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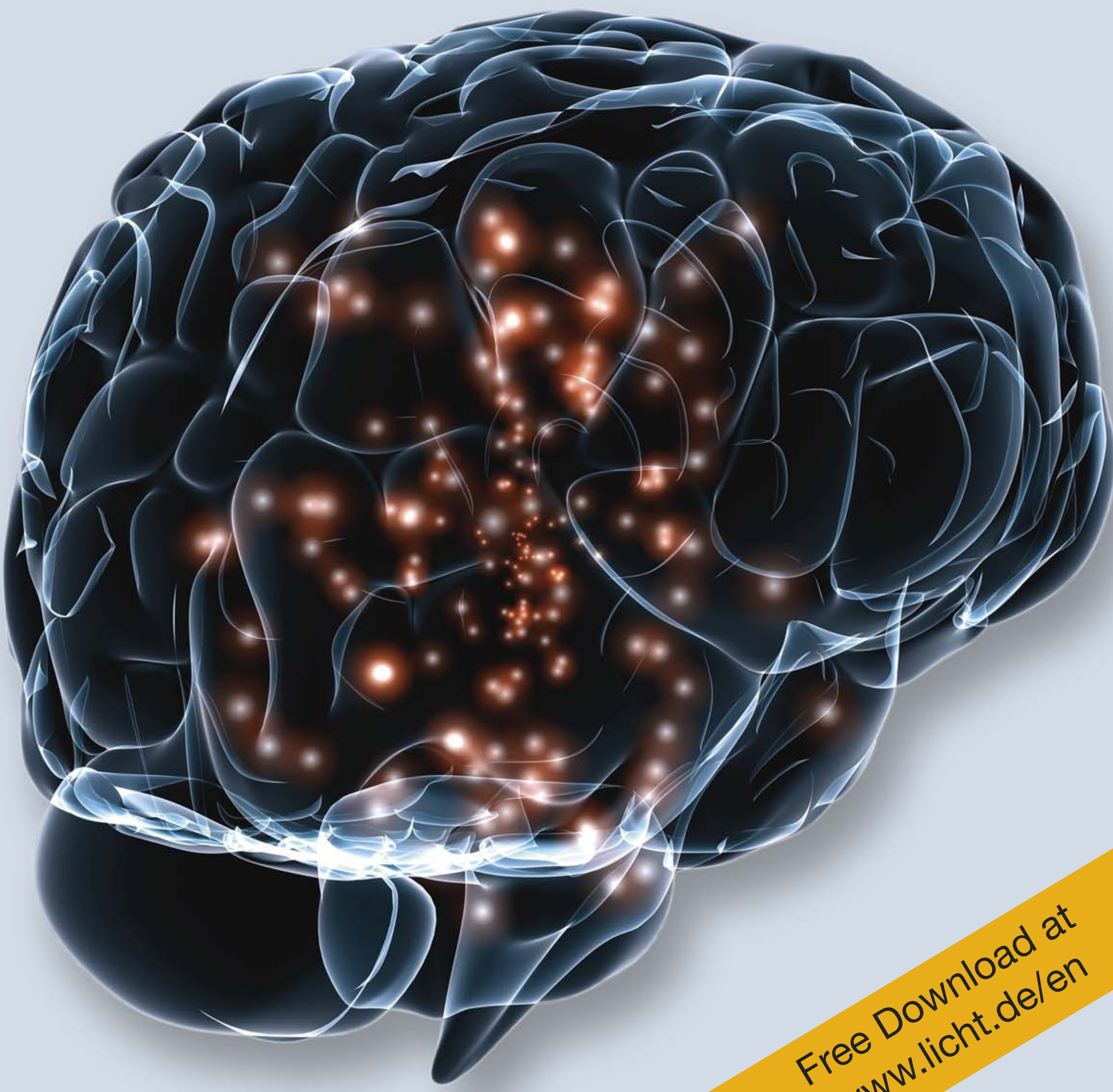
Impact of Light on Human Beings



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01

Editorial

Since launching its LED Lead Market Initiative at the end of 2008, Germany's Federal Ministry of Education and Research has put up more than €40 million for technology and municipal pilot projects. With the public lighting competition "Kommunen in neuem Licht" and the two sectoral projects "UNILED" and "Performance Quality Label" (PQL), it has shown that LED technology

- *is usable within the existing infrastructure without major additional investment*
- *permits energy savings between 50 and 90 percent*
- *is felt by users and residents to bring an improvement in lighting.*

In the light of these project findings, the Federal Government has driven forward the implementation of the new lighting technology. Under the municipal directive for energy efficiency, the Federal Environment Ministry has supported hundreds of LED projects. In a decree issued in 2013, the Federal Ministry of Transport made LED the lighting solution of choice for federal buildings. The federal states (Baden-Württemberg and shortly NRW) have started to follow suit. The LED Lead Market Initiative has thus achieved its objective. By international standards too, Germany is a lead market for LED technology – not only in terms of international high-profile flagship projects in Freiburg, Munich, Trier and elsewhere but also in terms of euros and cents for the large number of mostly small and medium-sized enterprises.

One of the issues closely connected with LED technology is the impact of light on human beings. Modern testing and measurement methods enable the physiological, psychological and social effects of light to be investigated much more thoroughly than in the past. And with the new scope for colour control and colour rendering that LED technology offers, the findings are much easier to harness than with conventional lighting technology. When public utility companies marketed the new municipal gaslight in the early decades of the 20th century, brightness – measured in "candlepower" – was pretty much the only yardstick used. As the century progressed, luminance, illuminance, contrast rendition and glare were added as quality criteria. Today, light colour, colour temperature and the interplay between light, illuminated surfaces and human perception are starting to play a central role.

In 2013, the Federal Ministry of Education and Research called for "intelligent lighting". sending out an invitation for basic research to be conducted in these areas. The projects selected will be launched shortly. With the new technology, research is again an important issue for the lighting industry. I look forward to the new lighting solutions signalled by numerous examples in this booklet.

Dr. Frank Schlie-Roosen
Head of Optical Technologies/Photonics Division
Federal Ministry of Education and Research

Lighting Special

Better light for a better quality of life

Light synchronises our “internal clock”. Lighting that copies daylight has more than just a visual impact; it supports bodily functions 24 hours a day. We feel good, we are productive and we can sleep better.

Light does us good. We are reminded of that every year in spring: when the days get brighter we feel more active, we are in a better mood and we are generally more focused than in the dark winter months.

This shows that we need light for more than just vision. Its importance is a lot more far-reaching than that: It synchronises our “internal clock” – a complicated control system that coordinates all bodily functions in a 24-hour rhythm. That control system needs to be recalibrated daily by daylight. Without light as a cue, our internal clock gets out of synch. This can result in lethargy and tiredness, mood swings or even a weakened immune system.

Around the turn of the millennium, scientists identified photoreceptors in the retina that do not facilitate vision but set our internal clock. They respond very sensitively to light with a high blue content.

That discovery injected a whole new dynamism into the topic of light and health. Today, adaptive lighting can crucially improve quality of life. Circadian lighting that brings daylight indoors and is supplemented as required by artificial light

- supports the human sleep/wake rhythm
- thus boosts vitality and helps us sleep better
- promotes wellbeing and health
- enhances productive capacity and concentration.

The right lighting helps meet human needs

The advantages of dynamic lighting are shown by numerous studies worldwide and a growing number of practical applications. Modern industrial society fosters an almost 24/7 lifestyle and dynamic lighting has the ability to help us reconnect with our internal clock.

We no longer spend much time outdoors. Our lives are predominantly played out in enclosed spaces under artificial lighting that normally lacks the dynamism and biological effect of daylight. That has consequences for human health and performance: during the winter months, nearly 40 percent of Germans experience a lack of drive and mood swings that can develop into depression. Lighting that delivers non-visual impacts can nip that development in the bud.

Good lighting is particularly important for older people. Their numbers will continue to grow in the course of demographic change and good lighting design needs to take account of that. As we get older, we need more light to perform visual tasks, e.g. at work. But that is not all. Quality of sleep also steadily deteriorates. Melanopic lighting and illuminance levels tailored to older people’s needs have a stabilising effect here – enhancing wellbeing and motivation.

The new edition of booklet 19 takes account of the latest research findings and presents examples of new applications. The switch to energy-efficient LED lighting and the development of intelligent lighting control systems are not just the key to extremely energy-efficient lighting solutions. They also open up totally new opportunities for supporting human functional, emotional and biological needs.

Biologically effective lighting concepts play a growing role

market study conducted by international management consulting firm A.T. Kearney for the German Electrical and Electronic Manufacturers’ Association (ZVEI) and LightingEurope forecasts that “human centric lighting” will command around seven percent of the lighting market by 2020. The majority of applications, according to the researchers, will be in office buildings, healthcare facilities, industry, educational establishments and private homes.

Joint efforts by everyone involved are needed to pave the way ahead. More re-

Terminology

Chronobiology is concerned with the **non-visual effects of light**. Many in this context speak of **biologically effective lighting** but that is not a precise descriptor because “biological” also encompasses visual processes. A more accurate term – one that is used in the new draft pre-standard DIN SPEC 5031-100 – is **“melanopic effects of light”.** These are the non-visual effects facilitated by special photoreceptors containing the photosensitive pigment melanopsin.

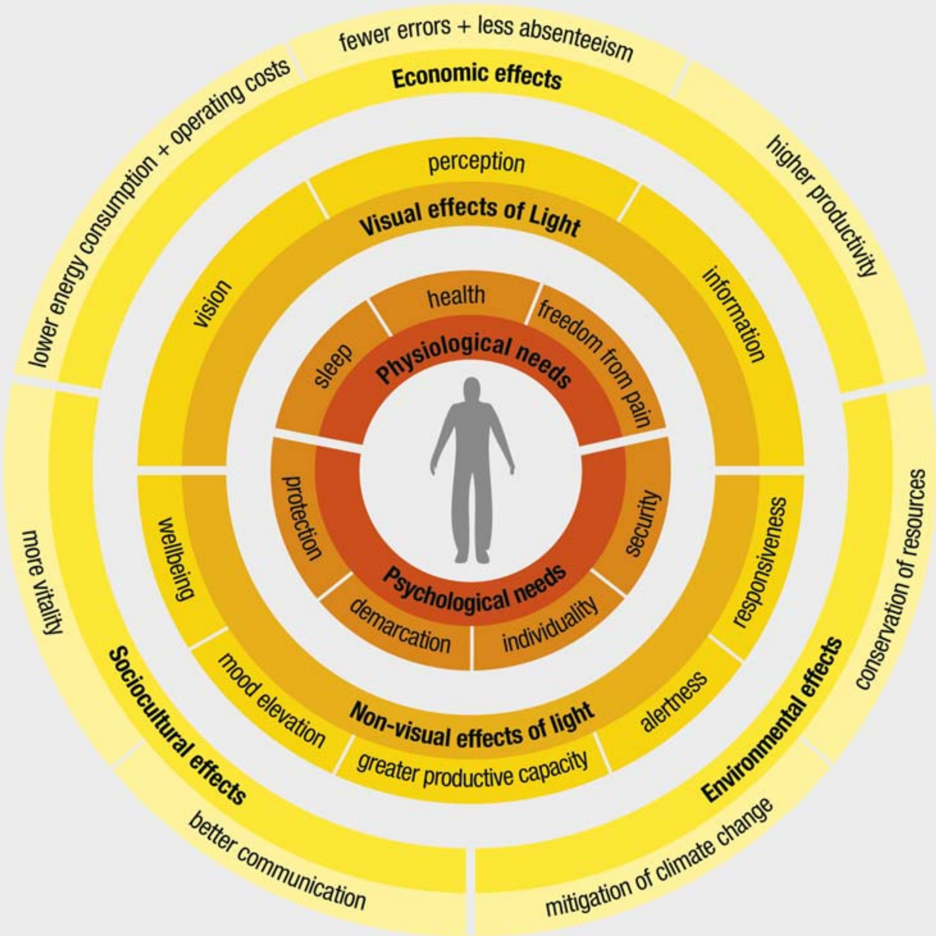
At times, the expression **circadian lighting** is also heard. This is a correct term where lighting is designed to stabilise the human day/night rhythm. It should not be used for brief activating “showers of light”.

The term **dynamic lighting** is also commonly used. This can have an effect on circadian rhythms if colour temperature and illuminance vary in the same way as daylight. At the same time, however, the term also describes light that changes (e.g. in colour) but has no biological impact.

search is required; so is comprehensive information about the connections between light and health. This booklet aims to help provide that information. Action should also be taken by policymakers. For example, the non-visual effects of light need to be more fully taken into account in relevant regulations. Designers and decision-makers require reliable design recommendations, such as those formulated for the first time in the draft pre-standard DIN SPEC 67600. Designing a biologically effective lighting installation calls for a great deal of detailed knowledge, which needs to be reflected in the official scale of fees for services by architects and engineers (HOAI).

An important step has been taken. After a ruling by Düsseldorf Higher Regional Court, it is now possible to select and assess not only the energy efficiency but also the quality of a lighting installation as a criterion for the award of public contracts. This makes biologically effective lighting an important aspect of the quality of a building. In future, energy performance will not be the only rating that counts; a lighting installation's contribution to human wellbeing will be another.

Model of the effects of light on human beings



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02

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[03] Light is life: it does more than just enable us see, it also has a direct effect on our wellbeing and health.

04

Human evolution is shaped by light

Light is life. The first life on Earth developed three billion years ago with the help of the sun. Homo sapiens – the "wise" or "knowing" man – has been around for about 200,000 years. For much of that time his sole source of light was fire. Electric light has only been in use for around 150 years. No wonder daylight plays such a key role in human life.

[04–06] Day or night, summer or winter: light determines the rhythm of life on Earth – including human life. In the course of evolution, human beings have also adapted and developed an internal clock.

All life on Earth is spatially and temporally organised. Many processes in nature are rhythmic. The Earth rotates around its axis every 24 hours and orbits the sun every 365 days. Hence the sequence of day and night, summer and winter. The Moon, in turn, orbits the Earth, joining with the Sun to create tides and establish a monthly rhythm. These cycles have had a major impact on habitats. Many plants, for example, adapt their survival strategy to day and night. They open their flowers in response to the first sunlight, making their nectar accessible for insects. The insects, timing their foraging accordingly, pollinate the plant – thus ensuring their own and the plant's survival.

The example shows that over the course of time, organisms have repeatedly had to adapt their internal clock to external rhythms. The ability to do has proven a useful evolutionary skill.

Human beings have also developed a genetically internalised awareness of the passage of time. At night, for example, our body functions in a very different way than during the day. This was vital for survival in prehistoric times. During the day, people needed to be physically fit to go hunting and obtain food; at night, the body needed sleep and rest. Even today, our body is still programmed to switch regularly between waking and sleep phases. They play a crucial role in health and wellbeing.

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Biological rhythms

Controlled by the brain, the same programme is re-run day after day in the human body. An internal clock controls not only our sleep and waking phases but also our heart rate, blood pressure and mood. Every cell and every organ has a rhythm of its own that needs to be synchronised regularly with the outside world. Brightness during the day and darkness at night provide the most important cues.

Many bodily functions are cyclical – both in human beings and in other living creatures. Chronobiologists distinguish between three major categories based on length of cycle:

- *Ultradian rhythms* span only a few hours. Examples include times of day and hunger, sleep and waking phases in infants.
- *Circadian rhythms* are geared to day and night. They last around 24 hours (circa = approximate, dies = day).
- *Infradian rhythms* have cycles longer than 24 hours, e.g. the changing seasons.

Circadian rhythm

Human beings and their bodily functions have daily and seasonal rhythms. From individual cells to entire organs, every unit controls its own time programme. Breathing and heartbeat, waking and sleep – all biochemically controlled functions have their individual highs and lows over the course of the day.

Shortly before we wake up, our body temperature, blood pressure and pulse rate rise. Around an hour later, the body produces stimulating hormones. Doctors know that the risk of heart attack is at its greatest *between 10 a.m. and noon.* But this is also the time of day when we find brain teasers like Sudoku easiest and when short-term memory is at its best. So it is a good time for an exam or job interview.

Stomach acid production peaks *between noon and 2 p.m.*, facilitating digestion of a midday meal. When producing acid, the stomach consumes so much energy that the rest of body feels fatigued.

But even if we skip lunch, we hit a performance "low" at *midday*. In the *early after-*

09

10

noon, body and mind start to pick up again. Now, it is sensitivity to pain that reaches its lowest level. So patients who are sensitive should make dental appointments at *around 3 p.m.*, not during the morning.

Anyone engaging in sport *between 4 and 5 p.m.* gets more benefit than at any other time of the day. It is the perfect time for muscle-building and fitness training. And the glass of beer afterwards is most efficiently digested *between 6 and 8 p.m.* This is when liver performance peaks; alcohol tolerance is high.

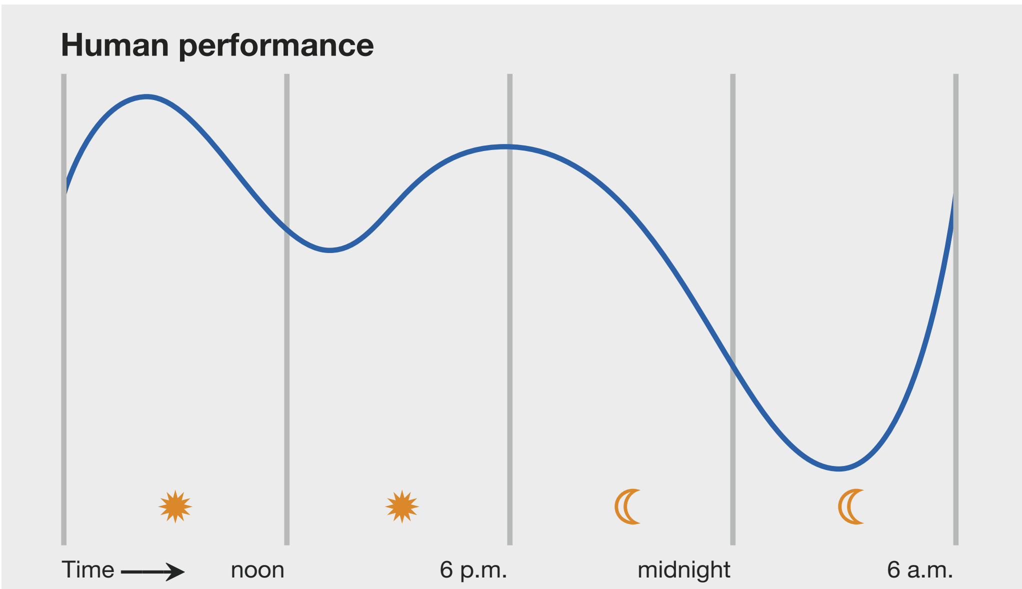
When it gets dark, we feel tired. *At 3 a.m.*, our body reaches an absolute low. Incidentally, statistics show that this is the time when the largest number of natural fatalities occur.

Rhythm is genetically conditioned
Human beings have internalised the rhythm of day and night. The ability to adjust to the time of day is anchored in our genetic makeup. Experiments with test subjects in isolation chambers have shown that regular sleep and waking phases are maintained even if they are not stimulated by daylight. However, the genetically programmed rhythm for human beings is normally slightly more than 24 hours (see also the chart on page 17) For some people, the cycle is shorter than 24 hours; for others, it is considerably longer. On the basis of these differences, people are divided into what are known as chronotypes.

Chronotypes: “owls” and “larks”
Chronotypes are identified mainly by their sleeping habits. Many people are early risers – “larks” wide awake at the crack of

[07 – 10] alternate but all bodily functions have their own rhythms – with highs and lows at particular times of the day.

[11] Human performance curve over the day: body and mind are fittest around 10 a.m. and hit a low at 3 a.m.



11

dawn. But there are also “owls”, who need more time to face the new day. Their internal clock runs significantly slower than that of other people. Conversely, the internal clock of a lark runs too fast. Its cycle may be complete within 23 hours, while that of an owl may be as long as 26 hours.

Compared to the average, both groups have a displaced sleep/wake rhythm. Larks are urged by their internal clock to get up early, owls are turned into a morning grouch. The latter group, in particular, experience a kind of permanent “social jetlag” if they are wrenched from sleep early in the morning, long before they have a subjective sense of having slept enough. Despite external cues as work-times or daylight, they find it difficult to adapt to the shorter rhythm of the Earth’s rotation. Each new day adds to their sleep deficit, which has to be made up at weekends.

But early risers also find their internal clock annoying – especially at the weekend when they go to bed late but still wake up early in the morning as usual. Extreme chronotypes often suffer from permanent conflict with their biological clock. They are more prone to illness.

Seasonal differences

Our chronobiological rhythms are also influenced by summer and winter. In the dark months of the year, we tend to be less fit and have difficulties concentrating. We also eat more, so our body weight increases and blood sugar levels rise.

The seasons also have a psychological impact. In places with distinct seasons, people are tenser in winter than in summer and also generally more bad-tempered. A daily 30-minute walk in daylight helps here. Support is provided by circadian lighting.

However, some people do not just get into a bit of a low mood in winter; they become clinically depressed. They suffer from SAD – seasonal affective disorder (see also pages 24 ff)..

Rhythm and age

Young parents are often stressed and tired, and that may well be due to the internal clock of their child. Infants and toddlers are still governed by ultradian rhythms, i.e. phases of three or four hours’ duration. Children do not develop pronounced sleep and waking phases until around the age of two.

When youngsters reach their teens, their sleep patterns change again: with the onset of puberty, the internal clock ticks slower. Teenagers will go to bed later and sleep longer in the morning, often for more than eight hours. When school starts, they are often still not properly awake and – unlike their teachers – in “social jetlag”. At around the age of 20, sleep requirements then decrease again to between seven and eight hours.

From the age of 30 onwards, the quality of sleep steadily declines. We sleep less deeply and feel less refreshed, although we go to bed earlier and at more regular times.

At the age of 70, these symptoms become more acute. The older we are, the less our body distinguishes between day and night. Sleep requirements remain the same but sleep/wake rhythm gets increasingly out of synch with the external sequence of day and night. Sleep cycles become irregular, naps during the day a frequent occurrence. Lighting that has non-visual effects helps stabilise the circadian rhythm, enabling older people to sleep better at night and be more active during the day.

[12] Sleep/wake rhythms change over the course of our life.

[13] From birth to old age: sleep patterns are shaped and synchronised by external cues known as ‘zeitgeber’.

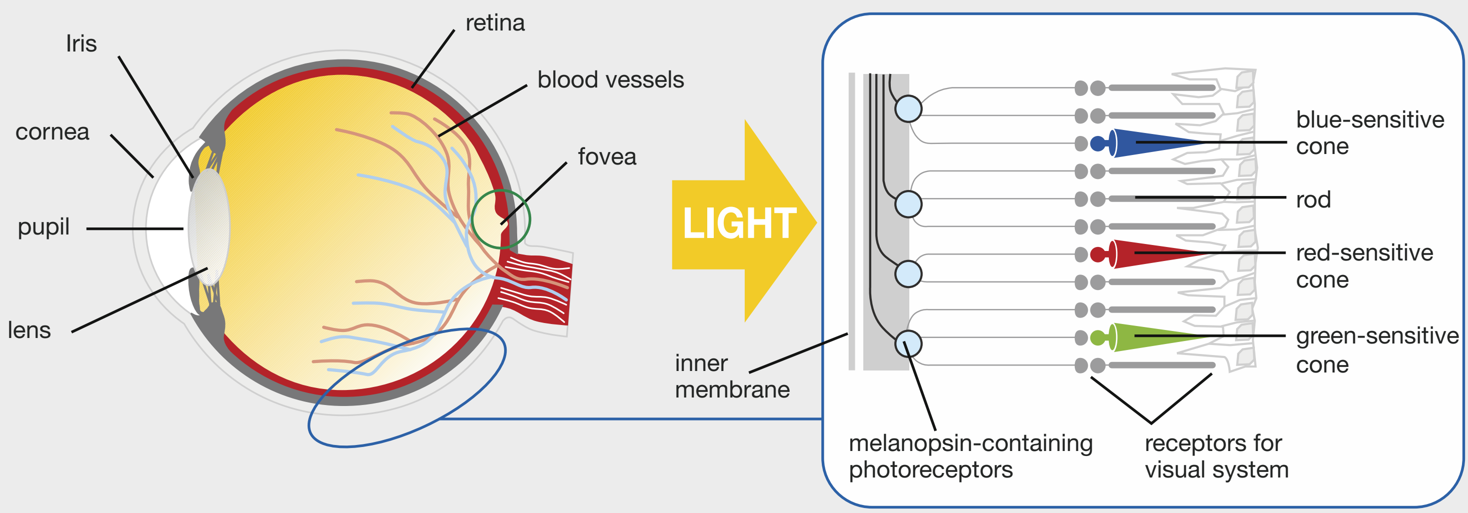
12

Development and synchronisation of sleep patterns

13

Based on: Prof. Dr. Jürgen Staedt, Prof. Dr. Dieter Riemann (2007): Diagnose und Therapie von Schlafstörungen, Stuttgart

Sensitive ganglion cells



Photoreceptors for daytime vision are particularly concentrated in the fovea (the small depression at the centre of the retina responsible for sharpness of vision, Ø~1.5 mm). The area contains around 60,000 cones but no rods.

Melanopsin-containing ganglion cells are distributed over the entire retina; the most sensitive are in the lower and nasal areas.

15

Our internal clock

Every human being ticks at a different rate. But we all respond to day and night. Many cells have their own rhythm in the "concert" of the human body. However, they are blind to the outside world. For all of the peripheral clocks involved in biological processes, central control and synchronisation with the environment are provided by a "master clock". It takes its cue from light.

[14] Human beings regularly synchronise their internal clock with the outside world. Daylight is the natural pacemaker.

[15] In 2002, scientists discovered special ganglion cells in the retina that do not have a visual function. They are most sensitive in the nasal and lower part of the retina. Rods and cones are responsible for vision.

Parents know the phenomenon: it is bedtime and the children are tired but after cleaning their teeth in the bathroom they are wide awake again. The cause of the sudden liveliness could well be the bathroom lighting, which often has a high blue content – and a small group of light-sensitive sensory cells in the eye sending clear signals to the internal clock.

The "master clock" in our brain

These so-called retinal ganglion cells are located in the deep layers of the retina and have a direct connection with the brain or, more specifically, with the suprachiasmatic nucleus (SCN) of the hypothalamus behind the root of the nose. The SCN is the mediator between light and the body's response to it. It is the central control point, the "master pacemaker" that precisely synchronises the many tiny clocks in the body. Neurotransmitters work from here, regulating bodily rhythms and adjusting metabolism to the time of day. Enzymes are activated or inhibited, hormones produced or prevented.

The SCN consists of two brain nuclei the size of a grain of rice located directly above where the two optic nerves cross. Each nucleus is comprised of thousands of nerve cells whose rhythms are re synchronised daily by daylight.

The third photoreceptor

For a long time it was not clear how we perceive these light stimuli. But in 2002 scientists identified a third photoreceptor in the retina alongside the cones (for colour vision) and rods (for night vision) already known. These special ganglion cells are photosensitive but they are not used for vision. Their sole purpose is to register ambient brightness and regulate biological processes in the body in response to the incident light – the pupillary light reflex, for example, or the internal clocks.

Only around one to three percent of ganglion cells are non-visual photoreceptors. Inside this type of cell, researchers found a photosensitive protein known as melanopsin, a photopigment that is also responsible, for example, for a frog's ability to adapt the colour of its skin to its surroundings. Melanopsin-containing ganglion cells are distributed all over the retina but they are particularly sensitive in the lower and nasal part of it.

In experiments, light-insensitive cells in mice were transformed into light-sensitive ones after being injected with human melanopsin. Their response was most sensitive to the blue light of the visible spectrum.

The first evidence of the new photoreceptor in humans was indirect. It was found by scientists irradiating test subjects for an hour and a half at night with monochromatic light of different wavelengths and observing the level of melatonin (sleep hormone) in their blood. A comparison of the results obtained with different coloured light showed that blue light with a wavelength around 480 nanometres suppresses melatonin production at night.

The protein melanopsin

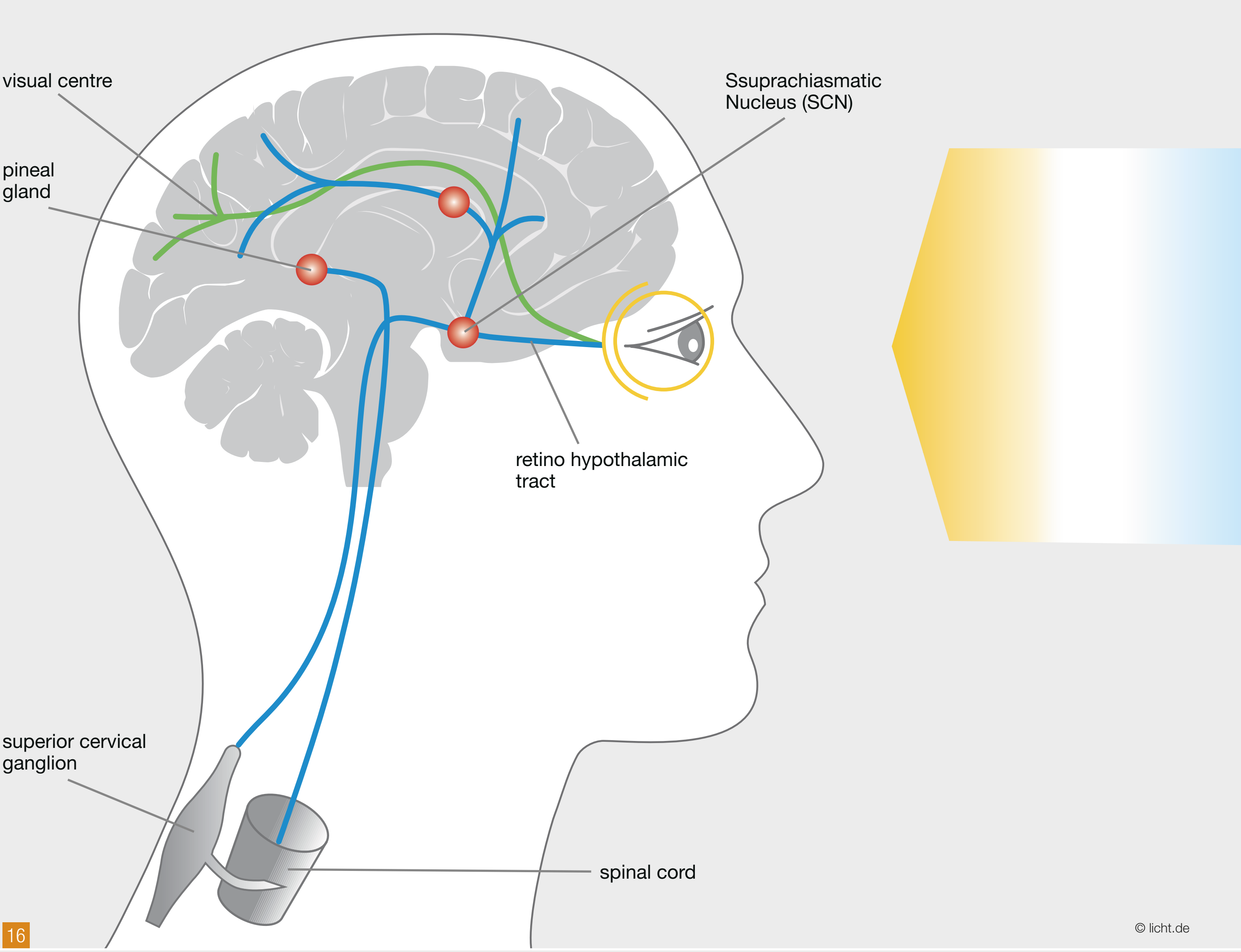
The photosensitive ganglion cells report light stimuli to the SCN, ensuring that melatonin production slows down.

At the same time, melanopsin plays a key role in the photoreceptors of the human eye. It responds particularly sensitively to blue light – and therefore reliably prevents melatonin being released during the day.

Light acts as a pacemaker for our internal clock

So the crucial cues for regulating our internal clock are provided by light. The signals are sent through the retinohypothalamic

Visual (green) and biological (blue) path



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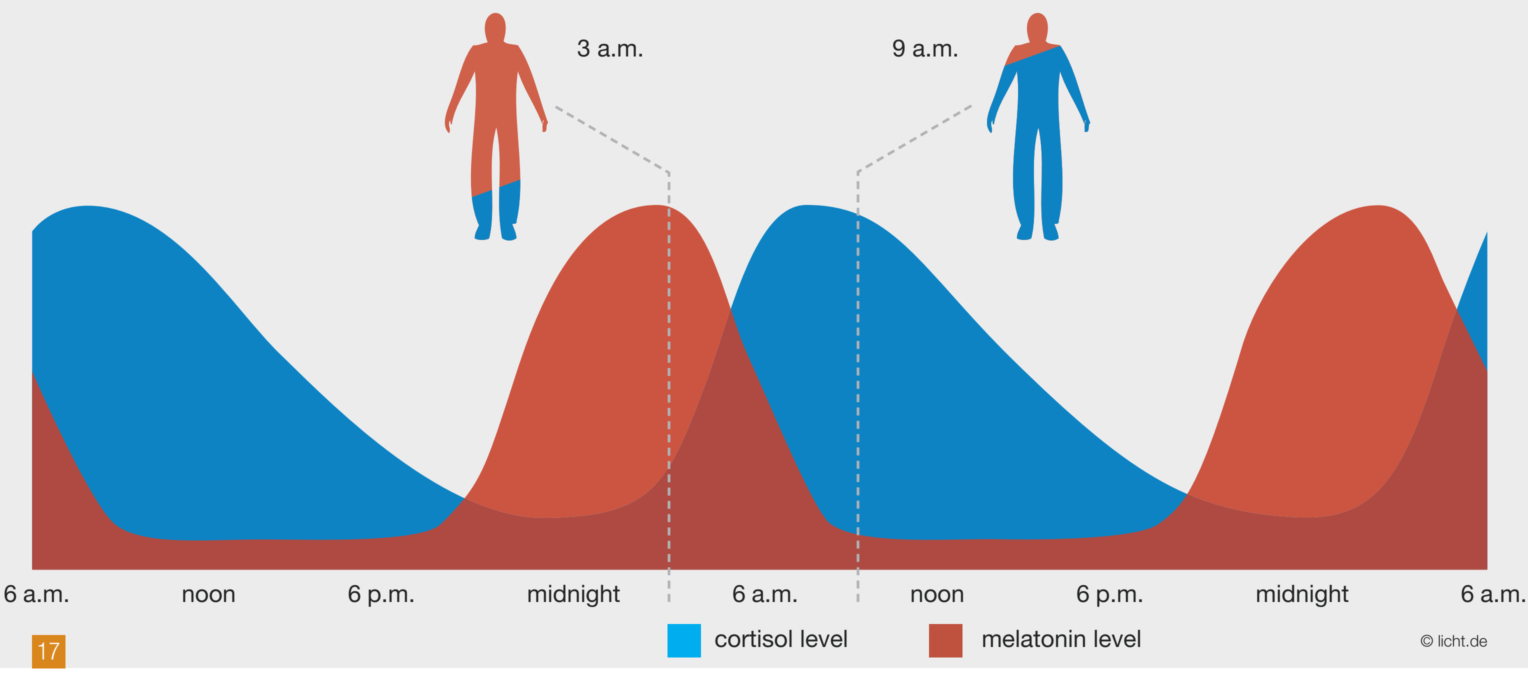
Influence of daylight on the human body



17

tract, which connects the ganglion cells directly with the pineal gland (epiphysis cerebri), the SCN and the hypothalamus. The latter is probably the most important control centre of the autonomic nervous system.

In the evening, the pineal gland secretes melatonin, which makes us feel tired. In the morning, the level of melatonin in the blood then ebbs. The first sunlight promotes this genetically conditioned rhythm by additionally inhibiting the hormone's production

Hormones: the internal clock's messenger substances
Digestion, mood, sleep – human beings are governed by complex biochemical processes. Hormones regulate when food is easily digested, when performance peaks and when sleep is at its deepest. Circadian rhythms are determined particularly by melatonin and cortisol because they impact on the body in opposite cycles. Serotonin – a natural anti-depressant – also plays a vital role in this biochemical process..

Melatonin
Melatonin makes us feel drowsy, slows down bodily functions and lowers activity levels to facilitate a good night's sleep. It also ensures that a large number of metabolic processes are wound down. Body temperature falls; the organism, as it were, is put on the back burner. In this phase, the body secretes growth hormones that repair cells at night.

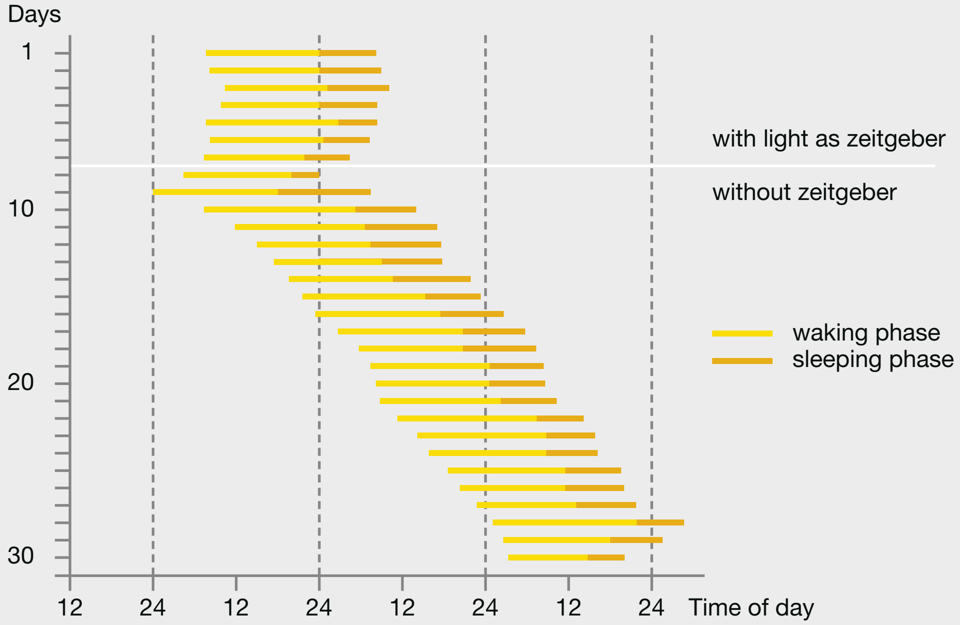
Cortisol
Cortisol is a stress hormone, produced from around 3 a.m. onwards in the adrenal cortex. It stimulates metabolism again and programmes the body for day-time operation. The first light of the day then stimulates the third receptor in the eye and suppresses the production of melatonin in the pituitary gland (hypophysis). At the same time, the pituitary gland makes sure the body secretes more serotonin.

Serotonin
Serotonin acts as a mood-elevating, motivating messenger. While the level of cortisol in the blood falls during the day in a counter-cycle to melatonin, serotonin helps us achieve a number of performance peaks. When daylight fades, the internal clock switches back to night mode.

If our body gets too little light during the day, it produces only a low level of melatonin. The result is that we sleep badly, we wake feeling unrested, we are tired during the day and lack energy and motivation. When the dark months of winter arrive, the process can become more acute. At that time of year, some people develop seasonal affective disorder (SAD). Their internal clock misses its cues because the hormonal balance in the brain is upset.

Indoors, lighting with non-visual effects can support the effect of natural daylight. In a 24/7 society in particular, it plays a valuable role in helping to stabilise human circadian rhythms.

Light as zeitgeber



18 Schematic representation based on Wever, Rütger and Aschoff, Jürgen

[16] Rods and cones transmit visual stimuli to the visual centre of the brain via the optic nerve (green path). The ganglion cells of the third photoreceptor, on the other hand, are connected with the superior cervical ganglion in the spinal cord and with the SCN by the retinohypothalamic tract (blue path). The SCN uses pineal gland and hormone balance to synchronise the body with the outside world.

[17] Cortisol and melatonin run opposite to one another: Cortisol is produced in the mornings, reaching a peak concentration at around 9 a.m. which then steadily declines during the day. Melatonin production starts at night, peaking at around 3 a.m.

[18] Light synchronises our internal clock. In the absence of the 'prompt' that light provides, our body reverts to the length of cycle determined by our genetic makeup; our sleep/wake rhythm gets out of synch with the time of day. The chart shows the sleep and waking phases of a common "owl" chronotype with a genetically based cycle length of 25 hours.

19

20

21

22

Melanopic effects of light

Outdoors, at home or at work – light is essential for human life. But there is not always enough daylight available. Melanopically effective lighting helps synchronise our bodily processes with the environment.

In a developed industrial society, people spend most of their time indoors with artificial lighting, living a lifestyle that is increasingly divorced from natural rhythms. Many work shifts or work in windowless buildings. So, like darkness at night, brightness and dynamism of daylight figure less and less in the pattern of modern daily life. But while outdoor illuminance reaches thousands of lux even on a cloudy day, the level of artificial lighting provided at a workplace is significantly lower than natural daylight.

That has consequences. Too little light during the day can disrupt our internal clock or cause sleep and waking phases to be less pronounced. Both have a negative effect on chronobiological rhythms and may cause health problems.

Daylight sets the standard

Daylight defines the parameters for biologically effective light:

- illuminance
- planarity
- direction of light,
- colour temperature
- dynamism of light over the day and the seasons.

The brightness of daylight varies considerably, depending on geographical position, weather, season and time of day. In Central Europe, most interiors could be illuminated with natural light from around 8 a.m. through to 5 p.m. In the majority of cases, however, the daylight admitted by windows does not reach deep into the room.

Lighting for non-visual effects

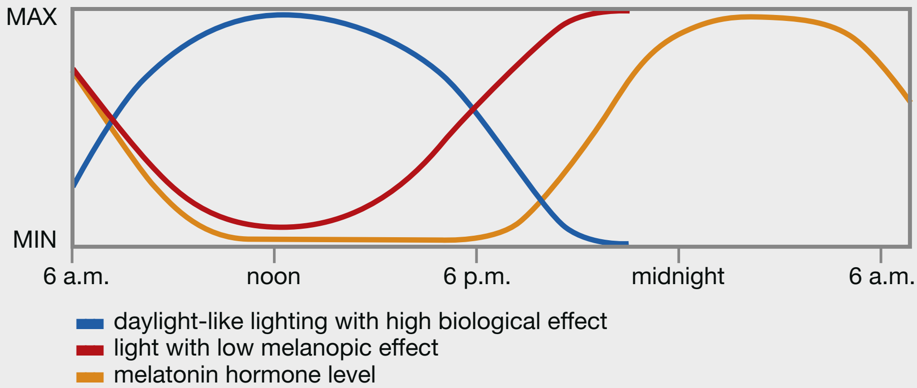
For technical reasons and because of the need to save energy, lighting for non-visual effects cannot simulate natural daylight precisely. But it can provide valuable support. Studies show, for example, that 500 to 1,500 lux illuminance can be biologically effective at a workplace.

Melanopically effective lighting can either be additionally activated or automatically regulated to compensate steplessly for changes in daylight incidence. Harnessing daylight enhances the quality of light, makes for a greater sense of wellbeing and optimises energy input.

For light to reach the particularly sensitive photoreceptors in the lower and nasal part of the retina, it needs – like daylight – to come from a planar light source and enter the eye from above. Colour temperature also plays a crucial role: during the day, it should be close to that of natural light with a high blue content.

Another key consideration in designing artificial lighting for non-visual effects is the need to deliver the right light at the right time. The greatest melanopic effect is achieved after a period of darkness, especially in the morning. Apart from supporting long-term diurnal synchronisation, melanopically effective light can also be used to activate. In this case, for example, illuminance and colour temperature are briefly raised at mid-day or early in the afternoon. In the evening, when activation is undesirable, warm light colours and lowered illuminance prepare the body for sleep.

Circadian lighting



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23

[19] Light energises and influences our mood.

[20 – 22] Like daylight, melanopically effective lighting changes over the course of the day: from invigorating cool white light colours and high illuminance levels in the morning, the light undergoes a dynamic transformation that ends in warm light colours and lower brightness levels for the evening.

[23] Daylight-like lighting with non-visual effect is advisable only during the day (blue curve). At night, in the evening and in the early morning hours, light with only little biological effect is correct. This avoids any disruption of biological processes in the body such as the rise in melatonin level (orange) in the evening.

Biologically effective light indoors

Melanopically effective lighting simulates the changes in natural daylight. Modern light sources ensure the required spectrum, luminaires the right distribution of light and an intelligent control system makes the lighting dynamic.

Biologically effective artificial lighting should be geared to the circadian rhythms of the user. It needs to support the biological processes that define active and rest phases. Applications harnessing non visual effects of light use changes in illuminance and light colour to recreate the dynamism of daylight indoors and are increasingly superseding static lighting solutions.

The health advice from chronobiologists is that everyone should spend at least half an hour a day outdoors. And as for indoor lighting, the message is: the more daylight can be harnessed the better. The ideal setup is where windows, skylights and daylight systems are used to maximise the natural daylight harnessed indoors. Combined with melanopically effective artificial lighting, this significantly enhances quality of life and wellbeing: during the day, we are more productive and focused, at night we can sleep better and recharge our batteries.

Activating: bright light with a high blue content
In terms of biological impact, daylight-like light with a high blue content is far more effective than a warmer, more reddish light. The light with the greatest non-visual effect has a wavelength of around 480 nanometres. In combination with high illuminance, this cool blue daylight white has an invigorating effect and helps us concentrate better: it stimulates the receptors in the eye and thus also the control centre of our brain.

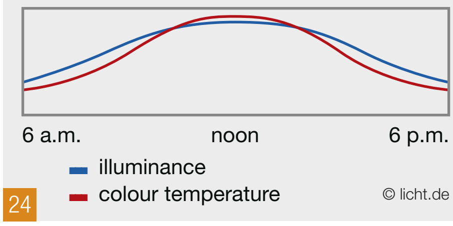
The distribution and spectral sensitivity of the third type of receptor in the retina show how perfectly the eye has adapted to natural conditions. The most sensitive melanopsin-containing ganglion cells are located in the rear and lower part of the eye (see fig. 15 on page 14 and fig. 27 on page 21). They are thus optimally positioned to receive light from the sky, which enters the eye from above and from the front as if emanating from a large dome. To be biologically effective, artificial lighting needs to direct light in the same way.

Studies have shown that the receptor can reach a state of saturation. So to achieve a circadian effect, it is not enough to use a punctual light source delivering high blue content light. As many receptors in the eye as possible need to be addressed – a requirement that can be met, for example, by appropriately dimensioned large-area luminaires.

The effect is intensified where room surfaces – such as the ceiling and the upper part of a wall – are used as large secondary reflectors. Luminaires that radiate both direct and indirect light are suitable here. Wall and ceiling washers that provide only indirect lighting are also an option.

The right light at the right time
Lighting for non-visual effects can influence biological processes in two ways. The first (lighting concept A) conveys a sense of day/night rhythm even where daylight is insufficient: illuminance and the blue content of the light are steadily raised through up to mid-day and then gradually lowered again through to evening.

Lighting concept A: Diurnal synchronisation



24

[25] Large-area luminaires direct light to the eye in a biologically effective manner. The activating effect is enhanced if ceilings and upper walls are bright and reflective.

[26] Action spectrum of melatonin suppression [$s_{mel}(\lambda)$] compared to the brightness sensitivity of the eye during the day [$v(\lambda)$]: the most biologically effective light has a wavelength around 480 nm.

[27] The ganglion cells of the third photoreceptor are most sensitive in the nasal and lower area of the retina. This is due to the eye adapting to natural lighting conditions, because daylight enters the eye from above.

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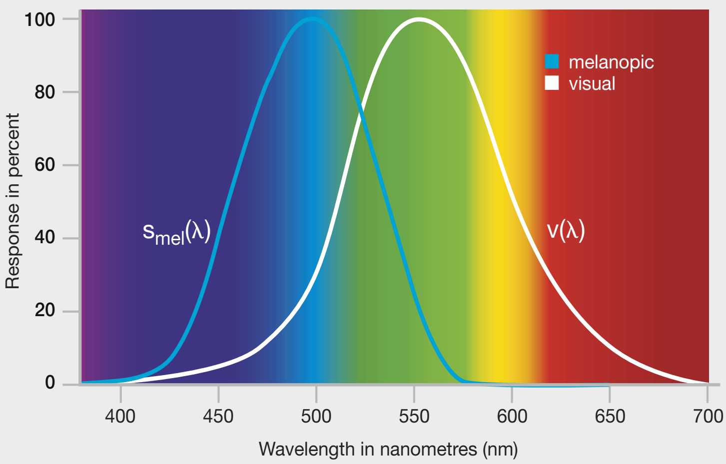
Spectral response functions



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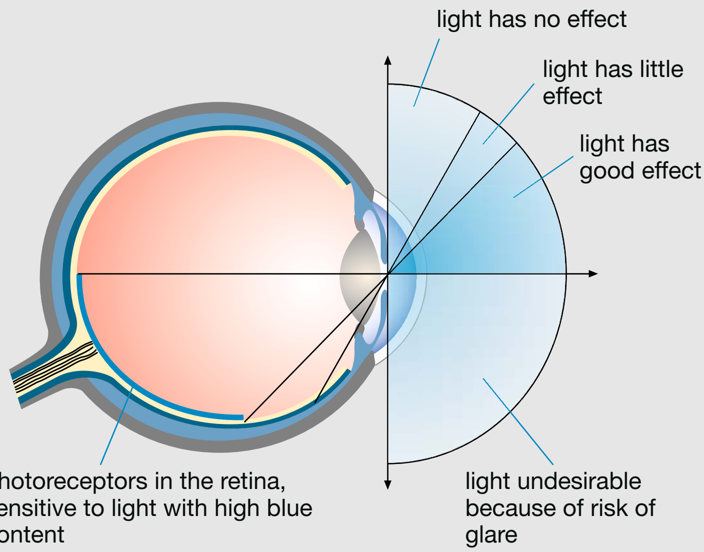
26

Addressing photoreceptors



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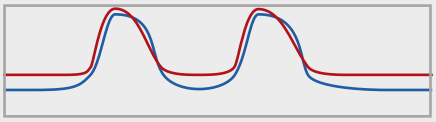
27

The second variant (lighting concept B) can take the form of "light showers". which have an energising effect and promote concentration. Studies have shown that this activating light delivers positive results in schools. Because the high illuminance is produced by only short bursts of power, this is a very energy-efficient solution (see also page 32f.).

Lighting concept B: Activation



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With both concepts, the following should be noted: activating light is advisable only during the day; it should not interfere with valuable night-time rest. In the evening, warm light colours (up to 3,300 kelvin) are recommended in combination with low illuminance. Evening light should also be directional to minimise stimulation of the melanopsin-containing photoreceptors in the eye. With the right choice of luminaires and light sources, lighting can be regulated to suit the time of day.

Suitable luminaires and light sources

The lighting industry today markets numerous luminaires designed to offer a combination of different light colours and deliver both direct and indirect light. Colour temperature and light incidence can thus be varied over the course of the day. The use of different luminaires is a good alternative, e.g. a combination of luminous ceiling elements that cast cool white light into the room over a large area and directional spots or task luminaires that provide non-activating lighting in the evening.

Initially, the only light sources where it was technically possible to add the increased blue content needed to address the third

29

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photoreceptor were fluorescent lamps. In the meantime, other light sources have also been optimised for biological effect.

Light emitting diodes (LEDs) are a particularly flexible option. A single LED luminaire – fitted with an appropriate module – can provide a range of different white tones. LED lighting with dynamic colour control thus permits a simple and efficient switch from light that promotes concentration and light that soothes and relaxes. In this way, biological and visual effect can be balanced and varied as required.

Different light sources are also frequently combined. In this case, dynamic lighting is produced by a combination of e.g. warm white fluorescent lamps and daylight white LEDs.

Dynamic lighting control
During the course of a day, biologically effective lighting not only varies its colour temperature from warm white to daylight white; it also adapts its 500 –1,500 lux illuminance to the human circadian rhythm and produces the right stimuli for the time of day.

The required dynamic lighting control is provided by lighting management systems. Regulation of the individual luminaires is balanced and stepless, so change is not immediately perceived but has a sustained biological effect. An ideal set-up also allows pre-programmed lighting scenes to be activated as required from a clearly designed control panel or remote control device.

Lighting management systems can be easily integrated into higher-level building systems. Fitted with daylight and presence control systems, they save a great deal of energy in combination with modern luminaires and efficient light sources – and they deliver the visual, emotional and non-visual effects needed for an optimal quality of light.

[29 + 30] Dynamic lighting for more motivation: in the morning, high illuminance and cool colour temperatures tuned to incident daylight stimulate our internal clock; towards evening, dimmed, directional light prepares us for sleep.

[31] Older people need more light than their younger colleagues. Supplementary light is provided by well-shielded desk luminaires.

[32] Particularly important during the dark months of the year: circadian-effective light helps compensate for the weaker daylight stimulus.


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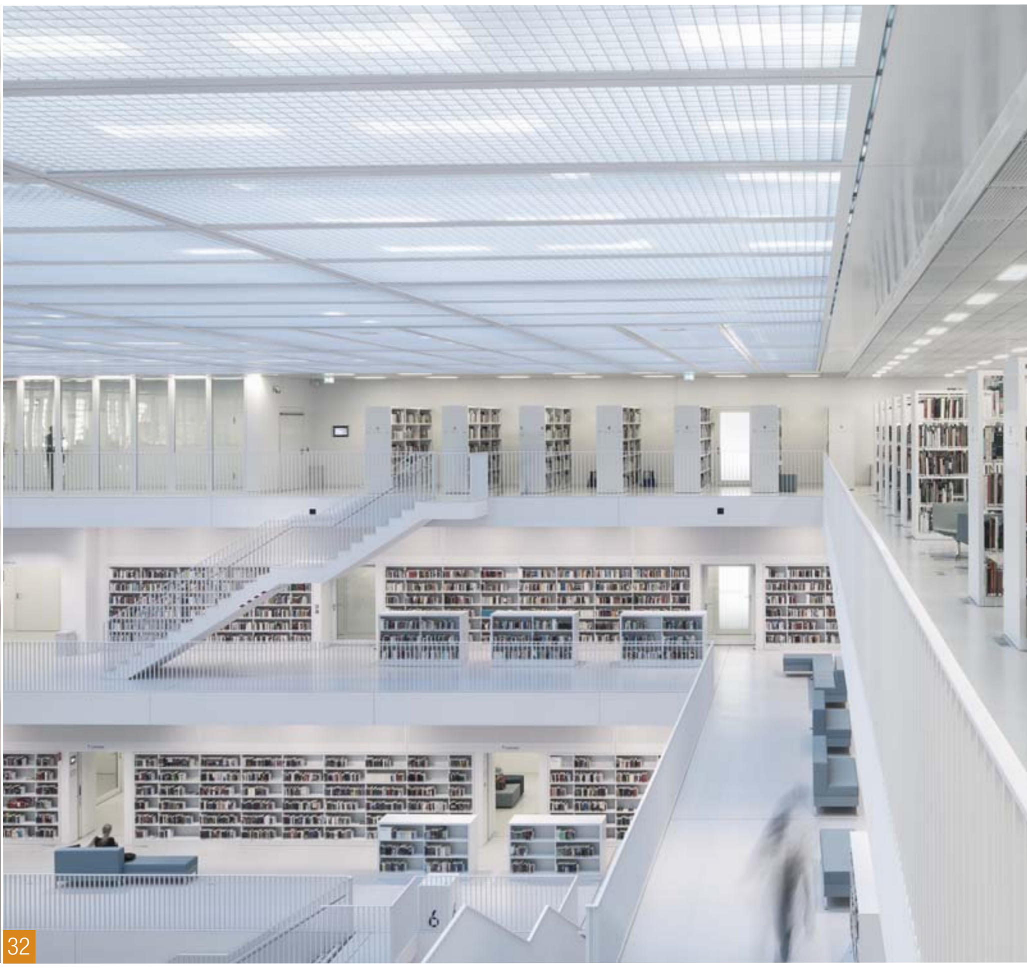
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Light therapy

Biologically effective light is also used in medicine. Seasonal affective disorder (SAD), a mood disorder that occurs in the darker months of the year, is already being successfully treated with light. Studies show that light therapy is also effective against non-seasonal depression and other ailments.

Trees lose their leaves, storks fly south, hedgehogs hibernate. Only human beings think they can defy the seasons. Clearly, a life ruled by nature does not fit easily into our industrialised world. No employer would accept employees working to a schedule determined by biorhythms. As a result, many people struggle through autumn and winter in noticeably low spirits.

Seasonal affective disorder (SAD)
Lack of light is indeed a serious problem: if insufficient natural light is available, 5–20 % of all people develop veritable "deficiency symptoms". Symptoms such as greater need for sleep, lack of energy, mood swings and even depression can develop during winter months into SAD, a condition that needs to be treated.

US scientists have been studying this phenomenon since the early 1980s. What distinguishes SAD from other forms of depression is mainly the fact that symptoms subside as the days grow longer in spring but then return again in autumn.

Ravenous appetite from lack of light
In contrast to other depressive patients, people affected by SAD do not suffer from insomnia. On the contrary, they go to bed earlier. Yet they still have difficulties getting up. Nor do they lose their appetite, which is a typical symptom of depression. They may actually develop cravings, especially for carbohydrates such as chocolate, potato products or bread.

So scientists believe there may be several causes for SAD: malfunctioning photoreceptors on the retina might be one of them, an insufficiently pronounced sleep/wake rhythm could be another.

One probable factor is that SAD patients are less able to adapt to the shorter days of winter. This throws their internal clock

33

[33] At the doctor's, in hospital or at home: light therapy is an effective and straightforward safeguard against seasonal affective disorder.

out of kilter. Lack of available light in absolute terms is also discussed as a contributory factor. Supporters of this theory point to the fact that SAD affects one in three adults in Alaska but only one in 25 in Florida.

However, a comparative representative survey by leading chronobiologists in the US and Switzerland leads to a different conclusion. The researchers found that in 1999 a significantly larger percentage of Americans suffered from a milder form of SAD than Swiss – despite comparable weather. So the study shows that SAD is not dependent on hours of sunshine but on personal exposure to light. To keep our internal flywheel turning, it is advisable to spend a sufficient amount of time outdoors even in winter.

Daylight spectrum therapy devices

For people who do not get enough daylight during the day, light therapy devices are a genuine alternative. Smaller devices are also available for home or office use. What distinguishes them from the professional equipment used in hospitals or doctors' surgeries is mainly the size of the luminous surface. Hospital devices are the largest. They can be used to treat three to four patients simultaneously. Devices for the home, however, are designed for only one person.

The lamps are monitored by an operating hours counter. After 8,000 operating hours, their luminous flux is around 20 percent reduced and they should be replaced. The beam angle of a light therapy device is specially designed to take account of the geometry of the eye. Melanopsin-containing ganglion cells (see illustrations on pages 14 and 21) are widely distributed over the retina and most sensitive in the lower nasal part of it. The more receptors are addressed, the more successful the treatment.

Another factor to consider is that human pupils open to different degrees. So the same luminance does not necessarily result in the same irradiation of the retina. Finally, the lens of the human eye becomes more and more opaque with age, letting less light through. Therapy devices thus need to be sufficiently bright.

Technical requirements for light therapy devices

Therapeutic light sources should have a luminance of around 8,000 candela per square metre (cd/m²). Luminance is the measure of brightness of a luminous or illuminated surface as perceived by the human eye. Research has shown that it should not exceed 10,000 cd/m².

The luminous face of a therapy device should be as large as possible. The brightness needs to be spread as evenly as possible over the luminous surface.

Therapy devices radiate light in a wide beam so that the patient can move around in front of the luminaire within a relatively large area. Depending on distance from the device, illuminance can be as much as 10,000 lux. Light is considered therapeutically effective from 2,000 lux upwards. The colour temperature – around 6,500 kelvin – corresponds to that of daylight at noon.

The rays are particularly intensive in the short-wave blue region of the visible spectrum. Special glass filters cut out all harmful ultraviolet light. Light therapy devices cannot and should not tan the skin.

Light therapy suppresses sleep hormone

So far, medical research shows that light therapy works exclusively via the eye. When daylight falls on the retina, the pituitary gland in the brain produces hormones and


34

[34 + 37] Light therapy devices are also easy to use at office or factory workplaces.

[35] Luminance distribution of a light therapy device with 26 mm diameter fluorescent lamps

[36] Spectrum of a light therapy device: the light colour resembles daylight.

neurotransmitters such as serotonin. Too little serotonin is a frequent cause of depression because it works as a messenger substance transmitting information between brain cells. Vital functions and thought processes work only when sufficient serotonin is present. And whether they work or not impacts on our mental state.

Serotonin brightens our mood, increases our sense of wellbeing and boosts our motivation. To enable the body to step up the secretion of serotonin, light therapy lamps simulate the intensity and colour temperature of daylight. What is more, they produce short-wave light in the blue region of the visible spectrum, which stimulates the ganglion cells of the third photoreceptor in the retina. These then inhibit the production of the hormone melatonin. As a result, we are alert and productive during the day and sleep better at night. Melatonin thus stabilises our circadian rhythm. The artificial lighting normally found at a workplace is not usually enough to achieve this effect.

Light in the morning is the most effective
Light therapy is best administered in the morning. It tells our biological clock that the day has begun and that bodily functions need to be activated. Conversely, it is not a good idea to apply light therapy in the evening because it will cause melatonin production to be suppressed and make it harder to fall asleep.

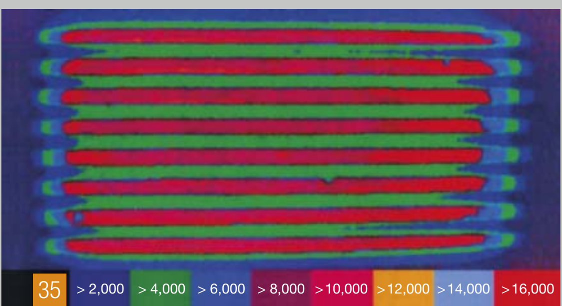
The frequency and length of therapy sessions required vary. The regime is prescribed by the doctor in consultation with the patient and depends on the severity of the symptoms. In most cases, a beneficial effect is noted within one to two weeks.

Light therapy is also an effective preventive measure for patients who suffer regularly from SAD. There are no known serious side-effects. Occasional complaints such as eye irritations, headaches and dry skin clear up after a few hours. As a general rule, however, anyone considering light therapy should first have a word with an ophthalmologist because caution is advised in the case of certain eye disorders.

Great potential of light therapy
Light therapy has recently been used to cure a variety of ills. There are even reports of Parkinson's and Alzheimer's patients being irradiated with biologically effective light, although there is currently no clear scientific evidence of therapeutic efficacy.

What studies do show, however, is that light therapy can be successfully used to treat premenstrual complaints, for example, especially the attendant emotional symptoms. There are also indications that light therapy can help those with bulimic eating disorders, especially seasonal bulimia.

Light looks like a promising therapeutic tool. But one thing is certain already: light therapy is a natural anti-depressant against the "winter blues", as the milder form of SAD is also known.



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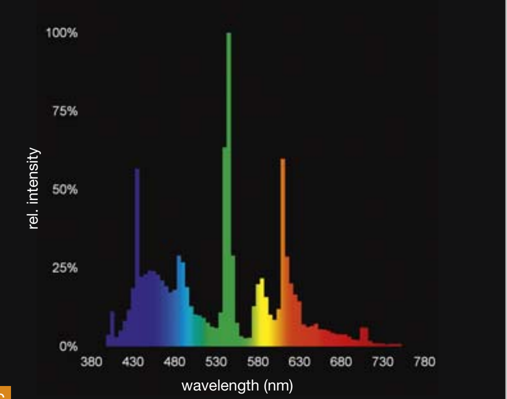

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38

DIN SPEC 67600: Lighting design recommendations

Professional lighting concepts today have the ability to create biologically effective lighting indoors. To ensure that the light really does have a melanopic effect and at the same time provides comfortable visual conditions, lighting designers need to pay attention to a number of factors. Design recommendations are provided in the draft pre-standard DIN SPEC 67600.

Good light helps us perform our daily tasks. At a desk, at a machine or in an operating theatre, light needs to provide optimal task area illumination and permit fatigue-free work. Biologically effective lighting also needs to meet all visual quality requirements.

General quality features

A good lighting installation tailors illuminance to the visual tasks that need to be performed and distributes luminance evenly in the room. It limits direct and reflected glare and delivers light with good colour rendering properties. That light does not flicker and takes account of incident daylight.

The basic requirements that lighting needs to meet are set out both in the DIN 5035 standards series and in the standard DIN EN 12464-1 “Light and lighting – Lighting of indoor work places”. These standards stipulate maintained values for the relevant lighting variables and define minimum requirements for good lighting quality. For work premise in Germany, the requirements of workplace regulation ASR A3.4 “Beleuchtung” also need to be taken into account. The ASR concretises the health and safety requirements that need to be met for employees at work.

DIN SPEC 67600 facilitates planning

If lighting is to be melanopically effective, light colour, illuminance and direction of light also need to be adjustable. Preliminary design recommendations are provided by the draft pre-standard DIN SPEC 67600 published in April 2013, which takes account of current research findings and successfully trialled applications.

In conformity with DIN EN 12464-1, DIN SPEC 67600 looks at the use of biologically effective lighting for different interiors, task areas or activity zones and makes recommendations for “living spaces”. which may be work premises or non-work premises. The pre-standard refers exclusively to non-visual effects mediated by the eye – as a result of exposure to daylight, artificial lighting or a mixture of the two. Information about the melanopic action factor of modern light sources is provided in DIN SPEC 5031-100 published in 2014.

39

Holistic lighting design

Designing a biologically effective lighting installation is a challenging task. For this reason, DIN SPEC 67600 recommends integrated, holistic lighting and spatial planning. This ensures that room use and the effects of light are considered in the design process from the outset and that all systems and materials are suitably coordinated. Holistic design also helps ensure – e.g. by appropriately harnessing daylight – that a lighting installation that has circadian effects is energy-efficient (see also page 32f.).

The design recommendations in DIN SPEC 67600 mainly relate to places where people spend a good length of time, e.g. indoor workplaces and communication zones or high-footfall areas in care facilities. Design needs to take account of daily and monthly rhythms as well as the seasons and the orientation of buildings.

Melanopic effects are achieved by

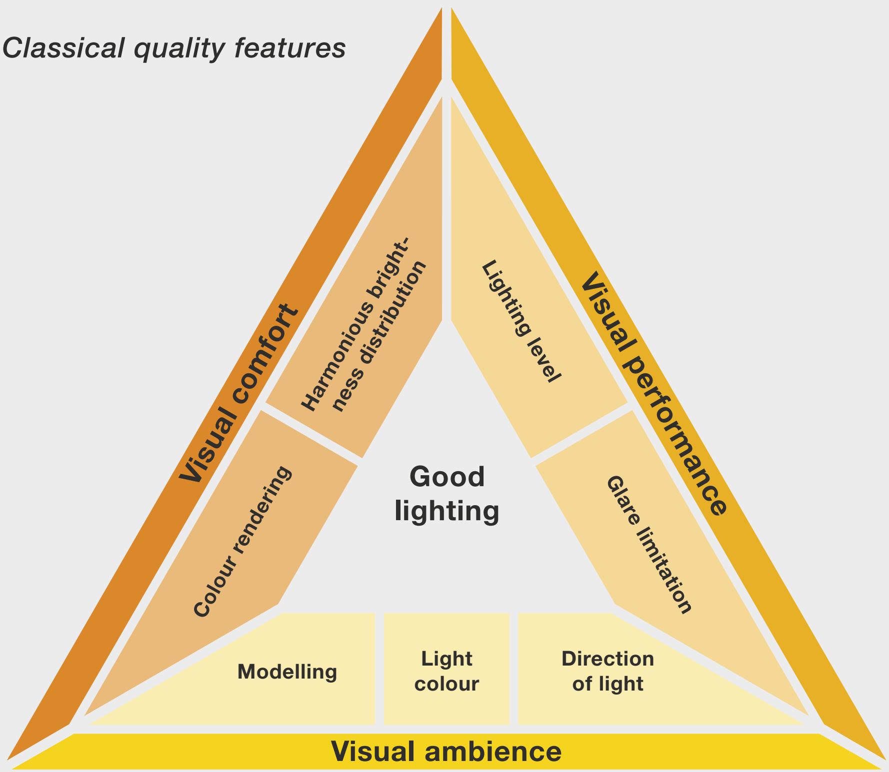
- higher illuminance
- a higher blue content
- planar light sources
- time-variable dynamic light and
- correct timing: biologically effective light is most effect in the morning, after hours of darkness.

Light colour is crucial

Light colour is expressed as a colour temperature in kelvin (K). It indicates the intrinsic colour of the light emitted by a light source. For comparison: the colour temperature of the sky generally varies between 6,000 and 10,000 kelvin.

Lighting quality features according to DIN EN 12464-1

Classical quality features



More lighting design criteria

Daylight integration	**Energy efficiency**
Change of lighting situation	**Scope for personalised settings**

40

[38 + 39] Biologically effective lighting makes for a greater sense of wellbeing, promotes health and boosts performance. Biologically activating and relaxing light alternate over the course of the day, simulating the changes in natural daylight.

[40] DIN standards and workplace regulations (ASRs) identify features that in toto define the quality of a lighting installation. They also need to be taken into account in the design of melanopically effective lighting.

The light sources used for biologically effective lighting need to have similar colour temperatures so that, like daylight, they can optimally address the relevant photoreceptors in the human eye. This is achieved by daylight white light sources with a colour temperature above 5,300 kelvin. They have a higher blue content and are much more circadian-effective than warm white light. For activating light, fluorescent lamps and LEDs are an appropriate choice.

Illuminance

Although blue spectral content is crucial for achieving a biological effect with artificial lighting, light colour is not the only factor that needs to be considered: another key variable is illuminance (measured in lux (lx)). What counts is the vertical illuminance at the observer's eye, which is largely defined by the perceived luminance of the surfaces observed: for compliance with DIN SPEC 67600, it needs to reach at least 250 lux at 8,000 kelvin because anything less has no significant demonstrable biological effect. At other colour temperatures, illuminance needs to be adjusted according to the new DIN SPEC 5031-100.

Spatial distribution of light

For light to have a biological effect, our eyes need to be able to perceive bright areas in the room as effectively as possible. Because melanopsin-containing ganglion cells are particularly sensitive in the lower and nasal part of the eye, bright planar lighting in the upper part of the visual field is recommended.

This is achieved with

- glarge windows, skylights and daylight control systems for brightening the ceiling;
- large-area luminaires or luminous ceilings;
- luminaires casting indirect light over large areas, so that the ceiling and the upper third of the walls are illuminated;
- back-lit transparent materials such as luminous ceilings, skylights with artificial light, light boxes or net curtains;
- lighting with indirect light components on room elements and furnishings.

The right light for the time of day

Every human being has his or her own individual day/night rhythm, which is regularly synchronised by daylight. For most people, light with a stimulating biological effect is useful mainly in the morning. Dynamic lighting can either simulate the changes in daylight and steadily raise illuminance and the blue content of the light through to mid-day or it can support activities during the day by varying illuminance and light colour at particular times. Periodic changes in lighting must always be designed with

41

42

room use in mind. To ensure that they have a biological effect and that undesirable flicker effects do not occur, they should take at least several minutes to complete.

In the evening, light with an activating effect should generally be avoided. This is to prevent interference with melatonin production and prepare the body for sleep. DIN SPEC 67600 recommends the use of dimmed, directional light in warm light colours with a higher red and sharply reduced blue content for around two hours before going to bed.

Shift work

For people who work shifts, the requirements that need to be met by melanopically effective lighting are very complex. A shiftworker's circadian rhythm is often different from the sleep/wake rhythm that nature intended. Hence the call by chronobiologists for shift work models that are less disruptive for the human biological clock. DIN SPEC 67600 contains proposals for supportive lighting.

Material characteristics and light colour

The designer of a circadian-effective lighting installation must also ensure that the spectrum radiated by a light source is not distorted, either by the luminaire or by ambient colours in the room.

Lamp light is altered in luminaires, especially by optical control elements such as louvers, enclosures or prisms. This may result in the light that reaches the eye having a different spectral composition than that radiated by the lamp. The spectral properties of optical control elements determine the quality of dynamic lighting. In the worst event, the colour temperature of an 8,000 kelvin lamp can be lowered to just 6,500 kelvin in the room.

Room environment and light colour

Visual atmosphere is influenced significantly not only by the light colour of the light sources used but also by the colours of furniture, walls and ceiling. Dark colours reflect less light than light ones. A great deal of light can be "lost" here, especially where light is cast exclusively onto room surfaces by indirect luminaires. Wood finishes, reds and browns as well as opalescent furnishing elements absorb the blue content of the spectrum and thus considerably reduce the biological effect of lighting.

[41] Our internal clock is best synchronised by artificial light in the morning. Higher illuminance on ceiling and upper walls, a higher blue content and planar light distribution are recommended to ensure that the right photoreceptors are reached.

[42] Towards evening, the body is prepared for rest: lighting should be geared only to the performance of visual tasks, delivering directional light with a minimum blue content.

[43] Biologically effective lighting supports circadian rhythms with dynamic changes in light colour and illuminance.

43

Lighting quality and energy efficiency

Good lighting is lighting that meets human needs – and nowadays also environmental standards. Lighting quality and energy efficiency are not conflicting goals. With modern lighting technology, circadian effective lighting can be realised without jeopardising energy saving targets.

[44] Example of circadian-effective lighting in an office (37 m²): horizontal illuminance and light colour change over the course of the day.

[45] The older a lighting installation is, the more energy it consumes. Depending on the age of the installation, biologically effective lighting may actually be a cost neutral or even cost saving refurbishment option.

Light enables us to get our bearings, helps us perform tasks at work, creates atmosphere and can have positive health effects. Energy-saving lighting solutions perform these functions while making responsible use of resources.

According to the International Energy Agency (IEA), lighting accounts for 15 percent of global electricity consumption. In Germany, according to figures published by the Federal Environment Agency, the figure was 11 percent in 2011. So, intelligent use of light can make a major contribution to energy efficiency.

Intelligent lighting technology conserves resources

Minimum efficiency requirements for the operating energy consumption of lighting installations are set out in the German Energy Conservation Ordinance (EnEV). The criteria and boundary conditions of use defined in the pre-standard DIN V 18599 enable the energy consumption of rooms and buildings to be rated. The efficiency requirements will become tougher each time the EnEV is updated.

To ensure compliance with the limits or achieve even greater efficiency, modern lighting management should be used with efficient light fittings such as LED luminaires. Lighting control requires luminaires that are dimmable. Daylight-dependent lighting control can reduce energy consumption by as much as 35 percent. Combined with timers and presence sensors, economies of 55 percent or more are actually possible.

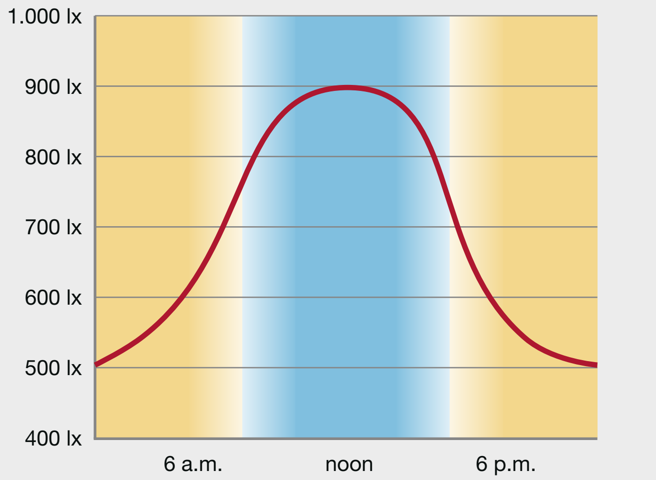
Maintaining lighting quality

At the same time, care must be taken to ensure that the lighting quality required is actually delivered. Workplace regulation ASR A3.4 requires that work premises should be sufficiently served by daylight and furnished with appropriate artificial lighting. DIN EN 12464-1 also stipulates that energy consumption should not be reduced at the expense of lighting quality.

A good lighting installation takes account of light's visual, emotional and biological effects – and is energy-efficient at the same time. Important features of lighting quality are:

- appearance

Circadian office lighting



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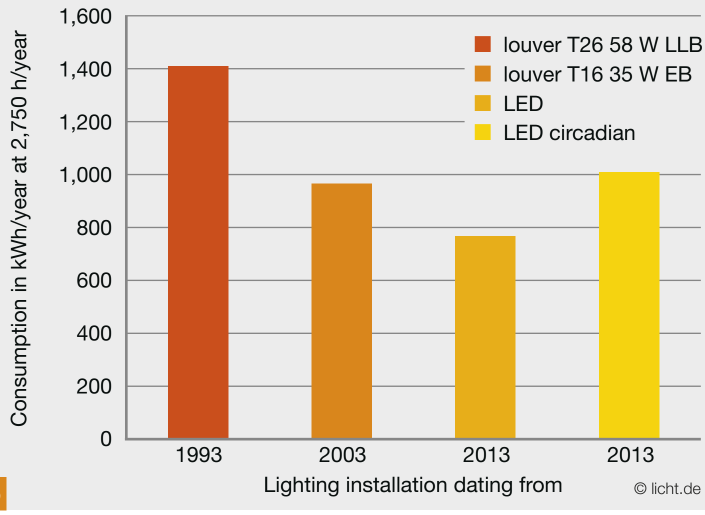
Energy consumption of a lighting installation



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- visual comfort
- vitality and
- individuality.

Circadian lighting solutions
How energy-efficient is circadian-effective lighting? Does circadian lighting consume more energy than conventional lighting? Answering those questions calls for a detailed professional lighting design and a cost-effectiveness analysis that permits fair comparison with the alternatives.

It is also a question of perspective: if a circadian lighting installation is compared with the best available LED technology, the answer to the question of higher consumption is yes. But if it is compared with an older installation replaced in the course of refurbishment, the answer is a clear no.

Because annual electricity consumption has steadily decreased in recent decades, the age of the existing installation plays an important role. The following example – a lighting installation for a 37m² four-person office – shows why. If the lights are on for 2,750 hours a year (as estimated in German energy conservation ordinance EnEV), annual consumption will be as follows:

- 30 years old – approx. 2,310 kWh/year
- 20 years old – approx. 1,410 kWh/year
- 10 years old – approx. 965 kWh/year
- new, LED – approx. 770 kWh/year

For the assessment and calculation of electricity consumption it is important to consider that circadian effective LED lighting changes light colour and horizontal illuminance during the course of the day, while always meeting the normative requirements of DIN EN 12464-1. The change in illuminance in particular has a major effect on energy consumption.

Diurnal synchronisation
During diurnal synchronisation (see fig. 24, page 20, "Lighting concept A"), the light colour changes from warm white in the morning to daylight white at mid-day and back to warm white in the evening. At the same time, illuminance increases during to morning from 500 to 900 lux (see fig. 44, page 32). That increase in illuminance naturally impacts on the amount of electricity consumed over the year. The illuminance rises steadily to a peak at mid-day then falls again in the afternoon. So the maximum level is maintained for only a limited period. As a result, the annual consumption of the circadian lighting is around 1,010 kWh/year, which is around 30 percent more than a modern energy efficient, non-regulated LED lighting installation. However, that is without taking account of the "maintenance factor saving" made possible in circadian lighting by lighting control and sensor technology. The new installation is designed for a setpoint value and requires significantly less electricity when it goes into service than when it reaches the time for maintenance. That energy saving is initially around 25 percent and decreases steadily thereafter.

But even more savings are possible. The annual consumption of the lighting installation can be further reduced by the use of presence detectors. And a final economy can be achieved with daylight sensors, although this requires sophisticated equipment because the setpoint value needs to be dynamically adjusted over the course of the day. Here, the EnEV cites energy saving figures of 28.5 percent for presence control and 55 percent for daylight control systems.

So, establishing whether circadian lighting consumes more energy than a static installation calls for professional analysis. The answer depends on individual circumstances.

Top marks for LEDs and lighting control
In a research project at the Fraunhofer Institute for Building Physics at Holzkirchen near Munich, scientists studied different building service systems – e.g. heating, cooling, ventilation and lighting systems – under realistic conditions in rooms with natural and artificial lighting.

As far as lighting is concerned, the most efficient option available is daylight-controlled direct/indirect working area lighting that also illuminates the walls. In the morning and late afternoon, the end walls of the room are additionally illuminated to provide higher vertical illuminance for better visual and emotional impact and visual comfort. Monitoring results show that the lighting installation described merits a "very good" rating.

The optimal balance between lighting quality and energy efficiency is achieved by highly automated installations. Daylight control and presence control significantly lower energy consumption.

Greater productivity
In one of the most comprehensive studies of its kind, researchers working for the Light Right Consortium in New York also concluded that good lighting improves productivity. Nine to 31 percent of persons whose workplace was illuminated only by direct lighting systems judged this to be disagreeable. On the other hand, 91 percent of test subjects found a high-luminance direct/indirect lighting system agreeable. Where the workplace lighting was also individually dimmable, employees were found to be more motivated, more persevering and more alert. The work they performed was also more accurate and thorough.

In view of these findings, lighting quality and energy efficiency cannot simply be played off against one another. The somewhat higher energy consumption of a circadian installation in comparison to an installation optimised for energy efficiency is compensated by enhanced motivation, performance and health.

46

Office lighting

Illuminance, light colour and performance at work are more closely connected than they appear at first glance. The right lighting not only makes office workers more alert; it also motivates and boosts efficiency.

47

Design recommendation

Office activities present a wide range of requirements. Biologically effective lighting can sustainably strengthen our sense of wellbeing, especially in offices and conference rooms in which people spend long periods at work as well as in the winter months, when our internal clock is poorly synchronised with daylight. Illuminance levels and changing colour temperatures should be dynamically tuned to the time of day and regulated to take account of incident daylight. DIN SPEC 67600 points out that an activating effect, for example, is achieved between 8 and 10 a.m. by 250 lux vertical illuminance at eye level and a colour temperature of 8,000 kelvin. The same combination can also provide a stimulating boost between 1 and 2 p.m. In the evening between 6 and 8 p.m. lighting should help us unwind with around 200 lux vertical illuminance at eye level and a colour temperature of no more than 3,000 kelvin. At other times during the working day, the lighting level should be designed to meet the requirements of the relevant visual tasks. Designers in Germany thus need to take account of not only DIN EN 12464-1 and DIN 5035-7 but also workplace regulation ASR3.4.

Digitisation and globalisation are transforming the office workplace. Employees are becoming more mobile, new types of organisation are emerging and work-time is increasingly project-oriented. Modern lighting concepts go beyond ergonomic and emotional aspects of lighting quality: they bring the dynamism of natural daylight indoors and support human biological rhythms.

Especially during the darker months of the year, many people's internal clock fails to synchronise with daylight. Biologically effective lighting can have a positive influence on mood and wellbeing and thus also boosts the motivation of employees. Lighting solutions with non-visual effects are particularly recommended for rooms where people spend a good deal of time, e.g. offices, conference and meeting rooms or canteens. Rooms that are not well served by daylight, such as open plan offices or corridors, are also suitable candidates for dynamic lighting.

The right light – it's all in the mix

Aided by lighting control and sensor technology, biologically effective lighting changes the brightness and colour of light dynamically over the course of the day. Large-format luminaires and illuminated ceilings simulate the sky during the day, delivering energising planar light with a high blue content and more than 500 lux illuminance. In the evening, lighting should not have an activating effect; the body needs a chance to produce sleep hormone, melatonin. That is facilitated by lower illuminance and directional warm white light from direct luminaires.

Electronic control

Many applications and studies show the positive effects of circadian-effective lighting:

- Employees feel more alert.
- They are measurably more motivated.
- Small pools of higher illuminance and dynamically changing light colours have a positive impact on concentration.

Some office buildings are now completely fitted out with dynamic lighting. At one Hamburg company, lighting is electronically controlled throughout the day to create programmed lighting atmospheres that support circadian rhythms. Large-area luminaires fitted with daylight white and warm white fluorescent lamps steplessly produce light of any colour temperature between 3,000 and 5,500 kelvin at different illuminance levels. The lighting at workplaces can also be tailored to individual requirements.

The energy requirement of a complete solution like this is around 30 percent greater than that of a non-regulated, fixed-colour lighting installation with LEDs (as of 2014). At the same time, however, employees are more focused and motivated.

[46] Dynamic office lighting makes for a greater sense of wellbeing, especially in parts of the premises that are less well served by daylight. Following nature's example, light colour, illuminance and direction of light change over the course of the day. Cool light colours with a high blue content activate, warm light colours relax.

Industrial lighting

At machines or on assembly lines, a biologically effective lighting installation provides workplace lighting that makes industrial workers more alert and more focused. They can sleep better and arrive at work better rested. That reduces errors and heightens safety during the day.

[48] By simulating the changes in daylight, circadian lighting has an activating effect at the beginning of the working day and helps us relax as evening approaches.

[49] Shorter stimulation cycles also make for a greater sense of wellbeing at work. This dynamic lighting variant entails comparatively little cost.

[50 – 52] Studies show that the use of biologically effective light in manufacturing promotes health in the workforce and heightens productivity. Combining dynamic lighting with as much daylight as possible makes sense and saves energy.

Melanopically effective lighting can also support human circadian rhythms at industrial work premises. Dynamic lighting with non-visual effects has an energising impact in the morning and at mid-day and makes for a better night's sleep.

Many people in industry work shifts, having to get up, for example, very early in the morning. They often complain of sleeping badly and being tired during the day. The result is lower productivity, because workers who cannot regenerate overnight are not very efficient during the day. As an Austrian study in 2010 showed, biologically effective light helps.

Greater sense of wellbeing, better concentration

The research team chose two dynamic lighting scenarios for the general lighting: in both cases, illuminance varied from the standard 1,000 lux to a biologically effective 2,000 lux at a colour temperature of 4,000 kelvin. In the first test set-up, the doubling of the lighting level was clearly perceptible and implemented at longish intervals so that the lighting had an activating effect at the beginning of a shift and a relaxing effect at the end. In an alternative set-up, the researchers introduced an imperceptible dynamic brightness cycle with shorter intervals. The findings show the positive impacts of dynamic room lighting with non-visual effects:

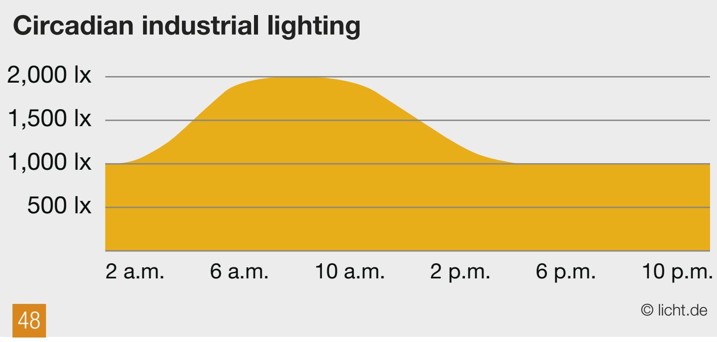
- significantly better quality of sleep
- greater sense of wellbeing during and after shift work
- faster performance of assigned tasks.

Shorter cycles also work

In a lab experiment involving 29 test persons, a programme was then run – also in 2010 – to see if dynamic lighting with a biologically effective colour temperature of 4,000 kelvin also works if the sequence is speeded up. This type of dynamic lighting entails comparatively little expense because the illuminance varies and is not kept at a constant high level for long periods of time.

The lab study showed that light which gradually increases from 500 to 2,000 lux and is then imperceptibly lowered to its original level reduces physiological responses to stress. More research needs to be done in this area.

One thing is certain: biologically effective lighting demonstrably improves quality of sleep, so employees are more active and motivated during the day. An optimal lighting level and melanopic lighting are good for employees' health and help maintain their productivity.



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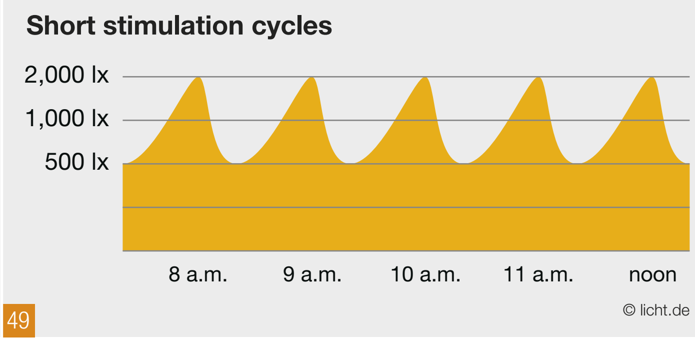

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School lighting

Good light is a vital requirement in a learning environment. Studies show that biologically effective lighting impacts positively on learning and helps students concentrate and work more attentively.

In the morning, many students are still sleepy. This is because an adolescent's internal clock often gets out of synch. Many teenagers are still wide awake late at night but find it hard to get up in the morning and are not very motivated for learning. Their internal clock is geared to a different schedule than the school; they suffer from "social jetlag".

Numerous studies in recent years have shown that daylight-like lighting can provide important stimuli for student's circadian rhythms:

- Students are more alert in the morning.
- They thus perform much better.
- Concentration and retentiveness increase.
- The number of mistakes made significantly declines.

More focused

These positive effects revealed by a study in Hamburg in 2007/2008 were confirmed in 2012 by a study conducted at two grammar schools in Ulm. Young people aged between 17 and 20 were taught in one classroom with biologically optimised lighting and in one room with conventional lighting. The students were required to do a number of performance and attention tests.

The classroom with dynamic lighting was fitted with pendant-mounted LED luminaires (blue and white LEDs) that could be separately controlled and together achieved a very high colour temperature of up to 14,000 kelvin, which is comparable to daylight. The luminaires provided both direct and indirect light. An integrated lighting control system ensured that the colour temperature was dynamically adjusted over the course of the day. The conventional lighting, with fluorescent lamps, reached a colour temperature of 4,000 kelvin. Illuminance was the same in both classrooms: 700 lux horizontal illuminance on the desktop and 300 lux vertical illuminance at eye level.

The findings were distinctly positive: students were much more focused under the biologically effective lighting. They worked faster and their performance was better.

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Tired in the evening, fit in the morning
At the same time, students in both groups kept a sleep diary. This showed that the young people had comparatively long nights' sleep overall. However, in the case of students who spent the day working under light with a higher blue content, the sleep cycle shifted: they went to bed earlier and were rested and fit when school started in the morning. This shows that sleep/wake rhythm and lighting history are important factors for effective learning by students.

The best effects are achieved by biologically effective lighting when it is used long-term and the circadian system is sustainably stabilised. But even short-term exposure produces positive results: brief "showers" of light with a high blue content have been shown to promote concentration.

As well as being a key activator, dynamic light can play an important role in calming youngsters down. Warm light colours and subdued lighting help make for calmer group discussions and help students relax after class tests. Soothing lighting atmospheres are also successfully used in therapy for youngsters with attention deficient hyperactivity disorder (ADHD).

The design of a biologically effective lighting installation needs to take account of the students' age and the time when exposure will occur: children and teenagers have different lighting requirements than adults, for whom classes often take place in the evening.

More information about school lighting is found in the booklet licht.wissen 02 "Good Lighting for a Better Learning Environment".

[53 + 54] Dynamic lighting supports learning and defuses stress situations. Cool light colours coupled with high illuminance invigorate and promote concentration; warm light colours in conjunction with low illuminance have a calming effect.

Design recommendation

For concentrated classroom work, DIN SPEC 67600 recommends higher illuminance and a colour temperature of at least 5,000 kelvin. The activating light helps keep students alert, e.g. during class tests or reading assignments.

For a relaxed learning atmosphere for group work, a lower lighting level and a colour temperature no higher than 3,000 kelvin are advisable. This lighting situation also helps reduce restlessness.

At the start of the day's lessons, biologically effective light can be used to synchronise the students' circadian phase with the natural rhythm of the day. This activating effect can also be used for evening classes, although care must be taken to ensure that light with little biological effect is available at least two hours before participants retire for the night.


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Design recommendation

For the design of hospital ward lighting, DIN SPEC 67600 indicates the need to take account of the predominantly recumbent posture of patients. Planar illumination of the ceiling with high blue content light (over 5,300 kelvin) and up to 1,600 lux illuminance (at least 250 lux vertical illuminance at eye level) is correct during the day. Discomforting glare should be avoided. For the evening and night, dimmable warm white light sources that have no activating effect are recommended.

The designer also needs to ensure that ergonomically correct light is available for acute patient care in an emergency, even if it may disrupt circadian rhythms.

Hospital lighting

For a person who is ill, light is like medicine. Dynamic lighting designed to simulate the changes in daylight that occur during the day support patients' circadian rhythms, raise their spirits and thus promote recovery.

Professional medical care is not the only thing needed to make patients feel they are in good hands. A comfortable atmosphere is also a factor. Light plays a key role here. As well as having an aesthetic effect, it is an important zeitgeber – a cue or synchroniser – for our internal clock. Numerous studies show the connection between good lighting, health and wellbeing – and a growing number of hospitals use lighting that is not just ergonomic but also elicits a positive emotional response and promotes health. The result: patients and staff feel better, treatments are more efficient.

Patients in hospital rarely or never go outdoors and their bed is not always near a window. Lighting that has non-visual effects positively influences biological processes in the human body. Particularly bright light, for instance, helps strengthen waking phases; dynamic light that simulates the changes in natural daylight by modulating illuminance and light colour supports a patient's sleep/wake rhythm.

Circadian lighting is not only suitable for rooms in normal nursing wards. Because light is also perceived subconsciously, it can be harnessed to promote the recovery of patients fresh from the operating theatre and very poorly patients in intensive care units.

Light colour and illuminance

In the morning, cool white light with high illuminance up to 1,600 lux has an activating effect. Large area wall or ceiling luminaires ensure that the light enters the eye from the upper part of the room. It thus reaches the photoreceptors in the lower part of the retina that are particularly sensitive to the activating blue content of the light. In the evening, warm light colours below 3,300 kelvin and lowered brightness levels prepare the body for sleep.

Dynamic lighting is based on an intelligently networked system that can be regulated to meet specific requirements. Functional glare-free lighting can be activated by hospital staff for evening or night-time examinations or emergency procedures and indirect lighting along the wall can be regulated for night lighting. A control module enables patients to operate the reading light and their personal mood light, e.g. with coloured LEDs.

Reassuring light in waiting areas

A bright, cheerful atmosphere in hospital waiting areas is the right medicine for fear and anxiety. Soft light adapted for the time of day has a calming effect. It is very useful in corridors, which are also a meeting-place for patients and visitors. Sufficient luminance and uniform glare-free route lighting facilitates orientation and safe movement here – an important requirement even at night.

Visual comfort for hospital staff

Dynamic lighting solutions ease the burden on hospital staff. Therapy times and nursing requirements are reduced when a patient's circadian rhythm is stable. Lighting systems with pre-set lighting atmospheres also enhance staff motivation and concentration – and make for more effective rest breaks in the nurses' room.

Biologically effective lighting is based on large-area illuminated ceilings or luminaires with an asymmetrical light distribution curve, so-called wallwashers. The light they emit is directed onto the walls, which then reflect it back into the room. While offices and staff rooms are best served by bright, intensely bio-effective lighting, treatment rooms require a healthy mix of functional light for examinations and agreeable room lighting to put patients at their ease.

For more information, please refer to the booklet licht.wissen 07 "Light as a Factor in Health" in the licht.de series of publications.

[56 – 58] Biologically effective lighting helps bedridden patients maintain a day/night rhythm and promotes recovery.

[59] Circadian-effective lighting does good work in corridors and waiting areas. Light that changes like daylight synchronises patients and nursing staff with their internal clock.

Retirement home lighting

Circadian-effective lighting sustainably improves the circadian rhythms of the elderly and dementia patients: it activates during the day and promotes sleep at night. At the same time, optimal lighting conditions make it easier for carers to perform their duties.

Retirement home lighting needs to meet high requirements to cater for ailments that come with old age. Many residents have poor eyesight. But quality of life depends crucially on how well a person can see. Clouding of the lens alone, for example, means that older people require up to 1,500 lux illuminance for reading and craft activities – over four times more than a twenty-year-old.

[61] Natural daylight and circadian-effective artificial lighting stabilise older people's sleep/wake rhythm and help significantly improve their quality of life.

[63 + 64] Melanopic lighting is particularly recommended for lounge areas, corridors and special care units.

What is more, 60 to 80 percent of retirement home residents suffer from some form of dementia. Those affected are often restless and wander around. Their movements become progressively more unsteady and the risk of a fall increases. People with dementia can easily mistake shadows on the floor for obstacles, which they find unsettling. They also often become disoriented or have a disrupted sleep/wake cycle.

Biologically effective light helps

Lack of activity leads to sleepiness during the day and restless nights – a situation that also puts a strain on nursing staff and makes increased staffing levels necessary.

Many applications today show that sufficiently bright light and a lighting installation with non-visual effects can have a significant impact on the wellbeing and activity levels of retirement home residents. Impressive evidence of this was furnished by a 15-month research project in Austria. The lighting of a Vienna home for dementia sufferers was equipped to create three lighting situations:

- Lighting situation 1 increased illuminance from 300 lux (standard situation) to 2,000 lux.
- Lighting situation 2 raised colour temperature from 3,000 kelvin (standard situation) to 6,500 kelvin in corridors and 8,000 kelvin in living/dining areas.
- Lighting situation 3 dynamically modified illuminance and light colour according to the time of day.

In rhythm: activity and rest

The researchers compared the effects of standard lighting with those of the three new lighting situations – in each case from the beginning to the end of the day. The results were compelling. In all three lighting situations, residents communicated more intensively and participated more frequently in domestic activities. Socially, too, they

61

Design recommendation

Elderly people especially dementia sufferers – spend less time outdoors; their sleep/wake cycle is often poorly synchronised. DIN SPEC 67600 recommends that lounge areas, in particular, should be furnished with large windows for natural daylight and circadian-effective lighting. The same applies to corridors and special care units for bedridden patients.

In the morning and at mid-day, planar lighting with 250 lux vertical illuminance at eye level and a colour temperature no lower than 5,000 kelvin has an activating effect; in the evening, direct luminaires should be used with lowered illuminance and no more than 3,000 kelvin. During the night, the lighting should be reduced to the standard-compliant level needed for orientation.

became more active. They were more likely to engage in craft activities and singing – especially under high illuminance. And they spent more time in the brightly lit corridors, where they evidently now felt more secure.

Owing to the increased activity during the day as well as the right light in the evening – reduced illuminance and warm white light – the residents slept better at night. Sleep patterns and deep sleep phases are sustainably supported by circadian lighting. So it is a natural tool for helping dementia sufferers, whose day/night cycle is often completely reversed.

Dignified care and light

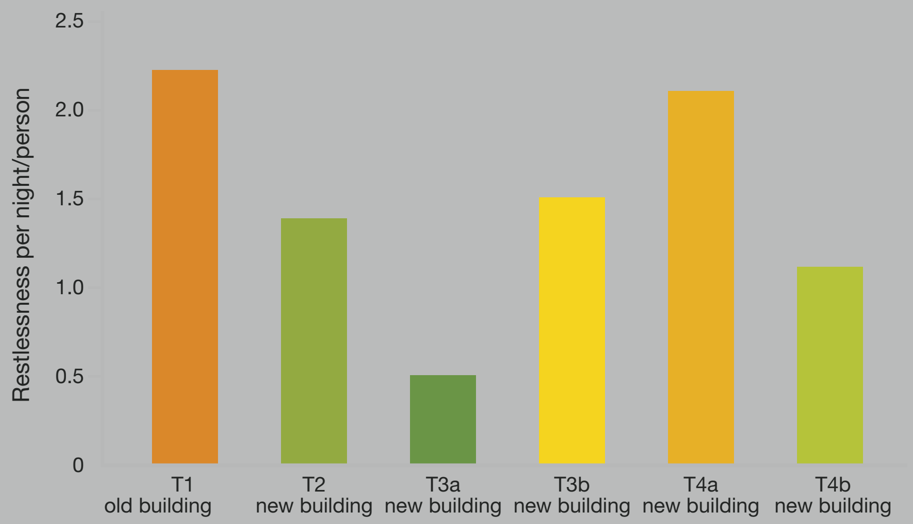
Within 30 years at most, the number of people in care will have doubled. Demographic change needs to be taken into account now in retirement home design. Maximum use of natural daylight and biologically effective lighting can do a lot to help preserve the elderly's quality of life for a long time. At the same time, fewer sleeping pills are required and the pressure on nursing staff is eased.

Restful sleep

Circadian-effective lighting helps keep sleep/wake cycles regular in retirement and nursing homes. This was also confirmed by a project implemented at a retirement home in the Black forest town of Hüfingen in Germany. Manufacturers and researchers conducted a scientific evaluation there from August 2007 to March 2009, monitoring the sleep patterns of residents with and without circadian-effective lighting (each lighting scenario at least 13 nights long, 36 observations a night). First of all, quality of sleep in the old building was observed under conventional lighting. Then the residents moved into a new building equipped with melanopically effective lighting.

The study showed that residents' quality of sleep under circadian lighting improved after just eight weeks. After around a year, nursing staff reported that 75 percent of nights were significantly quieter. The home's residents – who are predominantly dementia sufferers – were also said to be more balanced and in better spirits than before. The nursing staff also felt a benefit from the melanopically effective lighting. Nocturnal agitation among residents was mostly observed in the old building (T1) and at times without biologically effective light (T3b and T4a). As the time under circadian lighting increased (T3a and T4b), residents enjoyed a significantly more peaceful night's sleep.

Circadian lighting and sleep



T1: normal basic lighting
T2: after 8 weeks of circadian lighting
T3a: after 12 months of circadian lighting
T3b: only basic lighting
T4a: after 6 weeks of basic lighting
T4b: circadian lighting after 8 weeks of basic lighting

Source: DeSSorientiert, issue 1/10, Demenz Support Stuttgart, 2010 © licht.de

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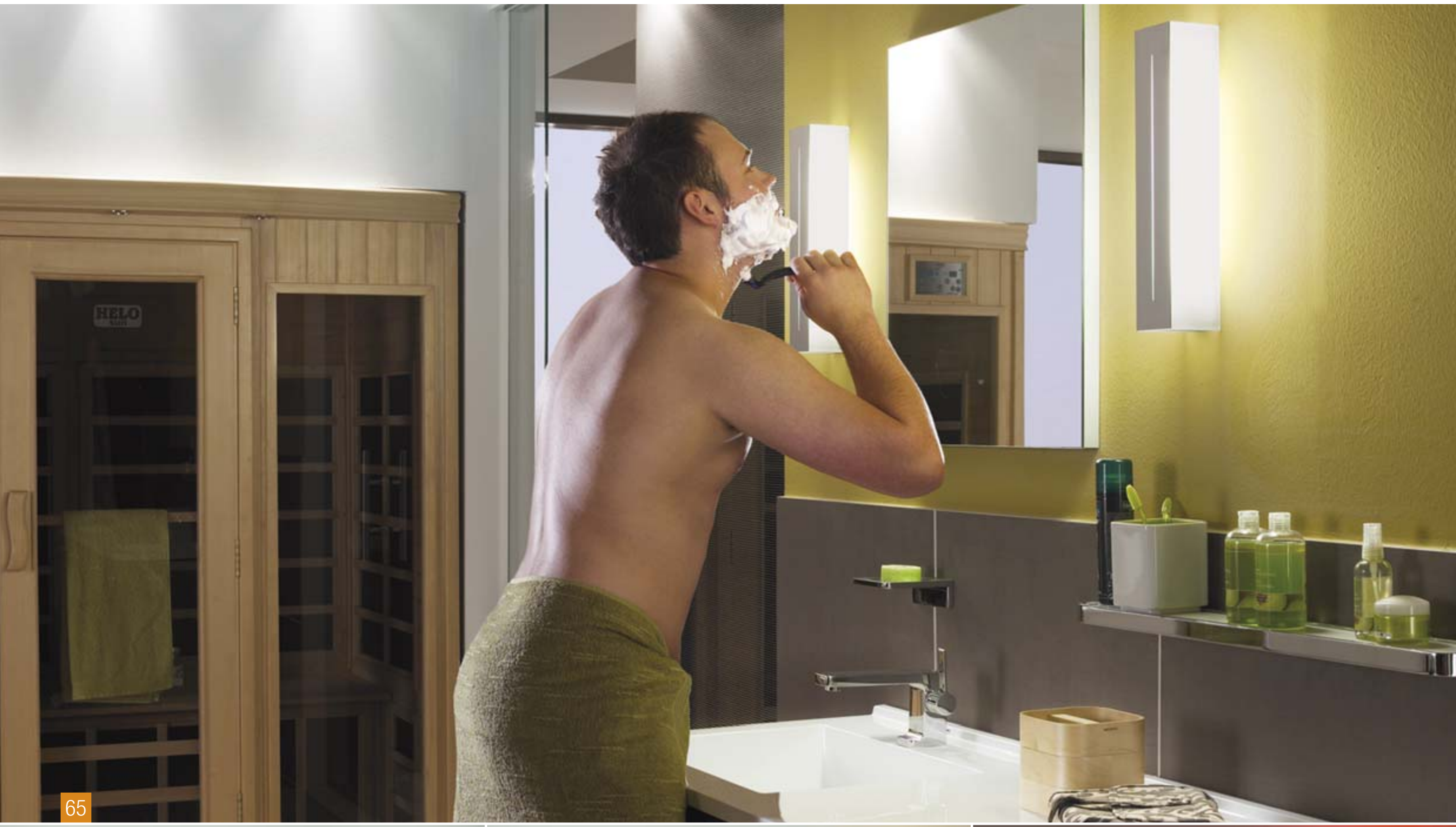

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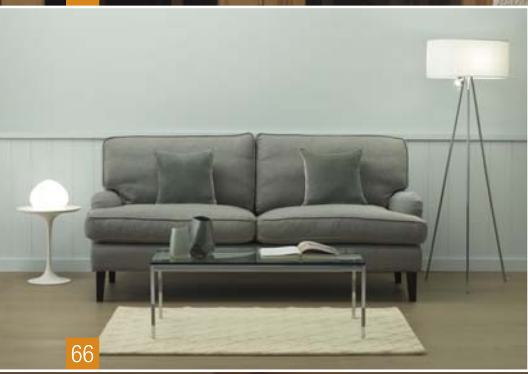

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Domestic lighting

Dynamic lighting can also contribute significantly to wellbeing at home. Complete circadian lighting solutions are still fairly rare at present. But with the correct choice of luminaires and lamps, domestic lighting can be put on the right basic footing.

We all need light to wake up and feel fit. The right lighting helps improve quality of sleep and wellbeing and – especially in the dark months of the year - fight off the widespread winter blues. This is confirmed by a study conducted at a wellness hotel by a team from Wuppertal University. 80 test persons took part in the study, which permitted conclusions to be drawn about domestic lighting.

More active and more rested

While half of the participants were exposed for two days to normal, typical hotel lighting, the other half spent two days under lighting that changed in brightness and colour like natural sunlight. During the day, they enjoyed cool white light with a high blue content and high illuminance; in the evening, that turned to subdued warm white light with a greater red content.

The result: participants

- went to sleep more easily
- woke up less frequently
- were more alert and more active during the day.

Activating light in the morning

The positive lighting effects can also be harnessed at home – and are particularly useful during the winter and when the clocks change. Anyone who cannot spend much time outdoors should make sure they get enough exposure to daylight or cool white artificial light (light sources with ratings above 5,300 kelvin or corresponding LED lamps).

Experiments at the sleep lab of the Charité Psychiatric University Hospital in Berlin have confirmed that even with the use of conventional lamps emitting daylight or cool white light, melatonin production is significantly reduced within ten minutes – the signal to sleep is not given. Activating light in the morning, e.g. in the form of planar general lighting in the bathroom or at breakfast in the kitchen, 'kick-starts' the body.

Light therapy

Many people suffer from light deficiency symptoms during the darker months of the year. They feel tired and listless and experience mood swings that can develop into seasonal affective disorder (SAD). SAD can be effectively treated at home using small light therapy devices. They radiate planar cool white light in the short-wave blue region. Quality devices reliably deliver colour temperatures from around 6,500 to 10,000 kelvin, which is similar to daylight.

Light alarm clock for a good start to the day

Biologically effective light is also provided by special light alarm clocks. 30 minutes before the wake-up time set, they raise the illuminance in the room, simulating the sun's strengthening rays at dawn. The sleeper is woken naturally and feels rested and refreshed.

In the case of SAD patients, the improvement in their morning mood is comparable to the effect of medication. The level of cortisol is also significantly higher than when a light alarm clock is not used. Users start the day full of energy – and get up within an average of nine minutes. Without a light alarm, it can take them up to 25 minutes to get out of bed.

Relaxing light in the evening

In the evening, the body should be prepared for sleep. So, at least two hours before going to bed, warm white light with a low blue content is recommended to promote melatonin production. Halogen lamps and corresponding warm white LEDs are a suitable solution.

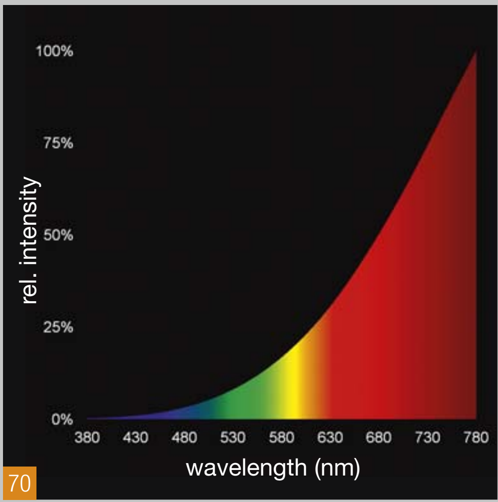
Apart from that, lighting in the evening should be spot-like – directional, not planar. This also applies to bedside reading lights. Anyone who spends a long time at a computer in the evening should check the specifications of the monitor: modern LED monitors generally have a high blue content, which has an activating effect. It is therefore better to switch off the PC two hours before going to bed or change the screen to an appropriate setting.

Many LED luminaires and lamps today offer different nuances of white light and even coloured light. Fitted with a digital controller, they can thus be regulated to provide the right light at the right time in the home.

[65] Daylight white light coupled with high illuminance in the bathroom 'kick-starts' the body in the morning.

[66 – 68] The right light at the right time: stimulating during the day, relaxing in the evening.

[69] Light alarm clocks simulate sunrise: users wake up naturally and feel refreshed.



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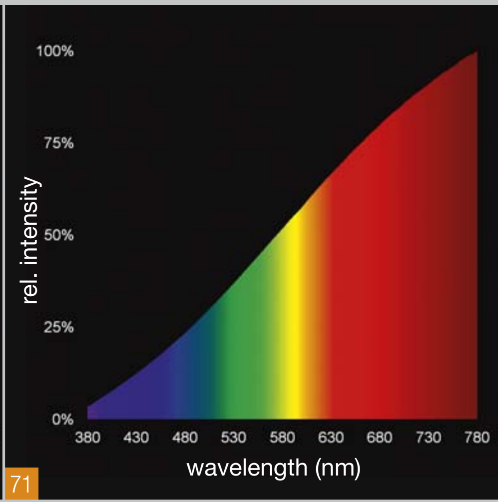

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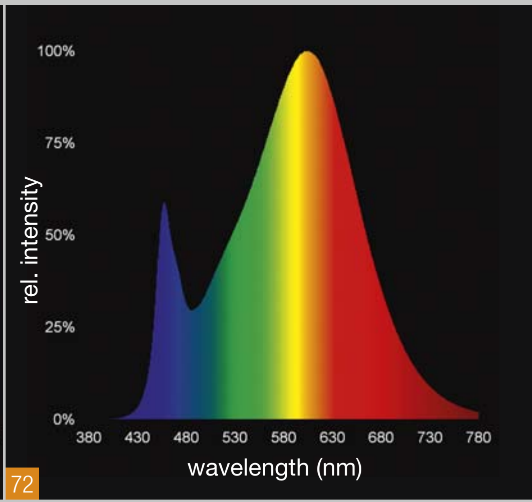

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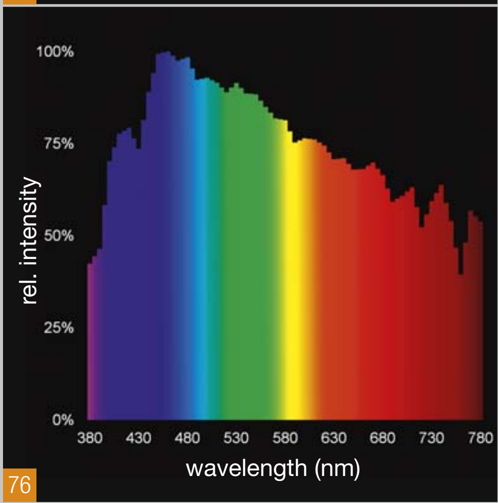

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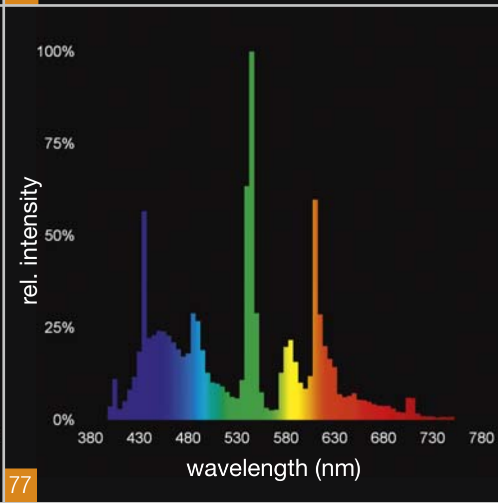

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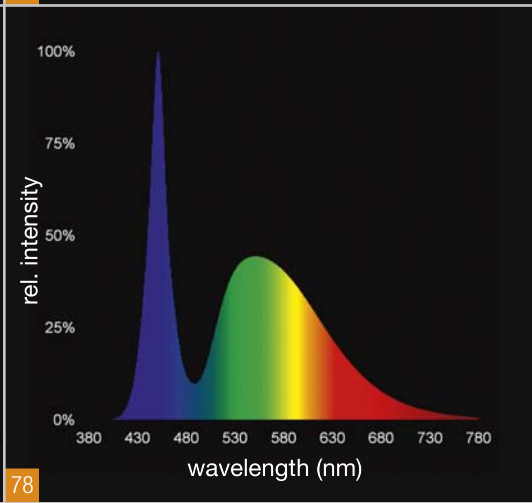

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Please note: The spectral ranges shown are based on relative values

The light source spectrum

For the design of a biologically effective indoor lighting installation, the spectrum of the light sources used is an important consideration. A metric enables the melanopic effect of different light sources to be compared.

Light colour is a major criterion for the design of biologically effective lighting. Expressed as a correlated colour temperature in kelvin (K), it indicates the colour appearance of a light source's light. The light colour of the sky mostly varies between 6,000 and 10,000 kelvin.

The melanopsin-containing photoreceptors in the human eye are particularly responsive to blue light. Their sensitivity is greatest at wavelengths around 480 nanometres. Lighting technologists refer to the range of those wavelengths as the "action spectrum" - the spectral bandwidth that triggers a particular effect in the human body. Use of the right light colour at the right time – in conjunction with the right illuminance - enables human biological rhythms to be supported.

Lighting design metric

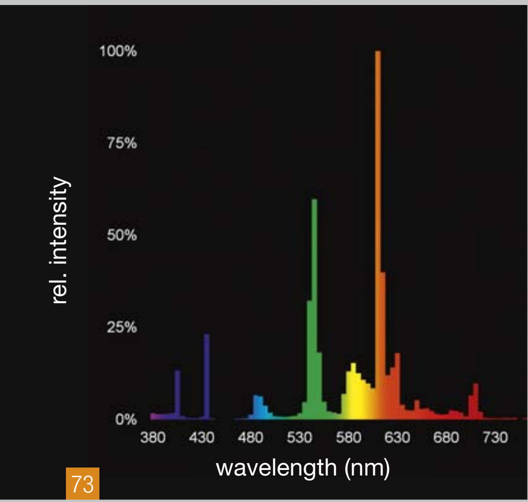
Today, the yardstick used for assessing the biological effectiveness of a light source is the spectrum of the melanopsin photoreceptor for the circadian response function $s_{mel}(\lambda)$ (see fig. 26, page 21). That function and the $v(\lambda)$ curve, which represents the brightness sensitivity of the human eye, form the basis for the metric for the comparative assessment of light source spectra described in DIN SPEC 5031-100.

One assessment parameter is the melanopic action factor $a_{mel,\,v}$. This is the ratio between the biological and visual effects of a light source's radiant output. Because the melanopic action factor is a somewhat opaque variable, a "melanopic lighting factor". e.g. luminous flux, is also identified. This factor takes daylight (D65) as its reference, accepting that visual (photopic) lux is exactly equal to melanopic lux in the standard daylight spectrum. For example: at D65, 1,000 lux (lx) photopic illuminance corresponds to 1,000 lux melanopic illuminance. For other light sources, the examples given show the melanopic luminous flux produced when photopic luminous flux is 1,000 lumen. The correction factor is the quotient of the melanopic action factor of the light source and the melanopic action factor for D65, which is 0.906. The melanopic value is thus the value of another light source that corresponds to daylight.

Lighting designers use these values to deploy different types of lamps in intelligent combinations and control them so that they create a biologically effective lighting installation that simulates the dynamic changes of daylight in illuminance and light colour.

Choosing light sources

The activating light that is desirable in the morning is furnished by the short-wave blue content of cool white light with a



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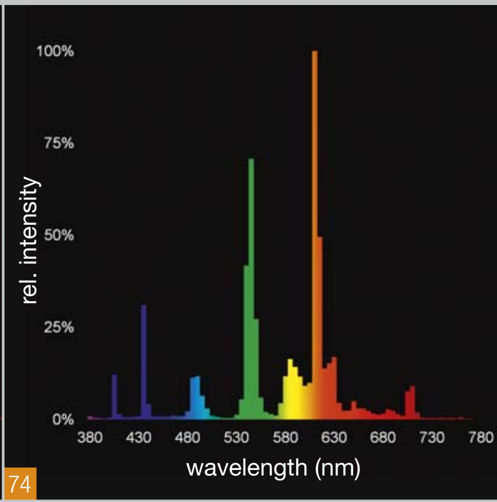

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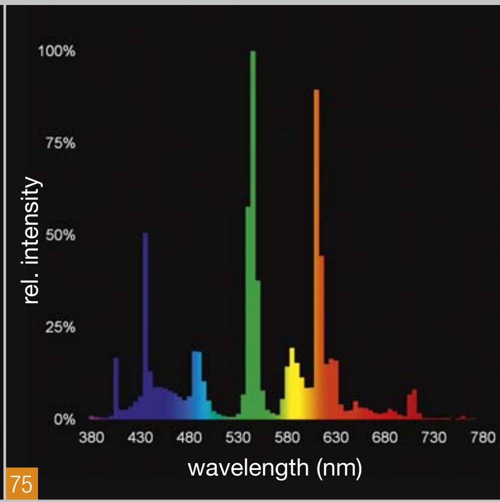

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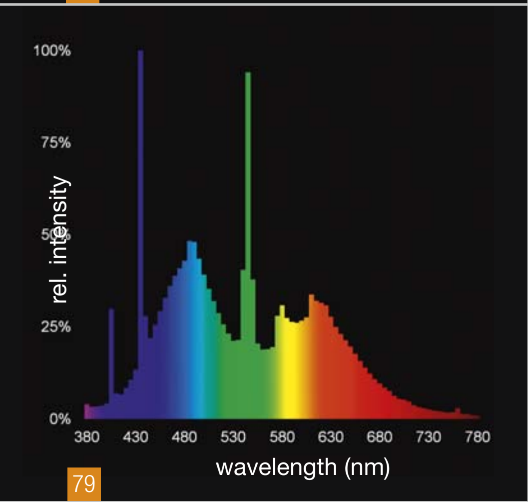

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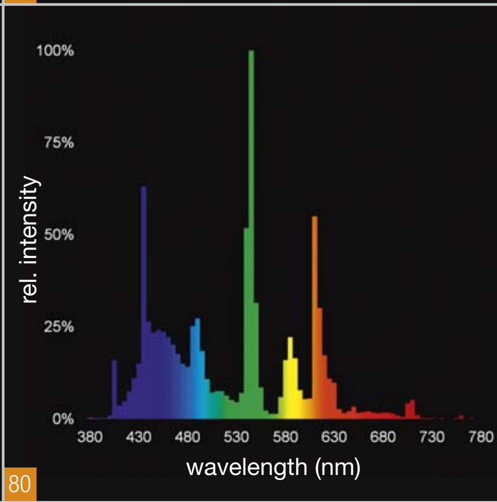

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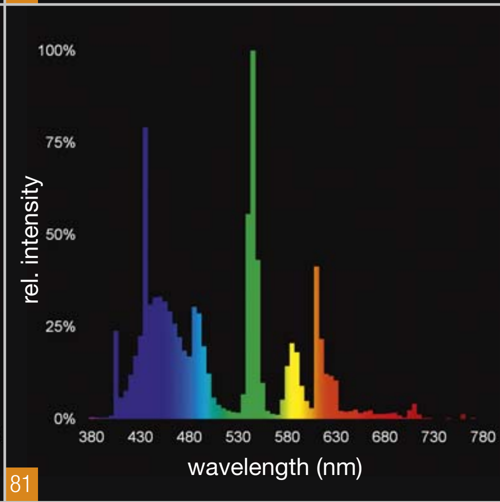

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colour temperature of 6,000 kelvin upwards. Light sources with this spectrum can stabilise our internal clock, stimulate bodily functions and improve concentration. In the evening, warmer light colours lower than 3,300 kelvin with little or no blue content should be used to help prepare the body for night. They ensure unimpeded production of melatonin, so we sleep better.

[70] The spectrum of a candle flame is continuous with high red content and very high infrared radiation ($a_{mel,\,v}$ = 0,26; melanopic illuminance at 1,000 lx photopic: 288 lx)

[71] Spectrum of a halogen lamp: continuous spectrum with high red content ($a_{mel,\,v}$ = 0.47; melanopic lumen: 520 lx)

[72] LEDs with warm white light colour and high colour rendering index have a high red content but emit no infrared radiation ($a_{mel,\,v}$ = 0.46; melanopic illuminance at 1,000 lx photopic: 506 lx)

[73] Light colour 825, fluorescent lamp: similar in appearance to the warm tone of a dimmed incandescent lamp, it has very little biological effect ($a_{mel,\,v}$ = 0.25; melanopic illuminance at 1,000 lx photopic: 278 lx)

[74] Light colour 827, fluorescent lamp: incandescent-like light with little biological effect ($a_{mel,\,v}$ = 0.32; melanopic illuminance at 1,000 lx photopic: 354 lx)

[75] Light colour 840, fluorescent lamp: neutral white light ($a_{mel,\,v}$ = 0.50; melanopic illuminance at 1,000 lx photopic: 547 lx)

[76] Daylight has a continuous spectrum with high blue content and a pronounced biological effect ($a_{mel,\,v}$ = 0.91; melanopic illuminance at 1,000 lx photopic: 1,000 lx)

[77] Light colour 965 for light therapy: daylight white of special fluorescent lamps with higher blue content ($a_{mel,\,v}$ = 0.83; melanopic illuminance at 1,000 lx photopic: 914 lx)

[78] LEDs with a cool light colour have a high blue content in the biologically effective range ($a_{mel,\,v}$ = 0.73; melanopic illuminance at 1,000 lx photopic: 805 lx)

[79] Light colour 965 optimised for maximum colour rendering: daylight white light of fluorescent lamps ($a_{mel,\,v}$ = 0.96; melanopic illuminance at 1,000 lx photopic: 1,058 lx)

[80] Light colour 880, fluorescent lamp: daylight white with higher blue content ($a_{mel,\,v}$ = 0,87; melanopic illuminance at 1,000 lx photopic: 957 lx)

[81] Fluorescent lamps with 17,000 kelvin colour temperature: higher blue content than daylight, correspondingly pronounced biological effect ($a_{mel,\,v}$ = 1.00; melanopic illuminance at 1,000 lx photopic: 1,108 lx)

82

Outlook: Sharing knowledge and researching further

In recent years, there has been a vast increase in research findings about the significance of light's non-visual effects on human beings. The basic mechanisms are well understood and viable concepts for adaptive lighting systems have been developed. What is needed now is to incorporate the findings in professional training and in the market.

Today, we know we need light for more than just vision. There is now sound scientific evidence showing that light is actually a form of nutrition. But like the food we eat, the wrong amount can have negative effects – from winter blues due to too little sunlight through to skin cancer due to too much. Artificial light at the right time with the right spectrum can make up for insufficient exposure to natural light.

That said, a regular, uninterrupted day/-night rhythm – or rather light/dark rhythm – is a crucial factor for human wellbeing and maintenance of health. The wrong light at the wrong time has been shown to result in the disruption of hormone rhythms.

Years of shift work with regular interruption of the day/night rhythm has even been classified by the WHO as a probable human carcinogen.

New stimuli for preventive healthcare

In future, adaptive lighting systems will increasingly be regarded as essential for the maintenance of human health. From the mood-elevating "light shower" in the morning to the sleep-neutral reading light in the evening at home – or to 24-hour biodynamic lighting at work as part of occupational health management – modern lighting installations will provide new stimuli for preventive healthcare.

As with food, the amount of light required and the times when it is needed differ from one person to another. Future lighting systems will be mass produced but also personalisable (mass customisation) so that the light they emit is dosed to meet the personal requirements of the user. Non-disturbing ambient and body sensors could help here.

Assistive technology
Dynamic lighting will become assistive technology, used to help us stay healthy. The way will largely be paved by energy saving LED technology, which has the double advantage of helping reduce carbon emissions. But it would be wrong to focus exclusively on energy efficiency. Harnessing the non visual effects of light – which were ignored in the past – comes at a cost. We need to find a happy medium between meeting human needs and cutting energy requirements.

To help develop the market and secure valuable empirical evidence from diverse applications, it is now important to expand education and training vigorously on a broad front. Not only do we need to train up lighting designers, architects, energy consultants and electricians as experts in the design of the new lighting installations; was also have a duty as a society to channel information through schools and companies to disseminate the latest findings about light's effects on hormones – and also to spread awareness of "light hygiene". i.e. the need for time without light.

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[82] Over the rooftops of Vienna, research shows foresight. In future, wherever people spend time indoors, they will be supported by light in the tasks they perform.

Glossary

Action spectrum – Spectral sensitivity to an action triggered by light. The maximum action spectrum of the third receptor (→ Third receptor) lies at around 460 nanometres, i.e. in the blue region of the spectrum visible to the human eye.

Adrenaline – Hormone with a stimulating effect, e.g. on heart, vascular system or breathing. It is produced in the adrenal gland.

Alzheimer's disease – The most common form of dementia. It is accompanied by progressive diminishing brain volume.

Biological darkness – Despite standard-compliant lighting, human biological rhythms are not sufficiently supported in modern day-to-day life by biologically effective light. Biological darkness is the term used to describe this state of deficiency.

Biorhythm – Non-specific term for a natural rhythm of biological cycles in living organisms.

Chronobiology – The field of biology concerned with the timing of biological processes

Chronotype – Our chronotype is defined by our internal clock. The two extremes are early risers (larks) and the late risers (owls) with all the nuances in between. Chronotype is also influenced by gender and age.

Circadian rhythm – A biological rhythm occurring at intervals of around 24 hours (from the Latin circa = approximate, dies = day), e.g. the sleep/wake rhythm in human beings. Light is the most important cue (see Zeitgeber) for synchronising circadian rhythms.

Colour rendering (index) – This indicates how natural colours appear under a lamp's light. The general colour rendering index (R_a) is based on eight frequently found test colours. R_a = 100 is the best possible rating. For most indoor applications, R_a should be ≥ 80.

Cones – see photoreceptors

Correlated colour temperature – The correlated colour temperature of a light source is the light colour of that source expressed in kelvin (K). Low colour temperatures (e.g. 2,700 K) make for warm yellowish/reddish-white light colours, such as those of candles, halogen lamps and other thermal radiators as well as warm white LEDs. High colour temperatures make for bluish-white light colours, such as that of daylight with around 6,500 K (overcast sky).

Cortisol (hydrocortisone) – Hormone with stimulating effect on various bodily functions ("stress hormone").

Dementia – Pathological loss of cognitive ability that mostly affects elderly people.

Depression – Pathological emotional low that requires treatment.

Epiphysis – see Pineal gland

Ganglion cells – Nerve cells in a ganglion (a mass of nerve cell bodies) that transmit visual information from retina to brain via the optic nerve. Two to three percent of ganglion cells are themselves photosensitive. They contain the pigment melanopsin and trigger biological responses in the body.

Hypophysis (pituitary gland) – This regulates the hormone balance of the body by producing hormones itself or using neurotransmitters to prompt other organs to do so.

Hypothalamus – Probably the most important control centre of the autonomic nervous system, the hypothalamus is located in the diencephalon (interbrain), where it regulates circadian rhythms via the suprachiasmatic nucleus (SCN).

Illuminance – Illuminance (symbol: E, unit of measurement: lux) defines how much light – technically speaking, how much luminous flux (in lumen) – falls on a given area. Where an area of one square metre is uniformly illuminated by one lumen of luminous flux, illuminance is one lux.

Infradian rhythm – Rhythm with a period longer than 24 hours.

Internal clock – Also known as the master clock, it synchronises the body with the external day/night cycle. It is located in the suprachiasmatic nucleus (SCN). Light is thus the most important synchroniser for the internal clock. It uses hormones and neurotransmitters to regulate the many tiny clocks in body cells that have no direct contact with the environment.

Intrinsic – originating within the body, not caused by environmental factors.

ipRGC (intrinsically photosensitive ganglion cells) – see ganglion cells

LEDs (light emitting diodes) – Electronic semiconductors which, when energised, emit red, green, yellow or blue light. Furnished with an internal luminescent coating, blue LEDs can be made to yield white light.

Light colour – Light colour describes the colour appearance of a lamp's light and is based on its colour temperature in kelvin (K): lamps of the same light colour can have very different colour rendering properties because of the spectral composition of the light they produce.

Light therapy – Treating ailments by irradiating patients with biologically effective (including ultraviolet or infrared) light. Light therapy is largely used for skin complaints and forms of depression.

Luminaire efficacy – The quotient of a luminaire's radiant luminous flux in lumens (lm) and the power it consumes in watts (W). Luminaire efficacy is the measure of a luminaire's efficiency. The higher the ratio of lumens to watts, the better the luminaire transforms the incoming energy into light.

Luminance – Luminance (symbol: L) is the brightness of a luminous or illuminated surface as perceived by the human eye. It is measured in candelas per unit area (cd/m^2).

Luminous flux – Luminous flux (symbol: Φ, unit of measurement: lm) is the rate at which light is emitted by a lamp. It describes the visible light radiating from a light source in all directions.

Luminous intensity – Luminous intensity (symbol: I) is the amount of luminous flux radiating in a particular direction. It is measured in candelas (cd).

Melanopic action factor – A measure for a light source's circadian effect (formula described in DIN SPEC 5031-100:2014).

Melanopsin – Photosensitive pigment contained in retinal ganglion cells involved in the signal transduction of the non-visual effects of light. Its maximum sensitivity lies at around 480 nanometres – i.e. in the blue spectral region.

Melatonin – Hormone that signals "night rest" to the human body and makes us feel tired. Also referred to a "sleep hormone", it is produced from serotonin in the pineal gland and secreted during the night. It can be inhibited by exposure to light during the night.

Monochromatic light– Light of a single wavelength creating an impression of colour in the human visual system.

Optic nerve – Neural connector via which the rod and cone cells transmit visual information from the retina to the brain.

Photopic vision – Day vision (mainly produced by cone cells in the eye), which requires an average illuminance above around 3 cd/m^2.

Photoreceptors – Photosensitive sensory cells that absorb photons and forward the information to the nervous system as electrical signals. In the retina of the human eye, this is done by cones, rods and melanopsin containing ganglion cells. Cones are responsible for colour vision. Rods, because they are more light-sensitive than cones, enable us to see in low light. Melanopsin containing ganglion cells are not visual cells. They transmit light information to the central nervous system and thus control our internal clock.

Pineal gland – Hormone-producing gland between the cerebrum and cerebellum. It produces the "sleep hormone" melatonin, which it secretes into the blood at night.

Rated input power – This is the effective power of the luminaire (in watt) in terms of rated voltage. It is used for planning the energy consumption of a luminaire and includes the power consumed by all components (including control gear) incorporated in the luminaire and required for its operation.

Rated luminous flux – The rated luminous flux of a luminaire (in lumen) is the total power radiated in all directions within the visible spectrum; it always refers to the initial luminous flux emitted by the semiconductor light sources in the luminaire under defined operating conditions.

Retina – Layered structure of cells lining the rear wall of the eye. It contains the photoreceptors (cones and rods) that convert light stimuli into visual nerve impulses These impulses are then forwarded by ganglion cells to the brain. The melanopsin containing ganglion cells (third receptor) are also located in the retina. But they do not forward their impulses as visual information to the diencephalon ("interbrain") via the optic nerve ; they transmit biological signals via the retinohypothalamic tract.

Retinohypothalamic tract – Neural connector between the retina and the suprachiasmatic nucleus (SCN) in the diencephalon (interbrain), via which melanopsin containing ganglion cells (third receptor) transmit light stimuli as biological signals.

Rods – see photoreceptors

SAD (seasonal affective disorder) – Pathological depression which is generally due to lack of light in the winter months and which can be treated by light therapy. The symptoms subside automatically in the spring.

SCN (suprachiasmatic nucleus) – Collection of thousands of nerve cells whose rhythms are synchronised daily by daylight. The SCN is located above (supra) the point where the optic nerves cross (optic chiasm) and is regarded as the control centre of the internal clock (master clock) that coordinates the timing of biological processes in the body.

Scotopic vision – Night vision (produced by rod cells in the eye) at luminance levels of less than 1 cd/m^2.

Serotonin – Neurotransmitter, or messenger substance, that carries signals between nerve cells and acts as a mood elevator. Its production is stimulated by daylight. At night, serotonin is biochemically converted into melatonin by the pineal gland.

Social jetlag – Disparity between external (social) zeitgebers and our internal clock. Over time, this disparity leads to sleep deprivation with all its negative consequences.

Third receptor – Melanopsin-containing sensory cells (ganglion cells) that are sensitive to light in the blue region of the spectrum and transmit light information to the SCN and the pineal gland in the central nervous system.

Ultradian rhythms – Rhythms with a period spanning less than 24 hours, e.g. sleep phases.

Visual field – The part of the environment that can be perceived by the eye and registered on the retina without the eye moving.

Zeitgeber – A zeitgeber (German for synchroniser) is any external cue that influences the internal clock. The most important zeitgeber is light, which influences the suprachiasmatic nucleus (SCN) via the third receptor in the eye. The SCN, in turn, acts as a master clock, synchronising the circadian rhythms of individual cells and coordinating their functions. There are also social zeitgebers such as work times.

Standards and literature

DIN EN 12464-1 Light and lighting – Lighting of work places, Part 1: Indoor work places

DIN EN 12464-2 Light and lighting – Lighting of work places, Part 2: Outdoor work places

DIN 5035-7 Artificial Lighting - Part 7: Lighting of interiors with visual display work stations

DIN EN 12665 Light and lighting - Basic terms and criteria for specifying lighting requirements

DIN V 18599 Energy efficiency of buildings - Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting

DIN EN 15193 Energy performance of buildings - Energy requirements for lighting

DIN SPEC 5031-100 Optical radiation physics and illuminating engineering – Part 100: Non-visual effects of ocular light on human beings - Quantities, symbols and action spectra

DIN SPEC 67600 Biologically effective illumination – Design guidelines. This document contains design recommendations for living spaces, which may be work premises or non-work premises. Also covered are areas in which forms of use may overlap or be mixed.

ASR A3.4 Technische Regeln für Arbeitsstätten – Beleuchtung

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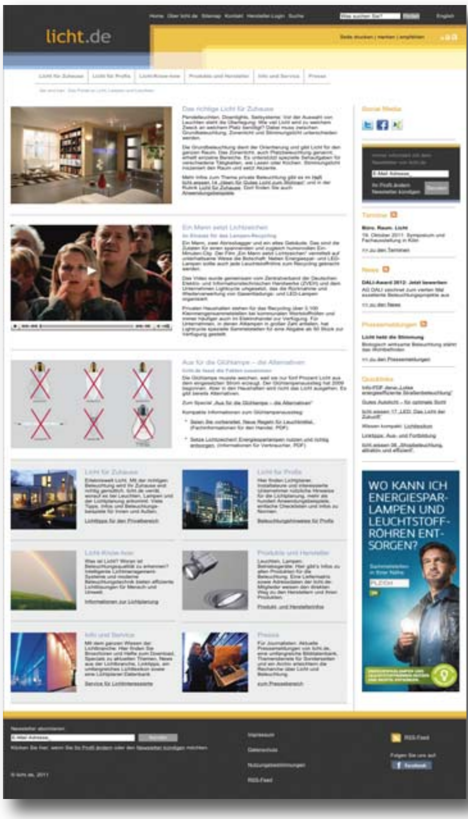

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