Bat Conservation Trust

INSTITUTION OF LIGHTING PROFESSIONALS

GUIDANCE NOTE 08/23

BATS AND ARTIFICIAL LIGHTING AT NIGHT

Brown long-eared bat. Image credit Hugh Clark / BCT

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1. Bat ecology and lighting impacts

What bats live in the UK and where are they?

1.1 There are 17 species of bat that breed in Britain. Generally, the further south and west you go in the UK the more species there are and therefore the more potential to impact them. Further information on species and their distribution can be found here https://www.bats.org.uk/about-bats/what-are-bats/uk-bats. All British species are small (most weigh less than a £1 coin) and eat insects; bats' preferred prey dictates their hunting behaviour, flight speed and echolocation type. Bat species in the UK are therefore faster or slower-flying in their ecology because of the way they hunt their insect prey. Insect-rich habitats such as ancient woodlands and wetlands are key feeding areas for bats, and the associated trees provide key roosting habitat. However, since the industrial revolution, factors such as intensification of agriculture and land clearance have caused the widespread loss of these essential habitats and a decline in bat populations.

1.2 For those more manoeuvrable slower-flying species, more typically associated with cluttered dark environments such as woodlands, the key dark habitats where they can avoid predation have been drastically reduced. These 'clutter space' species (see Figure 1) are considered to be more 'light averse'. Only the faster-flying species, traditionally considered to be 'light opportunistic' are now found throughout our towns and cities. The 'open space' and 'edge space' species (see Figure 1) have been forced to try and adapt, some even becoming building-reliant for roost sites, and foraging through our urban green spaces.

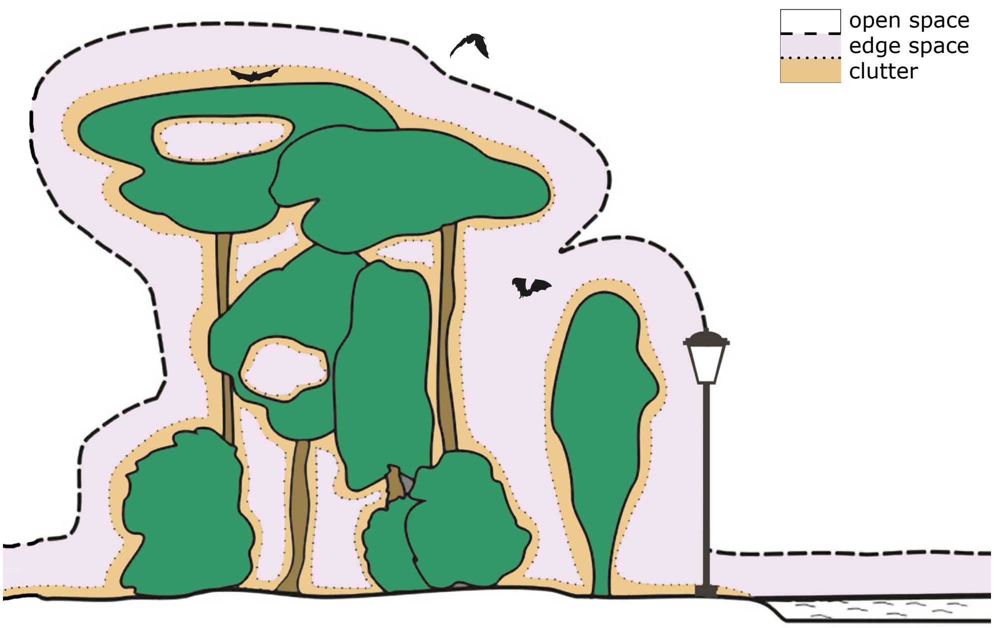


Figure 1. Bat species' foraging behaviour.

Why are bats protected under the law?

1.3 Due to the decline in bat numbers over the last century, the important part bats play as indicator species in the environment, and the importance of specific roost requirements in their life cycle, all species of bat and their roost sites (whether bats are present at the time or not) are fully protected under international and domestic legislation. The international protection (the European Commission (EC) Habitats Directive) has been transposed into national laws by means of the Conservation of Habitats and Species Regulations 2017 (England and Wales) as amended by the Conservation of Habitats and Species (Amendment) (EU Exit) Regulations 2019, the Conservation (Natural Habitats, &c.) Regulations 1994 (as amended) (Scotland) and the Conservation (Natural Habitats, etc) Regulations (Northern Ireland) 1995 (as amended). Commonly the regulations are referred to as the Habitats Regulations.

1.4 This makes it illegal to kill, injure, capture, or cause disturbance that affects populations of bats, obstruct access to bat roosts, or damage or destroy bat roosts. Individual bats are protected from 'intentional' or 'reckless' disturbance under the Wildlife and Countryside Act 1981 (as amended). Recent monitoring shows a slow recovery for many bat species, due to conservation efforts and their legal protection. However, a few ecological traits make them extremely vulnerable, such as their lifecycle and how difficult it can be to detect their roosts.

1.5 During the winter there are relatively few insects available, so bats hibernate. They seek out appropriate sheltered roosts, 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 greatly reduces their energy requirements so that their food reserves last as long as possible. If fat reserves are lost when a hibernating bat is disturbed, these cannot easily be replaced, this may jeopardise successful attempts to become pregnant and give birth to live young in the following spring.

Photo 1: Natterer's bat.
Image credit: Ross Baker.

1.6 During the spring and summer period, female bats gather together into maternity colonies for a few weeks to give birth and rear their young (called pups). Usually only one pup is born each year. Bats may congregate from a large area to form these maternity roosts in warm and dry environments, so impacts at the summer breeding site can affect the whole colony of bats from a wide surrounding area. Both winter and summer roosts have specific conditions that bats require at those times of the year, and that is why bats are so faithful to their roosts. They are also an unusually long-lived mammal with a slow reproductive rate for their size, meaning that they return year after year to roosts. If roosts are damaged or disturbed it takes a very long time for a population to recover. Their lifecycles make bats extremely ecologically vulnerable.

1.7 **Key message:** bat population recovery and status are important, not just because of their intrinsic value as unique mammals and their ecological vulnerability, but also because bats are bio-indicator species. This means a healthy bat population in an area indicates a properly functioning ecosystem for the species within it, which includes humans. Healthy ecosystems provide and regulate our environment and are critical in supporting our economy, as well as meeting our wider societal needs.[i] Coupled with the historical losses of bat numbers, this is why all of our bats are fully protected under the law.

Why can Artificial Light At Night (ALAN) be such a problem for bats?

1.8 Bats in the UK are nocturnal mammals with highly sophisticated echolocation systems that allow them to avoid obstacles, socialise and catch insect prey in complete darkness. When flying, bats produce a stream of high-pitched calls (above the range of human hearing) and listen to the echoes, to produce an acoustic picture of their surroundings, commonly called "echolocation". Echolocation has allowed bats to avoid competition from daytime insectivorous birds such as house martins, swifts and swallows. Fossil records have shown bats evolved echolocation over 50 million years ago[ii] so have adapted to a world without light since that time.

1.9 It is estimated that by 2016 more than 80% of the world human population and more than 99% of the United States of America and European population lived under light-polluted skies. Worldwide this is an increase of more than 14%[iii] since 2001.[iv v vi]

1.10 For bats, artificial lighting is thought to increase the chances of predation by avian predators, such as owls and hawks; in lit areas bats modify their behaviour, potentially in response to this threat.[vii] Many avian predators will hunt bats, which may be one reason why bats avoid flying in the day;[viii] species such as peregrine falcons have been recorded hunting bats in lit environments.[ix]

How are bats impacted:

At roosting sites?

1.11 Illuminating a bat roost can cause disturbance[x] and this may result in the bats deserting the roost, or even becoming entombed within it.[xi] Lighting would therefore be considered an obstruction under the legislation protecting bats and their roosts. Light falling on a roost access point will at least delay bats from emerging, and this shortens the amount of time available to them for foraging.[xii] As the main peak of nocturnal insect abundance occurs at and soon after dusk, a delay in emergence means this vital time for feeding is missed. This has been shown to have direct impacts on bats' reproductive ecology, such as a study showing slower growth rates and starvation of young.[xiii] In addition, the associated flightpath to and from the access point is just as valuable, and vulnerable, as the roost itself. Severing a key flightpath some distance from the roost could cause desertion in its own right, and this loss of a roosting site could constitute an offence under the legislation.

When foraging?

1.12 In addition to causing disturbance to bats at the roost, artificial lighting can also affect the feeding behaviour of bats. Many night-flying species of insect that bats hunt are attracted to light,[xiv] especially those light sources that emit an ultraviolet component (Light Emitting Diodes (LEDs) have removed this) or have a high blue spectral content (this can include LEDs).

1.13 The slower-flying, broad winged species have been shown to avoid commuting and foraging routes illuminated with a variety of different street luminaires[xv xvi xvii] such as:

- long-eared
- Myotis species (which include Brandt's, whiskered, Daubenton's, Natterer's and Bechstein's)
- barbastelle
- greater and lesser horseshoe

1.14 Consequently, these bat species are put at a competitive disadvantage and are less able to forage successfully and efficiently. This may have an impact upon fitness and breeding success. It is noticeable that most of Britain's rarest bats are among those species recorded as avoiding ALAN, so ALAN has potentially devastating conservation consequences for these species.[xviii]

1.15 For a number of years studies have recorded that faster-flying species can congregate around white light sources, species such as:

- noctule
- Leisler's
- serotine
- pipistrelle

1.16 This is particularly true for lights sources with ultra-violet spectrum light, with the bats subsequently feeding on the insects attracted to the light.[xix xx xxi] This is a problem especially if it is a single light source in a dark area, as it creates a 'vacuum effect', denuding the surrounding area of invertebrate prey.[xxii] As well as moths,[xxiii] a range of other insects can be attracted to light, such as craneflies, midges and lacewings.[xxiv] While this might seem to give these faster-flying species a competitive advantage, the bats are risking predation, but have little choice if insects are attracted to a light source. This only takes into account the benefits to these species from a foraging perspective when considering their roosting and commuting behaviours, the cumulative impacts from ALAN are likely to be negative to their Favourable Conservation Status (FCS).[xxv]

1.17 Dense tree cover has been shown to dampen the negative effect of street luminaires without UV (in this case LEDs) for open-space foraging faster-flying bats such as noctules, Leisler's and serotines. Yet dense tree cover did not mitigate the negative impacts of light sources with UV (in this case metal halides and mercury vapour lamps) or without UV on clutter-adapted slower-flying Myotis species.

1.18 **Key message:** it is important to minimise ALAN close to vegetation, particularly for slower-flying species, and the need to increase dense vegetation in urban landscape to provide, not just roosting opportunities, but also protection against ALAN for open-space foraging bats in city landscapes.[xxvi]

1.19 The effects of artificial lighting on drinking resources for bats has also been recorded to have a negative impact. White light has been shown to stop slower-flying species drinking at cattle troughs, and even for faster-flying species drinking behaviour was reduced.[xxvii]

When commuting through the landscape?

1.20 **Key message**: when considering how bats move through the landscape, ALAN has been shown to be particularly harmful along river corridors, near woodland edges and hedgerows.

1.21 Continuous lighting in the landscape, such as along roads or waterways, creates barriers[xxviii] which many bat species cannot cross, especially slower-flying species,[xxix] even at very low light levels. lesser horseshoe bats have been shown to move their flight paths which link their roosts and foraging grounds to avoid artificial light installed on their usual commuting routes. Significant effects have been recorded from as low as 3.6 lux.[xiv] Furthermore, the average light level on hedgerows most regularly used by this species has been recorded at 0.45 lux.[xiii]

Photo 2: common pipistrelle bat flying. Image credit: Hugh Clark.

1.22 Another slow flying species group (Myotis) exhibited avoidance behaviour from luminaires while commuting through an urban landscape, showing negative impacts through avoidance behaviour below 1 lux, and up to 25m from the light source. A positive effect was observed for two faster-flying species groups (Pipistrellus and Nyctalus), where bat activity increased, indicating attraction to the light source for foraging, at 10m range from the luminaire, however this activity was only observed between 1 and 5 lux. [xxx]

1.23 **Key message**: the very low light levels and distances from light sources shown in these studies indicates the considerable sensitivity of many of the UK's light averse species, emphasising the need to maintain or reduce existing light levels in the environment.

1.24 Even bat species that have been shown to opportunistically forage in lit conditions (see above) are also impacted by ALAN when commuting through the landscape. In our cities, for example, common pipistrelles, the UK's most numerous species, have been recorded avoiding gaps that are well lit, thereby creating a barrier effect. [xxxi]

1.25 Fast-flying noctule bats being radio-tracked in an urban setting were only recorded around artificial lighting by water, where insects are likely to gather and provide a food source. Illuminated roads were avoided in favour of dark corridors that were used for commuting. [xxxii] This has significant implications when we think about how fragmented the vegetation often is in the urban environment, and the lack of dark green corridors.

1.26 Lack of dark blue corridors (rivers and canals without light on them) has also been shown to be an issue for commuting fast-flying bat species, with one study finding that bat activity for *Pipistrelle* spp. was 1.7 times lower in lit urban bridge sites. Bats tended to keep a greater distance from, and to fly faster close to, illuminated bridges. [xxxiii]

1.27 An experiment testing the impacts of Part Night Lighting on Riparian bat species [xxxiv] showed that overall activity under full-night treatments was significantly lower in comparison to both unlit and PNL treatments. This suggests PNL limits negative impacts of ALAN. However, a 50% reduction in relative feeding activity by Myotis bats in the 4 hour PNL treatment, (but not the 2 hr PNL treatment), suggests an interaction exists between timing and the duration of lighting treatments, and the peak activity windows of these light adverse and late emerging Myotis bats. This highlights the need to consider carefully how, when and for how long each night we should light our waterways for leisure and safe access, see Case Study 1.

1.28 An experiment testing the effects of dimming street luminaires [xxxv] revealed that Myotis bats showed no significant difference in activity levels between unlit treatments and light sources dimmed between 0 - 25%. Once luminaire intensity exceeded 11.35 lux, Myotis passes were significantly reduced.

1.29 **Key message:** These studies show that even species known to display some light opportunistic behaviours can be detrimentally impacted by ALAN, and that it is a complicated picture requiring knowledge gathered at a site level to make accurate predictions of impacts. This is a particular issue in recent years with moves to save energy by using PNL schemes, or switching from low pressure sodium to LED Light sources. This is because it can lead to an increase in light intensity, so in an attempt to tackle climate change this may impact bat conservation, especially where there are light averse species present [xxxvi] and/or at high light intensities. [xxxvii]

What difference does the spectrum of the light make?

1.30 While the harmful impact caused by blue-rich light has been recorded for a number of years, recent studies have revealed that at the other end of the colour spectrum there may be a chance to reduce or even avoid many impacts to some bat species. Acoustic research into the impacts of white, green and red light treatments in the Netherlands recorded slower-flying, long-eared and Myotis species avoided white and green spectrum light sources, however faster-flying pipistrellus species were significantly more abundant feeding at these lights. However, both groups were equally abundant in the red light areas, compared to the dark control. [xxxviii] [xxxix] Referred to here as 'red light', light sources in the red spectrum mainly consist of long wavelength light above 600nm with an RA value of 60 so as to allow good colour recognition, in this document 'red' light sources are referred to as 'red spectrum' light sources.

1.31 A study in France looked at how fast and slow flying foraging bats changed their flight behaviours in response to white and red streetlights placed in the forest edge, using an emerging scientific method for bat surveying, 3D mapping. This study showed that all bats strongly change flight patterns, increasing the probability of the bats flying in the forest. [xl] The study showed avoidance behaviour that acoustic studies alone could potentially miss. It is important therefore to try and understand what the different spectrum of light could mean for reducing impacts on UK species.

1.32 A recent study in Scotland looking at foraging activity by slower-flying Daubenton's bats recorded that activity was significantly reduced in white and amber lighting, compared to the dark control, but not in red lighting. [xli]

1.33 Another study, in the UK, where one side of a hedgerow was illuminated over four nights using lights with different spectra, recorded slow-flying Myotis spp. avoided orange, white and green light. Faster-flying pipistrellus spp. were significantly more abundant at these light types, compared to dark controls, most probably in response to accumulations of insect prey. No effect of any light type was found for fast flying Nyctalus or Eptesicus spp. However, for one of the UK's rarest and most light shy species, the lesser horseshoe bat, this study showed that even red light resulted in avoidance behaviour, with bats flying on to the darker side of a vegetated flightline. [xlii]

1.34 Reaction has also been recorded in a laboratory setting; in a cave entrance experiment, all light colours reduced the activity of all emerging species, with light sources in the red spectrum having the least negative effect overall. However, horseshoe bat species were impacted most strongly, matching their refusal to fly at all under any light treatment in the flight room.[xliii]

Photo 3: 'red spectrum' street luminaires deployed in Worcestershire. Image credit: Worcestershire County Council.

1.35 The picture for the impacts of red light on faster-flying species might also be more complex than it appears; when analysing avoidance behaviour to the species level, rather than genus, pipistrellus species (frequently grouped together when discussing impacts) have been shown to exhibit different levels of impact. A study in Southampton looking at the viability of replacing white spectrum luminaires in an urban park with red spectrum luminaires, to reduce ALAN impacts on bats and people, recorded reduced levels of avoidance behaviour for all bat species present except where there were high activity levels of soprano pipistrelle. However, when the common and soprano pipistrelle behaviour was analysed together, it appeared that pipistrelle species were unaffected as common pipistrelles dominated the dataset. This study is being expanded to collect further data and help understand these initial results in a wider context.

1.36 **Key message**: This work emphasises the importance of always completing analysis of bat survey data past guild level to species level to truly understand how species are impacted at a particular site.

1.37 Green light has been shown to not only impact upon foraging bats (see above), but also bats migrating through Europe. Nathusius' and soprano pipistrelles have been shown to be attracted to green light from a distance further than their echolocation calls reach, indicating that they are attracted to the light rather than insects.[xliv] This demonstrates positive light attraction for this species, meaning limiting UV is only part of the solution and indicates impacts from artificial light at night that aren't yet fully understood for migrating bats. This is especially true given that the most recent studies in this area suggest that red light also causes positive light responses over and above warm-white light for both of these bat species, when they are migrating.[xlv]

1.38 These studies show that ALAN across the visible spectrum can adversely impact bat species, with some particularly sensitive species, such as horseshoe bats, often displaying light averse behaviour. Some studies indicate that monochromatic red lighting can, in certain contexts, have reduced adverse impacts on a number of bat species.

1.39 **Key message:** this research highlights the importance of integrating avoidance measures (as per the first step of the mitigation hierarchy see Figure 2) into developmental design, by retaining ecologically functional 'dark corridors' within schemes wherever feasible, and in preference to seeking lighting mitigation strategies.

Table 1: Summary of the effect of ALAN on UK bat species.

Species	Roost	Flight Corridor	Foraging Area	Drinking Site	Migration	Landscape Level	Habitat Type
Greater Horseshoe *Rhinolophus ferrumequinum*	Negative effect	na	na	na	na	na	clutter
Lesser Horseshoe *Rhinolophus hipposideros*	Negative effect	Negative effect	na	na	na	Negative effect	clutter
Brown Long-eared *Plecotus auritus*	Negative effect	Negative effect	Negative effect	Negative effect	na	Negative effect	clutter
Grey Long-eared *Plecotus austriacus*	na	na	na	na	na	na	clutter
Bechstein's *Myotis bechsteinii*	na	na	na	na	na	na	clutter
Natterer's *Myotis nattereri*	Negative effect	na	na	Negative effect	na	na	clutter
Daubenton's *Myotis daubentonii*	na	No effect	Negative effect	na	na	Negative effect	edge
Whiskered *Myotis mystacinus*	na	na	na	na	na	na	edge
Brandt's *Myotis brandtii*	na	na	na	na	na	na	edge
Alcathoe *Myotis brandtii alcathoe*	na	na	na	na	na	na	edge
Western Barbastelle *Barbastella barbastellus*	Negative effect	Negative effect	Negative effect	Negative effect	na	Negative effect	edge
Common Pipistrelle *Pipistrellus pipistrellus*	na	No effect	No effect	Negative effect	na	Positive / Negative effect	edge
Soprano Pipistrelle *Pipistrellus pygmaeus*	Negative effect	No effect	No effect	na	Negative effect	No effect	edge
Nathusius' Pipistrelle *Pipistrellus nathusii*	na	na	na	na	Negative effect	Positive / Negative effect	edge
Common Noctule *Nyctalus noctula*	na	No effect	Positive / Negative effect	na	na	Positive / Negative effect	open
Lesser Noctule *Nyctalus leisleri*	na	na	na	No effect	na	Positive effect	open
Serotine *Eptesicus serotinus*	na	na	na	na	na	Positive effect	open

(yellow)	**Positive effect**
(grey)	**No effect**
(blue)	**Negative effect**
na	**No data available**

Data in table is indicative only, is drawn predominantly from European studies (where data available) and shows numerous data gaps due to lack of research data, therefore bat behaviour within the UK may vary and needs assessing on a site by site basis.

2. Powers to install street lighting

2.1 In United Kingdom and Ireland, the provision of street lighting is a power not a duty, and once installed it must be maintained. It is primarily installed for perceived safety of the person, property and to stimulate the night-time economy. Though it is a power, once installed the asset owner has a duty of care to ensure it is safe for use and fit for purpose. The two functions are not the same:

- **Safe for Use** requires an asset to be managed in such a way that it does not pose an unacceptable risk to public safety
- **Fit for Purpose** requires an asset to be managed in such a way that it remains available for use by those permitted for the route

2.2 Local councils or central government agencies, or departments are responsible for the specification and design of street lighting in their administrative area. On new developments, prospective public highways (including lighting) are built under an agreement with the highway authority to ensure that it will comply with their requirements. The road remains in the ownership of the developer until works are completed. On completion of the road, it is offered to the highway for adoption. The highway authority carries out inspections to ensure compliance with their specification. If the road is compliant, it is 'adopted', where ownership passes to the highway authority, and they will maintain it as part of their network.

2.3 Responsibility for the management of roads and the highway authority role will vary depending on which part of United Kingdom or Ireland it is located. Even when lighting is not adopted, there is still a duty to maintain it.

Street lighting powers in England

2.4 The strategic road network, comprising motorways and trunk roads (the most significant 'A' roads) are administered by National Highways (formerly Highways England), a government-owned agency. All other public roads are maintained by local authorities, usually a city, metropolitan council, London borough or county council. In London, the area within the M25 motorway, the motorways are administered by National Highways and the main road network by Transport for London (TfL). National Highways, the Highway Authorities and TfL, in discharging their powers also assume the power for the provision of street lighting conferred in the Highways Act 1980. In addition, District and Parish Councils can assume the power to light roads and public places (not necessarily highways), conferred in Parish Councils Act and Section 7 of Highways Act.

Street lighting powers in Scotland

2.5 The major road network, comprising motorways and most important 'A' roads are managed by Transport Scotland, a government-owned agency. Almost all other public roads and the lighting on them are maintained by 32 local authorities. The powers for the provision of street lighting is conferred in the Roads (Scotland) Act.

Street lighting powers in Wales

2.6 Trunk roads and motorways and their lighting is managed by Welsh Government through either the North & Mid Wales Trunk Road Agency, or South Wales Trunk Road Agency. All other roads and the lighting on them are managed by one of the 22 county, city and county, or county borough councils.

Street lighting powers in Ireland

2.7 In the Irish republic, National Roads Network, prefixed M (motorway) or N (national road), is managed by a central government body, Transport Infrastructure Ireland. Other roads and the lighting on them are managed by the 31 county, city or city and county councils.

2.8 In Northern Ireland, the Northern Ireland Assembly has responsibility for all roads and lighting through their Department of Infrastructure.

The Appendix contains light and lighting terms for reference.

3. Regulation and control of street lighting

3.1 Influencing practitioners' good design principles is a seemingly ever-changing landscape of local and national policy, evolving technology and scientific knowledge. Consequently, both lighting engineers and ecologists must maintain an up to date understanding, and ensure lighting designs respond to these drivers appropriately. Here we summarise some of the principal drivers operating in the English planning system, however practitioners should be aware of the scope of requirements posed by both devolved authorities and individual planning authorities.

3.2 In its **25 Year Environment Plan** (01/2018), the UK Government made a commitment to effectively manage light pollution. A fundamental principal to control light pollution, familiar to many practitioners, is application of the 'mitigation hierarchy'. This is operated through England's **National Planning Policy Framework** (NPPF, July 2021, Para 180(a)) as: *"if significant harm to biodiversity resulting from a development cannot be avoided (through locating on an alternative site with less harmful impacts), adequately mitigated, or, as a last resort, compensated for, then planning permission should be refused".* Subsequently, the NPPF sets out how effects of lighting should be considered in the planning system. Paragraph 180.c directs that policies and decisions must ensure new developments are appropriate for their location by considering, and limiting, the likely effects, including cumulative effects, of artificial light pollution on the natural environment. The NPPF draws particular attention to potential for light pollution to cause impacts on 'intrinsically dark landscapes' and on 'nature conservation'.

3.3 **National Planning Policy Guidance** (NPPG) provides further detail by encouraging good design to consider whether lighting is needed at all, and to ensure that the right light is used in the right place at the right time. This stepwise application of the mitigation hierarchy should therefore drive a design challenge to determine whether there is a justifiable requirement to light. As well as minimising energy use and carbon emissions, NPPG highlights that good design is preferable to potentially incurring costly and difficult retrofits. The NPPG describes how local authorities and applicants should consider whether a development has potential to cause an impact on protected sites, species, or on ecosystems. Paragraphs 5 and 6 (01/11/2019) of the NPPG highlights that the position, duration, type of light source, spectra (particularly blue or ultra-violet content) and level of lighting which might all be considerations when assessing potential for light pollution to cause an impact on wildlife. Aligned with the mitigation hierarchy, NPPG encourages avoidance measures (Para 4, 01/11/19) such as PNL, dimming or switching-off at sensitive times to avoid impacts on sensitive ecological receptors (e.g. protected sites, species or ecosystems) and it also highlights the importance of considering the polarising and reflectance values of materials, and the need to avoid the effects of glare. "*In Particular"* the NPPG notes "*lighting schemes for developments in protected areas of dark sky or intrinsically dark landscapes need to be carefully assessed as to their necessity and degree*". Case study 5 demonstrates a 'no light approach'.

3.4 Public authorities have a requirement to comply with the statutory Biodiversity Duty (S.40 of the NERC Act, 2006), this duty was recently strengthened through the Environment Act (2021). in May 2023 UK Government guidance on the newly strengthened Biodiversity Duty highlighted a requirement for public authorities to review policies and processes to ensure impacts to biodiversity are minimised and gains for wildlife secured where possible. As part of this duty, Government guidance highlights that artificial lighting should be designed to minimise effects on nature. Additionally, many Local Planning Authorities will also have relevant biodiversity policies within their **Local Development Plans** which might address impacts of pollution, including light pollution, on wildlife, and may have also produced **Supplementary Planning Documents** addressing ecological or biodiversity matters. These may provide further direction on assessment and control of light pollution on wildlife. A number of National Parks, Areas of Outstanding Natural Beauty and Dark Sky Reserves have also published **technical guidance,** and this often provides helpful direction on assessment and control of lighting impacts on the natural environment.

3.5 Getting the right information at the right stage of the planning process is critical. Government **Circular 05/2006** (ODPM 2005) states that "*It is essential that the presence or otherwise of protected species, and the extent that they may be affected by the proposed development, is established before the planning permission is granted, otherwise all relevant material considerations may not have been addressed in making the decision*".

3.6 Taking an appropriately proportional approach to assessing lighting impacts on wildlife is important, and **British Standard BS 42020:2013** Clause 5.5 states that "*The work involved in preparing and implementing all ecological surveys, impact assessments and measures for avoidance, mitigation, compensation and enhancement should be proportionate to the predicted degree of risk to biodiversity and to the nature and scale of the proposed development*". Ecological reports which assess effects of lighting on wildlife, and which propose any avoidance, mitigation or compensation measures required, must be prepared by a professionally competent ecologist (Clause 4.3) and provide sufficient detail and clarity to enable both applicant and decision-maker to establish whether the proposals and recommendations are practicable, deliverable and acceptable (Clause 6.6.1). Case study 8 demonstrates a multiple disciplinary approach to agreeing a complicated lighting mitigation strategy.

3.7 Once the extent of any effect on a protected species is understood, **BS 42020:2013** offers the following model condition for planning authorities to secure an appropriate lighting design (D.3.5):

> *"Prior to occupation, a 'lighting design strategy for biodiversity' for [… specify buildings, features or areas to be lit …] shall be submitted to and approved in writing by the local planning authority. The strategy shall:*
>
> *a) identify those areas/features on site that are particularly sensitive for [… insert species…] and that are likely to cause disturbance in or around their breeding sites and resting places or along important routes used to access key areas of their territory, for example, for foraging; and*

b) *show how and where external lighting will be installed (through the provision of appropriate lighting contour plans and technical specifications) so that it can be clearly demonstrated that areas to be lit will not disturb or prevent the above species using their territory or having access to their breeding sites and resting places.*

All external lighting shall be installed in accordance with the specifications and locations set out in the strategy, and these shall be maintained thereafter in accordance with the strategy. Under no circumstances should any other external lighting be installed without prior consent from the local planning authority."

3.8 A full understanding of the appropriate technologies to be used, and how this marries with the scientific data collected on site, is needed to inform any decisions and should be discussed and agreed with the suitably experienced experts on the project team. In terms of suitably experienced experts, item 'a)' above should be prepared by an ecological consultant and 'b)' a lighting engineer. In addition, depending on the potential impacts and receptors on a site, internal light spill may also require assessment lead by expert advice.

3.9 **Key message**: The mitigation hierarchy (see Figure 2) applies to lighting design: impacts to biodiversity should be avoided in the first instance through design and where this has been clearly demonstrated not to be possible, appropriate mitigation needs to be put in place. Compensation is the least desirable option, so all other avenues should first be explored and ruled out. In parallel, opportunities to design lighting betterment for biodiversity should be sought wherever possible. Subsequently, planning authorities should seek sufficient information to provide confidence that the mitigation hierarchy has been appropriately applied.

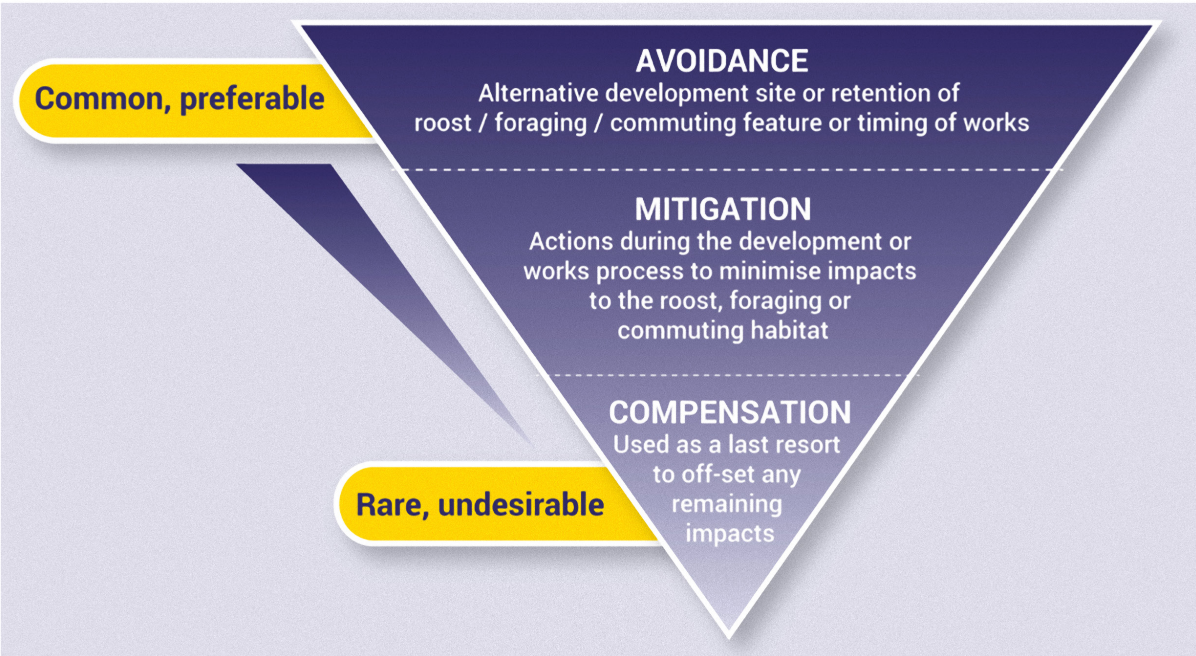


Figure 2. Mitigation hierarchy emphasising the importance of considering avoidance in the first instance (credit Bat Conservation Trust).

What do developers need to do to ensure bats and the laws protecting them are fully considered?

3.10 All of the research outlined above demonstrates the complexity of this topic; in terms of the impact type, species responses and where light is placed in the landscape, understanding which bat species are present, and how they are using a site, is essential.

3.11 Natural England, Natural Resources Wales, Scottish Natural Heritage or Northern Ireland Environment Agency will need to see that any impacts have been fully assessed, and appropriate mitigation considered within any mitigation licence applications in relation to bats. Similarly, these bodies will be statutory consultees in planning applications where impacts on Special Areas of Conservation (SACs) and Sites of Special Scientific Importance (SSSI), including those designated for bat conservation, are considered possible. Local authorities also have a duty to ensure impacts upon legally protected species are avoided, and impacts upon bats are a material consideration in any planning permission. Furthermore, local authorities typically have specific planning policies ensuring that impacts upon wildlife, including bats, are avoided within development.

3.12 Whether species present on a site are 'light opportunistic' (faster-flying) or 'light averse' (slower-flying), new lighting on any site, whether dark or currently illuminated to some extent, could potentially cause detrimental impacts on an individual, population and ecosystem level. Ecological and lighting design advice should be sought right at the start of a project whenever lighting is being considered, in advance of any lighting design or fixing of scheme layout. It is recommended this forms part of strategic planning decisions, as it could determine if a planning application is unviable if the site can't be illuminated to British Standard requirements.

3.13 **Key message**: There are no lux level thresholds available for individual species to negate the need for site specific advice. Every site is different and interactions between species at lit sites has even been shown to give site and species specific responses.[xlvi][xlvii] The key in the first instance is to maintain or reduce existing light levels, and reduce blue content to protect the bat species present; this is in line with the mitigation hierarchy where impacts are avoided in the first instance by being planned out, saving both time and costs. A scheme may then look at ecological betterment ('enhancement') through a sensitive lighting design. This is discussed in detail in the 'Mitigation' chapter. Ideally light levels should always be designed to minimise potential environmental impacts[xlviii] and to maximise the potential of habitat and species enhancement work, through multidisciplinary working and evidence-based new, or retrofit, scheme design.

4. Bats, lighting and the mitigation hierarchy

Introduction

4.1 This chapter provides a process for considering the impact on bats as part of a proposed lighting scheme or new development incorporating night-time lighting. It contains a toolkit of techniques which can be used on any site, whether a small domestic project or larger mixed-use, commercial or infrastructure development. It also provides best practice advice for the design of a lighting scheme, for both lighting professionals and other users who may be less familiar with the terminology and theory.

4.2 Under the Agent of Change principle within national planning policy, those seeking to introduce a new plan or project are also responsible for the management of its impact. Therefore, it is crucial that the impacts of obtrusive lighting are mitigated or avoided altogether. While this chapter focuses on how potential lighting impacts on bats can be identified, avoided and mitigated, opportunities for ecological betterment beyond maintaining the status quo should be pursued wherever possible. Doing so would not only fulfil our responsibilities under this principle but contribute to Biodiversity Net Gain in line with legislation. [xlix] Further information on Biodiversity Net Gain can be found here: https://cieem.net/i-am/current-projects/biodiversity-net-gain/

4.3 Effective avoidance and mitigation of lighting impacts on bats relies on close collaboration from the outset between multiple disciplines. Depending on the specific challenges this will almost certainly involve ecologists working alongside architects and/or engineers; however, lighting professionals and landscape architects should be approached when recommended by your ecologist. This should be done at as early a stage as possible, in order to ensure the proposed lighting strategy is acceptable to all disciplines, mitigation is effective and is not in breach of legislation. In this way, delays to approval/adoption and unforeseen costs or liability can be avoided.

4.4 The stepwise process and key follow-up actions are outlined in the flowchart overleaf see figure 3 and followed throughout the Chapter. The questions in the flowchart should be asked in good time to allow any necessary bat survey information to be gathered in advance of lighting design, or fixing a scheme design.

4.5 It should be noted that the measures discussed in this document relate only to the specific impacts of lighting upon retained or newly created bat habitat features, on or adjacent to the site. If loss or damage to roosting, foraging or commuting habitat is likely to be caused by other aspects of the development, separate ecological advice will likely be necessary in order to avoid, mitigate or compensate for this legally and/or in line with ecological planning policies.

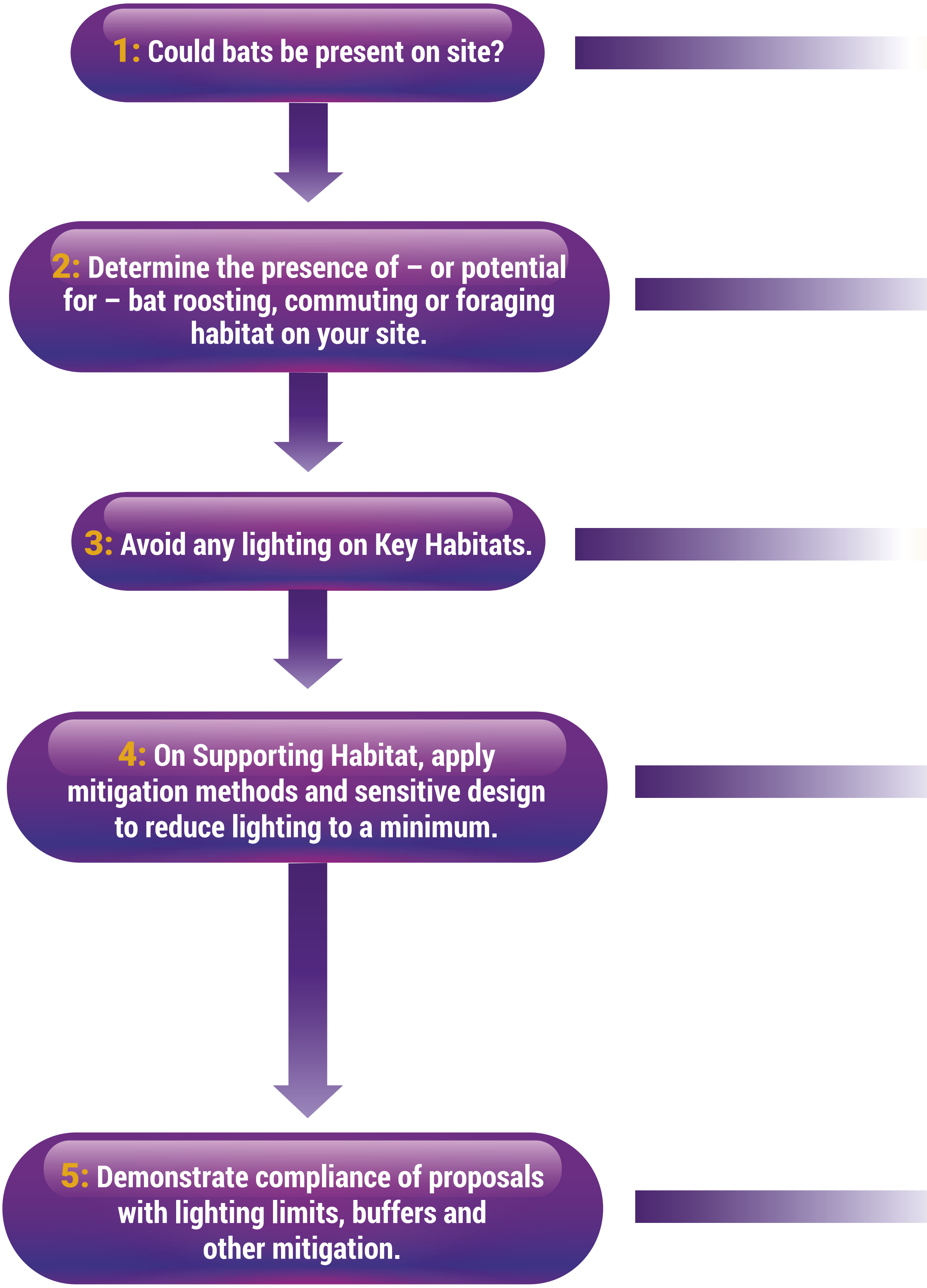

1: Could bats be present on site?
2: Determine the presence of – or potential for – bat roosting, commuting or foraging habitat on your site.
3: Avoid any lighting on Key Habitats.
4: On Supporting Habitat, apply mitigation methods and sensitive design to reduce lighting to a minimum.
5: Demonstrate compliance of proposals with lighting limits, buffers and other mitigation.

Figure 3. Ecology process for lighting.

Step 1: Could bats be present on site?

4.6 If there is no ecological data for your site, an ecologist should be contacted at the earliest opportunity to advise on an initial survey and any potential follow-on surveys. This information should be collected as early as possible in the design process, and certainly before lighting is being specified, so as to avoid the need for costly revisions.

4.7 If any of the following habitats occur on site, and are adjacent to or connected with any of these habitats on or off site, it is possible that proposed lighting may impact local bat populations (please note this list is indicative and advice should be sought from an ecological consultant):

- Woodland, individual mature trees or lines of trees
- Hedgerows and scrub
- Ponds, lakes and other wetland
- Ditches, streams, canals and rivers
- Infrequently managed grassland, or parks, gardens and Public Open Space
- Buildings - Especially, **but not limited to**, those in disrepair or built pre 1970s
- Gravel pits, quarries, cliff faces, caves and rock outcrops
- Any building or habitat known to support protected species
- Any additional scenarios as advised by your Local Planning Authority (LPA)

4.8 If you are unsure about whether bats may be impacted by your project, and an ecologist has not yet been consulted, sources of information on the presence of bats within the vicinity of your site include the following.

- Local Environmental Records Centres (LERC) - Will provide third-party records of protected and notable species for a fee. Search http://www.alerc.org.uk/ for more information
- The Wildlife Assessment Check is a free online tool designed by the Partnership for Biodiversity in Planning to support small-to-medium scale developments by helping identify whether ecological advice should be sought prior to submitting a planning application. The WAC is available online at www.biodiversityinplanning.org/wildlife-assessment-check/
- National Biodiversity Network Atlas - Provides a resource of third-party ecological records searchable online at https://nbnatlas.org - typically this is less complete than LERC data. Please note: Some datasets are only accessible on a non-commercial basis, while most can be used for any purpose, provided the original source is credited
- Local Authority Planning Portal - Most local planning authorities have a searchable online facility detailing recent planning applications. These may have been accompanied by ecological survey reports containing information on bat roosts and habitats

- Defra's MAGIC map - Provides an online searchable GIS database including details of recent European Protected Species licences, and details of any protected sites designated for bat conservation

4.9 The professional directory at the website of the Chartered Institute of Ecology and Environmental Management (www.cieem.net) provides details of ecologists in your area with the relevant skills/experience. The early involvement of a professional ecologist can minimise the likelihood of delays at the planning stage (if applicable) and ensure your project is compliant with conservation and planning legislation and policy.

Step 2: Determine the presence of/potential for bat roosts or habitat and evaluate their importance

4.10 Once a potential risk to bats has been identified, the ecologist will visit the site in order to record the habitats and features present, and evaluate their potential importance to bats. Additionally, they should consider the likelihood that bats could be affected by lighting both on and immediately off site. This survey may also include daytime building and tree inspections, and the deployment of automated bat detectors. On the basis of these inspections, further evening surveys may be recommended, either to determine the presence or likely absence of bats within buildings and/or trees, or to assess the use of the habitats by bats by means of a walked survey. Such surveys may be undertaken at different times during the active season (May - September) and should also involve the use of automated bat detectors left on site for a period of several days. The surveys should be carried out observing the recommendations within the Bat Conservation Trust's Bat Surveys for Professional Ecologists: Good Practice Guidelines (Collins, 2016), and the Interim Guidance Note: Use of Night Vision Aids for Bat Emergence Surveys (BCT, May 2022), or as superseded.

4.11 The resulting report will detail the relative conservation importance of each habitat feature to bats, including the roost-supporting potential of any built structures or trees. The ecologist's evaluation of the individual features will depend on the specific combination of contributing factors about the site, including:

- The conservation status of species likely to be present
- Geographic location
- Type of bat activity likely (breeding, hibernating, night roosting, foraging etc.)
- Habitat quality
- Habitat connectivity off-site
- The presence of nearby bat populations or protected sites for bats (usually identified in a desk study)

4.12 The evaluation will enable the ecologist to determine the presence of any Key Habitats or Supporting Habitats for bats. The whereabouts of these habitats should be set out on a plan of the site or as an Ecological Constraints and Opportunities Plan (ECOP), see Case Study 3. The bat habitat plan/ECOP and report can then be used to help guide the design of the lighting strategy (see next steps) as well as the wider project.

4.13 Key Habitats are those which are considered essential for the function and stability of local bat populations, while Supporting Habitats may be of lesser significance or usage. Habitats falling within neither category are considered to be of negligible or very low importance to bats.

4.14 Examples of Key Habitats include:

- Roosting and swarming sites for all species and their associated flightpaths and commuting habitat
- Foraging or commuting habitat for highly light-averse species (greater and lesser horseshoe bats, some Myotis bats, barbastelle bats and all long-eared bats) or nationally/locally rare species
- Foraging or commuting habitat supporting relatively large numbers of bats or high activity rates as assessed through survey
- Any habitat otherwise assessed by the ecologist as being of elevated importance in maintaining the 'favourable conservation status' of the bat population using it

Step 3: Avoid lighting on any Key Habitats

4.15 An adverse impact from illumination onto a Key Habitat feature is likely to have a significant effect on the bats using it. Therefore, an absence of artificial illumination and glare acting upon both the feature and an appropriately sized buffer zone is most often the only acceptable solution. An ecologist will be best placed to set the size of such a buffer zone according to the species present and the level of usage, and these can be tens of metres if unattenuated light spill or glare from local sources is predicted. The input of a lighting professional should be sought when determining the distances of light spill from new sources and likelihood of glare. It is recommended that proposals are communicated by them to the Principal Designer and the Highways Designer, (if applicable) as in some circumstances these decisions may influence highway function (e.g. visibility departures). Further information on demonstrating an absence of illumination within proposals via lux/illuminance contour plans is provided in Step 5.

4.16 As detailed in Section 2.1, there is no legal duty requiring any place to be lit. British Standards and other policy documents allow for deviation from their own guidance where there are significant ecological/environmental reasons for doing so. It is acknowledged that in certain situations lighting is critical in maintaining safety, such as some industrial sites with 24hr operation, or in high-risk security situations. Nevertheless, these are not exempt from the statutory protection afforded to bats, their roosts and commuting routes directly associated with roosts, and good design principles recommended under industrial documents such as the Institution of Lighting Professionals' GN01: The Reduction of Obtrusive Light remain best practice. However, in the public realm, while lighting can increase the perception of safety and security, measurable, objective benefits on safety and security are less well established. Consequently, lighting design should be holistic, taking into consideration the relevant British Standards or local policies concerning lighting but, through a risk assessment-style process, be able to fully take into account the presence of protected species and the likely adoption of mitigation approaches through proper engagement with local communities (see Case Study 4).

4.17 Completely avoiding any lighting conflicts in the first place is advantageous, because proposals would be automatically compliant with the relevant wildlife legislation and planning policy, and costly, time-consuming additional surveys, mitigation and post-development monitoring would be avoided. Furthermore, LPAs are likely to favour applications where steps have been taken to avoid such conflicts.

4.18 Sources of lighting which can have the potential to disturb bats are not limited to roadside, footpath or security lighting, but can also include light spill via windows, permanent but sporadically operated lighting such as sports floodlighting, and in some cases car headlights. It is important to note that these situations often comprise many complex variables, and light emission is often difficult to predict or model accurately.

4.19 A competent lighting professional should be involved in the design of proposals as soon as potential impacts (including from glare) are identified by the ecologist, in order to avoid planning difficulties, or late-stage design revision. The lighting professional will be able to make recommendations about placement of luminaires tailored to the project.

Glare

4.20 Glare (extremely high contrast between a source of light and the surrounding darkness - linked to the 'intensity' of a luminaire) may additionally affect bats over a greater distance than the area directly lit by a luminaire. Glare impacts on bats and other wildlife should be considered on the site alongside best practice advice on reducing obtrusive light (see ILP GN01).

Highways

4.21 Where highways lighting schemes are to be designed by the LPA, the ecology officer (or planning officer) should be consulted on the presence of important bat constraints, determined in Step 2, which may impact the design of the lighting scheme in order to ensure compliance with wildlife legislation.

LPA-specific guidance

4.22 Some LPAs have Supplementary Planning Documents (SPD) or other guidance concerning the management of potential development impacts on particular species of bats, or in relation to certain protected sites, such as Special Areas of Conservation (SACs). These should be consulted for particular advice concerning lighting. For example, the North Somerset and Mendip Bats SAC Guidance on Development SPD provides a methodology for calculating the specification of compensatory habitat required to off-set certain development impacts on the bat population of the SAC. In it, retained or created habitats that are subject to lighting above certain lux levels, are considered to be lost to development, with implications for compensation requirements[1].

Environmental Impact Assessment (EIA)

4.23 For plans and projects subject to the Environmental Impact Assessment (EIA) Regulations screening process, it is important for LPAs to understand the nature of mitigation measures at this relatively early stage. Under current EIA Regulations, schemes planning to avoid likely significant effects on the environment through either embedded design measures, such as sensitive site configuration or strategic land/building usage etc., or by other robust mitigation, may be exempt from EIA and therefore less costly. However, the over-reliance on conditions to effect environmental mitigation may be open to legal challenge.

Step 4: On Supporting Habitat, apply mitigation methods and sensitive design to reduce lighting to a minimum

4.24 Supporting Habitats may be less frequently used by bats compared to Key Habitats, or support fewer, or more light-opportunistic species. Consequently, a balance between a reduced lighting level appropriate to the ecological importance of each feature and species, and the lighting objectives for that area will need to be achieved.

4.25 It is important to reiterate the legal protection from disturbance that bats receive under the Wildlife and Countryside Act 1981, as amended. Where the risk of offences originating from lighting is sufficiently high, it may be best to apply the avoidance approach in Step 3. (see Case Study 5).

4.26 Advice from an ecologist and lighting professional will be essential in finding the right approach for the site according to their evaluation. The following are techniques which have been successfully used on projects to limit lighting impacts on bats, and are often used in combination for best results.

[1] https://n-somerset.gov.uk/sites/default/files/2020-03/North%20Somerset%20and%20Mendip%20Bats%20SAC%20guidance%20supplementary%20planning%20document.pdf

Dark buffers and concentric zonation

4.27 A buffer zone subdivided to into smaller zones of increasing illuminance limit further away from the Supporting Habitat would ensure light levels (illuminance - measured in lux) do not exceed certain defined limits. This has the effect of a gradual decrease in lighting from the developed zone, rather than a distinct cut-off, which may provide useable area for the project which also limits lighting impacts on less sensitive species, or less well-used habitat.

4.28 The ecologist (in collaboration with a lighting professional) can help determine the most appropriate buffer widths and illuminance limits according to the value of that habitat to bats. Figure 4 gives an example of a multi-zoned approach which includes Key Habitat (Zone A) which would receive no ALAN, and Supporting Habitat (Zones B and C) which would act as a 'light attenuation zone', but remain within the public realm, and so receive reduced light levels.

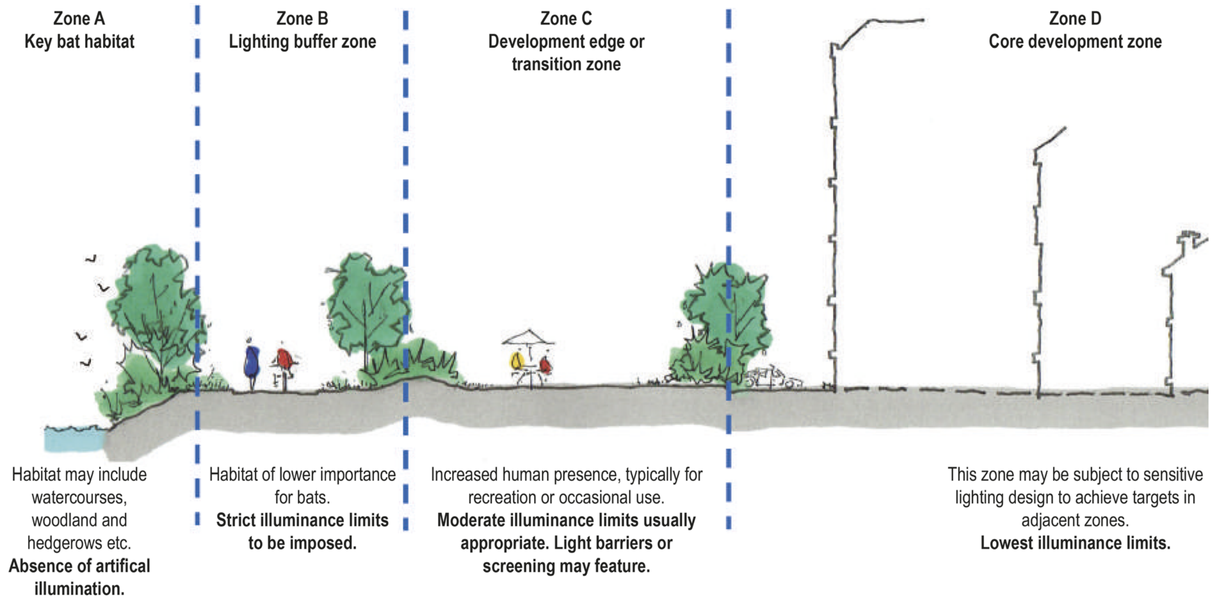


Figure 4. Example of illuminance limit zonation.

Appropriate luminaire specifications

4.29 Light sources, lamps, LEDs and their fittings come in a myriad of different specifications which a lighting professional can help to select. However, the following should be considered when choosing luminaires and their potential impact on Key Habitats and features:

- All luminaires should lack UV elements when manufactured. Metal halide, compact fluorescent sources should not be used
- LED luminaires should be used where possible due to their sharp cut-off, lower intensity, good colour rendition and dimming capability
- A warm white light source (2700Kelvin or lower) should be adopted to reduce blue light component

- Light sources should feature peak wavelengths higher than 550nm to avoid the component of light most disturbing to bats (Stone, 2012)
- Internal luminaires can be recessed (as opposed to using a pendant fitting - See Figure 5) where installed in proximity to windows to reduce glare and light spill
- Waymarking inground markers (low output with cowls or similar to minimise upward light spill) to delineate path edges (see Case Study 1)
- Column heights should be carefully considered to minimise light spill and glare visibility. This should be balanced with the potential for increased numbers of columns and upward light reflectance as with bollards
- Only luminaires with a negligible or zero Upward Light Ratio, and with good optical control, should be considered - See ILP GN01
- Luminaires should always be mounted horizontally, with no light output above 90° and/or no upward tilt
- Where appropriate, external security lighting should be set on motion-sensors and set to as short a possible a timer as the risk assessment will allow. For most general residential purposes, a 1 or 2 minute timer is likely to be appropriate
- Use of a Central Management System (CMS) with additional web-enabled devices to light on demand
- Use of motion sensors for local authority street lighting may not be feasible unless the authority has the potential for smart metering through a CMS
- The use of bollard or low-level downward-directional luminaires is strongly discouraged. This is due to a considerable range of issues, such as unacceptable glare, poor illumination efficiency, unacceptable upward light output, increased upward light scatter from surfaces and poor facial recognition which makes them unsuitable for most sites. Therefore, they should only be considered in specific cases where the lighting professional and project manager are able to resolve these issues. See Case Study 6
- Only if all other options have been explored, accessories such as baffles, hoods or louvres can be used to reduce light spill and direct it only to where it is needed. However, due to the lensing and fine cut-off control of the beam inherent in modern LED luminaires, the effect of cowls and baffles is often far less than anticipated and so should not be relied upon solely

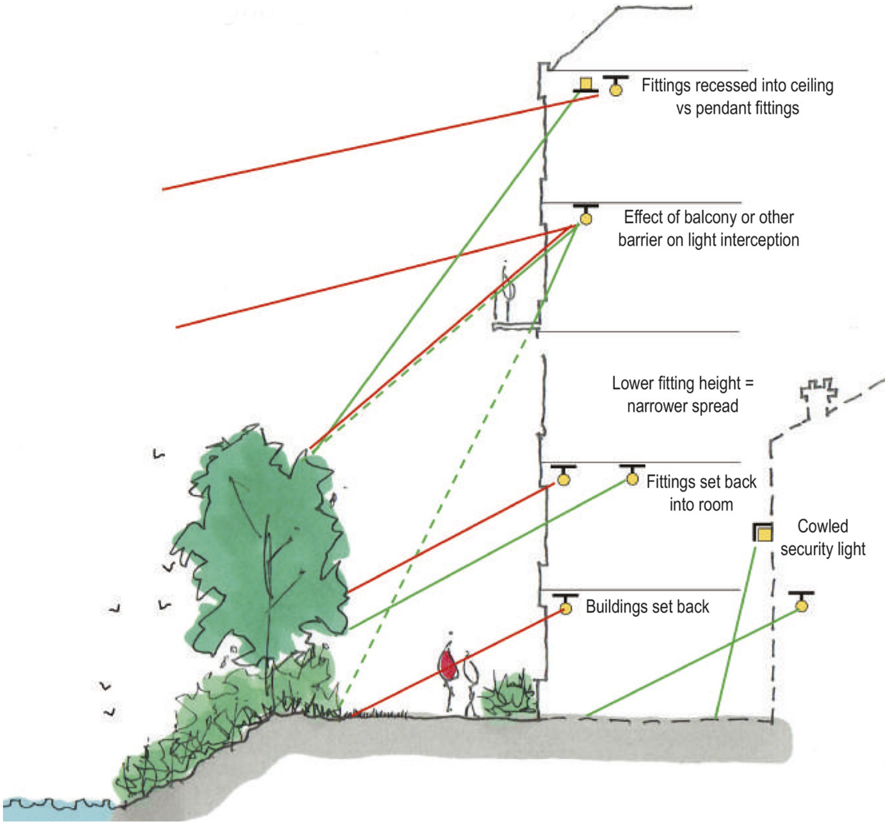


Figure 5. Internal lighting mitigation options.

Sensitive site configuration

4.30 The location, orientation and height of newly built structures, and hard standing, relative to each other can have a considerable impact on light spill. Small changes in terms of the placement of footpaths, open space and windows can all help to achieve a better outcome in terms of minimising light spill onto Key Habitats and features.

- Key or Supporting Habitat is often located alongside, or to the rear of buildings, on new developments. In this case, the removal or reduction of windows can be the most effective way to permanently limit light spill, potentially alongside the internal reconfiguration of the building, to ensure high-use spaces are not as impacted by loss of natural light
- It may be possible to include Key or Supporting Habitat into unlit public open space such as parks. However, avoid including into residential gardens, as uncontrolled and inappropriate lighting may be introduced by residents following occupation
- It is often considered better for a residential scheme to specify good quality downward-directional external light fittings for security, and/or at the front entrance, on short PIR timers, rather than risk the imposition of poor quality and poorly controlled lighting at a later date
- Buildings, walls and hard landscaping may be sited and designed so as to block light spill from reaching habitats and features

- Paved surfaces should not be located within Key Habitat or buffer zones, unless they form part of unlit public open space
- Taller buildings may be best located toward the centre of the site, or sufficiently set back from Key Habitats, to minimise the effect of their light spill
- Column mounted luminaires can be located so that the rear shields are adjacent to habitats, or narrow optics selected that direct light into the task area where needed

Physical screening

4.31 Light spill can be successfully screened through landscaping and the installation of walls and fences, or even banks and bunds (See Figure 6). In order to ensure that fencing makes a long-term contribution, it is recommended that it is supported on concrete or metal posts. Fencing can also be over planted with hedgerow species or climbing plants to soften its appearance and provide a vegetated feature which bats can use for navigation or foraging.

4.32 The planting of substantial landscape features integrated to the wider network of green corridors such as hedgerows, woodland and scrub would make a long-term positive contribution to the overall connectivity of bat habitat and light attenuation. It would also contribute to any local Nature Recovery and Green Infrastructure policies and help achieve obligatory Biodiversity Net Gain targets. A landscape architect can be appointed to collaborate with the ecologist on maximising these natural light screening opportunities.

4.33 It should be noted that newly planted vegetation (trees, shrubs and scrub) is unlikely to adequately contribute to light attenuation upon Key Habitats for a number of years, until it is well established. Sufficient maintenance to achieve this is also likely to be required. Consequently, this approach is best suited to the planting of dense, mature or translocated vegetation. In some cases, it is appropriate to install temporary fencing, or other barrier, to provide the desired physical screening effects until the vegetation is determined to be sufficiently established.

4.34 Given the fact that planting may be removed, die back or inadequately replaced over time, it should never be relied on as the sole means of attenuating light spill.

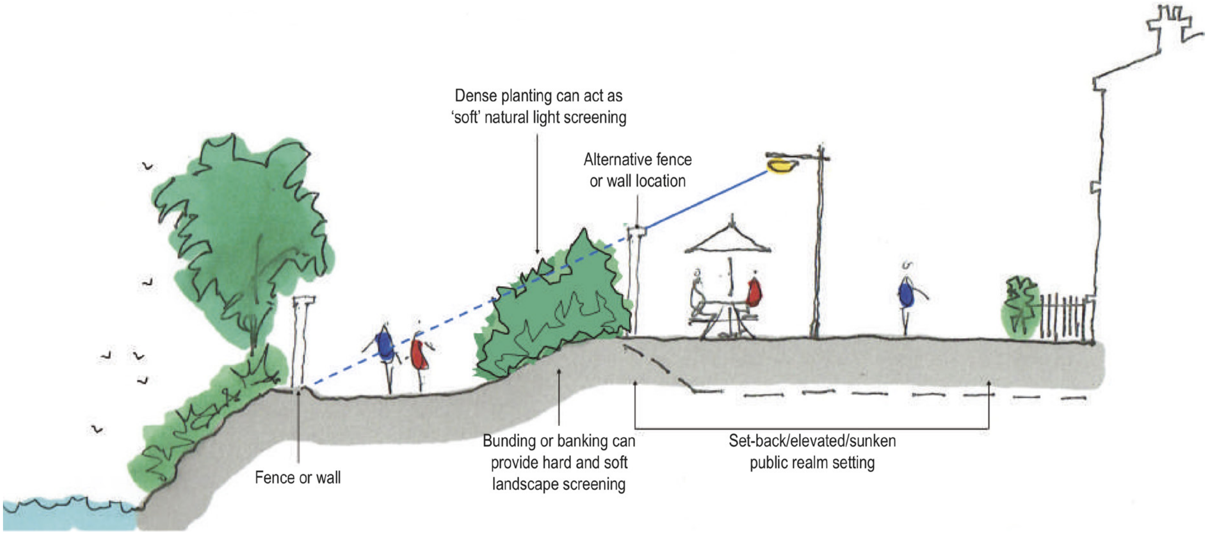


Figure 6. Examples of physical light screening options.

Dimming and part-night lighting

4.35 Depending on the pattern of bat activity across the Supporting Habitat identified by the ecologist, it may be appropriate for an element of on-site lighting to be controlled by dimming or switching either diurnally, seasonally, or according to human activity (light on demand). This is known as Part-Night Lighting (PNL). It is important to state that PNL is not likely to be appropriate where Key Habitats are at risk, especially as PNL often results in lighting when bats are most active.

4.36 A Central Management System (CMS) can be specified by the lighting engineer to dim or turn off individual or groups of luminaires when not in use or during less busy times. Dimming can be precisely controlled, with dimming states often being as low as 10 or 20%. However, due to the electrical difficulties of maintaining a dimming state of under 10%, luminaires should be set to off below this point.

4.37 Lighting could be set to a low output state by default, to turn up to a pre-determined output in response to a trigger, and be combined with a timeclock or photocell to further add an element of seasonal or diurnal control. For example, Passive Infrared (PIR), Artificial Intelligence enabled cameras, on demand controls, or pressure sensors may be used to trigger lights to come on or dim in response to movements, either by vehicles (for example at car parks or industrial loading bays) or by pedestrians (for example a footpath leading from residential development through an area of Supporting Habitat). The timeclock or photocell could ensure that this response only occurs during a set window of hours after sunset and before sunrise, or during certain months.

4.38 Where some trigger is used to temporarily modify lighting states, it will be necessary to specify the timed trigger window during which the response is maintained beyond the last triggering activity. For most typical residential purposes, 1-2 minutes is likely to be sufficient, however risk assessments must be performed in line with BS5489-1. The proposed system of lighting control will be determined by the outcome of the risk assessment. Where used in locations which receive distinct busy periods, such as cycle paths used by commuters, care will be needed to ensure lighting responds adequately to permit safe usage, but avoids both over-illumination and potentially disruptive dimming states of lighting groups.

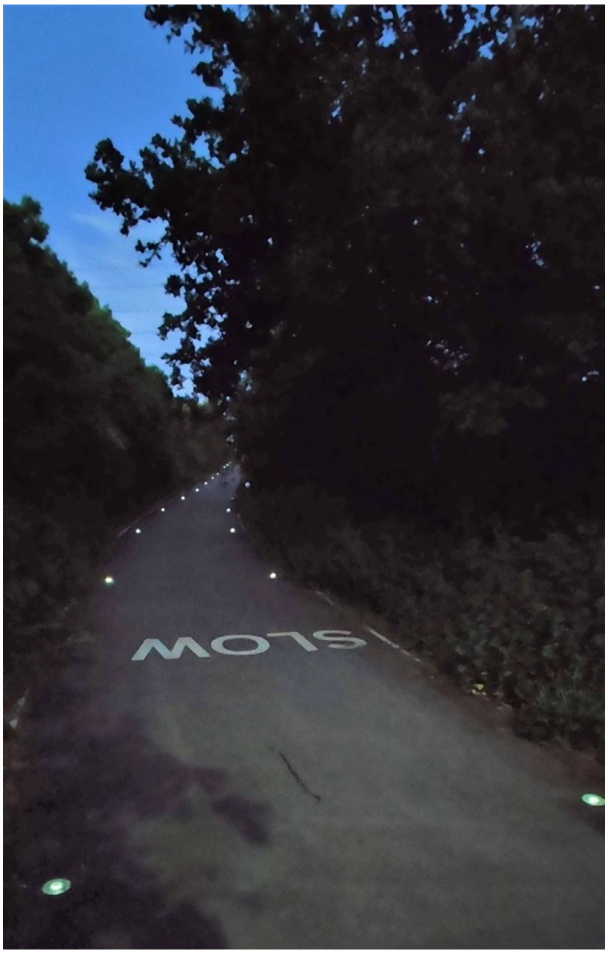


Photo 4: Waymarkers installed on a multi-user path in Worcester. Image credit: Cody Levine.

4.39 Alternative lighting designed for subtle waymarking, rather than illumination, may be more appropriate, such as very low-wattage, ground-level luminaires (photo 4). This lighting option can have a number of additional benefits such as a reduced risk of vandalism, lower carbon footprint during manufacture and fitting and no requirement for cabling. However, it should be noted that these systems depend on regular maintenance and a long-term commitment for them to be successful, as well as a clear view of the sky for solar-powered options. Due to this, proposals and potential planning conditions should be considered in liaison with maintenance teams, to ensure success (and any handover of assets) post install. See Case Study 1 for further information.

4.40 Part-Night Lighting should be designed with input from an ecologist as it may still produce unacceptably high light levels when active or dimmed. Part-Night Lighting is not usually appropriate where lights are undimmed during key bat activity times, as derived from bat survey data or within riparian habitats (see research chapter 1.27). Research has indicated that impacts upon commuting bats are still prevalent where lighting is dimmed during the middle of the night at a time when illumination for humans' use is less necessary (Azam et. al., 2015) thus this approach should not always be seen as a solution, unless backed up by robust ecological survey and assessment of nightly bat activity. In this case, designing areas to be lit to avoid retained Key Habitat, or the provision of sufficient alternative dark corridors, may be the only solution.

Glazing treatments on buildings

4.41 As mentioned, glazing should be restricted and reduced wherever the ecologist and lighting professional determine there to be a likely significant effect upon bats' Key Habitat and associated features.

4.42 Where Supporting Habitat is present, glazing treatments such as tinted, frosted or low transmission glazing treatments are not generally considered suitable ways of fully mitigating light spill. In the case of frosted or 'frit' glazing, windows typically remain luminous surfaces in their own right, defeating the objective of reducing lighting impacts. Although promisingly named, low-transmission glazing (glazing with a lower visible light transmittance) often makes only a very small difference to light spill in practice - a window's fundamental objective is to transmit light!

4.43 Automatic blinds should be discouraged as their longevity depends on regular maintenance and successful routine operation by the occupant. Such blinds are generally only suited to commercial situations where maintenance can be incorporated into the long-term regime routine for the building.

4.44 Depending on the height of the building and windows, and therefore predicted light spill, glazing treatments or window design restrictions may not be required on all storeys. This effect can be more accurately determined by a lighting professional.

Creation of alternative valuable bat habitat on site

4.45 The provision of new, additional or alternative bat flightpaths, commuting or foraging habitat is encouraged and could result in appropriate compensation for any such habitat being lost to the development. The ecologist will be able to suggest and design such alternative habitats, although particular consideration should be given as to its connectivity to other features, the species to be used, the lag time required for a habitat to sufficiently establish and the provision for its ongoing protection and maintenance.

4.46 As almost all new development will be required to result in at least 10% Biodiversity Net Gain (BNG), opportunities to improve habitat connectivity for bats should always be considered. Further to the 10 principles at the core of BNG, the implementation of sensitively sited habitat features for bats would be a clear contribution to 'additionality'. Particularly when considering achieving BNG off-site, assessment should be made of the impacts of altering the type and proportion of bat-suitable habitats, both within and beyond the site, upon the potential Core Sustenance Zone of any maternity roosts which use them.[2]

[2] https://cdn.bats.org.uk/uploads/pdf/Bat-Species-Core-Sustenance-Zones-and-Habitats-for-Biodiversity-Net-Gain.pdf

Step 5: Demonstrate compliance with illuminance (lux) limits and buffers within proposals and, where appropriate, the operational scheme

4.47 Once it has been determined through the above process how Key and Supporting Habitats will be protected, or impacts on them mitigated or compensated for, it will be necessary to demonstrate how this will be achieved. For a planning application, this information is increasingly required prior to determination in order for the LPA to make an informed decision and discharge statutory duties towards protected species legislation and policies. This is most likely to be the case for 'Full' planning applications. For 'Outline', phased or complex applications, this information is, at times, deemed a 'Reserved Matter', for which detail will normally follow at a later date before final consent is granted, or in the discharging of reserved matters. Incidences include EIAs and should be made prior to determination. It is appropriate for a pre-commencement planning condition to be imposed on a consented application which would require that an ecologically sensitive lighting plan is prepared, or is achievable.

4.48 In all cases where impacts from lighting on bats are possible, the LPA will require some form of documentation to be produced by the lighting engineer, either in collaboration with the ecologist, or working to the constraints set out within the bat habitat plan/ECOP (see Step 2), in order to demonstrate compliance. Usually, this will take the form of a 'Lighting Strategy', 'Lighting Design' or 'Lighting Impact Assessment', depending on the level of detail in the application. A Lighting Strategy may simply set out the agreed lighting parameters, objectives and likely mitigation requirements (e.g. unlit zones and any other bat mitigation), together with a plan. A Lighting Design/Impact Assessment would provide finalised details, consisting of a plan to show modelled illuminance from all proposed (and existing, where necessary) light sources, taking into account all site configuration, physical screening and glazing measures adopted. It would usually be accompanied by an explanatory document detailing the specification of each luminaire, as well as all assessment assumptions made and any other rationale for lighting mitigation, such as recessed light fittings or part-night lighting.

4.49 In the case of Outline or phased applications, the precise detail of architectural materials, glazing, landscaping etc. might not be known at the time of submission, therefore a Lighting Strategy may be the most appropriate document to provide. As described above, the bat mitigation objectives derived from the ecologist's bat habitat plan/ECOP should be referenced. It is worth being aware of the potential for matters such as highways (incorporating highways-specific lighting needs) to be fixed at Outline consent stage, which can make the resolution of bat mitigation requirements at a later stage challenging. This highlights the importance of inter-discipline collaboration and early communication of ecological constraints.

4.50 In the case of small or simple planning applications, where significant impacts upon bats from lighting are of a low likelihood, the production of a full Lighting Design package may be disproportionately costly and time-consuming. It may therefore be appropriate to provide a simplified document produced between the ecologist and lighting engineer, setting out design decisions undertaken and the likely achievability of the recommendations within the ECOP according to the lighting engineer's professional judgment.

Lighting contour plans

4.51 A horizontal illuminance contour plan can be prepared by a suitably experienced and competent lighting professional (Member of the Institution of Lighting Professionals (ILP), Chartered Institution of Building Services Engineers (CIBSE), Society of Light and Lighting (SLL) or similar to ensure competency) using an appropriate software package to model 'Day 1', extent of light spill from the proposed, retained and, possibly, existing luminaires. The various buffer zone widths and illuminance limits which may have been agreed can then be overlaid to determine if any further mitigation is necessary. In some circumstances, a vertical illuminance contour plot may be necessary to demonstrate the light in sensitive areas, such as entrances to roosts or the Key Habitat associated with it (see Appendix).

4.52 Such calculations and documentation would enable the LPA ecologist to fully assess impacts and compliance.

4.53 Because illuminance contour plots and plans may need to be understood and examined by non-lighting professionals, such as architects and local planning authority ecologists, the following should be observed when producing or assessing illuminance contour plans, to ensure the correct information is displayed.

- A calculation showing output of luminaires to be expected at 'Day 1' of operation should be included, where the luminaire and/or scheme Maintenance Factor is set to 1. Schemes using Constant Light Output (CLO) luminaires should also be calculated using 'Day 1' output
- Where deemed necessary by a lighting professional, models should be issued so that all luminaires (i.e. internal and external, or between different phases/plots) can be assessed and each should be set to the maximum output anticipated to be used in normal operation on site (i.e. no dimming where dimming is not anticipated during normal operation)
- Where dimming, PIR, or variable illuminance states are to be used, an individual set of calculation results should accompany each of these states
- A horizontal calculation plane representing levels of illuminance at ground level should always be used
- Vertical calculation planes should be used wherever appropriate, for example along the site-facing aspects of a hedgerow or façade of buildings containing roosts, to show the illumination directly upon the vertical faces of the feature. Vertical planes can also show a cross-sectional view within open space (however, they will only face one direction.) Vertical planes will enable a visualisation of the effects of illumination at the various heights at which different bat species fly. An ecologist can

advise on the most appropriate dimensions to use according to the likely locations of bat flight around the site's habitats

- The contours (and/or coloured numbers) for 0.2, 0.5, 1, 5, and 10 lux must be clearly shown, as well as appropriate contours for values above these
- Each illuminance/lux contour plan should be accompanied by a table showing their minimum and maximum illuminance/lux values
- Where buildings are proposed in proximity to key features or habitats, plots should also model the contribution of light spill through nearby windows, making assumptions as to internal luminaire specification, internal lighting levels, and visible light transmittance of windows. It should be assumed that blinds or curtains are absent or fully open. Assumptions will need to be made as to the internal luminaire specification and levels of illuminance likely to occur on 'Day 1' of operation. These assumptions should be clearly stated and guided by the building/room type and discussions between architect, client and lighting professional. Consideration may also need to given to the site topography, and differences in ground levels between key features and lit areas or buildings. It is acknowledged that in many circumstances, only a 'best effort' can be made in terms of accuracy of these calculations as it is often not possible to account for all 'real world' conditions and variables which influence light. Note that evidence-based professional judgement is needed to assess whether light from windows should undergo a full assessment, dependent on factors such as the distance between light source and critical habitats
- Modelled plots should not include any light attenuation factor from new or existing planting, due to the lag time between planting and establishment and the risk of damage, removal or failure of vegetation. This may result in difficulties in the long-term achievement of the screening effect and hamper any post-construction compliance surveys
- The illuminance contour plots should be accompanied by an explanatory note from the lighting professional to list where, in their opinion, sources of glare acting upon the key habitats and features may occur, and what has been done/can be done to reduce their impacts

4.54 **N.B.** It is acknowledged that, especially for vertical calculation planes, very low levels of light (<0.5 lux) may occur even at considerable distances from the source if there is little intervening attenuation. It is therefore very difficult to demonstrate 'complete darkness' or a 'complete absence of illumination' on vertical planes where some form of lighting is proposed on site, despite efforts to reduce them as far as possible and where horizontal plane illuminance levels are zero. Consequently, where 'complete darkness' on a feature or buffer is required, it may be appropriate to consider this to be where illuminance is at or below 0.2 lux on the horizontal plane, and at or below 0.4 lux on the vertical plane. These figures are still lower than what may be expected on a moonlit night and are in line with research findings for the illuminance found at hedgerows used by lesser horseshoe bats, a species well known for its light averse behaviour. [xvi]

Baseline and post-completion light monitoring surveys

4.55 Baseline, pre-development lighting surveys may be useful where existing on or off-site lighting is suspected to be acting on Key and Supporting Habitats and features, and so may prevent the agreed or modelled illuminance limits being achieved. This data can then be used to help isolate which luminaires might need to be removed, or where screening should be implemented, or establish a new illuminance limit reduced below existing levels. For example, where baseline surveys establish that on or off-site lighting illuminates potential Key Habitat, improvements could be made by installing a tall perimeter fence adjacent to the habitat, and alterations to the siting and specification of new lighting, to avoid further illumination.

4.56 Baseline lighting surveys must be carried out by a suitably qualified competent person with the correct equipment. As a minimum, readings should be taken at ground level on the horizontal plane (to give illuminance hitting the ground), and in at least one direction on the vertical plane at between either 1.5m or 2m above ground (to replicate the likely location of bats using the feature or site). The orientation should be perpendicular to the dominant light sources, or perpendicular to the surface/edge of the feature in question (such as a wall or hedgerow), in order to produce a 'worst case' reading. Further measurements at other orientations may prove beneficial in capturing influence of all luminaires in proximity to the feature, or principal directions of flight used by bats. This should be discussed with the ecologist.

4.57 Baseline measurements should be taken systematically across the site or features in question, with time, date and time of sunset also recorded. They will need to be repeated at intervals to sample across the site or feature, either in a grid or linear transect, as appropriate. The lighting professional will be able to recommend the most appropriate grid spacing.

4.58 Measurements should always be taken in the absence of moonlight, either on nights of a new moon or heavy cloud, to avoid artificially raising the baseline. As an alternative, moonlight can be measured at a place where no artificial light is likely to affect the reading.

4.59 As all illuminance level contours will be produced from modelled luminaires at 100% output, baseline measurements should, wherever practicable, be taken with all lights on and undimmed, and with blinds or screens over windows removed. Cowls and other fittings on luminaires can remain in place.

4.60 Where possible, measurements should be taken during the spring and summer, when vegetation is mostly in leaf, in order to accurately represent the baseline during the principal active season for bats, and to avoid artificially raising the baseline.

4.61 The topography of the immediate surrounding landscape should be considered in order to determine the potential for increased or decreased light spill beyond the site.

Post-construction/operational phase compliance-checking

4.62 Post-completion lighting surveys are often required where planning permission has been obtained on the condition that the proposed lighting levels are checked to confirm they are in fact achieved on site, and test that the lighting specification (including luminaire heights, design and presence of shielding etc.) is as proposed.

4.63 All lighting surveys should be conducted by a suitably qualified competent person. They should be conducted using the same measurement criteria and lighting states used in the preparation of the illuminance contour plots and/or baseline surveys, as discussed above. It may be necessary to conduct multiple repeats over different illumination states, or other conditions specific to the project.

4.64 Depending on the potential for residual impacts on bats, and the scale of the proposed scheme, it is often appropriate to factor in bat monitoring surveys. These should have the aim of confirming an absence of significant changes in bat presence, species assemblage or behaviour between lit and unlit areas, compared to baseline results. Results should always be reported to the LPA as per any such planning condition. A 'Statement of Conformity' or similar report should be prepared in order to provide an assessment of compliance by the lighting professional, and a discussion of any remedial measures which are likely to be required in order to achieve compliance. Any limitations or notable conditions such as deviation from the desired lighting state, or use of blinds/barriers should be clearly reported. Ongoing monitoring schedules can also be set, especially where compliance is contingent on automated lighting and dimming systems, or on physical screening solutions.

Conclusion

4.65 **In summary,** the importance of integrating avoidance measures (as per the first step of the mitigation hierarchy) into developmental design, cannot be overemphasised. Retaining ecologically functional 'dark corridors' and Key Habitats for bats within schemes (in preference to seeking lighting mitigation strategies), avoids costly and time-consuming additional surveys, mitigation and post-development monitoring. Furthermore, LPAs are likely to favour applications where steps have been taken to avoid such conflicts. This master-planning work needs to be informed by robust ecological survey data and lighting assessments, carried out by the relevant experts at the earliest opportunity in the project. Ultimately, light levels should always be designed to minimise potential environmental impact, and maximise the potential of habitat and species enhancement work, through multidisciplinary working and evidence-based new, or retrofit, scheme design.

5. Case Studies

1. Worcester City lesser horseshoe dark city way marker project

Photo 5: Ground-mounted, solar-powered, cowled, way-markers installed in the green infrastructure of a residential development near Worcester Cathedral.

5.1 A Green Infrastructure objective to reduce vehicular journeys into Worcester's city centre led to Worcestershire County Council upgrading the River Severn's network of footbridges and pathways. In its urban context, this Local Wildlife Site links the wider countryside with Worcester's city centre.

5.2 Floodproof (IP68) bollard lighting was initially selected as it was considered a design least likely to contribute to skyglow, or illuminate the adjacent River Severn LWS. Bollards contain 180degree LED arrays and are set at 12m intervals meeting BS5489. Subsequent monitoring by the Worcestershire Bat Group identified that bollard cowls were being vandalised, casting light on the river embankments. Additionally, the traditional commuting flightlines of a lesser horseshoe bat roost in the nearby cathedral was effectively being severed by the bollard lighting, as this focuses illumination in the first 1.5m from ground-level. In their urban context the horseshoes' commuting route threaded from roost, through partially illuminated, gardens to reach the River Severn and wider countryside beyond the city's fringes. The bollard lighting effectively created a lit barrier to horseshoe bats along the river's embankments. Monitoring of the hibernation roost near the cathedral indicated a downward trend in numbers.

5.3 Modification of bollards would have compromised the housing’s IP68 protection and external cowls were vandalised. The bat group had identified key flightlines by horseshoe bats however de-illuminating these bollards was deemed an unacceptable departure from standards by highways safety assessors. Key concerns raised were increased risk of crime, and trips and falls along the river’s steep embankments. Working with the highway authority, street lighting team, county and city councils, together with consulting a local charity, Sightconcern, to understand what highway users with visual impairments may require from lighting schemes, a modified departure from standards was negotiated for highways authority adoption.

5.4 100m of bollard lighting was programmed by timeclock to independently turn off at civil sunset. Conservation area compliant fencing was installed at the river’s margins. Within this ‘dark corridor’ ground-mounted solar-powered, cowled way-markers were installed to demark pathway extents.

5.5 Post-installation monitoring by the local bat group and county council indicated preferential use of this new ‘dark corridor’ by lesser horseshoe bats. Winter numbers, within the nearby roost, increased in the following three years of post-installation monitoring. No accidents or uplift in crime in this area was reported to Worcestershire County Council, and the solar-powered waymarkers have subsequently been integrated into downstream developments to protect bat foraging habitats, where these intersect with key green infrastructure components.

2. Dark Corridors at Foxlydiate

Figure 7.

5.6 Monarch Green is a mixed-use development of 127.34Ha in size, located in Bromsgrove, Worcestershire. The scheme gained planning consent in early 2022 and will provide up to 2560 homes across 69Ha, a new local centre and 3-form entry primary school. Around 37% of the site (47.62Ha) has been allocated for Green Infrastructure, and will include parkland and informal public open spaces, new walking and cycling routes, sustainable drainage systems and wildlife habitats, including a purpose-built wildlife tower.

5.7 Following site allocation in Bromsgrove's Local Development Plan (2011-2030, adopted January 2017), a Green Infrastructure (GI) Concept Plan was prepared by the Worcestershire GI Partnership. This report identified and prioritised opportunities to protect, enhance and link multifunctional GI assets, and it summarised good design principles including recommendations to incorporate dark corridors, as described in Landscape and Urban Design for Bats and Biodiversity (BCT, 2012). Subsequently, ecological surveys undertaken by Wardell Armstrong on behalf of St Philips, identified light sensitive bat species (Myotis and long-eared bats) to be present, and areas of commuting and foraging activity by these bats were mapped.

5.8 In developing a 'landscape-led' masterplan responding to the initial GI Concept Plan, dark corridors were assigned to provide connectivity across the site and into adjoining off-site habitats. These dark corridors incorporate the majority of hedgerows where bat activity was recorded, and link these hedgerows to other GI features, such as woodlands and watercourses likely to be used by bats. Dark corridors became integrated into a site-wide Green, Blue and Dark Infrastructure Parameters Plan, which formed part of the evidence base within the scheme's Environmental Impact Assessment.

5.9 Dark areas are intended to be entirely unlit; however, early in the design process, unavoidable severance effects were anticipated to meet public health and safety need, where road crossings would broach GI and dark corridors.

5.10 Measures to reduce artificial lighting impact to acceptable levels were agreed through early consultation efforts with stakeholders, including the Highway Authority and Local Planning Authorities. A sensitive lighting strategy was prepared, underpinned by an Ecological Lighting Impact Assessment, and indicative outline scheme of lighting for the completed development. This approach controls obtrusive lighting by use of good lighting design principles: careful location and orientation of columns with suitable optics, relocation of infrastructure such as bus stops and dropped curbs, use of cowls and dimming technology, sensitive highway design narrowing carriageway widths within GI corridors, stand-off zones to features such as highway T-junctions, corner junctions and road crossings, so that columns can be minimised and illuminance reduced to <0.5 lux within dark corridors. In addition, structural landscaping will be used to buffer GI and dark corridors and new adjacent tree planting will minimise new permanent gaps in hedgerows; when mature, these trees will assist bats to fly at higher levels over GI crossing points.

5.11 At each Reserved Matters stage, a detailed lighting strategy will be prepared which will reference the green, blue and dark corridors, and will include maps showing lux contours and forecast spread and power of lighting. This will give the LPA and stakeholders confidence that the dark corridors designed early in the scheme's masterplanning will continue to form a cohesive element through later detailed design work.

5.12 This GI-led approach illustrates the benefits of early consultation and collaborative planning; integration of Green, Dark and Blue Infrastructure Parameters provides additionality and helps align future management prescriptions to maximise the benefits of GI for bats and broader biodiversity.

3. Ecological Constraints and Opportunities Plan (ECOP)

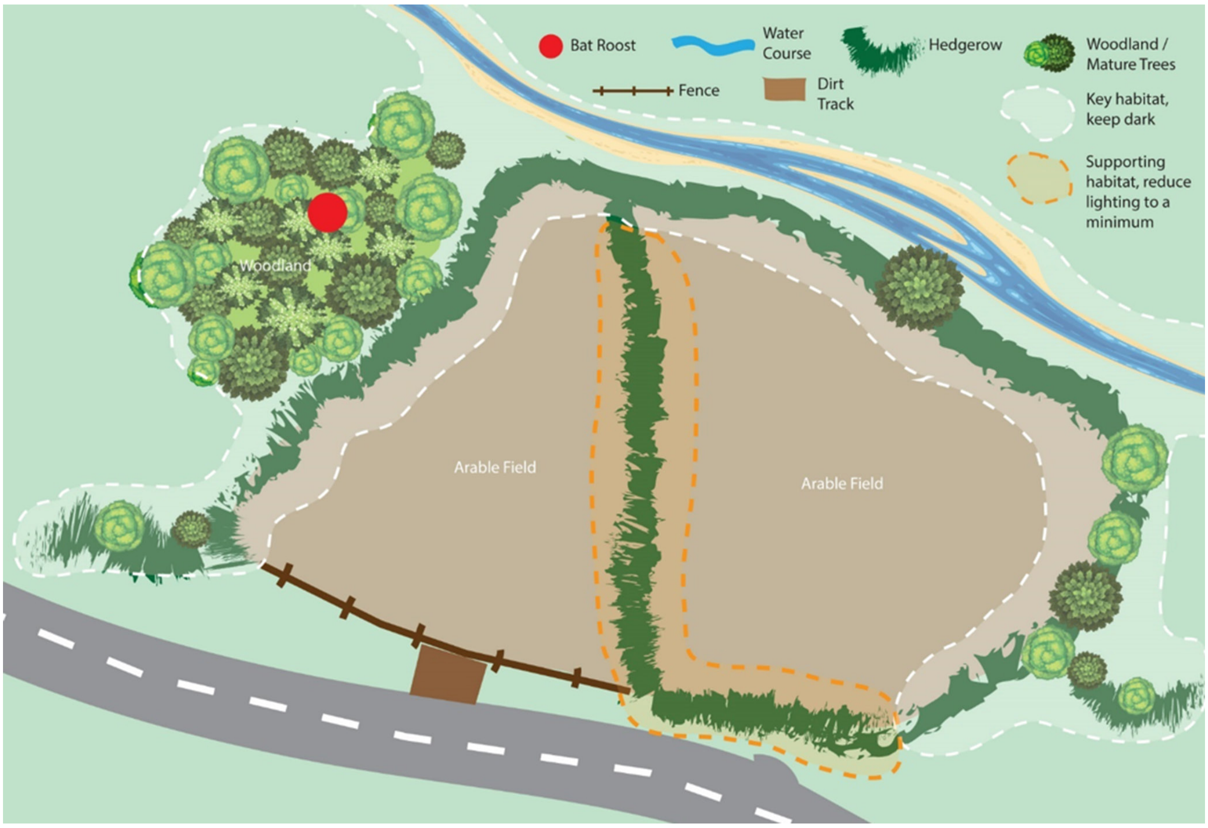


Figure 8. Lighting Ecological Constraints and Opportunities Plan. Credit Matthew Ward / BCT.

5.13 The following case study illustrates the principles of formulating and applying a lighting ecology opportunities and constraints plan (or 'L.ECOP') to a hypothetical development scenario.

5.14 Tinear Ecology Ltd. were commissioned by Bigpharm to prepare ecological studies of the site of their proposed new headquarters, currently arable fields. Bigshire's recent Local Development Plan has allocated this site for a commercial development. The site's allocation policy notes the proximity of Bigwood (a semi natural ancient woodland, located immediately to the west of these agricultural fields) and also notes the adjacent Bigriver, which is located just beyond the mature, species-rich hedgerows on the site's northern boundary. The network of hedgerows and adjacent watercourse connects this site to other nearby woodlands and a wider agricultural and pastoral landscape, which fringes the nearby Bigtown.

5.15 The local biological record centre has provided historic records of multiple bat species in and around this site, they've also been seen and heard foraging and commuting near Bigwood. Tinear's Preliminary Ecological Appraisal (PEA) highlighted risk of impacts to bats from development. Consequently, bat activity surveys were undertaken, and these identified consistent use of hedgerows across and on the site boundaries by light-sensitive bat species. This included acoustic signatures of long-eared bats and several different Myotis bats. No bat roosts were identified on site. Subsequent backtracking, emergence and roost characterisation surveys identified day roosts of brown long-eared bats, and a maternity roost of Brandt's/whiskered bats in the adjacent Bigwood.

5.16 As a first step following surveys, Tinear Ecology produced the Lighting Ecological Constraints and Opportunities Plan (L.ECOP), as illustrated above, to designate Key and Supporting Habitats of importance for bats and indicate features recommended for retention and protection through development. Key Habitat was taken to be the habitat most regularly used by commuting Myotis and long-eared bats and which was directly linked Bigwood with Bigriver and the wider landscape. It was also taken to include a 5m buffer from the habitat, to account for bats' flightpaths and foraging usage alongside it. Secondary Habitat was taken to be any indirectly linked habitat which was found to be used by these species to a lesser degree, plus a 3m buffer, and this included the north-south species-rich hedgerow dividing the site. The L.ECOP was then used to inform the design of Bigpharm's new headquarters and development of a lighting strategy.

5.17 The recommended Key and Supporting Habitat zonation, together with buffer zones, helped guide configuration of proposed new buildings and glazing, landscaping, car parking, and overall lighting design. The Key Habitats (boundary hedgerows, Bigwood and Bigriver) used by foraging and commuting Plecotus and Myotis bats will be unilluminated and protected to remain completely dark. The lighting strategy demonstrated this by overlaying these features with horizontal lux contour modelling, and also by including vertical lux contour modelling illustrating predicted lux levels at the canopy of Bigwood's boundaries, the edge of the hedgerows and the edge of the buffer. Modelling indicated key habitats would be illuminated to no more than 0.2 lux above baseline levels.

5.18 During the design of the scheme, two layout options were considered which would both result in impacts on the Secondary Habitat comprising the hedgerow separating the western arable field from the eastern arable field.

Option 1:

5.19 Bigpharm's new offices will be constructed on the site's eastern half, and in order to create vehicle and pedestrian access from carparking on the site's western half, around 30% of the species-rich hedgerow traversing the site needed to be removed. Lighting sources would be carefully re-positioned away from the remainder of this Supporting Habitat, and a combination of fencing and shields installed to ensure it and the 3m buffer was illuminated to <5 lux, following recommendations as set out in the L.ECOP's report. Motion activated sensors could be installed on the closest light sources to ensure a maximum of 2 lux when not triggered. The 3m buffers would be managed to provide a mosaic of tussocky grassland to support flying invertebrates. An equivalent length of species-rich hedgerow habitat would be incorporated into the landscaping design so as to ensure no net loss of hedgerow, although it would no longer connect to the Key Habitat to the north. In this way, the Supporting Habitat would remain accessible to foraging bats from the south and would be impacted by lighting to an acceptable degree.

Option 2:

5.20 In order to create the ground levels needed to construct Bigpharm's new buildings and carpark, the hedgerow traversing the site needed to be removed in its entirety. The ecological significance of the loss of a Supporting Habitat was set clearly out and justified in the scheme's planning application. A proportional onsite 'offset' for hedgerow loss in terms of bat foraging and commuting habitat was proposed through enhancement measures to the retained Key Habitats: boundary hedgerows were thickened and widened, with new standard trees included and the management of buffer grassland to promote flowering species diversity. Additionally, a new waterbody was integrated into the site's SuDs scheme. This new feature is intended to provide enhanced foraging opportunities for bats and so was located within the buffer zones of Key Habitats. In this buffer zone, it's envisaged that reduced light levels will help avoid compromising foraging activity by Myotis and Plecotus bats. Following recommendations set out by the project ecologist in the L.ECOP's report, the lighting strategy confirms that key habitat buffers are to be lit at levels no greater than 0.2 lux.

Conclusion

5.21 In the end, Option 2 was followed and post-development lighting monitoring secured by planning condition confirmed levels as predicted, while ecological monitoring revealed the number of bat species identified prior to development remained consistent. Levels of activity by these species were broadly similar post-construction, however the increased number of feeding buzzes recorded, particularly around newly created features within the Key Habitat buffer zones, indicates lighting buffers were successful in ensuring their intended ecological function as new foraging resources. A brief Statement of Conformity and monitoring results were returned to the LPA and biological record centre.

4. Reconciling urban bat conservation and public accessibility: good practice in engaging the public and gauging perceptions around red spectrum lighting deployment

5.22 This case study highlights how any change in lighting to an area should (alongside the appropriate ecology surveys, mitigation and compensation work) involve engagement and consultation with the general public. Informing the stakeholders on the design and the considerations of why certain lighting, or no lighting was considered, should be part of the process.

5.23 This project explored public perceptions of red spectrum lighting deployment in Southampton Common, the largest urban park in Southampton, UK. The park is a hub for local wildlife, but is also a valued public recreation and commuting space. Public demand for path streetlighting on Southampton Common has previously been highlighted in surveys carried out by Southampton Common Forum, because the area is perceived as unsafe at night. However, the need for streetlighting conflicts with bat conservation.

5.24 Public perception of red spectrum lighting was assessed through questionnaires aimed at night-time users of Southampton Common. Eight sites adjacent to frequently used public footpaths in Southampton Common were lit for 3 nights (see Figure 9). Red spectrum luminaires were selected so as to contribute towards the evidence base, evaluating effects on UK bat species, and also to gain an insight into public perceptions and to assess any sensitivities in the deployment of red spectrum lighting.

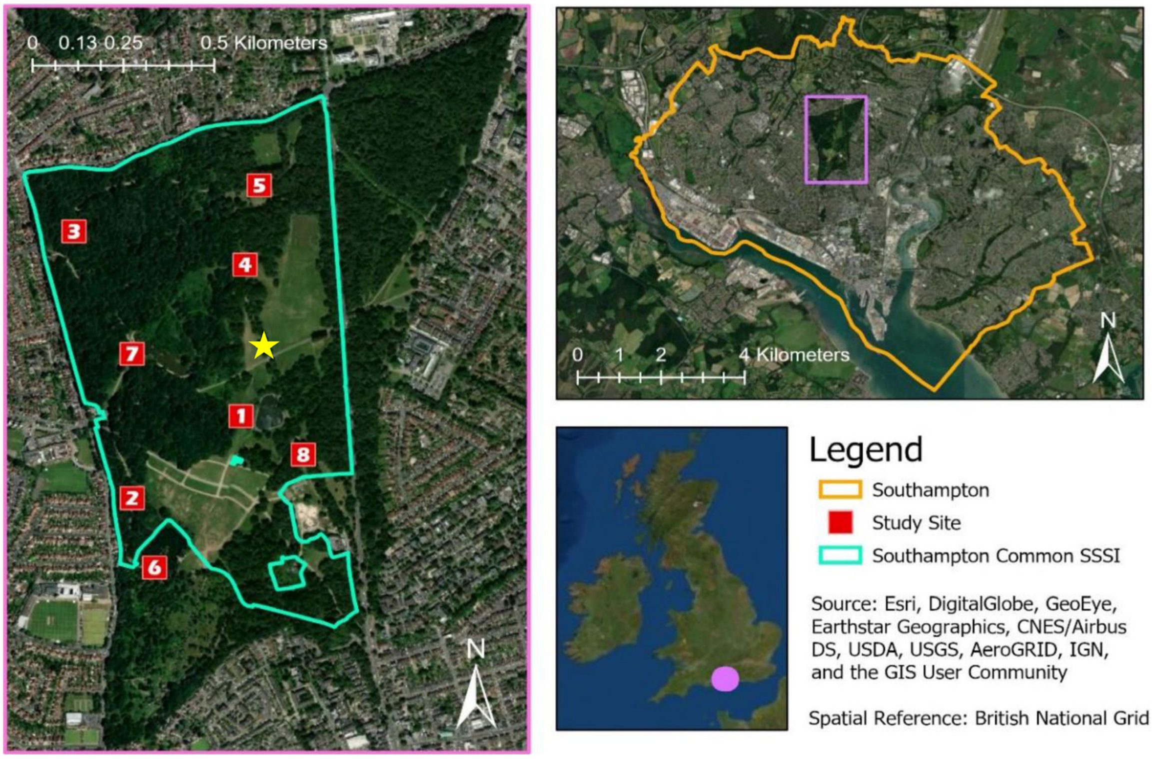


Figure 9. Experiment study sites on Southampton Common.
Map series showing the location of the 8 experimental sites used and Southampton Common's Site of Special Scientific Interest (SSI) boundary.

Figure 10. The 8 experimental sites.

5.25 Each three night block was lit under a different streetlighting condition; darkness (no lights, a control), white LED luminaires, and red spectrum LED luinaires. Two 3.3m lighting fixtures were set up 30m apart, adjacent to a public footpath, mimicking streetlighting in the local area (see Figure 10 Photo 1). On nights trialling the red spectrum LED luminaires, questionnaires were handed out to members of the public passing by experimental sites. These collected anonymous information about participants' use of Southampton Common after dark, views about the current amount of street lighting in the area and opinions of the new red spectrum LED luminaires, both before and after knowing their purpose.

5.26 91 people completed the questionnaire over the 11 nights and the response to red spectrum luminaires was mostly positive:

- 73% of respondents thought red lights performed the same or better than normal white luminaires
- Over half of respondents (54%) stated that their use of Southampton Common at night would not be affected by changing current path lighting to red spectrum luminaires, and another third (33%) of respondents said they would use the park more if they were converted
- 67% of respondents made very positive comments about the red spectrum luminaires, with many stating that they would feel as safe as they would with normal white luminaires
- Some concerns about the lights included that they were "ominous", "scary" and "weaker", though these comments were in the minority (8 of 91 respondents)
- Many people stated that their opinion was positively affected if the luminaires were wildlife-friendly and that they preferred lights which were

"better for wildlife and the environment" or entailed "less disruption or harm to wildlife" (see Figure 12 word cloud)

- 37 people wanted all footpaths on Southampton Common illuminated and 9 people wanted no paths illuminated, with the remaining respondents wishing for a select few paths in the park to be illuminated

Table 2: The questions asked in the public questionnaires given to people passing the experimental site on nights testing red spectrum luminaires

Question Number	Question
Part 1: Use of Southampton Common	
1.1	What do you identify yourself as?
1.2	What is your age group?
1.3	Which Southampton neighbourhood, if any, do you live in?
1.4	How often do you use Southampton Common at night/after dark (after sunset and before sunrise)?
1.5	What are your main reasons for using Southampton Common after dark?
1.6	What are your main concerns with using Southampton Common after dark?
1.7	What is the most important action for facilitating (improving/increasing) your use of Southampton Common after dark?
Part 2: Red Lighting Questions	
2.1	How well can you see under the red light?
2.2	How well do these red lights compare to your pre-conception of red lights?
Part 3: Night Lighting in Southampton Common	
3.1	What do you think about the current provision of street lighting in the Southampton Common?
3.2	Do you use different paths at night on Southampton Common when in a group of people (2+ individuals) vs when on your own?
3.3	If you would like to see more streetlights, where on Southampton Common would you like them to be implemented?
3.4	A new type of red streetlight has been developed that enables object recognition and colour perception. How safe would you feel with these red lights?
3.5	If current path lights were converted to red lights, would your use of Southampton Common at night be affected?
3.6	These new streetlights may be less disruptive to nocturnal wildlife on Southampton Common. Would this affect your opinions of the red lighting?

5.27 Overall it was found that night-time users of Southampton Common were generally receptive to red spectrum luminaires, particularly if they were beneficial to wildlife.

5.28 In this study, data gathered indicates red spectrum luminaires appear effective in mitigating impacts of artificial lighting on bat behaviour, except in areas where high densities of soprano pipistrelles are recorded. While results of this study did not conflict with prior investigations of red light sources, they highlight the importance of trialling new luminaire types under multiple contexts, and in different habitats because wildlife may react differently under different circumstances. Soprano pipistrelle activity reduced on red light nights (but not white) and light- sensitive bats (long-eared and Myotis bats) showed a reduction in activity on white light nights, but not red.[3] The lack of effect caused by small sample size only impacted Nyctalus/serotine groups and some single species activity.

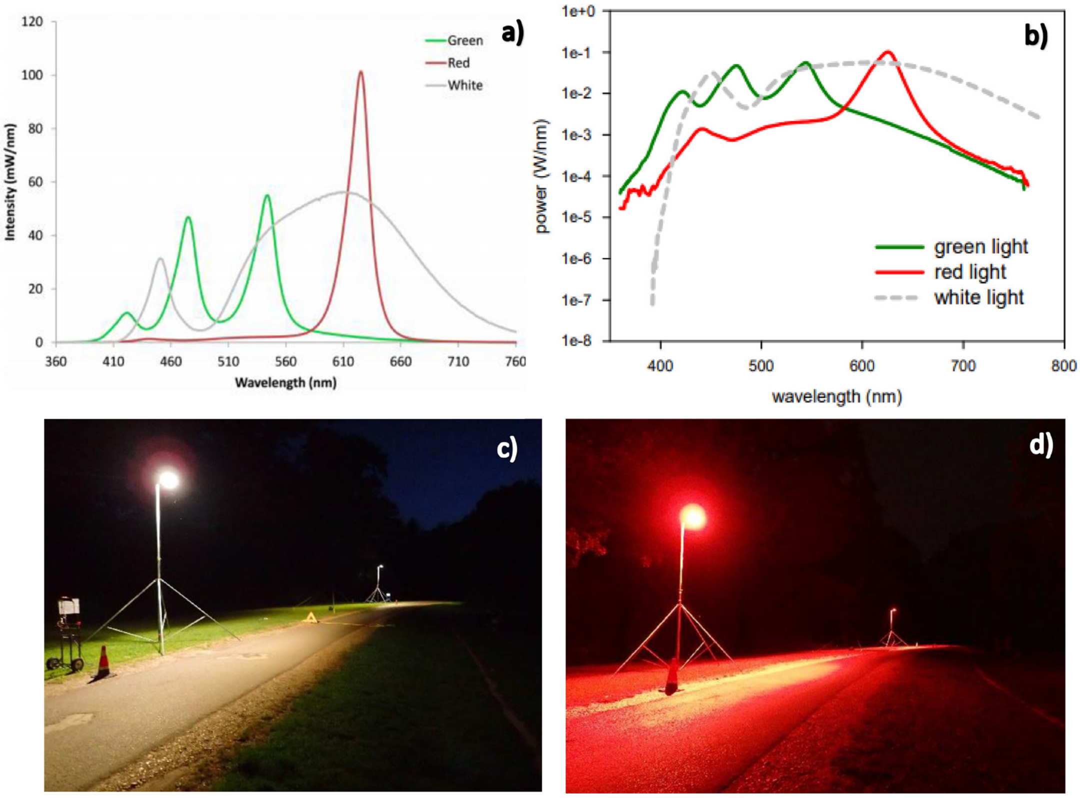


Figure 11. Spectral composition and appearance of LED lighting of white and types

5.29 Longer and more extensive studies on the effects of red lighting on UK bat species were recommended and have seen been rolled out, results are pending. Following this study, recommendations were formulated to expand lighting trials to test effects on both bats and other UK wildlife in the area. This included development of a mitigation strategy to include new lighting types, motion sensors and deactivation of the lights during hours of minimal use. In combination, this mitigation approach seeks to balance night-time public comfort and safety, and the benefits to biodiversity which Southampton Common provides.

Figure 12. Word Cloud

[3] Reconciling urban bat conservation and public accessibility: spectrum-dependent responses to artificial lights at night in urban parkland Rozel Hopkins, MSci Zoology (4th Year) BIOL6069 Advanced Field Project http://www.southamptoncommonforum.org/scfdownloaddocs/bats/BIOL6069%20Dissertation%20-%20Rozel%20Hopkins.pdf

5. No Lighting - Case Study, S38 Lower Howsell Road, Malvern

Figure 13. S38 Lower Howsell Road, Malvern.

Introduction

5.30 A lighting designer was engaged by the developer to provide a street lighting design. The scheme comprised of 110 properties, located near to the Malvern Hills Area of Outstanding Natural Beauty (AONB). The AONB has published guidance on lighting, intended to "minimise impacts of lighting on wildlife, people and on natural landscapes". Prior to being developed the land was a greenfield site and had no lighting / dark baseline. This would be classed as dark district brightness as per Institution of Lighting Professionals Guidance Note 1, (ILP GN01/21) the reduction of obtrusive light.

5.31 The development is accessed from Lower Howsell Road, which has limited lighting provision. Many of the adjacent side roads also have limited lighting provision, this is typical of semi-rural areas of Worcestershire. The road layout is in line with the Streetscape Design Guide. There were no features that should be illuminated in line with Manual For Streets.

5.32 Ecological surveys determined bats were using peripheral hedge lines as linear commuting and foraging features. The project ecologist recommended this feature should remain unlit to avoid impacting light sensitive fauna. Bats and their roosts are afforded legal protection under international and national legislation. In certain circumstances, such as where foraging or commuting routes are deemed to be 'functionally linked' to a bat roost (and hence important in supporting the favourable conservation status of that bat population), these features may also benefit from strict legal protection.

Challenge

5.33 Subsequently, during design it became apparent that the entire site was used by lesser and greater horseshoe bats, no longer confined to the extremity of the site as advised during planning. The species of bats found within the development are highly light averse, if lighting was provided it could fragment or disrupt commuting and foraging habitat.

5.34 Due to its location and dark baseline, the site has a semi-rural context and additionally is located within the setting of an Area Of Outstanding Natural Beauty (AONB). Artificial lighting would therefore need to be sensitively controlled. Institute of Lighting Professionals (ILP) GN01/21-the reduction of obtrusive light states: *"lighting should limit the impact of light pollution on intrinsically dark landscapes".*

Solution

5.35 Due to the significance of the ecological findings, the dark baseline, the semi-rural nature and the provision of a standard road layout, it was decided an unilluminated approach was the best option.

Benefits

5.36 By not providing street lighting, the developer has avoided causing an ecological impact by removing risk to severance effects on an identified linear commuting/foraging feature, thus reducing risk of contravening legislation by un-intentionally disrupting features which might be considered as functionally linked to a bat roost.

- The scheme is in line with national planning policy framework and lighting guidance
- The scheme has removed maintenance liability and risk to energy revenue budgets
- Additionally, this removes carbon burden from the County Council's Net Zero plan

6. Land at Collaton Cross, near Newton Ferrers, Devon

5.37 The Proposed Development comprised of the erection of 125 new dwellings, Community Parkland, commercial business space, community hub and boat storage area, together with associated access, car parking and landscaping.

5.38 The 14.6ha site is situated in the local authority of South Hams, within the South Devon Area of Outstanding Natural Beauty (AONB) in the Parish of Newton Ferrers, approximately 1 mile northeast of the existing settlement.

5.39 Bats are currently using the linear habitats at the Site boundaries for commuting and foraging. Dark corridors were proposed along part of the southern and eastern boundaries and within the POS. These linear corridors connected to extensive woodland to the south, and the network of existing hedgerows in the surrounding landscape. Barn owls are also present on site, with a wildlife tower with an integrated barn owl nest box proposed within the POS. Combined with the ecological sensitivities of the site, were the potential visual impacts, and impacts from lighting on the AONB setting.

5.40 The proposed lighting scheme is intended to be as minimalistic and sensitive as possible, to be in keeping with the rural location within the AONB, and to mitigate ecological impacts from lighting.

5.41 Careful consideration was given to the locations of the residential roads within the application site and their hierarchy. The commercial offer, and new bus stop are also located close to the entrance of the site which enables street lighting to be provided only in the areas where there is the highest concentration of activity. All section 38 roads have been located away from the dark corridors for bats, so any impacts from street lighting or vehicular headlights into these areas will be limited.

5.42 Following discussions between the lighting consultant, the Client, Devon Highway Authority, and Devon street lighting team proposals were developed to mitigate the lighting impacts. These were also discussed and agreed, including a product demonstration with the members of the County Council and Parish Council.

5.43 The current proposals provide very limited lighting to the residential roads within the site, lighting to the access junction, and a lit pedestrian link on-site and off-site back to Butts Park. The lit pedestrian link was challenging, typically as an adopted route it would require column mounted lighting along its length, which is approximately 600m, with the potential to have a significant impact on the setting of the AONB and the ecological receptors. Therefore, it was agreed that this path would be lit to adoptable standards, although maintained by a private management company, so that a bespoke solution could be applied with specialist bollard luminaires utlised.

5.44 Lighting to the B3186 main road is based on:

- Lanterns with 0-degree tilt, 0% Upward Light Output

- Back shields are proposed to all the lanterns to minimise spill
- Lanterns will have PC Amber 1700K colour temperature - this is the warmest colour temperature available without going to red lighting, and offers a significant improvement over the neutral white that was previously approved/ proposed as part of the earlier planning application. It goes above the standard that is currently being installed in other counties, where 3000K is being installed as a warm white option, and is often only installed for certain road types/ scenarios, and to residential roads, rather than main highway roads
- It was previously proposed that the lanterns would be mounted on 8m columns with 40m spacings between lanterns - this height was selected to meet the M5 class requested by the council. To meet this class with 6m columns, spacings between lanterns would be in the region of 20m, which would result in twice as many lanterns (lighting points) being required, and not a very economical design. Following further liaison, the design was revised with the column heights along the main road being reduced to 6m, with the design being based on a P3 class instead (7.5 lux ave and 1.5 lux minimum). Technically, this class should apply to subsidiary roads, with a speed limit of 30mph or less. This was deemed to be a good compromise as it allowed spacings to only slightly be reduced to approx.36m. It offered equivalent lighting levels to an M5 class; however, the focus is on levels of illuminance, rather than luminance, and is used where the safety of pedestrians is the primary concern
- Part Night Control is proposed in addition to dimming the lights. The lighting will come on at 100% at dusk, and dim down to 75% output at 20:00, and switch off at 00:30, coming on again at 05:30 until dusk
- The speed limit along the main road is proposed to be reduced to 40mph in the vicinity of the site, which has allowed the approach distance to the be lit to be reduced. It was also agreed with Devon County Council’s street lighting team to use the distance for a 30mph road of 67m either side of the junction, rather than 89m for 40mph, as a further derogation and compromise to minimise lighting impacts. (For 60mph roads it would be 133m)

5.45 Lighting to the S38 residential roads within the site is based on:

- Lanterns with 0-degree tilt, 0% Upward Light Output
- Lanterns will have PC Amber 1700K colour temperature
- Mounted on 5m columns
- Part Night Control is proposed whereby the lights will switch off between 00:30 and 05:30
- A P5 class was applied to the residential roads (with an average level of illuminance of 3 lux and a minimum of 0.6 lux.) This is the lowest class applicable for roads
- Street lighting will be limited to two sections of roads only within the site, that provide routes from the main access point east and south into the site

5.46 Lighting to the standalone on-site footpath is based on:

- Single sided distribution bollards with back shields
- Bollards with a low upward light output (<1.5%). Images of the proposed bollards are shown in photos 6 & 7


Photos 6 & 7: Images of bollards installed on other projects. The warm white version is shown rather than the Amber version described in the case study.

- Bollards will be placed on the south side of the footpath facing the existing hedgerow/main road, to limit any visibility of the bollard lights from within the AONB
- The bollards will have PC Amber 1750K colour temperature
- The bollards are 1.3m height. The height of the bollard is slightly higher than a typical bollard which allows the path to be lit to adoptable standards
- Part Night Control is proposed in addition to dimming the bollard luminaires to match the control/operating regime of the street lighting, however lights will be dimmed to 50% rather than 75%. Therefore, the lighting along the path is proposed to come on at 100% at dusk, and dim down to 50% output at 20:00, and switch off at 00:30, coming on again at 05:30 until dusk
- A P6 class is proposed, and will be provided during peak times of use, prior to dimming as outlined above. This is the very lowest lighting class applicable (with an average level of illuminance of 2 lux and a minimum of 0.4 lux). Outside of these times, a level of lighting for wayfinding will be provided by the dimmed lights prior to switch off at 00:30
- It should be noted that these levels are very low, with full moonlight often producing in the region of 0.5 - 2 lux. Specialist bollards were carefully selected, so that these levels are closely met rather than the path being over lit, which often happens when bollard luminaires are specified and installed.
- Spacings between bollards are 11m
- The bollard specification has been carefully considered and selected to balance all parameters to have the least impact, whilst meeting the councils' requirements for lighting to an adoptable standard. These bollards have

a very low output compared with other bollards that are often used, and offer a significant improvement over typical bollard specifications

- The output of each bollard is only 180 lumens, so a fraction of what is emitted from a streetlight, and much less than the output of even a typical domestic outside light. The design of the bollard means that visibility of the lit part will be very limited
- Following discussions with the council it was agreed that this path would be a permissive pathway built to adoptable standards, but remaining under a management company

5.47 Other Lighting within the site

- All public realm lighting will be specified with LED Amber light sources, with research showing that this colour temperature will minimise the impacts from lighting on dark skies and ecological receptors
- Any additional bollards, if required for wayfinding in the commercial parking areas, will be the same specification as proposed for the standalone footpath, in order to minimise impacts
- Building mounted lighting to the residential and commercial properties will be LED with warm white colour temperatures (3000K or less), and downward directional with 0% Upward Light Output Ratios to minimise the impacts on bats, and to comply with the requirements for an E1 Environmental Zone. Building mounted luminaries to the residential properties will operate via combined PIR (movement) detectors on short timers, and photocells to prevent daytime operation

5.48 Additional proposals included:

- Improvements were also proposed to upgrade the lighting to the HM Coastguard facility at Collaton, adjacent to the site, which may be secured under a S106 agreement
- There are approximately six floodlights and two amenity style luminaires to this building. These were operating via various control methods, which included manual switching-on and PIR controls. The floodlights are orientated at high angles and are therefore not installed in accordance with the parameters for an E1 Environmental Zone. One of the flood lights appeared to be permanently switched on during the baseline survey, and due to its high tilted angle, was highly visible both from within the site and from a significant distance outside of the site
- This lighting will be replaced with completely downward directional luminaires, with warm white colour temperatures, PIR controls, with design and specification in accordance with the parameters for an E1 zone
- Improvements are proposed under a S106 agreement to upgrade the existing lanterns on the B3186 at Butts Park, as vehicles enter and exit Newton Ferrers. These lanterns are approximately 15 years old, do not have backshields fitted. The existing lanterns are proposed be retrofitted with warm white LEDs, to offer a betterment to the existing situation

7. Kidderminster heavy mitigation site

5.49 In this case study, there was a requirement to light a spine road however it was agreed that sides roads would remain unlit due to the highly light averse species of bats found within the development site. If insensitive lighting had been provided, it was deemed likely to risk fragmentation or disruption of bat commuting and foraging features, particularly hedgerow and blocks of linear woodland which were identified in the project ecologist's 'dark corridor' maps. Key measures agreed here include:

- Red lighting (to reduce potential impact)
- Low levels of lighting during quiet periods of the night
- Post monitoring of the bats on site to understand impact of lighting
- Implementation of a Central Management System (CMS) to amend the lighting levels if necessary

Figure 14. S38 Lea Castle (Phase 1), Kidderminster.

Introduction

5.50 A lighting designer was engaged by the developer to provide a street lighting design. The scheme comprised of over 600 properties, based on the former Lea Castle Hospital site, located within Wolverley Parish. It is located north of Kidderminster between Stour Vale Marsh Site of Special Scientific Interest (SSSI) & Puxton Marsh SSSI to the West, and Hurcott Pasture SSSI and Hurcott and Podmore Pools SSSI to the East.

5.51 Prior to being developed the land was mostly a greenfield site, with limited private lighting. The lighting designer estimated the site to have an existing very low / almost dark lighting baseline. As per ILP GN01/21-the reduction of obtrusive light, this site would be classed as mix of dark district brightness and low district brightness.

5.52 The development is accessed from Park Gate Road, which has no lighting provision and Wolverhampton Road (A449), which has a high level of lighting provision associated with a busy A class road. Many of the comparable roads in Wolverley have no lighting provision and is typical of rural areas of Worcestershire.

5.53 The road design is in line with the Streetscape Design Guide. There were no features that should be illuminated in line with Manual For Streets but the main spine road was to be used by a bus service, cyclists, access to shops and be used by school children.

5.54 During planning it was advised that a variety of bat species were using the site. In compensation for licensed destruction of existing roosts, a number of bat barns were constructed on site. Lesser horseshoe bats were subsequently understood to be both roosting, foraging and commuting within site boundaries as well as commuting to the nearby network of sites considered to be of conservation significance in order to forage.

Challenge

5.55 Bats and their roosts are afforded legal protection under international and national legislation. In certain circumstances, such as where foraging or commuting routes are deemed to be ‘functionally linked’ or key in supporting the favourable conservation status of the population, these features may also benefit from strict legal protection. The species of bats found within the development are highly light averse, if insensitive lighting was provided it was deemed likely to risk fragmentation or disruption of bat commuting and foraging features, particularly hedgerow and blocks of linear woodland which were identified in the project ecologist’s ‘dark corridor’ maps.

5.56 The developer’s ecologist proposed dark corridors on the spine road but these interacted with sharp bends and were in proximity to junctions and bus stops. Therefore, the dark corridors would not be endorsed by the Highways Authority Development Control team, due to perceived safety issues.

Solution

5.57 Due to the significance of the ecology, rural nature, use of the spine road and un-endorsed dark corridors for the spine road and provision of a standard road layout for side roads it was decided to masterplan the lighting for the entire development.

5.58 All side roads were to be unilluminated however the spine road was to be lit in its entirety with the following mitigation measures:

- Red spectrum lighting to reduce potential impact
- Low levels of lighting during quiet periods of the night
- Post monitoring of the bats on site to understand impact of lighting
- Implementation of a Central Management System (CMS) to amend the lighting levels if necessary

5.59 The local planning authority, highways authority development control team and scheme designers felt this was the best option to move the development forward.

Photo 8: Red spectrum street luminaires deployed as lighting mitigation on a residential estate's spine road, at Lea Castle, Kidderminster. Image credit: Cody Levine.

Benefits

- By providing Street Lighting on the main spine road, the developer has focused on providing safe usage for the major risk factors; interactions between motorised users incl. buses and non-motorised users enables a safer night-time environment
- By not providing Street Lighting on the side roads, the developer has avoided potential for ecological impact to protected bat species by un-intentionally disrupting and severing commuting and foraging routes

functionally linked to a known roost. This has the added bonus of being comparable to the lighting status of many roads within the Parish of Wolverley and will help the development feel rural at night

- The scheme is in line with national planning policy framework and lighting guidance
- The scheme has partially removed maintenance liability and risk to energy revenue budgets with its careful approach to lighting. Additionally, this partially removes carbon burden from the Net Zero plan
- By securing a period of post-installation bat and lighting monitoring, reasonably related to the predicted scale of impact, a refined insight will be gained into the effectiveness of the lighting mitigation strategy for bats

8. Rapid LED Roll-out (RLR) project

Background

5.60 Due to unprecedented rising energy costs Worcestershire County Council (WCC) committed to invest £6 million in its 2022-23 'Rapid LED Roll-out' (RLR) programme. RLR will replace the county's remaining conventional street lighting inventory with energy efficient LED streetlights, targeting c.20,000 lanterns across the county's trunk and residential road networks.

5.61 This case study focuses on processes used to balance safety, carbon and energy reduction alongside biodiversity conservation associated with RLR of c.10,000 lanterns on the county's trunk roads.

Introduction

5.62 Worcestershire is a predominantly rural county, but with several urbanised town centres and Worcester City itself. Street lighting provision is centred around urbanised areas, some major A-roads and the primary links to motorway networks. Many A-roads are unilluminated. The county is home to two Areas of Outstanding Natural Beauty, the Cotswolds & Malvern Hills. It is also home to the largest woodland National Nature Reserve in the country, the Wyre Forest. Worcestershire is thought to support 17 of the 18 species of bats thought resident in the UK, with increasing populations of light-intolerant species, such as lesser and greater horseshoes.

Figure 15. An illustration of some of the mapping, monitoring and assessment of existing lighting levels. Trunk road lighting interacts here with a broadleaved woodland component of the local ecological network. Image © Crown copyright and database rights 2023 Ordnance Survey 100024230, © Getmapping Plc and Bluesky International Ltd 2023.

5.63 Recognising the considerable evidence-base illustrating the adverse impacts of Artificial Lighting At Night (ALAN) on flora and fauna, and more specifically by high intensity and blue light emitted by LED light sources, the RLR programme offers an opportunity to evaluate landscape-scale effects of transitioning to a modern LED street lighting inventory. Additionally, RLR also provides opportunities to trial effects of multiple 'warmer' lighting spectra as ALAN mitigation measures.

Approach

5.64 The upgrade to LED is anticipated to modify existing ALAN's interaction with flora and fauna. By evaluating changes in bat activity an inference can be made of wider faunal and floral impact, with bat populations effectively acting as a proxy indicator for the cohesion, resilience and health of ecological networks.

5.65 The underpinning environmental data was provided by WCC in conjunction with the Worcestershire Biological Record Centre and Worcestershire Bat Group. The modelled distribution of each existing conventional luminaire was spatially mapped over the county's habitat inventory[4]. This identifies ecological networks using a 'least-cost' distance analysis of the known and predicted 'priority habitats' (as listed under S.41 of the 2006 Natural Environment and Rural Communities Act). Street lighting which was considered likely to interact with the county's ecological networks were then assessed using multiple scoring criteria to gauge the risk of severance/deterioration effects. Mapping, monitoring, and assessment of existing lighting levels and proposed lighting calculations were undertaken (See Figure 15).

5.66 Following desktop analysis, a site-by-site evaluation of RLR's 'triaged' street lighting columns was undertaken by WCC's ecologist in collaboration with the consultant, to verify results and to identify opportunities for mitigation and / or enhancement through blue light reduction. Jacobs tempered these requirements by reducing light levels in line with British Standards.

5.67 Research on the effectiveness of red and amber lighting treatments continues across the UK and Europe. Locally since 2018, WCC has adopted multiple 'reduced impact on bats' streetlighting schemes including the first highway use of a red spectrum recipe in the UK. The authority has nonetheless struggled to satisfactorily control experimental variables in monitoring effectiveness of these mitigation strategies. To minimise predicted impacts of blue light, three 'warmer' CCT spectra were selected: monochromatic 'red' (1,000K) (See Figure 16), phosphor converted with (PC) 'amber' (1,750K) (See Figure 17) and 'warm white' (3,000K) (See Figure 17). This simplified colour palette gives the RLR programme opportunity to test effects on abundance and diversity of bat species of three lighting spectra.

[4] www.worcestershire.gov.uk/info/20302/worcestershire_habitat_inventory

[5] White Paper Reducing impact on night behaviour nocturnal mammals, Outdoor LED light recipe for bats

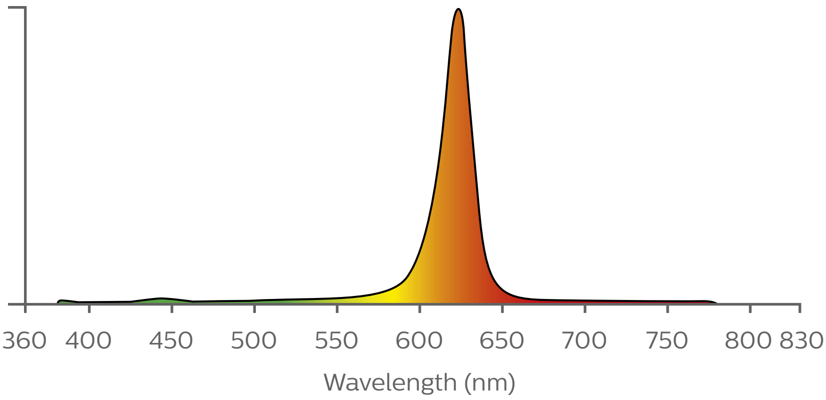


Figure 16. spectral distribution of monochromatic Red solution.

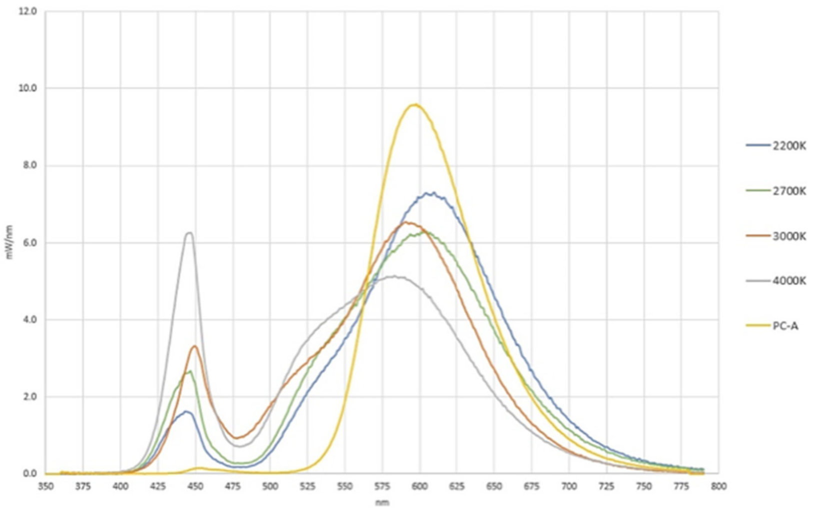


Figure 17. Comparisons of spectral distribution of multiple CCTs illustrating the reductions in blue light peaks possible through use of warmer CCTs.

Table 3: Severance and mitigation rationale.

Severance rationale summary	Columns scoped	%	Mitigation approach
Illuminated highway crosses a statutory or non-statutory site designated for its nature conservation value, and/or is located in proximity to a known bat roost (i.e. where modelled lighting distribution is deemed reasonably likely to interact with a historically recorded bat roost).	99	1%	1,000K CCT ('red'), shielded
An illuminated highway located in an urbanised environment bounds a statutory or non-statutory designated site, a watercourse, waterbody or woodland.	2,499	26.6%	1,750 CCT ('phosphor coated amber'), shielded
An illuminated highway crosses or bounds any other priority habitat.	829	8.8%	3,000K CCT ('warm white'), shielded
For expediency, all other RLR street lighting is considered less likely to pose significant/notable adverse effects on known receptors.	5,953	63.4%	3,000K CCT ('warm white'), un-shielded

Photo 9: PC Amber LED lighting install, Dugdale Drive, Worcester.

Monitoring

5.68 WCC continues to study its existing ALAN mitigation sites, but the RLR programme offers an opportunity to establish frameworks for managing and evaluating effects of ALAN at landscape-scales. A subset of six sample sites was selected, representative of urban, peri-urban and rural lighting contexts (monitoring the effectiveness of the mitigation approach at a whole-county scale would be prohibitively expensive). Two replicates were monitored of each LED treatment: 'red', 'amber' and 'warm white'. One Wildlife Acoustic Song Meter Mini was installed per site, making use of extended battery compartments and 128gb SD cards for their long-term deployment. Ultrasound recordings were captured over five nights per month during July to October 2022, with recording due to recommence in May to June 2023 to establish a measure of baseline bat activity and diversity. The upgrade to LED lighting treatments for the sample sites is scheduled for early July 2023.

5.69 Post-installation monitoring is scheduled for July to October 2023, recommencing in May to June 2024. By sampling in spring, summer and autumn over multiple years, we hope to capture seasonal variations in colony behaviour and abrogate risks of inclement weather or other energy saving initiatives potentially skewing results. The core objective of monitoring is to evaluate impacts (positive or negative) of each LED treatment on bats, as a proxy of the health of ecological networks, and subsequently to infer effects of the county-wide upgrade and CCT mitigation approaches deployed. We anticipate publishing findings in winter 2024/25.

Photo 10: Red spectrum lighting install, A4440 Trotshill Way, Worcester.

Benefits

5.70 In line with Worcestershire County Council net-zero goals, this investment reduced risk to the energy revenue budget by lowering energy consumption (by c.49%) and direct carbon emissions. The investment will reduce indirect carbon emissions incurred by the maintenance team due to the nature of LEDs typically lasting significantly longer than conventional lamps. The findings of each mitigation measure's efficacy will allow refinement of criteria used in our framework to determine their deployment and improve future conservation outcomes.

5.71 **Key messages**

- Landscape scale strategic planning of LED deployment.
- Importance of mitigation monitoring.
- Understanding environmental vs economic case, cost / benefits of street light management.
- Collaborative, sharing of research with wider industry.
- Continual learning and best practice.

6. Appendix

Light and lighting terms

Visible light

6.1 To see we need light, and it is an emission of electromagnetic radiation. The electromagnetic spectrum varies from radio waves through to infrared, ultra violet, x-rays and on to gamma rays. Light visible to humans is a very small part of this with wavelengths from 380 to 760 nanometres (1nm = 10^{-9}m). A diagram of the electromagnetic spectrum is demonstrated in Figure 18.

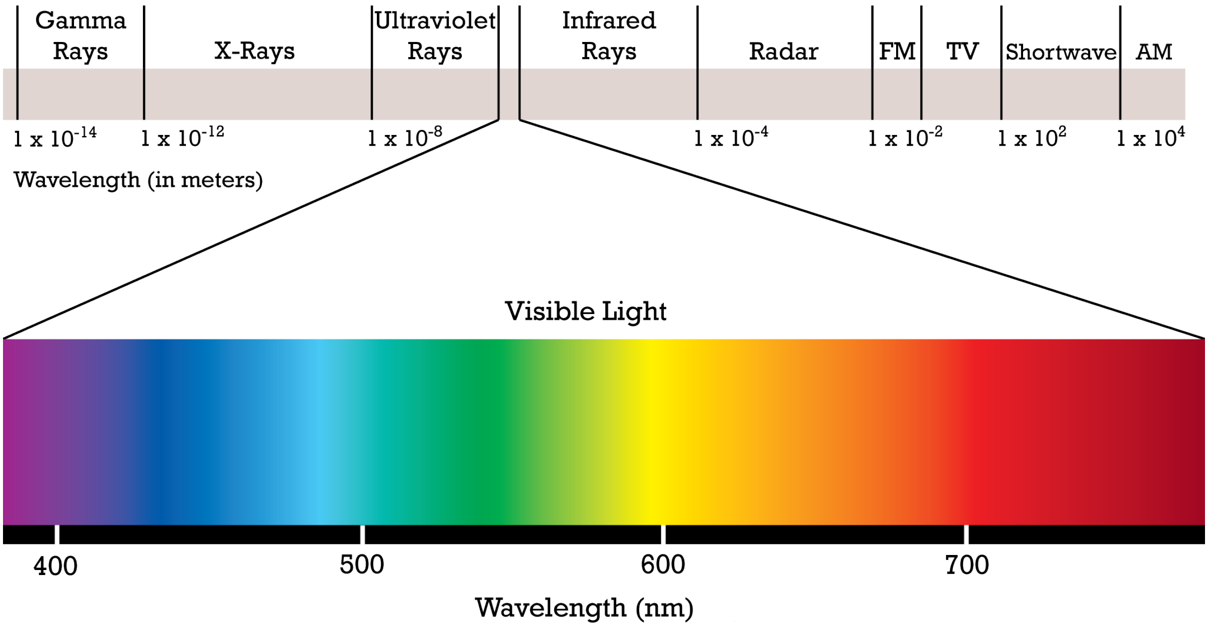


Figure 18. Electromagnetic spectrum.

Units of light

6.2 Though light is itself invisible, the surfaces it strikes absorb its energy and radiates it, becoming a light source.

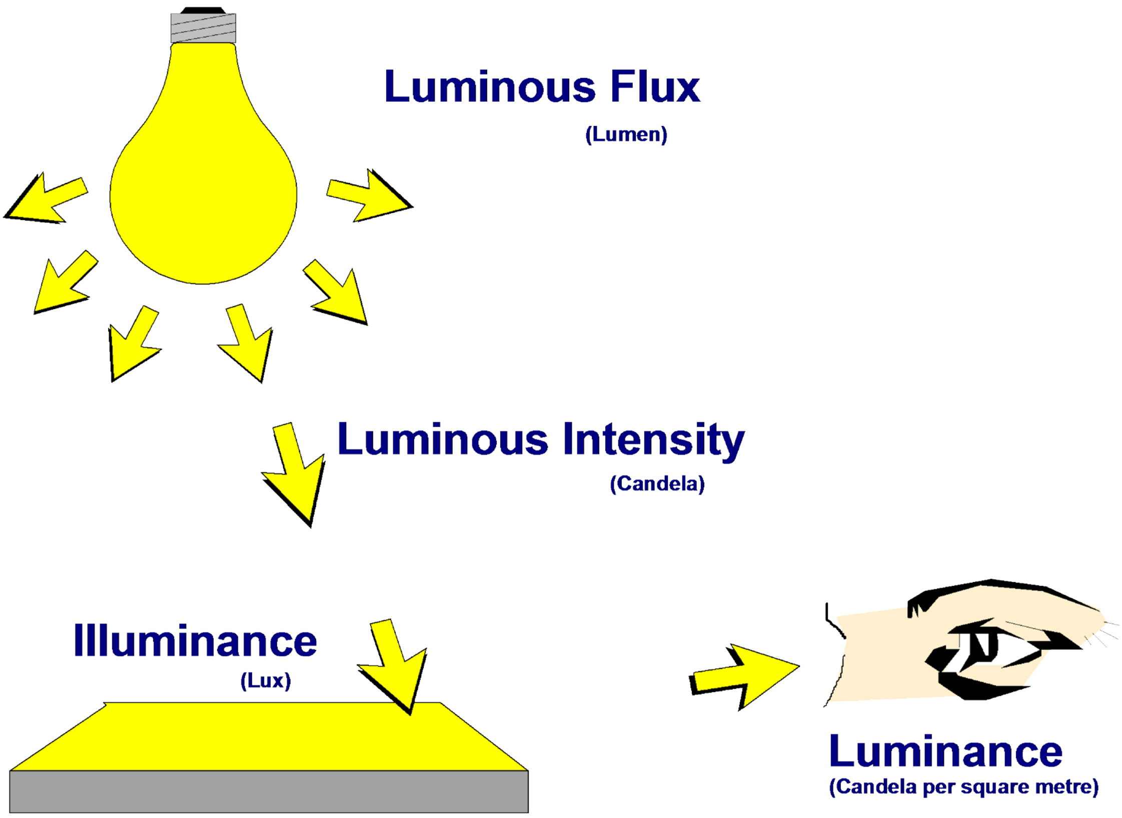


Figure 19. Units of light.

6.3 The amount of light emitted by a body or source is the **luminous flux**, measured in **lumens (lm)**. The intensity of light emitted by a source in a particular direction is **luminous intensity** and measured in **candelas (cd)**. Luminous flux from a source falling onto a surface is the **illuminance**, measured in lumens per m^2 or **lux (lx)**. What we actually see is the brightness of a surface, or the light emitted by the surface or body, and is the **luminance**, measured in **candelas per m^2 (cd/m^2)**. The units of light are demonstrated in Figure 19.

6.4 **Luminance** is difficult to measure because, apart from the surface texture and colour, it changes depending on the angle at which the surface is viewed so where its use is specified in, for example, British Standards, an observer position is described from which it should be measured. **Illuminance** is a much simpler metric to use but, for road lighting traffic routes, **luminance** must be used as drivers see the brightness of the road ahead, so the brightness of the road surface and the uniformity of light are essential metrics.

Inverse square law

6.5 As light is emitted from a source, its energy is dissipated. As a result, the illuminance (the light falling onto a surface) diminishes because the same quantity of lumens are spread over a bigger area, such that:

$$E = I/d^2$$

where: E is the illuminance (lux),
I is the luminous intensity (candelas)
d is the distance from the source (m)

This is known as the inverse square law as the illuminance diminishes by the square of the distance.

Correlated Colour Temperature (CCT) and Colour Appearance

6.6 The International Commission on Illumination is the international authority on light, illumination, colour, and colour spaces, known as CIE, in 1931 CIE published a chromaticity diagram mapping the colours visible to the human eye.

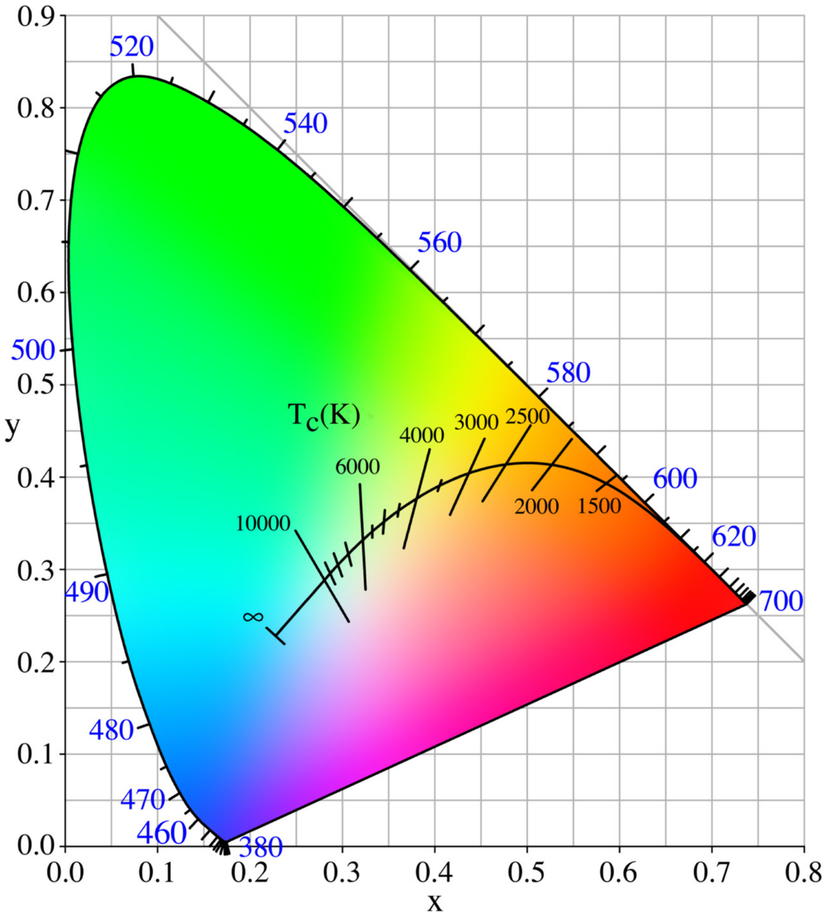
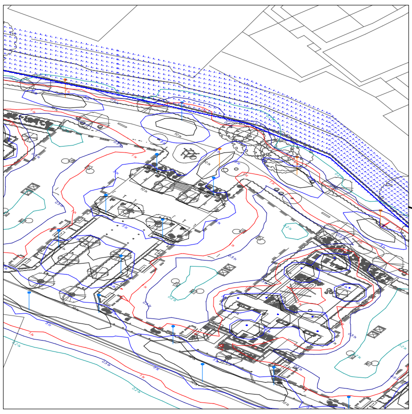


Figure 20. CIE Chromaticity chart and black body locus.

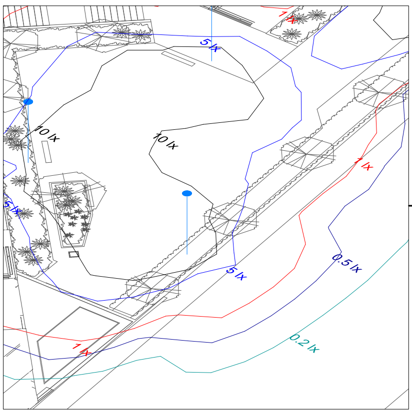
6.7 Within the chromaticity chart is the locus of a black body. You can imagine the black body as a piece of iron as it gets hotter its colour changes from cherry red to bright red, then orange to yellow until it melts at around 1,500°C. If it could keep getting hotter without melting then it would follow the black line locus shown in Figure 20.

6.8 The black body locus temperature is measured in degrees Kelvin, rather than degrees Celsius, a different scale but the incremental degrees are the same. The odd fact here is that the higher the temperature, the COOLER the colour temperature is said to be and the lower the temperature, the WARMER the colour appearance is said to be.

Lighting contour plan



Vertical Calculation



Isoline Contours

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