# LIGHT@WORK

[Adapted from the website http://www.osram.com/lightatwork/]

## 1. What about light?

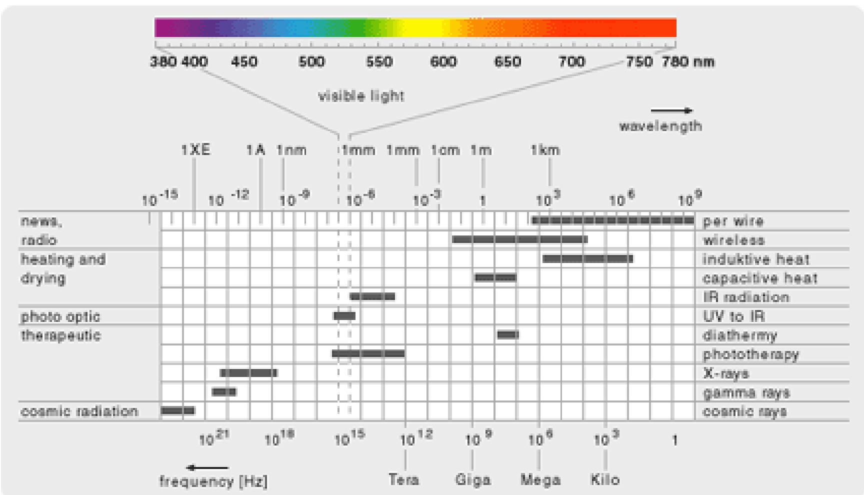
Light means energy, life and information.

Daylight provides the qualities and characteristics that serve as a basis for optimising artificial light.

### 1.1 The electromagnetic spectrum

Visible light is only a small section of electromagnetic radiation which produces a sensation of brightness and colour in the human eye.

Electromagnetic radiation is a form of energy. The spectrum of such radiation provides information on its energy composition. The entire spectrum of electromagnetic radiation ranges from X-ray radiation at the high-energy, short-wave end to radio waves at the low-energy, long-wave end.




*Electromagnetic radiation*

*Prismatic breakdown of light*

Our perception of light is essentially characterised by its prismatic breakdown into its spectral components. Our brain assigns particular colours to these different components of the light spectrum.

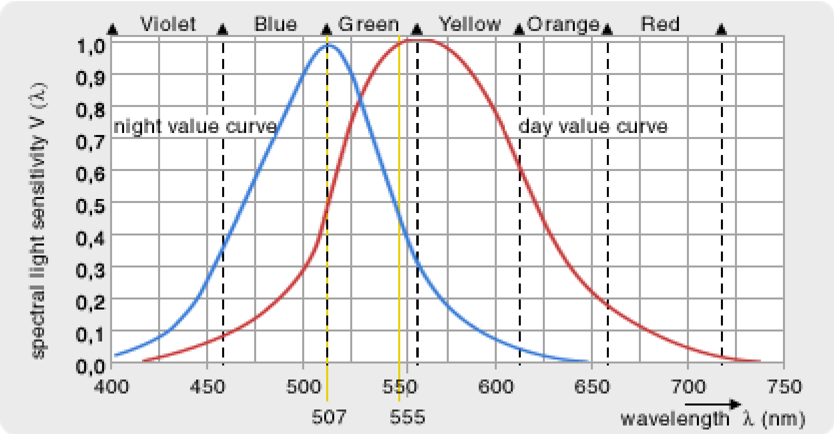
The speed of light is the speed at which light travels in a vacuum. In fact, all electromagnetic radiation travels at this speed. It is approximately 300 000 km/s. Light covers the 150 million km from the sun to the earth in about eight minutes.

## 1.2 Technical basics of light

A distinction is made between spectrometry values and photometric values.

Spectrometry values are purely technical values that do not relate to the effect of light on human beings. The values are derived from the watt.

Photometric values always take into consideration the spectral luminous efficiency curve (V( λ ) curve) of the human eye. Consequently, photometric values are linked specifically to human sensitivity. Photometric values are derived from the lumen. The luminous efficiency curve results from the following relationships: Radiation that is visible to the human eye lies between wavelengths of 380 nm for blue light and 780 nm for red light. The eye is most sensitive in the green area of the spectrum around 555 nm. At longer and shorter wavelengths the eye is less sensitive, which means that a higher radiated power is needed for these wavelengths to achieve an impression of identical brightness. The ratio between the radiated power at 555 nm (1 nm = $10^{-9}$ m) and the radiated powers for the various wavelengths in the visible spectrum is called the spectral luminous efficiency V ( λ ). A graph of these values is called the V ( λ )-curve.

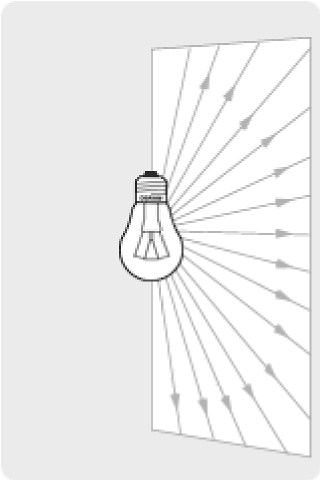



V ( λ )/V '( λ )-curve

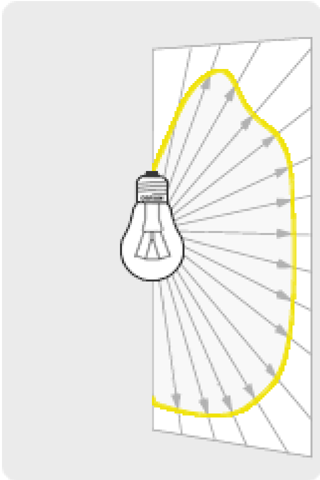
### *1.2.1 Technical basics of light – Quantitatives*

| Type | Value | Symbol | Formula | Name | Unit |
|---|---|---|---|---|---|
| Radiation value | Luminous flux | Φ | $\Phi = I \cdot \Omega$ | Lumen | [lm] |
| Sender-side value | Luminous intensity<br><br>Luminance | I<br><br>L | $I = \Phi / \Omega$<br><br>$L = I / A$ | Candela<br><br>Candela per square metre | [cd]<br><br>[cd/m$^2$] |
| Recipient-side value | Illuminance | E | $E = \Phi / A$ | Lux | [lux] |

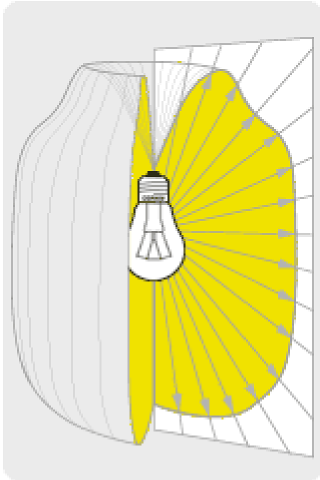
*Luminous intensity* is the luminous flux of a light source in a particular direction and not dependent on the size of the recipient. It can be indicated by a vector. If we connect the ends of all the luminous intensity vectors lying in one plane for a light source we obtain the *luminous intensity distribution curve*. The *luminous flux* indicates the radiated power emitted by a light source in all directions. This radiation is evaluated according to the sensitivity of the human eye. All other photometric values are derived from this basic value.



*Luminous intensity*

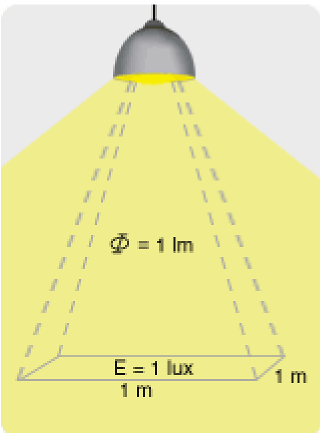


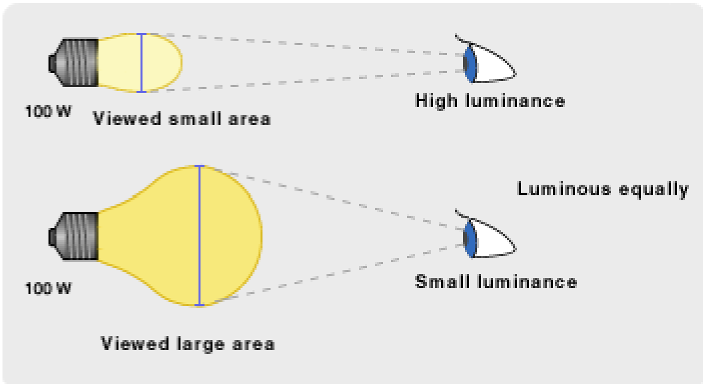
*Luminous intensity distribution curve*



*Luminous flux*

*Illuminance* is purely a physical measurement value. It is the ratio between the luminous flux and the area to be illuminated, irrespective of the reflectance of the surface. An illuminance of 1 lux occurs when a luminous flux of 1 lumen falls evenly on an area of 1 $m^2$. Illuminance reduces with the square of the distance between the light source and the surface.




*Luminance* indicates the luminous intensity of a light source or an illuminated surface, referred to its observed area. For humans, light is not visible until radiation enters the eye. Luminance is the only variable that can be perceived by humans.

Illuminance is a value that is easy to calculate. Luminance, on the other hand, depends on the reflection properties and the reflectance of the materials illuminated and these variables are often not known. Lighting designers therefore use illuminance for planning indoor lighting systems.

| Light source | Average luminance [cd/m$^2$] |
| --- | --- |
| Sun at high noon | 1.6 x $10^9$ |
| Xenon short-arc lamp | 1.5 x $10^8$ – 2.7 x $10^9$ |
| Metal halide short arc lamps HMI, HTI | 5 x $10^7$ – 1 x $10^8$ |
| Metal halide lamps HQI | 5.3 x $10^6$ |
| Incandescent lamps clear | 2 x $10^6$ – 2 x $10^7$ |
| Incandescent lamps frosted | 5 x $10^4$ – 4 x $10^5$ |
| Low-pressure sodium lamp | 7.5 x $10^4$ |
| Fluorescent lamp / Compact fluorescent lamp | 1.2 x $10^4$ – 1.4 x $10^4$ |
| White illuminated cloud | 10 000 |
| Candle | 7 500 |
| Clear Sky | 3 000 – 5 000 |
| Moon | 2 500 |
| Glow discharge lamp | 200 – 600 |
| Nightsky | 0.001 |

### *1.2.2 Technical basics of light - Qualitatives*

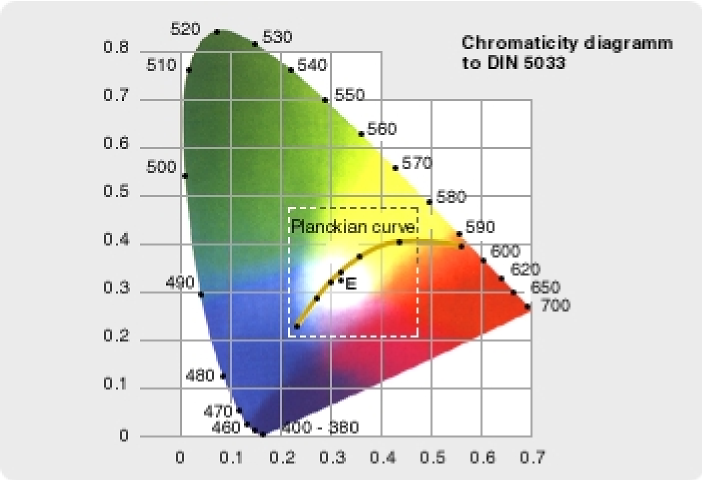
The quality of the light from a lamp is defined by two properties, namely, colour temperature and colour rendering. High-quality light renders colours in the same way as natural daylight with cloud cover around mid-day.

A *black body* is a body with a surface that absorbs all the radiation falling upon it. A black body is also a full radiator, so it represents an idealised light source.

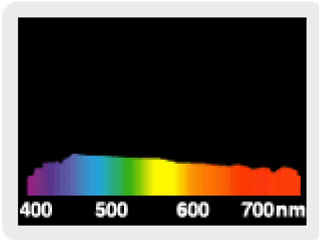
A *terminal radiator* is a light source that radiates light owing to the high temperature of a solid body (such as a tungsten filament). The black body defines the radiation spectrum of a thermal radiator.

The sun and all incandescent lamps and tungsten-halogen lamps emit light with a spectrum that very closely resembles that of a black body. For this reason, comparing a light source with natural daylight is like comparing it to a black body.

White light can be broken up by a prism into its spectral components. Conversely, adding together all the spectral components of a radiation source produces a colour impression (white, for example, in the case of daylight).

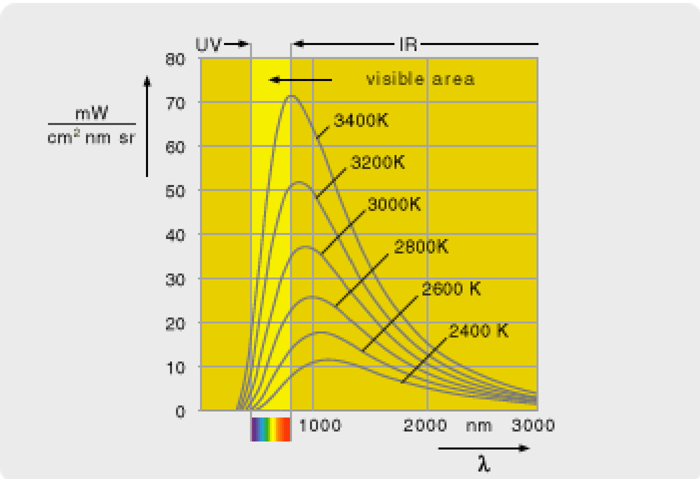



Colour triangle with planckian locus



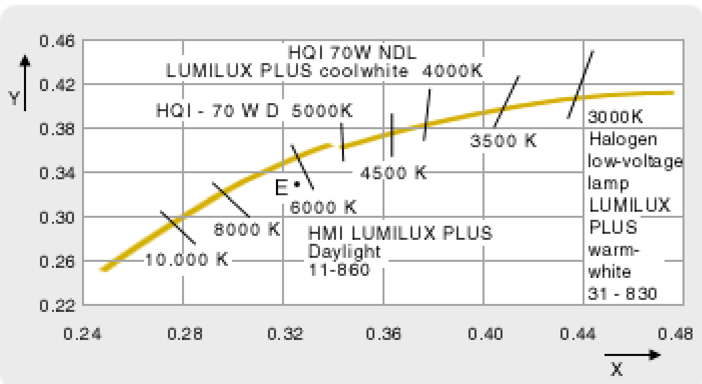

Daylight spectrum

Increasing the temperature of a black body produces different spectrums. All the light of these spectrums causes various impressions of colour in the eye of an observer. Imagine a horseshoe in the blacksmith's fire. First it glows red, then yellow as its temperature rises, until finally it is white hot. Each temperature corresponds to a different spectrum and each spectrum corresponds in turn to a location in the colour triangle. If you join up all the locations you get the *Planckian curve*.




*Spectrums of the Planckian curve*

To determine the colour temperature of a light source the colour location in the colour triangle of its spectrum is compared with the colour locations of a black body at different temperatures. If the spectrum cannot be compared with that of a black body then the spectrums (of, say, discharge lamps) are assigned to the closest colour temperatures using *Judd lines*.




*Planckian curve with Judd lines*

Black bodies such as the sun or tungsten-halogen lamps render colours accurately because they emit a continuous spectrum. If a light source does not emit all colours in a balanced spectrum, some body colours will not be rendered as well as if they were illuminated with a continuous spectrum.

The *colour rendering index* of a lamp indicates the extent of this deviation from the ideal light source. In a comparison test the remission spectrums of eight test colours, illuminated with the lamp to be tested, are measured and compared with the values of a given reference light source. The colour temperatures of the lamp under test and those of the reference light source should be as close as possible (*correlated colour temperatures*).

The deviations in the measurements are evaluated using a standardised procedure. If the spectrums of both lamps are identical then the colour rendering index ($R_a$) will be 100. The index is generally less than this. The highest possible colour rendering index ($R_a$=100) is assigned to the black body.

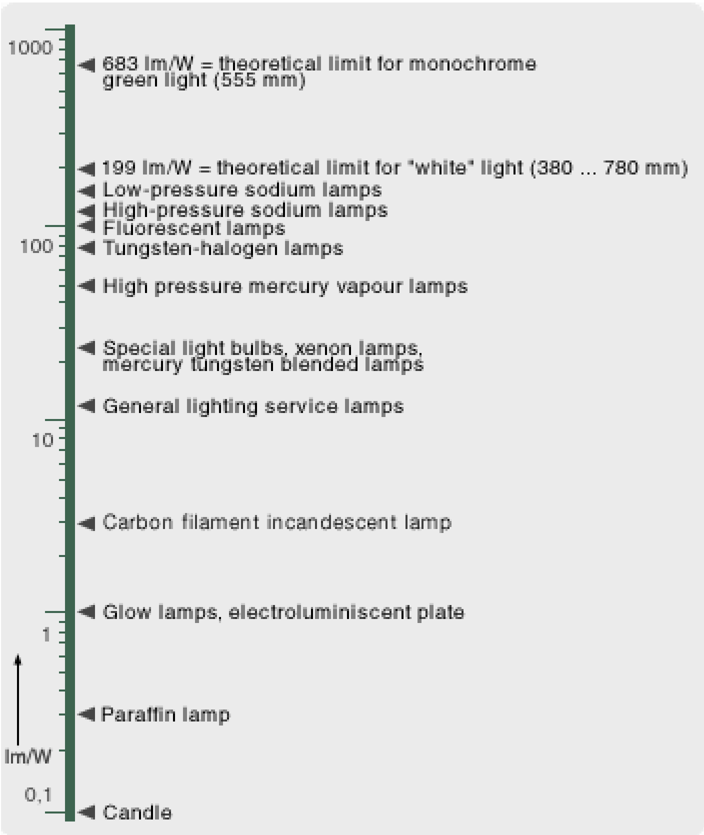
| **Test colours for Ra8** | | | |
|---|---|---|---|
| $R_1$ | Old rose | $R_5$ | Turquoise |
| $R_2$ | Mustard yellow | $R_6$ | Sky blue |
| $R_3$ | Yellow-green | $R_7$ | Violet |
| $R_4$ | Light green | $R_8$ | Lilac |
| **Additional test colours with saturated colours (Ra14)** | | | |
| $R_9$ | Red | $R_{12}$ | Blue |
| $R_{10}$ | Yellow | $R_{13}$ | Skin tone |
| $R_{11}$ | Green | $R_{14}$ | Leaf green |

As specified in relevant standard like DIN 5035, the colour rendering indices are assigned to colour rendering properties and colour rendering groups as follows:

| **Colour rendering property** | **Colour rendering group** | **Colour rendering index Ra** | **Typical lamp** |
|---|---|---|---|
| Excellent | 1 A | 90 | Tungsten halogen lamps, LUMILUX DE LUXE fluorescent lamps HQI.../D |
| Very good | 1 B | 80 - 89 | LUMILUX fluorescent lamps HQI.../NDL or WDL |
| Good | 2 A | 70 - 79 | Basic fluorescent lamps (25) |
| Satisfactory | 2 B | 60 - 69 | Basic fluorescent lamps (20,23,30) |
| Fair | 3 | 40 - 59 | HQL |
| Poor | 4 | 39 | High-pressure and low-pressure sodium discharge lamps |

### 1.2.3 *Technical basics of light - Economic*

*Luminous efficacy* $\eta$ is ratio of the luminous flux emitted by a light source in lumens to the electrical power in watts needed to generate the light. The unit is [lm/W]. The maximum that can be achieved in theory, with all the energy being converted into visible light, is 683 lm/W. In reality, the figures are much lower, between 10 and 150 lm/W.



*Luminous efficacies of various light sources*

*Luminaire efficiency* $\eta_{LB}$ is the ratio between the luminous flux that is available for lighting and the total luminous flux emitted by the lamp or lamps. The unit is [%].

The life of a lamp is defined in various ways depending on the type of lamp. The "*average rated life*" of a group of lamps is average of the lives of all the lamps in the group. Accordingly, 50 % of the lamps will have failed by this time. The "*service life*" is the number of hours after which the system luminous flux has reached 70 % of its initial value, taking into consideration the available luminous flux of the lamps still operating at this time.

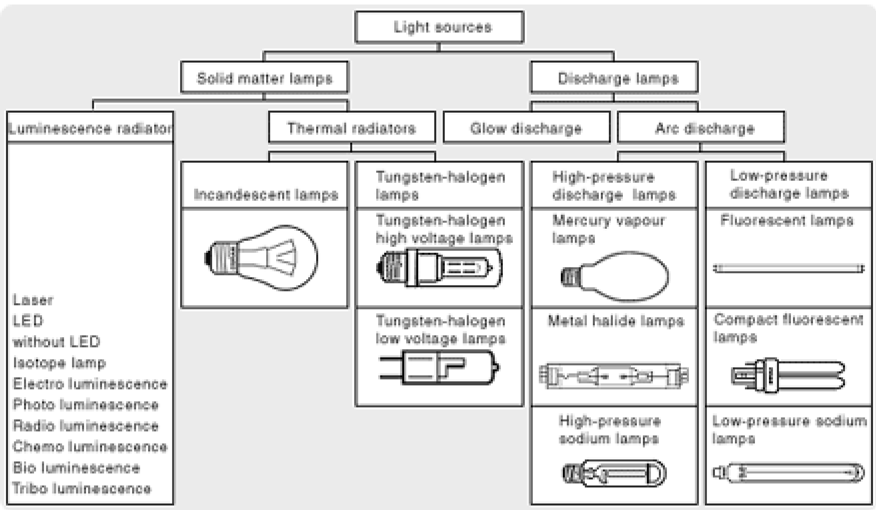
Generally speaking, a compromise between quality of light and economy has to be found when selecting a lamp. We now have the following four criteria for evaluating a lamp:

- luminous efficacy
- life
- colour temperature
- colour rendering index

| Light source | Luminous efficacy [lm/W] | Life [h] | Correlated colour temperature [K] | Colour rendering index $R_a$ |
|---|---|---|---|---|
| Incandescent lamp | 14 | 1000 | 2750 | 100 |
| Tungsten-halogen lamp | 20 | 2000 | 2850 | 100 |
| Xenon lamp, short-arc lamp | 15-50 | 1200 | 6000 | >94 |
| Compact fluorescent lamp | 87 | 12000 | 2700-6000 | 85 |
| Fluorescent lamp | 104 | 12000 | 2700-6000 | 85 |
| Metal halide lamp HQI | 100 | 9000 | 3000-6000 | 85 |
| Metal halide lamp, short-arc lamp HMI, HTI | 80 | 300 - 1000 | 5500 | >90 |
| High-pressure sodium lamp | 130 | 9000 | 2000 | 20 |
| Low- pressure sodium lamp | 197 | 10000 | 1800 | -20 |
| Hypothetical black body at 555 nm | 683 | --- | --- | --- |

## 1.3 Characters of light generating

The world of lamps can be divided into thermal radiators and luminescence radiators. Basically, there are three ways in which electricity can be used to produce light: thermal radiation, low-pressure discharge and high-pressure discharge.




**Thermal radiation**
Current is passed through a wire to heat it to high temperature. The model here is the sun with its surface temperature of 6000 K. Because it has the highest melting point of any metal (3683 K), the element tungsten is best suited for this purpose. Examples: incandescent lamps and tungsten-halogen lamps.

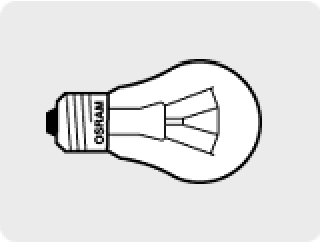
**Gas discharge**
A voltage is applied across two electrodes in a glass enclosure filled with inert gases, metal vapours and rare earths metals to produce an arc discharge. The direct radiation from the gaseous filler substances combines to produce the desired light colour. Examples: mercury vapour, metal halide and

sodium vapour lamps.

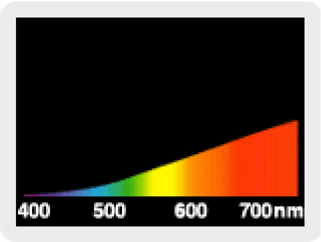
**Luminescence**
The invisible UV radiation generated in mercury gas discharge lamps is converted into visible light by phosphors. Examples: fluorescent lamps and compact fluorescent lamps. The process by which electricity is directly converted into light is electroluminescence. Examples: Light Emitting Diodes (LEDs).

### *1.3.1 Characters of light generating - Thermal radiations*

Incandescent lamps and tungsten-halogen lamps are thermal radiators. When a tungsten filament enclosed in a bulb filled with gas is heated by passing electricity through it, these lamps emit a spectrum that is similar to that of the black body radiator.




*Incandescent lamp*

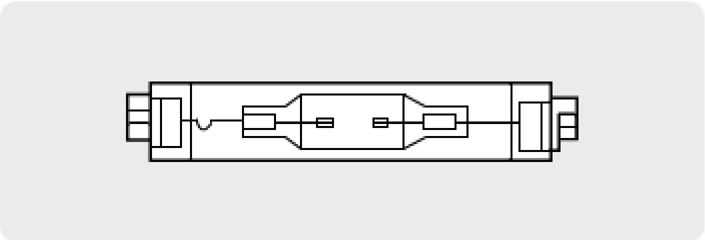



*Spectrum of an incandescent lamp*

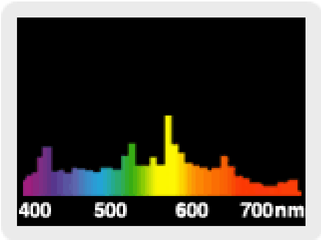
### *1.3.2 Characters of light generating - Discharge lamps*

In discharge lamps, light is generated when an electrical current is passed through gas or metal vapour plasma in sealed discharge tubes. There are two types of discharge lamp depending on the pressure of the filler material: high-pressure discharge lamps and low-pressure discharge lamps.

**High-pressure discharge lamps**
The most common representatives of this group of lamps are the metal halide lamps. Under high pressure (~10 bar) the filler substances in the gas atmosphere emit directly visible light through electron excitation. The light colours and the colour rendering properties can be influenced by adding carefully controlled doses of what are known as "rare earths".

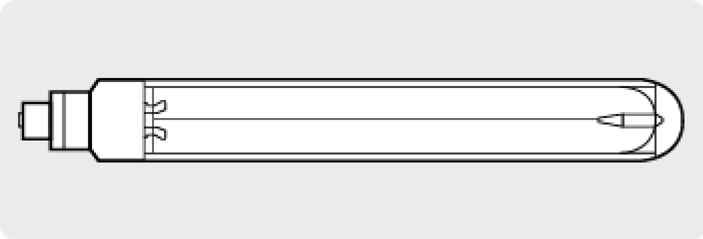


*HQI lamp*

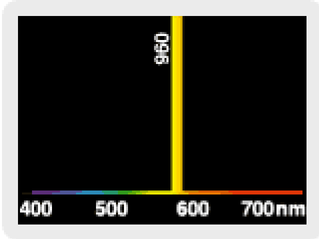



*Spectrum of an HQI discharge lamp*

**Low-pressure discharge lamps**
A distinction is made here between low-pressure mercury and sodium lamps. The fill pressure is only a few millibars. Like the high-pressure discharge lamps, low-pressure sodium lamps emit directly visible light, but exclusively with a wavelength of 585 nm.

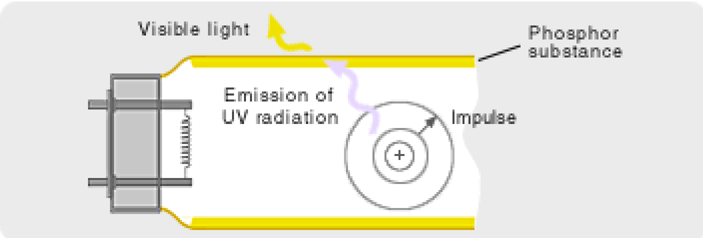


*Low-pressure sodium lamp*

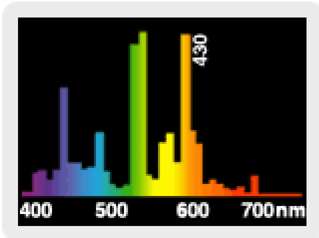



*Spectrum of an SOX lamp*

In low-pressure mercury lamps (fluorescent and compact fluorescent lamps) on the other hand, mercury atoms are made to emit UV radiation as a result of electron collisions. This UV radiation is converted into visible light by phosphors applied to the inside of the tube.




*Principle of a fluorescent lamp*




*Spectrum of a fluorescent lamp*

### *1.3.3 Characters of light generating - Luminescent emitters*

All light radiation that is not based on the temperature of a solid body is called *luminescence radiation*. Luminescence radiation is produced when electrons move from one energy level to another. The necessary energy can be applied to the luminescence radiator in the form of various excitation energies.

| Designation | Excitation energy | Typical examples |
|---|---|---|
| Electro luminescence | Electrical power | Gas discharge, pn – transition |
| Photo luminescence | Electro-magnetic radiation | UV-conversion with luminescent materials |
| Chemo- and bio luminescence | Energy caused by chemical reactions | Burning, oxidation, enzymatic reactions |
| Tribo luminescence | Mechanical power | e.g., excitation of luminous effects in crystals through mechanical energy |
| Thermo luminescence | Thermal power | e.g., excitation of luminous effects in crystals through heat |
| Radio luminescence | Radioactivity | Aurora Borealis (polar aurora) |

High-pressure discharge lamps and low-pressure sodium lamps are therefore luminescence radiators in which the excitation energy is supplied in the form of an electrical current. In contrast, the luminescence of low-pressure mercury lamps comes from radiation energy (UV radiation).

Technical innovations in the luminescence of semiconductor materials (LEDs) and plastics (organic LEDs) are already being put to practical use. For a long time, the options were restricted to yellow, green and red LEDs. Blue and white LEDs are now available. The luminous efficacy of the blue and white LEDs is comparable to that of thermal radiators.

As further developments are made, the luminous efficacy of these products will increase and this will revolutionise the lighting industry and lighting applications.

# 2. Light and human being

The effects of light on human beings are many and varied, and not all the effects are fully known. They go far beyond the simple process of recognising objects.

Light gives rise to moods and emotions and affects our biorhythms. To understand these effects we need to know something of the physics, physiology, neurology and psychology of light.

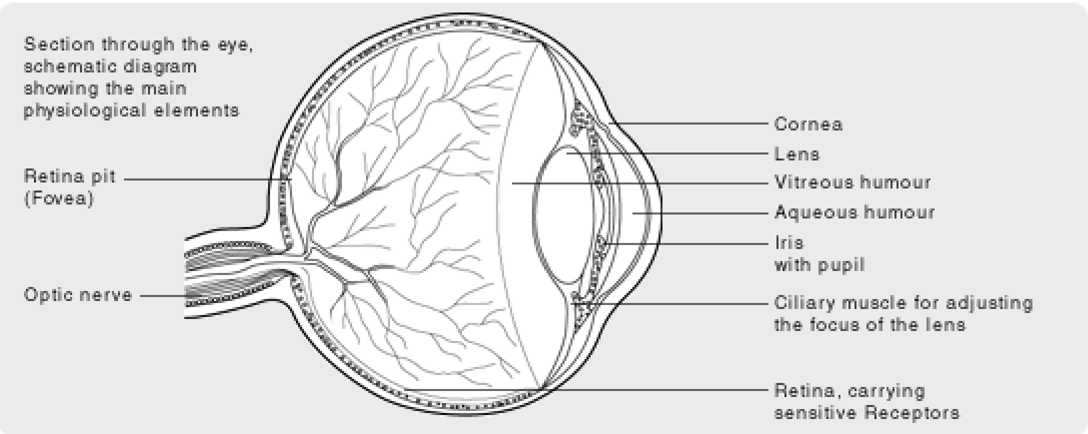
## 2.1 Light and human being – Physiology

Despite its relatively simple construction, the human eye is capable of performing a number of astounding tasks that are very difficult for technical equipment to match.

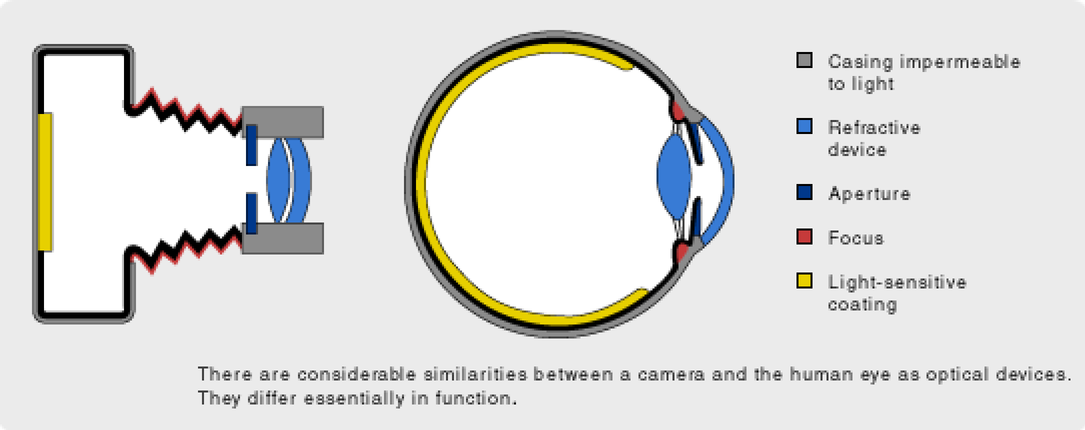
Just compare the human eye with a camera. The retina corresponds to light-sensitive film. The cornea, front chamber and lens correspond to the lens on the camera. The iris corresponds to the aperture. Both change in diameter to change the illuminance on the retina or film.

However, the camera and the eye function in very different ways. The camera produces a fixed image in the light-sensitive film. The eye provides the brain with a constant stream of data. Even if the eye is focused on a non-moving image the data is still transferred many times a second. By way of simplification, we can say that vision is a result of the combination of the eye as an optical and neural system and a complex and powerful "image processing system" in the brain.

Vision is a mixture of innate and learned skills. Known images are recognised faster, for example, than new images. There is still no complete explanation of how the signals and images are processed or how these images are then integrated into our consciousness.




*Structure of the human eye*

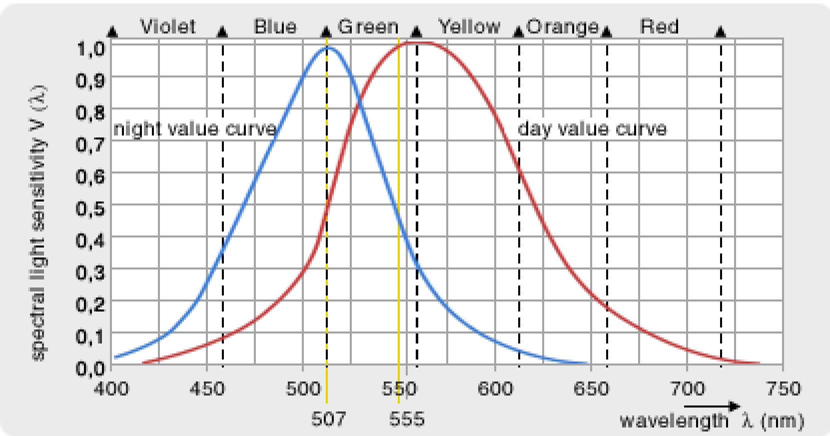



*Principle of the camera*

## 2.2 Light and human being – Perception

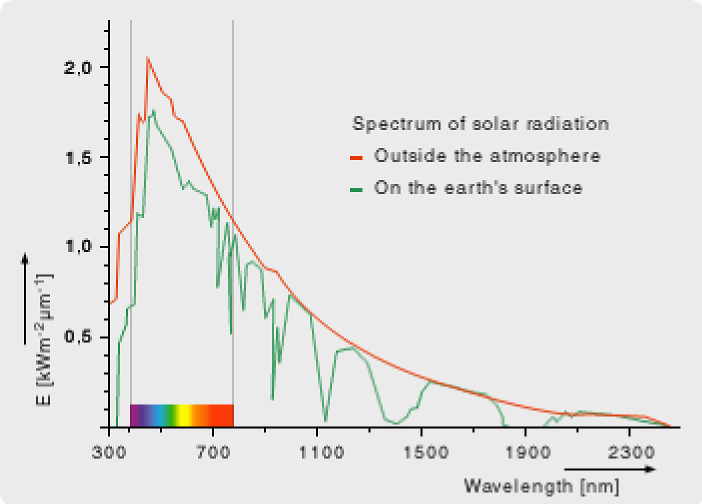
Of all the information that we take in from our surroundings, 80% comes through our eyes. The data transfer rate is ten times greater than for hearing. Three-dimensional or stereoscopic vision is possible because we have two eyes a certain distance apart. When we focus on an object, both our eyeballs are directed at it. The patters that this object creates on our retinas differs slightly in each eye because of the different perspective, and our brain uses all this information to "compute" an impression of space so that we can judge distances.

When we look across a landscape our brains distinguish between objects close by and those further away by the blue component in the light from these objects. Objects near by appear in warmer and more intense tones whereas objects far away appear in bluish and pale tones.



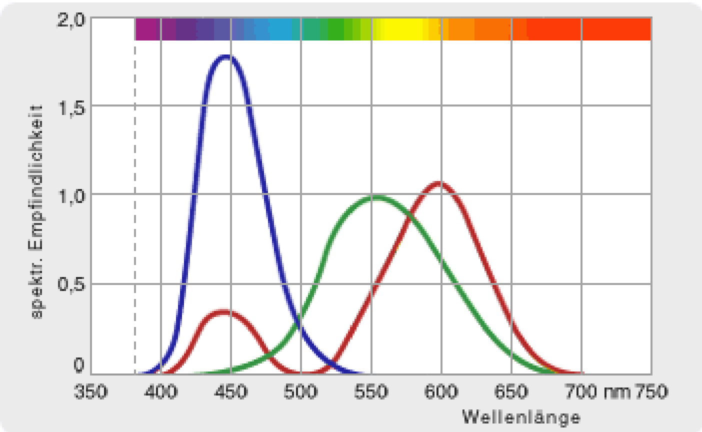

*Day and night vision*

In order to see, human beings make use of electromagnetic radiation in only a small wavelength band between 380 nm and 780 nm. This band is called visible light. In the course of evolution our eyes have adapted specifically to the wavelength band of the solar spectrum, which manages to penetrate the earth's atmosphere in sufficient quantity and with a certain constancy.



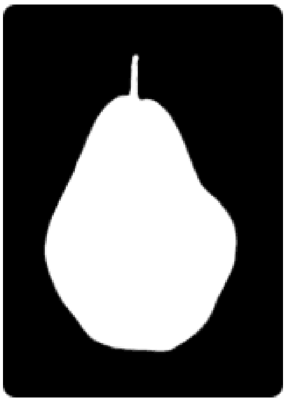

*Transmission spectrum of the earth's atmosphere*

We are able to see in colour because we have cone receptors in out eyes that divide light into three different spectral ranges. One type of cone is sensitive to each of the three radiation ranges that we call red, green and blue. As these different types of cone are triggered the brain can cover the entire colour spectrum by the process of additive colour mixing.




*V( λ ) for RGB*

The human perception system uses the following information:



*Contrast*

*Brightness*

*Color*

Human perception is greatly influenced by the choice of light source with its specific properties in terms of light colours and colour rendering.

| | 2000 | 2700 | 3000 | 4000 | 6000 | 6500 | 9000 |
|---|---|---|---|---|---|---|---|
| Thermal radiators | | Incande-scent lamps | Tungsten-halogen lamps | | | | Blue sky |
| Low-pressure discharge lamps | | INTERNA 41-827 | Warmwhite 31-830 | Intermediate 21-840 | Daylight 11-860 | Daylight 72-965 | |
| High-pressure discharge lamps | NAV | | WDL | NDL | D | | |

*Color temperature*

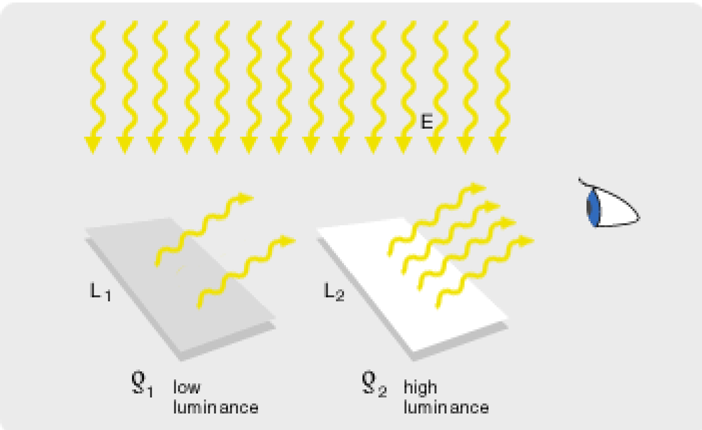
| Ra | 100 | 90 | 80 | 70 | 60 | 50 | 40 |
|---|---|---|---|---|---|---|---|
| Colour rendering index | 1A | 1B | 2A | 2B | 3 | 3 | 4 |
| Thermal radiators | Incandescent lamps<br>Tungsten-halogen lamps | | | | | | |
| Low-pressure discharge lamps | LUMILUX DE LUXE 12-950/ 22-940/32-930/ BIOLUX 72-965 | LUMILUX 11-960/ 21-940/31- 930/41-827 | L10<br>L25 | L20 | L30 | | |
| High-pressure discharge lamps | HQI D | HQI NDL / WDL<br>HCI NDL / WDL | | HWL | HQL | | NAV NA SOX |
| Nature | Daylight | | | | | | |

*Colour rendering*

Only the light that hits our eyes is visible to us. Illuminance is defined by the luminous flux from a light source that falls on a surface. Illuminance reduces with the square of the distance between the light source and the surface.

It is purely a measurement value and plays no real role in perception. Only when light falls on an object and is reflected from it or diffused by it and then hits our eyes do we have the information we need to see an image.

The only photometric variable that we can perceive is luminance. This depends on the surface properties of the illuminated object. These properties are defined by the reflection coefficient "$\rho$". Two objects with different reflection properties will look different in the same illuminance.




*Luminance and illuminance*

$L = \rho * E$

L: Luminance
$\rho$ : Reflection coefficient
E: Illuminance

## 2.3 Light and human being – History

Long ago, the sun was the only source of light for the inhabitants of the Earth. 400,000 years ago Peking Man first used fire as a source of heat and light. 80,000 years ago Neanderthal Man learnt how to make fire so was not forced to keep the embers burning day and night. 40,000 years ago oil lamps were being used to provide light by which to make cave paintings. The development of light sources is closely linked to advances in our understanding of physical processes.

Oil lamps, torches and candles were in common use right up to the 19th century. Then came gas lamps. All these lamps burned oils or gases to provide light. The smell was extremely unpleasant, and the smoke and open flames were extremely dangerous. It was not until the end of the 19th century that advances in material research (leading to the tungsten filament) enabled electric lamps to be produced in quantity. A short time later came the first discharge lamps.

Since then, light has been available in almost unlimited quantity. The wide range of ways in which light can be used, however, has meant that we have had to make decisions.

The discipline of lighting design has arisen as a result, with attention being paid to aspects of safety and comfort in designing lighting systems.

Simple compliance with industrial standards such as DIN or workplace regulations would lead to a series of uniform lighting solutions. Optimum lighting design therefore involves a number of other important criteria.

# 3. Getting the best possible light

Of all the information that we take in from our surroundings, 80% comes through our eyes. On average, central Europeans spend 90 % of their time indoors. In many cases, daylight is at least supplemented by artificial light throughout the day; in some cases it is replaced entirely.

Artificial light therefore has an important role to play. Its prime functions are undisputedly to allow people to find their way around and to offer them a high level of safety. In addition, by making the right use of light (at workplaces for example) it is possible to reduce fatigue and encourage concentration.

In some situations, emotional effects are important. Light can be used, for example, to create an atmosphere of comfort, or relaxation or trust. Appropriate lighting can help people recover from illness or fatigue. Light can also be used to create active zones for greater awareness and decision-making.

## 3.1 Review

Artificial light makes us independent of natural daylight, whatever the season and whatever the location. It enables cultural and technical advances to be made and prolongs production times.

The purpose of using light is not just to increase illuminance indiscriminately but to compose in light, to create bright and dark zones and to provide the light that meets the needs of the situation. Modern lighting design also aims to provide the necessary lighting moods for domestic, commercial, professional and public premises so that these moods can be called up as the need arises.

## 3.2 The perfect light design

Lighting design can be said to be optimum when it has taken account of the nature of the space, its purpose, the special features of the building and the intentions of the architect, and has treated light as an additional material and design element. Artificial lighting can be superior to natural lighting. It can help people find their way around the interior of a building. Light becomes the fourth dimension in architecture.

### *3.2.1 Major factors*

**Space and function**
The space to be lit is divided into functions and areas for the purpose of defining the lighting tasks. These areas may be workplaces, sales areas, counters and shelving, entrances and walkways. We talk about "zoning". The zones are defined according to the tasks to be performed in them, their functionality and their emotional impact.

**Light shapes the space**
Based on experience and intuition, lighting designers decide which lighting effects will best serve the intended purpose. In the various zones, light is used for background lighting, for accent lighting or for marking routes, for helping people find their way around and for highlighting architectural features. Light shapes the space and helps people perceive their surroundings. There is a virtually unlimited number of ways in which style elements, lights and lamps can be combined.

**Light and lamps**
Depending on the task that the lighting has to perform, one or more different types of lamp may be needed. With the aid of initial estimates and computer programs, it is possible to define the number of light sources required, their wattage and other technical details. This goes hand in hand with selecting

the luminaires.

**Selecting the luminaires**
In selecting the luminaires, lighting designers must take into account the characteristics described in the following paragraphs and ensure that the luminaires meet the requirements of the relevant regulations and workplace guidelines. Selecting the burning positions and determining the number of lamps and their positioning are often iterative processes.

**Fine tuning**
Lighting designers often have to reconcile a number of conflicting requirements. They have to take into consideration overall design, luminaire technology, economy, energy savings and interaction with other equipment.

### *3.2.2 Quality features of lighting systems*

The following quality features are described below:

- lighting level
- luminance distribution
- glare reduction and directed light
- directed light and the effects of shadow
- light colours and colour rendering
- comfort

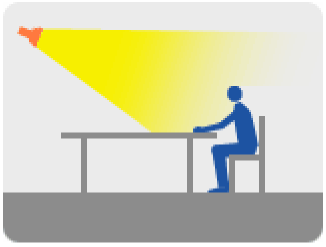
**Lighting level**
The lighting level has a major influence of performance, productivity and safety at work. However, as the lighting level increases so too do the costs. Consequently, the recommended values for illuminance are generally compromises between visibility, comfort, cost and energy consumption.
The typical recommended illuminances are shown below:

| E [Lux] | Application |
|---|---|
| ≧ 20 | Corridors and service rooms |
| ≧ 50 | Production facilities with no manual intervention |
| ≧ 100 | Production facilities with occasional manual intervention |
| 200 | Minimum for work rooms that are constantly occupied |
| 300 | Work rooms for medium-fine work(e.g. locksmiths and plumbers) |
| 300 - 500 | Zones with computer terminals |
| 500 | Work rooms for normal and fine work(e.g. office work) |
| ≧ 1000 | Individual workplace lighting with additional general lighting for extremely fine work (e.g. assembly of small parts) |

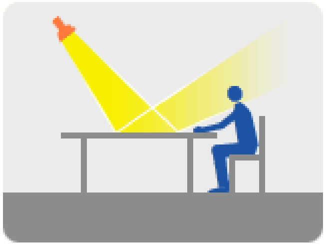
**Luminance distribution**
For optimum vision, typical lighting design standard recommends a luminance ratio of 3:1 between the close field and the ambient field. The close field is the work area and ambient field is the immediate environment of the work area. This ensures that the eye adapts properly.

**Reducing glare**
When choosing and positioning lamps and luminaires the danger of glare must be taken into account.

Thus an unfavourable positioning can lead to direct glare (looking directly into the lamp) or to reflected glare (across shiny or reflecting surfaces). This can impair the vision. In order to minimize reflected glare surfaces of workplaces should be mat. Furthermore the medium light density at the room boundaries should not be more than 200 cd/m$^2$.



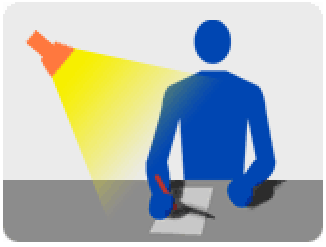
*Direct glare*

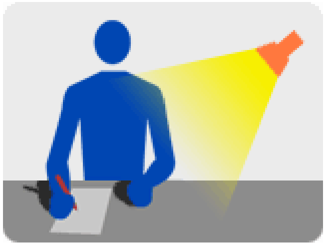


*Indirect glare*

**Directed light and the effects of shadow**

For right handed people the light should fall onto the work surface from the left side. Otherwise shadows could impair perception. Strong contrasts should be avoided.





**Light colours and colour rendering**

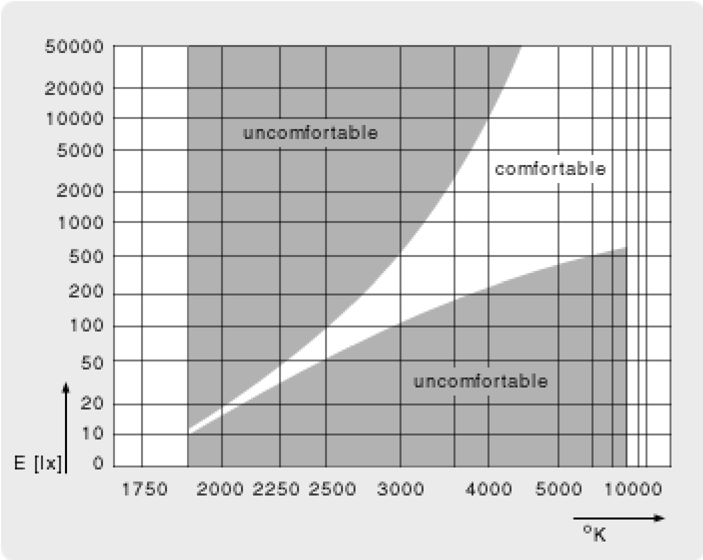
In order to naturally represent furnishings and other materials, only use lamps with good to very good colour rendering (like halogen lamps or full-colour fluorescent lamps).

*Good colour rendering*

*Bad colour rendering*

**Comfort**

The Kruithof comfort curve (shown below) indicates which range of illuminance is seen as comfortable at which colour temperature. This shows that lighting systems with low colour temperatures of 2700° to 3000° K are seen as comfortable in the range from 50 to 100 lux, whereas higher illuminances are seen as unpleasant. At a colour temperature of 6000° K, for example, illuminances of at least 500 lux have to be provided so that people in the room feel comfortable.



Kruithof comfort curve

### *3.2.3 Computer workstations*

Guidelines for lighting at computer workstations are given in relevant standards or guidebooks, such as DIN 5035, Part 2 and EU Directive 90/270/EWG. The minimum requirements include:

**Lighting**

- General lighting and/or special lighting (task lamps) must be dimensioned and arranged so that lighting conditions are satisfactory and contrast between the screen and its surroundings is adequate, according to the type of activity and the viewing requirements of the user.
- Glare, reflex or reflections on the screen or any reflective surface must be avoided by arranging the objects in the work area according to the arrangement and technical properties of the artificial light sources.

**Reflex and glare**

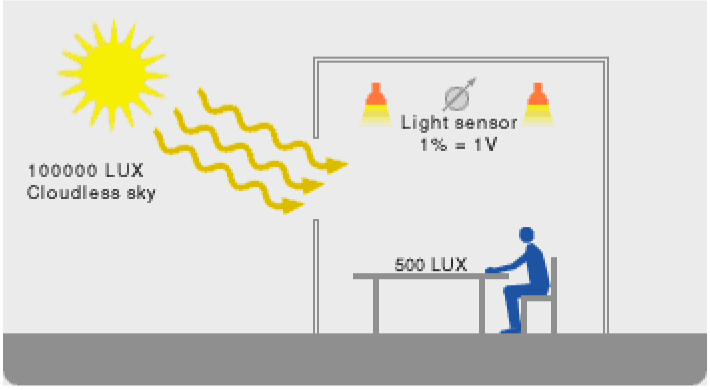
- Computer workstations must be set up so that light sources such as windows, other openings, transparent or translucent partitions, bright items of furniture and light coloured walls do not produce reflections on the screen.
- Windows have to be equipped with suitable adjustable mechanisms for preventing or reducing the amount of daylight falling on the workplace.

## 3.3 Intelligent controllers

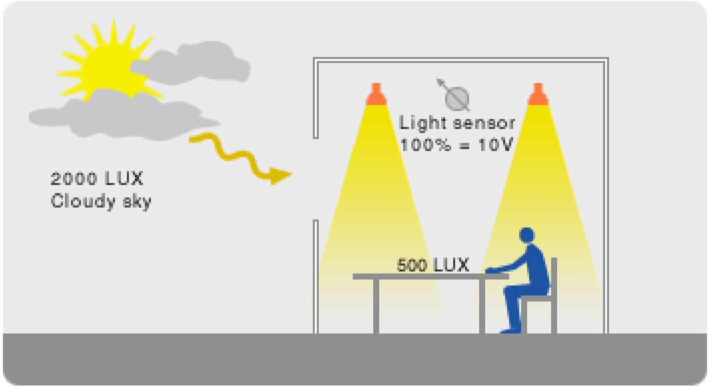
The requirements being placed on control systems in buildings are becoming more and more complex. Bus systems can control the heating, air conditioning, blinds, timers, access systems, cameras and video machines and of course also the lighting.

Often, several hundred luminaires are combined into complex switching groups depending on the various ways in which rooms are used, and these luminaires can produce an extremely wide range of lighting moods in time or event-controlled scenes. Lighting control systems offer a high level of convenience, reduce operating costs and help conserve energy for the benefit of the environment.

A light sensor, for example, may be placed above a work area in a room. It will measure the total amount of light, comprising natural daylight and artificial light. The user can enter a setpoint value.




*Daylight dependent dimming*




*High outdoor illuminance - Low outdoor illuminance*

If this value is exceeded (when sun shines in for example) the artificial lighting will be turned down until the setpoint value is reached again. These "intelligent controllers" can save up to 75% in electricity costs compared with conventional systems.

## 3.4 Outlook

From the dawn of time, light has been man's constant companion. There is definitely a strong mutual link between the development of light and man's cultural, scientific and economic achievements.

Light is the key to life in enclosed spaces, it allows us to live independently of the rhythms of the sun and provides us with a sense of well-being and security. Light is therefore one of the most complex substances in our modern world.