Lighting Guide 6: The exterior environment

The Society of
Light and Lighting

Lighting for the
built environment

Lighting Guide 6: The exterior environment

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CIBSE

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Note from the publisher

This publication is primarily intended to provide guidance to those responsible for the design, installation, commissioning, operation and maintenance of building services. It is not intended to be exhaustive or definitive and it will be necessary for users of the guidance given to exercise their own professional judgement when deciding whether to abide by or depart from it.

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Foreword

Since the last edition of this guide, in 1992, there has been a surge of interest in lighting the exterior environment – in particular, light pollution, energy use and long-term sustainability have become more pertinent than ever. In the 1990s, LEDs that could produce a functional amount of light were simply not available. This technology will continue to develop and there is a strong expectation that it will replace conventional light sources.

The aim of this guide is to reflect these changes and provide readers with a firm foundation from which to approach exterior lighting design. Since light source technology is advancing rapidly, the guide provides a holistic approach to the design of the exterior environment, rather than concentrating on product performance, which quickly becomes out of date.

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1 Introduction

One of the major differences between this current guide and the previous edition is the emphasis on environmental and energy issues. Digitally controlled lighting is becoming an increasingly important facet of lighting design.

Any new outdoor lighting design will be subject to much more scrutiny in terms of its impact on the night environment and energy consumption. Most major planning applications require a visual impact assessment of both the daytime and the night-time appearance.

There is a balance to be struck between increased social amenity and the desire for darkness. A typical example is the tension between the need to provide floodlighting for sports while minimising light pollution and sky glow. The social benefits to be gained by adults and children being able to play sport after dark must be balanced against the environmental (in its widest sense) impact. There is also an increasing trend towards 'lighting for darkness' in exterior design.

Another major difference is the growing use of solid state lighting (SSL). This normally refers to LEDs, although other SSL sources are being introduced. The major difference between these and conventional light sources is that they are very easily controllable using digital signals; for example, they can easily restrike from hot or dim smoothly to 10% (or less) output and are therefore highly responsive to pedestrian and traffic movement. They can easily be made to respond to other factors, such as atmospheric conditions, temperature, visibility, etc.

Apart from the fact that LEDs have luminous efficacies which can sometimes exceed those of high-pressure sodium, there are also major energy savings to be made by programmed switching (as opposed to simple photocell control) and dimming. Dimming and proactive controls should play a major part in any exterior lighting scheme.

It is anticipated that LEDs will replace conventional light sources for most applications.

The relative cost of energy will inevitably increase in the long term, so we discuss ways of minimising consumption without compromising the function or visual aspect of the design.

The longevity of exterior lighting installations means that issues can arise which were not seen as important at the time of the design (e.g. the energy cost of streetlighting or recycling of electronic components, such as LEDs or their drivers).

Of particular relevance to exterior lighting is the issue of light pollution in all its forms. Any new lighting installation makes an impact on the night-time environment and this should be balanced against the needs of the population and improved social amenity.

A lighting scheme that does not benefit society in some way should not be installed in the first place.

2 General design aspects for exterior lighting

A comfortable and stimulating outdoor environment is usually the result of a combination of factors: location, topology, history, architecture, the physical structure of the environment and the elements and activities contained within it.

External lighting can greatly enhance the outdoor environment by creating a heightened sense of place. It can extend the use of an area or activity well into the evening, contributing to a real and perceived sense of security at night, enhancing the night-time experience for visitors and residents alike. On a broader scale, sensitive exterior lighting can instil a feeling of civic pride and significantly contribute to the regeneration of urban areas. Lighting can also be used as a means to guide people, in much the same way as a road sign or traffic signal can, but perhaps in a more subtle and intuitive manner.

Lighting can be used to reveal and enhance a space, creating a sense of place, especially at focal points and nodes of activity, while making positive connections between the various elements of a development and its locale. Lighting can sometimes become a focal point in itself.

In addition to the visual impact, there are a number of other aspects that need to be considered in the development of any external lighting design: the creation of a safe and pleasant environment, the appropriate use of energy, ease of maintenance, countering the threat of vandalism and harmonising the appearance of the lighting equipment with its surroundings.

Inappropriate external lighting is a potential environmental nuisance in any context. Artificial light should always be delivered to the point where it is required, and nowhere else. Issues such as brightness, direction and context also need to be considered in the development of the external lighting design to ensure that light pollution and light spill is avoided.

Savings can be made throughout the entire life of an installation by the careful consideration of energy efficiency, light-source and luminaire efficiency, the overall cost of a scheme, maintenance regimes and ensuring that the most environmentally sustainable schemes are installed.

People's reactions to the nocturnal environment are centred on a sense of well-being resulting from a complex combination of factors, such as:

— visual comfort
— sense of place
— spatial legibility
— way finding
— personal safety and security
— a psychologically comfortable balance between lit and unlit spaces.

2.1 Context

2.1.1 Lighting masterplans

A lighting masterplan considers all elements of the exterior lighting of a development, from the macro-scale to the micro-scale. It lays down a set of rules and guidance that need to be adhered to for any new project within the boundaries of the development in order to ensure consistency of approach in the lit effect. A lighting masterplan can be applied to smaller areas, such as a new residential development, business park or town square, or to larger scale areas, such as entire towns or cities.

For new developments, this can sometimes be more easily achieved as they present the opportunity to ensure that appropriate provision is made to include certain items within the lighting masterplan. For existing developments, such as a city quarter, with a myriad of architectural styles, street layouts and existing lighting equipment, a lighting masterplan can really help to bring cohesion to the night-time appearance of an area, creating a more legible and attractive space, reducing the fear of crime, helping to promote the night-time economy and, ultimately, promoting the brand and identity of the area.

The lighting masterplan can then act as a guide for further development, identifying priority projects and encouraging funding from stakeholders.

2.1.2 Research

Any lighting masterplan has to start with detailed research on the local area. For a new development, this is likely to be driven by the desires of the client and design team, but for existing developments it is important to undertake detailed daytime and night-time surveys and photographic surveys. As well as helping to understand the local context and architectural style(s), exploring an area at pedestrian level also helps to establish and confirm a number of the criteria which must be considered within the lighting masterplan; these considerations are discussed in further detail below.

2.1.3 Approaches and gateways

By what method do occupants, workers and visitors arrive in the space, and therefore what defines the person's arrival sequence?

Do people mainly arrive via a high-speed road network, by air, by train, by foot or by slow-moving vehicle?

Gateway structures can help to signify arrival in a new location. These can take the form of public artwork and sculpture, iconic buildings, bridges or existing geographical features.

The size and scale of any gateway feature needs to be carefully considered so that it is relevant to the speed of arrival, viewing distance and viewing direction to ensure it has an appropriate visual impact.

The appropriate illumination of such structures can highlight these important gateway features, signifying an approach to a different area and helping to promote interest on arrival during the night-time.

2.1.4 Circulation routes

Any large development is likely to have a multitude of different types of circulation routes, including primary, secondary and tertiary roads, pedestrian routes and cycle paths (both segregated and non-segregated from vehicular traffic). There may also be other circulation routes, such as beach promenades and rivers.

Using different light colours and varying the visual brightness of surfaces, directions of light and types and spacing of lighting equipment can all help to visually indicate different circulation routes, subtly aiding navigation, speed of travel and use of space. A lighting masterplan should provide guidance on these criteria for each different circulation route, thereby creating a visual hierarchy of the different routes that exist within the development.

For example, primary vehicular routes may all be illuminated with a cool white light source using street lighting luminaires mounted on tall columns, whereas a pedestrian route may be illuminated at a lower illuminance level using a warm white light source and human-scale bollard luminaires.

2.1.5 Landmarks, destinations and nodes of activity

Landmarks can help people to navigate through a space by acting as visual markers, thereby helping individuals to identify their current location and determine their direction of travel. Landmarks can include items such as government and municipal buildings, statues, bridges, tall buildings, historical buildings, geographical features, or sometimes just buildings that are visually prominent due to their location.

During the daytime, these landmarks can be quite distinctive, but at night they may be unlit or poorly illuminated, making them difficult to identify and therefore creating confusion when trying to use them as navigational aids. Appropriate lighting of these landmarks can help them to be identified at night, reinforcing their presence (Figure 2.1).

Figure 2.1 A typical landmark: Wembley Stadium arch (photograph courtesy of Thorn Zumtobel)

Sometimes a landmark can be a single destination in itself, at other times a destination can be a group of buildings, such as restaurants, theatres, transport hub or a retail street. Nodes of activity can include areas such as public squares, parks and major junctions. By varying the lighting approaches for destinations and nodes of activity it is possible to create visual interest and define the area as distinct from its surroundings. Extending an area's activities into the nocturnal hours helps to animate the night-time environment and extend hours of operation, which can give a boost to the local economy.

2.1.6 Views and vistas

As alluded to above, views from both within the area of the masterplan and from afar can help people to navigate at night by indicating the direction of travel required. Consideration must be given to the visual brightness of key items along a line of sight to ensure that they are appropriately illuminated in contrast with their surroundings to help promote the view.

Vistas can help create iconic scenes of an area at night, such as a city skyline, which can help to attract visitors to the location, further enhancing the local economy.

2.1.7 Lighting palette and equipment

An important aspect of any lighting masterplan is to consider the visual appearance of the light and the lighting equipment, both of which can be used to characterise the development and the different areas and circulation routes within it.

In the development of the lighting masterplan, a lighting hierarchy must be established for the following aspects:

— *Visual brightness and contrast*: can help to subtly indicate different areas, buildings and activities.

— *Light colour* (both varying colour temperature of white light and saturated coloured light): can help to subtly indicate different areas, buildings and activities. The application of saturated coloured light should generally only be considered for a few key structures and spaces to help make them more easily recognisable.

— *Colour rendering*: areas of high pedestrian usage will benefit from light sources with a better colour rendering.

— *Luminaires*: differentiating between luminaire types helps to identify different application areas within the masterplan area through varying the distribution and direction of light as well as the visual appearance of the luminaires themselves. For example, the use of a visually different lighting column within the masterplan area can help to signify the area's status in a subtle but intuitive way. The development of a custom column can add an iconic nature that is exclusive to the masterplan area.

Taking these features into account, consideration should be given to how the various elements of the masterplan will be lit, to help identify them as a discrete group within the broader masterplan area while retaining their separate identities.

2.1.8 Lighting details and integration

In the application of any masterplan, consideration must be given to standard lighting details for application within the areas defined by the masterplan. In addition to reducing street clutter though the use of integrated lighting, the lighting details themselves can help to give character to particular areas and spaces or define the limits of the masterplan (Figure 2.2). For example, it may be desirable to utilise a bench detail with concealed integrated lighting, helping to mark the space as a destination and encouraging people to rest for a while within the space.

To help further reduce street clutter, it may be desirable to consider the integration of more visual elements of lighting equipment, such as street lighting columns, with other items of street furniture, such as street signage, banners and litter bins. Detailing of such items will need to be co-ordinated with the other members of the design team.

Figure 2.2 Excerpt from masterplan

2.1.9 Maintenance

As with any lighting scheme, the maintenance regime needs to be appropriate to ensure the designed lit effect is maintained over time. To this end it is important to develop all lighting proposals in collaboration with the client's maintenance team to agree appropriate maintenance intervals for cleaning and lamp replacement, as well as the number and types of different lighting equipment and lamps that will need to be serviced and replaced. Therefore, the lighting equipment selected should be sufficiently varied to ensure that the aims of the masterplan are met, but without introducing an excessively large number of different lamps and luminaires, which would make ongoing maintenance difficult. If the maintenance regime is too onerous or difficult to implement then, ultimately, over time, the lighting masterplan will fail.

2.1.10 Environmental zones E0–E4

In the design of any exterior lighting scheme it is important to consider the local context, ensuring that any exterior lighting design is appropriate so that it does not appear visually out of keeping with the immediate surrounds. It is also important in the design of all exterior lighting schemes to avoid obtrusive light, ensuring that luminance, illuminance and source intensity levels are within appropriate limits for the immediate area.

The ambient brightness of a space will vary depending on its location, therefore lighting guidance sets out values for each of the lighting criteria that are suitable for a development's immediate area, so that buildings and spaces appear appropriately lit in comparison with their surroundings. The locations vary from the darkest, E0, protected areas such as Dark Sky Parks, where no electric lighting is permitted, through to the brightest, E4, which encompasses urban areas with a high district brightness, such as a city centre with a busy night-time economy (Table 2.1).

It is therefore important during the design stages of any external lighting scheme to undertake detailed daytime and night-time surveys of the area. Information gathered during a survey on the existing lighting and character of the area can help to inform the selection of the correct environmental zone.

Table 2.1 Environmental zones

Zone	Surroundings	Lighting environment	Examples
E0	Protected	Dark	IDA Dark Sky Parks, UNESCO Starlight Reserves
E1	Natural	Intrinsically dark	Areas of Outstanding Natural Beauty, relatively uninhabited rural areas
E2	Rural	Low district brightness	Village or relatively dark outer suburban locations
E3	Suburban	Medium district brightness	Small town centres or suburban locations
E4	Urban	High district brightness	Town and city centres, commercial areas

Source: CIE 150: 2003.

2.1.11 Dark Sky Parks

Dark Sky Parks are areas of outstanding natural beauty with exceptional views of starry skies and nocturnal habitat, where all light pollution, whether from direct upward light or reflected light, is mitigated to ensure the preservation of the area's night-time beauty and educational, cultural, scenic and natural resources. Guidance on the requirements for classification as a Dark Sky Park is given by the International Dark-Sky Association.

2.1.12 Reducing visual clutter

Visual clutter can be defined as a visually chaotic scene, caused by the inclusion of multiple elements of street furniture without consideration of the overall scene, which detracts from the overall quality of the environment. Street furniture contributing to visual clutter can include (but is not limited to) such items as lighting columns, signage, litter bins, pedestrian barriers, planters, benches and bollards.

Poorly planned street furniture, signage and lighting equipment can all add to visual clutter, detracting from the visual character of an area and making it increasingly difficult to navigate a space and potentially devaluing the external scene (Figure 2.3).

A well thought out public realm can minimise the impact of visual clutter through the careful location and integration of these various elements, thereby reducing the number of items cluttering the streetscape. Further reduction of the impact caused by the installation of lighting equipment can be achieved through the integration of lighting with other items of street furniture, such as mounting

Figure 2.3 Visual clutter (Ilia Torlin/ Shutterstock.com)

bins and signage on street lighting columns. Alternatively, building-mounted street lighting could be used although, in order to implement this approach, the appropriate permission, such as wayleaves in the UK, would need to be sought from the building owner.

2.1.13 Environmental impact assessments (EIA)

An EIA is normally required for new developments, such as buildings, hard landscaping, residential and industrial estates, etc. The environmental assessment includes factors such as impact on flora and fauna, noise, traffic, air quality, the character of the location and many others. One section of the EIA deals with the visual impact assessment (VIA). This will include issues such as the visual appearance/impact of the buildings or development on the landscape, commenting on visual clutter, character of the area, etc.

Any artificial lighting is normally included in the VIA and known as a lighting visual impact assessment (LVIA). (Note that the term LVIA can also refer to a landscape and visual impact assessment.) The assessment will include issues such as the daytime visibility of lighting columns or any building-mounted lighting equipment. This assessment is normally carried out by an independent lighting consultant. The report will include the existing 'baseline' conditions plus the impact of the proposed lighting.

See section 2.2 for more information

In terms of the night-time assessment of the development proposal, guidance is available on minimising light pollution and glare, such as SLL Lighting Factfile 7, ILP GN01 and CIE 126-1997 (see section 2.2). These documents

Figure 2.4 Sky glow over Los Angeles (logoboom/shutterstock.com)

contain recommended values for the luminance of buildings, source intensity towards viewers, light spill into windows, minimising the contribution to sky glow, etc. (Figure 2.4). Although the recommended values in these documents were reached subjectively by groups of experts and interested parties, they do represent objective criteria against which the values calculated for a lighting proposal can be compared, allowing the proposal to be judged to be compliant or non-compliant with the criteria.

Related to these 'hard' criteria are others where compliance cannot simply be calculated. One example is whether the lighting could be considered to be a nuisance. This issue is described more fully in DEFRA's guidance: *Statutory nuisance from insects and artificial light* (2006). Another example concerns whether the lighting is in keeping with the character of the location – for example, whether coloured light would be acceptable in a given location.

2.2 Legislation and guidance

The need to minimise sky glow and upward light applies to all exterior lighting applications. Specific guidance can be found in the Society of Light and Lighting (SLL) Lighting Factfile 7: *Design and assessment of exterior lighting schemes*, the Institution of Lighting Professionals (ILP) Guidance Note GN01: *Guidance notes for the reduction of obtrusive light* and the International Commission on Illumination (CIE) 126-1997 *Guidelines for minimizing sky glow*.

Lighting for outdoor workplaces is covered by BS EN 12464-2, which gives recommendations for various tasks taking place on building sites, farms, fuel filling stations, shipyards, builders' storage compounds and vehicle parking areas. Note that there is often supplementary guidance for a particular activity (e.g. railway companies have extra criteria for the lighting of platforms and petrochemical companies make recommendations for specific task areas). Airports and their approaches will also have particular guidance relating to column height, upward light spill, etc.

Before starting any design, information should be gathered from the client and any related industry-specific criteria established.

Lighting of roads, highways and residential areas is covered by BS EN 13201-2 and BS 5489-1. Again, these deal solely with the functional and safety aspects of lighting. These documents also consider areas such as car parks, ramps and stairs.

See section 3.4 for more information

The Equality Act 2010 (which replaced the Disability Discrimination Act 1995) and BS 8300:2009 *Design of buildings and their approaches to meet the needs of disabled people* are of particular relevance to open areas, such as pedestrian precincts. Lighting is discussed as part of the overall design to allow greater access for disabled people. In terms of lighting, ramps, steps and changes of direction need the most attention. Recommendations for these areas are given in section 3.4 of this guide.

In the UK, light can be considered to be a statutory nuisance under the Environmental Protection Act 1990. This is defined as 'Artificial light emitted from premises so as to be prejudicial to health or a nuisance'. Note that it applies to 'premises' and not to landscapes. There are many exceptions, such as airports, railways, dockyards, etc. Special conditions also apply to sports pitches and industrial and business premises. Highway lighting should also be considered to fall within this Act. Note that some local authorities exclude highways because they consider them not to be premises. The SLL *Guide to Limiting Obtrusive Light* covers all aspects of this topic. A further related document is produced by the ILP: PLG04: *Guidance on undertaking environmental lighting impact assessments*.

Mounting luminaires on buildings can make them subject to wayleaves. These can be costly and the process of obtaining approval often takes a long time.

Similarly, access for maintenance can sometimes be problematic, especially if the equipment is on private land/buildings but lighting a public space or right of way. You should check, as early as possible, whether wayleaves apply.

2.2.1 Guidance

Much of the guidance on luminance, illuminance values, glare and intensity limits is based on the concept of environmental zones (see section 2.1.10). These range from E0 for a protected environment, such as a Dark Sky Park, to E4 for busy city centres. There are no hard and fast descriptions of these zones and so you should use your professional judgement, or ask others, to determine the classification of the area under consideration. If there is doubt, use the more onerous values recommended.

See section 2.8 for more information

The *Secured by Design* (SBD) series of design guides published by the Association of Chief Police Officers (ACPO) concern mainly residential areas. The SBD guides stress that BS 5489-1 must be achieved and that a competent designer must be engaged to do the design. See section 2.8 on roadways for more detail.

Information on exterior lighting for specific applications can be found in other SLL guides:

— Sports lighting recommendations can be found in SLL Lighting Guide 4: *Sports lighting*. Sports organisations such as the Lawn Tennis Association also give guidance.

— Tram/train platforms and bus stops are covered by the forthcoming SLL Lighting Guide 14: *Transport lighting*.

— Building and construction sites are dealt with in SLL Lighting Guide 1: *The industrial environment*.

The latest research on the whole range of lighting issues can be found in the journal *Lighting Research and Technology* (*LR&T*) published by Sage Publications in association with the SLL. A list of relevant publications and legislation is given in the references section.

2.3 Area lighting

This section deals with general open areas, such as car parks, hardstandings, kickabout areas and non-specific open spaces that need to be illuminated.

The first question to be asked is why the area needs to be lit. This may seem obvious, but the answer may well determine the solution. For example, security lighting for a storage yard may not require good colour rendering, whereas locations which are used by people during the evening and night-time will be much more amenable if a ‘white light’ source is used. Conversely, much greater uniformity may be required for the storage area so that CCTV can see into the shadows.

Floodlighting for security is almost invariably switched on from dusk to dawn. Car parks often have peak periods of use and considerable energy savings can be made by reducing the lighting level when it is not required. It is not recommended that lighting is totally switched off because this can dissuade people from using the space.

Car parks need lighting from several directions. Lighting from one side only will produce deep shadows (Figure 2.5). Single-side illumination also means that people and the sides of vehicles away from the light can only be seen in silhouette. This can generate a feeling of insecurity among users. Related to this, low-level lighting, such as bollards, can easily be obscured by vehicles. The ACPO *Secure by Design* series does not recommend the use of bollards.

Figure 2.5 Typical area with deep shadows (Tumarkin Igor - ITPS/Shutterstock.com)

See SLL Lighting Guide 4 for more information

Kickabout areas can usually be illuminated to a fairly low level of illumination – refer to the football section of the SLL Lighting Guide 4: *Sports lighting*.

2.3.1 Layout and mounting height

The major problem at the initial stage of designing a floodlighting installation is that there are so many possible variables. Unlike interior lighting, where the boundaries are clearly defined by walls and ceiling and floor, floodlighting equipment can be placed within the area to be lit or located on columns well outside the area. The height of the columns and their distance outside the area will have to be considered because, until such matters are decided, it is impossible to tell what beam distributions are required or how the floodlights should be aimed. The best advice for anyone beginning a design is to start by studying the characteristics and limitations of the site. With areas of regular shape and set dimensions, such as sports areas, standard column layouts may be available to guide the designer, but this is rarely the case with industrial and commercial areas.

Generally, the greater the mounting height, the smaller the number of columns, masts and towers required. As a result, a higher mounting height generally achieves the most effective and efficient floodlighting at the lowest installation cost, but the relationship between mounting height H and the depth of the area to be lit D is important, see Figures 2.6 to 2.8.

If an open area is to be lit from one side (shadows permitting), the ratio D/H should not be greater than 5. If there are obstructions within the area, such as in a stock yard, then the ratio should be reduced to 3 or even 2 in the case of extensive obstructions (the ratio also expresses the relationship between shadow length and object height at the far edge). When lighting from two or more directions, the ratio can be increased to 6, but should be reduced to 4 if there are obstructions. In terms of actual aiming angle, there is little difference between a 4:1 throw (76° from the downward vertical) and a 6:1 throw (80° from the downward vertical). Of course, the higher the aiming angle, the greater the chance of glare or light being emitted above the horizontal.

The height of the column is also dependent on the surrounding buildings. In residential areas, columns should be no higher than the eaves of the adjacent buildings. If this proves impractical (due to the number of columns required), then the columns should be no higher than the adjacent road lighting.

It is important to minimise glare to residents and this can be achieved by low D/H ratios (e.g. 2–3 rather than 5–6).

A solution for car parks where the area is wide in relation to the column height is to mount columns inside the area, usually centrally. In this way, the D/H ratio can

Figure 2.6 Typical floodlight aiming for an area 2*H* wide

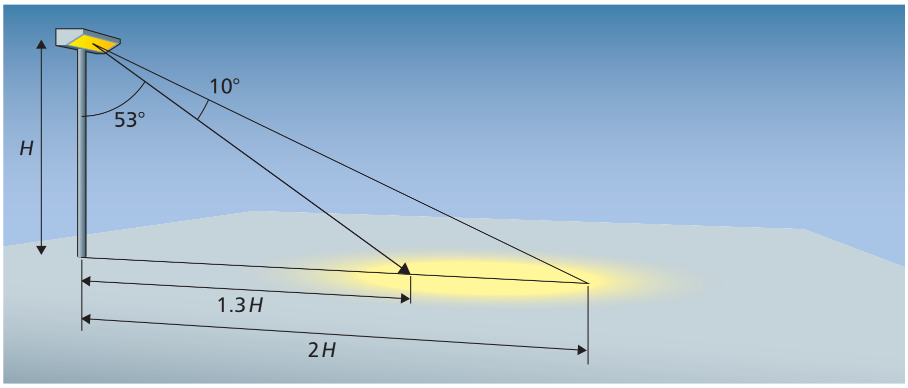


Figure 2.7 Typical floodlight aiming for an area 3*H* wide

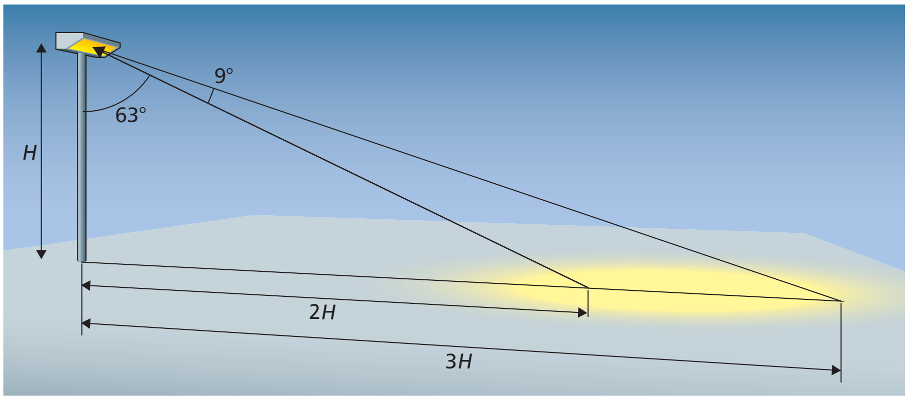
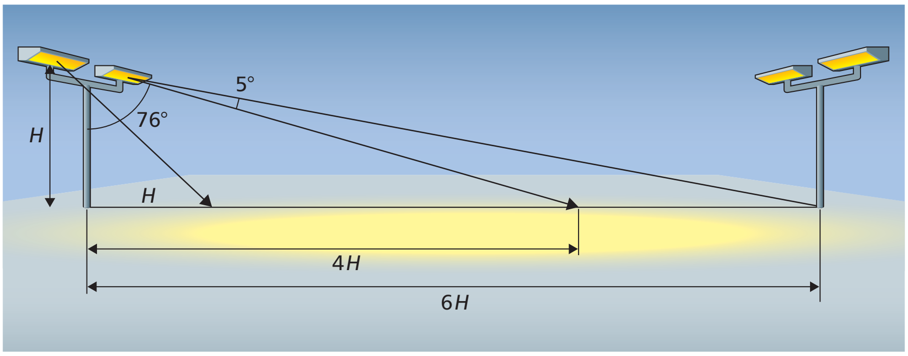


Figure 2.8 Typical floodlight aiming for an area 6*H* wide from both sides



be much smaller, thus reducing column height, aiming angle and possible glare. To make best use of the columns, it is usual to mount several lanterns on each. A common solution is to mount four lanterns at 90° intervals. An alternative is to use lanterns with a road lighting type of distribution, back to back, to light the circulation routes within the car park.

In the initial design, the peak intensity of the floodlight is usually directed at a point some two-thirds of the way across the depth of the area. Floodlights with double asymmetric light distributions can provide vertical beam spreads suitable for different *D*/*H* ratios, but such floodlights have wide horizontal distributions. Where the *D*/*H* ratio exceeds 3, it is often necessary to use a supplementary floodlight with a wide vertical beam angle aimed at a lower elevation to fill in the area close to the base of the column. If floodlights with symmetrical light distributions are installed to illuminate very large spaces, a series of projectors is used. Those aimed at high elevations have narrower beam angles than those aimed at lower elevations.

Note that higher aiming angles put proportionately more flux onto vertical surfaces than horizontal ones. High levels of vertical illumination can be a benefit in terms of facial recognition but may also cause glare.

One disadvantage of high aiming angles is that the reflector needs to have a sharp run-back above the peak intensity to avoid wasting light (and contributing to sky glow) above the horizontal. At a 6:1 throw (80°), there is only a narrow angle (10°) above the peak intensity before light is emitted upwards – thus wasting energy and contributing to light pollution.

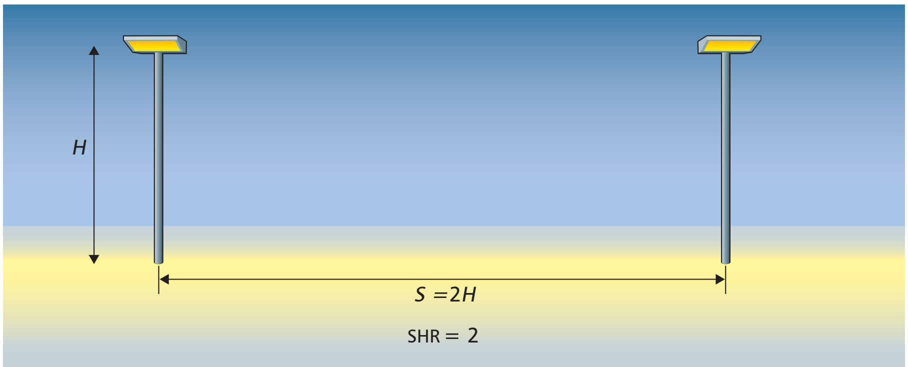
Bollards are commonly used to light car parks but they suffer from several disadvantages, the main one being that a single vehicle adjacent to the bollard can block the spread of light. Also, in order to achieve any reasonable uniformity, the bollards need to be placed relatively close together (e.g. 1 m high bollards should be no more than 10 m apart unless calculations show that the required degree of uniformity can be achieved). Due to their accessibility, they are also vulnerable to vandalism.

2.3.2 Spacing

Where areas are to be lit from one or two sides, the spacing between columns may be dictated by site limitations (Figure 2.9). Given no constraints, the spacing to height ratio (SHR) is determined primarily by the horizontal beam spread of the floodlights, selected in the first place because of their vertical beam characteristics.

Values of SHR in the range 1.5–2.0 are commonly used with asymmetrical floodlights: values over 3.0 are unlikely to provide acceptable uniformity. Where higher SHR values prove to be necessary because of site constraints, some floodlights may have to be aimed at points which do not lie on a transverse line from their column, or a more complex aiming pattern of symmetrical floodlights may have to be used. It will be necessary to check the consequences of the aiming pattern on both illuminance and uniformity by point-by-point calculations.

Figure 2.9 Column spacing



2.4 Amenity lighting

2.4.1 Public realm area lighting

The general description of public areas can include many different types of space, including squares, entrance foyers, courtyards and piazzas, single-owner and multi-owner shopping centres, breakout spaces associated with stadia and public buildings. For the purposes of this section of the guide, open areas are considered as pedestrian-dominated spaces with minimal vehicular movements, which would normally be restricted to out-of-hours deliveries, maintenance and emergency services access.

To illustrate the wide range of lighting projects that could be covered by the term public open area, these could be anything from spaces of national significance, such as Trafalgar Square, to small shopping squares (Figures 2.10 and 2.11).

The largest square in the world is Xinghai Square in Dalian, China in which 1 100 000 m^2 is lit by a combination of lighting techniques (Figure 2.12). Trafalgar Square is the UK's largest single public square at 23 000 m^2.

Figure 2.10 Trafalgar Square (Kiev.Victor/Shutterstock.com)

Figure 2.11 Village square (Sean Pavone/Shutterstock.com)

The non-lighting aspects of design criteria for open areas need to be considered at the outset of the design process. It is important to consider ownership of the area itself and the surrounding properties. A single owner of the whole area offers the simplest situation, giving the designer the freedom to evaluate all options. When multiple owners are involved, it is important to assess the effect on the lighting options available and to advise the client early of the effects of ownership on the lighting strategy. Stakeholder engagement is essential in achieving acceptance of the scheme.

Depending on the complexity of the open area, the design drivers should be identified before lighting techniques are considered. The feasibility of the client's brief should be carefully evaluated and challenged where necessary. It is always worth writing a basis of design (BoD) and obtaining client agreement before moving on to the concept design stage. The agreed design drivers should be separated into pros and cons to enable viable solutions to be identified before

Figure 2.12 Xinghai Square, Dalian (kitzcorner/Shutterstock.com)

evaluating concepts. A good method of identifying and rating the pros and cons is to carry out a strengths, weaknesses, opportunities and threats (SWOT) analysis.

The following is an example of the types of design drivers that will be common for most open area lighting schemes:

- client's aspirations
- use of the space
- cultural significance (local and national)
- listed buildings
- aesthetic considerations, including architectural appropriateness
- entertainment and theatrical effect
- local pressure groups (e.g. historical societies)
- planning consent and listed building consent
- local infrastructure: water, gas, electricity and drainage
- ownership of site and adjacent buildings
- local planning guidance and lighting masterplanning requirements
- requirements of vehicular traffic in and around the area
- availability of electrical power at luminaire locations
- local authority lighting specifications and highways adoption
- availability of suitable luminaire mounting positions
- colour and types of existing materials
- changes in level and identification of obstructions
- choice of light source
- choice of luminaire
- vulnerability to vandalism/strength of equipment
- maintenance and construction design and management issues
- access requirements (visually impaired and physically disabled people)
- health and safety of the public/staff and local fauna and flora
- environmental considerations, including disposal of lamps and luminaires at the end of their lives
- obtrusive light
- cost of maintenance
- capital cost, including installation costs and equipment costs
- interfacing with temporary installations (including theatrical lighting)
- energy usage and availability
- lighting control.

While the above is not an exhaustive list of design drivers, it does illustrate the potential complexity of open area lighting and the fact that each scheme is likely to have certain special requirements. The mix of design drivers is likely to make each project unique, even for similar types of space.

Identification of the client's key performance indicators and stakeholder requirements early in the design process, usually at RIBA Stage 2, is essential to establishing the scope and the basis of design. Only when these documents have been signed off, is it worth entering into the concept design and 'optioneering' phase.

See section 2.1.1 for more information

In the early stages of the design process, it is important to assess the scope of the lighting over which the designer has control and the adjacent existing and proposed third party schemes. There may be a lighting masterplan (see section 2.1.1) in place; if so, the key aspirations of the masterplan need to be considered early as they could represent specific planning constraints. Key vistas are normally a prime consideration of masterplans and may restrict options for the placement of lighting columns.

Third party and existing lighting schemes need to be evaluated via surveys and consultations so that the appropriate project target maintained illuminance levels and light source types can be agreed.

There are no specific illuminance levels detailed in BS EN 12464-2 for open squares. The figures mentioned in Table 2.2 should be seen as a starting point for the design and provide the benchmark for establishing good practice from a health and safety standpoint. BS 5489-1 and BS EN 13201-2 should also be considered.

Table 2.2 Excerpt from BS EN 12464-2:2014 (reproduced by permission of BSI)

Ref. no.	Type of area, task or activity	$\bar{E}_m$ (lux)	U_o (–)	R_{GL} (–)	R_a (–)	Remarks
5.1.1	Walkways exclusively for pedestrians	5	0.25	50	20	
5.1.2	Traffic areas for slowly moving vehicles (max. 10 km/h), e.g. bicycles, trucks and excavators	10	0.40	50	20	
5.1.3	Regular vehicle traffic (max. 40 km/h)	20	0.40	45	20	At shipyards and in docks, R_{GL} may be 50
5.1.4	Pedestrian passage, vehicle turning, loading and unloading points	50	0.40	50	20	

It should be noted that privately owned open areas are considered workplaces from a legal standpoint, so a duty of care exists for both the landlord and tenants.

Access requirements are of particular concern in open areas when considering the placement or use of luminaires that are directly in the visual field of disabled persons. Luminaires such as bollards and ground-mounted uplights and floodlights should be sited carefully so that disability glare is not caused. This is especially important for in-ground luminaires; the surface temperature of the glass is also a concern if children are likely to be present. A glass surface temperature of below 60 °C is recommended.

Luminaires can also be integrated into structures and street furniture where lighting columns are considered undesirable (e.g. in front of architecturally and historically significant buildings). Focal lighting to statues and monuments can also aid the general brightness of an open area. Glare can be a particular concern in the lighting of monuments and statues. All viewing angles should be investigated at the design stage. 3D computer modelling for proposed installations and site trials for existing ones are especially useful.

2.5 Landscape lighting

Landscape and public realm projects offer many opportunities for imaginative lighting design approaches. Lighting can be designed to cover a broad view of a scene and the arrangement of elements within a view; alternatively, a more

Figure 2.13 Mapping on building at Fête des lumières, Lyon (Pierre-Jean Durieu/ Shutterstock.com)

selective approach can be taken to highlight key elements. Regardless of the approach adopted, the design brief and scope should be based on the satisfaction of the client's needs, established by assessing the various outdoor activities, the social context, any CCTV presence and key features, balanced by the need to minimise energy consumption. The overall experience must also be considered to design a scheme which adds value to the locality.

3D mapping projection events, short-term 'guerrilla lighting' and son et lumière performances have made the public aware of the potential of light to produce special effects at landscape scale (Figure 2.13).

By night, the landscape architect and lighting designer can use light to reveal objects and form selectively. Through directional lighting, designers can emphasise modelling, and by modulating and composing the areas of brightness a sense of depth and perspective can be given to a scene. Designers might consider the possibility of creating an enhanced sense of visual hierarchy by emphasising particular areas of detail.

This approach is equally applicable to the view of a town as to a park or a domestic garden.

2.5.1 Landscape lighting design method

The following subsections provide a guide to the basic stages and principles in the development of an outdoor lighting scheme. When considering the development in the context of landscape design, it is important to understand the design process involved.

This may be summarised in the following stages: survey; analysis; design; appraisal; installation; and commissioning/focusing.

2.5.2 Survey

It is important to be familiar with and fully understand the site. Existing sites should be surveyed during both day and night, ideally over a period of time, to understand the ambient conditions. It is also worthwhile making a preliminary risk assessment in terms of where the proposed lighting equipment could be located. Where sites are being newly developed, copies of the project drawings should be obtained. Useful scales are 1:500 for site plans and 1:200 for details and sections. Google Earth may be helpful in identifying the general context and existing site attributes.

2.5.3 Plans

Information may include:

- roads: classification, alignment, width, crossings, lay-bys, bollards, signs, parking
- paths: alignment, width, steps, ramps, signs, users (e.g. pedestrians, cyclists)
- buildings: use, shape and location, entrances, services
- artefacts: phone points, post boxes, seats, signs, urban features, art objects
- natural environment: tree species, locations, shrub species, hedge species, pools, water channels/features.

2.5.4 Elevation/sections

Vertical features and levels provide the principal clues for identifying places and opportunities for potential lighting solutions. Consider:

- buildings: form, texture, colour, night-time use/appearance
- trees/shrubs: species, height, form, density of foliage, type and colour.

2.5.5 Functional requirements

As well as addressing health and safety issues and the general need for people to feel safe, there may be other requirements, such as CCTV. A first step is to consult the standards which are recommended or laid down for the proposed site uses; for example, the following may have specific requirements:

- Department for Transport classification (transport)
- sports councils (sport)
- Health and Safety Executive (places of work)
- police and insurance companies (security)
- local authority, community or developers.

In some cases, this information may not readily be available so a brief will need to be developed with the key stakeholders. In areas such as National Parks or Sites of Special Scientific Interest (SSSI) there may be specific limitations.

2.5.6 Visual and creativity requirements

The need for inspirational and aesthetically pleasing schemes has never been greater because both planners and developers are seeking to craft and create more interesting outdoor environments. In urban areas, there is often the desire to create a ‘café society’ feel to a space.

Detailed consideration needs to be given to the holistic effect from the outset. This has a profound impact on the final lighting scheme provided. The client’s expectations and landscape designer’s vision must be developed together to achieve the best results.

2.5.7 Analysis

The purpose of this stage is to produce a performance brief, providing the basic criteria against which the success of the design can be measured.

The most direct technique is to document and note on a survey drawing of the site all the factors which must be considered, indicating the relevant features. The major factors to be considered are:

- site conditions: obstacles, changes of level, security of people, key elements and principal views, movement patterns and routes, destinations, etc.
- performance: activity-related areas where lighting needs are known (e.g. sports events, workplaces, roads, stations, airports, ports, etc.)
- character: ambience, image, mood
- public interaction and main circulation routes
- intended experience for those using the space.

2.5.8 Design

The basis of all design is usually human need, perception and response. A successful lighting design must principally fulfil the practical requirements of safety and security, and at the same time satisfy both psychological and aesthetic needs.

The eye adjusts to ambient light – depending on the individual, the eye can be extremely sensitive to low levels of illuminance where only the minimum of visual information is required. The lighting design is often required to function at various incremental levels for differing applications:

- minimum lighting for safety at times of least use
- general lighting for normal use
- special lighting for visual effects.

Care and attention during the design stages should be given to appropriate surface and feature brightness to ensure that a space is not overly lit, or indeed underlit. A scheme should not make the eye work hard through an imbalance of light levels and luminance contrast. Consideration must be given to a wide potential user base, including the very young and old, and the range of uses of the space.

2.5.9 Technical solutions

It is advisable to seek professional guidance at an early stage. The best schemes are the direct result of a close partnership between the lighting designer or project engineer and the environmental designers. The skill of the lighting designer/engineer lies in the practical realisation of the design objectives, using the most appropriate technical resources.

2.5.10 Basic decisions

There is no absolute single solution to any given situation. The brief, aspirations and site constraints will always vary, therefore each design must be approached in a unique way.

There can, however, be basic design correlation between:

(*a*) locations of light sources (i.e. identifying mounting locations, mounting height, spacing, distance from lit objects, etc.) and

(*b*) the types of light sources (i.e. intensity, distribution, resulting light colour, controls etc.).

If lighting equipment can be integrated within a landscape to take advantage of existing materials, surfaces, buildings and structures, a more holistic scheme can be developed. This, in turn, also reduces unnecessary clutter and the introduction of additional structures.

Most design processes begin with a trial proposal, which presupposes elements of both (*a*) and (*b*) above, based on experience. This proposal is then modified to take account of other considerations, such as:

- further review and approval/opinion from clients and stakeholders on aesthetics
- the colour of light, colour temperature, brightness and colour rendering
- efficiency, capital equipment and operational costs
- visibility of light sources (concealed, visible, directly seen).

2.5.11 Technical design

The lighting proposals are normally documented on a site plan, supplemented by sections and elevations where necessary.

Generally, these will need to show:

- the location of each lighting source (ideally both in plan and in section, showing tilt/aiming angle)
- a specification of the type of light source
- the means of supporting the luminaires
- maintenance provisions (e.g. hardstanding requirements for tower access)
- switching arrangements, cableing and protective devices
- location of control or supply equipment.

2.5.12 Design appraisal

Skilled designers can easily interpret a technical drawing and will be able to understand and assess the design intent of a scheme from a visual and technical perspective. Lay clients may need help, which can be offered in a number of ways:

- demonstrations can be provided: luminaires can be rigged up temporarily, samples provided or similar installations visited
- drawings can be highlighted: plans can be coloured to illustrate the distribution of light on a given horizontal plane
- illustrations can be drawn: elevations and perspective sketches can convey an impression of the visual effect; alternatively, computer-generated illustrations can be provided to demonstrate the effects proposed
- models can also be made: these can be used to demonstrate principles; however, light sources must be reduced in power and relate to the scale.

2.5.13 Parameters for choice

The main design objectives can always be met by a wide variety of equipment and a range of solutions. The following considerations may influence the development of an optimum solution:

- capital cost of initial installation
- running costs
- maintenance costs
- resistance to anticipated abuse
- colour rendering
- daytime appearance
- appropriate specification of light source and technology for the scheme

- appropriateness/acceptability within the community
- appreciation of improved environment
- increased utilisation of the landscape
- increased sense of security
- increased sense of civic pride
- mitigation of light pollution and glare
- regulations and local authority requirements
- legal/statutory requirements and duties.

2.6 Facade lighting

2.6.1 Benefits of exterior lighting of buildings, structures and features

Many of Britain's towns and cities owe much of their individual character to fine historic buildings and well-designed contemporary buildings and structures which boast rich, ornate facades and beautiful architecture.

Other places, perhaps less fortunate in having a legacy of fine historic buildings, are nevertheless likely to have many interesting buildings and structures of one form or another, churches, monuments and other features, together with an increasing wealth of modern architecture, even if impressive facades conceal commercial office complexes, precincts, flats and hotels.

The grandeur of the historic and the qualities of the modern can both be accentuated during the hours of darkness by well-conceived installations of exterior lighting and architectural lighting. It is important not to over-light external buildings and spaces or use poor light sources, as this can be detrimental if not fully considered.

Floodlighting was the term previously applied to the general method for illuminating building facades. It is a generic term which is still often used. With the introduction of smaller and more focused technologies, such as LEDs and narrow beam metal halides, more integrated and detailed lighting can be provided to illuminate specific architectural details and forms at night. The term floodlighting is becoming increasingly less frequently used within the lighting design community as it suggests a large volume of lighting, which is often flat and uncontrolled in nature.

In the case of the commercial sector in urban areas, the buildings are likely to be offices, retail stores and accommodation for hospitality-based activities. Exterior lighting can attract attention and create a favourable impression, which enhances the appearance of a building and its offering. Good exterior lighting can be an extremely effective form of advertising. A high-quality lighting design will complement the building's function, boost its success and enhance the appearance of its location, adding considerable value to a community.

A significant advantage to exterior building facade lighting is that it is likely to increase a general sense of well-being at night. Lit buildings tend to look more welcoming and attractive; they can offer an enhanced sense of permanence and reinforce community safety. Well-planned lighting acts as a deterrent to anti-social behaviour as criminals prefer not to be seen; good illumination will draw people out in the evenings, increasing footfall and promoting self-policing.

As natural daylight and sunlight is general and non-selective, the daytime presence of a space will differ markedly from what will be seen at night. The most obvious difference being that, by day, light comes from above whereas, by night, the floodlight beams are usually shining upwards.

Artificial lighting can reveal specific buildings and highlight particular characteristics, and the effects can be modified with lighting controls to vary the appearance. The lighting designer is able to select precisely which aspects to accent or ignore. Most buildings of any merit can be successfully lit and the techniques for achieving a good lighting effect are not based solely on the science of illumination engineering but include an appreciation of the aesthetic values of the architecture.

This is particularly applicable in the exterior lighting of key civic and community buildings, such as cathedrals, castles, churches, bridges and ancient monuments, which respond remarkably well to light. Not only are the buildings themselves enhanced, so is the landscape as a whole.

Modern buildings and the dynamics of material trends are constantly evolving. Lighting methods and selection need to carefully consider the building finishes and how light will affect them.

2.6.2 General design considerations

Any external lighting project should not be started until a comprehensive survey has been made of the building and the surroundings in which it stands. It is essential to study the features of the facade under the conditions of natural light and preferably to view it in sunlight at regular intervals throughout the day. A detailed appraisal of the effects created by variations in the angles of sunlight striking the architecture can reveal which features of the building are the most attractive and identify the principal aspects that lend themselves to enhancement with artificial lighting.

Close consideration must be given to the architectural character. Features such as window reveals, columns, entry points, repetitive facade expressions and principal surfaces (vertical, horizontal or fragmented) should be identified and appraised during the development of the lighting design. A selective approach is often appropriate to allow shadows and three-dimensional qualities to be clearly expressed. There will be choices to make at this stage, for example it might be best to backlight a series of columns to express them in silhouette or, alternatively, front light them if they are decorative, but not both. A good lighting designer will be able to articulate these choices to optimise the unique opportunities. An architectural lighting designer will have much to contribute to these choices as they will have a valuable insight into the architectural references and their origins.

Many early architectural styles were considered only in relation to the natural light of day and decorative illumination after the sun had set would have been impossible. There is now no limit to the form that a modern building may take; living architects are more inclined to believe that a building should also be attractive to view after dark, when the various surfaces and textures may be illuminated electrically. The appearance of the building at night-time may well have been considered when the design was in its early stages and it is often helpful if the original architect can be consulted in order to ensure that the correct interpretation of the original concept is maintained.

2.6.3 Viewpoints

It is helpful to identify whether there are principal locations from which the building will be viewed. There may be one or two preferred viewing positions (Figure 2.14). Some facades can be partially obscured and there is little value in lighting a building from all directions if there is a singular vantage point. Tall features, such as church spires and towers, often have their best viewpoints from some distance away.

These aspects should be identified prior to starting and developing the design process.

Figure 2.14 The principal viewpoint here is from across the lake (np/Shutterstock.com)

The location of the lighting equipment must also be considered in relation to the building and to the predominant view.

It is helpful for design purposes to decide what should be considered as the normal distance between the viewer and the building, based on the optimal directions of view, as this will affect the scale and form of the selected fixtures. It may be desirable to conceal fittings so that the lighting effect is seen but the equipment that creates the effect is not obvious or visible.

Whether an observer will be able to discern all or any of the architectural details on the facade will depend on the distances involved, the modelling and the urban context.

Often, a tall building will be seen standing against a black night sky. If the immediate surroundings and background are also dark, a relatively small amount of illumination will make the building appear much lighter and give it prominence. This might also be achievable from selective internal lighting within the building, which can offer a different night-time appearance. A thorough approach to the lighting design development will assist in defining which options are viable and which is best for the project.

If there are other buildings adjacent to the subject building, which are themselves illuminated, or if the ambient light levels are already high due to road lighting or signage, the illuminance on the building facade will normally have to be of a higher value in order to achieve an effective contrast between the building and its surroundings.

Alternative solutions where ambient light levels are high may be achieved by creating a contrast in colour, tone or texture rather than a contrast in brightness. The use of colour in exterior lighting enables differences in planes and surfaces to be highlighted but, as a general approach, colour should be used sparingly and with great discretion to avoid the result looking garish.

Local buildings, cityscape and surrounding buildings must be considered prior to introducing colour on buildings.

Figure 2.15 Collégiale Notre-Dame, Beaune, showing strong modelling (photograph courtesy of iGuzzini illuminazione)

Local restrictions, local authority requirements and relevant guidance (such as ILP GN01) must be fully consulted. Where heritage buildings or conservation areas are affected, it is essential to ensure that all the statutory requirements are followed correctly and any permission, such as wayleaves, obtained. Some buildings will have features and, in certain cases, lighting equipment, that is specifically listed. Other buildings will have separate requirements to fulfil, such as churches and cathedrals, which are likely to require further or additional approvals from a trust or fabric advisory committee or specific agreements to be made.

2.6.4 Techniques

If spotlights are positioned parallel to the line of the building and aimed directly at the facade it is possible that the lighting effect will be flat and disappointing. It is often desirable to achieve fairly strong modelling on all but the plainest facade. A degree of modelling can be obtained by ensuring that the highest proportion of light arriving at principal surfaces ideally comes from a single direction, although the actual number of spotlights providing this flow of light may be large. The greater the angle between the line of view to the building and the direction at which the light incident upon the surface arrives, the stronger and more dramatic the modelling effect is likely to be (Figure 2.15). The optimum effect is likely to be achieved when the direction of light flow is between 30° and 60° to the direction of view.

A complete facade could potentially be illuminated to show the entire building outline to the viewer. This approach maintains the proportions of the architecture and allows the more prominent and desirable features to be given due emphasis. In any case, the building needs to appear as more than simply an illuminated, two-dimensional front face. Its solidity can be emphasised by adding light at a lower illuminance to the sides or, at the very least, to the return corners, allowing the illuminance to decay gradually towards the rear of the end wall. It may be necessary to illuminate a sloping roof in order to achieve a coherent picture, otherwise chimney stacks may appear as if they are suspended in mid-air.

The view of a building can appear incomplete if lower areas of the walls or facade are partially concealed from a distance by trees or other larger structures. Trees and bushes may usefully be allowed to show up in silhouette against the building, or be provided with their own separate lighting arrangement in a contrasting colour. Alternatively, should the obstructions detract from the effect, the illuminance can be decreased in the lower areas of the building, thereby diminishing the presence of silhouettes.

It may be desirable in some instances to soften the strong modelling effect of unidirectional light. This can be achieved by illumination in the form of fill-in light from the opposite direction to the main flow of light. In most cases, it is likely that there will be sufficient ambient or inter-reflected light to give the desired result. Any fill-in light should generally be based at approximately one-tenth of the value of the main illuminance.

It may be desirable to add lighting to highlight the outline of the building, to prevent it disappearing against the backdrop of the dark sky. It is in assisting with these types of choices and decisions that an experienced lighting designer can add value to a project.

2.6.5 Practical considerations for specific characteristics

There are four basic architectural forms which may serve to classify or describe the general style of many building facades/envelopes.

- degree of detailing
- vertical characteristics
- horizontal characteristics
- external recesses.

Facades which are basically flat

Typical examples of buildings with completely flat facades are the plain brick fronts of factory units or unadorned concrete office blocks (Figure 2.16).

Functional forms without any projections or architectural detailing are not always ideal subjects for architectural lighting. In these instances a more layered approach might be worth considering, where interior lighting plays a role in the external expression of the form.

The achievement of any definition may only be possible by placing the luminaires at exceptionally close offset positions. This approach may not be helpful for security surveillance, where a high level of uniformity is required. However, a certain degree of unevenness in the brightness patterns across the facade can provide visual interest.

Figure 2.16 **Lighting a building with a predominantly flat facade** (photograph courtesy of NDY Light)

This effect can be achieved by variations in placement and aiming of the light sources. However, if the surface is pitted or has deep slots, the result may be an unevenly lit surface. To overcome this, the light sources should be positioned closer together.

Facades with predominantly vertical characteristics

Strong vertical lines on a facade are characteristic of both medieval and classical architecture. Many modern buildings have a strong vertical emphasis not only in their basic forms but in details such as pillars, support columns or the sinews of the cladding framework; this is often seen in contemporary office and hotel structures.

It can be helpful to acknowledge pronounced vertical influences and the form can then be emphasised by applying illumination from the left and/or right sides of the facade with medium or narrow beam spotlights (Figure 2.17). Generally, if a fairly pale coloured surface material is used, the shadows formed by sharply oblique lighting can be too strong and create too distinct a contrast. In-fill lighting from the opposite direction using light sources with wider beam reflectors is likely to reduce the contrast and soften the appearance. The overall visual impression is often optimised when the direction of view is towards the areas of shadow, i.e. parallel to the flow of in-fill illumination.

Uplighting to facade reveals and integrated building lighting can be incorporated during the development of the building design to create striking visual features within the building.

Light projections may be considered to create visual interest on flat facades, but the cut-off and exact angle of the fittings needs careful planning to ensure that waste upward light is minimised. In some instances, local restrictions may apply with regard to uplighting.

Figure 2.17 Lighting a facade with predominantly vertical characteristics (Peter Wallace/Shutterstock.com)

Visual interest and lighting effects can also be created by using internal lighting to give a sense of occupancy within a building. By using controls that can be programmed to fade, increase or colour shift, a sequence of scenes can be achieved. The narrative of the subtleties of colour, brightness and the natural hierarchy can be adjusted over time to change the emphasis from one feature to another.

Facades with predominantly horizontal characteristics

Post-war changes in planning and the introduction of new materials and construction techniques enabled architects who were trained with modernist values to exploit the full potential of prestressed concrete forms and a wide variety of both vertical and horizontal cladding (Figure 2.18).

A great many of the impressively high modernist office and hotel blocks have a markedly horizontal emphasis. Often, such design includes horizontal elements which project slightly, for example window ledges or continuous bands that run across the facade from one side of the building to the other.

Architectural lighting placed close to the facade and aimed upward will produce bands of dark shadow above any physical protrusion. The wider the shadow band the more likely it will be that the surface area of the facade above the projecting ledge will appear to be floating on air and the building can appear as a series of dismembered sections.

Supplementary lighting may be placed on the ledge to in-fill and eliminate the shadow if this effect is not desired. Alternatively, the projectors may have to be moved away from a close offset position to gain a greater distance between the facade and the light source. There are a wide variety of possibilities in these varying parameters and the totality of the lighting effect will be influenced by the offsets and locations selected.

Figure 2.18 A facade with predominantly horizontal characteristics (George Green/Shutterstock.com)

Facades with external recesses

A facade is often designed to incorporate features such as balconies or recessed galleries, which may project forward or be set deep into the facade (Figure 2.19). In both cases the lighting could be located some distance back from the building in order to prevent excessively dark shadows being formed. If a lack of available space in front of the facade prevents this, supplementary illumination can be placed inside the balcony/recess space or incorporated within the zone creating the shadow. Supplementary light of a contrasting colour may be used to good effect in some circumstances. In many cases the use of shadow can be helpful to express the form of a building. The lighting designer should ensure that the concept design clearly defines the intentions of the scheme so the client or local planners can understand the overall intent and range of possibilities achievable.

Figure 2.19 Lighting a facade with external recesses (photograph courtesy of it does Lighting Ltd)

Triangular pediments with sculptured compositions, such as those found in classical architecture, dominate the entrance porches of some historic buildings. Due regard should be given to these features in the lighting design and specific lighting can be applied to highlight them to good effect. Specific illumination in these instances can be achieved by locating spotlights at some distance away – permissions from neighbouring buildings may be required to achieve this. Alternatively, linear sources positioned at close offset to the base of the triangle can work, but are generally less effective and can be difficult to service.

Balustrading can be visually attractive if given prominence by lighting. One method to achieve this would be to use a line of fluorescent or LED luminaires mounted on a balcony and aimed outwards to provide a pleasing modelling of the balusters. These features can also be very effective when revealed in silhouette against an illuminated wall.

Generally, the appearance of a lit facade can be greatly enhanced if any balconies, galleries with railings at the front and similar recesses are illuminated individually, preferably by lighting which contrasts subtly in colour, tone or intensity with that used for the principal facade lighting.

1.6.6 Columned arcades and porticoes

Columned arcades and porticoes present interesting opportunities for lighting design. Columns may be incorporated as part of the lighting effect in silhouette. Lighting concealed behind the columns can be used to illuminate the inner walls and soffit of the portico, thereby silhouetting the columns against their background. A discreet use of colour or a shift in tone in this situation may help to emphasise the effect. Columns that are relatively close to the facade are often best revealed by lighting them directly using narrow or medium beam spotlights which have an elongated light distribution horizontally and with asymmetric distribution vertically. Ordinarily these luminaires would preferably be positioned at ground level. They should be vandal-resistant and the surface temperature of the glass should be kept low. The luminaires will then need to be aimed upwards at a high angle with the lighting finely adjusted on site to achieve the best effect. The capitals of certain column types can be particularly ornate; revealing these features with light can add significant interest to the craftsmanship and design of these components. The final design should provide a pleasing and balanced appearance of all of the principal features.

1.6.7 Windows

It is worth considering that when a building is lit from the exterior, light will only illuminate the frames, and not the glass itself. As a result, the windows themselves will often appear dark compared with the other surfaces of the building and facade. Window lighting should, therefore, be treated separately. With the exception of stained glass, it is usually the window reveals that are the more important elements.

A decision should be taken as to whether it is the windows, the frames or the glass within them that is more important architecturally. The design and form of the window will offer a range of possibilities for lighting. Sometimes the window reveal is of significant architectural merit, for example a gothic window reveal or a building with roman references where deep recesses of rusticated stonework have been applied. In more contemporary buildings, the frames and architectural rhythm of repeated offsets can be attractive if lit and these offer interesting visual expressions with light. The glass itself should also be considered; ancient glass will provide a rippled surface which can be visually striking if lit with a grazing beam of of narrow light. The glass can also add sparkle and visual interest if etched or cut.

With general exterior lighting, especially close offset, care must be taken to avoid unwanted shadows being cast upwards by ledges or into the interior ceilings. Shadows can be reduced or avoided by mounting small luminaires on ledges and using lenses and cowls. Luminaires should be as inconspicuous as possible. It is preferable to specify them to be supplied in a colour to match the surroundings.

Sometimes fittings can be hidden behind mouldings or balustrades. Fixtures that provide a general wash should have a wide angle asymmetric vertical beam with a sharp run-back above its peak. If fittings are aimed upwards, they should be completely waterproof when mounted in a forward configuration. Water, snow and ice may accumulate on the lenses' surface so the fitting must be suitably ingress protection (IP) rated.

If fluorescent lamps or linear LED luminaires are mounted on a continuous ledge close to the surface they light, care must be taken to minimise the gaps between the fittings to avoid dark patches.

Figure 2.20 Regular pattern of windows lit from inside (photograph courtesy of dpa lighting consultants)

Shielded battens or LED fittings can be mounted at the top and/or bottom of a window. Some manufacturers make luminaires dedicated to this particular purpose. Light will reflect from curtains or blinds if present – their appearance should harmonise, in brightness, tone and colour, with any facade lighting. Windows in a building that is not lit externally may be attractively revealed by this form of lighting (Figure 2.20). However, if windows are lit in this way care must be taken by the building users to ensure that all the blinds or curtains remain in planned positions, otherwise a patchy and unsightly appearance can result.

Alternatively, the lighting of the interior itself can be designed with a view to the night-time appearance from outside – for retail premises this a common approach.

2.6.8 Stained glass

In buildings of a religious or educational nature there are often stained glass windows which offer the opportunity for backlighting, front lighting or sometimes both.

At night, internal backlighting will add visual interest to these features and will command attention to possibly previously unseen features. Internally, this can also be helpful as the ornate detail can become legible at night – for evening events and services this additional effect can be dramatic.

Coloured glass windows can present both opportunities and challenges. If a window is to appear lit from inside the building as well as from outside, the relationships and methods of lighting need to be carefully planned. If the glazing is very lightly coloured then specific care and attention must be given to the aiming angles. It is likely that the interior surfaces around the window will need to be lit to achieve a reference value against which the colouring can be viewed.

In Figure 2.21(a) the light from floodlight A passes straight through the clear glass with little or no scatter so that the window will appear dull or black from positions on either side. The floodlight at B will be seen directly through the glass, the rest of the window remaining dark. If a single light source is used at A, a projected image and shadow of the window itself will appear on the surface of any overhang or ceiling, assuming that this is reasonably light coloured.

In Figure 2.21(b) diffusing glass will scatter the light from a floodlight at position A, its apparent brightness depending on the degree of diffusion or colour saturation. Position B may be unsuitable as the degree of diffusion is unlikely to be such that the source image is completely obliterated. Owing to the angle of incidence of the light on the surface of the glass and the consequent losses by reflection, absorption and diffusion, only a limited component of the light falling directly on the windows will be effective in providing a glow (but it may be sufficient to create a pleasing effect). As every heritage window is unique, a test in situ is ideally required. Consequently, in direct lighting of stained glass windows which are rich in colour saturation and where the pane is thick, the use of high output projection equipment with good colour rendering sources is likely to be required.

In Figure 2.21(c), light coloured surfaces inside the room or screens placed behind the window are lit by equipment placed in either position A or B to give the effect of a lit window without the use of a diffusing medium against the glass. General interior lighting can produce a similar effect if the walls and ceilings have reasonably high surface reflectance characteristics. It is almost always necessary to experiment on site to achieve optimised results due to the many variables but, in spite of the difficulties, lighting stained glass windows can, with care and patience, produce some extremely striking effects (Figure 2.22).

Figure 2.21 Stained glass window lighting (a) with clear glass (b) with diffusing glass (c) using reflected light

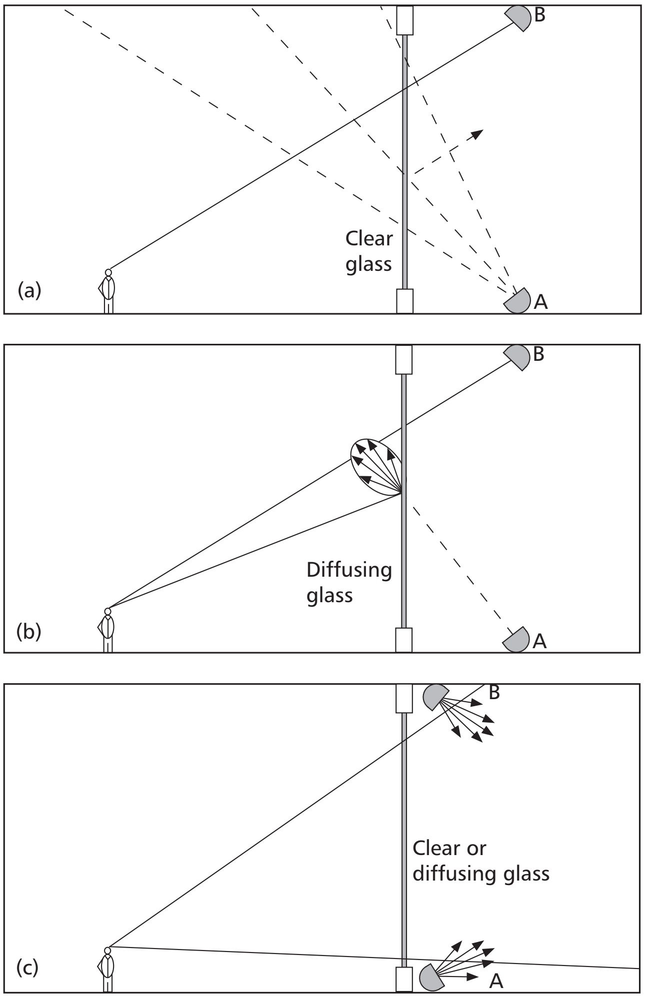
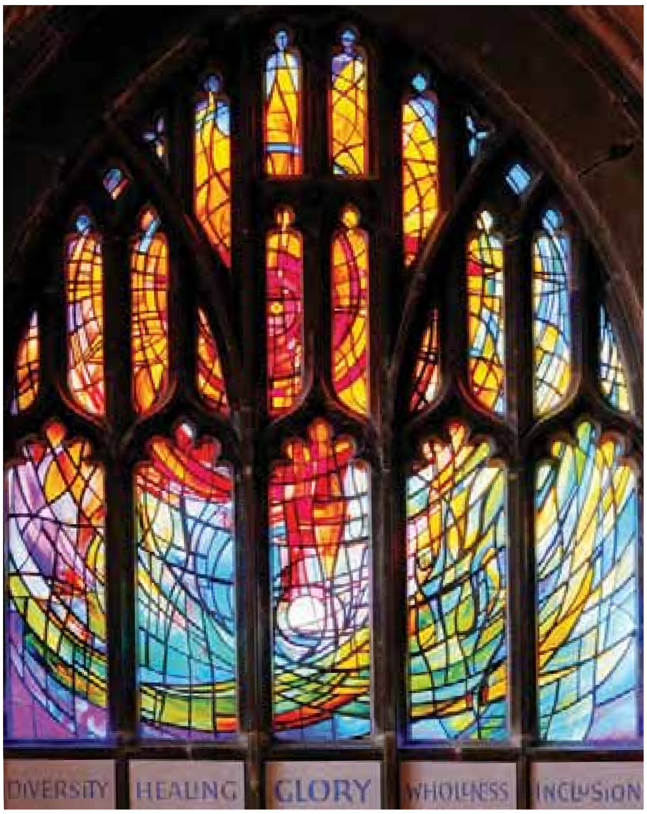


Figure 2.22 Illuminated abstract stained glass (Alastair Wallace/Shutterstock.com)



2.6.9 Modern buildings

New materials and methods of construction play a significant role in developing the distinctive character of contemporary buildings. For example, the external and internal walls of modern steel-framed buildings are non-loadbearing and are often made from lightweight materials and prefabricated before delivery to the site. Reinforced concrete structures, some with roofs spanning 40 m or more, are also typical.

Provided that the type of structure is suitable and location is appropriate, external lighting can be used to emphasise the social and architectural significance of civic, educational and commercial buildings. It may also serve to advertise the products of the company that owns or occupies a building.

Generally, flooding the exterior with light is inappropriate if a building facade is flat and extensively glazed. Where detailed exterior lighting is suitable, the system design should be focused on the emphasis of the important features of the building. Provision for any external lighting should preferably be made in the early stages of design. Wiring outlets and mountings for lights can then be incorporated within the building structure or provided at the necessary points in the surroundings, resulting in a fully considered installation and reducing unsightly clutter (Figure 2.23).

Economics usually demand that the building footprint in the central areas of towns and cities is fully utilised. Consequently, the boundary line of a building's edge may not be sufficiently set back for exterior lights to be installed within it.

A close offset system, with the lights mounted on the building, or in recesses, could then be considered (Figure 2.24). Careful planning in consultation with the architect/owner is necessary to locate the luminaires in suitable positions to ensure that that coverage is adequate, shadows are not excessively distorted, the scheme can be readily maintained and unintended patches of brightness are not produced on the facade adjacent to the external light fittings.

Figure 2.23 LEDs integrated into the architecture due to lack of mounting positions (photograph courtesy of NDY Light)

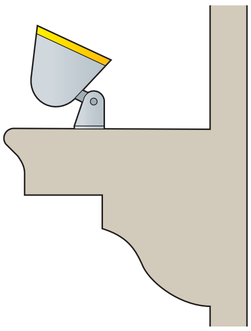


Figure 2.24 [above and right] Close offset floodlights mounted on a ledge

If the height of a lit high-rise block is accentuated by reducing the brightness progressively towards the top, it may be worth considering whether the building should be 'capped' or 'expressed' with light, perhaps of a linear presentation or possibly a different tone/character from that used for the main facades.

Some modern buildings are raised on columns and have an open paved area at ground level for car-parking or pedestrian access. If the building is intended to be lit or lighting is added later, the structural ceiling above the paved area and the supporting columns should also be lit to provide an illuminated base, otherwise the building may appear to be floating incongruously.

Linear features and structures can be picked out using LED/cold cathode tubing or side-emitting fibre optics for easier remote access. These effects can be very beautiful if carefully designed and detailed, but an overly intense scheme or a poor selection of colour can be over-the-top or garish. Care and integrity are key factors in developing the overall lighting concept.

2.6.10 Heritage lighting

Listed buildings and historic sites need careful treatment and permission from the relevant local authority must be obtained prior to works being carried out. It is a criminal offence to carry out work which needs listed building consent without obtaining it in advance.

It is important to note that the term 'listed building' includes:

- the building itself
- any object or structure fixed to it
- any object or structure that has been within the curtilage of the building since 1948.

Figure 2.25 Stepped luminaire mounting to uplight a wall (photograph courtesy of dpa lighting consultants)

In addition to listed buildings, consent must be obtained for scheduled monuments; these are 'nationally important' buildings or sites.

Permission must be sought if you want to 'alter or extend a listed building in a manner which would affect its character as a building of special architectural or historic interest' and, as a listing applies to the whole building or site, lighting is likely to fall into that category, certainly any new lighting installation.

What can, and what cannot, be done is under the control of the local authority, although guidance is often sought from English Heritage, Historic Scotland and other conservation/heritage groups.

In theory, you cannot drill holes into the building fabric or damage it in any way. This can pose a challenge for new lighting installations. The key is to do everything possible to mitigate any damage or alteration to the appearance of the building.

For example, cabling can often be run in mortar joints of stone or brick buildings and cable colour can be specified to blend in or be painted to match if necessary. In some cases, an outer layer of new mortar may be specified to cover the cabling.

If it is not possible to utilise mortar joints, then self-adhesive cable tie holders may be used as these cause no permanent change or damage to the building.

Mounting luminaires can also prove tricky but, for facade lighting especially, paving slabs can be an invaluable tool as luminaires can be slab-mounted and the slabs laid, unfixed, onto ledges or other parts of the building, eliminating any intrusion onto the fabric itself.

Sometimes it is necessary to manufacture new housings within which to mount luminaires. Figure 2.25 shows stone steps with a newly constructed luminaire housing that sits on the steps, allowing 'recessed' luminaires to graze up the wall.

2.6.11 Spires and towers

Towers, steeples and domes are often challenging structures to light and so careful planning is required. Towers and steeples appear more natural when illuminated from only one general direction. An impression of greater height can be obtained by diminishing the value of illuminance progressively from the base to the top.

Richly decorated spires are usually shown to best advantage when lit from the main supporting structure of the building; the resulting patterns of light and shade are, in general, more pleasing than those produced by spotlights located on distant buildings. It is sometimes necessary to use both methods to achieve the best effect, particularly when the aiming angles and distances vary around the specific structure. Lanterns within a spire can be illuminated effectively by internal lighting (this can be visually rewarding if created by a warmer light source). Pinnacles, crockets and similar features can be lit with narrow-beam spotlights mounted ideally at close offset positions; a similar method can be used to reveal the decoration of ornamental brick or stone chimneys.

2.6.12 Colour

Attractive effects can be achieved by using light of different colours at different times of the year or for special events. For example, cool LED or metal halide lamps can be used in winter, their bluish-white light suggesting the cold of the season.

It is important to remember that the colour of surface materials is accentuated more effectively and accurately if light of the same colour is used. Alternatively, if white light from various light sources is used, it may be balanced or converted into a more suitable colour by the use of filters (Figure 2.26).

Figure 2.26 Good use of colour on a facade (photograph courtesy of it does Lighting Ltd)

2.6.13 Design stages and considerations

Having decided on the external lighting effects required from key viewing positions and the direction(s) from which the light should come, the more practical aspects of the lighting design should be resolved in detail.

It should be noted that the illuminance required to achieve certain brightness contrasts on a given facade depends on a number of factors:

- building surface material reflectance values
- environmental zone (existing and any prescribed limits/ recommendations)
- location of the building relative to the general surroundings
- the dimensions of the building
- the quality and location of the lighting equipment selected.

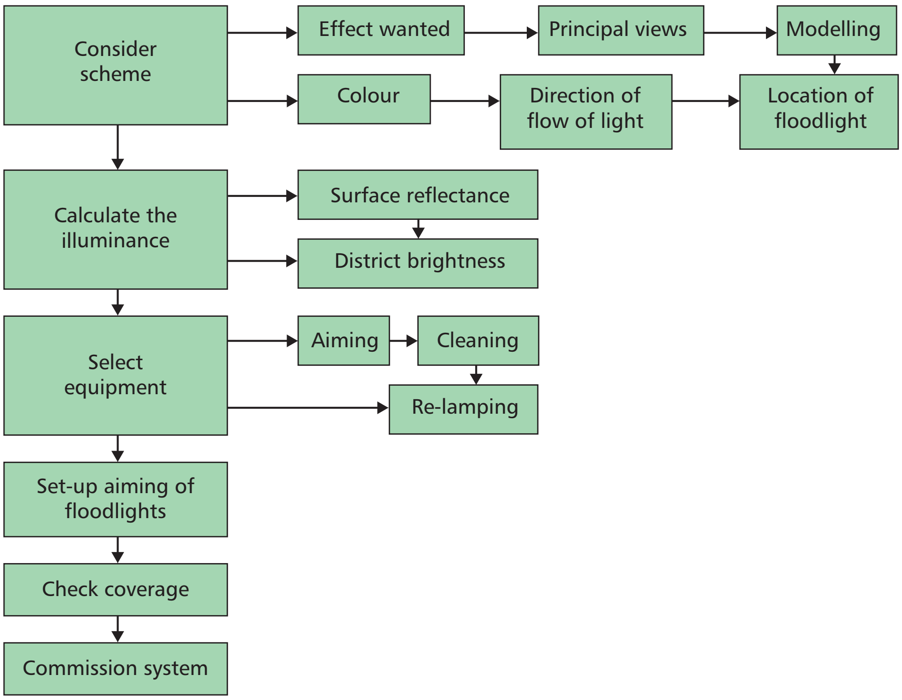


Figure 2.27 Flowchart of design stages

Facades or areas of surface material that have reflectance values of less than 20% will generally be more difficult to light. It may be more practical to accentuate a part of the building which has a higher reflectance, rather than attempt to make dark stone appear visually bright.

2.6.14 Useful checks

There are certain essentials that should be an integral part of the design specification, although it might only be possible to check some of these aspects on site prior to the final commissioning of the installation:

- no spill light should be allowed to fall onto neighbouring buildings
- no glare should be caused to road users, the occupants of nearby buildings or visitors to the building being lit
- there should be no confusion with transport signalling or navigation
- there should be no danger to the public from inconsiderate placing of lighting equipment, cabling or control gear boxes – all electrical and lighting equipment should be vandal-resistant and mechanically, electrically and thermally safe
- lighting, cabling and associated accessories should be as discreetly concealed as is practical
- check the internal lighting arrangements and understand the method of window curtaining/blinds to be used
- explore all relevant options to test whether the interior and exterior lighting can be organised differently to improve the overall effect
- there may be good reasons why it is not possible to conceal all luminaires from view and every effort should be made to ensure there are no objectionable highlights caused by excessive patches of brightness or bright objects close to the luminaires
- check that the control and switching systems operate correctly and that these reflect the client's expectations.

2.7 Security lighting

The general approach is to provide a uniform, shadowless, glare-free environment with good vertical and horizontal illumination. When dealing with security lighting issues, the aim is to increase the feeling of safety for those using the space. Lighting alone cannot prevent crime; however, it does make natural surveillance easier and increases visual acuity, making crime less likely.

Shadows should be minimised since they can hide miscreants. Shadows can also be used to conceal stolen goods or tools to aid in the commission of crime later.

Generally, white light is preferable as it gives the greatest feeling of security to those using the space. Having a high colour rendering index (CRI) enables the eye to see colour and skin tone clearly and this allows us to more readily recognise people and make more informed judgements about those sharing the space.

Maintenance is a significant consideration as lamps which are hard to replace, or luminaires which cannot be changed, will result in the scheme quickly deteriorating and potentially allowing security to be compromised. Ensure that maintenance staff can easily access the luminaires and that lamp life is as long as possible to avoid outages.

Vandal-resistant luminaires with an impact protection (IK) rating of 10 will be the most suitable for these types of designs. An IP rating of at least 65 is also desired for outdoor use. Check that fixings are robust. If the luminaires are mounted on columns, fit vandal-resistant fixings to the doors so they cannot easily be opened by the general public or vandals.

2.7.1 Switching

Basic-level security lighting is often controlled via a passive infrared (PIR) sensor where the location is dark until someone approaches. However, this can lead to nuisance switching, where the lights are switched on too frequently or unnecessarily. Generally, a better option is to have a constant uniform level of light or lighting that dims to a low level (but never switches off completely) when absence is detected so that the area never falls into complete darkness. LED and compact fluorescent luminaires can be easily dimmed, making this option is far more viable and cost effective than when halogen or discharge lighting was in favour.

A photocell or timer should be fitted to switch off the luminaires during daylight hours.

2.7.2 Glare

For basic- and intermediate-level security, lighting should be designed so that glare is eliminated. A bright source which causes glare will affect the eye adaptation level, making it difficult, or impossible, to see into shadows. Having a direct line of sight to the actual light source is not advisable. Light source in this case also refers to the reflector.

High security installations often use glare as a technique to deter intruders. High power point sources facing 'outwards' disable the vision of someone approaching the installation. Additionally, this same technique means that security staff have a very good view of people approaching. Similarly, security checkpoints have high levels of illumination outside and staff work behind mirror glass and are unseen.

2.7.3 Fences

A technique for perimeter fences is to use streetlighting lanterns (Figure 2.28). These give wide lateral spacing and can be configured to minimise rearward spill light (i.e. the lanterns face outwards, allowing people approaching the fence to be easily seen). Streetlighting optics are also better suited to providing good uniformity along the fence line.

2.7.4 Open areas

Large areas are best illuminated by floodlights. Lighting from several directions will minimise shadows. This can often be achieved by locating multi-lantern columns in the centre of the area. Care needs to be taken to avoid glare to security staff.

Figure 2.28 Security lighting using streetlighting lanterns (photograph courtesy of DW Windsor)

As well as lighting the area around the building, a useful technique is to provide uniform illumination on the walls. This enables possible intruders (or their shadows) to be easily seen against a light background.

Good vertical illumination is necessary for facial recognition by the security staff and CCTV.

The aiming of floodlights must be carefully managed so that the beam does not spill above the horizontal. This wastes energy and contributes to sky glow. Double asymmetric, flat glass lanterns are ideal for this purpose (see Figure 2.51). There will inevitably be a balance to strike between the spread of light required and the height of the column. This can only be determined by the particular site conditions.

Wall-mounted bulkheads are also used for security lighting and should be mounted at around 2–3 m for maximum effect. Luminaires which throw light downwards rather than just forward will generally give better horizontal illuminance; however, for good facial recognition, luminaires with some vertical output may be preferable. It is worth considering whether a small streetlighting luminaire will perform the function more effectively than a conventional bulkhead unit.

2.7.5 CCTV

CCTV camera suppliers often have their own particular requirements and advice should be sought whenever cameras are to be used. The light source must also have sufficient colour rendering (CRI > 80) for images to be obtained which can be used for prosecution.

2.8 Roadways

2.8.1 Industrial estates

Roadway lighting should meet BS 5489-1 and BS EN 13201. Although non-adopted and private roads need not meet these standards, it is good practice to do so, even if for the simple expedient that they may be adopted in the future.

Care should be taken that floodlighting on private property does not adversely affect the road lighting (e.g. reflections in windows or other sources of glare).

See section 2.9.3 for more information

Note that BS 5489-1:2013 has introduced the concept of mesopic vision in determining lighting levels. The lighting levels are based on the scotopic/photopic (S/P) ratio of the light sources (see section 2.9.3). This concept only applies to light sources with a CRI > 60.

2.8.2 Residential lighting

Where there are blocks of flats, social housing, care homes, dementia residences, etc. it may be a requirement that the design meets the guidance in the *Secured by Design* guides published by ACPO. Much of the content of these documents covers hardware, such as window locks and doors, and architectural features, such as avoiding recesses in alleyways or dark corners. However, there are references to lighting, the most important being that the lighting design meets the requirements of BS 5489-1 and is carried out by a competent person.

Another requirement is that the design reduces fear of crime because the police feel that if residents and visitors feel safe, they are more likely to be safe. The reasoning is that if more people go out and use the space, then criminals are more likely to be spotted and deterred.

In terms of lighting, bollards are not seen as suitable since they can be vandalised and the light can easily be blocked by vehicles. Another requirement is for white light sources with a CRI > 80. Long-life sources are seen as an advantage since they require less maintenance and stay illuminated for longer periods, thus reducing the possibility of lamp outages and dark spots.

2.8.3 Use of BS 5489-1 and BS EN 13201-2

Note that it is not mandatory to light roads and highways to these standards or, in fact, to provide any lighting at all. However, local authorities have a 'duty of care' to residents and to road users. This is usually taken to mean conformance to these standards. The local authority needs to undertake a risk assessment to determine whether lighting is required and, if so, to what level.

2.9 Vision

2.9.1 Photopic vision

Photopic vision is well understood by most lighting practitioners. All interior lighting design is based on photopic viewing conditions, where both the rods and cones in the retina are fully operational. The cones in the fovea (the central high-resolution area in the centre of the retina) enable fine detail to be seen, the degree of accuracy and repeatability being based on the task illuminance. There are many other issues concerned with interior lighting design, such as glare, colour rendering, uniformity and luminance contrast, all based on photopic viewing conditions.

It is also worth pointing out that the current recommendations for exterior sports lighting applications are based on photopic vision.

It is important to remember that the lumen, the SI unit of luminous flux, is a photopic unit based on the CIE photopic luminosity standard ($V(\lambda)$) response curve.

2.9.2 Scotopic vision

This is the situation under very low levels of illuminance, when which the cones are no longer able to operate. We are literally colour blind. Since there are no rods in the fovea, discrimination of fine detail is impossible. Scotopic vision occurs at very low levels of adaptation – the usual upper limit given is 1×10^{-3} cd/m^2. Depending on the average reflectance of objects in the field of view, this might represent an illuminance of 0.01 lux. In practical terms, this will not occur under artificial lighting – it is only moonlight and starlight that result in such conditions. A full moon in a clear sky in the UK can produce an illuminance of 0.3–0.5 lux.

Note that, under these conditions, the rods are much more responsive to light from the blue end of the spectrum. This is known as the Purkinje shift and means that objects with a high blue content (or illuminated by light sources containing significant blue wavelengths) are seen as 'brighter' than they would be under normal photopic viewing conditions.

2.9.3 Mesopic vision

As darkness falls and the luminance of the visual field reduces from photopic to scotopic conditions, we enter a condition known as mesopic vision. Since this is a transitional stage, there is no standard CIE mesopic eye response curve as there is with photopic and scotopic vision (Figure 2.29).

The lower limit of mesopic vision is the same as that of the upper limit of scotopic (i.e. 1×10^{-3} cd/m^2). However, opinion varies as to the upper limit of the mesopic

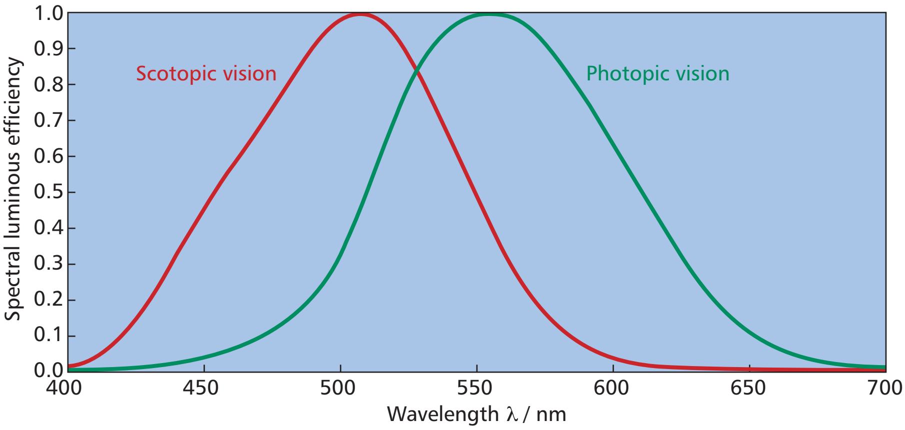


Figure 2.29 Photopic and scotopic sensitivity curves (mesopic spans the two, depending on the adaptation level)

See *SLL Code for Lighting* for more information

condition: the *SLL Code for Lighting* gives 3 cd/m², whereas the US ASSIST (Alliance for Solid-State Illumination Systems and Technologies) programme gives 0.6 cd/m².

The relevance of mesopic vision to exterior lighting is that most streetlighting is seen under these conditions. In a city centre, where the streets are brightly illuminated by shop fronts, advertising hoardings, video signs, vehicular traffic and the streetlighting lanterns themselves, our vision may well be considered to be photopic or just slightly entering mesopic. Conversely, in lightly populated areas, where the streetlighting is only giving mean values of illuminance of less than 3 lux, then the Purkinje effect is more significant.

The effect of this is that light sources with greater blue content may give better viewing ability than other sources with an equal (photopic) lumen output. This is especially true for objects seen in the periphery of the eye, where there is a high concentration of rods.

BS 5489-1 incorporates mesopic vision into its recommendations for road lighting, where the illuminance values may be reduced if light sources with a high blue content are used. Sources are categorised by the S/P ratio of their spectral power distribution (SPD).

Another useful reference is the Lighting Industry Association (LIA) Technical Statements on topics such as mesopic vision, S/P ratio and illuminance meters when used with LED luminaires.

Mesopic vision is also significant for the floodlighting of car parks and building facades, where only low levels of illuminance are required. If the concept of S/P ratios becomes more accepted, this is bound to have an impact on the way we light our exterior environment.

2.10 Video walls, streaming onto building facades

2.10.1 Media architecture

In the past few years, the presence of large screens and urban projections for commercial purposes has intensified, thanks to decreasing production costs, to the introduction of new lighting and imaging technologies and to the miniaturisation of digital components.

Public spaces have been gradually invaded by a new flow of visual information, with an impact seldom planned and often dictated exclusively by commercial and advertising pressures (Figure 2.30). At the same time, new possibilities for

Figure 2.30 Piccadilly Circus, London (GTS Productions/ Shutterstock.com)

artistic and architectural exploration have opened up, and some buildings have been transformed into entities which are not only able to show pictures in motion, but to communicate with the surrounding environment and their occupants, providing the basis for the definition of the concept of media-building.

The convergence of architecture, lighting and facade design, motion picture production, high-power computer graphics processors, information and audio/visual technologies has therefore led to the development of a new design discipline: media architecture.

The definition of media architecture is continuously evolving and difficult to capture and frame in a short description. In its simplest manifestation, it appears as the juxtaposition of a screen on a building facade. This approach has gradually evolved into the concept of media facade, where the screen is not a separate product but is integrated into the facade of a building. Media architecture has recently emerged which incorporates a higher degree of integration between digital and physical technologies, to the point of creating buildings that are able to change their appearance, to interact dynamically with their occupants and to communicate with their surroundings.

In all this, light plays one of the most important roles. With its easily changeable appearance and digital control, it has become a new building material that is able to communicate information through dynamic visual sensations. On the one hand, the very idea of 'media facade' can be framed as an evolution of architectural lighting, with the introduction of increasingly complex and versatile control systems, initially borrowed from theatre and performance lighting. On the other hand, 'urban screens' can be seen as a magnification and expansion of television and computer screens, with large screens, initially used for sports and entertainment, now increasingly being integrated into the building fabric.

Note that, in the UK, advertisements are subject to planning restrictions and require consent (deemed or otherwise) from the local planning authority. In the absence of other guidance, these restrictions are often applied to media facades.

2.10.2 Classification

Media architecture projects are very diverse and difficult to categorise. However, it is possible to provide an initial classification based on the type of technology that has been adopted.

Figure 2.31 Moving digital facade (Lev Radin/Shutterstock.com)

— *Urban screens*: These are perhaps, historically, the first type of intervention where multimedia content has been introduced on a building envelope, with large-scale screens attached to building facades without any architectural integration effort (Figure 2.31). The screen and the building remain two separate layers, in both technical and communication terms. Urban screens are independent elements, devised with the sole purpose of communicating and displaying pictures in motion. Their size, height, resolution, pixel pitch and viewing directions are optimised to follow the streams of urban circulation and to capture the attention of their target group (e.g. 4 Times Square in New York and the Galeries Lafayette in Berlin).

— *Media facades*: In this case, building facades integrate light sources or kinetic elements and a network infrastructure to distribute power and data. This level of integration is achieved in two principal ways:

- Dynamically illuminated facades, where exterior lighting systems that illuminate the facade can be designed in a modular way and connected to programmable control systems. In this case the communicative aspect becomes

Figure 2.32 Yas Hotel, Abu Dhabi (photograph courtesy of Arup)

Figure 2.33 Flame Towers, Baku (cesc_assawin / Shutterstock.com)

more abstract, such as in the Agbar Tower in Barcelona, GreenPix in Beijing, Star Place in Taiwan or the Yas Hotel in Abu Dhabi (Figure 2.32).

- Integration of multimedia systems on the facade, where modular lighting systems (usually LEDs) specifically designed for this type of application are integrated into the facade, such as in front of the Flame Towers in Baku (Figure 2.33).

Further distinctions can be made in relation to the following aspects: transparency or opacity of the media surface, high or low resolution, colour characteristics, brightness and level of interaction.

2.10.3 Design of the media facade

The design of the media facade presents a challenge in terms of creativity and integration between different disciplines: architecture, materials, structure, lighting and multimedia content are just some of the aspects to be considered in the design phase.

It is possible initially to subdivide the design of such systems into two categories:

- design of the multimedia surface
- design of the visual content: this is normally done by specialists and is beyond the scope of this guide.

In this context, this guide only considers the main aspects related to the design of multimedia surfaces that may involve skills related to the lighting design profession. The wider criteria to consider in the design include:

- structural aspects, including:
  - forces transmitted from the building and the structure of the facade system
  - loads due to weather conditions, such as wind and snow
- architectural aspects, for example:
  - integration between the facade and the building
  - form
  - construction details and their visual impact
  - resistance to atmospheric agents
- technological aspects related to viewing and appearance:
  - area of the 'screen'
  - required minimum viewing distance
  - viewing angle (there may be a need to restrict the viewing angle to avoid the screen being seen from, or throwing light onto, buildings, roads, flight paths or railway tracks from certain directions)
  - content type and display type appropriate in relation to the level of content definition to be conveyed (e.g. text, still images, moving images)
  - external conditions of vision (night, day)
  - orientation of the facade.

Related to the above are issues such as communication, the purpose of the media facade, the level of public attention and level of interaction with the public.

Finally, there are the economic and operational aspects, such as budget and maintenance strategy.

From the above considerations, it is possible to define the performance criteria of the media surface:

- type of display (colour, monochrome, required levels of brightness, colour depth)
- resolution and distance between the pixels (pixel pitch)
- dimensions

— duration of operation (24 hours a day, only at night, etc.)
— typology of light sources (LED, fluorescent, etc.) and peak luminance
— mode of integration with the building and its envelope
— degree of transparency (for example, in case it is important to ensure there is natural lighting and views to the outside through the media facade system)
— data transfer protocol (HDMI, DVI, DMX, RDM, ArtNet, etc.)
— environmental conditions (temperature, humidity, etc.)
— sustainability of the installation (energy consumption, materials, installation lifetime, etc.).

Finally, the development of full-scale mock-ups and prototypes of the proposed media surface system is always beneficial to the project. It allows the process of construction and maintenance of the system to be clearly understood and limits or avoids integration problems later, when the project has reached an advanced stage and correction of inappropriate choices would be more expensive.

2.10.4 Choice of screen performance parameters

The first performance parameters to be considered for the design of the media architecture intervention are whether the display is in colour or monochrome and which brightness level is required. These choices have a direct impact on the selection of the type of light source and are obviously closely related to the final cost of the intervention.

The choice of colour is a prerequisite for the representation of high resolution advertising; however, in some cases the use of monochromatic sources may be sufficient or even deliberate – for example, in the case of text or abstract visual effects.

The media screen brightness is technically translated into the peak luminance of its lighting elements and must be related to the viewing conditions and the brightness of the surrounding environment (refer to Table 2.3 for typical diurnal and nocturnal luminance values). High dynamic range imaging techniques can

Table 2.3 Typical luminance values experienced by humans

Vision type	Condition	Luminance (cd/m²)
Photopic	Direct view of the sun	900 000 000
	Tungsten filament (2700 K)	3 000 000
	Snow on a clear day	25 000
	Surface of T5 fluorescent lamp	14 000
	Surface of the moon high in the sky in clear sky conditions	2 000
	Typical bright computer screen luminance	200
	Surface of the moon low in the sky in clear sky conditions	100
	White paper under good reading conditions (300 lux)	80
Mesopic	Road surface under street lighting	0.2–2
	Busy traffic route	1
	White paper in moonlight	0.1
	White paper in clear night sky	0.001
Scotopic	Snow in starlight	0.000 3
	Grass in starlight	0.000 05
	Threshold of vision	0.000 003

be used to capture the daytime and night-time luminance of the site location for a more responsive approach to the design of the peak luminance of the media surface. For instance, if the design brief requires visibility in daytime conditions, the peak luminance should be in the order of 1500–3000 cd/m^2. This is excessive in night-time conditions: consequently, if the average facade is designed to operate both day and night, it will be appropriate to provide a mechanism for reducing the luminous flux, which can, for example, be connected to a light sensor or to a timer. Some LED matrix systems currently on the market already include devices that automatically vary the luminous intensity, thereby reducing the brightness, the energy load and the running costs.

Guidance on the luminance of digital media depending on location and use can be found in ILP PLG05: *The brightness of illuminated advertisements*.

The relative contrast between the pixels forming the image is another important factor in the design of the media screen. Commercial LED screens are typically finished in black in order to reduce the brightness of the support elements in relation to the brightness of the pixels, and this approach should also be used in the design of larger media surfaces if the design intent is to create 'crisp' images. In daytime conditions, these requirements would translate into shielding the pixels and background supporting structures from direct sunlight and bright illumination as far as possible.

The dimensions and proportions of the media surface are the next important performance parameter to consider, as they strongly influence the overall visual appearance and are particularly critical for the success of a media facade project.

Commercial pressures are pushing towards the adoption of increasing screen resolutions, bigger media surface sizes and denser pixel arrangements.

A higher resolution allows any type of visual content to be played, whether a motion picture with photographic quality, high contrast graphics or simple text. The flexibility to play a diverse range of media content may be important on the one hand but, on the other hand, lower resolutions allow large-scale displays to integrate more intimately with the architecture of the building, revealing a more abstract and artistic nature.

In the UK, there are restrictions on the frame rates for signs that are visible to moving traffic. This is especially relevant because most media facades are in locations where there is a lot of vehicular traffic.

A rule of thumb to be used to define the screen size in relation to the viewing distance is to specify the diagonal of the screen (i.e. the distance between the pixels furthest apart) as half the minimum viewing distance, and approximately equal to one-tenth of the maximum viewing distance (Figure 2.34). This rule also applies in reverse: if a particular dimension of the screen has been chosen

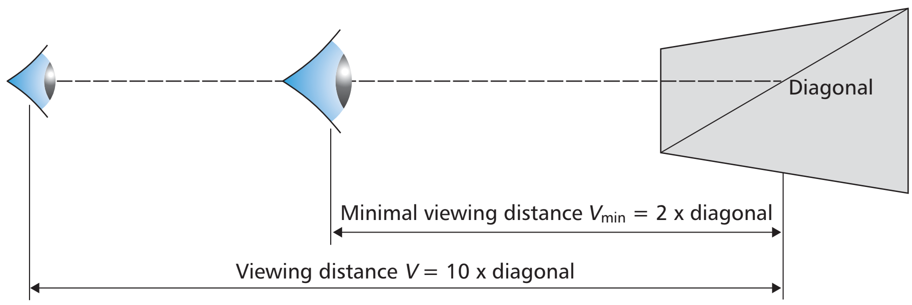


Figure 2.34 Recommended relationship between viewing distance and screen diagonal

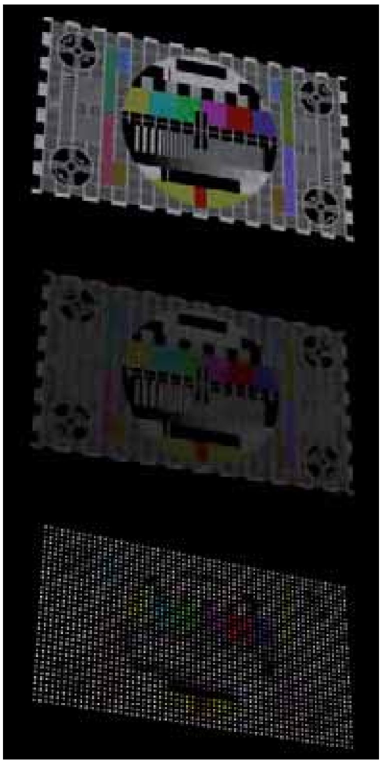


Figure 2.35 Visual effects created by varying the pixel pitch (photograph courtesy of Francesco Anselmo)

for architectural reasons (for example, limited by the available wall space), it is possible to derive the viewing distance.

For example, according to this rule, to view the media surface from a distance of 100 m, the diagonal of the screen should be at least 10 m, and the minimum viewing distance for a comfortable view would be approximately 20 m.

For high-resolution screens, the pixel pitch (i.e. the distance between the pixels) can be calculated in relation to the viewing distance by using another simple rule: the viewing distance at which the typical human eye with normal visual acuity cannot distinguish the cells of the pixel matrix is equal to 1 m for each millimetre of distance between the pixels. Therefore, if the screen is seen from at least 20 m away, the recommended pixel pitch must be 20 mm or less. Billboard LED screens have typical pixel pitches between 4 and 30 mm; however, newer products can now reach pixel pitches of around 1 mm.

The pixel pitch also defines the final screen brightness. For the same pixel luminance, a denser arrangement of pixels (smaller pixel pitch) would pack in a higher number of pixels, and that would therefore translate into a higher luminance Figure 2.35 shows the different visual effects created by varying the pixel pitch with the same geometrical configuration of the screen and the same viewing distance.

A higher pixel density implies a higher cost per unit area but, in general, as density increases, the cost per pixel tends to decrease. In principle, arrays with a pixel pitch of 10 mm can cost up to five times more than arrays with inter-pixel distances of 25 mm, with the same pixel type. Economies of scale can obviously distort these figures.

2.10.5 Choice of light source

Any dimmable and digitally controllable source of light can be a viable candidate for the design and implementation of media architecture. However, LEDs are almost invariably used in preference to other sources.

Higher resolution media screens can also be created by tessellating different plasma or LCD screens, especially for indoor applications, and although the cost of this technology may seem prohibitive, high-resolution media screens are becoming a ubiquitous medium for advertising in the urban environment and in public spaces.

LED systems have become the lighting system of choice for media surfaces for the following reasons:

- the coloured light emitted from LED sources has higher saturation and allows a wider range of colours, and although the luminous flux can degrade with time at different rates for each colour, it is possible to correct this behaviour via software with image based recalibration techniques
- it is possible to achieve finer dimming control with LEDs
- LED light sources are solid state and have a small form factor, and therefore can be more easily integrated with the architecture of the facade
- the longevity of LED sources is, in general, greater than that of other lighting technologies.

LED light sources and luminaires are far more robust than fluorescent lighting; linear fluorescent lamps are fragile and contain a small amount of mercury, which constitutes an environmental hazard if not disposed of in an appropriate manner.

The lighting modules used for the LED arrays are constituted by pixels with one or more LED. A colour display requires the use of at least three LEDs per pixel (red, green and blue – RGB) that are able to recreate a range of colours by additive mixing. The addition of one or more white LEDs with different colour temperatures can be useful in case there is a specific demand for greater precision in the tone reproduction of white light.

The positioning and integration of lighting systems in the facade poses substantial challenges to their operation. For this reason it is necessary to check the environmental conditions (temperature and humidity range, facade loads, water, snow, etc.) of the light sources and their power supplies and drivers and ensure that the operational limits are not reached. This means that lighting systems used for media facade applications require a greater robustness and weather protection than interior ones. They also require an increased tolerance to thermal stress and action of atmospheric pollutants. For example, in the case of sealed facades, the temperature and range to which the lighting devices may be subjected can be outside the manufacturer's recommended limits and it may be necessary to discuss having a special warranty written for the project.

In the context of media architecture, it is extremely important to design the lighting system for easy access, maintenance and upgrade, because failure of luminaires is visible. The replacement of the LEDs in case of early failure or at the end of their life cycle is an aspect which needs to be considered early in the design stage. Some manufacturers provide modular and replaceable LEDs.

Finally, emerging lighting and material technologies can also offer potential applications for media architecture. Recent developments in the field of organic LEDs (OLEDs), large-scale electronic ink (e-ink) and electro-chromic glass have offered new tools to designers, which can transform the appearance of exterior and interior architectural surfaces.

2.10.6 Choice of lighting control system and data transfer protocol

Ultimately, media surfaces are designed to convey information and visual effects, and the desired content must be transformed into a useful data protocol that can be transmitted by the media player and lighting control software and hardware.

There are some preliminary steps that must be followed to ensure that the content is shown in the desired way on the media surface.

The first step is to 'patch' the luminaires to lighting control addresses. If the lighting pixels are varying only their intensity (but not colour), each luminaire has a single address. But if the lighting pixels are RGB, at least three control channels will be needed to control each luminaire as a single entity and create the desired colour mix. It will then be important to patch the luminaire so that the control system can relate the three independent colour channels to a single luminaire.

The second step is called 'pixel mapping'. The virtual pixel matrix of the media content layer must be mapped to the physical lighting layer by creating a relationship between the pixel position in the media player and the physical position in space of the luminaires, using their patched control addresses (Figure 2.36).

Once these operations are done, the control software is able to send the media content, pixel-by-pixel, to the mapped luminaires, displaying the required visual effect and media stream.

The media communication protocol is generally chosen in relation to the type of system used. For example, for an array of LEDs (media screen) it would be most

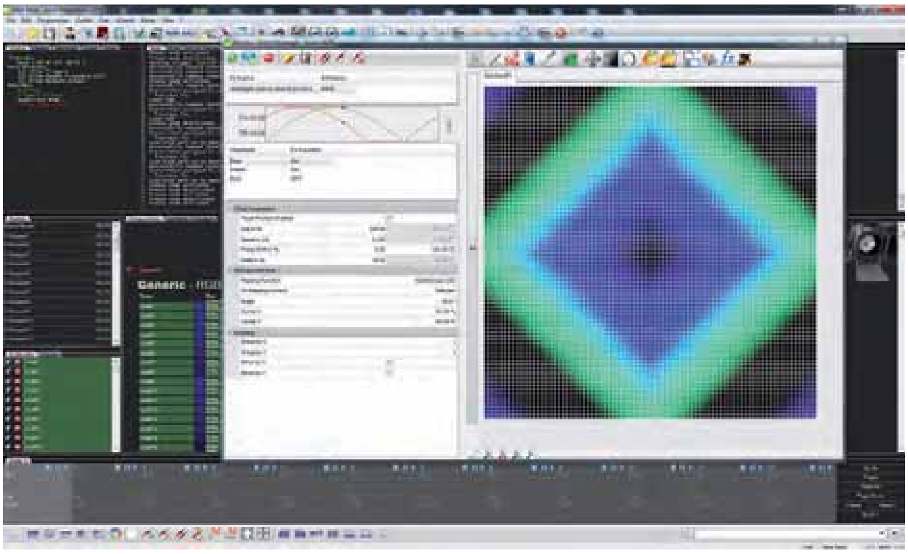


Figure 2.36 Example of media player and pixel mapping software for lighting control (photograph courtesy of Traxon Technologies)

effective to design the system architecture to input a video signal (employing the DVI format, for example).

In the case of systems that integrate multiple lighting devices, these devices can instead use a standard and open protocol of transmission (for example DMX512, the standard protocol for the control of entertainment lighting) for which each unit is equipped with one or more addresses to which the control software will assign particular values in relation to the required colour or intensity.

2.10.7 Energy and environmental aspects

In the design phase it is necessary to consider the energy consumption implications and the environmental and light pollution impacts of the media surface intervention (Figures 2.37 and 2.38).

Due to their large area, any lighting system or bright screen requires a substantial amount of energy to operate; for example, the typical consumption of an LED matrix display with a pixel pitch of 30 mm is approximately 300 W/m^2.

Figure 2.37 The GreenPix facade integrates photovoltaics to achieve a zero-energy balance in operation (photograph courtesy of Arup Lighting)

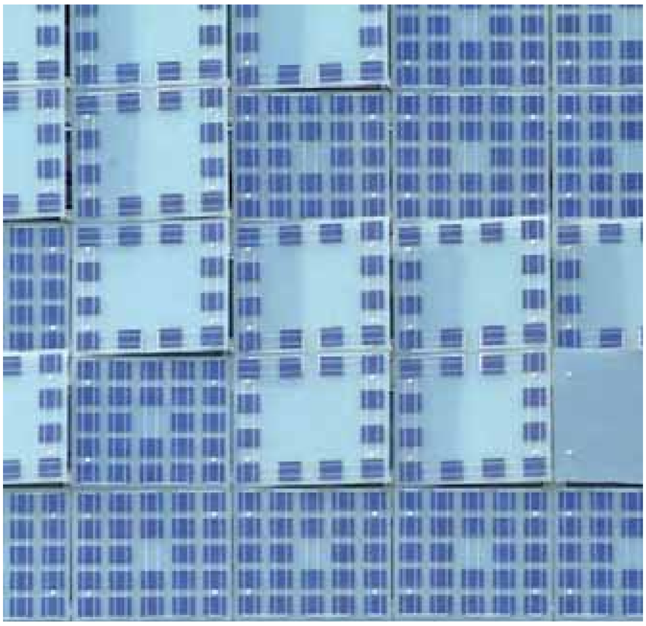


Figure 2.38 Close-up of GreenPix's facade (photograph courtesy of Arup Lighting)

Media facades rarely need to be seen from above, so there is no need for them to emit any upward light. However, many commonly available screens have little or no, upward light control. Steps should be taken to save energy and minimise the contribution to sky glow by ensuring that no light is emitted above the horizontal.

2.10.8 Media screen product typologies and selection

Depending on the topological configuration, it is possible to classify media screen systems into three categories:

— dot systems
— linear systems
— mesh systems.

A further distinction can be made between systems where the light source is directly visible and systems where the light source illuminates the architectural elements of the facade.

Some of these products are directly related to the application of LED matrix screen technologies in architecture, while others have their roots in the evolution of theatre and entertainment lighting equipment.

Figure 2.39 Examples of dot systems: white and GRB (images courtesy of Traxon Technologies)

Dot systems

Dot systems are typically made of compact RGB LEDs, connected by flexible cables and individually addressable (Figure 2.39). They may be supported by mechanical structures that can be configured in a free-form manner or which have a more regular arrangement.

Dot systems are usually designed for direct view and the LEDs require colour control to maintain a level of colour consistency similar to that achieved on tiled LED displays. The distance between the pixels is usually standardised, but it is also possible to request a project-specific configuration.

Linear systems

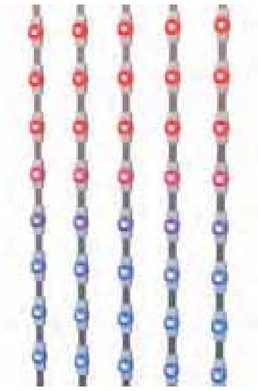
In linear systems, LEDs are arranged in rows and typically mounted on dedicated supports, which in turn may be distributed in continuous rows with appropriate vertical spacing (Figure 2.40).

The horizontal and vertical distances between pixels can be varied as required, and the mapping between the image and the illuminated pixels is assigned to the control software. The option to achieve different horizontal and vertical spacing makes it possible to create effects of transparency and achieve solar shading.

Most of these systems are designed for direct viewing of the pixel or include a diffuser, but some systems can also be used as lighting projectors to illuminate the architectural surfaces and details of the facade.

Mesh systems

In mesh systems, the light sources (typically LEDs) are arranged in a rigid or deformable matrix (Figure 2.41). Again, the light sources are most frequently designed to be viewed directly.



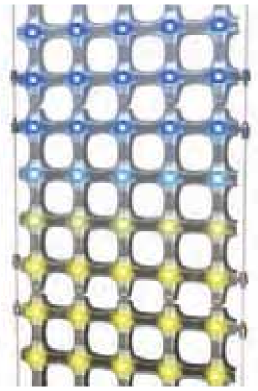


Figure 2.40 [left] Example of a linear system
Figure 2.41 [right] Example of a mesh system (images courtesy of Traxon Technologies)

Several manufacturers market solutions offering different levels of architectural integration.

2.11 Digital advertising signs

These signs are increasingly widespread and are often found alongside major traffic routes. They can be very large (> 50 m^2). By definition, an advertisement needs to be noticeable. However, for reasons of safety, they should not be distracting to drivers, hence a delicate balance must be struck between attracting attention and not distracting drivers. This is made more difficult by the fact that digital signs usually have moving images.

The night-time luminance of a sign should be set according to the context of its surroundings. The environmental zone classification of E0–E4 is a useful starting point. BS EN 12899-1 gives recommendations for traffic signs. While, within the limits of ILP PLG05, advertisements may be brighter than traffic signs, it is important to consider what difference in brightness can be justified.

If possible, the luminance of the existing road and advertising hoardings should be measured to give a baseline from which to determine the luminance of the proposed digital sign.

2.11.1 Luminance

General guidance on the brightness of illuminated advertisements is found in ILP PLG05: *The brightness of illuminated advertisements*. However, this does not refer to the brightness of signs during the day.

Signs which face the sun may be allowed to be brighter than those facing north. In the absence of any specific requirements, we recommend an upper limit of 3000 cd/m^2. Night-time values should be much lower and based on the specific, local conditions. Programmed controls can handle dimming regimes and turn off at set times for energy saving or to suit planning restrictions.

Signs can be set to dim to specified levels at particular times of day. It is recommended that the maximum luminance levels should only be altered by the local authority rather than the advertiser or landlord.

2.11.2 Moving images

Moving images are obviously more distracting than static ones. The more slowly the images change, the less distracting they will be. Guidance can be found in the ILP PLG05. This recommends that images or text should not be changed more frequently than once every 5 seconds.

Moving images, animation, video or full motion images should not be displayed at locations where they could present a hazard, for example if they could be seen by drivers in moving traffic. Local planning authorities may also wish to impose additional controls by setting limits on the times when the illuminated advertisement may be lit.

Sky glow and spill light

Many of these signs have no control over the emission of upward light. In luminaire terminology, they have an upward light output ratio (ULOR) of 50%. This obviously wastes a great deal of energy and contributes to sky glow.

Some manufacturers offer louvres as an option or have the LEDs set back in the sign face, which reduces the upward spill. Similarly, the lateral beam angle is typically 140° (2 × 70° about the axis). A site survey should be conducted to see whether the beam should be reduced in width to avoid spill light.

2.12 Presentation of lighting concepts and lighting software

2.12.1 Introduction

It is often necessary for lighting designers to accurately express their design to non-specialists, such as planners, councillors and architects. There is currently a large number of tools and methods available to lighting designers, which allow them to produce and present their lighting design concepts and ideas to clients.

A number of methods and practices commonly used by lighting designers are listed below. The final choice and preference depends mainly on the designers' skills and expertise in using each tool.

2.12.2 Pencil and crayon sketches

A traditional and still very common method of presenting lighting design concepts is through the use of coloured pencils/crayons on a black background (Figure 2.42). This method is simple and effective, providing clients with an image that is easily understood.

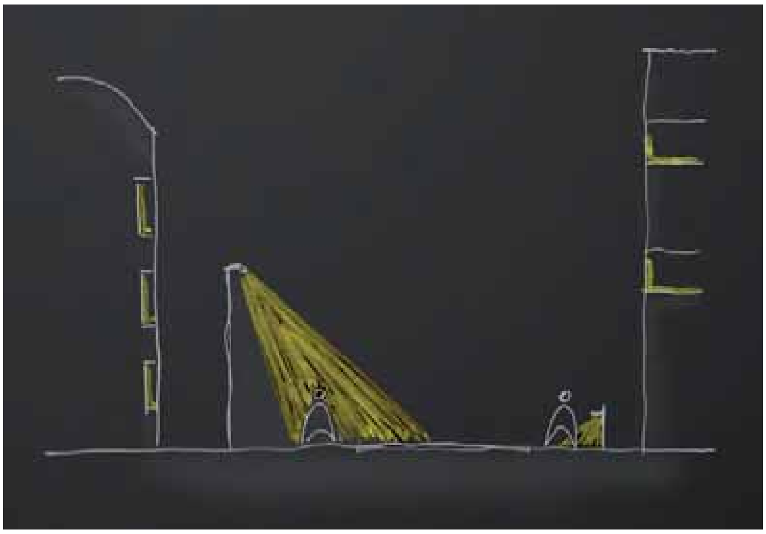


Figure 2.42 Crayons on black paper (image courtesy of Ray Pang)

2.12.3 Combined sketch and Photoshop illustrations

Freehand or computer-generated sketches assist the lighting designer and team to understand the architectural design and aspirations. To successfully illustrate a concept, black and white sketches can be turned into colourful lighting design images through computer software such as Adobe Photoshop (Figure 2.43).

Very often there are no sketches available and the project may involve the illumination of an existing site or building. In these instances it is common to use available photo-realistic renders or site photographs by photo-manipulating (e.g. in Photoshop) these into a night-time shot to illustrate lighting design ideas (Figures 2.44 and 2.45).

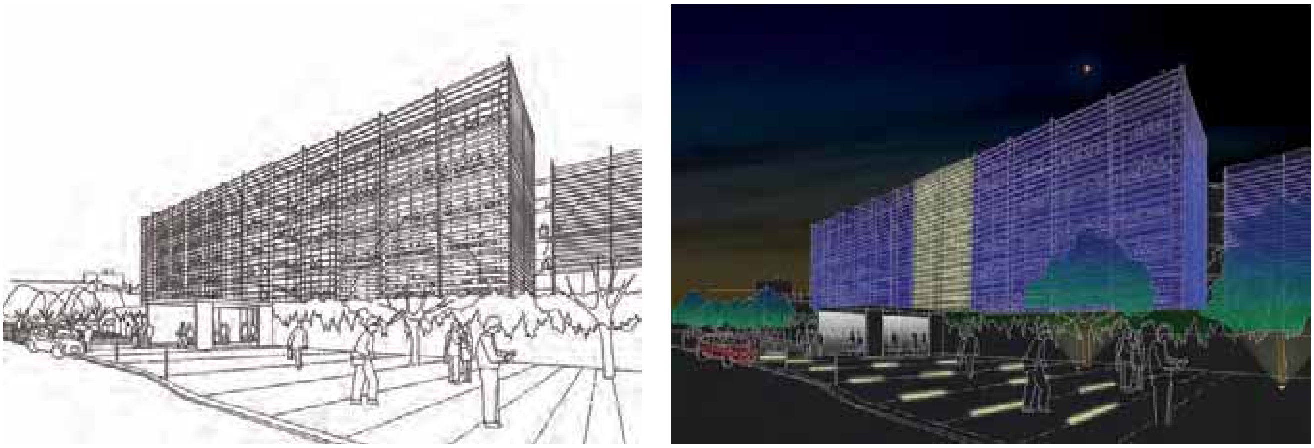


Figure 2.43 Architect's sketched image [left]; night-time concept generated using Photoshop [right] (images courtesy of Ray Pang)

Figure 2.44 External lighting render by architect [left]; night-time concept generated using Photoshop [right] (images courtesy of NDY Light)

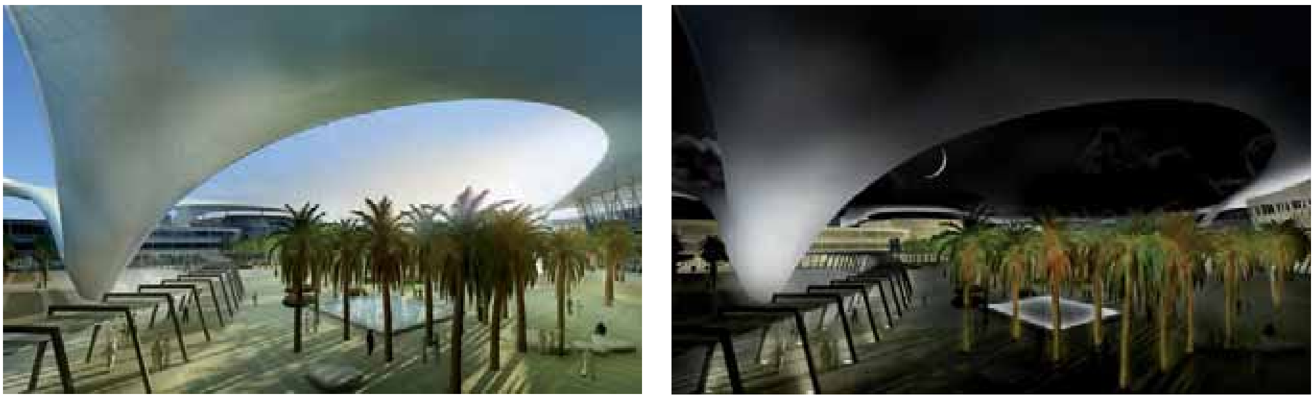
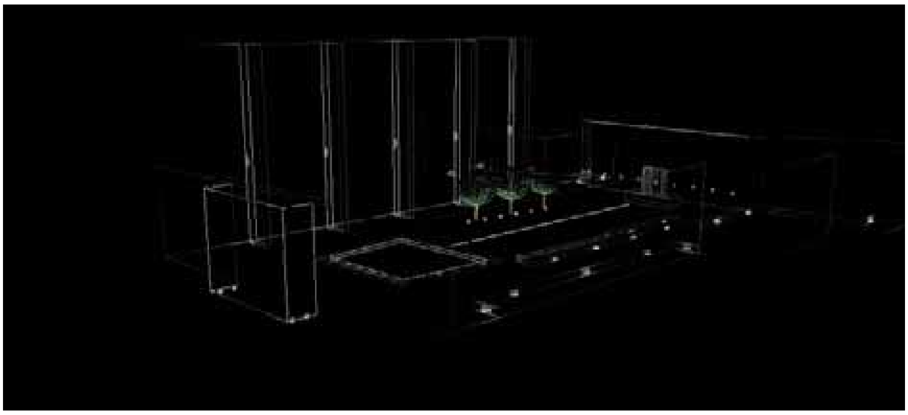


Figure 2.45 External lighting render by architect [left]; night-time concept generated using Photoshop [right] (images courtesy of NDY Light)

Figure 2.46 DIALux modelling in wireframe model (image courtesy of Ray Pang)



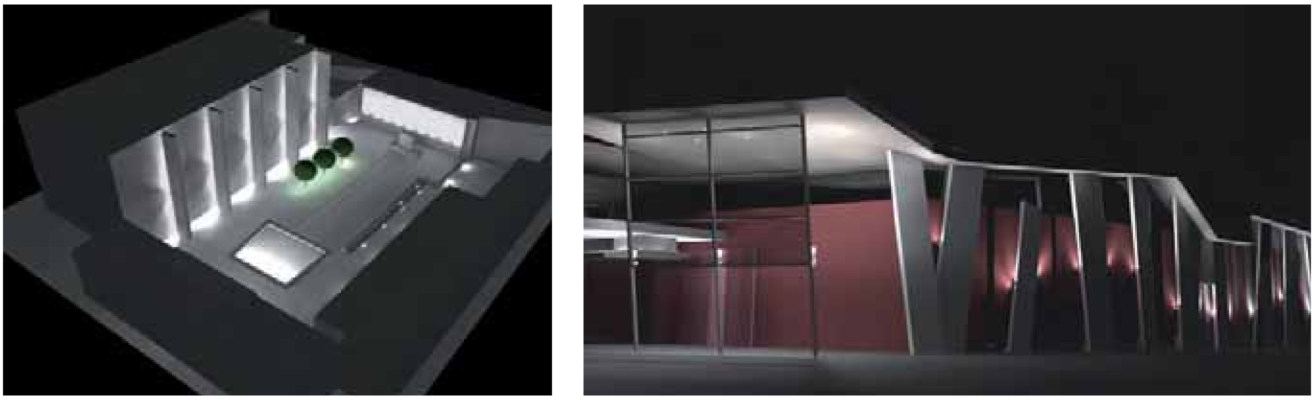


Figure 2.47 Two examples of external lighting modelling in DIALux (images courtesy of Ray Pang)

2.12.5 3D modelling

A number of lighting calculation packages incorporate a 3D visual element within them to allow the designers to view their concepts in addition to obtaining accurate technical data on their designs. The most common method of illustrating designs to clients is to build a simple 3D model.

With the increasing computing power of office computers, 3D modelling can be taken to a high level of detail. Most software packages have the capacity for construction of 3D models (Figures 2.46 and 2.47). Alternatively, software such as SketchUp and Autodesk 3ds Max can be used, which permits the resulting model to be exported into the lighting calculation software in a commonly used format such as .drg, .dxf or .3ds (Figures 2.48 and 2.49).

2.12.6 Computer programs used for external lighting design and calculations

Today, lighting calculations are invariably performed by computer. While the results are accurate, certain precautions should be taken.

Where performance is critical, such as the avoidance of glare, overspill light or illuminance over a small area, it is important to check that the original photometry has been measured with sufficient accuracy. Some photometric measurements are taken at 5° intervals, rather than 1° or 2.5°. An interval of 5° is greater than the difference between aiming a floodlight at 4 times the mounting height and at 6 times the mounting height (i.e. a 20 m difference in aiming point if using a 10 m column).

Always check that the photometric data are suitable for the particular optical combination of light source type, source position and reflector/refractor. If in doubt, ask the manufacturer.

Figure 2.48 3D modelling using SketchUp (image courtesy of Ray Pang)

Figure 2.49 Modelling in 2D using Photoshop (left); 3D modelling and DIALux render in Ray-Trace (images courtesy of Ray Pang)

Some luminaires supplied by manufacturers can have multiple distribution options for the same source within the same housing, so if a lighting design requires a number of different tasks to be lit (car park, road, path, etc.), it is perfectly possible to find luminaires from many suppliers that can accommodate those lighting requirements within a single housing.

There is currently a large number of software packages available which are capable of producing lighting design calculations and 3D visualisations. Computer simulation plays a significant role within the lighting industry and the standard way in which we present and formalise the technical elements of a design.

Note that these programs often require powerful processors and large amounts of memory so are not suitable for most tablet devices or laptops.

Many programs have the ability not only to perform complex calculations and models, but to generate information on numerous technical parameters, such as illuminance, luminance, glare, etc. This information can be generated in the form of ISO-contour and ‘false-colour’ images. Additionally, most programs also incorporate rendering and ray-tracing software, offering the potential to generate visual aids, such as rendered perspectives.

Some software is free and some requires a paid licence; some is more visual while other packages are more calculation based and technical.

A number of manufacturers offer their own, free lighting software in which their products’ photometry is preloaded but into which other manufacturers’ data can also be imported.

The following are some of the most common, independent software packages used by lighting designers to run calculations:

- DIALux (free)
- Relux (free)
- AGi32
- Lighting Reality PRO
- Autodesk 3ds Max.

2.12.7 DIALux and Relux

DIALux and Relux are free programs that can run both daylighting and lighting calculations for interior and exterior scenarios. They are the two most commonly used software packages in the lighting industry and can import and export to all CAD programs using the .dwg and .dxf file formats. Complex architectural environments can be created internally, or externally created 3D environments can be imported via .dwg or .dfx format files.

The basic technique for both electric and daylight calculation is a radiosity method for the calculation similar to the AGi32 software.

2.12.8 AGi32

AGi32 is a paid for 3D lighting design and rendering software package for electric lighting and daylight analysis.

Compared with many free packages, AGi32 offers more scope in terms of views and the options to add information to create really smart presentations. Some contributors to this guide consider that AGi32 produces renderings that more faithfully reflect the real-life experience of the space. AGi32 is a complex program that requires training or a reasonable level of experience to use effectively.

2.12.9 Lighting Reality PRO

Lighting Reality PRO is a real-time lighting design package intended as a fast and easy-to-use PC software package, enabling lighting designers to quickly produce standards-compliant street and outdoor area lighting plans in real time. Its predominant use in the UK is for highway lighting design.

The Lighting Reality PRO application comes ready-loaded with photometric data supporting all the key road-lighting standards, including ANSI/IES RP-8-14 for North American users and BS EN 13201-2 for European users.

2.12.10 Autodesk 3ds Max

For those who are familiar with the old Autodesk 'lighting design' software, such as Lightscape and VIZ, these have been merged into the 3ds Max. The software offers further benefits in terms of continuity and consistency with the AutoCAD, Autodesk Revit and Autodesk Inventor families of software products. It is said to be capable of performing photometrically accurate calculations.

2.13 Equipment – off-grid systems

This section focuses purely on projects where there is no cabled mains power. Often, photovoltaic (PV) and wind power are used in combination (Figure 2.50).

2.13.1 Introduction

Since PV cells are only operational during the daylight hours and the wind blows only intermittently, both PV and wind-powered luminaires will require stand-by power in the form of batteries. This is exacerbated in northern latitudes during winter months, when sunlight is weak and daylight hours are few, making it difficut to accumulate energy. By contrast, equatorial countries have almost 12 hours of sunlight every day, with little seasonal variation, from which to accumulate energy.

Comprehensive guidance on solar irradiation is offered in the CIBSE guides KS15 and TM25.

Electrical storage is probably the most important single element in the design of off-grid systems. The aim of the lighting design should therefore be to minimise electrical energy consumption (techniques are given below).

The other major consideration is the projected area of the PV cells and wind speed. Obviously, the greater the area of the PV array, the stronger the support column must be and, in turn, the larger the foundations.

2.13.2 PV cells

Some cells are manufactured to give optimum output under overcast conditions, while others are designed to achieve maximum output in direct sunlight. Obviously, the latter have an optimum tilt and orientation depending on latitude.

Figure 2.50 **Column with PV array and wind vane** (photograph courtesy of Abacus Lighting and Marlec Engineering)

There is always an element of compromise concerning the tilt angle. A shallow tilt will absorb most irradiance from an overcast sky and sunlight during the summer. Conversely, in winter when the sun is low, a steep tilt will maximise the collection of sunlight but at the expense of irradiance from overcast conditions. It is advisable to speak to a reputable PV panel supplier regarding the best combination of cell type, tilt and orientation.

Most installations have a PV array for each lighting position, but some, especially low-wattage ones, have a large array that feeds several lighting positions.

As a general rule, regardless of orientation, cells should be tilted at an angle greater than 30° so that any dust that accumulates will be washed off by rain.

2.13.3 Light sources

Obviously, these should be as efficient as possible in terms of lumens/watt. If appearance or colour rendering is not critical, consider sources with a high correlated colour temperature (CCT) since these often have greater efficacy and their blue content may be beneficial under mesopic conditions. LED sources are particularly suited to this application.

A related factor is the control gear. Since the output of most PV panels is 12 V or 24 V, it makes sense to use control gear/drivers at this voltage rather than converting the panel output to 230 V and using conventional gear. It should be borne in mind that transforming voltage or frequency always entails power losses and therefore reduces efficiency.

Light sources which are easily dimmable can considerably reduce the drain on batteries.

2.13.4 Batteries

Some installations mount the batteries at high level, under the PV array, for reasons of safety and security. However, this has two serious disadvantages. First, the batteries are subject to large fluctuations in temperature and are open to the elements. This reduces their life – possibly by as much as 70%. Second, a heavy mass oscillating at the top of a column means that the column and foundations have to be larger than would otherwise be needed.

If the batteries are mounted at ground level, they must be protected against vandalism and theft. However, access for maintenance is much simpler. A better solution is to mount the batteries in a pit with drainage. This option both reduces temperature fluctuations and keeps the equipment out of sight. It is also easier to protect them against vandalism.

Lead-acid batteries, despite being large and heavy, are often chosen for reasons of capital cost. Batteries should be of the sealed type, as topping up is not practical. They are also comparatively easy to recycle. Lithium-ion batteries are considerably lighter and more resistant to vibration, but the cost of storage in terms of watt-hour/£ is much higher.

Consideration needs to be given to whether the batteries can be recycled as this will have a significant effect on the financial viability of the project.

2.13.5 Standby period

Since the quantity of daylight and sunlight varies, especially in the winter when there are many dull, overcast days, it is necessary to have extra storage power in the batteries (i.e. the number of nights' standby power required must be calculated). Typically, for a traffic route, this may be 3–5 nights.

The amount of storage power required will depend on the daytime irradiance available, the length of night and the illuminance level.

Where the lighting is functional, it may be necessary to have a much longer standby period than for a more decorative purpose, such as the floodlighting of a building.

2.13.6 Techniques for minimising electrical energy consumption

- Use the most efficient light source for the project. How important is colour rendering and the colour temperature?
- Consider the efficiency of the electrical system. There is no point in stepping up the voltage from a PV cell for the 230 V control gear only to step it down to feed the lamp circuitry.
- Do the luminaires need to be on all the time? Speed limit signs and some security signs only operate when the presence of a vehicle or person is detected.
- Use dimming whenever possible. Can parks and traffic routes be dimmed to a much lower level when there is little or no traffic?
- Consider how long a standby period is required during periods when there is not enough daylight or sunlight to fully charge the batteries. This directly affects the number and size of batteries required. Lighting for traffic routes and security will need a longer standby period and, most probably, higher levels of illumination.

2.14 Luminaires

There is a general requirement that luminaires and associated accessories adhere to the relevant directives as outlined in the bibliography section of this guide by testing to the appropriate standards, with the key standards being:

- BS EN 60598 – in particular Part 1, and Parts 2-1, 2, 3 and 5 depending on the type of luminaire
- BS EN 55015, BS EN 61000 and BS EN 61547, in relation to electromagnetic compatibility testing.

In choosing luminaires for outdoor use, the design life of the installation and total cost of ownership must be considered. The initial cost of equipment may be a small part of the total cost in use of the installation, as the cost of electricity and the ease and frequency of necessary maintenance can greatly affect the economics.

Other initial considerations are:

- the requirement that the daytime appearance of luminaires and columns should be in keeping and scale with the surroundings
- the luminaires are physically suitable for their environment, in terms of IP rating, temperature fluctuation tolerance, vandal resistance, etc.
- some lamps, such as low-pressure sodium or high wattage metal halide, permit only limited burning positions; however, most light

sources sold in new luminaires are only minimally affected by burning position and the majority are unaffected

— where floodlights or spotlights are used, it is better to choose equipment that can be relamped without altering the aiming position. If this is unavoidable, the correct position should be indicated with durable paint or an engraved mark.

2.14.1 General requirements

Mechanical characteristics

An outdoor luminaire must be well constructed if it is to function for a number of years without problems arising. Metalwork should be protected against corrosion, and luminaire parts which have to be removed for access to the interior should have proper gaskets to restrict the entrance of moisture and dirt where appropriate. Columns, brackets and stirrup mounting, etc. should be appropriately galvanised (or otherwise protected) to ensure longevity of the parts.

It is advisable to use luminaires that allow the door/glass frontage to hang freely during re-lamping/cleaning for ease and simplicity of maintenance. However, movement should be restricted so they cannot impact walls, columns, etc.

As light sources continue to develop, they are tending to have longer operational lives than their predecessors. This is a benefit of technological advance, but it should be remembered that the optical cover/luminaire will still need to be cleaned/maintained at regular intervals to ensure optimal performance. All light sources reduce in output over time.

Regular maintenance includes:

— cleaning of the optical system/reflector in line with the dirt depreciation maintenance factor used at the lighting design stage

— examining the luminaire interior for the ingress of moisture or dirt

— checking that moveable parts have not seized and lubricating/greasing exposed bolts and joints.

It is recommended that screws on luminaires that need to be loosened to allow for maintenance should be captive to allow for ease of handling, especially on luminaires at high mounting positions, where the retrieval of a dropped screw could be a major task.

Some plastic/polymer materials used in outdoor luminaires can ‘outgas’ for the first few hours of use. This can cause a film on the cover glass and reflector, thus reducing the optical efficiency. Normally, this can be removed using a petrol-based cleaner, but always check any cleaner’s suitability with the manufacturer first.

Consideration should be given to vibration. This can simply be from high wind making the mast/column oscillate, but can also be caused by passing vehicles, a situation which is especially applicable to structures such as steel bridges. All threaded components should have locknuts or another anti-vibration device, such as nylon inserts or threadlocker.

Weather protection

See Appendix 1 for more information

The IP rating against the ingress of water and dust is well established. The first digit of the IP number represents the degree to which solid objects and dust can enter the luminaire. The second digit applies to moisture and water (see Appendix 1).

Note that the testing of the IP rating of luminaires differs from the testing of related equipment, such as electrical junction boxes. Luminaire testing involves switching on and off the equipment, letting it warm up and cool down, so that it ‘breathes’ and dust/moisture can be sucked in. Currently available outdoor luminaires can be fitted with breathable membrane 'plugs' that allow this process to take place while maintaining the required IP rating.

The tests are based on whether the thermal, electrical and mechanical characteristics and the safety of the luminaires are affected.

Although it is tempting to use the highest rated IP luminaire available, there may be countervailing factors, such as cost or maximum operating temperature. Therefore, IP65 or higher is not necessarily recommended as a minimum requirement of an outdoor luminaire. Components within luminaires, such as the driver or reflector, can be 'IP sealed' in a more cost effective manner than sealing the whole luminaire.

Where luminaires are flush-mounted in the ground, it is recommended that IP68 is used, since puddling can occur and the equipment is, in effect, submerged. Note that luminaires marked IP68 should state the depth at which testing was carried out. A shallow submersion depth at IP68 can be less onerous than an IP67 test rating.

An additional letter suffix can be used with the IP system to denote the level of protection from access to hazardous parts (e.g. A – Back of hand, B – Finger, etc.), but these are rarely used.

2.14.2 Mechanical impact resistance

See Appendix 2 for more information

Sometimes a third digit was added to the IP rating to represent the degree of impact resistance, but this has been superseded by the IK rating system (see Appendix 2).

This mechanical impact rating is classified by the energy needed to exceed a specified resistance level, which is measured in joules (J). This is called the IK number, as specified in BS EN 62262. Put simply, the higher the figure, the higher the impact resistance.

The IK impact tests differ from those used by the IP rating system, so there is no direct equivalence.

Note that the BS standard lists ratings up to IK10, although some manufacturers quote higher IK ratings to denote higher impact resistance. In this case, the impact value and test method should be checked with the manufacturer. BS EN 60068-2-75:2014 *Hammer tests* is often used for this purpose.

2.14.3 Vandal resistance

If vandal resistance is required, other techniques than simply using an impact-resistant luminaire can be employed, for example (but not limited to):

- mounting the luminaires out of reach
- using a wire or polycarbonate enclosure – some manufacturers offer these as an option
- applying anti-graffiti finishes to luminaires, allowing for easy cleaning
- using non-drying paint.

If there is a concern about possible vandalism when purchasing luminaires, it is advisable to discuss this with potential suppliers, as they may well be able to offer several of these options, as standard, with their luminaires.

Ground-mounted luminaires have particular issues. Small luminaires (pavers) can be set into the ground using soft silicone adhesive. This has the advantage that if the pavers are damaged or fail in some other way, they can easily be removed and replaced. However, this ease of removal can be a vulnerability. An alternative is to use an epoxy-based adhesive. This permanently fixes the paver to its surroundings. The disadvantage is that if the paver does need to be removed, it often involves breaking up and replacing the stone or concrete paving, which can be costly and time consuming.

Luminaires which are obscured from general view, such as in underpasses, are likely to be more prone to vandalism and should be carefully assessed to ensure that they are fit for purpose. In these instances it is recommended to chose more hardwearing substances, for example polycarbonate rather than glass (unless the glass can be proved to be adequately toughened or otherwise protected).

With low-level luminaires, such as pavers, bollards and wall lights, an advisable course of action would be to specify fittings that have, or can be fitted with, vandal-resistant screws and which have high impact resistance. It should be noted that the ACPO's Secured by Design initiative recommends that these types of luminaire should not be used. Instead. pole-mounted fittings should be used wherever possible. Several ACPO documents on the topic of security based on the principles of 'designing out crime' are available.

There are other mechanical design considerations of importance in lighting systems, i.e. those affecting their installation, their aiming and their maintenance, which depend on the particular application. For example, the characteristics of a low wattage unit to be used to light features in a garden will be quite different to those provided on a high wattage narrow beam discharge projector intended to light railway sidings from a height of 30 m.

2.14.4 Luminaire efficiency and distribution

There is a tendency to choose a luminaire with the highest light output ratio (LOR) on the grounds that this will be the most efficient. However, more often than not, this is an incorrect assumption. Controlling light and directing it to precisely where it is required inevitably reduces LOR. The more you control the light, the lower the LOR will be. However, this usually lights the space more effectively because spill and nuisance light is kept to a minimum. A better metric is the utilisation factor of the luminaire as it applies to a specific application. The best way to investigate this is with the advice of a lighting designer and the photometric files from luminaire manufacturers.

The vast majority of outdoor lighting luminaires have at least a bilaterally symmetric distribution (where the light emitted from the 'left' of the axis is identical to the light emitted from the 'right' of the axis).

2.14.5 Protection for extreme conditions

When designing exterior schemes for more extreme weather conditions than we experience in Europe, it is worth looking at the local conditions to see what types of construction and materials have been used successfully. It is equally useful to see which materials have failed. Some general guidance follows on conditions that might affect the longevity of the equipment.

Dry, hot regions, such as deserts

The UV in sunlight can have a dramatically detrimental effect on plastics. Polycarbonates can yellow within a short space of time. This is exacerbated where they are used as the front cover of a luminaire, since the yellowing causes the polycarbonate to absorb more heat from the lamp, causing it to degrade even faster. Acrylics, such as PMMA, are affected to a lesser extent.

Note that the body of the luminaire can heat up during the day, even when switched off. Thus, when darkness falls, the ambient temperature inside the luminaire can be higher than outside. This is not normally a problem for high-power luminaires with remote gear but can be an issue with smaller luminaires, especially LEDs, where the electronics and light source share the same housing.

Aluminium or bronze are therefore more suitable materials for the luminaire body than stainless steel, since the latter is a poor conductor of heat.

As a rule, luminaires should be suitable for operation in an ambient air temperature of > 40 °C, but specifications for the Middle East will often ask for 50 °C or more. At this point the project-specific requirements must be considered. If the peak temperature is only reached on one or two occasions a year, then a luminaire with a maximum ambient temperature rating (T_a) of 40 °C should be acceptable. The very brief occasions when the luminaire has to operate at higher temperatures will not have a detrimental effect on the life of the luminaire. The luminaire supplier should be consulted and may be able to supply an extended warranty based on the specific site conditions.

The manufacturer should be able to provide a declaration of conformity and, if required, a test report to demonstrate the performance.

Generally, LEDs with low junction temperatures will give a longer life.

Note that the light output of LEDs reduces with increased temperature. Where illuminance levels are critical, the luminaire (not the LED chip) manufacturer should supply details of the flux output at the relevant temperature. Similarly, LED life is reduced at elevated temperatures.

Related equipment, such as photocells, should also be considered.

If the dry, hot region is prone to dust storms, the luminaire manufacturer should be asked to run dust tests on their luminaire in line with BS EN 60068-2-68, or similar. If the fitting has not already been tested to this standard, consider the IP rating and construction of other luminaires that are operating successfully in the environment.

Marine environments

Salt is the main enemy here since, in principle, all outdoor luminaires are designed to resist water and moisture ingress. Untreated aluminium is not recommended, neither is painted mild steel.

Powder-coated paint finishes offer good protection, but the pre-treatment of the base material must be thorough and paint must be applied properly. Luminaires should be examined for any abrasions or scratches.

It is preferable to use aluminium with a low copper content (LM6), although higher copper content aluminium can be used if treated appropriately. Salt air can attack the copper and cause the paint finish to lift. If this may be an issue, the luminaire should be tested to BS EN ISO 9227. Alternatively, a risk assessment could be based on similar luminaires installed in similar applications if the test data is not available.

Control gear should be potted with a flexible resin. Brittle resins can crack when flexed due to fluctuations of temperature.

Use stainless steel fastenings wherever possible. Be especially careful of electrolytic corrosion caused by dissimilar adjacent metals.

Extreme cold

The main issue here is electrical insulation becoming brittle. PVC, in particular, can crack when flexed below about 0 °C. This also applies to the supply cables during installation.

The ability of the drivers and ballasts to function at low temperatures should be confirmed. Drivers will often be listed as being able to function below 0 °C.

Where the equipment is not running 24/7, potential formation of condensation should be considered. For example, it can form on the inside of columns and on electronics or build up on the inside of cabinets. The condensation can then go through a cycle of freezing and thawing, putting stress on joints and glands.

Most materials become more brittle when cold. This may not be an issue for fixed equipment, but where there are high winds or significant vibration it should be taken into account.

Fluorescent lamps have considerably reduced output at lower temperatures. This effect is sometimes overcome by putting the fluorescent lamps in a clear outer sleeve.

Restriking when cold can also be an issue. As a rule, T5 lamps will not operate below 5 °C.

Since LEDs emit more light when cold and are more efficient than many other light sources, they are becoming the de facto light source for cold environments.

2.14.6 Floodlights

Minimising upward light is becoming increasingly important. Today, many floodlights are of the 'flat glass' type where the aperture is horizontal in both planes (Figure 2.51). This does not mean that the luminaire has to have a flat piece of glass, simply that the lamp and reflector are not visible from above. These floodlights emit no light upwards, but there is a tendency for them to produce a 'hot spot' directly underneath, especially with columns of 4–6 m, unless appropriate optics are used. This may not be an issue for general areas, such as car parks, but can cause problems of uniformity in sports applications, such as tennis courts.

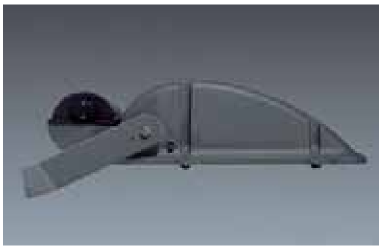


Figure 2.51 Flat glass floodlight, the peak intensity is projected forwards at 60°–70° (photograph courtesy of Thorn Zumtobel)

Naturally, a 'flat glass' luminaire with a standard optic does not have the forward throw of a conventional tilted floodlight; however:

- a small tilt (5°–10°), can be given to the luminaire (but the upward light would have to be calculated to demonstrate compliance with obtrusive light guidance)
- many of these luminaires have a reflector with a strong forward throw at a particular angle.

Floodlights come with an array of different optics, to provide a range of beam shapes, within the same housing to suit the requirements of the area they are mounted in. It is essential to obtain the range of photometric files from the manufacturer to allow the lighting to be designed in the most efficient manner possible.

2.14.7 In-ground uplights

Luminaires mounted flush with the ground and shining upwards are a popular way of lighting facades and statues. Since the light is emitted upwards, minimising sky glow is a priority. However, by choosing the correct beam width, using internal louvres and tilting the luminaire so that most of the light falls on the facade, an environmentally satisfactory solution can usually be found.

Some lenses become slippery when wet. Anti-slip coatings are available, but these may affect the light output and distribution.

Unless there is no chance of the uplight being submersed in a puddle, IP68 is recommended. Note that clay soils can flood more easily than well-drained ones.

The surface temperature of the glass is not normally an issue except where it is likely to be touched. Examples would be in a swimming pool, a tiered seating area or places where young children are likely to be present. A maximum surface temperature below 60 °C is recommended.

Drive-over uplights need particular consideration. Obviously, the static load from vehicles is much greater than that from pedestrians. Specifications showing the maximum allowable load should be available from the manufacturer. Of greater concern are moving vehicles; the flexing of the tyre as it moves over the uplight can tend to pull it from its mountings. This is exacerbated where vehicles are braking or accelerating. The solution is to ensure that the uplight is firmly fixed in the ground. This may mean adding extra foundations or using longer fixing bolts. Consider whether speed limit signs are necessary.

Long-life light sources are preferred since relamping may mean that the uplight is not resealed correctly. Similarly, the cable glands need special attention during installation and maintenance.

Small uplights are often held in place using adhesive. Soft, flexible adhesives, such as silicone rubber, have the advantage that the uplight can easily be removed in case of failure. However, this facility does make them more prone to vandalism. More permanent adhesives, such as two-part epoxy resins, overcome this problem, but their use may mean disturbing the adjacent paving in circumstances where the uplight does need to be removed.

Where high wattage uplights are used, consideration should be given to the heat transfer to the adjacent ground. Damp soil and concrete conduct heat reasonably well; sand and clay do not.

2.15 Light sources

2.15.1 Light sources

Since the last edition of this guide and, in particular, over the past 5–10 years, light source technology has undergone a seismic shift compared with the steady development in the preceding 30–50 years. LEDs have entered the professional lighting market, causing a revolution in the design of luminaires and lighting design.

This rapid change to LED lighting is still ongoing, so data on these particular technologies' performance characteristics (lumen output, life, etc.) within this guide are given as indicative at the time of writing. Users of this guide should refer to light source or luminaire manufacturers' technical literature to ensure that they have the most up-to-date information. A useful reference document for the specification of LED products for exterior light applications is the *Guide to the Specification of LED Lighting Products*, jointly produced by the Lighting Industry Liaison Group.

A light source not only provides light, it can also influence the way in which the light is distributed by the optical system, none more so than the LED, which will generally only emit light in a 180° cone, while conventional sources are much more omni-directional. This strong directionality from the LED source dramatically changes the nature of the optical design, as Figure 2.52 indicates.

The smaller the physical size of the light source, the more accurately the distribution of the light can be controlled, and/or the smaller the luminaire can be. This should be countered with the caution that the smaller the luminaire/optic, the greater the chance of glare situations being caused by it. A 1 mm^2 high-output LED is much more likely to cause glare than a traditional low-pressure sodium lamp with its comparably huge surface area and large optic. Precise optical control is the key element in minimising or reducing glare from small sources.

The light source also provides an intrinsic colour to the light emitted by the luminaire.

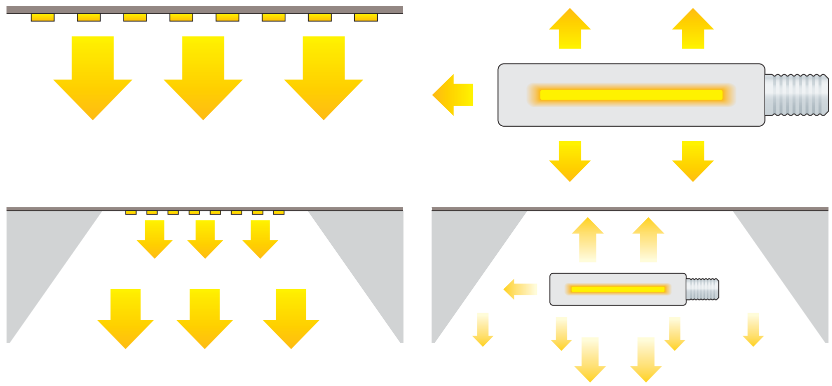


Figure 2.52 Light from LEDs (left)can be accurately directed from the start; conventional sources (right) have to redirect the light, losing efficacy in the process

See section 2.9.3 for more information

The choice of lamp for a particular installation may be influenced by the following considerations:

- The general requirement that lamps comply with the recommendations of the relevant British and European Standards. This includes labelling and energy requirements such as DIM1 and DIM2 and the Energy-using Products Directive.
- The need to reduce running costs and conserve electricity by utilising light as efficiently as possible, and by using lamps of the highest luminous efficacy consistent with satisfying other requirements (e.g. those of acceptable colour appearance and colour rendering).
- The spectral distribution and S/P ratio of the light. These need to be considered in exterior lighting at lower levels:
  - Where strong colours are required, a lamp that emits light of a predominant colour is normally chosen. Colour intrinsic to the light source is more efficient than that obtained by filtration. For example, if blue light is required, then it is more efficient to use a blue LED than to transmit by filter what little blue light there is in a high-pressure sodium lamp.
  - The spectral distribution of the light source also affects how our eye perceives the amount of light available. In external lighting at low levels (car parks, roads) a light source with a high S/P ratio has the potential to save more energy, by lighting to a lower photopic lux level but giving the same perceived performance (see also section 2.9.3). More information on this subject is available in the LIA's TS24: *SP ratios and mesopic vision*.
- The maintenance facilities available and the cost of servicing. In general, costs will be reduced if light sources with a longer life are used. It is strongly recommended that LED luminaires have replaceable modules and drivers (i.e. it should not be necessary to dispose of the complete luminaire in the case of LED or driver failure).
- Limitations imposed on the light source size, for example by the size of enclosure, as in handrail lighting (e.g. LEDs are more suited to this application than metal halide).
- The conditions under which the lamp will operate – for instance, at low ambient temperatures fluorescent lamps may not strike or may give low output. In contrast, the efficiency (lm/W) of LEDs increases at low temperatures and starting is not an issue, but their light output reduces at high temperatures.

— The range, rate of change of light level and accuracy of control of dimming of the light source.

Current data for light sources readily available in the UK at the time of publication of this guide are presented in Table 2.4 and Figure 2.53. Within each type, there is a range of lamps available which differ in construction, wattage, luminous efficacy, colour properties, cost, etc. For exact details of the characteristics of a specific light source, the manufacturer should be consulted or the LIA's *Lamp guide*.

It should be noted that, at the time of writing, LEDs in luminaires tend not to be easily replaceable by the end user. Due to the thermal characteristics and electronic nature of LEDs, they are often engineered into the body of the luminaire in a much more integral way than conventional light sources. The luminaire manufacturers generally design the LEDs on bespoke printed circuit boards or attached directly to castings, which are difficult, or impossible, to source from third parties. There are moves towards introducing standardised connection

Table 2.4 Typical characteristics of light sources

Light source type	Construction and appearance	Luminous efficacy (lm/W)	Life (hours)	Colour rendering	Restrike time (min)	Run-up time (min)	Typical application
Metal halide reflector (PAR lamps)	An electric discharge in high-pressure mercury atmosphere with metal halide	84	1000	Good	0–10	1	Feature lighting – tall buildings
Metal halide	An electric discharge in a high-pressure mercury atmosphere with metal halide additives in an arc tube (quartz, but more commonly ceramic). Needs control gear	66–84	4000–12 000	Good	4–10	2	Building and area floodlighting, used where better colour rendering of cool appearance is required
Fluorescent	An electric discharge in a low-pressure mercury atmosphere contained in a glass tube internally coated with a fluorescent material. Needs control gear	37–100	5000–15 000 Lives of >50 000 are available from specialist suppliers	Moderate to excellent, depending on the properties of the fluorescent coating	0	0	Generally more suitable for indoor than outdoor use but valuable for some types of precinct lighting and close offset floodlighting. Compact versions suitable as replacements for tungsten lamps
Induction	An electrodeless fluorescent, usually rectangular in section	80–90	60 000	Good	0	0	Inaccessible areas where lamp changing is costly or difficult
High-pressure sodium	An electric discharge in a high pressure sodium atmosphere. The arc is contained within an outer envelope	67–137	6000–24 000	Varies from poor to acceptable depending on pressure used, and if clear of coated lamp	1	3–6	Building, area lighting, floodlighting, road lighting, security lighting
Low-pressure sodium	An electric discharge in a low-pressure sodium atmosphere. The arc is contained within an outer envelope	101–190	5000–20 000	Non-existent	0–10	8–12	Road lighting, security lighting. Suitable for applications
Light emitting diode	An electronic component, semiconductor, doped/gated to create an electrical imbalance. When electric energy is applied, energy is emitted in the form of light	50–130	25 000–100 000 but note lumen depreciation	Typically >80	0	0	LEDs can be used in almost every application, with a large potential range of light outputs, colours and colour temperatures
Organic light emitting diode	OLEDs are multiple layers of organic LED substrates contained within thin sheets, usually of glass, that emit light	40–80	10 000–30 000 depending on output	Typically >80	0	0	Small displays, such as smartphones and tablets

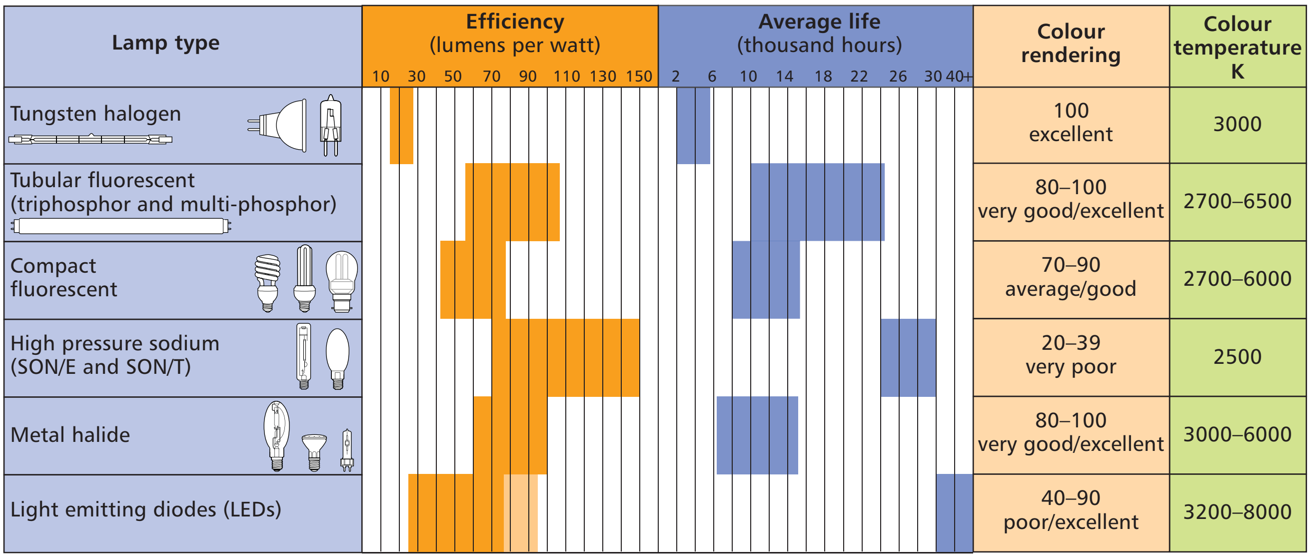


Figure 2.53 Performance characteristics of different lamp types

methods in the shape of initiatives by the Zhaga Consortium, to enable LED sources to be retrofitted in a similar way to conventional sources, but this is not currently common practice. However, the potentially long life of LEDs may mean that the light source will not need to be replaced within the useful life of the luminaire. It is recommended that luminaires which have easily replaceable LED modules and drivers are chosen.

2.15.2 Summary of light source characteristics

The broad properties of the light sources commonly used for exterior lighting are summarised in Table 2.4. The meaning of each column heading is given below:

Light source type

Different manufacturers (lamp and luminaire) throughout the UK and Europe refer to light sources using different prefixes, so within this guide a generic light sources description has been used to cause the least possible confusion.

Construction and appearance

This column describes the method of light production and the physical appearance of the light source.

Luminous efficacy

This is a measure of how efficiently the light source converts electrical power (watts) into light (lumens). With conventional sources, the higher the value of the luminous efficacy, the more efficient the lamp. With LEDs, the rule of thumb is the lower the drive current/junction temperature, the higher the efficacy. A range of values is given for each lamp type because luminous efficacy varies with power. These values do not include the power consumed by any control gear that may be required, nor do they take into account the optical efficiency of the luminaire.

Conventional sources generally provide the same amount of light both inside and outside the luminaire over a wide range of ambient temperatures. LEDs, on the other hand, can produce very different amounts of light at the same ambient temperatures, depending on whether they are inside or outside the luminaire. Care must therefore be taken by the designer regarding the values of luminous flux they actually require, bearing in mind the site conditions.

Life

The life of a light source will be affected by such factors as the switching cycle, the voltage supply and the physical operating conditions. The lives of metal halide and high-pressure sodium discharge lamps are particularly sensitive to the voltage applied. This can be overcome by the use of electronic control gear, provided it is available for the required wattage.

Within a range of light sources, the life can vary from one wattage to another:

- for conventional sources, generally the lower wattage lamps have a shorter life, though there are exceptions, especially at very high power (>1000 W)
- for LEDs, the lower the drive current, and the better the thermal management of the light source, the longer the life that can be expected, and the higher the efficacy (lm/W).

It is always advisable to contact the lamp manufacturer for current data regarding the particular light source under consideration. The range of lamp life given in Table 2.4 refers to the typical light source's life, defined as the point at which 50% of the lamps in a large installation fail. The lower value in each range refers to the lower wattage lamps and the higher value refers to the higher wattages. Typically, the life of LEDs is quoted as the point when the light output has dropped to 70% of its initial value. This is known as the L70 value. Other values of L*xx* may be applied, depending on the application.

Restrike time

Compact fluorescent, tubular fluorescent and LED light sources produce significant amounts of light immediately when switched on. All the other lamp types require several minutes to reach full light output; this may be important where installations have to be used at unexpected times (e.g. in emergency situations).

Run-up time

Compact fluorescent, tubular fluorescent and LED light sources can all be switched off and then on again immediately. All the other lamp types, unless fitted with special control gear, show a significant delay after switch-off before they will re-ignite. This property may have important safety implications as a momentary interruption in the electricity supply can extinguish these light sources and it may be some time before they can be re-lit. This is especially important for luminaires lighting emergency escape routes.

2.16 Saving energy, signalling and switching

In an age of energy-saving targets and carbon-reduction methods, street lighting is one of the largest contributors to energy bills in the public realm. As designers, it is our duty to reduce this impact as far as possible without compromising design integrity or public safety.

Dimming and switching is mainly used for streetlighting but can be applied to outdoor lighting systems (e.g. switching off shop window displays or decorative floodlighting of buildings after a certain time). This is often referred to as 'curfew'.

The commonest method of controlling outdoor lighting is via the simple and reliable method of timed on/off switching. An astronomical clock is often used, since this takes account of the changing daylight period and time due to seasonal variations.

Central management systems (CMS) have become increasingly popular in recent years as the variety of systems has increased and their technical advantages have become more apparent. There are two main types: mains-borne and radio. Certain systems use one or the other but a few combine the two to increase flexibility. In some cases this can eliminate the shortcomings of a single-source system.

The radio system uses line of sight to enable each luminaire to communicate with its neighbour and then ultimately with a transmitter, which sends data to the computer program for logging. As line of sight can be an issue in certain environments, this limits the system's flexibility, especially in built-up areas. However, the more successful manufacturers of radio systems have overcome this with additional equipment and sophisticated programming.

The mains-borne system works over the power line and uses its own section of the line to transmit data. This works well on a new cable but, as cables age, they can degrade and this causes transmission issues. This is referred to as a 'dirty mains' and can mean that the communication distance to each luminaire from the local collection point is reduced. When installing this type of system, this aspect should be considered and allowances made so that during its installed life the network is less likely to fail.

Note that mains-borne systems only work on private networks where there is a dedicated mains cable feeding the luminaires.

Both types of control have their challenges but, on the whole, they are useful and innovative tools for controlling and monitoring lighting. Dimming is possible from the desk of the client, and emergency services can also influence the levels should an incident occur that requires lighting to be lowered or, more likely, raised to assist emergency services.

The British Standard for road lighting, BS 5489-1, encourages the designer and client to use CMS. This is because it can aid the reduction of energy used for lighting the streets and can allow complex variable lighting levels to ensure that the public remains safe and areas are well lit without compromising the design integrity.

Other, simpler ways of controlling lighting are available; however, they do not give the flexibility or long-term gains that a full CMS can offer. They are worth considering when the budget does not allow for a CMS but some form of control is still required.

Standalone dimming ballasts are pre-set and dim to a percentage of output at a set time. This is useful where roads are mainly residential and therefore major incidents are less likely to occur. It also means that residents are able to benefit from reduced lighting levels at times when most people are at home and not using the streets.

Note that these ballasts can also be used in conventional floodlights, although they are normally considered a non-standard option.

Photocells are common in the UK and have been used to control lighting for decades. They used to be switched on at 130 lux and off at 70 lux (a 2:1 ratio) because low-pressure sodium (SOX) was the prevalent light source and needed a long warm-up period to achieve full light output. New light sources, such as LEDs, need very little time to stabilise and therefore can be switched very quickly.

Adjusting the lighting levels at which the photocell switches is known as trimming and can lead to small, but quantifiable, savings.

Other methods of saving energy relate to vehicle and pedestrian traffic. These can be based on PIR sensors or movement counters. The lighting can be dimmed during quiet periods. It is preferable to dim to a low level; total switch-off is not recommended since it can lead to feelings of insecurity and, in some circumstances, can be dangerous.

The maximum distance between the signal transmitter and the receiver in the luminaire varies with the signal protocol used. Digital signals will generally travel further than analogue voltage systems. Checks should always be made with both the signal equipment and the luminaire manufacturer to determine which cable to use.

Note that cable installations should be in accordance with local standards, such as BS 7671.

3 Lighting for specific applications

3.1 Flags and statues

3.1.1 Flags

By their very nature, flags are located high up so it is unlikely that they will be lit from above. The benefit of this positioning is that they are normally seen against a dark sky and, therefore, do not require high illuminance on them to make them visible. Hence, ground-mounted or recessed luminaires are normally used. The colours of the flag and how pale/dark they are will affect its visibility and contrast against the background. Obviously, pale flags are more easily seen against a night sky than darker ones.

Light sources with good colour rendering are essential.

Flags can be blown in any direction and are normally intended be seen from all directions. For this reason, the lighting should illuminate the whole swept area of the flag. Note that the beam only needs to illuminate the flag; anything beyond this is wasted light (e.g. a large 2 m wide flag only requires enough light to illuminate a 4 m diameter cylinder, the height of which is the same as the height of the flag).

The illuminance on the flag is highly dependent on the luminance of the background – most commonly, the sky. A trial is strongly recommended but, as a starting point, consider sources that will produce 50 lux on the flag.

It is important that there is enough spill light to illuminate a significant portion of the flagpole so that the flag itself does not appear to float in space.

Since the beam is narrow and only illuminates a small area, low wattage spotlights with deep louvres for glare control are a common solution. An alternative to louvres are prismatic covers, which can produce a fan-shaped beam in a vertical (the usual orientation) or horizontal plane.

3.1.2 Statues

Figure 3.1 King Alfred statue, Wantage (photograph courtesy of Alan Tulla Lighting)

Statues are often seen against the background of an illuminated building, streetlighting or shop windows. Hence, the illuminance level required to make the statue stand out is much higher than for flags in a similar location.

The luminance of the statue is greatly dependent on the material used. White marble, limestone and stainless steel will reflect a lot of light and, hence, the statue will easily be seen against a dark background (Figure 3.1). Conversely, materials such as bronze and wrought iron can rarely be made bright enough to stand out. In this case, it is better to highlight certain features or position the floodlights so that shadows recreate the shape and form of the statue.

Care should be taken when uplighting figurative statues such as people and animals so as to avoid unusual shadowing (e.g. dark areas above noses or bright areas on the underside of the body). Abstract sculpture should be illuminated to enhance its form.

It is generally better to light statues from above, such as from nearby buildings or columns.

Floodlighting of statues is highly subjective and a trial using hand-held equipment is advisable before the final installation.

3.2 Pedestrian routes, cycleways and subways

This application epitomises what exterior lighting is for; these areas are only used by people and cyclists and, as we do not have our own lighting, we rely heavily on what is provided for us. In these circumstances the designer needs to be particularly mindful of the user and how safe they will feel in the space and also how it will be maintained and accessed over the life of the project. Vandal resistance is a major consideration as sometimes these areas can be remote from natural surveillance and are easy targets.

BS 5489-1:2013 is the key document when designing these areas. The ILP document TR23: *Lighting of cycle tracks* gives some useful insight; however, it was last published in 1998 and technology and design have progressed significantly since then. The British Standard describes cycle tracks and footpaths in section 7.3 and P classes (formerly S classes) should be used when defining a lighting class.

Section 7 of BS 5489-1 also has relevance as it refers to crime prevention and detection, which must be a primary consideration in the design process for these areas. Good colour rendering (CRI > 80) should be specified to give the best visual clarity to users of the space.

Lighting installed in subways needs to be glare free and to give good uniform lighting across not only the horizontal plane but also the walls and ceiling. This makes the space feel less threatening and enables a clear field of vision through the subway. Each end of the subway, outside its entrance and exit, also needs sufficient lighting so the eye does not have to adapt from bright to dark on emerging from the space. Light is needed within the threshold zones during the daytime to aid safe transition from bright daylight into the relatively dark subway. In addition, this provision means that a person passing through the space can clearly see the exit and knows who or what is at the other end.

For longer cycle or pedestrian tunnels, low-maintenance lighting is needed along the entire route – especially if the tunnel curves. Emergency lighting may be required in longer tunnels where the exits are not clearly visible.

Vertical illuminance helps to give better visual appreciation to the user of all of these areas, and facial recognition is a priority. If people are able to see another person's face and features and the colour of their clothing, it helps to give a feeling of safety, and also provides better images for CCTV. White light is better for both facial recognition and CCTV.

In BS 5489-1, Table 4 in section 7.4.7.1 gives illuminance levels for subways. The values in this table are high compared to that of a standard P class route. This should be considered in the calculations to ensure that column-mounted lanterns on the exits are close to the subway and give the visibility required.

If pedestrian routes or cycleways are remote from roads and have their own lighting, hazards need to be designed out. Trees can cause undesirable shadowing, column access can be an issue and line of sight needs to be considered for the user. Unlit bollards, to prevent motor vehicles entering the subway, can also be a hazard. Bear in mind that the head height of a cyclist can be above that of a person on foot and therefore both need to be considered during the design process.

In cities, cycleways sometimes run alongside roads and if columns are installed close to the kerb edge this can cause a hazard. If possible, site columns at the back of a path so they are clear of the road and are at the furthest possible point from the cyclist. This positioning also means they are less likely to be damaged in a collision, diminishing the risk for drivers, pedestrians and cyclists.

Dimming may be considered in these areas, but only if the risk to the user is not increased. After midnight, when foot traffic may be lower, consideration should be given to reducing the level by a lighting class to reduce energy consumption and to lower the impact on local wildlife. This is best controlled via a CMS so that, in the event of an incident, the lighting can quickly be increased back to its full output to aid assistance and the emergency services.

Figure 3.2 **Coloured fountain lighting** (photograph courtesy of Ustigate Ltd)

3.3 Water features, fountains and pools

Lighting water can be one of the most challenging but also the most rewarding aspect of a lighting designer's work. Still water will reflect nearby trees and buildings. It is possible to 'light' a pool or small lake by lighting the surroundings, which are reflected in the water, achieving twice the effect. Small waves and ripples will produce even more interesting shapes and reflections.

As a general rule, cool light sources are preferred – 4000–5000 K would be a good starting point. Water is also highly amenable to the use of dynamic coloured light.

Moving water, such as fountains and waterfalls, works best when the droplets can 'catch' the light. This is done by positioning the spotlights in the water (Figure 3.2). A common technique is to locate the spotlights alongside the water jets, a process which is normally undertaken by a specialist water-feature designer/manufacturer.

Pools often have high-power spotlights positioned in the sides. Narrow beam spotlights can produce dramatic, contrasting effects. If the pools are used for swimming, wider beam luminaires should be used. These should be positioned 0.5–1 m under the surface so that the swimmers are illuminated. There is normally enough inter-reflection to light the sides and bottom of the pool.

A useful technique is to illuminate the border of the pool using a linear LED strip or fibre optic 'rope', having verified whether the equipment is resistant to any chemicals (such as chlorine) that may be used in the water. Some additives will attack stainless steel.

All luminaires used underwater should be IPX8, but note that the rating should be for the appropriate depth. Some IPX8 rated luminaires are only suitable for a submersion depth of 1 m.

High-power luminaires containing parabolic aluminised reflector (PAR) lamps are constructed so that they are cooled by water flowing around them. These are sometimes referred to as wet niche units. It is essential to ensure that they are fitted with a thermal cut-out so they will switch off if the water level drops.

3.4 Steps, stairs and changes of level

In exterior lighting, changes of level are important considerations as they can represent considerable hazards with possible injury if an accident occurs. The client is responsible for providing a safe visual environment up to the boundary of the client's site within the public realm.

It is not always clear where this boundary is and guidance should be taken from the client. If the boundary information is not available it can be obtained from the Land Registry. If any public rights of way cross the client's land, it would be reasonable to expect the client to maintain lighting that complies with minimal health and safety standards, as outlined in HSG38 *Lighting at work* at all times, but preferably to the good practice standards outlined in BS EN 12464-2 and BS 5489-1.

A typical example of a public right of way that continually crosses between private and public land is the Thames Path when passing through Central London.

It should be noted that some client bodies (such as London Underground) specify higher illuminance levels and uniformity ratios due to the large flow of people and adaptation problems when moving from internal illuminance levels to external illuminance levels during daylight hours. These problems are also present at underground car parks and subways. Where sight adaptation issues occur, it may be necessary to energise the lighting over external steps and stairs during bright sunlight conditions. Automatic lighting controls could be programmed to adjust threshold lighting, say with dual illuminance photocell energising lighting, when external levels fall below 100 lux or rise above 10 000 lux.

3.4.1 Lighting principles for staircases and steps

Shadowing of staircase treads is a major concern when considering the lighting of steps and staircases. The spacing of luminaires should ensure that all treads receive direct luminous flux. If luminaires are badly spaced the risers can cast shadows onto the next step, thus reducing contrast.

The emphasis should be on the first and last steps in any flight or the start and end of any slope or ramp, with no intermediate steps or ramp areas receiving less than 30% of this amount. Changes of direction should be clearly revealed.

Consideration always needs to be given to accessibility issues. The Equality Act 2010 makes the following recommendations for this type of exterior space:

— Designated parking spaces and any access routes from such spaces to the building entrance should be lit artificially to achieve a minimum illuminance of 20 lux, but with an illuminance of 100 lux on ramps or steps.

— Care should be exercised in the location and orientation of a ramp to avoid, where possible, glare and cross-shadows, which can prevent blind and partially sighted people distinguishing changes in gradient. Artificial lighting to a ramp should be evenly distributed, with an illuminance at ramp and landing level of at least 100 lux.

— Each flight and landing of a stepped access route should be well-illuminated, providing a clear distinction between each step and riser. The illuminance at tread level should be at least 100 lux. Lighting that will cause glare (such as poorly located wall lights, spotlights, floodlights or low-level light sources) should be avoided.

3.4.2 Siting of luminaires

The positioning of luminaires is important on external staircases as there are normally restricted mounting opportunities. Avoiding luminaires within the visual field of people using the stairs is a primary consideration as this can cause both discomfort and disability glare. Luminaires should either be above or below the observers' line of sight. Luminaires in the distance can drop into the field of view depending on whether the observer is ascending or descending the stairs.

Where luminaires are recessed into walls, their luminance should be controlled either by limiting the power of the luminaires or by use of controlling shading devices, such as louvres.

Figure 3.3 **Steps illuminated by luminaire within the handrail** (photograph courtesy of DW Windsor)

3.4.3 Choice of luminaires

The choice of luminaires on stairs is important, especially with regard to the intensity of the light source/reflector.

A luminance ratio of no more than 15:1 (treads:luminaire luminance in line of sight) is recommended. Optical devices, such as lenticular lenses and prismatic controllers, can be used to increase luminaire spacing. Asymmetric distributions can also be beneficial. Linear arrangements are preferable as the tread shadowing can be reduced. Handrail luminaires are a typical solution (Figure 3.3). Surface-mounted wall luminaires should not be sited in a manner that restricts access to the full width of the stair or impedes people using handrails.

3.4.4 Emergency lighting

See SLL Lighting Guide 12 for more information

It is implied within BS 5266-1 that emergency lighting should be provided through to the place of safety. This is normally interpreted to be the public realm or, in the case of large private sites, through to the muster/assembly points. Where external lighting is provided from a secondary power source, this would normally be deemed to provide the emergency lighting beyond the final exit doors of the building. Where there is no secondary power supplied lighting, then the emergency lighting should extend to the place of safety and this would include additional provisions for changes of direction and level. The emergency lighting levels should be as recommended in SLL Lighting Guide 12: *Emergency lighting*.

It is always advisable to conduct a risk assessment of the illuminance required.

Exterior places of work can be illuminated to quite high levels (e.g. train and vehicle maintenance yards). Similarly, if people have to move from a very bright interior, such as a supermarket, to a dark exterior they may have problems adapting to the much lower level of emergency illuminance.

As a general guide, the illuminance in the immediate vicinity and route to the exterior muster point should be no less than 5% of the working/interior illuminance.

3.4.5 Open plaza steps

It is important when the width of steps increases beyond 6 m that intermediate luminaire positions are found or area floodlighting solutions are employed to sufficiently illuminate the changes in level in open spaces. Stair-edge lighting can be useful but care must be taken not to create contrast problems between the luminaire luminance (in view) and the tread luminance. A contrast ratio of less than 15:1 is recommended. LED lines incorporated into stair treads can also cause problems to people who are visually impaired due to excessive contrast and glare. Luminaires incorporated into risers should also be chosen with care due to their close proximity to treads, to avoid creating a strong striped pattern on treads. Using a greater number of lower output luminaires tends to give a better solution.

Heritage sites can pose particular problems as choice and positioning of luminaires are likely to be restricted.

3.4.6 Recommended illuminance levels

In the *absence of other guidance*, a minimum maintained horizontal illuminance of 50 lux is recommended. The lighting level should be calculated on the leading edge at the centre point of the width of a step. Where the step is wider than 1.2 m the lighting level should be calculated 0.5 m from each edge. For steps over 2.4 m the lighting level should be calculated 0.5 m in from each side and at not more than 1 m intervals between. Intermediate steps should not receive less than 30% of the average of the top and bottom steps.

For compliance checks the readings should be taken on the leading edge of a step at the same points as used for the calculation. Note that, since most computer software cannot calculate the horizontal illuminance on a series of steps, it is easier to calculate the illuminance on a sloping plane representing the steps such that the horizontal component is 50 lux.

3.5 Maintenance of external lighting systems

Designers should always consider how the lighting systems they are designing are to be maintained. A good lighting design should look as good on the 3650th day as it does on handover to the client. It is the application of a well-considered maintenance strategy that allows the design intent to continue through time undiminished.

The designer needs to consider the following aspects in the maintenance strategy:

- Can the system be maintained safely?
- Who maintains the system?
- How is the system maintained?
- When is the system maintained?
- How frequently is maintenance required?
- How much does maintenance cost?
- How does the design age between regular maintenance periods?

The designer will normally be required to provide information, either as a section or a whole document, for the following:

- access statement
- designer's risk assessments
- Soft Landings document (required for publicly funded projects).

3.5.1 Health and safety

Designers of external lighting systems have a legal responsibility to minimise health and safety issues associated with their designs under the Construction (Design and Management) (CDM) Regulations 2015. Risks to be assessed by the designer include all activities associated with the location, specification, installation, operation, maintenance and disposal of the lighting system.

The designer is obligated to provide a designer's risk assessment that covers the lighting installation design from a health and safety standpoint.

Risks need to be assessed in terms of likelihood and their severity and mitigation measures analysed. Risk assessments must be agreed with the project principal designer to be included with the project health and safety file. Risk assessments are required to be reviewed at concept scheme and detailed design stages.

Designers should remember that falls from heights below 3 m are the most common accident at work.

3.5.2 Maintenance methodology

The designer should always talk to the client about the maintenance of the lighting system and, having understood the client's capabilities in terms of maintaining the system, recommend an appropriate maintenance strategy. This is especially important if regular maintenance is critical to maintain the design intent. The effect of failed lamps in an array of luminaires can be very noticeable. Colour consistency can be a particular problem where large arrays of high-intensity discharge (HID) sources, such as metal halide, are used. In some cases, the designer will need to consider the effect of the failure of individual luminaires on the functionality of their design. This may include health and safety issues or commercial aspects. Solutions may include alternative electrical supplies, additional luminaires or dual lamp sources.

3.5.3 Maintenance factor

BS EN 12464-2 requires the designer to calculate the maintenance factor according to CIE 154. The maintenance factor is made up of:

— *lamp survival factor*: the percentage of lamps that have failed between bulk lamp replacements

— *lamp lumen maintenance factor*: the percentage deterioration of light output between bulk lamp replacements

— *luminaire maintenance factor*: the percentage deterioration of photometric performance between luminaire cleanings.

All the above factors apply equally to LED sources as to conventional lamps.

External lighting maintenance differs from the maintenance of internal lighting in that there are no defined criteria for the cleaning of surfaces. It should be remembered that external surfaces age as well as becoming dirty. Aging of materials may include changes in reflection or changes in colour. Some polycarbonates will yellow from the UV in daylight and sunlight. The use of variable output light sources, such as LED, should be considered as a means of maintaining a constant building facade luminance over time.

3.5.4 Choice of lamp type

The designer should recommend the lamp type to be used in the design. For external lighting this is particularly important where lamp characteristics, such as mortality, lumen depreciation and efficacy vary markedly between manufacturers, lamp colours, lamp formats and operating positions. In the UK, streetlighting installations may also require the S/P ratio of the light source to be recorded.

The lighting designer should be involved in the specification of the contractor's obligations for the production of the operation and maintenance manuals for the lighting system.

3.5.5 Lighting equipment maintenance issues

It should be noted that maintenance procedures for external lighting equipment may be more involved than those for internal installations. The luminaires will be required to operate in a wide range of environmental/external conditions, such as temperature, humidity, water ingress, dust, impact, wind, etc.

External luminaires will normally be sealed according to BS EN 60598-1 (general enclosures should conform to BS EN 60529). Simple operations, such as lamp changing, may require particular procedures to be adopted, for example running the lamp for a period of time before closing the luminaire to evaporate water vapour before the luminaire is sealed. Adjustable components, such as swivel and knuckle joints, may require re-greasing at regular intervals. Special consideration will be required for underwater luminaires. Manufacturers' recommendations should always be sought at the design stage before finalising the choice of luminaire. Captive, quick release and no-tool fixings are particularly useful when working at height. Designs that utilise remote ballasts, low-level control boxes and low-level electrical isolation are recommended for reducing health and safety risks and maintenance costs and allowing ease of commissioning/reprogramming.

3.5.6 Soft Landings

Soft Landings is an approach that allows clients to be educated in how to utilise their building/system in line with the design intent of the design team. Soft Landings applies equally to external lighting as to internal lighting. Further information on Soft Landings is provided by the Usable Buildings Trust (UBT) and the Building Services Research and Information Association (BSRIA). The designer may be required to provide a presentation on the lighting systems or produce easy-to-follow guides on the use and maintenance of the systems.

Appendix 1: IP ratings

Table A1.1 Ingress protection (IP) ratings in accordance with BS EN 60529:1992+A2:2013

Level of protection against solid objects, materials or dust		Level of protection against water and other liquids	
0	No protection	0	No protection
1	Protected against solid objects of 50 mm diameter and above	1	Protection against vertically falling drops of water (e.g. condensation)
2	Protected against solid objects of 12.5 mm diameter and above	2	Protection against vertically falling drops of water when enclosure tilted up to 15° from vertical
3	Protected against solid objects of 2.5 mm diameter and above	3	Protection against water sprayed at an angle up to 60° from vertical
4	Protected against solid objects of 1 mm diameter and above	4	Protection against water splashed from all directions
5	Protected against dust, limited ingress (no harmful deposits)	5	Protection against jets of water from any direction
6	Totally protected against dust	6	Protection against powerful jets of water from any direction
		7	Protected against the effect of temporary immersion between 15 cm and 1 m
		8	Protected against long periods of immersion under pressure
		9	Protection against powerful jets of high-temperature water from any direction

Source: BS EN 60529:1992+A2:2013.

Appendix 2: IK ratings

Table A2.1 Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts in accordance with IEC 62262:2002 and BS EN 60068-2-75:2014

IK code	Protection against impacts
IK00	Not protected
IK01	Protected against 0.14 joules impact Equivalent to impact of 0.25 kg mass dropped from 56 mm above impacted surface
IK02	Protected against 0.2 joules impact Equivalent to impact of 0.25 kg mass dropped from 80 mm above impacted surface
IK03	Protected against 0.35 joules impact Equivalent to impact of 0.25 kg mass dropped from 140 mm above impacted surface
IK04	Protected against 0.5 joules impact Equivalent to impact of 0.25 kg mass dropped from 200 mm above impacted surface
IK05	Protected against 0.7 joules impact Equivalent to impact of 0.25 kg mass dropped from 280 mm above impacted surface
IK06	Protected against 1 joules impact Equivalent to impact of 0.25 kg mass dropped from 400 mm above impacted surface
IK07	Protected against 2 joules impact Equivalent to impact of 0.5 kg mass dropped from 400 mm above impacted surface
IK08	Protected against 5 joules impact Equivalent to impact of 1.7 kg mass dropped from 300 mm above impacted surface
IK09	Protected against 10 joules impact Equivalent to impact of 5 kg mass dropped from 200 mm above impacted surface
IK10	Protected against 20 joules impact Equivalent to impact of 5 kg mass dropped from 400 mm above impacted surface

Appendix 3: Floodlighting calculations

The majority of exterior lighting installations, certainly for the floodlighting of functional areas, succeed by satisfying the various lighting criteria, following a design process normally consisting of three stages:

1. An assessment is made of where to locate the floodlights, the type of light distribution required and the light source characteristics that suit the particular application.
2. A lumen calculation is carried out to find the number and loading of the lamps necessary to achieve the required average illuminance.
3. When necessary, point-by-point calculations are carried out to determine the aiming pattern of the floodlights for the required uniformity.

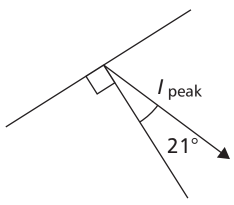
The third stage may modify the earlier calculations, and is the stage when the use of a computer becomes invaluable for a large and complex installation.

A3.1 Floodlighting data for manual calculations

There are several ways to present photometric data for floodlights. The simpler methods are dealt with here. For preliminary design work, the beam data are particularly useful. Table A3.1 shows an example for a wide-angle floodlight.

Table A3.1 Beam data

Peak intensity (*I*) cd/klm		1110
Beam factor to 10% peak (*I*)		0.74
Beam angle to 10% peak (*I*)	Horizontal Vertical	2 × 50° 36°/66°
Beam angle to 50% peak (*I*)	Horizontal Vertical	2 × 39° 7°/13°
Beam angle to 1% peak (*I*)	Horizontal Vertical	2 × 67° 49°/89°



The *peak intensity* is in a direction 21° to the normal of the front glass of the floodlight, expressed in candelas per kilolumen (cd/klm). To obtain the actual intensity in cd, the value (in this case, 1110) must be multiplied by the bare lamp lumens divided by 1000.

The beam factor (BF) to 10% peak is the fraction of the lamp flux in the beam to where the intensity is 10% of the peak value. This can be thought of as the amount of the total light from the lamp that goes into the beam.

The beam angle to percentage of peak is measured in a horizontal and vertical plane with respect to the peak intensity (Figure A3.1) The horizontal angle is doubled because the angle is either side of the central peak intensity. The first vertical angle is above the peak intensity and the second vertical angle is below the peak intensity.

The beam angle to 10% peak indicates the angular spread of the useful beam. The beam angle to 50% peak is useful for those occasions when beams from two

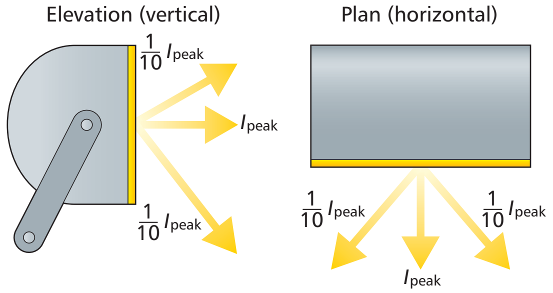


Figure A3.1 Beam angles

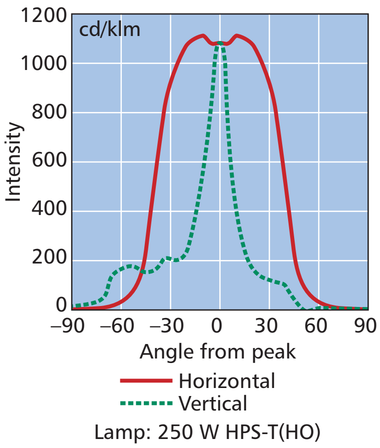


Figure A3.2 Intensity curves

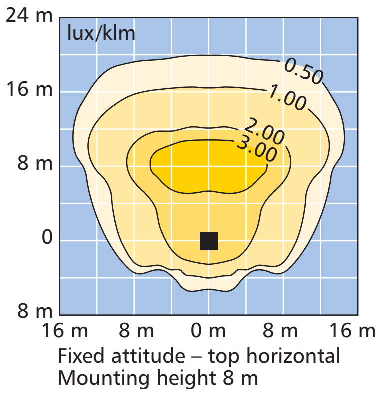


Figure A3.3 Floodlight isolux diagram

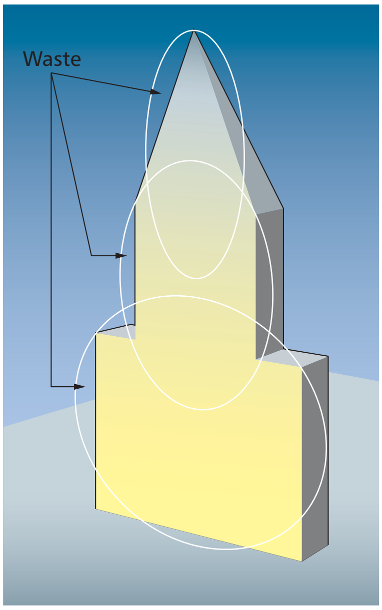


Figure A3.4 Wasted light in floodlighting

of the same type of floodlight overlap with the intention of giving an even wash of light. The beam angle to 1% peak is the boundary beyond which there is just spill light that will make no useful contribution to the lighting scheme. In effect, it is the cut-off angle.

The intensity curves for a floodlight show the lighting performance graphically (Figure A3.2) Most of the information given in the beam data can be read from these curves. The solid line denotes the intensity in the horizontal plane. The dashed line denotes the intensity in the vertical plane, positive angles are above the peak intensity. All angles are measured with respect to the peak intensity, which may, or may not, be normal to the front glass of the floodlight. It is important to check where the peak intensity is emitted.

The lighting performance of a floodlight can be evaluated by looking at an isolux diagram, if available (Figure A3.3). The format is similar to that for amenity luminaires. For a specified mounting height, on a grid in metres, contours of constant illuminance are shown in units of lux/klm. To obtain an actual value of illuminance, simply multiply by the bare lamp lumens divided by 1000. The isolux diagram can be used to assess the illuminance created when the floodlight is mounted at other mounting heights, by using the same conversion factors given for amenity luminaires:

— Multiply contour values by:

$$\frac{(\text{stated mounting height in m})^2}{(\text{new mounting height in m})^2}$$

— Multiply grid distance by:

$$\frac{\text{new mounting height in m}}{\text{stated mounting height in m}}$$

The boundary of the area to be lit will not necessarily coincide with the area covered by the floodlights as, in the case of a tall narrow building or one with a complicated profile, a considerable amount of light may be wasted (Figure A3.4).

This is accounted for by the waste light factor (WLF). More light may be wasted on a tower or chimney than on a rectangular building or advertising hoarding. The WLF is the fraction of light that falls *onto* the object being lit, not the fraction of light that is wasted. Under favourable conditions, a WLF of 0.9 might be assumed, but in difficult situations this may be reduced to 0.5 or lower. This factor, when multiplied by the beam factor (BF) gives the utilisation factor (UF):

$$\text{UF} = \text{WLF} \times \text{BF}$$

The lumen method of design can then be applied, as with interior lighting design:

$$E = \frac{N \times F \times \text{UF} \times \text{MF}}{A}$$

where: E is the average maintained illuminance, N is the number of luminaires, F is initial bare lamp lumens per luminaire, UF is the utilisation factor, MF is the maintenance factor and A is the area to be lit.

Even more simply, at the first stage of design calculations it is common practice to use an estimated utilisation factor of 0.3. This figure is low for asymmetric and some symmetric projectors (which give precise light control) and too high for wide-angle projectors (which will project light beyond the boundaries of the area being considered).

Appendix 4: Artificial lighting and its effect on animal and plant ecology

Sources of ecological light pollution include sky glow, lit buildings and towers, street lights, sports floodlighting, security measures, etc. It can also be caused by offshore fishing boats, bridges across rivers and estuaries and glare from oil platforms.

The effect of lighting on the natural environment can be difficult to quantify but when there are habitats rich in wildlife near lighting installations there is a possibility that lighting will have adverse effects on insects, animals and plants in the area.

A4.1 Sky luminance

Direct upward light reacts with and is diffused through cloud, mist and airborne particles (Figure A4.1). Note that these particles can often be natural in origin, such as pollen, dust from fields, rain, mist, etc. The area affected and the brightness are dependent on the presence and quantity of diffusing elements and the level of light being distributed by the source (luminaire).

Figure A4.1 Sky glow above a small city in Hampshire (photograph courtesy of Alan Tulla Lighting)

Light pollution is a global issue, with over 18% of the terrestrial surface of the earth exposed to night sky brightness that is considered to be polluted by astronomical standards.

A4.2 Lamp spectra

It is common for ecologists to measure light in terms of lux, which is readily understood by lighting designers and engineers. However, this ignores the biologically important information relating to the light source. A high-pressure sodium lamp may produce the same illuminance as a low-pressure sodium source but the latter contains less UV, which has been shown to attract moths and flying insects. As research continues in this field it will become essential to show measurements of radiation and spectrum-based information relevant to the organisms being discussed, in addition to the actual level of illumination. As a general rule, white light disturbs creatures more than monochromatic or narrow waveband sources.

A4.3 Effects on behaviour and population

Ecological light pollution has been shown to adversely affect behaviour and population of organisms in natural surroundings. These effects are shown in terms of changes in orientation, disorientation or mis-orientation, and attraction or repulsion from the altered lit environment, which may affect foraging, reproduction, migration and communication.

Orientation and disorientation are responses to ambient illumination (the amount of light incident on an object or building), whereas attraction or repulsion have been demonstrated to occur as a response to the intensity of the light source.

A4.4 Birds and flight

Birds will often circle around towers at night, apparently trying to orient their flight to the light, which they mistake for the moon or a star. It has been noted that this disorientation is less prevalent when there is a full moon.

It has long been understood that some migratory birds navigate by detecting the Earth's magnetic field. It has been suggested that light-sensitive molecules called cryptochromes could be the key to birds' magnetic sense. Cryptochromes are sensitive to blue and green light. A number of scientific experiments have been carried out with regard to magnetic orientation of birds under blue and green light and it has been shown that the wavelength and intensity of the light can affect birds' orientation.

Some birds rely on bioluminescent plankton to navigate by and are therefore drawn to light. These birds are fatally attracted to lighthouses, lights from oil and gas platforms and the high-intensity lights used on fishing boats (Figure A4.2).

Figure A4.2 Offshore oil and gas platform (curraheeshutter/Shutterstock.com)

A4.5 Mammals (excluding bats)

The behaviour of terrestrial nocturnal mammals is influenced by moonlight and any artificial light intervention can result in disruption of circadian rhythm, foraging and predation. This is particularly true of smaller mammals, which rely on darkness to avoid predators.

As mammals seek to avoid areas of increased light, this affects dispersal movement and corridor use, which can lead to a decline in reproductive behaviour and hence a shrinking population and, ultimately, a decrease in biodiversity.

Most nocturnal animals react to increasing moonlight by reducing their use of open areas, foraging and movement, reducing total activity or concentrating it to within the darkest parts of the night.

A4.6 Circadian rhythms

The free running period of activity cycle for an animal (including humans) under constant light and darkness ranges from 23 to 25 hours. For all vertebrates the primary influence on their internal clock setting is the change of quantity and spectral quality of light at dawn and dusk. A special photoreceptor, independent of the rods and cones, entrains the biological clock of vertebrates. The light regime and circadian clock also influence production of hormones, including melatonin. In all species, whether nocturnal or diurnal, melatonin is produced at night and suppressed during the daytime.

A4.7 Circannual rhythm

Mammals have an endogenous rhythm with a free running period of about a year. The circannual clock influences body mass, hormone production, reproductive status, hibernation and circadian pattern over the year.

A4.8 Bats

A4.8.1 Legal protection of bats

All species of bat are protected by law in the UK. It is illegal to kill, injure, capture or disturb bats, obstruct access to bat roosts or damage/destroy bat roosts. Lighting in the vicinity of a bat roost causing disturbance could constitute an offence.

A4.8.1 Roosts

Lighting bat roosts creates disturbance, which may cause the bats to desert the roost. Light spill onto a roost access point will at least delay bats seeking to emerge and this shortens the amount of time available to them for foraging. Bats seek food soon after dusk; hence the presence of artificial light can result in a reduction in available feeding time.

A4.8.1 Insects and foraging

The fact that certain types of lamps attract insects and the presence of lit conditions can also affect the feeding behaviour of bats. Many night-flying species of insect are attracted to light, especially to those lamps that emit a UV component and particularly if it is a single light source in a dark area. Moths and a range of other insects can be attracted to light. Studies have shown that, although various bats swarm around white mercury or metal halide street lights, feeding on the insects attracted to the light, this behaviour is not true for all bat species. The slower flying, broad winged species of bat generally avoid street lights.

Artificial lighting is thought to increase the chances of bats being preyed upon. Many avian predators will hunt bats, which may be one reason why bats avoid flying in the day.

Lighting can be particularly harmful if used along river corridors, near woodland edges and near hedgerows used by bats. In mainland Europe, in areas where there are foraging or ‘commuting’ bats, stretches of road are left unlit. Similarly, the lighting is designed in such a way as to avoid isolation of bat colonies.

Artificial lighting disrupts the normal 24-hour pattern of light and dark, which is likely to affect the behaviour of bats. Bright light may reduce social flight activity and cause bats to move away from the lit area. Studies have shown that continuous lighting along roads creates barriers that some bat species cannot cross.

A4.9 Mitigation of lighting impacts on bats

A4.9.1 Roosts

Direct lighting of bat roosts and access points should be avoided. Where buildings are to be lit in the neighbourhood of bat roosts, lighting should be positioned to avoid sensitive areas.

A4.9.2 Type of lamp

Low UV content sources with narrow wavebands, such as low-pressure sodium lamps or LEDs, have least impact on bats. Where white light sources are used, suitable UV filtration should be employed.

A4.9.3 Luminaire and light spill accessories

Lighting should be directed to where it is needed and light spill avoided. This can be achieved by selecting a suitably designed luminaire and by using accessories such as hoods, cowls, louvres and shields to direct the light to the intended area only.

A4.9.4 Lighting columns

Lighting columns should be as short as is possible, since light at a low height reduces the ecological impact. However, there are cases where a taller column will enable light to be directed downwards at a more acute angle and thereby reduce horizontal spill. The acceptable level of lighting will vary, dependent on the surroundings and on the species of bat affected.

Do not disturb dark flight corridors. Many insects and bats use these as routes between the roost and feeding areas.

A4.10 Reptiles and amphibians

Frogs and salamanders suffer from sudden exposure to light, which causes nocturnal species to suspend normal feeding and to sit motionless even after the light has been turned off. Salamanders cannot navigate under red or yellow light and are particularly susceptible to sodium lighting.

Light pollution also endangers sea turtles. Bright lights nearby discourage females from coming ashore to nest. Newly hatched turtles need a dark night sky to orient themselves towards the sea, but artificial lights behind beaches lure them away. Hatchlings are attracted to the artificial light and crawl inland, or crawl aimlessly down the beach, sometimes until dawn, when terrestrial predators or birds attack them.

Some tree frogs stop calling in brightly lit areas. If the males are not calling, they are not reproducing, which has a major effect on population levels.

Light affects the physical development of frogs. Studies show that the amount of light exposure affects hormone production. This regulates everything from how much fat the frogs store for the winter to when they produce eggs. Frogs living in constantly illuminated environments may not be getting the proper signals.

A4.11 Invertebrates

Day length is used by a number of hibernating insects to regulate behaviour. While the mechanism is not fully understood, insects are sensitive to ambient light levels barely above those in full-moon conditions.

Increased or inappropriate lighting can have further effects on insect populations. As an example, day-flying butterflies have larvae which feed at night. Artificial light can inhibit this behaviour, leaving the larvae susceptible to predators.

A4.11.1 Attraction to light

Insects can be affected in a number of ways by artificial light:

— *Fixation/captivity effect*: This occurs when insects are travelling and either fly directly into the light source or orbit endlessly until they are eaten by a predator or die of exhaustion. The insect can become trapped in a lit zone which interferes with its navigation.

— *Attraction effect*: This occurs when an insect is attracted to a light source and is drawn from its normal habitat. On a moonlit night the zone of attraction is as little as 50 m, but on a dark night it can rise to 500 m. This effect is a potential cause of reduction in diversity of species.

Lamp type is particularly important in determining attraction to light. High-pressure mercury vapour causes the strongest attraction, high-pressure sodium is about half as attractive and sources with UV filtering are least attractive, with low-pressure sodium attracting no insects.

A number of ecology experts recommend sodium lighting as a universal solution to the problem of light affecting insect populations.

In summary, artificial lighting affects feeding patterns, dispersal and migration and can influence circadian rhythm. So, to protect moths and other invertebrates, lighting should be turned off, dimmed or, as a minimum measure, have the UV content of lighting reduced.

While light is an important factor in reduction of diversity of species, loss of suitable habitat has caused more problems.

A4.11.2 Fireflies

Fireflies are a special case as they also use bioluminescence as part of their reproductive cycle, which is being affected by increased urban illumination. Mating males attract females by blinking their lights. Fireflies typically will not make an appearance when there are bright ambient lights, such as the time of the full moon. If increased urban illumination interrupts fireflies' ability to signal each other, it could disrupt mating with consequent reduction of population numbers.

A4.11.3 Amelioration and good practice

Artificial light in sensitive ecological communities should be kept to a minimum. It may not actually be necessary at all. Where possible, it should be avoided or limited in its distribution and hours of use. This is not always practical in areas of human activity.

Lighting designers need to think carefully about how they provide lighting in areas which are shared with animals and plant life:

- Use light only when and where it is needed, minimising it by the use of lighting controls, timers and motion detectors. Turn off lights when they are not required. Create a curfew period of nil/reduced illuminance.
- Use only as much as is needed. The use of excessive lighting levels reduces the eye's ability to see beyond the lit area. Always consider whether glare and spill light can be totally eliminated.
- Aim the lighting down (i.e. below horizontal). Well-designed luminaires direct light where it is required and nowhere else. It is important to select luminaires with good optical control and shielding.
- Consider the light source carefully. Direction, intensity, duration and spectral distribution all need to be considered.

Glossary

This glossary contains definitions and explanations for the specification of exterior lighting to facilitate an understanding of this guide. The definitions are based upon:

- BS EN 12665:2002 *Lighting Applications – Basic Terms and Criteria for Specifying Lighting Requirements*; and
- CIE17.4 *International Lighting Vocabulary*, fourth edition, joint publication IEC/CIE:1987.

These documents should be consulted if more precise definitions are needed.

Adaptation

A process which takes place as the visual system adjusts to the luminance and colour of the visual field or the final state of this process.

Technically defined: The process by which the state of the visual system is modified by previous and present exposure to stimuli that may have various luminances, spectral distributions and angular subtenses.

Note 1: The terms light adaptation and dark adaptation are also used, the former when the luminances of the stimuli are of at least several candelas per square metre and the latter when the luminances are of less than some hundredths of a candela per square metre.

Note 2: Adaptation to specific spatial frequencies, orientations, sizes etc. are recognised as being included in this definition.

Adaptation level

The state of adaptation of an individual at a particular time.

Aiming angle

The angle from the downward vertical at which the luminaire is aimed. This is normally the same point on the ground as the peak intensity but in some luminaires the peak intensity is emitted at angles other than a normal to the front glass.

Baffle

Sheet(s) of material, usually metal, placed in front of the luminaire to limit light spill. Also known as a *visor*. A *louvre* is similar but constructed of several slim blades to block the light from particular viewing angles.

Ballast

A device connected between the supply and one or more discharge lamps which serves mainly to limit the current of the lamp(s) to the required value.

Note: A ballast may also include means of transforming the supply voltage, correcting the power factor and, either alone or in combination with a starting device, provide the necessary conditions for starting the lamp(s).

Beam angle

The width of a beam measured in degrees. Normally taken to be the total width, including both sides of the axis, where the intensity is 10% of maximum. Sometimes 50% I_{peak} is taken to be the beam width.

Brightness

Attribute of the visual sensation associated with the amount of light emitted from a given area. It is a subjective correlate of luminance.

Technically defined: brightness, luminosity (obsolete): Attribute of a visual sensation according to which an area appears to emit more or less light.

Central management system (CMS)	This is mainly used in streetlighting or other large installations. The condition of the luminaires, lamp failures and power consumption is monitored and the data fed back to a central point. A CMS is usually linked to an inventory.
Close offset	Used to describe the situation where a luminaire is relatively close to the building or area it is lighting (e.g. where the height of the building is greater than five times the offset distance). This is a similar concept to the *depth to height ratio*.
Colour appearance	See *correlated colour temperature*.
Colour rendering (of a light source)	Effect of a light source on the colour appearance of objects compared with their colour appearance under a reference light source. The definition is more formally expressed as: Effect of an illuminant on the colour appearance of objects by conscious or subconscious comparison with their colour appearance under a reference illuminant.
Colour temperature (T_c)	The temperature of a Planckian (black body) radiator whose radiation has the same chromaticity as that of a given stimulus. *Unit*: kelvin (K) *Note*: The reciprocal colour temperature is also used, unit K^{-1}.
Contrast	In the perceptual sense: Assessment of the difference in appearance of two or more parts of a field seen simultaneously or successively (hence: brightness contrast, lightness contrast, colour contrast, simultaneous contrast, successive contrast etc). In the physical sense: Quantity intended to correlate with the perceived brightness contrast, usually defined by one of a number of formulae which involve the luminances of the stimuli considered, for example: $\Delta L/L$ near the luminance threshold, or L_1/L_2 for much higher luminances.
Correlated colour temperature (T_c)	The temperature of the Planckian (black body) radiator whose perceived colour most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions. *Unit*: kelvin (K) *Note 1*: The recommended method of calculating the correlated colour temperature of a stimulus is to determine on a chromaticity diagram the temperature corresponding to the point on the Planckian locus that is intersected by the agreed iso-temperature line containing the point representing the stimulus. *Note 2*: Reciprocal correlated colour temperature is used rather than reciprocal colour temperature whenever correlated colour temperature is appropriate.
Cylindrical illuminance (at a point) (E_z)	Total luminous flux falling on the curved surface of a very small cylinder located at the specified point divided by the curved surface area of the cylinder. The axis of the cylinder is taken to be vertical unless stated otherwise. *Unit*: lux (lx) = lumens per square metre Technically defined: Quantity defined by the formula: $E_z = \frac{1}{\pi}\int_{4\pi \mathrm{sr}} L \sin\varepsilon \, \mathrm{d}\Omega$

where $d\Omega$ is the solid angle of each elementary beam passing through the given point; L is its luminance at that point; and ε the angle between it and the given direction.

Dark Sky Park — A park or other public land possessing exceptional starry skies and natural nocturnal habitat where light pollution is mitigated and natural darkness is valuable as an important educational, cultural, scenic and natural resource.

Depth to height ratio (D/H) — Used to describe how far a luminaire is aimed in relation to its mounting height. This is a simpler and more easily understood value than the aiming angle (e.g. a 5:1 D/H is an aiming angle of 78.7°).

Diffused lighting — Lighting in which the light on the working plane or on an object is not incident predominantly from a particular direction.

Directional lighting — Lighting in which the light on the working plane or on an object is incident predominantly from a particular direction.

Disability glare — Glare that impairs the vision of objects without necessarily causing discomfort. *Note*: Disability glare may be produced directly or by reflection.

For specification: Disability glare may be expressed in a number of different ways. If threshold increment is used the following values of TI should be used:

5%, 10%, 15%, 20%, 25%, 30%.

If glare rating is used then the following values of GR should be used:

10, 20, 30, 40, 45, 50, 55, 60, 70, 80, 90.

Discomfort glare — Glare that causes discomfort without necessarily impairing the vision of objects. *Note:* Discomfort glare may be produced directly or by reflection.

For specification: If it is expressed using the unified glare rating the following values of UGR should be used:

10, 13, 16, 19, 22, 25, 28.

Diversity ratio — This is the ratio of maximum to minimum illuminance. See also *uniformity*.

Emergency lighting — Lighting provided for use when the supply to the normal lighting fails.

Escape lighting — That part of the emergency lighting which is provided to ensure that the escape route is illuminated at all material times.

Flicker — Impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time.

General lighting — Substantially uniform lighting of an area without provision for special local requirements.

Glare — Condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of luminance, or to extreme contrasts.

See also *disability glare* and *discomfort glare*.

Illuminance (at a point of a surface) (E)	Quotient of the luminous flux $\delta\Phi_v$, incident on an element of the surface containing the point, by the area δA of that element. Equivalent definition: Integral, taken over the hemisphere visible from the given point, of the expression: $L \cos\theta\, \delta\Omega$ (where L is the luminance at the given point in the various directions of the incident elementary beams of solid angle $\delta\Omega$; and θ is the angle between any of these beams and the normal to the surface at the given point). *Unit*: lux (lx) = lumens per square metre *Note*: The orientation of the surface may be defined, e.g. horizontal, vertical; hence horizontal illuminance, vertical illuminance. For specification: Illuminance should be specified as maintained illuminance and should take one of the following values: 1.0×10^N lux, 1.5×10^N lux, 2.0×10^N lux, 3.0×10^N lux, 5.0×10^N lux, 7.5×10^N lux (where N is an integer). The area over which the illuminance is to be calculated or measured shall be specified.
Illumination	Application of light to a scene or its surroundings so that they may be seen.
Illuminance gradient	Percentage difference of illuminance between adjacent measuring points (FIFA).
Illuminance uniformity	Ratio of minimum illuminance to average illuminance on a surface. *Note*: Use is also made of the ratio of minimum illuminance to maximum illuminance, in which case this should be specified explicitly.
In-fill lighting	Used to soften deep shadows, especially when floodlighting buildings.
In-ground luminaire	Also known as a 'ground recessed', 'paver' or 'burial' luminaire. This type of luminaire is recessed into the ground so that the top is flush with the surface/ pavement.
Initial illuminance	Average illuminance when the installation is new. *Unit*: lux (lx) = lumens per square metre
Intensity (luminous) (of a point source in a given direction) (I)	Luminous flux per unit solid angle in the direction in question, i.e. the luminous flux on a small surface, divided by the solid angle that the surface subtends at the source. *Unit*: candela = lumen per steradian (lm/sr) Technically defined: Quotient of the luminous flux ($\delta\Phi$) leaving the source and propagated in the element solid angle ($\delta\Omega$) containing the given direction, by the element solid angle: $I = \dfrac{\delta\Phi}{\delta\Omega}$

Isolux curve (iso-illuminance curve)	Locus of points on a surface where the illuminance has the same value.
Lamp	Source made in order to produce an optical radiation, usually visible. *Note*: This term is also sometimes used for certain types of luminaires.
Lamp cleaning interval	The illuminance provided by a lighting installation will decrease as the lamps age and dirt is deposited on the luminaire and room surfaces. The luminaire's luminous distribution will also be affected by dirt deposits. Planned maintenance is therefore essential if the design parameters are to be met throughout the life of an installation. Depreciation can be kept within technically and economically acceptable limits by ensuring: that luminaires are safe, reliable and constructed to relevant international standards; that luminaires are selected to suit location conditions; and that a programme of luminaire cleaning and lamp replacement is implemented.
Lamp lumen maintenance factor (LLMF)	Ratio of the luminous flux of a lamp at a given time to the initial luminous flux.
Lamp survival factor	Fraction of the total number of lamps that continue to operate at a given time under defined conditions and switching frequency.
Light output ratio (of a luminaire)	Ratio of the total flux of the luminaire, measured under specified practical conditions with its own lamps and equipment, to the sum of the individual luminous fluxes of the same lamps when operated outside the luminaire with the same equipment, under specified conditions. *Note*: For luminaires using incandescent lamps only, the optical light output ratio and the light output ratio are the same in practice.
Light pollution	Non-preferred term, use obtrusive light 'Obtrusive light': That light which is projected in any combination of upward and outward path beyond the boundaries of the site or object being illuminated, and by reason of that projected light's direction, magnitude, duration and presence is contrary to the general environment and those interests of life and livelihood. 'Light pollution': an expression promoted by astronomers, relates to light either into the night sky, resulting in 'sky glow', or light presence affecting the performance of their instruments.
Light nuisance	A legal definition under the Clean Neighbourhoods and Environment Act 2005. It is taken to be artificial light from premises that is prejudicial to health or a 'nuisance'.
Louvre	See *baffle*.
Luminance (L)	Luminous flux per unit solid angle transmitted by an elementary beam passing through the given point and propagating in the given direction, divided by the area of a section of that beam normal to the direction of the beam and containing the given. It can also be defined as: The luminous intensity of the light emitted or reflected in a given direction from an element of the surface, divided by the area of the element projected in the same direction. Or: The illuminance produced by the beam on a surface normal to its direction, divided by the solid angle of the source as seen from the illuminated surface.

It is the physical measurement of the stimulus which produces the sensation of brightness.

Unit: candela per square metre (cd/m^2)

Technically defined: Quantity defined by the formula:

$$L = \frac{\delta \Phi}{\delta A \cos\theta \, \delta \Omega}$$

where $\delta\Phi$ is the luminous flux transmitted by an elementary beam passing through the given point and propagating in the solid angle $\delta\Omega$ containing the given direction; δA is the area of a section of that beam containing the given point; and θ is the angle between the normal to that section and the direction of the beam.

For specification: Luminance should be specified as maintained luminance and should take one of the following values:

1.0×10^N cdm^{-2}, 1.5×10^N cdm^{-2}, 2.0×10^N cdm^{-2}, 3.0×10^N cdm^{-2}, 5.0×10^N cdm^{-2}, 7.5×10^N cdm^{-2} (where N is an integer)

The area over which the luminance is to be calculated or measured shall be specified.

Luminaire

Apparatus which distributes, filters or transforms the light transmitted from one or more lamps and which includes, except the lamps themselves, all the parts necessary for fixing and protecting the lamps and, where necessary, circuit auxiliaries together with the means for connecting them to the electricity supply.

Note: The term 'lighting fitting' is deprecated.

Luminous efficacy of a source (η)

Quotient of the luminous flux emitted by the power consumed by the source.

Unit: lumens per watt (lm/W)

Note 1: It must be specified whether or not the power dissipated by auxiliary equipment such as ballasts etc., if any, is included in the power consumed by the source.

Note 2: If not otherwise specified, the measurement conditions should be the reference conditions specified in the relevant IEC standard. See *rated luminous flux*.

Luminous flux

Quantity derived from radiant flux (radiant power) by evaluating the radiation according to the spectral sensitivity of the human eye (as defined by the CIE standard photometric observer). It is the light power emitted by a source or received by a surface.

Unit: lumen (lm)

Note 1: In this definition, the values used for the spectral sensitivity of the CIE standard photometric observer are those of the spectral luminous efficiency function $V(\lambda)$.

Note 2: See IEC 50 (845)/CIE 17.4: 845-01-22 for the definition of spectral luminous efficiency, 845-01-23 for the definition of the CIE standard photometric observer and 845-01-56 for the definition of luminous efficacy of radiation (see ISO/CIE 10527).

	Technically defined: Luminous flux Φ is given by: $\Phi = K_m \int_0^\infty \{\delta\Phi_\varepsilon(\lambda)/\delta\lambda\} V(\lambda)\delta\lambda$ where $\delta\Phi_\varepsilon(\lambda)/\delta\lambda$ is the spectral distribution of radiant flux; and $V(\lambda)$ is the spectral luminous efficiency.
Luminous intensity (of a point source in a given direction) (I)	Luminous flux per unit solid angle in the direction in question, i.e. the luminous flux on a small surface, divided by the solid angle that the surface subtends at the source. *Unit*: candela = lumen per steradian (lm/sr) Technically defined: Quotient of the luminous flux ($\delta\Phi$) leaving the source and propagated in the element solid angle ($\delta\Omega$) containing the given direction, by the element solid angle: $I = \frac{\delta\Phi}{\delta\Omega}$
Maintained illuminance	Value below which the average illuminance on the specified area should not fall. It is the average illuminance at the time maintenance should be carried out. *Unit:* lux (lx)
Maintenance factor	Ratio of the average illuminance on the working plane after a certain period of use of a lighting installation to the average illuminance obtained under the same condition for the installation considered conventionally as new. *Note 1*: The term 'depreciation factor' has been formerly used to designate the reciprocal of the above ratio. *Note 2*: Maintenance factor of an installation depends on lamp lumen maintenance factor, lamp survival factor, luminaire maintenance factor and (for an interior lighting installation) room surface maintenance factor.
Mesopic vision	The viewing condition between full photopic and full scotopic vision. In mesopic vision, both the cones and rods are active but the relative proportions of each depend on the luminance of the visual field in view.
Mounting height	Distance between the working plane and the plane of the luminaire.
Nightscape strategy	A coordinated strategic plan for the night-time lighting of an urban area. This would include a description of the lighting in various areas, such as traffic routes, residential areas, 'gateways', etc.
Obtrusive light	That light which is projected in any combination of upward and outward path beyond the boundaries of the site or object being illuminated, and by reason of that projected light's direction, magnitude, duration and presence is contrary to the general environment and those interests of life and livelihood.
Rated lamp life (ave)	The lamp operating hours at the period of 50% failures for a batch of lamps.
Rated luminous flux (of a type of lamp)	The value of the initial luminous flux of a given type of lamp declared by the manufacturer or the responsible vendor, the lamp being operated under specified conditions. *Unit*: lumens (lm)

Note 1: For most lamps, in reference conditions the lamp is usually operating at am ambient temperature of 25 °C in air, freely suspended in a defined burning position and with a reference ballast, but see the relevant IEC standard for the particular lamp.

Note 2: The initial luminous flux is the luminous flux of a lamp after a short ageing period as specified in the relevant lamp standard.

Note 3: The rated luminous flux is sometimes marked on the lamp.

Reflectance (*r*)
: Ratio of luminous flux reflected from a surface to the luminous flux incident on it.

Note: The reflectance generally depends on the spectral distribution and polarisation of the incident light, the surface finish and the geometry of the incident and reflected light relative to the surface.

Response time
: Time required for the change of detector output to reach, after a step variation of a steady detector input, a given final percentage of its final value.

Safety lighting
: That part of emergency escape lighting that provides illumination for the safety of people involved in a potentially dangerous process or situation and to enable proper shut down procedures for the safety of the operator and other occupants of the premises (known as 'high-risk task area lighting' in BS 5266-7/EN 1838).

Semi-cylindrical illuminance (at a point) (E_{sz})
: Total luminous flux falling on the curved surface of a very small semi-cylinder located at the specified point, divided by the curved surface area of the semi-cylinder. The axis of the semi-cylinder is taken to be vertical unless stated otherwise. The direction of the curved surface should be specified.

Unit: lux (lx)

Spacing (in an installation)
: Distance between the light centres of adjacent luminaires of the installation.

Spacing-to-height ratio
: Ratio of spacing to the height of the geometric centres of the luminaires above the reference plane.

Note: For indoor lighting the reference plane is usually the horizontal working plane; for exterior lighting the reference plane is usually the ground.

Spherical illuminance (at a point) (E_o)
: Total luminous flux falling onto the whole surface of a very small sphere located at the specified point divided by the total surface area of the sphere.

Unit: lux (lx)

Technically defined: Quantity defined by the formula

$$E_o = \int_{4\pi \mathrm{sr}} L \, \mathrm{d}\Omega$$

where $\mathrm{d}\Omega$ is the solid angle of each elementary beam passing through the given point; and L is its luminance at that point.

Spill light
: This is light falling outside the area which it is designed to illuminate.

S/P ratio
: The ratio of the luminous output of a light source, evaluated according to the CIE scotopic spectral luminous efficiency function, to the luminous output evaluated according to the CIE photopic spectral luminous efficiency function.

Standby lighting	That part of the emergency lighting which may be provided to enable normal activities to continue.
Stroboscopic effect	Apparent change of motion and/or appearance of a moving object when the object is illuminated by a light of varying intensity. *Note*: To obtain apparent immobilisation or constant change of movement, it is necessary that both the object movement and the light intensity variation are periodic and that some specific relation between the object movement and light variation frequencies exists. The effect is only observable if the amplitude of the light variation is above certain limits. The motion of the object may be rotational or translational.
Urban sky glow	The brightening of the night sky over inhabited areas.
Upward light output ratio (of a luminaire)	Ratio of the upward flux of the luminaire, measured under specified practical conditions with its own lamps and equipment, to the sum of the individual luminous fluxes of the same lamps when operated outside the luminaire with the same equipment, under specified conditions.
Uniformity ratio (of illuminance on a given plane)	Ratio of the minimum illuminance to the average illuminance on the plane.
Utilisation factor	Ratio of the luminous flux received by the reference surface to the sum of the rated lamp luminous fluxes of the lamps in the installation.
Veiling reflections	Specular reflections that appear on the object viewed and partially or wholly obscure details by reducing contrast.
Visual acuity	Capacity for seeing distinctly fine details that have a very small angular subtense at the eye. *Note*: Quantitatively, it can be expressed by the reciprocal of the angle, in minutes of arc, subtended at the entrance pupil by the extremities of the detail separation which is just visible. Technically defined: Qualitatively – capacity for seeing distinctly fine details that have very small angular separation. Quantitatively – any of a number of measures of spatial discrimination such as the reciprocal of the value of the angular separation in minutes of arc of two neighbouring objects (points or lines or other specified stimuli) which the observer can just perceive to be separate.
Visor	See *baffle*.
Visual field	Area or extent of physical space visible to an eye at a given position and direction of view. *Note*: The visual field may be either monocular or binocular.
Visual performance	Performance of the visual system as measured for instance by the speed and accuracy with which a visual task is performed.

References

Note that legislation and guidance is constantly being updated and reference should be made to the latest issue of these documents.

Legislation relevant to lighting

Clean Neighbourhoods and Environment Act 2005

Construction (Design and Management) Regulations 2015

Directive 2005/32/EC of the European Parliament and of the Council (Energy-using Products Directive)

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