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Lezione 1.2

LIGHTING THEORY

4 key messages:

- light is never alone

void

SOURCE > CONTEXT > PHOTORECEPTOR

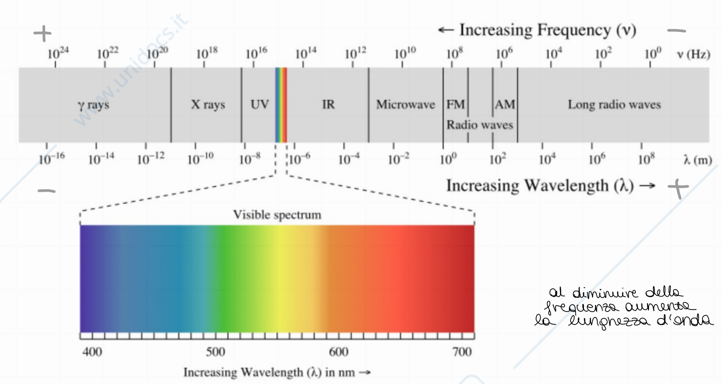
black hole / nothingness — darkness

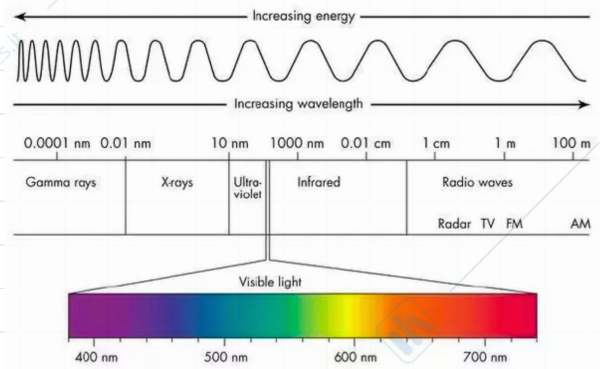
- light is everywhere
- light is the supreme finish
- light exists through space and time

• LIGHT is electromagnetic radiation within a certain portion of the electromagnetic spectrum.

photon → element of light

VISIBLE LIGHT → visible spectrum to the human eye.
wavelenghts are in the range of approx 400–700 nm
↳ between the infrared (longer wavelenghts) and the ultraviolet (shorter wavelenghts)





(red color → danger, alert)

• Light is measured with 2 main alternative sets of units:

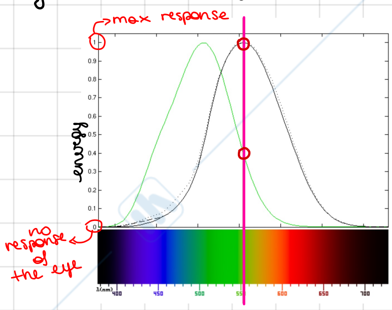
RADIOMETRY – measurements of "light" power at all wavelenghts (including visible light)

PHOTOMETRY – measures (visible) light with wavelenght weighted with respect to a standardised model of human perception (the eye)

• Photopic (black) and Scotopic (green) Luminosity Functions

standard functions established by the Commision International de l'Éclaraige (CIE)

How the standard human eye responds to different wavelengths
↓
it's good in perceiving radiations of 550 nm (yellow-green)



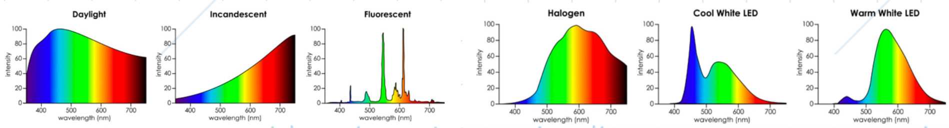
for certain wavelenghts we need more intensity and thus more energy to perceive the same luminosity (to obtain the same visual stimuli).

Human photoreceptor's (eye) sensivity varies by different wavelenghts – of the same energy values.

For instance, in Photopic vision, the eye is about 20 times more sensitive for light with a wavelenght of 550 nm (yellow), than for wavelenghts of 700 nm (deep red) or 450 nm (violet-blu).

The eye responds to the various wavelenghts with a color impression according to the increasing of the wavelenght values.

• According to the Visible Light Spectrum, crucial parameters of a light source are defined. In example, their spectral distribution, one of the most relevant qualitative aspects.



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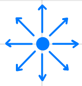
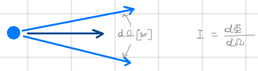
PHOTOMETRIC QUANTITIES

- luminous flux Φ lumen (lm)
  ↳ radiation of a light source emitted per second (in all directions)

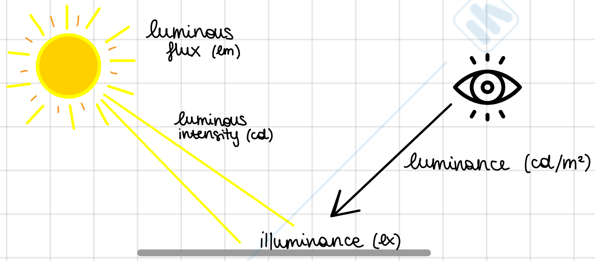


- luminous intensity I candela (cd)
  ↳ radiated luminous flux per unit of solid angle (in a specific direction)



- illuminance E lux (lx)
  ↳ total luminous flux incident on a surface

- luminance L cd/m^2
  ↳ luminous intensity per unit area of light (travelling in a given direction)



We don't perceive by absolute quantities. We perceive thanks to a dynamic interaction in between those quantities.

CASE STUDY : PEPSICO

- light
- interior design
- colours

- darkness
- use of black finishings and shadows

because thanks to the dark contex the light appears.

matte black absorb light

reflective floor (linoleum) → noise, light pollution → disturb with all the reflects

→ light designing is not throwing "lights" into a space

↓

perception of a space is important

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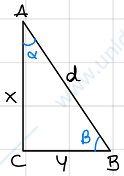
LEZIONE 2.2

TRIGONOMETRY FUNCTIONS



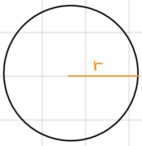
d = ipotenusa
x, y = cateti

$y = \sqrt{d - x^2}$

$y = d \cos\beta$ $\quad y = d \sin\alpha$ $\quad x = d \cos\alpha$ $\quad y = x \, tg\alpha$

$\beta = \arccos\frac{y}{d}$ $\quad \alpha = \arcsin\frac{x}{d}$ $\quad x = d \sin\beta$ $\quad \frac{y}{x} = tg\alpha$ $\quad \alpha = arctg\frac{y}{x}$

CIRCLE / SPHERE

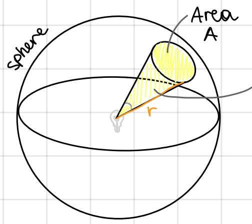


circonferenza = $2\pi r$

area = πr^2

superficie sfera = $4\pi r^2$

SOLID ANGLE



r = radius of the square

solid angle = 4π (based on the definition)

↓

$\Omega = \frac{A}{r^2}$ [sr] steradianti

CANDELA

In photometry, it's the fundamental unit in the International System of Units.
It's the unit measure of the LUMINOUS INTENSITY. All other photometric units are derived from it.

LUMINOUS FLUX AND LUMINOUS INTENSITY

In general a light source will not radiate its luminous flux uniformly in all directions.
Considering a point light source, if we image a sufficiently narrow radiation cone, when its vertex at the light source (which is considered as a point), then we can consider uniform the luminous flux inside the cone.

The concentration (density) of luminous flux within this narrow cone can now be defined as the luminous flux in this cone divided by the opening of the cone, expressed in terms of the solid angle of the cone.

The result is called the luminous intensity (I), measured in candelas [cd], in the direction of the center-line of the cone.

The light intensity is the radiated luminous flux per unit of solid angle in a specific direction.

Special case for solid angle:
1) The first case happens when the area A is equal to the all area of the sphere. In this case we have that the surface A is equal to $4\pi r^2$. The result is that the complete solid angle is 4π.
2) The second case happens when the area A is equal to a half of the sphere's surface, so the solid angle is equal to 2π.

$I = \frac{d\Phi}{d\Omega}$ [cd] $\quad \Omega = \frac{A}{R^2}$ [sr]

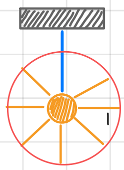
If a point emits all its flux evenly in the complete solid angle (4π) we have:

$I = \frac{\Phi}{4\pi}$

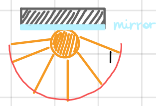
LUMINOUS INTENSITY: typical cases

a) constant intensity in all directions, so if we know the value of emitted flux, it is possible to evaluate the intensity of the source.

$I = \frac{d\Phi}{d\omega} = \frac{\Phi}{4\pi}$



b) same light source, but now placed on a (virtual) mirror reflective surface. In this case, the intensity is constant along a half of circle (or sphere) and the relationship between the luminous flux and the intensity is expressed by the formula: $I = \frac{d\Phi}{d\omega} = \frac{\Phi}{2\pi}$

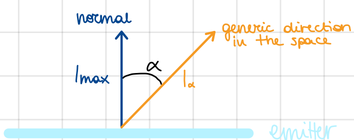


In optics, Lambertian's cosine law says that the luminous intensity observed from an ideal diffusely reflecting surface is directly proportional to the cosine of the angle α between the direction of the incident light and the surface normal.
The law is also known as the cosine emission law or Lambertian emission law.

A surface which obeys Lambert's law is said to be Lambertian. Such a surface has the same radiance when viewed from any angle. This means that to the human eye it has the same apparent brightness (or luminance). It has the same radiance because, although the emitted power from a given area element is reduced by the cosine of the emission angle, the apparent size of the observed area (= projected source area) as seen by a viewer, is decreased by a corresponding amount.

For a Lambertian light source, the relationship between luminous flux and intensity is given by the formula:

$\Phi = \pi \cdot I_{max}$



$I_\alpha = I_{max} \cdot \cos\alpha$ [cd]

Lambertian-like area source
↳ diffuse, flat, homogeneus.

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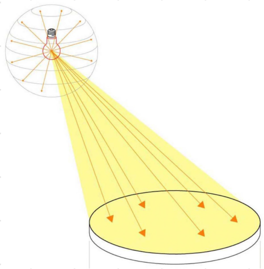
LUMINOUS FLUX AND ILLUMINANCE

Illuminance E [lx] is the total luminous flux incident Φ_{inc} on a surface S.

One lux equals one lumen per square meter (lm/m^2).

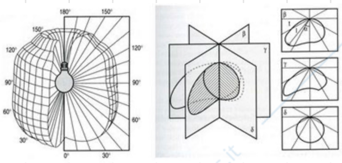
$$E = \frac{\Phi_{inc}}{S}$$



If a luminous flux of 10000 lm falls on a surface with an area of 12 m², the average illuminance (E_{ave}) will be:

$$E = \frac{\Phi_{inc}}{A} = \frac{10000}{12} = 833\ lx$$

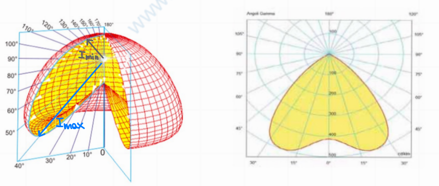
PHOTOMETRIC DISTRIBUTION OF A LIGHT SOURCE



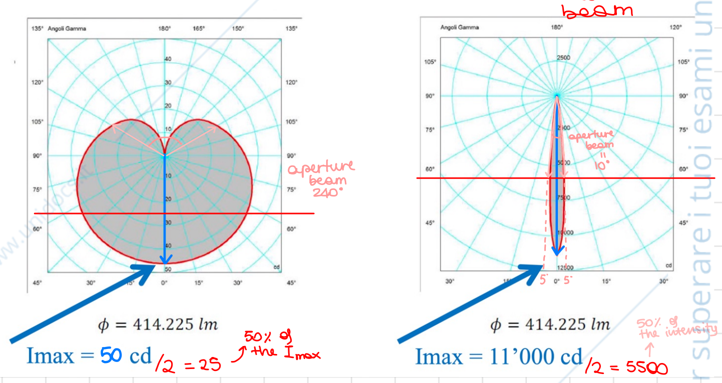
symmetrical distribution

rotosymmetrical

THE SHAPE OF LIGHT OUTPUT



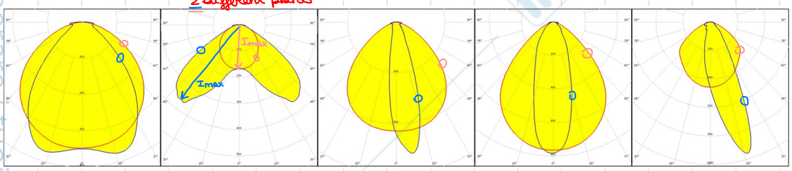
SAME FLUX, RADICALLY DIFFERENT INTESITIES!



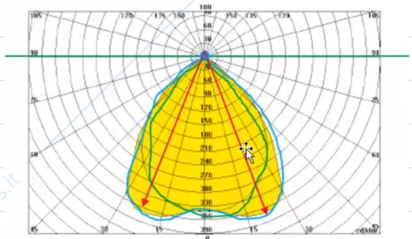
"APERTURE BEAM"

Aperture beam (of a projector or a lamp) is the angular extent in the specified plane in which all luminous intensities have values greater than 50% of the maximum.

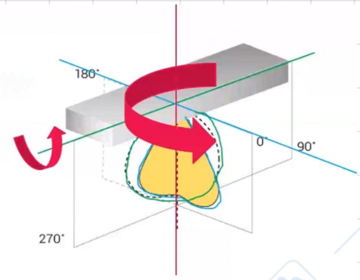
2 different planes

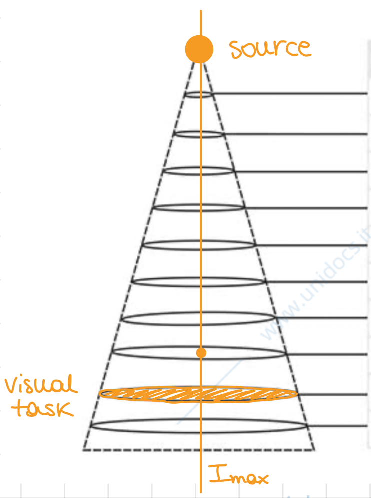


→ will have 2 ≠ aperture beams



DECORATIVE FIXTURES VS TECHNICAL FIXTURES





beam Angle:109.8°. flux Flux out:2629.0lm

Height (m)	Diameter (cm)	Eavg(lx)	Emax(lx)
0.5	142.0	1641.0	5278.0
1.0	284.6	410.3	1320.0
1.5	426.9	182.4	586.5
2.0	569.1	102.6	329.9
2.5	711.4	65.7	211.1
3.0	853.7	45.6	146.6
3.5	996.0	33.5	107.7
4.0	1138.3	25.6	82.5
4.5	1280.6	20.3	65.2
5.0	1422.9	16.4	52.8

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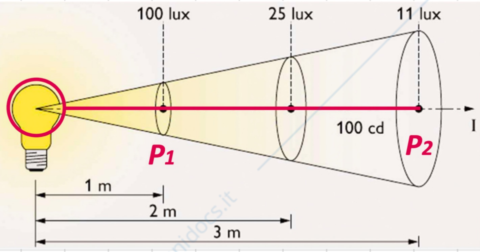
MAIN LIGHT-RELATED CHARACTERISTICS OF LIGHT SOURCES

- LUMINOUS FLUX → how much light / flux [lm]
- LUMINOUS INTENSITY / PHOTOMETRIC DISTRIBUTION → how much and where its going
- CCT - correlated Colour Temperature → warm (2600 K) / cold (5000 + K) white light [K]
- CRI - Colour Rendering Index → from 0 to 100, how good is the source in revealing colours

BASIC TYPES OF LIGHT SOURCE:
- POINT
- LINEAR
- AREA
- OTHERS (NON-COHERENT)

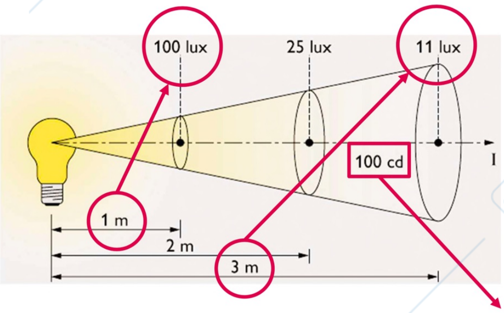
POINT LIGHT SOURCES

A light source can be defined as "point source" when the distance between the point of calculation and the source is almost 5 times the maximum dimension of the source itself.
The 5 time rule permits a computational accuracy of at worst 2% of diffuse emitters.



INVERSE SQUARE LAW

The illuminance E in a point of a plane perpendicular to the direction of incidence of the luminous intensity is equal to the light intensity I in the direction of that point divided by the square of the distance d between point light source and the point itself.



$$E = \frac{I}{d^2}$$

CONSTANT INTENSITY

LINEAR LIGHT SOURCES

Source having a diffuse distribution of intensity, in the planes passing through the lenght of the source itself.
linear sources are the ones that are "thin enough".

In this case, it has to be less than approximately 1/3 of the distance between the source and the point where we want to calculate the illuminance.

AREA SOURCES

can be:
- primary (luminaires or natural light)
- secondary (illuminated walls or ceilings)

They can't be treated as point or linear sources when both dimensions are longer than the distance from the point on which we calculate the illuminance (at least 1/3 of the distance).

light fixture:
- mechanical drawing
- electrical drawing
- lighting drawing

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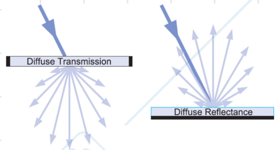
Lezione 3

OTHER LIGHT SOURCES (non-coherent)

DIFFUSE DISTRIBUTION - CONCEPT

When light strikes a rough surface, the light is reflected or transmitted in many different directions at once, which is called diffusion or scattering.



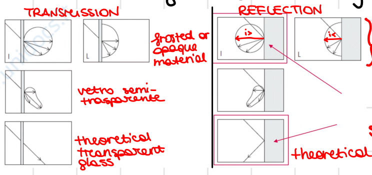
REFLECTION - CONCEPT

There are 3 general types of reflection: specular, spread and diffuse.

A specular reflection (what you see in a mirror or a polished surface) occurs when light is reflected away from the surface at the same angle as the incoming light's angle.

A spread reflection occurs when an uneven surface reflects light at more than one angle, but the reflected angles are all more or less the same as the incident angle.

A diffuse reflection (sometimes called Lambertian scattering or diffusion) occurs when a rough or matte surface reflects the light at many different angles.



MAIN CHARACTERISTICS OF LIGHT FIXTURES

Power absorption - Watt (W)
Efficiency - Lumen / Watt (lm / W)
Lifetime - Hours (Hrs)
"Driveability" (type of power feeding)
Control (type of data feeding)

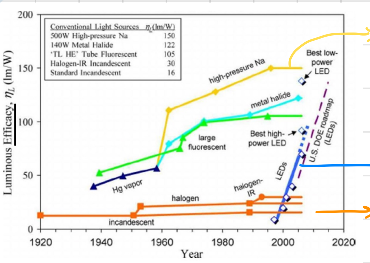
every surface is a light source

ENERGETIC EFFICIENCY

The energy efficiency (or Rendition) of a light source is typically characterized using efficacy, which is the ratio of emitted flux (lm) divided by electrical power consumption (W).

$$E = \frac{lm}{W} \quad \left(\frac{\Phi}{P}\right)$$

efficiency = rendition = efficacy



MAIN CHARACTERISTICS OF LIGHT SOURCES

IP rating - intrusion of external physical bodies, waterproof
IK rating - shock resistance
Law / code certifications
Quality certifications
Electrical safety

→ The perfect light source does not exist (yet). To each application, it's best compromise.

CRI - Color Rendering Index

It's defined by the International Commision on Illumination (CIE) as follows:

Color rendering: effect of an illuminant on the color appearance of objects by conscious or subconscious comparison with their color appearance under a reference illuminant.

The CRI of a light source doesn't indicate the apparent color of the light source (that is CCT) correlated color temperature

The CRI is determined by the light source spectrum

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The original test color samples (TCS) are taken from an early edition of the Munsell Atlas. The first eight samples are relatively low saturated colors, evenly distributed over the complete range of hues. These eight samples are employed to calculate CRI.
The last six samples provide supplementary information about the color rendering properties of the light source; the first four for high saturation, and the last two as representatives of well-known objects.

CRI

Discussion currently ongoing.

New samples in 1999.

Skin-tones added.

New methods currently under dvpt!

Name	Appr. Munsell	Appearance under daylight	Swatch
TCS01	7,5 R 6/4	Light greyish red	
TCS02	5 Y 6/4	Dark greyish yellow	
TCS03	5 GY 6/8	Strong yellow green	
TCS04	2,5 G 6/6	Moderate yellowish green	
TCS05	10 BG 6/4	Light bluish green	
TCS06	5 PB 6/8	Light blue	
TCS07	2,5 P 6/8	Light violet	
TCS08	10 P 6/8	Light reddish purple	
TCS09	4,5 R 4/13	Strong red	
TCS10	5 Y 8/10	Strong yellow	
TCS11	4,5 G 5/8	Strong green	
TCS12	3 PB 3/11	Strong blue	
TCS13	5 YR 8/4	Light yellowish pink	
TCS14	5 GY 4/4	Moderate olive green (leaf)	

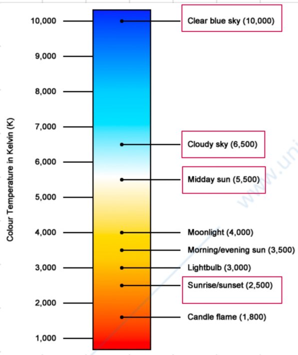
CCT - Correlated Color Temperature

The CCT is the temperature of the Planckian Radiator whose perceived color most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions.
→ definition from CIE

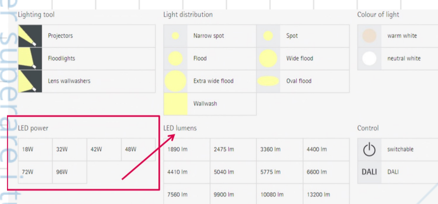
concept of warm or cold light

dynamic white

primary source: SUN
secondary source: SKY



POWER ABSORPTION

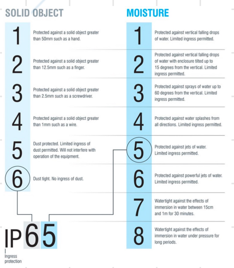


IP RATING

The IP code, International Protection Marketing (IEC standard 60529), sometimes interpreted as Ingress Protection Marking, classifies and rates the degree of protection provided against intrusion (body parts such as hands and fingers), dust, accidental contact, and water by mechanical casings and electrical enclosures.

FIRST DIGIT: solid particle protection
The first digit indicates the level of protection that the enclosure provides against access to hazardous parts (e.g. electrical conductors, moving parts) and the ingress of solid foreign objects.

SECOND DIGIT: liquid ingress protection
The second digit indicates the level of protection that enclosure provides against harmful ingress of water.



IK RATING

Impact protection

IK ratings are an international numeric classification to indicate the degrees of protection provided by enclosures for electrical equipment against external mechanical impacts.

It provides a means of specifying the capacity of an enclosure to protect its content from external impacts in accordance with IEC 62262:2002 and IEC 60068-2-75:1997.

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CONTROL

There are 2 main types of lighting control system which are:
- analog lighting control
- digital lighting control

examples for analog lighting control systems are:
0-10 V based system
AMX192 based system (USA standard)
D54 based system (EU standard)

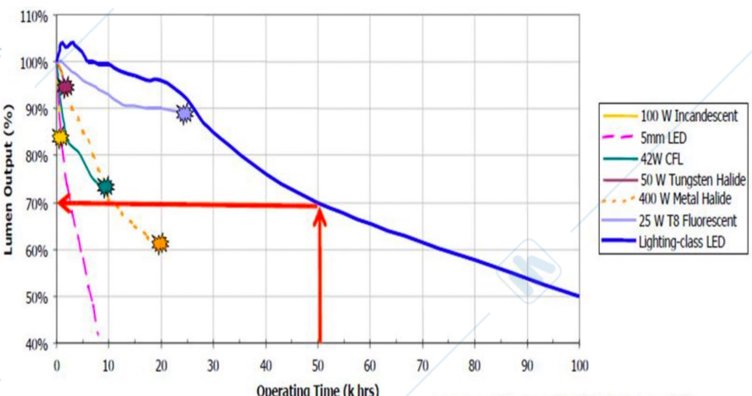
examples for digital lighting control systems are:
DALI based system → architecture
DMX → entertainment
KNX
DSI } home/office, building automation

The aforementioned are all wired light control system
There are also wireless lighting control system that are based on some standard protocols like MIDI, Bluetooth Mesh, Li-Fi ...
Integration with sensors and blurred lines in between latest lighting technologies and the IoT.

Intensity dimming - some applications:
- static regulation of emission (less or more flux)
- dynamic regulation of flux over time (strobos, adaptive lighting with sensors)
- dynamic white (CCT shift)
- RGB color shifting

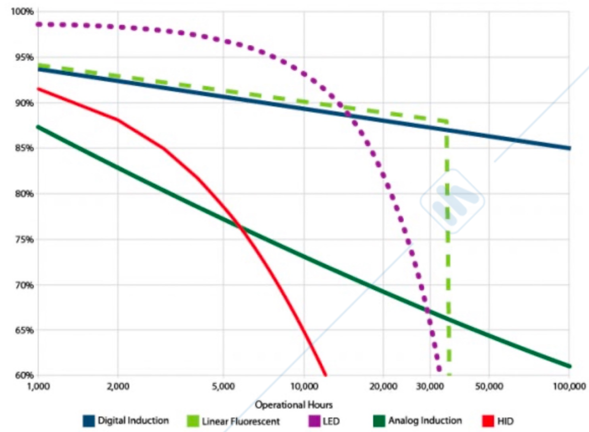
Mechanical movements:
- zoom/focusing
- moving heads / laser scanners

SOURCE LIFETIME



Courtesy LRC, Rensellaer Polytechnic Institute

LUMEN MAINTENANCE CURVES



CODE AND LAWS

About ISO
ISO is an independent, non-governmental international organization with a membership of 161 national standards bodies.
Through its members, it brings together experts to share knowledge and develop voluntary, consensus-based, market relevant International Standards that support innovation and provide solutions to global challenges.

What are standards?
International Standards make things work. They give world-class specifications for products, services and systems, to ensure quality, safety and efficiency. They are instrumental in facilitating international trade.
ISO has published 22147 International Standards and related documents, covering almost every industry, from technology, to food safety, to agriculture and healthcare. ISO International Standards impact everyone, everywhere.

The International Commission on Illumination - also known as the CIE from its French title, the Commission Internationale de l'Eclairage - is devoted to worldwide cooperation and the exchange of information on all matters relating to the science and art of light and lighting, colour and vision, photobiology and image technology.
With strong technical, scientific and cultural foundations, the CIE is an independent, non-profit organization that serves member countries on a voluntary basis.
Since its inception in 1913, the CIE has become a professional organization and has been accepted as representing the best authority on the subject and as such is recognized by **ISO** as an international standardization body.

The technical activities of CIE are carried out under the responsibility of six Divisions, each covering one sector of light and lighting.
Each Division establishes Technical Committees (TCs) to carry out the technical programme of the Division. The Divisions are:
Division 1: Vision and Colour
Division 2: Physical Measurement of Light and Radiation
Division 3: Interior Environment and Lighting Design
Division 4: Lighting and Signaling for Transport
Division 6: Photobiology and Photochemistry
Division 8: Image Technology

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Division 1: Vision and Colour
Terms of Reference:
To study visual responses to light and to establish standards of response functions, models and procedures of specification relevant to photometry, colorimetry, colour rendering, visual performance and visual assessment of light and lighting.

Division 2: Physical Measurement of Light and Radiation
Terms of Reference:
To study standard procedures for the evaluation of ultraviolet, visible and infrared radiation, global radiation, and optical properties of materials and luminaires, as well as the optical properties and performance of physical detectors and other devices required for their evaluation.

Division 3: Interior Environment and Lighting Design
Terms of Reference:
To study and evaluate visual factors which influence the satisfaction of the occupants of a building with their environment, and their interaction with thermal and acoustical aspects, and to provide guidance on relevant design criteria for both natural and man-made lighting; as well as to study design techniques, including relevant calculations, for the interior lighting of buildings; incorporating these findings and those of other CIE Divisions into lighting guides for interiors in general, for particular types of interiors and for specific problems in interior lighting practice.

Division 4: Lighting and Signalling for Transport
Terms of Reference:
To study lighting and visual signalling and information requirements of transport and traffic, such as road and vehicle lighting, delineation, signing and signalling for all types of public roads and all kinds of users and vehicles, and visual aids for modes other than road transport.

Division 6: Photobiology and Photochemistry
Terms of Reference:
To study and evaluate the effects of optical radiation on biological and photochemical systems (exclusive of vision).

Division 7 N.A.

Division 8: Image Technology
Terms of Reference:
To study procedures and prepare guides and standards for the optical, visual and metrological aspects of the communication, processing and reproduction of images, using all types of analogue and digital imaging devices, storage media and imaging media.

CEN → European Committee for Standardization
Italy → UNI = Ente Italiano di Normazione

EN 12464-1
Light and lighting - Lighting of work places
Part 1: Indoor work places
EN 12464-2
Light and lighting - Lighting of work places
Part 2: Outdoor work places
EN 1838
Lighting applications - Emergency lighting

Ref. no.	Type of room, task, or activity	$\bar{E}_m$	UGR_L	U_o	R_a	Notes
52.1	Arrival and departure halls, luggage claim areas	200	22	0,40	80	
52.2	Connecting areas	150	22	0,40	80	
52.3	Information desk, check-in desk	500	19	0,70	80	VDU work, see Chapter Ïllumination of offices and rooms with VDU workspaces".
52.4	Customs and passport control desks	500	19	0,70	80	Vertical lighting is important in order to identify faces (also see Chapter "Spatial lighting, direction oflight, modelling"). .
52.5	Waiting areas	200	22	0,40	80	
52.6	Luggage store rooms	200	25	0,40	80	
52.7	Security check areas	300	19	0,60	80	VDU work, see Chapter Ïllumination of offices and rooms with VDU workspaces".
52.8	Air traffic control tower	500	16	0,60	80	Lighting should always be dimmable. VDU work, see Chapter Ïllumination of offices and rooms with VDU workspaces". Daylight glare should be avoided. Reflections in windows should be avoided, especially at night.
52.9	Testing and repair hangars	500	22	0,60	80	
52.10	Engine test areas	500	22	0,60	80	
52.11	Measuring areas in hangars	500	22	0,60	80	

Table 5.26 — Offices

Ref. no.	Type of area, task or activity	$\bar{E}_m$ lx	UGR_L –	U_o –	R_a –	Specific requirements
5.26.1	Filing, copying, etc.	300	19	0,40	80	
5.26.2	Writing, typing, reading, data processing	500	19	0,60	80	DSE-work, see 4.9.
5.26.3	Technical drawing	750	16	0,70	80	
5.26.4	CAD work stations	500	19	0,60	80	DSE-work, see 4.9.
5.26.5	Conference and meeting rooms	500	19	0,60	80	Lighting should be controllable.
5.26.6	Reception desk	300	22	0,60	80	
5.26.7	Archives	200	25	0,40	80	

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LEZIONE 4

PHOTOMETRY

measures (visible) light with wavelenght weighted with respect to a standardised model of human perception.

MEASURING LIGHT

Luxmeter
Spectrometers
Luminance meter
Goniophotometer → used for measurement of the light emitted from a light fixtures (source), at different angles. → photometric distribution
Integrating sphere → may be thought of as a diffuser which preserves power but "destroy spatial information".
is typically equipped with a Luxmeter, a Wattmeter, spectrometer, retrieving useful optical (CRI, CCT) and electrical information about the light source (lamps (light engines)) subject to test. → efficency, flux

spectral distribution affects the perception

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