Austrian Guidelines for OUTDOOR LIGHTING

Light that does more good than harm

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FOREWORD

This guide is intended to support the planning of environmentally friendly outdoor lighting and applies to every federal province (Land) in Austria. It provides comprehensive information on the effects of artificial light in outdoor spaces and makes suggestions for efficient lighting that is also friendly to people and the environment.

For a long time, artificial lighting was implemented according to the motto "more light": more light on streets and squares, more light on facades, more illuminated advertising, brighter interior lighting, expansion of sports facility lighting and so on. This "more light" was intended to increase your sense of well-being and convey a feeling - although often merely an illusion - of "more safety".

In recent decades it has become increasingly clear that there is also "too much of a good thing", i.e. an excess of artificial light. New scientific findings clearly show that artificial light of the wrong quality and intensity at the wrong time and in the wrong place can cast a grave shadow:

the living conditions of many animals and plants have changed as a result. Also the day-night-rhythm of humans has become out of balance, frequently leading to health disturbances. Road users are dazzled and distracted. Energy is sent unused into the atmosphere and the starry sky can only be admired in remote areas.

The goal is "better light" - which helps us to see better without dazzling, to conserve health, to ensure traffic safety, not to unnecessarily brighten up the environment, not to disturb the animal world, and to save energy.

Better light is easy to implement and has advantages for everybody.

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1

EFFECTS OF ARTIFICIAL OUTDOOR LIGHTING

1.1 The human being

1.1.1 Physiology of the eye

Conscious optical perception is regulated in the retina of the human eye by different sensory cells. The rod cells recognize only black-and-white contrasts, are very light-sensitive and thus responsible for "night vision". Only at high light intensities does colour perception begin. This is ensured by different cone cells, each of which is sensitive to one of the basic colours red, green and blue and whose concentration is greatest in the macula, the point of sharpest vision.

The sensitivity for the various wavelengths is not distributed homogeneously over the **spectrum** of visible light; the highest **sensitivity** (under photopic conditions) is achieved in yellow-green (**Purkinje shift** in twilight (**scotopic**)). Sensitivity decreases towards the short-wave blue range as well as towards the long-wave red range.

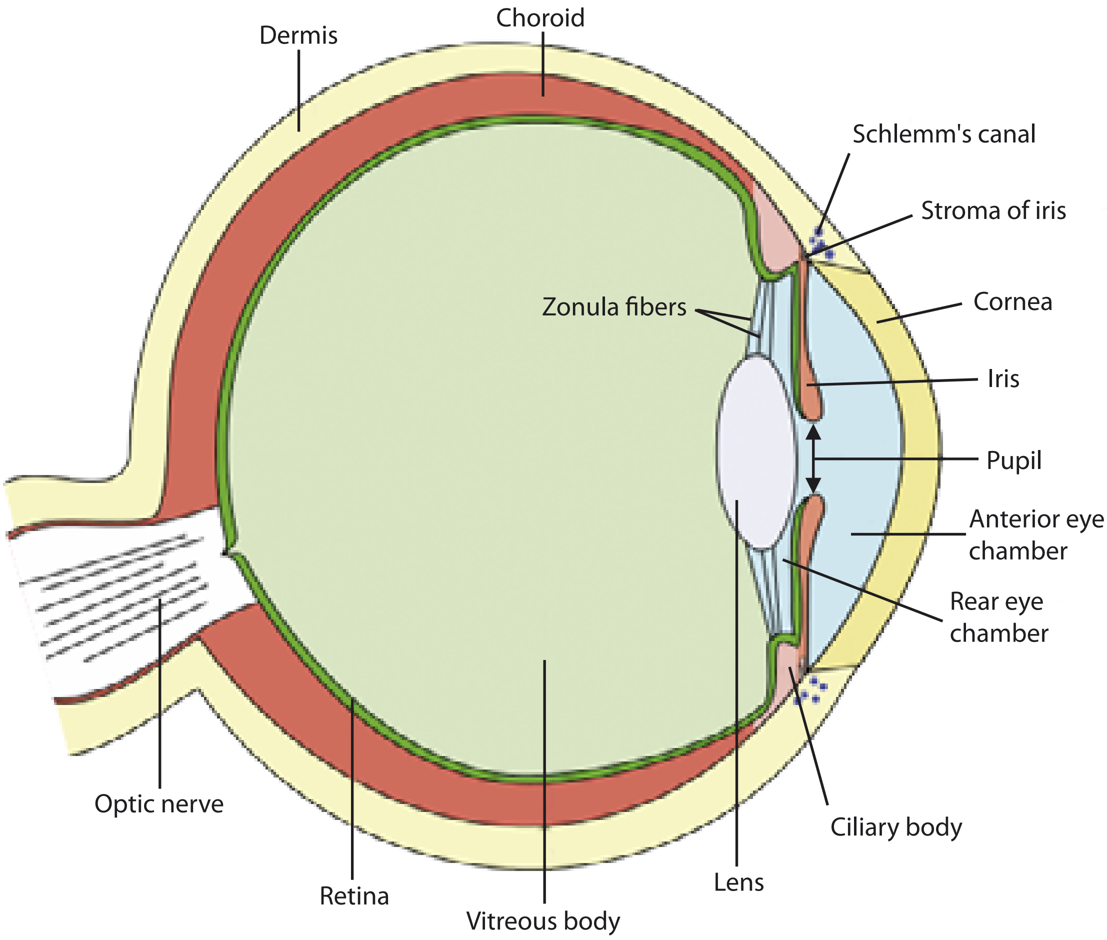


Fig. 1: The human eye

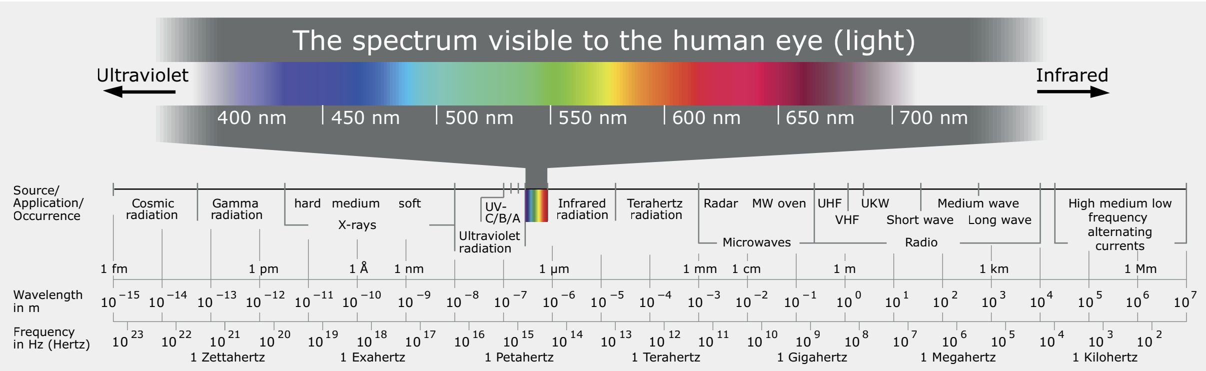


Fig. 2: Visible spectrum

In addition to the receptors responsible for vision, the retina also consists of many other cells. Particularly noteworthy are light-sensitive ganglion cells (intrinsically photosensitive retinal ganglion cells - ipGRCs). Their maximum sensitivity is between 460 and 480 nm [1, 2]. They react more slowly to light and serve, among other things, to perceive brightness. They are involved in regulating the release of melatonin and are thus responsible for controlling day/night rhythm, which is why they are also referred to as "circadian receptors".

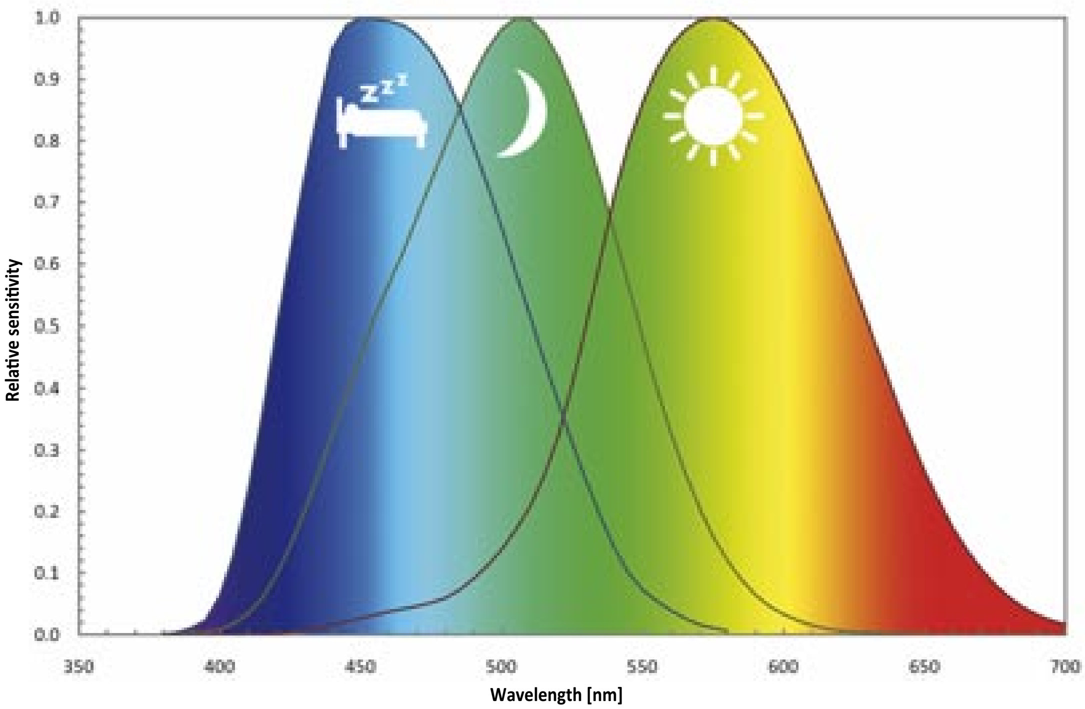


Fig. 3: Sensitivities of circadian receptors for controlling day-night rhythm (left), the rods that are sensitive at night (centre) and the cones responsible for day vision (right)

If the eye is exposed to high intensities of short-wave radiation (e.g. sun or projector), depending on dose, irreversible damage to the retina can occur after only a short time (see phototoxicity). Thus, short-wave light due to photochemical damage contributes to age-related macula degeneration [3].

The sensory cells in the middle of the retina may be destroyed, visual impairments and worse - e.g. central scotoma (legal blindness) - may be the consequences.

A recently discovered photo-sensitive retinal ganglion cell (ON delayed (OND) RGC), a possible "indicator for eye growth in childhood", is making people sit up and take notice. Artificial light spectra deviating from natural (sun) light are suspected to be causal or triggering factors to induce "abnormal overshooting" bulbus growth via "overstimulated" OND-RGCs.

For the first time, this would be an experimentally more reliable and "evidence-based" (EBM) evidence in favour of a myopia "prophylaxis" recommendation: "Increased outdoor exposure reduces or slows myopia growth." [4]

The interconnection of the OND-RGC with retinal structures, such as myriad other types of retinal ganglion cells, which further process the various visual stimuli, their influence on higher visual pathways, centres and cognitive processes and the decoding of their "genetic signature" etc. are being investigated within the framework of an NIH-funded study. The authors hope that this will open up new perspectives with regard to "possibilities of gene therapy to treat blindness and improve the function of artificial retinal prosthetics" [4].

1.1.2 Melatonin and health

Day and night have always determined the rhythm of life of almost all organisms. All body functions - including those of humans - are tuned to this day-night rhythm.

Studies show, however, that in economically highly developed countries, people today spend 95 percent of their lifetime inside buildings and, despite artificial lighting, receive far less light there than outdoors.

During the evening and night hours it is the other way round: artificial lighting, both indoors and outdoors, exposes us to much more light than we have ever had before at any point in our evolution. The result is a seriously negative influence on the physiological day-night rhythm.

Fig. 4: Too much light at night

Fig. 5: Too little light during the day

This so-called circadian rhythm is essentially determined by the hormone melatonin. The release of the hormone produced in the pineal gland during the evening hours is essentially controlled by light: In a nutshell, secretion is suppressed in the case of brightness and secretion is stimulated in the case of darkness. This process is controlled by special cells (ipRGCs) in the retina of the eye, which respond to light - especially to the short-wave region of the visible spectrum with a maximum sensitivity in the range of 460 to 480 nm. That the sensitivity to blue light is highest is probably due to evolutionary reasons and is related to the development of life beginning in water. Just 1.5 Lux at the wrong time can influence the circadian rhythm of humans [5].

However, melatonin not only promotes falling asleep and sleeping through the night, but also influences other functions through its involvement in many different systems:

- Melatonin has an antioxidant effect and thus neutralizes oxygen radicals in the body
- additional circadian functions such as secretion of other important hormones, control of body temperature, blood pressure, heart rate, digestion and much more
- positive effects on memory, learning and emotions through the influence on the hippocampus, a part of the brain belonging to the limbic system
- Growth inhibition of certain hormone-dependent tumours, such as breast or prostate cancer through its antigonadotropic effect
- positive effects on the immune system, especially the release of certain interleukins and the increase in the effectiveness of the body's own "killer cells"
- protective effects with regard to migraine, Alzheimer's and Parkinson's disease are also being discussed.

That is why it is necessary to make sure that the melatonin control loop is disrupted as little as possible in order to avoid negative health effects. However, it must be emphasized that "bad light" or "light at the wrong time of day" is never the only cause of a serious illness, but like many other unfavourable "lifestyle factors" (stress, conflicts at work or in private life, unhealthy food, etc.) it can be a contributor to the development of such an illness. So it is important to try and be exposed to more natural light during the day and to little or no artificial light at night. If artificial lighting is unavoidable at night, care should be taken to minimise light sources emitting at wavelengths between 300 and 500 nm, because short-wave light interferes with the physiological circadian rhythm even at low intensities.

Artificial light with short-wave components should be avoided, as it interferes with the day-night rhythm and inhibits the body's repair processes

Compensation, i.e. "catching up" on the melatonin production missed or hindered at night time during the day or by using medical therapies is problematic or even impossible.

There is a danger that the body functions of humans will adapt to "too much artificial light" in the evening and night hours in such a way that they then actually need these conditions. This getting used to artificial light could have epigenetic consequences for future generations.

1.1.3 Glare

The human eye has the ability to adapt to very different light intensities - dark or light adaptation. The adjustment range covers about twelve powers of ten (i.e. 1 to 1,000 billion). The adaptation from dark to light takes place quickly, whereas the adaptation from light to dark takes up to 30 minutes.

The German word for glare - blenden - literally means "to make blind". Glare is not only caused by light that is too bright, but also by large differences in brightness. When a light source with a high **luminance** becomes visible at night, the eye cannot adjust to this light source and at the same time to the much darker environment. As a result it adapts to the higher luminance of the dominant light source. At the same time, the scattering of light from this dominant light source draws a haze over the entire field of vision. Light scatter (especially with short-wave light) causes a "veil of light" to cover the entire field of vision, which impairs the quality of sensitive perception.

Frequently, severe glare occurs, which in extreme cases can cause pain thresholds to be exceeded. Weaker but irritating glare causes distraction and may mean that less bright objects are overlooked.

With advancing age, the lens of the eye becomes cloudy, incident light - especially blue light - is scattered more strongly, which also increases the susceptibility to glare. The recovery time of the retina after "light stress" becomes longer, not only due to increasing age, but also due to existing light damage. In view of our ageing society, it is particularly important that we minimise the causes of glare.

The **disability glare** is much stronger in blue/cold white light than in the red wavelength range, which is why, for example, the German Radiation Protection Commission recommends minimising the proportion of blue light when developing new light sources.

Fig. 6: Glare

Glare is caused by excessive luminance levels and high light-dark contrasts. If human visual perception is interrupted even just for an instant, it can have fatal consequences in terms of road safety, for example.

1.1.4 Road safety

Glare is a particularly serious problem in road traffic. If the eyes have become accustomed to night-time visibility, bright light dazzles and impairs visual perception. The human eye also needs a few seconds to re-adapt and restore partial perception when passing from bright zones to dark zones. On wet roads, glare is significantly increased by countless reflections.

LED screens, car headlights, side lights used during daytime, street lighting that does not meet safety standards, warning lights and traffic lights, etc. can cause visual impairments, glare, adaptation disturbances, confusion and distraction. This can cause loss of perception, so that pedestrians, traffic signs or obstacles are overlooked.

Non-traffic visual information transmitters (**VIT**), e.g.advertising installations, must neither dazzle nor distract, because otherwise they could seriously jeopardise road safety.

The measure for the brightness of a VIT is its luminance. The maximum permissible luminance of a VIT depends on its size and position in relation to the road and is defined in the guidelines issued by the Austrian Research Association for Road and Rail Traffic (FSV) RVS 05.06.12 and the criteria for their operation in RVS 05.06.11.

Road safety is impaired, for example, if the displays are too bright and dynamically distracting and are located in a position so as to visually obstruct traffic signs and are of an inadmissible size or colour.

The authorities can assess whether an impairment is contravention of the road laws and if necessary advise the operator to change, move or remove the (advertising) system in order to eliminate the impairment of traffic safety.

Fig. 7: Illuminated advertising in Times Square, New York

Whether more or brighter street lighting leads to a reduction in traffic accidents is a controversial issue, but is one that cannot be supported by scientific results [6, 7, 8, 9]. The same applies to daytime running lights. Such stimuli can distract in road traffic, cause irritation and glare.

Every "traffic-relevant" object deserves exactly the same amount of attention; the over-accentuation of a selected group increases its visible presence and inevitably reduces that of all others.

1.1.5 Crime

The argument often put forward for the need for artificial lighting in outdoor areas is that more light provides more safety. However, there are hardly any straightforward studies that confirm a correlation as simple as "more light equals more safety". In many illuminated environments the subjective sense of safety may be higher, but this does not mean a lower crime rate in bright places (some case studies even prove the opposite: more light leads to more vandalism).

In most cases, there is only localised repression of criminal acts, but no overall changes due to changed lighting. In addition, there is no doubt that not every type of lighting increases our subjective sense of safety. Only glare-free lighting and lighting adapted to the intended purpose and **illuminance** support our vision, while dazzling light is disorienting.

Illumination of private buildings

Statistics from Great Britain show that 48 percent of more than 284,000 properties that were broken into had exterior lighting[10].

A further study[11] shows which factors prevent break-ins efficiently:

- the appearance that someone is at home in the building targeted for burglary: 84 percent
- alarm systems: 84 percent
- visible surveillance cameras: 82 percent
- appearance of secure windows and doors: 55 percent [10]

Outdoor lighting, on the other hand, was not mentioned by respondents as a burglary prevention factor. So if lighting is to be used at all, it makes more sense to leave a small light switched on inside a house than to use powerful "security lighting" installed on the outside or even to rely on nearby street lamps as a deterrent.

More light outdoors does not necessarily mean more security against burglary or vandalism.

1.2 Fauna, flora & ecosystems

For insects, birds, amphibians, reptiles, fish, crustaceans, mammals, plants and ecosystems there is already scientific evidence of the influence of artificial light. The effect on organisms depends mainly on the spectral composition of the light and the intensity of illumination.

Animals active during the day that are disturbed during their resting phase have a problem with night illumination, but so do nocturnal animals that are dependent on darkness to live normally. The species-specific activity phase makes it easier for the animals to detect mating partners or animals of prey and avoid others competing for food or predators. Around 30 percent of vertebrates (mammals, birds, amphibians, fish, etc.) and more than 60 percent of invertebrates (insects, spiders, crabs, etc.) are nocturnal[12].

The following functions are compromised:

- orientation
- predator-prey relationship
- searching for food
- radius of action (habitat fragmentation, barrier effect and displacement)
- rest phases
- social interaction (development and propagation)

Not only humans, but also birds, fish and mammals produce the hormone **melatonin** during the dark evening hours that plays a role in a number of life functions. Artificial light can also inhibit melatonin synthesis in animals. Generally the day and night sequence as well as the seasonal change of the day length is an important timing element for the synchronisation of daytime and seasonal rhythms in the bodies of many living beings. The shortening of daytime announces that winter is coming and insects enter the diapause - for example caterpillars pupate. If the length of the day is extended by artificial light, they are prevented from entering the hibernation stage [13, 14]. This may prevent local insect populations from surviving the winter.

In summary, both localised effects (e.g. direct attraction of moths by a light source) and overall effects (e.g. effects on the day-night rhythm of songbirds) are essential in assessing the effects of night lighting on natural habitats and individual species. Particularly endangered are species that are confined to isolated habitats and occur in small populations.

1.2.1 Insects

With around 75 percent of all animal species, insects are the most diverse and prolific animal group on our planet. About 85 percent of all butterflies in Austria are active at night. Insects perform key functions in their respective ecosystems. They are irreplaceable for supporting ecosystems with duties such as plant pollination and as a food source for other animals. Falling population numbers, the decline in species diversity and the dispersion of moths have already been observed in some European countries [15, 16, 17].

At the ecosystem level, lighting systems can lead to permanent changes in insect communities [18]. A driving force behind this decline is the increase in light pollution.

The consequences of the attracting effect

- The empty trap effect: Artificial light can lead to the withdrawal of the entire insect population from a habitat. The extinction of individual isolated populations can be the consequence.
- Lack of insects as food basis: Nocturnal insects are a food source for bats, amphibians and nocturnal mammals. Larger butterflies and caterpillars also make up a considerable part of what birds eat[19, 20]. The insects attracted by artificial light are missing in their ancestral habitat as a food basis, which in turn has an effect on the population strength of their predators.
- Lack of nocturnal insects as pollinators: During the dark half of the day, moths pollinate a number of different plant species and play an important role in maintaining biodiversity. The most frequently examined butterfly-flower interactions have been attributed to the families of the owlet and hawk moths[21, 22]. If the moths are absent, the plants have no pollinators and are also decimated.

The numerous insect species that travel during the dark half of the day use the stars and the moon for orientation. Artificial light sources attract nocturnal insects. Single illuminated advertising or building illuminations can attract hundreds of thousands of insects every night. Depending on the type of insect and the lighting system, the attracting effect can reach several hundred metres.

If they get too close to the light sources, they are usually forced to buzz around the lamp until they die of exhaustion. It has been observed that different insect species are attracted depending on the spectral composition of the light source. The perceptive faculty of night moths, for example, ranges from the short-wave ultraviolet into the **infrared** range, although the greatest attracting effect is generally found in light sources which emit ultraviolet and short-wave radiation[23-28].

Lamps with UV and a high blue component in the emission spectrum should be avoided because moths are particularly sensitive to them.

Fig. 8: Moths buzzing around a lamp

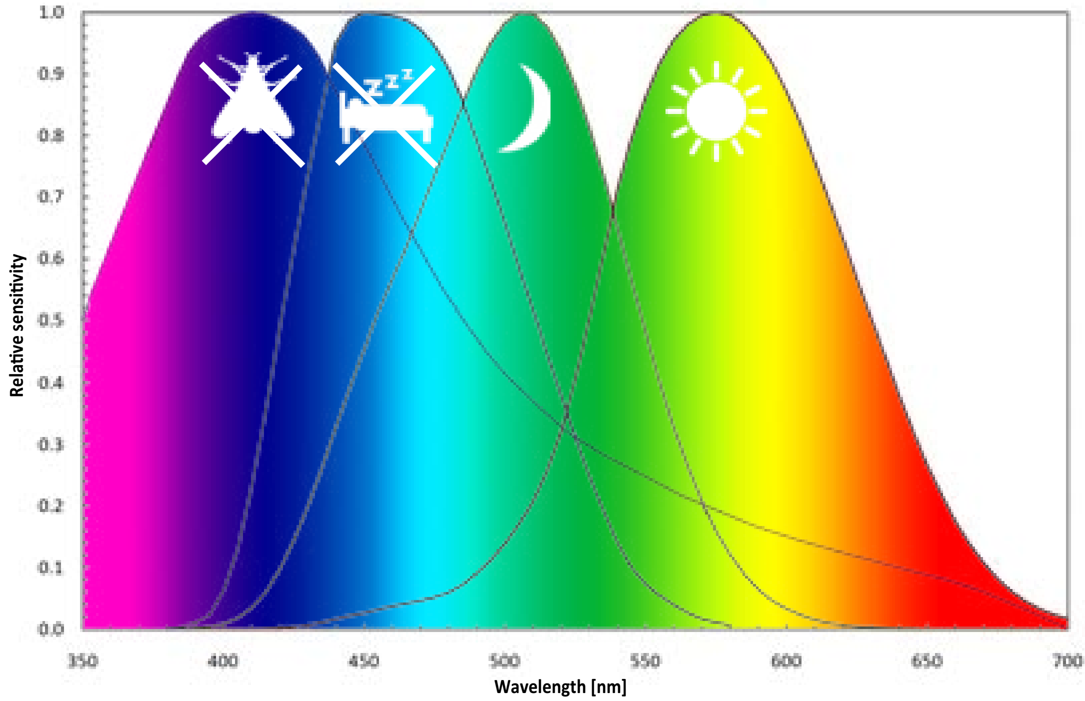


Fig. 9: Sensitivities (from left to right): moths, human circadian receptors, rods and cones of the human retina

1.2.2 Birds

Bird migration

Artificial light at night is able to change the behaviour of birds, it can have a deterrent or disorienting effect on some birds, while other species use illuminated areas as hunting grounds or are attracted to light.

About two-thirds of migratory birds migrate at night and use the Earth's magnetic field as well as the starry sky as a compass. Particularly in bad weather conditions such as strong headwinds, fog, drizzle, snowfall or low-hanging clouds, points of light or large illuminated areas can cause birds to become disoriented. Birds cross the Alps in what is called broad front migration. Along the edge of the Alps - in valleys and at mountain passes - bird migration can become more concentrated, which is why illuminated ruins, castles, mountain huts, summit crosses, ski slopes and other light installations have a critical affect at these locations.

The higher the structure and the more exposed the location, the more likely the illuminated object is to be a trap for migratory birds.

Fig. 10: Many bird species are misled by artificial light

Most migratory birds show the following behavioural characteristics in artificial light: They reduce flight altitudes, change flight direction, turn round, reduce speed or circle the light sources and can collide with structures and die. Many land exhausted on the ground nearby and become victims of predators or die of exhaustion and stress after hours of aimless flight. A one-year investigation of the 160 m high illuminated Post Tower in Bonn proved that over one thousand birds from 29 species were drawn in by the lights; approx. 200 of them were killed immediately on impact, while others were injured. Examples from Germany, Switzerland and other countries have recorded the death of thousands of migratory birds during the main migration periods in August to November and February to May. These deaths can have significant effects on the populations of each bird species. There are also considerable energy losses, which have a negative effect on the next migration[29-42].

Warning lights in beacon mode (flashes at least 3 seconds apart) on tall buildings or for air traffic control are less attractive for migratory birds than permanent lighting, rotating light and flashing light [32, 33, 43-45].

Disturbance of the daily and seasonal rhythm

If the day-night rhythm is disturbed by artificial light, this can have stress-related effects on animals. A low illuminance of 0.3 lux is already sufficient for this. Many bird species like robins, blackbirds, coal tits and blue-tits begin their dawn chorus earlier in the year and earlier in the morning.

The consequence is earlier breeding, foraging and development. This altered behaviour is attributed to changes in the hormone balance, with impairments in terms of fitness and life expectancy likely [33, 46-52].

1.2.3 Mammals

Bats

Approximately 69 percent of mammals are nocturnally active and a third of them are bats[53]. Bats are among the most endangered animal species and are protected in accordance with the European FFH (Flora Fauna Habitat) Directive and state nature conservation laws. Bats navigate using echolocation, but also have light-sensitive eyes.

If access to roosts is illuminated, for example in a church roof, the female bats fly out later than normal.

This reduces the active time available for searching for food - with possible consequences for reproductive success because the young remain behind and wait for their suckling mother. There are also known cases in which bats have abandoned their quarters after lighting has been installed. The negative effects apply mainly in the summer months, since they use other quarters in winter.

Access openings in roof trusses used by bats during summer must not be illuminated.

Some bat species such as the dwarf bat or the noctule bat can be seen hunting nocturnal insects in the glow of street lanterns. However, many species of bats avoid light. For example, horseshoe-nosed and mouse-eared bats are driven away by artificial light, resulting in habitat restriction and food reduction for these species [53-59].

Fig. 11: Many bat species are disturbed by artificial light

Small mammals and game

Studies show that small rodents such as mice and also hares limit their activity and foraging at high illuminance levels and their habitats are reduced in size [60-62].

A negative effect on the resting and recovery phase of game can also result from the use of light. This is particularly relevant in winter, because if red deer are disturbed when they take their daily rest, they suddenly need much more energy.

The consequences are increased damage to young trees, weaker animals, leading possibly to death. Even if artificial light does not directly disturb game, the noise emission associated with night time operation (ski lifts, slope preparation, etc.) can have an adverse effect in the case of ski slope lighting, for example.

Fig. 12: Game disoriented by artificial light

1.2.4 Aquatic species with wetland habitats

Amphibians

Due to the increasing fragmentation and destruction of their habitats, amphibians are among the highly endangered animal groups. The "frog concert" every evening during the reproductive period makes it clear that they are predominantly active at night. Amphibians often avoid daylight to protect themselves from predators and dehydration.

Artificial light can be their downfall, because frogs and toads profit from the insects attracted by artificial light. However, if they dwell in the vicinity of lights, they themselves easily become victims of road traffic or predators. In addition, their vision is overloaded, frogs sometimes need hours to get used to the darkness again[63].

There are indications that nocturnal artificial light also hinders or impedes migration to spawning grounds and thus reproduction.

Fig. 13: Frogs often become victims of artificial light

Fig. 14: Fish react sensitively to artificial light

Fish

Artificial light at night influences the hormonal balance of fish, which in turn has an effect on growth and reproduction. The migration behaviour can also be impaired by artificial light, illuminated bridges can act as barriers. Many species of fish are attracted by artificial light, which is used in commercial fishing. But most fish larvae and young fish avoid light[64].

Zooplankton-Phytoplankton balance

Zooplankton is a diverse group of microorganisms that live in water. Under natural conditions, the organisms rise to the surface of the water at night and feed on algae. During the day, the zooplankton, which also includes water fleas, can be found in deeper water layers.

If this daily vertical migration is disrupted by light smog in the city or illuminated promenades along the bank, this can lead to an algae bloom - increased growth of phytoplankton - and thus to a deterioration of the water quality[64, 65].

Wetland habitats and water bodies are sensitive and endangered; they are home to a large number of rare animal and plant species. The use of artificial light in the immediate vicinity should therefore be avoided or at least reduced to a minimum.

1.2.5 Plants

Plants react to the natural length of the day (photoperiod), their growth and development are linked to it. Shorter days in autumn, for example, stimulate bud growth in woody plants for the next season. Longer days in spring and summer induce flowering in many wild plants of our latitudes.

So plants are also affected by an increase in artificial light at night. For example, it is known that trees or individual branches illuminated by street lights lose their foliage later, leading to frost damage and weakening of the tree[66]. If plants are constantly exposed to light, they become more susceptible to disease. Artificial lighting at night, for example, leads to increased sensitivity to ground-level ozone and consequently to leaf damage[67].

Fig. 15: Illuminated trees in a park

Pests, beneficial insects and pollinators of plants can also be influenced by artificial light. As already mentioned in the "Insects" chapter, some plants depend on nocturnal partners for their pollination. If pollination does not take place, this can lead to a change in the composition of vegetation and even to the loss of species. In particular, those plants are affected that rely on individual insect species for pollination.

Most of the plant families studied, which are pollinated by moths, belong to the orchid family and the carnation family. For example, *Platanthera bifolia* (the lesser butterfly orchid) and *Silene vulgaris* (bladder campion) are referred to as moth plants in German (Nachtfalter-pflanzen)[21].

1.3 Night landscapes

The effect of night landscapes relies on the absence of artificial light both from landscape elements as well as from the deep shade of structures. Visual perception diminishes while other senses such as the sense of hearing and smell are heightened - this dimension is also a component of the night landscape. Finally, the visibility of the firmament and phenomena such as the moon, shooting stars, comets or the Milky Way are a fascinating and essential part of the nocturnal landscape. The night landscape was and remains mysterious for us human beings; its character and its characteristics are unique and identity-giving.

If used excessively, artificial light can disfigure the landscape at night. If attention is drawn to individual lights such as sky beamers or illuminated buildings and structures such as fortresses, chapels or ski slopes, the experience of the night landscape is significantly reduced. The domes of light that envelope cities and regions at night make an average of 90 percent of the stars visible to the naked eye disappear. When it's cloudy, the sky brightness in urban areas can rise tenfold. Measurements show a rapid and exponential increase in the brightening of the night sky - depending on the location - from two to eight percent annually. Already 83 percent of the world's population and 99 percent of Europeans live under a sky polluted by artificial light. For 60 percent of Europeans, the Milky Way remains hidden[68-70].

The atmosphere scatters blue light much more strongly than red light, which is why a cloudless sky is blue during daytime (Rayleigh scattering). Blue or cold white light sources are therefore highly effective light polluters and should be avoided wherever possible.

Fig. 16: Light-polluted night landscape

Nature deficit syndrome is a term that describes disturbances caused by the weaning of humans from nature (including physical impairments such as vitamin D deficiency due to insufficient exposure to sunlight). Among other things, nature is not only the natural night landscape but also the starry night sky, which makes us aware of the limitations of our planet's natural resources. The absence of the experience of nature leads to a lack of empathy for the necessity of preserving living spaces and, subsequently, to the destruction of one's own basis for life[71].

Organisations such as the Royal Astronomical Society of Canada (RASC), the International Dark Sky Association (IDA) in the USA and the UNESCO Starlight Initiative based in the Canary Islands have launched programmes and awards for the protection of the night sky and the natural night landscape. Objectives are the protection of the nocturnal habitat, saving energy through intelligent lighting, awareness of how artificial light is used and appreciation of the starry sky and the night landscape by accompanying programmes. Light protection areas or star parks are particularly interesting from a tourism point of view, and soft tourism can benefit more from them in the future. Especially in the Alps, there are areas where the sight of the starry sky on a clear night is breathtaking. In many countries (e.g. Germany, Great Britain, Hungary) there are already areas in which the night sky has been especially protected for some years. In the Weinviertel, not far from Vienna, there is the stargazers' footpath "Großmugl on the Milky Way" which is an innovative tourist attraction that has attracted worldwide attention among experts. The theme trail was designed in 2014 by project night-flight in close cooperation with the market town of Grossmugl (www.sternenweg-grossmugl.at). The project has been submitted for an award as a UNESCO "Starlight Oasis".

1.4 Astronomy

Since the introduction of artificial lighting over 120 years ago, astronomers have recognized the problem of light pollution. Particularly in observatories located within built-up areas where it has become more and more difficult to observe the night sky and more and more observatories have relocated to rural areas. Meanwhile, professional astronomers are forced to set up their observatories on remote mountain peaks. The largest telescope in the world is located at an elevation of 2600 metres in the Atacama Desert in Chile. Legal regulations in Chile and other countries with astronomical observatories ensure that no more artificial light is emitted in the vicinity of these facilities than is absolutely necessary.

Fig. 17: Observatory in the countryside

The night sky is the "window to the universe", through which we can look into our galaxy. Our ancestors saw the same night sky thousands of years ago. In many cultures it was used for navigation, inspired artists and numerous myths were conjured up as constellations of stars in the night sky.

Fig. 18: Summer Milky Way over the Tauern wind farm (Styria)

1.5 Energy consumption

Today, electrical energy can be converted into light very efficiently. With relatively little electricity, which is also comparatively inexpensive, a lot of artificial light can be released - which in turn leads to the wasteful use of artificial light.

Instead of generating the same amount of light with less energy, more light is generated with the same amount of energy (rebound effect).

Lighting accounts for 19 percent of electricity consumption worldwide, compared with 16 percent in the EU. Of this, 80 percent is accounted for by industrial and office lighting, illuminated advertising and street lighting, etc., 20 percent by private household lighting. Street lighting alone accounts for one to two percent of electricity consumption in the EU (with exact percentages varying from country to country). At municipal level, however, street lighting accounts for up to 45 percent of public electricity consumption[72]. And about a third of the energy is wasted with conventional street lighting and old technology, because this proportion of light does not land where it is needed. It is estimated that around five billion kWh per year is wasted on street lighting across the EU in this way (e.g. 843 million kWh in the UK alone[10]). In Austria, the energy lost is assumed to be in the order of 100 million kWh per year, in other words 15 million Euro (assuming 0.15 Euro/kWh) or 19,500 tons of carbon dioxide. The value is many times higher if you add private lighting and illuminated advertising.

Optimised lighting in many places not only guarantees lower power consumption and lower costs, but also lower carbon dioxide emissions. Excessive carbon dioxide in the atmosphere promotes the greenhouse effect, which accelerates global warming. Carbon dioxide is created during the production, operation and disposal of all products that are necessary for the generation of light. Lighting thus indirectly produces thousands of tons of this greenhouse gas every year. The power consumed during operation is easy to measure and compare. Carbon dioxide is emitted during the generation of electricity, especially in the combustion of non-renewable energy sources. On average, Austria's electricity consumption creates approximately 195 g of carbon dioxide per kWh generated. According to the UCTE mix, the figure for the whole of Europe is 432 g of carbon dioxide per kWh generated.

Using lighting sensibly and efficiently makes a valuable contribution to protecting the climate.

Fig. 19: Light directed upwards wastes energy

2

LAWS AND STANDARDS

The majority of issues relating to lighting are currently not covered by law in Austria. However, there are standards that set certain minimum criteria for lighting as well as for preventing undesirable interference from artificial light. Standards are recognised "technical rules", which are particularly important in areas where laws only lay down rough guidelines.

The European EN 13201 series of standards is currently used in a total of 28 European countries for the planning of public lighting - especially street lighting. Parts 2 to 5 were updated in 2016, while Part 1 "Selection of lighting classes" does not apply to the whole of the EU because the member states were unable to agree on a common Part 1. In Austria, Part 1 is replaced by ÖNORM O 1055"Street lighting - Selection of lighting classes - Rules for the implementation of CEN/TR 13201-1".

The Austrian standard ÖNORM O 1051 is the national supplement to EN 13201. ÖNORM O 1051 contains specifications for the lighting of so-called conflict zones (protected paths, cycle crossings, roundabouts, car parks, etc.).

An important basis is provided by Austrian standard ÖNORM O 1052, "Light immissions - Measurement and assessment", which came into force in autumn 2012. This standard does not deal with a specific type of lighting, but more generally with how artificial lighting can be designed in such a way that glare, illumination of space, environmental illumination, sky illumination, etc. can be avoided as far as possible. In short: ÖNORM O 1052 is about how to prevent light pollution.

Key points have been taken from ÖNORM O 1052 and the other standards mentioned above and incorporated into these guidelines.

The following standards and directives have also been taken into account:

- ÖNORM EN 12193 "Light and lighting - Lighting for sports facilities"
- ÖNORM EN 12464 "Light and lighting - Lighting of workplaces" - Part 1 Indoor work places and Part 2 Outdoor work places
- RVS 05.06.11 and RVS 05.06.12: These guidelines and regulations applying to roads describe, among other things, limit values and criteria for minimising the negative impact of light on road users (e.g. glare from illuminated advertising).

These guidelines are not intended to replace any of the standards mentioned above. The main purpose of these guidelines is to provide information on lighting that is compatible with the environment and our health and to give recommendations for action.

3

LIGHT SOURCES

3.1 Light sources for outdoor lighting

Since the 1930s, gas discharge lamps have mainly been used in outdoor lighting. Light is produced by a gas plasma and an electrical ballast is needed to operate the lamp. Technically, a distinction is made between low-pressure and high-pressure discharge lamps.

At the beginning of the 21st century, an entirely new light source made of semiconductor material became commercially available: the LED or Light Emitting Diode.

Today, LEDs have replaced gas discharge lamps in many areas of street and outdoor lighting. The incandescent and halogen incandescent lamps still widespread in domestic indoor lighting have always played a subordinate role in outdoor lighting.

In this chapter, we will be looking at light spectra, efficiency, and the pollutant content of modern light sources.

3.2 Spectra of modern light sources

3.2.1 Fluorescent lamps and compact fluorescent lamps

Fluorescent lamps and compact fluorescent lamps are technically low-pressure mercury discharge lamps. Following ignition of the lamp, the mercury gas mixture of the flourescent lamp emits mainly ultraviolet and a little bit of blue radiation. In order to produce white light, the glass bulb of the lamp is coated with a mixture of different fluorescent powders which convert the ultraviolet radiation into visible light. The result is a spectrum with pronounced **emission lines** which is perceived by the human eye as white light. **Wavelength** and the intensity of the emission lines depend on the fluorescent powders used, but all mercury low pressure discharge lamps have more or less pronounced lines in the blue spectral range. In terms of environmental compatibility, these light sources need to be assessed individually according to their spectra. Care must be taken to keep the radiation emission in the wavelength range smaller than 500 nm as low as possible. Figure 20 and Figure 21 show typical spectra of different low-pressure mercury discharge lamps. Due to its high emission levels in the wavelength range below 500 nm, the lamp in Figure 20, for example, should not be used for outdoor lighting. Emissions in the wavelength range above 680 nm - i.e. the infrared range - should also be avoided

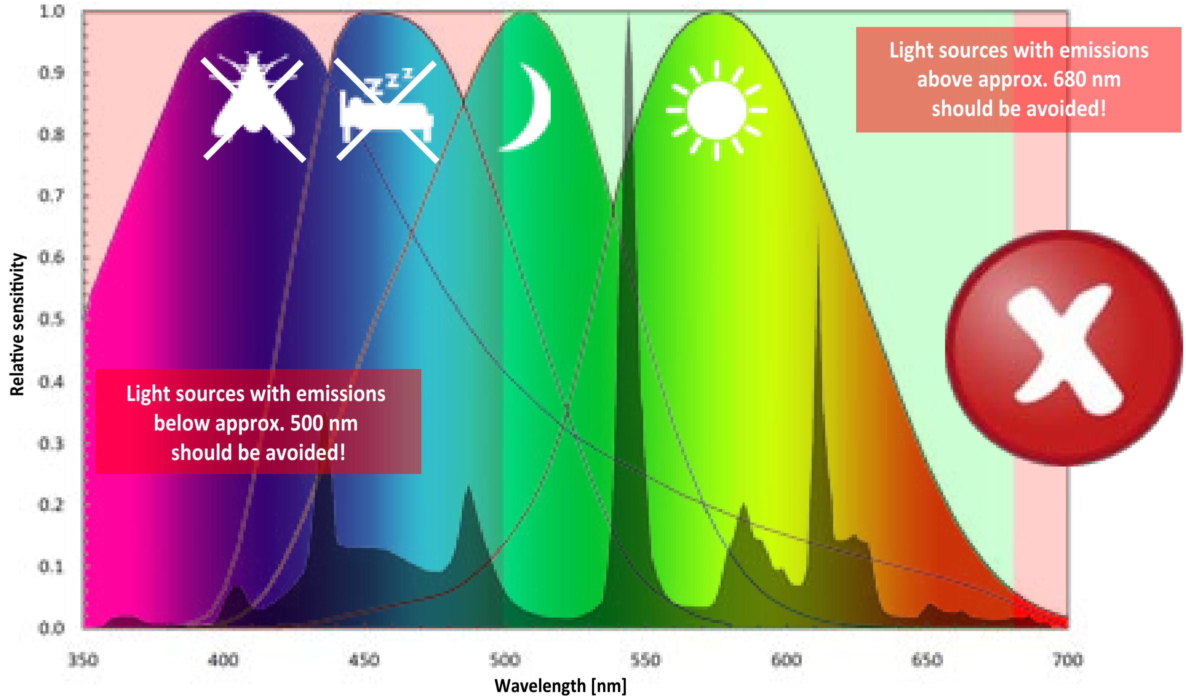


*Fig. 20: Typical **spectrum** of a fluorescent lamp with a correlated color temperature of 5000 K*

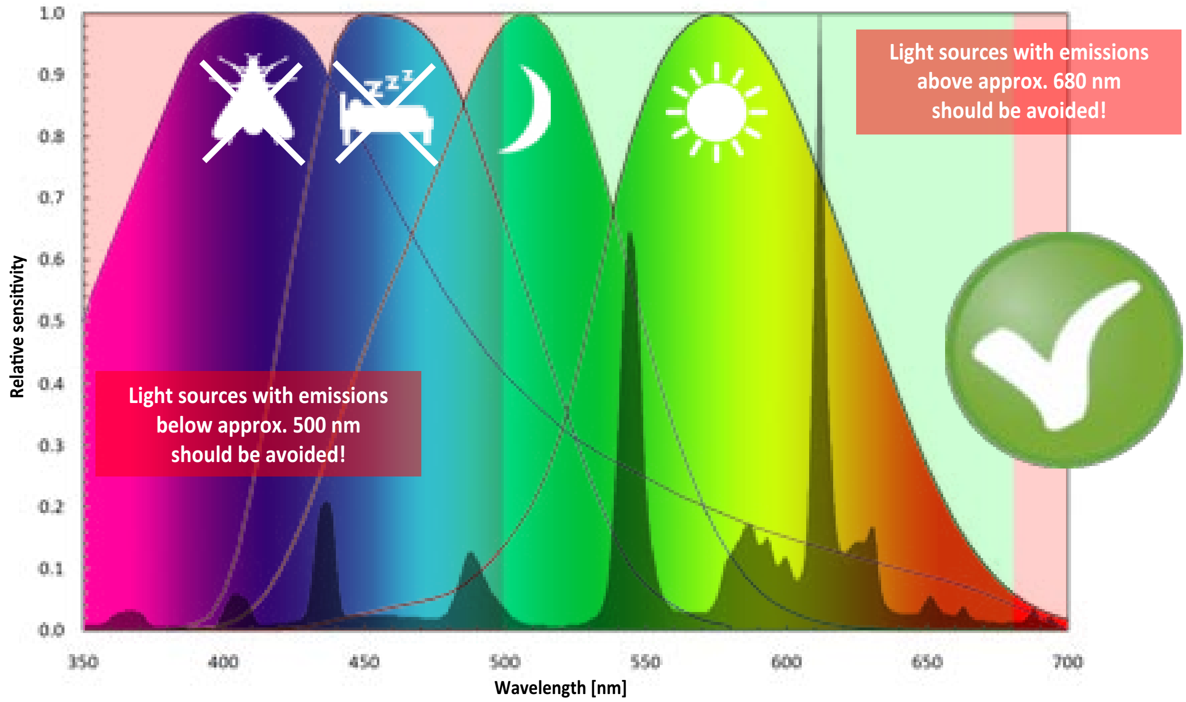


Fig. 21: Spectrum of a fluorescent lamp or energy-saving lamp with a correlated color temperature of 3000 K and a low blue component

3.2.2 Metal halide lamps

Metal halide lamps belong technically to the group of high-pressure mercury discharge lamps. In addition to mercury, there are halogenide compounds and rare earths inside the hot combustion chamber that are also involved in the discharge process and emit their own spectrum. This ultimately results in a spectrum that is perceived by the human eye as white light. Due to the omission of the fluorescent coating, the discharge chamber itself is the emitting surface, which makes these lamps compact and suitable for use in reflector luminaires and floodlighting. Similar to fluorescent lamps, the spectra of these light sources also show distinct emission lines, both in the ultraviolet and in the blue spectral range. In terms of their environmental compatibility, these lamps should also be assessed individually according to their spectrum and should be used with a UV blocking filter. Coloured glass filters (long pass filter starting at 440 nm or 400 nm) are suitable for blocking UV, for example.

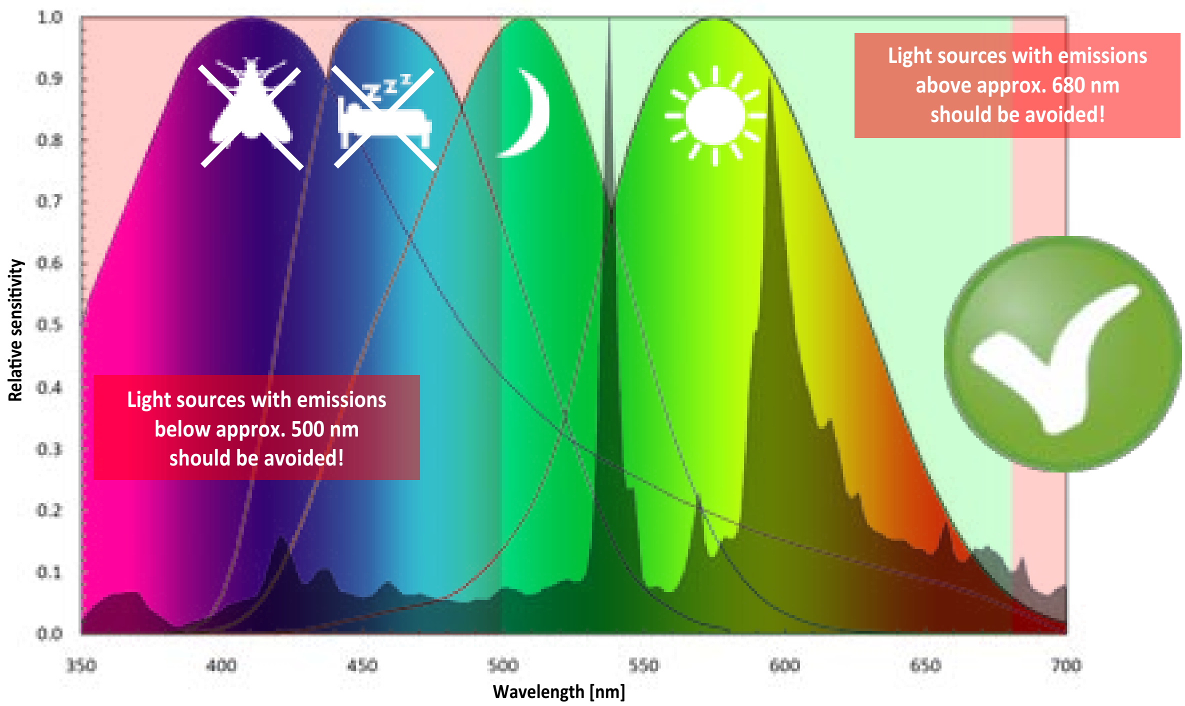


Fig. 22: Spectrum of a metal halide lamp

3.2.3 Light emitting diodes (LEDs)

White light from LEDs

Due to the physical principles of generating light in crystals, a light-emitting diode always emits a very narrow, almost monochromatic, spectrum, which is therefore seen as coloured light. A spectrum that is perceived by the human eye as white light can be achieved either by combining different coloured LEDs or by combining a blue LED with fluorescent material. In street lighting, practically only the latter technology is used. Part of the energy-rich blue radiation of the LED is transformed by a conversion layer into light with numerous other wavelengths. In contrast to gas discharge lamps, the spectrum produced in this way is continuous, but the amplitude of its blue component depends on the temperature of the colour that is most similar to it.

LEDs with a nominal similar correlated color temperature over 3000 K should not be taken into consideration for ecologically sensitive areas.

Warm white LEDs with a nominal similar correlated color temperature of 3000 K or lower usually radiate a very low blue component and can be recommended from a health and ecological point of view.

High-pressure sodium vapour lamps, warm white LEDs (2700 Kelvin) and neutral white LEDs (4000 Kelvin) were tested for their attracting effect on nocturnal insects. It was found that most nocturnal insects are attracted by high-pressure sodium vapour lamps while warm white LEDs attract the lowest number. Significant results are available for each species, in particular for moths and flies[73].

Currently, white LEDs are among the most efficient commercially available light sources.

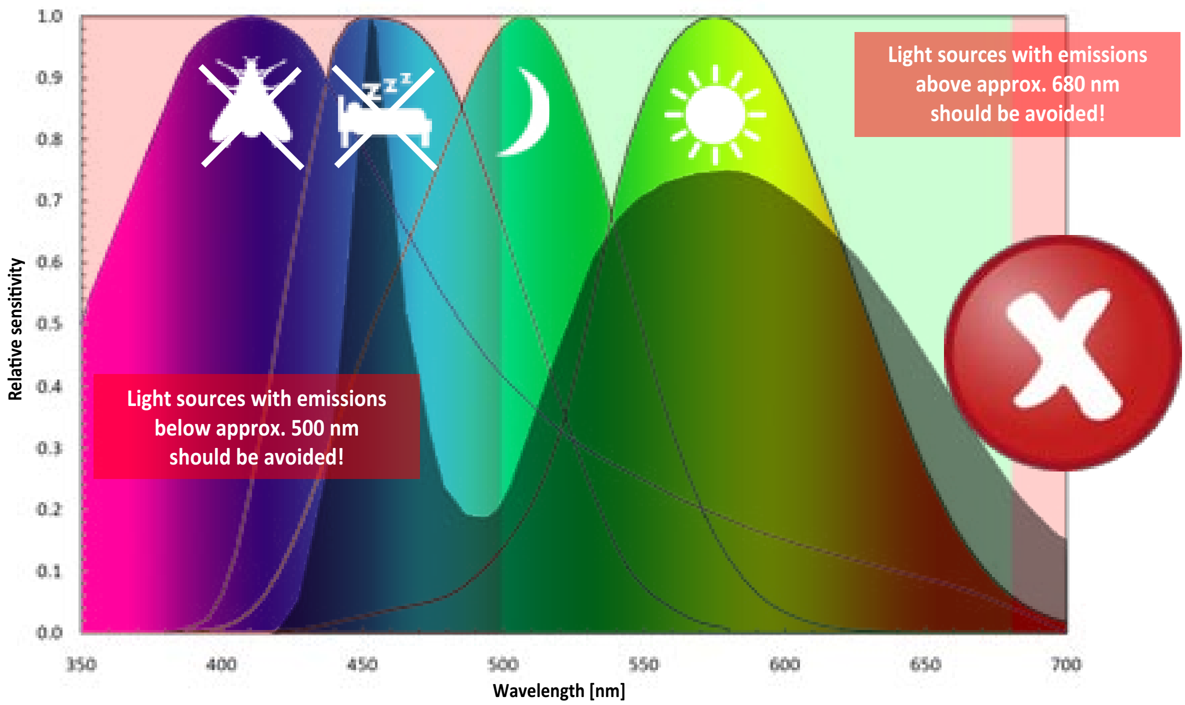


Fig. 23: Spectrum of a neutral white LED

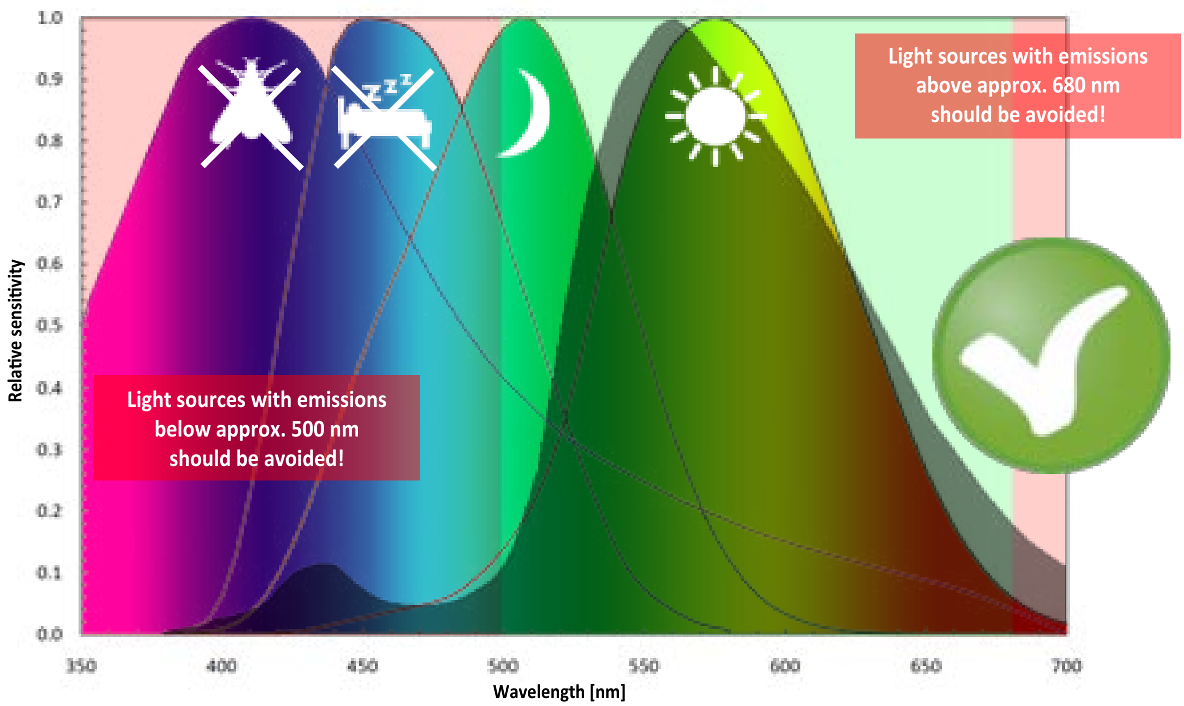


Fig. 24: Spectrum of a warm white LED (2700 Kelvin)

Yellow LEDs

Yellow LEDs, which are suitable for general lighting purposes, generate their light spectrum in the same way as white LEDs by the combination of a blue LED with fluorescent material. In contrast to the white LED, the fluorescent layer of the yellow LED is designed in such a way that only light in the yellow spectral range is emitted and the short-wave blue radiation of the driver LED is transformed almost completely.

Due to the limited spectral distribution (see Figure 25), there is a significant loss in colour rendering, but if this is not important then yellow LEDs are recommended for lighting in ecologically sensitive areas, for example.

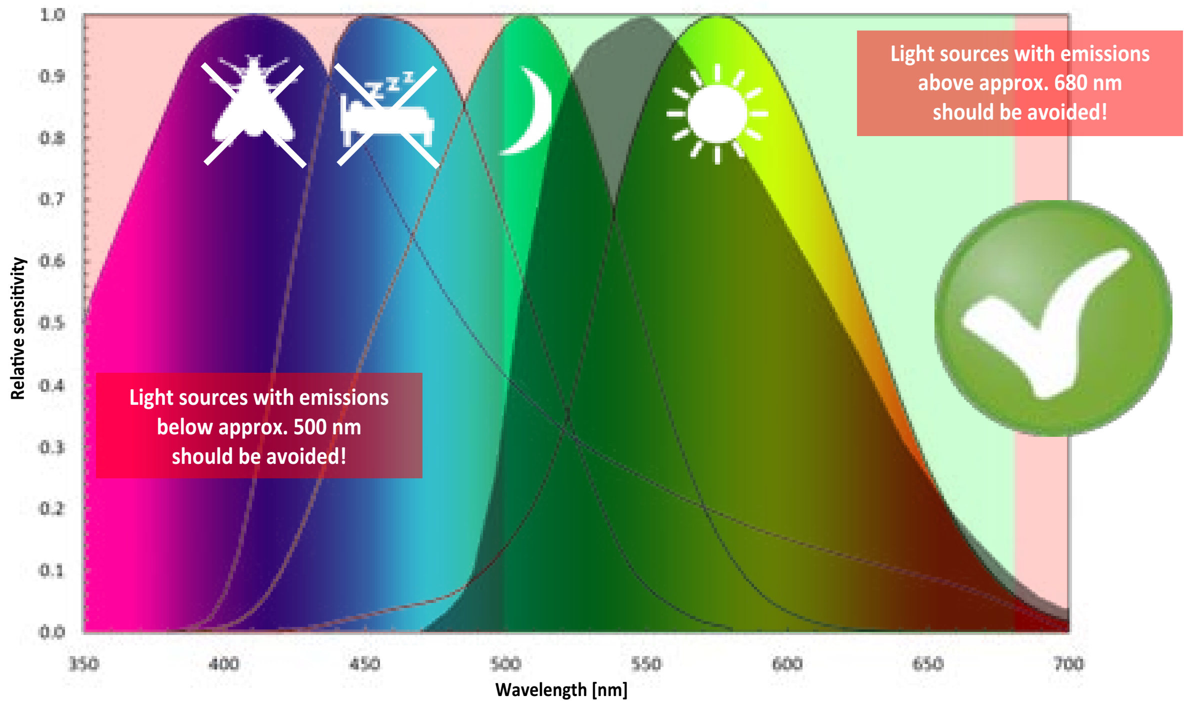


Fig. 25: Spectrum of a yellow LED

3.2.4 Low pressure sodium vapour lamps

Low-pressure sodium vapour lamps are currently the most efficient commercially available light sources. They emit practically monochromatic light with a wavelength of 589 nm that is close to the wavelength of maximum eye sensitivity of 555 nm, which also explains the high efficiency. However, due to the physically length of this kind of lamp, it is not possible to direct the light precisely using reflectors and a high proportion of scattered light is produced.

The monochromatic light makes colour recognition impossible. Low pressure sodium vapour lamps do not require mercury.

3.2.5 High-pressure sodium vapour lamps

Like all high-pressure gas discharge lamps, high-pressure sodium vapour lamps have a compact design and their light can be directed with reflectors better than with low-pressure lamps. Due to the high pressure in the combustion chamber, the sodium spectral lines widen so that at least limited colour perception is possible with these lamps. The efficiency of high-pressure sodium vapour lamps is currently comparable to that of LEDs. Depending on the design, it is also possible to dispense with mercury in high-pressure sodium vapour lamps

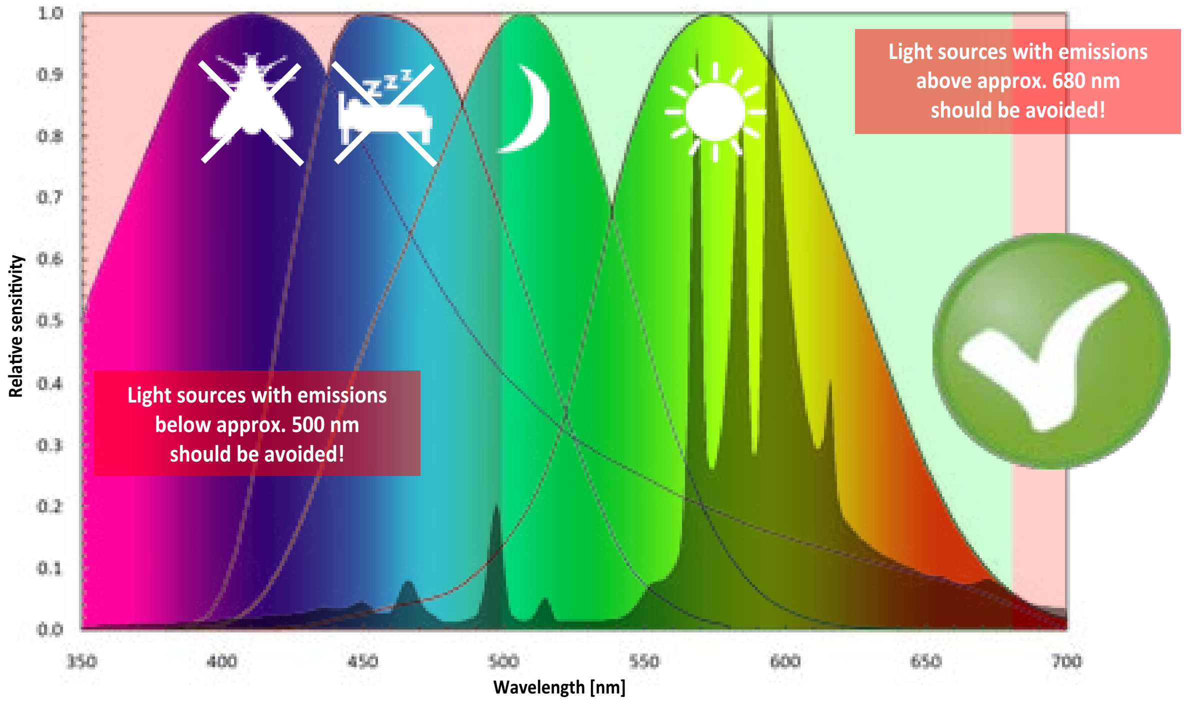


Fig. 26: Spectrum of a high-pressure sodium vapour lamp

3.2.6 Incandescent and halogen bulbs

Although the spectrum of incandescent lamps and halogen incandescent lamps hardly shows any emissions in the blue range, most of their radiation is too far into the red range - or more precisely into the infrared (see Figure 16) - which causes their efficiency to be very low. A major part of the electrical energy is converted into heat and not into useful light. Incandescent and halogen lamps are therefore not recommended for outdoor lighting.

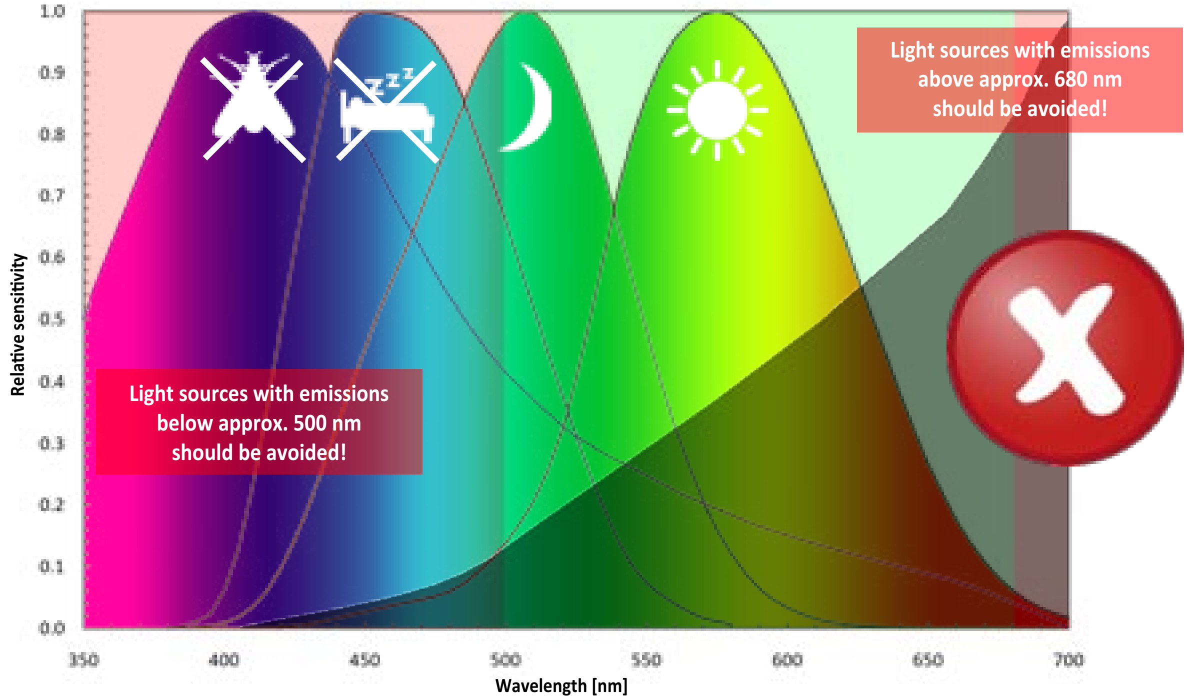


Fig. 27: Typical spectrum of incandescent and halogen lamps

3.3 Efficiency comparison of light sources

Currently, low-pressure sodium vapour lamps are still the most efficient, but, as already described above, colour perception is not possible. The efficiency of LEDs has increased dramatically in recent years and is currently slightly above that of the high pressure sodium lamp.

The advantages of LEDs are good to very good colour rendering and, due to their small size, offer a very good possibility of directing light using lenses or reflectors, as well as the possibility of dimming with the advantage of extending their service life.

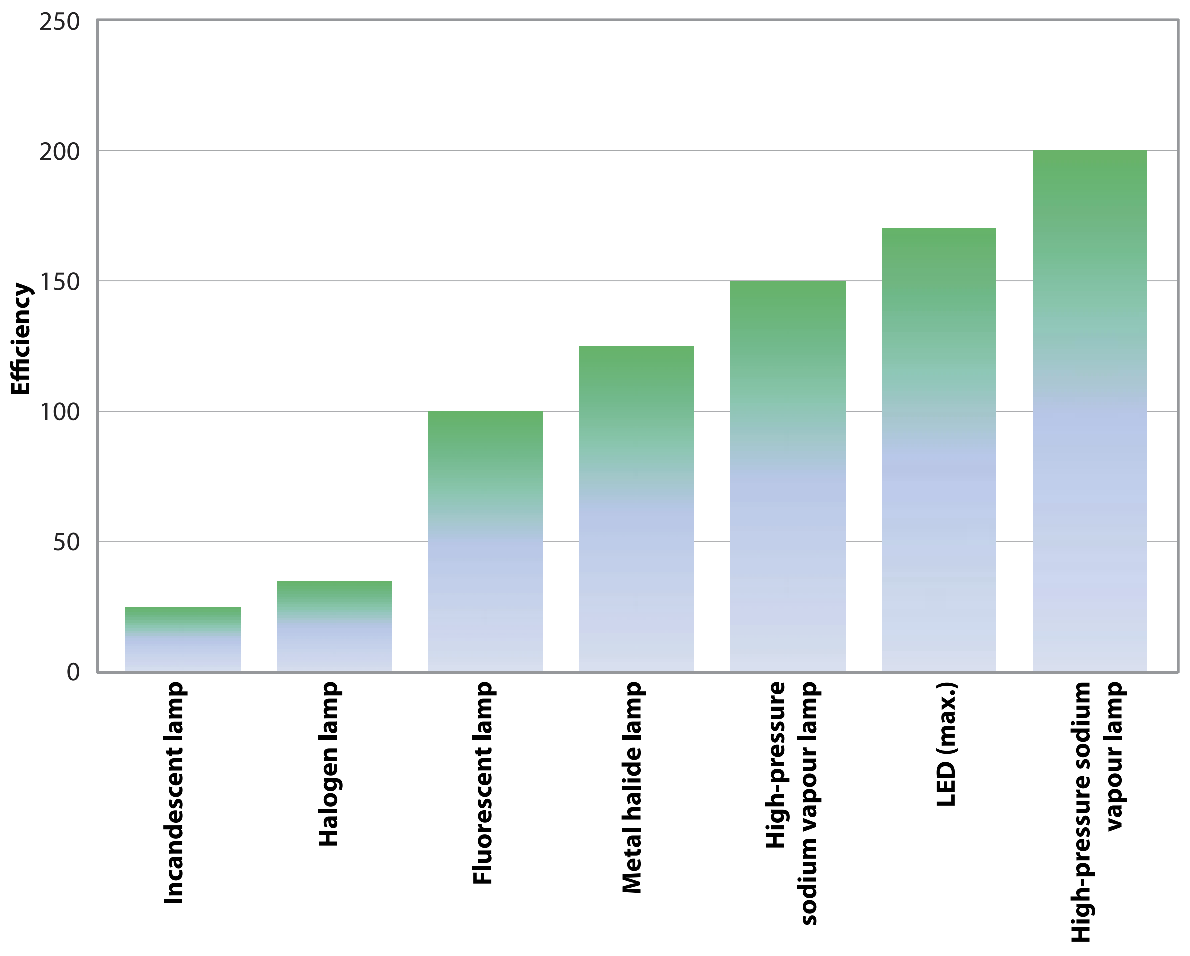


Fig. 28: Efficiency comparison of light sources (efficiency = luminous efficacy)

Warm white LEDs and high pressure sodium lamps can be recommended due to their high efficiency and their light spectrum.

3.4 Pollutant content of modern light sources

With regard to pollutant content, fluorescent lamps, compact fluorescent lamps, metal halide lamps and LEDs need to be analysed critically. Fluorescent lamps and compact fluorescent lamps only work with mercury and rare earths, and rare earths are also indispensable for LEDs. While rare earths are usually extracted under dubious conditions from an ecological point of view, mercury is a toxic heavy metal and one of the most harmful environmental toxins. Defective or disused LEDs must be disposed of properly as electronic scrap. It is important to remember that all modern light sources must be properly recycled.

3.5 Recommendation for outdoor lighting

For medical reasons, the Robert Koch Institute [74] recommends that light sources should not emit light at a wavelength of less than 500 nm, as this would interfere with the natural rhythm of day and night. Likewise, if these wavelengths are avoided, flora and fauna in the natural surroundings (e.g. insects) will be less adversely affected. There are currently no light sources that fully meet this specification. A good compromise are common LED lights with a maximum specified correlated color temperature of 3000 K. Due to their design, there is still residual emission in the blue range, but this can be eliminated by using a blue blocking filter. This filter is also recommended because it counteracts the ageing of the light source and a consequent shift of the emitted wavelengths into the shorter wavelength range.

For directional light sources with high light emission/luminance (e.g. spotlights) it is recommended not to use light sources which emit light in the wavelength range below 500 nm due to their phototoxic and the high glare effect.

In terms of medical, nature conservation and environmental protection perspectives, warm white light sources up to 3000 K correlated color temperature with the lowest possible blue component in their spectrum are recommended for outdoor lighting.

4

ILLUMINATION

In this chapter we will be looking at how beams of light can be directed, the illumination of buildings, and the light intensities required.

4.1 The basic principle

With modern lighting technology it is particularly important to pay attention to the correct beam direction and the correct beam geometry. Because the light sources have a small luminous surface and high light intensity, very high luminances are achieved.

This means that there is a risk of disability glare if you look directly into the light source (see chapter 1.1.3).

Glare and stray light immissions can be easily reduced by observing one simple principle:

The illuminated surface should be visible, not the light source itself!

Fig. 29: Shielded lamps only illuminate the road and do not create glare

Low-intensity light emissions can certainly contribute to optical guidance. There should still not be a direct view into the light source.

4.2 Ideal beam geometry

When selecting light sources, it is essential that no light is emitted on or above the horizontal plane. This is achieved using full cut-off lamps, providing they are mounted properly and horizontally.

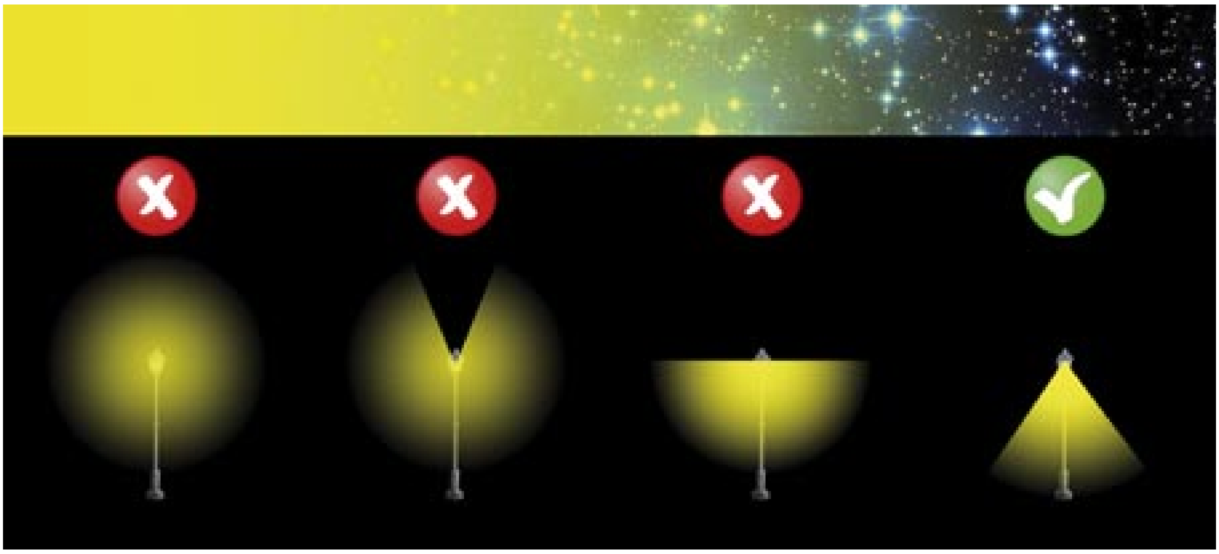
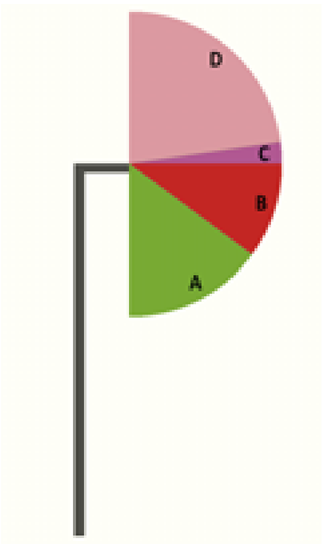


Fig. 30: Illustration showing the ideal beam geometry

Light emitted outside Zone A does not practically contribute to the lighting of squares or streets and thus to the useful light, but is wasted, as is the energy required to generate it.



Zone D (beam angle 95 to 180 degrees):
Does not contribute to useful light. Illuminates the sky very clearly, especially within several kilometres around the light source.

Zone C (beam angle 90 to 95 degrees):
No additional contribution to the useful light, critical area for the impairment of living beings and illumination of the sky. Strongly disturbing long-distance effect, light emitted in this direction can also be perceived from a great distance, many dozens of kilometres away.

Zone B (beam angle 70 to 90 degrees):
Limited additional contribution to the useful light, significant area for the impairment of living beings, risk of glare.

Zone A (beam angle 0 to 70 degrees):
Ideal beam angle. Maximum contribution to useful light, minimum disturbance from a distance.

Fig. 31: Radiation zones according to ÖNORM O 1052

Full cut-off light sources are to be given preference as they save energy and therefore costs and have a much lower impact on lighting up the sky. In addition, fauna, flora and habitats are affected to a much lesser extent.

Fig. 32: Previous lighting of a street in Vienna using fluorescent lamps

Fig. 33: After the street lighting had been changed to LEDs

4.3 Luminous intensity distribution curves and bodies

The light beam characteristics of a lamp are represented by luminous intensity distribution curves. Luminous intensity distribution curves describe how much light is emitted by the light source in which direction and are usually provided by the manufacturer of the light source. Luminous intensity distribution curves are required for the design of lighting systems and clearly show the spatial areas in which light is emitted. Usually, two perpendicular section planes are deduced from the entire set of curves to form the luminous intensity distribution body (see Figure 34).

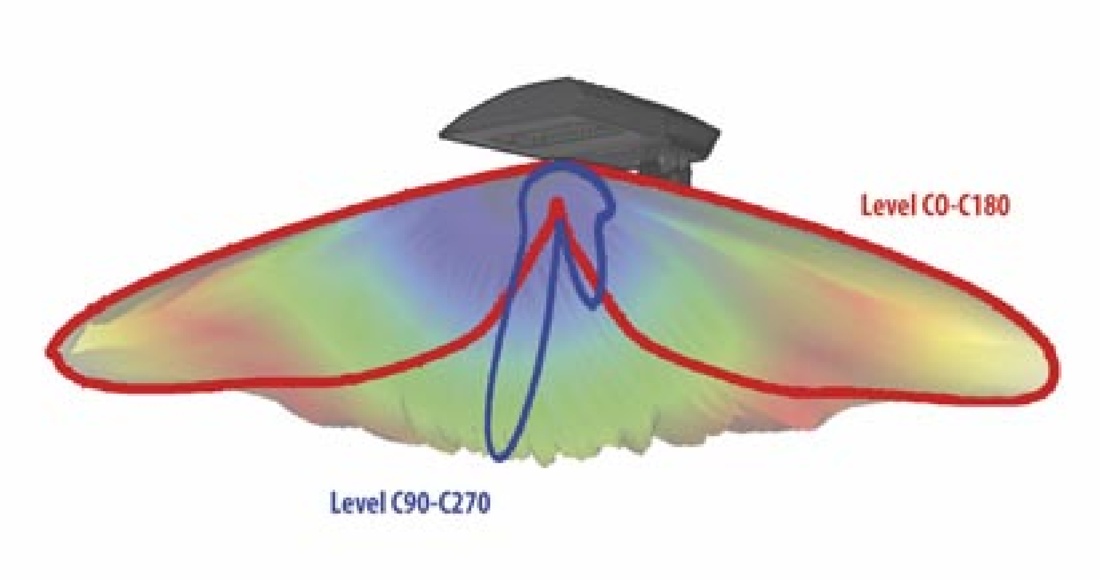


Fig. 34: Illustration of two measuring levels of a luminous intensity distribution curve for a street lamp

The luminous intensity distribution curve shows the luminous intensity emitted in the respective section plane in candela. Figure 34 shows the intensity distribution body of a street lamp. With lights that emit an asymmetrical beam, the light distributions of two planes are shown in a diagram (see Figure 36).

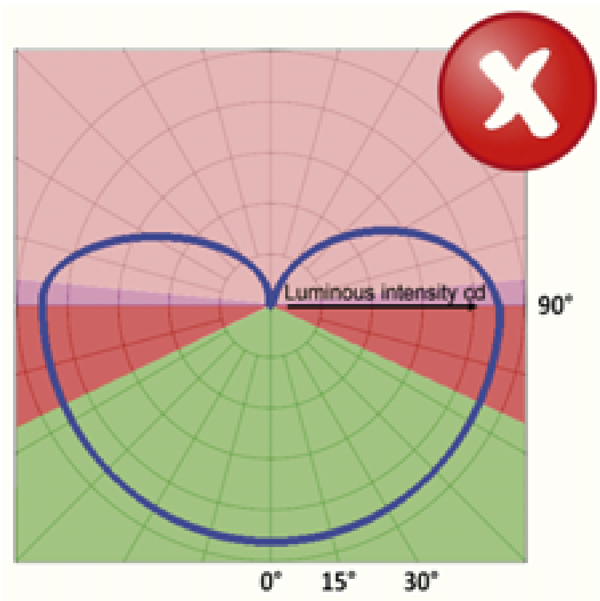


Fig. 35: Intensity distribution curve of an old-style street light lamp suspended on cables in the middle of the street

With respect to stray light emissions, luminous intensity distribution curves are evaluated according to Austrian standard ÖNORM O 1052. Ideally, there should be no light beam above an angle of 70°. The old-style street light in Figure 35 does not meet this criterion by far. The blue curve should be limited to zone A, shown in green.

Typical examples of the luminous intensity distribution curve

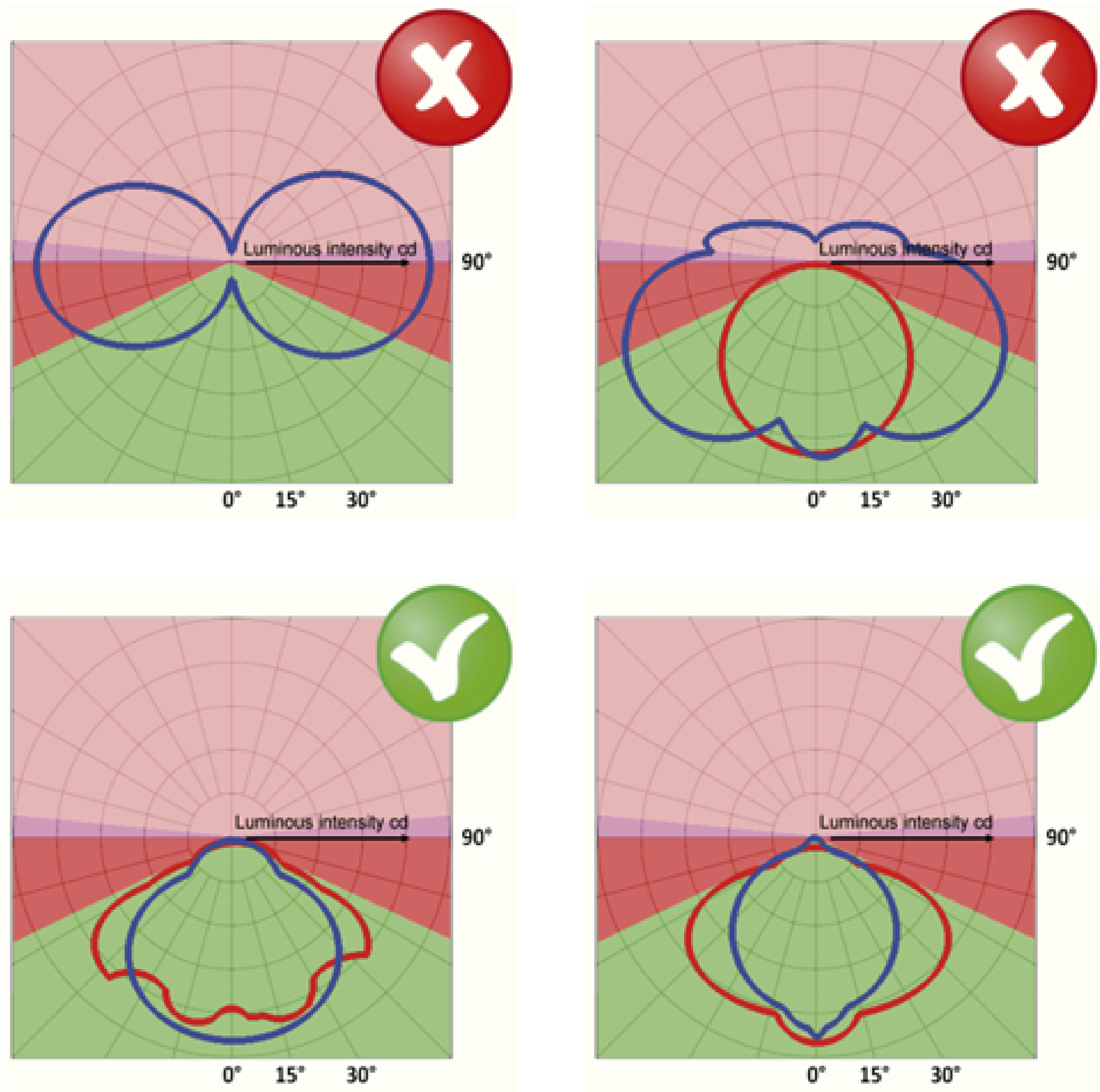


Fig. 36: typical luminous intensity distribution curves

4.4 Mounting height

Both the attracting effect for nocturnal insects and the contribution to light pollution are lower the lower the light spot height is. On the other hand, the number of light sources required increases as the height of the light point decreases. For practical reasons, it is usually not possible to choose the light point height freely.

4.5 Illumination direction

In the case of illuminating buildings, it is preferable to light the building from above; only in cases where this is not possible illumination from below can be achieved with suitable spotlights (see Figure 37). This type of illumination using outdoor spotlights must comply with the requirements of Austrian standard ÖNORM O 1052.

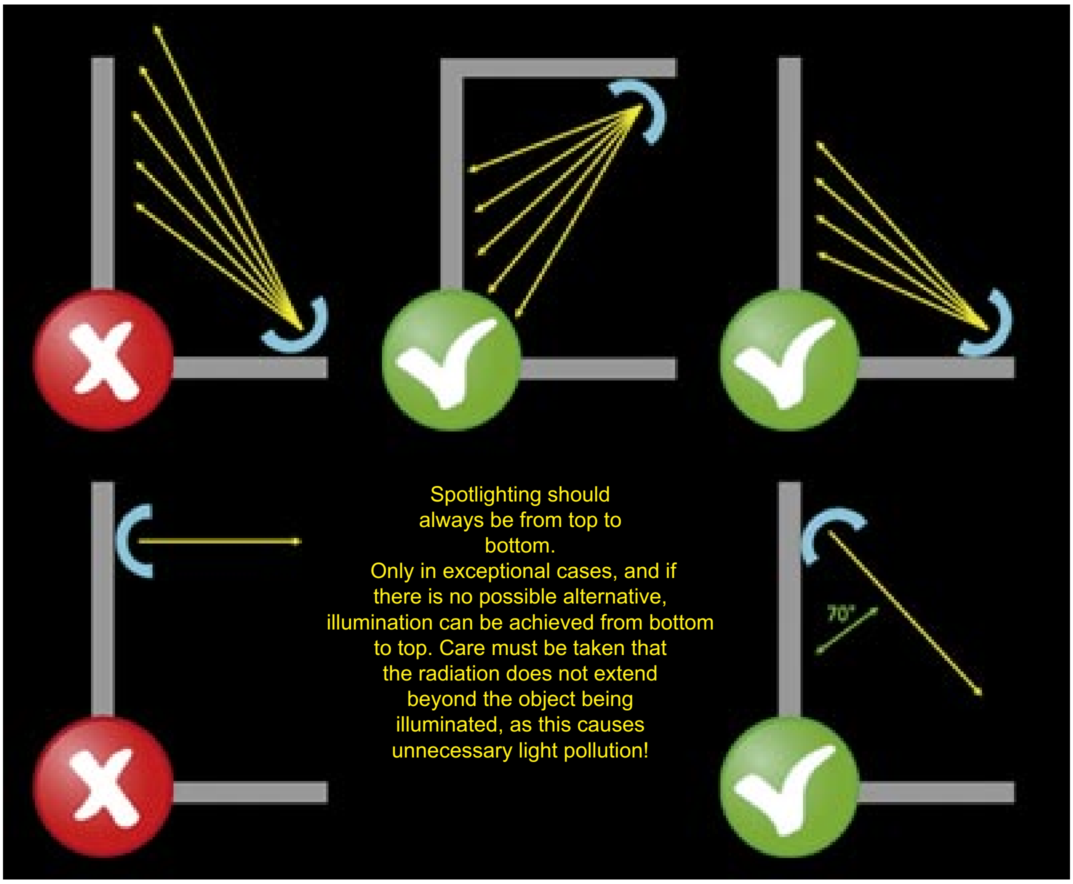


Fig. 37: Recommendation for lighting installations

4.6 Mode of operation

Artificial light should only be used at the times and in the intensities in which it is needed.

4.6.1 Dimming at night

Night dimming is the reduction of the lighting level within certain periods of the night. Care must be taken to ensure that the uniformity of roadway brightness is not reduced. Reducing the lighting level by switching off individual lights along the road is therefore not favourable, as this would lead to a reduction in uniformity and the formation of camouflage zones.

Following the introduction of modern control devices, it has become possible to dim practically all light sources - at least in a certain power and brightness range - and LEDs have the largest control range of the light sources used outdoors.

Detailed instructions for night-time dimming can be found in Austrian standard ÖNORM O 1055.

Dimming at night saves energy and reduces stray light emission.

4.6.2 Switching off at night

If circumstances permit, lighting can be completely dispensed with at certain times of the night. Neither the obligation to provide lighting nor the switching off of street lighting is explicitly regulated by law in Austria. It is therefore common practice in some municipalities to switch off street lighting during the second half of the night.

When assessing the need for lighting, it can be assumed that road users comply with traffic regulations. The maintainers of a road may rely on road users adhering to the traffic regulations and, for example, illuminating their vehicle properly[75].

As a rule, gross negligence is not in evidence if no attention is drawn to obstacles that will not cause an accident providing the traffic regulations are observed[76]. The necessity and scope of street lighting depend on the intended purpose of the route[76].

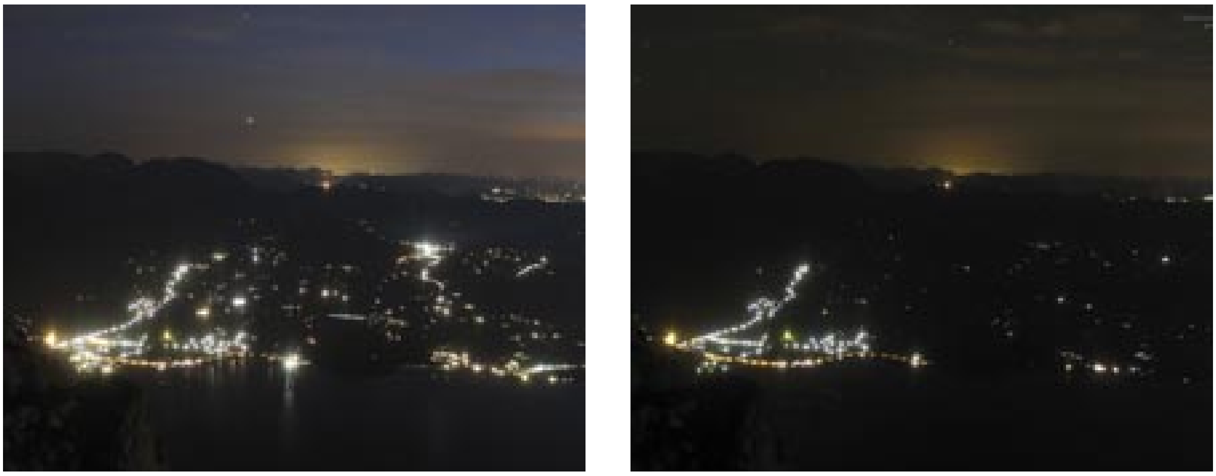


Fig. 38: View from Gmundnerhütte on Traunstein mountain looking towards Salzburg across the town of Gmunden (Upper Austria) before and after partial switching off at night

4.6.3 Sensor controlled lighting

Sensor-controlled lighting systems ensure that there is only light when it is actually needed. New technologies allow the lighting to be dimmed, corresponding to a significant reduction in energy and light.

These systems can lead to considerable savings, especially in rural areas with low traffic density. Information on night dimming can be found in Austrian standard ÖNORM O 1055.

Fig. 39: Traffic-sensing light in Urdorf (CH): Illuminance varies between 100 % (left) and 40 % (right) depending on the volume of traffic

5

RECOMMENDATIONS

Recommendations are based on the principle of what is appropriate. These recommendations serve as a guideline for the lighting level to be achieved, the lighting atmosphere and light colour to be created, the choice of light source in relation to their immediate environment and, last but not least, for the economic, energy and ecological conditions associated with artificial lighting.

Unfortunately, the concept of what is appropriate is currently not very often taken into account during the planning of installations, which is why there is an annual increase in light pollution of six percent[69].

The ecological approach of the lighting concept is based on a comprehensive, scientifically based assessment of the influence of artificial light on human health and the habitat of humans and animals.

5.1 Assessing the necessity of lighting

Before planning a lighting concept, it should be determined to what extent lighting is necessary and what effects it will have on people and the environment. If artificial lighting is required, it must be implemented in accordance with current regulations, taking into account the medical and ecological principles of each regulation.

Lighting systems that do not enhance safety or the subjective perception of safety, such as advertising lighting and illuminated buildings, must be critically assessed for the health and ecological reasons described previously, and, if unavoidable, be reduced to a minimum.

This recommendation also applies to outdoor lighting on private property.

In principle, lighting should be avoided as far as possible in areas of Austria protected by nature conservation law. The possible negative effects of artificial light at night time are usually not compatible with the nature conservation objectives.

Before planning a lighting project, ask yourself whether it is really needed!

5.2 Limitation of light emissions according to the state of the art

The relevant technical regulations shall be used to determine the state of the art. If the relevant regulations do not sufficiently cover the health and ecological requirements, the basic principles of the guideline shall be applied.

5.2.1 Choosing the colour of the light

The correlated color temperature of the light source used should not exceed 3000 Kelvin. In justifiable cases, light sources can be used with a correlated color temperature of up to 4000 Kelvin - or in special cases - greater than 4000 Kelvin (e.g. sports facilities hosting events broadcast on television or for junior athlete sports). The short-wave (blue) part of the light spectrum should be kept as low as possible (see chapter 3.2).

5.2.2 Targeted lighting

Light should only be directed lighting at the areas that need to be illuminated. Full cut-off lights or lights which emit light only in zone A (see chapter 4.2) should be preferred and mounted horizontally, i.e. not directed along the horizontal plane. If necessary, the light source should be shielded.

On slopes, the lighting should be installed on the valley side of the road or path if possible.

Reflections on building facades or other surfaces should be avoided.

5.2.3 Demand-specific lighting times

In all areas, artificial light should only be used at those times when it is needed.

- In the case of street lighting, the lighting level should be adapted to the volume of traffic in question at least between 10 pm and 6 am in accordance with Austrian standard ÖNORM O 1055.
- The outdoor lighting of commercial and industrial facilities outside operating hours must be critically assessed and, if unavoidable, reduced to a minimum.
- The lighting of advertising, facades and buildings - municipal as well as private - should be avoided at least between 10 pm or midnight and 6 am (see Austrian standard ÖNORM O 1052).

5.2.4 Intensity

Artificial light intensities must under no circumstances exceed sensory physiological limits. In order to allow for individual differences in perception of glare, irritation and distraction, especially in road traffic, lighting intensities should generally be kept as low as possible[77].

5.3 Maintenance and repair costs

The cost of lighting often focuses on energy costs. In many cases, however, these make up only half of the operating costs, with the other half consisting of maintenance and testing costs. Among the factors that increase the maintenance requirement is contamination due to spider webs and insects.

The external contamination of the lights is influenced by local conditions and must be taken into account in the maintenance factor.

5.4 Lighting in public traffic areas and paths in parks

The lighting of public traffic areas is regulated by the series of Austrian standards ÖNORM EN 13201 - Part 2 - 5, ÖNORM O 1055 and ÖNORM O 1051. The essential quality features for road users, such as the lighting level and its uniformity, glare limitation, etc., are determined by the choice of lighting class. The lighting level is adapted to traffic conditions and is to be reduced during dark hours in accordance with Austrian standard ÖNORM O 1055. In addition to the minimum lighting levels listed in ÖNORM EN 13201-2, Austrian standard ÖNORM EN 13201-5 also introduces two metrics (power density DP and annual power consumption DE) to describe the energy efficiency of street lighting systems.

In addition, ÖNORM EN 13201-5 states that when planning a lighting installation, the normative lighting level is only provided at the correct times and for the required minimum duration, and that if the normative requirements are exceeded, it must be limited to the minimum that is technically necessary.

It makes sense to apply the series of standards ÖNORM EN 13201 - Part 2 - 5, ÖNORM O 1055 and ÖNORM O 1051 also to lighting on privately owned paths and driveways and car parking spaces in residential areas.

Planning according to lighting, traffic, ecological and economic specifications is crucial for a good lighting system. In order to enhance road safety using the lighting system, lighting criteria must be applied that correspond to the perception of each of the road users in traffic.

For this reason, the methods described in lighting class M must be used for motor traffic, irrespective of the type of road and its purpose. If the conditions for using the calculation method of luminance in lighting class M according to Austrian standard ÖNORM EN 13201-3 are not met,

- Visual distance (observer) to calculation field: 60 m
- Calculation field and position of the calculation points

then the method of illuminance in lighting classes C or P shall be used.

Lighting class C is to be used in situations that apply mainly to motorised road users, especially in conflict zones (ÖNORM O 1051).

Lighting class P is intended for pedestrians and cyclists whose traffic routes are separated from the main flow of traffic, or are parallel to a road, and for traffic areas used mainly by these road users, such as pedestrian zones.

In the case of rural roads, classification may be difficult due to local conditions, the composition of traffic and the low volume of traffic. The standard EN 13201-2, which describes in point 6.1 General requirements, first paragraph, that mentions "... as well as on residential streets ...", can be helpful here for determining the lighting class.

The following examples show how, having selected the lighting class, the necessary lighting parameters can be determined based on the weighting of traffic and traffic psychological parameters and how additional site-specific requirements can be taken into account using these weighting parameters.

The coloured weightings indicate the adaptation to these site-specific requirements and the change/reduction in lighting conditions during the hours of darkness.

Example 1 - lighting class M

This example is based on a road with predominantly motorised traffic in both directions without a central reservation, with traffic moving at < 70 kph, and an annual average traffic volume of 5000 vehicles per day (AATV). The remaining assumptions can be taken from the table:

Δt1: The weighting parameters are selected for the main traffic volume and the environment parameters at the time of switching on.

Parameter	Select	Description		Weighting	V_W for selected time periods			
				V_W	Δt1	Δt2	Δt3	Δt4
Decisive speed	Very high	≥ 100 kph		2	-1	-1	-1	-1
	High	≥ 70 and < 100 kph		1				
	Medium	> 40 and < 70 kph		-1				
	Slow	≤ 40 kph		-2				
Traffic volume [a]		Directional traffic (Motorways and roads with more than one lane)	Two-way traffic (also for directional traffic with only one lane)					
	High	≥ 45.000	≥ 7.000	1	0	-1	-1	-2
	Medium	≥ 25.000 and < 45.000	≥ 2.000 and < 7.000	0				
	Low	< 25.000	< 2.000	-1				
Traffic composition	Mixed, with a high proportion of non-motorised traffic			2	1	1	1	1
	Mixed traffic			1				
	Motorised traffic only			0				
Separation of directional lanes	No			1	1	1	1	1
	Yes			0				
Distance between traffic junctions, intersection density		Distance between connection points, distance between bridges	Number of crossings per km					
	High	< 3 km	> 3	1	0	0	0	0
	Normal	≥ 3 km	≤ 3	0				
Parking vehicles	Permitted			1	1	1	1	1
	Not permitted			0				
Luminance of the environment	High	High ambient luminance throughout the area due to shop windows, illuminated advertising, sports grounds, rail stations, freight handling areas, etc.		1	0	-1	-1	-1
	Medium	Normal situation, moderate ambient brightness		0				
	Low	Darker than normal, unlit		-1				
Difficulty of the driving task	Very difficult			2	1	1	1	1
	Difficult			1				
	Easy			0				
				Sum of weighting V_{WS}	3	1	1	0
				$M = 6 - V_{WS}$	3	5	5	6
				L_{av} cd/m²	1,00	0,50	0,50	0,30

[a] *Extended weighting of traffic volume based on AATV and HTV*

Table 1: Austrian standard ÖNORM O 1055 - Time-dependent selection of parameters - lighting class M, example 1

AATV (average traffic volume)	Weighting V_w	***AATV*** (average traffic volume)
	10pm to 6am	
Directional traffic		Two-way traffic
(motorways and roads with more than one lane)		(also for directional traffic with only one lane)
	1	greater than 21.000
greater than 45.000	0	7.000 to 21.000
25.000 to 45.000	-1	4.000 to 6.999
less than 25.000	-2	less than 4.000

Table 2: Dimming over a fixed period of time

HTV	Weighting V_w	***HTV***
Directional traffic		Two-way traffic
(motorways and roads with more than one lane)		(also for directional traffic with only one lane)
	1	greater than 300
greater than 600	0	100 to 300
350 to 599	-1	40 to 100
less than 350	-2	20 to 40
	-3	less than 20

Table 3: Dimming over a variable time period

In this example, two dimming versions are shown:

- Due to the AATV of 5000, dimming can take place according to the table over the fixed period from 10 pm to 6 am - see Δt2.
- Based on the hourly traffic volume (HTV), variable dimming can take place according to the table - see Δt3 (10 pm to midnight, HTV: 45) and Δt4 (midnight to 6 am, HTV: 25).

The traffic volumes on which the planning is based - AATV and HTV - must be verified by traffic census or other approved methods.

Example 2 - lighting class P

This example looks at a traffic area with a lively volume of traffic - mainly cyclists and pedestrians - moving at slower speeds of 5 to 40 kph, other information can be taken from the table.

Nominal operation: Δt1: The weighting parameters are selected for the main traffic volume and the environment parameters at the time of switching on.

Parameter	Select	Description	Weighting V_w	V_w for selected time periods Δt1	Δt2	Δt3
Decisive speed	Slow	≤ 40 kph	1	1	1	1
	Very slow	Walking speed	0			
Volume of traffic	Lively		1	1	0	-1
	Normal		0			
	Quiet		-1			
Traffic composition	Pedestrians, cyclists and motorised traffic		2	1	1	1
	Pedestrians and motorised traffic		1			
	Pedestrians and cyclists		1			
	Pedestrians only		0			
	Cyclists only		0			
Parking vehicles	permissible		1	0	0	0
	not permitted		0			
Luminance of the environment	High	High ambient luminance throughout the area due to shop windows, illuminated advertising, sports grounds, rail stations, freight handling areas, etc.	1	0	-1	-1
	Medium	Normal situation, moderate ambient brightness	0			
	Low	Darker than normal, unlit	-1			
			Sum of weighting V_{WS}	3	1	0
			P = 6 - V_{WS}	3	5	6
			E_{av} Lux	7,50	3,00	2,00

Table 4: Austrian standard ÖNORM O 1055 - Time-dependent selection of parameters - lighting class P, example 2

This example shows the following dimming options:

- Due to the low traffic volume (normal) and the reduced ambient lighting (low), the lighting is lowered - see Δt2 (9 pm to 11 pm).
- Due to the further decrease in traffic (quiet), the lighting is dimmed even further - see Δt3 (11 pm to 6 am).

The lighting classes calculated in both selection procedures (Example 1: M3, M5, M6 and Example 2: P3, P5, P6) result in the assigned lighting values taken from Austrian standard ÖNORM EN 13201, Street lighting - Part 2: Quality characteristics.

Only the luminance values or illuminance without uniformity and glare limitation are provided as examples. Adjacent traffic areas such as pavements, parking spaces etc. are not considered in this selection procedure.

Lighting is dimmed during the night based on changing parameters in accordance with Austrian standard ÖNORM O 1055.

Lighting systems which cause glare and/or uneven illumination of the traffic area cause more problems than unlit traffic areas in terms of health and ecology as well as road safety.

5.5 Lighting in commercial and industrial facilities, airports, railways and port facilities etc.

In the course of granting planning permission for commercial operations and industrial facilities, particular care must be taken to ensure that outdoor lighting systems, including illuminated advertising, are not an unacceptable nuisance to neighbours in accordance with clause 74 (2) and (3) of Austrian Trade and Energy law 1994.

When applications are submitted to the trade authority, care should be taken to ensure that light emissions - including those from the interior of buildings - are minimised in terms of light colour, intensity, lighting area and lighting time (see point 5.2) in order to minimise adverse effects on health and the environment.

Outdoor lighting of commercial and industrial facilities should be limited to work and operational requirements.

5.6 Workplace lighting

Workplaces are generally to be illuminated in accordance with Austrian standards ÖNORM EN 12464-1 and ÖNORM EN 12464-2. Light emissions that extend beyond the work area shall be limited in accordance with the relevant standards, guidelines and recommendations as set out in this guide.

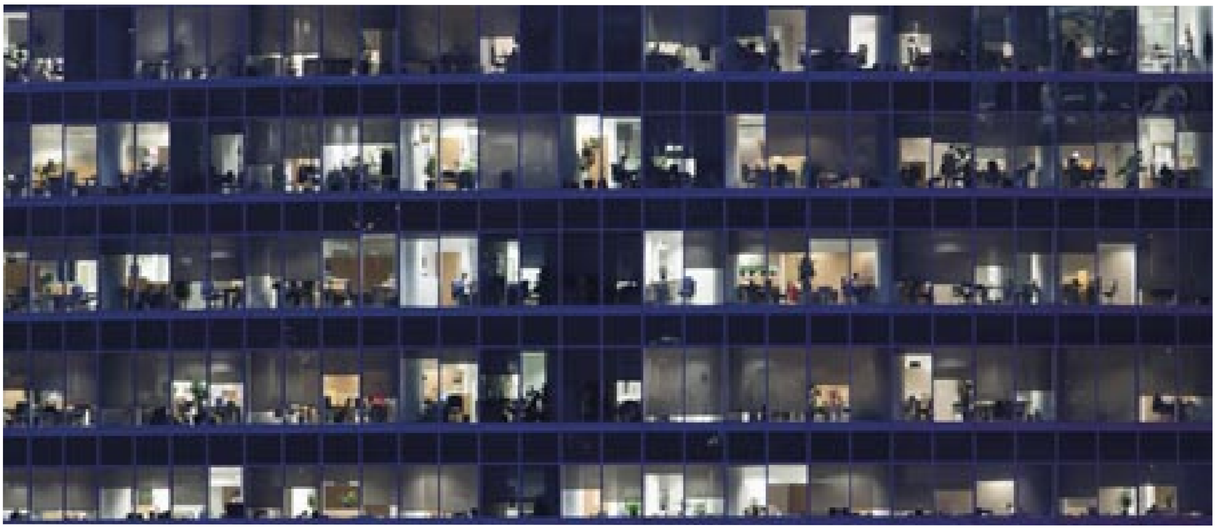


Fig. 40: Example of interior lighting illuminating the outdoors

Light from inside buildings can also be disturbing.

5.7 Sports facilities lighting

Lighting systems for school and leisure sports grounds, training areas and professional sports facilities must be designed in accordance with Austrian standard ÖNORM EN 12193 in terms of their lighting quality characteristics. The use of vertical floodlight with a horizontal light emission surfaces and glare protection is recommended. The light irradiation must be limited to the sports area and any safety zones. Light immissions shall be assessed in accordance with Austrian standard ÖNORM O 1052 (see 5.10.2 and 5.10.3). In addition, any impairment of road safety must be avoided.

If the limit values according to ÖNORM O 1052 cannot be adhered to with regard to immission protection - e.g. sports facilities designed for television coverage - the operating times of their lighting systems must be limited to specific days and specified times. Any adverse affects for neighbours shall be assessed with the assistance of a medical expert by taking into account the impact (duration and intensity).

In particular, match days, operating times and the increased intensity of the light immission must be taken into account. As a rule, the operating time of all sports facility lighting systems should be limited to 10 pm.

If the lighting system is designed for several lighting levels, e.g. competition and training, then a level-switchable system is recommended.

High intensity/luminance spotlights are often used for sports facilities. In order to minimise negative effects such as glare - which may also affect the people doing the sports - including phototoxic effects, immissions affecting neighbours and environmental impact, it is recommended that lighting with a correlated color temperature above 3000 K be avoided.

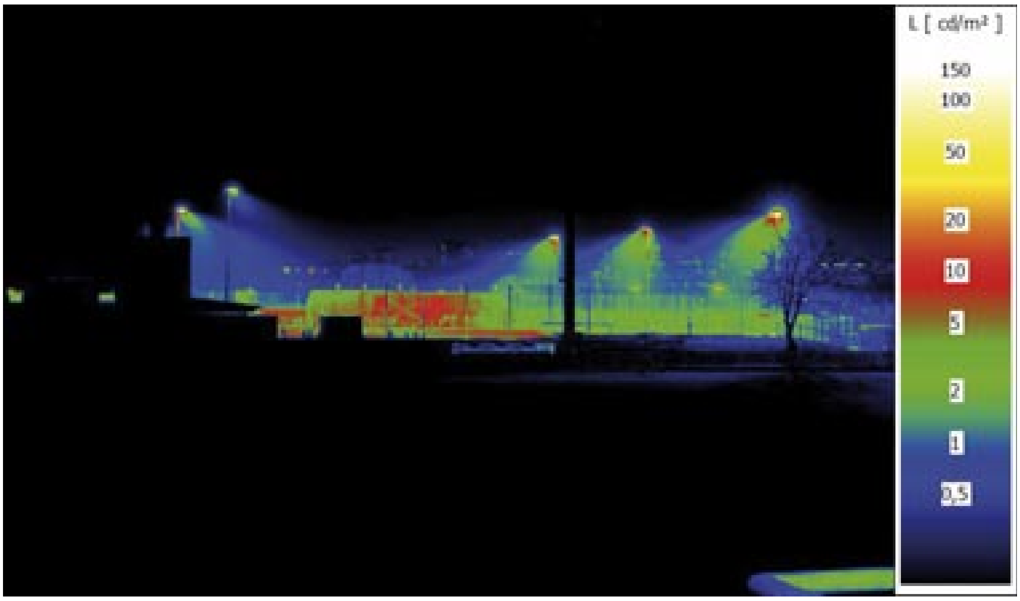


Fig. 41: Example of optimized lighting at a sports ground (luminance measurement using inverse colour image)

Sports-specific lighting according to Austrian standard ÖNORM EN 12193 must also comply with ÖNORM O 1052 in terms of immissions.

5.8 Lighting for paths, driveways and car parking spaces in residential complexes

In the assessment of road and driveway lighting in residential areas, the application of regulations can lead to a discrepancy between regulations for the workplace and street lighting.

If necessary, the lowest lighting class according to Austrian standards ÖNORM O 1055 and ÖNORM EN 13201 should be selected from a health and environment standpoint.

The use of sensor-controlled lighting systems is recommended in these areas.

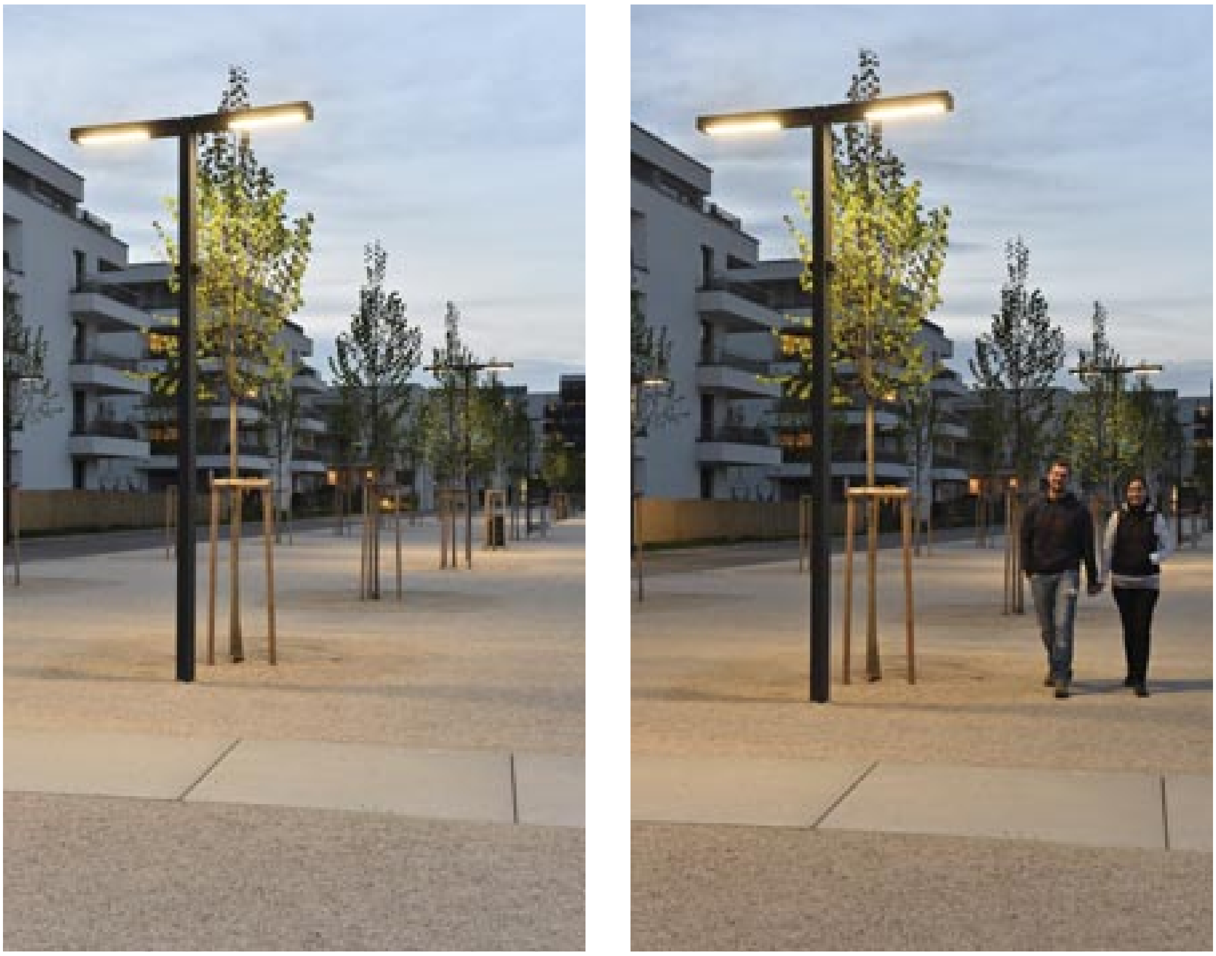


Fig. 42: Smart lighting system at "Linz green centre", a project by LINZ AG

5.9 Structural and lighting design of entrances and exits for car parks and underground garages

Parking garages and underground garages must be designed in such a way as to avoid glare from vehicle headlights and to avoid unacceptable emissions by taking into account traffic management and the position and orientation of ramps and traffic lanes.

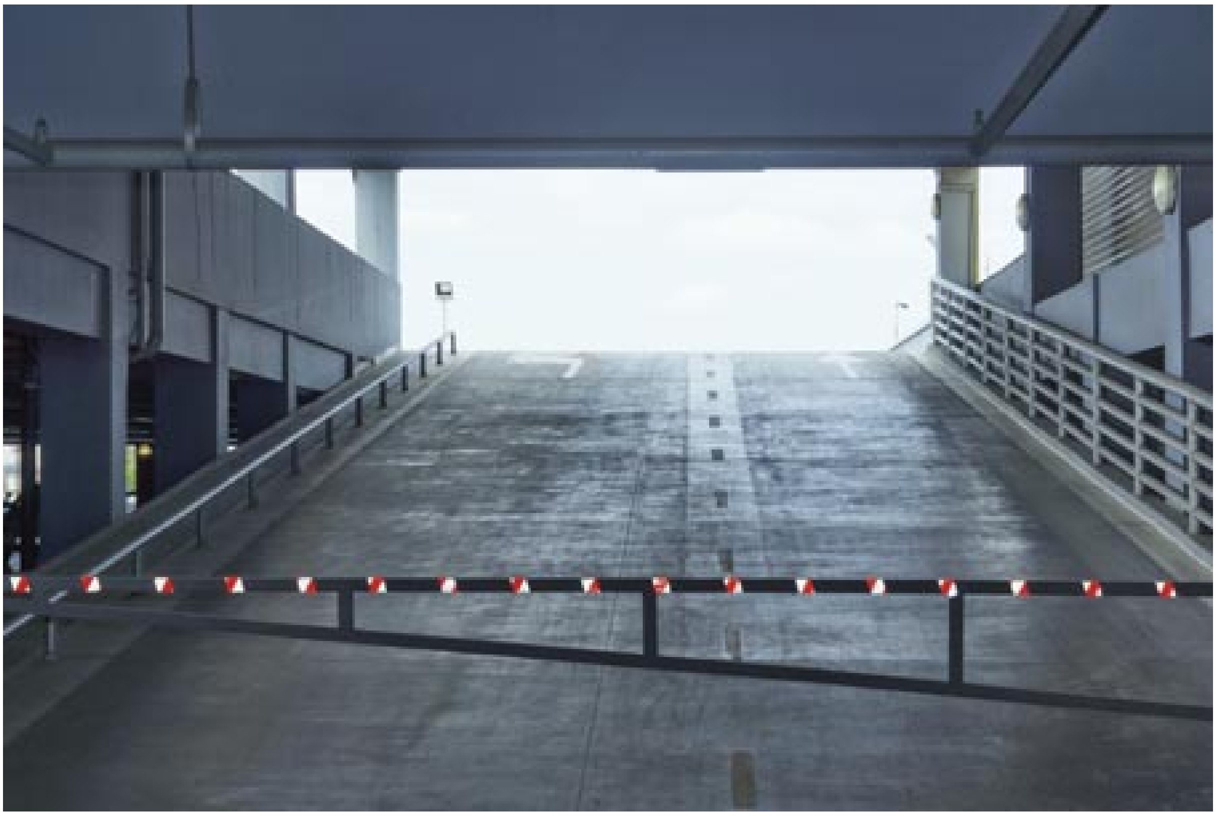


Fig. 43: On leaving the car park, the vehicle's headlights illuminate the flats in the building opposite the exit

The lighting of the driveways, exits and entrances as well as the parking areas in multi-storey car parks and underground garages must comply with Austrian standard ÖNORM EN 12464-1. The transition from covered areas into the outdoors must comply with ÖNORM O 1051. Glare and impermissible light immissions must be avoided.

The use of sensor-controlled lighting systems is recommended in these areas.

5.10 Illumination of facades and buildings, illuminated advertising

As far as the standards are concerned, illuminated advertising, facades or buildings are deemed unnecessary and contradict health and the environment protection regulations. Non-compliance with the traffic regulations can lead to an unacceptable impairment of traffic safety (distraction, attention grabbing). Generally, the intensity and duration of the lighting must be limited.

Specifications for illuminated advertising are essentially derived from:

- Traffic law/traffic engineering (Austrian traffic law StVO, Highway code RVS 05.06.12, RVS 05.06.11)
- Immission control to protect residents (Austrian standard ÖNORMO 1052)
- Environmental protection (ÖNORM O 1052, Austrian province conservation laws)

The requirements of all specifications must be fulfilled. Special reference is made to the requirements for limiting luminance densities in accordance with RVS 05.06.12 and ÖNORM O 1052 and limiting operating times in ÖNORM O 1052.

In addition to the limit values for illumination and brightness described in this chapter, other requirements apply with regard to glare caused by the lighting system. Criteria for the evaluation of glare would go beyond the scope of this guideline - for more information on this, please refer to the regulations listed above.

General lighting requirements such as correlated color temperature, beam direction and intensity can be found in chapter 5.2.

This section provides guidance on how to assess illuminated advertising facilities. Detailed knowledge of the above rules and regulations is indispensable for the planning and assessment of such facilities.

In France, a law came into effect in July 2013 restricting the operation of shop window lighting and partly also façade lighting between 1 am and 6 am. The aim is to save an amount of electricity every year that could supply 260,000 households[78].

5.10.1 Avoidance of adverse effects on traffic safety

According to the Austrian traffic law 1960 and according to the criteria in the Austrian highway code RVS 05.06.12, traffic control systems may in no way be reduced in their recognisability. It is generally forbidden, for example, to display traffic signs on advertising spaces as they can cause irritation; the length of the text must also be kept short in order to ensure that it can be read quickly.

According to the Austrian highway code RVS 05.06.12 and depending on the average illuminance or lighting class in accordance with EN 13201 ÖNORM O 1055, and on the size of the advertising surface, specific maximum permissible values for luminance (brightness) apply to non-traffic visual information transmitters (VIT) that are located in the vicinity of a road with traffic.

Locations where non-traffic visual information transmitters (VIT) must not be installed according to highway code RVS 05.06.12 include:

- Accident black spots - places with a high accident frequency and/or above-average accident rates
- Concealment - when a device for regulating traffic and enhancing traffic safety is concealed
- Smothering - if the sheer number of VITs drowns out traffic-related information and causes one or more of the following:
  - Glare with impairment to visibility
  - Confusion
  - Stray light
  - Blinking, flashing, flickering
  - Rapid image changes, rapid movements
  - Distraction from traffic that lasts too long (long reading times)
- Projection onto the road surface.

Even stricter criteria apply to illuminated advertising in the immediate vicinity of the road (traffic sign area).

According to the Austrian traffic law 1960 (latest amendment), advertising installations are generally only permitted within built-up areas; they are generally prohibited within 100 metres of the road if they are outside built-up areas.

For illuminated visual information transmitters (VIT), in particular those that are semi-dynamic or dynamic and not related to traffic, the Austrian highway code RVS 05.06.11 must also be complied with. According to highway code RVS 05.06.12, film sequences, videos and the like are generally prohibited in the road area.

In terms of lighting, the illuminance of the adjacent roads must be taken as a basis.

Highway code RVS 05.06.12 regulates the permissible luminance for VITs during the day and during the hours of darkness. The maximum permissible luminance (brightness) values are determined according to the average illuminance of the road close to the VIT and the size of the advertising surface (see Figure 44).

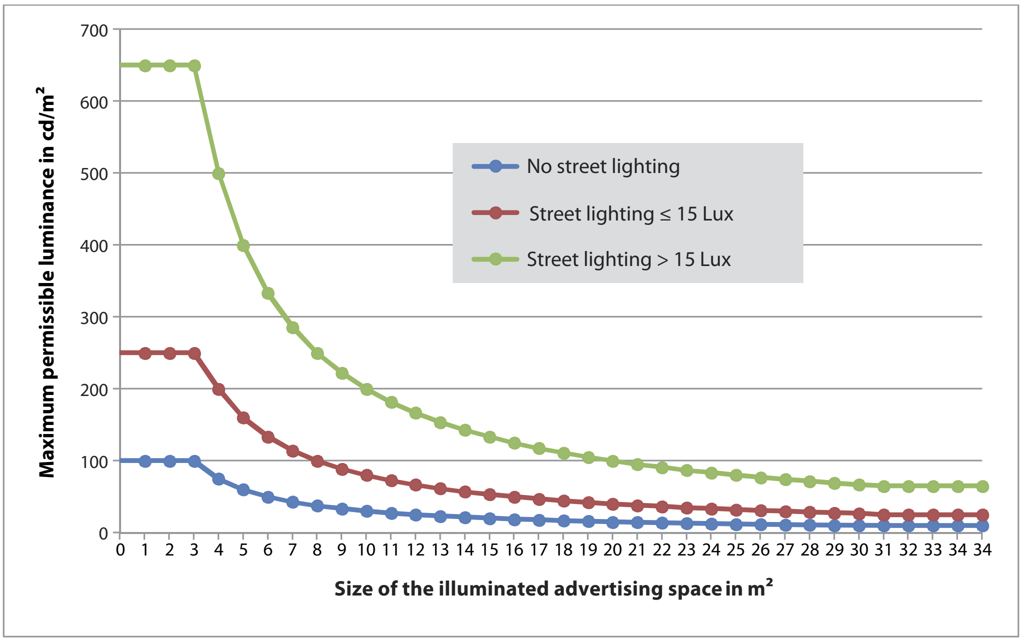


Fig. 44: Rating zones for the maximum permissible luminance levels in darkness

Fig. 45: Example of an impairment to traffic safety: the shop sign overwhelms the pedestrian traffic light

Lower luminance densities may be required in accordance with nature conservation requirements as defined by Austrian standard ÖNORM O 1052.

5.10.2 Immission protection

The procedure for assessing light immissions is described in Austrian standard ÖNORM O 1052 "Light imissions - Measurement and assessment".

ÖNORM O 1052 specifies the following limit values for the maximum permissible average vertical illuminance in lux at the window level of the room to be assessed in terms of the illumination of living spaces by illuminated advertising, depending on the operating time and assigned assessment area. Impact from lighting installations for traffic purposes, e.g. street lighting, are not taken into account.

Assessment area	6am-8pm	8-10pm	10pm-6am
Area A Built-up area with special protection needs, e.g. area around health resorts, hospitals, nursing homes	1 lx	1 lx	1 lx
Area B Residential areas, areas mainly used for housing, only occasional business premises, small housing estates	5 lx	3 lx	1 lx
Area C Mixed areas, business premises and apartments, local shopping streets	10 lx	5 lx	1 lx
Area D Core areas, business and industrial areas, major shopping streets	25 lx	15 lx	5 lx

Table 5: Austrian standard ÖNORM O 1052 - Maximum permissible mean vertical illuminance limits in lux at window level

Comments on Table 5:

The assignment of an assessment area is to be used as a guideline only and has no direct connection with building regulations, regional planning or zoning plans.

The limit values must be adjusted using correction factors in accordance with ÖNORM O 1052 for intensely coloured, moving, dynamic or flashing light sources.

When assessing the permissibility of new light sources, consideration must be given to the existing stock. If the existing immission value at the immission site to be assessed exceeds the limit values, then this value is to be regarded as an accepted level. According to Austrian standard ÖNORM O 1052 any further increase of the value (by additional light sources) is not permitted.

The methods described in ÖNORM O 1052 must be used to assess glare.

5.10.3 Nature and landscape conservation

According to Austrian standard ÖNORM O 1052, a distinction is made between safety-related lighting (SL) - e.g. street lighting or lighting from occupational health and safety installations - and non-essential lighting (NEL) which does not serve safety-related purposes.

Illuminated advertising, and the illumination of facades and buildings are examples of non-essential lighting (NEL).

In principle, advertising installations require a nature conservation permit if they are installed outside a built-up area (on the outskirts of Vienna, for example).

ÖNORM O 1052 defines the following operating times for non-essential lighting (NEL), depending on the assignment to an assessment area:

Assessment area	Permissible operating time
Area I Areas defined by law for the protection of nature, e.g. national parks, nature reserves, etc.	not permitted
Area II Areas not dedicated to development, open-air areas, undeveloped areas, grassland	not permitted *)
Area III Edge of residential area, rural and green areas	5am - 10pm *)
Area IV Densely built-up areas, urban areas, industrial areas	5am - midnight *)
*) *In areas II, III and IV, there are also isolated lighting installations with different operating times (in area II, however, only until 10pm) permitted. The remote effect must always be assessed. Any requirement to deviate from the recommended operating time must be justified.*	

Table 6: Austrian standard ÖNORM O 1052 - Assessment areas and permissible operating times

The following maximum luminance values apply to illuminated advertising signs:

Assessment area	Maximum luminance cd/m²
Area II	100
Area III	250
Area IV	650
NOTE: For area IV, it is recommended to switch off the lighting for advertising installations at 10pm.	

Table 7: ÖNORM O 1052 - Assessment areas and maximum luminance for illuminated advertising signs

Comments on Table 7:

Traffic regulations according to the Austrian highway code (RVS) may require even lower luminance levels.

The values apply to advertising surfaces up to 10 m². Larger advertising surfaces are to be given special ecological consideration - an assessment according to the RVS or consultation with the nature conservation authority is recommended

Illuminations only achieve their effect if they are above the threshold of perception and thus stand out from their surroundings. Eyes that have already adjusted to the dark have higher sensitivity; the darker the environment, the lower the intensity of the illumination can be.

Illuminated facades and floodlit buildings must be assessed in the same way and must not exceed the maximum mean luminance values listed in Table 8. In addition, it must be ensured that a uniformity of Lmean/Lmax ≥ 0.05 is maintained.

Assessment area	Maximum luminance cd/m²
Area II	5
Area III	10
Area IV	25

Table 8: Austrian standard ÖNORM O 1052 - Assessment areas and maximum mean luminance for floodlighting systems

The values in table 8 were derived from urban areas. The Slovenian Light Pollution Act (2007) stipulates a maximum average luminance of 1 cd/m² for facades.

In areas with low ambient brightness, facade luminances of 1 cd/m² are sufficient for effective illumination.

In areas with low ambient brightness, mean facade luminances of 1 cd/m² are sufficient for effective illumination.

Fig. 46: Standard-compliant building illumination is very bright in a dark environment and therefore not required for optimum perception, Hotel Alpenblick, Kirchschlag bei Linz

5.10.4 Illuminated advertising vs. cityscape

Illuminated advertising, even if it does not exceed the limit values, can have a disturbing effect on the cityscape at night, as sometimes visual accents are set that are completely interchangeable and have nothing to do with the city in which they are displayed.

5.11 Illumination of monuments

Monuments for which the criteria for façade lighting are not applicable should be illuminated from top to bottom as far as possible. The light beam should not extend beyond the monument to be illuminated. The use of shutters is recommended for this purpose.

5.12 Emissions from residential buildings

Interior lighting customary for residential purposes is not taken into account in the assessment of immissions according to ÖNORM O 1052. At the same time, the problem increases with larger window surfaces; sun protection systems and blinds or shutters can help here.

5.13 Illuminating private buildings and gardens

The lighting of private buildings and gardens should be as limited as possible - avoid inappropriate settings that do not fit into the surroundings.

5.14 Christmas illuminations

Decorative lighting should be limited to the period between 15 November and 15 January of the following calendar year. Operation during the night hours (10 pm to 6 am) with regard to business hours and tourism should be avoided.

5.15 Searchlights

According to Austrian standard ÖNORM O 1052, the use of light emitted directly upwards (e.g. search lights, spotlights recessed into the ground) should be avoided. The use of searchlights, lasers or similar long-range light sources is therefore to be limited to temporary events. The requirements of the Austrian Highway Code RVS 05.06.11 and RVS 05.06.12 and nature conservation regulations must be complied with.

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Glossary

Illuminance:
Illuminance is the luminous flux from a light source that illuminates a specific area.

Candela per square meter:
Physical unit of luminance (brightness per size of area). This is related, for example, to carriageways. The luminance value is independent of the distance.

Emission line:
Light colour that emits more radiation than other light colours.

Full cut-off light:
Type of light which emits practically no light above the horizontal plane. Luminous intensity class G6 according to EN 13201.

Infrared:
Range of electromagnetic radiation with lower energy - thus longer wavelength - than visible light; sometimes also referred to as thermal radiation.

Luminance:
Luminance is the impression of brightness given to the eye by an illuminated or luminous surface. Luminance describes the physiological effect of light on the eye and is used in outdoor lighting as a planning parameter.

Lux:
Physical unit of illuminance, defined as lumens per square metre.

Melatonin:
Hormone that is released in living beings during rest periods - in humans especially in the second half of the night.

Monochromatic light:
Light emitted only at a certain wavelength or frequency (e.g. from a laser, but also from a low-pressure sodium vapour lamp).

Photopic vision:
Day vision or cone vision, describes the vision of humans with sufficient brightness.

Disability glare:
Form of glare that measurably reduces the perception of visual information. It is caused by scattered light inside the eye, which reduces the perceptible contrasts by its veil luminance.

Purkinje shift:
Purkinje effect or Purkinje phenomenon (according to Jan Evangelista Purkinje) is the term used to describe the different perception of brightness for colours by day and night. It is based on the varied spectral sensitivity of the photoreceptors in day and night vision. During the day the cones are mainly active, at night the rods.

Scotopic vision:
Night vision or rod vision, at low brightness.

Searchlights:
Intense light source directed towards the sky (often swivelled periodically, often used in Austria to advertise discotheques).

Spectrum:
Breakdown of electromagnetic radiation into its wavelength or frequency components.

VIT:
Visual information transmitter with content not related to traffic (e.g. advertising).

Wavelength:
Measure for light colour. Red light has a greater wavelength than yellow, green and blue light.

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