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A RATIONALE FOR THE MANDATORY LIMITATION OF OUTDOOR LIGHTING

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Summary

The great value of artificial outdoor lighting has largely obscured the social, ecological and environmental problems resulting from present lighting practice. The exponential growth of outdoor lighting observed in Australia and elsewhere is unsustainable and greatly at odds with the need to reduce greenhouse gas emissions. Artificial skyglow resulting largely from wasteful lighting design and overuse of lighting is increasingly hampering astronomical research and education. Stray light entering bedrooms at night disturbs sleep and contributes to sleepiness and fatigue, known factors in traffic and industrial accidents. Exposure to artificial light at night is also a known risk factor for breast cancer and other cancers, and it may be an underlying cause of widespread obesity. Outdoor lighting does not inhibit crime but increases it. Drastic reductions in outdoor ambient light levels are justified and will require legislation to be achieved.

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1. INTRODUCTION

Although the ubiquitous application of artificial lighting has transformed civilisation and enhanced the quality of life, these benefits have been accompanied by the largely hidden costs of substantial ecological and environmental degradation and undesirable social and health consequences.

Light pollution is now an accepted term for any unwanted or nuisance (trespass) artificial light that has adverse effects. Many of the problems caused by light pollution could be overcome by using minimal light for the circumstances and confining the light to where it is needed. These are necessary but not sufficient conditions for sustainable, safe and responsible outdoor lighting. In the present context, it is also necessary to deal with the increasingly serious effects of artificial skyglow on astronomical observations. Organisations concerned with this problem have concentrated their efforts largely on campaigns for mandatory shielding of all outdoor light sources to block the direct emission of light at or above the horizontal. But even if improved shielding and aiming of lights were fully achieved overnight, the resulting once-off reduction of about 30% in skyglow is likely to be negated within a few years by the present unsustainable rate of growth of outdoor lighting (Clark 2003).

New and updated information on light pollution and its adverse effects is presented in this paper and in a more detailed version to follow (Clark 2006). Both papers put a case for a permanent solution along the lines of legally enforced national and regional maxima on the amount of outdoor artificial light, capped at well below present values. The increasingly urgent need to reduce greenhouse gas emissions would appear to justify similar restrictive caps on energy used for outdoor lighting.

2. BENEFITS OF OUTDOOR LIGHTING

Outdoor lighting provides many benefits:

- More lights and brighter illumination generally improve visibility at night.
- Improved visibility facilitates mobility and travel in dim or dark conditions.
- Outdoor work and recreation can be continued through the natural dark hours.
- It decreases the fear of crime.
- Bright lighting helps attract customers to shops, and gives an impression of prosperity.
- Road safety authorities believe that road lighting reduces traffic accidents at night.[1]
- Extensive use of electric light at night helps to raise the base (night) load on the electricity supply system, thereby facilitating performance improvement of fossil-fueled power stations in the system (an economic and greenhouse gas issue).

[1] But the vehicle window tinting industry has been successful in convincing politicians that reducing the amount of light reaching the driver's eyes at night has no adverse effects on road safety!

Satellite imagery of Earth at night indicates marked worldwide trends for more and brighter artificial lighting (Cinzano, Falchi and Elvidge 2001). City lighting is generally becoming brighter and extending further into the surrounding countryside (eg CPRE 2003). Attempts to reduce existing lighting or to restrict new lighting will have to be justified against the potential reduction or loss of benefits such as those listed.

3. ARTIFICIAL SKYGLOW

3.1 ENERGY LOSS AND SKYGLOW

The total artificial light flux emitted by a city is proportional to the product of two quantities, the number of light sources and their mean output of light. Often both of these quantities increase over time in individual cities. This suggests exponential growth in the total flux. The same result can be reached by considering the typically increasing amount of light in use per person (eg Hänel 2001), coupled with population growth in cities.

Exponential growth in a product of consumption of finite resources is generally unsustainable. In studying the situation for outdoor lighting to guide corrective action, it would be useful to know the relationships between energy consumption for outdoor lighting, the outdoor light flux produced and the resulting amount of artificial skyglow. Unfortunately, the simple proportionalities that might exist at a particular epoch tend to vary with time. It may be difficult to determine some of these variations with the accuracy desirable, especially when the rate of change in one quantity points to the need for controlling the rate of change in another.

The amount of electricity used to produce a unit of light depends on the type of lamp. The replacement of incandescent lamps in streetlights by low pressure sodium, mercury and fluorescent lamps after World War 2 produced much more light for the electricity used. From 1950 to 1980 in the USA and to 1990 in Germany, the *estimated* outdoor light flux grew at an increasing rate (Hänel 2001), ie exponentially. In the town of Osnabrück, electricity usage for (street?) lighting was approximately constant from 1981 to 1997 while the luminous efficacy and the number of lamps there both increased by about 20% (Hänel 2001). This indicates an exponential increase of about 40% in the outdoor light flux, but this has not been checked by direct photometry. Within the last ten years, metal halide lamps have been replacing or supplementing the more efficacious sodium lamps. This would tend to reduce the rate of growth of outdoor light flux relative to the growth of electrical energy used for lighting. There seems to be a severe shortage of quantitative data about the actual situation.

Towards the end of the 20th century, increasing protests by astronomers led to various generally small reductions in the proportion of upward waste light permitted by national standards for public lighting. Accordingly, artificial skyglow should not have grown quite as fast as total outdoor light flux. Improving air quality would have added to this trend. But there would have been an opposing increase in atmospheric light scatter during this time and since, when white light from metal halide lamps and compact fluorescent lamps replaced or supplemented orange (ie blue-deficient) light from sodium lamps. In the last two or three decades, as a first approximation the overall amount of skyglow has probably remained more or less proportional to the amount of electricity used for outdoor lighting.

Although street lighting is a major contributor to ambient artificial outdoor light at night and hence to skyglow, account also needs to be taken of additional sources such as vehicle lights, traffic signals and signs, architectural floodlighting, illuminated billboards, and internal light escaping from shop, office and residential windows. This was recognised in Japan, and led to measurements in Tokyo of the relative skyglow effects resulting from street lighting, light from buildings and light from illuminated signs (Oba, Kawakami, Iwata, Uozomi and Kohko 2005). The relative contributions from these three categories were roughly comparable.

Therefore energy use for street lighting may be as small as one-third of the energy involved in providing the total outdoor ambient light of a city. As about a third of the total ambient light flux ends up in the sky where it causes artificial skyglow, the cost of the energy used in producing skyglow may sometimes be as much as the cost of the energy used for street lighting! In another measure of the problem, in the Australian state of Victoria the amount of energy lost by avoidable light pollution well exceeds the total generating capacity of Victoria's operational wind farms.

Skyglow is not trivial. Most of it is avoidable by modifying lighting practices in line with present knowledge. Reducing or eliminating light pollution will generally save money as well as improving the environment.

3.2 GROWTH IN SKYGLOW

The paucity of quantitative historical data about the total artificial light flux in cities or countries and the corresponding electricity consumption is regrettable. The first global comparison between cities in respect of lighting, population and area[2] seems to be Isobe and Hamamura (2000), who used satellite measures of upwelling light from cities at night. Monitoring of this light by aircraft or spacecraft could be important in the control of outdoor lighting. As it is also the light that is scattered as artificial skyglow, monitoring of skyglow from the ground would provide a relatively inexpensive input for control of outdoor lighting.

In natural dark sky conditions, about 2700 stars are detectable without optical aid in the hemisphere above. Artificial skyglow blots out the fainter stars: in the middle suburbs of Melbourne (total population 3.5 million, state capital of Victoria), for example, only 2% to 3% of the 2700 naturally visible stars per hemisphere can now be seen.[3] Starting from the 1880s, when the luminance of the cloudless and moonless night sky at Melbourne effectively had just the natural value, the artificial component of Melbourne's skyglow appears to have doubled about every ten years since then (Figure 1), an increase of about 100% per decade. This can be compared with the exponential growth rates of 7% to 10% per annum in skyglow observed in Italy, ie 97% to 159% increase per decade (Cinzano 2002a), 6% pa or an increase of 72% per decade derived as typical for the USA by Cinzano (2002b), and 3% pa (34% increase per decade) in the UK (Clark 2003). Actual growth rates will fluctuate over time and

[2] The writer was able to find crime rate data for many of the USA and English cities as well. Brighter cities tend to have reliably higher crime rates (Clark 2003).

[3] An indication of how much worse skyglow could become in Australian cities is given by the writer's casual observations of the number of stars visible unaided in moonless and cloudless night skies above London (none), Los Angeles (none, but Jupiter seen), Cairo (6) and Kuala Lumpur (6 with 2 octas of cloud).

depend on location, of course, but the exponential approximation provides a good basis for comparison.

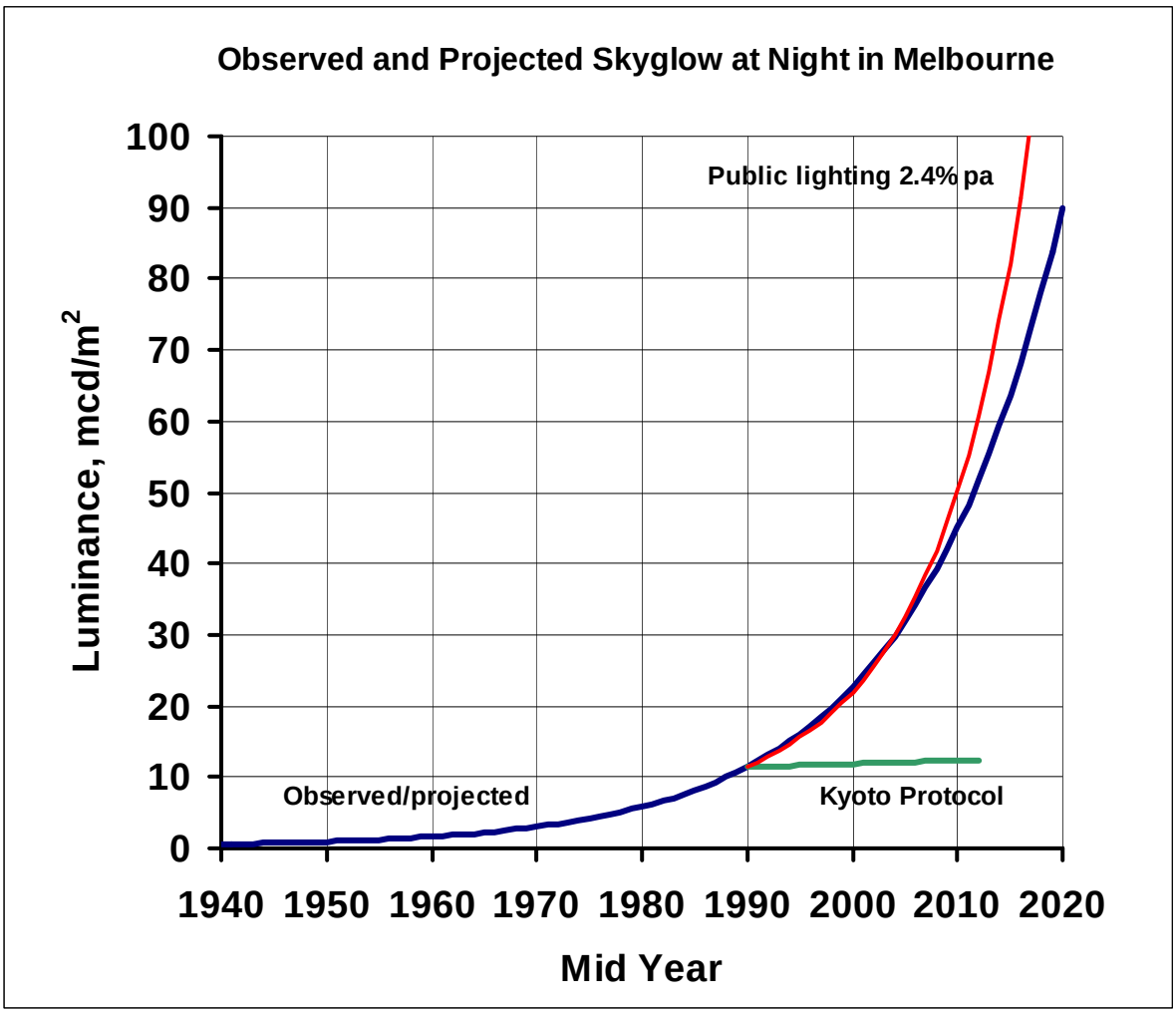


Figure 1. The blue curve is based on a smooth exponential fit to inferred and direct observations of artificial skyglow over Melbourne from 1880 to 2006. It is shown here from 1940 (ignoring the wartime blackout) and extrapolated from 2006 to 2020. The green curve shows the internationally agreed maximum growth in greenhouse gas emissions for Australia according to the Kyoto Protocol, starting from the blue curve value in the Protocol base year of 1990. The red curve shows the course of skyglow if it is growing from the 1990 value by 2.4% pa, which is indicative of the present after-inflation growth of municipal expenditure on public lighting in Melbourne municipalities.

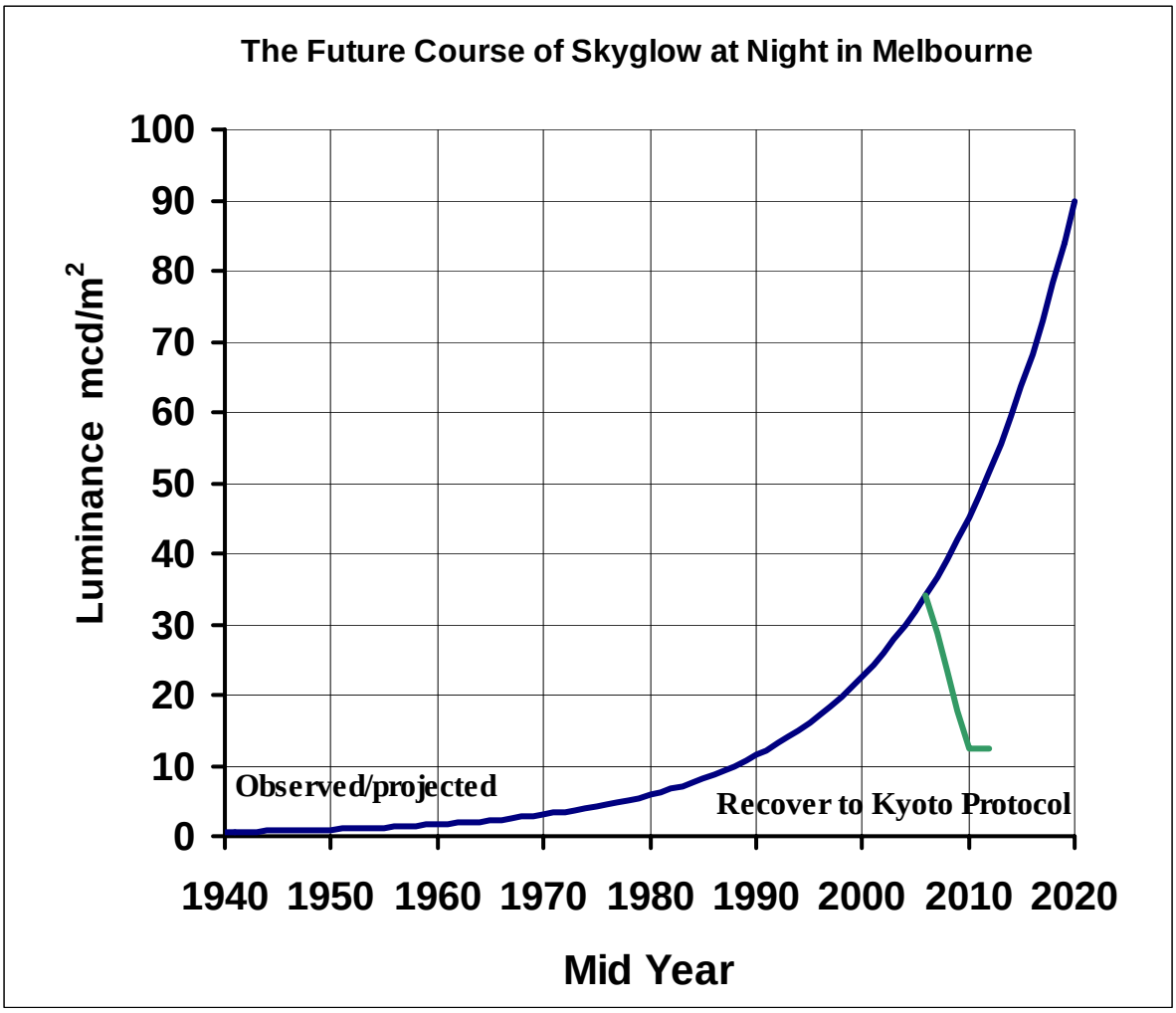
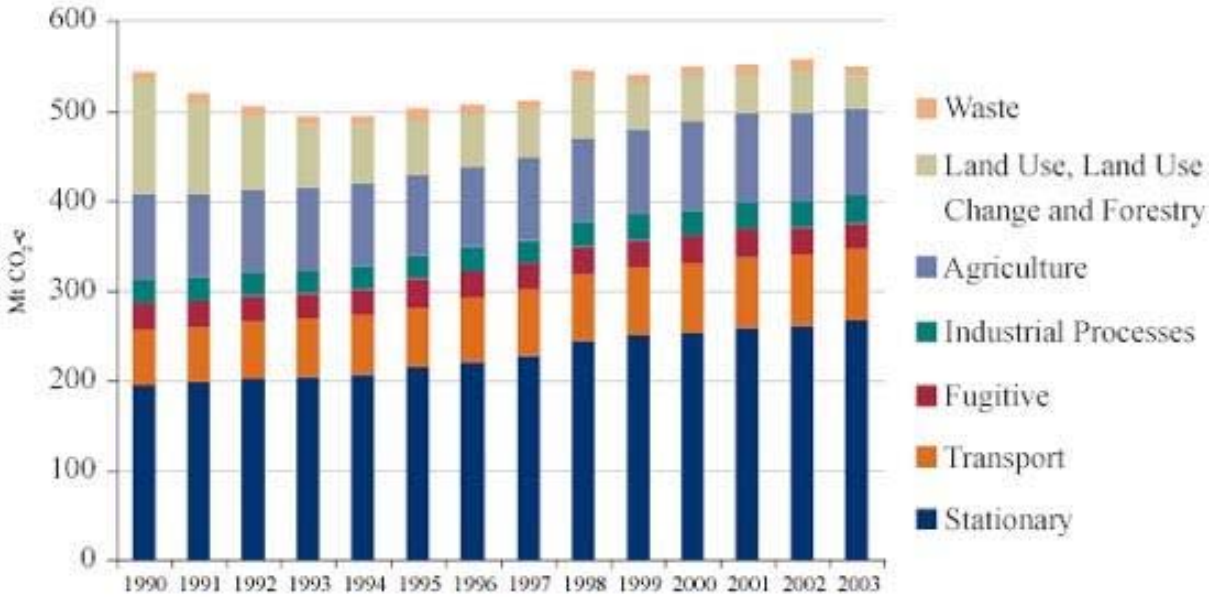


Figure 2. The green curve shows how Kyoto Protocol compliance of energy consumption for Melbourne's outdoor lighting could be achieved by a reduction to 36% of the present (2006) level over the years to 2010. If this drastic action is not taken and the present unsustainable growth is allowed to continue, subsequent compliance with the expected post-2012 energy reductions of about 60% by 2050 will become even more difficult. Note that a moratorium in which no new installations or increases of outdoor lighting are allowed would be represented by a horizontal line extending from the 2006 point on the blue curve. Although a moratorium would be better than the present uncontrolled growth, it would still leave the outdoor lighting energy sector of Melbourne in severe breach of the internationally agreed greenhouse gas limits for Australia under the Kyoto Protocol, thereby placing pressure on other sectors for additional reductions in greenhouse gas emissions to compensate.

Regardless of whether Australia ratifies the Kyoto Protocol or not, Australia has at least a moral obligation to comply with the Protocol. Australia is probably the world's worst emitter of greenhouse gases on a per capita basis, and Victoria is the worst state of Australia in this regard because of its reliance on brown coal for electricity generation. Australia also has a legally binding commitment under the UN Framework Convention on Climate Change to

reduce its greenhouse gas emissions. If the federal and state governments of Australia were serious about compliance, one of the actions they would already have introduced would be a reduction of public lighting according to the green curve in Figure 2. Instead, the federal government in particular has encouraged local councils to manage greenhouse gas emissions in their municipalities according to the Cities for Climate Protection (CCP) program. CCP actually predates the Kyoto Protocol, and allows a choice of base year. The base year generally chosen is 1996.

In the USA, greenhouse gas emissions for 1996 were approximately at the same level as those for 1990. This has given rise to the widely circulated notion that compliance with the Kyoto Protocol can be achieved by similar limits on emissions relative to 1996 levels. But for Melbourne's outdoor lighting as indicated by the blue curve in Figures 1 and 2, it is apparent that this 1996 CCP baseline is 50% higher than the 1990 Kyoto baseline. Not knowing this, local governments in Melbourne and presumably elsewhere have unwittingly contributed to the blowout in greenhouse gas emissions connected with outdoor lighting.[4] Although figures for annual increases in local government expenditure on lighting do not appear to be readily available, council representatives at recent sustainable public lighting seminars in Victoria have described increases of up to 5% pa after allowing for inflation (about 2% pa).



Source: Australian Greenhouse Office, 2006, http://www.greenhouse.gov.au/inventory/

Figure 3. Greenhouse gas emissions in Australia. The Australian stationary energy sector emissions for 1996 are about 18% higher than they were for the Kyoto Protocol base year of 1990. Compare this with the observed photometric increase in Melbourne's artificial skyglow in this period, 50%, an approximate indication of the corresponding increase in energy consumption for outdoor lighting.

[4] The author has alerted the federal and Victorian governments to this problem on several occasions since 2004, but no actions to correct the problem have been apparent.

Figure 3 indicates that the 1996 level of Australia's total greenhouse gas emissions from stationary sources is clearly well above the 1990 level, although not as markedly as the blue curves of Figures 1 and 2 show for outdoor lighting in Melbourne. Light pollution reports by amateur astronomers in other large Australian cities indicate rapid growth much like that in Melbourne, so it appears that CCP procedures are unwittingly fostering unsustainable growth in energy use for public lighting in Australia.

Using country sites for dark sky observations is a current work-around for amateur and professional astronomers in Australian and other developed nations. But artificial skyglow from cities is now detectable over hundreds of kilometers away with inexpensive equipment.[5] If the present unsustainable growth in outdoor lighting continues over a few more decades, many existing Australian dark sky sites will be afflicted by skyglow like, for example, that of Melbourne outer suburbs at present. New observing sites will need to be established at locations several times further away from cities than the present distances. Amateurs would face unpalatable or prohibitive increases in travel time and costs. Given that amateurs are contributing more than ever before to knowledge of the universe, hampering their scientific endeavours comes at a cost to humanity.

For the professional observatories at Siding Spring (a sparsely populated part of the Australian state of New South Wales), the spread in skyglow from Sydney (the state capital) and nearer population centres poses an increasingly severe threat. Unless the growth in outdoor ambient light flux at night is stopped or reversed, in due course Siding Spring will inevitably experience the unacceptably bright skyglow levels that currently afflict Mount Stromlo Observatory near Canberra in the Australian Capital Territory. The costs of forced relocation to more remote sites would be worrying for the various national governments and organisations involved. Transport of goods and personnel could be increasingly discouraged by greenhouse gas emission controls. Again the handicapping of astronomical research needs to be considered seriously, given that astronomy is one of the prime wellsprings of scientific and technological progress.

4. JUSTIFYING CHANGES IN LIGHTING PRACTICE

Clark (2003) showed that the astronomical problem will continue to worsen unhindered in the longer term even if light spill control measures such as those proposed by lighting organisations (eg ILE 2000) or the International Dark Sky Association (IDA 2006) are introduced and high levels of compliance are achieved. National and regional reducing caps on outdoor ambient light flux are required instead or as well, but the astronomical problem by itself seems unlikely to be accepted by governments as sufficient reason for imposing such drastic restrictions. But other reasons do exist to justify mandatory control of the amount of outdoor ambient artificial light at night, as distinct from control of the energy used to produce that light. The most compelling of these relate to health and wellbeing.

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[5] Reliable physical data is necessary but not sufficient to justify changes in lighting practice. Fortunately, the new Sky Quality Meter from Unihedron[5] of Canada is relatively inexpensive and much more convenient than existing methods of measuring sky luminance.

4.1 SLEEP DISTURBANCE AND ACCIDENTS

Firstly, quite small amounts of light at night can disturb sleep.[6] The Australian Standard AS 4282-1997, *Control of the obtrusive effects of outdoor lighting*, sets the maximum illuminance allowed in the plane of bedroom windows at between 1 and 25 lux depending on the circumstances, despite citing a German study in which complaints began when the external illuminance at windows at night was as small as 0.1 lux. AS 4282 includes a denial that its window illuminance limits merely perpetuate existing lighting practices, but this denial seems hollow. Extensive questionnaire surveys in Czechia by Forejt, Skočovský, Skotnica and Hollan (2004) indicated that for sleep to be undisturbed by lighting, the maximum external illuminance in the plane of bedroom windows should not exceed 0.1 lux, regardless of where the dwelling is located.[7] Ad hoc observations by the writer and colleagues using Sky Quality Meters in several suburban bedrooms, together with occupants' reports of spill light effects on sleep, definitely support this 0.1 lux maximum. Note that the best conventional light meters have a tolerance of 0.1 lux at their most sensitive settings, so setting the limit at 0.2 lux instead could allow exposure to 0.3 lux or more in practice, which would be quite inadvisable.

Sleep loss and sleep disturbance degrade wellbeing (Dement and Vaughan 1999) and can substantially increase the risk of road and industrial accidents in which daytime sleepiness and fatigue are factors (Dawson and Reid 1997; Stutts, Wilkins and Vaughn 1999; Williamson and Feyer 2000). The use of heavy drapes or even blackout blinds to block excessive stray artificial light is undesirable as such barriers also block the important beneficial waking effect of morning light for the bulk of the population (Forejt and Hollan 2004; Forejt, Skočovský, Skotnica and Hollan 2004). If governments are as serious as they claim to be about reducing accidents, they should act to limit total artificial illuminance to 0.1 lux at windows of habitable rooms, regardless of rural, suburban or urban location. Current international guidelines on this matter are in urgent need of correction.

4.2 LIGHT AT NIGHT, OBESITY, MELATONIN AND CANCER

Unnatural light exposure at night can have other serious effects on health and wellbeing (Wiley and Formby 2000; Pauley 2004).

Many mammal species exhibit a food craving known to be related to the extended duration of daylight during summer, leading to storage of body fat in preparation for the coming winter famine. Wiley and Formby (2000) suggested that the same mechanism affects humans who are incompletely adapted to artificial light simulation of year-long summer light durations and not subject to a winter food shortage. This is an explanation of the increasing global

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[6] Note that the light of the full moon at normal incidence never exceeds 0.27 lux. Generally it does not exceed 0.2 lux in the vertical plane. For individual windows that can receive moonlight, values approaching 0.2 lux occur only for a few hours each month at most.

[7] It is international practice for lighting standards to allow greater illumination of windows in city lighting zones but this practice now appears to be unsupportable. Health and safety should not be compromised by allowing excessive stray light in the middle and inner zones of cities, particularly as stray light is largely a product of careless lighting practices and indicative of glare.

incidence of obesity and obesity-related illnesses such as Type 2 diabetes. It is supported by laboratory trials (Spiegel, Tasali, Penev and Van Cauter 2004) in which human sleep curtailment resulted in decreased levels of the satiety hormone leptin, which is a response to a caloric shortage, and elevated levels of the hunger hormone ghrelin, which stimulates appetite. Speigel et al. noted that mean sleep duration in the US population had decreased by one to two hours over the past forty years. Spiegel et al. did not refer to the Wiley and Formby book.

Like most living things, the human body produces the hormone-like substance melatonin in dark conditions at night. Light exposure at night, especially in the small hours, can interfere with this process. In particularly careful laboratory experiments, as little as 0.4 photopic lux of blue light has been found to cause a half-saturation nocturnal melatonin response in humans (Glickman, Levin and Brainard 2002). In ordinary domestic situations, light exposures would be more likely to be polychromatic white rather than near-monochromatic blue. Exposures of less than a hundred lux of white light can have an appreciable effect on melatonin, depending on the deep-blue spectral component of the light.[8] Evening exposure to 500 to 1000 lux for 1 to 2 hours is typical for sporting teams and many of the spectators in high-level competition and televised games at night. Such exposures suppress melatonin levels by 40 to 60% (NAPBC 1997).

It has been known since the 1980s that melatonin is one of the body's most powerful agents for retarding the growth of breast cancer and other cancers, and many laboratory and field studies have shown reliable positive connections between breast cancer incidence and light exposure at night (eg Davis, Mirick and Stevens 2001; Schernhammer and Hankinson 2005; Blask, Brainard, Dauchy et al. 2005).

Kloog, Haim and Portnov (2005) found a positive association between night light intensity measured by satellite and breast cancer rates in towns in Israel. Abnormally high cancer rates were found along the 'seam lines' where intense security lighting is extensively used. Abnormally low cancer incidence rates were found in low-income areas where outdoor and indoor artificial illumination is dimmer than elsewhere for economic reasons. For these two groups, the rate of breast cancer incidence was highly correlated with in-situ measures of illuminance at night. All of these results have statistical reliability. In a pre-publication presentation, Kloog et al. concluded:

- "The survey thus reveals a strong association between the exposure to high nightlight intensity and the incidence of breast cancer."
- "We thus suggest that municipalities should adopt a smart policy of illumination. Such a policy should reduce illumination when and where not absolutely necessary, to both save energy (and money) and prevent excessive light pollution which appears to be a general environmental hazard to human health."

[8] But researchers funded by the lighting industry found that 18 lux from blue light-emitting diodes was more effective at suppressing melatonin than 450 lux from mercury vapor lamps. Instead of finding out why their thresholds were much higher than those reported by others, they concluded that white light used in buildings was much less effective at suppressing melatonin than was previously thought (LRC 2004)!

4.3 OUTDOOR LIGHTING AND CRIME

By the early 1990s, scientific reviews in the USA and UK had established that the use of outdoor lighting was ineffectual for actual crime prevention. However, common belief in the efficacy of lighting against actual crime seems to have persisted, perhaps because of confusion with the commonly experienced beneficial effect of lighting in reducing the fear of crime. Since the mid 1990s, the resurgence of interest in the UK in the use of lighting for crime prevention can be traced primarily to one researcher whose published scientific work sometimes acknowledged funding assistance from the lighting industry but failed to acknowledge a personal relationship with a lighting industry leader. Before this relationship was admitted in 2005, the UK government had spent £300 million on streetlighting upgrades to reduce crime. Street crime has actually increased in the UK since the program began.

Controlled field trials intended to determine the effect of lighting changes on crime have been shown by Marchant (2005) to be invalid because the statistical analyses have not taken account of the fact that individual criminals often commit multiple crimes. The meta analysis of such trials by Farrington and (Welsh 2002) added to the confusion because it does not overcome the systematic bias of most existing trials towards a beneficial effect of lighting. This bias arises because areas with elevated crime rates are usually chosen for lighting increases and 'regression to the mean' tends to produce a reduction in crime that is wrongly ascribed as an effect of the treatment.

The claim that lighting does assist crime deterrence by natural surveillance is reasonable, but most writers on the subject omit mention of the assistance it simultaneously provides in the commission of crime. There is absolutely no reliable evidence to support a beneficial net effect of lighting, but plenty to support the contrary, that lighting actually provides net assistance to criminals (Clark 2002, 2003, 2006). Installation of more and brighter lighting is also counterproductive as an anti-graffiti measure.

It is ironical that people feel safer in lighting conditions (Boyce, Eklund, Hamilton and Bruno 2000) that are now known to be conducive to increased actual crime. At present, there seems to be no way around this problem, although reduced-glare lighting might help a little by optimising the fear-reducing effect. Fortunately, full-cutoff lighting advocated to minimise light pollution is also reduced-glare lighting.

Whenever lighting reductions are proposed for environmental reasons, vested interests tend to trumpet the need of lighting for security. The use of the word 'security' in this context can now be considered to be 'spin', in that it implies both actual safety and feelings of safety, a false combination of opposites insofar as the effects of lighting are concerned. 'Security lighting' is an oxymoron, and use of the term in advertisements should be subject to sanctions under fair trading laws.

It is a dangerous myth that lighting prevents or reduces crime.[9] As modern lighting practice is permeated by this myth, particularly in the use of bright illumination and emphasis on near-horizontal spreading of light from luminaires, fundamental changes in lighting practice are now required by the facts.

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[9] This condemnation does not extend to the use of lights switched on temporarily by intrusion detectors to provide a visible alarm.

5. MANDATORY LIGHTING CONTROLS

5.1 EXISTING LIGHT POLLUTION LAWS

Many regions and states in other countries have mandatory controls on obtrusive light emission and energy consumption of outdoor light sources. But the honour of being the first country with a national law on light pollution goes to Czechia, which included lighting controls in its Protection of the Atmosphere Act of 25 March 2002. When introduction of the Czech law was being debated, opponents with vested interests predicted lawlessness and accidents. Their fears have proved unfounded, while the degree of compliance with the law continues to increase at an acceptable rate.

The Czech law was based on law number 17/2000 of the Lombardy region in Italy. In Lombardy itself, introduction of the law had a large measure of popular support, and produced a somewhat surprising result: it revitalised the Italian lighting market by introducing an emphasis on improved technical performance (Bonata 2002). Of all the available laws, regulations and ordinances on light pollution, this one appears to provide an excellent foundation for other governments to start with (Bonata 2002). It was formulated before the present results on the unsustainable expansion of lighting in Melbourne were assembled, however, and the inclusion of mandatory reducing caps will require extension of the principles embodied in the Lombardy law.

The world's second national law on light pollution came into force in the UK in April 2006. Following a House of Commons inquiry into light pollution, the UK Environment Protection Act 1990 was amended by Section 102 of the Clean Neighbourhoods and Environment Act 2005. Artificial light is included in the statutory nuisance provisions. Allowing 'exterior light' to be 'emitted from premises so as to be prejudicial to health or a nuisance' is now a criminal offence. The restriction to light from 'premises' was quite deliberate. It is understood that other important sources of light and light pollution such as streetlights, public transport terminal lighting and so on will be the subject of separate UK legislation when appropriate limits to obtrusiveness have been devised and agreed.

5.2 FORM OF LIGHTING CONTROLS REQUIRED IN AUSTRALIA

From the foregoing, it is clear that governments in Australia have been slow off the mark in dealing with light pollution. Whether this is because of ignorance or disinterest is not known. In the case of the Victorian government, however, there has been no action despite the adoption of light pollution as a policy issue at the annual conference of the governing political party.

This paper puts the case that the introduction of mandatory lighting controls in Australia is overdue and urgent. The federal and state governments must lead on this issue rather than merely delegate uncoordinated action to local governments. The form of the controls should:

a. allow just enough outdoor ambient artificial light at night in populated areas for wayfinding and safe movement of pedestrians and vehicles,
b. limit unnecessary exposure to artificial light at night to minimize weakening of a key natural defence against breast cancer and other cancers,

c. limit the total amount of outdoor artificial light in the plane of windows of habitable rooms to 0.1 lux, given that even faint light inside bedrooms at night can lead to
    - circadian dysrhythmia and associated health and wellbeing deficits , and
    - sleep loss and sleep disturbance, with subsequent increased risk of traffic and industrial accidents,
d. minimise the greenhouse gas emissions associated with all forms of outdoor artificial lighting, including street and public lighting, traffic signal lights, illuminated road traffic signs, illuminated billboards and outdoor display screens, sports lighting and internal artificial light loss from buildings,
e. ensure that the lighting energy sector meets or surpasses national and state obligations under the UN Framework Convention on Climate Change, the Kyoto Protocol and related or follow-on protocols,
f. achieve sustainability in the total national and regional energy usage for the production of ambient outdoor artificial light,
g. eliminate visual amenity loss and traffic hazards arising from glare and distraction caused by inadequately shielded lights and excessively bright illuminated or transilluminated surfaces,
h. reduce artificial skyglow interference with astronomical research, education and recreation, maintenance of indigenous culture, aesthetic pleasure and tourism,
i. reduce crime to the minimum possible with minimal lighting while limiting the fear of crime to tolerable levels,
j. minimise the adverse effects of ecological light pollution (Longcore and Rich 2004) on
    - health and wellbeing of outdoor pets (Wiley and Formby 2000),
    - all forms of biodiversity (Flannery 2005; Rich and Longcore 2005), and
    - primary food production,

    and
k. turn around from bad to good the example Australia sets for other nations in global environmental responsibility.

One outcome of these findings is the need to wean Australians off the use of outdoor sports lighting at night, especially for the light levels used in elite and professional competitions. Another is the need to eliminate most, if not all, architectural and decorative floodlighting, billboard lighting and outdoor video displays. Whatever might be retained, of course, will mean correspondingly less light for streets and public places.

Of the possible measures required for enforcement, taxes on the amount of light emitted above the horizontal or its energy equivalent could well have a salutary effect.

6. RECOMMENDATIONS

Based on this paper and more detailed information in Clark (2006), all levels of government in Australia should implement the following.

a. Apply mandatory outdoor lighting strategies and controls, including provisions to:
    - limit *total* external incident artificial illuminance in the plane of windows of habitable rooms to 0.1 lux regardless of location of the dwelling,
    - conserve energy and assist seeing by reducing glare, limiting spill light and preventing overbright lighting,

- require full cutoff shielding of outdoor luminaires in all cases, including commercial lighting, road lighting and sports lighting, with exemptions only by specific exception subject to public scrutiny and appeal,
- limit the size, luminance, intensity and hours of operation of all illuminated advertising signs and outdoor video displays, and cap their total energy use (which may well need to be small or zero),
- ban all outdoor use of laser beam displays,
- ban all commercial skybeams,
- ban all upwardly aimed floodlighting,
- specify curfew times for certain types and locations of outdoor lighting,
- limit the emission of internal light at night from doors, windows and skylights,
- avoid waste of resources by inappropriate use of lighting to try to control crime and graffiti, and
- cap outdoor lighting energy usage in line with Australia's international obligations to reduce its greenhouse gases emissions, and insist that only a 1990 base year should be used in lighting energy constraints under the Cities for Climate Protection (CCP) scheme.

b. Educate the public about actual lighting effects on crime and the fear of crime.

c. Encourage the continued use or revival of *low pressure* sodium lamps for energy efficiency where appropriate, and investigate their value for graffiti deterrence.

d. Introduce national and regional lighting strategies with laws and regulations, including mandatory technical constraints in cases where the relevant Australian Standards do not adequately represent the national interest in general or the specific interests of professional and amateur astronomers.

Inclusion of energy constraints on lighting and lighting waste is on the basis that limitation of greenhouse gas emissions will continue to be of high priority. Of course, if low-emissions energy supply technology succeeds to the extent that fossil-fuel usage declines substantially, this constraint could be relaxed. The present prospect of this happening is not zero, but it is small and the precautionary principle must be applied in the meantime.

It is expected that these recommendations will also be applicable in countries other than Australia provided that appropriate allowance is made for differences in political and legal systems.

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