Improving the Efficiency and Attractiveness of Vocational Education/Training of Electricians

Erasmus+ Project Nr. 2021-1-DE02-KA220-VET-000029591

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Web-based VET modules in the energy efficiency of intelligent buildings for electricians: EE-VET

Module - 2

Energy Efficient Lighting Technologies in Buildings

EUROPEAN CENTER FOR EDUCATION, SCIENCE AND INNOVATION

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Co-funded by the Erasmus+ Programme of the European Union

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MODULE 2
ENERGY EFFICIENT LIGHTING TECHNOLOGIES IN BUILDINGS

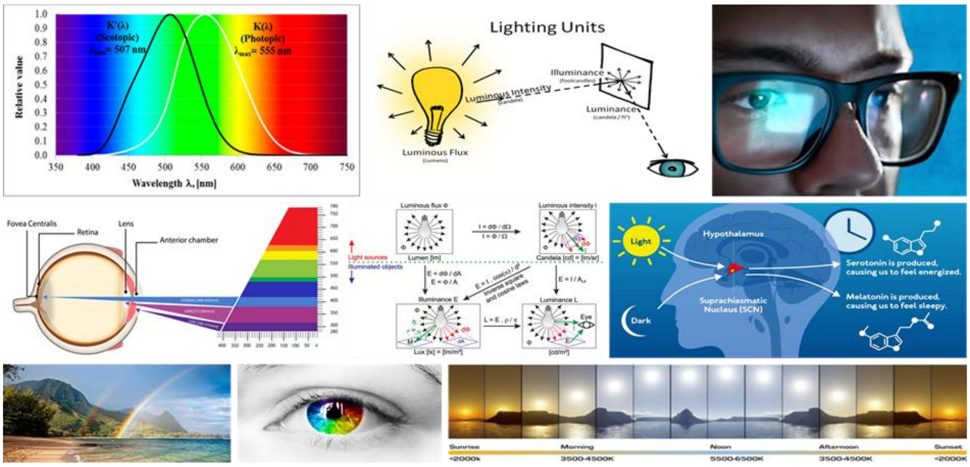
1 TOPICS

1.1 TOPIC 1 – LIGHTING FUNDAMENTALS

1.1.1 INTRODUCTION

Learning more about the physical basis of light and the photobiological effects of light on humans will help to understand better the energy efficiency and safety of lighting technologies in buildings. The eye delivers 80 percent of the information we need to perceive the world, which is highly dependent on the quantity and quality of lighting.

The LIGHTING FUNDAMENTALS section will show details about the electromagnetic and visible spectrum, the spectral sensitivity of the human eye, the effect of light on humans, the main lighting parameters and dependencies, color characteristics, and the light efficiency of light sources.



This general information about light is the basis not only of lighting technologies in buildings, but also in many other devices in daily life that use light, for example, smartphones, tablets, laptops, computer monitors, televisions and others.

1.1.2 ELECTROMAGNETIC AND VISIBLE SPECTRUM

Light is an electromagnetic wave that spreads in space and time. The light wave is characterized by its amplitude and wavelength. Visible light is within a narrow segment of the electromagnetic radiation spectrum. Radiant energy may be seen (visible light), felt (infrared radiation or heat transferred from warm objects), or it can

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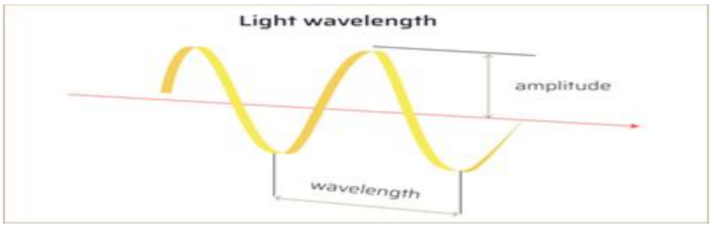
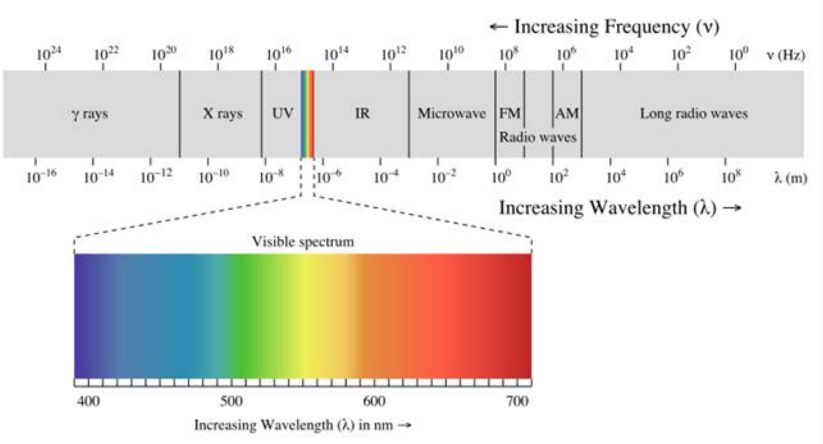
actually penetrate (x-rays) and do physical damage to the cells of the human body (gamma rays or nuclear radiation). Light can be defined as any radiation generating immediately a visual sensation.



Source: http://proximal-lighting.com/en/science-and-technology-proximal/fundamentals-lighting/



Source:EE-VET_Module_Lighting_for meeting in Latvia

Light is electromagnetic radiation with wavelengths between 380 and 770 nm visible to the human eye. Visible light forms the visible spectrum, or colours of the rainbow. Blue and violet light contain more energy and have a shorter wavelength than orange and red light.

Interesting and Useful: What Causes a Rainbow? https://scijinks.gov/rainbow/

Source: https://science.howstuffworks.com/nature/climate-weather/storms/rainbow.htm

Human Vision

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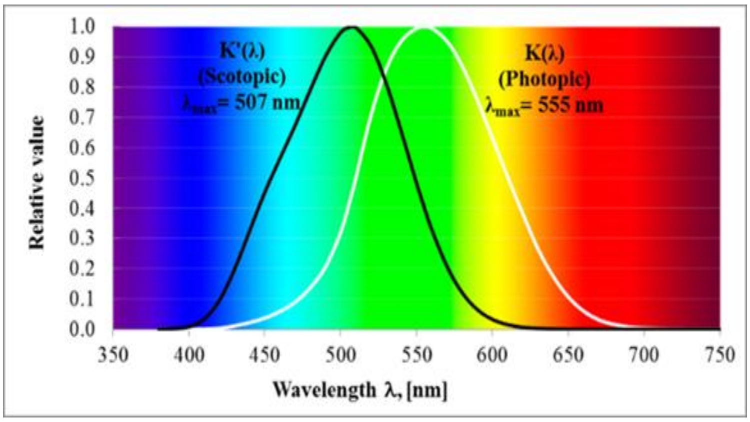
The human eye is a sensory organ, part of the sensory nervous system, that reacts to visible light and allows humans to use visual information for various purposes including seeing things, keeping balance, and maintaining circadian rhythm.

Source: https://www.redsharknews.com/technology-computing/item/4741-human-vision-and-why-the-colour-green-is-so-important

The response of the human eye over the visible light spectrum defines the so-called luminosity function or photopic curve. The peak of this curve is in the yellow-green, at a wavelength of 555 nano-meters (nm). The curve shifts toward the blue under very dark conditions (called scotopic or dark-adapted) because of differences in the chemistry of the rod and cone cells in the human retina.



Source:EE-VET_Module_Lighting_for meeting in Latvia

Scotopic vision is more blue-sensitive, but it is perceived as a black-and-white image by the human brain, since the rods do not have a means to differentiate colour. While scotopic vision is important in observing the night sky and the landscape at night, light measurement (or photometry) is based upon daytime vision or the photopic curve. Light meters are designed with a filter in the optical system which appears green and mimics the photopic response of the human eye.

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1.1.3 PHOTOBIOLOGICAL IMPACT OF LIGHT ON HUMAN

- Blue Light Hazard

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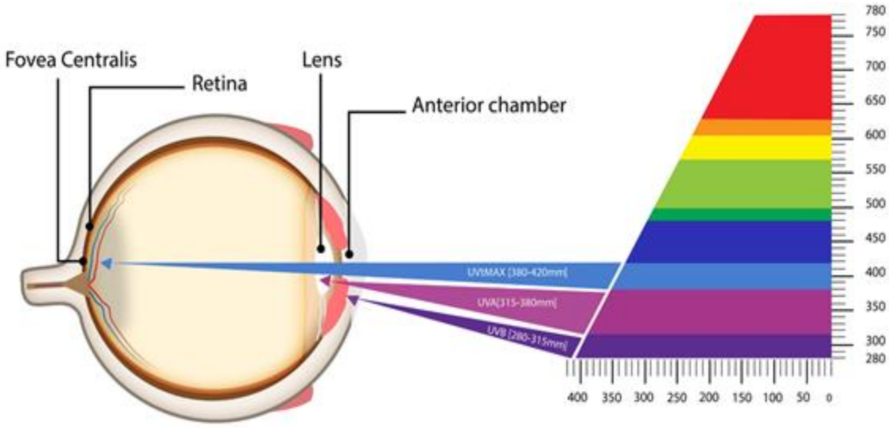
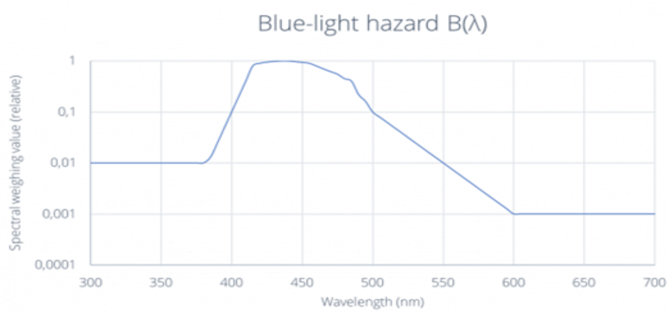
The B(λ) function, also called the blue light hazard function represents the relative spectral sensitivity of the human eye to the blue light hazard.

Source:https://www.medicalnewstoday.com/articles/best-blue-light-blocking-glasses#_noHeaderPrefixedContent



Source:EE-VET_Module_Lighting_for meeting in Latvia

The term “blue light hazard” should only be used when considering the photochemical risk to the retinal tissues of the eye (technically referred to as “photomaculopathy”), usually associated with staring into bright sources, such as the sun or welding arcs. “Blue” is included in the term because the risk of photochemical injury is wavelength-dependent, peaking in the blue part of the optical radiation spectrum around 435 nm to 440 nm.



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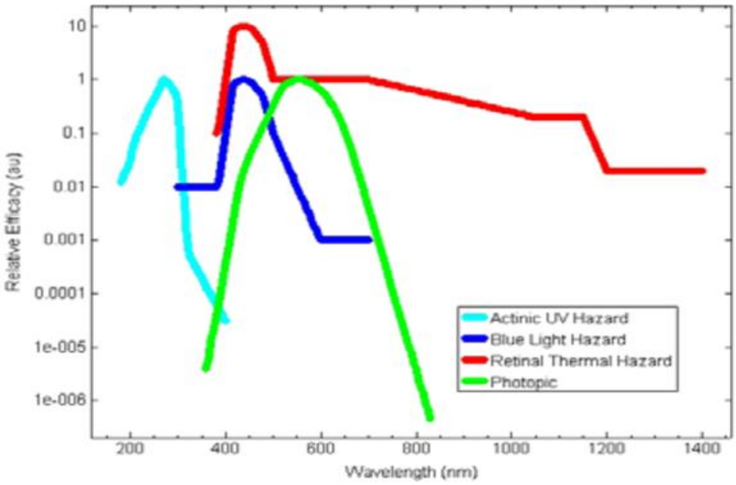
Source:https://www.gigahertz-optik.com/en-us/app-groups/light-hazard/assessment-of-blue-light-hazard-from-artificial-light-sources/

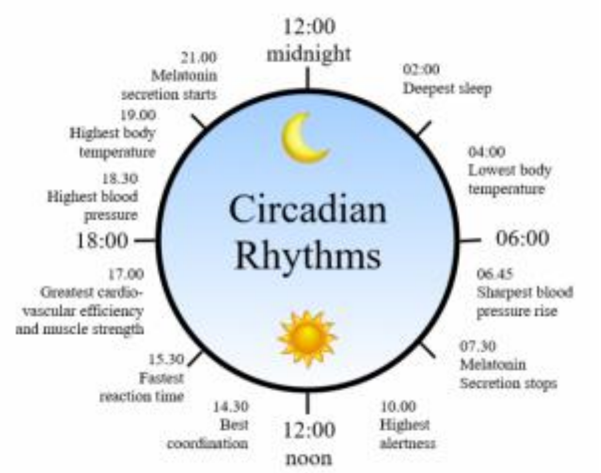
Lamps, including LEDs, which emit primarily white light will usually contain a proportion of light at wavelengths that are relevant to the assessment of the blue light hazard. Lamps that are “cooler”, or attributed to a high color temperature, are likely to contain a higher proportion of blue light than sources that are “warmer” or of a lower color temperature. Indeed the blue light hazard exposure limit from incandescent and LED lamps for general lighting is similar for similar color temperatures. Practical assessments have shown that the blue light hazard exposure limits are not exceeded under all reasonably foreseeable use conditions.



Source: The Sun and Photovoltaic Technologies_online

-Circadian rhythm cycle

What is importance of light?



Source:https://en.getmoona.com/blogs/mission-sleep/how-your-circadian-rhythm-influences-your-sleep

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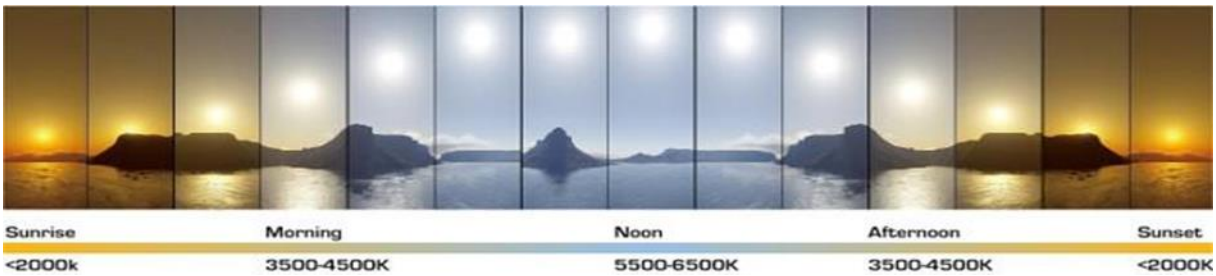
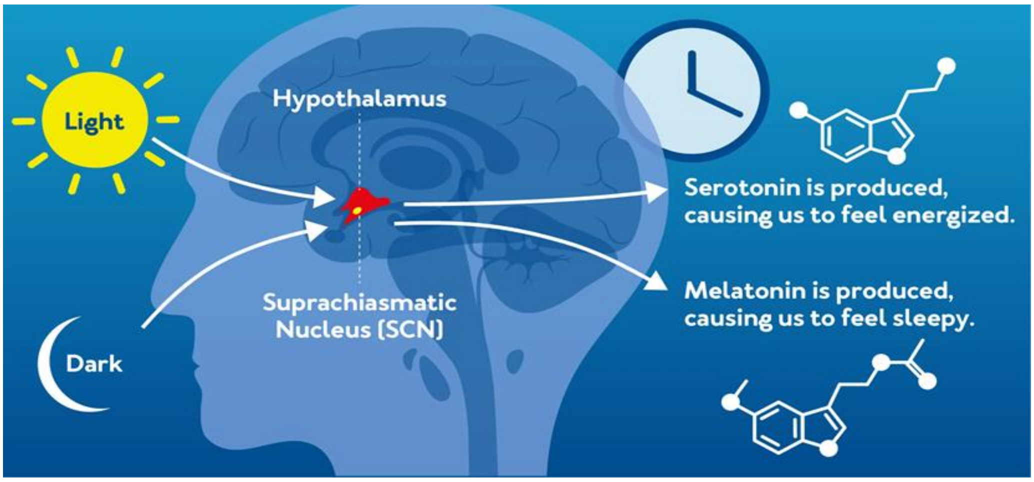


Source:https://www.idealista.it/news/immobiliare/costruzioni/2020/07/20/149126-i-benefici-di-unadeguata-illuminazione-delle-facciate-degli-edifici

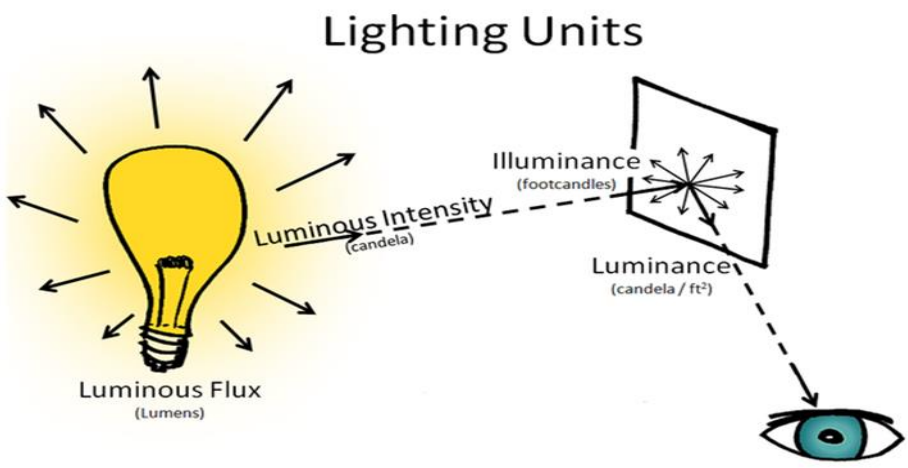
Light is essential to our health and wellbeing; it regulates our sleep-wake cycle. It can also help with our daily routines: from bright functional light to keep you energized and up your concentration level, to warm light that creates a cozy ambiance that helps you to unwind in the evening. The light/dark cycle of the sun has a powerful effect on the circadian clock, sleep, and alertness. Your body's circadian clock responds to light, as a signal to be awake, and dark, as a signal to fall asleep. Increase your amount of light during the day to be more alert. There are many examples of circadian rhythms, such as the sleep-wake cycle, the body-temperature cycle, and the cycles in which a number of hormones are secreted.



Source:EE-VET_Module_Lighting_for meeting in Latvia

1.1.4 BASIC PHOTOMETRIC QUANTITIES AND DEPENDENCIES

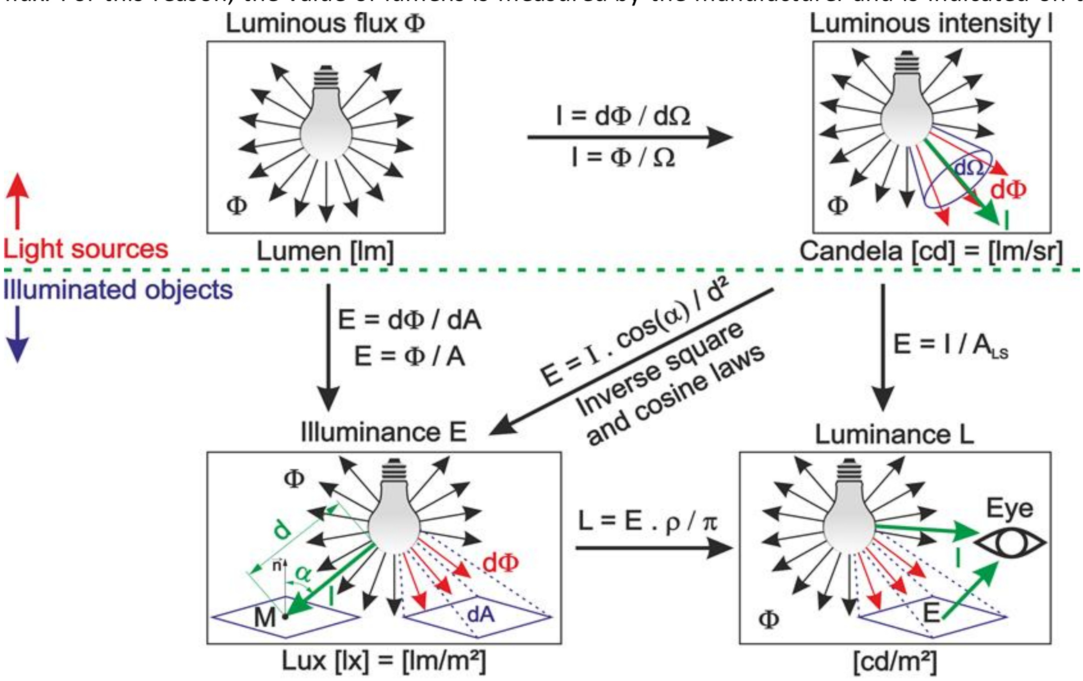
Photometry is the science of the measurement of light. Photometry deals with the properties of the light as perceived by the human eye as a subjective photodetector, in other words, the fact that the eye has a different sensitivity for different colours. Photometry consists of four basic concepts, namely the luminous flux, luminous intensity, illuminance, and luminance.



Source:https://en.wikipedia.org/wiki/File:Lighting_units.png

- luminous flux Φ [lm]

Luminous flux expresses to the total amount of light which emitted by a lighting element in all directions, in other words, it expresses the power of light. The unit of the light flux is lumen. In order to measure the lumen of a light source, we need special equipment. An integrating sphere or a set of sensors is required to measure the light flux. For this reason, the value of lumens is measured by the manufacturer and is indicated on the product.



Source:EE-VET_Module_Lighting_for meeting in Latvia

- luminous intensity I [cd]

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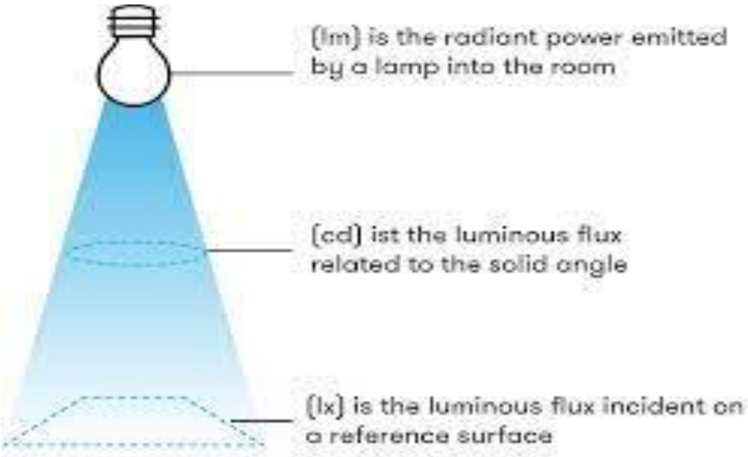
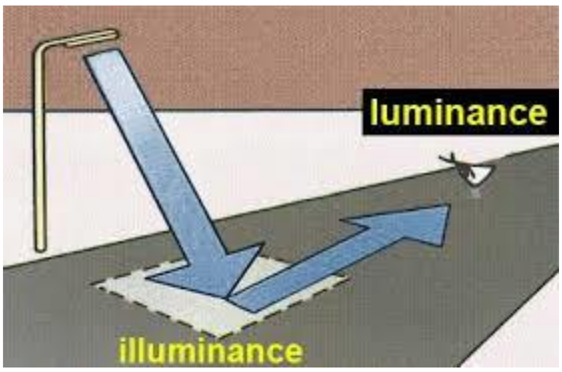
Luminous intensity, a measure of the luminous power emitted by a light source, in a particular direction, per steradian. The candela (cd), the unit of luminous intensity, is the International System of Units (SI) base unit for photometry — the science of measuring light as perceived by the human eye. Luminous intensity is the perceived power per unit solid angle. If a lamp has a 1 lumen bulb and the optics of the lamp are set up to focus the light evenly into a 1 steradian beam, then the beam would have a luminous intensity of 1 candela.



Source:https://www.auersignal.com/en/technical-information/visual-signalling-equipment/luminous-intensity/

- illuminance E [lx]

In photometry, illuminance is the total luminous flux incident on a surface, per unit area. It can be used as a reference measurement of the performance of a lighting system as related to the activity. The lux (symbol: lx) is the unit of illuminance, or luminous flux per unit area, in the International System of Units (SI). Illuminance is calculated with the following formula: Lux [lx] = luminous flux [lm] / area [m2]. The illuminance is 1 lux if a luminous flux of 1 lumen falls uniformly on an area of 1 m². The further away the area is from the light source, the lower the illuminance.



Source:https://gharpedia.com/blog/illuminance-vs-luminance-know-differences/

- luminance L [cd/m2]

Luminance is the luminous intensity of a surface in a given direction per unit of projected area. It can be used as a reference measurement the quality or state of being luminous. Luminance is the measurable quality of light

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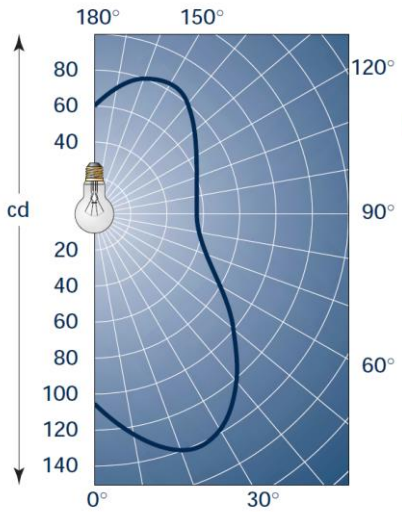
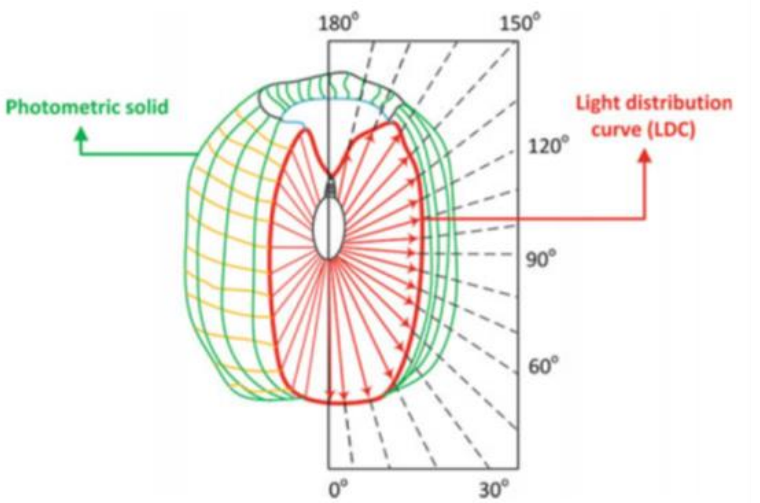
that most closely corresponds to brightness, which we cannot objectively measure. The derived SI unit of luminance is candela per square metre (cd/m2).

- Luminous intensity distribution curve

The distribution of the luminous intensity of a light source in all directions throughout a space produces a three-dimensional graph—photometric solid. A section through this graph results in a luminous intensity distribution curve, which describes the luminous intensity on one plane. The luminous intensity is usually indicated in a polar coordinate system as the function of the beam angle. To allow comparison between different light sources to be made, the light distribution curves are based on an output of 1000 lm. In the case of symmetrical luminaire, one light distribution curve is sufficient to describe one luminaire, and axially symmetrical luminaires require two curves, which are usually depicted in one diagram.





Source:17456137-Lighting-Handbook-INDAL-Guide Source:The Sun and Photovoltaic Technologies_online

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1.1.5 LUMINOUS EFFICACY

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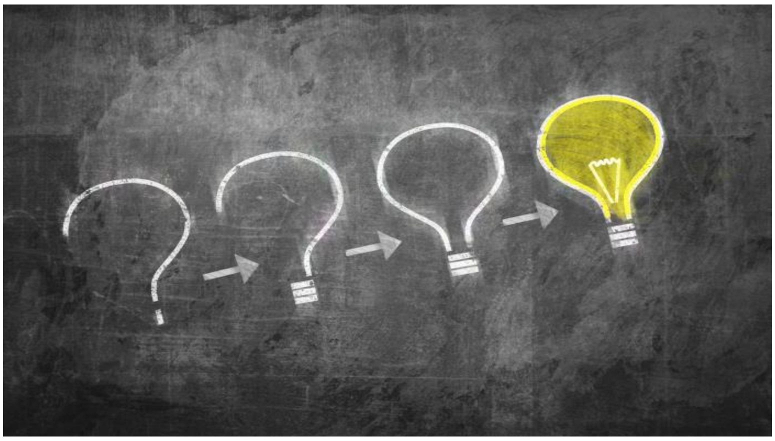
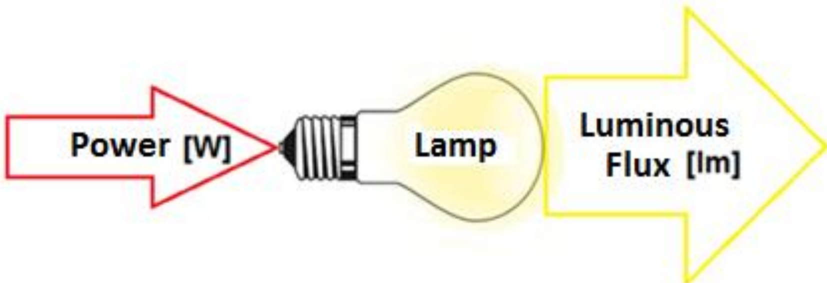


Source:https://shrednorthwest.com/how-to-come-up-with-a-great-idea/

Luminous efficacy is a measure of how well a light source produces visible light. The equation will be efficacy = luminous flux / power. Luminous efficacy is measured in units of lumens (lm), a measure of light that factors in the human visual response to various wavelengths, per watt (W). Most lamps will have this information on the box it came in.



Source:EE-VET_Module_Lighting_for meeting in Latvia

How to calculate luminous efficacy?

As an example, let's imagine a light source emitting 500 lumens with 10W of power. In that case the luminous efficacy would be 50 lumens per watt, the result of dividing five hundred by ten. On the other hand we have another bulb of 10W and that has the capacity to emit 1000 lumens, in this case its efficiency will be 100 lumens per watt and therefore much more convenient than the first one, since we will have more luminosity with the same consumed power.

$$n=\frac{\Phi}{P}$$

Energy labels:

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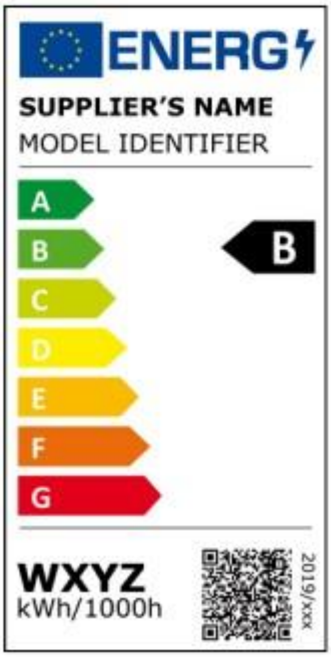

Source: https://www.any-lamp.com/blog/the-energylabel-of-a-light-bulb

New energy label as of 01.09.2021 must be indicated on all light sources with a luminous flux between 60 and 82,000 lumens and OLED (lamps, LED modules and fixtures where the light source cannot be removed without destroying it).

Information on the label:

Name / Trademark

Model

Energy label scale A to G

Energy consumption for 1,000 hours of use

Energy efficiency class of the product

QR code to EPREL (product database of the European Product Registry for Energy Labelling)

Energy efficiency class:

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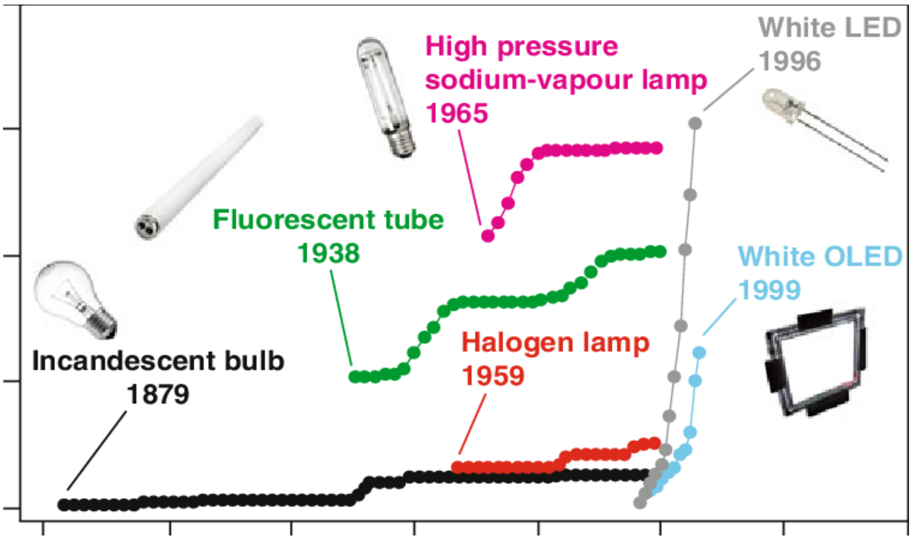
$\eta TM = (\Phi use / Pon) \cdot FTM$ (lm/W)

Energy efficiency class	Total mains efficacy ηtm (lm /w)
A	$210 \leq \eta_{tm}$
B	$185 \leq \eta_{tm} < 210$
C	$160 \leq \eta_{tm} < 185$
D	$135 \leq \eta_{tm} < 160$
E	$110 \leq \eta_{tm} < 135$
F	$85 \leq \eta_{tm} < 110$
G	$\eta_{tm} < 85$

Light source type	Factor F_{tm}
Non-directional (NDLS) operating on mains (MLS)	1,000
Non-directional (NDLS) not operating on mains (NMLS)	0,926
Directional (DLS) operating on mains (MLS)	1,176
Directional (DLS) not operating on mains (NMLS)	1,089

Source: https://www.lucide.com/en/blogs/new-energy-labels-in-2021-these-are-the-changes-for-lighting/



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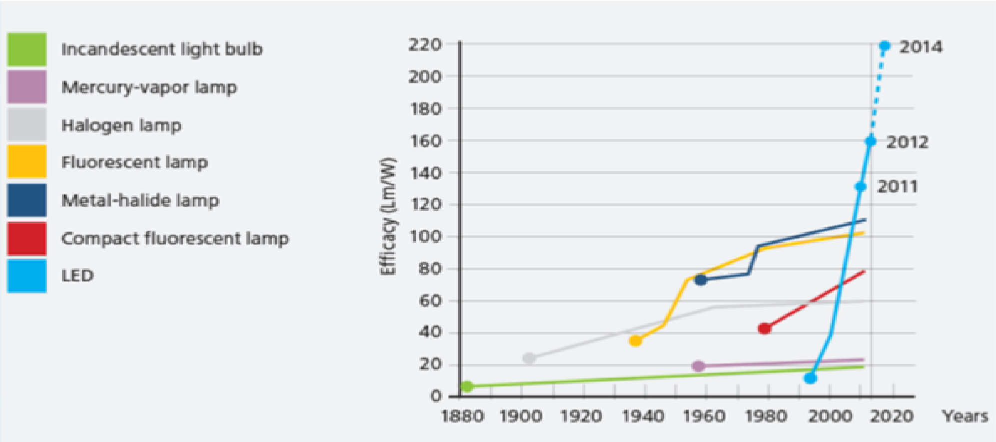

Source:EE-VET_Module_Lighting_for meeting in Latvia

Historical trend of luminous efficacy for some light sources

Luminous efficiency goes beyond the relationship between luminous flux and power consumption. Its value is expressed as a percentage and the following factors are taken into account to establish an evaluation:

- Internal temperature of the system: The lower the operating temperature of the light source, the better the efficiency of the luminaire. This aspect is very important and is determined by the quality and shape of the heat sink as well as the location and ventilation capacity of the heat sink.

- Optical components: The reflectors and optics of a luminaire absorb and redirect the direction of the emitted lumens. They can therefore reduce the amount of light output from the luminaire. Depending on the material and type of finish, diffusers can significantly vary the percentage of luminous flux affecting the overall efficiency of the system.

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1.1.6 COLOR RENDERING INDEX (CRI)

The Colour Rendering Index (CRI) measures the ability of a light source to accurately render all frequencies of the colour spectrum when compared to a perfect reference light of a similar type or ability to show object colours realistically or naturally. It's rated on a scale of 1-100 with 100 being the highest. Typically, light sources with a

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CRI of 80 to 90 are regarded as good and those with a CRI of 90+ are excellent.

Source:EE-VET_Module_Lighting_for meeting in Latvia

Source:https://insights.regencylighting.com/how-to-choose-color-rendering-index-cri-a-practical-guide

The CRI is calculated by comparing the colour rendering of the test source to that of a "perfect" source. So to test the CRI, you set up a number of colour patches with precisely known colours on them. You then measure the colour of these patches under the light source using a device called a spectrophotometer, which measures the colour of the light being reflected from it. .

Source:https://www.elementalled.com/why-is-cri-important-2/

R9 is the score that represents how accurately a light source will reproduce strong red colours. "Accurate" is defined as similarity to daylight or incandescent bulbs, depending on the colour temperature.

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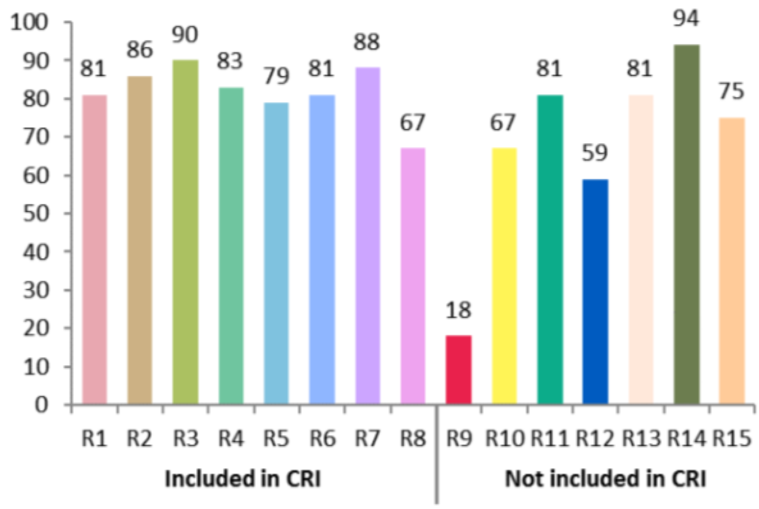
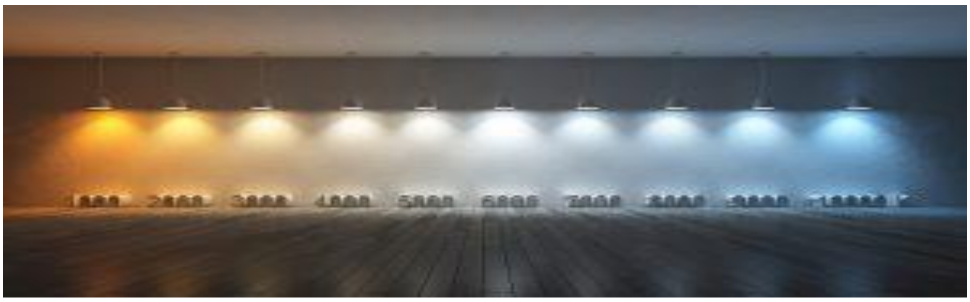


Source:EE-VET_Module_Lighting_for meeting in Latvia

CRI is a simple and helpful lighting spec to predict how good the visual output of a lighting product will be. Simply put, the metric is a number between 0 and 100 that is used to predict how well a product renders colour. The closer to 100, the better – or truer – colours should look under its light.

1.1.7 CORRELATED COLOR TEMPERATURE (CCT)

The CCT or Correlated Colour Temperature is a specification of the colour appearance of the light emitted by a light source, relating its colour to the colour of light from a reference source when heated to a particular temperature, measured in degrees Kelvin (K). The CCT rating for a light is a general "warmth" or "coolness" measure of its appearance. However, opposite to the temperature scale, lamps with a CCT rating below 3200 K are usually considered "warm" light sources, while those with a CCT above 4000K are usually considered "cool" in appearance.



Source:https://www.ccair.com/blog/color-temperature-in-your-home/

There are nominal CCT categories: Warm: 2,200K, 2,500K, 2,700K, 3,000K, Neutral: 3,500K, 4,000K, 4,500K, 5,000K, Cool: 5,700K and 6,500 K.

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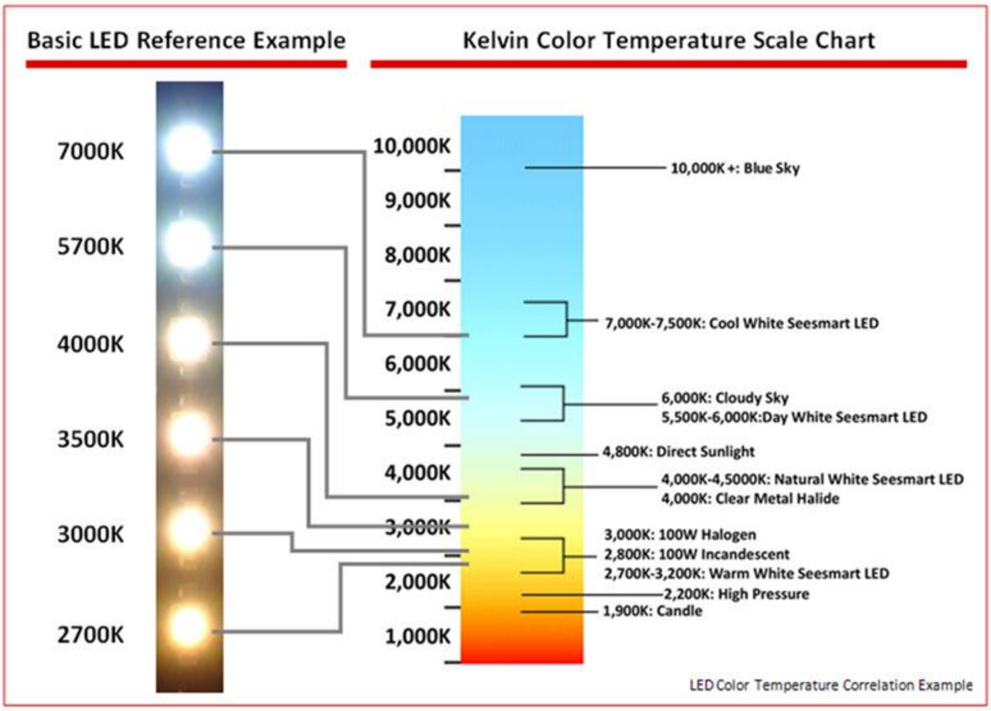

Source:EE-VET_Module_Lighting_for meeting in Latvia

For example the daylight colour temperature changes thru the day. At sunrise and sunset the CCT is around 3000K. On the other hand at noon the CCT is on the highest level around 5500K or higher. The colour temperature of light has important effects on human beings. For the places where people are gathering such as coffee shops, restaurants, and hotel lobbies the warmer light colour around 3000K is desired. The warmer colour of light causes people to relax. For the places where people should be more focused on their work, like in classrooms, offices and conference rooms the light colour temperature should be cooler around 4000K. LED lights have the best possibilities to tune the desired CCT.

Kelvin Color Temperature	2700K	3000K	3500K	4100K	5000K	6500K
Associated Effects and Moods	Ambiant Intimate Personal	Calm Warm	Friendly Inviting	Precise Clean Efficient	Daylight Vibrant	Daylight Alert
Appropriate Applications	Living/Family Rooms Commercial/ Hospitality	Living/Family Rooms Commercial/ Hospitality	Kitchen/Bath Light Commercial	Garage Commercial	Commercial Industrial Institutional	Commercial Industrial Institutional

Source:EE-VET_Module_Lighting_for meeting in Latvia

Warm light sources, such as incandescent bulbs, have a low colour temperature (2200-3000K) and feature more light in the red, orange and yellow range. When you think of a warm colour temperature, think of the warm, inviting light of a fire in the fireplace. Cool light sources, such as some HID or fluorescent lamps, have a high colour temperature (>4000K) and feature more light in the blue range. When you think of a cool colour temperature, think of the crisp white or blue light.

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Quiz questions to Topic 1

1.2 TOPIC 2 - LAMPS

1.2.1 INTRODUCTION

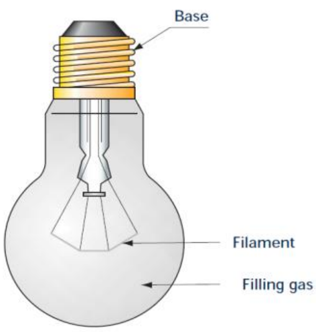
Twentieth century has seen a huge increase in the number of available light sources in the marketplace, starting with improvements in the Edison lamp, then the introduction of mercury-vapour lamps in the 1930s, followed closely by fluorescent lamps at the 1939 World Fair. Tungsten-halogen lamps were introduced in the 1950s and metal-halide and high-pressure sodium (HPS) lamps in the 1960s. The introduction of electrodeless lamps and "white" LEDs in the 1990s is an indication that the industry is dynamic, and the introduction of new light sources is expected to continue at least at the present rate well in the twenty-first century.

Source:https://www.assetguardian.com/obsolescence-management-of-software-components/

1.2.2 PRINCIPLE OF OPERATION, PARAMETERS AND CHARACTERISTICS OF THE LAMPS

Incandescent lamp

Incandescent lamp is an electric light with a wire filament heated until it glows. The wolfram filament is enclosed in a glass bulb with a vacuum or inert gas (argon) to protect the filament from oxidation. Current is supplied to the filament by terminals or wires embedded in the glass. A lamp socket provides mechanical support and electrical connections.



Source:17456137-Lighting-Handbook-INDAL-Guide

A 230-volt incandescent light lamp with a medium-sized E27 (Edison 27 mm) male screw base.

Pros: Incandescent bulbs are manufactured in a wide range of sizes, light output, and voltage ratings, from 1.5 volts to about 300 volts. They require no external regulating equipment, have low manufacturing costs, and work equally well on either alternating current or direct current.

Source:https://architectureideas.info/2010/03/lamp-types-incandescent-lamp/

Cons: Incandescent bulbs are much less efficient than other types of electric lighting. The remaining energy is lost as heat. Because of this high heat output you'll see incandescent bulbs used as heating lamps, grow bulbs and incubator lights. Incandescent bulbs typically have short lifetimes compared with other types of lighting. The high temperature of the filament for a normal incandescent lamp makes wolfram particles to evaporate and condense on the wall of the glass bulb, darkening this, as a result.

- Incandescent halogen lamps have a halogen component (iodine, chlorine, bromine), added to the filling gas and work with the halogen regenerative cycle to prevent darkening. The evaporated wolfram is combined with the halogen to form a halogen wolfram compose. As opposed to wolfram vapour, it is maintained in the form of gas, the glass bulb temperature being high enough as to prevent condensation. When such a gas approaches the incandescent filament, it is decomposed due to the high temperature in wolfram that is again deposited in the filament, and in halogen, which continues with its task within the regenerative cycle.

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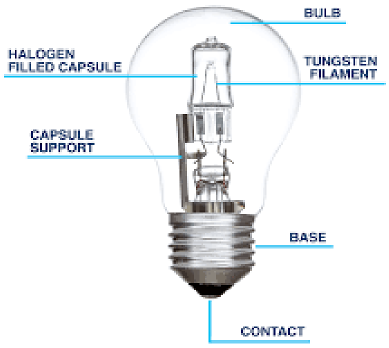

Source:https://www.thelightbulb.co.uk/resources/guide-buying-halogen/

The main difference between an incandescent lamp, apart from the halogen additive mentioned before, is in the glass bulb. Due to the fact that temperature of the glass bulb must be high, halogen lamps are of a smaller size than regular incandescent lamps.

Source:https://www.thelightbulb.co.uk/resources/guide-buying-halogen/

Source:https://www.vision-doctor.com/en/illumination-types/halogen-lamps.html

Their tubular- shaped glass bulb is made out of a special quartz glass (which must not be touched with the fingers). Since their introduction, wolfram halogen lamps have entered almost all applications where incandescent lamps were used. The advantages of wolfram halogen lamps with regard to regular incandescent lamps are the following: longer duration, greater luminous efficiency, smaller size, greater colour temperature and little or no luminous depreciation in time.

Fluorescent lamp

Source: httpsen.wikipedia.orgwikiFluorescent_lamp

Fluorescent tubes are a low pressure mercury discharge lamp in which light is produced predominantly through fluorescent powder activated by the discharge ultraviolet energy. The lamp, generally with a long tubular-shaped glass bulb and a sealed electrode for each terminal, contains low pressure mercury and a small amount of inter gas for ignition and arc regulation. The glass bulb inner surface is covered by a luminescent substance (fluorescent powder or phosphorous) whose composition determines the amount of emitted light and the lamp color temperature).

 

Source: The Sun and Photovoltaic Technologies_online

Typical fluorescent lamp electrode and lamps

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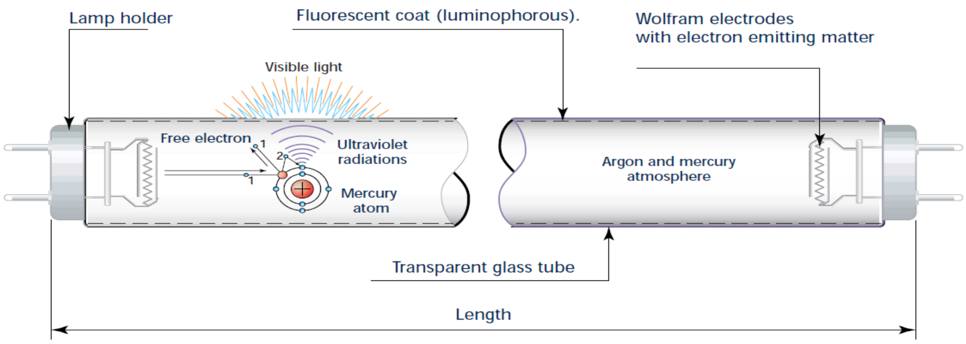
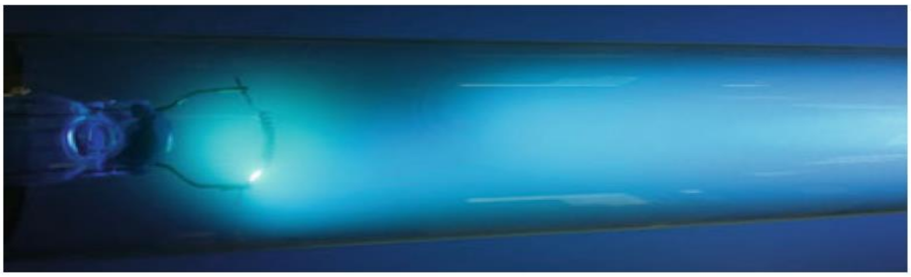


Source:17456137-Lighting-Handbook-INDAL-Guide

The main parts of the fluorescent lamp are the glass tube, the fluorescent layer, the electrodes, the filling gas and the base. The most important factor to determine the characteristics of the light of a fluorescent lamp is the type and composition of the fluorescent powder (or phosphorous) used. This establishes colour temperature (and, as a consequence, colour appearance), colour reproduction index (CRI) and, lamp luminous efficiency, to a great extent. Filling gas of a fluorescent lamp consists in a mixture of saturated mercury and an inert gas trimmer (argon and krypton). These lamps require an auxiliary equipment formed by a ballast and an igniter (starter), besides a compensation condenser to improve the power factor.



Source: The Sun and Photovoltaic Technologies_online

Gas discharge in a mercury fluorescent lamp without phosphor.

Compact fluorescent lamp

A compact fluorescent lamp (CFL) is a lamp designed to replace an incandescent light bulb; some types fit into light fixtures designed for incandescent bulbs.

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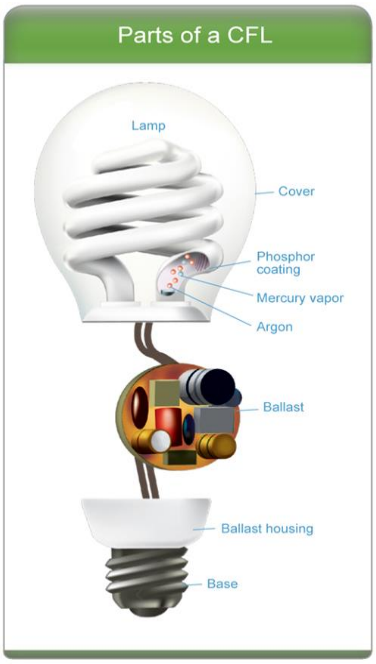
Source: https://eu.wikipedia.org/wiki/Lanpara_fluoreszente_konpaktu

The lamps use a tube that is curved or folded to fit into the space of an incandescent bulb, and a compact electronic ballast in the base of the lamp. A CFL has a higher purchase price than an incandescent lamp, but can save over five times its purchase price in electricity costs over the lamp's lifetime.



Source: https://www.energystar.gov/products/lighting_fans/light_bulbs/learn_about_cfls

The principle of operation remains the same as in other fluorescent lighting: electrons that are bound to mercury atoms are excited to states where they will radiate ultraviolet light as they return to a lower energy level; this emitted ultraviolet light is converted into visible light as it strikes the fluorescent coating, and into heat when absorbed by other materials such as glass. Phosphor designs are a compromise between the shades of the emitted light, energy efficiency and cost.

Only some CFLs are labelled for dimming control. Using a dimmer with a standard CFL is ineffective and can shorten bulb life.

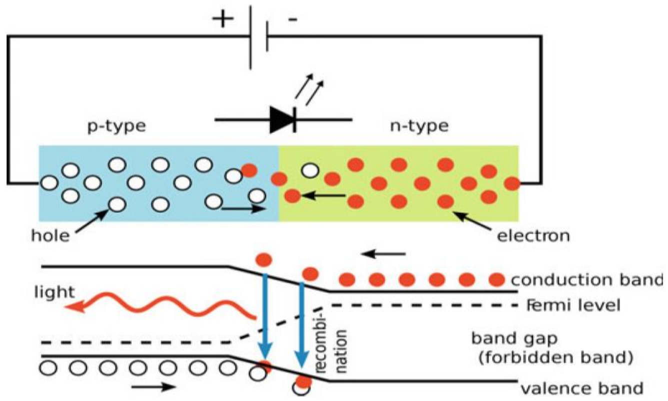
CFLs take longer than other lights to become fully lit. CFLs with decorative covers like globe or reflector shapes have a unique design challenge that results in the trade-off of a slower warm up time, which is why these CFLs take longer than bare spirals to reach full brightness.

Light Emitting Diode (LED)

The light-emitting diode (LED) is today's most energy-efficient and rapidly-developing lighting technology. Because of their ability to dramatically reduce energy consumption, LED lights are regarded as a green lighting alternative. And, because they contain no hazardous chemicals, their disposal represents less of an environmental threat.

A light-emitting diode (LED) is a semiconductor light source that emits light when current flows through it. Electrons in the semiconductor recombine with electron holes, releasing energy in the form of photons. The colour of the light (corresponding to the energy of the photons) is determined by the energy required for electrons to cross the band gap of the semiconductor.

Schematic diagram of an LED p–n junction:



Source:The Sun and Photovoltaic Technologies_online

LEDs emitting different, almost all monochromatic colors, and therefore it is possible to obtain a good and continuous spectrum and white light.

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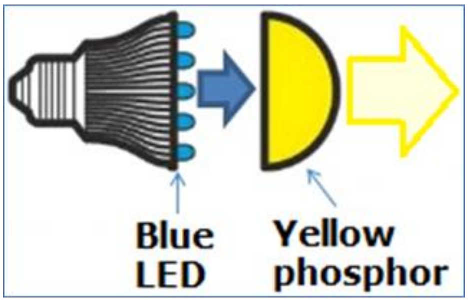
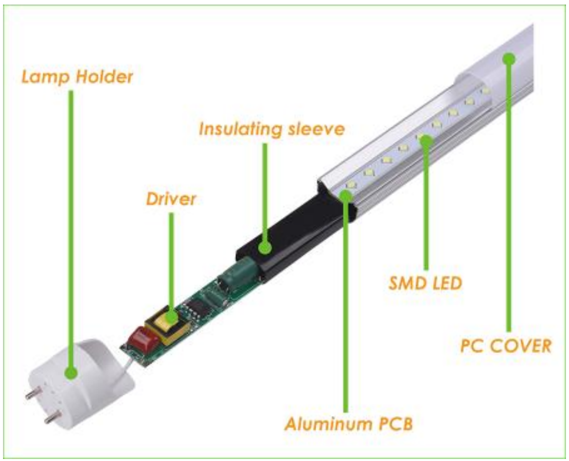
Source:The Sun and Photovoltaic Technologies_online

White light LEDs are made using two principal methods: either mixing light from multiple LEDs of various colors or using a phosphor to convert some of the light to other colors..

• Blue LED chip coated by yellow phosphor;



Source:EE-VET_Module_Lighting_for meeting in Latvia



Source: https://www.manufacturer.lighting/info/41/

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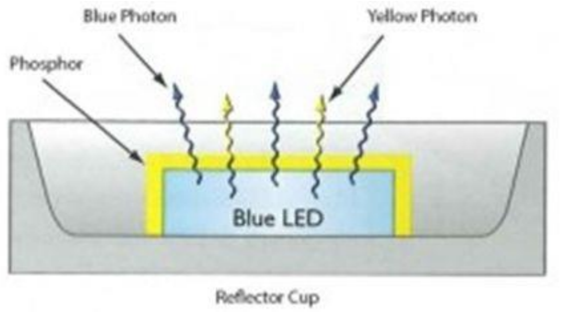
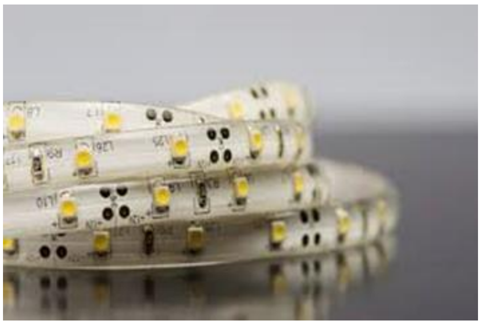
Blue LED + Yellow phosphor technology is most common at this time, due to its highest and continues to increase luminous efficacy achieved by a white light source of 100–230 lm/W and colour rendering index—80 to 85..

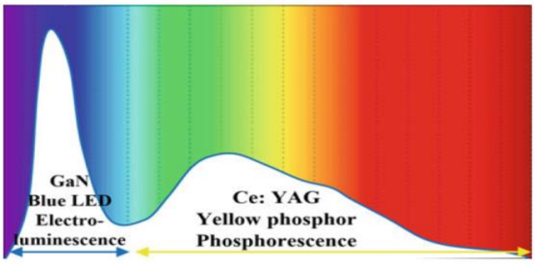


Source: EE-VET_Module_Lighting_for meeting in Latvia



Source: httpswww.elstarled.comconnecting-led-light-strips

SMD LED Strips



Source:The Sun and Photovoltaic Technologies_online

Spectrum formation of Blue LED + Yellow phosphor technology LEDs.

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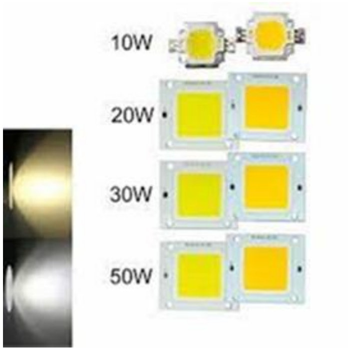
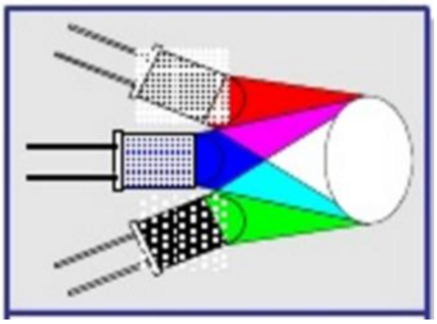


Source: https://www.indiamart.com/proddetail/led-light-emitting-diode-21188403433.html

COB (Chip-On-Board) LED

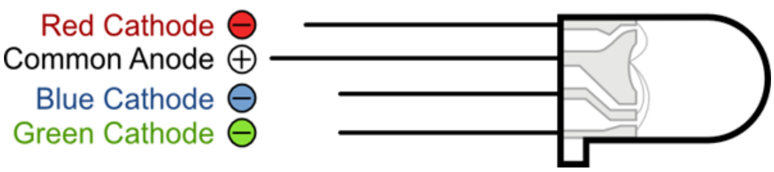
• Mixing of the light form red, green and blue LEDs—RGB LED;

RGB technology LEDs use mixing of the light from three colour LEDs, usually embedded in a common housing. The possibility of separately adjusting the intensity of the individual sub-diodes leads to the main advantage of RGB LEDs—the ability to adjust the colour of the light.



Source:EE-VET_Module_Lighting_for meeting in Latvia

In white light in RGB LEDs, except the powerful blue LED, the less efficient green and red are used. This leads to a slightly lower efficacy of RGB LEDs than of the Blue LED + Yellow phosphor technology LEDs of about 70–80 lm/W.



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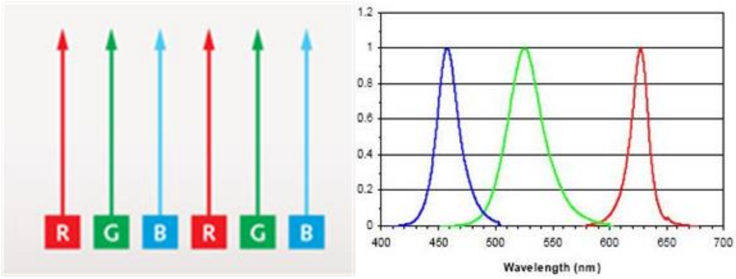
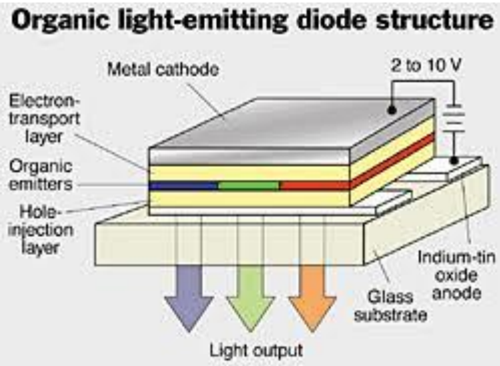


Source:EE-VET_Module_Lighting_for meeting in Latvia

•Other LEDs

The technology with ultraviolet LED covered by red, green and blue/yellow phosphors is not very common in practice and in the market at present. White light is made by coating near-ultraviolet (NUV) LEDs with a mixture of high-efficiency europium-based phosphors that emit red and blue, plus copper and aluminium-doped zinc sulphide (ZnS:Cu, Al) that emits green.



Source: Copyright Chemical & Engineering News, June 26, 2000 httpschem.beloit.eduedetcbackgroundLEDindex.html

Basic OLED design

In recent years, two promising LED technologies have entered into practice, which in the near future may be the basis of innovative white light sources: organic LED (OLED) and quantum dot LED (QLED or QDLED). In an OLED, the electroluminescent material composing the emissive layer of the diode is an organic compound. The organic material is electrically conductive due to the delocalization of pi electrons caused by conjugation over all or part of the molecule, and the material therefore functions as an organic semiconductor. Specific parts of the QLEDs are semiconductor nanocrystals with optical properties that let their emission color be tuned from the visible into the infrared spectrum. This allows quantum dot LEDs to create almost any color on the CIE diagram.

After optimization of still booming LED technology, it is expected to reach the theoretical maximum luminous efficacy of about 270 lm/W of light source with good colour rendering (CRI > 80), and even higher, for lighting applications that do not require so good color rendering.

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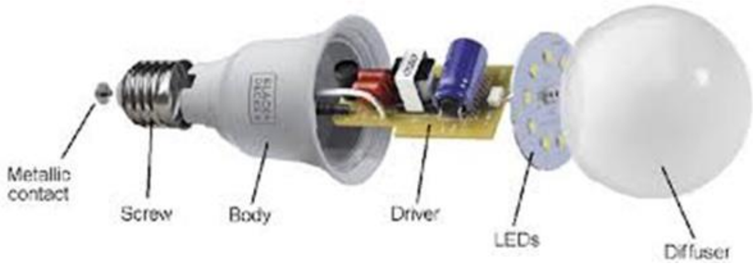
Source:https://arktura.com/10-creative-office-ceiling-lighting-ideas/

One of the benefits of the LED is its long lifetime, because they have no movable parts or filaments that may break. Technical life of LED is about 100,000 h, but usually they are not fully utilized due to the reduction of the luminous flux at the end of their life.

The operating temperature is the main parameter on which the life and efficiency of the LEDs depend. According to technical data of leading manufacturers and laboratory measurements, when the temperature is increased by 10 °C, the life of the LED is reduced twice, and the light output by 3–8%.



Source:https://www.researchgate.net/figure/Complete-composition-of-light-emitting-diode-LED-lamp-available-in-the-Brazilian-market_fig1_354227975

The power supply to the LED light sources is not directly carried out by the mains voltage and special drivers need to be developed, based on different electronic circuits. LED luminaires drivers most frequently use the electronic circuit with pulse width modulation (PWM) driver or with bridge rectifier driver with capacitive divider (BRC). With PWM drivers, a stable external current and corresponding light output of the LEDs are guaranteed in a wide range of supply voltage variations. The quality of the electronic LED drivers is of great importance for their reliable operation, as the life of the electronic components used in them, especially the capacitors, is commensurate and often less than that of the LEDs themselves.

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Source: https://www.gardeningknowhow.com/houseplants/hpgen/led-grow-light-information.htm

LED Grow Lights

Advantages of LED Lighting: long lifespan; energy efficiency; improved environmental performance; the ability to operate in cold conditions; no heat or UV emissions; design flexibility; instant lighting and the ability to withstand frequent switching; low voltage operation. LEDs are the most modern light sources with significant advantages over conventional lamps that allow them to become a major light source.

….

1.2.3 COMPARISON OF THE PARAMETERS AND CHARACTERISTICS OF THE LAMPS

To compare different light bulbs, you need to know about lumens. Lumens, not watts, tell you how bright a light bulb is, no matter the type of bulb. The more lumens, the brighter the light. Labels on the front of light bulb packages now state a bulb's brightness in lumens, instead of the bulb's energy usage in watts.

Parameter	Light source							
	Incandes-cent	Halogen	High-pressure sodium	Low-pressure sodium	Metal halide	Linear fluorescent	Compact fluorescent	Light – emitting diode

Life (h)	1000	3000	16000 - 24000	10000 - 18000	10000 - 16000	10000 - 15000	6000 - 12000	25000[a] - 100000
Luminous efficacy (lm/W)	9 - 13	15 - 25	70 - 140	140 - 170	70 - 110	50 - 90	40 - 70	80 – 180[b]
Colour rendering index CRI	98	100	25	0	75 - 95	80 - 95	80 - 90	70 - 85
Correlated colour temperature CCT	2700	3000	2100	1700	2700 - 6500	2700 – 6500[c]	2700 – 6500[c]	2700 – 6500[c]

a It is highly dependent on the temperature mode (cooling) of the LED module

b Luminous efficacy of LEDs continues to increase by approximately 10 lm/W per year the last 10 years

c It depends on the chemical composition of the phosphors used

Source: EE-VET_Module_Lighting_for meeting in Latvia

For most CFLs and many LEDs, life, performance and efficacy may be sharply reduced by their various sensitivities depending on lamp quality and how they are used. And nominal life is not the same thing as useful life, since lamps will become weaker with age.

Characteristics :Life; Luminous efficacy; Colour rendering index CRI; Correlated colour temperature CCT; Sensitivity to low temperatures; Sensitive to humidity; On/off Cycling; Turns on instantly; Durability; Heat Emitted; Failure Modes;

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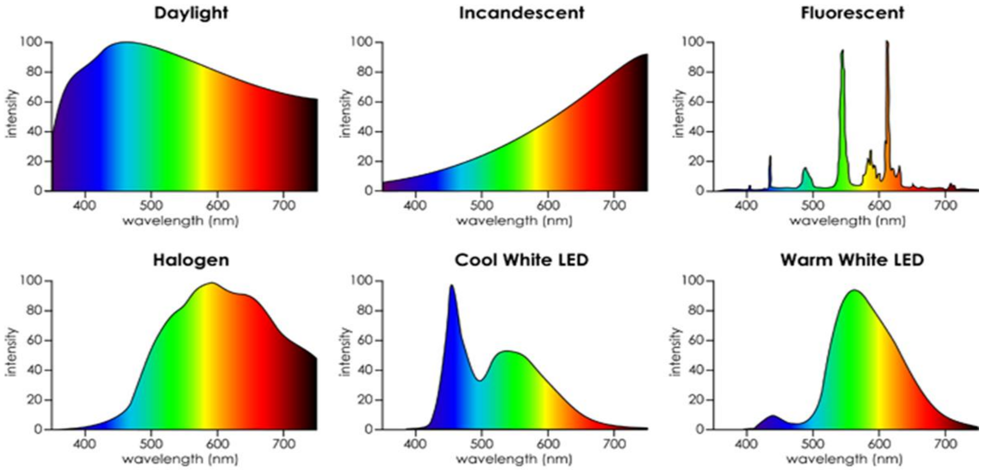
Typical spectral characteristics and corresponding colours of various lighting sources



Source: EE-VET_Module_Lighting_for meeting in Latvia

There's never been more energy-efficient ways to light your home or business, but it can be difficult to keep up as the technology continues improving and older products are phased out.

Quiz questions to Topic 2

1.3 TOPIC 3 - LUMINAIRES

1.3.1 INTRODUCTION

A luminaire is an electrical device used to create artificial light by use of an electric lamp or integrated LED module, which primary function is to deliver light. All light fixtures have a fixture body and a connection to the energy supply. Due to the high luminance of lamps, it is necessary to increase the emission apparent surface in order to avoid visual problems (glare). Also, it is necessary to shield lamps to protect them from external agents and to direct their flux in the most convenient way for visual task. According to the UNE-EN 60598-1* Norm, a luminaire may be defined as a lighting apparatus which spreads, filters or transforms light emitted by a lamp or lamps including all components necessary for supporting, fixing and protecting the lamps, (except for the lamps themselves).

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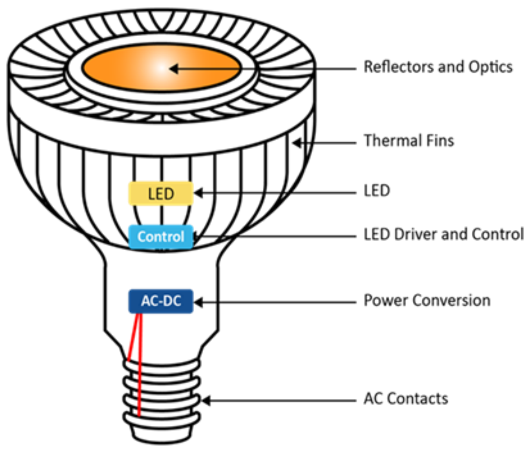


Source: EE-VET_Module_Lighting_for meeting in Latvia

Main components (EN 60598-1):

Body - the minimum physical element which supports and defines the volume of the luminaire and contains the key components.

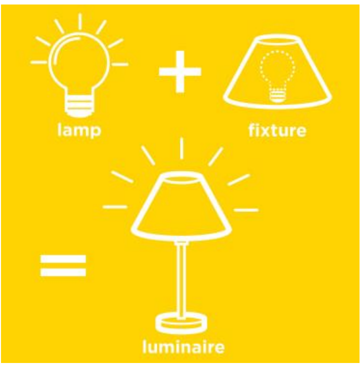
Control gear - appropriate control gear would be selected to suit different sources of artificial light.

Reflector - a specific surface inside the luminaire which models form and direction of the lamp flux.

Diffuser - this forms the cover of the luminaire in the direction of the luminous radiation.

Filters - in possible combination with diffusers, they are used to protect or lessen certain characteristics of luminous radiation.

Formal design solves luminous control depending on needs, which is the main aim: both a thermal control which makes its functioning stable and an electric control which offers adequate guarantees to the user, an easily installed luminaire, and minimum maintenance while in use. Regarding the most fundamental characteristic components, body, control gear, reflector, diffuser, and filter among others, must be mentioned..



Source: https://oculuslightstudio.com/2014/whats-a-luminaire/

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1.3.2 LUMINAIRE CLASSIFICATION ACCORDING TO

- the degree of protection from electric contacts:

Luminaires must secure protection of people from electric contacts. Depending on the degree of electric insulation, luminaires can be classified as:

Class 0: Luminaire with basic insulation, lacking double insulation or overall reinforcement as well as an earth connection.

Class I: Luminaire with functional basic insulation and an earth connection terminal or contact.

Class II: Luminaire with double basic insulation and /or reinforced overall insulation lacking provision for earth discharge.

Class III: Luminaire designed to be connected to extra-low voltage circuits, lacking internal or external circuits not working at an extra-low security voltage.

Source: https://www.barbier-luminaire.com/fr/collections/

- working conditions: IP, IK

The IP system (International Protection) established by the UNE-EN 60598 classifies luminaires according to their degree of protection from mechanical shock, dust and water. The term mechanical shock includes those elements like tools or fingers that are in contact with energy transmitting parts

The designation to indicate degrees of protection consists in characteristic IP letters followed by two numbers which indicate the compliance of conditions. The first of these numbers is an indication of protection from dust, the second number indicates the degree of protection from water.

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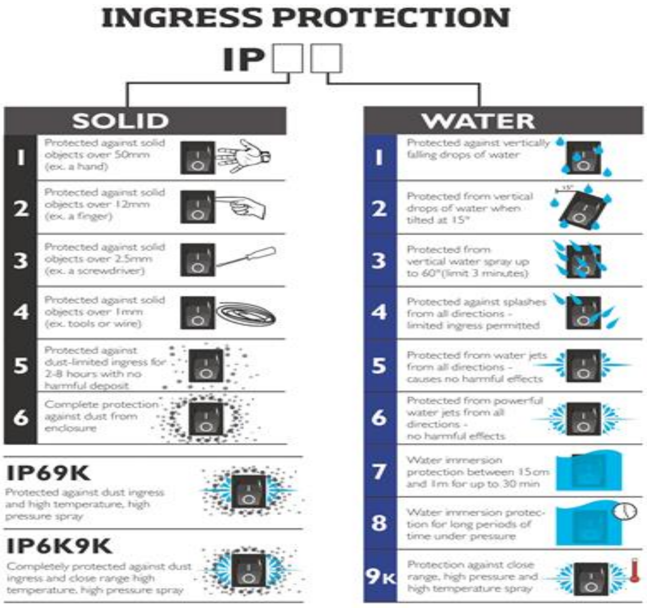

Source: EE-VET_Module_Lighting_for meeting in Latvia

IK ratings are defined as IK and a number from 00 to 10, this indicates the degree of protection provided by the electrical enclosures against external mechanical impacts.

Source: www.premiseled.comik-ratings-here-is-everything-you-need-to-know

- the mounting surface flammability

Luminaires cannot be mounted on any surface at hand. The surface flammability and the luminaire body temperature impose certain restrictions. Of course, if the surface is non-combustible, there is no problem. For classification purposes, the EN-60598 Norm defines flammable surfaces as usually flammable or easily flammable. The usual flammable classification refers to those materials whose ignition temperature is, at least, 200 ºC, degrees and do not weaken or deform at that temperature.

Classification	Symbol
Luminaires suitable for direct mounting only on non- combustible surfaces.	No symbol, but a warning notice is required.
Luminaires suitable for direct mounting only on easily flammable surfaces.	▽F On plaque.

Source: 17456137-Lighting-Handbook-INDAL-Guide

The easily flammable classification refers to those materials which cannot be classified as usually flammable or non-combustible. Materials in this category may be used as mounting surface for luminaires. Suspended mounting is the only option for this type of material.

- service conditions

Luminaires for general indoor lighting are classified by the C.I.E. according to the total percentage of luminous flux distributed above and below the horizontal plane.

Luminaire type	% Upward flux distribution	% Downward flux distribution
Direct	0 - 10	90 - 100
Semi-direct	10 - 40	60 - 90
Direct-indirect	40 - 60	40 - 60
General diffuse	40 - 60	40 - 60
Semi-indirect	60 - 90	10 - 40
Indirect	90 - 100	0 - 10

Source: 17456137-Lighting-Handbook-INDAL-Guide

Luminaire classification according to radiation of luminous flux.

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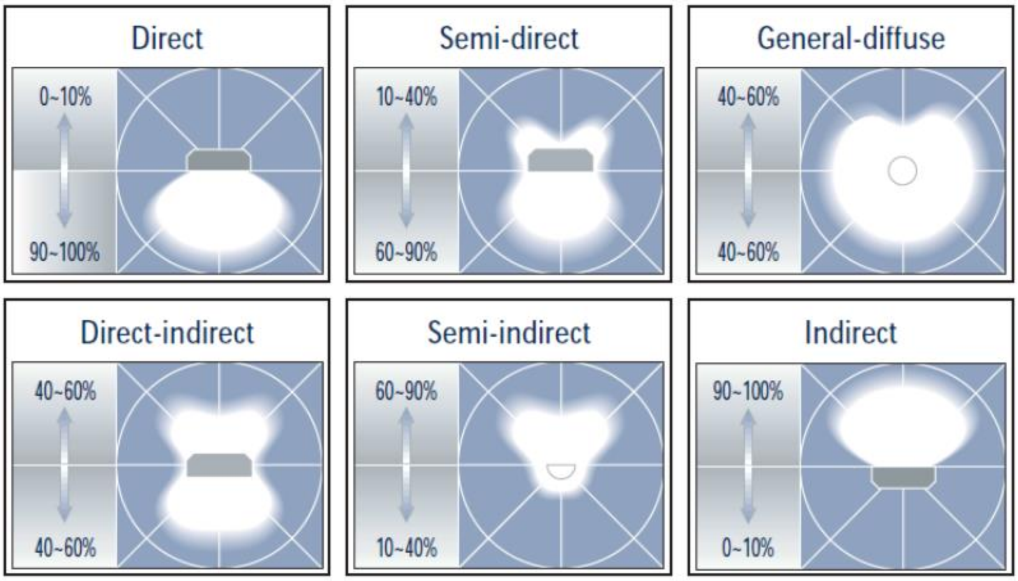
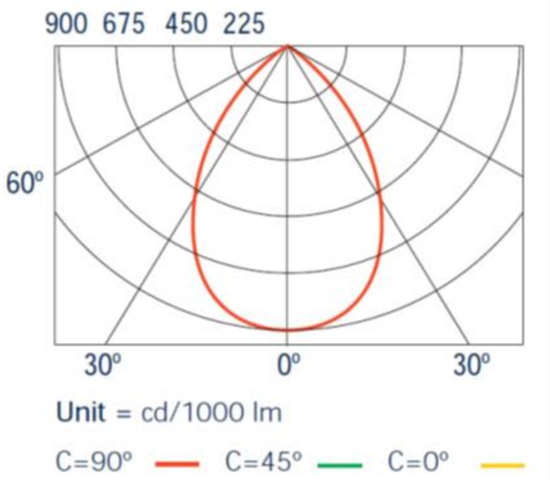


Source: 17456137-Lighting-Handbook-INDAL-Guide

In turn, with regards to the symmetric flux emitted, a classification may be considered into two groups:

Symmetrical distribution luminaires: Those in which the luminous flux is spread symmetrically with respect to the symmetric axis and spatial distribution of luminous intensities. It may be represented as a single photometric curve.



Source: 17456137-Lighting-Handbook-INDAL-Guide

2) Asymmetric distribution luminaires: Those in which the luminous flux is spread asymmetrically with respect to the symmetric axis and the spatial distribution of luminous intensities. It may expressed by a photometric solid, or, partially, by a flat curve of such a solid, depending on certain characteristic planes.

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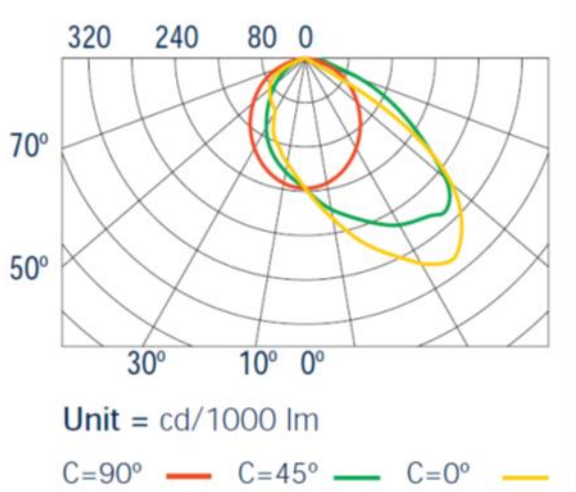
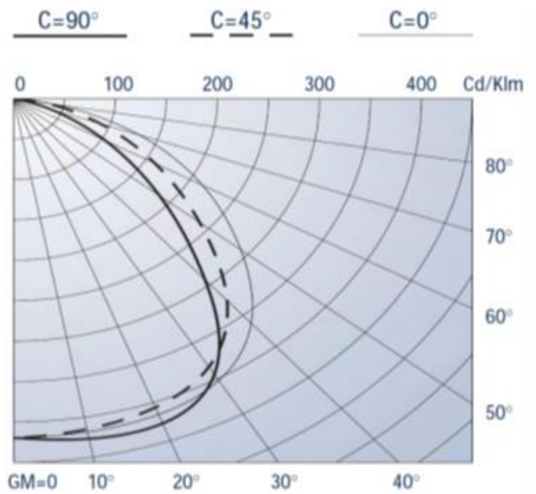


- photometric information which accompanies indoor lighting luminaires

Polar distribution curves - these curves are generally represented in the coordinate system C- γ. Since there are infinite planes, in general, three C planes are represented, which are the following:



Source: 17456137-Lighting-Handbook-INDAL-Guide

- Plane C = 0°.

- Plane C = 45°.

- Plane C = 90°.

Polar distribution curves are in the cd units per 1 000 lumens of flux emitted by the lamp. They are represented in cd/1 000 lm or cd/Klm. Polar diagram in the C-γ system.

Quiz questions to Topic 3

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1.4 TOPIC 4 – LIGHTING CONTROL AND PROTECTION

1.4.1 INTRODUCTION

Protective devices are used to guard against fires that might be caused by a short-circuit, overload, insulation fault; protect people against electric shock in the event of indirect contact. Circuit breakers are used to protect lighting installations in buildings.

Although the protective devices are sometimes used as lighting circuit control units, it is recommended to install separate control devices which are more suitable for frequent switching operations of the lighting circuits - switches, impulse relays. Control devices as switches and impulse releys are used to control luminaires switching on and off by switching the phase conductor(s). They are located downstream of the protective devices of lighting circuit.

Lighting switches are very important components to lighting control in any building. A lighting switch is directly responsible for completing or breaking a circuit for a specific purpose. Most lighting switches are devoted to turn on and off the luminaires, but can also be installed for a variety of different uses, such as controlling fans. The switches are not intended to protect the lighting installation. The main types of lighting switches are as one-way switches, two-way switches, multiway switches, crossover switches, switches with infrared sensor, and luminaires with a built-in infrared sensor (without switches).

1.4.2 LIGHTING CONTROL WITH ONE-WAY SWITCH

The one-way switches is used to control one luminaire, regardless of the number of lamps. All lamps turn on and off at the same time – Figure 4.1 and Figure 4.2. In contemporary homes, the one-way switch used in small rooms (e.g. guest bathrooms and pantries) or basements.

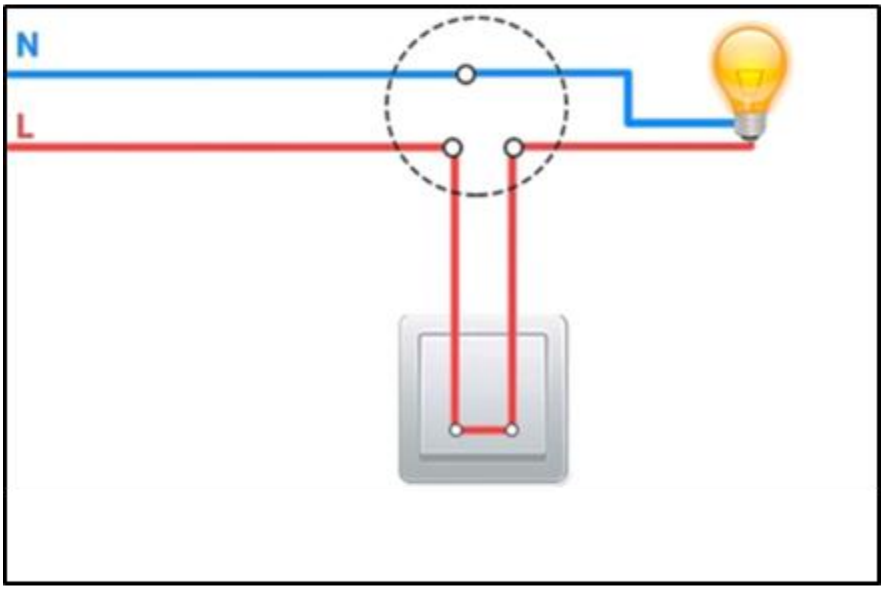

Figure 4.1. One-way switch wiring diagram

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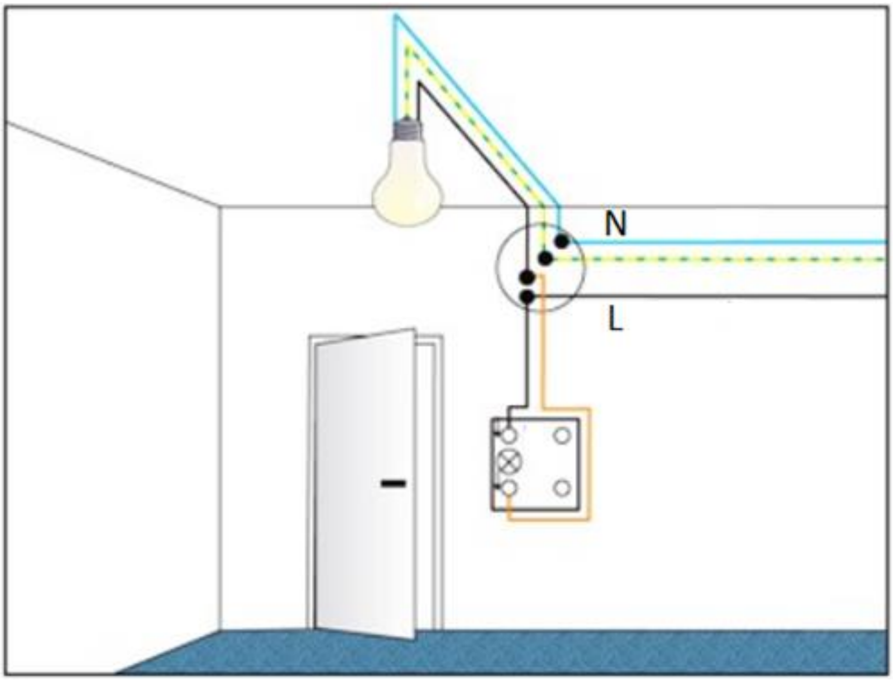

Figure 4.2. Installation with one-way switch (source: https://napravisam.net/?p=12475)

1.4.3 LIGHTING CONTROL WITH TWO-WAY SWITCH

Two-way switch represents two buttons mounted in a common fixture. Each of them controls an independent current circuit and this allows greater flexibility in lighting control – two groups of luminaires can be turned on separately or simultaneously – shown in Figure 4.3 and Figure 4.4. It consists of two separate rockers so that it can turn each lamp on or off individually. This solution proves convenient in rooms with at least two lighting sources – one on the ceiling and one beneath a wall cupboard, for example.

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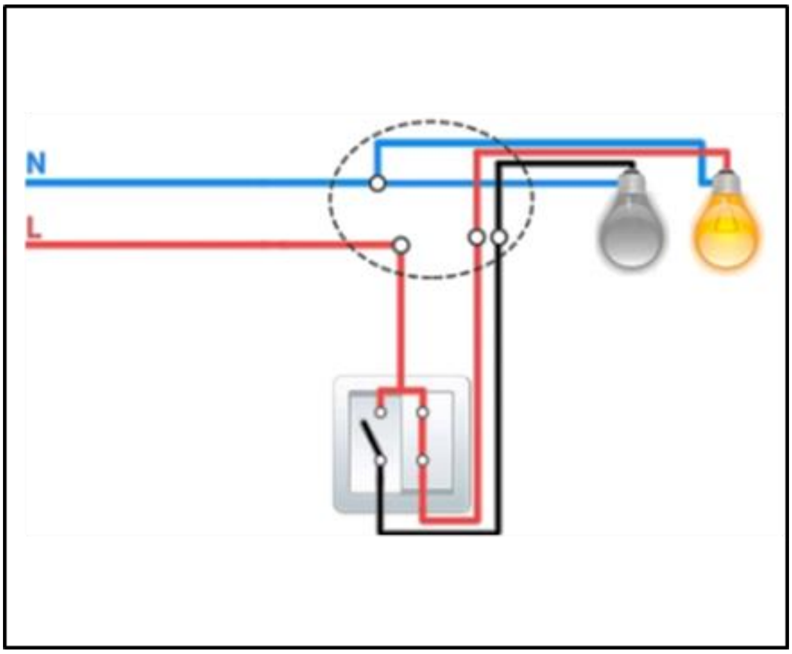

Figure 4.3. Two-way switch wiring diagram

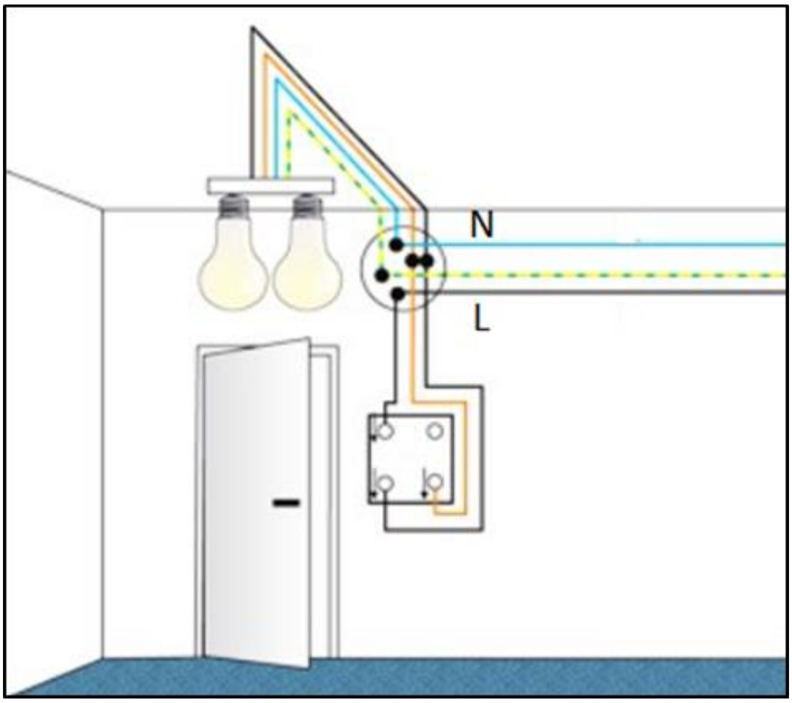

Figure 4.4. Installation with two-way switch (source: https://napravisam.net/?p=12475)

1.4.4 LIGHTING CONTROL WITH DEVIATOR AND CROSSOVER SWITCHES

Deviator switches, also knowns as multiway or toggle, can control one lamp or luminaire from two different spots – shown in Figure 4.5 and Figure 4.6. Double toggle switches have a double rocker and rely on two electric circuits (two wires) which are triggered separately. Installations with deviator switchers come in handy in long hallways or staircases, where the luminaires can be turn on from alternating directions.

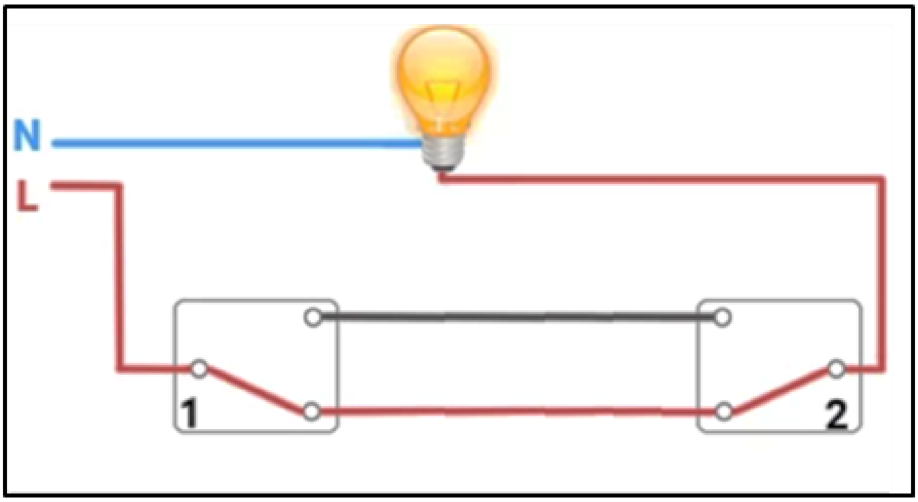

Figure 4.5. Deviator switch wiring diagram

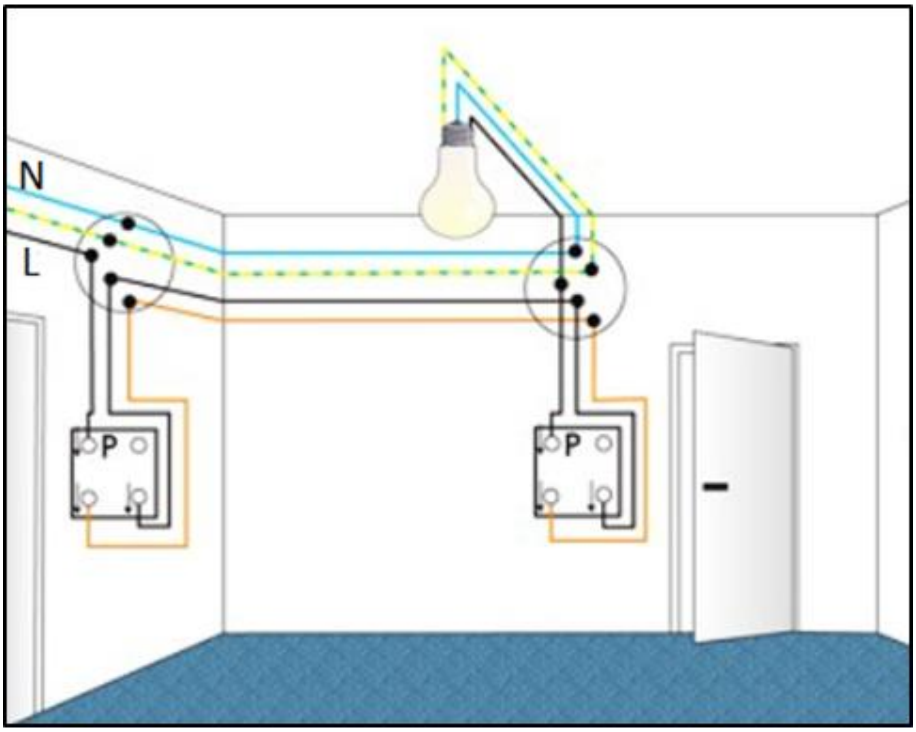

Figure 4.6. Installation with deviator switch diagram (source: https://napravisam.net/?p=12475)

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In larger living areas, often find crossover switches – shown in Figure 4.7. They enable to operate one lamp from at least three different spots. In the bedroom, for instance, this type of light switch next to the door and on both sides of the bed might be install.

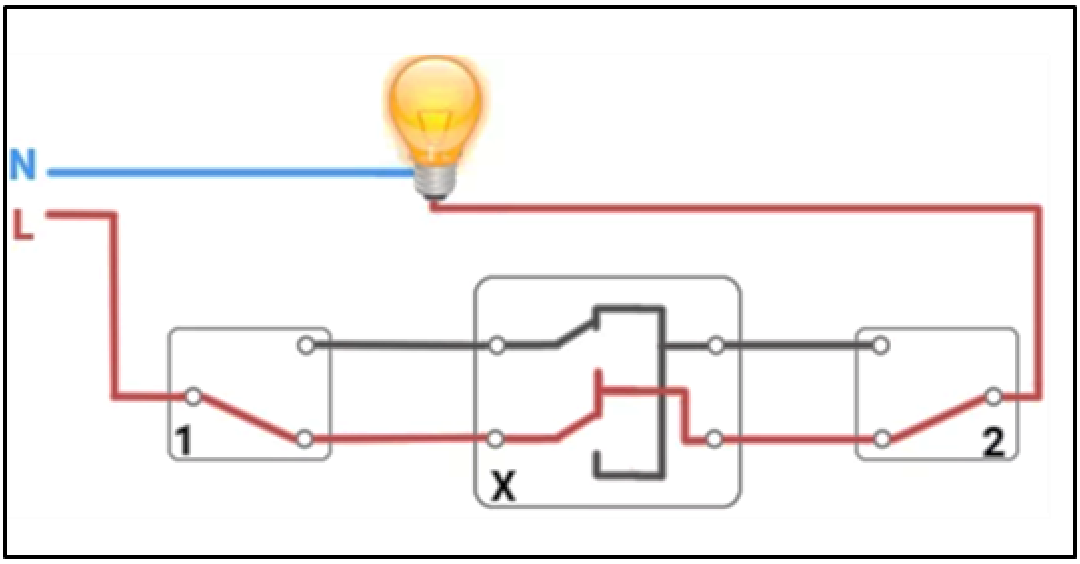

Figure 4.7. Crossover switch wiring diagram

1.4.5 LIGHTING CONTROL WITH SENSORS

A modern alternative solution to the problem of long halls and corridors is the installation of electric switches with sensor, shown in Figure 7.8, or luminaires with a built-in infrared sensor, shown in Figure 7.9.

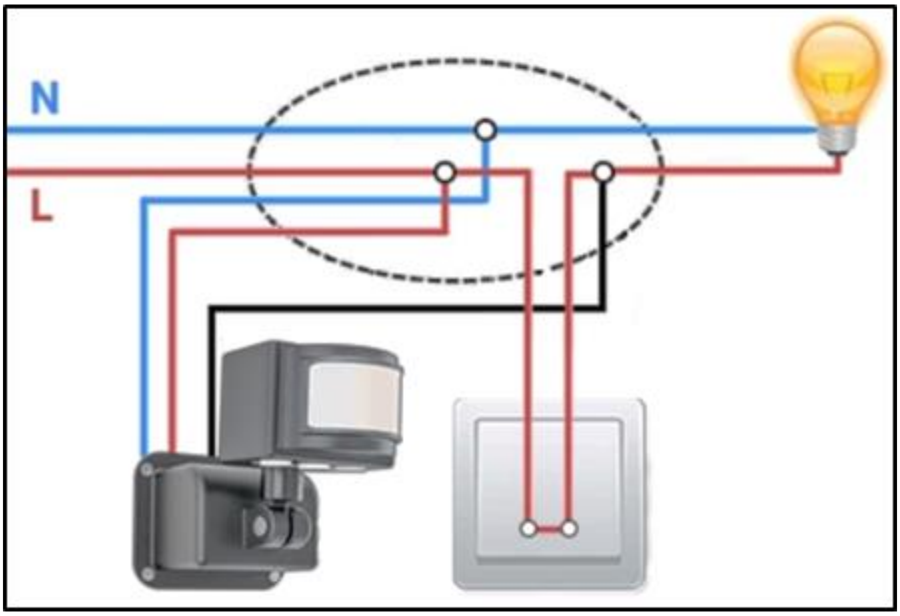

Figure 4.8. Switch with infrared sensor

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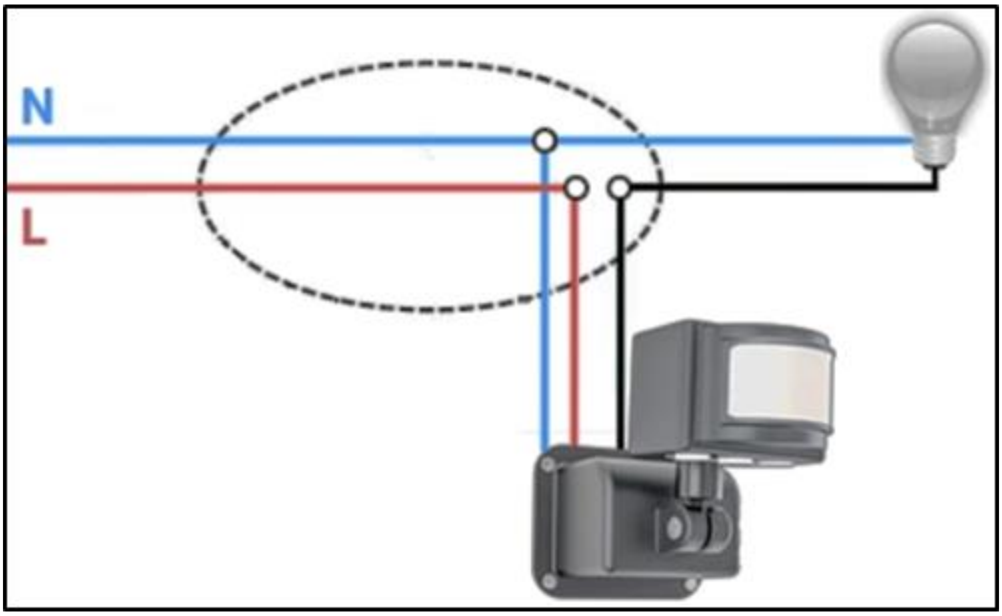

Figure 4.9. Luminaire with a built-in infrared sensor

With a built-in infrared sensor, the switch is activated and turns on the lighting as soon as a moving person comes into the "sight" area of the sensor. The switch has a time relay and turns itself off after the set period has elapsed. Luminaires with a built-in infrared sensor (shown in Figure 4.10) are suitable for corridors of multi-storey apartment buildings, because only those floors where people pass are illuminated, and energy efficiency of buildings is increased.

4.10. Luminaires with a built-in infrared sensor

1.4.6 LIGHTING CONTROL WITH IMPULSE RELAY

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In recent years, impulse relay controlled by buttons have been widely used to control lighting circuits. They are installed on a busbar in the electrical boards, together with the protective devices – shown in Figure 4.11 and Figure 4.12. This type of implementation has an advantage over electric switch schemes because they can to control more lamps than a switches. Another advantage of the impulse relay is the ability to be controlled by multiple buttons in single circuit, which saves wires compared to the deviator switches circuit.

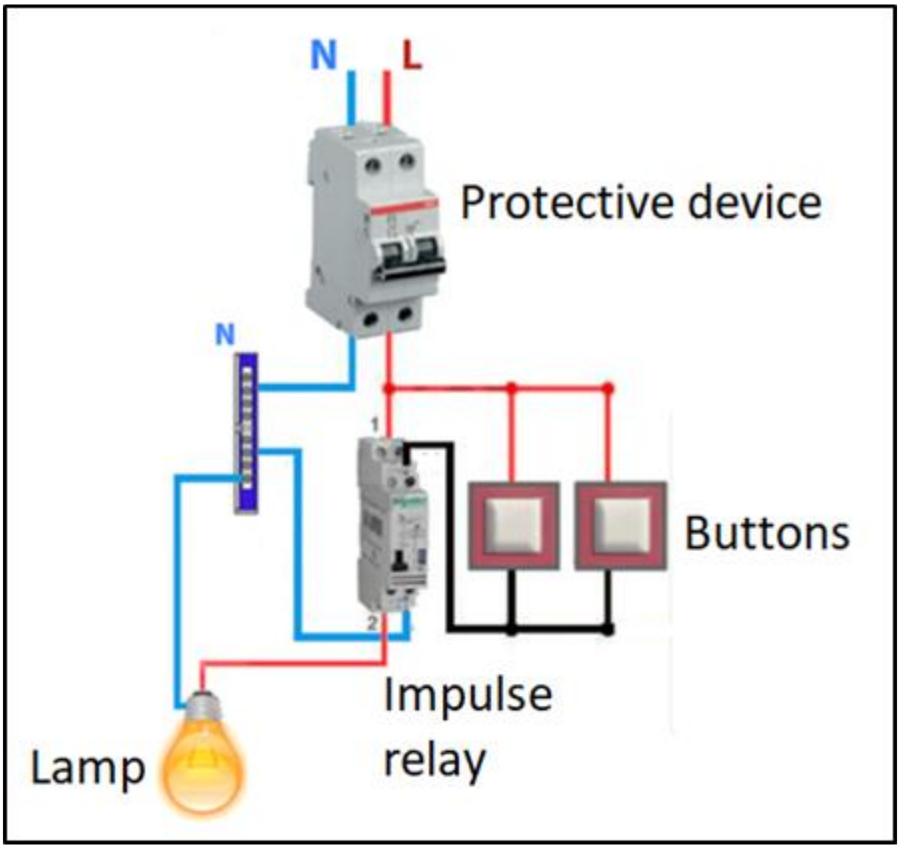

Figure 4.11. Wiring diagram of lighting circuit with impulse relay to control

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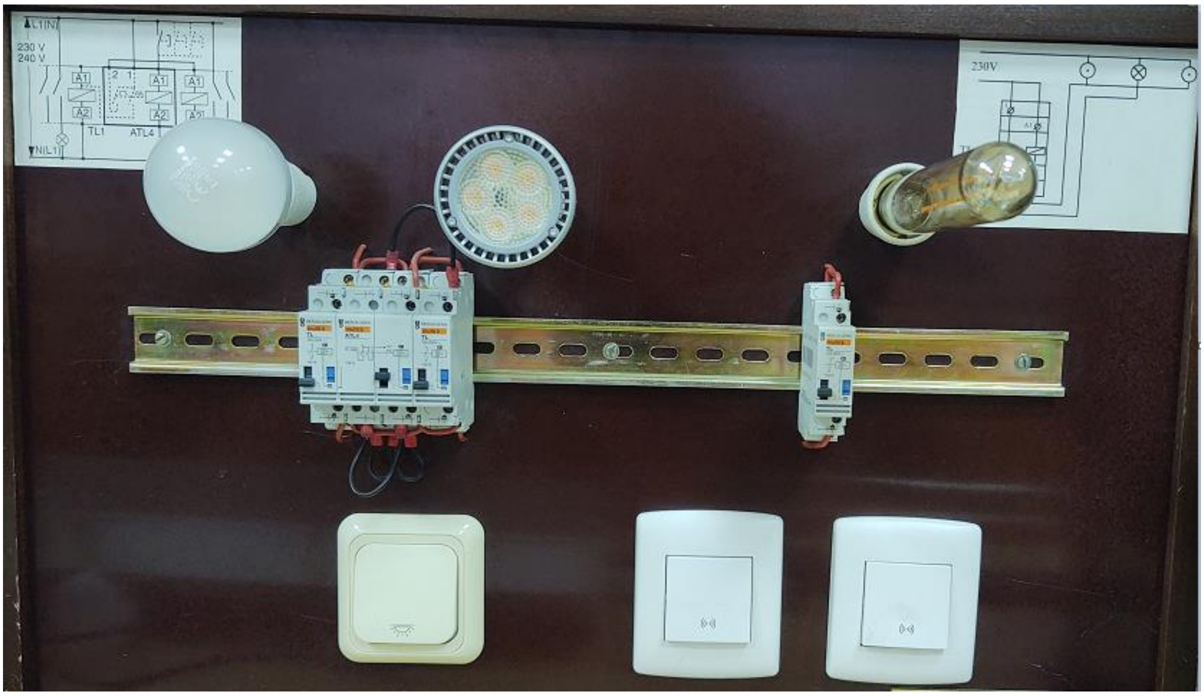

Figure 4.12. View of lighting circuit with impulse relays to control

1.4.7 LIGHTING PROTECTION

To guard against fires that might be caused by a faulty electric circuit or overload, protective devices are used in lighting circuits.

Circuit breakers as protective devices are used to protection of electrical distribution, electrical loads, and lighting circuits against short-circuits and overloads. For protecting electrical circuits with circuit breakers, the same are installed on all normally unearthed poles (P) or phases (L) as shown in Figure 4.13.

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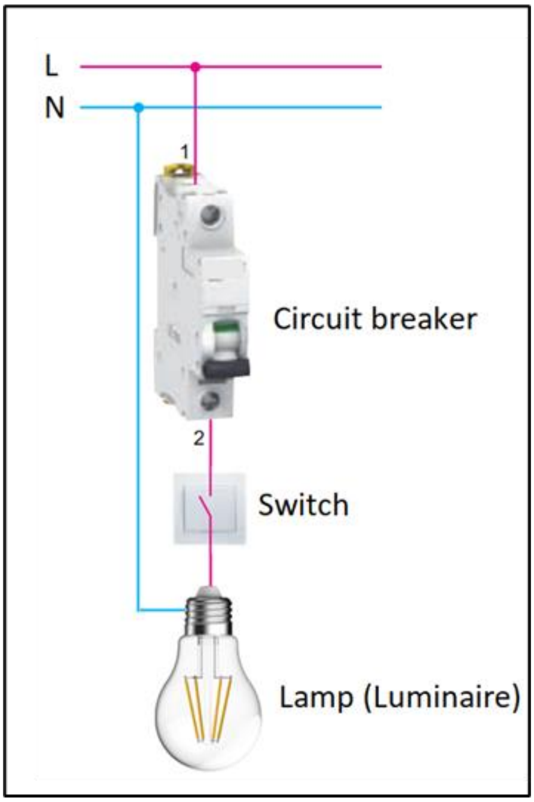

Figure 4.13. Wiring diagram of lighting circuit protected with circuit breaker

The rating current In of the circuit breaker is chosen above all to protect the electrical conductors - for cables it is chosen according to the cross-section. Generally, the rating should be greater than the nominal current of the circuits. In lighting circuits, to ensure continuity of service, it is recommended that this rating be approximately twice the rated current In of the circuit by limiting the number of lamps per circuit.

Depending on the inrush current of the electric load, circuit breakers are mainly selected with type B, C or D tripping curves – Table 4.1. Electricians most often use the type C tripping curve for lighting circuits.

Table 4.1. Choosing of tripping curves a circuit breaker

Tripping curve	Range of the inrush current
B	(3÷5).In
C	(5÷10).In
D	(10÷20).In

Lighting circuits are protected by circuit breakers for a rating current In that does not exceed:

- for industrial and public buildings – In ≤ 25 A;

- for residential buildings, if the maintenance of the lighting system is not carried out by a specialist – In ≤ 16 A.

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Recommended maximum power output values per phase of a lighting circuit at supply voltage 230 V (frequency f = 50 Hz) and power factor PF = 0,9 are up to 2200 W.

1.4.8 QUIZ QUESTIONS

What types of electrical switches for lighting circuits do you know?

What does a circuit breaker do?

What are the advantages of impulse relay than a switches?

1.5 TOPIC 5 – INDOOR LIGHTING DESIGN AND MAINTENANCE

1.5.1 INTRODUCTION

Lighting requirements of the indoor lighting must satisfy three basic human needs: visual comfort, where observers feel comfortable and it contributes to a higher level of productivity; visual performance, where observers are able to perform their visual tasks for extended periods of time; and safety.

The standard EN 12464-1:2021 - Light and lighting - Lighting of work places - Part 1: Indoor work places specifies lighting requirements for humans in indoor work places, which meet the needs for visual comfort and performance of people having normal, or corrected to normal ophthalmic (visual) capacity [1]. This document specifies requirements during lighting design and maintenance for most indoor work places and their associated areas in terms of quantity and quality of illumination.

The lighting requirements in EN 12464-1:2021 for activity area (task area) are maintained illuminance $\bar{E}_m$, modified maintained illuminance $\bar{E}_m$, minimum illuminance uniformity Uo, minimum colour rendering indices Ra, UGR limits (Unified Glare Rating limit, R_{UGL}), maintained cylindrical illuminance $\bar{E}_{m,z}$, maintained illuminance on walls $\bar{E}_{m,wall}$ and maintained illuminance on ceilings $\bar{E}_{m,ceiling}$. The illuminance and its distribution on the activity area and on its immediate surrounding area have a great impact on how quickly, safely and comfortably a person perceives and carries out the visual task.

1.5.2 LIGHTING REQUIREMENTS FOR INDOOR LIGHTING DESIGN AND MAINTENANCE

The main criteria determining the luminous environment with respect to electric lighting and daylighting are: luminance distribution, illuminance, glare, directionality of light, lighting in the interior space, colour rendering and colour appearance of the light, flicker, variability of light (levels and colour of light) [1].

Luminance Distribution and Reflectance

The luminance distribution in the visual field controls the adaptation level of the eyes which affects task visibility. The luminance distribution in the visual field also affects visual comfort. The following should be avoided for the reasons given: too high luminances and luminance contrasts which can give rise to glare, too high luminance variation which will cause fatigue because of constant re-adaptation of the eyes, too low luminances and too low luminance contrasts which result in a dull and non-stimulating working environment. To create a well-balanced luminance distribution the luminances of all surfaces shall be taken into

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consideration. They are determined by the reflectance of and the illuminance on the surfaces. To avoid gloom and to raise adaptation levels and comfort of people in buildings, it is highly desirable to have bright interior surfaces. Room brightness is considered by specifying illuminances on walls and ceiling and by recommending reflectances. High surface reflectances contribute to energy savings and can lead to better visual comfort. For choice of materials, the following ranges of reflectances are recommended:

- ceiling: 0,7 to 0,9;
- walls: 0,5 to 0,8;
- floor: 0,2 to 0,6.

The reflectance of major objects (like furniture, machinery, etc.) should be in the range of 0,2 to 0,7. Clear interior glass has a typical reflectance of 0,1. In design calculations, surface reflectances should be defined as close to the real surfaces as possible taking into account the variation in reflectance across the surface. It is recommended that the ratio of luminances of the work surface and walls is less than 5:1 - Figure 1 [2].

Figure 1. Recommended ratios of luminances (left) and illuminance (right) of the task area and walls

Maintained illuminance

The maintained illuminance value Ēm shall at least meet the requirement as given in [1] and shall be used for normal visual conditions taking into account the following factors: psycho-physiological aspects such as visual comfort and well-being; requirements for visual tasks; visual ergonomics; practical experience; contribution to functional safety; economy. The scale of illuminance (in lx) sets the recommended increments of maintained illuminance that are in accordance with EN 12665 to create a different visual perception:

5 - 7,5 - 10 - 15 - 20 - 30 - 50 - 75 - 100 - 150 - 200 - 300 - 500 - 750 - 1 000 - 1 500 - 2 000 - 3 000 -

5 000 - 7 500 - 10 000 lx.

The required values of the maintained illuminance Ēm, modified maintained illuminance Ēm, minimum illuminance uniformity Uo, minimum colour rendering indices Ra, UGR limits (Unified Glare Rating limit, R_{UGL}), maintained cylindrical illuminance Ēm,z, maintained illuminance on walls Ēm,wall and maintained illuminance on ceilings Ēm,ceiling are given in [1]. An example table with lighting requirements for task areas, activity areas, room and space brightness is presented in Table 1 - (a) - required: minimum value; (b) - modified: considers common context modifiers in Table 2.

Table 1. Lighting requirements for task areas, activity areas, room and space brightness for typical rooms

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Type of task or activity area	$\bar{E}_m$ [lx] (a)	$\bar{E}_m$ [lx] (b)	U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$ [lx] ($U_o \geq 0,10$)	$\bar{E}_{m,wall}$ [lx] ($U_o \geq 0,10$)	$\bar{E}_{m,ceiling}$ [lx] ($U_o \geq 0,10$)
Corridors and circulation areas	100	150	0,40	40	28	50	50	30
Stairs, escalators, travolators	100	150	0,40	40	25	50	50	30
Reception/cashier desk, porters desk	300	500	0,60	80	22	75	75	50
Washrooms, bathrooms, dressing-, lockers-, shower-, sink- and toilet areas	200	300	0,40	80	25	75	75	50
Store and stockrooms	100	150	0,40	80	25	100	50	30
Offices - Filing, copying	300	500	0,40	80	19	100	100	75
Offices - Writing, typing, reading, data processing	500	1 000	0,60	80	19	150	150	100
Conference and meeting rooms	500	1 000	0,60	80	19	150	150	100
Nursery and play room	300	500	0,40	80	19	100	100	75
Classroom	500	1 000	0,60	80	19	150	150	100
Auditorium, lecture halls	500	750	0,60	80	19	150	150	50
Computer work only	300	500	0,60	80	19	100	100	75
Practical rooms and laboratories; handcraft rooms	500	750	0,60	80	19	150	100	100
Libraries - Reading area	500	750	0,60	80	19	100	100	50
Sports halls, gymnasiums, swimming pools	300	500	0,60	80	22	100	75	30
Health care premises - Simple examinations	300	500	0,60	80	19	100	100	75
Examination and treatment; operating areas	1 000	1 500	0,60	90	19	150	150	100
Sewing, fine knitting, taking up stitches	750	1 500	0,70	80	22	150	150	100
Kitchen	500	1 000	0,60	80	22	100	100	75
Resting rooms	100	200	0,40	80	22	50	50	30
Canteens and break areas	200	500	0,40	80	22	75	75	50

Recommended to increase the maintained illuminance Ēm by one or two steps in the scale of illuminances, depending on the context modifiers given in Table 2 if the assumptions differ from the normal visual conditions [1].

Table 2. Context modifiers for increase of maintained illuminance

visual work is critical;
errors are costly to rectify;
accuracy, higher productivity or increased concentration is of great importance;
task details are of unusually small size or low contrast;
the task is undertaken for an unusually long time;
the task area or activity area has a low daylight provision;
the visual capacity of the worker is below normal.

Decreasing illuminance by one step may be considered when conditions apply: task details are of an unusually large size or high contrast; the task is undertaken for an unusually short time [1].

The size and position of the task or the activity area shall be stated and documented. For work stations where the size and/or location of the task area is unknown: the whole area is treated as the task area or the whole area is uniformly (Uo ≥ 0,40) lit to an illuminance level specified by the designer; if the task area becomes. If the whole area is lit to a given illuminance value then it is recommended that the lighting is controlled in appropriate zones. When multiple tasks take place in the area, requirements for all these tasks shall be complied with [1].

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Immediate Surrounding Area and Background Area

The illuminance of the immediate surrounding area (Figure 2) shall be related to the illuminance of the task area or activity area and should provide a well-balanced luminance distribution in the visual field. The immediate surrounding area should be a band with a width of at least 0,5 m around the task area within the visual field. The illuminance of the immediate surrounding area may be lower than the illuminance on the task area but shall be not less than the values given in Table 3 [1].

In indoor work places, particularly those devoid of daylight, a large area outside the immediate surrounding area needs to be illuminated. The background area (Figure 2) is a horizontal area on floor level. It is adjacent to the immediate surrounding area within the limits of space and shall be illuminated with a maintained illuminance of 1/3 of the value of the immediate surrounding area. For larger rooms the band shall be at least 3 m wide. The size and position of the background area shall be stated and documented [1].

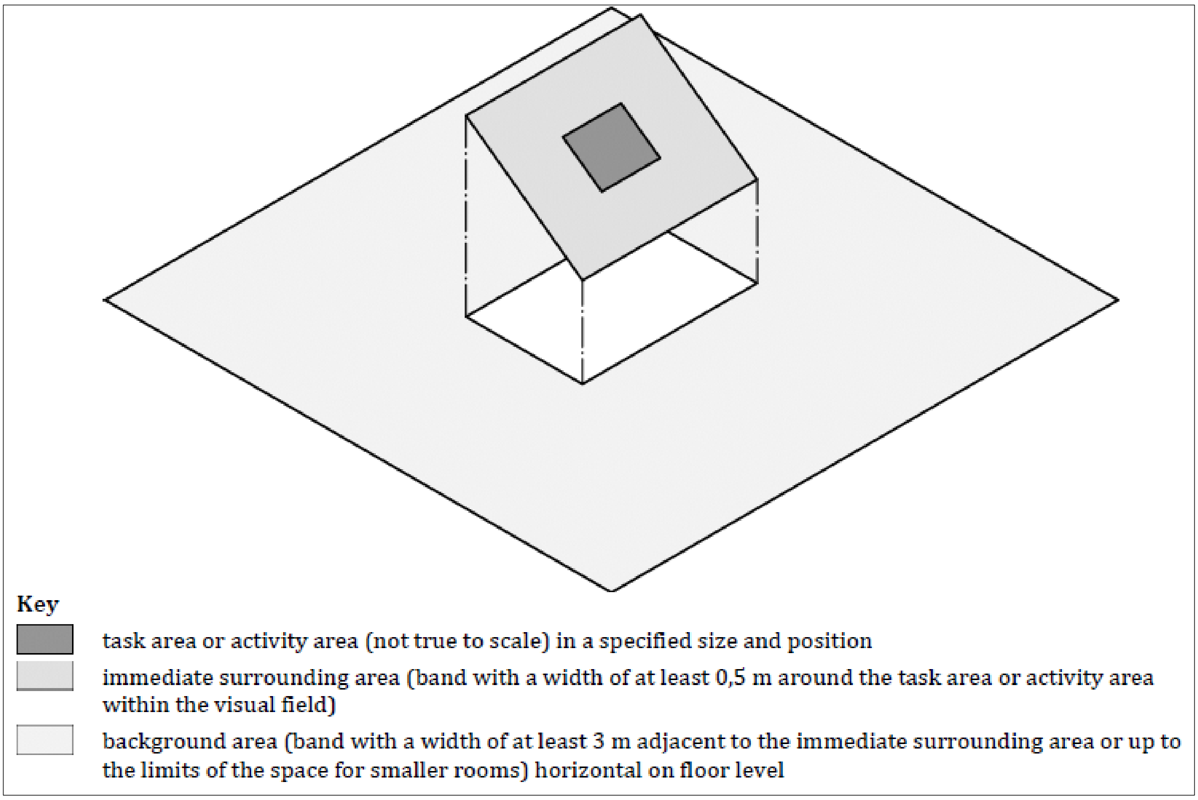

Figure 2. Minimum dimensions of immediate surrounding area and background area in relation to task and activity area (not true to scale)

Table 3. Relationship of illuminances on immediate surrounding to the illuminance on the task area

Illuminance on the task area or activity area Ēm, [lx]	Illuminance on immediate surrounding areas, [lx]
≥ 750	500

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500	300
300	200
200	150
≤ 150	equal to task area

In the task area or activity area, **the illuminance uniformity** Uo shall be not less than the minimum uniformity values given in [1]. Uniformity in the immediate surrounding area shall be Uo ≥ 0,40. On the background area, the walls and the ceiling the uniformity shall be Uo ≥ 0,10.

Good visual communication and recognition of objects within a space require that the volume of space in which people move or work shall be illuminated. This is fulfilled by providing adequate average cylindrical illuminance in the space. The required **maintained average cylindrical illuminance** $\bar{E}_{m,z}$ to be determined on a horizontal plane in the room and space for each type of task is given in [1] and Table 1. The uniformity of the average cylindrical illuminance shall be Uo ≥ 0,10. The height of the horizontal plane shall be 1,2 m for seated people and 1,6 m for standing people above the floor.

Discomfort Glare

Bright sources of light can cause glare and can impair the vision of objects. It shall be avoided by suitable shielding of light sources - Figure 3. For luminaires where the light source is directly visible, the minimum shielding angles α in the visual field given in Table 4 shall be applied for the specified light source luminance. For luminaires where a direct view of the light source is obscured via optics, the maximum average luminaire luminance for the values of vertical photometric angle γ given in Table 5 shall be applied. The values given in Table 4 and Table 5 do not apply to luminaires with an upward component only, mounted above normal eye level or to luminaires with a downward component only, mounted below normal eye level [1].

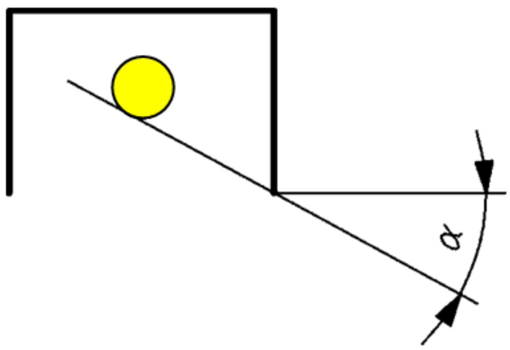

Figure 3a

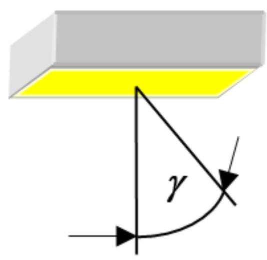

Figure 3b

Figure 3. Shielding angle a and vertical photometric angle g (Figure 3-a shows a cross section of a conventional luminaire with a separate light source; Figure 3-b shows a cross section of a luminous part of the optical element, e.g. a part of a LED luminaire)

Table 4. Minimum shielding angles at specified light source luminance

Light source luminance, [kcd/m^2]	Minimum shielding angle α
20 to < 50	15°

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50 to < 500	20°
≥ 500	30°

Table 5. Minimum shielding angles at specified light source luminance

Vertical photometric angle γ	Maximum average luminance of a luminous optical element, [kcd/m^2]
$75° \leq \gamma < 90°$	≤ 20
$70° \leq \gamma < 75°$	≤ 50
$60° \leq \gamma < 70°$	≤ 500

To select a luminaire suitable for the lighting installation of a given space the rating of discomfort glare caused directly from the luminaires shall be determined using the CIE Unified Glare Rating (UGR) tabular method. This UGR value determined using the UGR tabular method shall not exceed the RUG limit value (RUGL) given in Table 1. The tabular method is based on applying of the following formula to a set of standard conditions as observer position, room dimensions and reflection factors:

$$R_{UG} = 8 \log_{10} \left(\frac{0{,}25}{L_B} \sum \frac{L^2\, \omega}{p^2} \right),$$

where: R_{UG} is the value of the Unified Glare Rating (UGR); L_B is the background luminance in cd/m^2, calculated as (E_{ind}/π), in which E_{ind} is the vertical indirect illuminance at the observer's eye; L is the luminance in cd/m^2 of the luminous parts of each luminaire in the direction of the observer's eye; ϖ is the solid angle in steradian of the luminous parts of each luminaire at the observer's eye; p is the Guth position.

High brightness reflections in the visual task can alter task visibility, usually detrimentally. Veiling reflections and reflected glare can be prevented or minimised by the following measures: arrangement of work stations with respect to luminaires; matt surfaces; luminance restriction of luminaires; bright ceiling and bright walls.

Colour Appearance of the Light and Colour Rendering Index

The choice of colour appearance of the light during indoor lighting design and maintenance is a matter of psychology, aesthetics and what is preferred [1]. The choice will depend on illuminance level (Kruithof curve - Figure 4), colours of the room and furniture, surrounding climate and the application. Additionally, dynamic colour temperature can be considered for increased personalization [3].

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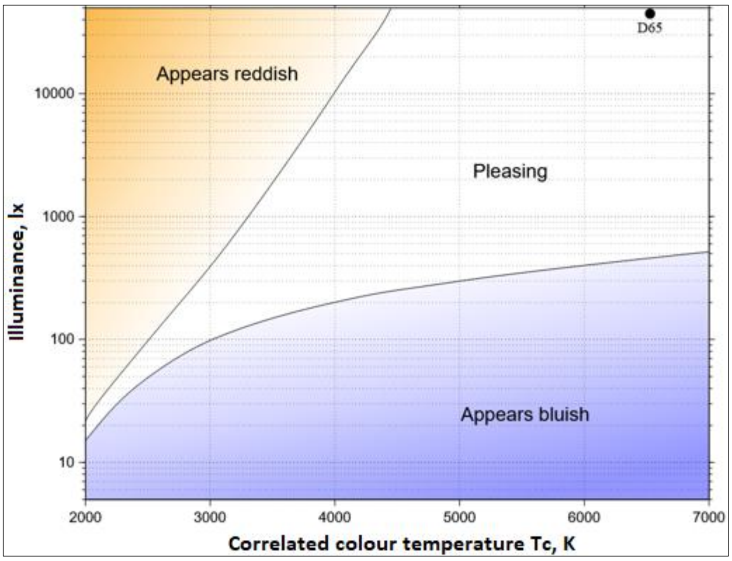

Figure 4. Region of illuminance levels and color temperatures that are often viewed as comfortable or pleasing to an observer (Kruithof curve)

For visual performance and the feeling of comfort and well-being colours in the environment, of objects and of human skin, shall be rendered with sufficient. To provide an objective indication of the colour rendering properties of a light source the general colour rendering index Ra is used. The maximum value of Ra is 100. The minimum value of colour rendering index for distinct types of task and activity areas within a space are given in [1] and Table 1.

Lighting systems should be designed to avoid the negative effects of flicker and stroboscopic effect throughout the full dimming range (this includes light sources and control gears). Flicker and stroboscopic effect can lead to undesired effects such as reducing visual comfort and reducing task performance and can lead to physiological effects such as fatigue or headaches. Stroboscopic effects can also lead to dangerous situations by changing the perceived motion of rotating or reciprocating machinery [1]. A high-quality driver well matched with its luminaire may produce less lamp flicker [4].

Maintenance Factor

The lighting scheme shall be designed taking into account an overall **maintenance factor** fm calculated for the selected lighting equipment, environment and specified maintenance schedule for the task area. The illuminance requirements for each task as specified in [1] are given as maintained illuminance $\bar{E}_m$ values. The initial illuminance $\bar{E}_i$ can be calculated from $\bar{E}_m$ as follows:

$$\bar{E}_i = \frac{\bar{E}_m}{f_m},$$

where: $\bar{E}_m$ is maintained illuminance; $\bar{E}_i$ is initial illuminance; fm is maintenance factor.

The designer of the indoor lighting shall to state the fm and list all assumptions made in the derivation of the value, to specify lighting equipment suitable for the application environment, and prepare a maintenance

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schedule to include e.g. frequency of light source replacement, luminaire and room cleaning intervals. The maintenance factor fm has a large impact on energy efficiency, as it sets the degree of resizing of the installed electrical power of the luminaires so that the illuminance at a given stage of the life of the lighting equipment is not lower than the maintained illuminance Ēm. The maintenance factor is defined in the ISO/CIE publication TS 22012 by the following formula:

$$f_m = f_{LF} f_S f_{LM} f_{SM},$$

where: f_{LF} is luminous flux factor which expresses the deprecation of the luminous flux over time due to ageing of the light source or luminaire during regular operation (Figure 5); f_S is the survival factor; f_{LM} is the luminaire maintenance factor; f_{SM} is the surface maintenance factor [5,6].

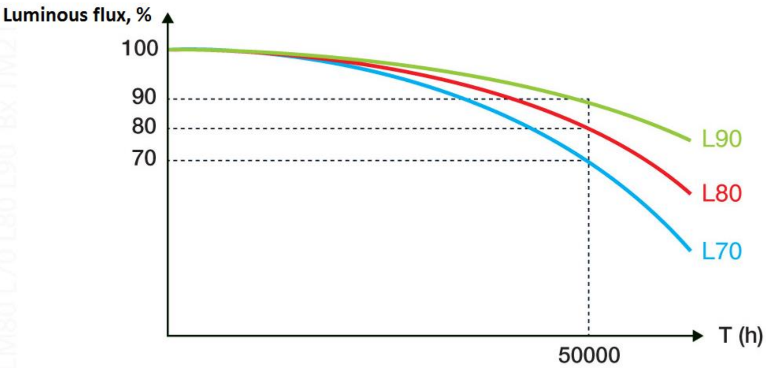

Figure 5. Decreasing of the luminous flux over time (without function constant light output)

For approximate calculations or when detailed information is not available, one of the following values for the maintenance factor shown in Table 6 may initially be selected. For maintenance-free lighting systems, it is recommended to use an maintenance factor fm = 0,67.

Table 6. Approximate values of the maintenance factor

Example	Maintenance factor fm
Very clean room, low yearly usage	0,80
Clean room, 3-year maintenence cycle	0,67
Exterior installation, 3-year maintenence cycle	0,57
Interior or exterior installation, high pollution	0,50

1.5.3 AUTOMATED CALCULATION OF THE QUANTITATIVE AND QUALITATIVE INDICATORS OF INDOOR LIGHTING

Solving the indoor lighting design task goes through separate stages. The realization of tasks from the stages is carried out in specialized lighting design software with options for calculating the indicators according to the requirements of EN 12464-1:2021. There are contemporary professional lighting design software products, as Relux, DIALux evo, Litecalc by OxyTech (Figure 6), etc., which offer automated calculation of the quantitative and qualitative indicators of indoor lighting to the requirements of EN 12464-1:2021 and at the same time offer a three-dimensional (3D) realistic visualization of the designed lighting system. In this section, the main stages of the automated calculation of the indicators of indoor lighting with the lighting design software product Relux are considered. The sequence of actions when working with an indoor lighting design software Relux is as follows.

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Figure 6. Lighting design software products

After starting of the Relux lighting design software, the module for working with Interior lighting is selected - Figure 7 [1].

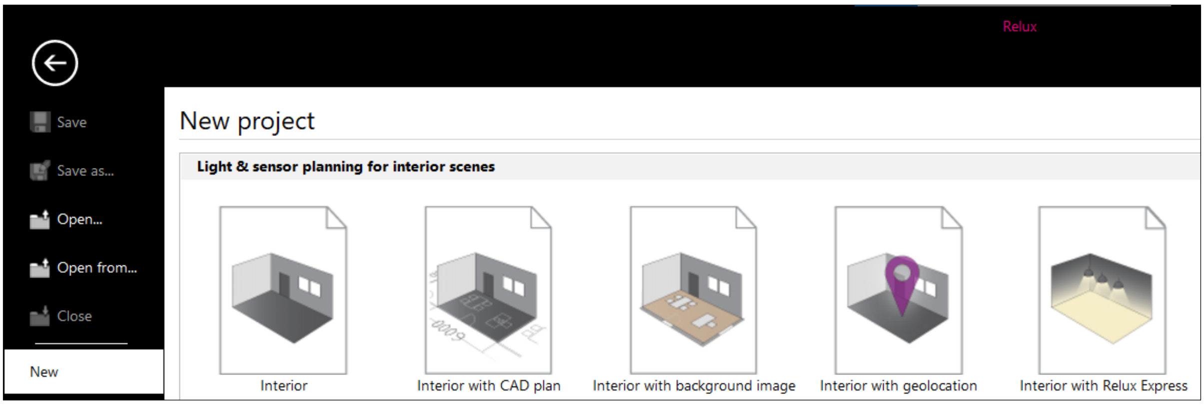

Figure 7. Starting of the Relux indoor lighting design software

Designation of the Room Dimension and Reflectance

The room dimensions as length, width, height, and height of the activity area are designate - Figure 8. For people working in a sitting position, for example in offices, handcraft rooms, computer halls, classrooms, lecture and conference halls, the height of the activity area is between 0,75 and 0,80 m. For indoor sports halls, corridors, circulation areas, stairs, the height of the activity area is 0 m, i.e. the floor level. The reflectance coefficient ρ (rho) of the floor, walls and ceiling in the room are designate - Figure 9. High surface reflectances contribute to energy savings and can lead to better visual comfort. For choice of materials, the following ranges of reflectances are recommended: ceiling: 0,70 to 0,90; walls: 0,50 to 0,80; floor: 0,20 to 0,60. By option Materials/Textures in Relux, a specific material with the appropriate reflective characteristics can be selected.

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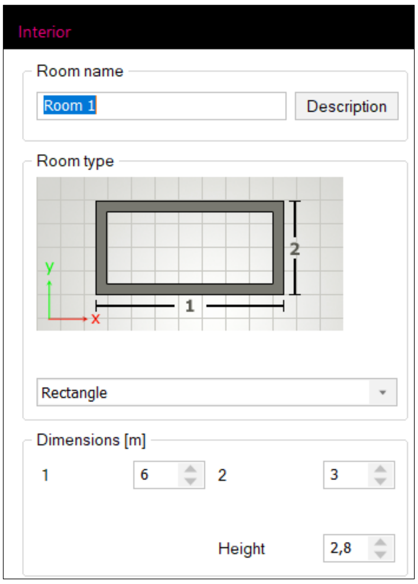

Figure 8. Designation of the room dimension

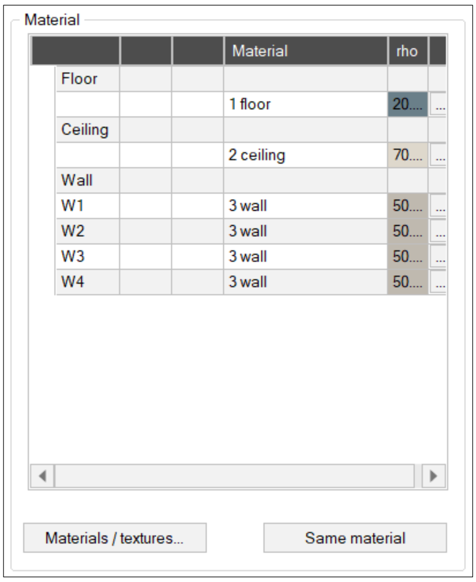

Figure 9. Designation of the reflectance coefficient

Utilization Profile for a Room

In the Nominal values field - Edit nominal values, the type of room, for example Office – Writing, typing, reading, data processing, and the nominal lighting indicators: illuminance Em (lx), uniform overall Uo, glare UGRL and colour rendering index Ra are selected - Figures 10 and 11.

Figure 10. Edit nominal lighting values

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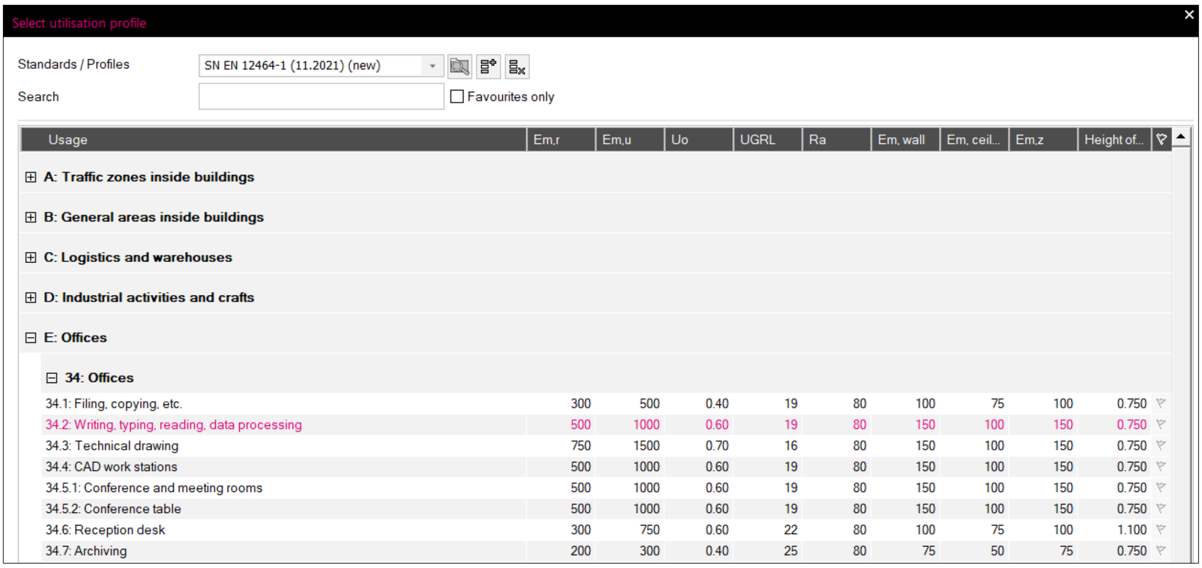

Select utilisation profile

Standards / Profiles: SN EN 12464-1 (11.2021) (new)

Search: Favourites only

Usage	Em,r	Em,u	Uo	UGRL	Ra	Em, wall	Em, ceil...	Em,z	Height of...
A: Traffic zones inside buildings									
B: General areas inside buildings									
C: Logistics and warehouses									
D: Industrial activities and crafts									
E: Offices									
34: Offices									
34.1: Filing, copying, etc.	300	500	0.40	19	80	100	75	100	0.750
34.2: Writing, typing, reading, data processing	500	1000	0.60	19	80	150	100	150	0.750
34.3: Technical drawing	750	1500	0.70	16	80	150	100	150	0.750
34.4: CAD work stations	500	1000	0.60	19	80	150	100	150	0.750
34.5.1: Conference and meeting rooms	500	1000	0.60	19	80	150	100	150	0.750
34.5.2: Conference table	500	1000	0.60	19	80	150	100	150	0.750
34.6: Reception desk	300	750	0.60	22	80	100	75	100	1.100
34.7: Archiving	200	300	0.40	25	80	75	50	75	0.750

Figure 11. Utilisation profile - lighting requirements for task areas or activity areas in office room

The Relux lighting design software suggestions the possibility to enter conditions aggravating the normal visual task, according to the EN 12464-1:2021 (see Table 2). In this way, a higher illuminance value can be selected. For example the task is undertaken for an unusually long time and increased concentration is of great importance – the nominal illumination Ēm for office room is increase from 500 up to 750 lx - Figure 12.

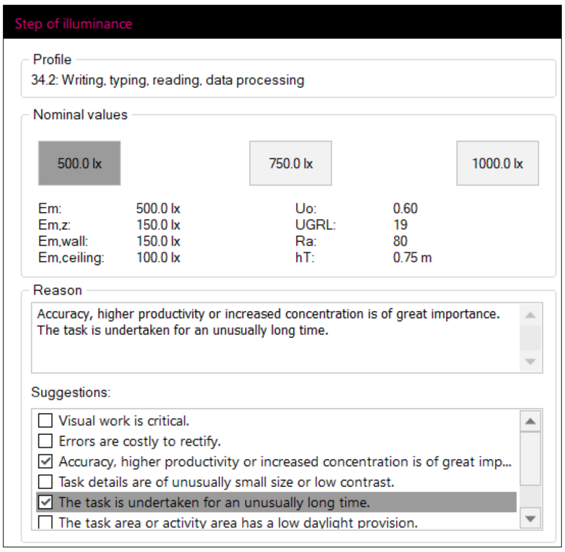

Figure 12. Increasing the maintained illuminance Ēm by one step, depending on the modifiers (suggestions)

In the absence of data on the furniture elements in the room and theirs location, the entire horizontal area is taken as the task area, for which they are defined the nominal values - Figures 13 and 14. To avoid high impact on uniformity from calculation points near the wall, a band next to the wall can be excluded from the calculation except when the task area is in or extends into this border area. The width of this band is specified as 15 % of the smallest dimension of the area under consideration or 0,5 m, whichever of the two is smaller [1,7].

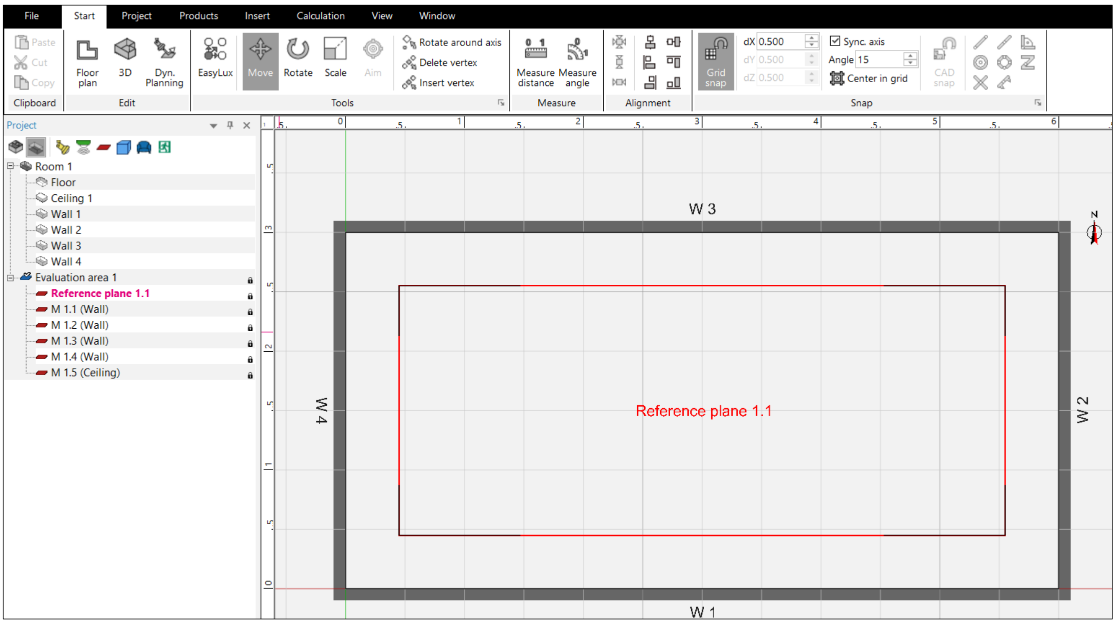

Figure 13. Reference plane (task area) in the room in the absence of data on the furniture elements

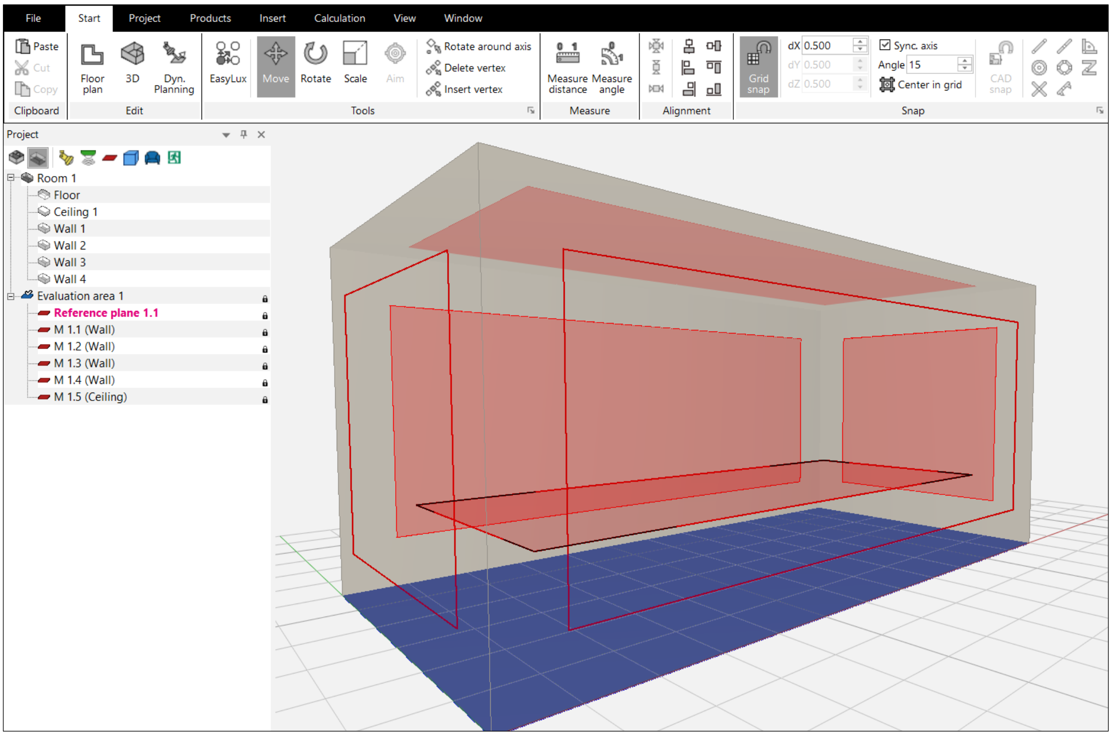

Figure 14. 3D visualisation on the room in the absence of data on the furniture elements

Insert 3D Objects in the Room

Importing objects to create a realistic 3D visualization in the room into the Relux is done by a menu Insert-3D object-Add... (Figure 15), or Load from ReluxNet (https://reluxnet.relux.com/en/search/three_d/BG/).

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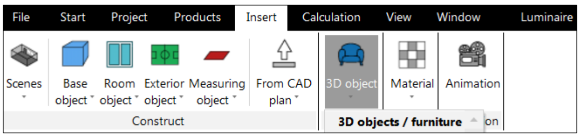

Figure 15. Insert 3D objects to create a realistic visualization in the room

The insert, positioning and sizing of the task area and surrounding area after importing 3D objects in the office room is done by a menu Insert-Measuring object-Task areas - Figure 16. From a menu Insert-Measuring object-Observers-UGR the points for which the uniform glare rating (UGR) will be calculated are entered – Figure 17.

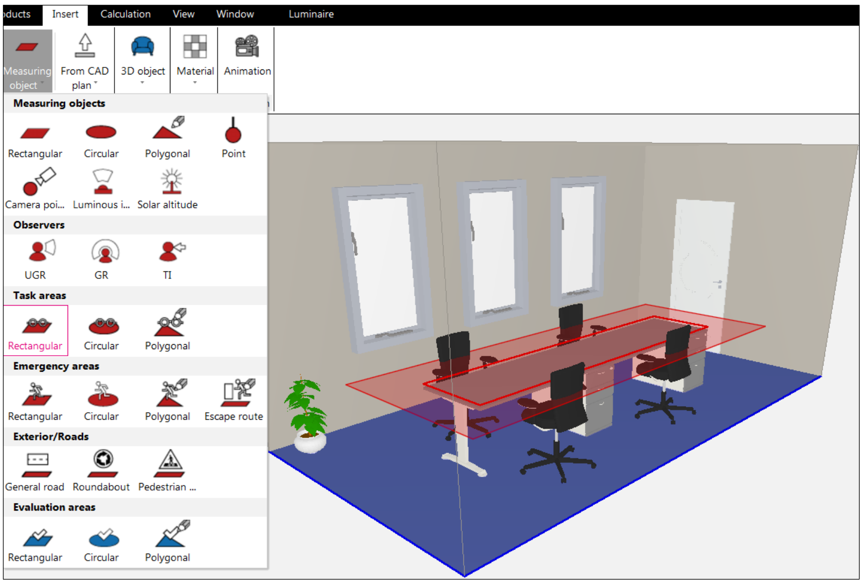

Figure 16. Insert, positioning and sizing of task area and surrounding area relative to the furniture elements

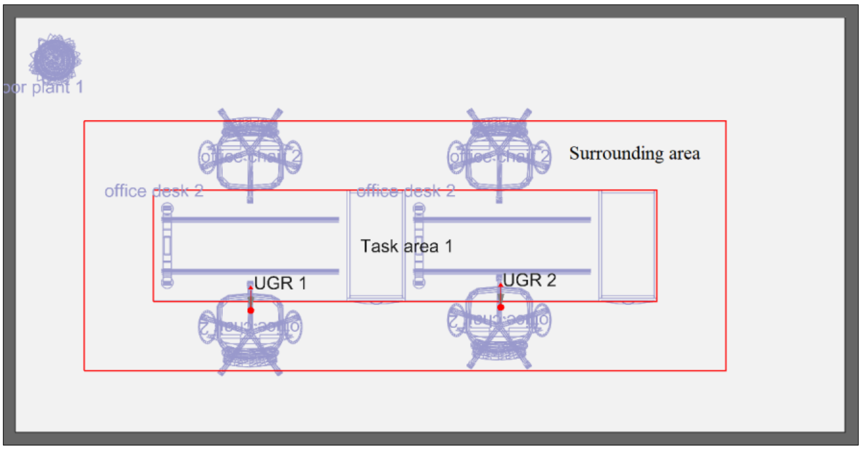

Figure 17. Top view of the office room with the inserted furniture elements, task area and surrounding area, and observers in points UGR 1 and UGR 2

Luminaire Selection for a Room

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The choice of a luminaire is an important stage in the automated calculation of lighting indicators. The requirements of the standard EN 12464-1:2021 relative the rating of discomfort glare UGR caused directly from the luminaires, colour rendering index CRI, and the correlated colour temperature CCT of the lamps in the luminaires must be observed. When choosing luminaires for indoor lighting design and maintenance, it is known that technologically LED has taken over as the main light source from previous technologies.

When choosing a LED luminaire, depending on the application and the characteristics of the environment in the room, the following are taken into account: light distribution, brightness, minimum shielding angle, luminaire efficacy, degree of protection (IP code), good aesthetic appearance of the luminaire, and etc. The increasing requirements for the energy efficiency of the lighting systems is a prerequisite for the use of contemporary LED luminaires that have an efficacy of more than 100 lm/W.

At typical indoor office illuminance levels from 300 up to 500 lx, pleasing colour temperatures are between 3000 and 6000 K. At typical home illuminance levels of about 75-150 lx, pleasing colour temperatures are between 2400 and 2700 K (see Figure 4 - the Kruithof curve).

In software Relux, the luminaire are selected from the Products menu with the Luminaires function in a specialized Product selection module, allowing the addition to the project of lighting characteristics of luminaires from the following options: Local database (in Relux Demo); ReluxNet; Online; pre-installed company databases (Plud-in); adding of Individual luminaire from standard photometric file formats (IES, Eulumdat) - Figure 18.

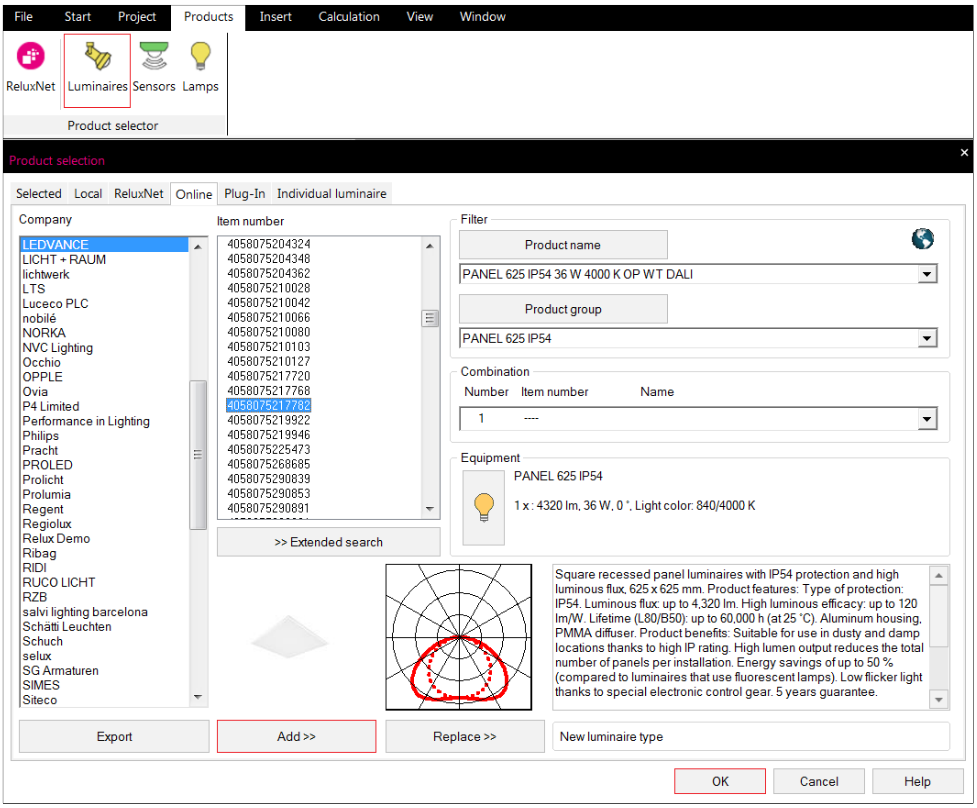

Figure 18. LED luminaire selection for indoor lighting in Product selection module

Automated Calculation of the Indicators of Indoor Lighting

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The determination of the required number of luminaires to realize the maintained illuminance Ēm is carried out by a specialized module for simplified lighting calculations EasyLux, activated from the Start menu - Figure 19.

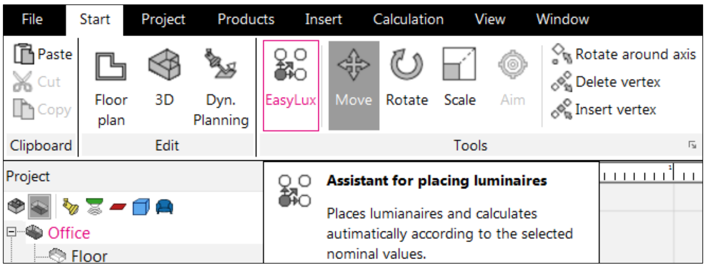

Figure 19. Module EasyLux for doing simplified indoor lighting calculations

In this stage of the automated calculation of the indicators of indoor lighting with lighting design software, information must be obtained about the indicators influencing the maintenance factor fm, as: cleanness/dirtiness of the space; the planned maintenance schedule; the degree decreasing of the luminous flux over time. This information about maintenance factor allows the illuminance of does not decrease below nominal maintained value and at the same time can save costs and energy. In Relux, the maintenance factor can be defined simplified or in detail according EN 12464-1 and CIE 97-2005 - Figures 20 and 21.

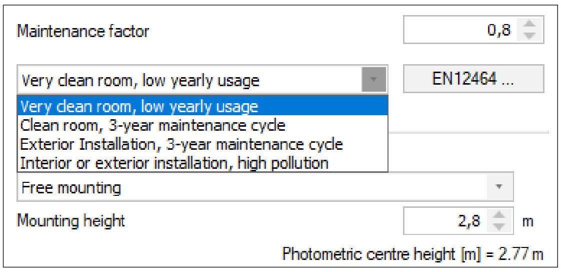

Figure 20. Simplified defined of the maintenance factor

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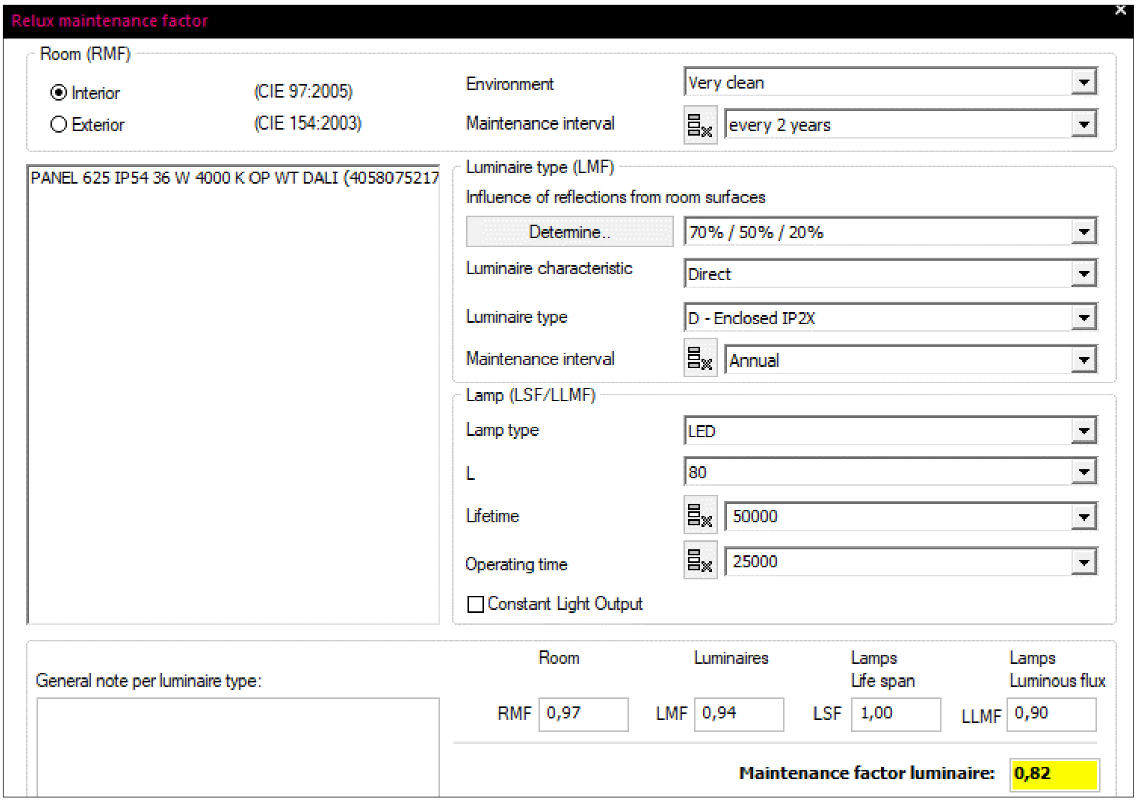

Figure 21. Detail defined of the maintenance factor

After determining the maintenance factor, selecting the mounting type of luminaires (free mounting or ceiling mounting) and setting the value of maintained illuminance Ēm for office room in the module EasyLux, quick approximate lighting calculations are performed – Figure 22. Upon confirmation of the proposed number of luminaires, they are automatically placed on the ceiling of the room. Starting the lighting calculations in the Relux software is done after selecting the Close function button in the EasyLux module.

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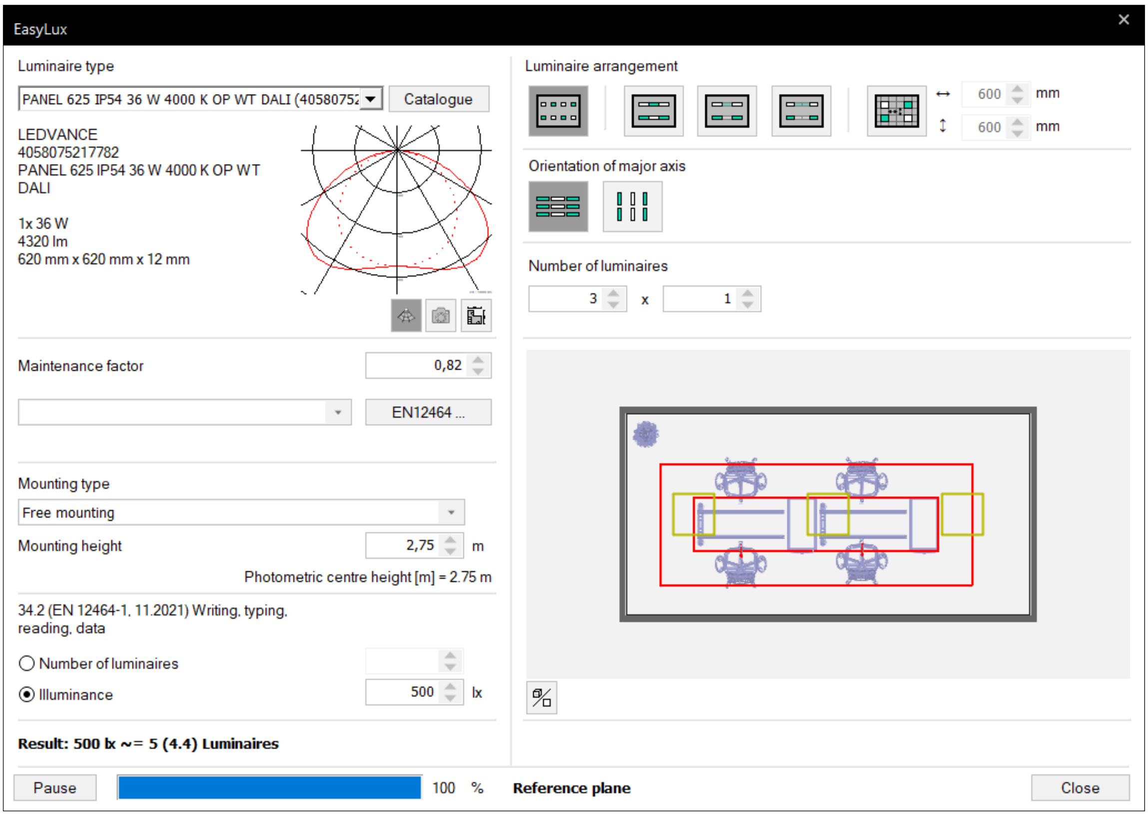

Figure 22. Quick approximate indoor lighting calculations in module EasyLux

Overview of the Indoor Lighting Calculation Results

A detailed presentation of the calculation results in indoor lighting - maintained luminance Em and uniform overall Uo for the task area, surrounding area and background, also power density of the lighting (in W/m^2) and normalized power density (in W/(m^2.100 lx)) for office room is obtained in the Result menu via the Overview function button and the Results Overview screen window - Figure 23.

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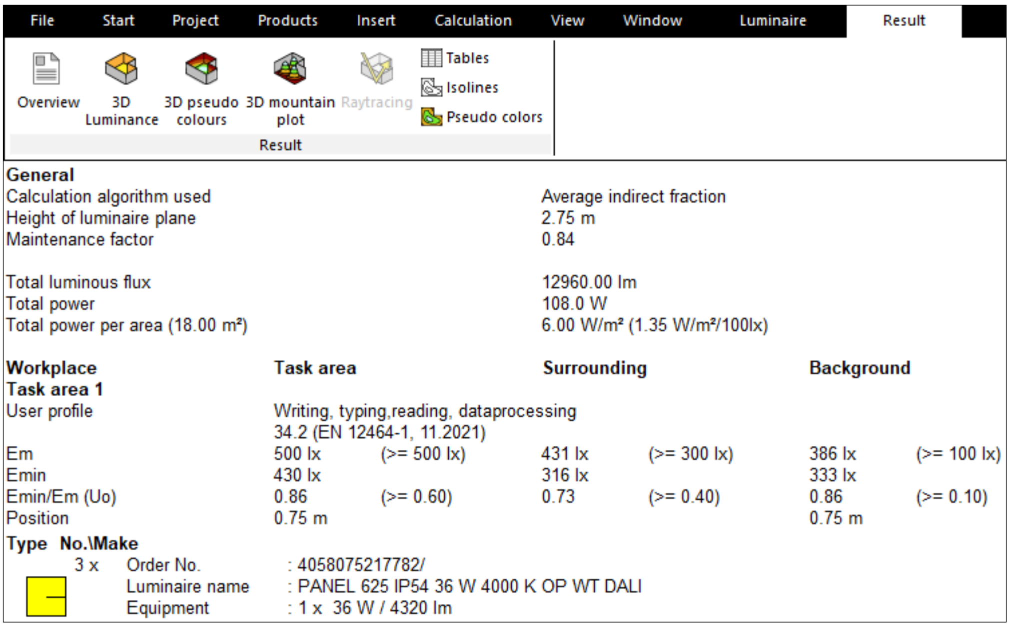

Figure 23. Overview of the indoor lighting calculation results

Three-dimensional luminance distribution view in the office room after lighting calculation in Relux are shown in Figure 24; three-dimensional pseudo colors of the realized illuminance after lighting calculation in Relux are shown I n Figure 25.

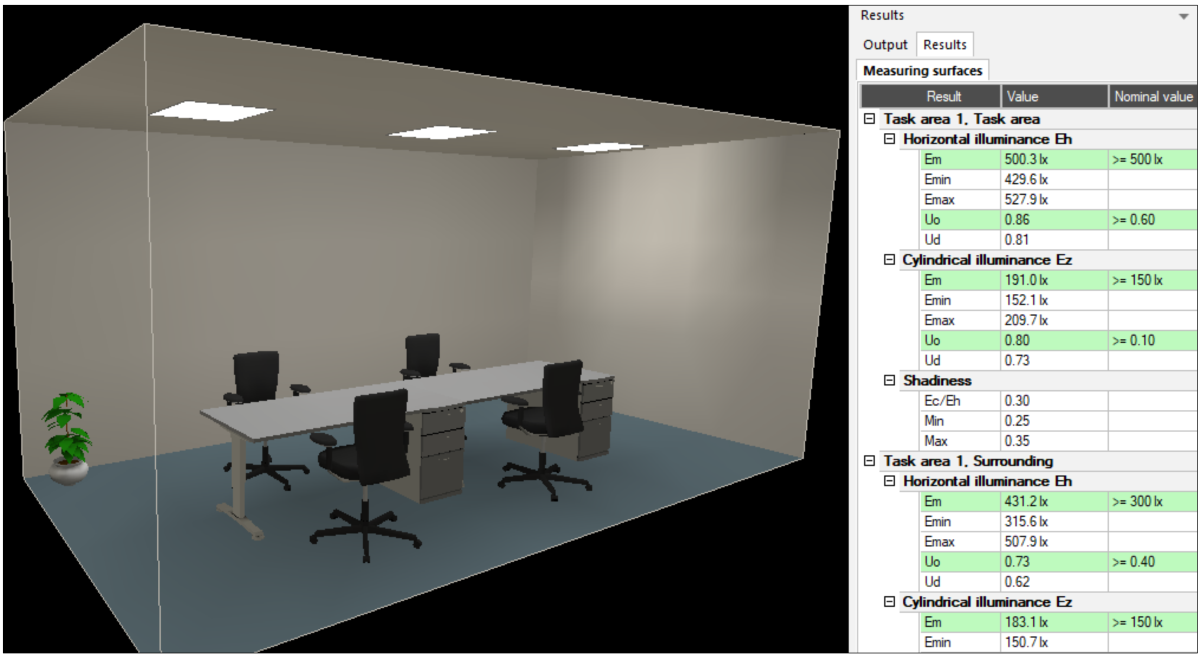

Figure 24. 3D luminance view after lighting calculation in Relux

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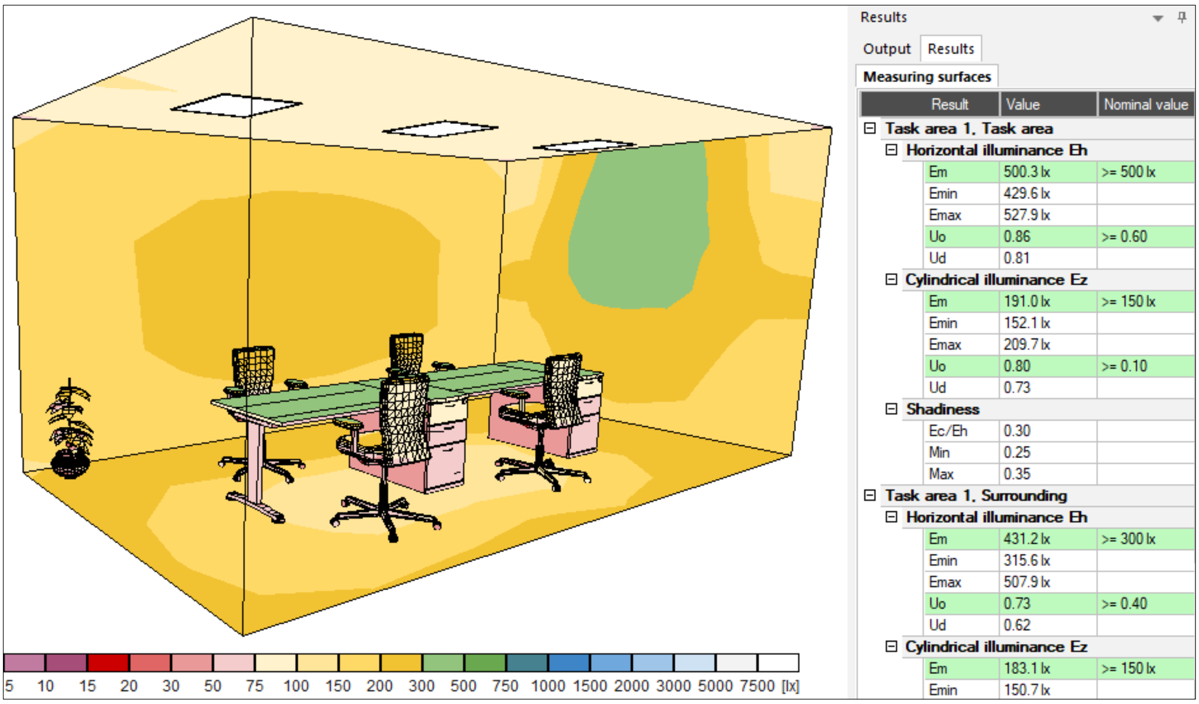

Figure 25. 3D pseudo colors of the realized illuminance after lighting calculation in Relux

The calculation of R_{UG} at the observers positions UGR 1 and UGR 2 in the office room (see Figure 17) is carried out from the menu Calculation with option Calculate – Figure 26. After lighting calculations, R_{UG} value for observers UGR 1 and UGR 2 are selected in menu Window – in Output – Figure 27. Figure 28 shows calculated and graphical representation of the R_{UG} at observers UGR 1 and UGR 2.

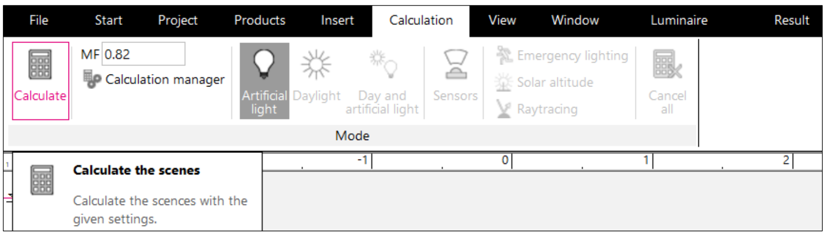

Figure 26. The calculation of R_{UG} at the observers positions UGR 1 and UGR 2

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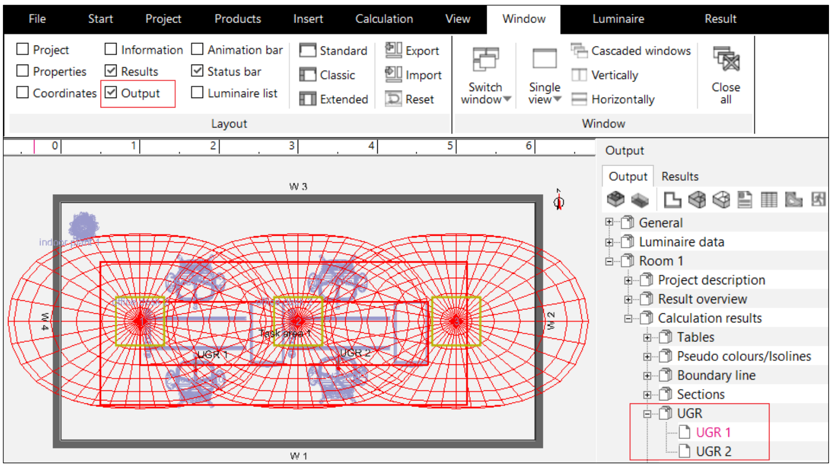
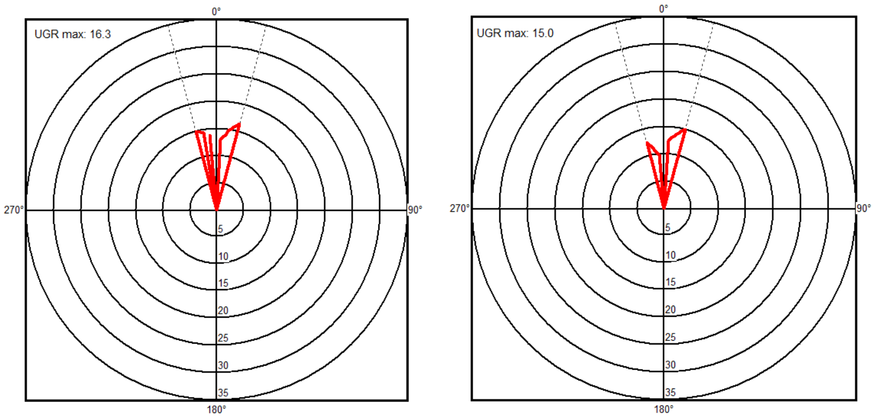


Figure 27. Selecting the UGR



UGR 1 UGR 2

Figure 28. Calculated and graphical representation of the R_{UG} at observers UGR 1 and UGR 2

1.5.4 QUIZ QUESTIONS

What input data is required to be entered for a single room in a software for indoor lighting calculation?

What are nominal lighting indicators for a reference plane on the room?

What is the difference between the activity area, immediately surrounding area and background area in the room?

What is the main indicators influencing of the indoor lighting maintenance factor?

What determines the glare rating caused by interior lighting?

1.6 TOPIC 6 – PHOTOVOLTAIC (PV-LED) SYSTEMS FOR LIGHTING

1.6.1 INTRODUCTION

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At the base of the PV–LED systems is the combination of the advantages of two innovative technologies—photovoltaics (PV) and light-emitting diodes (LED) . Both main elements of this type of solar lighting systems are solid state and long lifetime, making PV–LED systems very simple and reliable. The application of the two technologies is among the most environmentally friendly options for electric power supply of lighting systems. With the advancement of photovoltaic module manufacturing technology, it is possible to have a variety of sizes, electrical and operational parameters to allow installation in various small and large devices for indoor and outdoor installation. [The Sun and PV…].

Among the numerous applications of photovoltaic electricity, the most appealing is certainly for low-power electrical appliances. Among those low-power appliances, domestic lighting is certainly one of the most demanded. Lighting technology has known an important evolution from the carbon arc to the filament light bulb, the fluorescent tubes to the LEDs that are top of the line today. LEDs can cover several applications that were not covered before, especially because of the geometry and color range they can reach and their power efficiency and life span which are continuously increasing [35, The Sun and PV…].

Both the PV and LED have low weight, resistance to vibrations and DC voltage operation, enabling the easy creation of portable autonomous PV–LED devices. In recent years, PV–LED lighting systems are widely applied from PV–LED street lighting to PV–LED keychain.

PV–LED outdoor lighting

LED keychain torch with solar photovoltaic charge

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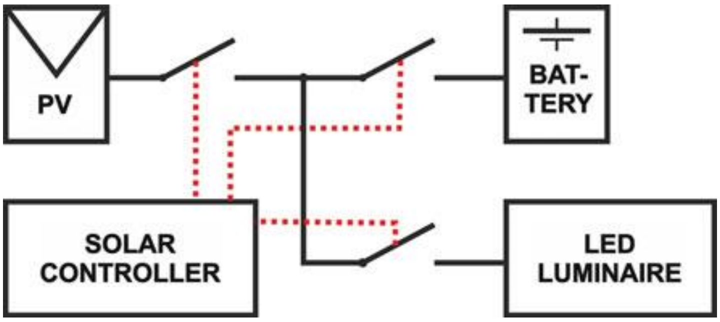
1.6.2 STRUCTURE

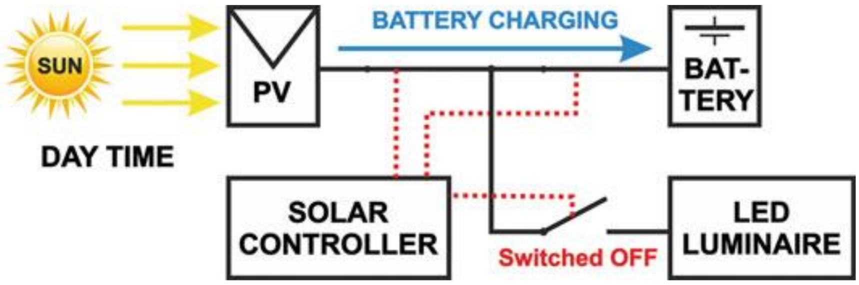


Block diagram of PV–LED system

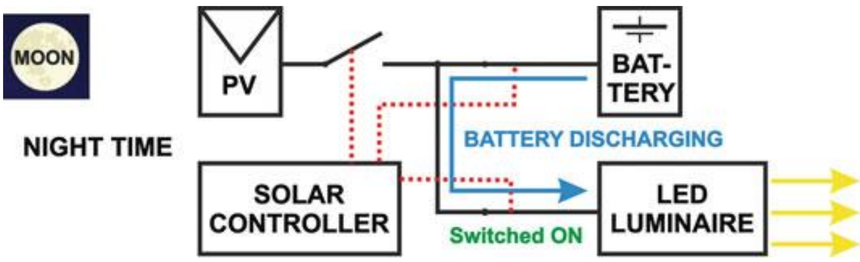
The Figure shows a block diagram of the main components of a PV–LED system: PV panel (module), storage battery (accumulator), solar controller and LED luminaire, including itself LED driver and LED lamps (sources). Since both PV modules and LED lamps are low-voltage DC devices, it is more appropriate for PV–LED systems to use a DC LED drivers, which are simpler and more energy efficient than the AC LED drivers. Moreover, this way is avoided using of DC/AC inverter, and therefore, the entire PV–LED system is cheaper and more energy efficient.

1.6.3 PRINCIPLE OF WORK

The main operating modes of the outdoor lighting PV–LED system elements during day and night are shown in the following Figures:



Operating mode of PV–LED system during the day sunlight time



Operating mode of PV–LED system during the night time

The generated electric energy from PV modules is stored by rechargeable batteries during the day, if the. solar irradiation is available, and LED luminaires lighted by the batteries at night.

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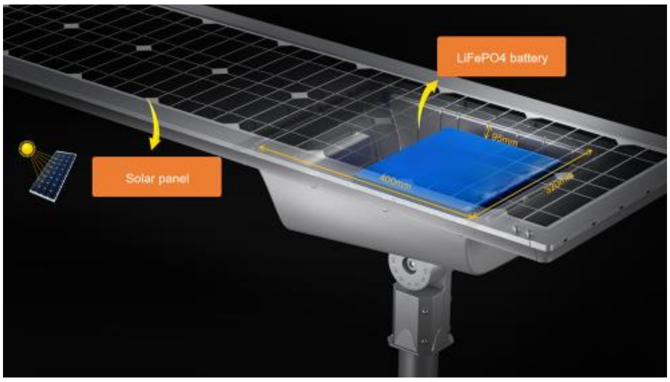
The types, parameters and characteristics of PV modules, Solar controllers and LED lamps are discussed in detail in the relevant parts of the VET Course Modules, so in this section is presented only additional information on Storage batteries for PV–LED systems.

1.6.4 STORAGE BATTERIES FOR PV–LED SYSTEM

Storage batteries (accumulators) are designed to store the electrical energy produced by the PV module in the daytime when it is charging, and it gives it to the LED luminaire at night (it is discharging). Each battery technology requires an optimized charging strategy to maximize life span and capacity. A valve-regulated lead–acid battery (VRLA), more commonly known as a sealed battery or maintenance-free battery, is a type of lead–acid rechargeable battery. Due to their construction, they can be mounted in any orientation and do not require constant maintenance. They are widely used in stand-alone systems, such as PV–LED systems, and similar roles, where large amounts of storage are needed at a lower cost than other low-maintenance technologies like lithium–ion. There are two primary types of VRLA batteries, gel cells and absorbed glass mat (AGM). Gel cells add silica dust to the electrolyte, forming a thick putty-like gel. These are sometimes referred to as “silicone batteries,” AGM batteries feature fiberglass mesh between the battery plates which serves to contain the electrolyte. Lead–acid batteries with absorption glass mat (AGM) have immobilized electrolyte and offer high capacity at a lower cost per amp-hour compared to other chemistries. All available PV panel energy is stored in the battery until it reaches its maximum charge voltage, at which point trickle charging begins. The battery must be maintained at the proper float voltage, which should be adjusted with a negative temperature coefficient.



https://www.agcled.com/blog/for-solar-led-lights-why-choose-lifepo4-battery.html

For PV applications, most commonly used battery types and with the most appropriate performance parameters are lead–acid, Ni–Cd and lithium–ion. Their life expressed in no of cycles is about 500–1500 [36]. It means that on a normal operated daily charge–discharge cycle of a PV–LED system, they will work for 3–5 years. This life expectancy is significantly lower than that of PV modules and LED lamps, which is about 20–25 years under the same conditions.

The short lifetime, combined with their high cost, turns the batteries into the weakest part of the PV–LED systems. These are the main reasons for the poor economic indicators of stand-alone PV–LED systems in some countries like Bulgaria, where the price of energy from the grid is relatively low. The design and construction of autonomous PV–LED systems are economically feasible primarily in areas where no conventional power grid is built, but there is a need for lighting system.

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The feature for dimming the light output of LED luminaires provides an interesting opportunity for further optimization of PV–LED systems. A Photovoltaic-Fed LED Lighting System with SOC-Based Dimmable LED Load allows minimizing the components size. Effective energy management is allowed by battery-driven load dimming, thus avoiding the use of big solar panels and big batteries which, in most cases, provide only marginal benefits in terms of energy productivity. The energy productivity and the quality of the service can be modulated by a dynamic change of the type of dimming criterion with respect to the battery SOC [37].

Depending on the functional capabilities, the solar controllers can be connected to a specialized hardware or PC with software for monitoring the process of operation of a PV–LED system: visualization of the charging and discharging process of the battery, the input voltage, current and power PV modules, amount of charge to the battery, consumed electrical energy from the load.

Continuous improvement in PV–LED system technology causes these systems to be preferred when existing electrical infrastructure is remote or non-existing— for roads, tunnels, car parks, parks and trails. The return on investment to install a PV–LED lighting system can be achieved by avoiding the cost of channelling, buying cables and other electrical and utility costs associated with installing a new lighting system powered by the power grid.

Quiz questions to Topic 6

1.7 TOPIC 7 – COURSE PROJECT ON LIGHTING DESIGN

1.7.1 INTRODUCTION

In the present topic, a course project is developed for the automatic calculation of basic lighting indicators for one room of a building by using lighting design software Relux. Input data is set by the supervisor of the course project on lighting design. The development of the course project is being carried out after studying the methodology for the indoor lighting design and maintenance described in Topic 5. The course project on lighting design consists of the following four stages:

- setting input data by the supervisor;

- entering of the input data in software of the lighting design;

- selecting of the of LED luminaire;

- automated calculation of the lighting indicators in the room and tabular presentation of the obtained output results.system.

1.7.2 STAGE 1 - SETTING INPUT DATA BY THE SUPERVISOR

The input data for the implementation of the course project on lighting design includes length x, width y and height H of the room, height h of the activity area, reflection coefficients of the ceiling, walls, and floor, and type of the room - utilisation profile according standard EN 12464-1:2021 for lighting requirements.

In Stage 1, the following necessary inputs data with example values are presented: length of the room x = 5 m; width of the room y = 4 m; height of the room H = 2,8 m; height of the activity area h = 0,75 m; reflection

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coefficients ρ of the ceiling: ρc = 0,80; walls: ρw = 0,50; and floor: ρf = 0,30; maintenance factor fm at clean room and 3-year maintenance cycle is 0,67 up to 0,8 – Table 7.1 and Figure 7.1.

Table 7.1. Input data of the course project on lighting design

Type of the room	Room dimensions				f_m	Reflection coefficients ρ		
	x	y	H	h				
	[m]	[m]	[m]	[m]	-	Ceiling	Walls	Floor
Office	5	4	2,8	0,75	0,67	0,80	0,50	0,30

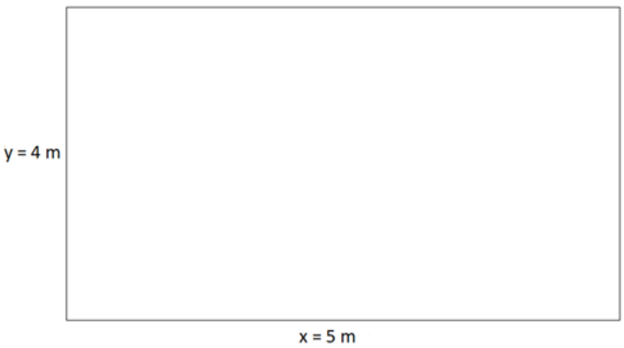

Figure 7.1-a. Top view of the room

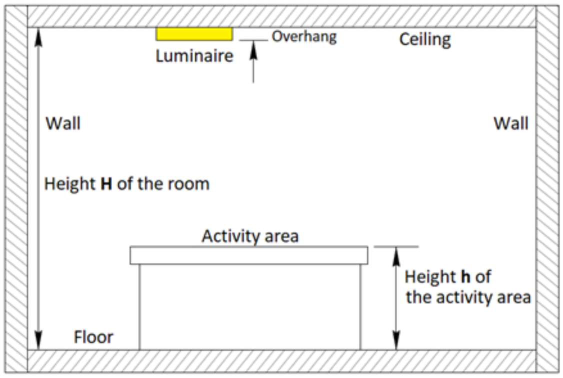

Figure 7.1-b. Front view of the room

The setting profile room (utilisation profile of the room) is carried out according standard EN 12464-1:2021 – office type of the room is selected for the course project; type of the activity area Writing, typing, reading, data processing. Lighting values requirements for task areas, activity areas, room and space brightness for office room are maintained illuminance Ēm, minimum illuminance uniformity Uo, minimum colour rendering index Ra, Unified Glare Rating limit, RUGL, maintained cylindrical illuminance Ēm,z, maintained illuminance on walls Ēm,wall and maintained illuminance on ceilings Ēm,ceiling and values are shown in Table 7.2.

Table 7.2. Lighting requirements for task areas, activity areas, room and space brightness for office room

Type of task or activity area	$\bar{E}_m$ [lx]		U_o	R_a	R_{UGL}	$\bar{E}_{m,z}$ [lx]	$\bar{E}_{m,wall}$ [lx]	$\bar{E}_{m,ceiling}$ [lx]
	(a)	(b)				$U_o \geq 0,10$		
Offices - Writing, typing, reading, data processing	500	1 000	0,60	80	19	150	150	100
Note: The entire horizontal area is taken as the task area, for which they are defined the nominal values - in course project not available data on the furniture elements in the room and theirs location.								

Recommended values of the correlated colour temperature Tc of the lighting are from 4000 K up to 5500 K - typical values for office rooms in public buildings.

1.7.3 STAGE 2 - ENTERING OF THE INPUT DATA IN THE LIGHTING DESIGN SOFTWARE

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In Stage 2, the sequence of entering the input data for single room into the lighting design software Relux (version 2022) is shown.

The room dimensions: length 5 m, width 4 m, height of the room 2,8 m, and height of the activity area 0,75 m are designate in fields "Dimensions" and "Evaluation area" in software Reluxe and shown in Figure 7.2. The reflectance coefficient of the floor – 0,80, walls – 0,50, and ceiling – 0,30 are designate in "Material" field and shown in Figure 7.3.

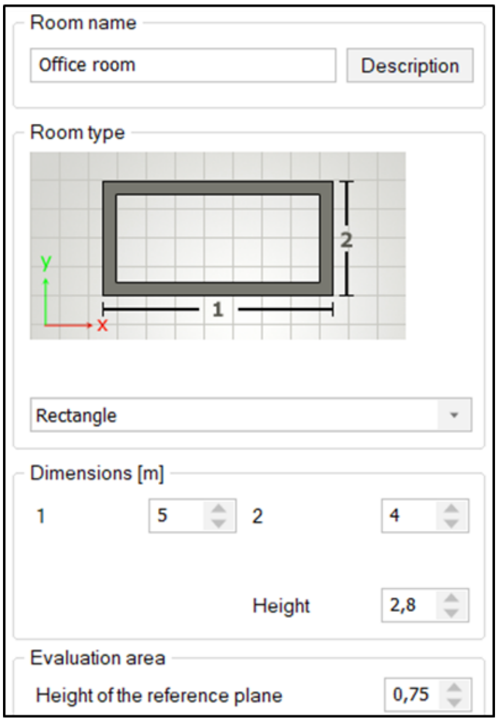

Figure 7.2. Designation of the room dimension

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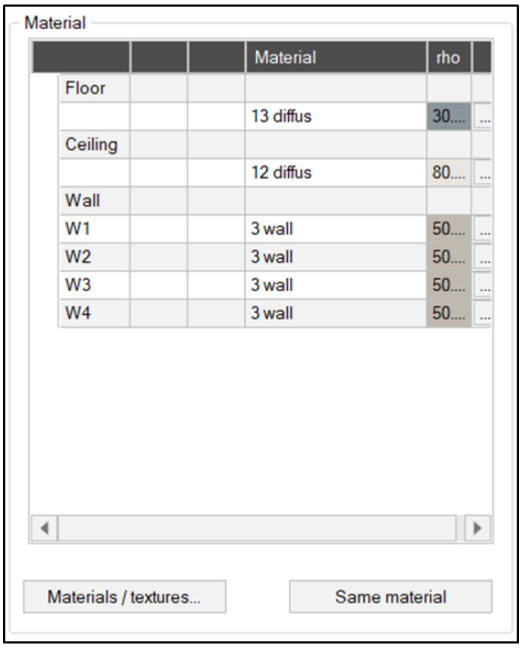

Figure 7.3. Designation of the reflectance coefficient

In the “Edit nominal values” field, the type of room – Office – Writing, typing, reading, data processing, and the nominal lighting indicators according standard EN 12464-1:2021: illuminance Em (lx), uniform overall Uo, glare UGRL and colour rendering index Ra are selected - Figure 7.4 and Table 7.1.

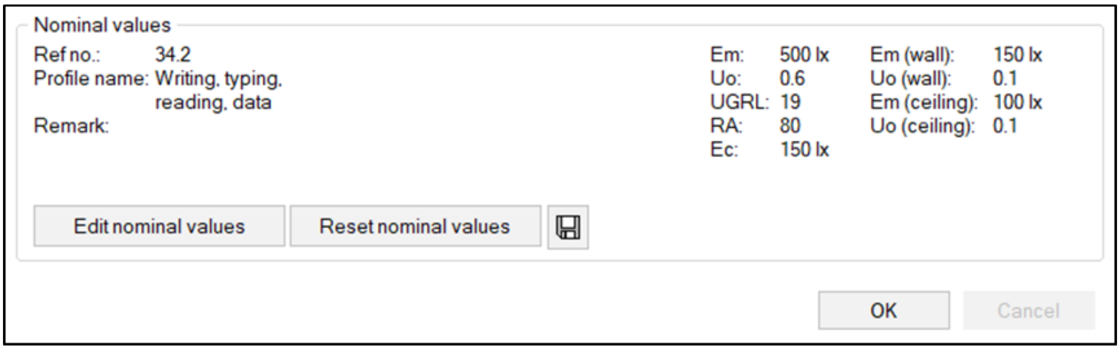

Figure 7.4. Utilisation profile - lighting requirements for task areas or activity areas in office room

At not available data of the furniture elements and their location in the office room, the entire horizontal area is taken as the task area (reference plane), for which they are defined the nominal values – Figure 7.5. To avoid high impact on uniformity from calculation points near the wall, a band next to the wall is excluded from the calculation except when the task area is in or extends into this border area. The width of this band in the office room is 0,5 m (Figure 7.5).

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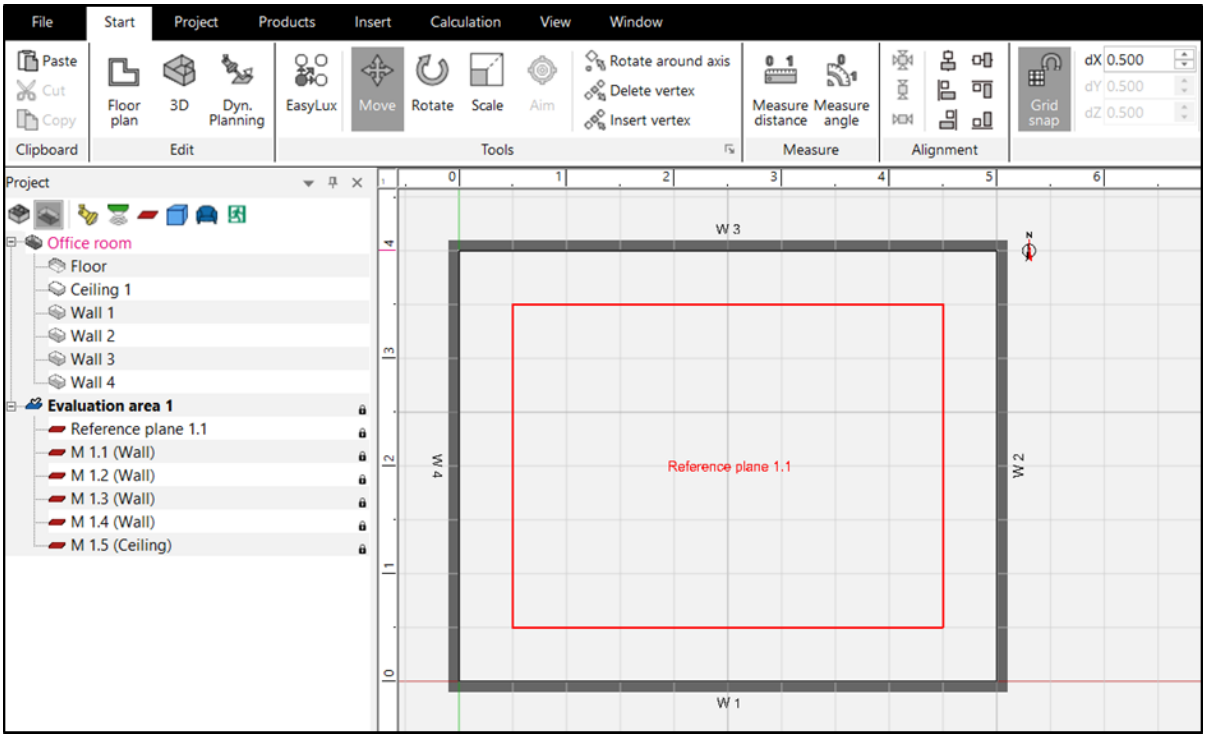

Figure 7.5. Reference plane in the office room (top view)

Created office room in 3D view with height of the reference plane 0,75 m are shown in Figure 7.6.

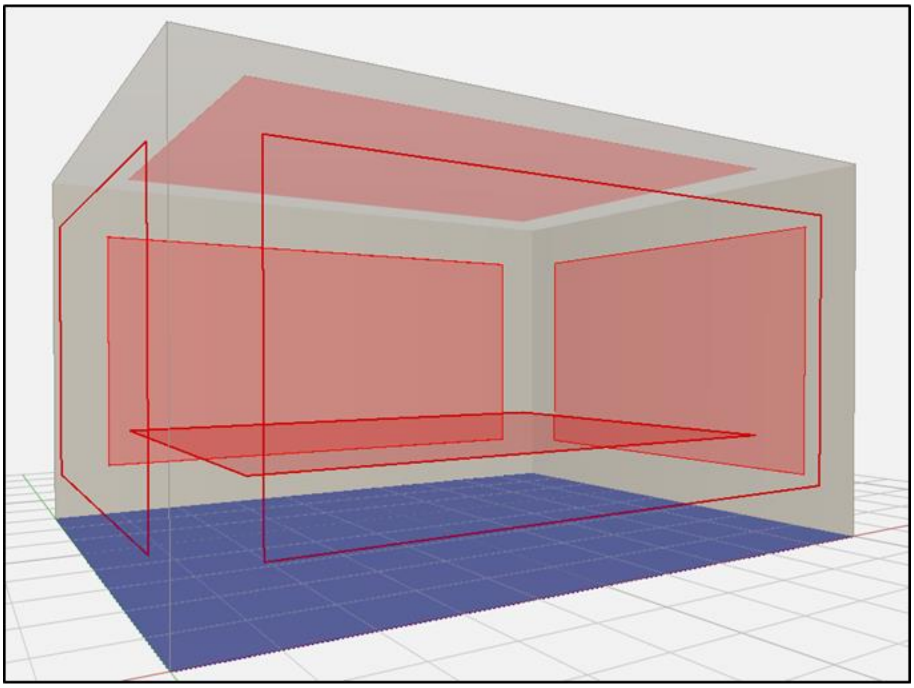

Figure 7.6. 3D visualisation on the office room

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1.7.4 STAGE 3 - SELECTING OF THE LED LUMINAIRE

In Stage 3, selecting of the LED luminaire for the office room is done.

In software Relux, the LED luminaire are selected from the “Products” menu with the “Luminaires” function in a specialized “Product selection” module, allowing the addition to the project of lighting characteristics of luminaires. Adding of LED luminaire it's actually adding standard photometric file format (*.ies or *.ldt) of the luminaire in software Relux which is carried out performed from menu “Products” with option” Online” – buttons “Add” and “OK” – shown in Figure 7.7.

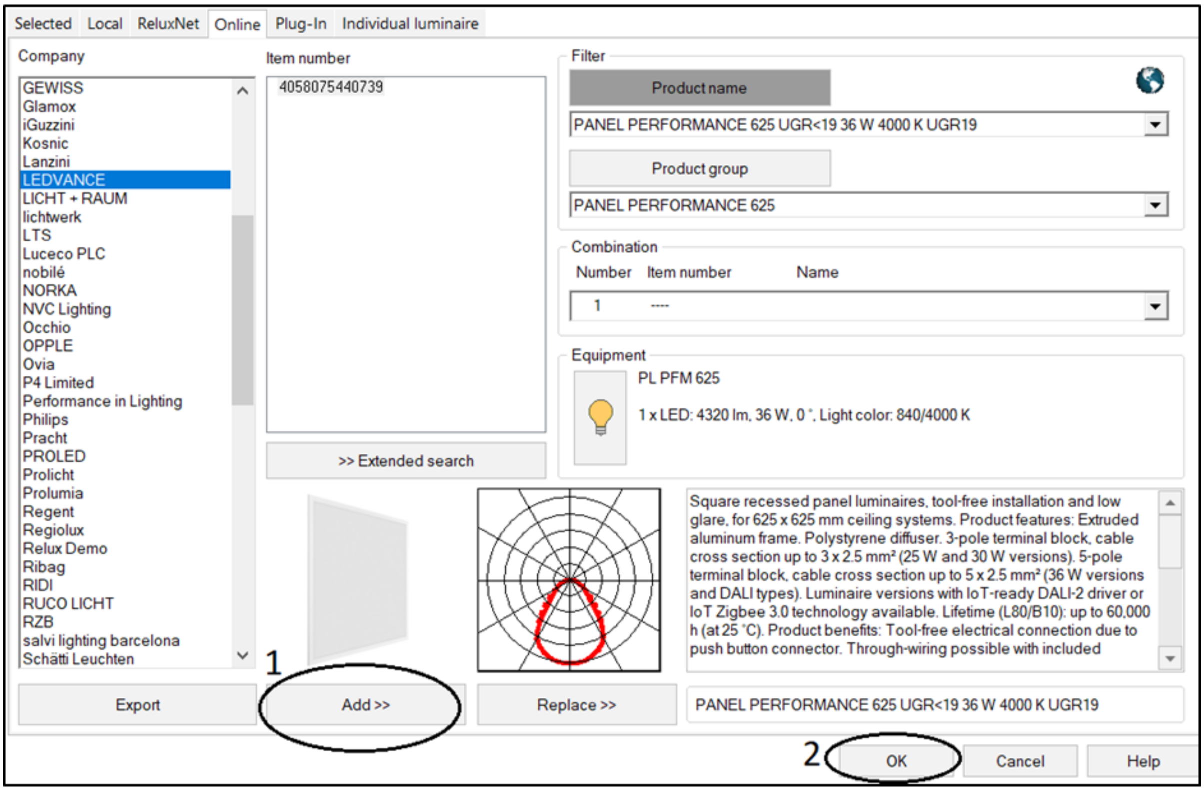

Figure 7.7. Selecting of the LED luminaire for the office room

In field Luminaires of the lighting design software, the technical data sheet of the selected LED luminaire can be seen. The selected luminaire has a square form and is designed for a recessed ceiling (without overhang). The selected LED luminaire has the following parameters: active power P = 36 W, luminous flux Φ = 4320 lm, efficacy η = 120 lm/W (energy efficiency class E), color rendering index Ra = 80, and correlated color temperature Tc = 4000 K.

The requirements of the standard EN 12464-1:2021 for unified glare rating limit RUGL caused directly from the luminaires, colour rendering index Ra, and the correlated colour temperature Tc of the lamps in the luminaires must be observed. Light distribution curve of the selected luminaire significantly affects of the realized illuminance on the activity area, walls and ceiling, illuminance uniformity, and glare rating of the room.

The increasing requirements for the energy efficiency of the electric lighting a requires the use of contemporary LED luminaires that have a high efficacy - more than 120 lm/W.

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1.7.5 STAGE 4 - AUTOMATED CALCULATION OF THE LIGHTING INDICATORS IN THE ROOM AND TABULAR PRESENTATION OF THE OBTAINED OUTPUT RESULTS

In Sage 4, are carried out automated calculation of the lighting indicators in the room and tabular presentation of the obtained output results.

Automated calculation of the lighting indicators in software Relux for office room are performed by a specialized module for simplified lighting calculations “EasyLux”, activated from the “Start” menu - Figure 7.8.

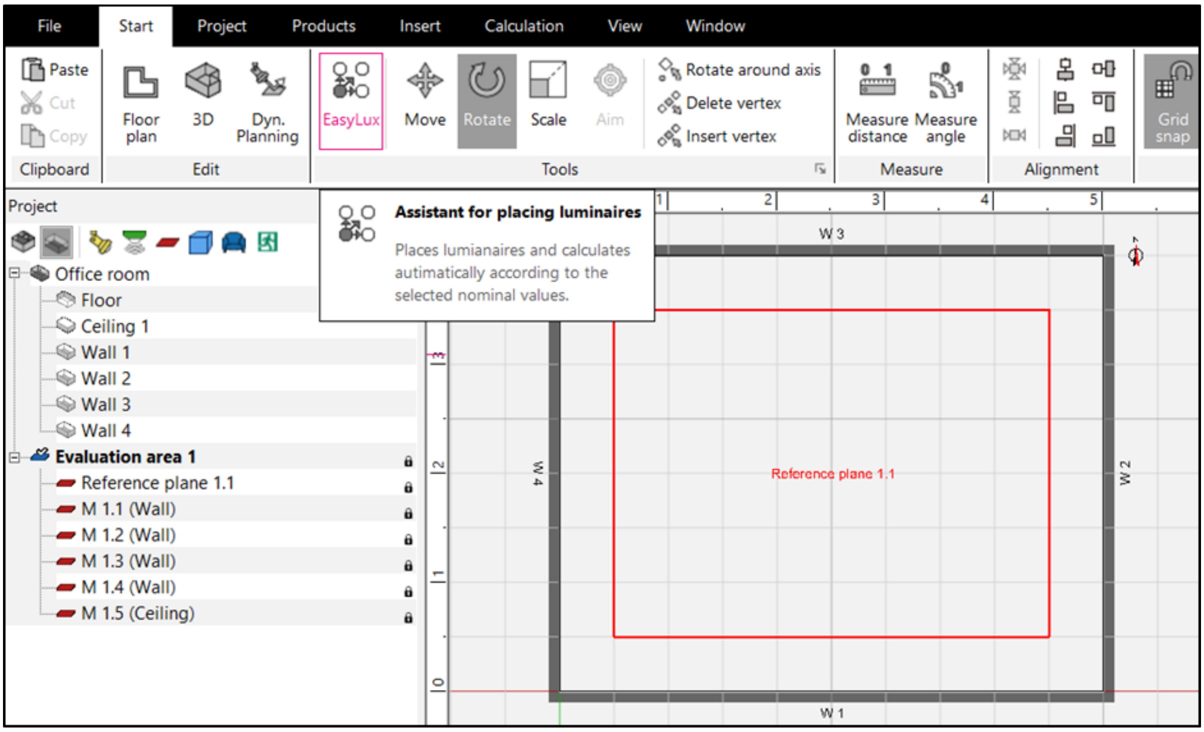

Figure 7.8. Selecting of the module “EasyLux”

Module “EasyLux” allow to place luminaires and automatically calculates of the lighting indicators according to the standard EN 12464-1:2021 with the selected nominal values for office room – Figure 7.9.

The “Luminaire type” field in module “EasyLux” shows the technical data of the selected LED luminaire.

The “Maintenance factor” field in module “EasyLux”, the maintenance factor can be defined simplified – office room is typically clear room with 3-yearly maintenance cycle, and maintenance factor fm = 0,67 - Figure 7.9.

The “Mounting type” field in module “EasyLux”, can be selected the type of hang of the luminaires - in the specific case, a ceiling mounting (recessed ceiling) is chosen – Figure 7.9.

By setting the nominal illuminance value in the module “EasyLux”, quick approximations are made, presenting a variant with regularly spaced LED luminaires, where the closest realized illuminance exceeding the standard is obtained - demonstrated for $\bar{E}m$ = 500 lx. After confirming the proposed number of LED luminaires, they are

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automatically placed on the ceiling of the office room and lighting calculations begin - with activation of button "Run" – Figure 7.9.

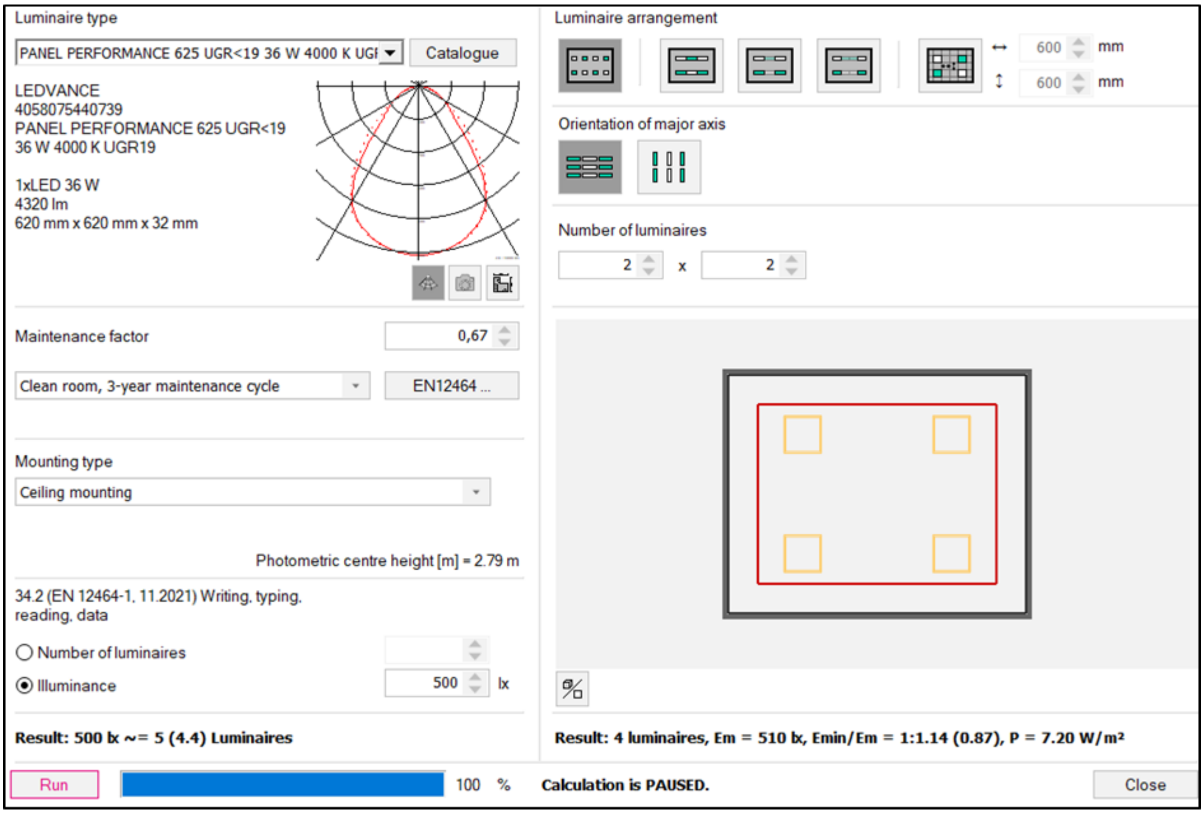

Figure 7.9. Setting in module "EasyLux" to prepare of the lighting calculations

After completing the calculations, in menu "Result" images with 3D realistic simulations of lighting in the office room are visualized, from which a visual idea of the level and uniformity of lighting is obtained – Figure 7.10.

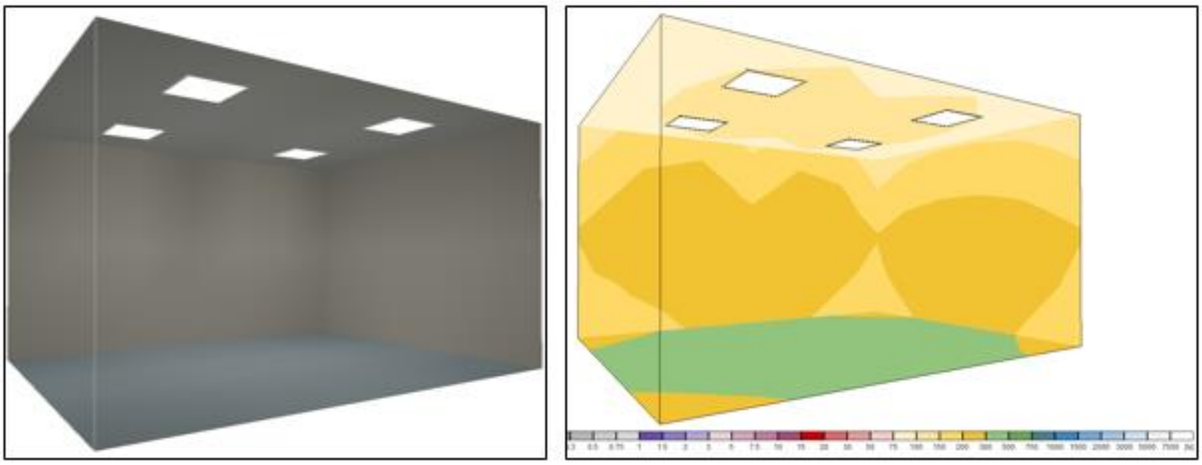

Figure 7.10. 3D realistic simulations of lighting in the office room

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A detailed tabular and graphical presentation of the calculation results is obtained in the "Overview" field. The visualization of the desired results is done by selecting and marking the corresponding position from the tree structure of the possible results for presentation – Figure 7.11.

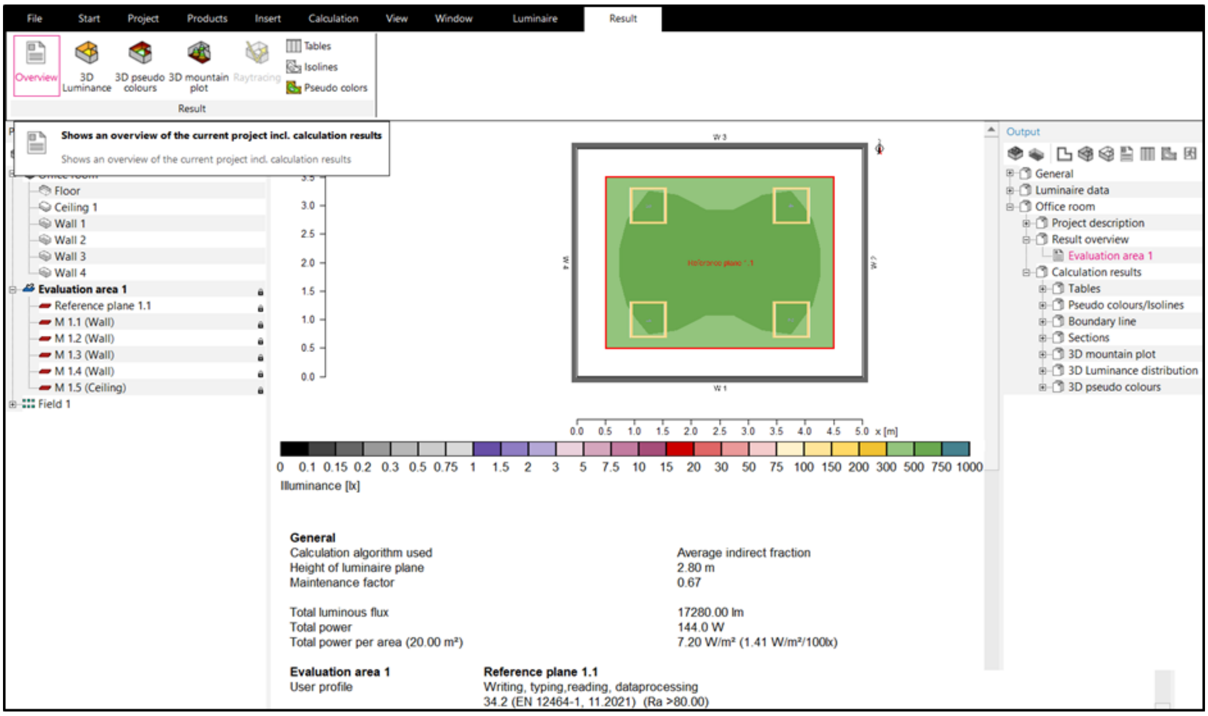

Figure 7.11. Calculation results in "Overview" field

Finally, the output results of the calculated quantitative and qualitative lighting indicators and LED luminaire data for the office room are presented in Table 7.3 where: N – number of luminaires in the room; IP - type of protection of the luminaire; Φ – luminous flux; P – active power; Tc – correlated colour temperature; Ra – color rendering index; Eav – average illuminance of the activity area; Uo - uniform illuminance; RUG – glare rating; Ez – cylindrical illuminance; Ew – illuminance of the walls; Ec – illuminance of the ceiling, and W/m2/100 lx – normalized power density (good practices indicate that it should be less than 2 $W/m^2/100$ lx).

Table 7.3. Output results of the calculated lighting indicators and luminaire data for the office room

Type of the room	Luminaire data						Calculated lighting indicators						
	N	IP	Φ	P	Tc	Ra	Eav	Uo	RUG	Ez	Ew	Ec	W/
	-	-	[lm]	[W]	[K]	-	[lx]	-	-	[lx]	[lx]	[lx]	m2/ 100 lx
Offices	4	40	4320	36	4000	80	510	0,87	16,1	196	248	111	1,41

1.7.6 QUIZ QUESTIONS

What are the main stages of automated interior lighting design?

What input data need to be entered into the interior lighting design software?

Which indicators are affected by the light distribution curve of the luminaires?

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Quiz Module 2 Energy efficient lighting technologies in buildings

1. What is the electromagnetic visible radiation wavelengths range?

- 380 nm up to 770 nm
- 10 nm up to 1000 nm
- 200 nm up to 280 nm

2. What is the unit of luminous flux?

- lm (lumen)
- kg (kilogram)
- m (meter)

3. What is the formula for illumination?

- Current [A] = Voltage [V] / Resistance [Ω]
- Force [N] = mass [kg] * acceleration [m/s^2]
- Lux [lx] = luminous flux [lm] / area [m^2].lx (lux)

4. What is the luminous efficacy of the lamp with active power 10 W and luminous flux 1000 lm?

- 555 lm/W
- 10 lm/W
- 100 lm/W

5. What is the energy label scale of a lamp with an efficacy of 210 lm/W?

- Energy efficiency label class A
- Energy efficiency label class D
- Energy efficiency label class F

6. Which type of the lamp listed below has the highest efficacy?

- Fluorescent lamp
- Incandescent lamp
- LED lamp

7. At which one of the listed below values of Colour Rendering Index (CRI) colour reproduction is most true?

- 90 ÷ 100
- 70 ÷ 80

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- 60 ÷ 75

8. **Which one of the listed below values of Correlated Colour Temperature (CCT), in Kelvin [K], is in Warm White light category?**
- (2 200 ÷ 3 000) K
- (4 500 ÷ 6 500) K
- > 6 500 K

TOPIC 2 – Lamps

9. **When were the first electrodeless lamps and "white" LEDs introduced?**
- in the 1990s
- 1875 year
- 1939 year

10. **What material is the filament in an incandescent lamp made of?**
- gold
- copper
- tungsten

11. **What is the main disadvantage of incandescent lamps?**
- very low colour rendering index (CRI)
- low efficiency due to losses such as heat
- low manufacturing costs

12. **What component is added to the filling gas in the incandescent halogen lamps?**
- carbon dioxide
- nitrogen
- a halogen component (iodine, chlorine, bromine)

13. **What does the filling gas of a fluorescent lamp contain?**
- a mixture of saturated mercury and an inert gas
- oxygen
- water vapours

14. **What is the most important factor that determines the light characteristics of a fluorescent lamp?**
- the electrodes

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- the type and composition of the fluorescent powder
- the glass tube

15. The compact fluorescent lamp (CFL) is designed to replace an older technology lamp. What is this lamp?

- LED (Light Emitting Diode) lamp
- OLED (Organic Light Emitting Diode) lamp
- incandescent lamp

16. What is today's most energy-efficient and rapidly-developing lighting technology?

- High Pressure technology
- Fluorescent technology
- LED (Light Emitting Diode) technology

17. Which is the most common LED technology for obtaining white light?

- monochromatic light source
- Blue LED chip coated by yellow phosphor
- LED emitting green colour

18. What are the advantages of LED technology?

- high luminous efficacy, good colour rendering , long lifetime
- high price
- low reliability

TOPIC 3. Luminaires

19. What is luminaire in electrical engineering?

- An electrical device used to create artificial light by use of an electric lamp or integrated LED module
- An electrical device used to create torque by use of an electric motor
- An electrical device used to create rotational speed by use of an engine or integrated a central processing unit (CPU)

20. What is the IP system (International Protection) for luminaires?

- Classifies luminaires according to their degree of efficacy from initial luminous flux

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- Classifies luminaires according to their degree of efficacy from correlated colour temperature
- Classifies luminaires according to their degree of protection from mechanical shock, dust and water

21. What is the highest possible IP for luminaires?
- IP68
- IP66
- IP86

22. What is light distribution curve of the luminaire?
- Spatial distribution of correlated colour temperature
- Spatial distribution of luminous intensity
- Spatial distribution of luminous efficacy

23. What is necessary to avoid glare from the luminaire?
- Attachment of an optical diffuser
- Attachment of a LED driver
- Attachment of a thermal housing

TOPIC 4. Lighting Control with One-Way Switch

24. What protective device is used for protection against short-circuit and overload in lighting installations in buildings?
- Circuit breaker
- Anti-glare optical lens
- Infrared sensor

25. What device is used to turn on and off the luminaires?
- Circuit breakers
- Lighting switches
- Temperature sensors

26. What switch type is used to control one lamp or luminaire from two different spots?
- One-way switch
- Deviator switches
- Two-way switch

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27. What is the line wire to the lighting switch?

- Phase conductor (L)
- Neutral conductor (N)
- Protective conductor (PE)

28. What shows tripping curve "C" for a circuit breaker?

- Inrush current reaches between 10 to 20 times the rated current (In)
- Inrush current reaches between 20 to 50 times the rated current (In)
- Inrush current reaches between 5 to 10 times the rated current (In)

29. In industrial and public buildings lighting circuits are protected by circuit breakers for a rating current (In) that does not exceed?

- In ≤ 25 A
- In ≤ 50 A
- In ≤ 100 A

30. In residential buildings, if the maintenance of the lighting system is not carried out by a specialist, lighting circuits are protected by circuit breakers for a rating current that does not exceed?

- In ≤ 16 A
- In ≤ 50 A
- In ≤ 100 A

31. What is the main advantage of impulse relay compared to a switch?

- Impulse relay can control more lamps than a switches
- Impulse relay cannot control more lamps than a switches
- Impulse relay can control only one lamp

TOPIC 5. Indoor Lighting Design and Maintenance

32. What of the following is the lighting requirement for an activity area (task area) according to EN 12464-1:2021?

- Maintained illuminance
- Rated current
- Peak wavelength

33. What is the required value of the Unified Glare Rating for an activity area in EN 12464-1:2021?

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- Minimum value
- Maximum value
- Root means square value

34. For maintenance-free lighting systems, it is recommended to use a maintenance factor (fm) value?

- fm = 1
- fm = 0.67
- fm = 3.14

35. What is the reason the designer of the indoor lighting shall state the maintenance factor?

- The cause is decreasing of the luminous flux over time due to ageing and pollution of the luminaire
- The cause is decreasing of the correlated colour temperature over time due to heating of the luminaire
- The cause is increasing of the luminaire efficacy over time

36. How does the luminous flux of the luminaire change during operation without function constant light output?

- Remains constant
- Increases
- Decreases

37. What kind of software products are DIALux evo and Relux?

- Lighting design software
- Electrical design software
- Software solution for information management

38. What determines the glare caused by interior lighting?

- Maintained illuminance
- UGR (Unified Glare Rating)
- IP code (Ingress Protection) of the luminaire

39. What input data is required to be entered for a single room in a software for indoor lighting calculation?

- Designation of the room dimension, reflectance, and utilization profile
- Three-dimensional luminance distribution view
- Selecting a transformer

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TOPIC 6. Photovoltaic (PV-LED) Systems for Lighting

40. PV–LED systems are a combination of the advantages of which two innovative technologies?
- Light-emitting diodes and thermal power plants
- Photovoltaics and fuel cell
- Photovoltaics and light-emitting diodes

41. What are the main components of a PV–LED system?
- PV panel (module), storage battery (accumulator), solar controller and LED luminaire
- PV panel (module), storage battery (accumulator) and solar water heating
- PV panel (module), solar water heating and solar controller

42. What is the operating mode of PV–LED system during the day at sunlight time?
- LED luminaire is switched on and battery discharging
- Battery discharging in PV-LED system
- Battery charging in PV-LED system

43. What is the operating mode of PV–LED system during the night time?
- LED luminaire is switched off and battery charging
- Battery discharging in PV-LED system
- Battery charging in PV-LED system

44. How long will the lead-acid battery work on a normally operated daily charge–discharge cycle of a PV–LED system?
- 3–5 years
- 20–25 years
- 15–18 years

45. How long is the life of PV modules on a normal operating cell temperature (25 °C)?
- 3–5 years
- 20–25 years
- 5–10 years

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Glossary - Module 2 Lighting...

C

COB LED - A CoB LED (or chip-on-board LED) is a single device with many LED chips mounted on a thermally efficient substrate placed below a uniform phosphor coating.

Colour Rendering Index (CRI) - measure of the degree to which the psychophysical colour of an object illuminated by the test illuminant conforms to that of the same object illuminated by the reference illuminant, suitable allowance having been made for the state of chromatic adaptation.

Note 1 to entry: See also CIE 13 Method of Measuring and Specifying Colour Rendering of Light Sources.

Note 2 to entry: This entry was numbered 845-02-61 in IEC 60050-845:1987.

Note 3 to entry: This entry was numbered 17-222 and 17-263 in CIE S 017:2011.

Reference: https://cie.co.at/eilvterm/17-22-109

Correlated colour temperature CCT - temperature of a Planckian radiator having the chromaticity nearest the chromaticity associated with the given spectral distribution on a modified 1976 UCS diagram, where u′, $\frac{1}{3}$ v′ are the coordinates of the Planckian locus and the test stimulus.

Note 1 to entry: The concept of correlated colour temperature should not be used if the chromaticity of the test source differs more than

$$\Delta C = \left[\left(u'_t - u'_p \right)^2 + \frac{4}{9} \left(v'_t - v'_p \right)^2 \right]^{1/2} = 5 \times 10^{-2}$$

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from the Planckian radiator, where u'_t, v'_t refer to the test source, and u'_p, v'_p to the Planckian radiator.

Note 2 to entry: Correlated colour temperature can be calculated by a simple minimum search computer program that searches for that Planckian temperature that provides the smallest chromaticity difference between the test chromaticity and the Planckian locus, or for example by a method recommended by Robertson, A.R. "Computation of correlated color temperature and distribution temperature", J. Opt. Soc. Am. 58, 1528-1535, 1968. (Note that the values in some of the tables in this reference are not up to date.)

Note 3 to entry: The chromaticity diagram originally used to determine the correlated colour temperature was the CIE 1960 uniform-chromaticity-scale diagram. The CIE 1976 uniform-chromaticity-scale diagram is a modified version of the CIE 1960 uniform-chromaticity-scale diagram and is equivalent to the (u, 3/2 v) diagram.

Note 4 to entry: The correlated colour temperature is expressed in kelvin (K).

Note 5 to entry: This entry was numbered 845-03-50 in IEC 60050-845:1987.

Note 6 to entry: This entry was numbered 17-258 and 17-130 in CIE S 017:2011.

Reference: https://cie.co.at/eilvterm/17-23-068

D

Driver - LED driver is an electrical circuit used to power a light-emitting diode (LED). The circuit must provide sufficient current to light the LED at the required brightness, but must limit the current to prevent damaging the LED.

Reference: https://en.wikipedia.org/wiki/LED_circuit

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L

LED - Light Emitting Diode **-** solid-state device embodying a p-n junction, emitting incoherent optical radiation when excited by an electric current.

Note 1 to entry: This definition is independent from the existence of enclosure(s) and of terminals.

Note 2 to entry: The output of an LED is a function of its physical construction, the material from which the LED is constructed and the exciting current. The optical emission can be in the ultraviolet, visible, or infrared wavelength regions.

Note 3 to entry: The term "LED" represents the LED die (or chip), or LED package. It is also used as part of a compound term, e.g. "LED technology", "LED television".

Note 4 to entry: The term "LED" shall not be used as an adjective for reporting product performance as for example "LED luminous flux", "LED colour rendering" or "LED lifetime". Instead use for example "luminous flux of the LED package", "colour rendering of the LED module" or "lifetime of the LED lamp".

Note 5 to entry: This entry was numbered 845-04-40 in IEC 60050-845:1987.

Note 6 to entry: This entry was numbered 17-662 in CIE S 017:2011.

Reference: https://cie.co.at/eilvterm/17-27-050

luminaire - apparatus which distributes, filters or transforms the light transmitted from at least one source of optical radiation and which includes, except the sources themselves, all the parts necessary for fixing and protecting the sources and, where necessary, circuit auxiliaries together with the means for connecting them to the power supply.

Note 1 to entry: This entry was numbered 845-10-01 in IEC 60050-845:1987.

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Note 2 to entry: This entry was numbered 17-707 in CIE S 017:2011.

Reference: https://cie.co.at/eilvterm/17-30-001

M

Maintained illuminance (Ēm) - the maintained illuminance value shall at least meet the requirement as given in EN 12464-1:2021 and shall be used for normal visual conditions taking into account the following factors: psycho-physiological aspects such as visual comfort and well-being; requirements for visual tasks; visual ergonomics; practical experience; contribution to functional safety; economy.

N

Normalized power density - Normalized power density is the lighting power density related to the level of 100 lx. This parameter is a classic measure of energy efficiency for various types of lighting installations.

photopic vision - Daylight human vision **-** vision by the normal eye in which cones are the principal active photoreceptors.

Note 1 to entry: Photopic vision normally occurs when the eye is adapted to levels of luminance of at least 5 $cd \cdot m^{-2}$.

Note 2 to entry: Colour perception is typical of photopic vision.

Note 3 to entry: This entry was numbered 845-02-09 in IEC 60050-845:1987.

Note 4 to entry: This entry was numbered 17-938 in CIE S 017:2011.

Reference: https://cie.co.at/eilvterm/17-22-016

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P

Photovoltaic (PV) - Photovoltaic (PV) devices generate electricity directly from sunlight via an electronic process that occurs naturally in certain types of material, called semiconductors. Electrons in these materials are freed by solar energy and can be induced to travel through an electrical circuit, powering electrical devices or sending electricity to the grid.

Reference: https://www.seia.org/initiatives/photovoltaics

Power factor (PF) - Power factor (PF) is the ratio of real (active) power, measured in kilowatts (kW), to apparent power, measured in kilovolt amperes (kVA).

R

RGB - Red Green Blue

scotopic vision - vision by the normal eye in which rods are the principal active photoreceptors.

Note 1 to entry: Scotopic vision normally occurs when the eye is adapted to levels of luminance of less than 0,005 cd·m−2.

Note 2 to entry: In comparison with photopic vision, scotopic vision is characterized by the lack of colour perception and by a shift of the visual sensitivity function towards shorter wavelengths.

Note 3 to entry: This entry was numbered 845-02-10 in IEC 60050-845:1987.

Note 4 to entry: This entry was numbered 17-1142 in CIE S 017:2011.

Reference: https://cie.co.at/eilvterm/17-22-017

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S

SMD **-** Surface Mount Device **-** An electronic component that mounts on the surface of a printed circuit board (as opposed to "through-hole" components which have pins that are inserted into holes).

U

Unified Glare Rating (UGR) **-** maximum allowed value given by the CIE Glare Rating system.

Note 1 to entry: See also CIE 112-1994 Glare Evaluation System for Use within Outdoor Sports- and Area Lighting.

Note 2 to entry: The glare rating limit has unit one.

Note 3 to entry: This entry was numbered 17-494 and 17-510 in CIE S 017:2011.

Reference: https://cie.co.at/eilvterm/17-22-106

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