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www.britastro.org/dark-skies

Blinded by the Light?

A handbook for campaigners against the misuse of artificial light, victims of light pollution and friends of the terrestrial and celestial natural environments.

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Introduction

There is no doubt that, since its invention in the nineteenth century, artificial light, both public and domestic, has brought great benefits. Only now, as we move into a 24-hour society, and swathes of light have become visible from space on the night side of our planet, are we beginning to realise that lighting also has its “dark side”.

This is a guide to the adverse impact upon the environment, on humans and on wildlife of wasted artificial light (commonly known as light pollution, or LAN – Light at Night). This guide will define the problem. It will explore both the evident and the less evident ill-effects of poor lighting practice. It will suggest courses of action (see chapter 6) to turn back the tide of wasted light which has appeared across the UK and the rest of the developed world since the 1950s: a trend which continues unabated.

Adverse impacts of poor artificial lighting

Light pollution is an obvious waste of energy, money and resources. It affects all of us in various ways. Its adverse impacts are:

- **Cost to the environment** To produce the electricity for misdirected and superfluous light, more fossil fuels are burned in power stations than would otherwise be burned, extra greenhouse gases are produced, and more atmospheric pollution created.

- **Skyglow** This is the visible glow caused by scattering and reflection from atmospheric aerosols and droplets, even on what seem to be the clearest of nights, veiling the stars and degrading the environment above. A more technical explanation of the skyglow phenomenon is given in the Appendix at the end of this handbook.

- **Light nuisance** Light pollution is *not just an astronomers' problem*. The quality of many people's lives, whether or not they observe the stars, is seriously degraded by neighbours' poor-quality exterior lighting, or direct light from road lamps, needlessly entering their property. The adverse effects upon human health of intrusive light are discussed in chapter 4. Unwanted light entering neighbouring premises is also sometimes referred to as “light trespass”, although, strictly speaking, this term applies in law only if the light is deliberately and maliciously aimed, which is almost never the case. Ignorance of the effects of intrusive light is the usual cause. Humans are not the only species troubled by stray light (see chapter 2). Millions of our fellow creatures are disturbed, disoriented, injured and killed every day by unsuitable lighting installations.

- **Glare** Over-bright and poorly directed lights can dazzle or discomfit those who need to see, *concealing* rather than revealing. Much sports floodlighting, and cheap and vastly overstated 300-500W ‘security’ lights, so common in domestic use, often fall into this category.

Chapter 1 The night sky and wasted light

Bob Mizon, coordinator, BAA CfDS

“The natural world, our traditional source of direct insights, is rapidly disappearing. Modern city-dwellers cannot even see the stars at night. This humbling reminder of Man’s place in the greater scheme of things, which human beings formerly saw once every twenty-four hours, is denied them. It’s no wonder that people lose their bearings, that they lose track of who they really are, and what their lives are really about”.

Michael Crichton, *Travels* (Pan/Macmillan, 1988. ISBN 0-330-30126-8, reproduced with permission).

A sad paradox of modern life is the fact that our telescopes can offer stunning images of the near and far universe, and at the same time our lighting technology, if inadequately designed and installed, can steal our view of the stars above. The Campaign for Dark Skies (CfDS) has been in existence since 1989, publicising the problem of light pollution in all its forms and trying to win back the night sky. The campaign is about quality lighting for *everybody*, not just for astronomers. Some ‘eco-warriors’ recommend militant action, but, as CfDS has often stated in its literature, “broadsides don’t win friends, while reasoned argument and persistence just might”! Education and dialogue are the watchwords. CfDS’ policy: working with the relevant agencies, persuading the decision-makers of the need for ‘star-quality’ lights, and pursuing dialogue with the lighting engineers and manufacturers who have the expertise physically to solve the problem of light pollution.

The Campaign to Protect Rural England (CPRE)¹ concluded, as part of their 2003 *Night Blight* initiative: “*The problem is getting worse. Between 1993 and 2000 light pollution increased 24%; nationally, the amount of truly dark night sky in this country fell from 15% to 11%; the amount of light-saturated night sky rose to 7%.*”

In 2003, light pollution was chosen as a suitable subject for investigation by the UK Parliamentary Science and Technology Select Committee. The Select Committee considered a large amount of evidence on its effects upon both the night sky and on the quality of life (and bank balances) of UK citizens. One of the many called to give evidence to the committee was a now prominent politician, at that time a junior education minister. Worryingly, he implied that, because children see the universe on the Internet, they no longer need to be able to see the stars from their back gardens (!).

Fortunately, the Committee strongly disagreed. After sitting for several days, it made many positive recommendations, which led to some legislation against light intrusion under the Clean Neighbourhoods and Environment Act 2005².

In the relevant section (S.102) of this Act, which deals with sources of potential light nuisance, there are (inexplicably, in the opinion of the CfDS) some exclusions: transport-related premises, some of which may be serious light-nuisance offenders, and cause considerable skyglow, are not covered.

Since the early 2000s, public and political awareness about light pollution has grown, to the extent that light-waste dominated a *general* discussion on energy problems on a national radio phone-in programme in 2007. Light-waste is one of the most visible, yet too often unaddressed, aspects of the current energy debate. Unnecessary and over-bright lights are common sights, and it has been estimated (7th European Symposium on Light Pollution and

Global Warming, 2007, Bled, Slovenia) that Europe's streetlights alone waste 1700 million Euros annually by illuminating the night sky and casting light outside the area to be lit. Add other types of light, and the figure is much larger. See www.britastro.org/dark-skies/economic.html?70

Thousands of stars should be visible to the unaided human eye from a dark place, but it has become, since the 1950s, increasingly difficult to find such places. There are sites in modern town centres where almost nothing outside the solar system is ever seen in the night sky.

For countless years, on every clear night, human beings were able to gaze in wonderment at the starry heavens, traversed by the Milky Way, lit by mysterious auroral displays and punctuated by the flashes of shooting stars. Nature's grandest free show has spurred us to consider our place in the great scheme, has given rise to many themes and aspects of our cultures and religions, and has inspired both artistic achievement and scientific endeavour.

The unspoiled starry sky is, unofficially but undeniably, **a site of special scientific interest**, and an **area of outstanding natural beauty**. Ill-directed artificial light is quietly and rapidly stealing it away from most people in the developed world. In spite of legislation (see above) about light intrusion into premises, **the night sky, half of our environment, remains the only part of that environment with no protection in law**. At the time of writing (2008), the penalty for fly-tipping in the green fields of the British countryside is a substantial fine or even a prison term of up to five years; but veiling the beauty of the night sky from one's fellow citizens with wasted light carries no penalty at all (see photo 1).

The nature of skyglow

'Skyglow' is light which is being carelessly, or sometimes deliberately, projected from the ground or a structure, degrading the night sky and reducing the visibility of astronomical objects.

Skyglow is caused by light emitted above the horizontal, especially at shallow angles, from poorly designed or badly aimed lamps, scattered and reflected by aerosols in the atmosphere. This light returns to Earth; to an observer on the ground, some or all of the detail of the night sky may be lost. The effect is not always localised, as sources emitting light at shallow angles can taint the sky for a rural observer many tens of kilometres away³. In a crowded country like England, for example, it is possible to travel at night for long distances without ever escaping strong skyglow from chains of towns and large villages. Waste light from towns introduces a suburban feel to the countryside. The tranquillity and remoteness we associate with rural landscapes are lost; and the character of historic buildings and villages is compromised. On a more local scale, a poorly aimed domestic 'security' light with a typically excessive wattage of 300W to 500W (what journalist and broadcaster Libby Purves once christened "the Rottweiler light"), will make observation of the night sky difficult, if not impossible, for a nearby observer. Add to this the inappropriate use of very bright lights to illuminate relatively small areas, and the fact that lights are often left on when there can be nobody around who might conceivably need the light or appreciate its effects, and the extent of the problem becomes apparent.

A survey⁴ carried out by the British Astronomical Association in 1991 concluded that over 90% of Britons live beneath light-polluted night skies, and the growth of the problem can be clearly seen in **Philip's/CfDS Dark Skies Map of Britain and Ireland** (ISBN 0-540-08612-6) published in 2004. Only a few areas in Wales, Scotland, Ireland and south-west England now have really starry skies.

Minimising skyglow does not involve any complicated technology. Correct **aiming** and

thoughtful **shielding** of lamps are needed, and ground reflection (which will never be eliminated) can be reduced to acceptable levels by using the **minimum power** of lamp necessary for the lighting task

Dr John Mason MBE⁵ spoke eloquently of the progress made by the Campaign for Dark Skies at its European Symposium⁶ in Portsmouth in 2006. After seventeen years of the Campaign's existence, he said, we had crossed a watershed: at the time the CfDS was founded, almost nobody had heard of light pollution, while nowadays nearly everyone knows the term and can understand that light is not always a force for the good. If improperly used, he continued, it can be a threat to humans, to safety, to wildlife and the environment in general. Now, we have a great opportunity to cross a second watershed. Energy prices are rising, and more rapidly all the time.

This is the single most important thing to have happened in the field of lighting for years, concluded Dr Mason: it will provide the focus for what CfDS does in the future. There is now serious concern nationally about the cost of night-time lighting.

We need to identify lighting which is unnecessary, and identify locations where levels may safely be reduced (for example, where a main road through a town has been downgraded because of a by-pass being built). Part-night lighting (involving switch-offs from, for example, midnight onwards) has proved to be a popular and money-saving measure in many local authority areas. Dimming and remote-monitoring lamp technologies now exist, and are in use in certain places. They are much to be encouraged.

One of the things that nearly everybody 'knows' about the Earth as seen from space is that, if an alien craft ever approached this planet, the first sign to the crew of our tenure on it would be a view of the Great Wall of China, commonly said to be the only artefact of humankind visible from outer space. In fact, the Wall is not seen from above our atmosphere, as astronauts have confirmed⁷, being a surprisingly narrow and mostly ruined structure, not strikingly different in colour from its surroundings. The wakes of ships, plumes of steam from power stations, and similar extended objects contrasting strongly with darker backgrounds, are more likely to be seen from above the atmosphere than the Wall. However, as our hypothetical visitors rounded the night side of the Earth, what they *would* see, spread across the darkness, would be the chains and patches of light, by no means all reflected from the ground, thrown up from our towns and cities, road networks, sports and industrial installations, and countless other sites. Then they would know for certain that the Earth is inhabited by technologically-minded beings, though the energy that we so visibly waste would be likely to count against us in the minds of these hypothetical advanced observers (see photo 2).

What harm does wasted light do to us?

Chapter 4 will go further into the health implications of misplaced light. However, there is a deeper, psychological aspect to light pollution of the night sky.

If we are led to assume that the Earth is all that exists, and that stars and planets belong in picture books, on cinema and TV screens and computer monitors, because they cannot be seen in skies invaded by wasted upward light, we fall into an ultimate and dangerous vanity. We are divorced by skyglow, as Michael Crichton wrote in *Travels* (see above), from the reality of our very being.

Human beings, and indeed all living and inanimate things, are made of star-stuff. Nearly every atom in our bodies and in the things around us was created in some distant and probably long-dead star, or some explosive event whose reverberations have long since dissipated. Whatever is left of our material selves, when our planet finally sears in what Bertrand Russell

called “the vast death of the solar system”⁸, will be redistributed, recycled, into the cosmic depths which we can no longer, at the beginning of this twenty-first century, properly see and contemplate.

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“The light from distant stars and galaxies takes hundreds, thousands, even millions of years to reach us. What a tragedy to lose it in the last millisecond of its journey!”

Bob Mizon

Chapter 2 The (sometimes hidden) adverse environmental effects of light pollution

Graham Cliff, Colin Henshaw (www.lightpollution.org.uk)

“Insects are sucked out of habitat areas by the vacuum cleaner effect of artificial lighting”.
Professor Gerhard Eisenbeis¹, University of Mainz

The true extent of light pollution in Great Britain becomes apparent from satellite images of the country at night (see photo 3). Inappropriate lighting is known to have a major environmental impact, and the decline of sparrows and other common species of birds, insects and small mammals may well be just one manifestation of light pollution.

The data to prove this argument have too often been seen as little more than circumstantial, even apocryphal; however, in 2006, Catherine Rich and Travis Longcore edited a well documented book with the title “Ecological Consequences of Artificial Night Lighting” (Island Press, 2006 – ISBN 1-55963-129-5 (pbk)). This book has seventeen chapters divided into six sections dealing with mammals, birds, reptiles and amphibians, fish, invertebrates and plants. It is the most comprehensive survey to date, although the recent meeting in Barcelona produced the Red List of the IUCN (the International Union for the Conservation of Nature). This states that “...of the world’s 5,487 mammal species, from rodents to humans ... one in four is facing immediate extinction”! BBC web correspondent Richard Black has written an excellent account of the meeting, held in Barcelona, Spain in October, 2008. (<http://news.bbc.co.uk/1/hi/sci/tech/7651981.stm>)

The decline of common species over the past fifty years has been identified by numerous conservation groups, such as the Royal Society for the Protection of Birds, Butterfly Conservation, the Bat Conservation Trust and Bug-Life, and it mirrors the expansion of extensive outdoor lighting over the same period.

The ideas contained here have wide-ranging implications. The writers of this chapter hope that something may be done to redress the balance of nature before it is just too late.

In 1994, the Journal of the British Astronomical Association (JBAA) carried a letter from one of the authors (Colin Henshaw)² entitled *The Environmental Effects of Light Pollution*. The letter concluded by predicting that the anticipated reduction in the insect population, caused by light pollution, would affect predators higher up the food chain. Recent research has shown a reduction in the populations of moths, spiders, birds and amphibians, supporting the case for light pollution being considered a threat to the environment as well as to astronomers (experiencing skyglow) and householders (troubled by intrusive light).

It is a matter of common observation that high-powered security and street lamps attract insects. Indeed, 2000-watt light traps are used by scientists to study insect species in the Brazilian rain forest. If not killed outright by the high temperatures, the insects circle aimlessly round them until they fall to the ground. Physician and amateur moth enthusiast Kenneth D. Frank (Frank, 1988)³ first brought this to the attention of entomologists, suggesting it was worthy of further study. The authors think that the increasing numbers of urban street and security lights must have a measurable impact on the environment, as insects flying around the lights all night might no longer have the energy to feed or procreate. This would have hidden, concomitant effects, as many higher-order consumers which feed on insects would have their food supply compromised.

Consequently, with lights often left on all night, 365 nights a year, the number of insects must be significantly reduced. “As a child, I was amazed by the profusion of insects to be seen in the countryside on holidays in Cornwall,” recalls Colin Henshaw, “but, returning home to Manchester, I noted there were fewer insects.” Considering the number of lights in an average city and the rate at which this number has grown in recent years, they must sweep up millions of insects every day. So it comes as no surprise to find that many urban and suburban environments are now increasingly sterile as far as insects are concerned. Insects are the primary food source for many predators (such as bats, birds, lizards and frogs), and their decline has a serious knock-on effect for other creatures.

The situation is exacerbated by the fact that many insects are pollinators, a fact pointed out by Colin Henshaw in his letter to the JBAA. Could this be a vicious circle of decline? This may lead to reduced plant biodiversity, which in turn may aggravate the already declining insect population in a positive feedback cycle (Henshaw & Cliff, 2006)⁴.

Colin’s 1994 letter effectively predicted a decline in the biodiversity of plants. Two facts are worth noting: first, Dr Kelvin Conrad (private communication), once of the Rothamsted Research Centre, has remarked that Holland is the most insect-sterile country in Europe; second, Dr P. Cinzano of Padua University has produced satellite evidence that, in Europe, light pollution is at its worst in Holland and its environs (including Belgium and north west Germany). The authors understand that although Holland is a major producer of horticultural products, its many flowers are hand pollinated. Whilst this provides breeding control it completely obviates a need for natural insect pollination.

In the mid-1990s, Colin Henshaw’s father commented that he had not seen a thrush in the garden for ten years. Most people in Britain are aware of the decline in the number of house sparrows (figure 2) and of many other previously ‘common or garden’ birds. Sparrows and their hatchlings had been presumed to be wholly granivorous, but recent research by Dr. Kate Vincent has shown that hatchlings in fact feed on insects (or spiders) to obtain protein; so, if they do not get enough insects when young, they do not survive. Spiders, too, feed on insects: if the number of insects decreases, spider numbers will likewise decline. And a discussion of insects cannot overlook recent reports on the populations of British moths. For instance, the environmental group Butterfly Conservation has found a decline of one-third in the larger moth species in Great Britain since 1968 (figure 2), and some have been reduced by as much as 98%.

This decline in moths and sparrows has mirrored the expansion of street lighting in the UK, and elsewhere around the world. As more and more conurbations have leaked more light into the environment, the effect on the insect population has been devastating. A German study presented at a symposium in 2003 concluded that a single streetlight would kill, on average, 150 insects nightly. Philipp Heck, president of Dark Sky Switzerland, has suggested that the 50,000 or so streetlights left on all night in Zürich kill over one million insects every night.

These facts are not unique to Europe. A Vietnamese news agency⁵ reports: “Nguyen Hoang Minh Vu, a lecturer in the Ho Chi Minh City Architecture University, said that in addition to its adverse effects on human health, as the WHO has warned (see chapter 4), artificial lighting also seriously affects nature. Scientists have discovered that even a weak advertising light can kill 350,000 insects a year. In the long term, light pollution will possibly have dangerous effects on ecological diversity” .

Recently, the Department for Environment, Food and Rural Affairs (DEFRA) published an Internet pdf pamphlet (*House sparrows in Great Britain*, 2007)⁶ describing the decline of the house sparrow (*passer domesticus*) in the United Kingdom (see photo 4). The DEFRA document,

whilst discussing insect decline, makes no mention that light pollution might be a significant player in the decline of many common species. The document states that the causes of sparrow decline are unclear. It goes on to blame causes such as habitat destruction (loss of nesting sites) and also cats! These contributory factors must be involved, but we now know that sparrow chicks need insects (Vincent, 2006)⁷. The negative effects of light pollution upon insects may well be a bigger, “hidden”, insidious and unexpected, part of the problem (see photo 5).

Light pollution has also had more direct effects. It is not always appreciated that many species of birds migrate at night, but it has been well documented that artificial lights attract such birds. Experiments have shown that immature white crowned sparrows (*zonotrichia leucophrys leucophrys*) will fly towards the direction of maximum horizon glow. In 1951 2,421 dead migrants of 39 species were found on the ground under lighting poles on Padre Island, Texas. Collisions can cause death or injury but attractions to lights may have other consequences such as reducing energy stores, because of delays and deviations from migration routes.

In Toronto, the Fatal Light Awareness Program⁸ was created by concerned environmentalists to draw attention to the many tens of thousands of birds flying into illuminated high-rise tower blocks. This programme is continuing, as local politicians now realise the substance of all these concerns, and actively pursue them. Nocturnal birds are in worldwide decline: perhaps because of the 24-hour day. Light at night sucks their insect food supply from habitat areas, and the 24-hour day destroys that night-time habitat.

Whippoorwills in the USA⁹, nightjars in Europe¹⁰ and even masked owls¹¹ in Australasia are all considered to be at risk; and, according to a CNN report¹², from Audubon, *common* backyard birds are becoming less common. Is light pollution killing our birds? The evidence is now overwhelming, and appropriate steps should be taken to recognise light pollution as a possible cause of species decline.

All-night lighting should be permitted in urban areas, and on major thoroughfares in suburban areas, only where people are active all night, while a curfew from 23.30 hrs till dawn should be imposed on minor suburban roads. This will give nocturnal organisms the chance to recover from the worst affects of intensive night lighting. Lighting in rural areas should be kept to a minimum, to maintain the distinction between town and country. A Government White Paper from 2000 recognised that light pollution of the night sky is an increasing intrusion into the countryside at night (CPRE *Night Blight*, 2003)¹³. The Highways Agency (see chapter 5) is right to seek alternative ways of improving road safety without recourse to the naïve use of excessive lighting, and to install it only when there is no other suitable alternative.

At the end of his BBC TV series *Life in the Undergrowth*, Sir David Attenborough made the concluding remark: “Insects: we would do well to remember them”. Well, quite simply, we haven’t remembered them. Light pollution is killing them. And the higher-order animals which have depended on them for food are simply dying out. We have many reports of species decline, most of which are generally ignored. There is no point in repeating that list in full: suffice it to say that these species declines were predicted by Colin Henshaw in 1994 when others like Ken Frank were raising a broader awareness of there being a problem. The future that Colin predicted is being lived by species now. Or rather they are dying the deaths he foresaw for them. He described light pollution as being an issue for green environmentalism. The future will show the extent to which such advice was wrongly perceived and ignored. The authors hope that their warning will receive the attention which it truly merits. “Just In Time” is the only positive choice that we now have. We must never wake up “Just Too Late” to a future devoid of Nature’s complex web of life.

Below we list a brief selection of examples of the possible harm being done. This list shows that the effects are not purely parochial; that they are wide-ranging and may be more serious than we realise.

We mentioned the Red List of the IUCN at the start of this article. It is worth repeating another line from the report –“The baiji dolphin is functionally extinct, (primarily because of toxic pollution and not light pollution), orangutans are disappearing (they will not have blackout curtains to enable their REM sleep patterns in SE Asia), *and even some bats - the most numerous of mammals - are dying out*”. Dr. Carol Williams, of the Bat Conservation Trust, has forwarded the URLs of one of the latest discussions concerning the harm possibly done to bats and their environment, caused by light at night. This has been created with the help of the Institution of Lighting Engineers and an ILE member, Tom Webster.

[http://www.bats.org.uk/publications_download.php/243/](http://www.bats.org.uk/publications_download.php/243/BATSANDLIGHTINGINTHEUKJan08.pdf)

[BATSANDLIGHTINGINTHEUKJan08.pdf](http://www.bats.org.uk/publications_download.php/243/BATSANDLIGHTINGINTHEUKJan08.pdf)

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Turtle hatchlings are attracted away from the sea, by the lights of sea-front roads and buildings. Hundreds of thousands of hatchlings are lost annually in this way (Witherington, 1997)¹⁴, and this year, 2008, confused sea turtles marched into an Italian restaurant. Presumably NOT to volunteer to become turtle soup? (Telegraph.co.uk, 19 August 2008)¹⁵.

Salmon predation, by seals in British Columbia, Canada, is increased where rivers are over-illuminated (Yurk and Trites, 2000)¹⁶. For small nocturnal mammals, artificial night lighting not only compromises their insect food supply but also increases their risk of being killed by predators, as has been shown by the reduction in beach mouse populations in Florida (Bird et al, 2004)¹⁷ and muskrats in Holland (Molenaar et al, 2003)¹⁸.

So we see a catalogue of creature decline, coincident with the advance of the 24-hour day and caused by light at night, which has been the bane of astronomers for decades and is now affecting Life On Earth. If you agree with this assessment, please help to spread the word.

Chapter 4 will go further into the adverse effects of light at night upon aspects of human health.

Please note that questions asked of CCD, Colony Collapse Disorder, in bees and the possible effect of circadian disruption on bees have met with no response from the British Bee Keepers Association. Moreover a question asked of Professor Steve Harris, noted Bristol University fox expert, about circadian disruption in foxes, has also met with no response. What is clear is that the concept of circadian disruption in wild life, caused by the modern 24 hour day, is neither well understood nor is it researched.

Conclusion:

The evidence is clear that the ‘24-hour day’ is having many harmful effects upon the natural environment. Other chapters in this handbook outline the many aspects of light at night which can now be seen to be damaging, not only to that natural environment but to our own health and to our “pocket books”.

Some of the above text is taken from Challenge magazine, Summer 2006.

The light pollution campaign web site <http://www.lightpollution.org.uk> was created as a result of this article.

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“Our neighbours’ lights are now all around their property. A request for lower powered bulbs was met with abuse. Once there used to be owls, foxes, deer around here...”

Letter to CfDS from a Yorkshire woman

Chapter 3 Lighting and Crime

based on the CfDS website www.britastro.org/dark-skies (*various authors*)

“Who benefits from a 500 - watt ‘security’ light left on at 3 o’clock in the morning? Is it the resident, fast asleep in bed, the police officer ten miles away in a car, or the burglar sorting out his tools beneath the light?”

Bill Eaves, CfDS local officer

By far the most common response to calls for obtrusive, environmentally damaging lighting to be abated is “...but we need these lights for safety and security”, completely missing the point that efficient lighting, and neighbours’ comfort and a view of the night sky, are NOT incompatible. The CfDS is a campaign against light pollution, and so any lighting, where it is necessary, needs to be ‘star-quality’ lighting. The CfDS acknowledges the need for certain lights at night, and has never called for the switching off of any necessary, unobtrusive light. Lights should be no brighter than needed, and they should illuminate only the area to be lit, for no longer than necessary. If street lighting is present, it should be just that: illuminating the street, and not shining brightly into adjacent homes, or above the horizontal. In cases where the majority of residents vote against the introduction of lighting for whatever reason, their wishes should be respected. Those who do not want stray light to shine onto their premises should also have their wishes respected. A national regulatory framework is much to be preferred, rather than mere guidelines.

Is there evidence that lighting does reduce crime?

If new, non-light-polluting (e.g. full cut-off) lighting were definitely shown to reduce crime, it would be a boost for the Campaign, which has been promoting the benefits of well designed lighting systems for many years. However, evidence for such a relationship remains far from conclusive.

Correctly positioned and angled lighting which makes a potential offender more visible than the potential victim is a sensible idea, assuming that witnesses are in fact present. Equally sensible is the reduction of glare in the direction of potential witnesses, and the avoidance of creating deep shadows providing hiding places. If the design of security lighting took such factors into account (which it largely does not), there might be a case to argue for lighting as a crime deterrent.

Studies exist which suggest that brighter or more numerous lights deter crime¹. These studies are used by manufacturers and others to argue that lighting can reduce the crime rate. They remain a source of debate.

Dr Paul Marchant, a chartered statistician at Leeds Metropolitan University, states: “Whether lighting in general reduces or increases crime is a difficult question to answer. The problem is that the research that has been done is of poor quality. There have been no Randomised Controlled Trials, the gold standard of evaluative methods, done in this field (RCTs are asked for in the Science Review of the Home Office and Ministry Of Justice www.dius.gov.uk/publications/ho_moj_sciencereview.pdf Recommendation 11).

The research which is done and is promoted tends to be produced by relatively few researchers and research groups. Some of these receive funding from the lighting industry. In other cases we do not know who paid for the research. This absence of information is an

example of poor research reporting which bedevils crime research; see <http://www.equator-network.org> and www.icmje.org for the higher standards operating in health care research.

We do not have a research register of all research conducted, so it would be easy for the results of research to be buried if the findings are unfavourable, for example, to those funding it.

Chapter 7 of the Proceedings of the 6th European Dark-Skies symposium (www.britastro.org/dark-skies/cfds2006/proceedings.pdf) (2007) discusses some of the problems with research, as does the somewhat earlier piece (2006), in *Radical Statistics* www.radstats.org.uk/no091/Marchant91.pdf, as well as giving some of the history of the research and the promotion of lighting.

Work which has been done in crime research has included statistical errors and oversights which the authors, claiming that there is evidence that lighting reduces crime, then try to recover from.

In September 2008, the authors of the flawed Home Office Research Study 251 (Farrington and Welsh) published another version of their work, through the Campbell Collaboration. It is essentially an attempt at 'patching up' their former work to try to account for some of the statistical problems that I pointed out in their earlier work. No new studies are brought into the synthesis but (at least) one (done in Chicago by Morrow et al.) should be included. The authors still however claim an estimated effect of a 20% reduction in crime (and at least about 10%). Such a reduction would make lighting an effective crime reduction intervention. But things which seem too good to be true often turn out to be just that.

Their work is not done properly in accordance with the published protocol (Nov. 2003) and still contains assertions which are untested and matters which are not properly addressed, failing to give alternative interpretations. Also where original studies that they use are examined, these show that the authors' conclusions about some of them are 'problematic' (for example, as seen from the Birmingham and Bristol studies data).

It is unfortunate that those marketing lighting can quote debatable and industry-funded studies on lighting and crime prevention, when there is no firm and scientifically secure evidential base for their claims.

A point seemingly often not recognised by those addressing the area of crime research is that large (well conducted) trials are needed in order to get useful information. For example, to see if security lights are effective against domestic burglary, in reducing it from say a risk of 10% per year to 8%, one would need, for a trial lasting at least one year, to involve at least 10,000, widely spaced dwellings. Such a trial has never been done. What tends to happen is that anecdote is repeated."

In the *Guardian* (November 2003), Martin Wainwright pointed out that:

"Over-anxious Britons are placing a blind, almost medieval, faith in brighter streetlamps and security lighting as crime deterrents, according to a statistical analysis which raises questions about Home Office research.

Government advice that surveys in Britain and the US show better lighting to have 'no negative effects and demonstrable benefits for law-abiding citizen' is flawed and unjustified, according to a study² to be published in the *British Journal of Criminology*.

The paper follows arguments at the Home Office over a summary of research on street lighting and its effects on crime. Independent criticism of the summary's use of statistics was initially expected to be incorporated as a 'serious health warning' but appeared only as a brief

addendum.

The scientist behind the criticisms, Paul Marchant. . . , said yesterday that the conclusions of the paper - The Effects of Improved Street Lighting on Crime; Home Office Research Study 251 - were unfounded and based on statistical mistakes.

‘They have all the trappings of the right sort of official information, but they contain major errors. Not only does the paper fail to demonstrate that improved street lighting decreases crime, its figures could equally well show that it increases it.’

The row comes at a time of growing concern about light pollution, with a warning about its effects, particularly on astronomy, sounded last month in a report by the Commons Select Committee on Science and Technology.

Dr Marchant said that pressure for supposedly ‘crime-detering’ extra street lighting was worsening the problem, abetted by householders’ security lights, whose effectiveness was also a matter of faith. ‘It may not be too fanciful to make comparisons with our medieval ancestors’ measures against witchcraft - tokens hung over the door and so forth,’ he said. ‘We know the ‘witches’ are out there, and we turn to deterrents which we think will scare them off. But we do not know. We do not have the evidence.

Meanwhile light pollution has substantial environmental consequences. If any decision is taken to increase lighting, it needs to be taken on the best possible evidence.’

The Home Office said officials had been made aware of the issues and had asked the report’s authors to look at them in detail. A spokesman said: ‘The need for further analysis of statistical variance calculations was accepted and an addendum has been added to reflect this change. But this did not substantially affect the report’s conclusions’.

Levels of crime can vary remarkably over time (perhaps due to prolific offenders starting and stopping criminal activity) and this makes statistical analysis of the impact of lighting difficult and unreliable.

Can lighting aid crime?

The fact that more intensely lit areas of the country tend to have higher crime rates might suggest that lighting actually increases crime.

Most crime, especially domestic break-ins, occurs in daylight: the likelihood of being seen will not always deter criminals. At night, over-powered lights, shining outwards, can hide criminal activity with glare, offering ideal cover for a burglar or other malefactor by blinding potential witnesses. Lighting can help criminals survey an area and sort out their tools, can highlight potential targets, easy pickings, security lapses and escape routes (see photo 6).

PIR-activated floodlights are so frequently triggered that, when they come on, this is usually ignored by neighbours and passers-by, and is often not noticed by anybody indoors. Retailers continue to sell such lamps (500W is half the wattage of Britain’s brightest lighthouse, the Longstone) while claiming that their products respect the environment. Approaches by environmental campaigners to these retailers have been largely ignored.

Lighting does not automatically reduce crime

According to the UK Government’s Home Security and Crime Reduction website³:
“Harsh, glaring floodlights are not a deterrent to criminals”.

To some, this seems counter-intuitive. Surely, they ask, being seen is the last thing the villains want? There are other questions to ask, however. Do the villains need to see what

they are doing? Are witnesses likely to intervene anyway?

The Association of British Insurers does not recommend outdoor lighting as a crime deterrent. Indeed, insurance companies do not offer a reduction in premiums if “security” floodlights are fitted, due to the lack of evidence that lighting reduces crime.

The Home Office website carries an interesting survey⁴ entitled Decision-making by House Burglars – Offenders’ Perspectives.

Based on a sample of 82 offenders, the percentages of respondents rating the following factors as a deterrent are:

Belief that house is occupied: 84%;

Presence of alarms outside property: 84%;

Presence of CCTV/camera near property: 82%;

Apparent strength of doors/window locks: 55%;

Evidence of membership of Neighbourhood Watch or similar: 29%;

Property marking campaigns: 25%;

Poster campaigns: 18%.

Other factors included convenient approach and exit routes, and there being a ready market for the goods. Nowhere in the report is the presence of lighting mentioned as a deterrent.

Outdoor lights provide no information about whether or not a house is occupied, the biggest factor influencing a criminal’s decision to break in. However, leaving a light on indoors can imply that premises are occupied, which is more off-putting to a potential intruder and at least 5 times more energy-efficient (assuming an indoor 100W bulb as opposed to an outdoor 500W bulb). Lights themselves are often targeted by vandals.

The National Institute of Justice in the USA published an assessment of crime and violence in Preventing Crime: What Works, What Doesn’t, What’s Promising. The study found little support for the misconception that “brighter is safer”, and even suggested that poorly designed lighting might actually increase personal vulnerability. The report states:

“The problematic relationship between lighting and crime increases when one considers that offenders need lighting to detect potential targets and low-risk situations. Consider lighting at outside ATM machines, for example. An ATM user might feel safer when the ATM and its immediate surrounding area are well lit. However, this same lighting makes the patron more visible to passing offenders. Whom the lighting serves is unclear.”

The Institute states: “...lighting has received considerable attention. Yet, evaluation designs are weak and the results are mixed. We can have very little confidence that improved lighting prevents crime”.

It is often argued that lights make people feel safer. This may often be true, but the relationship is in reality more complex. Glare, lack of uniformity and poor siting of lamps reduce vision, and, especially in the elderly, can confuse and endanger.

In 2002 the California Energy Commission found that lighting may have little correlation with a person’s perception of safety. A related study⁵ concluded that “lots of lights meant lots of glare, which in turn increased fear of crime.” Heightening ‘fear of crime’ makes money for the crime prevention industry.

Does darkness inevitably mean more crime?

Ever since early hominids crouched around their campfires, aware of the predators in the surrounding darkness, people have associated light with safety and darkness with danger. We may, in the UK, have eliminated the carnivores which wanted to eat us, but there are still

malefactors out there. Does darkness help them and work against the potential victim?

Some international cases:

During the power blackout that affected Auckland (New Zealand) for several weeks in early 1998, criminals almost deserted the darkened streets, a police inspector remarking: "It's been almost a crime-free zone. The normal levels of muggings, violence, fights, burglars and robbery have just not happened."^{6,7}

Detroit, Michigan, a city with a high crime rate, experienced less crime than normal during the power failure of August 2003, which lasted throughout the night. Officials stated that: "Police had fewer calls within the city of Detroit than on an average day, even with the blackout."⁸

The International Dark-Sky Association reports that "Dark Campus Programs" reduced vandalism on school campuses when lights were turned off⁹.

Closer to home, recent energy-saving late-night switch-offs of street lighting in Essex, Buckinghamshire, West Sussex and other areas were not followed by increases in crime rates and indeed substantial falls in crime have occurred.

The CfDS does not advocate switching all lights off. If it is shown that switch-offs are on balance generally beneficial, well and good; the main message is that, where lighting is shown to be necessary, it should be the right light for the task.

"Security" floodlighting: anti-lights?

In October 2003 the Parliamentary Select Committee on Science and Technology called for an end to the retail of 500W "security" lights, and for the nuisance that they cause to be classified as actionable in law.

Such floodlights, with excessive high-wattage bulbs in them, impede the vision of both potential witnesses of crime and of CCTV cameras, with their blindingly powerful light. Also, they create very dark shadows, thereby offering double concealment. These are indeed anti-lights, negating the whole point of a light, which is to reveal rather than conceal. Floodlights need to be pointed downwards to illuminate the area of interest - even the slightest upward angle can render a security light useless and make it a nuisance.

The CfDS' interactive web page www.britastro.org/dark-skies/floodlights.html⁶⁰ has some interesting images to illustrate this point.

The advice the CfDS gives to those enquiring about security lighting: Angle your lights downwards, and use low power. Even the Institution of Lighting Engineers, a body promoting the interests of the lighting industry, says in its Guidance Notes for the Reduction of Light Pollution that for most domestic tasks, the 150W full cut-off floodlight, correctly positioned with no light spillage, is the maximum wattage needed, and indeed recommends lower wattages (and, in CfDS' opinion, even 150W is excessive) (see photos 7 and 8). The Government's Home Security/Crime Reduction website¹⁰ states "The form of lighting currently found on the overwhelming majority of domestic locations is a 250 or 500 watt tungsten halogen floodlight controlled by a movement sensor. This is unfortunate, as in many locations this is the most inappropriate form of lighting available."

If you go out at night, leave a light on indoors instead of outdoors. Research by Bennett and Wright¹¹ into what motivates burglars concluded, after interviews with 300 experienced burglars, that their main concern was whether or not the premises were occupied. If an indoor light is on then there is a possibility of somebody being at home, but outdoor lights do not convey anything about who might or might not be there.

CfDS committee member Martin Morgan-Taylor, of the Law Department of de Montfort University, is author (with Professor David Hughes) of *Exterior Lighting as a Statutory Nuisance*, (2005, J.P.L.1131-1144). He notes that “lights in secluded areas are just that: nobody can see what the criminal is doing, and he has a courtesy light to illuminate his activities”. So, consider whether flooding an area with light will cause more harm than good. Consider a completely dark environment; is it more likely that someone flashing a torch around in the dark will be noticed, and create more suspicion in the minds of witnesses than someone moving in a lit environment?

Or use low-powered lighting. According to the US Army Corps of Engineers, security CCTV cameras that are used day and night work the best if the light contrast between the bright foreground and the dark background is less than 4 to 1; otherwise the CCTV images are dominated by glare.

Conclusions

Better, independent research is needed to quantify the effect of light on crime, and higher scientific standards are required – especially as large amounts of money are spent on lighting in the hope of a reduction in crime. The only thing that we can say for certain is that the common assumption that light will always deter criminals is incorrect.

When lighting is installed, the question must be asked “Who will benefit most from these lights? Criminals or witnesses?” There is still no proven link between lighting levels and crime rates. Crime is a societal problem rather than a lighting problem.

Lighting should not be installed in the hope of crime being reduced. However, if light is needed for other reasons (e.g. to help people use an area), then shielded lighting should be installed, of minimum brightness and minimum duration. Remember that lighting and dark skies need not be mutually exclusive - the use of modern full cut-off light means lit areas are more satisfactory for all law-abiding people, with the likelihood of an optimum night sky.

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“Lighting a small garden with a 500W lamp is like watering a flower-pot with a lawn sprinkler”

IDA

Chapter 4 Light pollution and human health

“...I have been forced to sleep in the spare bedroom at the front. It has made me ill”.

“...The neighbours and their persistent love of illumination... eventually ...forced me to leave where I was living”.

Letters to CfDS from a Hertfordshire man

Contributed article: Human health implications of light pollution

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(Adapted with the author’s approval by Pauline Cliff and Dr Darren Baskill)

Introduction

Humans, like many other species, have evolved in the presence of the daily light-dark cycle generated by the Earth’s rotation about its axis. This 24-hour light-dark signal has provided a powerful evolutionary pressure for adaptation to particular temporal niches, for example, adaptation to being day-active (diurnal), night-active (nocturnal), dawn- and dusk-active (crepuscular) and many variations thereon. Multiple specialised adaptations have evolved to optimise physiology and behaviour in relation to the time of day, solar orientation, season, and the amount of light or dark in the environment.

It is only relatively recently that humans have developed the capacity to generate light. Our ability to artificially light the night began about 250,000 years ago with the use of fire. Candles were developed about 5,000 years ago, and gas street lighting was possible beginning in the mid-1700s. In the last 120 years, however, our ability to alter environmental lighting

dramatically expanded with the introduction of electric lighting. As described elsewhere in this handbook, access and exposure to artificial light at night has become pervasive in all industrialised nations and is becoming increasingly so in the developing world. This light affects all organisms exposed to it, not just humans, and the consequences of such a dramatic alteration in one of the most powerful environmental signals is not yet known. Given its relatively recent introduction, we are only at the beginning of understanding the impact of artificial light on human health. Research over the past 80 years, however, has shown that light exerts very powerful effects on human physiology, endocrinology and behaviour, and, having evolved in a distinct light-dark cycle, it is possible that unnatural exposure to artificial light at night is hazardous to human health.

Photoreception in humans

Before understanding the potential risks that exposure to light at night might pose, it is necessary to understand some of the basic mechanisms through which light affects human physiology.

About 10 years ago, a novel photoreceptor system was discovered in the mammalian eye, including humans, which is anatomically and functionally different from the rod and cone photoreceptors that are used for vision, and serves to detect light for a range of 'non-visual' responses. The photoreceptor cells are located in a different layer of the eye to rods and cones, in the ganglion cell layer, and contain a newly-discovered photopigment called melanopsin. Unlike normal ganglion cells which are stimulated by light indirectly from signals from rods and cones, these melanopsin-containing ganglion cells are directly photosensitive. They are small in number (about 3% of the total number of ganglion cells) but are spread across the retina in a network to cover the entire visual field. Such a distribution is ideal for detecting general light irradiance and changes in light according to time of day and season, as opposed to the dense distribution of cone photoreceptors required for colour vision. In fact, such general light detection is a more fundamental functionality than detailed vision, with even single-celled organisms capable of detecting the 24-hour light-dark environment.

So what does this novel photoreceptor system do? Much as the ear has dual functions for audition and balance, the human eye has a dual role in detecting light for a range of behavioural and physiological responses separate and apart from sight, including suppression of pineal melatonin production, stimulation of morning cortisol production, pupillary constriction, heart rate and temperature regulation, enhancement of alertness and performance, changes in brain activity patterns, phase-shifts of the circadian pacemaker and even stimulation of circadian clock gene expression. For want of a more appropriate expression, these wide-ranging effects of light are collectively called 'non-visual' or 'non-image forming' responses and are sometimes grouped under the term 'circadian photoreception', as much of the behavioural and neuroanatomical work that first identified these effects was focused on studies of the ability of light to shift the timing of the circadian pacemaker.

Circadian, neuroendocrine and neurobehavioural effects of light

How do the 'non-visual' effects of light affect human physiology? Many aspects of human physiology and metabolism are dominated by 24-hour rhythms that have a major impact on our health and well-being. For example, sleep-wake cycles, alertness and performance patterns, core body-temperature rhythms and the production of hormones such as melatonin and cortisol are all regulated by an internal near-24-hour clock in the brain. Specialised cells in the hypothalamus spontaneously generate rhythms with a period

close to, but not exactly 24 hours ('about a day', *circa-dian*) and in order for the circadian pacemaker to ensure that physiology and behaviour are appropriately timed to anticipate events in the outside world (the early bird must be awake before the worm in order to catch it!), environmental time cues must be able to reset this internal clock. The major environmental time cue that resets these rhythms in mammals is the 24-hour light-dark cycle. As outlined below, inappropriate light exposure can cause circadian rhythms to become desynchronised both from the environment and from each other, with potential adverse effects on physiology and metabolism.

Light also changes the major biochemical signal for darkness, which is provided by the pineal melatonin rhythm. Under normal light-dark conditions, melatonin is produced by the pineal gland only during the night and provides an internal signal of night-length. Light exposure during the night also inhibits melatonin production acutely, with suppression occurring immediately upon light exposure and stopping when the light is switched off. Under a natural light-dark environment, melatonin production would only occur at night in the dark and would not be suppressed by overnight light exposure. With the advent of artificial light, however, prolonged exposure to light during the melatonin secretion phase at night is a daily occurrence resulting in regular, chronic melatonin suppression.

Light exposure at night can also directly increase heart rate and core body temperature, and increase morning cortisol production. While these acute effects of light are relatively small and transient, the long-term consequences of small, chronic changes in these parameters are unknown.

Effects of inappropriate exposure to light: Shift Work Disorder and Jet-Lag

The most common chronic circadian rhythm disorder is shift-work sleep-wake disorder, experienced by many of the estimated 3.6 million shift-workers in the UK alone. Shift-workers experience sleep problems, fatigue, poor performance and memory, gastrointestinal problems and greater risk of accidents and injuries, and have increased long-term risk of cardiovascular disease, diabetes and some types of cancer. The underlying source of these problems is the desynchronisation between the shift-work schedule and the light-dark cycle. Jet-lag is essentially the same problem as shiftwork but is usually an acute, rather than chronic, disruption of circadian entrainment. As with shift-work, the rapid change in the light-dark cycle following transmeridian travel is too quick for the circadian system to adapt to and the symptoms (insomnia, fatigue, impaired cognition, gastrointestinal problems) persist until the circadian system has adapted to the new time zone.

There is an increasing number of studies detailing the detrimental effects of light, sleep restriction and circadian desynchrony which might underlie the increased health risks for shift-workers. In 2007, the World Health Organisation formally categorised shift-work as a probable carcinogen, stating that 'shift-work that involves circadian disruption is probably carcinogenic to humans'. Several high quality epidemiological studies (although not all studies) have shown that female shift-workers have a modest increased risk of breast and colorectal cancer than female non-shift workers, and some studies (but again not all) support similar findings for prostate cancer risk in men. Female flight attendants also have an increased risk of breast cancer, illustrating the potential similarities between shiftwork and jet-lag. While these epidemiological studies cannot address the mechanisms causing disease, several hypotheses have been postulated. Given that shift-workers and flight-attendants are often awake at night, hypotheses have emerged proposing that light exposure at night, circadian desynchronisation and/or sleep disruption may all represent potential mechanisms

underlying the increased cancer risk observed.

As described above, one of the effects of light exposure at night is to suppress production of the pineal hormone melatonin. Suppression of melatonin by exposure to constant light, or removal of the pineal gland, will increase breast cancer development in rodents. Melatonin administration will inhibit proliferation of human breast cancer cells in culture and also inhibit rat liver cancer growth via melatonin receptor-mediated suppression of tumour linoleic acid uptake. Linoleic acid is a dietary amino acid common in Western diets where cancer rates are high, and known to be a potent promoter of experimental mouse and human tumour growth. A recent study of human breast tumour growth after implantation in an immuno-suppressed rat host showed that infusion of human blood high in melatonin was able to almost completely stop tumour growth, whereas infusion of blood low in melatonin (drawn after exposure to light at night) was unable to slow tumour growth at all. Similar results were found for rat liver cancer. Melatonin is also a potent free radical scavenger which may also play a role in preventing cancer cell damage and proliferation. Melatonin has also been hypothesised to alter oestrogen levels, another hormone associated with certain types of cancer, particularly some breast cancers. High oestrogen levels or a long duration of oestrogen production is associated with an increased risk of cancer and melatonin has been proposed as having an oestrogen-suppressive effect. If melatonin can alter oestrogen production, then this may provide another mechanism for how light exposure at night affects cancer risk. Further work is ongoing to explore these relationships.

Another hypothesis that may underlie the increased cancer risk associated with shiftwork is disruption of circadian synchrony by exposure to unusual light-dark cycles. Studies comparing rodents living in a regular light-dark cycle with animals placed on a shiftwork or jet-lag-type light-dark schedule show higher rates of cancer initiation and progression in the irregular group. Removing the circadian clock in the hypothalamus, the central source of circadian rhythmicity, also increases cancer proliferation. These effects even persist in species that do not naturally produce melatonin thereby highlighting the potential for circadian disruption *per se* in increasing cancer risk, in addition to any effects of melatonin disruption.

The cell cycle is also under circadian control and therefore disruption of cellular rhythmicity may make cells more susceptible to damage. Tumours also express circadian rhythms and, in some cases, timed chemotherapy has been shown to be more potent than continuous infusion, likely due to increased susceptibility of tumour cells to damage at different times of day.

While these epidemiological and animal data suggest a potentially important association between light exposure, melatonin and cancer, however, there is as yet no direct evidence in humans proving that alteration of melatonin levels alters cancer risk, or that taking synthetic melatonin has any effect on cancer risk or proliferation.

Future considerations

While inappropriate light exposure and circadian disruption due to shift-work and jet-lag are well defined, the effects of inappropriate light exposure while living on more regular schedules have only just started to be explored. Given that dim light is capable of stimulating effects on human physiology, we cannot consider dim light an inert stimulus and must keep it in mind when reviewing the appropriateness of light environments. Studies are underway to measure the actual light levels that people are exposed to while indoors and, in urban environments, these light levels are likely to be significant, and even higher when individuals live closer to intrusive street lighting. Unnecessary horizontal and vertical street lighting

permeates living spaces, particularly bedrooms. This light intrusion, even if dim, is likely to have measurable effects on sleep disruption and melatonin suppression. Even if these effects are relatively small from night to night, continuous chronic circadian, sleep and hormonal disruption may have longer-term health risks. Short- and long-term measures to reduce light pollution are therefore likely to have a beneficial effect on human health, in addition to reducing energy demands. While we have yet to understand fully the environmental and health impact of being exposed to light at night, the data to date suggest a detrimental effect of prolonged exposure to light at night.

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“It should be remembered that we tamper with our age-old day/night responses at our peril!”.

Bob Mizon, *Light Pollution: Responses and Remedies* (Springer, 2001)

Chapter 5 Not just an astronomers' problem: wasted energy and money

Bob Mizon, Martin Morgan-Taylor

“Our disenchantment of the night through artificial lighting may appear, if it is noticed at all, as a regrettable but eventually trivial side-effect of contemporary life. That winter hour, though, up on the summit ridge with the stars falling plainly far above, it seemed to me that our estrangement from the dark was a great and serious loss. We are, as a species, finding it increasingly hard to imagine that we are part of something which is larger than our own capacity.”

Robert Macfarlane, *The Wild Places* (Granta, 2007. ISBN 978-1-86207-941-0)

It is difficult to estimate how much energy and money are wasted by lamps which send their emissions where they are not needed. One has only to look at the many websites on light pollution to realise that there is no real consensus as to how much money is wasted world-wide, and ever-changing energy prices and currency inflation rapidly invalidate the estimates anyway. As long ago as 1993, the CfDS, using figures for numbers of streetlights, the amount of light emitted above the horizontal by typical lamp types, and 1993 energy costs, calculated that £53 million was wasted skywards annually by Britain's streetlamps alone¹. All that can truly be said is that the human race wastes *a lot* of money, fuel and effort in sending light to the wrong places! Some idea of just how much can be derived from the statement made by Andrej Mohar (Dark Sky Slovenia - DSS) in the publicity for the Seventh European Symposium for the Protection of the Night Sky in Bled, Slovenia, 2007: *“Why does nobody care about 1700 million Euros ‘glowing to waste’ over Europe annually, based on a conservative estimate by DSS using energy prices for 2007 and on ground and satellite monitoring?”*. Perhaps the real figure is nearer 1 billion Euros, or 2 billion Euros; all that we *can* state without fear of contradiction is that it represents a vast waste of every nation's resources (see photo 9).

Perhaps Andrej was wrong in assuming that nobody cares: as energy costs rise, there is an ever increasing number of people who *do* care about this problem. Below are translated extracts from some French news reports which appeared in early 2008. They report a growing phenomenon in France, where some citizens are taking direct and quite visible action against light-energy waste.

(1) Demonstration against lit advertising signs in Tours

Ecological activism is quite the thing at present, and it comes in many forms.

Night-time: three coloured wigs, neon lights going out: it's the Clan du Néon – the Neon Clan – in action. Their mission: to turn off illuminated signs that stay on all night...

(2) Night in the city?

The Clan du Néon patrols French cities, reclaiming the night: its members combat energy waste from neon signs left on pointlessly all night long. They switch them off. In France, every neon sign has an outdoor switch, for security reasons. The practice is not illegal...

The Tours branch of the Clan du Néon write of themselves:

During the night, in the shopping area of Tours, we see all around us signs which have been left lit, but on shops which have already closed. What is the point of these signs? Are they supposed to make the town look more attractive? Or announce the continued presence of the shops? Or impose some brand or identity?

First of all, illuminated shop signs left on all night long represent an unwelcome trend in 'supplementary advertising'. Also, going beyond this idea of being 'got at' by publicity, what shop-owner really believes that lit neon signs in almost deserted streets will somehow boost sales? Because we should be working for the environment and drawing the public's attention to disastrous aspects of the consumer society, we are carrying out non-violent and damage-free action against illuminated signs...

... Ordinary citizens, very few of whom are astronomers, making their point about our too casual acceptance of light-energy waste. This report is just one of many examples of an increasing feeling among the general public that it is time that such problems should be addressed.

In the UK, some local councils are dimming or switching off streetlamps in the early hours of the morning; managers of office blocks are taking it upon themselves to enforce a strict lights-out policy when staff leave at night. Internationally, 'Earth Hours' and city-wide 'save-energy hours' are becoming more widely observed.

Estimates of the fraction of world energy use represented by lighting vary greatly. About one-quarter is a commonly quoted figure.

The Energy Gap, as the gulf between demand and resources is often called, is coming. In twenty years' time, according to a recent BBC report, lights could be going out all over the UK. Trouble-free, relatively low-cost energy generation will no longer be something we take for granted.

Surprising, then, that the Government has blown hot and cold about the future construction of new nuclear power stations in recent years, and projects such as the Severn Barrage are unlikely to be approved. Alternative energy sources from wind and waves are simply not being encouraged.

Rather than place all our faith in alternative sources, we need to **cut down** on the energy that we use, and waste, through inefficient lighting, heating etc. Probably the most *visible* aspect of energy waste is that of night-time lighting. Even in the twenty-first century, when awareness of the need to prevent waste is ever higher up the environmental agenda, we see new lights being installed which:

- a) are too bright for the purpose;
- b) shine into places where their emissions are not needed;
- c) are in many cases simply unnecessary.

How much energy is thrown away in the UK every year by light-energy waste?

Martin Morgan-Taylor (de Montfort University, Leicester) is the author of several articles on the legal aspects of light pollution³. He submits the following:

The Carbon Cost of Wasted Lighting

There are no formal governmental estimates of the amount of wasted light. However, DEFRA is investigating this as part of its role. In its reply to the UK Royal Commission on Environmental Pollution Consultation on its Short Study on the Impacts of Artificial Light in the Environment, January 2008, it stated, at page 2:

“Climate Change

DEFRA believes that a reduction in the amount of artificial light will have both direct and indirect benefits for the environment. Less light means a direct benefit of a reduction in emissions, helping us to achieve the goals we are setting ourselves. The Government, via its Market Transformation Programme, is currently consulting on efficiency standards for lighting products and the associated carbon savings that improvements can deliver: these can be found at www.mtprog.com/whitepaper.aspx. ...

Evidence Base

From the Domestic Energy Factfile, 2006, electricity use for lights and appliances in GB households was around 3,000 kWh/year per household. The document does not separate these two uses. Electricity is also used for space heating, water heating and cooking.

Average consumption per household, kWh/year					
2006	Space	Water	Cooking	Lts & appl	total
-	-	-	-	-	-
Solid fuel	6,538	1,798	47	0	8,384
Gas	252,924	102,354	7,860	36	363,174
Electricity	15,011	16,408	6,619	74,622	112,661
Oil	21,776	7,258	33	0	29,067
-	-	-	-	-	-
Total	296,250	127,819	14,558	74,658	513,286

Using data from the Office of National Statistics, the number of GB households in 2006 was 25,285,000, and so the total electricity used by households in GB for lights and appliances was 74.658 TWh/year, out of a total electricity demand from the domestic sector of 112.61 TWh/year (this is the value from the Domestic Energy Factfile 2006; the value in Digest of UK Energy Statistics (published by BERR) is close, but not identical, 116.449 TWh/year, as it includes Northern Ireland).

Separating lights and appliances is difficult. The Government's Market Transformation Programme (MTP) estimates that lighting in the domestic sector in the UK (not GB) uses around 17.2 TWh/year, which means that appliances account for 57.45 TWh/year¹. To put these into context, a 1 GW new nuclear plant, operating at baseload, would provide around 7.45 TWh/year². So, to produce the annual electricity required by lighting in the domestic sector would require around 2.5 nuclear power stations (after taking account of transmission & distribution losses of around 8%). The equivalent figure for domestic appliances is around 8.4 nuclear power stations. (Emphasis added.)

Using the average carbon factor for electricity in 2006 (0.527 kgCO₂/kWh)³, the CO₂ emitted from domestic lighting in 2006 is estimated as 9 MtCO₂ (9 million tonnes CO₂). The CO₂ emitted from domestic appliances is estimated at 30.3 MtCO₂.

The Market Transformation Programme figure for electricity use for commercial lighting in 2006 is 49.79 TWh/year, out of a total commercial electricity demand of 259.8 TWh/year.

The Market Transformation Programme also estimates the electricity used for street lighting in the UK in 2006 as 2.53 TWh/year, i.e. well below the figure for lighting in the domestic sector. The carbon emissions associated with this would be in the order of 1.1 MTCO₂/year (million tonnes CO₂)." (Emphasis added.)

The author of this module has estimated that the energy and carbon wasted from 500w consumer floodlights alone (which are commonly used for security) could be between 26.5m - 106m kgCO₂ per annum.⁴ This is considerably higher than the DEFRA statistics above. Although the author is confident on the statistic, the variance highlights the need for a detailed study to settle the matter. It is submitted that either way the statistic is high and that speculation should be avoided.

If there is twice the lighting wattage power consumption for the commercial/public sector floodlights used in the UK (excluding street lights), and these are on all night long, **then the economic cost of the waste would be c. £480M**, assuming a 50% waste factor from over-lighting, lighting empty and unused car parks.⁵ It is submitted that there is a clear need for public education and planning guidance over such a potential level of power consumption and waste. **If 10% of the population has a 10w CFL bulb on all night with a dusk until dawn photocell (on average 12 hours a night) would cost (2.2m x 0.01kw) x 12hours = 264,000 KW-hr per night, or 96,360,000 kW-hr per year. The carbon emitted, using the above statistics is therefore c. 51m kgCO₂ (50,781,720). This is similar to the carbon emissions of 10% of the population having a 500w light on for 15 minutes each night. If 10% of the population had a 10w CFL on for 30 minutes each night the carbon cost would be c. 4m kgCO₂ (2.2m x 0.01kw) x 0.5 hours = 11,000 kW-hr per night, or 4,015,000m kgCO₂.**

¹) <http://whatif.mtprog.com/Level3/SummaryData.aspx>

²) (this is using the capacity factor of 85% used in the Energy White Paper; the average capacity factor of UK nuclear power stations is substantially lower, at 72% (DUKES 2005)).

³) <http://defraweb/environment/climatechange/uk/individual/pdf/actonco2-calc-methodology.pdf>

⁴) There are no calculations as to the number of 500watt consumer floodlights in the UK. However, it is known that there are 25 million dwellings in the UK. Generating 1 kW-hr of electricity produces on average in the UK 0.527 kgCO₂ (DEFRA statistic: <http://defraweb/environment/climatechange/uk/individual/pdf/actonco2-calc-methodology.pdf>).

As a result, if 5% of homes have such a light which is on for 15 minutes each night (assuming that all are on infra-red switches, and trigger when for example pedestrians or cats walk by), **then the carbon dioxide produced as a by-product from producing the electricity needed to power UK domestic floodlights is 26,448,812.5, or 26.5m kg per year.** (If 1 kW-hr of energy creates 0.527kg of CO₂) The energy cost will be (1.1m x 0.5kw) x 0.25hours per night = 137,500 KW-hr per night. Per year the figure is 137,500 x 365 = 50,187,500, or 50M kW-hr per year. The financial cost, if energy was only 10p per KW/h would be £5M.

The figure is 53m kgCO₂ if 5% of households have light on for 30 minutes a night, or if 10% of households have a light on for 15 minutes a night. (£10M at 10p per Kw/h.)

The figure is 106m kgCO₂ if 10% of households have a light on for half an hour each night (£20M at 10p per Kw/h.).

⁵⁾ Assuming the lights are on all night long, with an average 12 hours night operation each night not the half hour assumed for consumer lighting, the figure is double the power consumption multiplied by the hours of use. So, if we take use the figure for 10% of the population having a 500w light on for half an hour a night: (2x £20M) x 24 = £960M. If 50% is taken as the waste factor and the balance taken to be necessary energy consumption for lighting then the waste is c. £480M.

Wasted energy costs money, and cash-strapped councils are finding that they can save money by not wasting energy. There are many estimates of the amount of energy wasted by poorly directed road lights. The website *Starry Night Lights*⁴ sums up the difficulty of arriving at any kind of accurate figure, stating that upward light “wastes billions of dollars annually in the United States: 5 to 10 billion dollars depending on whose numbers you want to use”. In the UK, there are some grounds for hoping that energy will be more efficiently used along our road network. Road lighting has for some years now shown a trend towards better direction, although over-bright lamps continue to be installed in some places as whiter light sources gradually assert themselves.

In 2008, members of the Campaign for Dark Skies presented an award to the UK Highways Agency (HA) at their Victoria headquarters in London. In the 1970s and 1980s the majority of Britain’s lit roads were lined with poorly controlled low-pressure sodium (orange) lighting, with a large percentage of the emissions going skywards. Now (2009), lit motorways and trunk roads have many replacement full cut-off units, which direct light only downwards. The Highways Agency lights all main roads in Britain, and in 2007 revised two of its standards (TD34 and TA49) which determined the criteria for whether roads should be lit, and the type of lighting employed. According to the HA, recent statistics had shown a 10% reduction in accidents on lit roads compared to the 1970s, when it was 30%. Whilst 10% still seems significant, they stated, there are other ways the same resources can be used to reduce accidents, which negates the need for lighting in some cases. In future we will see some new UK roads without lighting and some refurbishment where lighting is not replaced. Furthermore the classification of all lighting is now to the ‘G6 standard’⁵ across the country. This category, which stipulates no light above the horizontal, was previously mandatory only in National Parks. Scotland and Northern Ireland have also adopted the Highways Agency’s new standards, so they apply throughout the UK.

References

- 1) **Mizon, B.**, *Light Pollution: Responses and Remedies* (Springer, 2001, ISBN 1-85233-497-5)
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- 3) **Morgan-Taylor, M.**, *And God Divided the Light From the Darkness: Has Humanity Mixed Them Up Again?* Environmental Law and Management, Jan-Feb 1997.
Morgan-Taylor, M. *Exterior Lighting as a Statutory Nuisance* (with Professor David Hughes), 2005. J.P.L.1131-1144
- 4) <http://www.starrynightlights.com/lpIndex.html>
- 5) <http://www.highways.gov.uk/roads/projects/7411.aspx>

“It’s not rocket science”

Anon.

Chapter 6 What action can be taken by victims of light pollution?

“We have cut ourselves off from our evolutionary and cultural patrimony – the light of the stars and the rhythms of day and night.”

Verlynn Klinkenborg: *Our Vanishing Night* (National Geographic, Nov 2008).

This final chapter suggests how to counter skyglow and intrusive light.

What can astronomers and victims of intrusive light do about light pollution? (see photo 10).

Sources of glare and skyglow in the immediate vicinity (neighbours' exterior lights, sports facilities, street lights) are the usual source of light-related complaints from householders and amateur astronomers (UK professional astronomers having long since decamped to Hawaii, Chile and the Canaries!).

In a recent survey by the CfDS (2007), 70% of respondents felt the need to complain about nearby old street-lights, while 26% were troubled by new street-lighting. This shows that, while new street-lighting is usually an improvement, causing fewer complaints, it may still be far from ideal. The next most common cause for complaint was lighting from private homes (51% of respondents), followed by sports lighting (19%).

Street-lighting

Street-lighting is the major source of complaints about light pollution, with both modern and old street-lighting causing nuisance. In the first instance, complaints should be made directly to your local council's street-lighting department. Such complaints in the past have led to street-lights being replaced (councils already have programmes of replacing street-lighting, so a polite request could encourage the local council to replace the light outside your home as a higher priority), or the installation of shields around the light. Both solutions have, in some cases, been applied within weeks, and (rarely) even within hours! Shielded, full cut-off street lighting is the most effective at ensuring that light does not spill into neighbouring properties.

The following is an example from 2004 (note that the complainant was not an astronomer):

“My local council last week installed new street lighting along my road. My front bedroom is now bathed in permanent light and the shadows cast by my driveway gate reach the back of the house with light right into my back garden! I'm going to write to the council ...”

Seven months later, CfDS received the following: “Having had a few nights good sleep while the lights had been off (ongoing fault with them) I got fed up with them and decided to phone around. I told him that they cast shadows 200ft away in my back garden and he said something about looking into it when he could. I also told him my neighbours were annoyed as well. The next evening when the sun set I thought that the lights had gone out again as it was so dark in my garden that I went to look and low and behold the street light was on but not shining back onto my property!! They have fitted a “shield” at the back of the reflector which covers only about 25% of it but in my estimation has cut the glare onto my property/into my bedroom by 90%. My neighbours saw them doing it and it took about 10 minutes – the workmen have promised to come back and do another lamp for them when they've got more in stock.”

If the local council fails to act swiftly, encourage neighbours to support the complaint, stressing that you want the streets to be lit, but not your property - a council is more likely to react to numerous complaints than to a single one. Contact your local councillors and MP, asking for their advice and support in removing the nuisance. If all those avenues fail, contact your local CfDS officer via the website for further advice.

Home, Business & Sports Floodlighting

A good first step is to **approach individuals and organisations** with offending lights in your immediate area, and point out that it could be much better done. An environmental health officer at a light-nuisance conference in Glasgow in the 1990s claimed that about 80% of offenders approached about their poorly aimed lighting were willing to take prompt action to remedy the situation, and most were surprised that they had been causing a problem.

Your light-loving neighbours may be sceptical when you argue for light control. **Inviting them onto your premises** might just convince them. However, they may say that a 'well-lit' neighbourhood is essential in these crime-ridden days. Now's the time to show them, 'in the field', what 'well-lit' means. Try **three simple demonstrations** which might clear their minds:

- Ask neighbours with a blinding, outward-facing security light to stand in the street or in the back garden while you walk towards their property, disappearing behind the wall of light it emits. They will realize that theirs is really an 'anti-light', concealing rather than revealing, and they may well be moved to do something about it.

- If new, more downward-directed street lights are installed, locals may complain that the lamps have lost their 'sparkle' (they mean glare) and are dimmer, even though they may be of the same or even higher wattage than those they replace, and light the road more efficiently. Prove the effectiveness of the new lights by asking doubters to stand with you half-way between the columns, and ask them to read the 1-millimetre-high print on one of their credit cards. It is usually possible to do this, and difficult for anyone attending this demonstration still to maintain that it's dark between the lamps.

- Many neighbours have re-angled or re-sited lamps after looking through an astronomer's telescope: occasional star parties will sensitize neighbours to the existence and value of the environment above. (see photo 11). Perhaps astronomers could even arrange for offending security lights to be triggered while showing their owner the night sky, so that the effect can be appreciated first-hand!

Astronomers may not be able to convince all their neighbours, especially in high-crime areas, that a darker environment can be as much of a deterrent to wrongdoers as a brightly lit one, but can certainly make the point that a real human being outside at night is a far better security device than any lamp: an astronomer can take action if (s)he sees or hears anything suspicious, but a security light cannot.

If polite personal approaches fail, contact the **Environmental Health Officer** of your local council and, in the case of **light intrusion**, invoke the **Clean Neighbourhoods and Environment Act 2005** (see chapter 1, note 2). There have been instances when officials charged with the protection of the environment seem to have little knowledge of this legislation. If this is the case, consult the CfDS website www.britastro.org/dark-skies for further advice. The night sky has no protection in law, but sympathetic individuals on some councils have been known to intercede in the case of skyglow, on behalf of astronomers.

Alert **local media** to the problem caused. Contact local **action and pressure groups**

(for example, the local town heritage or preservation societies). Alert your local branch of the Campaign to Protect Rural England (CPRE), Campaign to Protect Rural Wales (CPRW, Ymgyrch Diogelu Cymru Wledig), Association for the Protection of Rural Scotland (APRS), Campaign for the Protection of the Countryside (N.I.), if the light pollution is such as to cause skyglow in a (possibly distant) rural area. If local intervention is not forthcoming, **contact CfDS**. A list of their local officers is on the website at www.britastro.org/darkskies/lo.htm#00.

Advice from DEFRA

DEFRA, the Government Department for the Environment, Farming & Rural Affairs, offers the following advice on its website for complaining about light pollution.

When informal action is not possible or fails, you can resolve the problem by taking formal action. The most common route involves complaining to your local authority about the light problem. Local authorities have a duty to investigate complaints. Under sections 79 to 81 of the Environmental Protection Act 1990 local authorities have a duty to deal with light nuisance from premises which they consider to be a statutory nuisance.

If you want to make a complaint about light nuisance you should contact your local authority, usually the Environmental Health Department. The number will be in your local telephone directory.

If they visit or witness the light problem and are satisfied that a statutory nuisance exists or is likely to occur or recur, they must take action. If the light nuisance is intermittent, they may ask you to keep details of the problem in the form of a diary. Sometimes they may measure the light as part of their investigation into a complaint. There is no set level at which artificial light from premises becomes a statutory nuisance.

Concerned astronomers often report the offenders' assumption, in spite of reasoned arguments, that they are against lighting. So, early on in any discussion or presentation, introduce the fact that good-quality lighting means a more evenly lit environment; discuss the demerits of glare, and the possibilities of concealment through glare or too-deep shadows. List the security and other benefits of a properly lit terrestrial environment before you move on to the astronomical arguments. It is worth remembering that not everyone considers the night sky an important thing. People have different priorities, and varied interests and leisure pursuits. Discuss the savings in money and energy that good lighting brings, since saving money and energy have far greater relevance than astronomy in most lives. Quote David Crawford (co-founder of IDA), who wrote that, when light pollution is correctly remedied, "everybody wins".

'Broadsides' don't convince, carping criticism builds barriers, and baldly accusing someone of being a polluter is unwise. Have the facts to hand: published engineers' guidelines (www.ile.org.uk), factsheets from CfDS and the International Dark-Sky Association (IDA, www.darksky.org), and other organisations which web searches may reveal. Join CfDS and IDA to benefit directly from their updates, literature and support, and refer to their websites .

Light pollution will not be solved at a stroke. It is an issue for the altruistic and patient. The solution depends very much on how many of us make a noise about light-energy waste, and our persistence in doing so.

CfDS, 2009

Technical Appendix

Dr Chris Baddiley is technical advisor to the Campaign for Dark Skies, and has written a definitive paper, *Towards Understanding Skyglow*, now published by the Institution of Lighting Engineers.

He summarises this work:

Description of a model for calculating sky luminance based on specific streetlight photometric files, road and environment parameters, atmospheric conditions, location and view direction

Ray tracing and surface scattering

The model takes industry photometry files and recasts them into a fine incremented all-direction look-up table format. Entire sphere luminaire photometry data are used for comparisons, and scaling can be applied for any gamma angle (that is, elevation angle viewed from the source with zero being vertically downwards).

The model then performs geometric ray tracing from and between horizontal and vertical surfaces if required, works out multiple paths, allowing for both reflections and obstructions depending on angle. Surface scattering is dependent on roughness and has spectrally dependent Lambertian (simple cosine-dependent scatter with view angle) and specular (mirror reflection) properties in combination, based on Fresnel theory and reflectivity data. Full spectral BRDFs (Bi-reflective Distribution Functions) are calculated. Surface incidence and view angle-dependent reflections are not very different from published data.

Atmospheric scattering

The model examines scattering in the atmosphere at different heights and increments along each of the selected viewpaths, which are angular-dependent in different ways for both particles and molecules. Molecular Rayleigh scattering has equal scattering probability forwards and backwards, and 50% of that sideways, and is highly wavelength-dependent, giving far more scattering in the blue, which accounts for the blue colour of the sky in clear weather.

Aerosols are suspended particles of dust and water droplets, and are extremely directional in forwards and backwards scattering; there is very little sideways scattering, and they are not so wavelength-dependent. That is why ice and snow are white, and clouds are white or grey.

Scattering is calculated for increments along the geometric path through varying density with altitude in the atmosphere, to each cell, along the observer's viewpath, illuminated by the source, at different angles. Spectral effects are included, with scattering in and out of the beam in the form of path extinction; there is also nominal multi-scattering correction. The model is normally run for good visibility, but can be changed to any degree of visibility.

Output

The output is a series of tables, incremented with selected variable parameters. The plots of these can be for any view distance or view elevation to the sky, in log-linear or polar plots. Intermediate calculations and incremented contributions can also be plotted. Comparisons

can be made between up to three streetlight designs simultaneously,

Results and conclusions

All these scattering effects make a significant difference to the remotely viewed angular dependence of sky luminance caused. These effects and their relative contribution for various types of luminaires and scenarios have been studied.

Relative importance of ground reflections, sideways illumination according to distance

Sky luminance is from a combination of direct light and surface reflections, including those which need not be illuminated, which tend to have higher reflectivity than roads. Ground reflection dominates only in towns. **The further the viewer is from the source location, that is, from a few km onwards, the more the direct light just above the horizontal becomes important.** For distant sources this dominates over long atmospheric path lengths, and ground reflection is much less significant.

Remote location viewing in the opposite direction and back scatter

Back scatter in the opposite direction to the source is predominantly from low-angle light above the horizontal which has not been obstructed. This is, after all, how most people would try to view the stars in the presence of a source of illumination.

Comparison between shallow bowls and flat glass

Non-flat glass is more intrusive directly compared to flat glass full-cut-off G6 designs. For rural areas between towns (with increasing distance), and especially when looking away from the source, these effects make a significant difference between one light design and another. The effect can be over 5 to 1 for some sources, for (say) at 10 km away, at 45 deg view elevation, by comparison with reflection differences of about 15% at most. These can significantly outweigh any possible reduction in the number of luminaires per kilometre, by using shallow bowls. The bowl scatter becomes significant at increasing distance; the worst offender is polycarbonate.

Modern flat-glass designs and efficiencies

Anti-reflection coatings are available for flat glass, reducing high-angle internal reflections. The difference in power consumption and optical uniformity distribution below 60° gamma of good-performance full cut-off luminaires is now very close to that of shallow bowls. In practice, for junctions and bends in roads, potential spacing increase in some curved glass designs is less relevant, as it is impractical.

Atmospheric conditions and the visibility of the Milky Way

The only atmospheric effects that matter concerning visibility of stars are those in relatively clear conditions, and differ significantly from those in poor and medium visibility.

Scaling up for a town, the absolute sky luminance from different designs for the same road for rural distances is the difference between Milky Way visibility and invisibility, and this surface luminance is a good threshold to work with.

Note on resolution and surface areas

Telescopes and lens optics with detectors have different response behaviour for point

sources and extended surface sources; surface area response varies as $1/F$ number squared. We should consider human-eye optics. Resolution is not so relevant.

Shifting from spectra peaking around the sodium D-line to broadband and white light sources

Moving the peak spectrum away from sodium yellow to green increases the off-road reflections in most cases. Grass is twice as reflective in the green as in the yellow, but is near zero reflection in the red, due to photosynthesis absorption. This is true of most vegetation, which is the dominant off-road reflection in suburban and rural areas. There is a drop then from green to blue from reduced reflections, but an increase in Rayleigh scattering.

This accounts for a large fraction of the total upward light. Shifting to shorter wavelengths increases ground reflection considerably. The molecular Rayleigh component, due to its strong blue bias, increases greatly. The possibility of reduction in luminance values due to increased perception does not help. The visibility to the sky has the same increased perception. This makes the perceived sky luminance for the same ground luminance considerably higher than in yellow.

