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Light pollution

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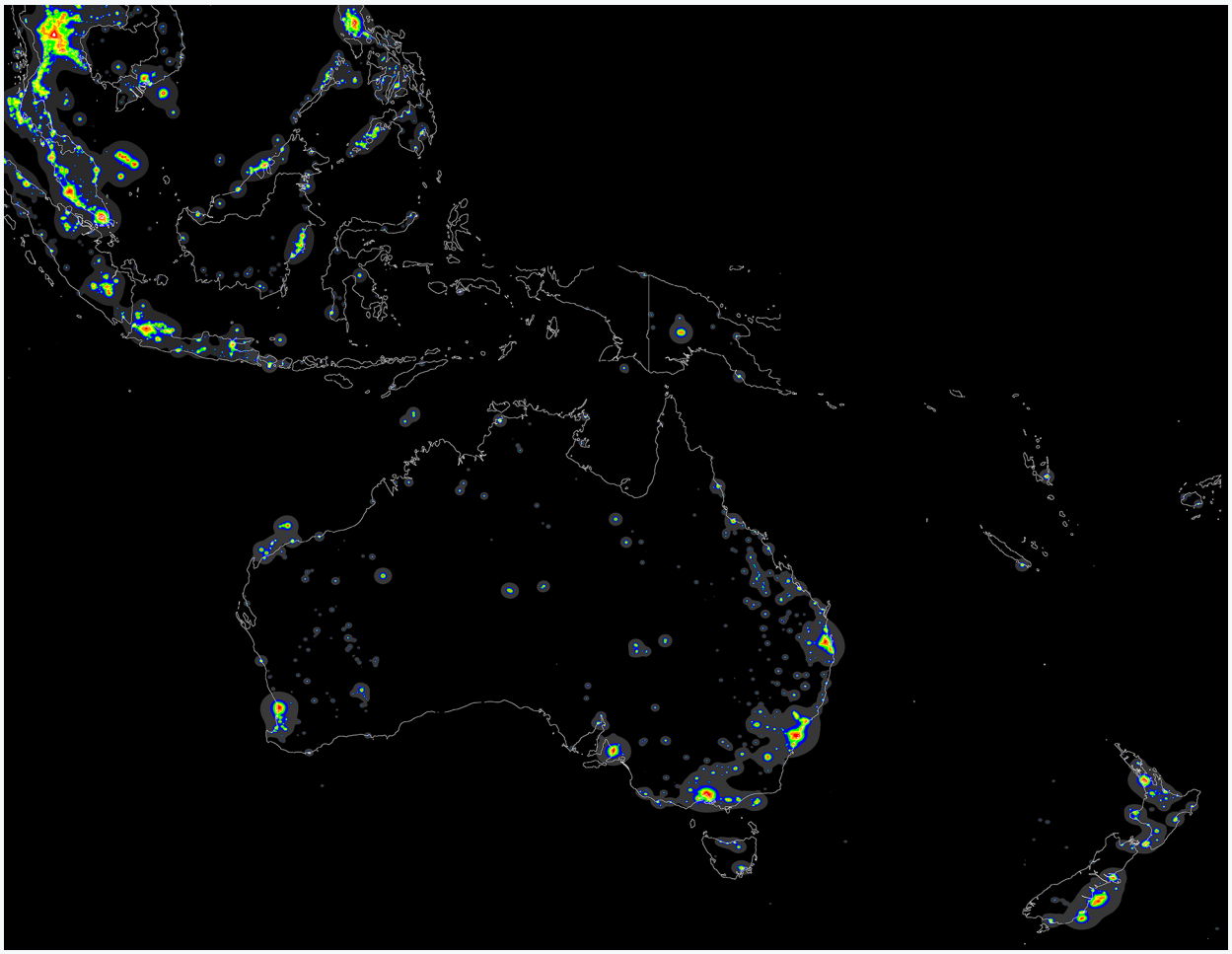

Cover image: Artificial night sky brightness for Oceania
(Credit: P. Cinzano, F. Falchi (University of Padova), C. D. Elvidge (NOAA National Geophysical Data Center, Boulder). Copyright Royal Astronomical Society. Reproduced from the Monthly Notices of the RAS by permission of Blackwell Science.
www.lightpollution.it/dmsp/)

Abstract

We need artificial light in our daily lives, but we can have too much of it. Light pollution might be defined as excess artificial light, in the wrong place at the wrong time. Awareness of the problem, in Australia and elsewhere, has been growing since the previous edition of this Note. Building design professionals have an important role to play in tackling light pollution but, sometimes, see light pollution simply in terms of nuisance or aesthetics. This Note seeks to raise designers' awareness of light pollution as a broader issue, by exploring the biological, ecological and functional effects, as well as nuisance and aesthetics. The Note also looks at what contributions can be made by designers and others in solving the problem.

Introduction

> '... light pollution is a blight on our cities which we must address. ... I believe the night sky is part of our environment and heritage – a natural treasure and one we should all be able to enjoy. To see it being blotted out by the insidious show of light above our sprawling communities is a tragedy. We must use our lighting responsibly, efficiently and sparingly. We must design lighting solutions which enhance our environment ...' (Bilmon, 1995)
>
> John Bilmon, RAIA NSW Chapter President 1995

Light pollution has been of concern since the 1930s, if not before. Excess light, in the wrong place at the wrong time, comes in the forms of sky glow, glare and light trespass. Like most other forms of pollution, it can affect human health and the wellbeing of plants and animals, it has an aesthetic dimension, and it is symptomatic of unnecessary resource consumption. It has some unusual impacts – on transport system users, on human security and on the work of astronomers. The problem is very extensive - it is not just an urban and suburban phenomenon.

Light pollution poses an unusual environmental problem in several respects. First, it is relatively easily and permanently solved – light pollution disappears once the offending light sources have been dealt with. For most other forms of pollution, removing the source still leaves the pollution and the effects of pollution to be dealt with.

For the most part light pollution arises from, and is therefore the responsibility of, decisions made by designers in the construction and infrastructure sectors. In contrast, for most other forms of pollution, construction sector designers have far less direct control over the source of the pollution.

Finally, the problem is solved by ensuring that just the right amount of light is provided – that is, a certain amount of this 'pollutant' is acceptable, even desirable. For most other forms of pollution, remedial action requires total removal of the offending agent.

This Note provides some background to the subject, showing that it is a serious problem, discussing some of the general principles involved in reducing light pollution, and showing that it can be readily dealt with. The Note does not address the more technical aspects of the design of outdoor lighting. The International Dark-Sky Association (IDA), founded in 1988, offers technical advice, as does the UK's BAA Commission for Dark Skies (CfDS) (see websites). For a social sciences perspective, Meier et al (2015) is of interest.

1.0 The problem areas

The six problem areas for light pollution discussed in this Note are (human) health and safety, plants and wildlife, aesthetics, resource consumption, security and the night sky. This is a broader range of issues than that considered by authors such as Longcore & Rich (2004), who focus on 'ecological light pollution', distinguishing this only from 'astronomical light pollution'. The problem areas may be affected independently or in combination. For example, it is possible for particular light sources to cause problems for public health and for plants and wildlife, but not for astronomy. It is also possible for particular light sources to cause problems across all these areas of concern, though the deleterious effects may be more significant for some areas than for others. That is, the relative importance of each of these problem areas varies from situation to situation.

Section 2.0 looks at the same six problem areas with respect to possible solutions.

1.1 Health and safety

The Australian Standard AS 4282-1997 identifies a 'perceived change in amenity' arising from the illumination of dark residential rooms by light spill or trespass and the residents' direct view of bright outdoor luminaires (glare). This can lead to serious community concerns, as in the case of a proposed night golf at a course in Darwin (Dunlop, 2014).

At best, these effects will be annoying. But when either light spill or glare, or both, occur in a neighbouring resident's bedroom when he or she is trying to sleep, the effects are likely to be more serious. Even 15 minutes of light at night causes the destruction of an enzyme that makes melatonin, a sleep-regulating hormone, in the pineal gland. Production normally reaches a peak in the middle of the night as part of the circadian rhythm. This destruction is the body's way of quickly adapting to an environmental change but, of course, it disrupts sleep. Associated sleep disorders include insomnia, shift-worker sleep disorder and delayed sleep-phase syndrome (Chepesiuk, 2009; IARC, 2010). However, more research is needed (Figueiro, 2017).

The problem is perhaps much wider than the production of melatonin – the production and release of nearly all hormones is tied to the circadian rhythm, so agents that disrupt this, such as shiftwork and light-at-night, can alter the levels of nearly all hormones (IARC, 2010).

If the effect happens every night, then health will probably be disrupted too, and not just through lack of decent sleep. For example, night-time illumination raises the oestrogen level in women, which is regulated by melatonin, and this can increase susceptibility to breast cancer (which is high in industrialised, ie over-illuminated, nations) (Bauer et al, 2013; Hurley et al, 2014; Haim & Zubidat, 2015; Kim et al, 2015).

As well as breast cancer, disrupting the circadian rhythm is linked to depression (eg through excessive exposure to light in early life), cardiovascular disease and perhaps even to colorectal cancer, prostate cancer, obesity and early-onset diabetes (Fonken et al, 2009; Chepesiuk, 2009; Kloog et al, 2009). In other words, light pollution can undermine public health, and the public health community needs to be aware of this issue (Grose, 2014).

On safety, AS 4282-1997 points out that disability glare from bright light sources can reduce a motorist's (or cyclist's, pedestrian's or pilot's) ability to see. This is particularly true for the expanding elderly population, whose eyes can take two to five minutes to adjust to low light levels after being exposed to high light levels at, for example, a petrol station, and whose vision is particularly susceptible to glare. Disability glare increases the chance of vehicular accidents and must be minimised. The Standard also points out that disability glare and visual clutter around transport signalling systems can reduce their effectiveness. The signals may be obscured and hard to read. For example, the Flight Safety Foundation reports that 'off-airport light patterns, such as brightly lighted parking lots or streets' can affect the flight crew's ability to accurately perceive the environment when landing (FSF, 2000).

1.2 Plants and wildlife

For plants, flowering and leaf retention are affected by light pollution. Budburst in trees has been shown to occur up to seven and a half days early in trees across the UK, due to lighting pollution (Ffrench-Constant et al, 2016). Deciduous roadside trees retain their leaves longer, a New Zealand species has been shown to flower more profusely near street lights, a wide variety of ornamental garden plants are affected by night lighting, and agricultural crops such as soya and maize are also affected (Bennie et al, 2016).

For wildlife, extensive lighting can affect perceived day length, with particular consequences for insects and nocturnal mammals though nesting or roosting birds may also be affected. Natural diurnal rhythms may be disrupted in many animal and plant species. While there has been no systematic study of these effects, there are plenty of examples in the literature.

Moths (which are nocturnal) settle when general lighting levels are high, so ceasing mating activities, and individual lights can cause them to fly in spirals, often to their death. Street lighting is believed to adversely affect moth populations (given that their lifespan is often only a few hours), by selecting those species not so strongly attracted to light. Outdoor lighting is blamed for declines in several American species in north-eastern USA. In Japan and the USA, firefly communication, mating and larvae are affected by artificial light (Samarri, 2016). Urban locations in Britain and elsewhere support much less diverse moth populations than they did 30 to 40 years ago, and it seems that increased street lighting is a significant factor in this decline. This is exacerbated by habitat fragmentation, also brought about by urbanisation (Verovnik et al, 2015).

Nocturnal mammals such as bats are likely to be deterred from establishing foraging areas in the presence of bright illumination, imposing extra pressure on many urban and suburban populations. River corridors, foraging areas and other areas of open countryside especially should be kept clear of security and sports floodlighting. Lighting can be used to keep species off roads – which reduces roadkill, but may block natural foraging routes (for example, some observers have suggested that continuous lighting along roads creates barriers which insectivorous bats will not cross) (Altringham & Kerth, 2016). Lighting schemes can interfere with bat foraging directly through loss of land and fragmentation, and indirectly by cutting commuting routes from roosts, and illuminating watercourses and water bodies.

Sea turtle hatchings on shore are affected by artificial light. Bright lights may stop females from coming ashore to lay their eggs, or may disorient them, and hatchlings will head towards the lights rather than towards the sea (to which they are guided by reflected moonlight, which can't compete with artificial light) (Sea Turtle Conservancy).

Artificial lighting may modify the timing of natural bird behaviours, such as dawn singing at sunrise (Da Silva et al, 2015). Reproduction in birds is controlled by seasonal changes in lighting, and artificial increase in day length can induce hormonal, physiological and behavioural changes, initiating breeding. Around 60 species of wild birds have been brought into breeding condition prematurely by exposure to artificially long days in winter (Da Silva et al, 2017). Birds avoid nesting at the Minsmere nature reserve 4 km away from the brightly lit Sizewell B nuclear power station in the UK (RSPB, 2017).

Windows confuse birds generally, even in the daytime, and window collisions are the second highest cause of anthropogenic bird fatalities in North America (free-ranging cats are the highest). But 90% of such collisions occur during migration (Ocampo-Penuela et al, 2016) and are exacerbated by lighting (McCarthy, 2016). It has been estimated that buildings kill 100 million to 1 billion birds a year in North America, with peaks at the spring and autumn migrations, particularly on the coast or next to lakes. At this time many species, such as warblers and sparrows, fly at night and at low altitude. They are confused by bright lights and glass (transparency and reflections) and become trapped among the buildings. Some collide with the buildings while others drop from exhaustion.

In the Greater Toronto Area and Ottawa region, the Fatal Light Awareness Program (FLAP) Canada has

documented the deaths from collisions, at just a few buildings, of over 75,000 birds from 170 species since 1993 (FLAP).

Longcore and Rich (2004) provide a broad survey of 'ecological light pollution', expanded in their subsequent book (2005), looking at the effects on orientation, attraction, reproduction, communication, competition, predation and ecosystems, across many species worldwide.

1.3 Aesthetics

Floodlighting of buildings is undertaken for aesthetic reasons, which may be debated, and can lead to light pollution if done badly.

A recent example of large-scale floodlighting in the United Kingdom was that of over 400 churches for the Millennium, through the Church Floodlighting Trust (Historic England, 2007). Refer section 2.3 Aesthetics for how light pollution was taken into consideration for this project.

Rural lighting also poses aesthetic problems – it 'may distort our impressions of the countryside, undermining some of the less tangible, perceptual dimensions of the landscape' (DoE/CC, 1997). Tranquillity, the sense of remoteness, the effects of moonlight and night-time beauty are all vulnerable to light pollution.

1.4 Resource consumption

> 'Street lighting is often the first or second largest local government energy use, typically accounting for 25–50% of a municipal energy bill.'
> (ACEEE, 2015)

In conventional street lighting systems, a substantial amount of the light emitted is not directed only where needed, but spills sideways and upwards (Figure 1). This is a waste of energy and money, and contributes to increased greenhouse emissions where the energy mix is high in fossil fuels, as it is in the USA and in several Australian states. It is also a major cause of light pollution. Given the scale of energy use in street lighting, even a small improvement will have substantial benefits. However, public lighting is excluded from AS 4282-1997 – reference should be made to the AS/NZS 1158 series.

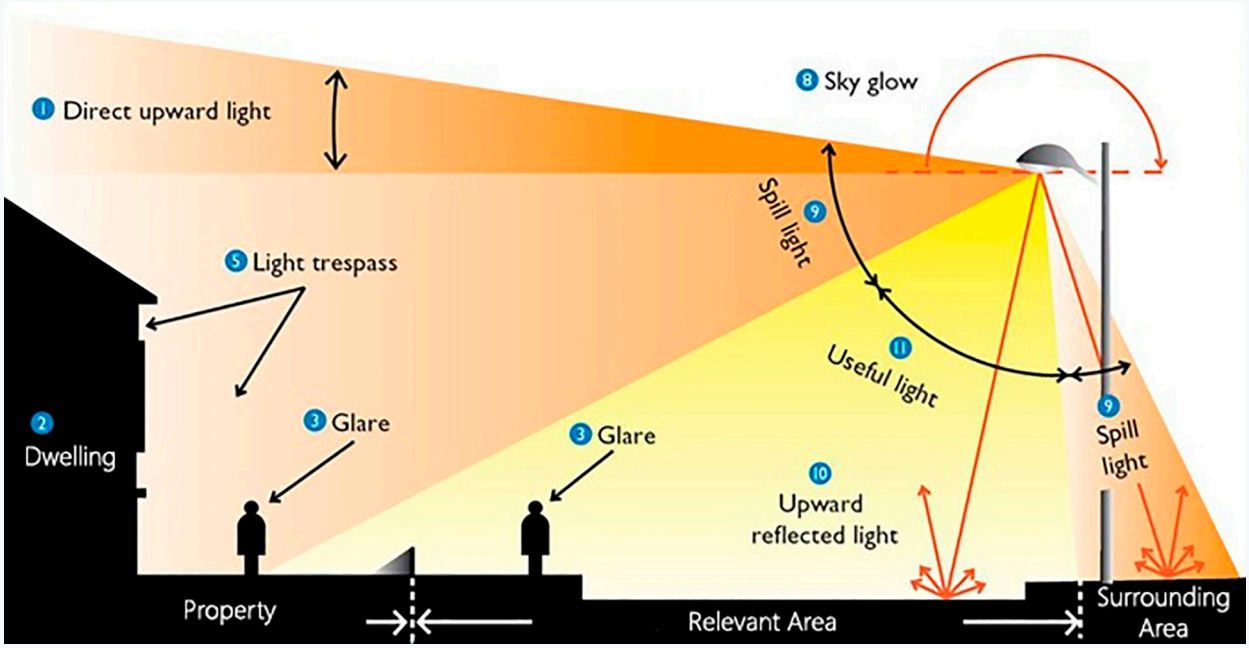

Figure 1. Diagram showing various light pollution problems that might be associated with street lighting: spill light, glare, upward reflected light, light trespass, direct upward light and sky glow (Source: Lumia).

1.5 Security

The argument that high levels of night lighting are needed to reduce theft and keep down road accidents can be disputed. The UK's LANTERNS study (Steinbach et al, 2015) of 14 years of data from 62 local authorities in England and Wales that had implemented street light reduction in various ways, found that there was no evidence of association between these actions and either increased crime or night-time road collisions.

A study of lighting in alleys in Chicago showed that 'there did not appear to be a suppression effect on crime as a result of increased alley lighting. In fact, it appears that with the increased lighting came an increase in the number of crimes reported to the Chicago Police Department.' This was set against a day-time decrease, suggesting that those committing crimes moved from day-time to night-time, thanks to the better lighting (Illinois CJIA, 2000).

However, street light reduction should be handled carefully; Green et al (2015) found strong concerns where lights had been switched off – some felt less safe, and some felt that a 'public good' had been removed.

1.6 The night sky

The night sky is both culturally and scientifically important. As late as 1858, Donati's Comet could be seen right down to the horizon from the centre of Paris – this wouldn't be possible today. In an unpolluted sky, around 4500 individual stars should be visible to the naked eye. Owing to urban-scale light pollution, in the suburbs typically only 900 stars are visible, and this is down to 35 in the major cities (King, 2014). Most Australians, like city dwellers everywhere, are 'denied the splendour of the night sky from their own backyards' (Dawe 1995), as any who have spent a night in the bush will recognise. For indigenous people, the night sky has particular significance with respect to Dreaming (Norris & Norris, 2009), and needs to be visible. In recognition of the importance of the night sky to indigenous people, the International Astronomical Union (IAU) has added 86 new star names drawn from indigenous cultures – four names are Australian (Hamacher, 2018).

AS 4282-1997 notes that lighting can disrupt astronomical observations through sky glow, caused by:

- upward directed lights and the scattering of light in the atmosphere;
- broad spectrum illumination, making it difficult for the light to be filtered out; and
- direct light falling on the observatory.

A number of observatories have relocated or become redundant in an ongoing quest for year-round clear, dark skies. For example, in 1935 the Vatican Observatory (re-established in 1891) relocated 25 km away to Castel Gandolfo, and then in 1981 the Observatory founded the Vatican Observatory Research Group in Tucson, Arizona. The Royal Greenwich Observatory in London (founded 1675) relocated to Herstmonceux Castle in Sussex in 1948, and then in 1984 its observing activities moved to La Palma in the Canary Islands. The Herstmonceux facility closed in 1989 (ING).

Light technical parameter	**Application**	**Recommended maximum values**		
		Commercial areas and at commercial/ residential boundaries	**Residential areas, light surrounds**	**Residential areas, dark surrounds**
Illuminance in vertical plane	Pre-curfew: at residential property boundaries	25 lux	10 lux	10 lux
	Curfew: at residential property windows	4 lux	2 lux	1 lux
Luminous intensity emitted by luminaires	Pre-curfew: each luminaire, in the principal plane	See Table 2		
	Curfew: in directions where luminaires are likely to trouble residents long-term	2,500 cd	1,000 cd	500 cd
Threshold increment	Users of transport systems have reduced ability to see essential information	20% based on adaptation luminance of 10 cd/ m2	20% based on adaptation luminance of 1 cd/ m2	20% based on adaptation luminance of 0.1 cd/m2

Table 1. Recommended maximum values of light technical parameters (Source: AS 4282-1997 Table 2.1)

2.0 The solutions

2.1 Health and safety

AS 4282-1997 was a world first when first published in 1995. It is a guide Standard, not a specification, and so should not be cited in regulations and specifications. It makes recommendations about controlling the adverse effects of outdoor lighting on nearby residents, road users, transport signalling system users (ie health and safety) and astronomical observations (discussed below).

Those serious about the subject should work to the recommendations of this Standard, which is intended for use by local authorities and designers of outdoor lighting (notably lighting engineers – it is a fairly technical document). The sections in the Standard are as follows:

- Scope and general
- Potential obtrusive effects and associated light technical parameters
- Design, installation, operation and maintenance
- Compliance with design objectives
- Calculation of light technical parameters
- Measurements of light technical parameters.

AS 4282-1997 provides two sets of limiting values, shown in simplified form in Tables 1 and 2. One, with higher permitted values, is for application before a curfew, and it is expected that this would apply to most installations covered by the Standard. The intention here is to avoid excessive obtrusion using conventional lighting technology and good design practice.

For comparison, the UK Institution of Lighting Engineers (ILE) suggests obtrusive light limitations for exterior lighting installations (Table 3), based on a corresponding table in the European Standard EN 12464-2:2014 – more recent than AS 4282-1997.

The other, with lower permitted values, is for application after a curfew. Maintenance of amenity and environmental integrity are the dominant considerations here, in which case the first question to ask is: Is the lighting really needed? If it is, then limitation of light spill must be carefully considered.

There are significant gaps in the coverage of AS 4282-1997. Public lighting (eg road lighting, lighting of parks), internally-lit advertising signs, TV broadcast lighting, cyclic or flashing lighting systems and daytime appearance of lighting installations are not covered. The outdoor impact of the internal lighting of buildings is not covered either.

The standard is being revised and will become a joint AS/NZS document. According to the Lighting Council Australia (2015), the revision will consider luminaire optics, the impacts of LED spectral characteristics, blue-rich white light (blue wavelengths being more problematic for health at night than others – Kraus, 2016; IDA, 2010), dynamic lighting controls and other issues.

Size of area	Controlling dimension	Cut-off for luminaires with Level 1 control	Cut-off for luminaires with Level 2 control
Large	>75 m	7.5 kcd	100 kcd
Medium	≥25 m ≤75 m	7.5 kcd	50 kcd
Small	<25 m	2.5 kcd	25 kcd

Table 2. Maximum luminous intensity per luminaire, pre-curfew (Source: AS 4282-1997 Table 2.2).

Zone	Sky glow, upward light ratio (max %)	Light trespass into windows (lux)		Source intensity (kcd)		Building luminance, average (cd/m2)
		Before curfew	After curfew	Before curfew	After curfew	Before curfew
E1: National parks	0	2	1	2.5	0	0
E2: Rural, small village	2.5	5	1	7.5	0.5	5
E3: Urban, small town centres	5	10	2	10	1	10
E4: Urban centres, down town	15	25	5	25	2.5	25

Table 3. ILE Recommendations (ILE, 2005)

AS 4282-1997 is intended to be used by local authorities, in planning controls, and it is. For example, Brisbane City Council's Light Nuisance Code cites the Standard, as do the ACT's Light pollution guide (Access Canberra, n.d.), the SA City of Burnside's Public lighting policy, and the Southern Downs Region Planning Scheme (2012) at clause 9.4.6 Outdoor lighting code. Accordingly AS 4282-1997 has been cited in environmental impact studies such as those for the Holcim Lynwood Quarry in 2014 and for the Kraft pulp mill at Bell's Bay, Tasmania in 2005.

The Standard is also cited in the Green Building Council of Australia (GBCA) Green Star 'Design & As-Built' environmental assessment tool (v1.1) as a compliance requirement in Credit 27 Light Pollution (GBCA, 2017). This deals with light pollution to neighbouring bodies (a conditional requirement) and light pollution to the night sky (1 point available). The latter can be achieved by managing either the Upward Light Output Ratio or the direct luminance into the night sky.

In 2012, the State of New York, USA, implemented an amendment to its environmental conservation law dealing with 'healthy, safe and energy efficient outdoor lighting'. This includes requirements covering permanent outdoor luminaires, establishing dark-sky preserves, and the development of a model outdoor lighting ordinance 'for the purpose of saving energy, reducing unnecessary glare and reducing unnecessary sky glow'. The preamble to the Act summarises many of the issues raised in this Note (New York State Senate, 2012).

Figure 2: Shields attached to floodlights – an example of retrofit. Shields may also be integral to the luminaire (Image: Craig Michael Utter and Dennis di Cicco, Sky & Telescope, www.skyandtelescope.com/astronomy-resources/home-lighting-guide/)

Local outdoor lighting control regulations might require the following:

- Shielding of luminaires, to direct light downwards, minimising sky glow (Figure 2)
- Height limits for luminaires relative to the property boundary, to minimise light trespass (Figure 3)
- Top-lighting for externally-lit signs, minimising sky glow (Figure 4)
- Prohibition of searchlights and laser lights, minimising sky glow
- Exchanging existing lighting systems for low light-spill alternatives
- Exemptions for emergency lighting and low-lumen lighting, e.g. around houses.

Many Australian councils also produce light nuisance guides for their residents, including Logan, Townsville, Gold Coast, Gladstone and Moreton Bay, all in Queensland, and Clarence Valley in New South Wales. The Access Canberra (n.d.) note on *Light pollution* advises a step-by-step approach to dealing with light trespass.

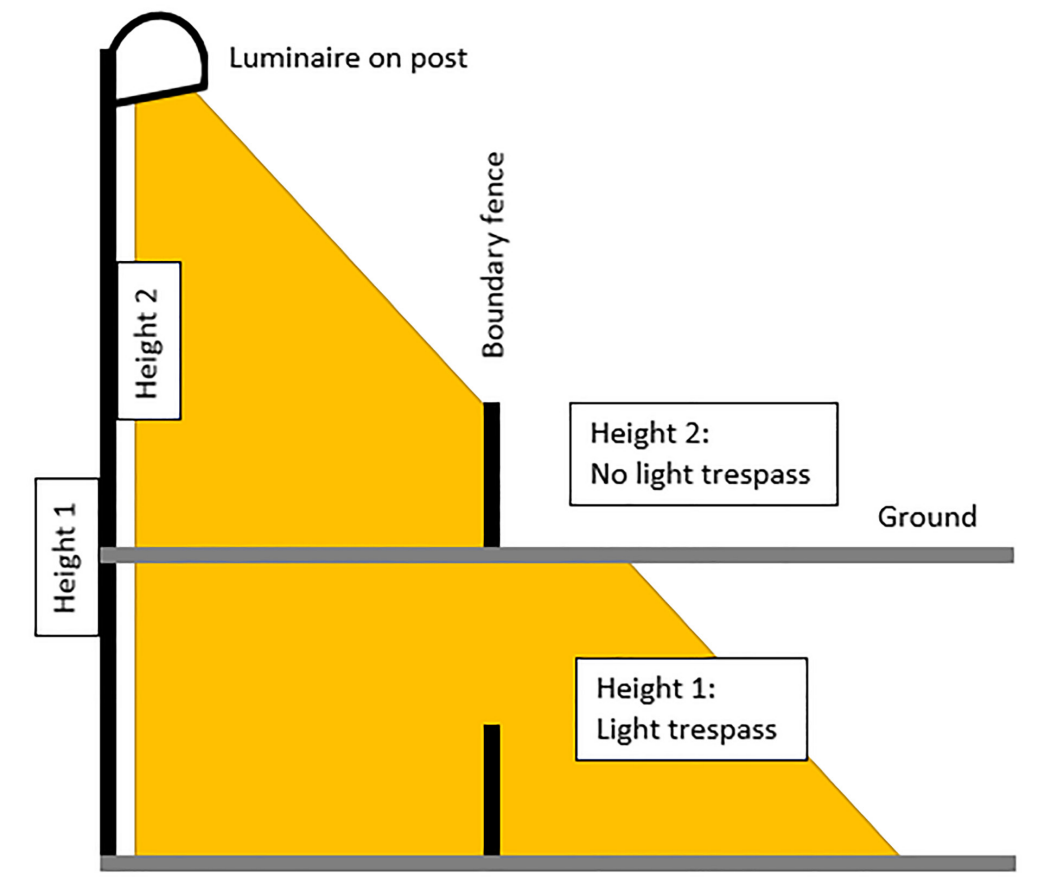

Figure 3. Height of outdoor luminaire selected to avoid light trespass, e.g. maximum height in code may be set at 1/3 distance from the boundary (Source: Author).

Figure 4. Top-lit signage – it could be more subtle. (Image: Visual FX, http://vfxsigns.com/non-electrical-wall-signs)

2.2 Plants and wildlife

Many fast-flying insectivorous bats have learned to benefit from mercury-vapour lamps, which emit across a broad spectrum, attracting moths and other nocturnal insects. One study showed that the switch to LED lighting does not seem to affect them, but slow-flying bat species, which include some of those considered most vulnerable in Europe, prefer no lighting at all (Rowse et al, 2016). Another study showed that the change to LED lighting does affect opportunistic bats, by reducing the number of available insects at the lamps, whereas bats sensitive to light may benefit (Lewanzik & Voigt, 2016). Presumably, Australian insectivorous bats would show similar preferences.

As much as 70% of the Florida coastline is protected by outdoor lighting ordinances, to protect nesting sea turtles (Florida Fish and Wildlife Conservation Commission).

FLAP Canada has developed the BirdSafe standards in collaboration with architects and bird experts, and will assess the threat levels buildings pose to birds and make recommendations for solutions such as the use of appropriate (with respect to contrast, size and surface) visual markers (FLAP) (Figure 5), ideally with UV-reflecting components (Klem, 2014; Ocampo-Penuela, 2016). These solutions are not related to light spill. However, in the mid-1980s, Toronto's CN Tower turned its floodlights off for eight weeks in the middle of each bird migration season, as part of the two-year long Bird-Friendly Building Program (involving 85 buildings), initiated by FLAP Canada. With the lights turned off, bird deaths by collision almost stopped. Turning off indoor night-time lighting of buildings also reduces collisions (Evans Ogden 2002; IDA, 2012, p.126; McCarthy, 2016). The Lights Out Toronto initiative, launched in 2006, is one outcome from this research (City of Toronto, 2017).

In general, reducing the ecological consequences of night-time light pollution might involve preventing areas from being lit, limiting the duration of lighting, reducing light trespass, changing light intensity and changing the spectral composition (Gaston et al, 2012).

Figure 5. Dot markers applied to the exterior of the glass, visible to birds but unobtrusive to the building occupants (Image: Feather Friendly, 2018, www.featherfriendly.com).

2.3 Aesthetics

Solving this problem is simply a question of asking whether illumination of facades, trees, fountains and so forth is warranted and, if so, how it can be minimised and contained.

Light pollution, eg from over-illuminating the facades, was considered in the UK Church Floodlighting Trust projects, which began with the question: Does the building need to be lit at all? One objective for external lighting is 'to promote observation and experience of the site against the night sky'. Historic England's guidance suggests that designers should consider the effect the lighting might have on creatures such as bats and owls that may reside in historic buildings, on other nocturnal animal and plant species in the vicinity, and on light spillage affecting the night sky itself and neighbouring residents (Historic England, 2007). In any case, the lighting of buildings for aesthetic purposes is not needed all night long, and can easily be controlled using timers.

2.4 Resource consumption

Where fossil fuels are a significant part of the energy mix, the reduction in the consumption of fossil fuels and the resultant greenhouse gas emissions are correspondingly significant. There are several strands to reducing resource consumption associated with lighting, most of which also reduce light pollution:

- **Providing the amount of light needed for the indoor task.** Revisiting recommended indoor lighting levels generally would reduce light spill from buildings as light pollution, particularly for high-rise buildings, which have a greater potential impact on light pollution. Over the years, recommended indoor lighting levels have got progressively higher. In 1915, the IES *Code of lighting factories, mills and otherwork places* required the following levels.

Task	Illuminance level (lux)†
Special cases of fine work	100-150
Fine manufacturing	35-60
Rough manufacturing	12.5-25
Storage, passageways, stairs	2.5-5

† 1 foot candle = 10.764 lux (approximated to 10 for this purpose).

Table 4. IES recommended indoor lighting levels in 1915 (Osterhaus, 1993)

These compare with the following recommended maintenance illuminances from AS/NZS 1680.1:2006:

Task example	Illuminance level (lux)
Watchmaking	1600
Hand tailoring	1200
Fine inspection	800
Drafting	600
Medium inspection	400
Reading and writing	320
Charts and chalkboards	240
Waiting rooms	160
Stores	80
Corridors	40

Table 5. Recommended maintenance illuminances (Source: AS/NZS 1680.1:2006, Table 3.1)

Similarly, GBCA Green Star Interiors proposes a maximum maintained illuminance level of 400 lux for 95% of a Class 5 commercial office net lettable area, to avoid lighting over-design.

Figure 3.3 in AS/NZS 1680.1:2006 makes clear that the subjective assessment of lighting quality correlates in a non-linear fashion to illuminance at the task (ie doubling illuminance does not double perceived quality). The benefit beyond say, 600 lux for desk lighting is marginal – it is certainly not worth the extra cost involved. AS/NZS 1680.1:2006 Figure 3.4 makes a similar point with respect to relative visual performance. Use of a Pareto (80/20 or 70/30) rule to determine the level used might bring the recommended levels down.

- **Providing the amount of light needed for the outdoor task.** Similar criteria could be developed for outdoor lighting. Recommended levels should also be revisited – do they really need to be as high as they are? Illuminating Engineering Society of North America (IESNA) recommended outdoor lighting levels as:

Task	Illuminance level (lux)
Commercial building entrances, active	50
Commercial building entrances, inactive	10
Parking/pedestrian areas	2-9 (minimum)
Pathways, outdoor steps	10
Service station (pump island)	200-300

Table 6. IESNA recommended outdoor lighting levels (Source: IES, 2014)

For outdoor domestic lighting, 150 W metal halide lamps are more than sufficient, and for porch lights a 9 W compact fluorescent will be adequate.

- **Making sure that all the light generated is directed towards the task area, where needed.** Use of full cut-off luminaires (90% of lumen output below 10° below the horizontal), with light targeted at least 20° below the horizontal, is recommended. Floodlights and uplights (for trees, facades, signs, etc) should not be used. Use of lower, and hence more, light poles with dimmer luminaires helps to contain the light and give a more even coverage. Accurate targeting of the luminaire is required. Glare should be checked for and shielding provided as necessary - though it is not such a problem for full cut-off luminaires (Figures 6 and 7).
- **Providing light only when it is needed.** The use of timers, motion-detector controls and curfews (eg no floodlighting between 11pm and 5am) would cover this.
- **Using efficient luminaires, with a long lamp life with consistent output levels.** LPS (low-pressure sodium) luminaires are the most efficient and, coincidentally, help astronomers (see section 2.6) in their work. However their colour rendering is very poor, so they are not appropriate in all circumstances. Where white light is needed for colour rendering, it should be provided. Industry is moving towards widespread use of LEDs (light-emitting diodes) (The Climate Group, 2012). Upgrading street lighting to high-efficiency cool colour-temperature LEDs will save 30-50% of the energy needed by conventional luminaires and provides an opportunity for smart management, eg allowing for dimming when there is no traffic. However, these are not always popular, and are likely to contribute to light pollution as they become more ubiquitous (Wheeler, 2017; Christensen & Li, 2016), unless properly managed.

2.5 Security

Some North American school districts keep all background lighting off from 11pm to 5am (the 'dark campus' approach). Because the school grounds are off limits during this period to students and staff (and to the community), and because the local police know about it, any lights arouse suspicion. Schools in San Antonio, Texas; Eugene, Oregon; Cupertino, California; Tucson, Arizona, and Chilliwack, BC (Canada) have all experienced considerable savings in energy and reduced damage from vandalism as a result of this approach (IDA, 1997; BC Hydro, 2014). Similarly, in Essex, UK, streetlights across the county are switched off from midnight to 5am. A trial for this, at Dunmow, reportedly led to a 12% reduction in crimes occurring between 11:30pm and 5:30am (Carabell, 2009).

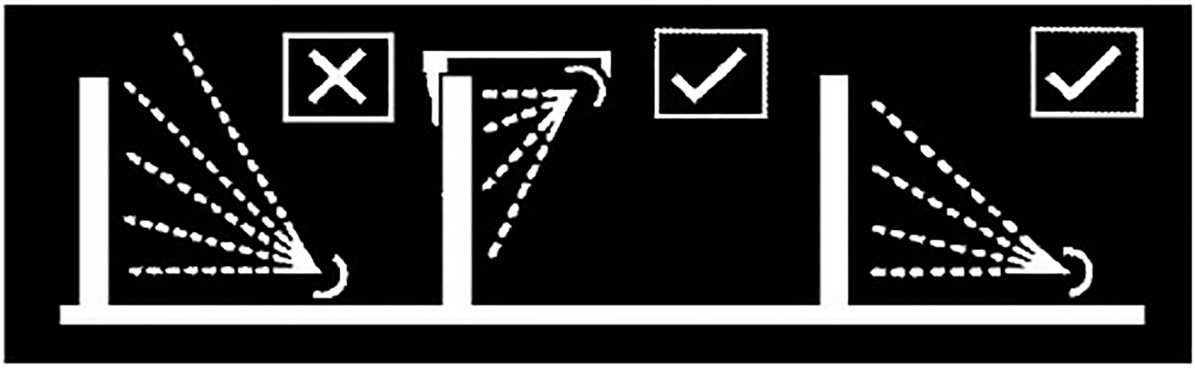

Figure 6. Where possible, direct light downwards. For up-lighting, use shields and baffles to reduce spill light (Source: AS 4282-1997 Appendix A, © Standards Australia Limited. Copied with the permission of Standards Australia under Licence 1801-c087).

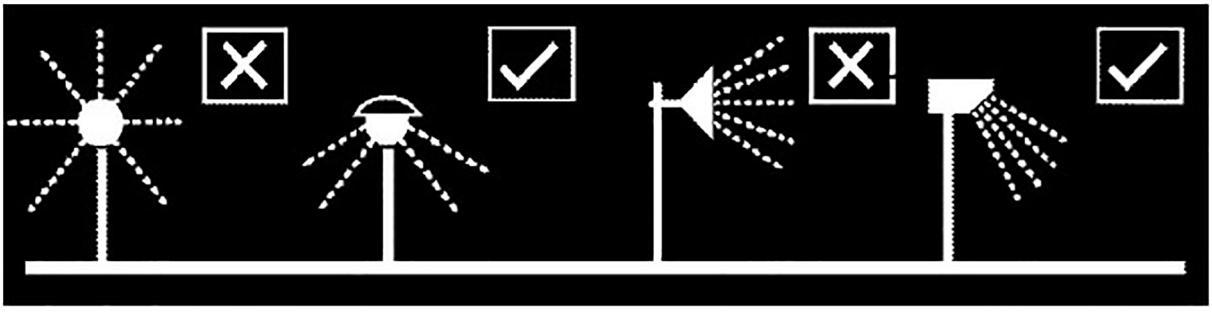

Figure 7. Use lighting equipment that minimises the spread of light near to and above the horizon (Source: AS 4282-1997 Appendix A, © Standards Australia Limited. Copied with the permission of Standards Australia under Licence 1801-c087).

2.6 The night sky

In 2016, the US National Park Service adopted a policy to 'preserve, to the greatest extent possible, the natural lightscapes of parks, which are natural resources and values that exist in the absence of human-caused light' (National Park Service, n.d.).

One way of helping astronomers is to use low-pressure sodium-vapour (LPS) lamps for street lighting, as it is easy to filter out their near-monochromatic, deep yellow light. This idea seems to be taking off, at least in Europe. LPS lamps use much less energy than the ubiquitous mercury-vapour ones, and do not contain the toxic metal (so disposal is not so much of a problem). LPS lamps are not to be confused with high-pressure sodium-vapour (HPS) lamps, which produce a peach-coloured light and are more widely available. Lamps with high colour rendering indexes should not be used. Full cut-off HPS lamps are the next preference in this respect. They are also more widely available.

Managing light pollution, especially sky glow, around major observatories requires area-wide strategies. For major observatories, local planning controls can be established to control lighting, as per the examples below.

The Canary Islands passed a lighting control ordinance in 1992 (Sky Law). Tucson, Arizona (near Kitt Peak National Observatory) is converting to LPS as part of its Light pollution ordinance (Arizona State Legislature, 2016). The Mount Palomar observatory and Caltech have worked with surrounding communities since the 1980s, resulting in the lighting codes of San Diego and Escondido (Palomar Observatory, 2017). Siding Spring Observatory (NSW) is at the centre of a Dark Sky Region with a 200 km radius, enforced through the Environmental Planning and Assessment Act 1979 (Department of Planning & Environment, 2016), while the contiguous Warrumbungle National Park is the first IDA Dark Sky Park in Australia.

But observatories, of course, are not all grand affairs. There are many private, community and scientific observatories in suburban environments (refer to the Astronomical Society of Australia's Current list of designated observatories). Many of these do important work. The solutions for these are likely to be more local – curfews, shielding and the like.

Conclusion

Light pollution is a widespread problem, affecting many people in many ways, and affecting our flora and fauna. But for both new and existing buildings and infrastructure it is relatively easy to deal with – it just requires awareness of the issues and the will to do something about them. Fortunately economic arguments are on the same side as environmental considerations, as is so often the case. It can be expected that local authorities will increasingly adopt the recommendations of AS 4282-1997, manufacturers will progressively provide more low-pollution luminaires, and revised lighting standards will consider the needs not just of players and spectators (for example), but also of neighbours and the environment.

There is no need for construction sector designers to wait for other players to deal with the problem. The solutions are well known and readily available for use.

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