Lighting with artificial light

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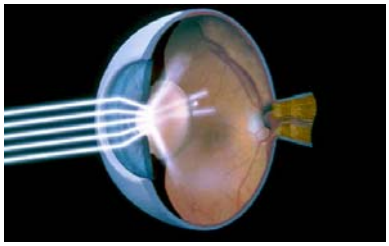
Light is necessary

Our vision and thus our contact with our environment are inextricably linked to the light.



Light is necessary

The sun as a light source of light that accompanies us since our inception has one big drawback: it is not shining during the night.

Light is necessary

In order to extend the day, and thus have a more opportunities for work, entertainment, development ... human is already very soon started to use artificial light sources.

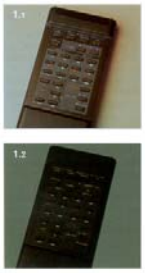
Light is necessary

Today lighting with artificial light sources is an indispensable part of our lives.

Vision and recognition

If we want to see and recognize objects four conditions need to be met:

Vision and recognition



Minimum luminance:

Objects that can be identified in detail easily during the day become indistinct at twilight and are no longer perceptible in darkness.

Vision and recognition

Minimum contrast:

For an object to be identified, there needs to be a difference between its brightness and the brightness of the immediate surroundings.

Vision and recognition

Minimum size:

Objects need to be of a minimum size if we want to see them. More light means we can see smaller objects.

Vision and recognition

Minimum time:

Perception requires a minimum time. A bullet, for instance, moves much too fast. Wheels turning slowly can be made out in detail but become blurred when spinning at higher velocities.

Challenge of lighting

The challenge for lighting technology is to create good visual conditions by drawing on our knowledge of the physiological and optical properties of the eye – e.g. by achieving:

- high luminance (illuminance) and
- good uniformity of luminance (illuminance) within the visual field.

Light: productivity factor

Good lighting can bring greater productivity, quality and safety.

Light: productivity factor

Light (good lighting) motivates to greater engagement in the work.

Light: productivity factor

Poor lighting means more fatigue: under normal conditions of vision, 25% of energy consumption goes for the nervous system; in poor conditions even much more. Fatigue, therefore comes sooner.

Light: productivity factor

Good lighting is viable investment.

Good and modern lighting can:

- reduce costs due to fewer errors and injuries;
- increase the productivity due to better motivation for work;
- increase quality due to better concentration at work.

Quality features in lighting

Just as the nature of occupational and recreational activities differs so too do the requirements for lighting presented by visual tasks. And those requirements define the quality criteria a lighting system needs to meet:

- visual performance
- visual comfort
- visual ambience

Quality features in lighting

Visual performance

Implementation of visual tasks

How accurate and how fast one can perform visual tasks aimed to score.

Quality features in lighting

Visual comfort

Sense of Well-being

To see (and work) in comfortable, pleasant conditions without strain, effort and fatigue.

Quality features in lighting

Visual ambiance

Good mood, emotion and feeling

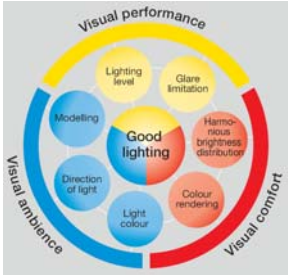
To experience environment positively and stimulating.

Quality features in lighting

- **Visual performance**
- **Visual comfort**
- **Visual ambience**

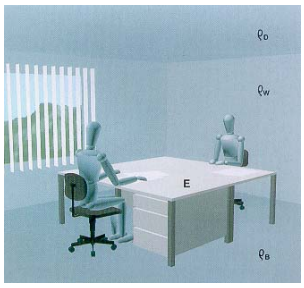
Depending on the purpose and appearance of the interior, the lighting should more or less pointed out each quality features.

Quality features in lighting



- **Visual performance**
  - Lighting level
  - Glare limitation
- **Visual comfort**
  - Harmonic brightness distribution
  - Color rendering
- **Visual ambience**
  - Light color
  - Direction of light
  - Modeling

Lighting level - luminance



Lighting level (luminance, impression of brightness) is influenced by illuminance and the reflective properties (ρ) of the illuminated surfaces. It is a defining factor of visual performance.

Lighting level - luminance

Some examples of reflectance:

White walls up to 85%

Light colored wood paneling up to 50%

Red bricks up to 25%

Lighting level - illuminance

Difficulty of visual tasks depends on the color and reflectance of the text and background.

Difficulty of visual tasks depends on the color and reflectance of the text and background.

Difficulty of visual tasks depends on the color and reflectance of the text and background.

If the reflectance is low the visual task is more difficult. To reduce this difficulty, the illuminance should be larger.

Lighting level - illuminance

When planning the lighting we so try to achieve necessary **illuminance** on the individual (e.g. work) or task or surface.

Lighting level - illuminance

Needed illuminance on the working area for different kinds of tasks or duties can be found in **standards** (e.g. EN 12464) and **recommendations** (e.g. CIE).

Lighting level - illuminance

The Standard specifies **maintained illuminance.** It is the value below which the average illuminance on the assessment plane is not allowed to fall.

Table 5.18 — Industrial activities and crafts – Metal working and processing

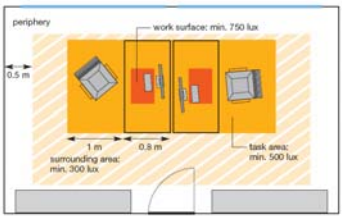
Ref. no.	Type of area, task or activity	$\bar{E}_m$ lx	UGR_L –	U_0 –	R_a –	Specific requirements
5.18.1	Open die forging	200	25	0,60	80	
5.18.2	Drop forging	300	25	0,60	80	
5.18.3	Welding	300	25	0,60	80	
5.18.4	Rough and average machining: tolerances ≥ 0,1 mm	300	22	0,60	80	

Lighting level - illuminance

The quality features identified by EN 12464 are not per se intended for the room as a whole; they actually apply only to the task area – i.e. the part of the workplace where the visual task is carried out.

Lighting level – task area

Concentrating lighting on the task area may reduce investment and energy costs but it presents risks in terms of lighting quality.

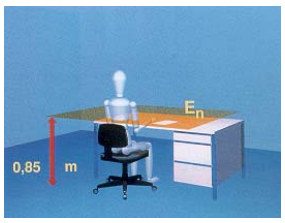


Such is always the case, for instance, if the task area and the less brightly illuminated area surrounding it are so closely aligned that luminance distribution within the field of vision is uneven. Task areas need to be carefully defined.

Lighting level – - room related lighting

If the precise arrangement of workplaces is not known at the time when a lighting installation is planned, EN 12464-1 stipulates that the areas of the room where workplaces could be located should be illuminated like the task area. This largely room-related lighting has the advantage that the arrangement of workplaces in this area of the room can be altered at any time.

Lighting level - illuminance



The surface on which the illuminance is realized is normally taken as the evaluation plane. Recommended heights: 0.85 m above floor level (0,75 m for sitting work) for office workplaces, max. 0.1 m in circulation areas.

Lighting level - illuminance

Some indicative values:

- outdoor excercise: 30 lx
- indoor excercise, orientation: 100 lx
- occasional work: 150 lx
- tasks with small seeing requirements: 300 lx
- tasks with average seeing requirements: 500 lx
- tasks with more than average seeing req.: 750 lx
- tasks with large seeing requirements: 1000 lx
- tasks with special seeing requirements: 1500 lx
- very precise visual tasks: over 2000 lx

Lighting level - illuminance

Standardized values (examples):

- Concert hall: 100 lx
- Library: 200 lx
- Reading room: 500 lx
- Office (general): 500 lx
- Stairway or corridor: 150 lx, 100 lx
- Classroom, lecture hall: 300 lx, 500 lx
- Drawing office: 750 lx
- Laboratory: 500 lx
- Operating theaters (working spot): over 10000 lx

Lighting level - uniformity

Given illuminance values are always spatial average values because the illuminance can not be the same in all parts of the room.

However, to avoid excessive differences between light and dark areas the standard also defines illuminance uniformity.

Lighting level - uniformity

Illuminance uniformity is defined as:

$$U = \frac{E_m}{E_{av}}$$

where:
E_m … lowest measured (calculated) value
E_{av} … average value (from all measured or calculate values)

Lighting level - uniformity

In the task area, the illuminance uniformity (U_o) shall be not less than the minimum uniformity values given in the Table 5.

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Lighting level - uniformity

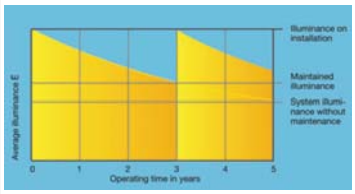
Ii is also necessary to consider the illuminance uniformity between adjacent spaces (rooms).

Recommended ratio between illuminances of adjacent spaces is 1:5.

In the case larger differences (ratio) problems with the adaptation of the eye (the adjustment to the brightness of the surroundings – some time is needed) could arise and make the transition from one room to another difficult.

Lighting level – - temporal uniformity

With increasing length of service, illuminance is reduced owing to ageing and soiling of lamps, luminaires and room surfaces. To compensate for this, a new system needs to be designed for higher illuminance (value on installation).



Lighting level – - maintenance factor

The reduction is taken into consideration by a maintenance factor:
maintained E = maintenance factor x E on installation.

The maintenance factor depends on the maintenance characteristics of lamps and luminaire, the degree of exposure to dust and soiling in the room or surroundings as well as on the maintenance programme and maintenance schedule.
Usual values are 0,8 or 0,66 (for some rooms even 0,5).

Lighting level – - special requirements

In certain cases it is necessary to provide greater illuminance of the room or work area, rather than the standardized value:

- at workplaces with abnormally low contrasts,
- for very difficult visual tasks,
- if it is necessarily to reduce the number of mistakes at work,
- when accuracy and productivity are very important,
- if visual performance of the worker is below average.

Lighting level – - special requirements

Larger illuminance allows proper execution of difficult visual tasks.

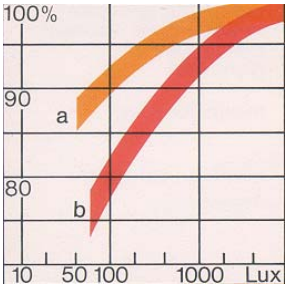
With large contrast text is easier to read. If the contrast is too small, it is necessary to increase the illuminance to achieve the same efficiency of reading.

Black on white: 95% reading effectiveness at 250 lx

With large contrast text is easier to read. If the contrast is too small, it is necessary to increase the illuminance to achieve the same efficiency of reading.

Black on gray: 95% reading effectiveness at 1000 lx

Lighting level – - special requirements

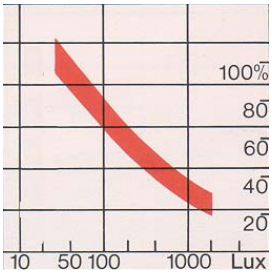


The relative ability of vision and its effectiveness increases with increasing illuminance:

a … black on white

b … black on gray.

Lighting level – - special requirements

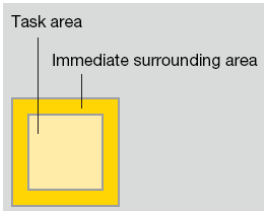


Fatigue of workers falls with increasing illuminance.

If at the illuminance of 20 lx all workers feel tired after work, at the illuminance of 1000 lx only 25% would feel so.

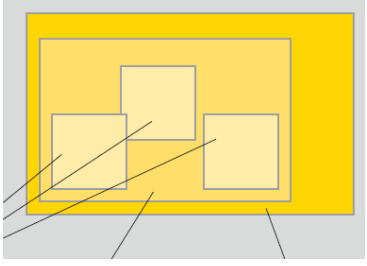
Lighting level – - surrounding area

Illuminance of the immediate surroundings of task area must be coordinated with illuminance of the tasks to ensure appropriate distribution of brightness.



Immediate surroundings of tasks area is area which worker has in his field of vision while working, or at least 0.5 m zone around the task area.

Lighting level – - surrounding area



Lighting level – - surrounding area

The illuminance of the immediate surrounding area shall be related to the illuminance of the task area and should provide a well-balanced luminance distribution in the visual field:

Illuminance of the task area (lx)	Illuminance on immediate surroundings areas(lx)
>750	500
500	300
300	200
200	150
<200	Edn

Lighting level – uniformity of surrounding areas

For lighting from artificial lighting or roof lights the illuminance uniformity:

- in the immediate surrounding area shall be $U_o \geq 0{,}40$;
- on the background area shall be $U_o \geq 0{,}10$.

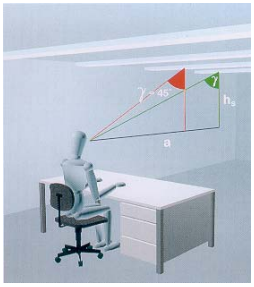
For lighting from windows:

in larger areas, activity areas and background areas the available daylight decreases rapidly with the distance from the window; the additional benefits of daylight (see 4.12) can compensate for the lack of uniformity.

Glare limitation – direct glare

Glare causes discomfort (psychological glare) and can also lead to a marked reduction in visual performance (physiological glare); it should therefore be limited.

Glare limitation – direct glare



Direct glare is caused by excessive luminance e.g. from unsuitably positioned luminaires. The critical beam angle starts at 45°.

Glare limitation – direct glare

When planning the lighting one should consider following:

- location of work areas,
- required illuminance,
- Selection of luminaires based on their luminance,
- positions of luminaires.

Glare limitation – direct glare

In indoor lighting, psychological glare is rated by the standardized UGR (Unified Glare Rating) method based on a formula bellow. Glare is assessed using UGR tables, which are based on the UGR formula and are available from luminaire manufacturers.

$$UGR = 8 \cdot \log_{10}\left(\frac{0{,}25}{L_b} \Sigma \frac{L^2 \omega}{p^2}\right)$$

Glare limitation – direct glare

$$UGR = 8 \cdot \log_{10}\left(\frac{0{,}25}{L_b} \Sigma \frac{L^2 \omega}{p^2}\right)$$

L_b … background luminance in cd/m², calculated as E_{ind}/π, where E_{ind} is vertical indirect illuminance at the observer's eye.

L … luminance of the luminous parts of each luminaire in the direction of the observer's eye in cd/m².

ω … solid angle (in steradian) of the luminous parts of each luminaire at the observer's eye.

p … Guth position index for each individual luminaire which relates to its displacement from the line of sight.

Glare limitation – direct glare

Standard EN 12464 specifies for each type of work (task) the maximum allowable UGR.

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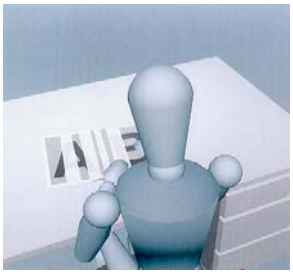
Glare limitation – direct glare

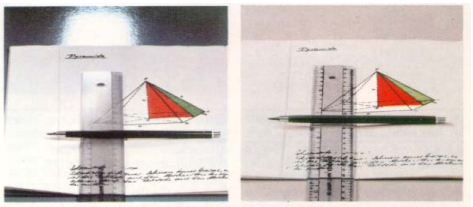
Glare can also cause windows or rooflights if they are in line of sight. In such a case, it is necessary to provide adequate shades.

Glare limitation – reflected glare



Reflected glare refers to the disturbing reflections of lamps, luminaires or bright windows found on reflective or glossy surfaces such as art paper or computer monitors.

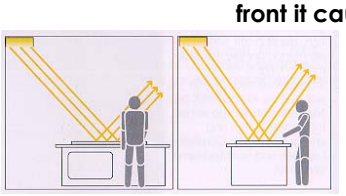
Glare limitation – reflected glare



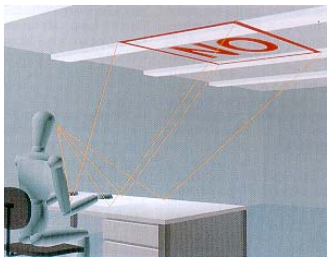
Reflected glare can be reduced by using non-reflective or textured (matt) surfaces.

Glare limitation – reflected glare

Reflected glare can also be reduced with the appropriate direction of light. In the incursion of light from the side, the light is reflected to the side also. But when incursion from the front it causes reflected glare.

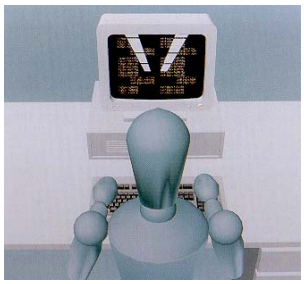


Glare limitation – reflected glare



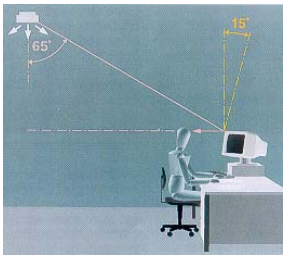
In order to avoid reflected glare from the incorrect luminaire arrangement, no luminaires should be installed within the “No zone”.

Glare limitation – reflected glare



Reflections onto computer screens are particularly disturbing. A difficult problem, but one that can be solved by using special VDU luminaires and a well planned arrangement.

Glare limitation – reflected glare



Depending on the class of VDU, the mean luminance of luminaires which could cast reflections onto the screen needs to be limited to 200 cd/m2 or 1,000 cd/m2

above the critical beam angle of = 65° (at 15° intervals all round the vertical axis).

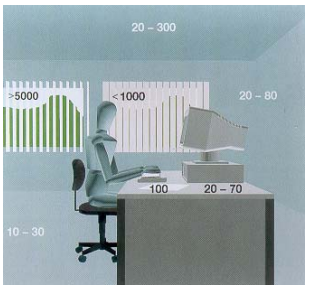
Harmonious distribution of brightness

Marked differences in luminance in the field of vision impair visual performance and cause discomfort, so they need to be avoided.

The luminance of a desktop, for example, should be no less than one third of the luminance of the document.

The same ratio is recommended between the luminance of the work surface and that of other areas further away in the room.

Harmonious distribution of brightness



The ratio of visual task luminance to the luminance of large surfaces further away should not exceed 10:1 (sometimes even 5:1).

Harmonious distribution of brightness

Where luminance contrasts are not sufficiently marked, a monotonous impression is created which is found disagreeable.

Harmonious distribution of brightness

Excessive differences in brightness look too hard and dramatically. This is also found disagreeable and in such a place it is difficult to relax.

Harmonious distribution of brightness

With harmonious distribution of brightness the room does not look monotonous but also dot to dramatically. So one will not get bored or tired (to soon).

Harmonious distribution of brightness

Factors which help create a balanced distribution of luminance in the field of vision include:

- room-related or task area lighting;
- use of lighting with an indirect component
- for better uniformity;
- a ratio of minimum to mean illuminance E_{min}/E_{avg} of at least 1/1,5;
- adequately high wall, floor and ceiling reflectance (ceiling min. 70%, walls min. 50%, floor min. 20%).

Harmonious distribution of brightness

Example of working environment with luminance values.

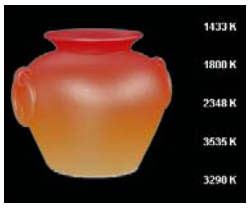
(in cd/m^2)

Light color

We experience our surroundings not just as brightness and darkness, light and shadow, but also in color!

The color of light from a light source is expressed in terms of color temperature (Tc) measured in Kelvin (K).

Light color



If (metal) object is heated it begins to emit energy in the form of visible light. First it looks dark red, then its color passes through orange and yellow to white and finally to bluish white.

It is so possible to describe the light color with the temperature of the (black) body which glows with the certain light color.

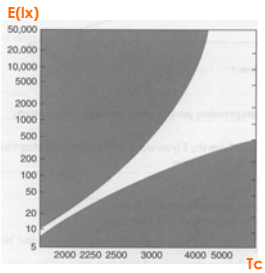
Light color

The characteristic light colors of electric light sources:

- incandescent lamp: 2700K
- tungsten halogen lamp: 3000K
- WW fluorescent l. (warm white): 3000K
- NW fluorescent l. (neutral white): 4000K
- DW fluorescent l. (daylight white): 6000K

Light color

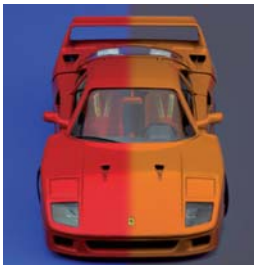
It was found out that:



- in rooms with lower illuminance (e.g. 200 lx) light color of lower color temperature (e.g. 3000 K) is preferred
- in rooms with higher illuminance (1000 lx) light color of higher color temperature (5000 K) is preferred.

Color rendering

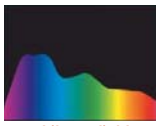
Light and colour define the atmosphere of a room and influence our mood and sense of wellbeing by their "warmth" or "coldness".



The appearance of colored objects is affected by the interaction between the colour – i.e. the spectral reflectance – of the objects we see and the spectral composition of the light illuminating them.

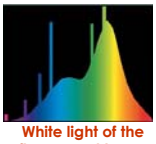
Color rendering

Even the light sources of the same color of light have different spectra and so also different color rendering index. On the basis of the color of light it is so not possible to estimated color rendering.



White sunlight

White light of the incandescent bulb

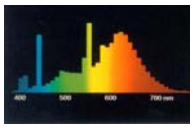


White light of the fluorescent lamp.

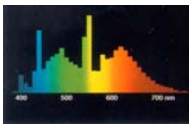
Color rendering

It is the spectrum of the light source which determines the color rendering properties.

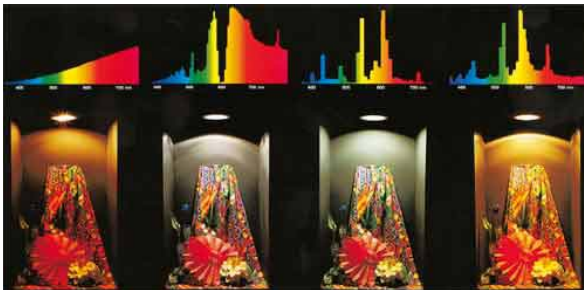
Light source with more red light highlights red colored objects.



Under light source with less red color red objects looks more dull.



Color rendering



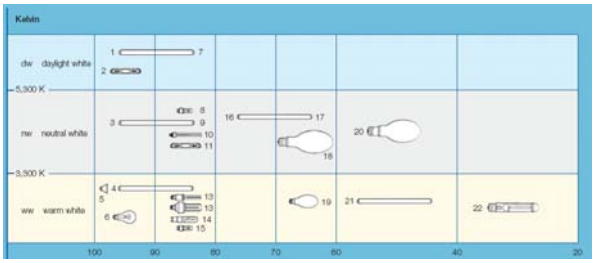
Color rendering

Standard EN 12464 specifies for each type of task required color rendering index (CRI or Ra).

Table 5.18 — Industrial activities and crafts – Metal working and processing

Ref. no.	Type of area, task or activity	$\bar{E}_m$ lx	UGR_L –	U_0 –	R_a –	Specific requirements
5.18.1	Open die forging	200	25	0,60	80	
5.18.2	Drop forging	300	25	0,60	80	
5.18.3	Welding	300	25	0,60	80	
5.18.4	Rough and average machining: tolerances ≥ 0,1 mm	300	22	0,60	80	

Color rendering



Color rendering

1 De luxe fluorescent lamps, daylight
2 Metal halide lamps
3 De luxe fluorescent lamps, white
4 De luxe fluorescent lamps, warm tone
5 Halogen lamps
6 Incandescent lamps
7 Three-band fluorescent lamps, daylight
8 Metal halide lamps
9 Three-band fluorescent lamps, white
10 Compact fluorescent lamps, white
11 Metal halide lamps
12 Three-band fluorescent lamps, warm tone
13 Compact fluorescent lamps, warm tone
14 High-pressure sodium vapor lamps (Ra 80)
15 Metal halide lamps
16 Fluorescent lamps, universal white
17 Standard fluorescent lamps, white
18 Metal halide lamps
19 High-pressure sodium vapor lamps (Ra 60)
20 High-pressure mercury vapor lamps
21 Standard fluorescent lamps, warm tone
22 High-pressure sodium vapour lamps (Ra 20)

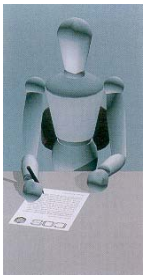
Direction of light and modeling

Without light we cannot make out objects, without shadow we see objects only as two-dimensional images. It takes directional lighting and modeling to permit 3D projection, to give objects depth.

Direction of light and modeling

Only under directional light from the side can the three-dimensional structure of the wall surface be perceived; in diffuse light it appears smooth.

Direction of light and modeling



Most (right handed) people prefer light to fall predominantly from above and the left, since this prevents disturbing shadows being cast on written work.

Direction of light and modeling

The direction of the light and shade depends on light distribution of luminaires and their distribution in space.

A single light source casts hard shadows, which can distort the subject.

Two light sources from different directions give a better picture of the object.

Light sources in long straight lines give a soft and blurred shadows.

Direction of light and modeling

For general interior lighting, balanced shadow with soft edges is correct.

A total lack of shadow impairs 3D vision.

In daylit rooms, the direction of light from luminaires should correspond to that of daylight.

Direction of light and modeling

For certain visual tasks e.g. for the appraisal of surface characteristics, marked modeling created by directional light is necessary.

This can be achieved with additional individual luminaires producing concentrated beams of light.

Direction of light and modeling

Direction of light is generally defined by daylight entering the room through a window from a particular direction (preferably from left for right hander). Excessively deep shadowing can be offset by artificial lighting.

Direction of light and modeling

In offices where desk arrangements are geared to incident daylight, it is advisable to control daylight incidence by means of window blinds and to use continuous rows of luminaires on separate switching circuits to lighten disturbing shadows.

Direction of light, modeling and glare

Wrong: Light from front is reflected and causes reflected glare.

Wrong: If light comes from back the body casts shadow on task area an so reduces the illuminance.

Wrong: Light from right causes disturbing shadow (with right-hander)

Correct: Light from left causes no reflected glare and no disturbing shadows (for right-hander)

At the end …

Interior design lighting is a challenging task in which we have to consider at least:

- illuminance and its uniformity;
- glare and its limitation;
- harmonious distribution of brightness;
- light color and color rendering;
- direction of light and modeling.

… and now:

Questions?