LED lamps

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LED lamps or LED lighting systems are suitable for energy-efficient interior and exterior lighting. They are an alternative to energy-saving and halogen lamps.

For technical reasons LED lamps cannot produce white light, but rather emit yellow and blue light components that when mixed together result in white light. As blue light, above a certain intensity and irradiation time, represents a risk to the retina of the eye, the lamps have to meet the limit value for blue light exposure. This limit value is attained after a longer or shorter irradiation time depending on the intensity of the blue light component.

Commercial LED lamps represent no health risk when used correctly. This is also true for vulnerable population groups, such as children or persons, who have very clear, synthetic eye lenses or none at all.

Lamps are classified into the following risk groups. Lamps in the "exempt group" are risk-free even with unlimited use. Lamps in the risk groups 1 and 2 are risk-free for a limited period of use, whereas lamps of risk group 3 exhibit a high risk even for very short periods of use.

Informazioni utili per un utilizzo corretto delle lampadine a LED:

- In general, use LED lamps at a distance of at least 20 cm.
- Use LED lamps of the "exempt group" if your eyes are exposed to direct light for very long periods. The exempt group primarily includes light bulb shaped LED lamps with a mat surface and a screw thread, as well as tubular LEDs.
- For household use, LED lamps of risk group 1 that are not hazardous to the eyes are also suitable, provided that people do not look at the LED for longer periods. This risk group primarily includes LED spotlights as well as some table lamps.
- Do not use LED lamps of risk groups 2 or 3 in the private sphere, as acute damage to the eyes is possible even after a very short look into the LED lamp. An indication to the risk groups 2 or 3 is found on the packaging.
- If possible, arrange light fixtures, table lamps, reading lamps and bedside lamps with a visible LED chip, such that the chip is not seen directly. Mat lamps reduce possible glare
- Use warm-white LED lamps or energy-saving lamps with colour temperatures of ca. 3000 Kelvin in areas where people stay for longer periods in the evening before going to bed. Colour temperatures are shown on the lamps. Cold-white lamps with colour temperatures above 4000 Kelvin are less suitable for such areas, as the lamps' blue light components affect the body and influence sleep and other functions in the body.
- Certain LED products as well as some dimmed LED lamps can flicker. It is not clear whether they

represent a risk to persons with a headache, migraines or epilepsy. Consequently, use flicker-free or undimmed LED lamps for lighting those areas where people stay for longer periods. Flickering properties of LEDs can be easily determined on the display of a smartphone camera or digital camera by focussing it close up to the LED. The LED flickers if a striped picture can be seen on the display.

– The electromagnetic fields generated by the electronics when operating LEDs do not represent a health risk as the fields are far below the health limit values that are intended to prevent health risks.
– LED lamps, because they do not emit ultraviolet radiation or almost none, are an alternative to halogen or energy-saving lamps for persons who are hypersensitive to ultraviolet radiation.

1 Introduction to white LED lamps

1.1 Design

LED lamps generally consist of one or more light-emitting diodes (LEDs). The key element of a light-emitting diode is a chip made up of two semiconductors joined together which when energised emits light. The combination of the semiconductor materials determines the wavelength of the emitted light that exhibits a narrow-band spectrum or a characteristic colour. The colours that are possible with today's semiconductor materials are in the ultraviolet, visible or infrared regions. White light, which consists of a mixture of many colours, cannot be directly generated by LED lamps but is obtained by mixing various colours.

LED diodes function in the low-voltage field. Consequently, LED lamps comprise an electronic transformer that reduces the voltage level and increases the frequency. These transformers, like other current-carrying components, generate electromagnetic fields that are measureable in the immediate vicinity of the LED lamp.

1.2 Emission properties

Spectral characteristics and colour temperatures

LED lighting systems, whose light is perceived by humans as white in colour, consist in principle of LEDs that emit blue or violet light. In order to obtain white light the transparent enclosure of the LED is coated on the inside with one or more fluorescent dyes. The molecules of this layer absorb part of the violet or blue light and thereby temporarily absorb energy. Depending on the type of layer, they subsequently radiate this energy again in the form of yellow-red light. The yellow-red and violet-blue light components stimulate the blue, green and red photoreceptors on the retina of the eye. In humans this creates the sensation of white light that, depending on the mixing ratio of the individual colour components, has a cold-white blueish or warm-white yellowish character. These colour characteristics of lamps can be described by their colour temperature. In warm-white lamps they are in the region of 3000 Kelvin and in cold-white lamps in the region between 4000 and 8000 Kelvin.

Depending on the design or operational mode, the electronic transformers supply the LED light diodes with a current that fluctuates to a greater or lesser extent. Consequently, the intensity of the radiated light also flickers or exhibits "flickering".

2 Health effects of white LED lamps

The characteristics of the radiation of white LED lamps are diverse. In this regard LEDs differ from the characteristics of incandescent lamps and somewhat also from those of energy-saving lamps. There are various possible mechanisms for how the radiation from LEDs can affect health. They are described below and evaluated.

2.1 Ultraviolet radiation

Conseguenze sulla salute

Ultraviolet radiation (UV) is highly energetic. High doses cause serious injury to the eyes and skin, although eyes and skin exhibit different sensitivity. In the eye, the cornea and the eye are particularly concerned as they absorb most ultraviolet radiation. Part of the UV-A radiation can penetrate the retina, particularly in children and adolescents. People who suffer from skin diseases also have sensitive reactions that may be triggered by small doses of ultraviolet radiation.

Limit values

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) recommended exposure limits for ultraviolet radiation which are intended to protect the skin and eyes (ICNIRP 2004). The recommended limit values for the skin are intended to preclude skin reddening; the recommended limit values for the eyes are intended to preclude inflammation of the cornea or the occurrence of cataracts.

Intensity of ultraviolet radiation from LEDs

The ultraviolet radiation produced by LEDs was determined on behalf of the Allgemeinen Unfallversicherungsanstalt AUVA in Austria (Schulmeister et al. 2011; Buberl et al. 2011). The measurements show that the ultraviolet radiation from today's LEDs fall well below the limit values for ultraviolet radiation.

Health assessment

LED lighting systems only radiate very little ultraviolet radiation, such that the health of skin and eyes is not endangered. Accordingly, LED lighting systems are suitable lighting for those people, who suffer from sensitivity to UV.

2.2 Visible light

Effects on health

Depending on one's age, visible light falls more or less unhindered on the retina. With very strong light intensities the retina, other tissues and the photoreceptor cells of the eye are too strongly illuminated. This results in thermal and photochemical processes that severely and irreversibly damage the eye, and lead to a partial loss of sight or even blindness.

With commercial LED lamps for general use, thermal damage to the retina is improbable, although photochemical damage from the highly energetic blue light component cannot be excluded per se (Anses 2010). Too strong a blue light component or a blue light hazard presents a risk for the general population and especially for children and people with operated cataracts whose eye lenses are very clear, have no filtering action or in rare cases are missing. In addition, photochemical damage can occur from the reaction of blue light with substances such as Lipofuscin that are stored in the eye and which accumulate with increasing age in the eye (Behar-Cohen et al. 2011).

Limit values and standardisation

In order to prevent acute risks from visible and infrared radiation, the International Commission on Non-Ionizing Radiation Protection has recommended limit values (ICNIRP 2013), which also concern the blue light hazard. The limit value for blue light hazard restricts the blue light radiance falling onto the retina and is intended to prevent acute dangers to health. Whether this limit value can also prevent possible health effects from chronic life-long blue light exposure, cannot be determined based on present scientific knowledge (Shang et al. 2014)

The basis for this limit value is given by the quantity of radiation, with which visible damage of the retina has occurred in 50 % of the examined eyes. This limit value is characterised as a dose, i.e. the product of the radiance multiplied by the duration of exposure. This means that for very long periods of irradiation the viewed radiance has to be small or for very short exposure periods the radiance can be high. The limit value for the blue light hazard distinguishes two cases. Normal eyes with eye lenses and 2) eyes that are sensitive to blue light such as those of children or of people, who either have no or very clear synthetic eye lenses as a result of a cataract operation.

The European Lamp Standard transposes the limit value for the blue light hazard into a (risk-free) exempt group and three different risk groups. A lamp with its given radiance is classified into a risk group based on the duration of exposure, as of which the limit value is reached. The standard differentiates between lamps that, based on their small radiance, represent no risk even for unlimited periods of use, and lamps that, based on their stronger or strong radiance, are non-hazardous only for limited or very short periods of use. These groups are defined as follows:

- Exempt group: Risk-free use even for very long periods of radiance of the retina untill 10 000 seconds (166.6 minutes)
- Risk group 1: risk-free use for periods of radiance untill 100 seconds ("low risk").
- Risk group 2: risk-free use for periods of radiance untill 0.25 seconds ("medium risk").
- Risk group 3: not risk-free even for very short periods of radiance ("high risk").

The risk groups give a relatively broad indication of the damage potential of lamps, as the permissible periods of radiance within a risk group cover a large range. A more meaningful assessment of a lamp is given by that period of radiance of the retina for which the limit value is no longer respected.

According to the recommendations of the International Electrotechnical Commission (IEC), lamps that do not belong to the exempt group should be supplied together with appropriate information and the necessary usage guidelines from the manufacturer. Lamps of risk groups 2 and 3 should also be supplied with a precautionary or warning message on the packaging or an instruction leaflet

Blue light exposure from LEDs

The Federal Office for Public Health and the Federal Office for Energy commissioned the Swiss Federal Institute of Metrology (METAS) to measure a selection of LED lamps and LED lighting having various designs and which were available on the Swiss market in 2015 (Rinderer and Thalmann 2015). The study determined the maximum period of radiance before the blue light hazard limit value is exceeded.

The European Standard for Lamps specifies that household lamps should be measured at a distance that results in an illuminance value of 500 Lux. As this requirement can lead to distances that do not correspond to possible real situations (e.g. lights that are close to the floor within the reach of small children), this requirement was changed and a measurement distance of 20 to 10 cm was specified. The distance of 20 cm corresponds to the distance from which adults can focus on an object, 10 cm is the corresponding distance for children (Duane 1908). In addition, the following abovementioned two cases were differentiated. 1) Eyes with eye lenses and normal sensitivity to blue light as well as 2) eyes with missing or very clear eye lenses and high sensitivity to blue light. The maximum periods of radiance for various types of LED are shown in Table 1 as a function of the distance and blue light dependence of the eye:

Table 1. Radiance period in minutes, which may possibly exceed the blue light hazard when looking directly at the LED. The LED product with the shortest and the longest radiance period at distances of 10 cm and 20 cm are given for each LED design type

LED design type	Distance Lamp-eye				Risk group class [RG]
	10 cm		20 cm		
	Sensitivity of the eye to blue light				
	Normal	High	Normal	High	
Light bulb shaped, screw connec-tion, matt	412 / >500	404 / >500	431 / >500	424 / >500	Exempt group
Light bulb shaped, screw connec-tion, clear	53 / >500	49 / >500	76 / >500	71 / >500	RG1 / Exempt group
Spotlight, matt	1.5 / 9	1.4 / 8.5	1.5 / 14.6	1.5 / 13.8	RG2 / RG1
Spotlight, clear	5.2 / >500	5 / >500	5.6 / >500	5.4 / >500	RG1 / Exempt group
Tubular for tubular substitute	338 / >500	321 / >500	>500	>500	Exempt group
Reflector lampReflector lamp	2.7 / 258	2.6 / 243	2.9 / 320	2.7 / 301	RG1 / Exempt group
Table lamp	1.8 / 368	1.7 / 353	2 / >500	1.8 / >500	RG1 / Exempt group
Garden spotlight	4 / >500	3.8 / >500	14.7 / >500	13.3 / >500	RG1 / Exempt group
Strip, cylindrical, floor spotlight	>500	480 / >500	>500	>500	Exempt group

As the study represents one sample of the commercially available LEDs, no general conclusions may be drawn from the results. Nevertheless, some indications for the blue light hazard or to the corresponding radiance periods can be deduced:

- Most of the tested LEDs belong to the exempt group or to risk group 1.
- Light bulb-shaped matt and tubular LEDs meet the requirements of the exempt group. Blue light hazards are possible after 400 minutes, in most cases after 500 minutes.
- Other design types, depending on the product, such as spotlights or LEDs with a built-in reflector, are in the exempt group, risk group 1 and in one case risk group 2.
- For table lamps that can be positioned very close to the eye a blue light hazard may already result after a short time, but also only after longer periods, depending on the model.
- For LEDs of the risk group 1 blue light hazards are possible already after two minutes or so. For LEDs of the risk group 2 this time is reduced to 90 seconds.
- The radiance period required for a blue light hazard may be shorter at a distance of 10 cm from the eye than for a distance of 20 cm. However, this effect is not so pronounced for lamps with short radiance periods.
- The blue light hazard for blue light-sensitive eyes with very clear or missing eye lenses tends to occur for shorter radiance periods although the difference to normal eyes is not pronounced.
- The radiance periods for a blue light hazard neither depend systematically on the colour temperature of the LED nor on the power of the LED (Fig. 1, Fig. 2).

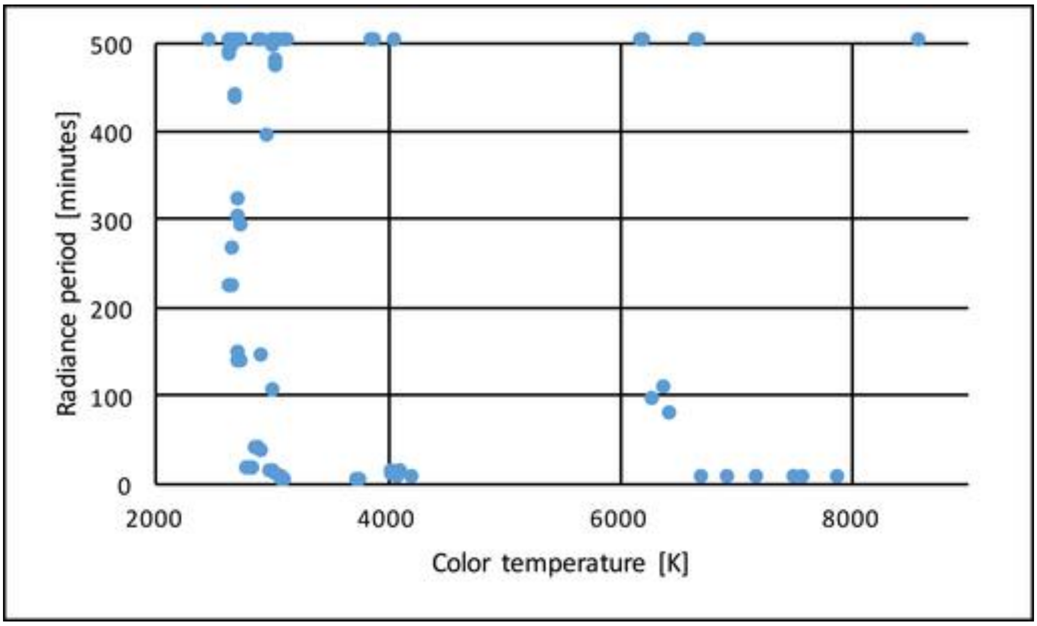

Fig. 1 Radiance period to reach the limit value for a blue light hazard as a function of the colour temperature (36 different LEDs)

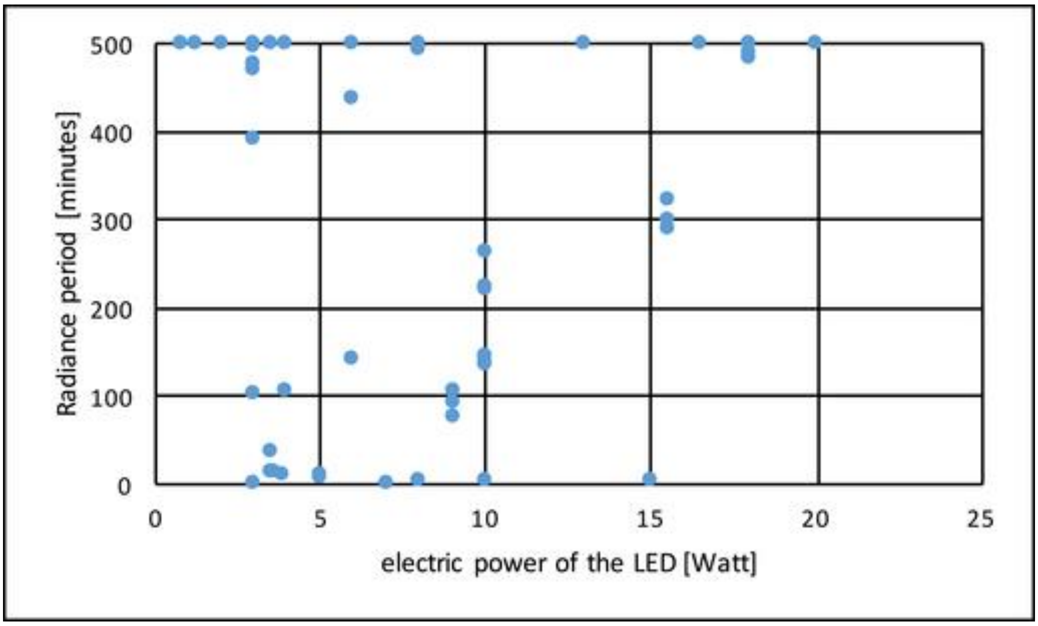

Fig. 2 Radiance period to reach the limit value for a blue light hazard as a function of the electric power (36 different LEDs)

Health assessment

According to the current state of knowledge, the blue-light component of LEDs does not endanger the health of eyes. This is also the case for children and people with very clear or missing eye lenses. However, caution is advised when LEDS are in close proximity to the eyes. As the current product classification only touches on the danger of blue light to health, it is recommended in such cases to use LED lamps or LED tubes, which belong to the exempt group. It is not possible to assess the long-term effects of blue light from LEDs.

2.3 Infrared radiation

The infrared radiation component of current LED lamps lies below the limit values for infrared radiation, such that the health of the eyes and skin is not endangered (Anses 2010).

2.4 Biological rhythms

Effects of blue light on circadian regulation of the body functions

Many physiological processes of humans run according to a predetermined temporal pattern or are subject to (circadian) 24-hour rhythms that are principally regulated by the "internal clock" localised in the brain. As this brain function does not have an exact 24-hour rhythm it has to be adjusted daily. This occurs with the help of the blue light component of daylight that falls onto the retina of the eye early in the morning. This blue light is absorbed by light-sensitive nerve cells of the retina and by the photoreceptors and converted into nerve impulses that are transmitted to the internal clock in the brain. Due to these nerve impulses the internal clock regulates the rhythms of hormones such as melatonin or cortisol, the immune system, the body temperature, the sleep-wake cycle, the mental performance and many other processes (CIE 2009).

Blue light that occurs predominantly in daylight has a stimulating effect on the organism in the morning and during the day. On the other hand, the stimulating effect of blue light in the evening or in the night can have unwanted consequences, as in spite of the nocturnal phase, it indicates to the body information for the diurnal phase. This may disturb those processes that prepare humans for the sleeping phase or that occur during the sleeping phase. Thus, for example, the alertness and attention is reinforced and the synthesis of the dark hormone melatonin is repressed which can bring about sleep disturbances. Such effects already appear with illuminances of a few lux, as may occur in weakly lighted apartments, for example (Chellappa et al. 2011). In addition to such acute effects, scientific findings increasingly show that as a consequence of the disturbed physiological rhythms even long-term severe health effects, such as for example cancer or obesity, cannot be ruled out (IARC 2010).

As LED lamps, depending on their colour temperature, have a more or less significant blue light component, the circadian properties were characterised by the colour temperature.

Limit values and Standards

Up to now no limit values for circadian effects from visible light have been published. The sole standard that treats the topic defines the circadian spectrum of activity of visible light in order to be able to compare the circadian properties of various light sources (DIN SPEC 5031-100). The measure is the melanopic or circadian action factor, which describes the ratio of the circadian-active radiation component of a light source to its radiation component that is visible to the eye (Bellia et al. 2014; Bellia and Seraceni 2014). A melanopic action factor of 1 corresponds approximately to the outdoor daylight under a cloudy sky. Melanopic action factors of less than 1 have fewer activating properties on the organism in comparison to daylight. Incandescent lamps or warm white energy-saving lamps have melanopic action factors in the region of 0.4 (Gall and Bieske 2004).

The study commissioned by the FOPH and BfE determined the melanopic action factors of LEDs (Fig. 3). The results show that LEDs with a colour temperature of 3000 Kelvin have melanopic action factors that are approximately those of incandescent lamps and warm-white energy-saving lamps. At colour temperatures of 6000 K and higher the action factors correspond to that of daylight.

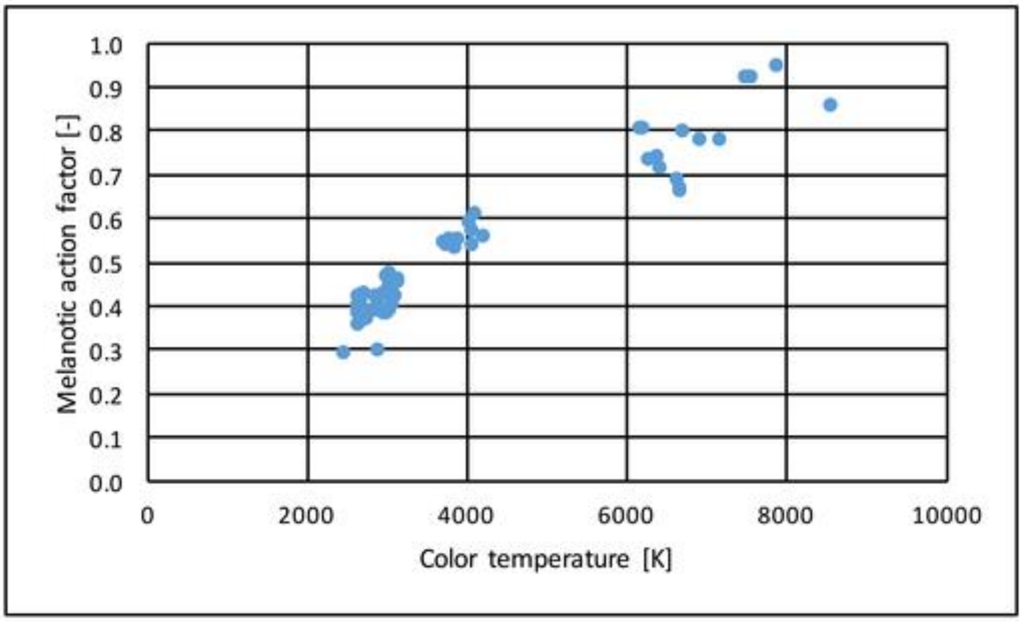

Fig 3: Circadian actions of LEDs: Melanopic action factor (the ratio of the circadian-active radiation component of a light source to its radiation component that is visible to the eye) as a function of the colour temperature (34 different LEDs).

Health assessment

The blue light component of LEDs, depending on its magnitude and the use of the LED, can influence circadian activities. A measure for this is the colour temperature, which is stated on the packaging of the lamps. LEDs with colour temperatures of 3000 Kelvin have similar properties to those of incandescent lamps or warm-white energy-saving lamps. They are suitable for lighting rooms in which people spend longer periods in the evening before going to bed. Cold-white or blue-white LEDs with higher colour temperatures of 4000 - 8000 Kelvin are suitable for lighting rooms in which people spend time during the day and pursue active occupations. Colour temperatures are stated on the LEDs (European Commission 2012).

2.5 Flicker

With LED lamps the emitted light can flicker when the current flowing in the lamp does not remain constant over time. The reason for this "flickering" is the alternating current of the mains power supply which changes direction 50 times per second or with 50 Hertz and thereby changes its intensity 100 times per second. If the electronic transformers in the LED lamps do not equalise these changes then the light generated in the LED chip is also not constant. However, flickering can also result from dimming LED lamps, such that in the un-dimmed state the already existing flickering is increased or new flickering is caused in flicker-free LED lamps (Poplawski and Miller 2013; Kitsinelis et al. 2012).

Mechanism of action

Most people can discern light fluctuations up to a frequency of 60 Hertz with their own eyes. Flicker with frequencies of 100 Hertz and higher, such as those that typically result with LED lamps, are no longer apparent to humans. However, the retina can detect flicker up to 200 Hertz, without the person knowingly perceiving it.

Little is known on the effects of flicker on health; most information originates from studies on fluorescent tubes with conventional ballast units. Flicker can evoke both immediate as well as long-term effects on health. Immediate effects concern especially those persons who suffer from photosensitive epilepsy. They are then endangered when the flicker frequency is between 3 and 70 Hertz. Longer-lasting occurrences of flicker can lead to headaches, migraine, eye strain, limited visual performance, distraction or limited productive efficiency (Wilkins et al. 2010; Karanovic et al. 2011; Shepherd 2010). Generally, flicker from large surface area light sources, such as matt lamps, is more disturbing than flicker from small point sources, as a greater part of the retina is illuminated..

Limit values

At present no mandatory limit values for flicker exist. Flicker properties for a lamp are stated as "percentage flicker" or also as the flicker index (Poplawski and Miller 2013).

A percentage of 0 means that a lamp does not flicker and radiates continuously; a percentage of 100 means that the intensity of the light changes periodically between the maximum and darkness. Flicker properties of LEDs are not declared by the manufacturer and are not shown on the packaging of the lamps.

Intensity of the LED flicker

The study commissioned by the FOPH and BfE shows that flicker properties of currently commercialised LEDs are purely product-specific and depend neither on the manufacturer nor on the design shape. LED lights, such as for example table lamps that tend to be used in close proximity to the eyes, can flicker strongly. The percentage flicker value for current LEDs lies between 5% (flicker-free) and 100% (strongly flickering).

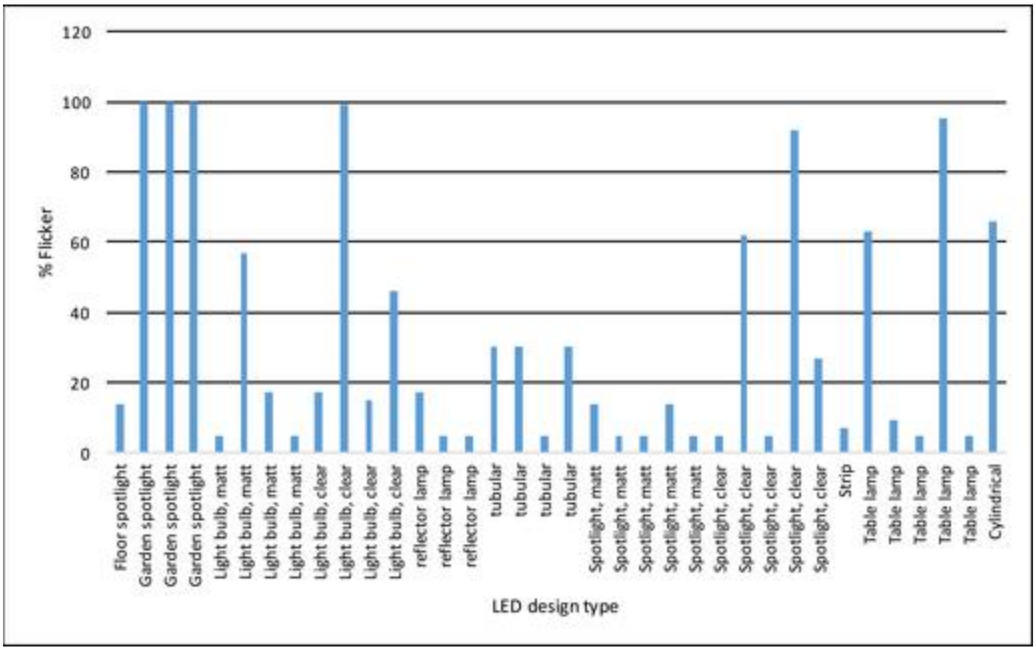

Fig. 4 Flicker properties of LEDs (36 different LEDs)

Health assessment

Depending on the brand, LEDs can be flicker-free, but also can emit a strongly flickering light. Whether flicker from LEDs represents a health risk cannot be assessed at present (SCENIHR 2012). As a precautionary measure it is therefore recommended:

– To use flicker-free LEDs for lighting areas where people spend longer periods of time. Flicker properties of LED lamps can be determined on the display of a smartphone camera or digital camera by focussing it close up to the LED. The LED flickers if a striped picture can be seen on the display.
– Do not dim LEDs in places where people who suffer from epilepsy, migraines or headaches stay.

3 Legal framework and Standardisation

LED lighting systems, as low-voltage products, must comply with the requirements of the Ordinance on electric low-voltage products (SR 734.26). Low-voltage products must not endanger people or objects and may only be placed on the market if they comply with the essential requirements of the European (EU) Low-voltage Guidelines for safety and health protection. The essential requirements are specified in European Standards. Electromagnetic fields of lighting equipment are regulated in the Standard IEC 62493 of the International Electrotechnical Commission as well as in the identical Standard EN SN 62493 of the EU and Switzerland. The permissible electric and magnetic fields correspond to the recommendation of the European Council for limiting the exposure of the population to electromagnetic fields (European Council 1999). The permissible optical radiation is defined in the European Standard EN SN 62471: 2008 and is based on the limits of exposure to incoherent visible and infrared radiation recommended by the International Commission on Non-ionizing Radiation Protection (ICNIRP 2013).

The manufacturers are themselves responsible for ensuring that their equipment complies with these conformity criteria; there is no comprehensive control of the market in Switzerland. The Swiss Inspectorate for High Current Installations (www.esti.admin.ch) checks compliance with the regulations by inspecting random samples of products on the market.

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