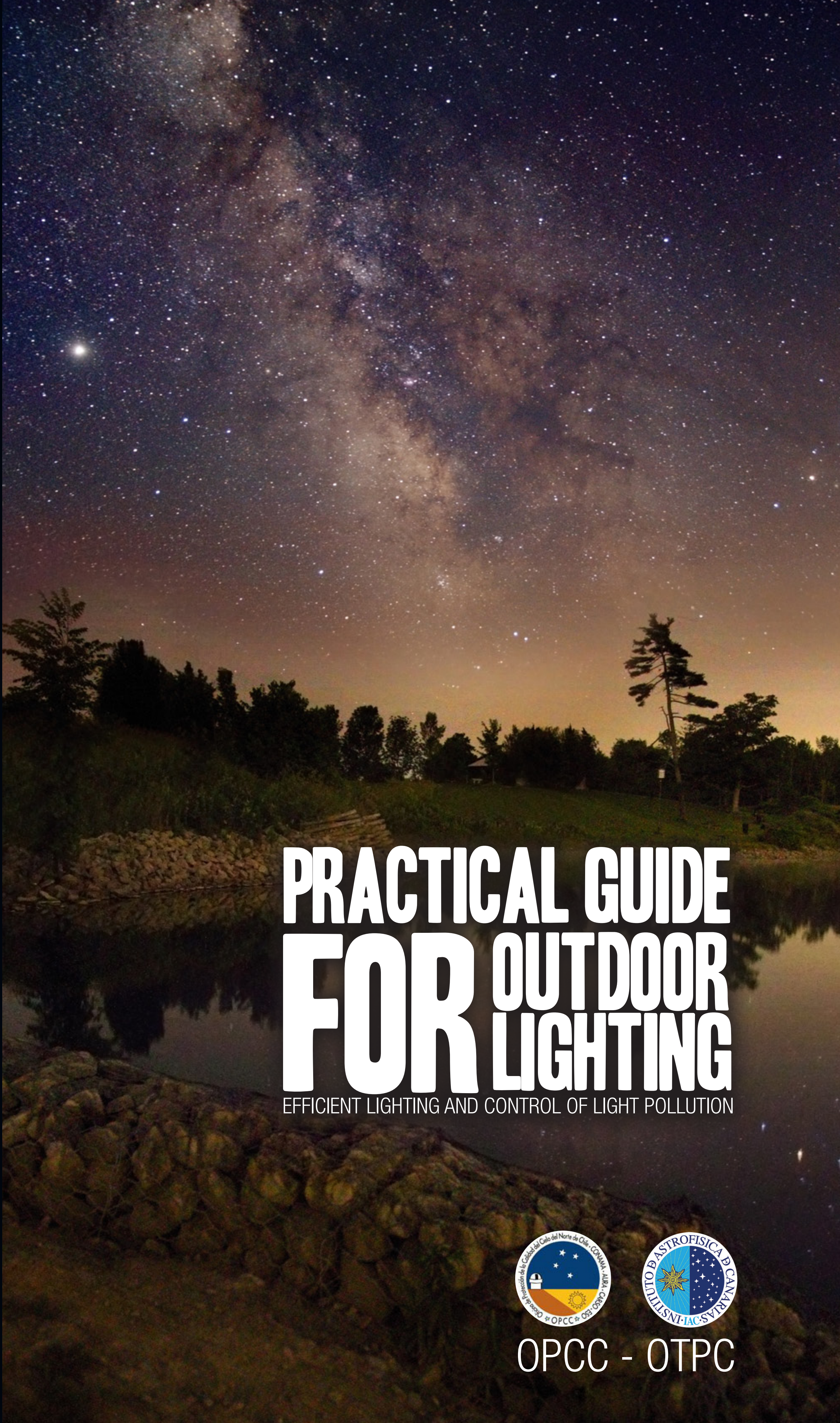
SKY QUALITY PROTECTION TECHNICAL OFFICES OF **CHILE** Y **CANARIAS**



PRACTICAL GUIDE FOR OUTDOOR LIGHTING

EFFICIENT LIGHTING AND CONTROL OF LIGHT POLLUTION

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PRACTICAL GUIDE FOR OUTDOOR LIGHTING

IAC/OTPC - CONAMA AURA CARSO ESO/OPCC
TENERIFE, SPAIN - ANTOFAGASTA, CHILE JULY 2010

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1.INTRODUCTION

Light pollution can be defined as the direct or indirect entry of artificial light into the environment. We can, however, prevent pollution from the emission of luminous flux from artificial night-time sources in intensities, directions, spectral ranges or at unnecessary times for activities planned for the areas where lighting is installed.

Light pollution has become a global problem that is gradually diminishing our capacity to observe the stars. It is new form of waste that gives rise to energy and environmental impacts, damage to ecosystems and the degradation of the night sky. White light leads to the degradation of night-time ambience, altering the nature of urban areas and environments, with unforeseeable consequences.

2.OBJECTIVES

This guide is largely aimed at professionals who are in some way involved in lighting projects, whether in design, development, start-up, management or maintenance of outdoor lighting installations. Its aim is to obtain efficient, environmentally friendly and sustainable lighting.

3.CRITERIA

TO PREVENT THE EMISSION OF DIRECT LIGHT UPWARDS AND AT ANGLES NEAR THE HORIZON.

-Use luminaires with reflectors and clear covers, preferably of flat glass. Avoid tilting the luminaires from their horizontal position.

-Use luminaires with a percentage of upper hemisphere emission installed below 0,2% (preferably 0%) in relation to the total output flux of the luminaire, and be sure to avoid directing light near the horizon (the first 10°, 20°), as it produces a sky glow 6 to 160 times greater than the same flux reflected off the ground.

-Use only asymmetric beam floodlights, with asymmetries adapted to the area to be lit, not installed at a tilt.

-Use aiming (direction of maximum intensity) for floodlights with angles lower than 70°. (This avoids glare for users and local residents).

AVOID EXCESS LIGHTING LEVELS.

Lighting levels should comply, in the following order, with the laws, regulations, standards and recommendations in order to establish appropriate levels for lighting public and private spaces, buildings, monuments and signposts in each case. The values contained in these documents should be considered as targets to be achieved and should never exceed plus 20% of the lighting levels indicated (even if set up as minimum levels).

Reduce lighting levels or switch off the installation after certain hours at night or if there is a change in the lighting requirements of the activity or reason for installation (e.g. commercial lighting for security lighting, lower traffic intensity, illumination for buildings and monuments, illuminated signs, etc.).

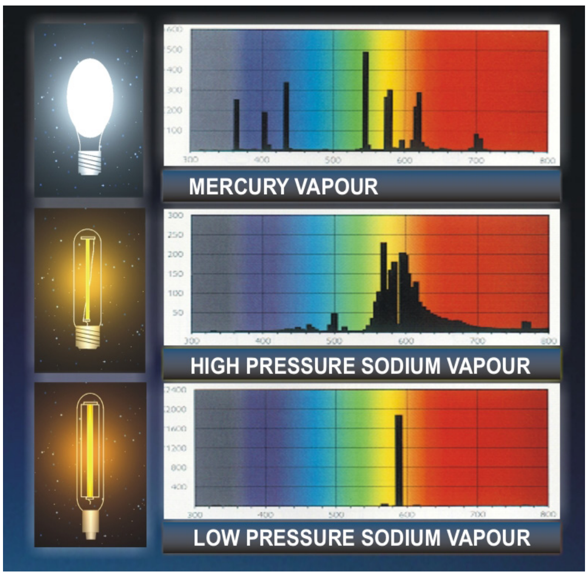
Do not justify excess lighting in new installations based on the simple fact that existing neighbourhood lighting was planned in excess. This should be corrected before a new plan is developed.

Exaggerated lighting levels should not be designed for areas of social conflict. Several studies indicate that lighting in excess and particularly glare can increase vandalism.

DO NOT USE LAMPS WITH RADIANT OUTPUT OF WAVELENGTHS SHORTER THAN 500 NM.

When the chromatic performance of an installation is not the foremost objective, use the bulb/luminaire assembly that offers the most efficient lighting but with minimum emissions below 500 nm (no blue light or UV).

Studies up until 2002 indicate that bulbs emitting blue and ultraviolet (mercury) radiation attract three times more insects than sodium vapour lamps. Radiations at around 460-470 nm control the circadian rhythms of living creatures and night-time emission damages and reduces the biodiversity of natural environments and causes disease in humans (effect on certain types of cancer, sleep disruption, etc.). In addition, the low emission to 500nm produces major dazzle to older people (problem with the crystalline).



The new neutral cool white (>3000 K) LED lamps emit at 470 nm (up to three times the maximum of the most visible zone), making them particularly harmful to health and the environment.

When white light is required, warm white LEDs (<3000 K), which are now available on the market, are recommended.

Moreover, light scattering in the atmosphere (glare) in clear skies (astronomical observatories) is approximately inversely proportional to the fourth power of the wavelength by which an amber coloured emission (590 nm) is three times less scattered than one at 440 nm. Therefore, radiation at wavelengths below 500 nm (blue light) must be avoided.

DESIGNING INSTALLATIONS WITH A MAXIMUM COEFFICIENT OF UTILIZATION.

The coefficient of utilization (K) should be over 30% or the utilance above 40% for the road, highway, square or enclosure. Luminaires or floodlights should not by placed far from the area to be lit or, where appropriate, light projection beyond the useful zone should be minimized (K = average maintained illuminance multiplied by the surface calculation and divided by the lumens installed).

FOR ORNAMENTAL LIGHTING, LUMINAIRES SHOULD PREFERABLY BE POINTED DOWNWARDS.

A wide range of devices and optics are available for use depending on the location and size of the object to be lit, thereby avoiding excess lighting and projecting light beyond the zone in question (avoid upward-facing built-in floor lights).

If necessary, visors, shields, deflectors and cowls to guarantee light control beyond the area of action.

In any case, these kinds of installations should be switched off after midnight or earlier, though luminous flux reducers are also an option, and should preferably be automatic with timer systems to guarantee operation.

AFTER MIDNIGHT (OR EARLIER):

1. Switch off sports lighting, luminous signs and everything not required for public safety.

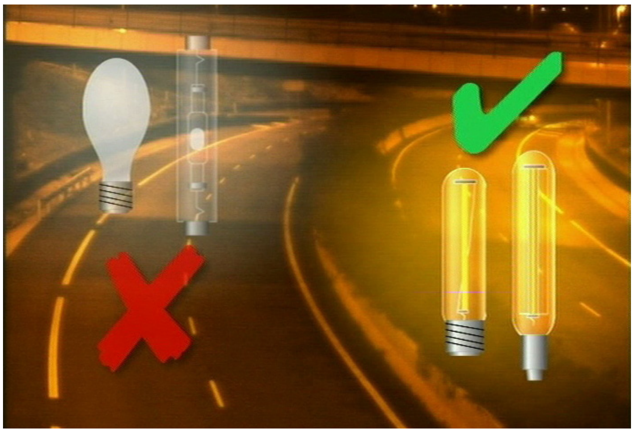
2. Reduce lighting to minimum recommended levels and adapted to the reduction of the activity in this schedule.

DO NOT POINT SPOTLIGHTS OR LASER GUNS AT THE SKY FOR ADVERTISING, RECREATIONAL OR CULTURAL PURPOSES.

FUNCTIONAL AND AMBIENT LIGHTING

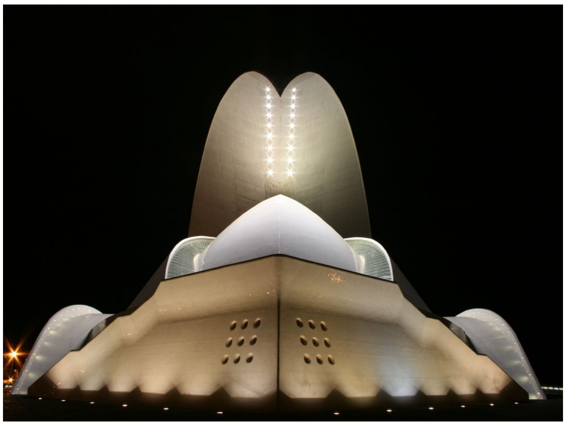
Functional lighting encompasses lighting installations for motorways, dual carriageways, urban streets and roads.

Ambient lighting, however, is generally placed on low supports (3-5 m) in urban areas for lighting pedestrian and commercial areas, pavements, parks and gardens, historic centres and roads with low speed limits.




ORNAMENTAL AND DECORATIVE LIGHTING

Ornamental lighting includes illumination for public buildings and monuments, as well as statues, city walls, fountains, gardens, etc., and outdoor illumination of landscapes, such as rivers, riversides, beaches, green areas, aquatic facilities and the like.

SPORTS LIGHTING

Sports lighting includes the illumination of all areas where sporting and recreational activities take place. This type of lighting is usually placed at a considerable height.

ILLUMINATED SIGNS AND WARNING SIGNS

Signals, signs, luminous advertising, illuminated advertising and shop window, urban furniture, shelter and telephone booth lighting, etc. All traffic signs and announcements are excluded.

SPECIFIC LIGHTING

In addition to the lighting mentioned above, other types are available for concrete and specific areas or uses. Below is a list of the most important:

- Lighting for pedestrian footpaths, stairs and ramps
- Additional lighting for zebra crossings
- Lighting for level crossings
- Lighting for roundabouts and cul-de-sacs
- Open air carparks
- Lighting for outdoor work areas
- Festive and Christmas lighting
- Outdoor lighting for housing

5.LUMINAIRES AND FLOODLIGHTS

DEFINITION OF LUMINAIRE AND FLOODLIGHT:

These devices distribute, filter and transform light emitted by one or several lamps and contain all the necessary accessories to mount, protect and connect them to the power supply circuit, thereby fulfilling a triple function: photometric, mechanical and electrical. Photometrically speaking, these devices are responsible for controlling and distributing the light emitted by the lamp.

The photometry of conventional luminaires used in functional and ambient lighting is adapted to these areas, thereby providing more effective illumination on the perpendicular axis of the luminaire.

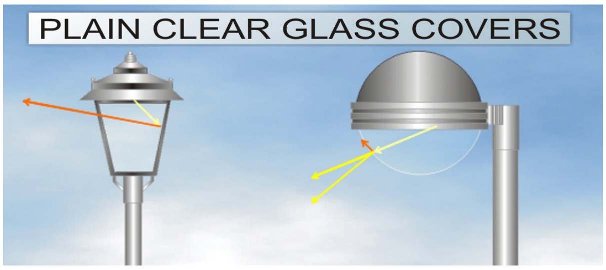
Floodlight configuration, on the other hand, varies and ranges from highly concentrated photometries to those where, according to the position of the lamp, long distances are reached without tilting the floodlight (asymmetric floodlight).

REQUIREMENTS FOR LUMINAIRES:

1. Choose luminaires with reflectors and clear covers, preferably of flat or lens-shaped glass, with an upper hemisphere flux of below 0,2%.

2. Use optics with high-performance luminaires (>55%) whose luminous beam adapts to the surface to be lit so that it only illuminates the required area and whose design has a high coefficient of utilization.

3. Like any other electrical equipment, a luminaire must comply with a series of safety requirements regarding electrical insulation (a IP65 is recommended for most applications), mechanical safety (IK), etc.



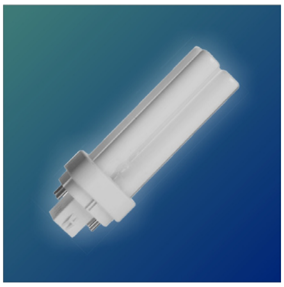
6.LAMPS

DEFINITION OF LAMPS:

Discharge lamps are generally used for outdoor lighting and can be classified according to the gas (mercury or sodium vapour) or pressure (high or low pressure) used. The properties vary considerably from lamp to lamp, making them suitable for one use or another. In recent times, there have been considerable developments in light emitting diodes, more commonly known by their English acronym, LED, and these are becoming increasingly popular for outdoor use.

TYPES OF LAMPS FOR OUTDOORS:

Fluorescent lamp:



A low-pressure mercury lamp normally used for domestic and industrial lighting. The advantage of this lamp compared with incandescent lamps is its energy efficiency. As outdoor lighting it is generally used in beacons, and there are various levels of power, colour temperatures and connection systems. Its average life is relatively short (10 000 hours). The use of lamps with a colour temperature below 3000 K is recommended because of their low impact on the environment and astronomy.

Mercury vapour and blended-light lamp:

Unlike fluorescent lamps, discharge is produced at high pressure. This type of lamp contains mercury vapour and its spectrum has a considerable amount of ultraviolet radiation, which is highly detrimental to astronomy and the environment. Its energy efficiency is poor in comparison with other lamps used for public lighting. Its use has diminished considerably and in all likelihood it will be banned in Europe in the next few years.

High pressure sodium vapour lamp:

The sodium vapour lamp comprises a translucent ceramic tube, which is able to withstand the highly corrosive nature of the sodium and the high temperatures generated. Two electrodes placed at both ends supply the electric power required to light the sodium vapour. High efficiency and long life (around 25 000 hours) make this an ideal lamp for use in public lighting. Chromatic performance is not high but is enough for most situations. Its capacity to contrast objects makes it suitable for areas of vehicular traffic.

Mercury vapour lamp with metal halide:

As with other gas discharge lamps, light is generated by passing an electric arc through a mixture of gases. In a metal halide lamp, the compact tube where the arc is formed contains a mixture of argon, mercury and a variety of metal halides. These lamps are moderately efficient and have a short life (around 10 000 hours), but they are particularly advantageous because of their great capacity for chromatic performance, which makes them suitable for ornamental, sports and recreational installations. Several types exist, but the most recommended is the new metal halide lamp with ceramic technology and colour temperature below 3000 K, given its lower ultraviolet radiation and environmental impact.

Low pressure sodium vapour lamp:

It works in much the same way as high pressure sodium vapour lamps, but in this case using low pressure gas. It generates the most lumens per watt of any lamp on the market. It is mainly used for lighting large avenues, motorways, streets and parks where the reproduction of colour is not an important factor (monochromatic light). Its average life is quite long (23 000 hours) and from an astronomical and environmental perspective it is the best option for outdoor lighting.

LED (light emitting diode):

This is a semiconductor device (diode) that emits narrow-spectrum light when its PN junction is directly polarized and electric current passes through it. LED lighting (or solid-state lighting) has revolutionized how illumination is achieved. Unlike discharge lamps, these diodes do not generate radiant-flux emission and can therefore be attached to several types of optics, emit multi-coloured light and then be monitored and modulated electronically. In recent years their efficiency has grown enormously and is expected to continue growing in the years to come. From an astronomical and environmental perspective, warm colour temperature LEDs (<3000 K) with a low blue light content are ideal for ambient use (squares, parks and pedestrian areas, etc.). LEDs with a similar spectrum to sodium vapour are also available, and in future this technology will most likely replace all previous technologies.

CONSIDERATIONS:

In cities, glare is mainly caused by white light. Consequently, this type of lamps is not recommended, and low light packages should be used whenever possible. Moreover, some types of lamps consume more energy than others with the same luminous flux, emitting in spectral zones undetectable to the human eye. The best options are lamps that have a low scattering effect, very low pollution of the electromagnetic spectrum, including ultraviolet and infrared, or do not at least flood the blue light (below 500 nm). Today's ideal lamps, therefore, are low-pressure sodium vapour (LPS), high pressure sodium vapour (HPS) and the warm LED with low blue emissions mentioned above.

BASIC LIGHTING CONCEPTS:

Luminous flux (lumens): Dimension of power.

1 cd = 1 lumen /steradian.

Luminance or brightness (cd/m2): The luminous intensity emitted by an element in a specific direction determined by a unit of surface.

Illuminance (lux): This indicates the amount of light that reaches a surface and not what we really see, which is a reflection (brightness).

Candela (cd): Luminous intensity in a given direction (1 cd = a body that emits a monochromatic radiation at 540 x 1012 Hz and has an intensity of radiation in that direction of 1/683 W per steradian).

A higher level can be less safe than a lower level with less power but better quality parameters.

Mean uniformity: Uo= minimum luminance / mean luminance

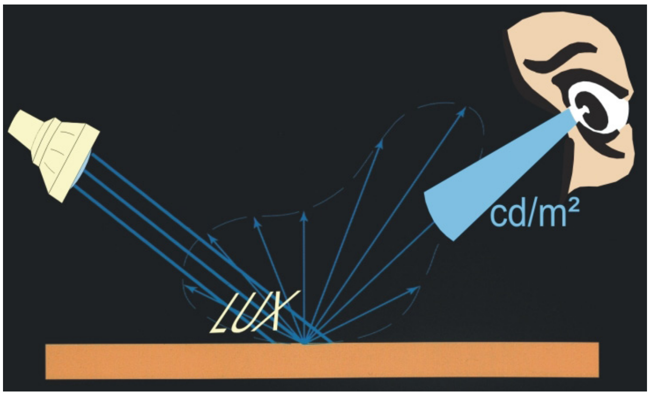
Ug= minimum illuminance / mean illuminance

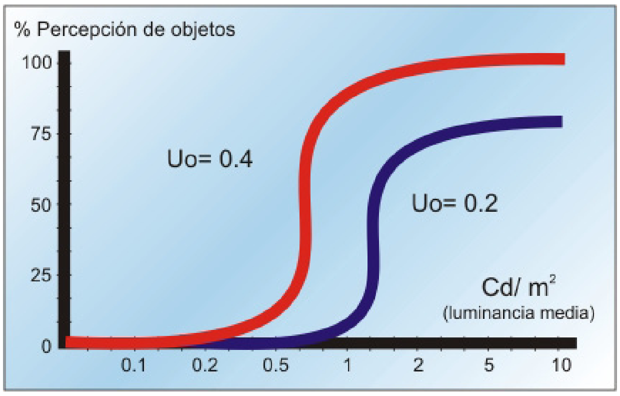
Extreme uniformity: Eu= minimum luminance / maximum luminance

Longitudinal uniformity: LU= minimum LU / mean LU

The graph shows the relation between the perception of objects, the mean luminance and uniformity.

Note: TI= 7%.





HOW TO DESIGN FUNCTIONAL AND AMBIENT LIGHTING:

When creating a lighting installation the following factors should be taken into account:

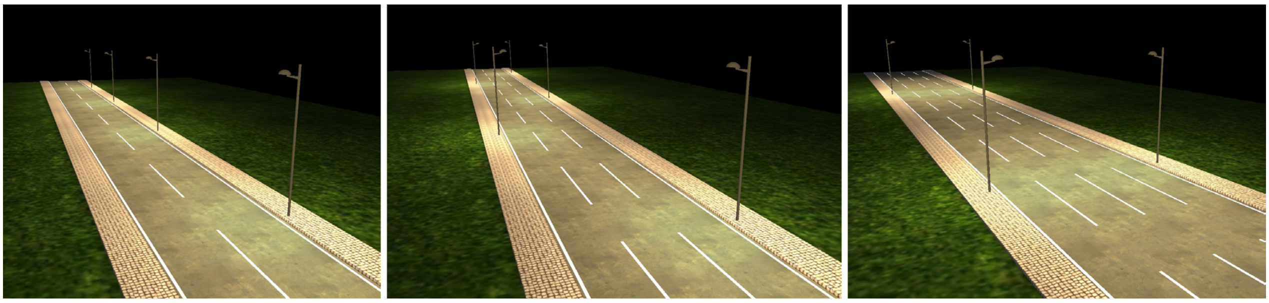
1. Luminaire distribution: Four ways of arranging luminaires have been recognized as apt for public thoroughfares with motorized traffic.

- One-sided: This layout consists of placing all the luminaires on the same side of the street and is used only when the width of the road is equal to or less than the mounting height of the luminaires. The luminance of the road on the opposite side to the row of luminaires will inevitably be lower compared with the side where they have been placed.

- Staggered: This layout consists of staggering the luminaires on both sides of the street and is generally used when the width of the road is between 1 and 1.5 times the mounting. Careful attention must be paid to the uniform arrangement of the luminaires along the road, since alternate bright and dark spots can cause an annoying zigzag effect.

- Opposite (pairing): This layout involves placing luminaires directly opposite each other and is generally used when the width of the road is 1.5 times greater than the mounting height.

- Suspended over the middle of the road: This layout entails hanging or placing the luminaires over the middle of the road. This system is normally used for narrow thoroughfares flanked by buildings on both sides onto which cables can be attached in order to suspend the luminaires.



Combinations of these four basic layouts are also used. Special layouts are also available for luminaires mounted at a low height for the purpose of providing visual orientation. In this case, the luminance of the road is very low, owing to the shadows cast by other passing vehicles and visual degradation due to dust covering the luminaires.

2. The dimensions of the area to be lit: An enormous variety of luminaires and optics are available for lighting areas of varying shapes and sizes. It is therefore important to choose those best fitted to the work plane. In this way, we can optimize light use and not waste energy by lighting areas beyond our area of action.

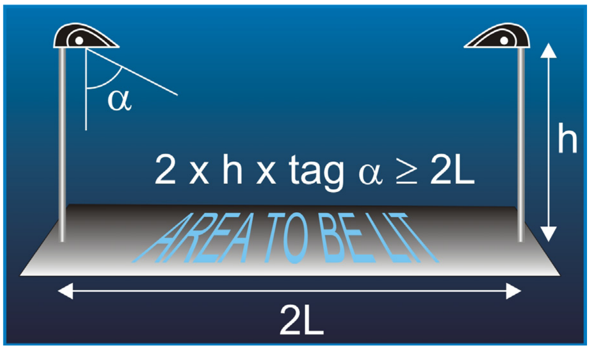
3. Use according to type (motorway, road, etc.): Each use follows specific requirements regarding levels of illuminance and luminance, including quality parameters (uniformities) in order to ensure safe, efficient and quality lighting. The rules and regulations, recommendations and type of road must be taken into consideration, and specific lighting criteria will be borne in mind and reasonably applied.

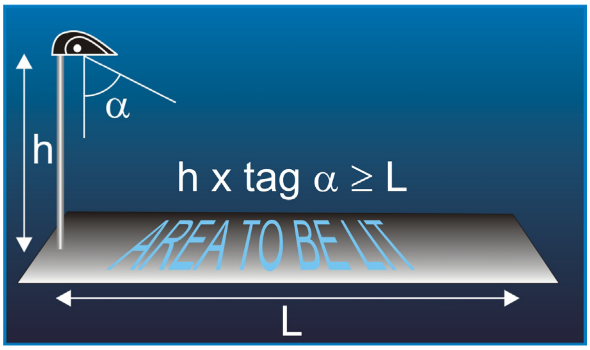
HOW TO DESIGN SPORTS LIGHTING:

This type of lighting is destined for sports or recreational areas illuminated by floodlights situated at specific points around the perimeter at a height proportional to the dimension of the area to be lit.

In general, this involves the use of floodlights whose main vertical beam is asymmetric; in other words, the maximum intensity of the light is sent forwards with an angle of asymmetry from a non-tilting floodlight (glass parallel to the ground).

The asymmetry and height (h) of the floodlight must match the length (L) of the area to be lit in front of each floodlight in such a way that h x tag $\alpha \approx$ L. Thus, if we illuminate an area with two facing towers, the distance between both towers should not be more than 2L≤2 x h x tag α.





The technical and practical limit for the α is 70°. Above this value, it is impossible to control the light on the horizon and the dazzling effect on both local residents and users of the installation.

To avoid excess illumination from towers with more than one floodlight, floodlights whose intensity towards the base of the tower is less than a third of the maximum intensity (Imax) should be used. Lighting levels, power and types of lamp must be adapted to comply with existing rules, regulations and recommendations.

The following general considerations should be taken into account:

1. Lighting levels according to sport and category.
2. Vertical and horizontal illuminance. Uniformity.
3. Dazzling effect on users, general public and local residents.
4. Shape and shadows of users.
5. Colour and reproduction of colour.
6. Floodlight orientation, location and optics
7. Zero direct upward flux, to reduce light pollution.
8. Energy efficiency and saving and maximum utilization factor or utilance.
9. Switch-off before midnight.

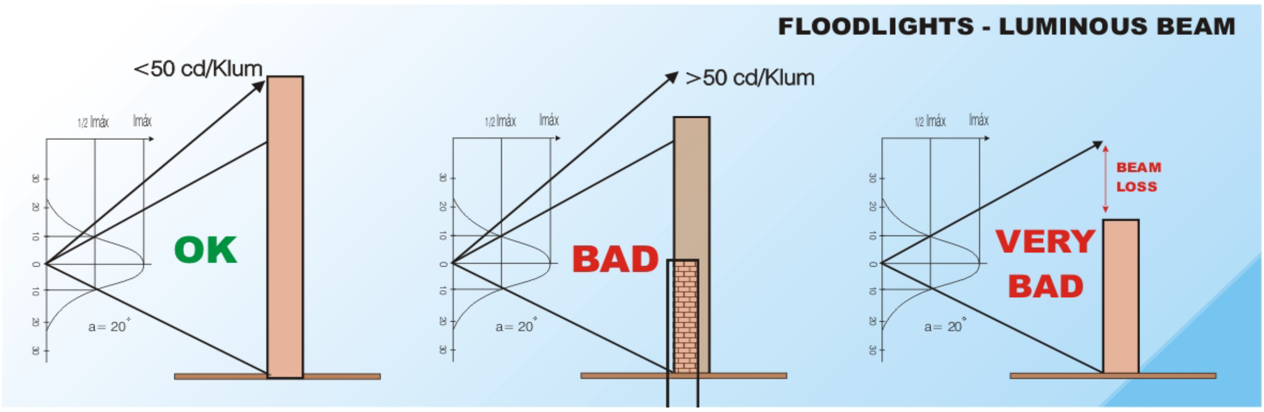
HOW TO DESIGN ORNAMENTAL AND DECORATIVE LIGHTING:

These installations include the ornamental lighting of public buildings, monuments and gardens. There is a wide range of devices available depending on the location and size of the object to be lit, but all must prevent light from falling beyond the area to be lit.

Floodlights should be installed and illuminate from top to bottom. Their optics should be adapted to the size and location of the object to be lit. If necessary, visors, shields, deflectors and cowls should be installed to guarantee light control beyond the area of action.

It is generally considered acceptable when more than 50% of the luminous flux output of the floodlight falls on the object to be illuminated, restricting emissions close the horizon. In any case, the main beam should be intercepted by the object to be lit.

National and international lighting level recommendations should be followed. For guidance, theoretical calculations to obtain the mean level can be obtained by using the following formula, supposing that the floodlights are evenly distributed: total lumens installed / in m2 x 0.8 x 0.7 x 0.7 (lux).



The following general considerations should be taken into account:

1. Distance and general direction from which the object is observed.
2. Background, surrounding area, obstacles that cause screening.
3. Possible inconveniences to other users of the surrounding area (intrusive light, glare).
4. Floodlight position, aiming and optics.
5. Lighting levels according to recommendations and the colour of the object to be lit.
6. Energy saving and installation switch-off.
7. Chromatic reproduction.
8. Guaranteed switch-off before midnight.

HOW TO DESIGN AN ILLUMINATED SIGN:

For signs such as illuminated box signs, lighting levels should not exceed CIE Zone E1 rating recommendations for a high sensitivity zone (50 cd / m²) and E2 for the rest (400 cd / m²). The same recommendations as those followed for illuminating building fronts can also be used for luminous signs or advertisements illuminated externally using floodlights, fluorescent luminaires or LEDs.

Signs illuminated by floodlights should be lit from top to bottom ensuring that the spotlight does not fall beyond the area of the sign and on and above the horizon (this design aspect must also be monitored from the side not being lit). To approximately determine mean lighting levels, add up the number of lumens installed and divide them by the useful area of the illuminated sign, then multiply this value by 0.4, as long as illumination is uniform (Ug >40%).

ENVIRONMENTAL IMPACT.

In the past few decades, the degree and intensity of artificial lighting at night has increased to such an extent that today no one can deny its negative effect on habitats and species. There are two distinct terms to describe the effects of light pollution on natural and protected areas: 'astronomical light pollution', which affects vision of the night sky regarded as part of the landscape, and 'ecological light pollution', which alters the natural light patterns of terrestrial and aquatic ecosystems.

The gradual occupation of the land exposes habitats, ecosystems and sensitive communities to the impact of artificial light at night, in addition to the direct effects of atmospheric pollution that reduce the quality of the night sky. Our current knowledge of the full gamut of ecological consequences arising from the loss of night sky quality is still very limited. It is essential that we become more aware and accept responsibility for the need for further research and for the development of scientific methodology capable of evaluating the scope of these phenomena.

Currently, there is an abundance of information about the effects on certain migratory species guided by starlight, or about such obvious phenomena as the mass deaths through dehydration of turtles disorientated by the lights of the very beaches where they were born. But the spread of artificial night into natural surroundings has other repercussions that are less known or less obvious. Particularly significant is the alteration of the decline and increase of marine plankton, which affects the marine food chain, or the adverse effects on the population balance of many species, resulting in disruption of consequence to numerous nocturnal insects and the balance between predator and prey.

Preserving nature in its entirety entails conserving 'landscapes of natural light', particularly at night. A 'landscape of natural light' is typified by the influence of natural light from the sun and lunar cycles, clear air and dark skies undisturbed by artificial light. The inclusion of dark skies as a feature of the protection of night-time landscapes is a vital resource for their maintenance and preservation, and contributes to enhancing visitor experience, in addition to opening up new scenarios for the natural sciences.

Protected natural areas should by definition be special areas for the development of initiatives for the protection of natural light at night. Particularly noteworthy is the role as laboratories for preserving the night sky that can be adopted by such emblematic areas as those included in the World Network of Biosphere Reserves, National

Parks, and World Heritage and Ramsar Sites. They are all capable of generating new scientific knowledge and advanced management systems based on light-related factors that affect night time and the preservation of biodiversity.

The astronomical quality of an observatory is largely defined by the clarity of its skies and the number of useful observation hours per year. This is closely tied up with the weather conditions of the place and its geographical features, as well as the absence of adverse factors that hinder observation. Sky quality criteria for astronomical observation substantially reduce the number of suitable places on the planet, which inevitably means that such areas must necessarily be considered a scarce resource that requires preservation.

EFFECTS OF LIGHT POLLUTION ON HUMAN HEALTH.

The usage of sources of artificial light after sundown has enabled humankind to carry out tasks and enjoy numerous activities for much longer. In fact, light at night has become so common that in many parts of the world true darkness is virtually disappearing. Biomedical scientists have realized that exposure to light at night also affects human and animal physiology. When night-time light is of sufficient intensity and suitable wavelength (blue), it is converted into an electric signal that travels to the central nervous system. This signal alters the biological clock and eventually the melatonin production of the pineal gland. Melatonin, which is exclusively secreted at night, has several important functions that are lost during exposure to light at night. These actions include synchronizing and regulating the sleep-wake cycle, circadian rhythms, and so forth.

Thus, a reduction in melatonin levels through exposure to light at night sends signals to many organs informing them that it is day, when in fact it is night, resulting in a physiological readjustment. This distorted information can have more serious consequences than a slight feeling of discomfort. The physiological changes stemming from light pollution can, in the long-term, become physio-pathological processes that could lead to disease. For example, an increase in the risk of cancer has been detected among individuals who are exposed to excessive light repeatedly or for lengthy periods, as occurs with night-time shift work.

Aside from the risk of a higher frequency of tumours, owing to the multiple actions of melatonin as a neutralizer of free radicals and wide-spectrum antioxidants, depriving the body of this important substance can contribute to the onset, progression and severity of several diseases. Many debilitating diseases, especially in the elderly, include the accumulation of oxidative damage due to free radicals as part of the degenerative process. It is evident that exposure to light at night should be avoided whenever possible because of its effectiveness at depriving the body of pineal melatonin.

Unfortunately, avoiding night-time light is not very feasible in this modern world. Accordingly, several more practical

alternatives would entail developing light sources to exclude the specific wavelengths that inhibit melatonin synthesis, producing spectacles or contact lenses to filter out such wavelengths and manufacturing lampshades or shields that would reduce the amount of light transfer.

The basic message is that any factor that will limit the circadian pattern of endogenous melatonin production, such as nocturnal exposure to light, can generate countless consequences as regards disease and the ageing process. The abuse of light must not be disregarded because, potentially, it can contribute to disease in young people and lead to increased weakness and disease in the elderly.

Source: *Juan Antonio Madrid Pérez,*
M.ª Ángeles Rol de Lama
Chronobiology Laboratory
University of Murcia, Spain

10. FINAL REFLECTIONS

Over and above the unquestionable cultural, educational and scientific value that astronomy represents, as well as the capacity to access starlight, we must concede that the impact and benefits it currently brings are not, generally speaking, sufficiently acknowledged or valued. Many of the great advances in the development of communications, navigation systems and even advanced medical imaging technologies must be attributed to the evolution of modern astronomy.

For several years now, we have begun to notice that the clarity of the sky also plays a vital part in conserving the biodiversity of natural ecosystems. We generally forget that more than half of all living beings are nocturnal, and therefore the diminished quality of the night sky will progressively and unpredictably affect the balance of the biosphere.

The right to observe the stars and a clear sky is something that goes far beyond guaranteeing the development of science or personal enjoyment. It also entails a commitment to conserving the environment and the chance to profit from the cultural, economic and technological benefits that it continuously provides. When all is said and done, it is also a commitment to future generations.

Source: *Starlight2007.net*