Bats and Lighting

Overview of current evidence and mitigation

Edited by – Emma L Stone

Bats and Lighting Research Project, University of Bristol

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Foreword

These guidelines have been drafted in response to a rising number of developments and associated artificial lighting impacting upon bat populations in the UK. There is increasing evidence of the impacts of artificial lighting on ecosystems and, as nocturnal animals, bats are likely to be impacted negatively. These guidelines are borne out of research undertaken by Emma Stone during her PhD investigating the impacts of street lighting on bats and provide a synthesis of the issues and evidence-based advice of the potential impact of lighting on bats and possible mitigation strategies.

These guidelines have been drafted with input from experts in lighting (Institute of Lighting Professionals), bat surveys, ecology and mitigation (Bat Conservation Trust), legislation (Natural England) and bat research and mitigation (University of Bristol) to provide the best current evidence and thinking in the field of mitigation of the impacts of lighting on bats. This document is aimed at ecologists, lighting engineers, architects, planners and ecologists in Local Authorities and Statutory Nature Conservation Organisations such as Natural England, Scottish Natural Heritage or Natural Resources Wales.

Acknowledgements

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List of Contributors

Kelly Gunnell

Bat Conservation Trust, 5th Floor, Quadrant House,

250 Kennington Lane, London, SE11 5RD, UK

www.bats.org.uk

List Hundt

Bat Conservation Trust, 5th Floor, Quadrant House,

250 Kennington Lane, London, SE11 5RD, UK

www.bats.org.uk

Emma Stone

Bats and Lighting Research Project, University of

Bristol, School of Biological Sciences, Woodland Road,

Bristol, BS8 1UG, UK

www.batsandlighting.co.uk

Katherine Walsh

Natural England, Landscape and Biodiversity, Electra

Way, Crewe Business Park, Crewe, CW1 6GJ, UK

www.naturalengland.org.uk

1 Introduction

Emma L. Stone

1.1 Urbanisation, lighting and bats

Almost a quarter of bat species globally are threatened and the key underlying threat to populations is pressure on resources from increasing human populations (Mickleburgh *et al.* 2002). In Europe, disturbance and modification of habitats and roosts due to development and urbanisation is arguably the biggest threat to bat populations. Nine of the twelve threats to bats outlined in the 2010 UK report to the EUROBATS committee are related to urbanisation and development i.e. building demolition, building alteration, barn conversions, habitat loss in planning proposals, loss of farmland landscapes, lack of knowledge on mitigation approaches, impacts of wind turbines, habitat fragmentation and zero/low carbon new build development (Anon. 2010).

Urbanisation and development affect bat habitats, either through direct loss or disturbance from light and noise pollution or human activities. Changes in habitat affect the quantity, quality and connectivity of foraging, drinking and roosting resources available to bats. Linear landscape features such as hedgerows, river banks and canals are important for bats, often being used for foraging and commuting (Limpens & Kapteyn 1991; Verboom *et al.* 1999).

Increasing urbanisation often results in higher levels of light pollution. Light pollution is a rising global problem affecting every inhabited continent, covering 100% of the land area in many countries (Cinzano *et al.* 2001). In some areas electric lighting has increased nocturnal sky brightness by 20% (Hendry 1984). Worldwide artificial lighting is increasing by around 6% per annum (Hölker *et al.* 2010b), and there has been a 24% increase in light pollution in the UK between 1993 and 2000 (Figure 1.1)(Anon. 2003).

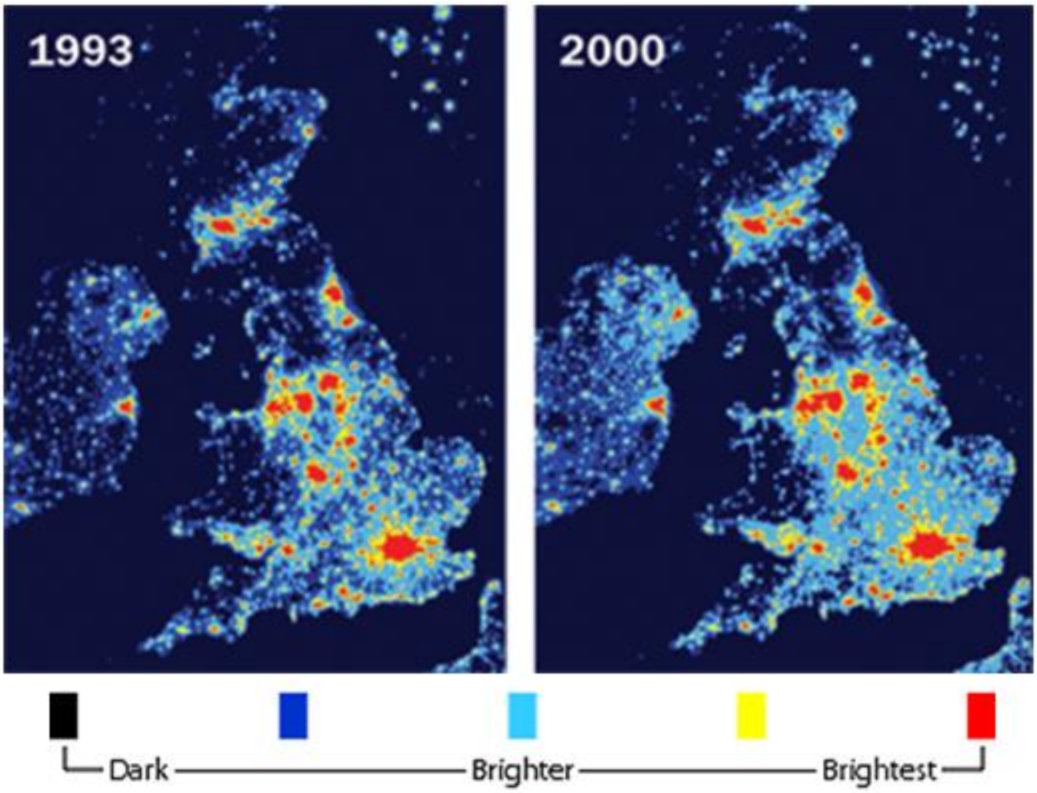

Figure 1.1. Levels of light pollution in Britain in 1993 and 2003: highest levels of light pollution are indicated with red, the black indicates no light pollution detected (Anon. 2003).

Bat habitats and roosts are under increasing pressure and disturbance from suburban development and its associated artificial lighting. Connectivity of habitat and foraging areas to roosts is fundamental to the survival of many bat populations (Verboom & Huitema 1997). Lighting schemes can damage bat foraging habitat directly through loss of land and spatial exclusion of bats due to high illuminance, or indirectly by severing commuting routes from roosts, through light spillage polluting hedgerows, tree lines and watercourses (Racey 2006). Lighting around roosts has also been shown to delay emergence, causing bats to miss the peak in insect prey abundance (Downs *et al.* 2003).

1.2 Aims and scope of this document

This document was developed during PhD research conducted by Emma Stone (2007-2011) investigating the impact of artificial lighting on bats. It provides best practice guidance relating to impact prediction and mitigation of artificial lighting on bats for the following users:

- Ecologists such as consultants involved in mitigating the impacts of development on bats;
- Lighting engineers and architects who may be developing lighting designs in support for planning applications in areas with bats;
- Planners and ecologists in local authorities who are responsible for reviewing planning applications affecting bats; and
- Statutory Nature Conservation Organisations such as Natural England, Scottish Natural Heritage or Natural Resources Wales who are responsible for reviewing, advising and implementing legislation affecting bats.

We provide an overview of the current evidence for the impacts of lighting on bats and outline potential mitigation strategies. Legislation refers to England, Scotland and Wales and does to include Northern Ireland. As research continues at pace we aim to update this guidance and build upon experience gained from case study examples. The recommendations are for guidance only and are based on current evidence at the time of printing.

2 Bat Ecology, Legislation and Planning

Katherine Walsh & Kelly Gunnell

2.1 Ecology and behaviour of bats

Bats are the only true flying mammals. They are warm-blooded, give birth and suckle their young. They are long-lived, intelligent and have a complex social life. In Britain there are 17 breeding bat species (Bat Conservation Trust 2012), all of which are small (most weigh less than a £1 coin) and eat insects.

Bats have evolved a number of unusual features, mainly connected with their ability to fly. Bat wings are formed from highly elastic skin stretched over greatly elongated finger bones, the legs and tail, though their thumbs remain free to help them cling on when roosting. Bats are not blind but have developed a highly sophisticated orientation system that allows them to avoid obstacles and catch tiny insects, which they seize in flight or pick off surfaces, even in complete darkness. In flight bats produce a stream of high-pitched calls and listen to the echoes to produce a sound picture of their surroundings. This is known as echolocation.

Bat behaviour can be divided into seven key categories: roosting, emergence, commuting, foraging, breeding, hibernation and swarming. Any potential impact or disturbance to bats should be evaluated against these behaviours.

- **Roosting**

The resting or sheltering places used by bats are known as roosts. Bats need a variety of places in which to roost, as they select and use different types of roosts at different times of the year, in order to suit their metabolic and social requirements. Bat roosts are either defined by their location, such as trees, buildings or underground roosts, or by their function, such as maternity, hibernation, swarming or feeding roosts, or by the time of year/day used, such as summer, winter, day or night roosts.

- **Emergence**

Bats spend the daylight hours resting inside a roost and emerge to feed at dusk. It is thought that the dependency on darkness for emergence is predation-avoidance behaviour. The timing of the emergence from the roost is critical as delayed emergence will reduce the amount of time available to forage at the time when the abundance of crepuscular insects is at its greatest. In the summer, which has short nights, any delays in feeding can reduce the opportunity to find enough food. (Jones & Rydell 1994; Verkem & Moermans 2002). Generally bat species that are more light tolerant tend to emerge earlier than light sensitive species.

- **Commuting**

The activity of flying between the roost and foraging area is known as commuting. Bats use set routes for commuting which are known as commuting corridors, flight paths or fly-ways. These routes tend to make use of linear features such as avenues of street trees, tree-lines along waterways, hedgerows, vegetated railway corridors, gardens and woodland edges as linkages in the landscape. These features are thought to act as navigation structures, provide cover from weather and predators, and also provide en-route foraging resources (Limpens & Kapteyn 1991; Verboom *et al.* 1999). Different bat species have varying degrees of dependency on these commuting features.

In general bats need to use the most efficient or economical route across the landscape to maximise foraging time. Obstruction or removal of a commuting feature, such as a tree-line, can mean that bats have to find alternative and less efficient routes to their foraging grounds. The more time a bat spends commuting rather than foraging, may negatively affect their energy reserves and thus overall fitness.

- **Foraging**

All UK bats eat insects. Their energy demands are such that bats need to eat a large proportion of their body weight in insects every night. *Pipistrellus pipistrellus* (our smallest species) is thought to eat about 3,000 midges in a single evening. Some bats specialise in catching large insects such as beetles or moths but others eat large numbers of very small insects, such as gnats, midges and mosquitoes (Dietz *et al.* 2009). Bats gather to feed wherever there are lots of insects, so the best places for them include traditional pasture, woodland, marshes, ponds and slow-moving rivers (Mitchell-Jones 2004).

The shape of a bat's wing influences its manoeuvrability and thus the type of prey and habitat in which it forages. Some bats are better able to fly in cluttered environments, such as woodlands, taking prey from vegetation; these are known as gleaning bats. Other bat species prefer to forage in uncluttered spaces, such as open areas; these are known as aerial hawking bats. There are also perch hunters, which watch the surroundings from a hanging space and only fly off if they discover a prey animal (Dietz et al. 2009).

- **Breeding**

During the spring and summer period female bats gather together into maternity roosts for a few weeks to give birth and rear their young (called pups). Usually only one pup is born each year which is looked after carefully and suckled for between four and six weeks until it is old enough to fly and hunt on its own (Mitchell-Jones 2004). Once the pups are independent, the roost breaks up and the bats generally move to other roosts. Bats may gather together from a large area to form these maternity roosts, so any disturbance at the summer breeding site can affect bats from a wide surrounding area (Mitchell-Jones 2004). Many of these maternity roosts are used every summer as bats have a strong tradition of returning to the same site year after year.

- **Hibernation**

During the winter there are relatively few insects available to provide the bats with sustenance. In response, bats have a developed a strategy whereby they let their body temperature drop to close to that of their surroundings and slow their heart rate to only a few beats per minute. This prolonged torpor is known as hibernation and greatly reduces their energy requirements so that their food reserves last as long as possible. Bats don't hibernate right through the winter but may wake up and go out to feed and drink on mild evenings when insects are active (Altringham 1996).

Bats generally hibernate in cool, dark, humid places such as underground tunnels and cellars. They will begin to seek out appropriate sheltered winter roosts starting in September and October as the weather starts to get colder. They will remain in their winter roosts through to March/ April as the weather warms and insects become more available. If a bat is unintentionally roused from hibernation, it will use up a significant amount of its energy reserves, which it is unable to replenish. This threatens bat survival therefore disturbance of hibernating bats should be avoided.

- **Swarming**

Swarming is the term used to describe the gathering of bats of both sexes in the autumn. The reason for this behaviour is not fully understood but it is most likely to be for mating (Dietz et al. 2009). The sites used for swarming are often used later in the year as hibernacula. Like most roosts, bats generally use the same sites each year.

2.2 Bat legislation

All British bats are protected by the Wildlife and Countryside Act 1981 (as amended) and by the Conservation (Natural Habitats &c.) Regulations 1994 ('the Habitats Regulations') as amended 2010.

2.2.1 The Wildlife and Countryside Act (1981) (England and Wales)

Under The Wildlife and Countryside Act (1981) (Schedule 5) in England and Wales it is an offence to:

i. Intentionally or recklessly disturb a bat while it is occupying a structure or place of shelter or protection;
ii. Intentionally or recklessly obstruct access to a structure or place used by a bat for protection or shelter;
iii. Sell, offer or expose for sale, or has in his possession or transports for the purpose of sale, any live or dead bat or any part of, or anything derived from a bat.

The Statutory Nature Conservation Agencies have a duty under the Wildlife and Countryside Act (1981) as amended, to notify any area of land, which in their opinion is of special interest by reason of any of its flora, fauna, or geological or physiographical features. Such areas are known as Sites of Special Scientific Interest (SSSIs). The guidelines for the selection of biological SSSIs are published by the JNCC. Chapter 13 relates to mammals and section 3.3 sets out guidance for the notification of bat sites. For further information, see; http://jncc.defra.gov.uk/page-2303 and http://jncc.defra.gov.uk/pdf/sssi_ptC13.pdf

2.2.2 The Conservation of Habitats and Species Regulations (2010) (England and Wales)

The Conservation of Habitats and Species Regulations (2010) transposes into law in England and Wales the Habitats and Species Directive (1992). Regulation 41 makes it an offence to:

i. Capture, injure or kill a bat deliberately;
ii. Disturb a bat deliberately (disturbance includes any disturbance which is likely to impair a bat's ability to: survive, to breed or reproduce, or to rear or nurture their young), hibernate or migrate (in the case of animals of a hibernating or migratory species);
iii. Affect significantly the local distribution or abundance of the species to which they belong;
iv. Damage or destroy a breeding site or resting place of a bat;
v. Possess, control, transport, exchange or sell a bat or parts of a bat, alive or dead.

All bats are European protected species as all are listed on Annex IV of the Habitats Directive. This means that member states are required to put in place a system of strict protection outlined in Article 12. Some species are also listed on Annex II of the Directive. Inclusion on Annex II relates to the designation of Special Areas of Conservation (SACs) and includes *Rhinolophus hipposideros* and *R. ferrumequinum*, *Barbastella barbastellus* and *Myotis bechsteinii*. Where these species occur outside SAC sites, inclusion on Annex II highlights their conservation significance.

2.2.3 Conservation (Natural Habitats, & c.) Regulations 1994 (Scotland)

The legislation in Scotland differs significantly in parts from that in England and Wales, noted above. The Wildlife and Countryside Act (1981) is no longer relevant to bat conservation in Scottish law. All bat species and their roosts are afforded full protection in Scotland by the Conservation (Natural Habitats, & c.) Regulations 1994 (as amended). It is an offence to: deliberately or recklessly kill, injure or capture a bat; deliberately or recklessly disturb or harass a bat; damage or destroy a bat roost; deliberately or recklessly obstruct access to a bat roost or otherwise deny a bat the use of its roost; possess or transport a bat or any part of a bat; sell or exchange (or offer as such) a bat, or any part of a bat.

There are several specific offences of deliberate or reckless disturbance. These are:

i. Disturbing a bat in its roost;
ii. Disturbing a bat while it is breeding;
iii. Disturbing a bat in a manner that is, or in circumstances which are, likely to significantly affect the local distribution or abundance of its species;
iv. Disturbing a bat in a manner that is, or in circumstances which are, likely to impair its ability to survive, breed or reproduce, or rear or otherwise care for its young;
v. Disturbing a bat while during migration or hibernation.

In all countries licences permit otherwise unlawful activities and can only be granted for certain purposes as set out in Regulation 53. Licences can only be issued by the relevant licensing authority where the proposed activity meets the criteria of the purpose, there is no satisfactory alternative and the action authorised will not be detrimental to the maintenance of the population of the species concerned at a favourable conservation status in their range. These are commonly referred to as the 'three tests'.

2.2.4 Local Planning Authorities (Scotland, England and Wales)

Local Planning Authorities in Scotland, England and Wales have a duty to ensure that protected species issues are taken into account as a material consideration when determining planning applications. The National Planning Policy Framework (NPPF) (England), Technical Advice Note 5 (TAN5) (Wales) and Scottish Planning Policy provide guidance on protecting and enhancing biodiversity during the planning process. Paragraph 125 of the NPPF states:

> *By encouraging good design, planning policies and decisions should limit the impact of light pollution from artificial light on local amenity, intrinsically dark landscapes and nature conservation.*

Where European Protected Species are present and affected by development proposals, Local Planning Authorities must take into account the ‘three tests’ as set out in Article 16 of the Habitats Directive and outlined previously when determining planning applications.

Local Planning Authorities (LPA) have a duty to ensure that protected species issues are taken into account in the preparation of strategic and local development plans as set out under Regulation 9 (5) of the Conservation of Habitats and Species Regulations (2010). Section 40 of the Natural Environment and Rural Communities Act (2006) also places an obligation on Public Bodies such as LPAs to have due regard to the purpose of conserving biodiversity.

For further information see: http://www.legislation.gov.uk/ukpga/2006/16/contents (Natural Environment & Rural Communities Act, 2006)

2.2.5 Resources

For further information on legislation relating to bats, see:
http://www.legislation.gov.uk/ukpga/1981/69/contents (Wildlife & Countryside Act, 1981);
http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm (The Habitats Directive); and
http://www.legislation.gov.uk/uksi/2010/490/contents/made (The Conservation of Habitats and Species Regulations, 2010).

2.3 Lighting

2.3.1 Statutory Bodies

Department for Environment Food and Rural Affairs (Defra) is responsible for policy on light pollution including statutory nuisance from artificial light In England and Wales. The **Department of Transport** (DoT) is responsible for street lighting policy and lighting on transport premises. **The Department for Communities and Local Government (DCLG)** is responsible for policy in the planning regime. In Scotland the Scottish Executive are responsible for establishing lighting controls under the Envionrmental Protection Act 2007.

2.3.2 Legislation pertaining to lighting in Britain

There is no legal duty for a lighting authority to illuminate roads in Britain and lighting is installed because the perceived benefits outweigh the negatives. Recent research by The Highways Agency found that the safety benefits of motorway lighting were 1/3 lower than previously thought. Additional field trials to switch-off lights on motorways have found lower numbers of accidents when lights were off than when illuminated (http://www.highways.gov.uk/knowledge/30236.aspx).

The Highways Agency (HA) recently undertook a survey to establish a modern cost benefit for highway lighting and identified that a lit street is likely to reduce the accident rate by around 10%. Previously this was held to be around 30%. A number of authorities have been trialling part night lighting solutions and even complete removal. The results have been mixed but a significantly large number of projects have shown no detriment from implementation of these changes.

2.3.2.1 British Standards

The British Standard BS5489-1 2003 states that the role of street lighting is as follows:

"Road lighting encompasses the lighting of all types of highways and public thoroughfares, assisting traffic safety and ease of passage for all users. It also has a wider social role, helping to reduce crime and the fear of crime and can contribute to the commercial and social use at night of town centres and tourist locations. Road lighting should reveal all the features of the road and traffic that are important to the different types of road user, including pedestrians and police."

Light intensity: British Standard BS5489-1 2013 requires that variable lighting regimes are considered as part of the 5 stage design process. Variable lighting regimes vary the light intensity of road lighting. Emerging dimming technology fitted to lights enables lights to be dimmed so that light intensity can be reduced during periods of low traffic use. The BS5489-1 2013 also requires local conditions and aspects to be considered at stage 3 of the design process.

Light colour: The colour rendering capability of a lamp refers to the ability of a light source to show or "render" an object's true colour (Schubert & Kim 2005). A colour-rendering index of 100 provides optimal rendering properties for human vision. BS5489 (2003) recommends the use of lamps with a colour rendering index (Ra) >20 for urban and residential roads. As low pressure sodium (SOX) lamps do not have any colour rendering properties they are not recommended for use in road lighting (Lockwood 2011).

2.3.2.2 Environmental Protection Act (EPA) (UK)

Artificial light from premises can have a detrimental impact on the quality of the local environment. Under section 79 of the Environmental Protection Act 1990 (amended 2007), local authorities have a duty to take reasonably practicable steps to investigate complaints of statutory nuisance, including: "Artificial light emitted from premises so as to be prejudicial to health or a nuisance". The EPA applies to England, Wales and Scotland.

2.3.2.3 The Clean Neighbourhoods and Environment Act 2005 (CNEA)

Clause 102 of the CNEA 2005 targets lighting that is "either a nuisance or is detrimental to health" in England and Wales. However, lighting from transport facilities (including harbours, airports, transport depots) and street lighting are both excluded from the Act. Therefore much exterior lighting is still designed without professional advice or consideration of the social and environmental effects (Coatham 2005). In Scotland there are no specific legislative controls on light pollution, but the Scottish Executive are considering adding artificial light pollution to the list of Statutory Nuisances under Part III of the Environmental Protection Act.

2.3.3 The Highways Act 1980 (HA)

The Highways Act empowers local authorities in England and Wales to light roads, but does not make it a legal requirement. County councils have a duty of care to road users and have an obligation to light obstructions on the highway. A Highway Authority (e.g. the Highways Agency in England) would not be negligent for accidents arising from a failure to light a highway unless the accident arises because the authority has failed to take reasonable steps to prevent objects it has placed in and around the highway from becoming a danger to the public.

2.3.3.1 Crime and Disorder Act (1998)

According to Section 17 of Crime and Disorder Act a Highway Authority in the UK (e.g. the Highways Agency in England) must consider the effect on crime and disorder in this exercise of reducing street lighting and the need to do all it reasonably can to prevent crime and disorder.

2.3.3.2 Road Traffic Regulation Act (1984)

Section 81 and 82 of the road Traffic Regulation Act (1984) states that unless provided by a separate order restricted roads, a 30mph speed limit automatically applies in any road in the UK containing a system of street lights placed not more than 200 yards apart, unless signposted with a different speed limit. There is no current law stating that these lights have to be switched on all night to be applicable. Therefore, motorists are advised that the usual 30mph speed limit will be in place regardless of whether the lights are switched on or off.

2.3.4 Planning

There is enormous variation as to how lighting is dealt with in the planning process across the country. Consideration of exterior lighting issues can be subject to planning control; conditions are often imposed on planning applications regarding the submission and implementation of lighting schemes.

3 Lighting

Stone, E.L.

3.1 Definitions and terminology

3.1.1 Definition of light

Light has been used by humans to illuminate the night and assist in navigation for over 2000 years (Anon. 2004). Light is defined by the Illuminating Engineering Society of North America (IESNA) as radiant energy that is capable of exciting the retina and producing a visual sensation. Each colour has a specific wavelength which is measured in nanometres (nm). One nanometre is a ten-millionth of a centimetre. Visible light is the relatively narrow band of electromagnetic radiation to which the eye is sensitive and occurs in a range of colours and extends from 380nm (violet) to 780 nm (red). The infrared range occurs from 780 nm to 1nm and is not visible to the human eye. Coloured objects only appear in colour if their colours are present in the spectrum of the light source (Anon. 2004). Light levels are generally measured in lux (see below). In sunlight light levels are around 100,000 lux, in the shade of a tree around 10,000 lux and at moonlight around 0.2 lux (Anon. 2004).

3.1.2 Lighting Terminology

The following definitions have been taken from (Anon. 2004), the Illuminating Engineering Society of North America (IESNA) and the Lighting Research Centre (www.lrc.rpi.edu).

Ballast: a device used with an electric-discharge lamp to obtain the necessary circuit conditions (voltage, current and waveform) for starting and operating (IESNA).

Candella (cd): the Standard International unit of luminous intensity. The intensity of a light source in a specific direction is measured in candelas. Each light source will have many different light intensities depending on the

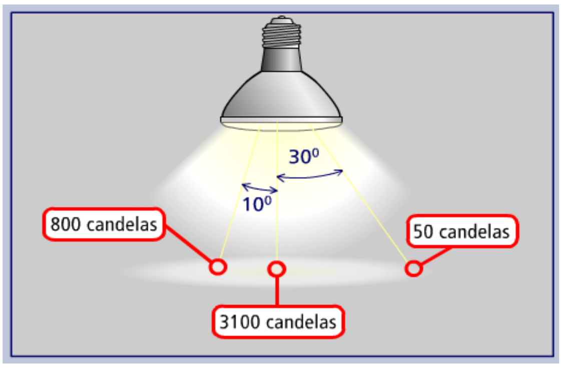

Figure 3.1. Differences in luminous intensity within a single light cone. Source:www.lrc.rpi.edu.

specific location at which intensity is measured within the light cone (Figure 3.1).

Correlated Colour Temperature (CCT): refers to the colour appearance of the light emitted by a light source and is measured in degrees Kelvin (K). The CCT of a light source is calculated by relating the colour of the lamp to the light colour of a reference source when heated to a particular temperature. CCT gives a general measure of the “coolness” or “warmth” of the light source: CCT ratings below 3200K are considered warm whereas ratings above 4000K are considered cool. CCT gives an indication of the general appearance of the light, but not its spectral power distribution, and so two lamps that appear the same may have different colour rendering properties.

Illuminance (E): is measured in lux (see below) and refers to the amount of luminous flux from a light source falling on a given surface and is measured on horizontal and vertical planes.

Luminance (L): relates to the brightness of an illuminated surface as perceived by the human eye and is measured in candelas per unit area (cd/m^2).

Luminaire: is the unit into which a lamp is fitted. Luminaires are required to comply with relevant European standards, but the light distribution outputs can vary considerably between different luminaire types.

Lumen (lm): defined by IESNA as the Standard International (SI) unit of luminous flux. The lumen rating can be considered as the measure of the summation of light output of a lamp. Ratings are determined and published by the lamp manufacturer.

Luminous flux (ϕ): refers to the rate at which light is emitted from a light source and is measured in lumens (see above).

Luminous intensity (I): is the amount of luminous flux radiating in a particular direction and is measured in candelas (see above). It is also termed the candlepower.

Lux (lx): is a measure of illuminance measured as the number of lumens (lm) per unit area (e.g. lux = lm/m^2).

Spectrum: refers to the wavelengths of electromagnetic radiation.

Wavelength: the distance between two corresponding points of a given wave. Wavelengths of light are measured in nanometers (1 nanometer = 1 billionth of a meter).

3.2 Light types

Lamps generate light by either thermal radiation or gas discharge (Anon. 2004).

Key light types are described below:

I. **Incandescent lamps (IL)**

Incandescent lamps generate light by resistance heating. They contain a tungsten filament in a glass bulb which is either evacuated or filled with nitrogen or inert gas (argon) (Anon. 2004).

II. **Tungsten halogen lamps (THL)**

Tungsten halogen lamps are a development of incandescent lamps. They are filled with halogen gas which prevents blackening of the bulb. THL have higher luminous efficacy and a longer service life compared to IL (Anon. 2004). THL are not used in new lighting schemes but may be encountered as security lights on a private household.

III. **Discharge lamps**

Generate light by electric discharge through a gas or vapour. The common discharge lamps are:

Low pressure sodium lamps (LPS, also known as Sodium Oxide (SOX)):
LPS emit an orange light and are often used in street lighting. Light is emitted at one wavelength and therefore has undesirable colour rendering for the human eye. LPS contains no ultraviolet (UV) light and the lamps tend to be large, which makes it more difficult to direct the light. In the UK LPS are gradually being replaced.

High pressure sodium lamps (HPS or SON):
HPS emit a pinkish yellow light and are commonly used as street lights. Light is emitted over a moderate band of long wavelengths including a small UV component.

The lamp is of medium size and the light can be more easily directed than LPS. HPS is whiter than LPS and has a larger component of UV light.

Metal halide (MH):

MH lights are small and this makes it easier to direct light where it is needed. MH lights emit less UV light than Mercury Lamps (below) but more than HPS. They have high luminous efficacy and excellent colour rendering. MH comes in three forms i) Quartz arc tube (HQI); ii) Ceramic arc tube (CDM-T) and iii) Cosmo, which is a new ceramic form. An example is Philips CosmoPolis lamps which are being installed in Cornwall. MH lights are becoming more popular for outdoor applications as they are more efficacious (lumens per watt) than HPS lamps and are better tuned to the spectral sensitivity of the human eye (Rea *et al.* 2009). The public consider areas illuminated with MH lamps to be brighter and safer than those lit with HPS lamps (Rea *et al.* 2009).

Mercury Lamps (MBF)*:*

These are bluish-white lamps which emit light over a moderate spectrum including a larger component of UV. They are now rare and are not used in new developments.

IV. Compact Fluorescent Lamps (CF)

CF lamps have good colour rendering, luminous efficacy and service life. The use of appropriate electronic ballasts for CF enable dimming control.

V. Light Emitting Diodes (LEDs)

LEDs lights are generated by passing electronic currents through solid-state crystal. LEDs produce monochromatic radiation and their colour tone is defined by the dominant wavelength (Figure 3.2), so LEDs can be red, orange, yellow, green, white and blue (Anon. 2005). LED light is produced in a narrow beam and is an instant light. LEDs are predicted to become the leading type of external lighting in the next ten years (Steele 2001; Steele 2010). The advantages of LEDs are their small dimensions, long lifespan, low failure rates and the lack of IR or UV radiation (Anon. 2005). In addition the light is more directional with low spill e.g. Monaro LED street lamps (DW Windsor Ltd) have a full horizontal cut off resulting in no light spill above or behind the lamp. LEDs provide considerable flexibility for mitigating the ecological impacts of lighting as composite bundles of LED lights within a lamp can be switched off to direct light where it is needed.

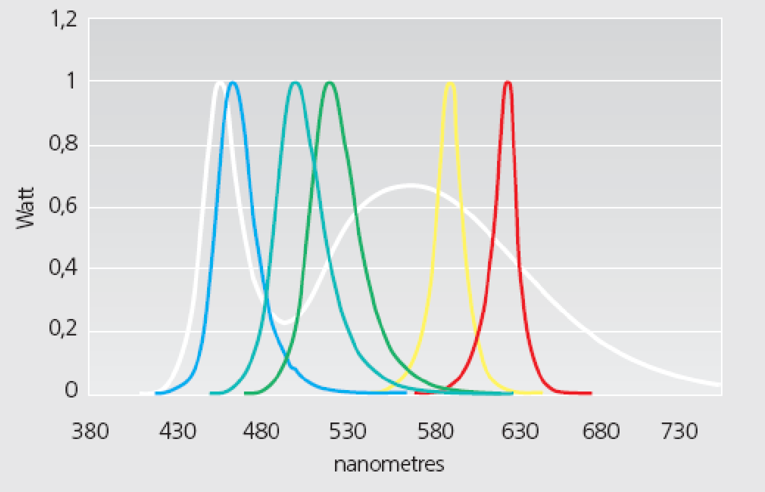

Figure 3.2. Spectra of coloured and white LEDS. Source: (Anon. 2005)

3.2.1 Spectral composition of lights

Street lights used in Britain can be divided into three categories based on their spectral outputs (Davies *et al.* 2013):

I. Narrow spectrum lights which do not emit UV (e.g. LPS);
II. Broad spectrum lights which emit little/no UV (e.g. HPS and LED); and
III. Broad spectrum lights which do emit UV (e.g. MH).

3.3 Lighting trends and technologies in the UK

3.3.1 Street lighting (A roads, B roads, pedestrian lighting)

There are over 7.5million street lights in the UK (Anon. 2009). Common light types used for external applications in the UK are described in Table 3.1.

Table 3.1. Common types of street light used in the Britain.

Light type	**Colour**	**% UV**	**Correlated colour temperature (K)**	**Approx % of UK lighting stock**
Low pressure sodium (LPS / SOX)	Yellow/orange	0.0	1807	44%
High pressure sodium (HPS / SON)	Pinkish / off white	0.3	2005-2108	41%
Compact fluorescent	Warm white	0.5-1.0	2766-5193	15%
Metal Halide (e.g. Philips CosmoPolis)	Blue-white	2.0-7.0	2720-4160 CosmoPolis 2720	N/A
Light emitting diode (LED)	White/warm -white	0.0	2800-7000	N/A

From Gaston *et al*.(2012); N/A = information not available.

In 2010 31% of UK street light columns had exceeded their lifespan (Anon. 2009). Many county councils and local authorities across Britain are conducting streetlight replacement programmes as part of the Highways Private Finance Initiative (PFI) scheme. In addition UK Climate Change Act (UK-CCA 2008) sets legally binding targets to reduce greenhouse gas emissions to levels at least 80% below those recorded in 1990 by 2050. As a result many county councils and local authorities have produced climate change strategies and action plans in order to meet Government targets.

The Carbon Reduction Commitment Energy Efficiency Scheme (CRC) is a mandatory carbon emissions reporting and pricing scheme with aims to reduce UK carbon emissions. The CRC was initiated in April 2010 and covers both private and public organisations using more than 6,000MWh of electricity per year. Although the direct relevance of the CRC will vary according to the category of the lighting supply (dynamic, passive and non-half hourly), it is likely to be a material consideration in the future management of road lighting (http://www.decc.gov.uk/en/content/cms/emissions/crc_efficiency/crc_efficiency.as_px).

Participants of the CRC are required to monitor their carbon emissions and purchase allowances for CO_2 emissions. The more CO_2 emitted the more allowances must be purchased providing a direct financial incentive to reduce carbon emissions. This has caused councils to re-assess their street lighting policies with the primary intention of reducing CO_2 emissions. The majority of UK local authorities and councils have commenced lighting reduction strategies consisting of: switching off street lights completely; part night lighting schemes (PNL); and/or dimming schemes (Table 3.2).

In response to recommendations in a report on Artificial Light by the Royal Commission on Environmental Pollution (Anon. 2009), Defra conducted a review of fifteen Local Authorities (LA) and their experiences in implementing changes to road lighting strategies (Lockwood 2011). The review comprised a desktop study and a discussion group which was attended by 13 of the 15 LAs. Trials and initiatives implemented by LAs included:

i. switching selected road lights off;
ii. lighting roads for part of the night only;
iii. dimming the level of lighting during the early hours of the morning; and
iv. using new and evolving technologies such as a central management system (CMS) or light emitting diode (LED) lights.

The Highways Agency is responsible for maintaining and improving all England's motorways and trunk roads. The Highways Agency have commenced PNL schemes whereby lights are switched off between midnight and 5.00am (using remote dimming technology) on several sections of the motorway network (http://www.highways.gov.uk/knowledge/30236.aspx). This has resulted in 30% reductions of carbon and electricity consumption in each section with PNL. The Highways Agency have conducted a benefit assessment of the impacts of switching off lights and recorded lower numbers of road traffic accidents after PNL was installed. The Highways Agency has since revised its road lighting standards and guidance.

3.3.2 Changes in light types

People perceive areas illuminated with white light as safer, brighter and more comfortable than areas lit with yellow light (Knight 2010). White lights also have better colour rendering for the human eye when compared to HPS or LPS lights (Knight 2010). White light sources with a Colour Rendering Index of $R\text{a} > 80$ can be advantageous because of the improved differentiation of colours, which enhances identification of objects and people (Lockwood 2011). As a result there has been a shift towards the use of white lights in outdoor lighting applications. For both new and on-going replacement schemes county and city councils in England are installing new white light units such as Philips CosmoPolis or WRTL IndelStela Lamps which have higher efficacy and thus lower CO_2 emissions (Table 3.2).

3.3.3 Central Monitoring Systems (CMS)

CMS are becoming increasingly popular and leading the way in the future management of lighting. CMS are electronic monitoring systems that allow two way communication with light units enabling the user to control and programme light units remotely. CMS enable remote switching or dimming to various degrees of brightness to facilitate part night lighting schemes.

CMS can save money through both dimming and switching off lights, and by automated performance monitoring. Automated monitoring enables identification of light unit failures and fault finding which reduces the requirement for onsite maintenance and night patrols, allowing operations managers to optimise their maintenance schedules. CMS gives considerable flexibility for wildlife managers, making it feasible to dim or switch off specific lights at selected times e.g. to avoid bat commuting or emergence times.

3.3.4 Current initiatives (footpaths, cycle-ways, underpasses etc.)

The development of LEDS has facilitated a growth in more flexible lighting approaches for many amenity applications such as footpaths, tow paths and cycle paths. Conventionally, areas are lit from above on a high column with the light directed downwards. LEDS are small and provide considerable flexibility. Examples include the use of LED based strip lighting for a towpath project where asymmetric LEDs are embedded in handrails along the path. The illuminated handrails provide sufficient light for pedestrian use of the path while directing light away from the water’s edge to reduce light intrusion into the waterway (**Figure 3.3**).

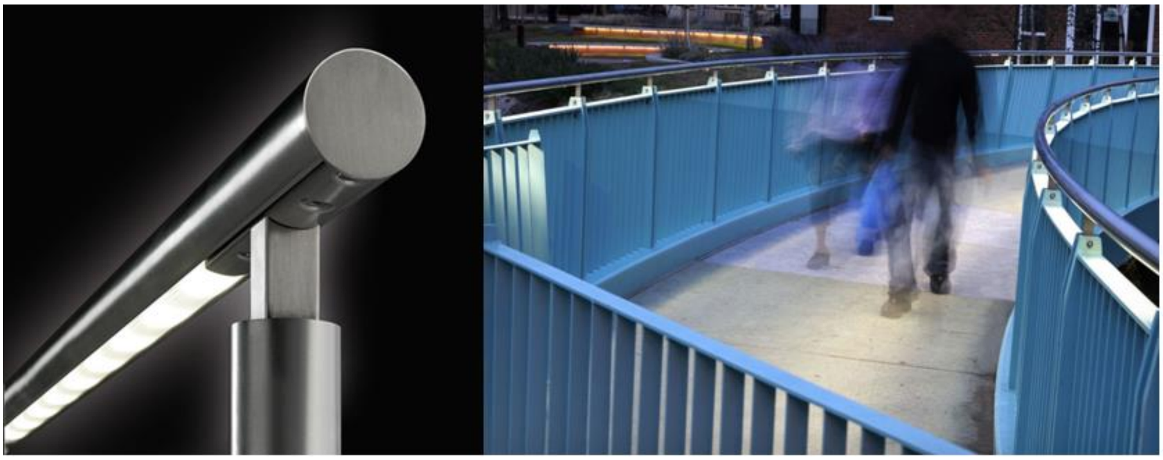

Figure 3.3. Garda LED illuminated balustrade (DW Windsor LTD)

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Table 3.2. County council lighting replacement/update schemes in England as obtained via direct contact with county councils in 2011/2012.

County Council	Details of scheme	Dimming	Part Night Lighting	Replacement	Switch Off Scheme	Est. CO_2 / energy saving	Comments
Buckinghamshire	Trial 2007-2010	Y	Y	Y – LED lights	N	N/A	Initial results show reduction in road collisions when lights where switched off (Lockwood 2011)
Cambridgeshire	2011-2015	N	N	Y – white discharge lamps 60% of units replaced	N	N/A	
Cumbria	No PFI but ongoing replacement using CosmoPolis since 2008	N	N	Y - ongoing replacement LPS and CosmoPolis for last 3 years; Like for like replacements and trialing white LED lights	N	N/A	
Cornwall	PFI 2009-2012	N	N	Y - replacing 100% of lamps with Philips CosmoPolis	N	N/A	
Derbyshire	2011-2015	N	Y - 12pm-5.30am	Y - white LED (WRTL IndelStela lights)	Y	N/A	
Devon	Scheme in operation, no details of dates	N	Y - 12.30pm - 5.30am	N	N	4000 t CO_2/year	
Dorset	PFI since 2011	N	Y - 12pm - 5.30am	Y- replacing 75% of stock – using SON, PLT, CosmoPolis or CDOTT Lamps and	N	Aiming to save £54.9million over 3 years from PNL;	

				not using LEDs		15% energy savings from replacement scheme	
East Sussex	Completed in December 2011	Y - 50% of lighting stock dimmed between 12pm - 6.00am	Y - between 12.30pm - 5.30am	Y – white light including PLT, CosmoPolis and LED	N/A	N/A	
Essex	Scheme in operation since 2007	Y – since 2007	Y – since 2007	Y - 70% to be replaced and CMS installed	N	PNL - £54,000/year and 312tonnes CO_2/year from PNL trials If extended to whole county would save between £600,000 and £2m/year	
Gloucestershire	Trials of LEDs 2009-2012	Y	Y - 12% of lights	Y - 65 LPS lamps and 104 HPS lamps replaced with LEDs and CMS installed	N	DS - 806t CO_2/year (£172, 800 / year)	
Hampshire	PFI 2010-2015	Y - by 25% for some lights – eventually all lights will be dimmed	N	Y – 50% of lamps (150,000) replaced with white LEDS and CMS installed	N	15% reduction in CO_2 over 25yrs; £181,000 saved between 2010 and 2011	
Hertfordshire	Since June 2010	N	Y - 60-70% of lighting	N/A	N/A	30-35% cost saving /year	
Kent	N – considering part night						

	lighting and dimming						
Lancashire	Scheme in operation, 2008-2012	Y - 80,000 HPS lamps on residential roads dimmed by 50% between 10pm-6am (using CMS); 27,100 lamps dimmed by 50% between midnight and 6am on main roads	Y - 600 HPS on the M65 motorway between 12pm - 5am	Y - 30,000 lamps replaced with StelaWhite LED (IDAL WRTL)	N	30% reduction in energy consumption	1000 illuminated road signs decommissioned and replaced with reflective signs
Leicestershire	April 2010 - 2014	Y - to 50% power for 3% of lights	Y - 60% of lights	N	Y - 15% of lights	3000tonnes CO_2/year (£700,000/year) Savings from dimming alone £70,000/year and 387tonnes/year .	
Lincolnshire	N/A						
Norfolk	PFI 2008-2028	Y - 11% of lights on main traffic routes between 8pm - 5.00am.	Y –24,000 street lights from 2010 (47% of lights)	Y -100% of lights will be white light sources by 2028; In residential areas 28,000 lanterns to white light with a mixture of CosmoPolis, PLL and PLT lamps; Son-t lamps installed on traffic routes; conducted trial of	N	Save £167,000/year	

				LED lamps in Kings Lynn in 2009 and installed 2,500 LEDs in Kings Lynn in 2011			
North Somerset	Scheme in operation, no details of dates	N	Y - 80% of lights	Y - 228 HPS lights changed to white ceramic metal halide lamps and CMS installed	N/A	25% reduction in CO_2 (750tonnes of CO_2) Saving £209, 000 from PNL	
North Yorkshire	April 2012-2016	N	Y -30,000 lights converted to PNL	Y - LED white lights (installed in new housing estates)	N/A	Total saving of £400,000 and >3000tonnes of CO_2	
Northamptonshire	PFI 2011-2016	Y	Y	Y - replacing bollards with LEDS	N/A	9500tonnes CO_2/year and 17.5kw of electricity/year	
Northumberland	N/A						
Nottinghamshire	October 2010 – 2014	Y	Y	N	Y	5,800tonnes/ year CO_2saved £1,25m / year	
Oxfordshire	N – no dedicated programme but ongoing replacements	N	N	Y - some use of LED white lights and HPS like for like as part of ongoing replacement	N	18% reduction in CO_2emissions from 2005 levels by 2012; total carbon saved 275 tonnes	
Somerset	PFI, no dates available	Y - reduce some lights by 50%	Y - PNL 20% of lights switched off from 12pm - 05.30am	N/A	N/A	N/A	

Staffordshire	PFI 2003-2028	N/A	N/A	Y - 60% of lamps changed to white 36 Watt PLL Compact Fluorescent Lamp	N/A	N/A	
Suffolk	2011-2013	Y - lights more than 6m high dimmed to 80% 9pm-1am and 60% power 1am-5am	Y - lights less than 6m high switched of between 12pm – 5.30am	Y - Telensa Intelligent lighting systems which allow remote control dimming	N/A	N/A	
Surrey	PFI March 2010-2035	N/A	N/A	Y - 79% of lights replaced; 21% of lights refurbished To white light and CMS installed	N/A	60,000tonnes of $CO_2$and 150million kw hours saved in total	
Warwickshire	Scheme in operation, no details of dates	N/A	Y – 80% to PNL between 12pm - 5.30am	Y – Philips CosmoPolis and LED	N/A	N/A	
West Sussex	PFI April 2010 - 2015	Y – dimmed by 40% power between 12pm - 5.30am	Y	Y – replacing 52,000 lighting columns, 2,600 lanterns and 11,500 illuminated signs	N/A	N/A	
Worcestershire	Scheme in operation, no details of dates	Y - 10% of stock	N	Y – Philips CosmoPolis, LED and CMS	N/A	N/A	

Symbols: CMS = Control Management System; PNL = Part Night Lighting Scheme; Y = yes; N = no; N/A = information not available.

4 Surveys

Emma L. Stone & Lisa Hundt

4.1 Introduction

Comprehensive standardised surveys before and after development are key to successful impact assessment and mitigation. Surveys should be standardised (using the same effort and timing) to ensure they are comparable before and after development. Failure to take account of the potential impacts of lighting on bats can result in failure to obtain a derogation licence and therefore should be considered in any development involving artificial light. However, the number of surveys required at each site will vary according to the scale of the proposed development, and should be proportional to the scale and likely impact of the development (see Table 4.1).

Pre development surveys for proposed lighting applications should include two elements:

- **Bat surveys:** to determine the amount, location and nature of bat use around the site; and
- **Lighting surveys**: to determine the baseline lighting levels in the areas used by bats prior to development.

4.2 Pre-development bat surveys (PrBS)

Comprehensive, appropriate and effective bat surveys are required to enable accurate assessments of potential impacts on bats and their populations. A survey is an essential part of the planning process and is required to provide adequate information to enable:

i. The developer to assess the possible impacts of the scheme and inform the design and mitigation strategy;
ii. Planning authorities to assess the likely effects of a development on bats and identify and stipulate any further information required on necessary avoidance, mitigation, compensation or enhancement measures in order to maintain the favourable conservation status of the species; and/or

iii. Ecologists to make an informed decision to be taken as to whether a European Protected Species (EPS) mitigation licence should be applied for; and/or

iv. Relevant licensing bodies to determine an application for an EPS licence that would then enable the lawful disturbance of bats or the damage/destruction of their roosts.

It is essential that the information gathered as part of a survey is of a standard that enables decisions on planning, mitigation and licensing to be taken. The overall aim of surveying at proposed sites is to collect robust data to allow an assessment of the potential impact of the proposed development on the bat species present on and around the site. This information is vital to allow the developer to decide whether to proceed with a development proposal or, where appropriate, how to modify the proposed layout. It is only then that the proposed development application can be submitted and determined by the appropriate authority.

Surveys must be designed to meet these key aims and provide all the relevant information needed for appropriate identification and subsequent assessment of the impacts. In designing the survey, it might also be useful to consider how the data can be used and presented as baseline data against which the scheme can be monitored once constructed.

Survey design will vary depending on the habitats present on and around a proposed site and may need adjustment throughout the survey period to continue to meet the aims. Best practice guidance on the methods used to undertake and design different bat surveys are detailed in the Bat Surveys Good Practice Guidelines (Hundt 2012). Additional considerations relating to the sampling of light are detailed below.

4.2.1 Types of survey

I. Roost surveys:

Roost surveys are conducted to determine potential roost sites for use by bats, which can include maternity and hibernation roosts. Roost surveys often include the following stages: preliminary roost assessment, presence/absence survey, and roost characterisation survey (Hundt 2012). It is important to record the numbers of bats emerging and the timing of emergence (first and last bat relative to sunset) during each survey. The timing and duration of bats flying around outside the roost (e.g. potential light sampling) should also be recorded. This is crucial to development of potential mitigation strategies which may need to avoid lighting areas during emergence.

II. Activity Surveys:

These surveys are surveys of active bats carried out by using non-invasive measures, such as bat detectors (hand-held or unattended).

Activity surveys should be conducted to:

- Identify the key areas of the site which are used by bats for foraging, commuting and swarming;
- Determine the spatial extent of bat use over a site; and
- Assess changes in bat activity over time.

This information is important to enable predictions of impacts of lighting on foraging, commuting and swarming behaviour. The most common form of activity survey is by line transect. Line transects are carried out by a surveyor carrying a bat detector, who walks at a constant speed along a planned route and records bat echolocation calls for subsequent analysis, and/or the number of bat passes or species (Hundt 2012). A transect should aim to capture the key features of the site as identified during the scoping survey and should be designed so that they can be safely completed by the surveyor in the appropriate timeframe. Light levels should be measured at standard intervals along each transect using a light meter (section 4.3.2.2). The location of any artificial light sources close to a transect should be documented and mapped for inclusion in final survey reports. Other types of activity survey methods are detailed in the Bat Surveys Good Practice Guidelines (Hundt 2012).

Produce a quantified pre-development bat habitat use map (PrBM): Once all surveys have been completed a quantified bat habitat use map should be produced. This should outline:

I. Locations of species presence across the site;

II. Locations of key foraging, commuting and swarming sites, including an index of relative activity at each site (e.g. no of bats/hour along each hedge/at point counts in woodlands etc.);

III. Maps of changes in activity at key sites over time (within or between seasons); and

IV. Location of areas with light averse species (e.g. *R. hipposideros* and *Myotis* spp.).

To enable comparisons before and after development and between sites it is essential that survey reports always include detailed descriptions of methods used including:

I. The index of activity used (e.g. number of bat files/number of bat passes per hour);

II. How a bat pass/file was defined;

III. The time (relative to sunset) and the height at which light measurements were recorded;

IV. The make and model of all equipment including acoustic analysis software (e.g. bat detectors, light meter etc.);

V. Date, start and end times of all surveys; and

VI. The number of observers and detectors.

4.3 Pre-development lighting surveys (PrLS)

4.3.1 Proposed lighting scheme and predictions

To assess the impacts of proposed lighting applications on bats accurately, it is important to obtain comprehensive details of the proposed lighting scheme from the lighting professional/engineer. Information regarding the amount, type (including spectral content), and location of any lights to be installed is required. As with the pre-development bat surveys, the number and extent of lighting surveys conducted should be proportional to the scale of the development. Large scale developments involving landscape-level impacts including loss or changes in key habitat features (e.g. loss/alteration of hedgerows/woodland areas) and associated installation of new roads and lighting (including amenity, security and industrial lighting) will require more comprehensive pre-development lighting surveys than small scale developments (see Table 4.1).

The following information should be obtained from the lighting professional/engineer and presented in the survey report:

i. Number and location of proposed luminaires;
ii. Luminaire light distribution type;
iii. Lamp type, lamp wattage and spectral distribution ;
iv. Mounting height;
v. Orientation direction;
vi. Beam angle (between 0^o and 90^o, the higher the angle the greater potential for obtrusive light above the horizontal plane);
vii. Type of control gear (this will help inform mitigation and it will influence the possibility for remote management of light intensity and regime);
viii. Proposed lighting regime (timing and duration of illumination); and
ix. Projected light distribution maps of each lamp (engineers can provide map which predict the distribution of the light (lux levels) emitted from each lamp, see 4.3.2).

4.3.2 Baseline light surveys

Standardised comprehensive lighting surveys are essential for the accurate predictions of the impacts of lighting applications on bats. It is important to survey pre-development light levels in the areas to be impacted by the proposed lighting regime to be able to assess the relative change in illuminance as a result of the scheme.

4.3.2.1 Surveys by lighting engineers/contractors

Lighting engineers often assess the existing light levels on site prior to installation of lighting so as to ensure that any proposed lighting does not spill into new areas, thereby exceeding existing site conditions. It is advisable that the predictions and calculations produced by the lighting engineer/contractor are obtained and considered along with the pre-development bat survey results to inform the impact prediction and mitigation planning process. During the lighting design process lighting engineers often produce maps of predicted light levels beam distributions and a lamp layout plan. These include calculated predictions, obtrusive light calculations, and surface colour schedules. These maps are important tools to enable accurate predictions of the impacts of lighting on bats.

4.3.2.2 Surveys by bat ecologists

In addition to the light surveys completed by lighting engineers/contractors, independent light surveys should be completed to assess specific areas currently or potentially used by bats. Lighting surveys should be completed either during or after bat surveys are conducted and focus on those habitat elements/areas currently and potentially used by bats (as identified during the bat activity surveys, section 4.2). It is important to ensure that light levels are recorded at all key areas used by bats on a site including:

i. Inside and outside roosts;
ii. Roost exits;
iii. Foraging sites; and
iv. Commuting routes (including potential alternative routes).

Light levels should be measured both within roosts (when conducting preliminary building checks) and externally as part of subsequent presence/absence and roost characterisation surveys (see below for guidance on how to record light levels). Readings at roost exit points should be taken at intervals throughout the emergence period of the bat species in question such that light levels are recorded for the period of time when bats normally leave the roost, as this is when they are most likely to be affected by light disturbance at the roost. It is important to assess ambient light levels along hedges and key habitat elements in areas/routes which are identified as possible alternative routes post development if existing routes are altered or removed. This information should be presented in the report including a map of light levels in relation to bat activity/use and including the times of the readings taken.

Measuring light: when recording light levels it is best practice to use a lux meter which can measure light levels at a resolution of 0.01 lux or lower (e.g. Konica Minolta T-10 illuminance meter, Konica Minolta Sensing, Inc.), enabling recording of light levels in dark areas. Light should be measured at the height at which the bats will be flying or if that is not possible a standardised height (e.g.1.7m, approx. head height). The time (relative to sunset) and height at which the light level was recorded should be reported to enable comparison between studies.

Produce a predicted post-development light distribution map (PstLM): a lighting distribution map should be created for large scale developments. This should include information obtained from the lighting engineers/contractors (section 4.3.2.1) and from the ecologists lighting (section 0) and bat surveys (section 4.2). This map can be used to inform predictions of the impacts of lighting on bats in the area. This map should combine the bat habitat use maps with predicted light distribution maps and current light levels to estimate the amount and type of impacts on bats in the area. Information regards predicting the impacts of lighting on bats is outlined in section 5.

4.4 Key action points for baseline bat and lighting surveys

i. Conduct standardised **pre-development bat surveys** (PrBS) to identify areas used by bats for commuting, foraging and roosting;

ii. Produce a **quantified pre-development bat habitat use map** (PrBM) showing species presence and absence, key foraging, commuting and swarming sites, and an index of relative activity at each site (e.g. no of bats/hour along each hedge/ at point counts in woodlands etc.);

iii. Conduct **pre-development light surveys** (PrLS) to quantify existing light levels in areas used by bats;

iv. Obtain **predicted post-development light distribution maps** (PstLM) and detailed descriptions of the lighting scheme from the lighting contractor/engineer;

v. Produce **a predicted lighting impact map** for bats combining the information obtained in the PrBS, PrBM, PrLS and PstLM**;**

vi. Report the time and height at which light measurements were recorded to enable comparisons before and after development.

Table 4.1. Summary of estimated survey effort and reporting required according to development type (large, medium, small).

Scale of Development	Example development	Surveys required	Reports & Outputs
Large	Large scale habitat loss/alteration Creation of new roads and lighting in dark areas	Comprehensive PrBS and PrLS across site	PrBM PstLM Predicted light impact map
Medium	Some habitat loss /alteration Changes in light types/amount of light in areas used by bats	Medium scale PrBS and PrLS	PrBM PstLM Predicted light impact map
Small	Little/no habitat loss/change Minimal changes in light levels /types (E.g. single security light installed)	Small scale targeted surveys in area affected: PrBS PrLS	PrBM PstLM

5 Impacts

Stone, E.L

5.1 Introduction

Light pollution is a key biodiversity threat. It is listed within the top ten emerging issues in biodiversity conservation and has important implications for policy development and strategic planning (Hölker *et al.* 2010b). There has been increasing awareness of the ecological impacts of light pollution (Harder 2002; Longcore & Rich 2004; Smith 2009; Hölker *et al.* 2010a; Hölker *et al.* 2010b). Light pollution affects ecological interactions across a range of taxa and negatively affects critical animal behaviours including foraging, reproduction and communication (for reviews see Longcore & Rich 2004; Rich & Longcore 2006). Being nocturnal bats are among those species most likely to be impacted by lighting, although artificial light can impact all species and behaviours.

5.2 Predicting the impacts of lighting on bats

This is an emerging and complex area of research with many knowledge gaps remaining. There are many aspects of ecological light pollution which are yet to be investigated, such as the impacts of polarized light on wildlife (Horvath *et al.* 2009), and so a precautionary approach is important.

5.2.1 Considerations when predicting the impacts of lighting on bats

It is important to consider the following when predicting the impacts of lighting on bats:

i. Impacts may be cumulative

Lighting is one of many anthropogenic impacts on bats and so it is important to consider impacts of lighting in the context of the site and other conditions affecting the species or colony. For example even a small amount of lighting may have a disproportionate impact on bats at sites where there are already high levels of disturbance, therefore impacts must be assessed in the context of other disturbances on the colony/roost in question.

ii. **Impacts will vary according to site, species and behaviour**

The impacts of lighting on bats is species specific and varies according to the specific behaviour being affected. Impacts on a site by site basis can be based on knowledge of the species involved and the type of behaviour affected.

iii. **Impacts may occur over different temporal scales**

Some impacts may occur over very short time frames making them more obvious (e.g. spatial avoidance) and therefore more likely to be recorded. However, lighting may impact behaviours over longer time scales (e.g. reduced breeding success) and may be harder to record and therefore underestimated. Therefore when predicting impacts an assessment must be made over the full range of potential time frames (seasons to generations).

iv. **Impacts may occur at both the individual or population level**

Lighting may impact on a few individuals in a colony or population, i.e. causing temporary avoidance of a commuting route used by a small percentage of bats occupying a roost. However, there may be effects at the population level, e.g. reduced juvenile growth rates due to reduced foraging or delayed emergence caused by lighting (e.g. see Boldogh *et al.* 2007).

v. **Impacts may be indirect occurring at the ecosystem or community level**

Lighting can impact bats via changes at the ecosystem level. Lighting may lead to a competitive advantage for some species which benefit from the increased foraging opportunities provided by moths attracted to lights with high UV content. This may lead to competitive exclusion of those species unable to take advantage of new artificially illuminated areas (Arlettaz *et al.* 2000).

Indirect effects include effects on bats' insect prey. Bats have a competitive advantage over moths at street lights (Svensson & Rydell 1998), which interferes with the relationship between predator and prey. Lighting causes direct mortality of insects. Currently there is little evidence of population level effects on insects (Fox 2013), but even local reductions in insect prey caused by artificial lighting may reduce feeding opportunities for bats, particularly for bat species which avoid illuminated areas. Artificial light may also change the community composition of insects. Davies *et al.* (2012) found that areas illuminated by HPS lights contained higher numbers of predatory and scavenging insects (e.g. ground beetles, harvestmen, ants and woodlice). Therefore lighting could affect entire ecosystems through changes in trophic interactions, which may in turn affect ecosystem services.

5.2.2 Summary of impacts according to bat behaviour

A summary of the key bat behaviours and the likely nature of impacts caused by artificial light disturbance are provided in **Table 5.1**. However the following information must be used as a guide, as impacts will vary according to the site, species and light type in question. As evidence is limited we have compiled research from both UK and non UK bat species, to enable comparisons and predictions of likely impacts from similar species outside the UK.

Table 5.1. Impacts of lighting on bat behaviour, including evidence and implications

Behaviour	Impact	Description of impact	Evidence	Implications
Emergence / Roosting	Delayed emergence	External lights can delay the timing and prolong the duration of emergence for some species	Extended twilight caused delayed emergence in *Rhinolophus hipposideros* (McAney & Fairley 1988) and light intensity was an important factor determining the onset of emergence. External lighting reduced the number of *Pipistrellus pygmaeus* emerging from roosts (Downs *et al.* 2003).	Reduced foraging time and bats will be forced to compensate if possible. Bats may miss the peak in abundance of insects that occurs at dusk, thereby reducing the quality of foraging time, impacting the fitness of individuals and the roost as whole
	Spatial avoidance /roost abandonment	Bats may use alternative exit/entrances if available. Bats may abandon the roost or become entombed	A maternity roost of 1,000 -1,200 female *Myotis emarginatus* (non UK species) was abandoned after lighting spilled directly onto the entrance (Boldogh *et al.* 2007). Full illumination of roosts has been shown to cause sudden declines in bat numbers. Over 1000 bats died after a 40watt light was left on for two days inside a roost of *Myotis myotis* (non UK species) in Germany (Karl Kugelschafter pers. comm.). Numbers of *Myotis lucifugus* (non UK species) and *Eptesicus fuscus* (non UK species) declined by between 53-89% and 41-96% respectively upon installation of incandescent lamps (40 and 60 watts), cool fluorescent lamps (40 watts) and spotlights	Lighting which spills directly into a roost can cause roost abandonment or death and should be avoided. Such disturbance would constitute an offence. Illumination of the roost entrance can have consequences for predation and connectivity. Bats may be forced to use alternative exits if available. Alternative exits may be suboptimal in terms of predation risk. Alternative exits may increase predation risk due to their location in relation to the surrounding landscape (e.g. bats may be forced to fly across open areas or roads once leaving the exit) or due to their situation (e.g. located low to the ground or near a window sill enabling easy access for predators such as domestic cats). Forcing bats to use exits which increase

			(150 watts) inside nursery roosts (n = 3 *Myotis lucifugus* roosts; n = 6 *Eptesicus fuscus* roosts) (Laidlaw & Fenton 1971).	predation risk can cause increased mortality and in the worst case scenario result in severe reductions in colony numbers (e.g. domestic cats have killed all bats in a colony during one summer season).
	Reduced reproductive success	Internal and external lighting around a bat roost can impact on the fitness of the colony through reduced juvenile growth rates	Colonies of *Myotis emarginatus* (non UK species) nd *Myotis oxignathus* (non UK species) in buildings which were illuminated from the outside had lower juvenile growth rates than colonies in non-illuminated buildings (Boldogh *et al.* 2007).	Reduced fitness can impact the long term survival of a colony, making them more susceptible to other threats causing them to be at increased risk. Bats are long lived and slow to reproduce, meaning they take time to recover from population declines. Illumination of buildings occupied by bats and the immediate surrounds should be avoided.
Commuting	Spatial avoidance and habitat fragmentation	Light that spills onto bat commuting routes or flyways can cause avoidance behaviour for some species and fragment the network of commuting routes	Activity of *Rhinolophus hipposideros* and *Myotis* spp. was significantly reduced along commuting routes illuminated with HPS and LED street lights (Stone *et al.* 2009; 2011; 2012). *Rhinolophus hipposideros* and *Myotis* spp. avoided commuting routes illuminated with LEDs even at low light levels of 3.7 lux (Stone *et al.* 2012). In Canada and Sweden *Myotis* spp. were only recorded away from street lights (Furlonger *et al.* 1987; Rydell 1992).	Bats may be forced to use suboptimal routes which may force them to fly further to reach their foraging grounds resulting in increased energetic costs (due to increased flight time). Alternative commuting routes may be suboptimal in terms of vegetation cover, resulting in increased predation risk or exposure to the elements (wind and rain) with increased energetic costs. In some cases there may not be an alternative route available and bats may be cut off from their foraging areas, forcing them to abandon

			Despite the presence of street lit areas within their home range, lit areas were never used by *Rhinolophus ferrumequinum* (Jones & Morton 1992; Jones *et al.* 1995). Torchlight appeared to reduce activity of *Myotis daubentonii* foraging over two rivers in England (Monhemius 2001), although these results must be viewed with caution as the analysis failed to account for repeated measurements within sites.	their roost. Such disturbance disrupts the ecological functionality of the landscape by creating barriers to effective animal movement.
Foraging	Increased foraging	Some bat species actively forage at lights due to the higher numbers of insects (particularly moths) attracted to street lights, in particular low wavelength light (Eisenbeis 2006; van Langevelde *et al.* 2011).	Bats of the following genera have been recorded foraging at street lights: *Chalinolobus* (non UK species), *Eptesicus, Lasiurus* (non UK species)*, Mormopterus* (non UK species)*, Myotis, Nyctalus, Nyctinomops* (non UK species)*, Pipistrellus, Tadarida* (non UK species) and *Vespertilio* (non UK species). Higher densities of bats have been recorded in lit compared to unlit areas e.g. densities of *Pipistrellus pipistrellus* were 10 times higher in lit versus dark areas in England (Rydell & Racey 1995), and densities of *Eptesicus nilssoni* (non UK species) *were* 5-20 times higher in lit compared to dark areas in Sweden (Rydell 1991). The highest levels of bat activity in lit areas have been recorded at white lights (Blake *et al.* 1994; Rydell & Racey 1995; Avila-Flores &	Fast flying species adapted to forage in open areas (particularly bats of the genus *Eptesicus, Pipistrellus* and *Nyctalus*) may benefit from the increased foraging opportunities provided at lamps which attract high densities of insects. Bats foraging at street lights may be subject to increased mortality risk due to collision with vehicles: juveniles may be at higher risk of predation due to their slower and less agile flight (Racey & Swift 1985). The increased densities of insects at street lights may have ecosystem-level effects. Moths attracted to street lights have increased mortality (Frank 1988; Longcore & Rich 2004) and larger moths are more attracted to lights than smaller moths (van Langevelde *et al.* 2011). This size-dependant mortality risk can have cascading effects for trophic interactions

			Fenton 2005). This is reflected in the higher numbers of insects attracted to white lights with five times more insects recorded at white versus sodium lights (Rydell 1992). In contrast LPS lights do not appear to attract insects, with insect numbers as low as recorded on unlit streets (Rydell 1992). HPS lights attracted 57% fewer insects than white mercury lamps in Germany (Eisenbeis 2009).	and ecosystem services. In addition, the insect prey of bats may be attracted away from dark areas, potentially reducing prey availability for species that do not forage in lit areas.
	Reduced foraging	Illumination of foraging areas can prevent or reduce foraging activity causing bats to pass quickly through the lit area or avoid it completely. Lighting can disrupt the composition and abundance of insect prey.	Acoustic tracking experiments demonstrated that *Eptesicus bottae* (non UK species) failed to forage in areas under lit conditions (Polak *et al.* 2011). It has been suggested that the population decline in *Rhinolophus hipposideros* in Switzerland was caused by competitive exclusion by *Pipistrellus pipistrellus,* which was able to take advantage of the increased foraging opportunities provided by street lights (Arlettaz 2000). Kuijper et al. (2008) suggested that a halogen lamp (1000 watt) placed along the commuting route of pond bats *(Myotis dasycneme*) (non UK species) resulted in a 60% reduction in feeding buzzes. However, these results should be viewed with caution as the statistical analyses failed to account for	Artificial illumination in foraging habitats can effectively cause a loss of foraging areas for some bat species. This can have negative effects on bat communities by potentially causing competitive exclusion of less tolerant species, as more light tolerant species may out-compete them for aerial insect prey.

			repeated measurements within sites. Currently there is a lack of evidence on the impact of lighting on foraging activity of bat species.	
Hibernation	Spatial avoidance	The illumination of hibernation sites may cause spatial avoidance so that bats have to find alternative hibernation sites	There is currently no evidence of the impacts of lighting on hibernation sites, but evidence from summer roosts suggests that bats would avoid roosting at illuminated hibernation sites. Further research is required to understand the conservation and energetic consequences of illuminating hibernation sites	If bats were deterred from using hibernation sites, this could have significant conservation consequences, affecting overwinter survival. The abundance and availability of suitable hibernation sites is unknown and so illumination of hibernation sites should be avoided.
	Increased arousal from hiberation	It is likely that disturbance within a hibernation site will cause bats to arouse from torpor	At present there is no empirical evidence that light stimulates arousal in hibernating bats. Laboratory studies found that bats do not arouse when exposed to slight variations in light (Speakman *et al.* 1991) although this study only tested the effect of the light emitted from a 14 watt petzel head torch. This is not therefore be representative of the impacts of other light types on bat hibernation	If hibernating bats were disturbed on a regular basis this would result in significant energetic costs, reducing their overall fitness and ability to survive the winter and subsequent spring
Swarming	Spatial avoidance / reduced activity	Swarming is characterized by intense chasing flights in and around underground sites by large, transient, multi-species bat assemblages, primarily in August and September (Glover & Altringham 2008).	Typical swarming species in the Britain are *Myotis brandtii, Myotis daubentonii, Myotis mystacinus, Myotis nattereri, Myotis alcathoe* and *Plecotus auritus*. Although there is no direct evidence of the impact of light disturbance on swarming bats, experimental studies have shown that *Myotis* spp. avoided hedgerows illuminated with HPS	Swarming is the primary mating system for many bat species allowing gene flow between populations (Glover & Altringham 2008). Disruption and disturbance of swarming sites have caused population declines of bats across the world (Hutson *et al.* 2001). Bats have shown high fidelity to individual swarming sites, and so

		Light disturbance at swarming sites may cause avoidance behaviour and disrupt swarming behaviour for light sensitive species.	and LED street lights (Stone *et al.* 2009; 2011; 2012). Light disturbance at swarming sites can negatively affect the orientation ability of *Myotis lucifugus* (non UK species), causing them to collide with large objects (McGuire & Fenton 2010).	disruption of swarming behaviour at swarming sites could significantly disrupt breeding behaviour.

5.2.3 Summary of impacts by species

A summary of the key impacts per species according to behaviour types is provided in Table 5.1. These are based on current knowledge and may change as more evidence emerges, so are given as guidance only and specific levels of impact will vary on a site by site basis. Low impact does not mean there is no impact, but suggests that impact is likely to have a negligible impact on the population.

Table 5.2. Summary of predicted impacts of lighting for each species/group according to bat behaviour. Further research is required to have high confidence in many of these predictions and therefore they should be used as guidance only.

Impact / Behaviour	High	Medium	Low
Maternity roost	All species	-	-
Night roost	*Rhinolophus hipposideros* *Rhinolophus ferrumequinum* *Myotis* spp. *Plecotus* spp.	*Pipistrellus* spp. *Nyctalus* spp. *Eptesicus serotinus* *Barbastella barbastellus*	-
Emergence	All species	-	-
Foraging	*Rhinolophus hipposideros* *Rhinolophus ferrumequinum* *Myotis* spp. *Plecotus* spp.	-	*Pipistrellus* spp. *Nyctalus* spp. *Eptesicus serotinus* *Barbastella barbastellus*
Commuting	*Rhinolophus hipposideros* *Rhinolophus ferrumequinum* *Myotis* spp. *Plecotus* spp.	-	*Pipistrellus* spp. *Nyctalus* spp. *Eptesicus serotinus* *Barbastella barbastellus*
Swarming	All species	-	-
Hibernation	All species	-	-

5.2.4 Key messages and recommendations:

5.2.4.1 Emergence and roosting

- Current evidence demonstrates that external light disturbance at emergence and return will have negative impacts for bats (especially *Rhinolophus*, *Myotis*, and *Plecotus* spp.) and should be avoided.
- Internal illumination of roosts is likely to impact negatively on on long-term population growth and survival and should be avoided for all species.
- Direct illumination of a roost exit/entrance may cause roost abandonment for all species (particularly for *Rhinolophus* and *Myotis* spp.) and should be avoided.

5.2.4.2 Commuting

- Light disturbance along commuting routes will cause avoidance behaviour for *R. hipposideros* and *Myotis* spp. and should be avoided.

5.2.4.3 Foraging

- Light disturbance can reduce the availability of foraging areas for some species;
- A precautionary approach must be taken and illumination of foraging areas avoided, particularly for light sensitive species (Table 5.2).

5.2.4.4 Hibernation

- There is limited evidence of the impact of lighting on hibernating bats. However illumination of hibernation sites should be avoided during the hibernation period.

5.2.4.5 Swarming

- There is a lack of evidence regarding the impact of lighting on bat swarming behaviour and so illumination of known or potential swarming sites should be avoided under the precautionary principle.

A summary of the key impacts of light and recommendations according to bat use are provided in Figure 5.1.

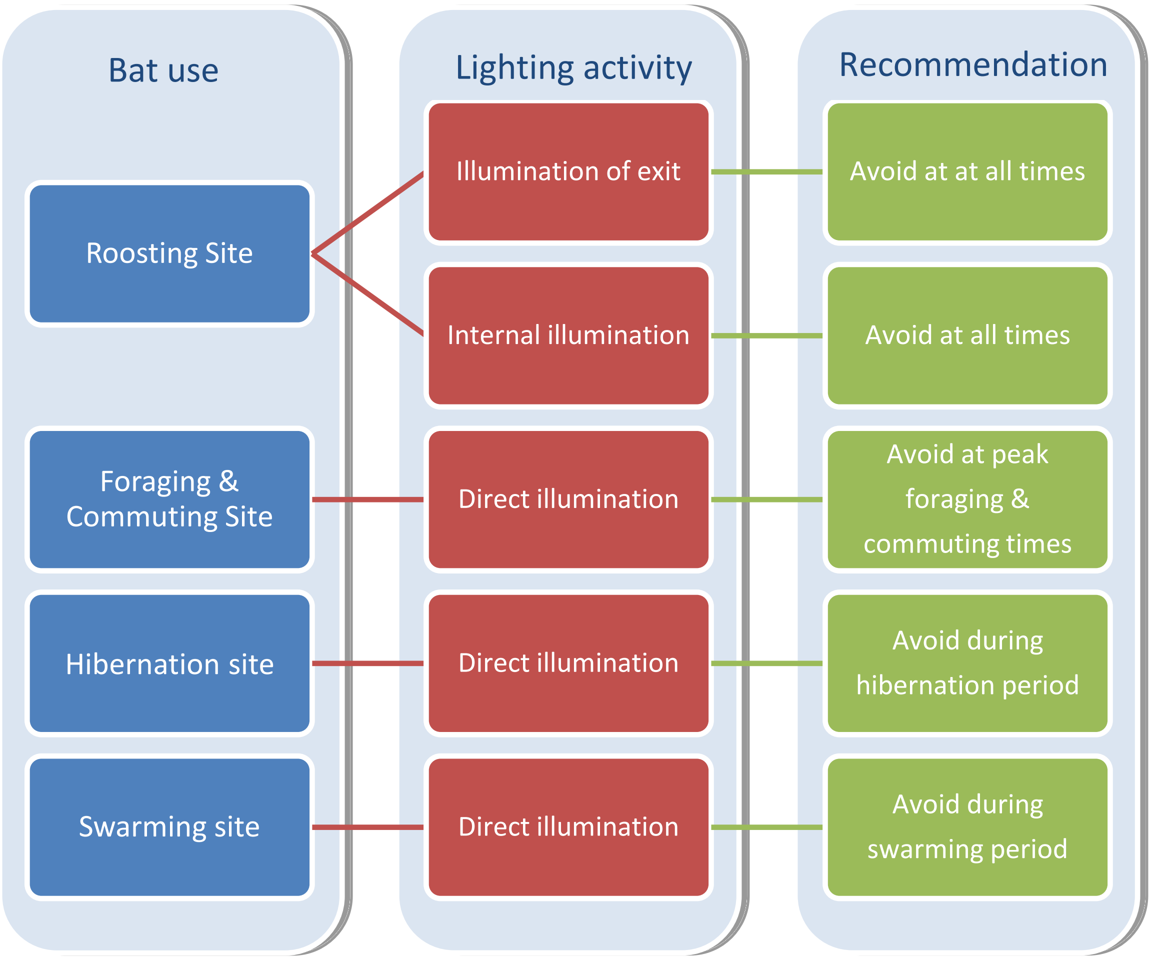


Figure 5.1. Summary of key impacts of light and recommendations according to bat behaviour

5.2.5 Summary of impacts of light types on bats

Light technology is rapidly developing and new light types are being installed and trialled across the UK. There is a general trend towards white light due to the increased colour rendering and increased perceived brightness for the human eye. Humans perceive white light as brighter than yellow light and so lower light intensities can be used to achieve the same perceived brightness. Commonly used emerging lamps include white LED (Philips Stela and DW Windsor Monaro), warm-white LED, and ceramic metal halide (e.g. Philips

CosmoPolis). Some companies are testing new light types to find a wildlife friendly lamp which has little or no impact on wildlife e.g. QL Philips Clearsky lamps which are said to prevent migrating birds from colliding with offshore platforms. To date no such product has been rigorously tested on bats. However, there is little evidence of the comparative impacts of different light types on different bat species and behaviours. A summary of the current evidence of the relative impacts of different light type son bats is provided in table 5.2.

Table 5.3. Summary of current evidence of the impacts of different light types on each UK bat species/group

Light type	Species	Impact	Evidence
White LED	*Rhinolophus hipposideros* and *Myotis* spp.	Reduced activity and spatial avoidance of commuting routes	Stone *et al*., 2012
Warm white LED	Unknown at present	Unknown - though likely to have less impact on light sensitive species than white light types	
Low pressure sodium	*Nyctalus noctula*	Increased activity and foraging	Rydell & Baagoe 1996
	Pipistrellus spp.	No significant increase in activity compared to dark areas	Blake *et al*., 1994
High pressure sodium	*Rhinolophus hipposideros and Myotis* spp.	Reduced activity and spatial avoidance of commuting routes; delayed commuting time	Stone *et al.,* 2009; 2011
	Pipistrellus spp., *Nyctalus noctula, Eptesicus serotinus*	Increased activity and foraging	Rydell & Baagoe 1996
Compact fluorescent	Unknown at present	Unknown - though likely to have a similar impact on light sensitive species as other white light types	
Mercury vapor lamps	*P. pipistrellus and Pipistrellus* spp. *Eptesicus* spp.	Increased activity (Rydell (1991) recorded increased activity of *Eptescius nilssoni* (a species not present in the UK) at mercury vapor lamps in Sweden in spring April – May)	Haffner & Stutz 1985; Blake *et al*. 1994, Rydell & Racey 1995.

Figure 5.2 provides a general summary of the **relative** impacts of light types on bats. However, there is a lack of evidence regarding the comparative impacts of different light types on bats and these summaries should be considered general rules of thumb until more detailed information is available.

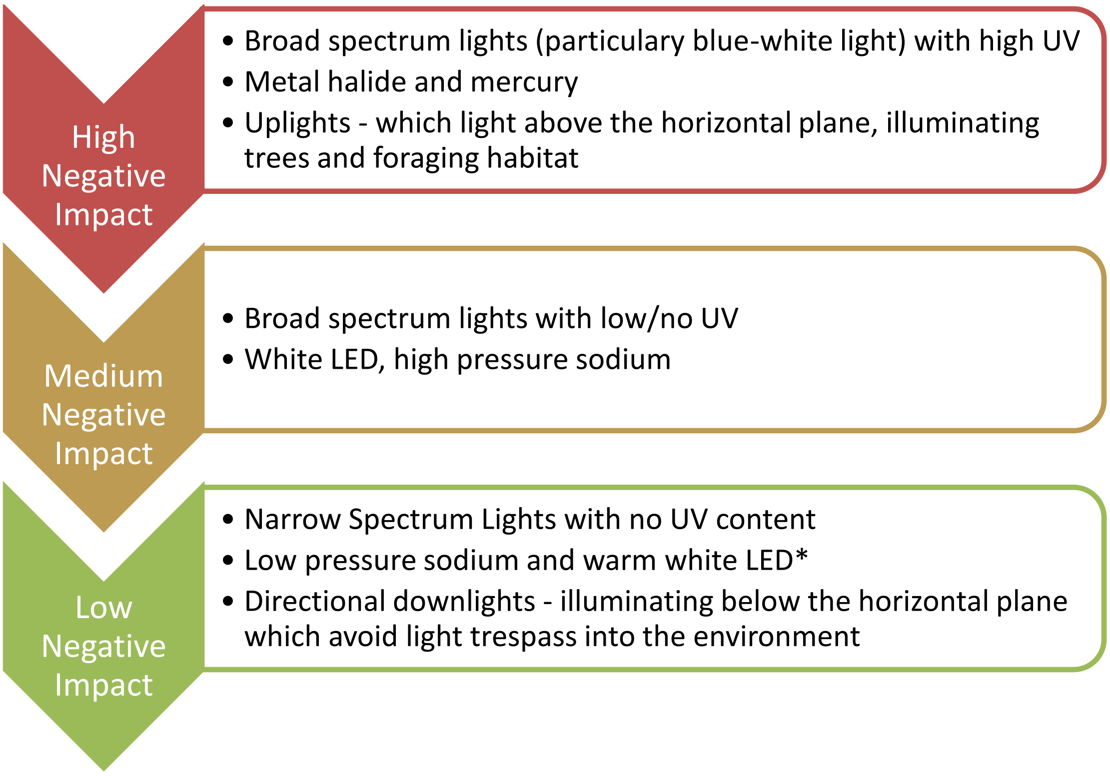


Figure 5.2. Summary of the relative impacts of light types on bats, * low relative attractiveness for insects compared to white light and therefore minimal impact on bats insect prey (Eisenbeis 2009).

6 Mitigation

6.1 Definition

Mitigation is defined in the EC Directive 85/337 as "measures envisaged in order to avoid, reduce and if possible remedy significant adverse effects" (CEC 1985). In accordance with Mitchell-Jones (2004), we use the term mitigation in its broadest sense, to incorporate both mitigation (practices to reduce or remove damage) and compensation (practices to offset potential negative effects/damage). As with other forms of mitigation, when mitigating the impacts of lighting on bats it is important to consider for following key principles:

Proportionality

The nature and extent of mitigation should be proportionate to the level of predicted impact and will therefore vary by site. It is important to avoid over-compensation or mitigation as this can cause increased conflict between bat conservation and humans.

Evidence-based actions

Proposed mitigation and compensation strategies should be based on evidence and rigorous appropriate pre-development site surveys for bats and lighting. Decision makers should consistently review current evidence for the best possible approach to ensure consistency and effectiveness of proposed strategies.

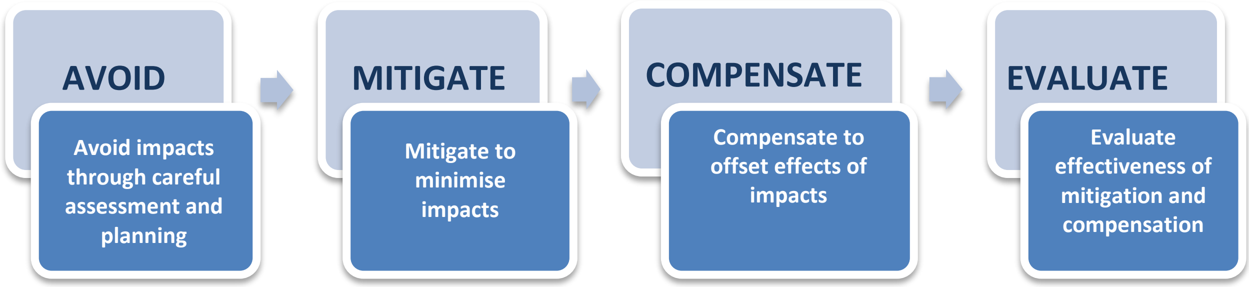
6.2 Approach to mitigation of artificial lighting

When mitigating the impacts of artificial lighting on bats it is important to ask the following key questions:

1. Do we need to light?
2. Where does the light need to be?
3. What is the light required for?
4. How much light is actually needed to perform the tasks required ?

5. When is the light required?

The following approach should be taken when developing a mitigation strategy:



6.3 Considerations

There are four key considerations which are important in developing effective strategies to mitigate the impacts of lighting on bats:

6.3.1 Standardised pre-development baseline surveys

It is important to conduct standardised surveys of light levels (lux) and bat activity and use at the pre-development and mitigation stage to inform and improve the mitigation process (section 4). Standardised surveys can then be repeated post-mitigation to facilitate monitoring and evaluation of the effectiveness of mitigation to ensure that the mitigation has been correctly installed, is operating properly and is having the intended effect. It will also allow the permitting authorities and licensing agencies to assess whether work has been completed according to the permission or license. Ecologists should work closely with lighting engineers and planners at an early stage to inform the development, design and installation of lighting schemes before they are installed. At this stage lighting engineers can use computer-based software to predict the distribution and intensity of the light from installations on a schematic diagram of each site. This can be very useful in both predicting impacts and planning mitigation.

6.3.2 Bats, behaviour and ecosystems

Species specific responses: many bat species respond in different ways to light disturbance. Some bats are light averse (section 5) whilst others actively forage in lit areas. In addition, the magnitude of the impact of lighting may vary between species. Therefore mitigation designed for one species may not be suitable for other species occupying the same site. This needs to be considered carefully when planning effective mitigation strategies.

Behavioural considerations: the impact of lighting on bats may vary according to the behavioural use of the site in question. This was highlighted in section 5 where the impacts were shown according to different bat behaviours (roosting, foraging, swarming, hibernating, and commuting).

6.3.3 Public perceptions and requirements

Good mitigation has to be effective for both bats and the public. It is important to consider and manage the public perception of safety in the area which is often associated with light levels. High levels of crime and vandalism often lead to public pressure for increased illumination. In such cases it is important to meet the public requirements while considering the requirements for bat use on site, to avoid increasing the conflict between bats and humans. A good understanding of the public requirements and usage patterns on the site can allow for effective proportional mitigation which meets the needs of both the public and wildlife (e.g. dimming during periods of low public use).

6.3.4 Wider habitats/ecosystem level effects

Mitigation should take into account measures to avoid/compensate/mitigate at the landscape and ecosystem level. Bat populations function as part of the entire ecosystem and therefore mitigation should ensure ecosystem level functioning is retained. Bats should be able to fly safely between their roosts and their foraging grounds along interconnected flight paths.

6.4 Mitigation Strategies

Mitigation strategies will vary on a site by site basis according to the required level of lighting, use of the area, the surrounding habitat, the species of bat and specific behaviour affected.

6.4.1 No light

Where possible the ideal scenario would be to have no light at all at locations used by bats. This may be possible with good planning and involvement of lighting engineers at the survey and pre-planning stage. This may involve switching off existing units on site and ensuring areas used by bats have no new light units installed and will have no light trespass from nearby lights. If possible sites should contain light exclusion zones (dark areas) which are interconnected to allow bats to move freely from their roosts along commuting routes to their foraging grounds without being subject to artificial illumination.

6.4.2 Variable lighting regimes (VLR)

In many cases it is not feasible to have light exclusion zones in all in the areas occupied by bats at a site. In such cases new generation lighting controlled by CMS systems (see section 3.3.3) may be preferable to enable variable lighting regimes (VLR) to suit both human and wildlife use of the site. VLR involve switching off or dimming lights for periods of the night. Many county councils are adopting VLR using CMS controlled units, switching off/dimming lights when human activity is low (e.g. 12.30 – 5.30am). This technology could also be used to create a lighting regime that switches off lights during periods of high bat activity, such as commuting or emergence. Lights can also be dimmed (e.g. to 30% power) for periods of the night to reduce illumination and spill. The exact regime of lighting at a site will depend on the nature of public use and type and amount of bat activity, and will therefore vary between sites. However, the effectiveness of VLRs is reliant upon rigorous and appropriate bat surveys prior to development (section 4.2), to establish the timing of bat activity around the site, followed by comprehensive post-development monitoring to evaluate effectiveness. There is currently a lack of research on the impact of VLR on bats and therefore comprehensive post-development monitoring will be key to evaluating the effectiveness of such strategies.

Lights can also be fitted with movement sensors which switch lights on as people walk by and switch them off when as people pass. Such lights will reduce the overall lit time for the environment, potentially reducing the impact on bats and insects. Further research is required to assess impacts of these schemes on bats.

6.4.3 Habitat creation

Light barriers: vegetation can be planted (e.g. hedgerows or trees) to reduce light spill so acts as a light barrier. Careful consideration should be given to the minimum size of the habitat required to restrict any light trespass when used as a light barrier. The size and depth of the corridor will vary according to the distance from the light source, light intensity, light spread and light type. The effectiveness of using dark corridors as light barriers is therefore dependent upon comprehensive pre-development light surveys (section 4.3) to understand the extent and level of light around the site.

Dark corridors: dark corridors can be created to encourage/guide bats away from lit areas or around lit obstacles (such as roads). Corridors should be placed with consideration for the use of the landscape as a whole in relation to key commuting routes, linking foraging sites and roosts. Therefore comprehensive pre-development bat surveys (section 4.2) determine the effectiveness of dark corridors as this information can be used to ensure they are well connected and functional. Corridors can be composed of man-made or natural materials (e.g. fences, brick walls, tree lines or hedges). Corridors with outgrown vegetation (e.g. **Figure 6.1**) are preferable as they create dark fly ways sheltered from predators and the elements. Heavily clipped low hedges or tree-lines are less suitable.

Figure 6.1. Examples of two dark corridors used by bats in Devon, England (© E.Stone)

To increase their effectiveness dark corridors should be:

i. Well-connected within the bat landscape – linking to existing flight paths, roosts or foraging areas;
ii. Outgrown with mature vegetation providing shelter for bats from the weather and predators as they fly;
iii. Planted with native species to encourage insect populations, thereby allowing bats to forage along the corridors;
iv. Located away from roads to avoid traffic noise which will reduce the foraging efficiency of passive listening bats (Schaub 2008); and
v. Monitored/maintained long-term to ensure they remain functional, e.g. have not been removed or altered in a way that will reduce effectiveness.

6.4.4 Spacing and height of units

Increasing the spacing between light units can reduce the intensity and spread of the light to minimise the area illuminated and give bats an opportunity to fly in relatively dark areas between lights. Reducing the height of light units will keep the light as close to the ground as possible, reducing the volume of illuminated space. This will also give bats a chance to fly over the light units in the dark area above the light (as long as the light does not spill above the vertical plane). There are many low level lighting options for pedestrian and cycle path lighting which minimise spill and reduce overall illumination including: low level illuminated bollards (**Figure 6.2**), down-lights, handrail lighting (**Figure 6.3**) or footpath lighting.

Figure 6.2. Pharola illuminated bollard. DW Windsor Ltd.

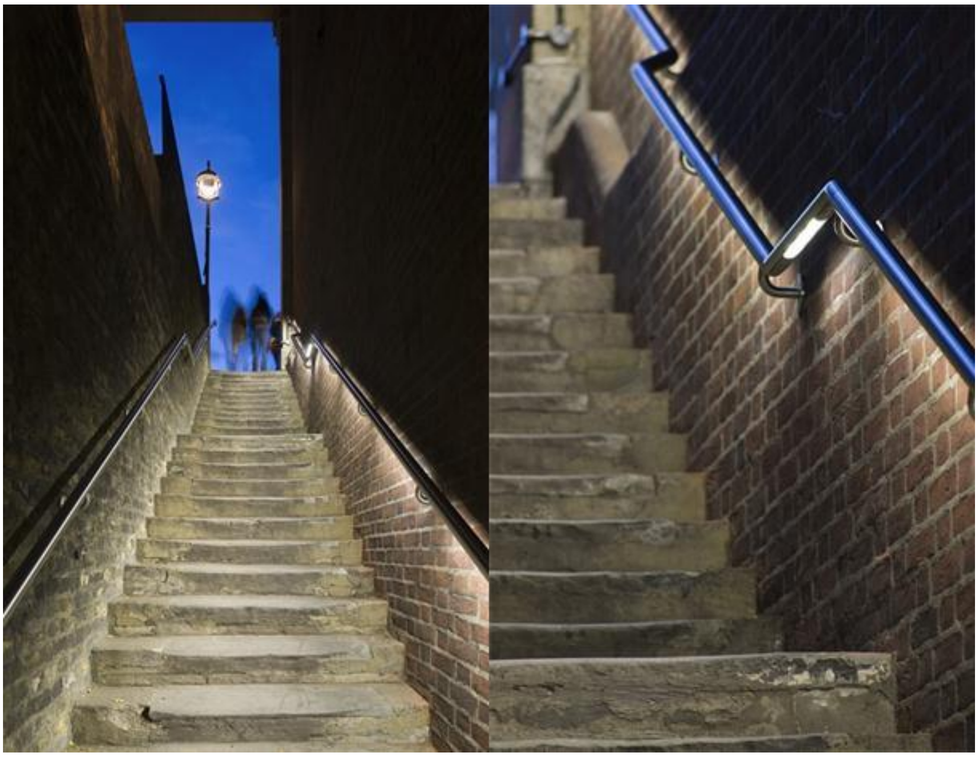


Figure 6.3. LED handrail Essex Street steps, WC2. DW Windsor Ltd.

6.4.5 Reducing intensity

Reducing light intensity will reduce the overall amount and spread of illumination. For some bat and insect species this may be sufficient to minimise disturbance or the magnitude of any negative impacts. However, some species may require very low light levels to have little/no impact on bat behaviour. Stone *et al*., (2012) found that levels as low as 3.6lux caused spatial avoidance of a preferred commuting route by *Rhinolophus hipposideros.* Average light levels recorded along preferred commuting routes of *Rhinolophus hipposideros* under natural unlit conditions were 0.04 lux across eight sites (Stone 2011). When mitigating the impacts of lighting for such species very low lux levels may not be suitable for human needs. In such cases reducing intensity may not be an option and alternative strategies may be preferable (e.g. dark corridors or light barriers). Currently there is a lack of evidence regarding the light levels below which there are no/reduced impacts on bats. Responses of bats to light levels are likely to vary between species and between behaviours. A “light threshold” below which there is little impact on bats may not exist for some species which may be light averse regardless of intensity (e.g. possibly *Rhinolophus hipposideros*).

Light levels at the site should be considered in the context of the light levels (lux data) recorded during pre-development lighting and bat surveys. Where possible post-development light levels should be as close to the mean naturally occurring light levels recorded at key areas of bat use on the site pre-development. Where this is not possible, a precautionary approach should be taken to keep light levels as low as possible, until further research is completed.

Light intensity can be reduced by:

- *Dimming*: CMS technology can be used to reduce the power of lights on request (e.g. by 80%) and can be used as part of a VLR for periods of high bat activity (section 6.4.2);
- *Changing the light source:* new technologies such as ceramic metal halide (e.g. Philips CosmoPolis, 45 watts) often have a lower wattage compared to old lamp types (e.g. HPS, 75 watts), and can be used to reduce light intensity. However, there is a trade-off between reduced intensity and the pattern of light distribution. Some older light types such as HPS, produce a heterogeneous light environment whereby light intensity declines steeply away from the light source. However some new technologies such as LEDs produce a uniform light distribution resulting in a loss of dark refuges between the lamps (Gaston *et al.* 2012). In such cases it may be preferable to increase the spacing between the units to create dark refuges. In addition when changing the light source it is important to consider the effects of the spectral content of the light (section 3.2); or
- *Creating light barriers:* light intensity can be reduced at a particular site by creating a light barrier which restricts the amount of light reaching the sensitive area. Barriers can be in the form of newly planted vegetation (section 6.4.3), walls, fences or buildings.

6.4.6 Changing the light type

When selecting a light type it is important to consider the colour appearance and rendering of the lamps in relation to human and bat vision. Different light types are likely to have different effects on bats, and these effects will be species and behaviour specific. Choosing the light type (colour/spectral distribution) will inevitably be a compromise between the environmental and public requirements. Currently there is a lack of evidence of the comparative impacts of light types on bats. However, the following key principles can reduce potential negative impacts on bats and wildlife in general:

- *Avoid blue-white short wavelength lights*: these have a significant negative impact on the insect prey of bats. Use alternatives such as warm-white (long wavelength) lights as this will reduce the impact on insects and therefore bats
- *Avoid lights with high UV content:* (e.g. metal halide or mercury light sources), or reduce/completely remove the UV content of the light. UV has a high attractiveness to insects leading to direct insect mortality at street lights thereby reducing the availability of insect prey (Frank 2006; Bruce-White & Shardlow 2011). Use UV filters or glass housings on lamps which filter out a lot of the UV content.

6.4.7 Reducing spill

Lighting should be directed only where it is needed to avoid trespass (spilling of light beyond the boundary of area being lit) (ILP 2011). Attention should be paid to avoid the upward spread of light near to and above the horizontal plane to minimise trespass and sky glow. It is important to avoid lighting above 90^0 and 100^0 (Figure 6.4).

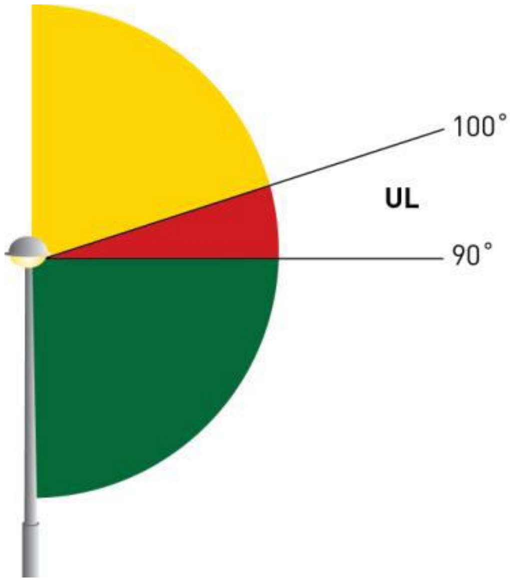


Figure 6.4. Critical luminaire angles for minimising sky glow, showing the upward light output zone (UL) which is between 90^{o} and 100^{o} above the horizontal (ILP 2011)

Trespass can be minimised either prior to installation with careful lighting design and selection of appropriate lamp units, or post installation using a range of lamp modifications to restrict and direct light.

Prior to installation:

- Ensure a low beam angle of the lights (ideally less than 70^{0} above the horizontal) (ILP, 2011)
- Install full horizontal cut off units (with no light more than 90^{0} above the horizontal)
- Avoid the use of upward light (e.g. ground recessed luminaires or ground mounted floodlights up-lighting trees, buildings and vegetation)
- For security lighting use ‘variable aim’ luminaries which allow you to change the beam angle by moving the lamp
- LED lamps allow for directional lighting as individual/groups of LED bulbs can be switched off to direct light to specific angles and most luminaires are full cut off

Post installation:

- Install directional accessories on existing light units to direct light away from sensitive areas and minimise spill (e.g. baffles, hoods and louvres, Figure 6.5)

- Where possible change the angle of the lamp housing to reduce the angle of the beam below 70^0

Figure 6.5. Luminaire accessories to direct light: (a) shield "barn doors"; (b) cowl (hood); (c) shield; and (d) external louvre. Images from Philips and Thorn (ILP 2011)

6.5 Mitigation strategies by project

6.5.1 Pathway lighting:

Hand rail LED lights can be used to illuminate foot/cycle paths which direct the light at the floor at a very low level, with no horizontal and upward spill. Lights can be full lateral cut off (i.e. directed away from a river towards the footpath), blue/white light should be avoided. Small bollard lights can be installed which have low mounting heights (Figure 6.2).

6.5.2 Road lighting:

LED units can be used to direct the light into small target areas. Composite LEDs can be switched off to reduce/direct the light beam to specific areas. New design down lights can be used to ensure minimal sky glow and limited trespass (Figure 6.6).

Figure 6.6. Down lights installed to reduce spill on A470 Cross Foxes to Maes-y-helmau, Wales (©Jill Jackson)

6.5.3 Security Lighting

No bat roost (including access points) should be directly illuminated. If it is considered necessary to illuminate a building known to be used by roosting bats, the lights should be positioned to avoid the sensitive areas. Close offset accent lighting causes less light pollution; it is more specific and can be designed to avoid bat sensitive areas, and better highlights the features of the subject of the illumination. Low wattage lamps are preferable (<70W) as they reduce glare, energy consumption and minimise impacts on bats. Lights can be fitted with movement sensors which turn the light on when the sensor is triggered. These are preferable as lights will be illuminated only when needed reducing the amount lit time.

6.5.4 Floodlighting

Low level lighting can be used to illuminate sports pitches and car parks. It is important to ensure the light is directed to the ground below the horizontal and away from surrounding vegetation (Figure 6.4). Or where new lights are being installed LEDs and new directional, full cut off lights can be used, or cowls and hoods (Figure 6.5) can be fitted to existing units to reduce light trespass. Ensuring lights are only illuminated when the area is in use will reduce impact on bats.

6.5.5 Riverside lighting

Directional lighting can be used to reduce spill onto the water surface and surrounding vegetation. London's Arcadia was granted funding to implement a lighting scheme to would reduce native impacts on nocturnal species. The Arcadia Project was implemented in consultation with local communities and designed by Philips Ltd. Ambient levels of 20lux were achieved by installing 30Watt LED lamps along the Warren Footpath (Figure 6.7). CMS were installed allowing lights to be remotely monitored and individually controlled. Bespoke dimming regimes can be installed or selected luminaires switched off or dimmed to1-5lux during periods of low pedestrian use.

Figure 6.7. LED lamps installed along Warren Footpath, London to reduce spill onto surrounding vegetation (© Alison Fure).

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