The right light for health and well-being

The importance of the biological effects of light and lighting concepts

An introduction to the subject by LEDVANCE experts

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1. INTRODUCTION

There is still little public knowledge about how great the impact of light is on the entire biological system of humans. The right light at the right time helps us to be efficient and active during the day and find sleep and rest at night.

More and more people have to keep up with high demands at work and often also in their private lives and still want to feel comfortable doing so. An increasing number of companies and organizations are therefore prepared to invest in the health and well-being of their employees as factors for economic success. Here light can make a valuable contribution because for thousands of years important biological processes in the human body have been geared toward living in natural light. The right light at the right time can create a lot of positive effects – for all age groups and in many areas of life.

It was only in 2002 that scientists discovered that in addition to the cones and rods that allow the eye to see there are other photoreceptors in the human eye. These are photosensitive ganglion cells which send signals to an area of the brain that regulates the hourly rhythm of our body as an internal clock. Other nerve pathways run from there to parts of the brain that control our cognitive abilities. As a result, light has an impact on hormones such as cortisol, serotonin, melatonin and many others, which in turn have an impact on blood pressure, heart rate, vitality, memory processes and mood. When it gets dark, the sleep hormone melatonin ensures that the body cells switch to “night-time mode”. This allows us to find a good and healthy night's sleep. Light therefore has crucial effects on the human body (see Glossary on page 16).

The human organism needs what it originally got from the sun: bright light with a high blue component in the morning and throughout the day, and less intense, yellowish-reddish light without these blue components in the evening. Many people do not experience these natural changes of light often enough because they spend most of their time indoors. Artificial indoor lighting mainly helps to improve vision because it has been designed for that purpose in line with valid standards, but it is less biologically effective. But light always has some biological effect. In conventional lighting it is unplanned and therefore undefined – probably too little during the day and too much at night – with potential negative consequences. Thanks to in-depth research, it is now possible to minimize such risks and to promote well-being, performance and health.

A human-oriented lighting concept – known as **human centric lighting (HCL)** – uses smart controllable LED lighting systems to simulate the characteristics of natural daylight, giving something back to us that we often lack indoors. Field studies show that all age groups can benefit from HCL solutions – from students to seniors. Scientific study results for different fields of application were collected and evaluated by renowned universities in Basel, Oxford, Groningen and Munich as part of the “SSL-erate” EU project which was completed in 2016 (cf. SSL-erate, 2014. See References, 1). The fact that HCL also has micro and macro benefits has been confirmed by a study carried out by international management consultancy A.T. Kearney which was published in 2015 by the Central Association of the German Electrical and Electronic Engineering Industry (ZVEI) and the European LightingEurope Association. **Because of all these opportunities** experts at LEDVANCE see an urgent need for greater clarification on biological lighting effects. The results of the SSL-erate studies and the study by A.T. Kearney form the basis for this HCL overview.

2. WHAT DO WE NEED? AND HOW CAN WE ACHIEVE IT?

Evolution has geared important biological processes in the human body toward living with a natural day/night cycle. This particularly includes bright light during the day and darkness at night, which is why we need daylight or comparable artificial light as a regulator for our internal clock, just like our ancestors thousands of years ago.

In the morning, the sensitivity of the photoreceptors in the eye that react specifically to the blue components in light is at its highest. Therefore a wake-up light (light alarm) slowly increasing in brightness helps us to be alert faster. Bright daylight-white light at the breakfast table promotes activity and performance and hence also the feeling of well-being for a good start to the day. This helps our internal clock to "synchronize" with the outside world and to adjust the body to "daytime mode" (cf. SSL-erate, p. 5).

During the day, bright light with a high blue component can increase concentration and also have a positive impact on our mood. To achieve these effects the light has to reach a certain brightness level, however (cf. SSL-erate, p. 5). Outdoors, we get high illuminance levels of 10,000 lux even on cloudy days. By comparison, normal indoor lighting levels today are between 50 and 100 lux in homes, and around 500 lux in offices. If we want to maintain concentration and alertness as much as possible throughout the day, we need a significant increase in the light intensity that is normally found indoors. This mainly refers to the biologically effective blue components in the light. Bright light during the day also means that we are less sensitive to disturbing light stimuli in the evening or at night, provided we received a sufficiently high dose of light during the day (cf. SSL-erate, p. 5-6).

People spend an average of 90 percent of their time indoors (Image rights: LightingEurope)

In the evening, at least two hours before bedtime we should only use warm white (yellowish/reddish) light with relatively low brightness (cf. SSL-erate, p. 6). This allows us to gradually wind down and relax, which is reinforced by the uninterrupted increase in the sleep hormone melatonin in the blood. Bright or cold white light with high blue components should therefore be avoided in the evening. It is important to slowly lower our alertness and vitality in the evening. That applies to lighting both in the workplace and at home. At night it should be as dark as possible.

Chronobiologists have demonstrated that not everyone ticks in exactly the same way. Some internal clocks run slower or faster for genetic reasons. Therefore, the individual circadian rhythms (from circa = approximately, and dies = day) of these people are a bit

longer or shorter than 24 hours. People known as “larks” are wide awake early in the morning, while “owls” on the other hand are alert longer in the evening. Something that all people have in common is that their internal clock needs to resynchronize with the outside world every day through light stimuli (cf. SSL-erate, p. 11).

If the right light stimuli are missing or reach us at the wrong time, our internal clock goes out of sync and with it the release of hormones which our body needs. This can lead to fatigue, lethargy, mood swings, depression and sleep disorders (cf. SSL-erate, p. 15). It can also weaken the immune system and lead to other illnesses because the body's own repair mechanisms are put out of action (cf. SSL-erate, p. 5, p. 42). Light and activity at the wrong time lead to a phenomenon in the long term called “social jetlag” which is connected with many negative side effects such as obesity, cardiovascular problems, sleep disorders and unhealthy behavior such as smoking and excess alcohol and caffeine consumption (cf. Wittmann et al., 2006; Roenneberg et al., 2012; Juda et al., 2013).

3. WHAT TYPE OF LIGHT HAS AN IMPACT?

In the past 20 years, fundamental research has led to many insights into human biological rhythms and the biological lighting effects.

Ever since the 1980s it has been a well-known fact that seasonal affective disorder (SAD) in the dark winter months can be treated using bright light with high blue components (cf. Rosenthal et al., 1984; Terman et al., 1995). We owe further insights to research from the last 20 years. Based on current knowledge, the following factors in particular are crucial for the non-visual, biological effect of light on people (see DIN SPEC 67600)

1. **The spectral proportion of the light**. Light similar to natural daylight with high blue components has the strongest activating effect. This particularly stimulates the receptors in the eye.
2. **The intensity of the light**. Research results show an activating effect starting at an illuminance level of 250 lux directly at the eye, if the light has a quality similar to natural daylight.
3. **The area of the light**. Large luminous surfaces that are visible on ceilings or walls intensify the activating effect. They perfectly address the photosensitive ganglion cells in the inferior part of the retina and, thanks to their large surface areas, they reach many of these photoreceptors. This means that large ceiling lights or indirectly illuminated ceilings can simulate the natural sky.
4. **The brightness levels during the day and at night**. A big difference between day and night supports our circadian rhythm and hence also sleep.

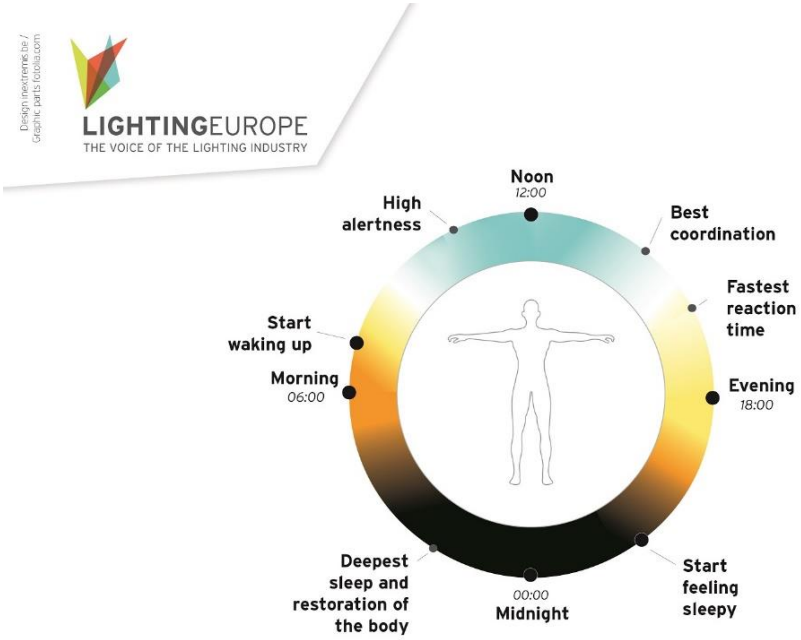
4. WHAT WOULD BE IDEAL HCL LIGHTING?

Lighting based on the latest scientific findings that addresses the needs of people is defined as “human centric lighting” (HCL).

When planning an ideal HCL concept, both the visual effects of light (for better vision) and the non-visual biological effects of light must be taken into account. Generally, the following principles apply (cf. SSL-erate, p. 6):

1. The more natural light that is used, the better.
2. Smart HCL solutions should automatically be oriented to the changes in natural daylight in terms of light colors, brightness and the spatial distribution of the light.

3. People are especially receptive to the biological effects of light in the first two hours after getting up and at least two hours before bedtime.
4. Large lights from above that imitate a sunlit (blue) sky have the greatest biologically activating effect. Therefore, at the start of the day until lunch time and after the lunch break, bright, cold white light with a high blue component (such as 6500 Kelvin at an illuminance of 300 lux at the eye) should be used. Indirect light which includes both ceilings and walls is ideal for this.
5. Towards the evening the lighting should be changed to direct warm white light without blue components (such as 2700 to 3000 kelvin) to help our bodies to relax and prepare for the night.



Biological functions throughout the day (image rights: LightingEurope)

5. MICRO AND MACRO BENEFITS OF HCL

In the study published in 2015 titled “Quantified Benefits of Human Centric Lighting”, international management consultancy A.T. Kearney illustrated the financial benefits resulting from the use of HCL from a micro and macro point of view.
All the calculations for the different areas of application were based on the comparison of a conventional high-quality LED solution with a lighting system that meets the criteria of human centric lighting. In HCL lighting, the visual and biological needs of people are taken into account. Seven indoor applications were selected for analysis: industry (repetitive), industry (advanced), office, education, medical, residential (elderly care) and residential (homes). The results are available on the websites of the associations (cf. A.T. Kearney, 2015).

HCL has higher energy requirements than an LED solution designed for visual purposes only. To achieve the desired biological effect, higher illuminance levels and blue components in the light are needed in some places. **However, if HCL is compared with an older conventional lighting system as part of an upgrade, there will be energy savings** (not calculated in this study). The additional costs of installing HCL lighting were not calculated. The study focused on the financial benefits of HCL compared with the necessary annual energy costs of the lighting system.

The most significant micro benefits of HCL can be found in the industrial segments. This is proven by previous studies which relate above all to projected productivity gains. When it comes to hospitals and care homes for the elderly, the operator often cannot leverage the entire potential alone. There are financial benefits through cost savings – including for insurance companies for example. More details can be found in the following sections.

All the areas of application are also looked at in more detail and quantified in the study **at macro level.** The assumptions on market penetration by 2020 are based on an estimate published in an earlier HCL study that the European market for HCL may be 1.4 billion euros by 2020 (cf. A.T. Kearney, 2013: p. 8). According to projections by A. T. Kearney, the benefits for Europe may be up to 870 million euros in 2020 for a realistic market penetration. 527 million thereof is extrapolated based on scientific studies which have already been carried out. The study comes to the conclusion that in most segments it is the owners and investors who benefit most. But there are also additional advantages in terms of social benefits that justify the additional expense for HCL. In the case of theoretical full market penetration with HCL in all areas of application, the study suggests a potential macro benefit of up to 12.8 billion euros for Europe.

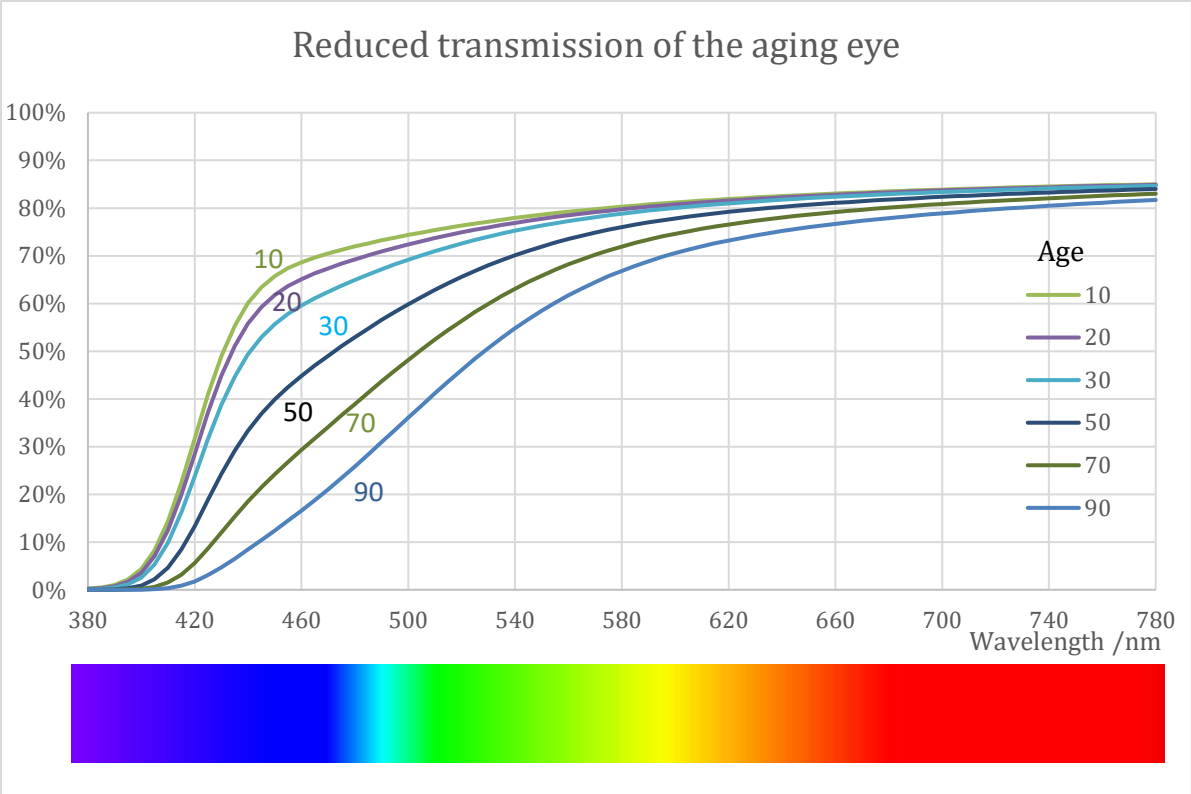
The following sections refer to the study results for the different application areas, simply quoting the “A.T. Kearney study”.

6. BENEFITS IN THE MEDICAL AND RESIDENTIAL (ELDERLY CARE) SECTORS

The non-visual effects of light can stabilize the biological rhythms of people in elderly care facilities and hospitals. Better quality of sleep relieves the burden on caregivers and can promote recovery and convalescence processes (cf. SSL-erate, p. 40).

Sufficient light similar to natural daylight at the right time can improve the mood of residents in retirement and care homes as well as patients in hospitals, helping prevent depression. The promotion of a healthy day/night rhythm improves the quality of sleep, helps seniors to avoid falls and relieves the burden on caregivers. This means that HCL increases the quality of life for everyone involved and is very helpful in most cases even in the early stages of dementia.

Age has a strong impact on the visual and biological effects of light: because of age-related clouding of the lens old people need two to three times as much light as young people, both for good vision and for the right effect on their internal clock and hormone system. At the same time, it is well-known that old people are more sensitive to glare. Reconciling the two increases the demands on the quality of light and light distribution in the room.



In old age the transmission of the lens for biologically effective blue light components is reduced significantly. (Image rights: Dieter Lang, based on CIE 203)

For HCL lighting concepts the following applies (in addition to the principles listed on pages 5-6):

1. Sick, frail and elderly people need plenty of light of particularly high quality because their bodies need to deal with impairments, injuries and illnesses (cf. SSL-erate, p. 5)
2. For the circadian rhythm to be strengthened, at least the common rooms, and ideally also the corridors and patients' and residents' rooms, should be equipped with HCL to ensure exposure over long periods of time.

The A.T. Kearney study from 2015 shows a number of micro and macro benefits for the medical and residential (elderly care) sectors.

In a care home with 100 beds, 90 residents and 63 employees, capacity utilization could be increased for more than two thirds of the floor space using HCL (cf. A.T. Kearney, 2015: p. 16). This is based on a reduction in accidents and an increase in well-being for the elderly. This would increase the attractiveness for new residents – even more so than for hospitals – because care homes are chosen by families. A potential reduction in drug doses could further increase utilization and attractiveness. The benefits for this case are quantified at 21,000 euros – three times as much as the electricity costs of 7,000 euros. The study points out that further scientific evaluations will be needed. More and more retirement homes, care facilities and hospitals are using HCL. In addition to financial considerations, medical and emotional factors are also being taken into account.

For a hospital (cf. A.T. Kearney, 2015: p. 15) with 1,000 beds and 1,500 employees the study shows how for about half the beds HCL can increase capacity utilization through higher attractiveness for new patients and can cut treatment costs through reduced treatment times. In addition, sick leave taken by care staff could go down, and employee satisfaction and therefore staff retention could go up. The estimated benefit of 323,000 euros is almost twice as high as the annual electricity costs of 174,000 euros (compared to 134,000 euros for an LED solution).

7. BENEFITS IN THE EDUCATION SECTOR

In the early hours of the school day in particular, human centric lighting can help students become alert and increase their powers of concentration. This is of special benefit for teenagers whose circadian rhythms correspond to the "owl" type.

At the onset of puberty, the sleep/wake cycle undergoes a shift for many teenagers. They go to sleep later in the evening and are often still half-asleep when school begins. The "owls" (see Chronotypes, page 5), who reach their full potential only later in the day, are therefore at a disadvantage compared to the "larks" among their classmates who are more active in the morning. Light can redress the balance here to a certain extent by having an energizing effect on students in the morning – particularly in the dark winter months (cf. SSL-erate, p. 10)

Learning is successful only if students can concentrate properly on the content. Human centric lighting can help here. The right lighting at the right time can not only reduce morning fatigue but also have an activating effect on students. It increases their alertness so they can follow the lessons more easily. A more focused learning environment reduces general restlessness, which in turn boosts the concentration of all students. Stabilizing the circadian rhythm also has a positive effect on the quality of night-time sleep in which the brain can better absorb and process what has been learned during the day. It makes no difference whether it is a school or a university here (cf. SSL-erate, p. 10)

Study results from SSL-erate show the following:

- The speed at which primary school children can read improved by almost 35 percent in a study with activating light (cf. SSL-erate, p. 14).
- In another study, concentration and sustained attention improved by about 30 percent (cf. SSL-erate, p. 16)

Educational establishments in particular place high demands on lighting concepts
(Image rights: Dieter Lang)

For HCL lighting concepts the following applies (in addition to the principles listed on pages 5-6):

- The teachers are exposed to the lighting as well as the students. Since they too have to be active and productive during lessons the same requirements apply. It is important to ensure that the lighting concept also takes into account the location of the teacher in the classroom and their line of vision.
- The demands that different lighting scenarios have to meet in schools are more varied than those in offices as each teaching method requires different lighting. Concentrated work, relaxed reading, music and art classes, or following a

presentation on a screen or whiteboard need very different lighting scenarios in which visual and biological needs have to be reconciled in an overall concept.

The 2015 A.T. Kearney study perfectly identifies the micro and macro benefits in the education sector.

In a school with 1,000 students and 80 teachers the electricity costs for HCL would be around 11,000 euros (compared to around 8,000 euros for an LED system). By contrast, there is a possible increase in the cognitive performance of students by up to 15 percent. Another factor is that the mental strain (stress, burnout, etc.) on teachers and associated sick leave are reduced by HCL solutions so teachers could remain longer in service (cf. A.T. Kearney, 2015: p. 14). On this basis, the financial benefits amount to 43,000 euros, contrasting with the increased electricity costs for HCL of 11,000 euros. The financial benefit is almost four times as high and can be viewed as a benefit to the economy as a whole.

8. BENEFITS IN THE INDUSTRIAL AND OFFICE SECTORS

Human centric lighting at the workplace can boost alertness, performance, morale, the sleep/wake cycle and general health (cf. SSL-erate, p. 21).

The objective for workplaces – as in other indoor areas of application – should be to give to people what they have traditionally received from natural daylight. Artificial light can make up for deficits resulting from lack of exposure to natural daylight. Extended lighting solutions with biological effects can improve wakefulness, alertness, mental and physical performance, vitality, mood, the sleep/wake cycle and general health.

HCL lighting solutions in offices, as in the educational “workplaces” described above, improve attentiveness and concentration. Although “productivity” is more difficult to measure in offices than in factories, the positive effects of HCL are verifiable. The latest studies have shown, for example, an increase in the level of satisfaction felt by employees in their own performance levels and the quality of their work. Studies also provide evidence that although the amount of work carried out at the end of the day is not greater, there is a different kind of productivity boost in that office workers find it easier to work. The reason is that less mental effort is needed for high levels of concentration, so performance is maintained for longer (cf. SSL-erate, pp. 20-34).

Lighting solutions for the work environment are now almost exclusively focused on good visibility but that is **no longer consistent with the current state of the art** (cf. SSL-erate, p. 21). At present, the German Technical Rules for Workplaces, for example, includes requirements only for certain minimum illuminance levels and minimum quality of light, and no specifications at all for daytime/nighttime or human centric lighting. As a result, existing lighting systems tend not to be sufficiently geared to achieving optimum performance levels from employees throughout the day and often provide excessive brightness and blue components for evening and nighttime work. The relevant authorities are currently investigating whether and how the latest findings from chronobiological research can be incorporated in the Technical Rules for Workplaces and the relevant standards.

Bright indirect light with a high blue component has an energizing effect and supports efficient working. (Image rights: Ledvance)

For HCL lighting concepts the following applies (in addition to the principles listed on pages 5-6):

1. Automatic control in accordance with changes in natural daylight is recommended. This may relate, for example, to indirect light sources such as the illumination of ceilings and walls and the regulation of blue components, which have a greater energizing effect. It may make sense to provide options for individually adjusting the luminaires that illuminate work areas directly (cf. SSL-erate, p. 43).
2. Separate desktop lights enable the lighting to be adjusted to suit individual chronotypes in the evening – with room lighting from luminaires further away adding to the effect in open-plan offices.
3. People working in the evenings and at night are particularly sensitive to the biological effects of light (cf. SSL-erate, p. 42). Solutions are therefore required that ensure adequate levels of attention and concentration for the particular tasks but which have as little a disruptive effect on the internal clock. Shift models should also be devised so that they have less impact on chronobiological rhythms.

The 2015 A.T. Kearney study identifies micro and macro benefits.

The study takes a **scenario in the industrial sector** as an example in which 750 employees assemble electronic components on a piecework basis (cf. A.T. Kearney, 2015: p. 11). An HCL lighting installation with 2,000 lux would increase productivity by 4.5 percent compared with an LED solution and reduce the error rate by 1 percent thanks to greater general alertness and the activating effect. This estimate is based on an actual research study. According to estimates by A.T. Kearney, there would also be 1 percent fewer sick days and one year longer retention thanks due to greater physical robustness (mid to long-term effect). The annual electricity costs for HCL lighting in this example are around 54,000 euros compared with approximately 42,000 euros for an LED solution. This stands in contrast to a benefit of almost 900,000 euros from HCL. The annual benefit of HCL is therefore 16.6 times the total electricity costs needed for the HCL system.

A factory with 1,000 employees involved in detailed work, such as precision engineering, would profit even more from HCL lighting with an illuminance of 2,000 lux. The study assumes that productivity would increase by 4.5 percent compared with an LED solution – that is by far the greatest factor. There would also be a reduction in the error rate and sick days plus a longer retention period. The estimated benefits of HCL of more than 2 million euros are 40 times greater than the electricity costs of around 54,000 euros (compared with 42,000 euros for an LED solution).

In the **scenario of an office** with 200 employees working at desks, the study assumes that about two-thirds of the office space is relevant for HCL lighting. The electricity costs for HCL would be approximately 9,000 euros – around 2,000 euros higher than in the case of an LED solution. Increased productivity of around 1 percent is assumed, plus fewer sick days and a longer retention period. As a result, annual savings from HCL are estimated at 111,000 euros, which is 12.3 times greater than the required electricity costs. Recently published studies even show potential productivity gains in the office sector of more than 10 percent if HCL is implemented as part of a holistic approach to improvements in the work environment (cf. CBRE, 2017).

9. BENEFITS IN THE RESIDENTIAL (HOMES) SECTOR

Artificial light in homes is often too dark throughout the day and not activating enough; even so, it may contain blue components that tend to have a negative impact on the body in the evening (cf. SSL-erate, p. 50).

For people who are at home during the day because they work at home or are engaged in personal activities the same requirements apply as in workplaces – they need more light and brighter light that simulates natural daylight to maintain concentration and alertness. This will also help improve their mood (cf. SSL-erate, p. 50).

In the evening it is particularly important in the home to avoid problems from high levels of blue light and to have only warm white (yellowish/reddish) light. In the hours before going to bed, this applies not only to reading lights and bathroom lights but also, and in particular, to the light from computer or tablet screens (cf. SSL-erate, p. 53). There are now solutions such as f.lux or nightshift which reduce any negative effects of screen lighting in the evening. During the night, bedrooms should ideally be dark. We are less sensitive to problematic light stimuli if we have had a high enough dose of light during the day.

In the morning, light that increases slowly in brightness (light alarm clock) helps us to reach full alertness more quickly. Bright daylight white light in the bathroom and at the breakfast table promotes activity and performance and therefore induces a feeling of well-being for a good start to the day.

Warm white light is recommended in the evening to promote relaxation
(Image rights: Ledvance)

A sample analysis for the residential (homes) sector was not undertaken for the 2015 A.T. Kearney study.

An analysis of the potential in this application segment led to an assessment by A.T. Kearney that private consumers would tend not to install HCL for monetary reasons. Private customers are wary of purchase costs and cannot expect gains in productivity. And it would be health insurance companies and employers who would benefit most from the financial implications. Even so, private customers are health-conscious and prepared to dip into their wallets for proven health benefits. The opportunity here is to position HCL as a healthy lifestyle product – like sport or healthy nutrition. But first the public needs to be properly educated. The study compares annual expenditure per person on things that compete with HCL: fitness studios, diet products, organic products and electronic devices such as fitness armbands. People living stressful lives who do not find relaxation at home can certainly expect improvements from having the right light in their houses.

10. OVERVIEW OF THE BIOLOGICAL EFFECTS OF LIGHT ON THE HORMONE SYSTEM AND CONSEQUENCES FOR WELL-BEING AND HEALTH

A word often heard in connection with the biological effects of light is **hormones**. Light does indeed influence a whole series of functions in the human body that are controlled by hormones.
This is a highly complex system that cannot be easily “dissected” into independent elements.

The biological effects of light on our organism are still often described in terms of the hormone **melatonin**, commonly known as the “sleep hormone”. The effect of light on melatonin in the night can be measured directly in our blood. The release of melatonin into our blood is controlled by the circadian rhythm and cannot be artificially accelerated. Melatonin is responsible for ensuring that we sleep for sufficiently long periods.

Whereas melatonin is present in blood in only very small concentrations during the day, its level rises significantly in the evening. This high melatonin level in the evening – together with fatigue at the end of a long day – means that we become tired and fall asleep. If, however, we are exposed to bright light in the evening the melatonin level will fall, which can lead to problems in falling asleep. It is therefore important to avoid bright light in the evening and at night.

Bright light during the day has no direct effect on melatonin because it is not normally present in the blood at that time. Instead, bright light produces **serotonin**. This “happiness hormone” has a positive effect on mood and promotes a feeling of well-being. What’s more, melatonin for the night is produced from serotonin. The two hormones are therefore inextricably linked. This means that plenty of light during the day will support the production of serotonin and therefore also melatonin.

If we are exposed to the right light at the right time our **circadian rhythm** will be stabilized and synchronized with the natural day/night cycle. A stable circadian rhythm also means that other important hormones such as cortisol, dopamine, adrenaline and many others will be in balance.

Human centric lighting, commonly referred to as “the right light at the right time”, therefore makes a valuable contribution to establishing and stabilizing human day/night biorhythms, boosting our sense of well-being and improving our health.

GLOSSARY

Biological effects of light
The effects of light on biological processes in the body as a result of light entering through the eyes. Such effects essentially include synchronization of the circadian rhythm and activation as a result of bright light. Also known as non-visual or melanopic effects of light. They do not include the effects of UV radiation (e.g. vitamin D production, erythema or tanning) or the effects of infrared radiation.

Chronotype
At its simplest, a distinction is made between early-risers (larks) and late-sleepers (owls). Between the two there are gradations particularly among people whose regular sleep/wake cycle is not disturbed by shift work, illness, small children or other such causes.

Circadian rhythm
A biological rhythm that naturally lasts around one day (e.g. sleep/wake cycle, digestion, body temperature, hormone levels). Circadian rhythms have to be resynchronized with the natural day each and every day through light since the genetically predetermined circadian rhythm is not precisely 24 hours long. Without this synchronization through light there would be discrepancies over the long term between the biological rhythm and the external day/night rhythm.

Cortisol
A hormone that controls our activity. It is sometimes referred to as the “stress hormone” because it is excreted in greater quantities during periods of stress. It is essential, however. Without it, we would not have the energy we need to get up in the morning and start the day.

Health
The World Health Organization WHO defines health as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity”. On the basis of this definition, the effects that light has on the well-being of people are also long-term effects on health. On this understanding, human centric lighting has a long-term positive impact on health.

Melatonin
A hormone secreted into the blood by the pineal gland in the evening and at night and which controls the sleep/wake cycle. Light during the night can reduce the level of melatonin in the blood. It can therefore have an adverse effect on sleep and disturb the day/night rhythm.

Melanopsin
A light-sensitive protein present in around 2 percent of all the ganglion cells of the retina, making them photosensitive. Melanopsin reacts only to light at the blue end of the spectrum; in simple terms we could say that it reacts only to daylight and to light that is similar to daylight.

Photoreceptors
Light-sensitive cells in the retina. The color-sensitive cells in the retina, known as cones, and the cells that help us see in low light levels, known as rods, were first identified more than 100 years ago.
It was only in 2001, however, after a number of studies had been evaluated, that scientists concluded that there had to be a third type of photoreceptor responsible for the biological effects of light. Subsequent studies identified this third type as photosensitive ganglion cells.

Photosensitive ganglion cells
Retinal photosensitive ganglion cells, to be more precise, are cells in the retina which occur alongside the familiar cone and rod receptors and which, like these, are sensitive to light because they contain melanopsin.

Serotonin
A hormone that acts as a neurotransmitter; in other words it forwards signals between nerve cells. It is produced mainly in the brain, particularly through the influence of bright light. Serotonin is converted into melatonin in the pineal gland.

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