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EDUCATIONAL SERIES | PART 3

Best practice public lighting design

The Shine a Light educational series considers the evidence around the need for appropriate lighting at night in public spaces, focusing on areas for informal use that are not covered by street lighting and how this should be delivered.

Part 3, *Best practice public lighting design* considers what good public lighting is and proposes how to achieve it.

Have you read Part 1 Public lighting for social, economic and environmental benefits & Part 2 Candidate locations for public lighting?



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Leadsun operations take place on the lands of First Nations people across Australia. We acknowledge them as Traditional Owners and Custodians of the lands and waters we depend on. We recognise their continuing connection to land, waters and culture and pay our respects to Elders past, present and emerging. In particular, the Leadsun team would like to acknowledge the Bunurong/Boon Wurrung and Wurundjeri Woi-wurrung people of the Kulin Nation on whose land we are based.

The Shine a Light educational series considers the evidence around the need for appropriate lighting at night in public spaces, focusing on areas for informal use that are not covered by street lighting.

Part 1, **Public Lighting for Social, Economic and Environmental Benefits** introduced the need for appropriate public lighting to support positive social, environmental, and economic outcomes including safety, accessibility, and equity.

Part 2, presents **Candidate Locations for Public Lighting**, how to identify them and assess their suitability.

This is part 3, **Best practice public lighting design**, which considers what good public lighting is and proposes how to achieve it. This involves exploring key technical lighting factors such as colour temperature, colour rendering, brightness, and uniformity, as well as strategies to minimise negative effects of lighting and lighting maintenance.

By understanding and implementing these principles, it is possible to create well-lit and inviting spaces for everyone to use at night.

WHAT IS 'GOOD' PUBLIC LIGHTING & HOW CAN WE ACHIEVE IT?

Good lighting design is compliant with Australian Standards but also understands the nuances of the environment and users in providing fit for purpose lighting. It can help people feel safe and welcome in public areas at night and is mindful of different perceptions, particularly by women and older people who have higher thresholds for feeling safe. Melbourne research suggests that consistent and layered lighting makes women feel safer than simply brighter light (Kalms & Hunt, 2019).

"The quality of the light, not the level or quantity, is the most important factor in how people perceive an environment."

Yang, retrieved May 2021.

What constitutes best practice is constantly changing and there is no consensus regarding the most effective lighting solutions (Peña-García, Hurtado, & Aguilar-Luzón, 2015). Guidelines and standards have not necessarily been based on evidence (Fotios, Yang, & Edwards, 2014) but tend to focus on factors that are easy to measure. Even then, many lighting studies focus on young, healthy people in their research and so findings are not specific to the broader population.

The most recent update to AS1158.3.1 was published in 2020 and has addressed some of the shortfalls identified in the previous (2005) version.

Determine what lighting is required

The optimum lighting design is dependent on the location and users, so there is no, one size fits all, solution. Key technical factors such as colour temperature, colour rendering, brightness and uniformity are independent and interact with each other and the surrounding environment to influence a person's overall experience.

To begin creating best-practice public lighting, we consider key technical factors, while keeping in mind the location and users.



Leadsun solar pathway lights,
[Tarneit Wayfinding Trail.](#)

Colour Temperature

Different light sources (luminaires) produce light of different colour temperatures, measured in Kelvin (K). As colour temperature increases the light changes from a warm yellow to a cool blue. City of Melbourne (2013) outlines the colour temperatures most often used in public lighting:

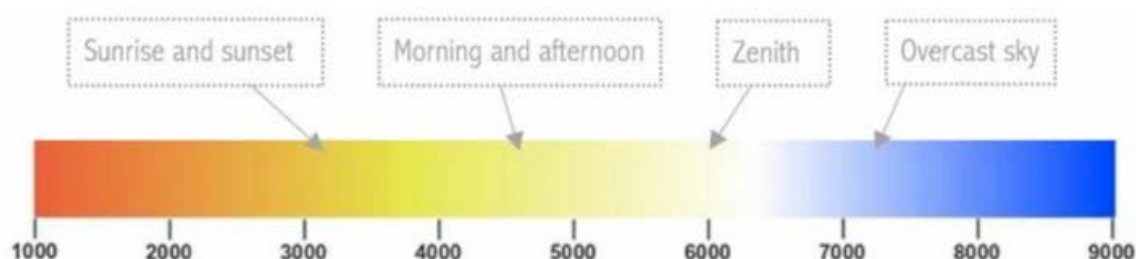
- **Blue-white (cool) light – greater than 4000K** with a minimum colour rendering index of 80. Typically emitted by metal halide, plasma, LED, induction and fluorescent lamps.
- **White light – greater than 3700K** in major streets and public areas or 3000K in minor spaces with a minimum colour rendering index of 80. Typically emitted by metal halide and LED lamps
- **Warm light - 3000K** Recommended in public spaces intended for relaxation, leisure and low lever activity. Available from new generation LED lamps.
- **Yellow light – less than 2000K.** Typically emitted by high pressure sodium lamps.

The colour temperature of daylight changes with the sun's position and level of cloud (Figure 2). There is more warm, yellow light at dawn and dusk and more cool, blue light in the middle of the day.

Until recently it was common for cooler colour temperatures (4000K and above) to be used for external lighting. These were considered to be more vibrant, and therefore increased human activity and engagement in external spaces at night. When LED's first became commercially viable around 2009 it was more cost effective to use cooler colour temperatures due to their higher efficacy and lower cost. White light has also been shown to provide road safety benefits compared to warmer colour temperatures (Institute of Public Works Engineering Australasia, 2020b).

City of Melbourne (2013) report that “white light [3500K to 5000K] reveals the natural colours of surfaces, and provides a more accurate sense of the size and shape of objects”, making it preferable to yellow light [less than 3000K] for orientation and wayfinding. White light makes it twice as easy to recognise another person's face than yellow light (University College London, 2004) and studies generally find that people feel safer when white light is used compared to yellow light (Pena-García, Hurtado, & Aguilar-Luzón, 2015).

Figure 2 Usual colour temperature in Kelvin for different sky conditions and sun position (Poirier, Demers, & Potvin, 2017)

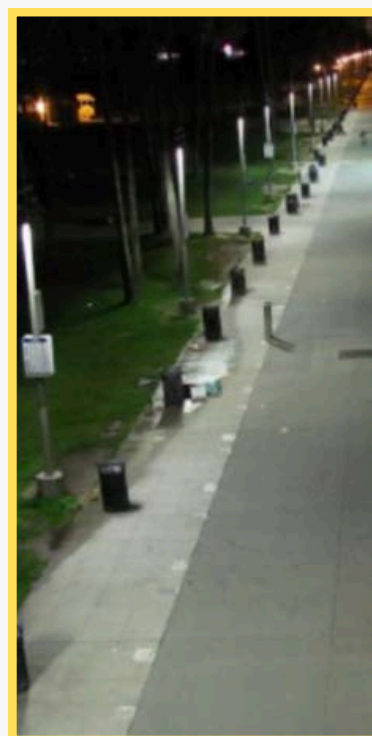
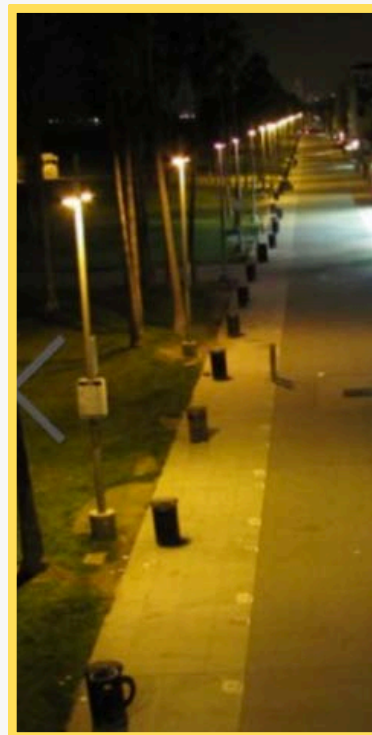


However, too high a colour temperature can be unwelcome. A study in Melbourne found that girls and young women actually perceived many sites with cool white light as unsafe compared to areas with warmer colour temperatures. Instead, places with consistent and layered lighting made them feel most safe (Kalms & Hunt, 2019). In US research, visitors to Arcadia National Park were given the ability to adjust the outdoor lighting between 3000K (defined in the study as yellow), 4200K (defined as white) and 6000K (defined as blue-white). The 4200K colour temperature was preferred for the pathway by 44% of participants, with 3000K preferred by 38%. The 6000K colour temperature was undesirable for all locations (Smith & Hallo, 2019).

These benefits of white light have led to broad agreement about the use of light in the range of 3000K to 4000K in public spaces. The Institute of Public Works Engineering Australasia (2020c), in their Model Public Lighting Strategy, recommend that 3000K lighting be used as default for pedestrian areas like parks and pathways, with the higher 4000K for main roads, commercial precincts and safety. They also recognise that human perception of light is dependent on the surrounds, and in areas of lower light there is a preference for lower colour temperatures.

“Typically, warmer colour temperatures (e.g. 3000K) would be recommended in public spaces intended for relaxation, leisure or low level activity.” Webb Australia.

Figure 3 Ocean Front Walk in Venice Beach, Los Angeles under both warm (top) and cool (bottom) public lighting (Scutti, 2019)



Leadsun's International Dark-sky Approved (IDA) pathway lighting, [The Gabels Riparian Corridor](#)

Impacts of colour temperature on people and wildlife

Research into the impacts of artificial lighting on circadian rhythms has found that cooler, blue lighting could affect sleep. Blue wavelengths suppress the production of melatonin – a hormone that helps control the sleep cycle. In 2016 a report by the American Medical Association recommended that all street lights should be less than 3000K due to both the environmental effects as well as possible damage to people's eyesight of higher colour temperatures (Institute of Public Works Engineering Australasia, 2020a). This led to an increase in the installation of warmer light sources in public spaces.

However, the research in this area is still developing and by no means conclusive. More recent studies suggest that public lighting at a colour temperature of 4000K are not harmful to humans. A 2019 Queensland report compared LED streetlights in the range of 3200K to 5900K with the light emitted from other commonly encountered personal devices at night such as TVs, computers and smartphones. It found that the LED streetlights emitted less than 1% of the recommended blue light exposure limit and that the hazard from these was less than from the use of personal devices (Wood, Black, & Isoardi, 2019).

Wildlife

Like humans, colour temperature can also have an impact on wildlife at night, although the evidence is still inconclusive. Most wildlife is more sensitive to blue light than humans. LEDs can emit high amounts of blue light and the colour temperature of a light source is only a guide for this (Department of the Environment and Energy, 2020). The Institute of Public Works Engineering Australasia (2020c) recommend using lower colour temperature lighting in environmentally sensitive areas.

Australian Standards AS 4282 'Obtrusive lighting' states that light at the blue end of the spectrum tends to scatter more, making it harder to see the night sky and more likely to spread to surrounding areas and buildings. To provide sufficient light for safety and amenity while minimising the impact on wildlife, ASDA approved lighting requires a colour temperature of no more than 3000K (Australasian Dark Sky Alliance, retrieved August 2021).

"...ASDA approved lighting requires a colour temperature of no more than 3000K (Australasian Dark Sky Alliance, retrieved August 2021)."

Colour Rendering

Although similar in name, colour rendering is not related to the colour temperature of light. Instead, it is the ability of a light source to show the true colours of objects as seen in daylight and is measured using a colour rendering index (CRI). A scale is used, from 100 CRI – the equivalent of light at midday in which all colours of the visible spectrum can be seen – to 0 CRI, where light of only one wavelength is emitted and so different colours cannot be distinguished. Figure 4 shows the effect of decreasing CRI for a given colour temperature.

The design of public lighting for pathways is mostly covered by the Australian Standards AS 1158 'Lighting for roads and public spaces' in Part 3.1 'Pedestrian area lighting' (Lighting Council Australia, 2020). Colour rendering is only briefly mentioned in this document. Lights with high CRI values improve the quality of the visual environment and experience within a space, possibly making it more important in

spaces where people congregate like malls and at outdoor events rather than simply pass through. City of Melbourne (2013) recommend that lighting with a minimum of 80 CRI be used in city squares and malls and where there is high pedestrian use.

The Australian Standards AS1158.3.1 (2020) note that colour temperature and colour rendering do not fully define the performance and characteristics of a light source. The technical limitations associated with the Colour Rendering Index have become evident with the increased use of LEDs. To address these, various other systems have been developed by the US Government such as the IES TM-30-15 system (U.S. Department of Energy, 2015) and the Colour Quality Scale (Ohno, 2019). However, these systems have not been widely adopted and a lot of Australian literature continues to refer to CRI.

Figure 4 An object appears differently under light sources with different colour rendering (Westinghouse Electric Corporation, 2021)



Leadsun's pathway lighting,
The Gabels Riparian Corridor

Perceived brightness of a lit space (illuminance)

The amount of light that a lamp produces is referred to as 'luminous flux' and is measured in lumen. It is measured only at the source and is constant for a given lamp irrespective of the surrounding environment. It also does not account for the distribution (direction) of the light from the source. However, the way an area is perceived is highly dependent on both the distribution of light from the source as well as the surrounds, because different surfaces and materials reflect light in different ways, or not at all.

"If a space is only designed to consider the amount of light being emitted by the light source and not the contextual makeup of the space, even though it meets the guidelines, it doesn't take the human experience and feeling of light into account."

Yang, retrieved May 2021

Instead, the amount of light falling onto a given surface area, or illuminance, can be measured. The unit of lux (lx) is used to measure illuminance, equivalent to one lumen per square metre. Simply put, a globe in a small space produces a higher amount of light on the adjacent surfaces than the same globe in a larger space. This measurement better represents the perceived brightness of a lit space because it accounts for the amount of light directed to a space from all light sources in the area.

"There is evidence to support the belief that lighting is a useful tool in the fight against crime; but too often the tool has been a sledgehammer."

Boyce, Eklund, Hamilton, & Bruno, 2000

Ongoing research projects in the UK are attempting to quantify the lighting needs for pedestrians in urban environments. It reports that for young people to see a 25 mm high obstacle on the path 6 m away, a minimum illuminance level of 0.6 lux is required. Increased illuminance levels greater than about 2 lux provided diminishing returns, including for older people (Fotios, Yang, & Edwards, 2014).

The study also looks at what lighting is required for a person to recognise whether another person is likely to be friendly, indifferent or aggressive. Lighting of approximately 7 lux is needed at 10 m, a distance slightly less than the 12 – 15 m people like to have to react and feel comfortable. Another study in urban environments found that small increases in illuminance for low levels (less than 10 lux) significantly improve perceived safety and that an illuminance around 30 lux provides similar feelings of safety as during the day (Boyce, Eklund, Hamilton, & Bruno, 2000).

The US study in Arcadia National Park found that visitors' preferences were for less brightness on the path (1.4 lux) and a much brighter 10.5 lux at the public toilets. Common reasons given included "to provide natural nighttime light levels, maintain natural darkness, create a soothing or subtle setting and to avoid tripping or falling" (Smith & Hallo, 2019).

In determining the minimum illumination level, the Australian Standards consider the level of activity on a path away from a road and the fear of crime. The highest required illuminance level is 10 lux for a path where the fear of crime is high, down to less than 1 lux for a little used path with low fear of crime.

Uniformity

Regardless of the colour temperature, colour rendering and brightness of a light, it is important to minimise abrupt changes between areas of light and dark.

“Impressions are also formed by comparison. Dimly lit areas appear darker if contrasted with patches of bright light.” City of Melbourne Public Lighting Strategy, 2013

Although brighter light generally makes people feel safer, more important still is providing uniform – or evenly distributed – lighting. This has been found by multiple studies such as Uttley, Monteiro & Fotios (2018) in the UK and Peña-García, Hurtado & Aguilar-Luzón (2015) in Spain.

When walking in a brightly lit area it is harder to see adjacent areas which are not lit as well or at all. If the area surrounding a path is not lit, this can lead to people feeling unsafe and avoiding walking there, even though the path itself is well lit. For a path away from a road the Australian Standards require lighting designers to consider the illuminance for 5 m either side or up to any structure/fence/property boundary. This helps ensure uniform lighting not only on the path, but also of the surrounds. The Urban Design Guidelines for Victoria (2017) state that paths which pass through public open space should be lit to the same level as surrounding streets.

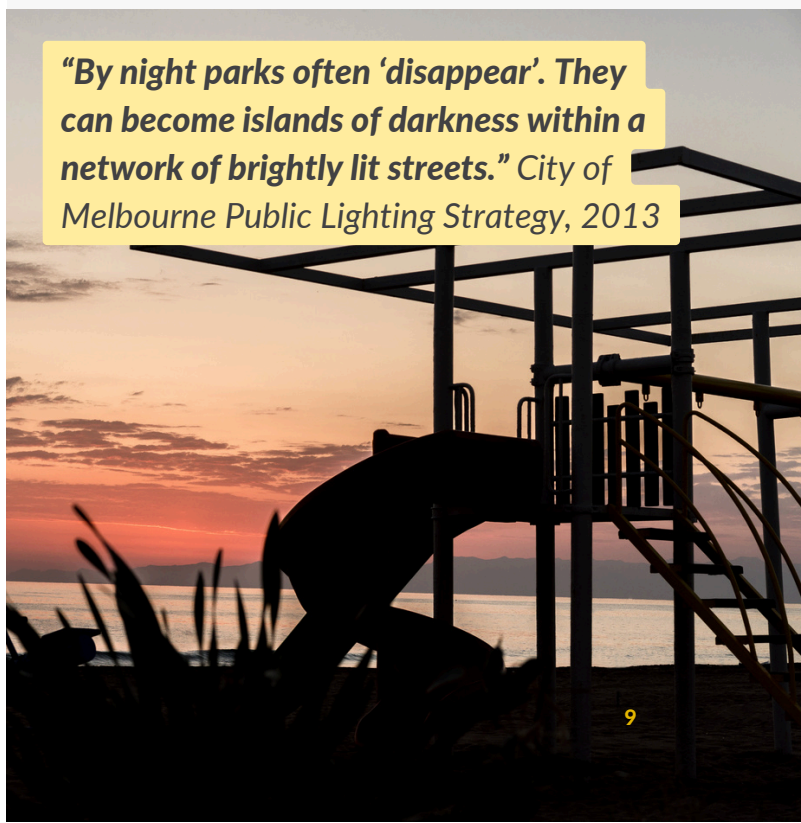
Although lighting may be provided for a particular space or path, consideration should be given to how it interacts with all adjacent space, including other public space, private areas (such as university campuses) and car parks.

Lighting paths and vegetation within a large park stops the park from becoming a vast expanse of darkness at night, especially when the surrounding streets are lit. Layering the lighting creates a sense of depth within the park, making it a more inviting place to walk.

Between 2019 and 2021, Victoria Walks assessed the walkability of eight activity centres (shopping streets/malls) of varying size in the north-eastern suburbs of Melbourne, including night audits. There were often significant variations in the level of lighting between different parts of these centres, perhaps reflecting the different organisations responsible for lighting different areas. For example, railway stations and shopping malls tend to be very brightly lit, creating a contrast with neighbouring residential areas. In residential areas street lighting tends to be focused on intersections. While it is important that intersections are well lit, this approach can leave other areas including footpaths and bus stops away from intersections comparatively poorly lit.

Uniformity is an important consideration for lights that can change in intensity. Lights which suddenly become significantly brighter are not necessarily best for users. One study used dim light which increased in brightness once people were detected. It found that people walked slower in the dimmer light compared to when the brightness was constant and that the slower walking continued even after the illuminance had increased. Participants were more likely to report stronger reactions with a greater increase in brightness (Pedersen & Johansson, 2016).

“By night parks often ‘disappear’. They can become islands of darkness within a network of brightly lit streets.” City of Melbourne Public Lighting Strategy, 2013



“Good lighting is not always equivalent to more, brighter lighting. Nuances are important.” Victoria Walks.

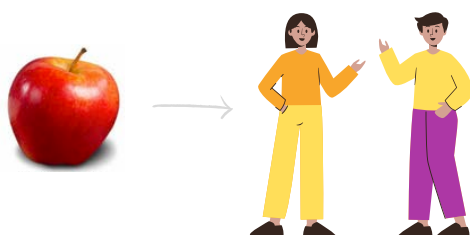
Leadsun's solar powered
bollard, River Valley
Stairs, Sunshine North.

In summary - locations where public lighting is appropriate, the evidence suggests:

- Colour temperature:** White light makes it easier to recognise others' faces and generally makes people feel safer than yellow light. However above a certain threshold (the exact value is disputed but somewhere around 3500 - 4000K), increases in colour temperature don't always equate to increases in feelings of safety.
- Perceived brightness:** Light needs to be bright enough to see clearly, however brighter is not always better. Studies suggest an illumination of 2 lux may be sufficient for most people to see a path, and 7 lux to see another person and guess their intent. Increases above 10 lux do not have significant increases in feelings of safety. However, the appropriate level of illumination is heavily dependent on the type of lighting used and the surrounding surfaces.
- Uniformity:** More important than brightness is the way the light interacts with the surrounds and the uniformity of lighting both on the path and of surrounds.
- Colour rendering:** High colour rendering improves the quality of the visual environment and helps people see and recognise their surrounds.

3000K

4000K



Minimise negative impact

Negative impacts of public lighting have been previously discussed, including the emissions and costs as well as impacts on people and wildlife. These can be minimised by:

1. Minimising spill and glare;
2. Installing lighting control systems, and
3. Improving efficiency and using renewable energy.



Spill and glare

Spill refers to light in areas not intended to be lit, such as street lighting that spills into people's houses. Australian Standard AS/NZS 4282:2019 *Control of the obtrusive effects of outdoor lighting* sets limits for both the spill and intensity of light into residential properties. It effectively exempts public lighting, which is considered of higher importance than limiting obtrusive lighting, due to public safety. However, it does state that "limits have been included ... so that obtrusive light can be controlled in areas where it may be seen as a problem without the need to calculate the impact of every streetlight." The Urban Design Guidelines for Victoria (2017) discuss the need for "a gradual transition between bright-lit and dimmer-lit areas" to protect adjacent areas from light spill. Lights with zero upward spill also significantly reduce light pollution and interference with nature.

Glare refers to light that is so bright it is hard to see, such as car headlights shining directly into a person's eyes. It can also affect people within a space, such as from streetlights or other lights. In order to minimise costs associated with multiple light poles, some luminaires are designed to produce a very wide beam. When that distribution gets too wide, the light may shine directly into people's eyes, making it difficult for them to see. Eg. Luminaires with excessive illuminance at high angles typically above 70-75 degrees from the vertical. AS 1158.3.1 provides limits for luminous intensity for angles between 80 and 90 degrees. Therefore, public lighting design can include a trade-off between lighting a space and limiting obtrusive lighting. It is something that needs to be considered as part of good lighting design although it's usually not too onerous to comply with both.

Figure 6 Light spill into nearby residences and upward into the sky produced by a street light (Source: Citelum, 2016)



Spill and glare can be minimised using the lowest intensity lighting appropriate along with shields or louvres (Australasian Dark Sky Alliance, retrieved June 2021). The International Dark-Sky Association provides certification of lighting that minimises glare and spill, making them more dark sky friendly (retrieved June 2021).

Control Systems

Historically, lighting systems operated at full intensity for the entire period of darkness (and sometimes even into the day) because the only control options were on or off. This makes sense in some locations, such as for busy roads, but less so for locations where people are much less likely to be walking in the very early hours of the morning, like local parks.

Recent developments allow more nuanced control of lighting in public spaces and can be varied to match the needs of specific situations. Lighting control systems, also called smart controls or adaptive controls, can be used to automatically change the intensity of lights dependent on time of day or use of the path. These includes timers, motion and light sensors, dimmers and they can even be managed remotely with internet based central management systems (AS/NZS 1158.3.1:2020).

Reducing the brightness of lights or length of time they are on reduces the energy used, emissions created and electricity costs. Photoelectric (PE) cells sense light levels and provide more control of lighting compared to pre-programmed timers that simply turn on or off at set times. A combination of controls allows for even more comprehensive lighting systems.

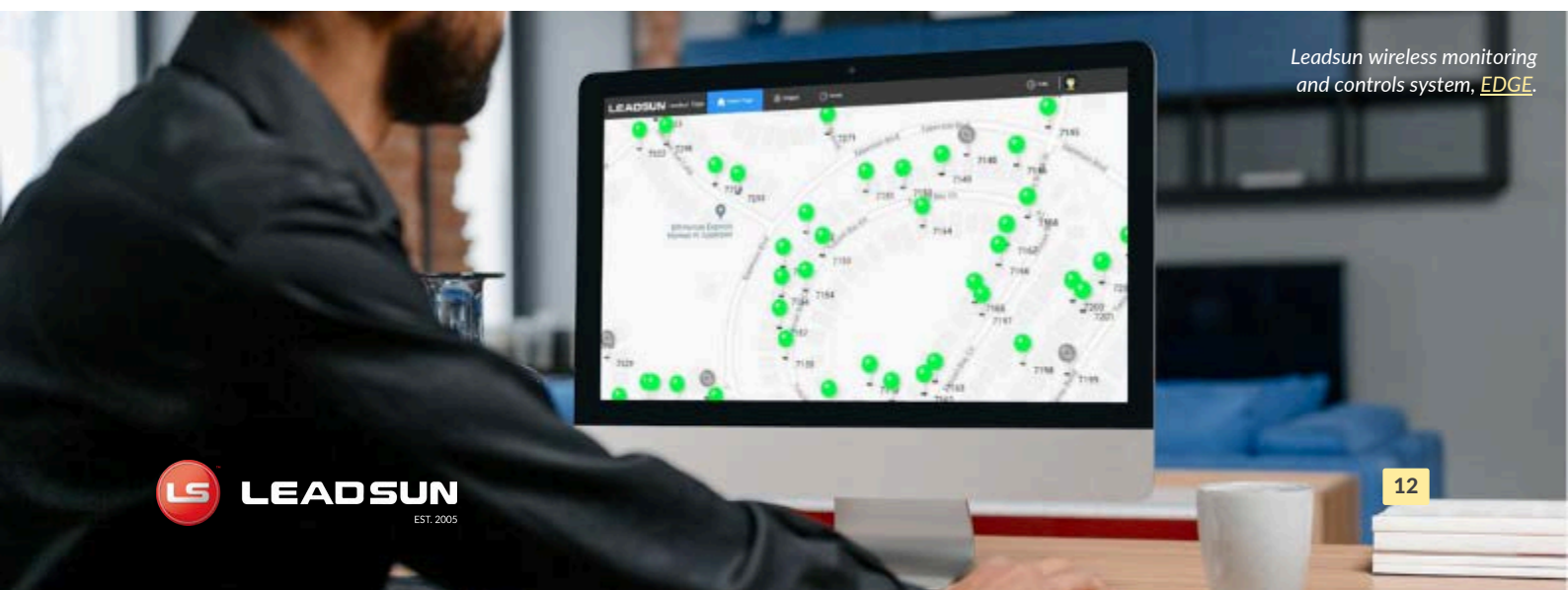
Lights with photoelectric (PE) cells, dimmers and motion detectors can be programmed to:

- **turn on to full brightness at dusk,**
- **dim, at a specific time or when there are few people around,**
- **trigger full brightness for a short time when motion is detected,**
- **increase to full brightness again in the early morning,**
- **and turn off at dawn.**

The Institute of Public Works Engineering Australasia (2020c) recommend that smart controls are used to dim lighting during low use periods. Using dimming only during periods where there are very few people, such as after midnight, helps balance the need for uniform, consistent lighting and using smart technology to minimise electricity consumption.

Nuisance changes in lighting – such as when lights turn on and off continuously – can be avoided by including a minimum time of say 30 seconds when no motion is detected before the lights turn off or are dimmed.

There is a possibility that people unaware the lights will brighten once they enter an area may be deterred from entering at all. However that must be balanced with the benefits of reduced electricity usage and impact on wildlife.



Leadsun wireless monitoring and controls system, [EDGE](#).

Control Systems

Other ways to reduce the emissions and costs associated with public lighting are to improve the efficiency or generate the electricity for direct use.

Where possible, existing lighting equipment should be upgraded to use the most efficient technology available. Newer technology can provide similar light output using less energy and lower, ongoing operating costs can often offset any higher purchase costs (Live Performance Australia, retrieved June 2021).

Installing equipment that generates electricity for direct use by the lighting system such as solar powered lighting removes the ongoing energy costs completely. Solar lights tend to be most cost effective in areas where there is no connection to the electricity grid because there is no need to dig and connect wiring for long distances underground. In some circumstances, solar lighting is more cost effective over the life of the system even where traditional connections are available (Rajeev & Nair, 2012).

Monitor & maintain

Whatever the context or type of lighting, regular maintenance to ensure appropriate operation is important. Victoria Walks' night audits commonly identify some lights that are not working. This may not be of great concern in areas that are very well lit with a high density of lights.

However, in more typical street or park environments where lights are individually spaced, a lamp that is not operating will leave an area of darkness that is effectively a gap in the light coverage. A walking route is only as good as its worst barrier so an unlit section of path may result in people avoiding the whole length.

Lighting managers should also consider the potential for structures or vegetation to block the light emitted from a lamp. During night audits Victoria Walks has observed the effectiveness of various streetlights being compromised by street trees growing in close proximity.

Conclusion

Good public lighting in areas of informal use is essential for ensuring safety, comfort, and accessibility. To achieve this, it's important to consider key technical factors such as colour temperature, colour rendering, brightness, and uniformity in lighting design. It is crucial to strike a balance between providing sufficient light for visibility and minimizing negative impacts such as spill and glare. The use of lighting control systems, including timers, motion and light sensors, and dimmers, can help optimize lighting levels and reduce energy consumption. Additionally, improving the efficiency of lighting equipment and exploring renewable energy options, such as solar-powered lighting, can further minimize the environmental impact and operating costs of public lighting. Regular maintenance is also important to ensure the proper functioning of lighting systems. By implementing these strategies, it is possible to achieve good public lighting in areas of informal use, creating safe, welcoming, and sustainable spaces for pedestrians.

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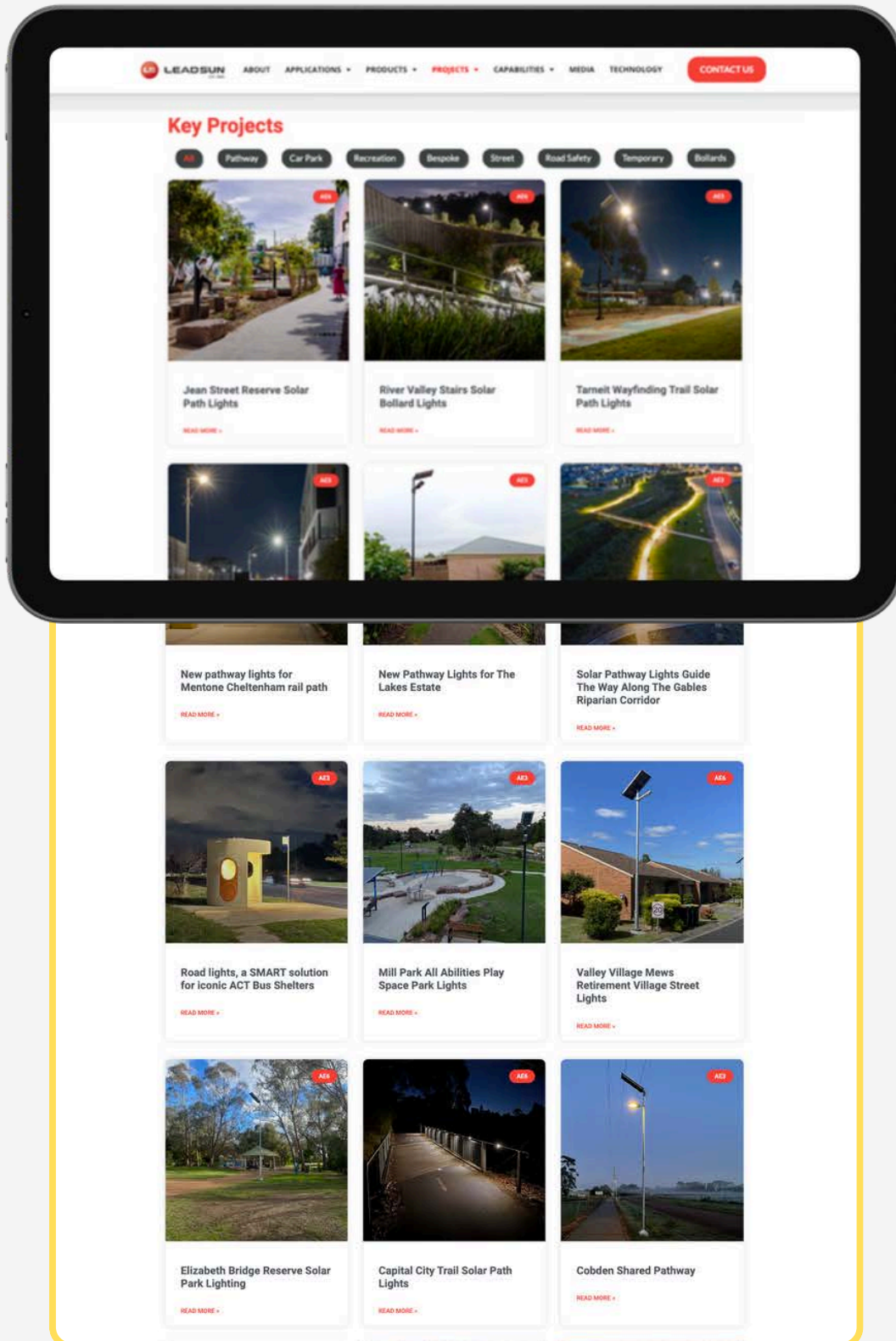
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