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Good Lighting for a Better Learning Environment

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Editorial

Most of us have memories of our first day at school. But who remembers what kind of lights were on the classroom ceiling? We may be forgiven for not recalling that because it is not something likely to attract a child's attention. And anyway, the light in the room will mostly have been supplied by daylight. The only time the artificial lighting needed to be switched on was in winter. Which made for a cosy, homely atmosphere.

I can clearly remember individual students – always the same ones – complaining that they could not read what was written on the board. One of the globe lights or a window was reflected in it, reducing or eliminating all perceptible contrasts along the sight line from their desks. The lighting was also obviously a problem during slide or film presentations, when it needed to be switched off. Now, as a university lecturer, I realise something else: the importance of not losing eye contact with students because of dazzling platform lighting. In short: one of the salient features of good lighting is that it goes unnoticed.

But that is not all. Good lighting can do more than just avoid being a nuisance. It is vital for good communication between teacher and student and among students themselves – also during media presentations and group work. It permits effortless and efficient use of teaching media and materials. It also makes for greater safety in workshops, laboratories and sports halls. But its impacts are not confined to improving visual perception; good lighting enhances students' ability to concentrate and thus facilitates their academic progress. Today, a cosy atmosphere can no longer be generated by inefficient incandescent lamps but improving wellbeing and helping create a balance between stimulation and relaxation are still key tasks for good educational lighting.

We have moved on from the time when students always sat in the same place. Teaching methods are more varied now; rigid seating arrangements are found only in lecture halls and the conventional chalkboard has been joined by a whole range of other teaching media, each with its own special lighting requirements. So good lighting today needs to be designed for more than just on/off control. Modern lighting management technologies permit a tailored response to diverse teaching requirements – from low-level lighting for a dark cosy corner in a nursery school to light for students taking notes during data projector presentations, to stage lighting for theatrical performances.

I hope that public authorities, teachers and lighting designers will view and use licht. wissen 02 as a tool and inspiration for realising lighting in educational establishments. One of the most important goals for the future of our society is to raise teaching and learning standards. Good daylight utilisation and artificial lighting can play a major role in promoting that.

Univ.-Prof. Dr. Christoph Schierz
Ilmenau University of Technology

[Cover] Finding the right book, working, reading, a sense of wellbeing – good library lighting makes them all possible.

[01] For concentrated work in the classroom, students and teachers both need bright uniform light.

Lighting Specials:

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Good lighting for a better learning environment

Light is the key to visual perception and human emotion. In a learning environment, good lighting plays a major role in permitting optimal absorption of information by students.

Our entire life is shaped by learning processes. Every individual goes through experiences in life and, as a result, acquires – consciously or subconsciously – the cultural, social, intellectual and physical abilities, knowledge and skills that mould and define his or her character. Everyone has heard the expression "life-long learning". Today, there is also an "EU Educational Programme for Life-Long Learning in Germany" with sub-programmes for projects in schools, higher education, vocational education and training, and adult education.

Light is a major factor in this context because, as the key to visual perception – the source of most of the sensory messages to our brain – it plays an absolutely crucial role in learning. Students permanently find themselves in learning situations. The better the lighting is suited to those situations, the more information can be absorbed, processed and stored, i.e. learnt.

The right lighting creates optimal conditions for effective learning, motivating learners and enabling them to concentrate for longer periods. A balanced lighting atmosphere contributes crucially to a sense of wellbeing and makes for a positive learning environment. Quite simply, we learn better in the right light!

Poor lighting is often found annoying; it can distract us from what we are doing and at worst can even be harmful. So apart from taking design requirements and energy issues into account, any plan for a lighting installation should always focus primarily on the people who will use the lighting, because, depending on their age, they may have widely differing lighting needs.

Modern educational establishments are well designed to cater for the diverse needs of learners. So is the lighting installed in them. This booklet takes a closer look at the requirements lighting needs to meet to support different tasks in different rooms.

As in real life, the focus is chiefly on schools, colleges and universities. The "Lighting Specials" in the booklet provide more in depth information on specific issues.

[02] The right light creates a perfect environment for effective learning. Alert students are more motivated and more attentive.

[03] Poor light quickly gives rise to fatigue, whereas good lighting contributes significantly to as successful study experience.

[04] Balanced lighting impacts positively on our sense of wellbeing and creates ideal conditions for the transfer of knowledge.

Playroom lighting

The right light is extremely important in nurseries and pre-schools to help encourage a spirit of adventure, discovery and investigation at all levels. An atmosphere of wellbeing helps promote positive child development.

They are greatly coveted and still very scarce. Despite being a legal entitlement since 1996, nursery and pre-school places remain in short supply in Germany. Nursery schools and pre-schools are an important part of the education landscape, establishments designed to promote a child's all-round development. So special care needs to be taken in nursery and pre-school facilities to ensure good quality lighting.

Young children are inquisitive and ask questions. They need to move, play and sometimes even let off steam; they learn by seeing and imitating. They need to recognise, discover, explore and literally "grasp" their environment. Which defines the first priority for the lighting designer. The lighting design needs to underpin the concept of early childhood education and, by providing a finely tuned mix of direct and indirect light, create the feel-good atmosphere needed for the development of a positive learning climate.

The heart of any nursery school is the group room, which is used for a whole range of activities – from crafts, games and boisterous play to story time and snuggling sessions. And each activity requires the right light. When children play, they need to be able to make out their surroundings clearly and gauge distances accurately. To permit this, importance needs to be attached to a lighting level optimally tuned to the visual task as well as balanced luminance distribution, well shielded luminaires and good colour rendering. The latter is particularly important where children are engaged in creative activities or when colours need to be reliably identified and sorted, e.g. for a jigsaw puzzle.

Multifunctional group rooms

Care must be taken to ensure that lighting is flexible and not only provides adequate general light but also supplementary lighting for specific activities. Multifunctional group rooms require differentiated lighting to cater to the different requirements of the various zoom zones. Daylight utilisation and lighting management systems are also certainly useful here. They enable a whole range of lighting moods to be pre-programmed as lighting scenes for activation at any time. Service rooms such as kitchens, sanitary facilities, cloakrooms and first aid rooms require functional lighting in compliance with DIN EN 12464-1.

In the pre-school environment, where children are prepared for primary education, it is even more important that youngsters should be able to concentrate. For lighting purposes, therefore, pre-school classrooms should be treated like school classrooms with flexible seating arrangements.

[06] The group room is the heart of the nursery school – a place for games, craft activities as well as more boisterous forms of play. It also has the "comfort corner" for any child who needs a rest.

[07] Optimal visual conditions are a fundamental requirement for a good playing and learning atmosphere.

[08] Lighting solutions that ensure balanced contrasts and glare-free light enable children to work with books and computers without getting tired.

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Playroom safety

Children want to play, romp and move about freely [05]: Furnishings and lighting need to be designed for that. Furniture should not have sharp edges and luminaires should be enclosed to avoid risk of injury. What is more, luminaire mountings need to be childproof. In multi-purpose rooms, it may be advisable to install impact-resistant luminaires. Because of the heightened risk of injury, the use of mobile luminaires is not recommended.

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Classroom lighting

Modern education is based on encouragement and challenge. And much of the learning process is visual. Good lighting is a vital requirement for concentration and fatigue-free work and plays a crucial role in helping increase student attentiveness.

Life-long learning is more important than ever. And the foundations on which we build to meet the ever-rising challenges of vocational life are laid during our younger years. Anyone who enjoys learning learns more easily and more effectively – from childhood through to old age. At nursery, primary and secondary schools, vocational colleges and universities, young people receive an education that shapes their entire life.

Rigid seating arrangements and unvarying "chalk and talk" instruction in the classroom are now a thing of the past. Most schools have abandoned fixed arrangements of desks. New forms of communication have taken their place. The purpose of flexible solutions is to tailor the room to learning objectives. The face of the classroom changes according to needs, permitting both direct instruction and group work. When students present projects, for instance, the classroom becomes a stage and auditorium. Supporting different types of learning and teaching situation also calls for flexible lighting – because that is what ultimately ensures that the scenarios required can be realised visually.

Flexible room use

With the right choice of lighting and a correct arrangement of luminaires, rooms can be put to flexible use. For perfectly free room use, the lighting system needs to create good lighting conditions for all room users whatever the arrangement of desks and/or chairs. To guarantee that, a room-related lighting solution is recommended, which means that all walls, including the rear wall, are well illuminated. To avoid marked differences in luminance along changing lines of sight – which cause visual fatigue and undermine concentration – it is important to ensure uniform brightness throughout the room.

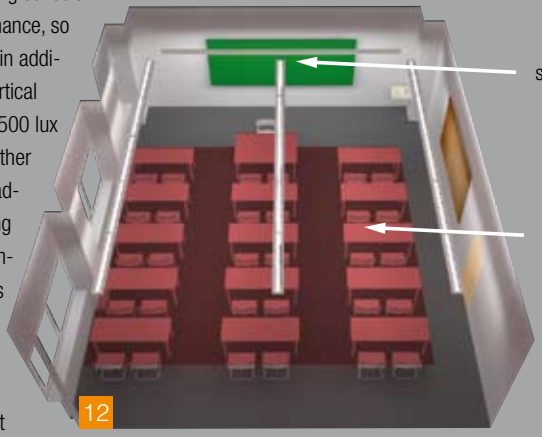
The primary purpose of the lighting is to illuminate the room evenly to suit the relevant teaching situation. Natural daylight is preferred where it is available. Artificial light, which should be dimmable, supplements daylight as required. Disturbing glare that interferes with concentration can be avoided by fitting luminaires with appropriate optical systems or by installing curtains or blinds. This enables daylight incidence to be regulated, depending on the position of the sun.

In the area of the board, separately switched, dimmable luminaires are needed to permit reflection-free vision. The same requirement applies to any secondary boards or the class wall newspaper, which should be uniformly illuminated by dedicated wallwashers. Moreover, cabinets and shelves in the classroom need to be bathed in sufficiently bright light to enable papers and objects to be stored away and found without any difficulty.

Classroom illuminance levels:

DIN EN 12464-1 [12]: For classrooms, DIN EN 12464-1 recommends an illuminance of 300 lux. However, the level required for compliance with the standard should be regarded as an absolute minimum. A higher illuminance of 500 lux is better for achieving good classwork results; it is also the brightness recommended for practical training rooms and rooms in evening schools.

Boards require uniform illuminance, so they require separate lighting in addition to the general lighting. Vertical illuminance here needs to be 500 lux for standard compliance. Another way in which lighting can be adjusted to suit changing learning and teaching situations and enhance learning performance is through the use of a lighting management system, which adapts the lighting flexibly to meet the needs of the relevant visual task.



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[09] The low-key design of recessed luminaires makes them useful where lighting quality needs to be combined with streamlined architecture.

[10] Pendant luminaires with direct and indirect lighting components brighten the ceiling and thus make for a spacious and agreeable lighting atmosphere in the room.

[11] Seating areas, board and flipchart have their own dedicated lighting here. Separate switching and dimming circuits make for greater convenience and permit significant energy savings.

Chalkboard and whiteboard lighting

Adequately bright, uniform lighting is very important for vertical board and presentation surfaces. Eyes that constantly need to adapt to differences in brightness can suffer fatigue. New presentation media call for differentiated lighting solutions.

Classical chalkboards are being increasingly superseded as a standard item of classroom furniture. Where a green or black board once hung on the wall, there is now often a whiteboard. The visual tasks are always the same, both with traditional boards and with modern projection surfaces, but the lighting requirements are different. Classical boards require sufficiently bright, uniform lighting. Whiteboards, with their very bright surfaces, need less light and are more susceptible to reflections.

Good school lighting depends crucially on good lighting for vertical presentation surfaces. Anything written on them needs to be clearly legible from every angle. Students sitting at the back of the room must not be at a disadvantage.

Raising vertical illuminance

Sufficiently bright, uniform lighting can be achieved by supplementing the general room lighting with asymmetric wallwashers mounted 0.85 – 1.30 metres in front of the board. The greater perceived brightness achieved with vertical light makes for better visibility from a distance. DIN EN 12464-1 recommends an average vertical illuminance of 500 lux for presentation surfaces. Uniformity – i.e. the ratio of lowest to average illuminance – should be 0.7. Where boards can be raised or have lateral extensions, care needs to be taken to ensure adequate planar illumination. This is also important for flipcharts or maps positioned alongside the board.

Whiteboard lighting

Whiteboards require less light but are more susceptible to reflections. Where luminaires are positioned close to whiteboards, special attention needs to be paid to the shielding and arrangement of light sources to avoid reflected glare. For beamer presentations, the lighting should be wired to permit separate dimming or deactivation.

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[13] In addition to the general room lighting, separate lighting delivering 500 lux or more sets the stage for the board. The R_a colour rendering index should be at least 80.

[14] In rooms where projection screens are used, it is important to ensure that lighting can be partially deactivated or dimmed.

[16] Whiteboards should be sufficiently illuminated. To avoid glare, however, the light should not be too bright. At the same time, the surroundings should not be too dark; constant adaptation puts a strain on students' and teachers' eyes and soon causes fatigue.

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Chalkboard lighting

For good chalkboard lighting [15] the following criteria must always be met:

- At least 500 lux illuminance on the vertical surface
- Avoidance of reflected glare, e.g. through the use of narrow-angle spots
- The R_a colour rendering index needs to be 80 or higher
- The uniformity of the board lighting should be 0.7 (ratio of minimum to average illuminance)
- Flipcharts or maps positioned alongside the board should also be uniformly illuminated by the wallwashers

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Computer and media room lighting

Computer and communication technologies play an integral role in classroom activity. Good computer and media room lighting needs to be tailored to the relevant task, form of instruction and mood.

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Studying at a computer monitor

Good lighting [20] should be adaptable to cater for different visual tasks and the visual requirements of different users. This calls for a balanced contrast between the screen and the work area around it. Computer work stations and the lighting required for them need to be specifically designed to ensure that disturbing glare and reflections on the screen or other materials are avoided. Luminous and illuminated surfaces must not cause glare at a computer workstation and, wherever possible, should not give rise to reflections. To reduce interference from incident daylight at a computer workstation, windows should be fitted with movable shades for effective daylight control.

Media competence and a willingness to accept life-long learning are every bit as important today as linguistic, artistic or scientific skills. Media competence is required in every occupation. There is virtually no career today that does not involve working at a computer and constantly upgrading IT skills and knowledge.

Teaching methods and materials have changed dramatically in modern educational establishments. The need for flexibility and communication in the classroom has never been greater. And as teaching methods have changed, so have the media used for instruction and communication. Working at a PC, whether for research or homework, has long been part of daily school life – a development reflected by the arrival of dedicated computer and media rooms in modern school buildings.

Need to avoid marked differences in brightness

Classroom lighting needs to meet higher requirements for "digitised" learning. Trouble-free work at a PC requires good visibility and glare-free lighting.

Marked contrasts in our field of vision cause visual fatigue. To counter that, the brightness of the screen, task area and surroundings needs to be carefully balanced. What can help here is a more pronounced indirect lighting component, which makes for an agreeably bright ceiling and distribution of light over the working plane. Glare, which impairs visibility, needs to be avoided for compliance with DIN EN 12464-1.

Cautious handling of direct daylight

Intense incident daylight can seriously interfere with work at a computer. Reflections on the screen can be avoided by effective sun screening at windows.

A simple, intuitive lighting control system which is easy to operate and tailor to changing visual tasks enables schools to respond to increasingly complex technologies and methods. Lighting that is ergonomically sound and adaptable to suit different activities, teaching methods and moods prevents the fatigue and complaints that are associated with working at a computer monitor.

[17] Lighting design needs to take account of daylight. For working at a computer screen, it is important to have both the means of shading windows and the artificial lighting needed to illuminate the interior of the building.

[18, 19] Linear lighting systems with good anti-glare shielding prevent annoying reflections on screens.

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Impact of light on human beings

Light impacts on human beings in a variety of ways, so it also influences our behaviour. It promotes a sense of wellbeing and strengthens powers of concentration and motivation. Light also has a positive influence on learning. Daylight and tailored lighting moods can help students learn efficiently.

[21, 22] Dynamic lighting installations permit a great deal more than just on/off lighting. They enable intensity of light and light colour to be adjusted to create a tailored lighting atmosphere for specific classroom situations. Cold light colours stimulate and promote concentration, warm light colours have a soothing effect on students.

Many children at school are still sleepy and unfocused during the first lesson of the morning. In most cases, the early start conflicts with the children's biological needs. Energising high-lux daylight-white light can help improve students' memory skills, concentration and general sense of wellbeing.

It has long been known that our sense of wellbeing is fundamentally influenced by light. We find natural daylight agreeable and it makes us feel good. So does sufficiently bright indoor lighting. But recent studies show that light has an even greater impact on human life than that. Light can support our circadian rhythm (day/night rhythm) and control biological processes in our body. Human biological rhythm is controlled by a "body clock", on which light has a crucial influence. Light supports the sleep-wake cycle by telling our body when day turns into night. Without sufficient light, our internal clock may be disrupted and sleep-waking phases may become less pronounced as a result. If our chronobiological rhythm is disturbed in this way, our sense of wellbeing and possibly even our health are significantly affected.

Taking a leaf from nature

Nature offers ideal conditions for keeping our body clock right. But a similar effect can be achieved by artificial lighting adjusted to recreate the natural rhythm of daylight. The intensity, colour temperature and direction of daylight change constantly during the course of the day. Artificial lighting that imitates those changes makes us feel better and more motivated in much the same way as natural daylight. There are also energetic advantages to dynamic adaptation. Targeted lighting control can help improve memory skills and concentration, general wellbeing and communication.

Cool cold-white light similar to daylight makes us alert and active. Warm-white light has a relaxing, soothing effect. To achieve biological performance-boosting impacts in schools, the lamps used should emit light with a high blue content. High-blue light sources specially developed for this purpose are already in widespread use.

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Parameters for biologically effective light:

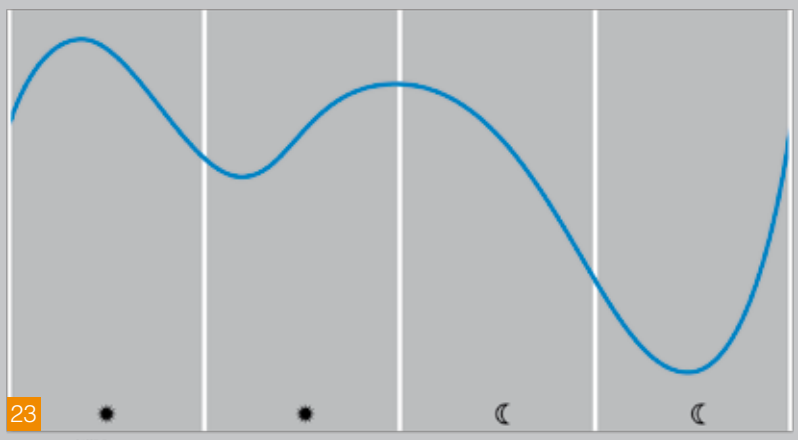
- Biological impact can be achieved through high illuminance
- Planarity is important; wherever possible, the light should be diffused through large luminous panels
- The direction of light should be chosen so that light enters the eye from above and from the front
- It is also advisable to choose a colour temperature similar to daylight, with a spectrum that also contains biologically effective blue light
- Colour temperature and illuminance should change dynamically in line with the natural progression of daylight

Emotional impact of light

For an effective learning environment, surroundings need to be found agreeable, allowing students to identify with their school. Colours, materials and finely tuned lighting/interior design help promote a sense of wellbeing. This calls for not only a stimulating atmosphere but also room for privacy, where students can rest and relax. Warm colour temperatures and accents help meet this requirement.

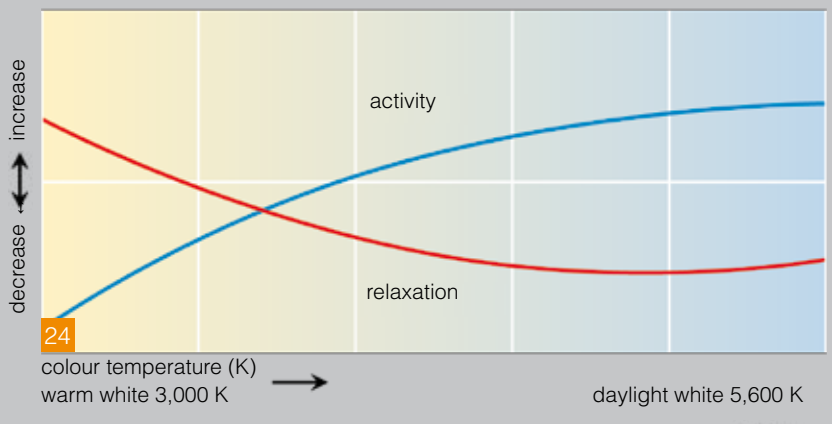
More information on this subject is found in licht.wissen 19 "Impact of Light on Human Beings".

Human performance



[23] Human performance varies, depending on the time of day or night. Our body and mind work most effectively in the morning and late afternoon; performance reaches a low during the deep sleep phase around 3 a.m.

Activity and relaxation



Source: Dr. Susanne Fleischer, Institute of Hygiene and Occupational Physiology, Swiss Federal Institute of Technology, Zurich

[24]] Biologically speaking, warm white light has a relaxing effect on the human organism, whereas daylight white boosts activity.

Energy efficiency and refurbishment

Lighting installations for schools need to ensure an agreeable working atmosphere. They also have to be energy-efficient. The need for energy efficiency is stipulated in the energy-saving ordinance EnEV. Within the specified limits, however, lighting quality requirements must always be observed.

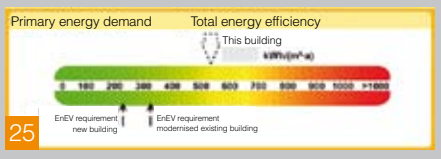
Everyone today is aware of the issue of energy-efficient lighting, especially in the wake of the phase-out of inefficient light sources such as the incandescent lamp. The need for both efficient use of increasingly scarce resources and intelligent use of daylight is now widely accepted. Growing importance is also attached to the issue in educational establishments. The most important components of effective and efficient lighting installations are modern light sources and luminaires incorporating modern control gear and reflectors as well as lighting management systems for optimal daylight utilisation.

With a daylight-dependent regulation system, the brightness in the room is monitored by a sensor. When daylight incidence is high, the artificial lighting is lowered to save energy. Presence control systems are also efficient tools. They detect the presence of persons in the room and automatically deactivate the lighting as soon as the room is vacated. Apart from ensuring high lighting quality, harnessing daylight – a natural resource – permits maximum energy conservation, saving as much as 50 percent of the electricity consumed by a previous lighting installation.

For more detail on lighting management, see the Lighting Special on the subject on page 24.

Energy Saving Ordinance

The German Energy Saving Ordinance (EnEV), which is concerned with the implementation of EU directives on the overall energy efficiency of buildings, applies throughout Germany. It covers the heating, ventilation and air conditioning of buildings. Artificial lighting also falls within the scope of the EnEV. Its catalogue of measures applies to any lighting designed to facilitate the performance of visual tasks – i.e. not lighting that serves only a decorative purpose. Energy certificates have been compulsory for buildings in Germany – including non-residential buildings – since 1 January 2009. They are an indicator of a building's current efficiency status.



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The EnEV stipulates that when a building is planned or refurbished, the primary energy demand of its lighting installations needs to be established. Preliminary planning must meet the guidelines of both the EnEV and the DIN standard cited in it. Official approval is required before construction work commences.

Numerous parameters are factored into the energy requirement calculation. Types of luminaire used, hours of day/night-time use, size of windows, lighting management systems, surrounding buildings and other factors are taken into account. The net energy requirement thus computed needs to be below a reference value based on tables. This requirement needs to be met before a building permit or energy certificate is issued.

Energy efficiency requirements will become even tougher in future, with lower benchmarks raising the bar for acceptable efficiency standards.

Refurbishment

An obsolete lighting installation reduces lighting quality and costs money. Over the years, soiling and ageing of materials can halve the light output ratio of an old lighting installation and its components (lamps, luminaires and electrical gear). Investment in efficient modern lighting reduces the annual operating costs considerably. Even higher acquisition costs are recouped within a few years – thanks to both lower electricity consumption and reduced maintenance costs.

Wherever new lighting is planned as part of a modernisation project, professional advice should be sought and taken as a basis for all subsequent decisions.

Modern lamps, luminaires and ballasts make the difference

New lamp, ballast and luminaire technologies pave the way to energy economies. They are the key to more efficient operation and better lighting quality. While modern light sources such as T5 fluorescent lamps and LEDs have a higher luminous efficacy, modern electronic ballasts reduce power loss and offer flicker-free light with the added bonus of enhanced starting performance. Apart from that, the latest reflector materials and optics make for luminaires with high light output ratios and optimal glare suppression.

Modern lighting management systems offer additional savings potential. In the course of refurbishment projects, they can even be installed in individual rooms or groups of rooms.

Refurbishment does not mean sacrificing aesthetics. State-of-the-art luminaires are available in designs for every architectural context. Increasingly small, powerful and energy-efficient, modern technology permits solutions that can be deployed without detracting from the visual impact of a room even in heritage-protected buildings. In some cases, the latest lighting technology can even be integrated in existing luminaires.

Measures and criteria for improving energy efficiency:

room

- Maximum utilisation of daylight
- Light-coloured walls, ceilings and floors

Luminaires

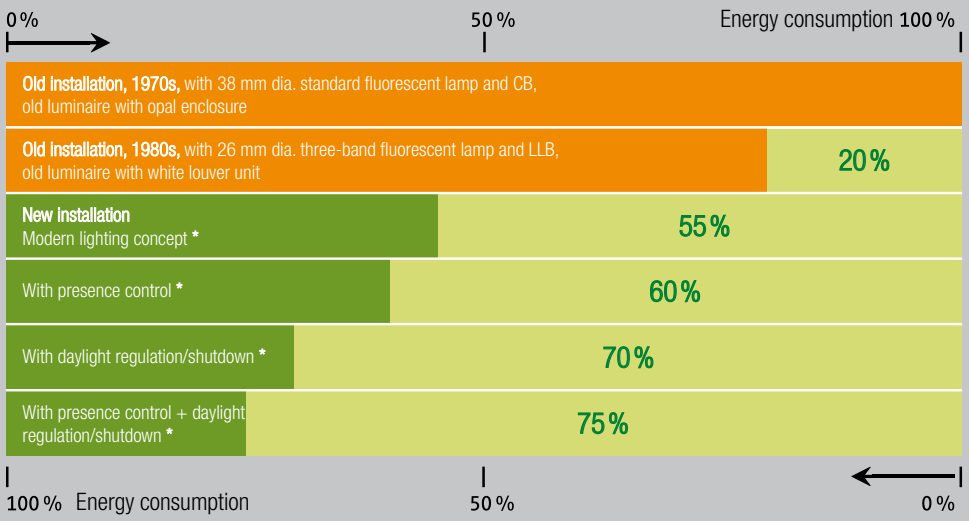
- Efficient lamps
- Modern electronic ballasts
- Optimised reflectors and optics
- Dimmability

Lighting management

- Daylight and presence monitoring
- User-friendly operating concepts and programmed lighting scenes
- Intelligent control strategies including sunscreening

Lighting concept

- Activity-related planning instead of room planning
- Use of switching groups for differentiated illumination and lighting effects
- Dynamic adjustment of lighting



28 * 16 mm diameter fluorescent lamp operated by EB with very low power loss, energy-efficient direct or direct/indirect luminaires with modern optical control technology.

[25] Detail of energy certificate label. Example: demand variant, non-residential building.

[26, 27] View of a classroom before and after refurbishment. Modern luminaires ensure agreeable – and above all energy-efficient – lighting.

[28] Example of the energy-saving impact of refurbishment with high-efficiency luminaires and lighting management systems.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Art and music room lighting

Art and music are an essential part of a good general education. Their positive impact on personal development are documented and confirmed by scientific studies. Lighting for art and music classes needs to cater for demanding visual tasks – but it also needs to strike the right emotional note.

Special subject classrooms require differentiated lighting solutions. In most cases, a minimum illuminance of 500 lux is recommended. However, demanding visual tasks such as drawing – where precision and attention to detail are crucial – call for a higher level of lighting. For compliance with DIN EN 12464-1, art rooms in art school require 750 lux illuminance.

Avoidance of direct and reflected glare
Glare-free vision is required in every special subject classroom, regardless of the activity performed. To meet standard requirements, the UGR (Unified Glare Rating) value, which defines direct glare, must be no higher than 19. Another source of interference for students examining or creating images is glare due to reflections on shiny surfaces. To avoid reflected glare, it is advisable to pay attention to good luminance limitation from the outset.

Colours need to be recognised correctly
Correct colour recognition plays a major role in special subject classrooms. To guarantee it, lamps with good to excellent colour rendering properties are required. Very good colour rendering is particularly important in rooms where art classes take place and students work with paints. The R_a colour rendering index there should be at least 80, preferably 90.

For boards and flipcharts, supplementary lighting with wallwashers is recommended so that the writing and images displayed can be seen from every student desk with no interference from reflections.

Shadow-free illumination in the music room
In music rooms, good lighting for musical instruments and notes has top priority. Luminaires with an indirect component help avoid disturbing shadows and ensure glare-free vision. What the lighting design also needs to take into account is that musicians often change positions – depending on the size of the ensemble or the instruments required for rehearsing a particular piece of music – so the same quality of light needs to be provided throughout the room.

If louver luminaires are to be used in a music room, attention needs to be paid to workmanship: luminaires and louvers must not vibrate. This is important to avoid acoustic interference.

[29, 30] In music rooms, musicians and instruments often change position. Luminaires with an indirect component help avoid disturbing shadows.

[31, 32] In art rooms, students work with a wide variety of materials. Here, it is important to ensure clear and absolutely glare-free vision – both across the room and along sight-lines onto working materials.

[33] The artificial lighting here is supplemented by daylight, which helps save energy. To avoid unnecessary acoustic inference in music rooms, it is important to ensure that luminaires are impervious to vibration.


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Laboratory and workshop lighting

Knowledge – now more important than ever – is largely based on observation and practical experimentation. Where experiments are conducted, safety is of paramount importance. Lighting needs to be tailored to promote it.

[34] Good lighting has an impact on learning capacity and boosts productivity. In workshops, it is important to ensure that workpieces do not cast shadows and that details are clearly visible.

[36] Uniform bright light underlines the impression of open space and provides constant background lighting. This is important to permit detailed observation of experiments under uniform conditions.

Experiments are an integral part of science lessons. Many of them – such as those with exploding hydrogen bubbles or light refracting prisms – make a lasting impression.

The modern technological world relies crucially on people with a grounding in physics, chemistry and biology. A sound knowledge of molecular and atomic structures is vital for many university courses and professions. So the successful transfer of scientific knowledge and the willingness of students to immerse themselves in a subject are matters of major importance. Experiments, whether presented by the teacher or performed by the students themselves, enliven a lesson.

For effective learning in special subject classrooms, an adequate level of lighting is essential to ensure that even small objects are clearly perceived. The 500 lux stipulated for standard compliance should be regarded as a minimum requirement. The more demanding the visual task, the higher the illuminance needs to be.

To ensure safe handling of chemicals and technical equipment during lessons, hard shadows on the desk top and reflections

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Workshop lighting

Handling wood, stone and metal [35] inevitably raises dust and microscopic particles into the air. In joinery shops and other premises where dusty atmospheres are anticipated, luminaires should always be fire-safe and explosion proof.

In workshops and science rooms, the handling of large and small objects is facilitated by bright background lighting. High colour rendering requirements also need to be met. Correct colour recognition is needed to enable results to be assessed and minor changes identified. Preference thus needs to be given to lamps with a high colour rendering index.

on glass and metal should be avoided. One solution here is to use luminaires with a high indirect lighting component. The higher vertical illuminance they deliver enables a harmonious distribution of light to be achieved, thus making for soft shadows and a reduced risk of reflected glare.

To ensure that all experiments are conducted in safety, it is important to build safety into the lighting. When room lighting is dimmed, steps and exits need to remain illuminated, e.g. lit by stair lights or safety lighting over the door. Experiments with fire or inflammable materials should be conducted only in specially designated areas. In experiment rooms and in the vicinity of the teacher's desk, the use of explosion-protected luminaires (IP 66 degree of protection) is recommended.

In all science subjects – physics, chemistry and biology – correct colour recognition is of paramount importance. Chemicals that differ only minimally in colour, slight discolorations in petri dishes and the colour coding of cables and connectors need to be clearly identifiable. So all lamps need to have good colour rendering properties. Fluorescent lamps delivering neutral white light with a colour rendering index of 90 are the solution of choice. To ensure that the standard of colour rendering is maintained, it is also advisable to choose high-grade protective glass enclosures that will remain colour-neutral for years.

Undesirable stroboscopic effects can be avoided by using luminaires with electronic ballasts. Where luminaires with conventional ballasts are used, flicker-free operation at 50 Hz cannot be guaranteed, so where rapidly rotating objects are present, they can appear to stand still if the speed of rotation is identical to the luminaire frequency. Another factor that needs to be considered is dimmability, especially for luminaires at the front of the classroom, because illuminance definitely needs to be lowered when monitors or projectors are used during lessons.

In science rooms, technical infrastructure systems can be integrated into the lighting. In combination with direct/indirect pendant luminaires, tables can be freely arranged for different sized groups.

Lighting control systems facilitate quick changes in lighting during lessons. The light required for experiments, lectures and TV or projector presentations can be provided at the push of a button.

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Lighting management

Daylight utilisation and lighting management offer many advantages for students of all age groups. The plus points range from support for circadian rhythms to enhancement of lessons by lighting scenes, to significant energy savings by automatic adjustment of light output volumes.

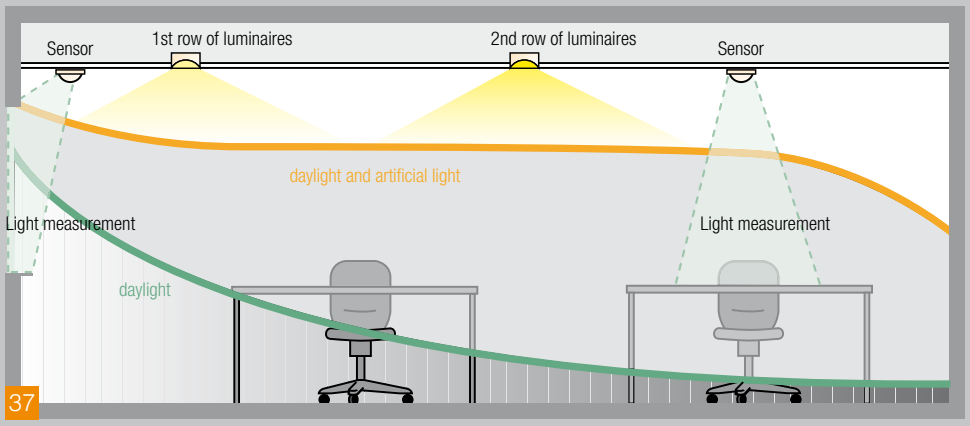
Natural sunlight is the source of all life. Without light, nothing grows or flourishes. Visual perception, thought, imagination and creativity are all connected with light. Colours, too, develop their natural brilliance only in daylight. And light plays a major role in shaping biological rhythms, both in our body and in nature. Wellbeing, performance and motivation are closely associated with a dynamic atmosphere, which is created by constantly changing daylight. Artificial lighting cannot match the innumerable positive and complex properties of natural light.

Daylight utilisation

Wherever possible, work premises should be furnished with sufficient daylight. This recommendation is embedded in Workplace Regulation ASR A3.4. A lighting scheme that includes natural daylight is preferable to a solution that relies exclusively on artificial lighting. This presupposes sufficient daylight-admitting windows. But daylight can be more effectively and economically harnessed if its incidence and distribution in a room is controlled. Specially developed daylight systems are a valuable tool for this. They ensure that daylight is distributed uniformly throughout the room and provide supplementary light for room zones that are not near a window.

Lighting management – the right amount of light at the right time

Energy costs can be significantly lowered through the use of lighting management systems with daylight sensors. Lighting management ensures adequate brightness in the room by supplementing daylight with artificial light as required. Another advantage is that it permits dynamic lighting, which motivates and makes for a greater sense of wellbeing. Bright cold-white light is known to guard against fatigue and promote concentration. Lighting management simulates the



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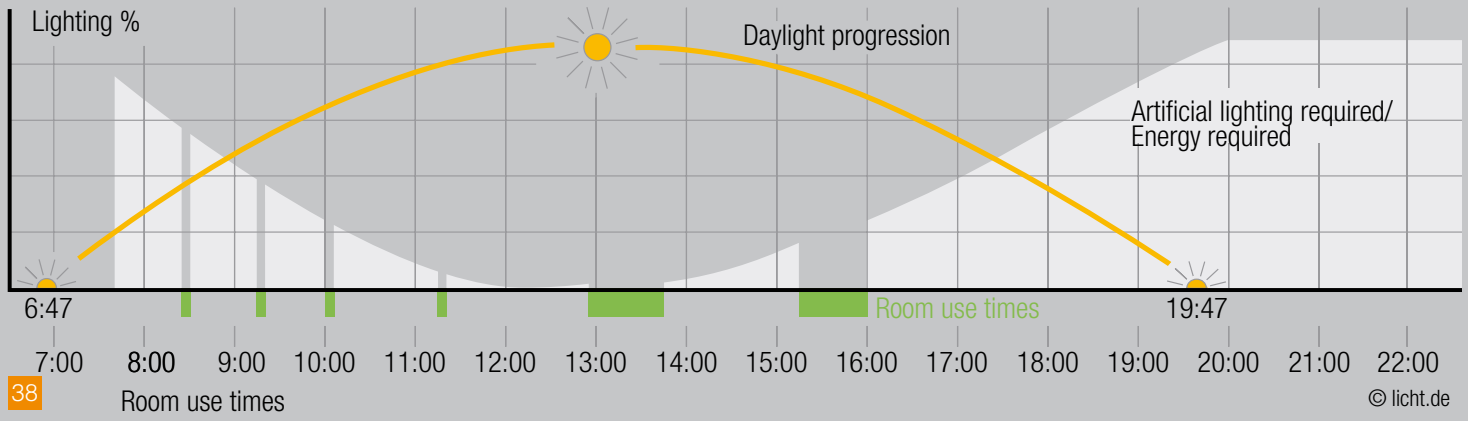
[37] Example of the energy-saving effect of daylight-dependent lighting with dimmable electronic ballasts. The amount of light required is determined by sensors and luminaires are regulated accordingly.

[38] The energy requirement of artificial lighting inversely proportional to daylight: low at midday and higher in the evening

[39] Lighting control systems present opportunities for saving energy. In the photograph, the luminaires near the window are deactivated, those in the middle of the room are dimmed and only those in the darker zone along the interior wall are switched to full power. Sensors monitor the incident daylight available and regulate the luminaires in the room to cater to the lighting requirements of the users.



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dynamic, energising changes that occur in natural daylight over the course of the day. If not enough daylight is available, intensity and light colour can be adjusted to compensate for the deficiency.

Lighting management systems based on the DALI protocol or realised as part of a KNX building control system offer a range of advantages, especially for schools and other educational establishments. For one thing, they permit a wide variety of lighting moods and stimulating room lighting tailored to specific situations. For another, they make for easy maintenance and operational economy. A further advantage is that emergency lighting can be integrated in the management system and lamps and luminaires can be optimally controlled. The failure of individual components is centrally registered and reported. All in all, lighting management systems offer maximum lighting comfort coupled with maximum energy efficiency.

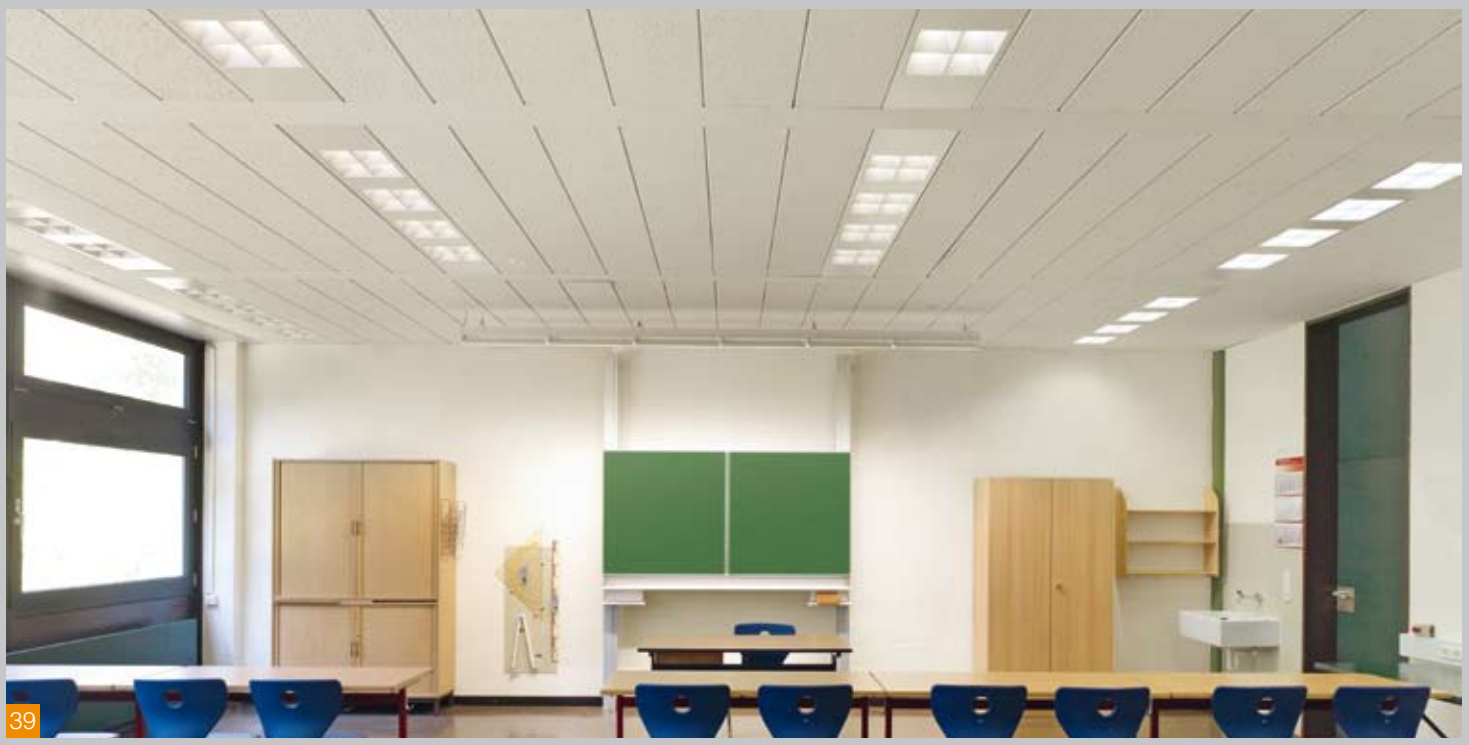
Presence detectors help save energy

Because of free periods and breaks, some classrooms are not in constant use throughout the day. For the sake of simplicity, or through negligence, the lights in unused rooms are often left on. That is a waste of energy. And there is a convenient and much more energy-efficient alternative: presence detectors automatically activate lights when a room is entered and deactivate them when it is vacated. By the same principle, energy can also be saved in corridors. Because they are not or only rarely used during lessons, when students are in classrooms, the lighting here can be dimmed to a minimum.

Lighting scenes

Lighting management systems are very useful in rooms that are constantly used for different purposes. In such rooms, tailored lighting scenes can be easily and conveniently activated from a central control unit to cater for different activities and teaching situations. Whether the room is to be used for a tutorial, lecture or media presentation, appropriate lighting can be provided at the push of a button.

Lighting concepts for schools increasingly incorporate presence detection and daylight utilisation systems. Where this is the case, care should be taken to ensure that manual intervention is possible for the control and selection of lighting scenes.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Adult education lighting

Beamer presentations, notes on boards or flipcharts, often new arrangements of chairs, desks and objects in the room – first and foremost, adult education lighting needs to be versatile and tuneable to the lighting mood required.

Adult education normally takes place at times when there is not enough daylight around to illuminate the room. Here, lighting needs to address the particularly important task of providing sufficiently bright light of an appropriate quality. Where instruction takes place during the day, daylight should be used as the main source of illumination for the room and the desks or training workplaces in it. It may be important to provide some form of shading to avoid glare.

According to DIN EN 12464-1, the illuminance in classrooms should be at least 500 lux. Where projections, boards or other presentation media are used, care must be taken to ensure that they are clearly visible from every seat in the classroom. Separately switched board lighting with an asymmetrical beam for illuminating vertical presentation surfaces is recommended here. It ensures optimal visual conditions – even for persons at the back of the room.

Evening classes

Adult education often extends well into the evening, so it is advisable to take account of the biological impacts of light in the design of the lighting. The right light at the right time supports the biological rhythms in our body and has a positive effect on the learning process. Adults attending evening classes have often had a long day at work and need to be re-motivated. Cool bright light at the start of a session helps to do this. It wakes us up, stimulates our mind and thus improves concentration and performance. To avoid upsetting our internal clock, which switches to rest and recuperation mode in the evening, the lighting should be designed to permit a switch to warm light colours around 30 to 45 minutes before the end of the session. This ensures that course participants can later sink swiftly into the sound sleep needed to make them fit for the next day. .

Seminar room lighting

Seminar rooms in conference centres, hotels and public buildings, which are used for adult education as well as a wide range of other events, need to be considered separately. Instruction in such multifunctional rooms takes many different forms and has many different facets. The spectrum ranges from lectures and panel discussions to workshops, team meetings, discussion groups and group presentations. The media options used to put across information are similarly diverse. A lecture will often be flanked by a beamer presentation – or a flipchart will be used for graphic support. Even brainstorming requires visual aids to record and develop lines of thought.

What is needed here is variable lighting catering to the requirements of every scenario. This is facilitated by a combination of different lighting systems and a coordinated mix of general and accent lighting. The ideal solution is a lighting control system – possibly in conjunction with room-darkening facilities – for swiftly switching between programmed lighting scenes. At the same time, there should be a possibility of adjusting the lighting manually for a given situation. To ensure that every option is easily accessible, lighting control systems with user-friendly control panels are recommended.

[40] In this seminar room, high-intensity recessed luminaires ensure that light is evenly distributed over the table.

[41] Uniform brightness is achieved throughout the room here by lighting with a high indirect component. This permits flexible room use for a wide range of activities, from practical demonstrations on patients to lectures and beamer presentations.

Lecture hall lighting

Modern lecture halls are packed with sophisticated technology. And lighting plays a key role in its use. Without light, the room cannot be used to its full potential.

Lecture halls – most of which are found in secondary and tertiary education – are rooms with a fixed seating arrangement facing the stage and almost invariably no windows. They certainly need to be designed to permit complete darkness. So artificial lighting is particularly important and needs to perform a variety of tasks..

Safety at entrances and exits

To guarantee the safe and smooth management of an event, it must be ensured that people can enter and exit the room without problems. Appropriate lighting needs to be provided at entrances and exits, staircases and steps. This can be done stylishly and effectively with recessed floor and wall luminaires or LED strip. To avoid compromising safety, these lights must never be deactivated even during an event. Before and after the event, the background brightness in the room should be raised to enable people to find their seats quickly and easily and make sure they have left nothing behind when the leave. In the darkened room, supplementary dimmable wall luminaires can be used to ensure a sense of security. For actual safety, however, emergency lighting and escape route signage are essential.

Presentation area and room lighting

It is particularly important in lecture halls to ensure bright, even illumination of the presentation area – including persons on the stage, board and experiment table. The entire area covered by the moving board needs to be illuminated without causing reflections or glare. Wallwashers or asymmetric luminaires are particularly suitable for this task. During the lecture or event, the room lighting needs to be bright enough to guarantee note-taking in comfort.

Lighting management and lighting scenes

Because of the wide range of possibilities they open up, lighting management systems are a particularly useful tool in lecture halls and auditoriums. Positioned near the lectern, the central control panel gives the speaker push button access to lighting scenes tailored to the needs of diverse forms of presentation. The level of lighting and distribution of light in each part of the room can be finely tuned to suit the current event. For a film presentation, for example, the auditorium and stage lighting can be dimmed right down; for a beamer presentation, sufficient light can be left to enable important notes to be taken.

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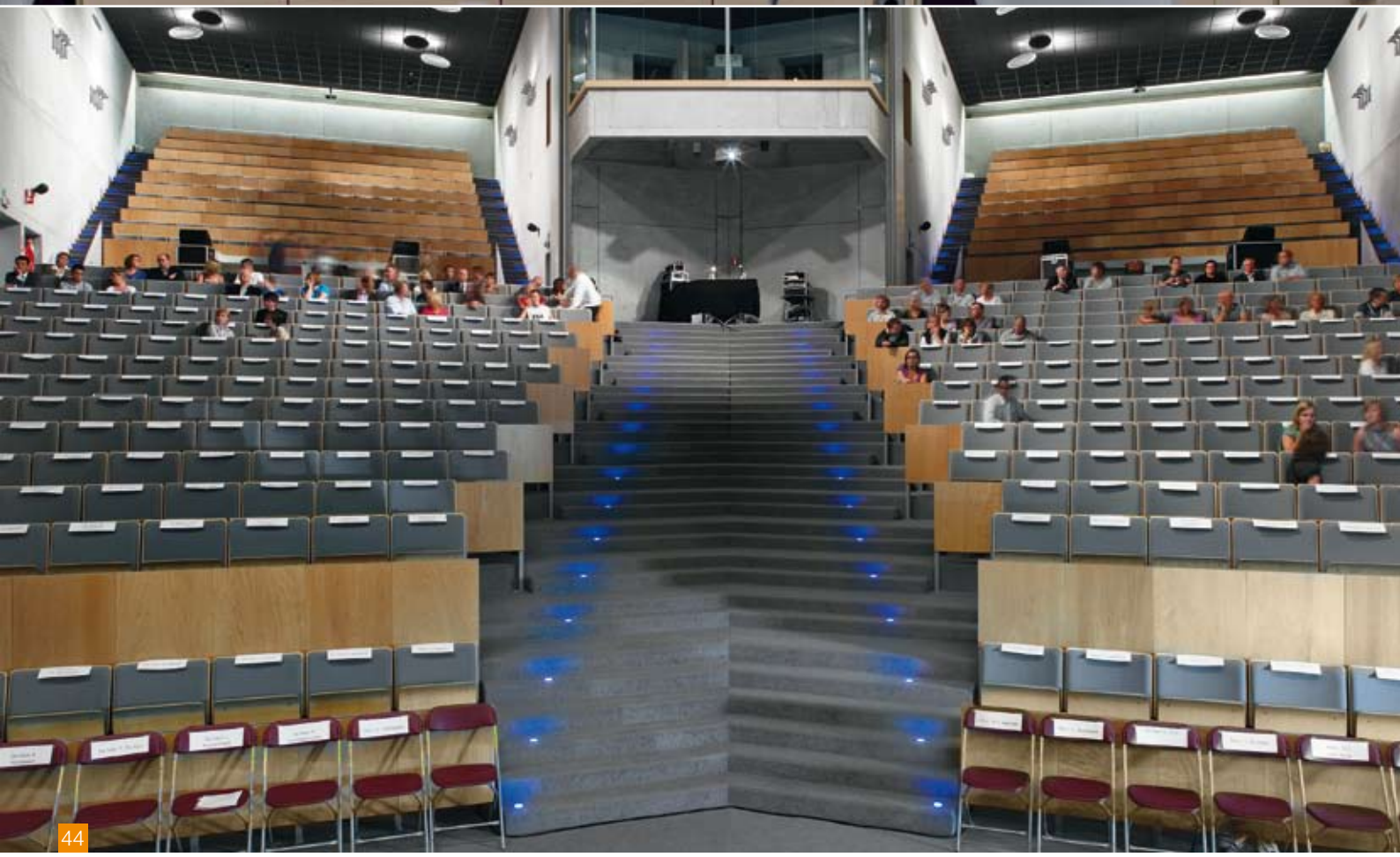
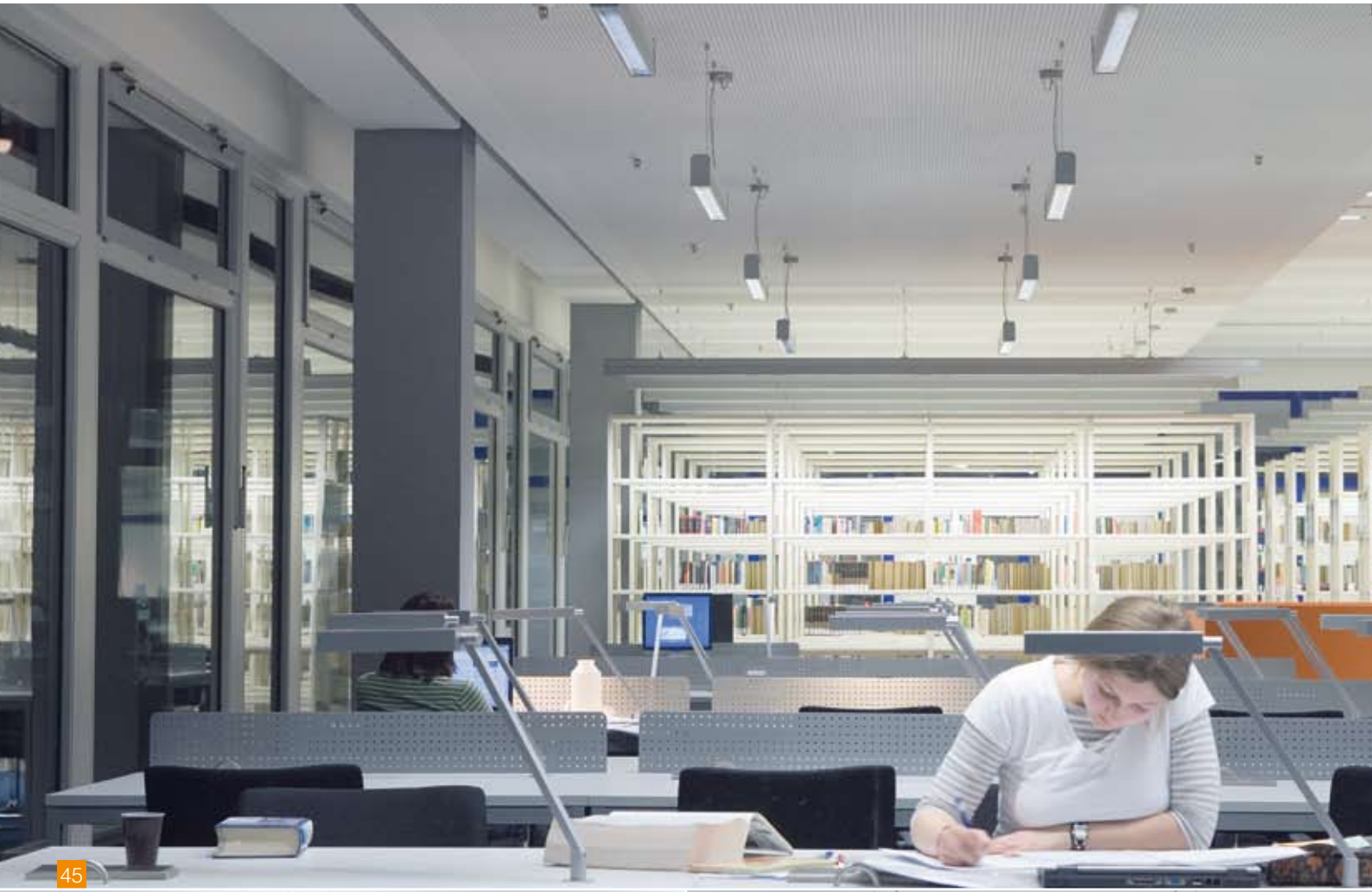
Presentation lighting

In the demonstration area [43] average illuminance needs to be at least one-and-a-half times higher than in the rest of the room. Where the level is 500 lux across the room, for example, 750 lux should be provided for the horizontal surfaces in the demonstration area. In all lighting situations, it is crucial to ensure good vertical illuminance for presentation areas. Complex manual controls permitting a wide range of lighting options can be simplified by means of a lighting management system. It is helpful here to position an operating panel near the speaker to permit manual settings as well as swift and direct access to pre-programmed lighting scenes.

[42] Good general lighting combined with the right presentation lighting makes the room look inviting, cheerful and, at the same time, functional.

[44] Well-lit rooms, stairs and aisles guide visitors safely to their seats. Exits marked by escape sign luminaires as well as emergency lighting facilitate swift evacuation in an emergency.





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Library lighting

A library requires an inviting, cheerful atmosphere. It also needs the right lighting conditions in aisles and shelf areas, at counters and desks. Light here ensures good visibility, optimal orientation and, last but not least, a sense of wellbeing.

Libraries have always been an important facility for independent study. Nowadays, however, they are much more high tech than in the past. As places for study – where books are sought, found and read, where Internet research is performed and assignments completed at computers – they are accorded a very high status. And since students spend very long periods at a stretch in a library, it is particularly important to ensure a friendly atmosphere in which users feel comfortable.

Reading area

Good visual and working conditions in a library depend crucially on the light that is available. Natural light, especially daylight, is found agreeable. Artificial lighting, which works with direct-indirect light distribution and ensures uniform illumination throughout the room, facilitates focused reading and work at computer terminals. One vital requirement in a library is avoidance of direct and reflected glare. Among other things, it is needed to enable glossy images to be studied without interference. In separate reading/working areas and consultation zones, general lighting is very effectively supplemented by mobile standalone luminaires for direct-indirect lighting and separately switched table luminaires for raising the lighting level on work surfaces.

Computer research

Every library today is equipped with computer workstations, which need to be ergonomically designed, illuminated to 500 lux and free of disturbing glare and reflections. To avoid unnecessary adaptation for the eyes and thus early visual fatigue, the surroundings should be attuned to the lighting level.

A modern lighting control system permits coordinated control of daylight, artificial lighting and blinds. As well as enhancing lighting comfort, this enables energy consumption to be significantly reduced.

Orientation and signage

Bright general lighting for main routes helps people quickly get their bearings in the room. Accentuated signage – especially on shelves and doors – guides users swiftly to the shelf and book they require. For the safety of library users, escape routes and exits need to be provided with safety lighting, which must be clearly recognisable from every point in the room.

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Shelf lighting

The focal point [48] of any library is the shelving system lined with books and media. Here, lighting needs to address the important task of guiding users through narrow aisles and facilitating orientation. Vertical illuminance is a particularly important requirement here – a requirement effectively met by separate lighting with asymmetric luminaires illuminating shelf fronts to 200 lux. It is vitally important that shelves should be uniformly illuminated so that the titles of books on the bottom shelf are still clearly legible. Another major requirement is that light sources should have good to very good colour rendering properties (R_a 80 or higher). Old books, in particular, are sensitive to long exposure to UV radiation. This problem can be avoided by the use of modern LED lighting.

[45] Separate workplace luminaires ensure glare-free lighting for studying books and working.

[46] Direct-indirect luminaires create an agreeable, bright room atmosphere and prevent interference from direct or reflected glare.

[47] Double asymmetric light distribution makes for uniform illumination of vertical shelf surfaces, permitting swift orientation in an extensive shelving system.

Assembly hall and exhibition lighting

School assembly halls are a multifunctional space used for a variety of events – from theatrical performances to school assemblies, to award ceremonies. Depending on the occasion, the lighting atmosphere may need to be dramatic, solemn or businesslike.

Because of their multifunctional nature as a place for communication, celebration and entertainment, assembly halls require lighting that is flexible and easily modified to suit the occasion. In this sense, it performs a room-structuring, architectural function. By dividing the – normally large – hall into lighting zones served by separately switched lighting units, it can thus cast the room in the right light for a wide variety of events.

Equally important in the versatile space of an assembly hall is the need to create an atmosphere in which people feel comfortable and enjoy coming together. This calls for professional lighting design and a sophisticated lighting concept, ideally in combination with a variable lighting control system.

As a place where students, teachers and visitors meet on special occasions, assembly halls have a considerable impact on public perception. They are also frequently used for external events. So they are often seen as a flagship for the establishment and thus designed and illuminated to make a particularly positive impression. In the stage area, glare- and reflection-free lighting is absolutely essential. It needs to ensure that speakers and actors can easily read notes and have a clear view of the audience. Many assembly halls are furnished with skylights or roof lights to increase daylight incidence. However, good room-darkening facilities are also needed. Theatrical performances and film presentations are simply not possible without them. To enable energy costs to be lowered despite prestige lighting, carefully planned lighting management is recommended, possibly including a daylight-dependent control system.

If an assembly hall is used for exhibitions, thought should also be given to uniform vertical illuminance in the exhibition areas to draw visitor's attention to the exhibits.

Safety lighting needs to be an integral part of the lighting design. What is more, aisles,

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steps and exits need to be marked so that it is possible for people to move around safely even when the room is darkened. Both of these requirements must be met to enable visitors to get their bearings in the room, find their seats and, in an emergency, vacate the premises quickly.

[49] A large daylight component helps save energy. At night, fluorescent lamps ensure uniform illuminance throughout the room.

[50] The stage is a special lighting application. Lighting effects, coloured light and highly focused beams are required here.

[52] Flexibly adjustable luminaires make for optimal wall and showcase lighting.

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Exhibitions

New work from the art room [51], photos of school trips or project weeks are normally presented in the foyer, assembly hall or corridors. To cater for these displays, the lighting design needs to provide sufficiently bright and uniform vertical illuminance for the relevant wall areas. The luminaires used should also be flexible enough to permit optimal illumination for diverse objects in changing exhibitions. Small exhibits should be illuminated with narrow-beam, flexible, easy-to-adjust luminaires; for large-format pictures, wide-angle floods are the better option. Spots on power track or gimbal-mounted surface or recessed spotlights are particularly good for these lighting tasks. When selecting lamps, care should be taken to ensure a good to very good colour rendering index (at least R_a 80).

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Cafeteria, refectory and kitchen lighting

Refectories and cafeterias perform an important function in modern educational establishments. Often designed as multi-purpose rooms, they are a place for rest and regeneration during breaks in the curriculum as well as a rendezvous point and a venue for events and parties.

Refectories and cafeterias require a cheerful room atmosphere so that people who use them can feel comfortable, relax and quickly recharge their batteries. This rapid regeneration is possible only in rooms that are flooded with light and have a communicative climate. In many cases, refectories are located on the outside of buildings where daylight is available and can be supplemented with artificial light as required.

The flexibility and control of artificial and natural light needed in cafeterias and refectories is ensured by the use of modern lighting management systems. In conjunction with energy-optimised lighting technology, they guarantee efficient, standard compliant lighting.

Communication and regeneration

Cafeterias and refectories are places where people go to rest and recuperate. They do not normally stay long. Good lighting helps ensure that even in very short breaks the rapid regeneration people seek is possible. Because refectories and cafeterias are also a place for communication, it is very important that faces, expressions and gestures should be easily recognisable. This can be achieved by lighting that balances direct and indirect

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The right table lighting

Good table lighting [54] casts bright light onto the table top and bathes persons around it in subdued scattered light. Pendant luminaires used for this purpose should be suspended just above eye level. It is important that the luminaire should not dazzle and should not obscure the view of others at the table. The optimum distance between the table top and the lower edge of the luminaire is around 60 cm. Luminaires with satinised or gloss opal glass enclosures, tinted glass or dense fabric shades are recommended. Where suspended luminaires would interfere with the sense of space, ceiling luminaires with a highly focused beam can be installed at tables as a zonal alternative.

components to eliminate hard shadows. The yardsticks for assessment are modelling and semi-cylindrical illuminance.

General lighting

Surface-mounted or recessed luminaires are recommended for general refectory/cafeteria lighting; so are spots and luminaires deployed on power track. An alternative solution is to use glare-free pendant luminaires over tables in combination with wall luminaires and direct or indirect light illuminating the ceiling and walls. To permit changes in lighting atmosphere, it is a good idea to install two or even three separately controlled lighting systems. The standard DIN EN 12464-1 recommends 200 lux general lighting for dining rooms.

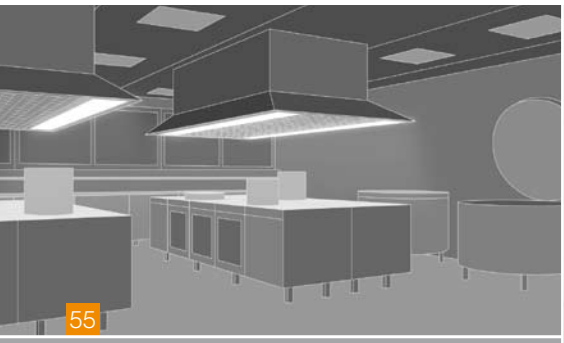
Good light stimulates the appetite

To ensure that food looks appetising and that the colours of dishes are not distorted, the light sources selected should have a high colour rendering index. Also, of course, lighting for food and till service areas needs to be glare-free.

All in all, refectories and cafeterias call for sophisticated lighting design and technology. To exploit the multifunctional options of the premises to the full, it is advisable to seek detailed advice from an experienced lighting designer. This will ensure that breaks during the day are relaxing and communication in its myriad forms is maintained.

[53] A regular arrangement of tables and chairs facilitates orientation in large rooms. Where lighting falls in line with the arrangement, the effect is intensified.

[56] A diverse and agreeable atmosphere is achieved by the use of indirect luminaires with a direct lighting component in conjunction with wall luminaires casting accentuating light onto a coloured wall.



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Functional kitchen lighting

Canteen kitchens [55] need to produce large amounts of food in a short time, which calls for perfect lighting. The often hectic operations involved in preparing ingredients and meals require a sophisticated lighting concept. Good light enables the quality and state of foodstuffs being cooked to be assessed more reliably. It also helps promote work safety, cleanliness and hygiene. In kitchens, it is advisable to use luminaires that are impervious to steam, high temperatures and chemical attack. And in areas where food is prepared or distributed, special shatter protection for light sources is recommended. DIN EN 12464-1 stipulates 500 lux illuminance as a minimum for kitchens.

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Circulation areas and communication zones

In foyers, stairwells and corridors, lighting performs a vital function as an orientation aid. It makes for safety, opens access routes to other parts of the building, sets design accents and creates space for the many different forms of communication that take place during breaks or on the way to the next lesson or lecture.

The circulation areas in an educational establishment are the spaces connecting the entrance and foyer with the different levels and rooms. Good light facilitates quick an easy orientation but also helps make for a sense of security and wellbeing. Insufficient corridor lighting can produce an unpleasant "tunnel effect" and dark corners make users feel uneasy. Corridors with bright walls and ceilings look bigger and permit faster orientation. Efficient wide-beam luminaires that provide good, planar vertical illumination for the walls are a recommended solution here. The important thing to remember is: dark floor coverings, walls and ceilings require more light and thus also more energy.

Staircases need to be particularly well illuminated for the sake of user safety. Glare-free lighting and sure recognition of the edge of treads need to be absolutely guaranteed. The ideal solution here is provided by recessed wall and floor luminaires installed as dedicated stair lighting. Hard and long shadows need to be avoided at all cost. Where wall luminaires are used in stairwells, care needs to be taken to ensure that light sources do not dazzle persons ascending or descending the stairs.

Circulation areas and communication zones

Foyers, corridors and stairwells are also communication zones and places where students spend breaks. Attractive furniture and good lighting here can help ensure a sense of wellbeing. The walls are used for notice-boards and for displaying students' work and project results. Supplementary, separately switched, individually adjustable asymmetric wallwashers are an appropriate solution for the vertical surfaces. A power track system with adjustable spots is an alternative.

Depending on the structural design of the educational establishment, foyers may also be used for theatrical performances. Variable stage spotlights are the correct solution here for casting productions in the right light – in addition to the separately regulated general lighting. An easy-to-operate lighting control system with predefined lighting scenes makes for convenience and suitability for everyday use.

Lighting control systems and presence detectors help save energy

Because lighting in many circulation areas of a school is needed only temporarily, significant energy savings can be made through the use of presence detectors – also in combination with lighting control systems. Where daylight is available, artificial lighting can be lowered by sensors to the minimum required.

Safety lighting is required for all circulation areas. More information on the subject is found in the "Safety lighting" section on pages 38-39.

[58, 59] Circulation areas become communication zones during breaks. Furniture and good lighting support the feel-good factor.

[60] Light-coloured walls, ceiling and floor as well as the right light make rooms look bigger.

[61] On a staircase, safety takes top priority. It is achieved with bright high-contrast lighting that makes treads clearly recognisable.

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Staff rooms

Information and communication [57]: As a central workroom and meeting-point, the staff room is an important place for holding meetings, clarifying organisational issues and a great deal more. Staff engage in a wide variety of activities here – preparing and following up lessons, correcting homework, working at PCs and exchanging information with colleagues. The role of lighting here is to create an agreeable sense of space and make focused work possible. A balanced lighting mood – with indirect lighting components on walls and ceiling as well as direct, adjustable light for individual work surfaces – helps make for a good working atmosphere. Well-shielded pendant luminaires or standalone luminaires with both direct and indirect lighting components are a suitable option here.


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Safety lighting

If the lights go out in a windowless or darkened room as the result of a sudden power failure, panic can quickly spread. Safety lighting provides a basic level of mains-independent lighting to help people keep their bearings and quickly find exits.

In most of the federal states in Germany, building regulations require all schools to be equipped with safety lighting. In the event of a power failure, safety lighting automatically ensures that a basic level of light is provided – by a mains-independent power source such as batteries – to prevent disorientation and avoid accidents. Escape sign luminaires identify routes leading out of the building, which saves lives in the event of an emergency.

Where is safety lighting mandatory?
Safety lighting is required by law in corridors and stairwells with little or no incident daylight as well as in windowless rooms where people spend time. If an educational establishment in Germany has an assembly hall accommodating a large number of people, it falls within the scope of the Ordinance Governing Places of Assembly (VStättVO). This requires safety lighting for any assembly room that accommodates 200 persons or more. If the room is darkened, safety lighting is required to make exits, aisles and steps visible.

In special-subject classrooms, safety lighting is always required if the room can be darkened. However, safety lighting may also be needed for compliance with rules on occupational health and safety. Safety lighting is similarly mandatory for cafeterias and refectories that seat more than 200 persons. And indoor sports facilities require safety lighting for users to comply with DIN EN 12193.

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Safety lighting requirements in schools
In corridors and stairwells with little or no incident daylight as well as in windowless public rooms, assembly halls, special-subject rooms, cafeterias, refectories and kitchens, the illuminance of the safety lighting in the event of a power failure needs to be at least 1 lux. In the case of stages, the guideline value is 3 lux.

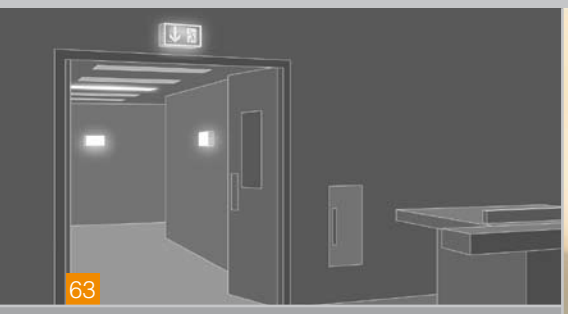
For sports facilities, the recommended illuminance for safety lighting ranges up to 10% of nominal illuminance, depending on the sport involved. Safety lighting here is not provided just to help people find exits quickly; it also serves athletes' safety, avoiding injury during matches, competitions and training sessions in the event of an unexpected lighting failure.

Safety lighting with LED technology
Safety lighting systems today are almost all based on LED technology. LEDs are a particularly effective alternative to current lamps because of their high luminous efficacy. In conjunction with special optics and lighting control elements, LEDs permit the realisation of particularly energy-efficient lighting concepts, lowering power consumption by as much as 70%. What is more, LEDs have a longer operating life (50,000+ hours is considered standard today), which means that maintenance costs are also reduced. Another advantage of LED technology is that it permits significantly smaller luminaires, thus paving the way for separately mounted emergency lights.

The places where safety lighting is required are listed in DIN EN 1838. Details of uniformity, start-up delay, colour rendering, glare limitation and illuminance requirements are also set out there.

More information about safety lighting is found in licht.wissen 10.

[62, 64] Corridors and staircases need to be fitted with emergency signs and safety lights to permit orientation in the event of a mains power failure.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Safety lighting systems

Safety lighting systems [63] in public buildings switch on automatically in the event of a general lighting failure due to a mains power outage. They thus make it possible for people to find their way safely out of the building even if they are unfamiliar with the surroundings. Safety lights and escape sign luminaires are the core requirements. They point the way to escape routes and safety equipment, thus permitting swift access e.g. to fire extinguishers. In this way, they help reduce risks for people in buildings and save lives. The minimum requirement set out for safety lighting in DIN EN 1838 is 1 lux horizontal illuminance on the central axis of an escape route up to two metres wide.


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Varied room use

Various sports [68] require lighting levels tailored to specific needs. Meeting these diverse requirements places high demands on a lighting installation. Also important is the need to ensure high uniformity of illuminance. The key to varied room use is an intelligent lighting management system that adjusts the lighting level to the sport – and at the same time saves energy. Programmed lighting scenes are accessible at the push of a button, e.g. for a simple sports lesson or for a competition match. In multi-purpose halls, it needs to be possible to switch and dim lighting separately in the different hall sections. Where daylight is available, brightness sensors enable the artificial lighting to be adjusted as required. And to cater for other forms of use – such as school events – luminaires should be wired so they can be switched and dimmed in groups from an intuitive control panel.

Indoor and outdoor sports facility lighting

In indoor and outdoor sports facilities, effort and enthusiasm are key. Fast action, ball games, gymnastics and wind-down exercises make variable illuminance a must. Different sports have different lighting requirements.

Meeting the diverse needs of sports hall users basically involves two things: firstly, ensuring the right quality of light, which is essentially a cocktail of illuminance, homogeneity, freedom from glare and colour rendering properties. Secondly, the light needs to be flexibly adjustable to enable the right lighting mood to be created for sporting events and competitions where high speed and precise perception are needed as well as for slower sports and relaxation exercises.

Illuminance

According to DIN EN 12193, 200 lux minimum horizontal illuminance is sufficient for most ball sports. Higher illuminance is needed for fast ball sports with small projectiles, such as squash or table tennis, where vertical illuminance needs to be 300 lux and more. For competitions and competition training, the recommended illuminance values are significantly higher at 500 to 750 lux.

Lighting design and choice of luminaires

The first step in the development of a lighting design for an indoor sports facility is to identify the sports for which the lighting needs to cater. The sport presenting the most demanding visual task is the one that needs to be used as a yardstick. As for the choice of luminaires, the following criteria need to be considered: type of mounting, optimal glare suppression and impact resistance. Depending on the type of ceiling, recessed or surface-mounted luminaires are an option. Pendant luminaires are a good solution for halls with higher ceilings. High-grade louvers in luminaires help improve visual performance during sport and ensure optimal glare suppression at all angles. Every luminaire deployed needs to be impact-resistant so there is no risk of breakage if it is hit by a stray ball. Planar luminaires are first choice. To ensure correct colour recognition, good colour rendering and a neutral-white light colour are also recommended.

Changing room lighting

Changing rooms require bright, uniform lighting. Hard shadows are unfavourable here. High vertical illuminance also makes items in lockers easier to find. To ensure that the colours of garments are not distorted, it is advisable to choose lamps with a good colour rendering index. For greater security – and also to save energy and prolong the life of lamps – changing rooms and sanitary facilities can usefully be fitted with a presence control system that switches lights on and off as required.

Outdoor sports facilities

As a general rule, lighting for outdoor sports facilities is provided by high-performance floodlights mounted on columns. The lighting task is optimally addressed by positioning the columns at the corners or sides of the playing field. Uniform illumination of the playing field and glare-free lighting is best achieved by mounting the luminaires as high as possible. To prevent hard cast shadows, the floods or spotlights need to be arranged so that every point on the playing field is illuminated from at least two directions. At the same time, care must be taken to avoid dazzling spectators.

The best way to ensure correct lighting for an indoor or outdoor sports facility is to rely on good foresighted planning by a professional lighting designer. .

For more information and guidance on planning, see licht.wissen 08 "Sport and Leisure".

[65] Floodlights allow training sessions to continue after dark. Uniform brightness over the entire playing field is an important requirement.

[66] The faster the sport and smaller the ball, the higher the illuminance required in the hall

[67] Artificial lighting is optimally supplemented by daylight through windows and skylights. The artificial lighting is adjusted to the required illuminance by a lighting control system, which significantly helps save energy and resources.

Schoolyard and parking facility lighting

The outdoor facilities of a school serve as recreation and communication areas, a place where younger students, in particular, can release pent-up energy. But they have other requirements as well. Safety, clear routes and enhancement of the school's physical appearance are key challenges for the lighting designer.

The outdoor areas of schools and other educational establishments are often used for recreational activities, games and sport. For the lighting designer, the most important criterion here is safety. Hazardous areas such as vehicle entrances and exits as well as steps and obstacles need to be visually emphasised by lighting. This calls for sufficient brightness on horizontal and vertical surfaces as well as glare-free uniform light. To facilitate orientation and permit facial recognition, cast shadows should be avoided wherever possible.

Special attention needs to be paid to step lighting. A balanced ratio of light and soft shadow makes steps stand out in 3D. Long cast shadows should be avoided because they cause people to misjudge steps and thus heighten the risk of accident.

Luminaires outdoors need to meet high requirements in terms of temperature tolerance and impermeability to water, insects and dust. The minimum degree of protection required is IP 44. When selecting luminaires, care must also be taken to ensure high-quality materials. The luminaires should be as vandal-proof as possible. Column and bollard luminaires are particularly suitable for outdoor areas; so are wall luminaires and recessed wall and ground lights. In covered areas, lighting can be provided by surface-mounted or recessed ceiling luminaires. Ideally, the lighting will also emphasise the architecture of the building and accentuate its special features.

Recommended light sources include energy-saving LEDs, fluorescent lamps and metal halide lamps. With suitable colour temperatures, the scope for moulding the school landscape can be extended by highlighting certain areas, such as groups of trees or facades.

Precise optical control can be achieved through the use of luminaires with directional reflector systems. They deliver light

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where it is needed and minimise dazzle and light pollution. To protect nocturnal wildlife, care should be taken to select a colour spectrum that has little attraction for insects.

[69, 72] School yards are communication zones. They are also places for exercise, where students compensate for the physical inactivity in the classroom. Bollard and column luminaires ensure an appropriate lighting level.

[70] Canopies literally invite recessed or surface-mounted luminaires. Steps need to be visually accentuated by dedicated lighting.


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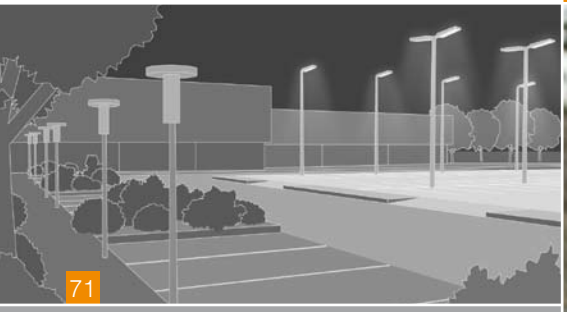
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Parking facility lighting

Safety first [71]: Car parks are circulation areas – a place where motorists, cyclists and pedestrians come together. The greater the volume of traffic, the higher the risk of collision. Good lighting reduces the danger of accidents. Well-lit roadways, paths and open areas facilitate orientation, make vehicles, persons, boundaries and obstacles easier to recognise and guard against crime. Hazardous areas such as vehicle entrances and exits need to be emphasised by lighting. The required (maintained) illuminance set out in DIN EN 12464-2 depends on traffic frequency: at least 20 lux is needed for heavy traffic, 10 lux for medium and 5 lux for light traffic. It is also important that the luminaires used should be well shielded and that the lighting should also cover peripheral areas.


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Standards and terminology

To ensure that lighting in schools and other educational establishments is standard-compliant, safe and user friendly, a number of important basic rules need to be observed. This section helps explain the relevant standards and technical terms of lighting technology and provides a knowledge base for good lighting design.

To guarantee lighting quality in schools and other educational establishments, a number of important criteria and standards need to be met. First of all, there is DIN EN 12464-1:2011 "Light and lighting – Lighting of work places – Part 1: Indoor work places", which applies throughout Europe. This is the standard most frequently referenced in practice. Workplace regulation ASR A3.4, published in April 2011, also needs to be observed. And the lighting designer should additionally consult "Beleuchtung 2006" published by the AMEV (Mechanical and Electrical Engineering Working Party of National, Regional and Local Authorities), which contains lots of advice on lighting design for public buildings. Educational establishments and sports facilities fall within the scope of these recommendations. Normative regulations governing sports facility lighting are contained in DIN EN 12193.

Illuminance

The illuminance on a surface under natural light reaches 10,000 lux on a cloudy day and as much as 100,000 lux in bright sunshine. Indoors, a great deal less light needs to suffice. Under artificial lighting, 300 to 500 lux on horizontal work surfaces is generally enough for writing and reading. Chalkboard lighting needs to be at least 500 lux.

It has been reliably established that higher illuminance boosts motivation and makes for a greater sense of wellbeing. In winter especially, when little daylight is available, signs of fatigue quickly develop. The phenomenon can be countered, however, by providing more light indoors.

Where the points at which classroom activities take place vary, the entire area needs to be brightened to the required illuminance. On page 47 of this booklet is a list of all the recommended illuminance values stipulated by DIN EN 12464 1 for different types of rooms in educational establishments. The values shown are for normal visual conditions. Where visual tasks are more demanding or students visually impaired, higher illuminance is needed.

Maintained illuminance

Illuminance gradually diminishes over the years as a result of ageing (luminaires, ballasts and light sources) and soiling

[73, 75] Bright, uniform illumination of horizontal surfaces is important in all rooms used for instructional purposes.

[74] Illuminance required in task areas and the areas immediately surrounding them.

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(luminaire housings and surrounding room). Maintained illuminance is the level below which the average illuminance $\bar{E}_m$ is not allowed to fall, regardless of the age and condition of the lighting installation. New installations are designed for a higher illuminance (value on installation) to take account of the decline in illuminance over time.

To calculate the maintained illuminance, a maintenance factor is applied as follows: **maintained illuminance = maintenance factor x value on installation**

Uniformity

In a classroom, students' eyes switch constantly back and forth between the desk (near range) and the board and teacher (far range). If the differences in brightness are marked, their eyes are constantly forced to adapt to the changing visual conditions. This causes fatigue and impacts negatively on visual performance and wellbeing. However, differences in illuminance should not be too small either. If they are, room users quickly find the surroundings monotonous and dull. According to DIN EN 12464-1, uniformity on walls and ceilings should be at least 0.1.

Immediate surroundings

Different levels of illuminance in the immediate surrounding area can give rise to eye strain and an impaired sense of wellbeing. The correct illuminance for the immediate surrounding area – defined in DIN EN 12464-1 as a band at least 0.5 metres wide surrounding the actual task area – depends essentially on the illuminance required for the task area.

Illuminance in the immediate surrounding area can be lower than in the task area. However, it must not fall below the following values:

Illuminance in the task area $\bar{E}_{task}$ in lux	Illuminance in the immediate surrounding area in lux
≥ 750	500
500	300
300	200
200	150
150	$\bar{E}_{task}$
100	$\bar{E}_{task}$
< 50	$\bar{E}_{task}$

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Uniformity U_0 in the immediate surrounding area needs to be ≥ 0,40.

Background

Adequate illumination is also needed for surfaces farther away – i.e. beyond the immediate surrounding area – especially in rooms that are poorly supplied with daylight. Background is the area extending at least three metres out from the immediate surrounding area. Illuminance should not exceed a third of the value for the immediate surrounding area.

Direct-indirect lighting

Luminaires for indirect light distribution ensure uniform illumination throughout the room and create a space that makes an agreeable, inviting impression. Because of the high uniformity of the light – which also minimises reflections – indirect lighting permits free arrangements of tables and chairs. With a system of suspended direct luminaires alone, the disadvantage is that the ceiling of the room remains relatively dark, creating a cave-like impression. Purely in terms of energy efficiency, however, direct lighting alone performs better than indirect lighting alone. So, with this in mind, a combination of direct and indirect systems is recommended.

Illuminance on vertical surfaces

Light-coloured walls and ceilings give the classroom a cheerful air and are explicitly required by DIN EN 12464-1. Vertical board and presentation surfaces require at least 500 lux to ensure optimal recognition right to the back of the class. Balanced luminance distribution in the visual field needs to be included in the calculations.

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Direct glare

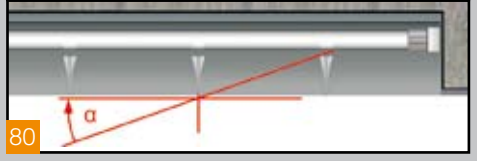
Dazzling light is a continuous source of interference that affects perception and impairs visual performance. The impact of direct glare is particularly marked where very bright and very dark surfaces come together or where a light source is in a direct line of sight. Signs of fatigue and lack of concentration are the result.

DIN EN 12464-1 stipulates that discomfort glare should be assessed by the UGR (unified glare rating) method. All the luminaires of a lighting installation that create a sensation of glare – as well as the brightness of walls and ceiling – are taken into account by the formula for calculating UGR values. The UGR limits for most types of room in an educational establishment are shown in the table on the page opposite.

Anti-glare shielding

Shielding helps prevent glare from bright light sources. This applies both to lamps and to windows, which should be fitted with shades to reduce incoming light. The following table shows the minimum shielding angles required for the lamp luminance indicated:

Lamp luminance cd/m²	Minimum shielding angle α
20.000bis < 50.000	15°
50.000bis < 500.000	20°
≤500.000	30°



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Reflected glare

Light reflecting from books or papers can be very disturbing and can undermine visual conditions. It can be avoided by well shielded luminaires, which permit unimpaired vision even where students work with glossy materials. Where work is performed at a monitor, unfavourably positioned luminaires or poor glare suppression can give rise to disturbing reflections, which cause visual impairment and visual fatigue.

Veiling reflections and reflected glare can be avoided or reduced by the following measures:

- Correct arrangement of workplaces in relation to luminaires, windows and skylights
- Screening for windows and skylights
- Use of correctly shielded luminaires
- Luminaires with a large luminous area that is not too bright
- Appropriate surface finishes (matt surfaces)
- Bright ceiling and bright walls

Shadows and modelling

Without light, we cannot identify objects; without shadows, they appear only as two dimensional figures. Creating a 3D effect calls for the right mix of directional light and shadow – the same mix that makes it possible to gauge distances. But shadows can also be disturbing. To ensure that they do not interfere with writing, light for a right-handed person should fall from the left. Care should also be taken to avoid multiple shadows, which can cause confusing visual phenomena. They occur where directional light falls on an object from various angles.

In communication zones, undesirable shadows are created if light is directed too intensely onto persons from above. Direct indirect lighting helps reduce disturbing shadows.

However, light should also not be too diffuse. Where this is the case, the modelling effect that makes good three dimensional perception possible is lost. What is more, the luminous environment is found monotonous and dull. Modelling is the balance between diffuse and directional light. Expressed as the ratio of cylindrical to horizontal illuminance at a given point, it should be within a value range of 0.30 to 0.60.

Colour rendering and light colours

Only where colours are rendered accurately can all study materials be properly assessed and people perceived as healthy and attractive. The standard of colour rendering achieved with artificial lighting is defined by the colour rendering index R_a. An R_a value of 100 means that colours are rendered and perceived exactly as they would be in natural light. Colour rendering values depend particularly on the spectral composition of the artificial light, i.e. on the type and quality of the light source. The table on the right shows the minimum colour rendering index values required as standard for different rooms, tasks and activities.

Lamps emit light of a particular light colour. In the case of some light sources, manufacturers group lamps into three categories: warm white, neutral white and cold white. Very often, light colour is expressed as a correlated colour temperature in Kelvin, the unit used by lighting technologists to measure the colour appearance of a light source.

For more information, see the section headed "Impact of light on human beings" on pages 16-17.

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[76, 77] Reflected glare and veiling reflections can be a major source of interference for someone working at a screen.

[78, 79] A low colour rendering index makes even the most beautiful bouquet of flowers look dull and unattractive. With lamps that render colours well, everything - including persons, books and work materials – is perceived more naturally.

[80] Minimum shielding angle for luminaires

[81, 82] To avoid disturbing shadows, light for right-handed persons should fall on the work surface from above and from the left.

[83, 84] Where glossy books and papers are present, reflected glare can cause major problems for someone trying to study. So it needs to be avoided. The disturbing effects of reflected glare can be prevented by using luminaires with direct-indirect lighting components and ensuring that they are correctly positioned.

[85] Extract from DIN EN 12464-1 2011(D) Source: Beuth Verlag, Berlin.

Type of interior, task or activity	$\bar{E}_m$ lux	UGR_L	U_0	R_a	Remarks
Educational premises – Nursery schools, play schools					
Play rooms	300	22	0.4	80	
Nurseries	300	22	0.4	80	
Handicraft rooms	300	19	0.6	80	
Educational premises – Educational buildings					
Classrooms, tutorial rooms	300	19	0.6	80	Lighting should be controllable
Classrooms for evening classes and adult education	500	19	0.6	80	Lighting should be controllable
Lecture halls	500	19	0.6	80	Lighting should be controllable to meet different A/V requirements
Blackboards, greenboards, whiteboards	500	19	0.7	80	1. Specular reflections need to be avoided. 2. Appropriate vertical illuminance required for speakers/ teachers
Demonstration table	500	19	0.7	80	In lecture halls 750 lux.
Art rooms	500	19	0.6	80	
Art rooms in art schools	750	19	0.7	90	5,000 K < colour temperature < 6500 K
Technical drawing rooms	750	16	0.7	80	
Practical rooms and laboratories	500	19	0.6	80	
Handicraft rooms	500	19	0.6	80	
Teaching workshops	500	19	0.6	80	
Music practice rooms	300	19	0.6	80	
Computer practice rooms (menu-driven)	300	19	0.6	80	DSE work
Language laboratories	300	19	0.6	80	
Preparation rooms and workshops	500	22	0.6	80	
Entrance halls	200	22	0.4	80	
Circulation areas, corridors	100	25	0.4	80	
Stairs	150	25	0.4	80	
Student common rooms and assembly halls	200	22	0.4	80	
Teachers rooms	300	19	0.6	80	
Library: bookshelves	200	19	0.6	80	
Library: reading areas	500	19	0.6	80	
Stock rooms for teaching materials	100	25	0.4	80	
Sports halls, gymnasiums, swimming pools	300	22	0.6	80	For training conditions see EN 12193
School canteens	200	22	0.4	80	
Break rooms	100	22	0.4	80	
Kitchens	500	22	0.6	80	
Cloakrooms, washrooms, bathrooms, toilets	200	25	0.4	80	In each individual toilet, if fully fitted.

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Luminaires and their applications

When it comes to selecting suitable luminaires for a school or other educational establishment, client, architect and lighting engineer should work closely together. Criteria such as light output ratio, design, material, lighting characteristics and possible integration in a lighting management system help ensure that the right decisions are taken.

Luminaires used in schools and other educational establishments need to be efficient, effective and easy to install. They also need to meet high normative, quality and design requirements – and should require little maintenance.

The term luminaire refers to the electric light fitting, including the lamp (light source) and all electronic and optical components.

Lighting characteristics and quality features

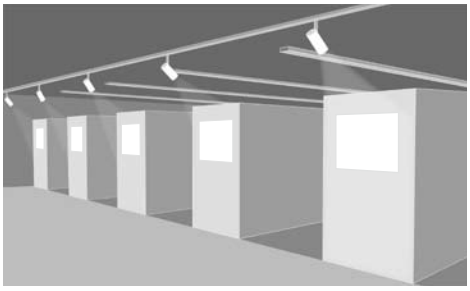
The intensity distribution curve (IDC) of a luminaire provides information about its lighting characteristics. It shows the pattern of light emitted and defines the local distribution of illuminance.

Light output ratio is an important quantity for assessing a luminaire's energy efficiency and lighting performance. It is an indicator of the total luminous flux radiated into the room. Glare limitation is another lighting quality feature that can sway the decision for or against the deployment of a particular luminaire. The luminaires need to be designed so that the lamps inserted in them are effectively shielded by louvers, diffusers or other anti-glare devices.

As a matter of principle, all luminaires and components must comply with current standards and display the ENEC mark. to permit the use of lighting control systems, luminaires must be dimmable. Fluorescent lamps need to be operated by appropriate electronic ballasts.

Continuous row systems (surface-mounted, recessed) for fluorescent lamps are rows of through-wired luminaires fitted with various anti-glare devices such as reflectors, louvers or prismatic enclosures.

Continuous row systems (suspended) for fluorescent lamps are available with various enclosures (reflector, louver or prismatic). To give a greater sense of space, preference should be given to models with an indirect lighting component for illuminating the ceiling.



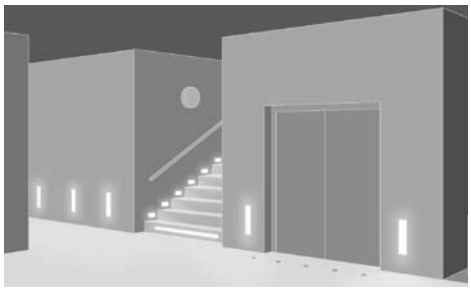
Power track systems sprovide flexibility for rooms where room situations change. Luminaires and spots can be mounted on adapters at any point on the track to deliver light precisely where it is needed.

Wallwashers as surface and recessed luminaires ensure homogeneous illumination of walls and boards. They are thus the ideal choice for vertical illumination.

Surface-mounted ceiling luminaires are used as an element of interior design and are available as models for direct or diffuse light distribution.

Recessed ceiling luminaires are mounted flush with the ceiling. Only the light makes a visual impact; the luminaire housing is largely out of sight.

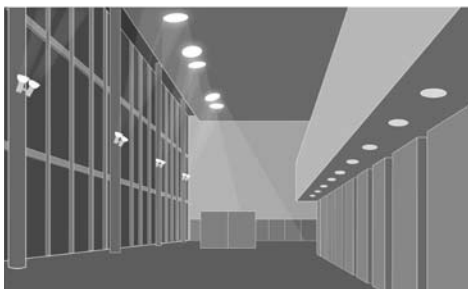
Wall luminaires are often used as an element of the general lighting in corridors and stairwells. They are also suitable for decorative lighting, delivering an accentuating light that supplements the general lighting.



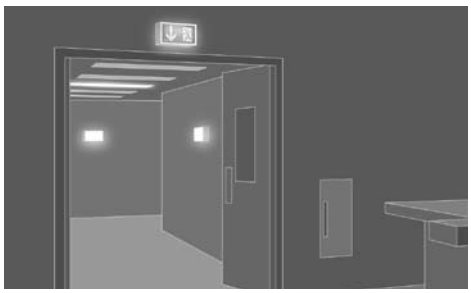
Recessed wall and floor luminaires fit smoothly and easily into the architecture, emphasising it at appropriate points from simple, flush mountings. They are often used as stair lighting to draw special attention to hazard zones.

Pendent luminaires are suspended from the ceiling and thus double as an element of interior design. They are available in a wide variety of designs with diverse light sources and direct-indirect light distribution characteristics.

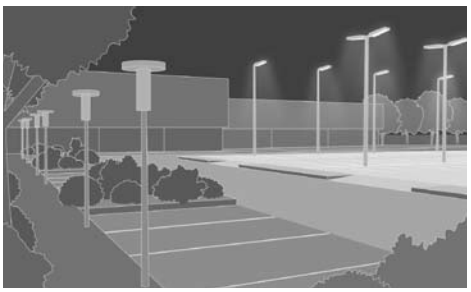
Standalone and table luminaires are used for non-static lighting and should be individually dimmable. Optionally available with direct-indirect light distribution, they are used in administrative areas and libraries.



Projector-reflector lighting systems ensure optimal visual conditions, especially in foyers and rooms with high ceilings. A high-intensity spotlight casts light onto what is normally a slightly convex specular reflector, which distributes the light in the room according to its orientation.

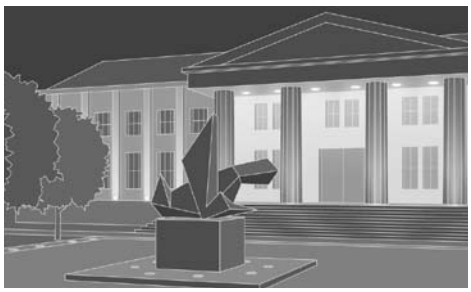


Emergency luminaires facilitate orientation in the event of a power failure and enable the building to be safely evacuated. Their operation must be independent of the mains, e.g. powered by single-use or rechargeable batteries.



Column luminaires and light pillars are used as technical and decorative exterior luminaires for illuminating roadways, paths and open areas. The lower the mounting height, the more luminaires are required.

High-performance column luminaires as floodlights are used for illuminating outdoor sports facilities. High intensity column luminaires ensure efficient, homogeneous illumination over even large areas.



Wall luminaires, recessed ground and ceiling luminaires outdoors are used to accentuate facades, vegetation or sculptures. They can also be used for guidance as path lighting.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Innovative LED and OLED technology

With its wide range of modules, lamps and luminaires, LED technology is becoming firmly established in the world of general lighting. In education too, the LED can do a great deal to help conserve resources and drive down lighting system operating costs.

[86, 87] Luminaires with LED technology are available in more and more aesthetic and functional designs. Whether realised as recessed luminaires or pendant luminaires with direct-indirect components, they are always shining examples of energy efficiency and longevity.

[88] In contrast to incandescent lamps (life approx. 1,000 hours) and fluorescent lamps (replacement required after around 18,000 hours), LEDs have an operating life in the region of 50,000 hours. That saves resources and reduces maintenance costs.

[89] Cross-section of a light-emitting diode

[90] Organic light-emitting diodes are made of very thin organic layers sandwiched between planar electrodes. When a current is passed through them, they emit visible radiation.

LED lamps are already on the market as one-to-one replacements for conventional light sources. Apart from classical "light bulb" models, there are also reflector lamps available in a wide range of designs and power ratings. Moreover, a growing number of luminaires incorporate LED modules, which – even after a very long operating life of up to 50,000 hours – can be replaced by future-generation modules. With so much choice, it is particularly important to make sure that LED products carry a manufacturer's guarantee of uniform high quality. Cut-price models are not only disappointing in terms of performance and lighting quality; they also have a shorter life.

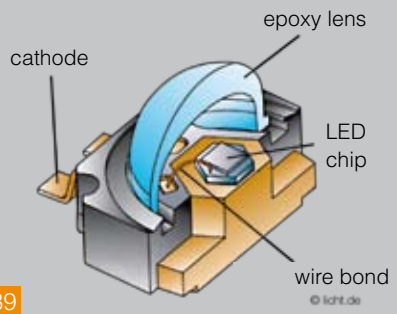
Advantages of LED technology:

- High efficiency
- Long life up to 50,000 h at 70% luminous flux, hence lower maintenance costs
- Less waste because light sources need to be replaced less frequently
- Disposal: unlike fluorescent lamps, LEDs contain no mercury
- Beam with no UV or infrared content
- High lighting quality
- 100% light on activation – no flicker, no delay
- LEDs are extremely robust: impact-, vibration- and switch-resistant
- Good to excellent colour rendering
- Different light colours
- Dimmable, depending on system

Despite the higher initial outlay for high-quality LED lighting solutions, the expense is quickly recouped thanks to a very long service life and low maintenance costs.

How does an LED work?

Light-emitting diodes are electronic semiconductor components. When a current passes through a semiconductor diode, the diode starts to glow and emits light. The process is known as electroluminescence and generates not only light but also heat. Good thermal management ensures high efficiency and long life. Light is emitted over an angle of up to 180° and can be focused by lenses.



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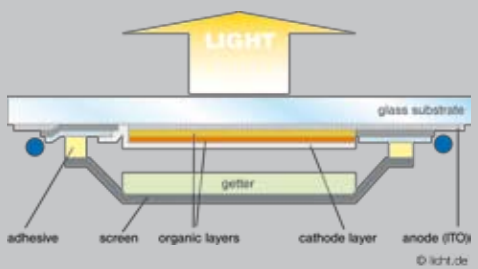
A glimpse of the future: OLED technology

In a few years' time, the luminaire market could again be revolutionised by the organic light-emitting diode OLED. While LEDs are point light sources, OLEDs generate an innovative planar light that is found to be very agreeable. Other positive features include warm-white light, homogeneity, absolute freedom from glare and good colour rendering. The onward development of organic light emitting diodes as a light source has only just begun; nevertheless, it is seen as a very promising technology for the future.



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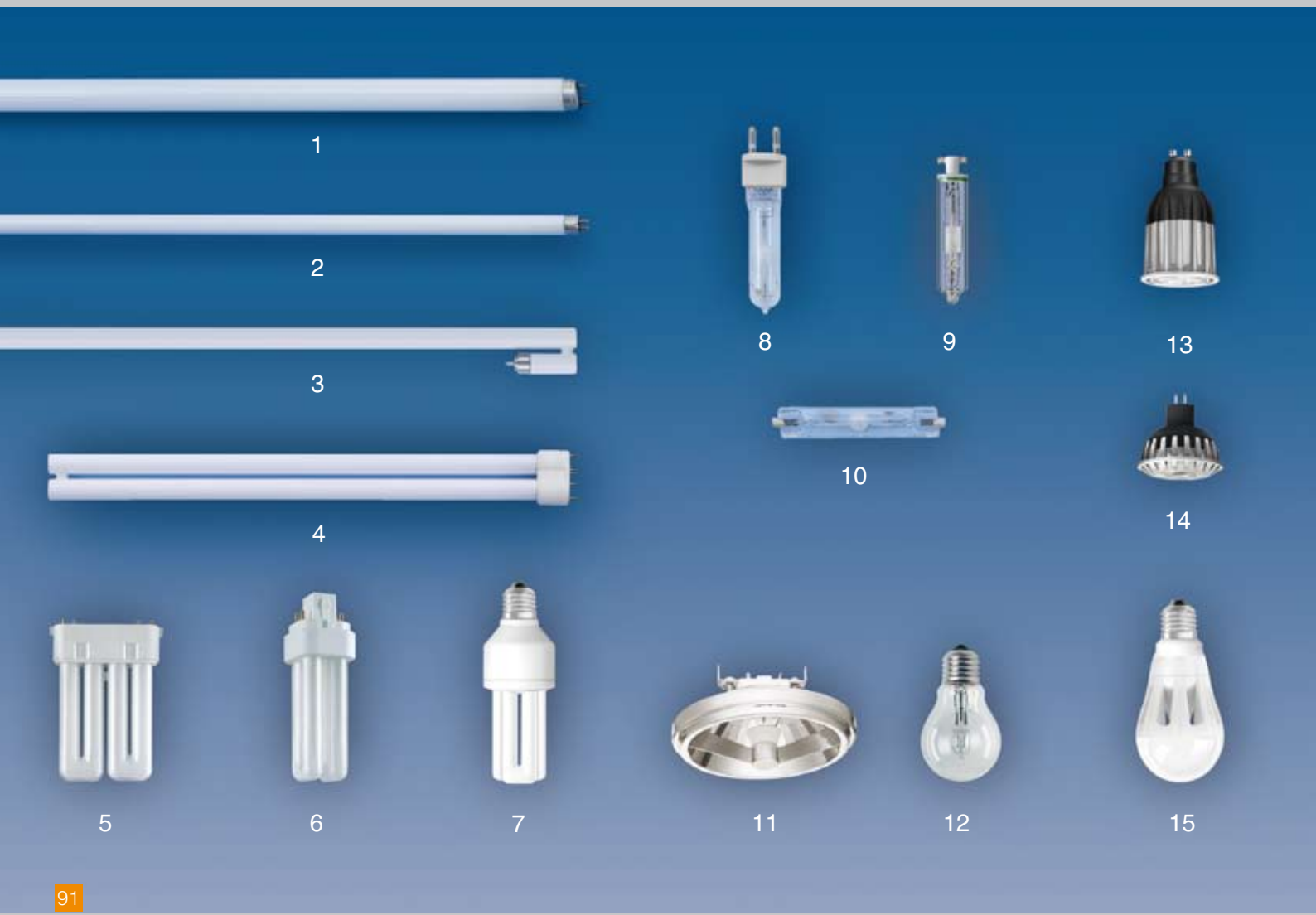

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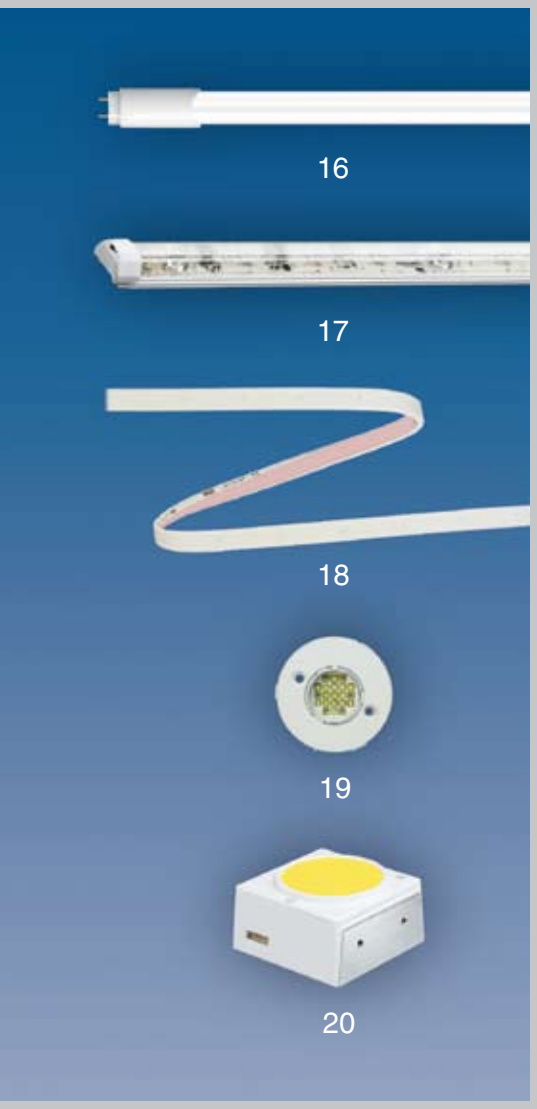
		Ø 26 mm fluorescent lamp	Ø 16 mm fluorescent lamp	Ø 16 mm fluorescent lamp	2-tube lamp elongated design	4-tube lamp square design	1-, 2- or 3-tube lamp compact design	3-tube lamp with integrated EB	Single-ended with ceramic technology	Single-ended with ceramic technology	Double-ended with ceramic technology
Lamp type		1	2	3	4	5	6	7	8	9	10
		Linear fluorescent lamps			Compact fluorescent lamps				Metal halide lamps		
Power rating (in W)	from	18	14	14	16	16	10	8	20	20	70
	to	70	80	54	80	38	42	30	400	35	150
Luminous flux (lm)	from	870	1,100**	1,100**	950	1,050	600	380	1,600	1,650	5,100
	to	6,200	6,150**	4,450**	6,500	2,800	3,200	1,940	41,000	3,000	14,500
Luminous efficacy (lm/W)	from	61	67	67	67	61	60	48	80	75-79	73
	to	89	104	104	100	78	75	65	108		104
Light colour		ww, nw, dw	ww, nw, dw	ww, nw, dw	ww, nw, dw	ww, nw, dw	ww, nw, dw	ww, cw	ww, nw	ww	ww, nw,
Colour rendering index R_a (in some cases as range)		85-98	85-93	80-90	80-93	80-90	80-90	80-90	80-95	85-90	75-95
Base		G13	G5	G5	2G11 2G7	2G10 GR8 GR10q	G23 G24 2G7 GX24	E14 E27 B22d	G8,5 G12 G22 GU6,5 GU8,5 GY22	PGJ5	RX7s RX7s-24



Light sources

Fluorescent lamps [1-3]
The distinguishing features of fluorescent lamps include high luminous efficacy, good colour rendering and longevity. Operation by electronic ballast (EB) – essential in the case of 16 mm diameter lamps – improves energy efficiency and lighting quality. In addition, the life expectancy of these lamps can be extended even more by the use of warm start EBs. With appropriate EBs, fluorescent lamps can also be dimmed and used in connection with lighting control systems.

Compact fluorescent lamps [4-7]
Compact fluorescent lamps have the same characteristics but because of their compact design can be integrated in smaller luminaires. They are also available with built-in ballasts for conventional screw lampholders [7]. Recent developments have produced compact fluorescent lamps with excellent starting performance, improved switching frequency and very warm light colours (2,500 K colour temperature).

Metal halide lamps [8-10]
Metal halide lamps have always been noted for their brilliant light and have become the light source of choice for attractive lighting in corridors, foyers or assembly halls. Lamps with ceramic burner technology achieve an even higher luminous efficacy of up to 100 lm/W, making them significantly more energy efficient.

Low-voltage halogen lamps [11]
Low-voltage halogen lamps are distinguished by an absolutely brilliant light with very good colour rendering properties. They need to be operated by a transformer that reduces the voltage to 12 V. With appropriate transformers, they can be dimmed to any level.

230 V halogen lamps [12]
Because of their brilliant and agreeable light, modern energy-saving halogen lamps for mains operation are a popular choice for accent lighting, especially as reflector lamps. They can also be dimmed to any level and have very good colour rendering properties (R_a 100).

LED lamps [13-16]
Directional or diffuse, LED lamps have a life of up to 25,000 hours and are available in a wide variety of designs. Their distinguishing features include high energy efficiency, good colour rendering and diverse light colours. They also produce a beam with no UV or infrared radiation and, depending on system, are dimmable. Where they are used to replace fluorescent lamp systems (16), LED lamps change the pattern of light distribution. Electrical reliability needs to be ensured by a professional.

LED modules [17-20]
LED modules – consisting of LEDs and lens – now achieve a high degree of luminous efficacy and, as a result, are regarded as the solution of the future for technical and decorative lighting in educational establishments.

Reflector design	Incandescent lamp design	Reflector design line voltage	Reflector design low voltage	Incandescent lamp design	Tubular design Ø 26 mm	Rigid LED-Modul	Flexible LED-Modul	Standardised LED-Modul	Standardised LED-Modul
11	12	13	14	15	16	17	18	19	20
Halogen lamps		LED lamps				LED modules			
10 100	18 105	4,5 10	4,5 10	2 12	11 30	11 30	24,5 72	9 39	17 44
350* 33,000*	170 2,000	450* 1,200*	180 450	95 900	630 2,600	100 2,100	765 3,650	800 3,000	1,100 3,000
- -	9 18	- -	- -	45 75	58 85	- -	31 50	52 85	55 75
ww	ww	ww, nw, dw	ww, nw, dw	ww, nw, dw	ww, nw, dw	ww, nw	ww, nw, dw, cw	ww, nw	ww, nw
100	100	80-90	80-90	80-90	70-85	75-80	80-89	80-95	80-90
GU4 GU5,3 G53	E14 E27 B22d	E14 E27 GU10	GU5,3 GU4 G53	E14 E27	G13	-	-	-	-

* = in candela
** = at 25°C ambient temperature

ww = **warm white** colour temperature 2,700 K to 3,300 K
nw = **neutral white** colour temperature 3,300 K to 5,300 K
dw = **daylight white** colour temperature 5,300 K to 6,500 K
cw = **cold white** colour temperature more than 6,500K

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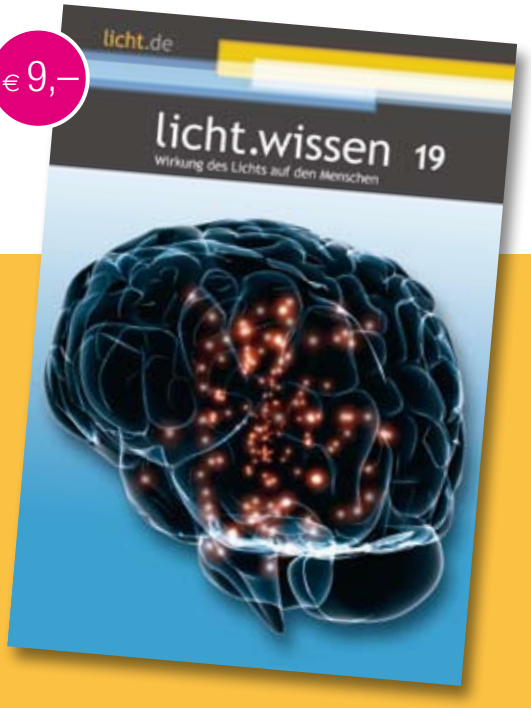

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licht.forum
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www.licht.de
The industry initiative also presents its knowledge of lighting on the Internet. At www.licht.de, architects, designers, lighting engineers and end consumers have access to around 5,000 pages of practical tips, details of a host of lighting applications and up-to-the-minute information on light and lighting. An extensive database of product overviews provides a direct link to manufacturers.

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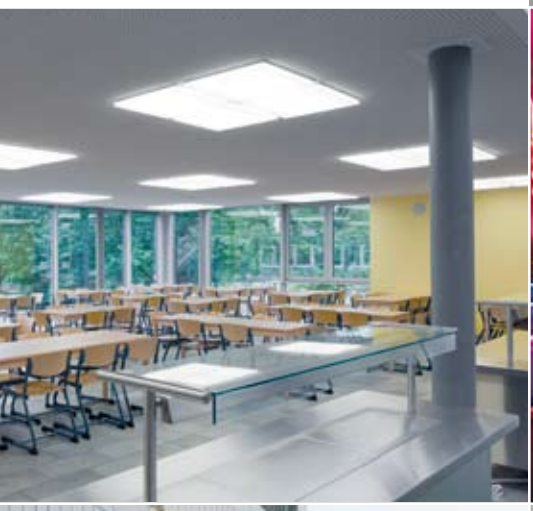

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