However as technology advances, others which used to be fixed at time of installation, can in some circumstances, be varied also by management or control. The drivers are:

(i) Light colour, or more scientifically “Spectral Power Distribution” (SPD) and “Correlated Colour Temperature” (CCT);

(ii) Light intensity;

(iii) Light dose;

(iv) Time of day/night;

(v) Luminaire design and installation orientation;

Light Colour

While the term “light colour” is simple for everyone to understand, it is not sufficiently precise to describe light if we are to minimise the negative impacts and maximise the positive impacts on human beings. Lighting engineers have used the terms “Correlated Colour Temperature” (CCT) or “Colour Temperature” to describe the colour of lighting but as research in the last decades has advanced, even that term is now considered scientifically imprecise. Thus, the concept that should be used to describe the performance of LED lighting where it has potential impacts on safety and health is “Spectral Power Distribution” (SPD) and Figure 1 provides an indication of why that is. Each lightsource shown has different SPDs and thus different impacts on humans. However, until lighting engineering practice advances to catch up with the science, Correlated Colour Temperature (CCT) is used in this briefing – and also shown in Figure 1 - as it refers to a single number (in contrast to an SPD graph).

The choice of lighting colour (referred to here only in CCT) reflects an evolution in lighting. Yellow 2000K CCT High Pressure Sodium (HPS) lamps superseded very inefficient white Mercury Vapour (MV) luminaries in most regions in the world (but not Australia) about 40+years ago. Commercial availability of very energy efficient and high colour rendering performance white light 4000K street lighting LEDs started in about 2008. Since then, recognition of their functional advantages from a transport and road safety perspective over 2000K yellow HPS has been enthusiastic. One of the further large disadvantages of yellow 2000K HPS lighting is its poor ability to allow humans to differentiate colours. This is referred to as the “colour rendering” ability of the lighting and is described by the Colour Rendering Index or CRI.

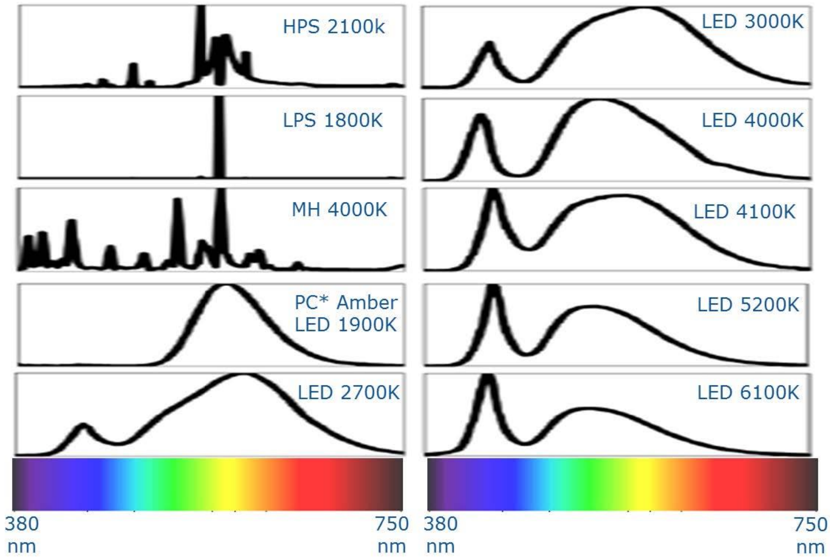

Figure 1 Representative Spectral Power Distributions (SPDs) of 10 different lights sources including three legacy High Intensity Discharge (HID) lamps and 7 LED light sources of differing Colour Temperature (Source: European Commission 2018[4]). NB "PC" stands for "Phosphor Converted"

US research on higher speed roads shows that driver reaction times are longer (and thus vehicle stopping distances larger) under 2000K yellow HPS light than with 3500K or 4000K LED lighting[5]. Conversely, 4000K LED lighting also suffers from colder appearance and has greater (potentially harmful) blue light percentage and melanopic disruption potential (scientifically described as Melatonin Suppression Index or MSI) and consequently there has been some public and interest group advocacy and push-back. However, recent applied research has shown the dose, and the melanopic disruption potential from street lighting to be very low[6]. Refer to the Lighting Dose section below.

There is also been much negative feedback among community groups about the use of 4000K in residential roads and people focused areas and that 3000K or less provides a more appealing result[7], except perhaps for tropical regions. Additionally, there is a 5-10% higher energy consumption penalty for the choice of 3000K luminaires in residential road applications.

On the issue of dimming or off-peak complete switch-off of street lighting, research was commissioned by the UK Institute for Health Research (NIHR)[8] to find out if road safety and crime rates were being negatively impacted under off-peak dimming or switch-off conditions. UK is the most advanced country in the world for the adoption of dimming and switch-off practices. The high budget medical-grade study examined 62 of the 174 Councils – who practised dimming and switch-off only outside of peak traffic conditions - in England and Wales to find out whether the introduction of white light (replacing the yellow HPS lighting) and the introduction of variable lighting instead of all-night lighting had negative impacts.

The study concluded that: "The results provide no evidence that switch off, part-night lighting, dimming, or white light adaptations to street lighting were associated with night-time traffic collisions. The results also provide no evidence that these lighting strategies are associated with an increase in crime at an area level. Results suggest that in the aggregate, dimming and white light regimes were associated with reductions in crime, though estimates were imprecise." Note that this statement only applies to activities during off-peak

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4 European Commission, JRC Technical Reports, Revision of the EU Green Public Procurement Criteria for Road Lighting, March 2018, Figure 19, p71.

5 Clanton, N. of Clanton & Associates & Gibbons, R. of Virginia Tech Transportation Institute (VTTI), 2014, Seattle LED Adaptive Lighting Study, Northwest Energy Efficiency Alliance, available at ResearchGate here.

6 "Assessment of Blue Light Hazards and Correlated Colour Temperature for Public LED Lighting", Wood J, Black A, Isoardi G. School of Optometry and Vision Science, Institute of Health and Biomedical Innovation, Queensland Institute of Technology, March 2019

7 Some examples of web-links: Rome, Davis California, Chicago and Brisbane

8 Steinbach R, Edwards, P., et al, The Effect of Reduced Street Lighting on Road Casualties and Crime in England and Wales: Controlled Interrupted Time Series Analysis, Department of Population Health, London School of Hygiene and Tropical Medicine. J Epidemiology Community Health 2015;0:1–7 doi:10.1136/jech-2015-206012, 3 June 2015

times. British Standards support this approach in the BS 5489-1:2013 Code of Practice for the design of road lighting,[9] and the AS/NZS 1158.3.1 standard currently being updated will include guidance on adaptive lighting[10].

IPWEA recommends that where traffic volumes are heavy or fast moving, such as on arterial routes, highways or motorways, 4000K LED lighting should be used to maximise alertness, minimise reaction times and improve road safety, and if justifiable, controlled so that it can be dimmed or switched-off when traffic volumes are low. In contrast, in residential or pedestrian areas 3000K or less LED lighting should be used to minimise any negative health effects of blue-rich lighting and similarly, should be dimmed or switched-off when not required.

Light Intensity

Significant research confirms the intuitive observation that an organism which is sensitive to light – be it human, animal or plant – will be sensitive to the *amount* of light energy that falls on it. Thus, where lighting is required for safety purposes such as for road transport, the greater the levels of light, the greater the safety benefit, but like all things, at some point the benefit/cost trade-off makes it not worth increasing light levels. More importantly, lighting, especially blue-rich white lighting, has negative effects, so that dimming, or switching-off blue-rich white light will reduce or eliminate potentially harmful melatonin suppression effects caused by that light.

In simple terms, less light equals less impact - whether positive or negative.

The recommended lighting levels for public lighting is covered in the standards series *AS/NZ 1158 Lighting for Roads and Public Spaces*. These and other standards provide some detail on the appropriate light levels to use, so its not the purpose of this brief to cover that. However, current AS/NZ 1158 Part 3.1 and Part 1.1 design standards are now dated, and are silent on adaptive lighting and the use of more than one (road) lighting subcategory or *when* lighting can be dimmed or switched-off, or to *what extent* dimming could occur when traffic volumes are low.

The forthcoming 2019 update to AS/NZS1158.3.1 will accommodate the use of more than one lighting subcategory and will provide overview guidance on the applicability of multiple subcategories. Further guidance is available in European Standard CEN/TR 13201-1:2014[11]. This recommends that the professional judgement of transport planners be utilised to adopt a risk-management approach. The European Standard evaluates the specific conditions of surrounding traffic, pedestrian and built environment. It recommends that road authorities update their road lighting hierachies accordingly to include appropriate temporary reduced light levels commensurate with times of reduced road activity. This risk-management approach may require measured evidence of off-peak traffic volumes to substantiate the decision to redefine the subcategories in specific locations at times of low traffic volume.

IPWEA recommends that transport planners be included in decisionmaking to update road lighting hierarchies to accommodate adaptive lighting and variable lighting subcategories, according to specific needs.

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[9] See Section 4.4.2 Measures to minimise electrical energy use – Part Night.

[10] The forthcoming AS/NZS1158.3.1:2019 update will include guidance for the application of adaptive lighting (using CMS control systems) by means of temporal reclassification of road lighting subcategories over the nightly period.

[11] European Standard CEN/TR 13201-1:2014 Road lighting guidelines on selection of lighting classes, Section 4 - Outline of selection process: "The normal lighting *subcategory* is selected using the most onerous parameter values, however, the application of this *subcategory* may not be justified throughout the hours of darkness due to changing conditions e.g. weekends, different weather conditions, different traffic volumes etc. Temporal changes in the parameters under consideration when selecting the normal lighting *subcategory* could allow, or may require, an adaption to the normal level of average luminance or illuminance, usually by reducing the level." Note: For clarity, the AS/NZS 1158 term "*subcategory*" has been substituted in this excerpt for the European Standard term "*class*".

Lighting Dose

Lighting is a form of electromagnetic radiation. The "dosage" received by a human determines its effect. Thus the light intensity multiplied by the time the human experienced that intensity is the dosage received. The dosage received will determine the level of negative impact on the human involved. The same is the case for the effects of blue-rich white light. The greater the dosage a human receives, the greater the negative impact they will experience. However, it is important to note that circadian influencing dosage levels from public lighting on humans are very small due to the distance of the light source to the human and the relatively brief time of exposure, even if walking slowly under the light. For example, some researchers have noted that the blue-rich white light dosage received by even stationary people under street lights are one tenth of that experienced by people reading on their mobile phones or tablets in bed at night[12].

More recent research by the Queensland Institute of Technology (QUT) in March 2019 has confirmed this in its statement that *"The Circadian Stimulus values recorded for common interior night time activities were between 10 and 100 times higher than those recorded for road users at night under all street lighting technologies"*[6] and *"All maximum exterior circadian stimulus (CS) values measured directly under the luminaires for each technology type were well below the threshold (8 times less) considered to induce melatonin suppression or circadian disruption"*

IPWEA recommends that strategists and decision makers involved in public lighting include methods to use control systems to dim or switch-off lighting when not required and increase public awareness of the positive and negative trade-offs, such as dosage, involved in LED lighting.

Time of Day / Night

All organisms on this planet – including of course human beings - are synchronised to the solar cycles of the rotating earth and the resultant day/night and seasonal cycles. Their biological and biochemical states are therefore related to the position in that cycle and are affected by the time of exposure to light. Using artificial light at night (often shortened to the acronym ALAN) potentially improves night activities and their safety for humans, but also potentially disrupts the biology of humans exposed to that light.

With modern control systems, it is a simple process to fully programme dosage and time of day/night to precisely target illumination only where and when it is required. Up to recent times, there has been no compromise possible - public lighting was full-on for all the dark hours. Now CMS control systems can alter individual luminaire settings to balance community, astronomical and ecological benefits against the detriments. The task to weigh up all the factors has become much more complex, but is now possible to establish and apply a net-benefit position as determined by the specific local community concerned.

IPWEA recommends the use of CMS controls to manage the "time of night" which artificial light at night is or dimmed or switched-off (or in some cases brightened, for accidents, incidents or planned special events).

Luminaire Design, Lighting Design and Installation Orientation

With the mass adoption of LED technology, it has become more important than ever that luminaire design, lighting design, site location and luminaire installation orientation minimises any light directed where it is not required. This will also help to reduce glare which is key to good visibility. Where light does spill unnecessarily, this is regarded as light pollution and results in unintended and/or undesirable consequences. These include

[12] Kinzey, B. Pacific Northwest National Laboratory, Portland Oregon, USA, IES Street and Area Lighting Conference September 17-21, 2016, Page 14

night sky and animal/bird interference, as well as light trespass into residential homes or other situations where the light is not required.

IPWEA recommends that MIESANZ or equivalent qualified lighting designers are appointed on all major lighting projects to ensure selection of appropriate luminaires with good photometric design that minimises glare, light spill and, upward waste light, and are fit for the application for which they are intended.

MORE READING:

1. IPWEA, 2016, "Street Lighting and Smart Controls (SLSC) Roadmap" Chapter 4, for Department of the Environment and Energy, Australian Government, by Strategic Lighting Partners and Next Energy
2. International Dark Sky Association's definition of blue-rich light: Page 5 "Visibility, Environmental, and Astronomical Issues Associated with Blue-Rich White Outdoor Lighting" May 4 2010
3. LEDs Magazine, Volume 9, Issue 7, "Understand colour science to maximize success with LEDs – part 2"
4. European Commission, JRC Technical Reports, "Revision of the EU Green Public Procurement Criteria for Road Lighting", March 2018, Figure 19, p71
5. Clanton, N. of Clanton & Associates & Gibbons, R. of Virginia Tech Transportation Institute (VTTI), 2014, "Seattle LED Adaptive Lighting Study", Northwest Energy Efficiency Alliance, available from Researchgate here.
6. "Roadway Lighting: An Investigation and Evaluation of Three Different Light Sources", Final Report 522, Arizona Department of Transportation, USA, May 2003.
7. Steinbach R, Edwards, P., et al, "The Effect of Reduced Street Lighting on Road Casualties and Crime in England and Wales: Controlled Interrupted Time Series Analysis", Department of Population Health, London School of Hygiene and Tropical Medicine. J Epidemiology Community Health 2015;0:1–7 doi:10.1136/jech-2015-206012, 3 June 2015
8. Kinzey, B. Pacific Northwest National Laboratory, Portland Oregon, USA, IES Street and Area Lighting Conference September 17-21, 2016.
9. European Standard CEN/TR 13201-1:2014 "Road Lighting Guidelines on selection of lighting classes: Section 4 - Outline of selection process".
10. "Assessment of Blue Light Hazards and Correlated Colour Temperature for Public LED Lighting", Wood J, Black A, Isoardi G. School of Optometry and Vision Science, Institute of Health and Biomedical Innovation, Queensland Institute of Technology, March 2019.