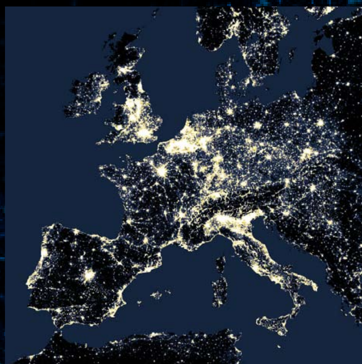
Loss of the Night

Transdisciplinary Research
on Light Pollution



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Berlin, 2010

Loss of the Night

Technology rarely fulfils only its intended function, but instead often shows unexpected impacts on natural and social systems. This especially applies to artificial light at night. The widespread application of artificial lighting has transformed civilization and certainly enhanced the quality of life. However, these benefits have been accompanied by hidden costs, leading to substantial ecological and environmental degradation and causing undesirable social, economic, and human health consequences. Because light has positive connotations with security, wealth, and modernity, humans tend to illuminate their environment. This is often done uncritically, with no regard for the manifold impacts of artificial lighting. As a result, the rapid increase in both the quantity and quality of artificial illumination has fundamentally transformed our nightscapes in the past few decades. Furthermore, lighting has become a major source of greenhouse gas emissions, being responsible for one-fourth of all energy consumption worldwide. Thus, the illumination of our nightscapes has potentially important, albeit almost completely neglected, impacts on culture, society, human health, economy, ecology, and coupled natural-social systems.

Light pollution is now a widely accepted concept for any unwanted or nuisance artificial light that has adverse effects on nature and humans. Nevertheless, our understanding of the adverse effects of light pollution is vague and based mostly on anecdotal observations and case studies. While air and water pollution have been investigated experimentally for decades, light pollution remains scientifically, culturally, and institutionally in the dark. Thus, we see an urgent need for transdisciplinary research on the physiological, human health, ecological, and socioeconomic significance of the loss of the night that addresses how illumination can be improved, both technically and institutionally, yet have fewer adverse effects. This requires enrolling multiple disciplines, including ecology, physiology, chronobiology, sociology, economics, landscape architecture, remote sensing and light engineering.

In 2009, seven institutes of the Leibniz Association have joined forces with three institutes of the Technische Universität Berlin, the Freie Universität Berlin, and the Helmholtz Centre for Environmental Research to found the transdisciplinary research platform "Verlust der Nacht" ("Loss of the Night"). Member institutes encapsulate a wide range of expertise in biological, social, and technological disciplines and aim to address the significance of artificial lighting with a holistic approach. The research platform is funded by the Federal Ministry of Education and Research (Germany) and the Senatsverwaltung für Bildung, Wissenschaft und Forschung (Berlin) and is embedded in the project MILIEU of the Freie Universität Berlin.

As our world grows ever-more illuminated, comprehensive research on the environmental effects of artificial light and their mitigation is critically important. This will enable us to better understand the consequences, to develop improved technologies, and to better adapt policies. It is our hope that the following series of articles initiates further research and debate on the loss of the night.

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Project leader ‚Verlust der Nacht'

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Photos: private

Astronomy/Cultural History

Enchantment and threat of the night

Historical and astronomical perspectives on artificial light and darkness

Photos: Andreas Hänel

This series of photos shows how greatly the degree of light pollution can vary, depending on the location. All photos were taken under almost identical external conditions with the same camera (Canon 350D), lens (Sigma 1.8/28mm), and the same camera settings (RAW-format, ISO 800, 20 second exposure). The upper row shows photos taken towards the zenith (upwards), while the bottom shows horizontal views. From left to right the pictures were taken in: Eisenthalhöhe in Carinthia (Austria), in a suburb of Osnabrück, in Radebeul close to Dresden, and Rheinaue close to Bonn (all three in Germany).

Axel Schwope (AIP),
Ute Hasenöhrl (IRS)

Light usually evokes positive connotations. In philosophy and religion, it is often regarded as an emblem of spiritual enlightenment. From early on, artificial light shared this symbolism. Electric light in particular was often equated with urban modernity, especially since its introduction in the 1880s corresponded with – and contributed to – a profound change in the working and living conditions of an increasingly industrial society. Large cities like the 'electropolis' Berlin were not only spaces of extensive artificial illumination, they were also deliberately framed as such (e.g. festivals of lights). Darkness and night, on the other hand, were frequently associated with poverty, danger, gloom, obscurity and (rural) backwardness. This tendency was fortified as brightly lighted urban nights became the rule and their absence linked to threatening irregularities like blackouts and outages. These polar images of dark and light, however, were (and are) neither universal nor uncontested. Romantic notions of the night as a time of mystery and romantic love persisted. Moreover, the negative impacts of artificial light – whether real or perceived – on the health of humans and animals, the aesthetic qualities of town- and landscapes (e.g. luminous advertising or flood-lighting), as well as the ecological aftermath of energy consumption were also criticised from early on. Historical research so far has mostly marginalised these opponents of artificial light, concentrating on its significance as a symbol of urban modernity instead. For a more differentiated story of artificial light, however, both positive and negative images of nightscapes have to be analysed, taking into consideration the genesis, continuity and change of its symbolic values as well as the interests and institutions connected with it in different spatial contexts. Cultural and environmental history can then provide valuable information for the development of new concepts of lighting, shedding light on the origins of social values, institutional and technical path dependencies and the scopes of actions available for the actors involved.

The oldest science, astronomy, is a particularly prominent argument for the dark side of bright light. The light domes above our cities are growing at rates of five percent or more. They are extinguishing the starry sky by creating an artificial twilight. Light emitted from point sources (street lighting, luminous advertising and others) becomes a light carpet through scattering and reflection. For about half of European citizens, the Milky Way has become unobservable in principle. Following this recognition, professional astronomy long ago started escaping the bigger cities towards less polluted, remote sites. E.g. the new observatory of Berlin, famous for its 1846 discovery of planet Neptun, moved from its central site to a hill 25 kilometers away by 1913. New observatories over the past 50 years were built only at very remote sites or even in space. The ground-breaking discoveries of extra-solar planets or the accelerated expansion of the Universe, which is thought to be related to a mysterious form of so-called Dark Energy, would not have been possible without going to those places. The scientific exploration of the skies seems to not yet be very seriously influenced, although protection of the remaining sites against further light pollution is important. The cultural loss, however, might be regarded immense already. The man on the street finds himself estranged from the universe by not being able to see the stars with his own eyes. It is worthwhile to preserve the skies via various routes. This would mean stopping further light pollution by intelligent lighting, awaking awareness for the problem and educating people about the mysteries and wonders of the skies.

Illuminated advertising at Potsdamer Platz in Berlin in 1928

Photo: Stiftung Stadtmusem Berlin. Reproduction: Michael Setzpfandt, Berlin

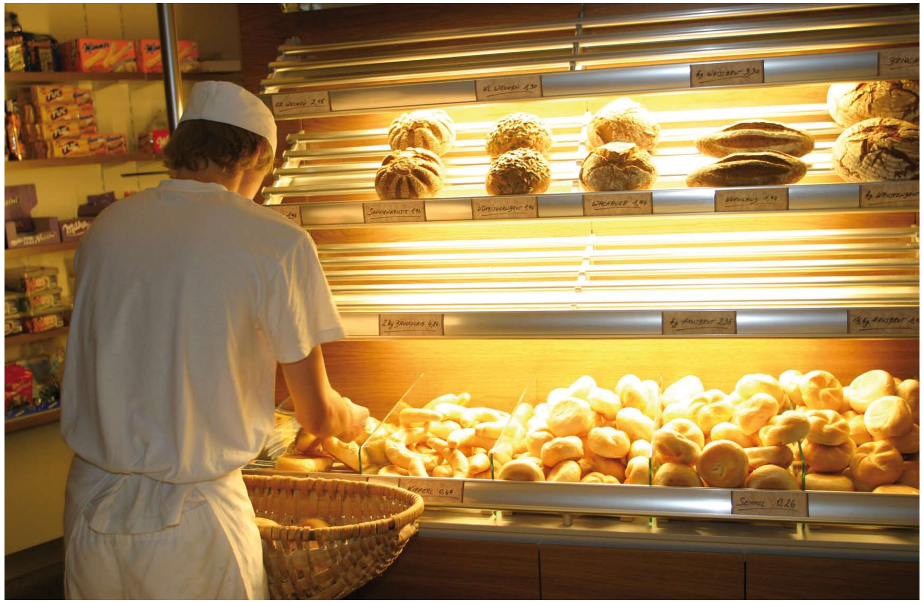


Photo: H. Kollinger/Digitalstock

An increasing fraction of people perform shift work during the night.

Nocturnal light exposure: Its relevance for humans

Barbara Griefahn (IfADo)

The natural light-dark cycle is the major *zeitgeber* (exogenous cue) for humans as well as animals. It synchronizes the individual circadian rhythm to the 24-hour period of the geophysical day. The individual period that deviates from the 24-hour rhythm demands a daily reset and causes the large inter-individual variations of the phase position which constitutes a personal trait. These variations concern physiological functions and personal behavior. This becomes particularly evident in persons with extreme phase positions i.e. in morning and evening types. Morning types go to bed, wake up and perform best at an earlier time than evening types. Moreover, the physiological rhythms of morning types are 3 to 4 h in advance of evening types.

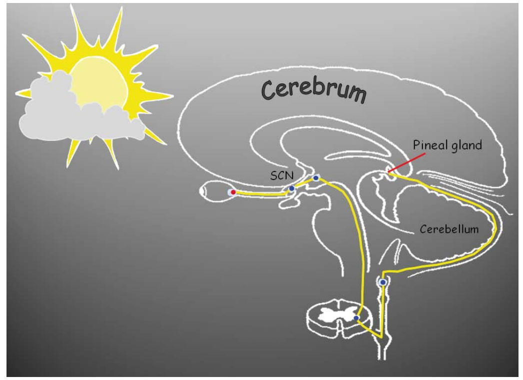
In contrast to the inter-individual variations, the intra-individual variations of the circadian rhythms are very low in a synchronized environment. This stability is, however, disturbed by artificial light and mediated by the suppression of melatonin synthesis. The extent of these disturbances depends on the intensity, color, and duration of light and on the time at which light exposure occurs. Light exposure in the late evening or in the early night delays the melatonin profile and other physiological rhythms; light exposure late at night or early in the morning advances the phase position. These changes are stronger when the temporal distance between light exposure and the crossover point which coincides with the minimum of core body temperature are shorter. Studies performed during the last few years have shown that even very low light intensities are sufficient to at least partially suppress melatonin synthesis.

These disturbances are relevant for flights across several time zones and for shift work. Westward flights correspond to a unique prolongation and eastward flights to a unique shortening of the day, i.e. a unique delay or advance of the sleep-activity-cycle. The various physiological functions follow these alterations with different delays and speed, thus causing an internal de-synchronization that causes the 'jet lag' symptoms i.e. sleepiness, tiredness, dizziness, irritation etc. To fully resynchronize the sleep-activity-cycle takes about the same number of days as the number of hours by which the sleep-activity-cycle was shifted.

Far more frequent are disturbances due to night work. The adaptation of the rhythms of the physiological functions (of the circadian system) to night work is hindered by the concurrent influence of light scenarios associated with work and of the natural light-dark-cycle. The dissociation between the sleep-activity-cycle that is delayed by eight hours and the physiological rhythms causes similar health-related symptom as in jet-lag. Acute symptoms (sleep disturbances, gastrointestinal problems, dizziness etc.) may in the long run contribute to the genesis of cardiovascular diseases and, as melatonin acts as an oncostatic agent, even to the genesis of cancer.

Studies on the effects of shift work and flights across several time zones have demonstrated that exposure to light at the wrong time causes adverse effects on health. Therefore, light pollution in built-up areas is regarded as critical. The respective light intensities are in a range that partially suppresses melatonin synthesis and might cause chronobiological instability of the phase position and contribute to the acceleration of multi-factorial diseases in the long run.

Illustration: IfADo



Neuronal connections of the pineal gland (modified from Tamarkin et al. 1985)

Chronobiology

Light: The pacemaker of life

Annette Krop-Benesch (IZW),
Melanie Dammhahn (DPZ)

Life on earth is subject to a permanent cyclic change of day and night, light and darkness. During the course of evolution, organisms adapted to certain periods of the day-night cycle in the same way as they adapted to other specific environmental conditions of their habitat. Now, daily rhythms are known for almost all organisms ranging from bacteria to humans. These rhythms are based on particular genes, which generate a pace at the cellular level. The internal pace is synchronised with the environment by a pacemaker. In vertebrates, this pacemaker is localised in the brain.

Under natural conditions, all rhythms of the body are synchronised with each other and to the day-night cycle. If an animal is kept in darkness, however, its rhythm deviates slightly from 24-hours and starts to run freely at an individual, endogenously generated pace. Depending on the species, these internal rhythms vary between 22-28 hours and are thus referred to as circadian (latin for about one day). One can compare this endogenous rhythm with a clock that runs either too slow or too fast. Synchronising the internal clock with the environment requires periodically occurring external signals, so called *zeitgebers*. The strongest *zeitgeber* is light. A strong change in light intensity, like that at dawn, sets the rhythm of the internal clock to zero and starts a new cycle with the internal period length.


Photos: Melanie Dammhahn/DPZ

Nocturnal primates like the Madame Berthe's mouse lemur (Microcebus berthae) *are characterised by big eyes and ears in contrast to diurnal primates like the Coquerel's Sifaka* (Propithecus coquereli)*. Both species live in Madagascar.*

The link between pacemaker and body is mediated by the hormone melatonin. This hormone is only produced during darkness in the pineal gland; light inhibits its production. Periodic changes of melatonin concentration in the body synchronise the basic functions of the body. Overall, they enable the organism to prepare for activity at the end of the resting period ensuring full performance. Further, synchronisation of many body functions facilitates effective regeneration during resting and sets resources free for important metabolic functions such as growth and development. The change between light and darkness, naturally occurring during twilight, is the signal to set the internal clock. If differences in the light intensity of day and night decrease, e.g. due to artificial lights, the signal gets weaker. As a result, internal clocks can no longer be correctly reset, ultimately leading to a distrupted synchronisation between organisms and their environment.

Predictable activity periods are indispensible for life; they facilitate locating prey and mates as well as avoiding predators and competitors. Concentrating activity to either the night or the day often allows two very different species communities to use the same habitat. One example is the diurnal and nocturnal primate species. Originally, primates were a group of small nocturnal mammals. After the extinction of the dinosaurs in the Tertiary Period, primates stepped out of the dinosaur's shadow and evolved into species that are entirely day-active. Interestingly, this evolution of diurnal primates happened several times independently. On the mainland, Old World and New World primates became diurnal, whereas most of their cousins, the bushbabies, lories and lemurs, stayed nocturnal. On the island of Madagascar, which was never colonised by primates other than lemurs, lemurs too evolved several diurnal species. Some primates even returned to the nocturnal niche, as the owl monkey of the New World. As a result, there is an impressive change between diurnal species and the "ghosts of the night" during the dawn in many tropical forests.

Additionally, seasonal change in day length is important to regulate behaviours such as mating, paternal care, hibernation, migration and moult. Artificial light elongates the perceived day and might suggest longer summer. As a result, offspring might be born too late in the year to find optimal conditions for growth and development. Also, there are already indications that some birds have postponed their autumn migrations, while other species have started preparing for hibernation later in the year, which might lead to a series of related changes in life-history patterns.

The illuminated city

Dietrich Henckel (TUB),
Timothy Moss (IRS)

Artificial light possesses powerful symbolic meaning. When introduced into cities over a hundred years ago it heralded the beginning of modernity. With artificial lighting urban life became transformed, no longer constrained by the rigid distinction between day- and night-time. Economic and social activities were extended into the night hours, streets and parks became safer, commercial goods, historic buildings and whole cities were lit up for adulation. Artificial lighting today fulfils multiple functions for society and, for this reason, enjoys a very positive image in general, if subject to socio-cultural variations.

The high esteem in which artificial lighting is held, however, helps to gloss over its 'dark side'. Light pollution – understood as the degradation of natural nocturnal light by artificial lighting – has a number of negative effects on nature and humans (see the other contributions in this publication). Today, criticism is increasingly being voiced not only about the high energy use associated with electrical lighting, but also about the negative ecological and health implications of excessive lighting. The positive images associated with streetlamps and floodlights, advertising lighting and sky beamers are being questioned. Perceptions of artificial lighting are gradually changing. This process is, however, seriously under-researched.

During events like Berlin's "Festival of Lights" (Germany), landmarks are specially illuminated to create an attraction.

Photo: Ricarda Pätzold/Institut für Stadt- und Regionalplanung der TU Berlin

Photo: T. Storm/Digitalstock

Extending the daytime – Changing current practices and policies relating to artificial light demands sound knowledge about the emergence and development of existing lighting systems and about the symbolic values, strategic interests and institutional rules which underpin them. The "lost night" is a consequence of economic and social activities being extended into the night with the help of artificial lighting. Examples include late-night shopping, shift work, round-the-clock public transportation and an attractive night-life, as captured in the motto "the city that never sleeps". This general trend conceals, however, some important distinctions:

Firstly, the dissemination of artificial lighting is spatially highly selective. Lighting is today an indicator for urbanisation: high in places of intensive human activity, low in sparsely populated areas.

Secondly, high intensity of artificial lighting is not necessarily a permanent phenomenon. Over time, lighting in any one place can be subject to cycles of high and low intensity.

The price of the "lost night" – Being liberated from the natural day/night rhythm – turning the night into day – comes at a price, however. The considerable costs to society include above all the installation and energy costs of producing artificial light. Germany's local authorities consume over four billion kilowatt hours each year for street lighting alone. Globally, artificial lighting is responsible for around a quarter of total energy consumption. In addition, lighting up the night causes a variety of indirect costs, including sleeplessness and associated health problems and disturbances to ecosystems dependent on day/night rhythms. These indirect costs, in particular, are very rarely considered when planning new lighting systems.

The opening of Berlin's new central station, with a one hour laser light show on May 27, 2006.

Lighting concepts of the future – Devising and implementing more sustainable forms of artificial lighting is not a purely technical task, but is dependent also on contributions from the social sciences and humanities. We need to know much more about the cultural significance of lighting and the willingness to consider ecologically sensitive lighting systems. We need to identify actor constellations likely to support (or block) such systems. We also need to generate knowledge about suitable institutional arrangements, learning from innovative lighting concepts and policies developed elsewhere at European, national, regional and local levels.

Artificial light and the environment

Photo: Fotolia.de (Claudio Baldini)

The large number of private and public artificial light sources can affect both individual organisms and ecosystem functions.

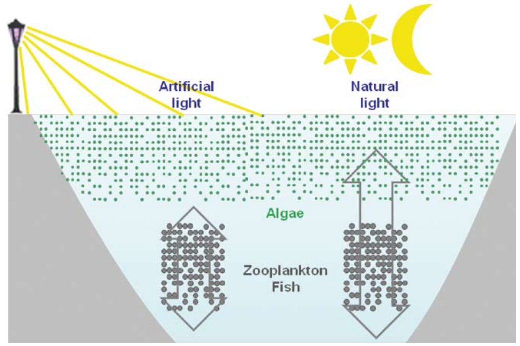
F. Hölker (IGB), E.K. Perkin (IGB),
C.C. Voigt (IZW), M.T. Monaghan (IGB),
C. Wolter (IGB) & K. Tockner (IGB)

Recent decades have seen a profound transformation of the nightscape, with an increasing proportion of the Earth's surface being illuminated at night. Artificial light provides countless benefits to humans, but has largely unknown effects on the natural ecosystems on which we depend. As our world grows ever-more illuminated, comprehensive research on the environmental effects and their mitigation is needed to better understand the consequences and to better adapt policies and practical responses to the loss of the night.

Natural patterns – With few exceptions, for example in the deep oceans and underground, all life on Earth has evolved to live in cycles of light and dark. Most plants and animals are adapted to a rhythm of light-dark, from 12-hour cycles at the equator to 6-month cycles at the poles, as well to lunar and seasonal cycles. Organisms respond to changes in light levels in ways that control or alter a broad range of behavioural and ecological patterns.

Ecosystem effects – Artificial lighting can disrupt the natural cycles of organisms, with largely unforeseen consequences to their biology and their interactions within an ecosystem. Depending on the intensity, colour spectrum, timing, and duration of illumination, artificial light can induce disorientation, attraction, or repulsion from the lit areas. In turn, this may impact daily or seasonal migrations, feeding, communication, and reproduction. For example, light can control the daily vertical or horizontal migrations of fish and their prey in lakes. Fish and birds may become confused by artificially lit bridges or buildings, impeding their migration. Insects are attracted and often exhausted by artificial lights which can "suck" them from their habitats as if by a vacuum cleaner. Removed insects are no longer available as a food source for fish and birds. Some predators take advantage of this attraction: many bat species are attracted to the insects that congregate around light sources; spiders build webs at street lights in order to capture disoriented and exhausted insects; geckos hunt on walls and ceilings near artificial light sources. Although this could be a positive effect of light; increased food concentrations benefit only those few species that exploit light sources. The result could be an altered community structure, distorting food webs and bringing ecosystems out of balance. Illuminated landscapes could also be vulnerable to invasive species where local populations have been depleted or eliminated as a result of artificial light.

Illustration: Franz Hölker/IGB



Light causes changes in the circadian rhythm (e.g. a reduction of the daily migration amplitude of fish and zooplankton). But what are the consequences for biodiversity as well as for the ecosystem and its productivity?

Evolutionary effects – Since many organisms have evolved with diurnal, lunar and seasonal rhythms, evolutionary consequences can be expected as well. Some species will be genetically capable of adapting their behavior, physiology, growth, and reproduction to new environments, but other species will not. Organisms with short generation times are likely to adapt artificial light more rapidly, and may have already done so.

Effects on ecosystem services – Light pollution can also be considered an important driver behind the erosion of ecosystem services (e.g. pollination of plants by moths, loss of biodiversity, and changes to food webs) and thus the productivity of a system.

Requirements for a sustainable illumination system

Dirk Uhrlandt (INP)

So far, the design of lighting systems has focused on design for human needs. A lighting system has to provide light with necessary intensity and quality as well as minimised energy consumption. In addition, the light should be provided only at the time and place where it is really needed. 'Light quality' needs to be defined in more detail, including information about new aspects. Well known parameters for human visual perception are the colour of the light and colour rendering. Non-visual influences of artificial light can result in negative effects on humans and ecosystems as mentioned in other sections. These effects, such as the impact on the human hormone balance and the circadian rhythm have to be taken into account when designing illumination systems. Similar effects on animals and ecosystems must also be considered. Therefore, the spectral sensitivity and the decisive dose of the light for all these effects and mechanisms behind them must be determined. Based on this knowledge, it would be possible to design light sources with tailor-made spectra even with techniques available today.

The City of Augsburg realized a sustainable illumination.

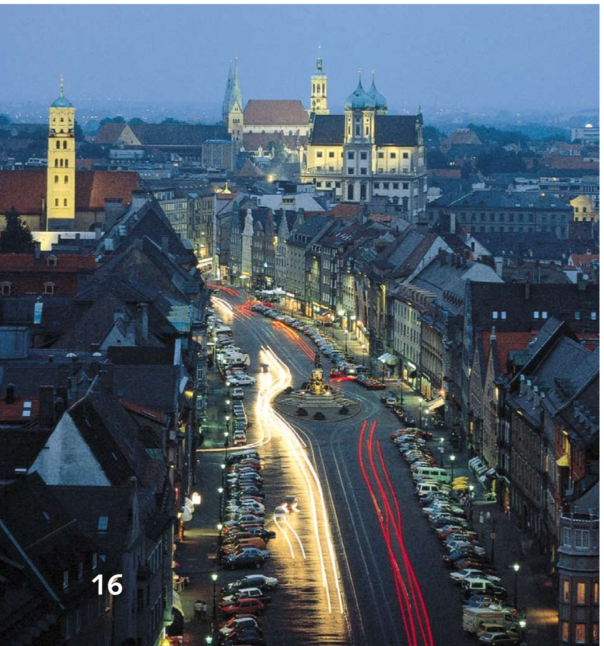


Photo: Regio Augsburg Tourismus GmbH

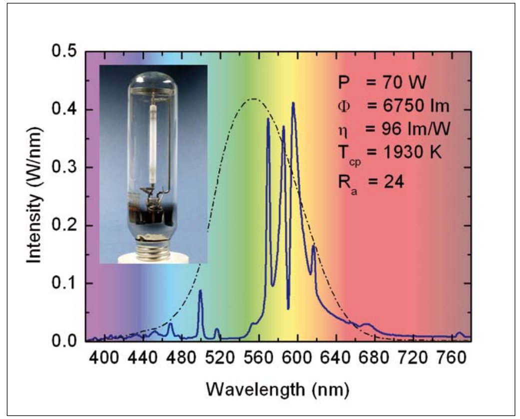
Fluorescent lamps (low-pressure plasma lamps in the form of tubes or compact lamps, known as power saving lamps) are currently common sources for indoor lighting because of their high efficiency. Here, white light is generated by a phosphor mixture on the tube wall which is excited by ultraviolet radiation originating from the plasma in the tube. The emitted spectrum is quite flexible and can be adapted by using different phosphors, for example. Radiation in the near ultraviolet range can be avoided to a large extent through absorption and transfer to phosphors.

These sources will be probably replaced in future by light emitting diodes (LED, a semiconductor light source) with an even higher efficiency. One of the ideas to produce white light with LEDs is to combine a blue-emitting diode with a phosphor which transfers a part of the blue light into a yellow one. The alternative concept of colour-mixing red, green and blue light can be applied to change the spectrum of LED systems.

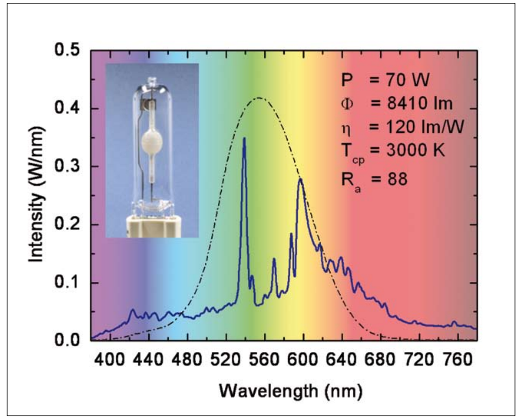
Currently, the main source in street lighting systems is the high-intensity discharge lamp (HID) based on high-pressure thermal plasma which emits visible and also white light directly without utilizing a phosphor. These sources provide light with high luminance and very good efficiency but are presently only available in high power units. The inclusion of new filling materials in metal-halide lamps provides a variety of spectral characteristic with the high energy efficiency of the HID source. The first attempts to change and control the spectrum just through the electrical ballast have been tested in labs.

High-quality and sustainable illumination includes the temporal control of light dependent on its real demand. For example, high light intensities are necessary at nightfall in street lighting, whereas a decreased luminance level is sufficient for road safety during night in most cases. In dynamic light systems, the light sources will be operated more and more in dimmed modes. However, dimming a light source, in most cases, means leaving the optimum operation zone; resulting in a loss of energy efficiency or lowering the source lifetime. The search for new operational modes (for energy efficient dimming) currently represents a main point of research.

Illustrations: INP



Spectrum of a high-pressure sodium lamp (solid line, OSRAM Vialox 70 W NAV(SON)-T) compared to the standard sensitivity of the human eye (dash-dotted line), with power P, luminous flux Φ, efficiency η, colour temperature T_{cp} and colour rendering R_a.



Specifications of a metal halide lamp (OSRAM Powerball HCI-T 70 W / WDL) compared to the standard sensitivity of the human eye (dash-dotted line).

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