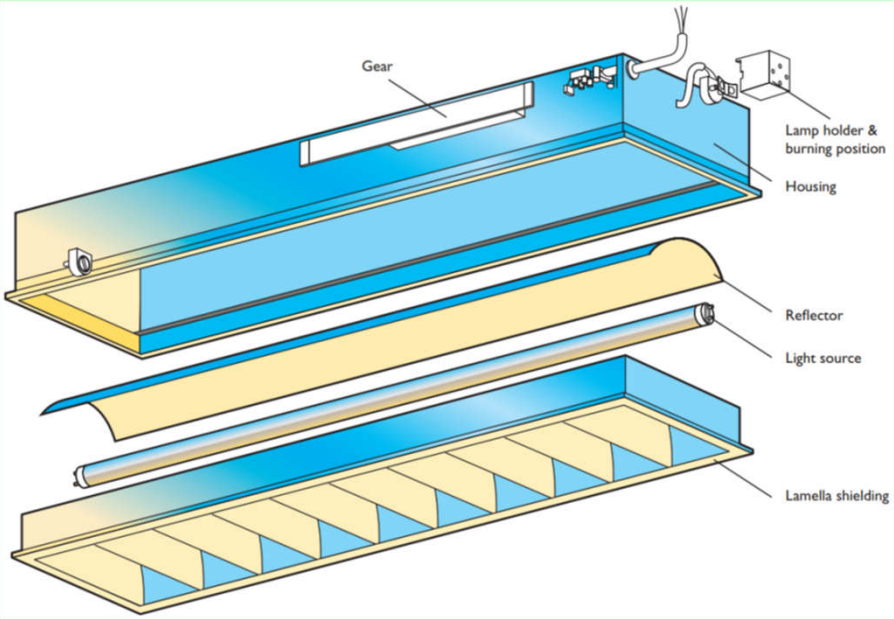
MEBS6004 Built Environment

http://ibse.hk/MEBS6004/



Lighting systems and components

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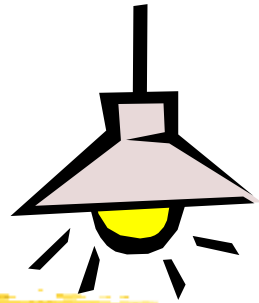
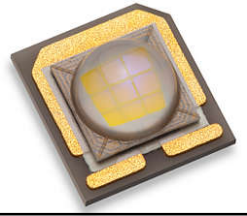
Contents

- Light sources
- Light emitting diode (LED)
- Applications & luminaires
- Control gear
- Lighting controls

Light sources

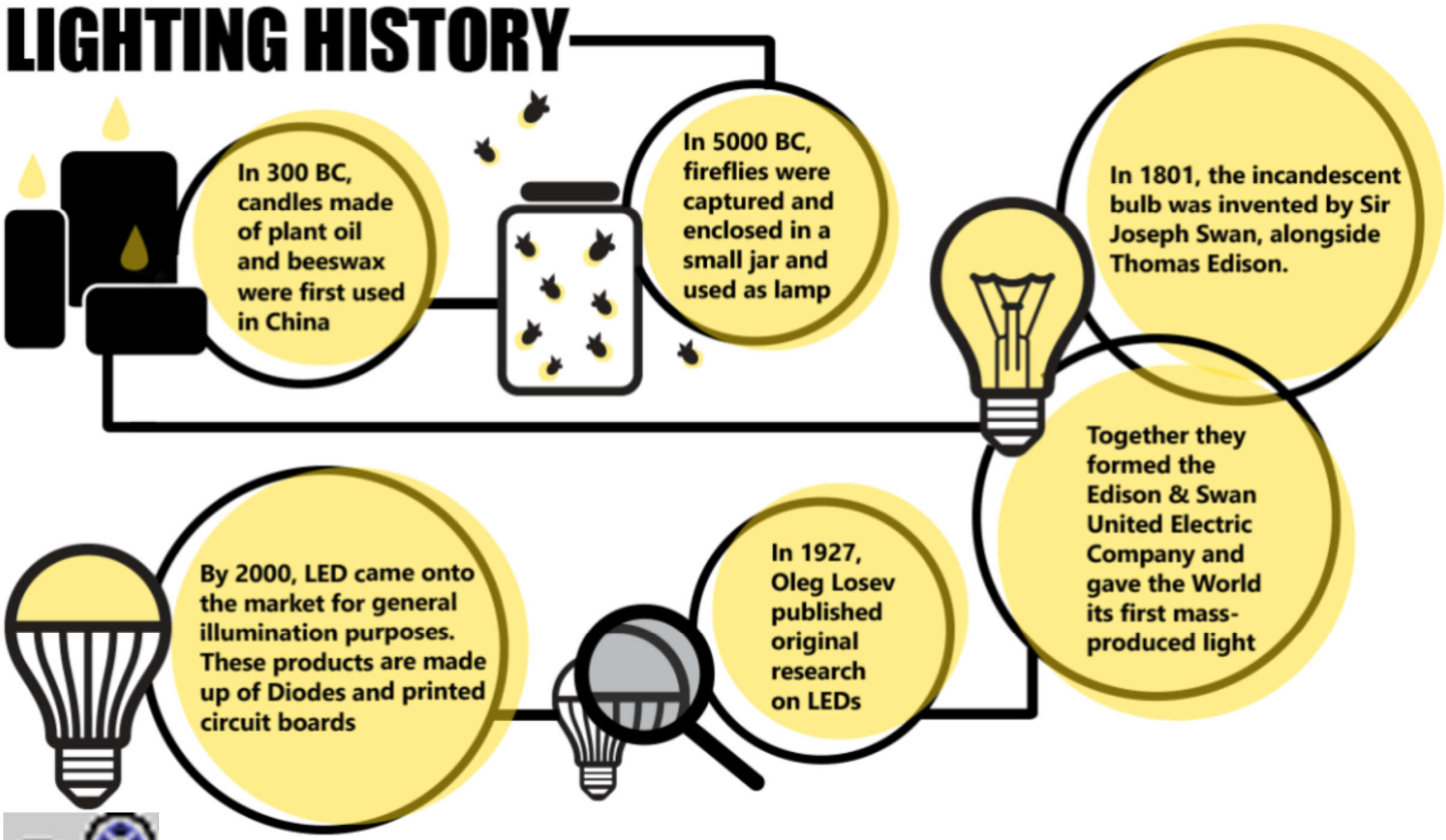


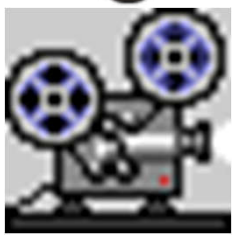
- Historical evolution of lighting
  - Natural light (the sun, daylight)
  - Torches (e.g. fire, wood + animal fat)
  - Candles & the wick
  - Gas lamps (e.g. street lighting)
  - Electric lamps
    - Incandescent light bulbs, fluorescent lights
    - Mercury-vapour & high intensity discharge lamps
    - Light emitting diode (LED) lighting



(Source: The Historical Evolution of Lighting https://www.stouchlighting.com/blog/the-historical-evolution-of-lighting)

Lighting history and light bulbs



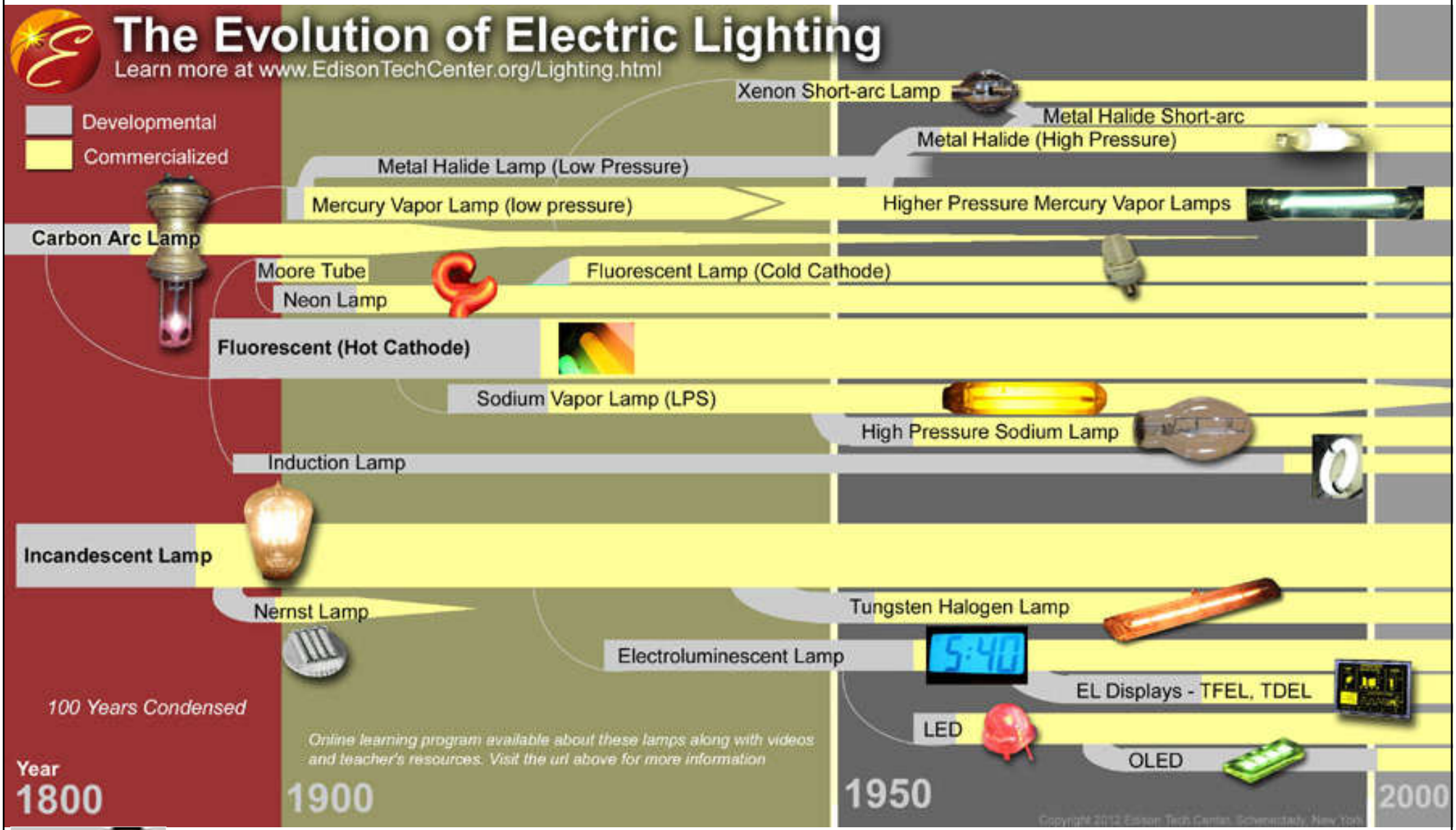


Video: Out of the Dark: The History of Lighting (2:16) https://youtu.be/85wz-jVfa1U

(Source: https://www.standardpro.com/advent-of-the-light-bulb/)


Traditional incandescent
Halogen incandescent
Compact fluorescent (CFL)
Light-emitting diode (LED)
Approximate wattage needed to produce 1,600 lumens
100 watts
77* watts
23 watts
20 watts
INPUT
OUTPUT
Wasted energy
1,600 lumens
1,600 lumens
1,600 lumens
1,600 lumens
Electric current heats an incandescent bulb's tungsten filament until it glows.
Halogen gas such as iodine inside the bulb prevents wear on the filament, allowing it to glow brighter.
Excited gas in a CFL tube emits ultraviolet photons, which coax the bulb's coating to emit visible light.
An LED bulb contains many small semiconductor units; each emits light when a voltage is applied.
LIFE SPAN: 750 hours
1,000 hours
10,000 hours
20,000 hours
PRICE: $0.37 per bulb
$1.59 per bulb
$2.23 per bulb
$45 per bulb

The evolution of electric lighting

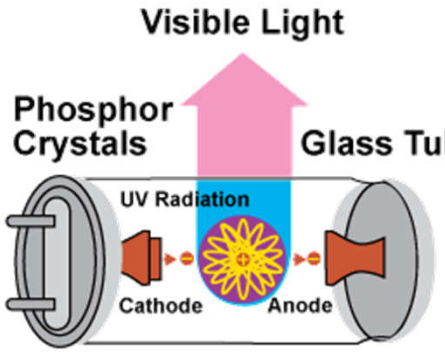


Video: Evolution of Light Bulbs, inventions - 2020 | History of Lighting, Documentary video (7:36) https://youtu.be/uszG5FD1_Uw

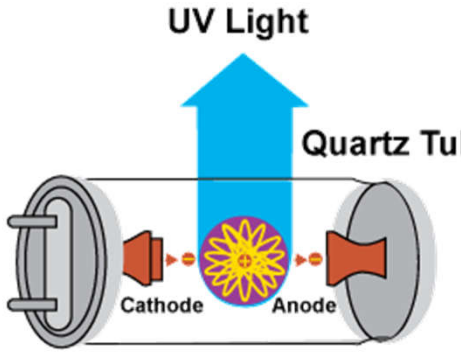
(Source: https://edisontechcenter.org/Lighting.html)

Light sources

- Mechanism for production of light radiation:
  - Incandescence
  - Electric discharges
  - Electroluminescence
  - Luminescence
  - Radioluminescence
  - Cathodoluminescence
  - Chemiluminescence
  - Thermoluminescence

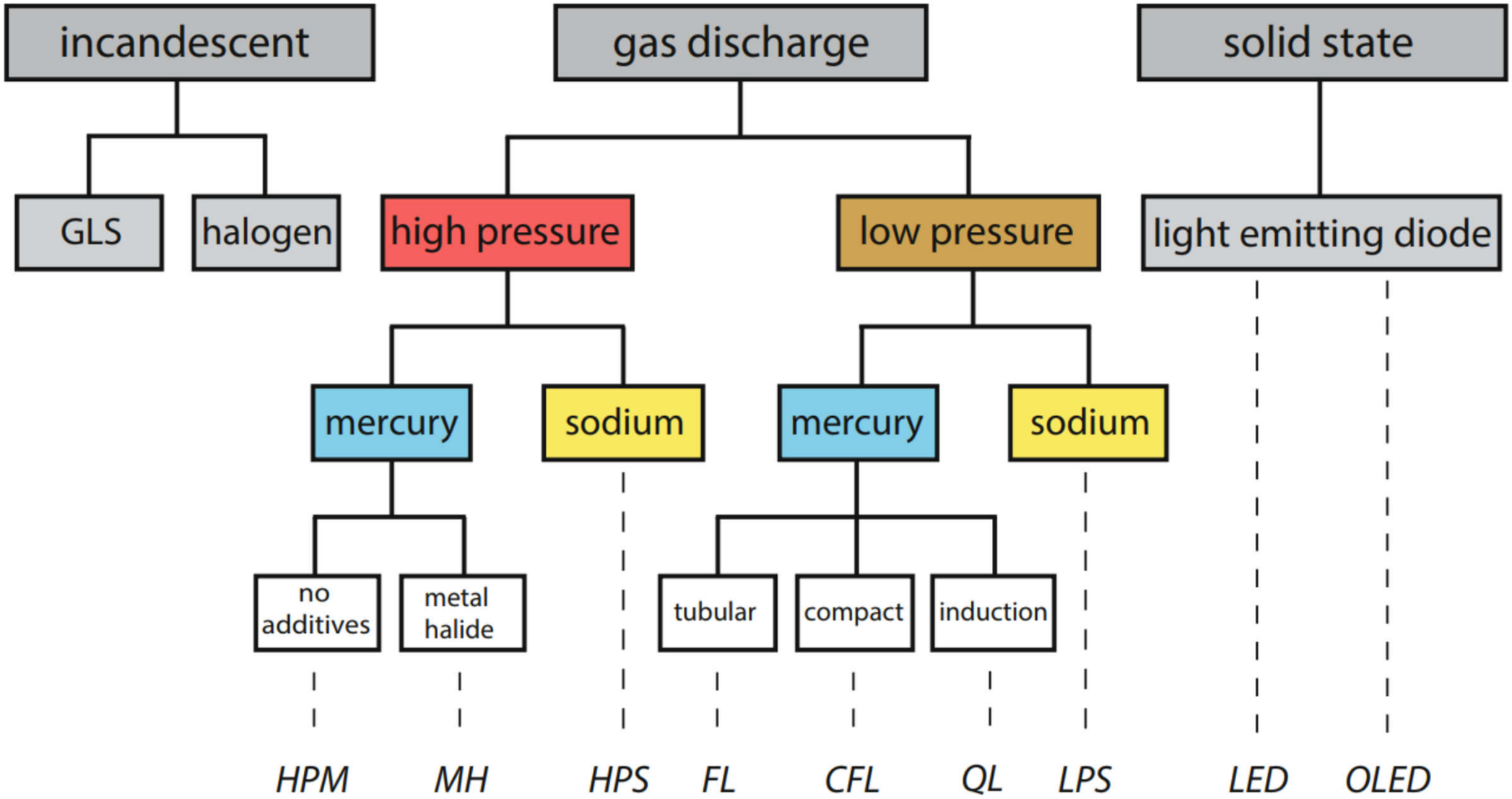


Fluorescent Lamp



Low Pressure Lamp

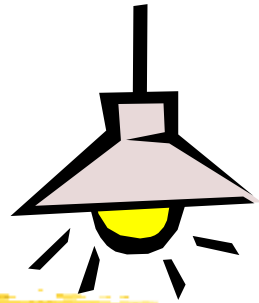
Light sources grouped according to the technology employed



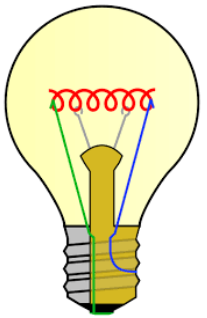
HPM = high-pressure mercury lamp, *MH* = metal-halide lamp, *GLS* = general lighting service incandescent lamp, *HPS* = high-pressure sodium lamp, *FL* = tubular fluorescent lamp, *CFL* = compact fluorescent lamp, *QL* = induction lamp, *LPS* = low-pressure sodium lamp, *LED* = light-emitting diode, *OLED* = organic light emitting diode

(Source: van Bommel W., 2019. *Interior Lighting: Fundamentals, Technology and Application*, Springer International Publishing, Cham.)

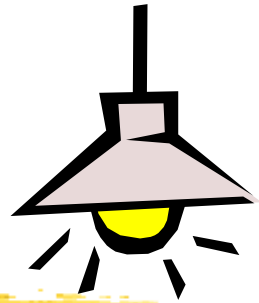
Light sources



- Commonly used light sources (abbrev./code)
  - Incandescent filament (I or GLS = general lighting service)
  - Tungsten-halogen (TH or H)
  - Fluorescent (F)
  - High intensity discharge (HID)
    - Metal halide (MH or MBI or M)
    - Mercury vapour (MBF or HPMV or Q)
    - High pressure sodium (HPS or S or SON)
  - Low pressure sodium (LPS or LS or SOX)



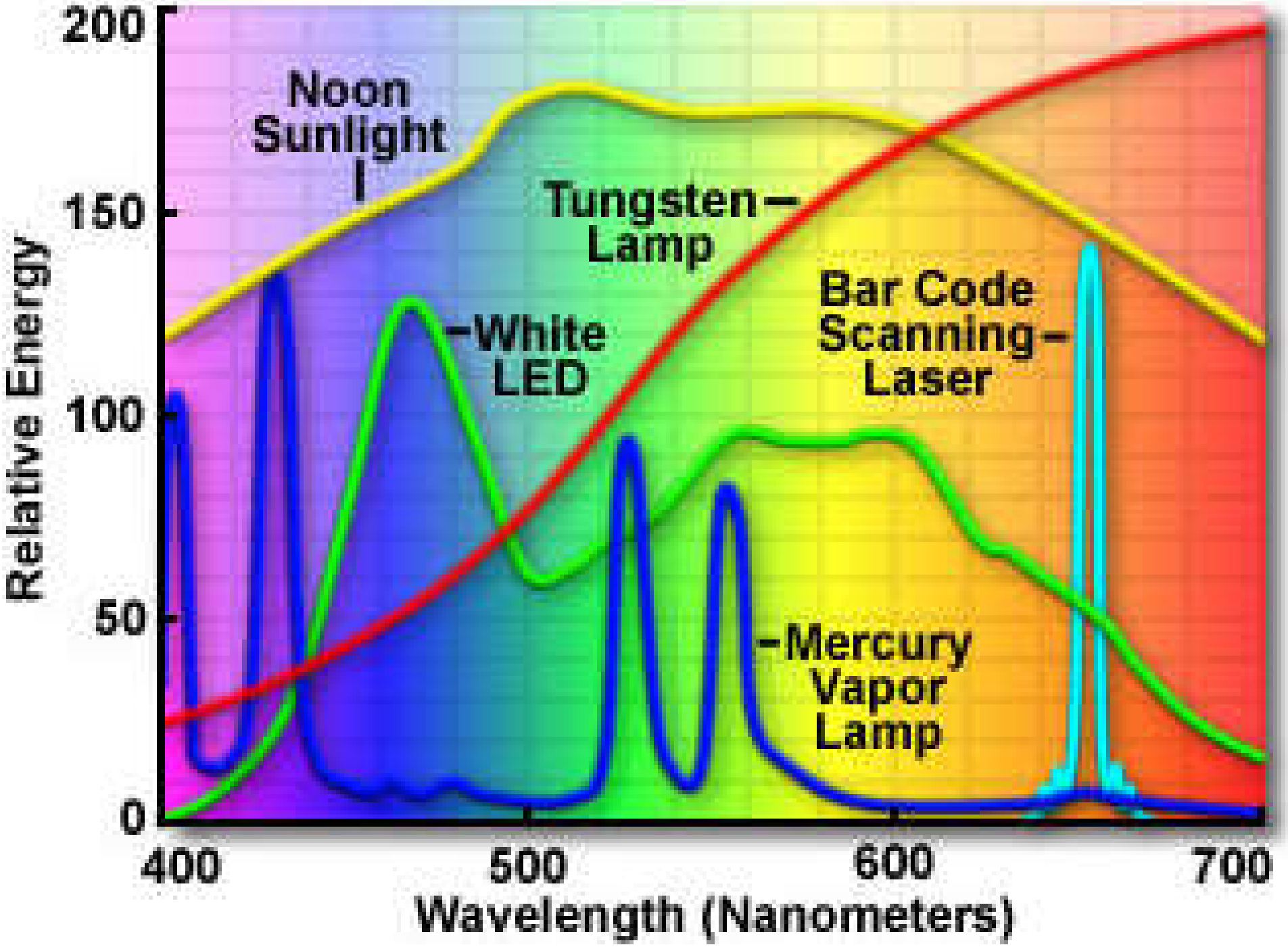
Light sources



- Other light sources
  - Induction lamps
  - Light emitting diodes (LEDs)
  - Electroluminscent lamps
  - Lasers
  - Combustion sources
    - Candle flame
    - Gas light (e.g. using kerosene)

(* See also http://en.wikipedia.org/wiki/List_of_light_sources)

Spectra from common sources of visible light



(Source: https://www.olympus-lifescience.com/en/microscope-resource/primer/lightandcolor/lightsourcesintro/)

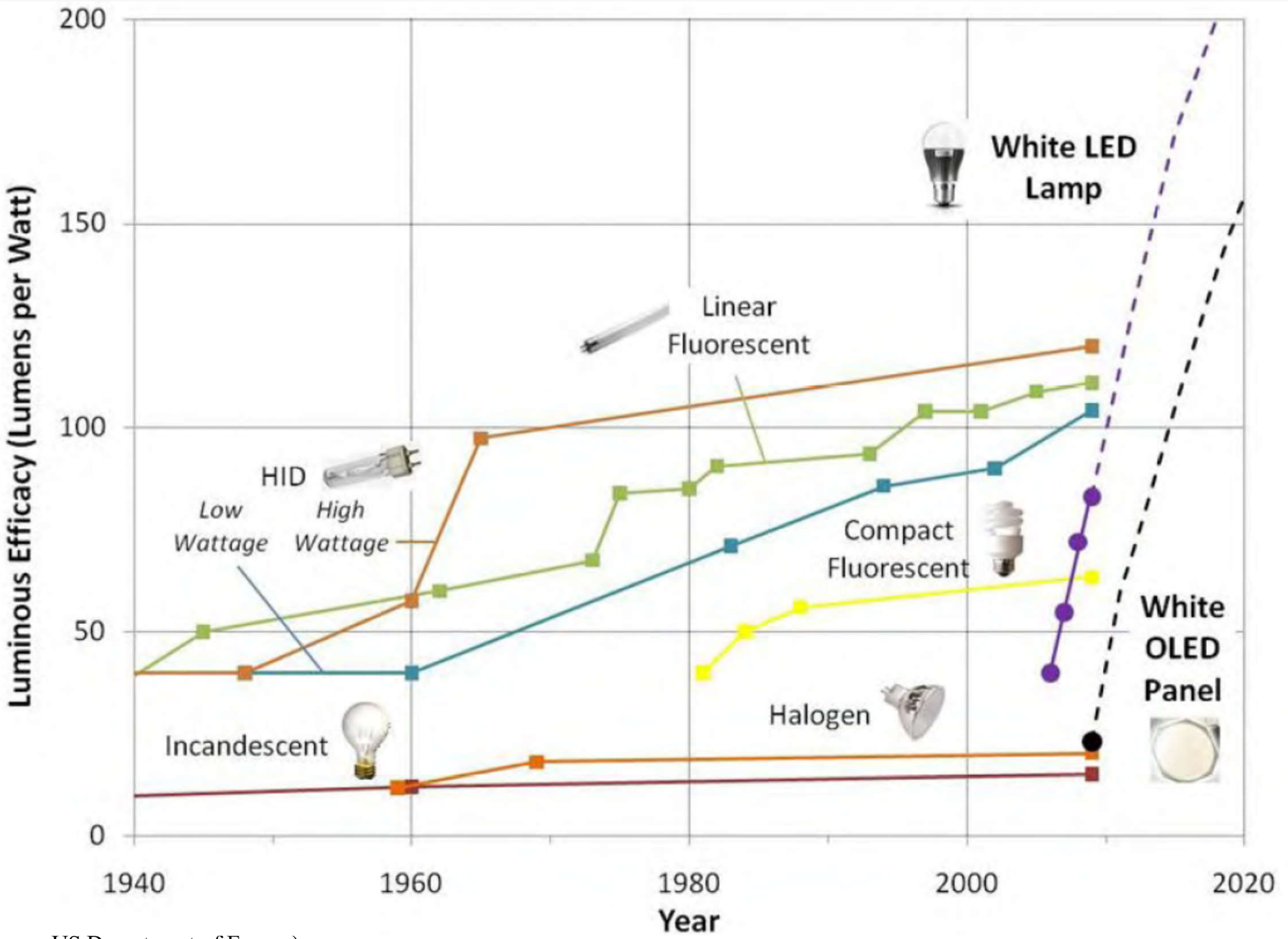
Important characteristics of lamps & light sources in interior lighting

Luminous efficacy (Lm/W)	Colour rendering (Ra)
Lumen package (Lm)	Luminance
Lamp price	Shape and dimensions
Lifetime (h)	Need of gear/driver (yes/no)
Lamp-lumen depreciation (Lx)	Run-up and reignition
Spectrum	Dimmable (yes/no)
Correlated colour temperature (CCT)	Ambient temperature sensitivity
Colour rendering	Environmentally unfriendly material

Lamp type	Lm/W	CCT	R_a	Lifetime (h)	Shape
Incandescent lamp	8–12	2700	100	1000	Compact
Halogen lamp	15–25	3000	100	2000	Very compact
Tubular fluorescent	70–105	2700–17,000	60–90	15,000–20,000	Long linear
Compact fluorescent CFL	70–80	2700–5000	60–90	12,000–20,000	Compact
Induction lamp	65–75	3000–4000	60–90	60,000–75,000	Compact
Compact metal-halide	70–95	2700–4500	70–95	7000–12,000	Compact
Single LED (white)	80–180	2700–10,000	60–95	20,000–100,000	Point source
LED system (white)	70–160	2700–10,000	60–95	20,000–100,000	Many shapes, compact to large
OLED (white)	40–80	2700–6000	60–95	10,000–40,000	Flat, up to 50 × 50 cm

(Source: van Bommel W., 2019. *Interior Lighting: Fundamentals, Technology and Application*, Springer International Publishing, Cham.)

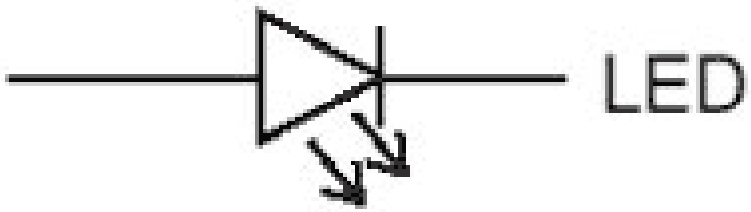
Historical and predicted luminous efficacy of light sources



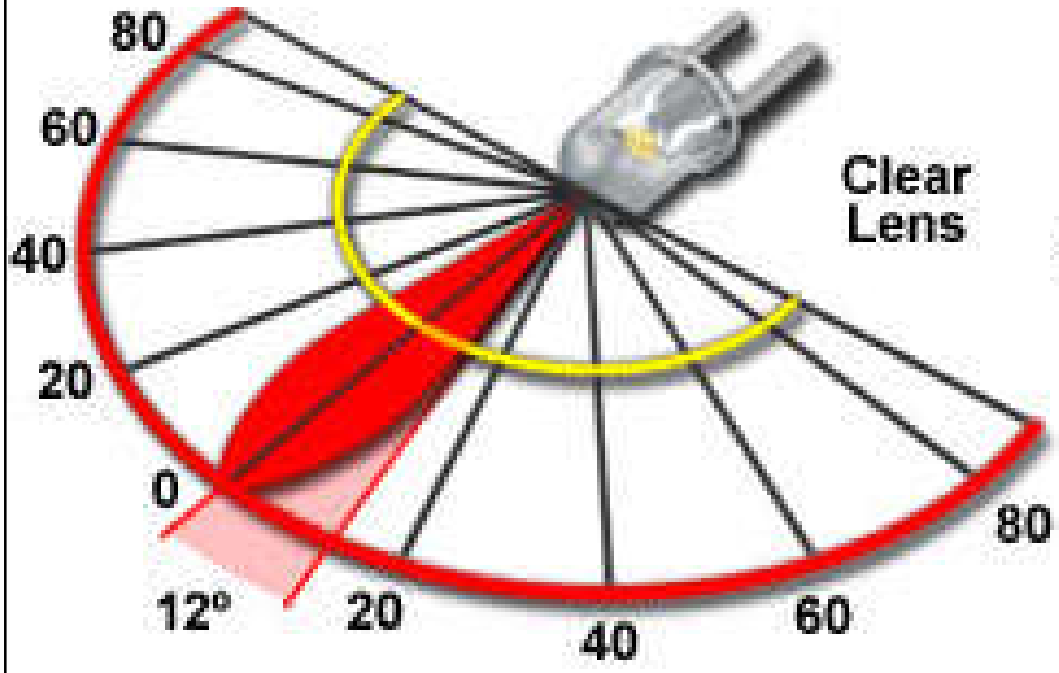
(Source: US Department of Energy)

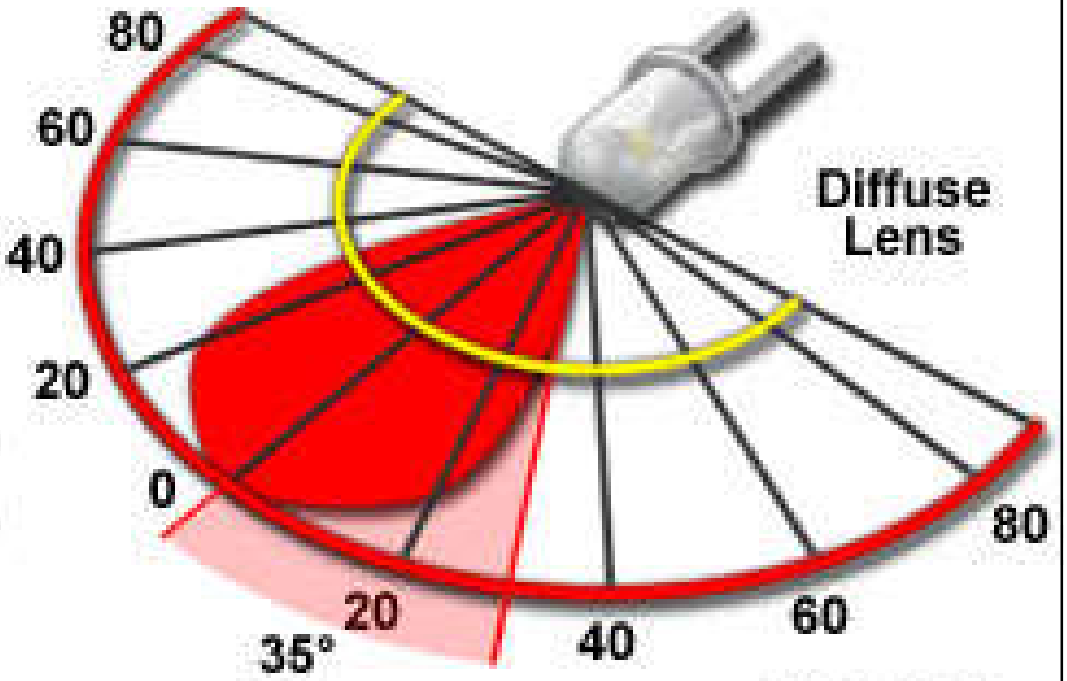
Light emitting diode (LED)

- Light emitting diode (LED)
  - Produces light by electroluminescence at low voltage “p-n” junction (e.g. indicator lights)
  - Development of white light & high output LEDs enables wider use in lighting systems

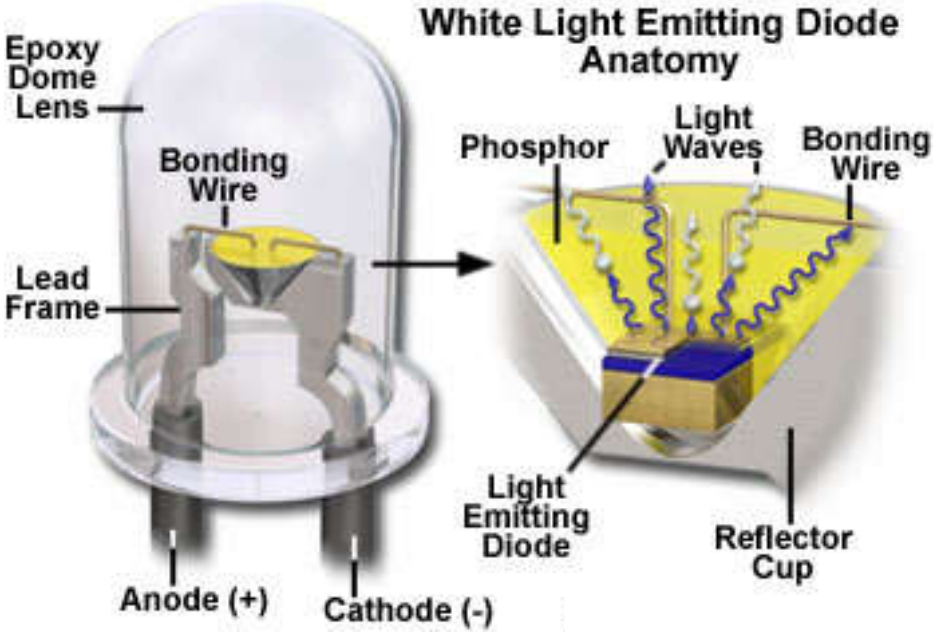


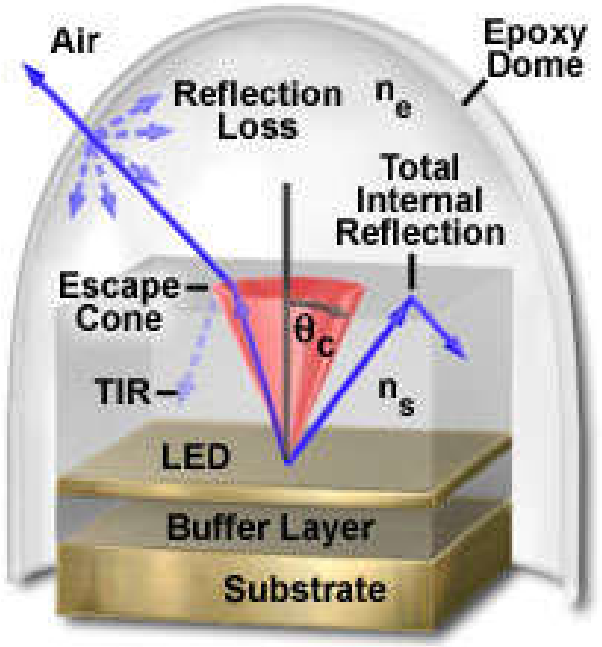
Light cones emitted by clear and diffuse LED lenses





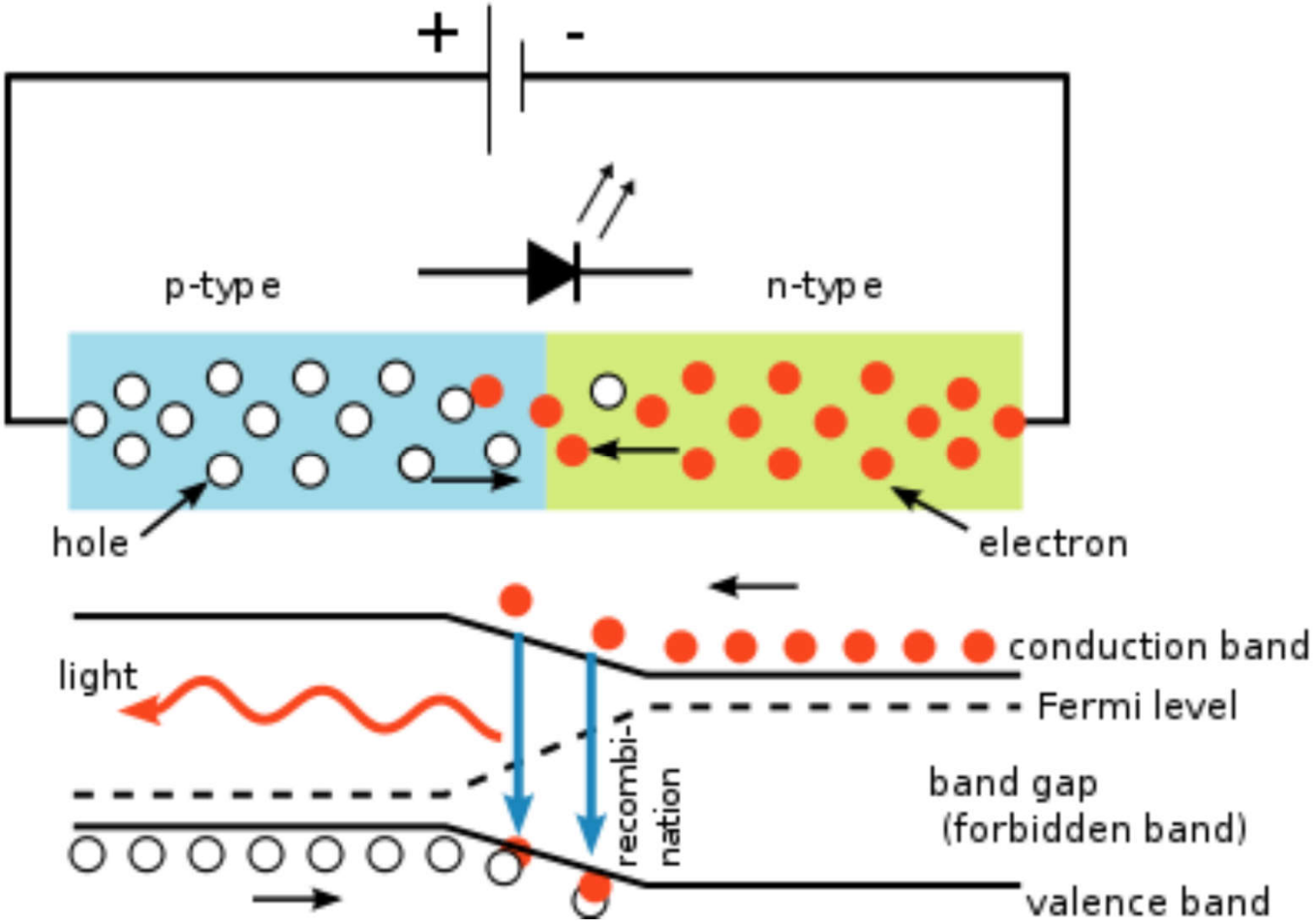
50% Intensity 100% Intensity

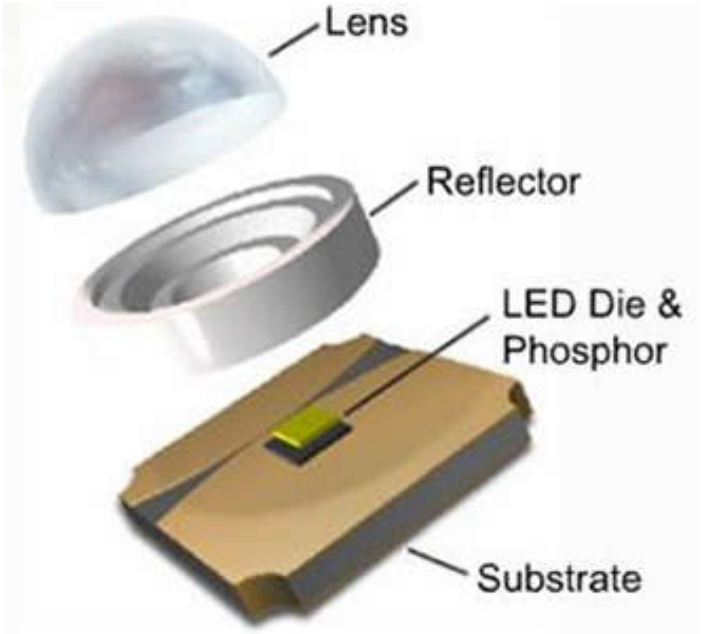




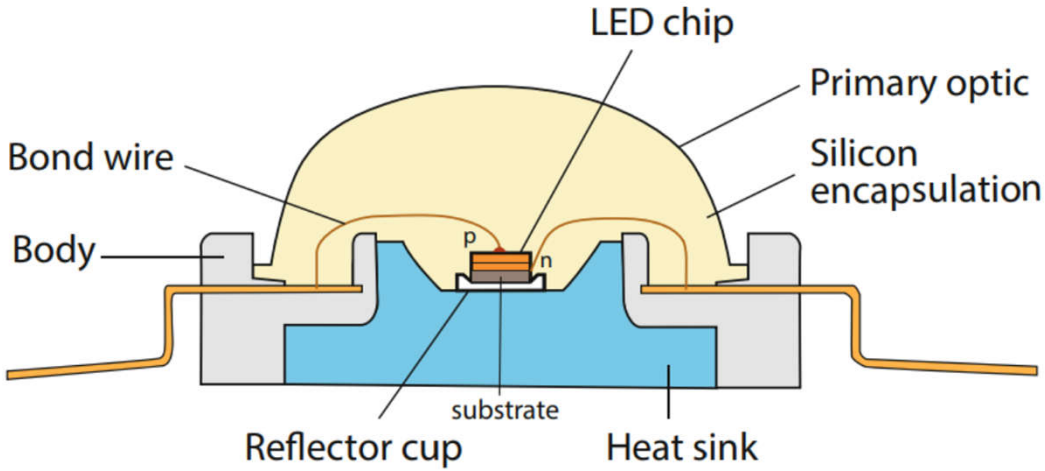
(Source: https://www.olympus-lifescience.com/en/microscope-resource/primer/lightandcolor/ledsintro/)

Principle of LED and structure of high power white LED*





Structure of high power white LED



(* Source: http://www.omslighting.com/ledacademy/)

Light emitting diode (LED)

- Solid state lighting (SSL)
  - Emits light from semi-conductor (solid)
    - Light emitting diode (LED)
    - Organic light-emitting diodes (OLED)
    - Polymer light-emitting diodes (PLED)
  - Advantages:
    - Low power consumption
    - Reduced heat generation
    - Greater resistance to shock, vibration, and wear
  - LED retrofits (not ideal), versus LED luminaires

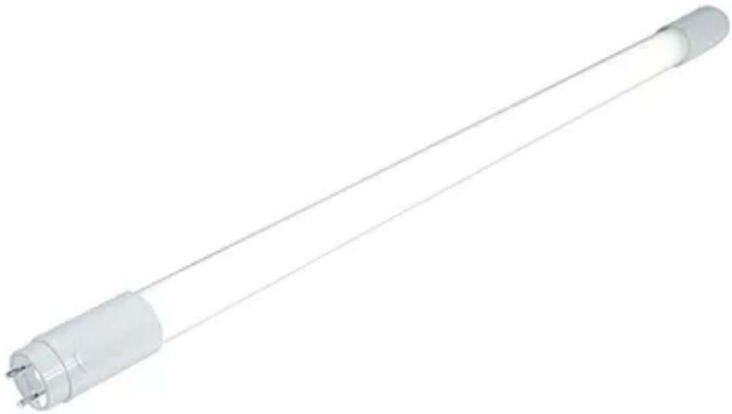
New generation of LED lighting fittings

Linear lights (flexible & rigid)

Recessed luminaires

Recessed downlights

LED panels



LED tubes

LED bulbs

(Source: https://www.lightengine-tech.com/led-general-lighting-solution

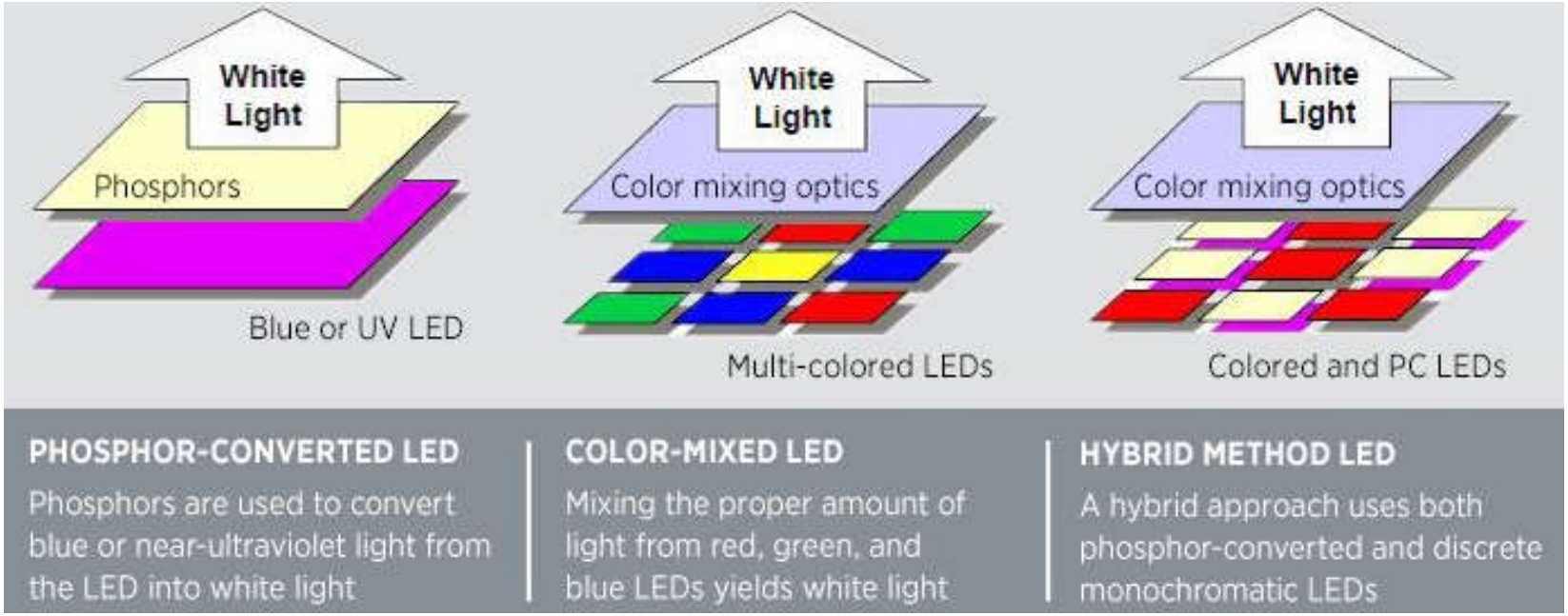
Light emitting diode (LED)

- Light emitting diode (LED)
  - Advantages
    - Low power consumption
    - Long lasting (long useful life)
    - Durable (withstand impact & vibration)
    - Cool (little heat produced)
    - Modular design & compact size
    - Controllability (colour balance & intensity)
    - Instant on, frequent switching
    - No annoying flicker
    - Low cost of manufacture
    - No ultraviolet & infrared radiation
    - Mercury free
  - Disadvantages
    - Focused, directional light
    - Need different optics design
    - May need heat sink (thermal management)

LED candles

Light emitting diode (LED)

- White light LED
  - Mixing light from multiple LEDs of various colours, or using a phosphor to convert some of the light to other colors



(Source: https://www.energy.gov/eere/ssl/led-basics)

Light emitting diode (LED)

- Colour changing LED lighting
  - Tunable lighting systems employ banks of coloured LEDs that can be individually controlled
- LED drivers
  - An appropriate circuit to control electrical power
- Thermal management & heat mitigation
  - The housing of high-power LEDs should be designed to adequately dissipate heat
  - Efficiency decreases with operating temperature

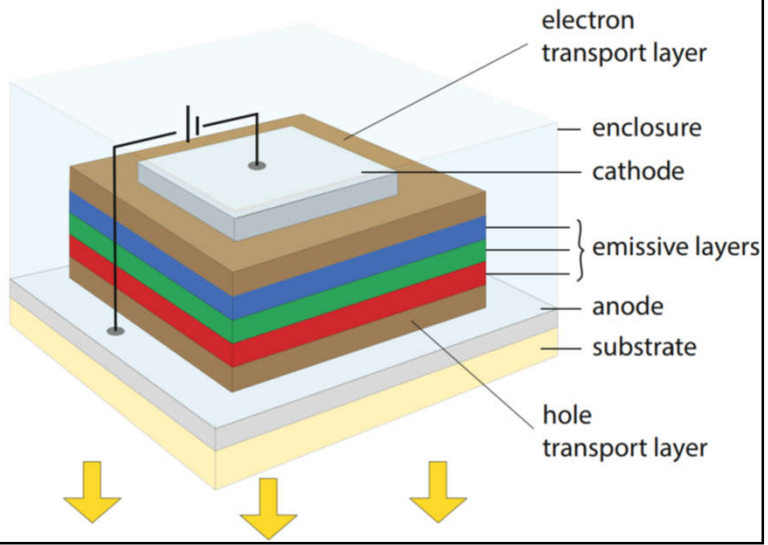
Light emitting diode (LED)

- Video: LEDs and OLEDs - How it Works, Inventors (7:18)

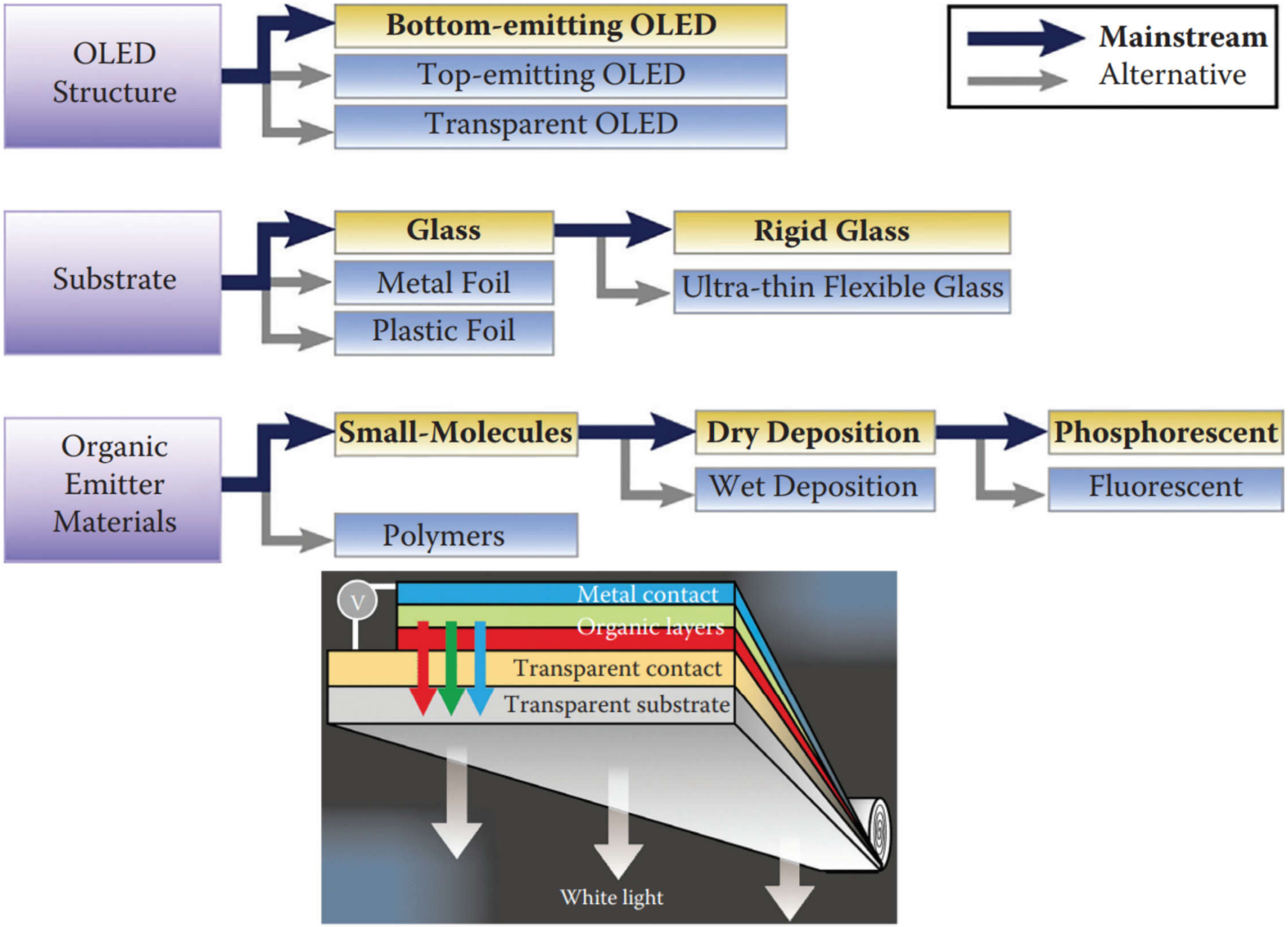
  - https://youtu.be/8quZrUcRFlw
  - All about Light Emitting Diodes and Organic LEDs. How they work, the difference between them.
  - Learn about the inventors of the lights at the end of the program.

Light emitting diode (LED)

- Organic light emitting diode (OLED)
  - LED made of organic semiconductor material
  - Can create large area lighting panels
  - Can be used to make flexible & transparent panels
  - They are expensive & difficult to produce



OLED structure and materials

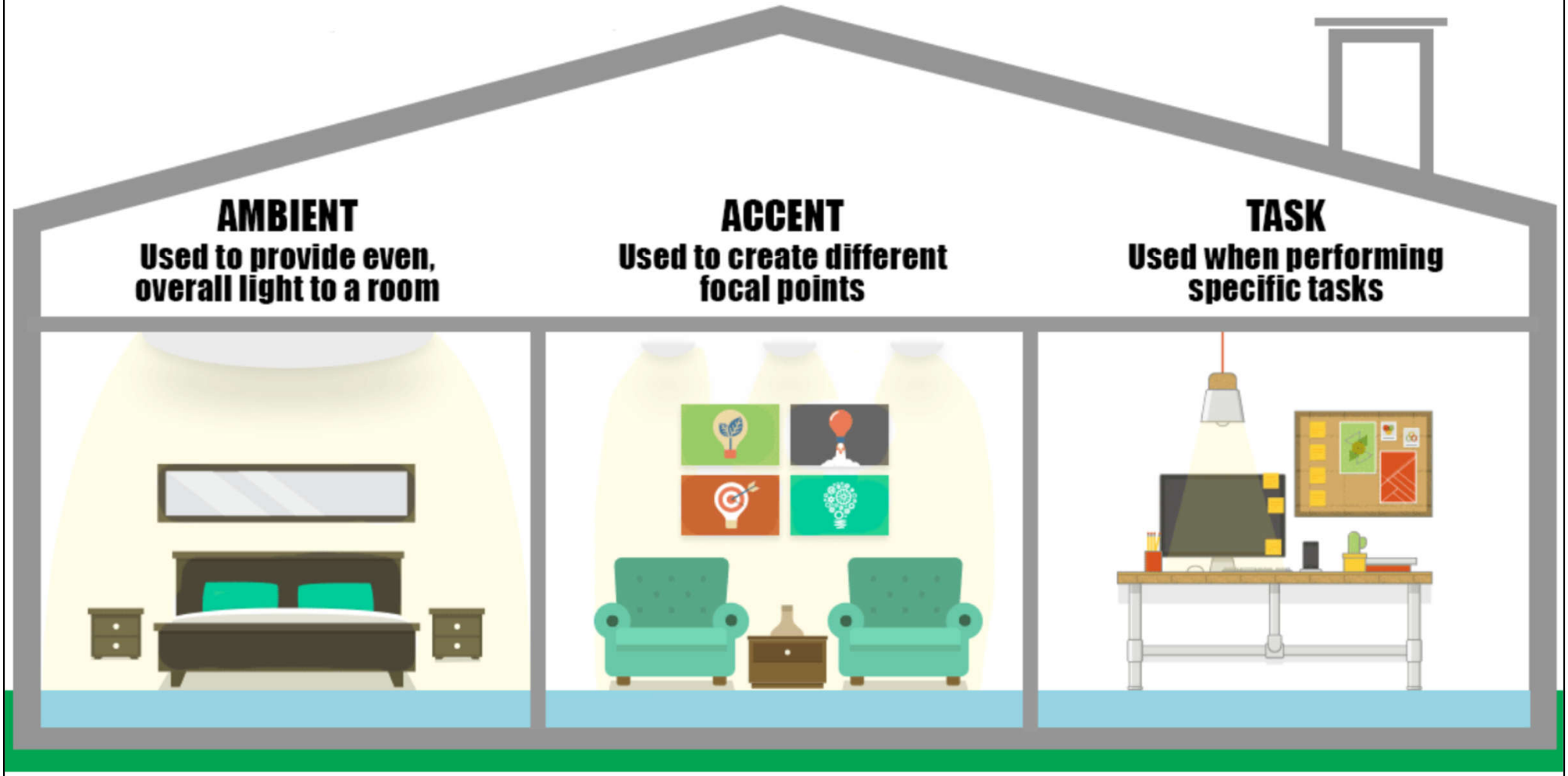


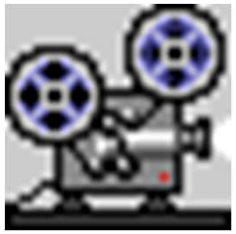
(Source: Kitsinelis S., 2015. *Light Sources: Basics of Lighting Technologies and Applications*, 2nd Ed., CRC Press, Boca Raton, FL.)

Applications & luminaires

- Common applications
  - Indoor lighting
    - Residences, offices, classrooms, health care, retails
  - Outdoor lighting
    - Street & stadium lighting, architectural floodlighting
- Special applications
  - Lighting for art, entertainment, emergency, safety
  - Lighting for transport, parking, manufacturing
  - Digital signage (e.g. advertisements, exit signs)

Three basic types of lighting





Video: Lighting Tips at a Glance (1:35) https://youtu.be/yR_Pa-a0W6k

Applications & luminaires

- Four types of lighting methods
  - General ambient indoor lighting
  - Ambient outdoor lighting
  - Task lighting
  - Accent lighting

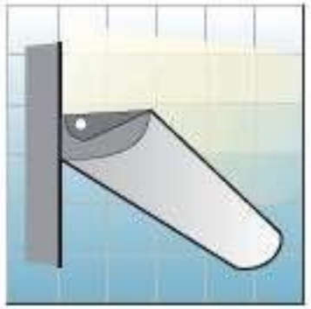
- Components of lighting systems
  - Lighting hardware & auxiliary equipment
  - Environmental components (architectural & interior design, decoration)

Types of fixtures for different lighting methods

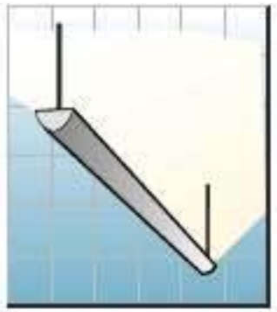
General ambient indoor lighting: • Chandelier (水晶吊燈) • Ceiling mounted fixture • Wall-mounted fixture • Traditional recessed fixtures and / or LED downlights • Track light • Floor lamp • Table lamp	**Ambient outdoor lighting:** • Spotlight • Hanging fixture • Garage and canopy lighting • Post lantern • Wall lighting • Recessed fixture used in overhanging structures
Task lighting: • Directional gimbal recessed fixture or downlight • Pendant lighting • Slim line bar and undercabinet • Tape and extrusion • Portable or desk lamp	**Accent lighting:** • Track light • Slim line bar and undercabinet • Tape and extrusion • Directional recessed fixture or downlight • Wall-mounted fixtures

(Source: https://www.standardpro.com/3-basic-types-of-lighting/)

Cove-mounted Uplighting



Wall-mounted Uplighting



Suspended Linear Fluorescent Luminaire

Recessed Round Downlight

Open HID High-bay (Metal Reflector) Luminaire

Recessed Round Wall-washers

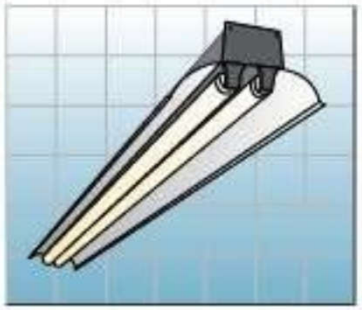
Decorative Pendant Downward Light

Portable Task Lighting

Track Lighting (Metal Halide)

Track Lighting (Incandescent)

Functional Wall Sconce

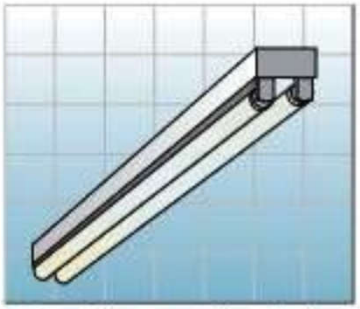


Open Fluorescent Luminaire, Refl. Industrial

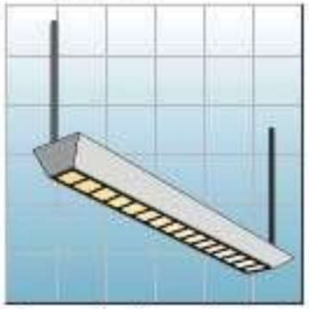
Portable Torchiere Uplight

Task Lighting, Fixed and Furniture Integrated

Decorative Wall Sconce

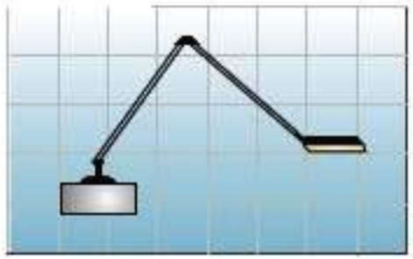


Open Fluorescent Luminaire, Striplight



Suspended Direct-Indirect Fluorescent Luminaire (mostly up)

Open HID High-bay Luminaire, Glass or Plastic Reflector

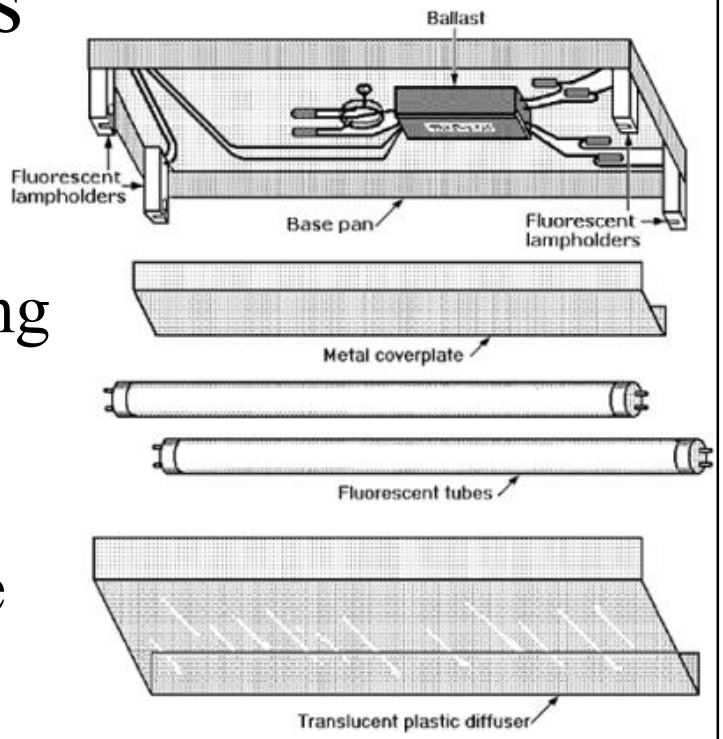


Typical Compact Fluorescent Task Light

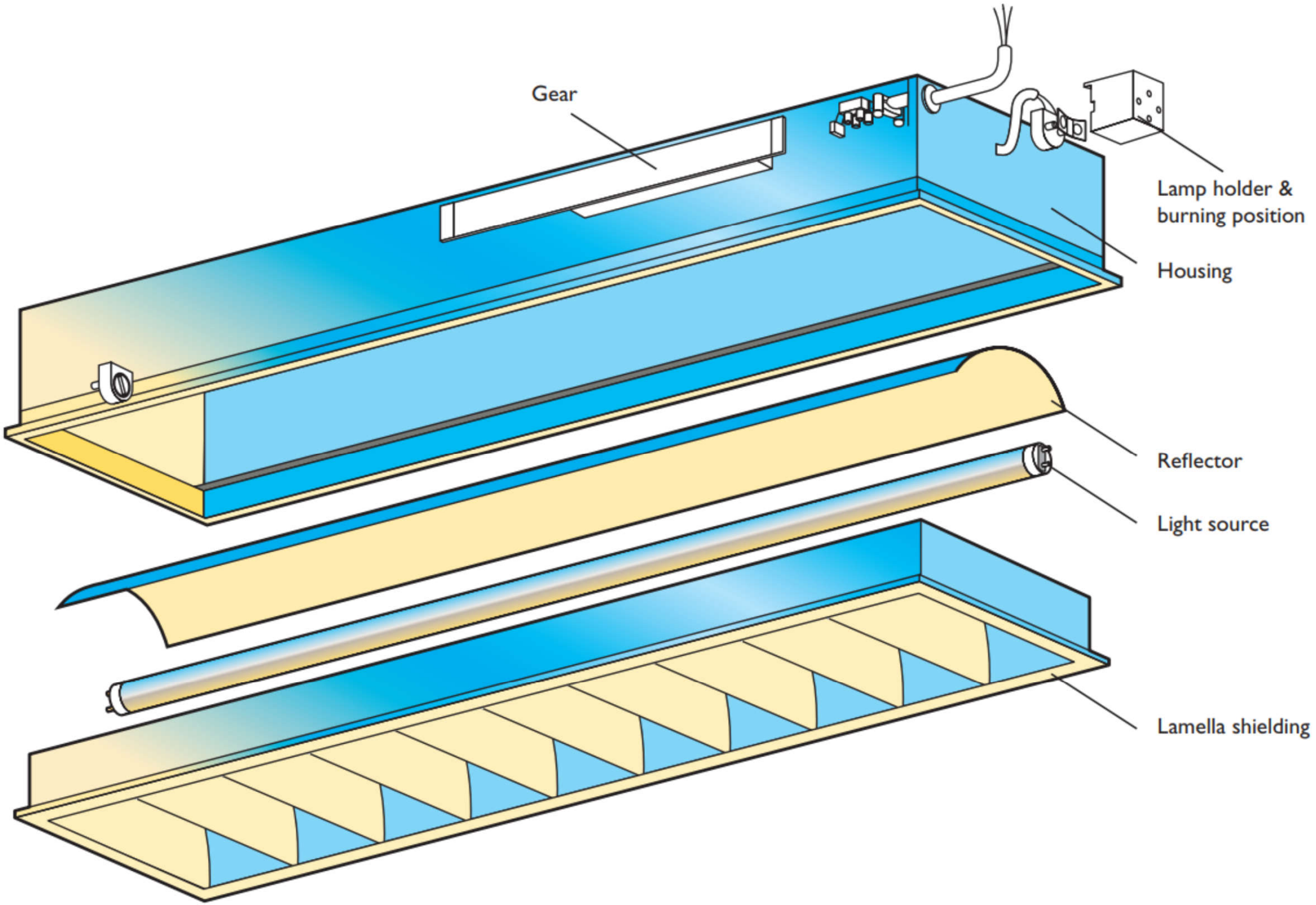
Different types of lighting fixtures

Applications & luminaires

- Components of lighting systems
  - Lighting components
    - Power source
    - Power controller: switching/dimming
    - Power regulators: ballasts
    - Light source: lamp
    - Optical control: luminaire or fixture
  - Environmental components
    - Room finishes: reflectances & texture
    - Spatial envelope: room boundaries
    - Fenestrations: windows & skylights



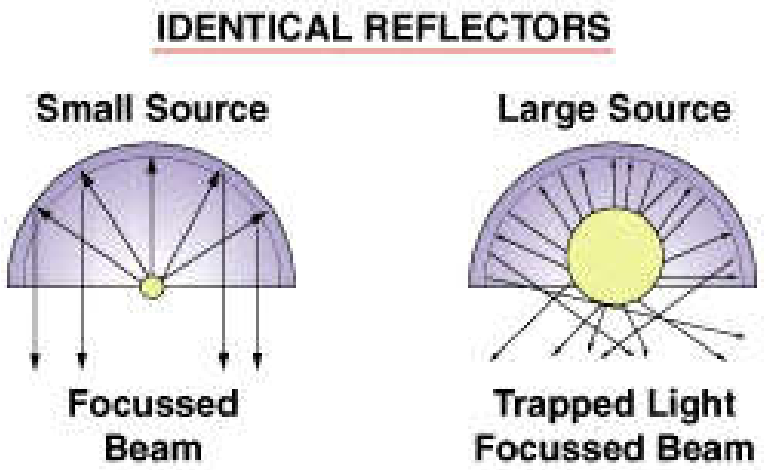
Basic components of luminaire 燈具的基本組成部分



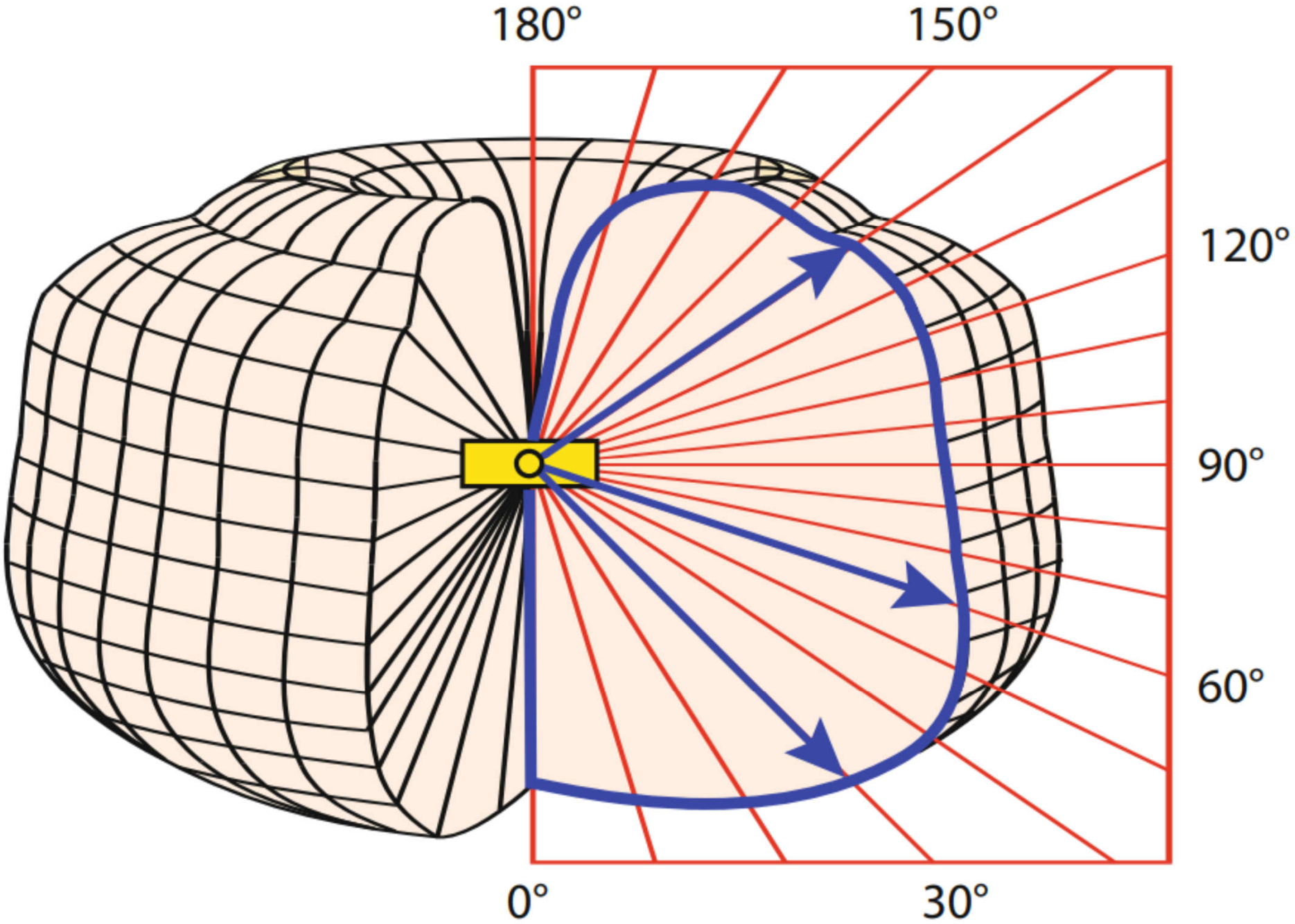
[Source: Philips Lighting]

Applications & luminaires

- Luminaire (light fixture)
  - A complete lighting system:
    - A housing and lampholders
    - Lamps (w/ a ballast/transformer)
    - Optical system
      - Reflector, and either a lens, louver or diffuser
      - For controlling brightness
  - It may also include some type of electrical control dimmers, hilo switching, daylight sensors, etc.
  - Control light distribution in various directions



Light distribution of a luminaire
(The lengths of the arrows represent the luminous intensities)

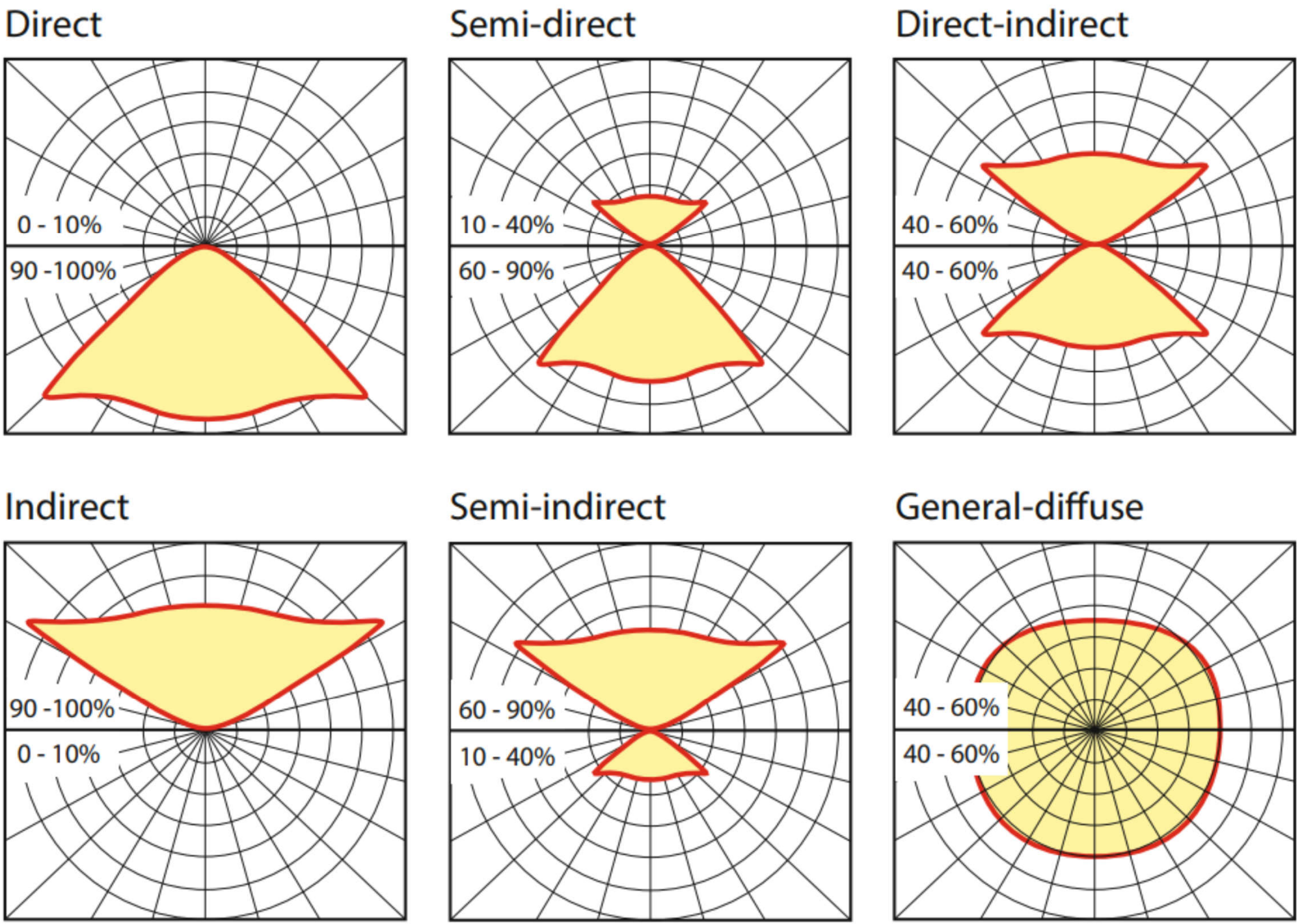


(Source: van Bommel W., 2019. *Interior Lighting: Fundamentals, Technology and Application*, Springer International Publishing, Cham.)

Applications & luminaires

- Six basic classifications of luminaires:
  - Direct luminaire where all the light is directed down
  - Semi-direct luminaire where the majority of the light is directed down
  - General diffuse luminaire where light is distributed in all directions
  - Direct-indirect luminaire where light is distributed equally up and down
  - Semi-indirect luminaire where the majority of light is directed up
  - Indirect luminaire where all the light is directed up

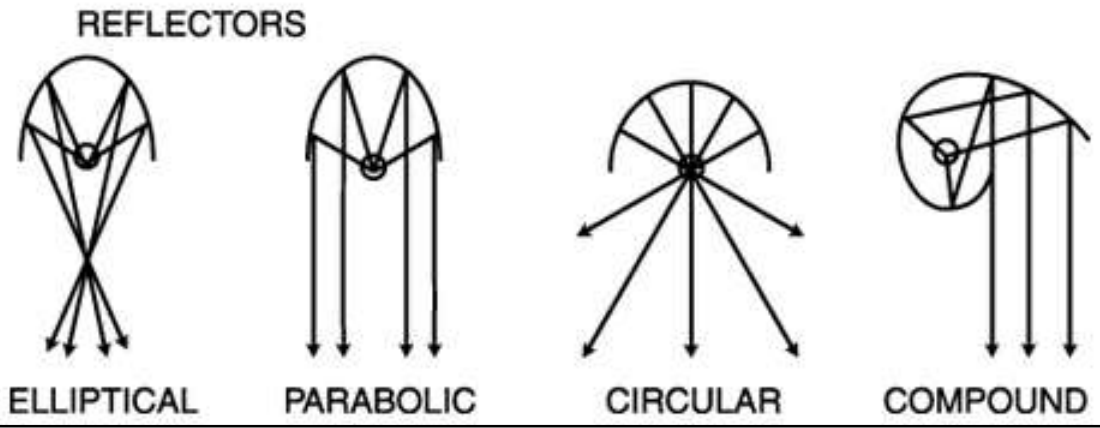
Luminaire classification system for indoor lighting luminaires

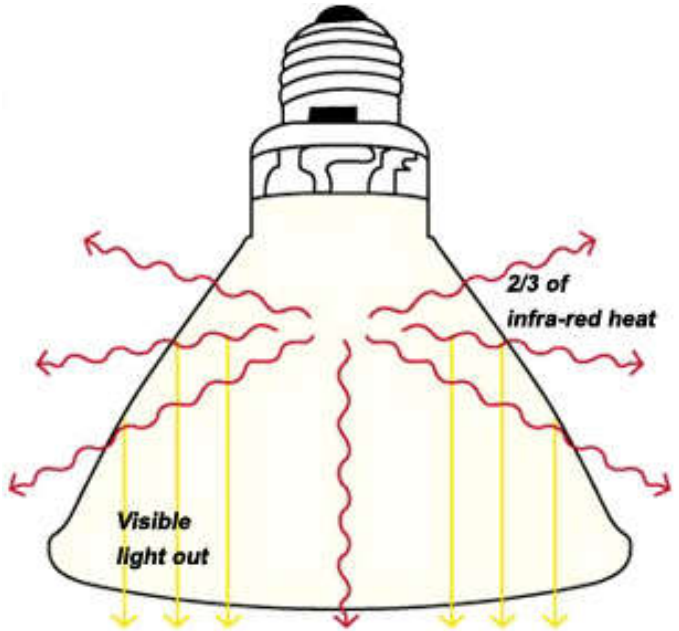


(Source: van Bommel W., 2019. *Interior Lighting: Fundamentals, Technology and Application*, Springer International Publishing, Cham.)

Applications & luminaires

- Optical systems (for controlling light)
  - Reflection
    - Specular, diffuse, spread, selective
  - Transmission
    - Direct, diffuse, spread, selective
  - Refraction





Methods of controlling light

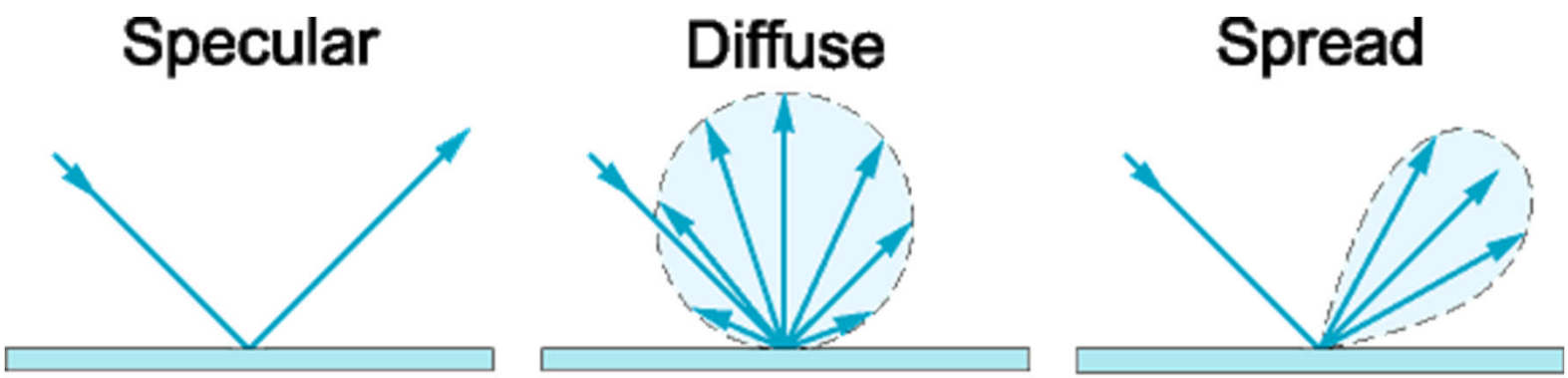


Fig. 3.2 Specular, diffuse, and spread reflection from a surface.

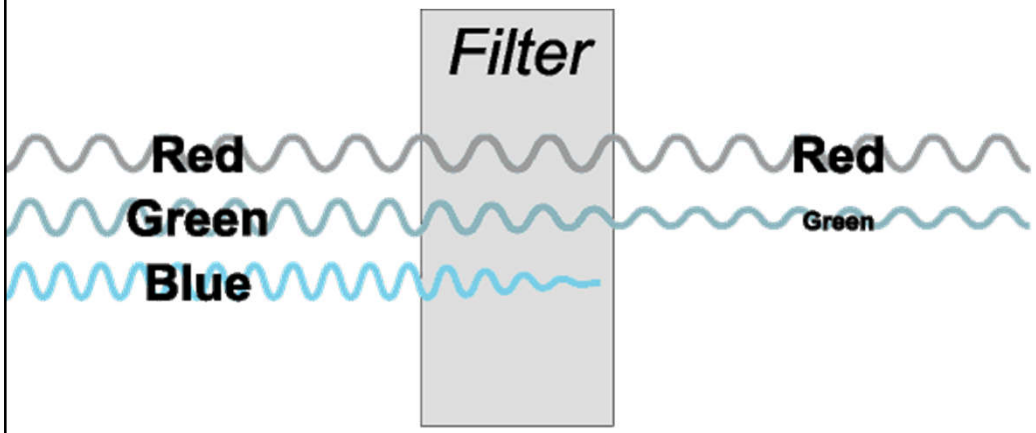


Fig. 3.3 Transmission through an optical filter.

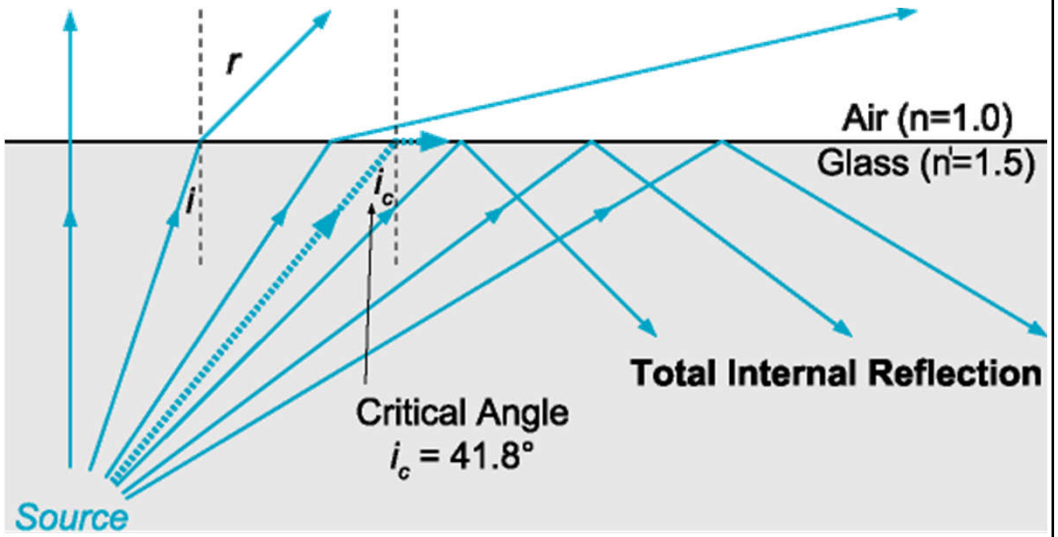
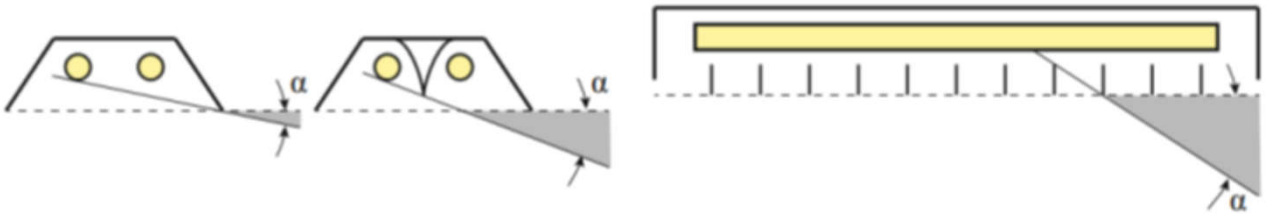


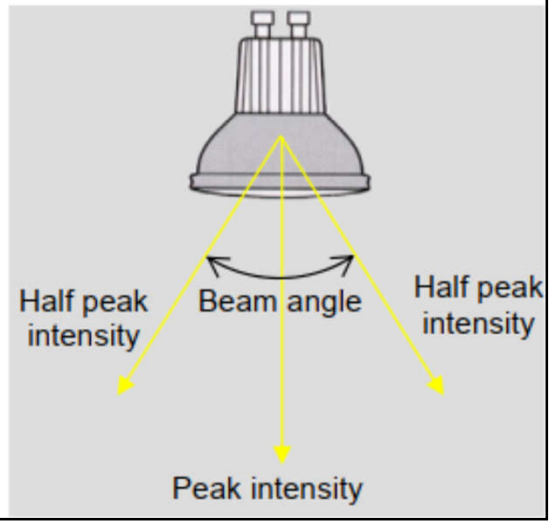
Fig. 3.5 Refraction and total internal reflection.

(Source: IESNA Handbook 9th ed.)

Applications & luminaires



- Shielding angle
  - Shielding lamps from direct view into critical directions with the aid of the housing of the luminaire or with mirrors or baffles
  - The higher the lamp luminance, the larger the shielding angle needs to be
- Beam angle
  - Angle where the light intensity has fallen to 50% of the peak value



Applications & luminaires

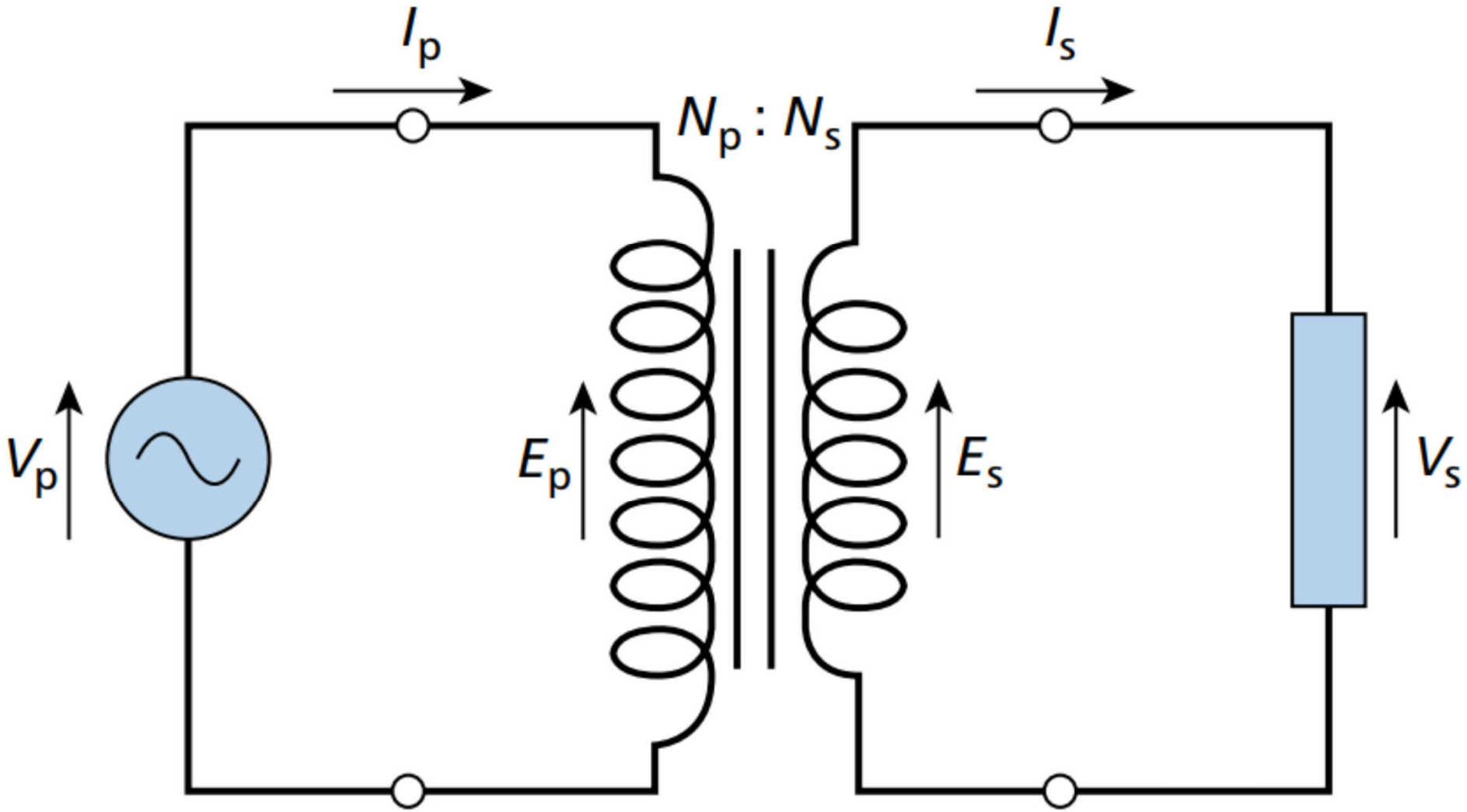
- Luminaries Efficacy Rating (LER)
  - LER = (Photometric Efficiency x Total Lamp Lumens x Ballast factor) / Luminaire Input Watts
- How to classify fluorescent luminaires & systems
  - Mounting: recessed, surface (ceiling or wall) & suspended
  - Distribution: direct, indirect, direct/indirect
  - Type of fluorescent lamp: T12, T8, T5
  - Nominal dimensions: 1 x 4, 2 x 4, etc
  - Application: commercial, industrial, residential, special purpose

Control gear

- Lamps & light sources requiring control gear:
  - Incandescent lamps (other than mains electricity rated)
  - Fluorescent lamps
  - High intensity discharge lamps
  - Other discharge lamps
  - LED/OLED light sources
  - Emergency luminaires

- Incorporated within the luminaire, separate or remote; may also supply multiple luminaires

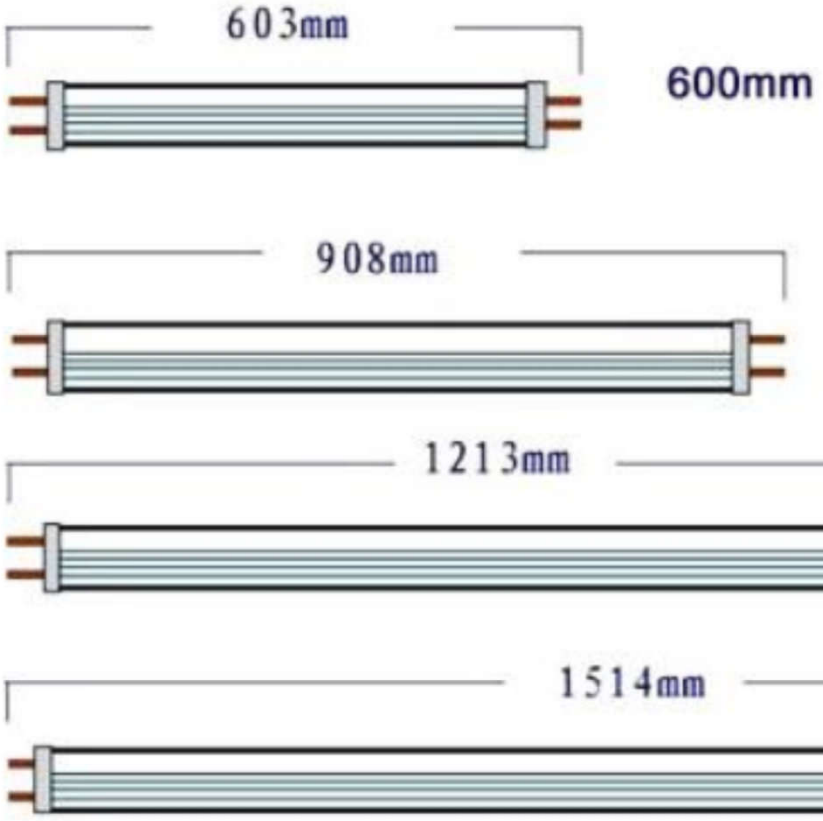
Transformer for low voltage incandescent lamps



$$\frac{V_p}{V_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s}$$

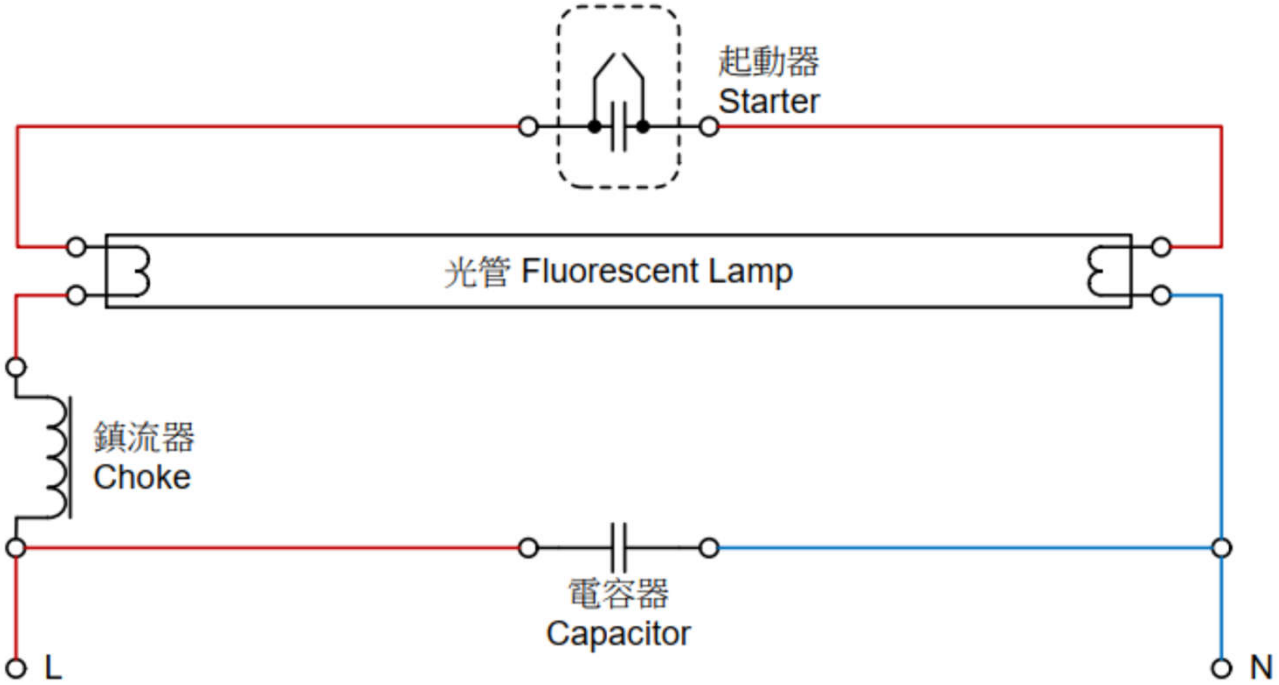
(Source: The SLL Lighting Handbook 2018)

Fluorescent lamps & starters 螢光管和起動器

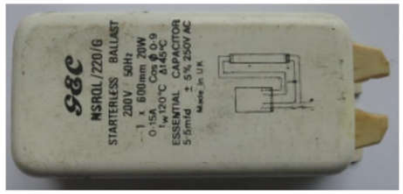


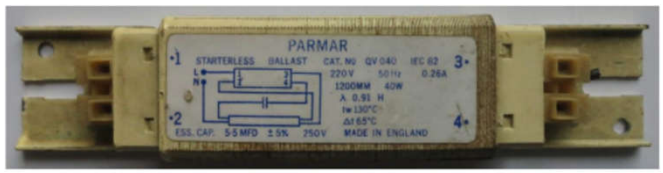
[Source: http://www.ksmak-sir.com/pdf/EIT.zip]

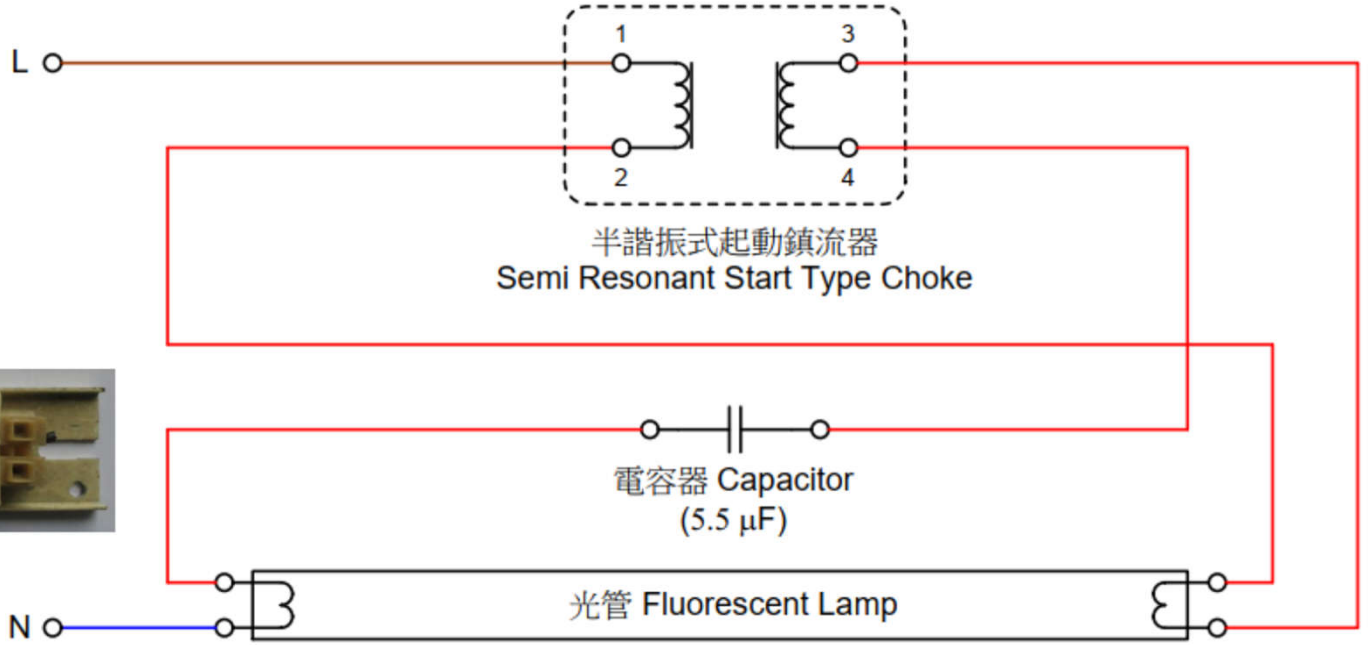
Glow Type Fluorescent Lamp Circuit (啟輝式光管電路):



Semi Resonant Start Type Fluorescent Lamp Circuit (半諧振式起動光管電路):

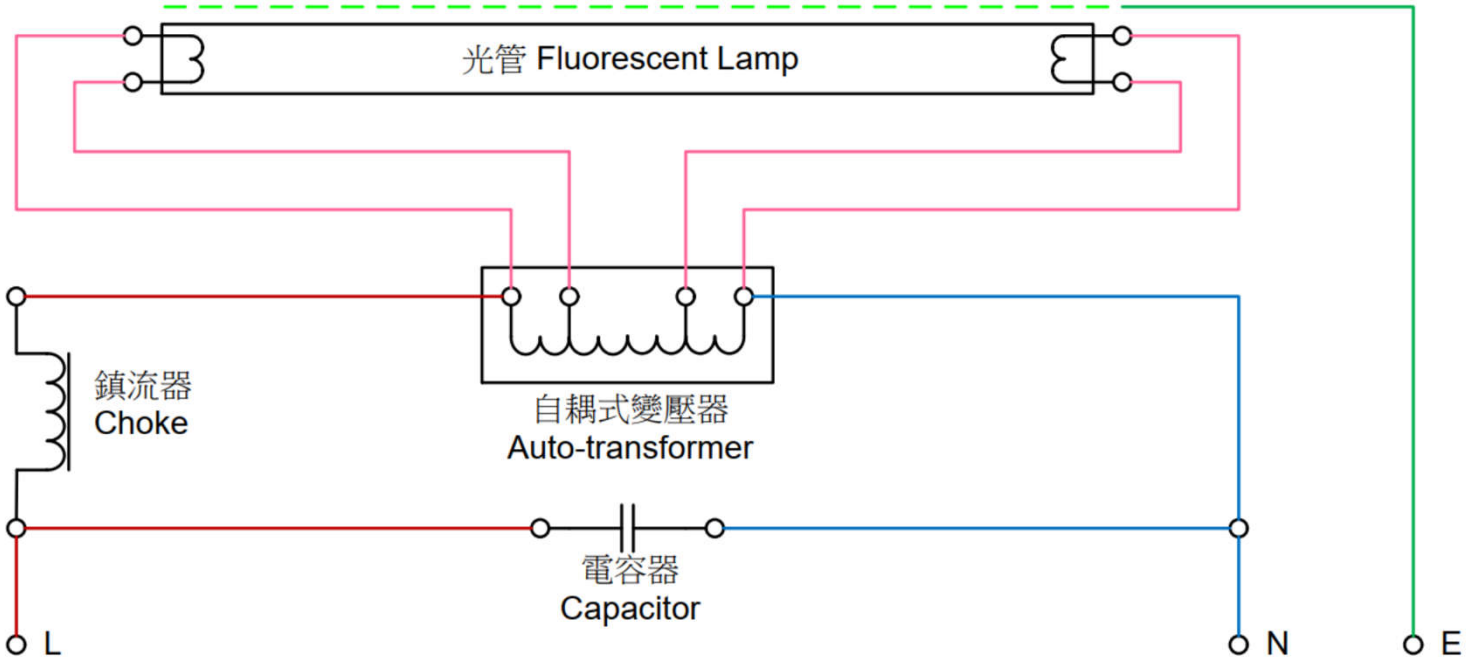




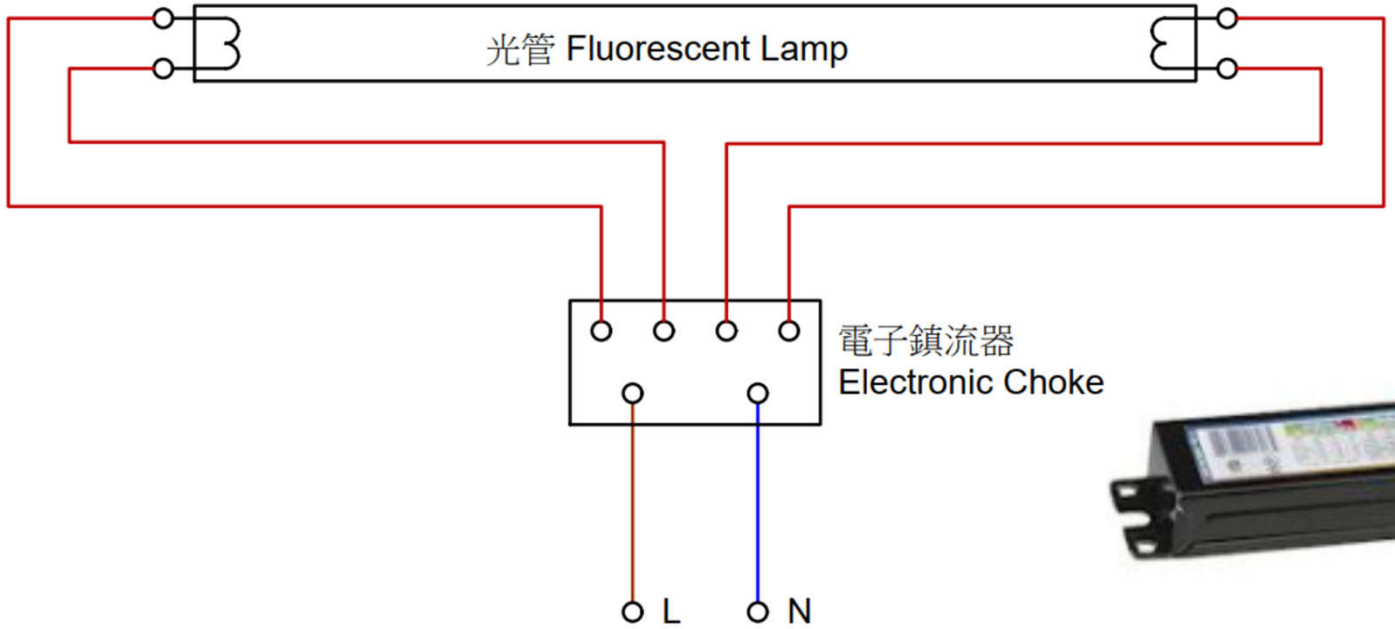


[Source: http://www.ksmak-sir.com/pdf/EIT.zip]

Quick Start Fluorescent Lamp Circuit (快速起動光管電路):

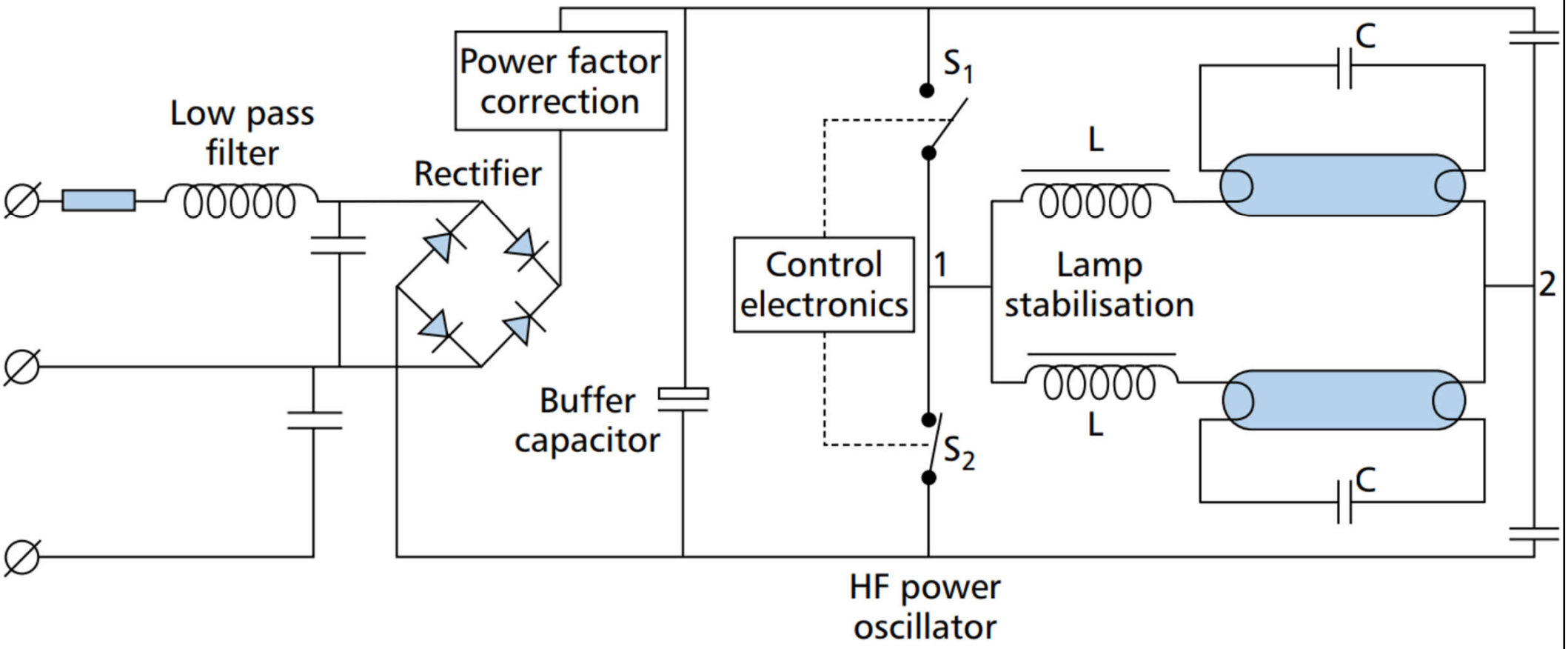


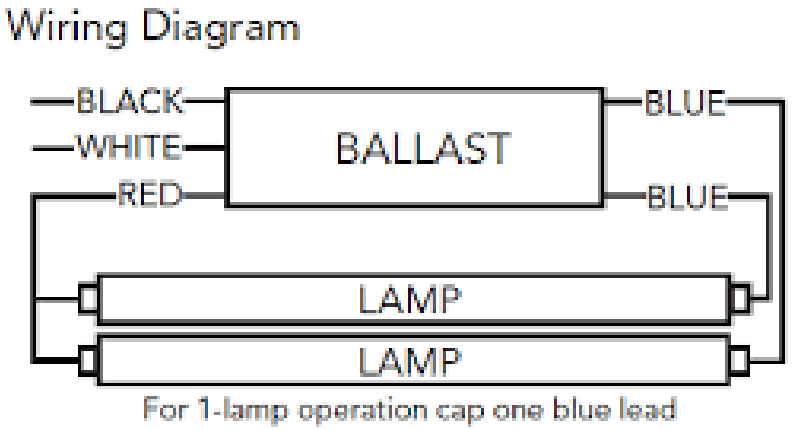
Electronic Choke Fluorescent Lamp Circuit (電子鎮流器光管電路):



[Source: http://www.ksmak-sir.com/pdf/EIT.zip]

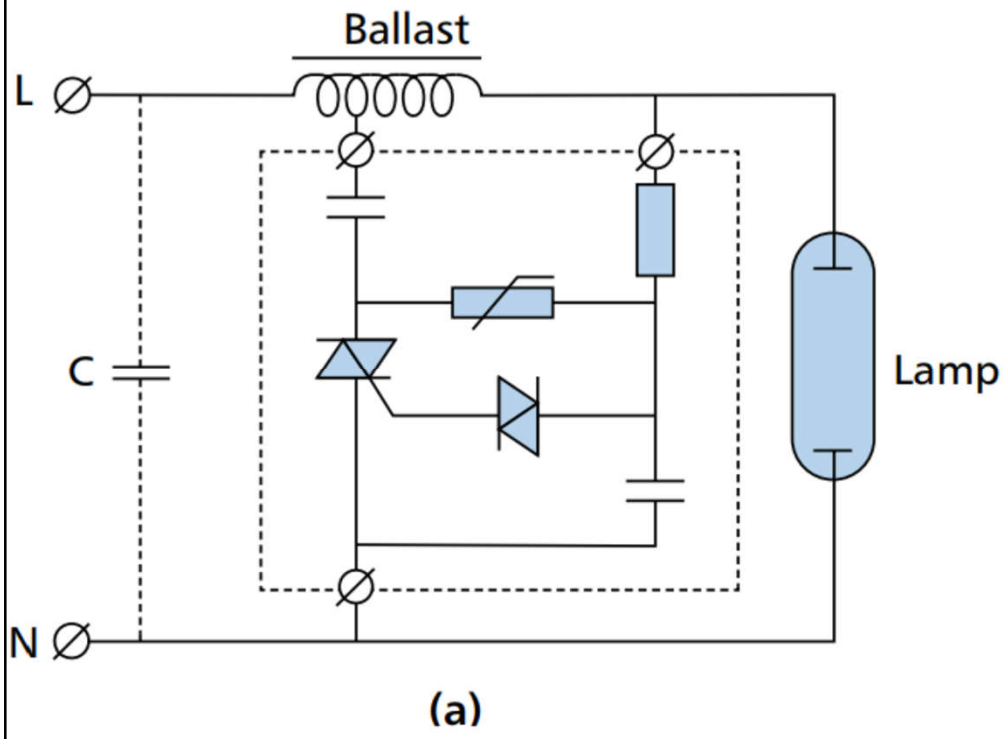
Circuit diagram of an electronic ballast for two fluorescent lamps



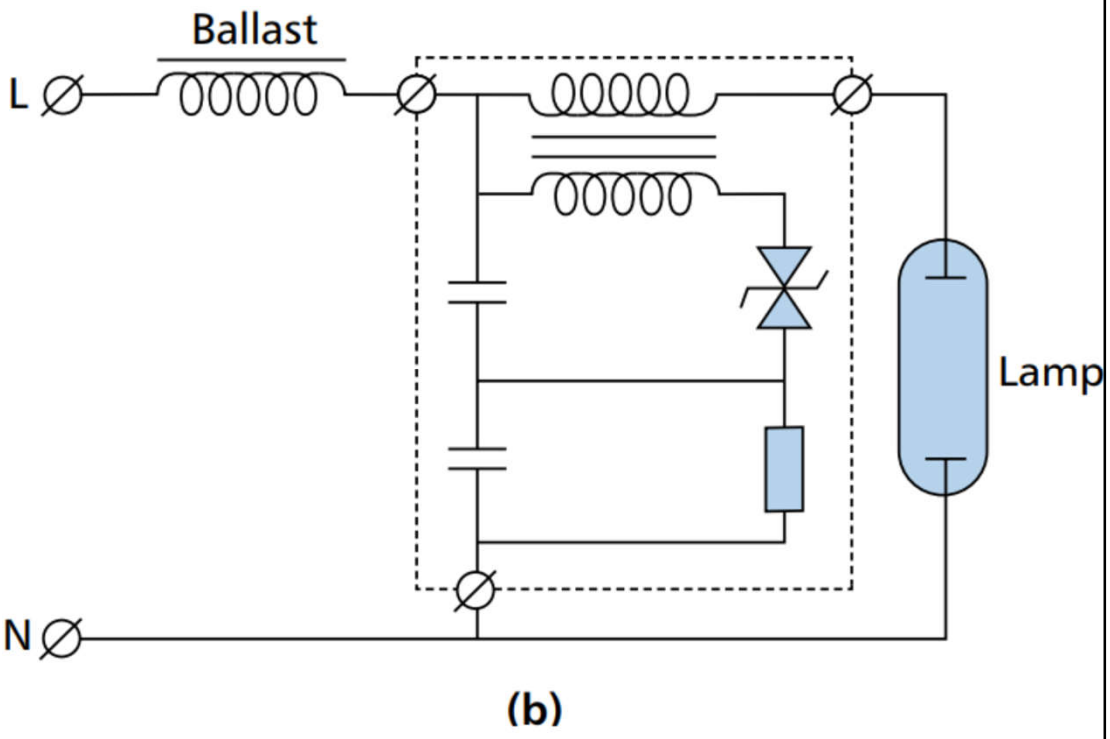


(Source: The SLL Lighting Handbook 2018)

Control gear for discharge lamps
Igniter circuits: (a) semi-parallel, (b) superimposed



(a)



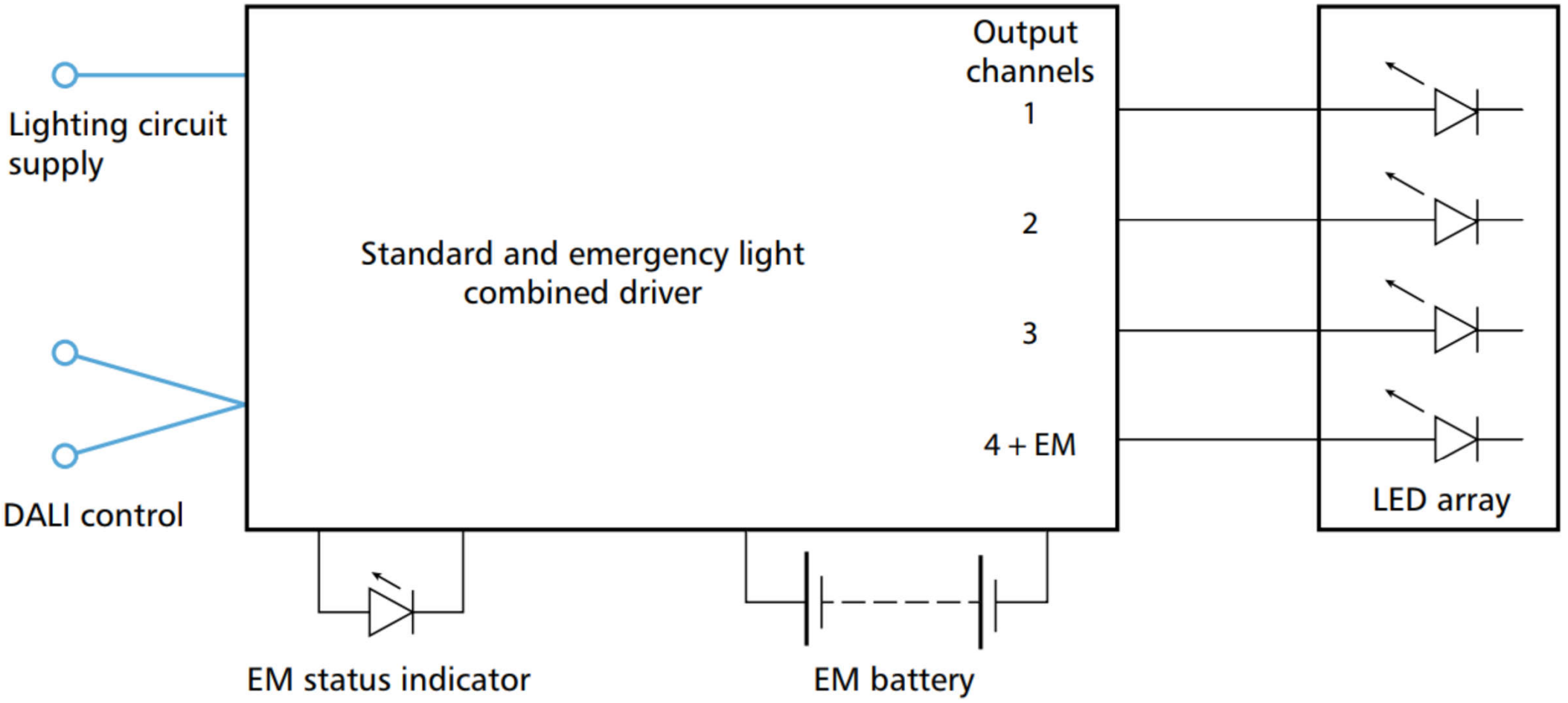
(b)

(Source: The SLL Lighting Handbook 2018)

Control gear

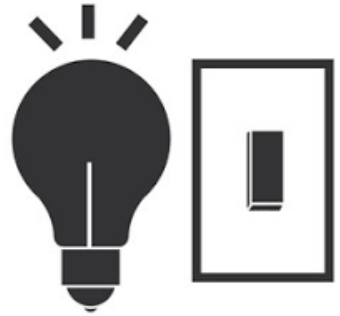
- Control gear or drivers for LED/OLED lights:
  - Constant current & constant voltage drivers
  - Galvanic insulated & non-insulated drivers
  - Indoor & outdoor drivers
  - Dimmable & non-dimmable drivers
  - Single-channel & multi-channel drivers
  - Built-in & independent (remote) drivers
  - Standard & industrial grade drivers
  - Linear & compact shaped drivers

Control gear for emergency lighting applications: Single driver with automatic control & remote monitoring; only channel 4 remains in operation during emergency conditions



(Source: The SLL Lighting Handbook 2018)

Lighting controls



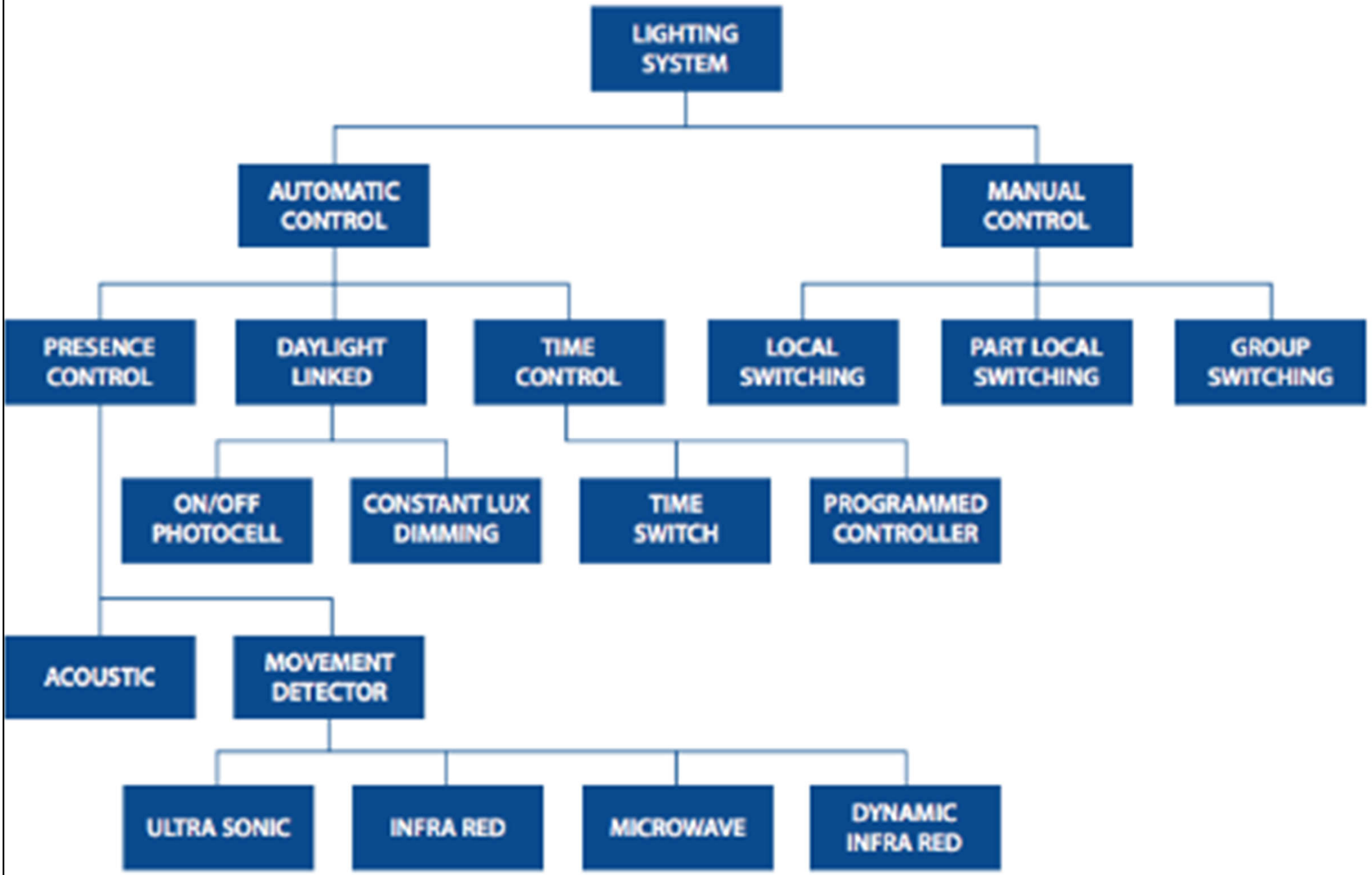
- A good lighting system design includes a good lighting controls design to enable users manually or automatically to:
  - Turn the lights ON & OFF using a switch; and/or
  - Adjust light output up & down using a dimmer
- Benefits for the owner:
  - Flexibility to satisfy user visual needs
  - Automation to reduce energy costs & improve sustainability

Benefits of good lighting controls

Visual Needs	Energy Management & Sustainability
• Change space appearance • Facilitate different functions of the space • Alter atmosphere & mood • Reduce glare & visual discomfort conditions • Increase user satisfaction by providing users the ability to control their lighting	• Reduce both energy demand & energy consumption • Reduces building operating costs • Comply with building energy codes • Facilitate more efficient building operation & maintenance • Provide data & information for building optimization

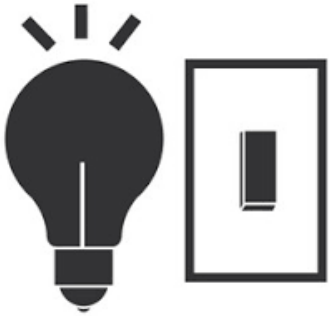
(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)

Overview of lighting control methods

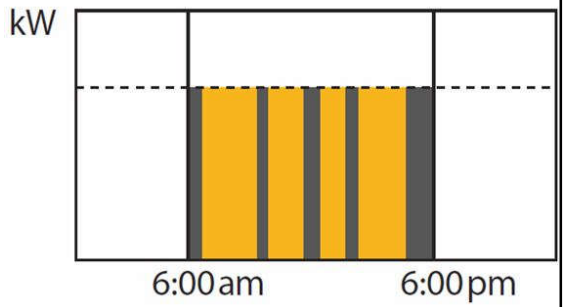


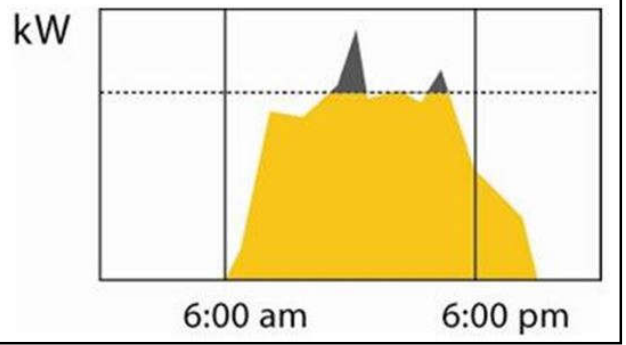
(Source: https://www.controlco.com.au/blog/2015/7/16/lighting-control-methods)

Lighting controls



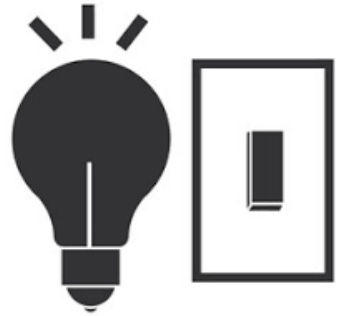
- Control strategies
  - Manual control (local/group)
  - Time scheduling (time-based control)
  - Occupancy sensing (vacancy sensing)
  - Daylight response (to reduce electric lights)
  - Institutional task tuning (user preference, scene)
  - Colour tuning (various effects)
  - Data generation (intelligence)
  - Demand response (↓demand costs)





(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)

Lighting controls

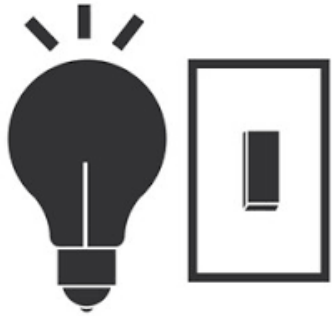


- General types of lighting controls
  - 1. Standalone devices (luminaire-based)
    - Autonomous operation of a lighting load, which may be a luminaire or luminaires installed on a switch leg
    - Standalone embedded sensors
  - 2. Room-based control systems
    - A package of lighting controllers & input devices designed for autonomous room-based operation
  - 3. Centralized building control systems
    - Programmable lighting control for entire floors, buildings or campuses

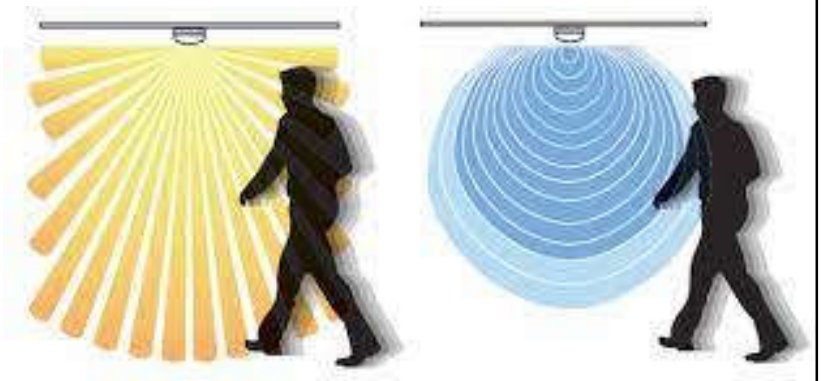
Lighting controls

- Lighting control techniques & tools
  - Manual control (switches)
  - Timed control (timeclocks)
  - Presence detection
  - Absence detection
  - Photocells
  - Daylight linking
  - Constant illuminance adjustment
  - Dimming & regulation

Lighting controls



- Occupancy sensing detection
  - Passive infrared detectors
  - Microwave detectors
  - Ultrasonic detectors

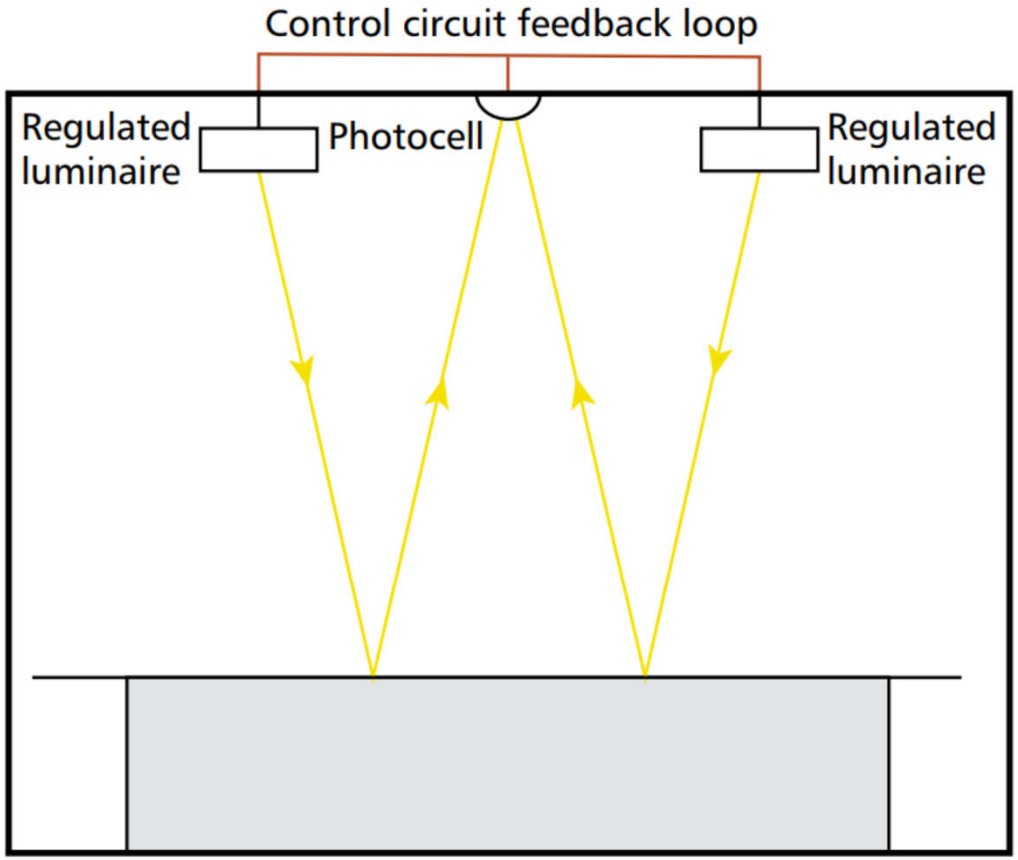


- Photocells & daylight linking
  - Measure available light at a specific location
  - Switch off or dim/regulate the electric lighting
    - Can adjust for constant illuminance at working plane
- Dimming: by supply voltage or electronic

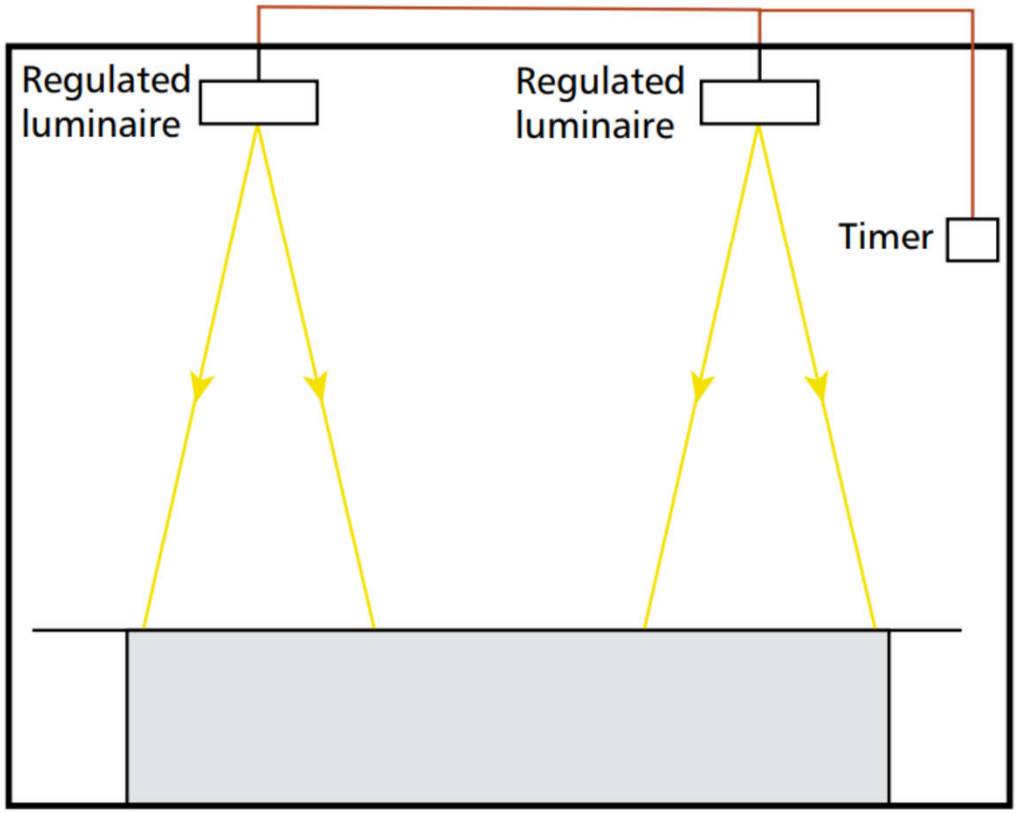
Daylight linking of luminaires from left to right

(Source: SLL, 2016. *Control of Electric Lighting*, Lighting Guide 14, Society of Light and Lighting (SLL), London.)

Lighting control for constant illuminance adjustment



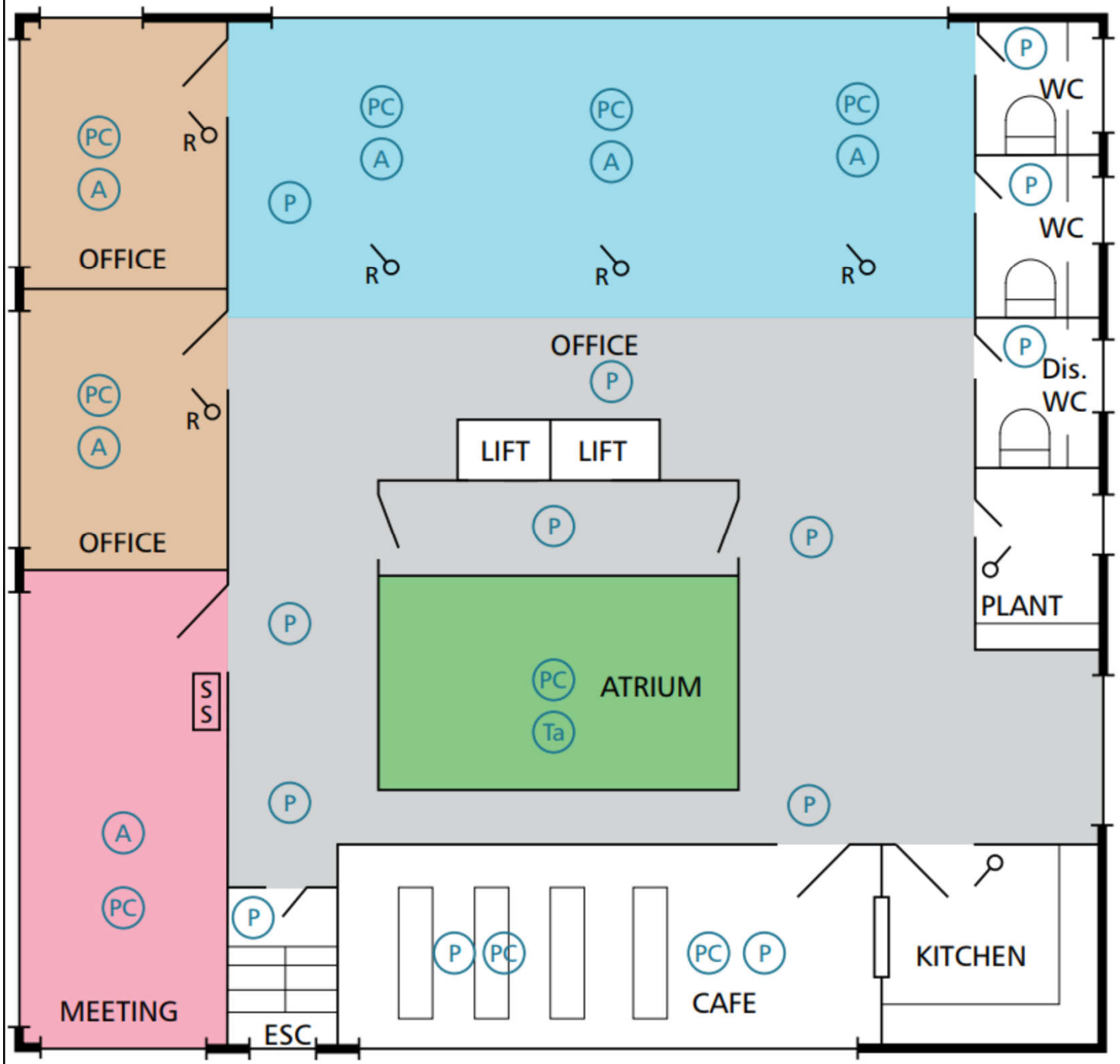
(a) A photocell is used to measure the reflected light from the working plane to adjust the light output to the required output



(b) a timer/data connection is used to regulate the luminaire output at a pre-set level based on 'hours run/maintenance offsets' feedback from the luminaires and manufacturer's data on lamp degradation

(Source: SLL, 2016. *Control of Electric Lighting*, Lighting Guide 14, Society of Light and Lighting (SLL), London.)

Example of lighting control arrangement for a typical office area



P Presence detector

A Absence detector

PC Daylight linking

SS Scene selection and manual dimming

R Retractive switch

Manual switch

Ta Astronomical time clock

Owned space

Managed space

Shared space

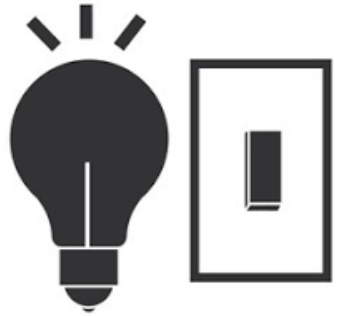
Temporarily owned space

Occasionally visited space

Unowned space

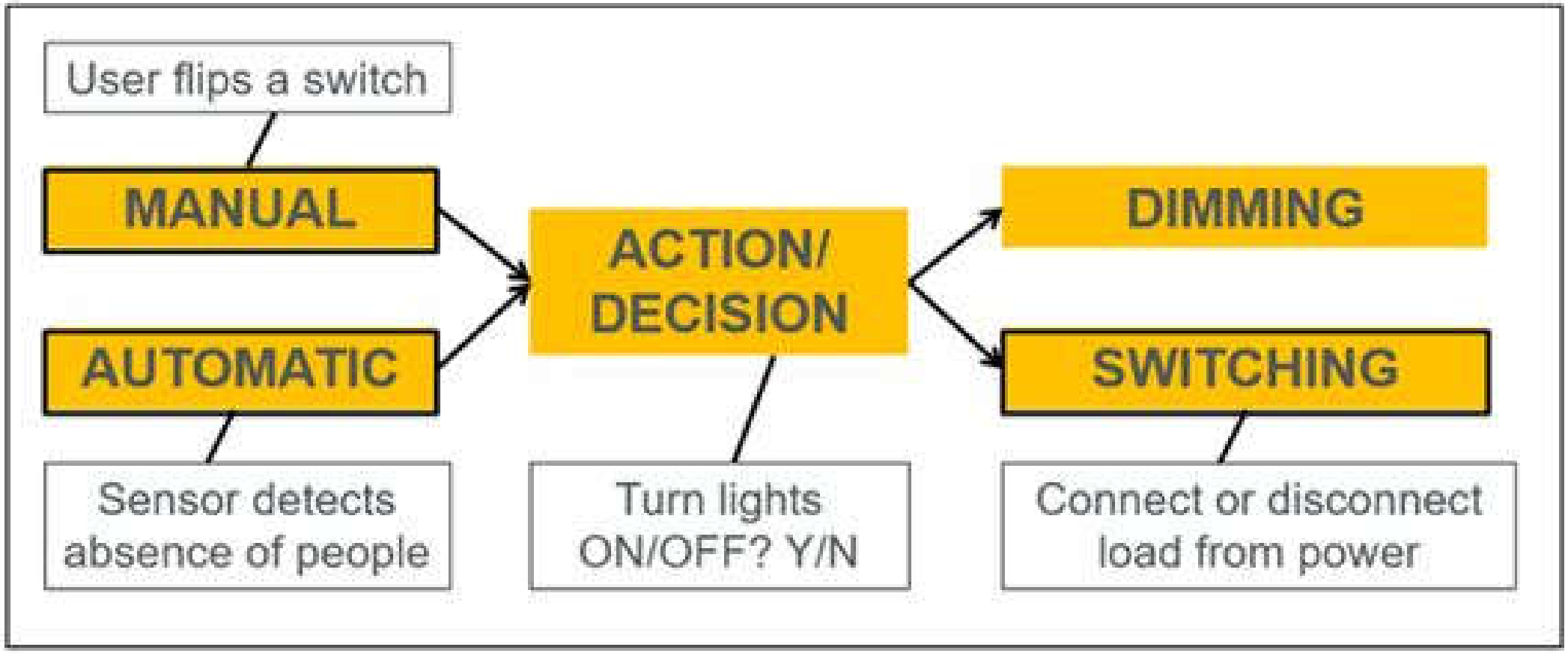
(Source: SLL, 2016. *Control of Electric Lighting*, Lighting Guide 14, Society of Light and Lighting (SLL), London.)

Lighting controls



- The input to lighting controls may be manual, automatic or a combination of the two
  - Such as a manual-ON wallbox occupancy sensor
  - The automatic input may be based on time of day, occupancy, light level or some other condition
    - A microprocessor or logic circuit performs this function
- Sensor-based lighting control
  - Occupancy-based
  - Illumination-based

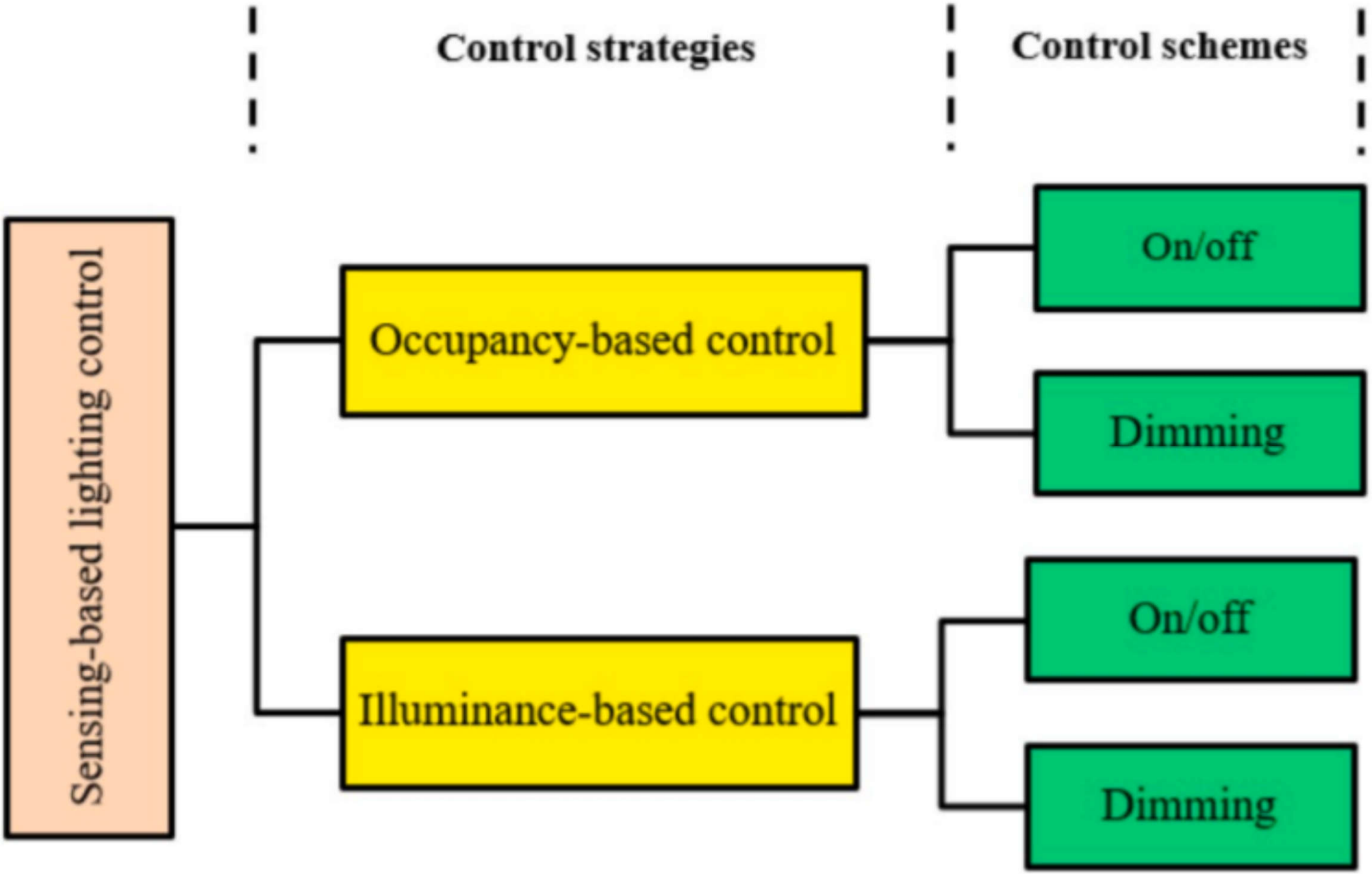
Manual & automatic lighting control strategies (manual-ON wallbox occupancy sensor)



MANUAL-ON OCCUPANCY (VACANCY) SENSOR

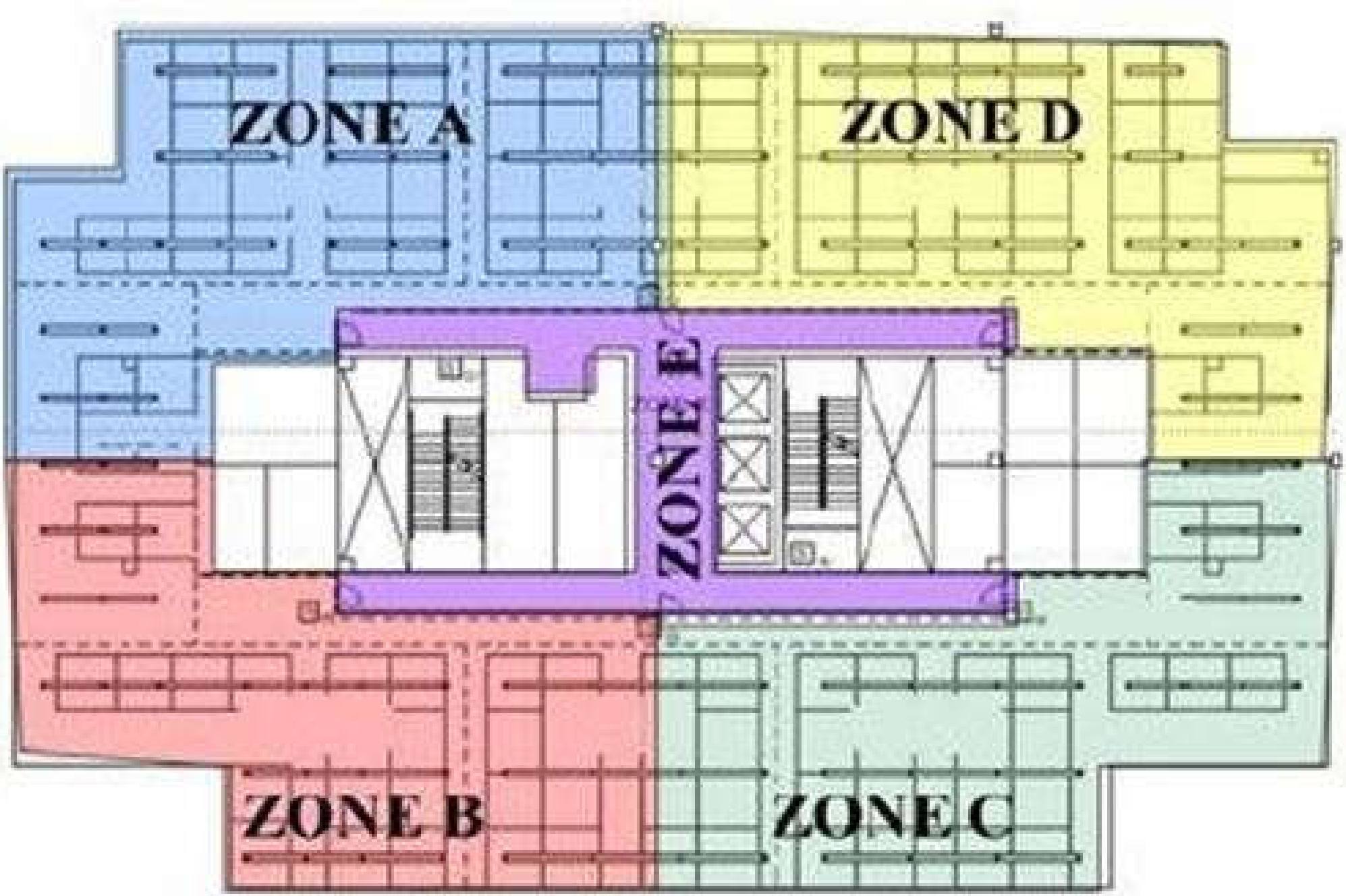
(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)

Categories of control strategies and schemes of lighting systems



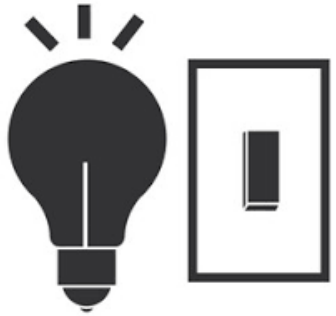
(Source: Journal of Building Engineering, 31 (2020) 101342)

An example of control zoning for lighting control system



(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)

Lighting controls



- In recent years, lighting controls have evolved two additional capabilities:
  - Adjust light source colour, including shade of white light (using LED light source)
  - Generate data via measuring and/or monitoring
- Basic functions of lighting controls
  - Switching (ON/OFF)
  - Dimming
  - Colour & correlated colour temperature (CCT)

Basic and advanced functions of lighting controls

(a) Basic functions:

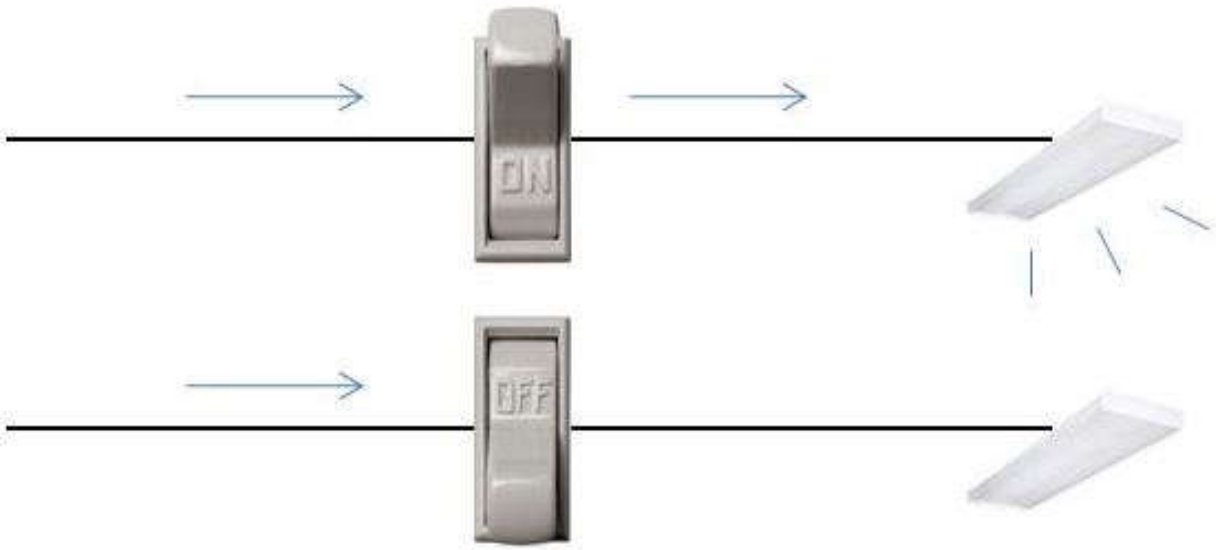
WHAT	HOW
Produce the right amount of light…	Light output (intensity) dimming
…where the light is needed…	Zoning of luminaires to controllers
…and when the light is needed…	Automatically reduce lighting when the space is unoccupied

(a) Advanced functions:

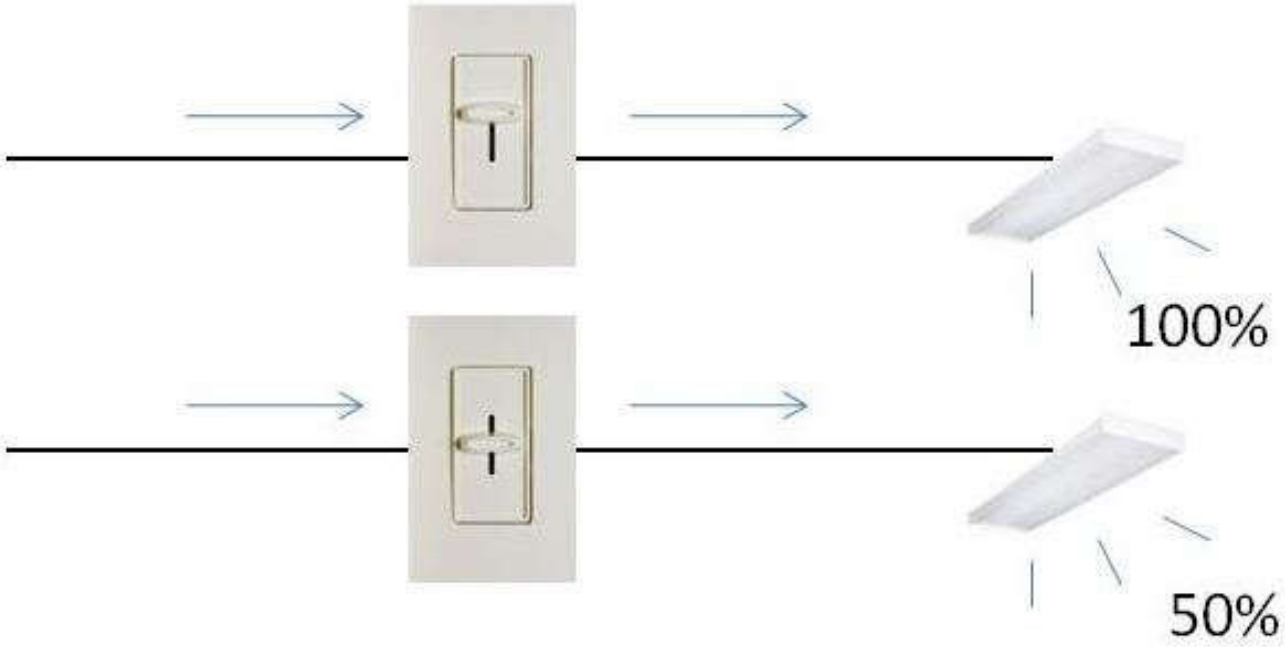
WHAT	HOW
Produce light at the right colour or shade of white light…	Separately dimming arrays of LEDs with different colours or white-light correlated colour temperatures (CCTs)
…allow remote programming and control…	Control systems with programming and lighting management capability
…and tell you how your lights are performing…	Centralized intelligent control systems with measuring and/or monitoring/alarm capability

(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)

Switching & dimming lighting controls



(a) Switching (ON/OFF)

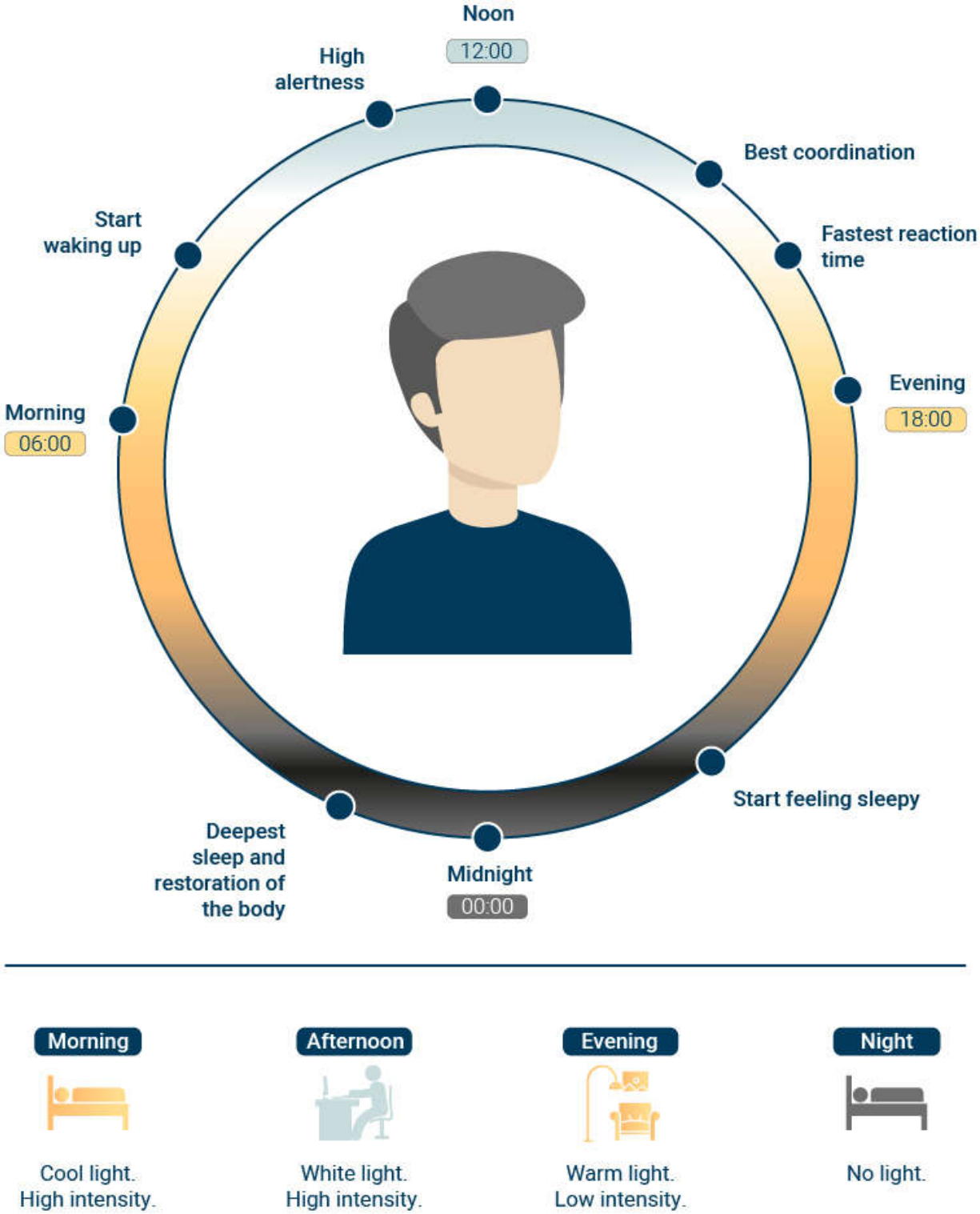


(b) Dimming

(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)

Lighting control of correlated colour temperature (CCT)

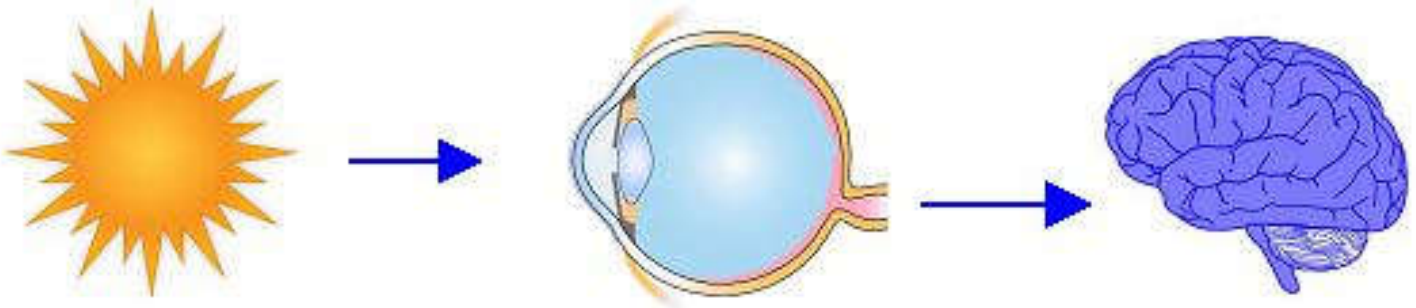
(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)



Physiological and psychological benefits of human centric lighting (HCL)

(Source: https://www.elt.es/en/human-centric-lighting)

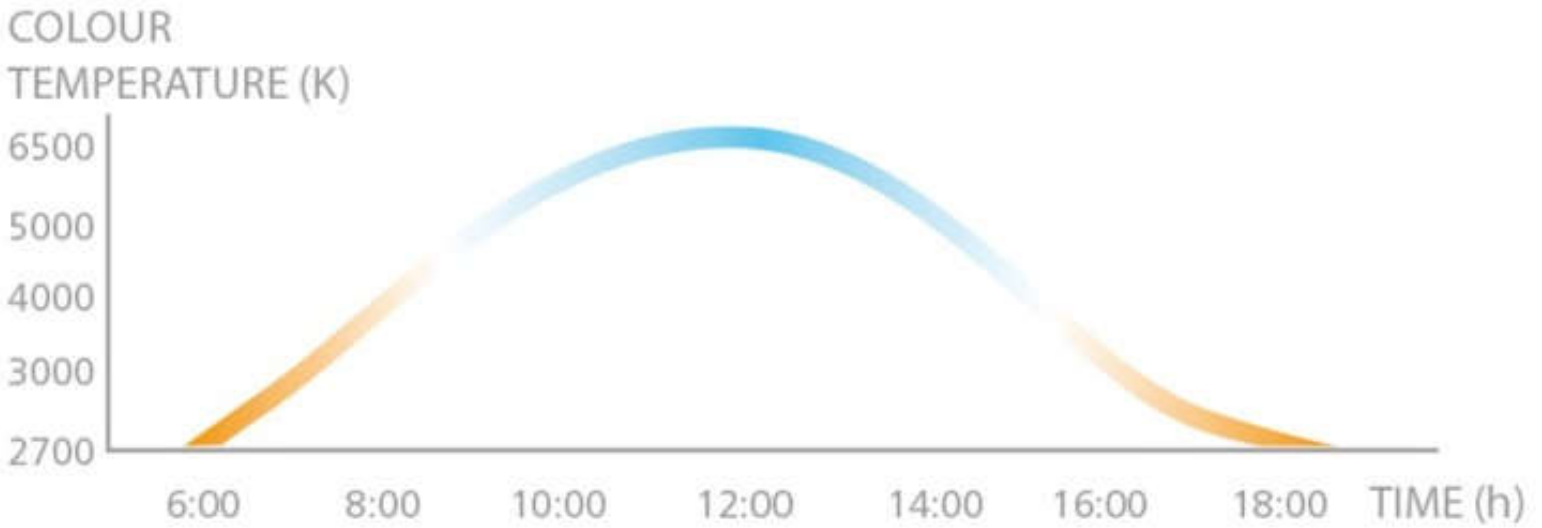
Control of colour temperature for human centric lighting (HCL) & circadian cycles



Blue light (480nm) from sun

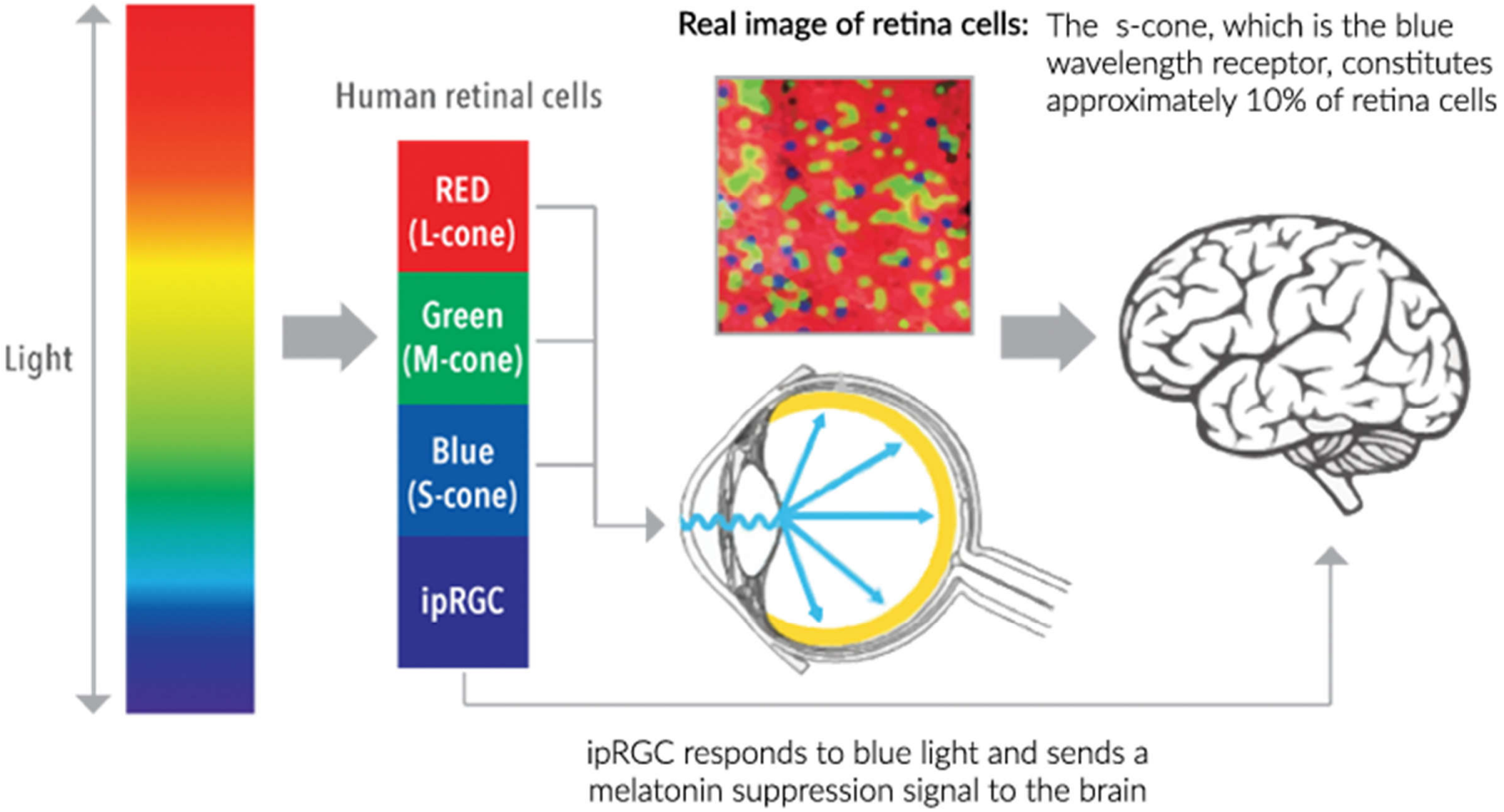
Affecting special photoreceptors - Retinal Ganglion Cells (pRGCs) in the eye

Controlling the circadian rhythm with hormones (Melatonin) in the brain



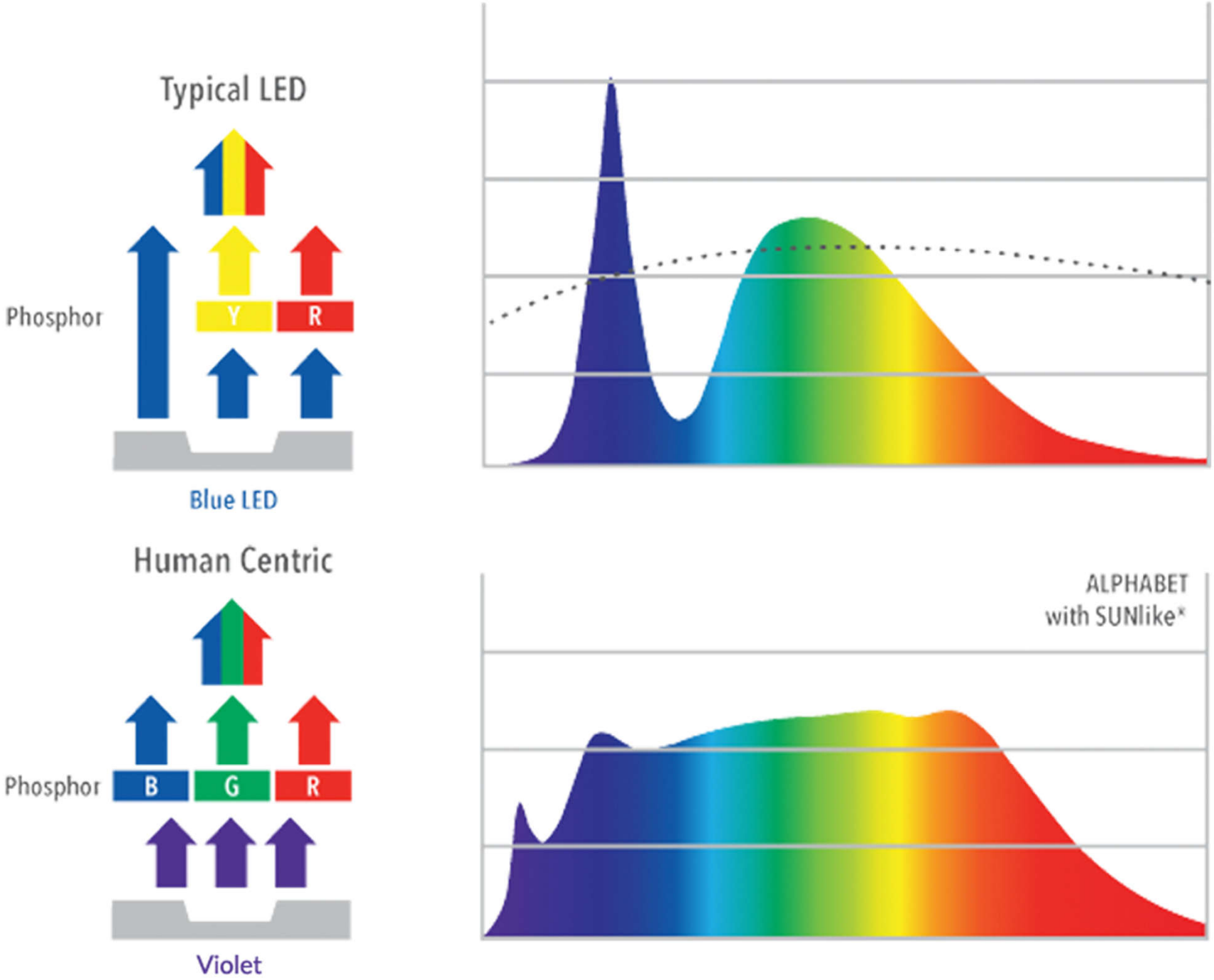
(Source: https://www.led-lighting.lighting/human-centric.php)

Considerations of lighting colour for non-visual effects



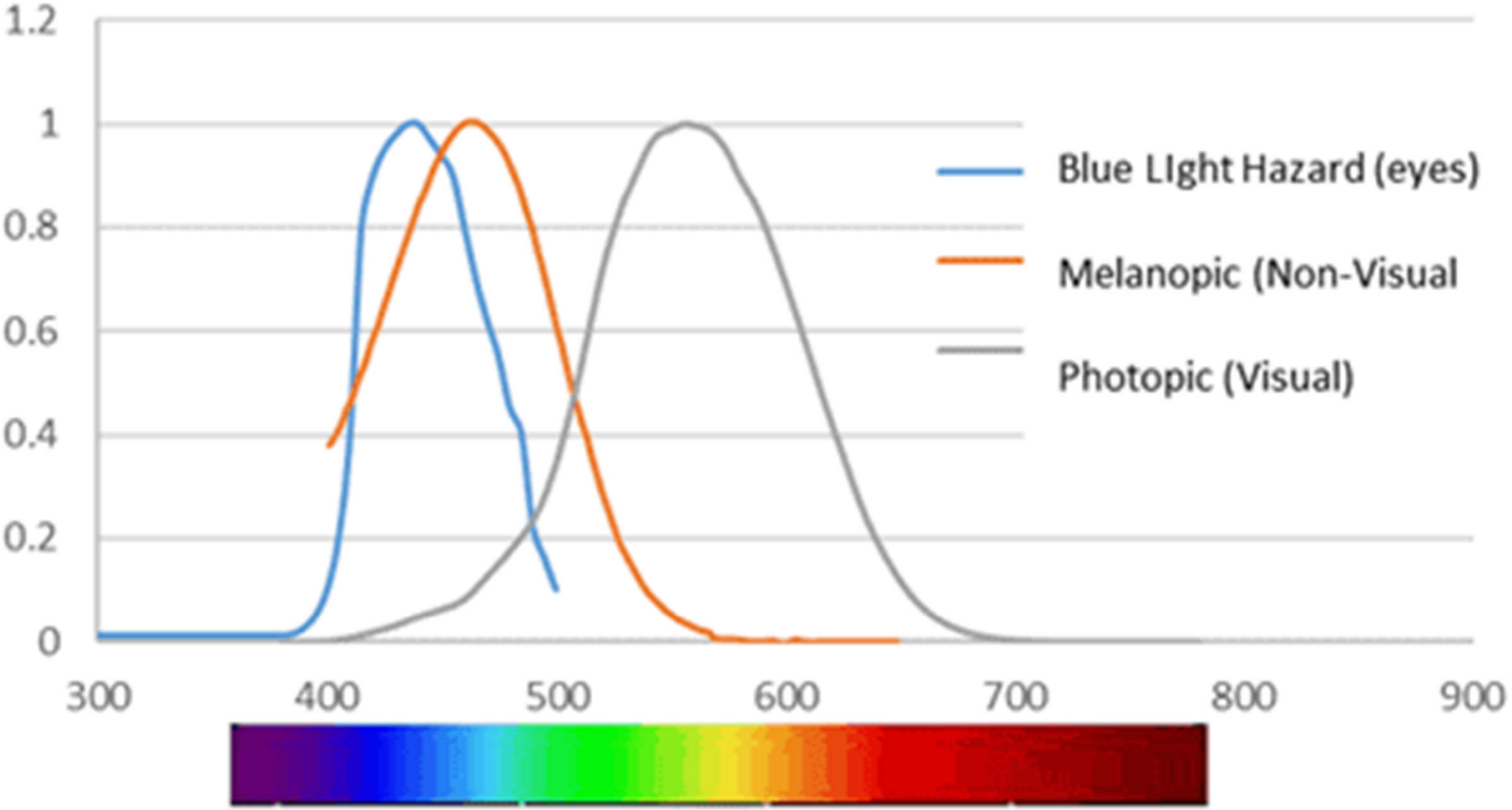
(Source: https://brucklighting.com/ledra-learning-lab/human-centric-lighting.html)

Tuning & control of spectrum for human centric lighting (HCL)



(Source: https://brucklighting.com/ledra-learning-lab/human-centric-lighting.html)

Photopic curves & spectral sensitivity for visual & non-visual biological responses (melanopic & blue light hazard)



(Source: https://www.oledworks.com/news/blog/from-lumen-centric-to-human-centric/)

Further Reading

- The Electric Light (Edison Tech Center) http://www.edisontechcenter.org/Lighting.html
- Electrical ballast - Wikipedia http://en.wikipedia.org/wiki/Electrical_ballast
- Introduction to Lighting Controls https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/