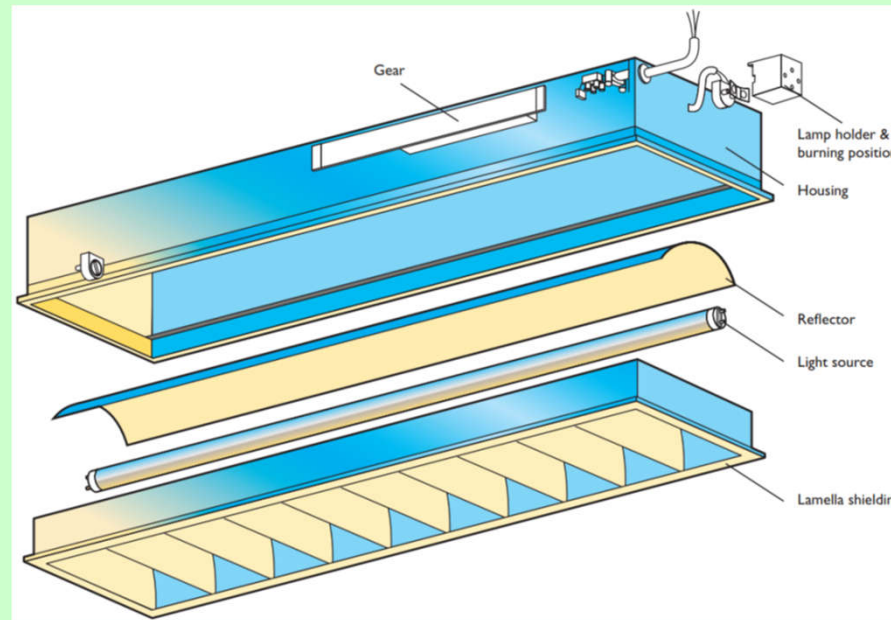


# MEBS6004 Built Environment

<http://ibse.hk/MEBS6004/>



## Lighting systems and components



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Department of Mechanical Engineering

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Sep 2024

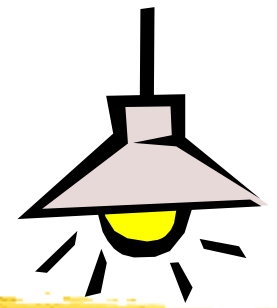
# Contents



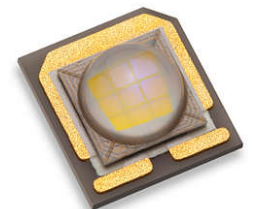
- Light sources
- Light emitting diode (LED)
- Applications & luminaires
- Control gear
- Lighting controls



# Light sources

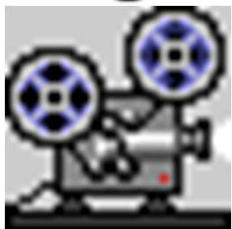
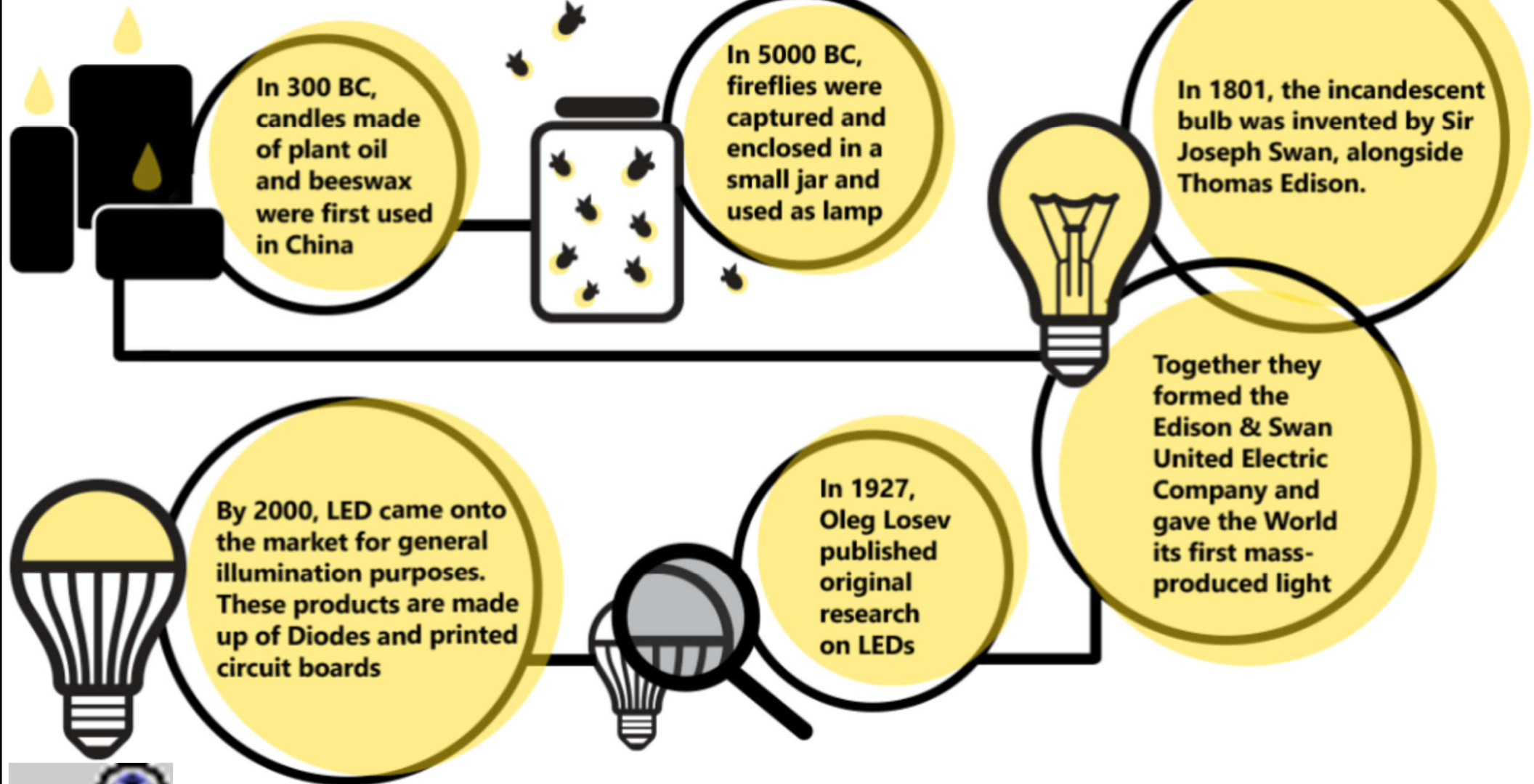


- Historical evolution of lighting
  - Natural light (the sun, daylight)
  - Torches (e.g. fire, wood + animal fat)
  - Candles & the wick
  - Gas lamps (e.g. street lighting)
  - Electric lamps
    - Incandescent light bulbs, fluorescent lights
    - Mercury-vapour & high intensity discharge lamps
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



# Lighting history and light bulbs

## LIGHTING HISTORY



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

### 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

Electric current heats an incandescent bulb's tungsten filament until it glows.



LIFE SPAN: 750 hours



PRICE: \$0.37 per bulb



1,600 lumens

Halogen gas such as iodine inside the bulb prevents wear on the filament, allowing it to glow brighter.



1,000 hours



\$1.59 per bulb



1,600 lumens

Excited gas in a CFL tube emits ultraviolet photons, which coax the bulb's coating to emit visible light.



10,000 hours



\$2.23 per bulb



1,600 lumens

An LED bulb contains many small semiconductor units; each emits light when a voltage is applied.



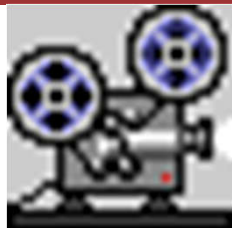
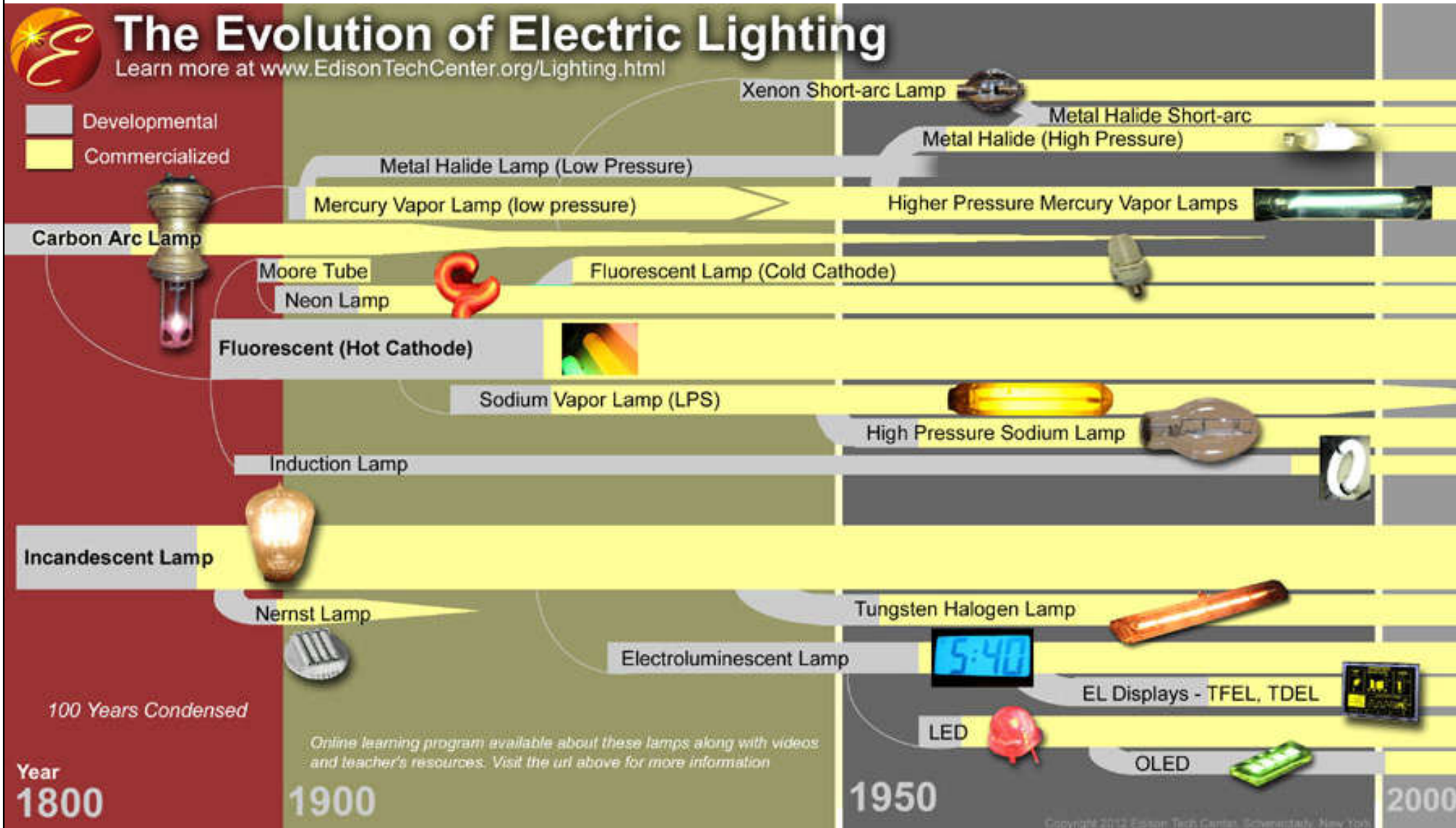
20,000 hours



\$45 per bulb



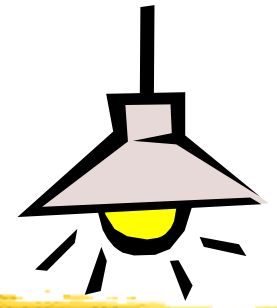
# The evolution of electric lighting



Video: Evolution of Light Bulbs, inventions - 2020 | History of Lighting, Documentary video (7:36) [https://youtu.be/uszG5FD1\\_Uw](https://youtu.be/uszG5FD1_Uw)

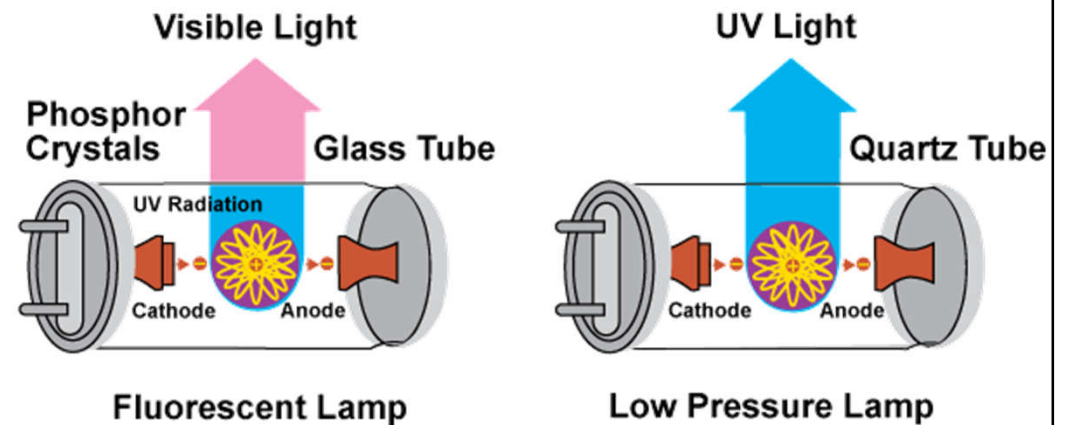
(Source: <https://edisontechcenter.org/Lighting.html>)

# Light sources

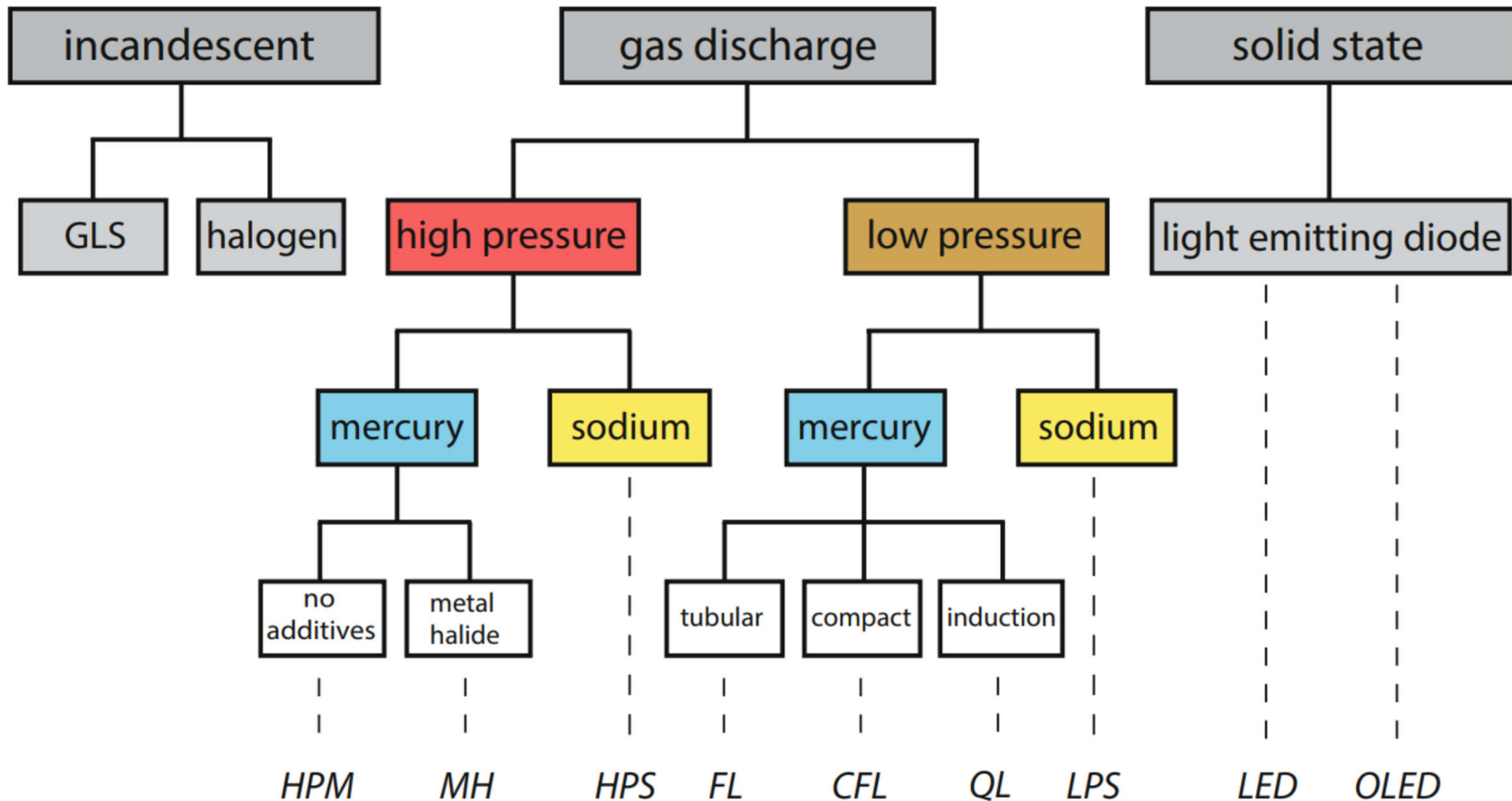


- Mechanism for production of light radiation:

- Incandescence
- Electric discharges
- Electroluminescence
- Luminescence
- Radioluminescence
- Cathodoluminescence
- Chemiluminescence
- Thermoluminescence



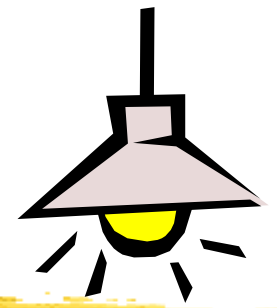
# Light sources grouped according to the technology employed



*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



# Light sources



- Commonly used light sources (abbrev./code)
  - Incandescent filament (I or GLS = general lighting service)

- Tungsten-halogen (TH or H)

- Fluorescent (F)

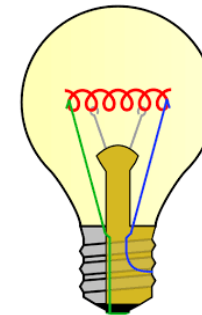
- High intensity discharge (HID)

- Metal halide (MH or MBI or M)

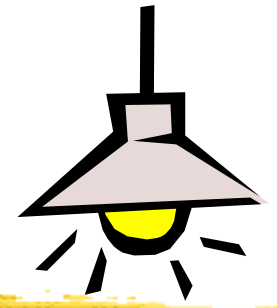
- Mercury vapour (MBF or HPMV or Q)

- High pressure sodium (HPS or S or SON)

- Low pressure sodium (LPS or LS or SOX)



# Light sources



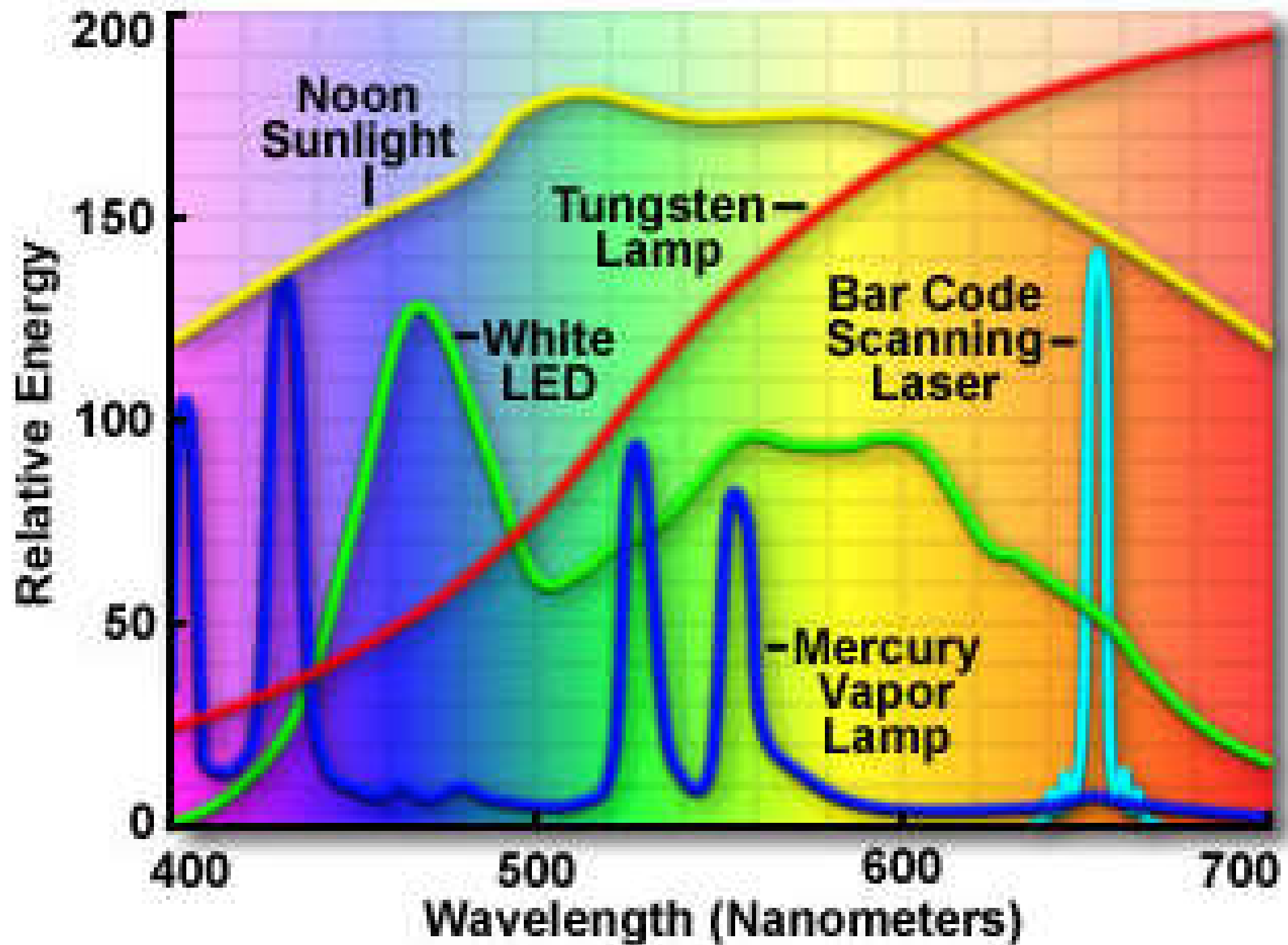
- Other light sources

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



(\* See also [http://en.wikipedia.org/wiki/List\\_of\\_light\\_sources](http://en.wikipedia.org/wiki/List_of_light_sources))

# Spectra from common sources of visible light



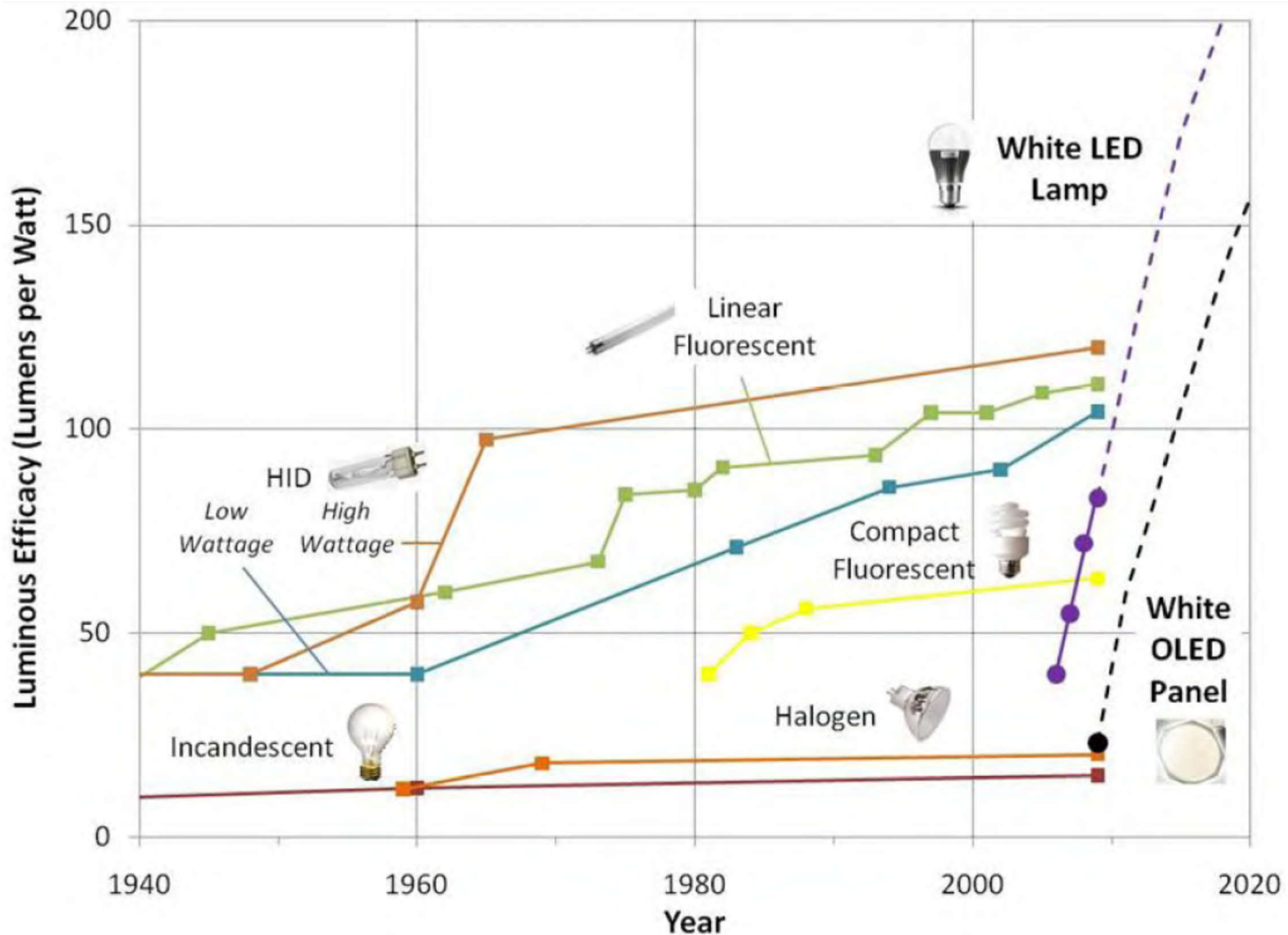
# Important characteristics of lamps & light sources in interior lighting

|                                     |                                     |
|-------------------------------------|-------------------------------------|
| 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 <sub>a</sub> | 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<br>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-<br>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,<br>compact to large |
| OLED (white)               | 40–80  | 2700–6000   | 60–95          | 10,000–40,000  | Flat, up to<br>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

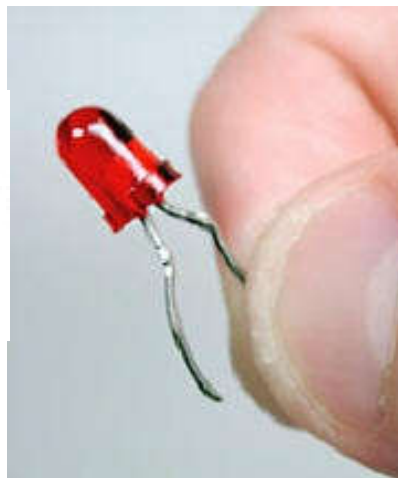


(Source: US Department of Energy)

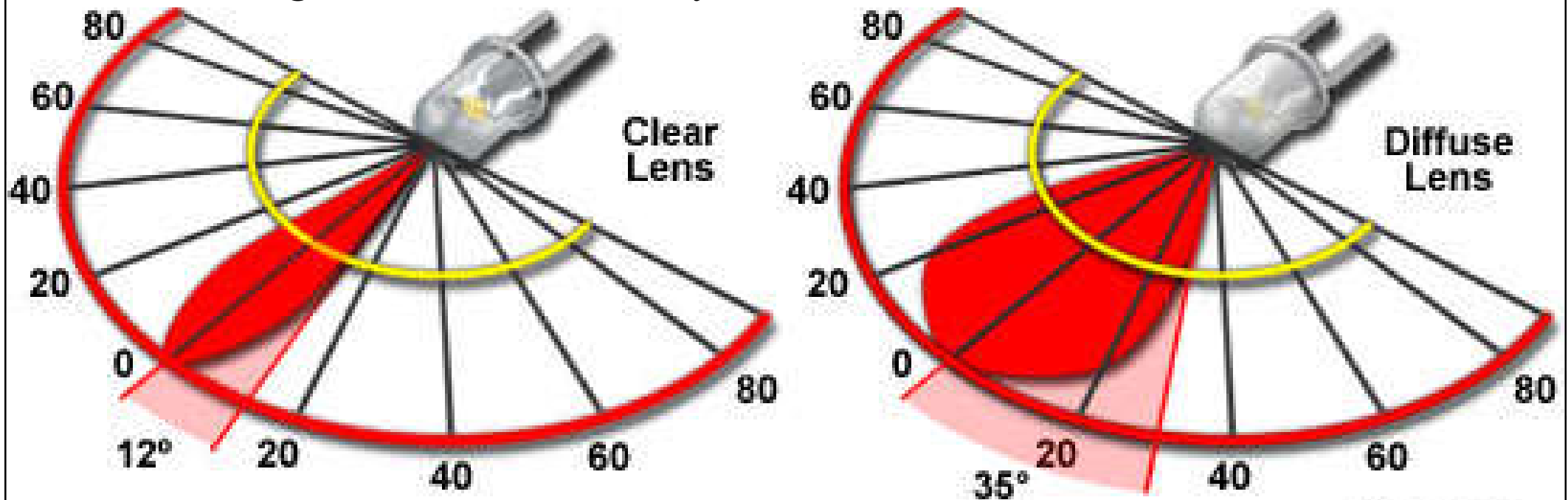


# Light emitting diode (LED)

- 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

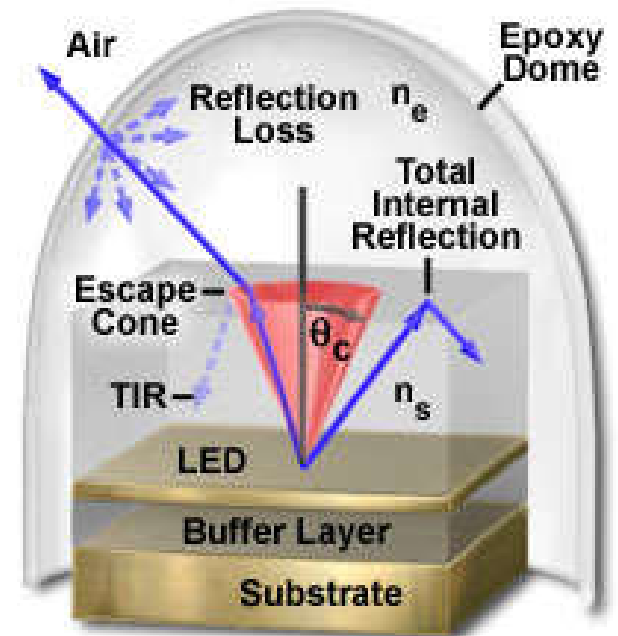
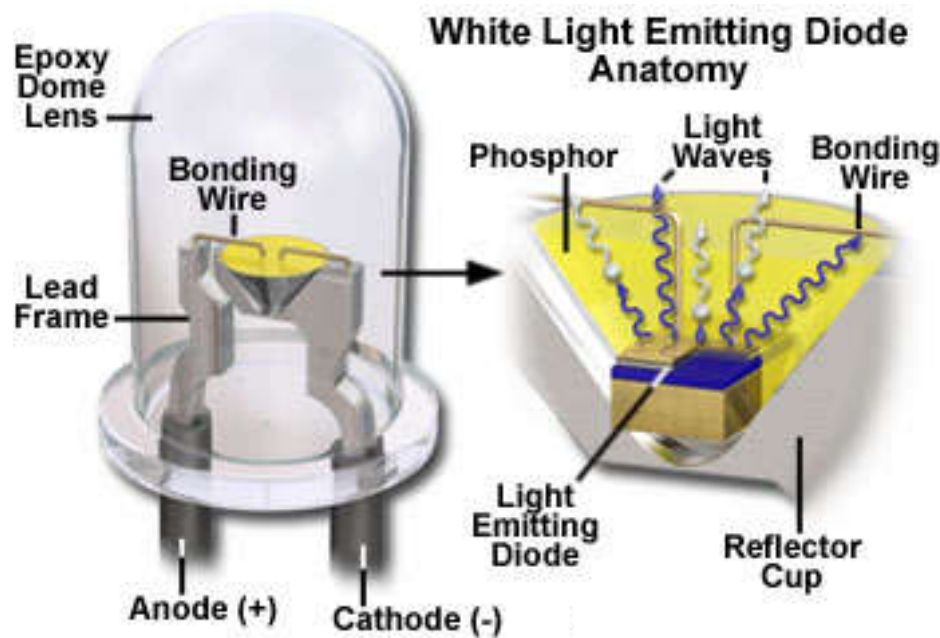


# Light cones emitted by clear and diffuse LED lenses

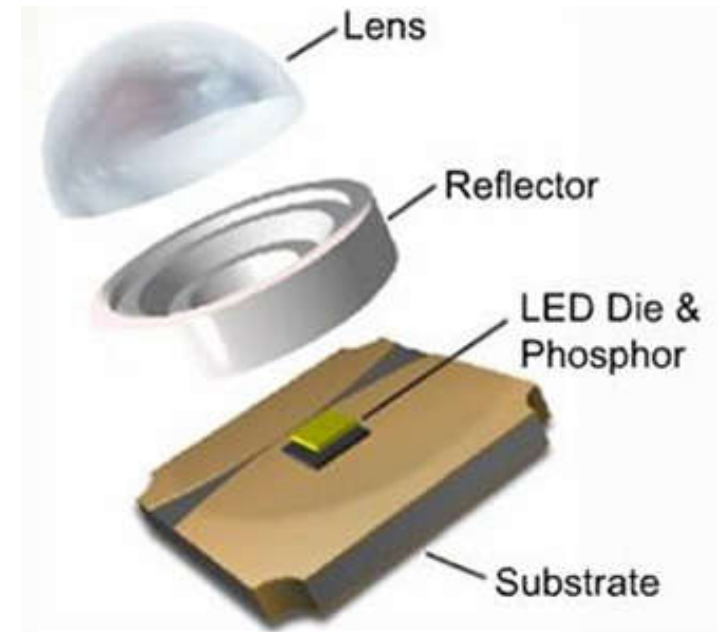
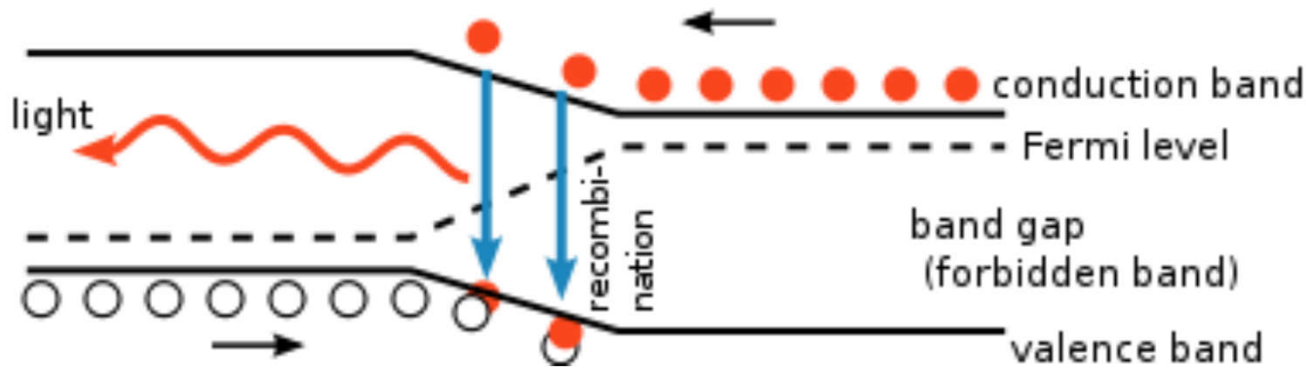
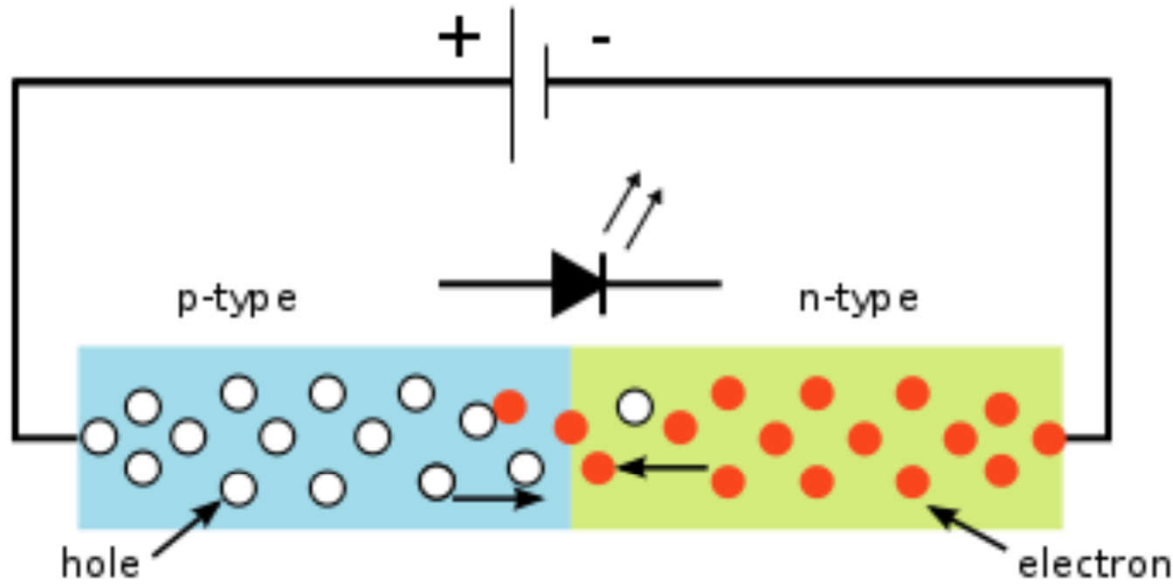


— 50% Intensity — 100% Intensity

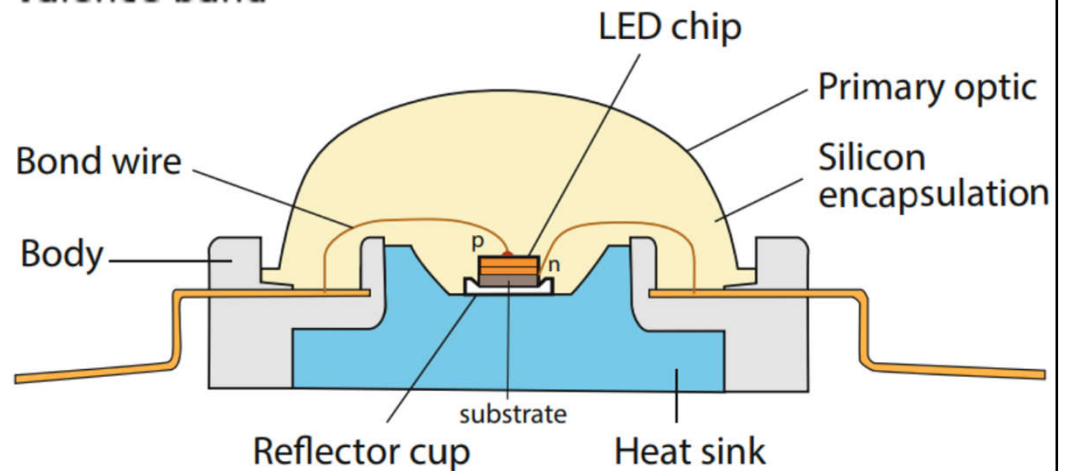
## LED Light Escape Cone



# 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



# 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)

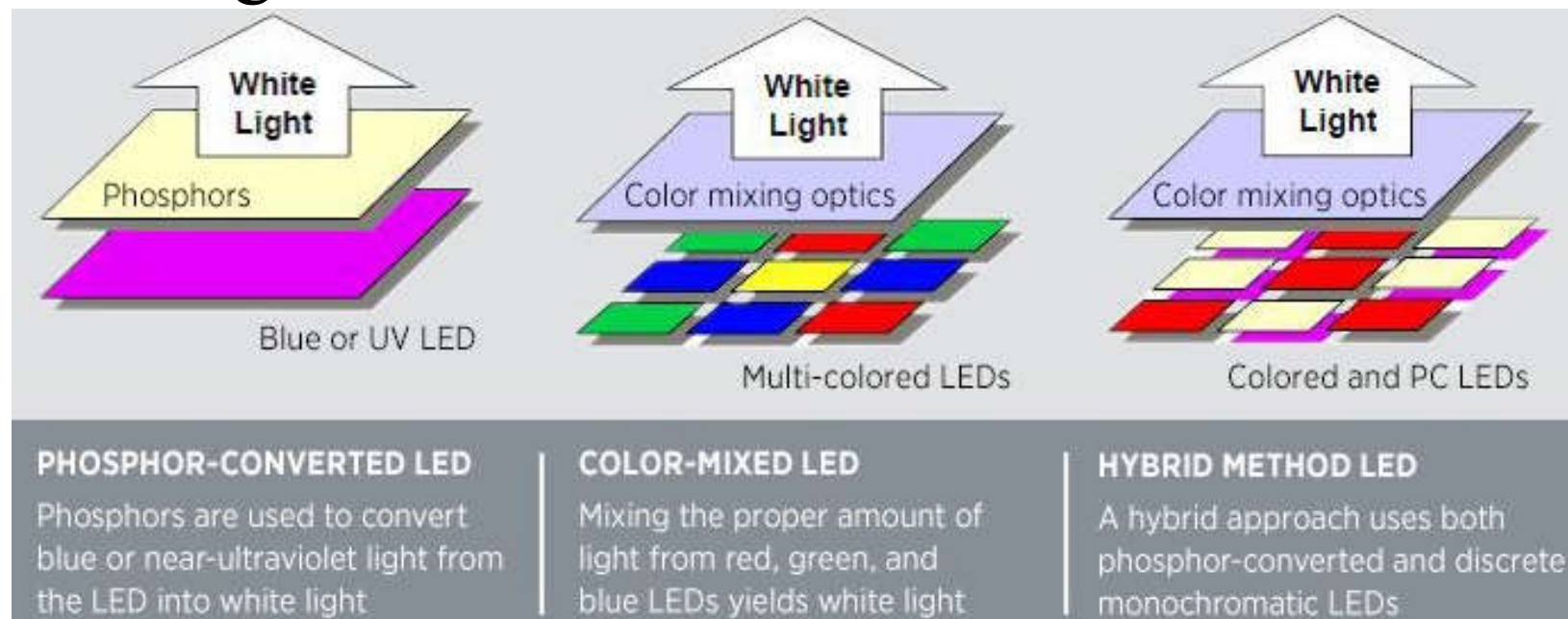
LED candles





# 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





# 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)

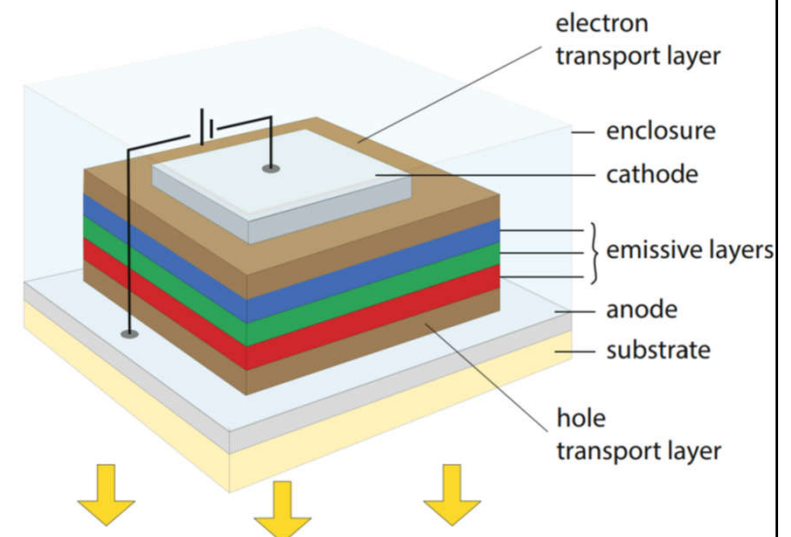
- Video: LEDs and OLEDs - How it Works, Inventors (7:18)
  - <https://youtu.be/8quZrUcRFlw>
  - All about Light Emitting Diodes and Organic LEDs. How they work, the difference between them.
  - Learn about the inventors of the lights at the end of the program.



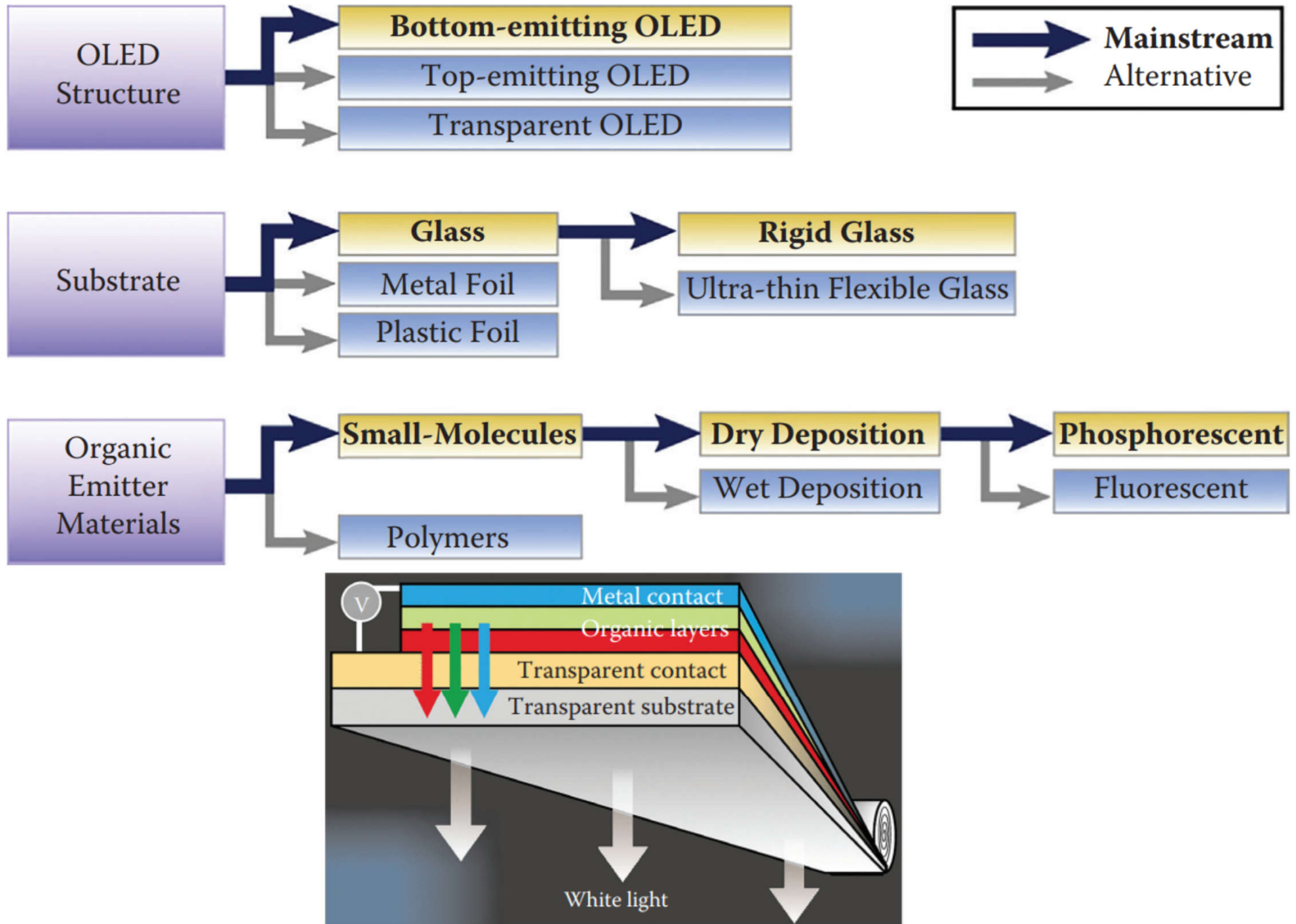


# Light emitting diode (LED)

- 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





# Applications & luminaires

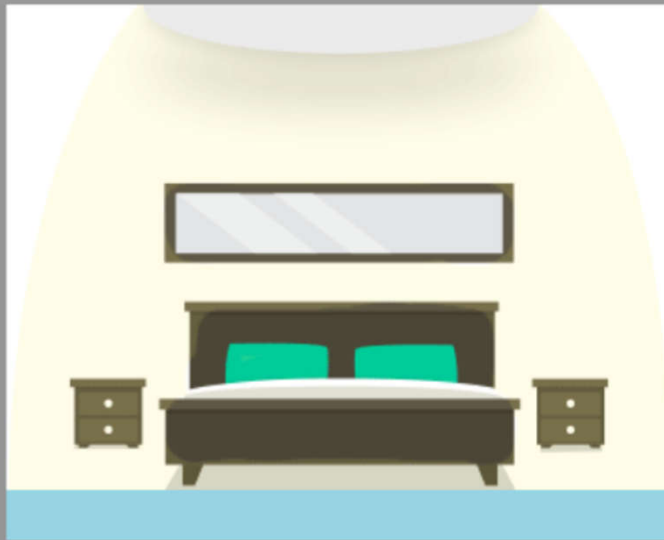


- Common applications
  - Indoor lighting
    - Residences, offices, classrooms, health care, retails
  - Outdoor lighting
    - Street & stadium lighting, architectural floodlighting
- Special applications
  - Lighting for art, entertainment, emergency, safety
  - Lighting for transport, parking, manufacturing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

# Three basic types of lighting

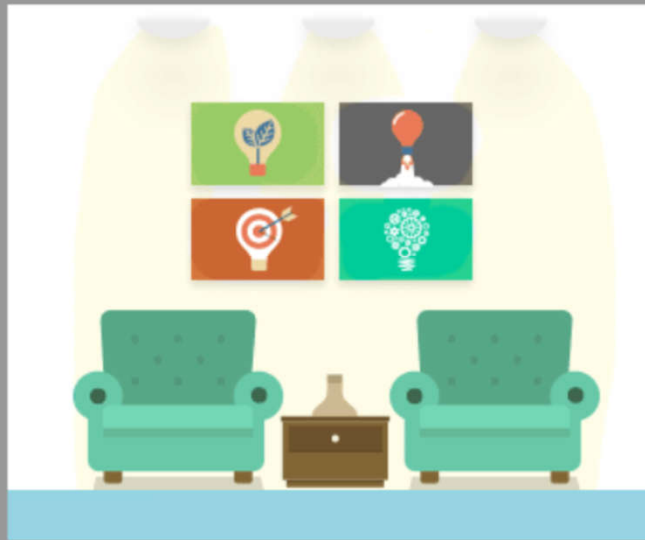
## AMBIENT

Used to provide even, overall light to a room



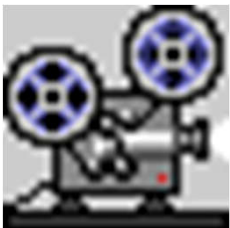
## ACCENT

Used to create different focal points



## TASK

Used when performing specific tasks



Video: Lighting Tips at a Glance (1:35) [https://youtu.be/yR\\_Pa-a0W6k](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:

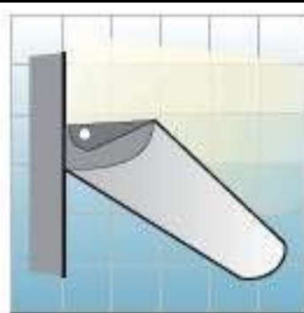
- Directional gimbal recessed fixture or downlight
- Pendant lighting
- Slim line bar and undercabinet
- Tape and extrusion
- Portable or desk lamp

## Accent lighting:

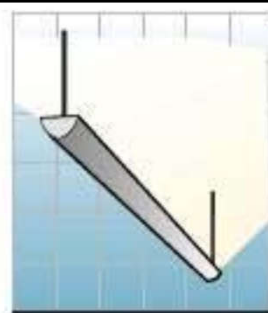
- Track light
- Slim line bar and undercabinet
- Tape and extrusion
- Directional recessed fixture or downlight
- Wall-mounted fixtures



*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*



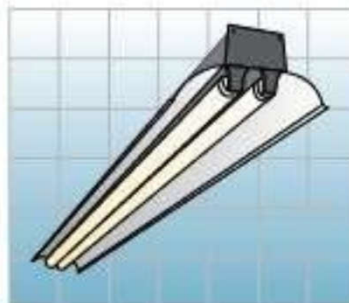
*Track Lighting (Metal Halide)*



*Track Lighting (Incandescent)*



*Functional Wall Sconce*



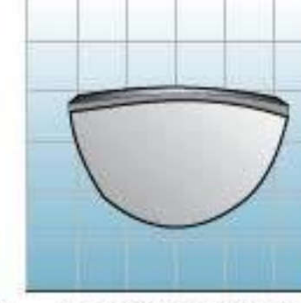
*Open Fluorescent Luminaire, Ref. Industrial*



*Portable Torchiere Uplight*



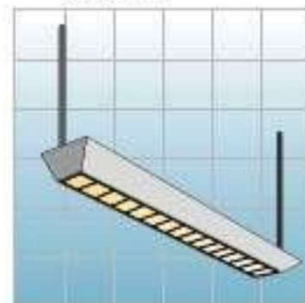
*Task Lighting, Fixed and Furniture Integrated*



*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



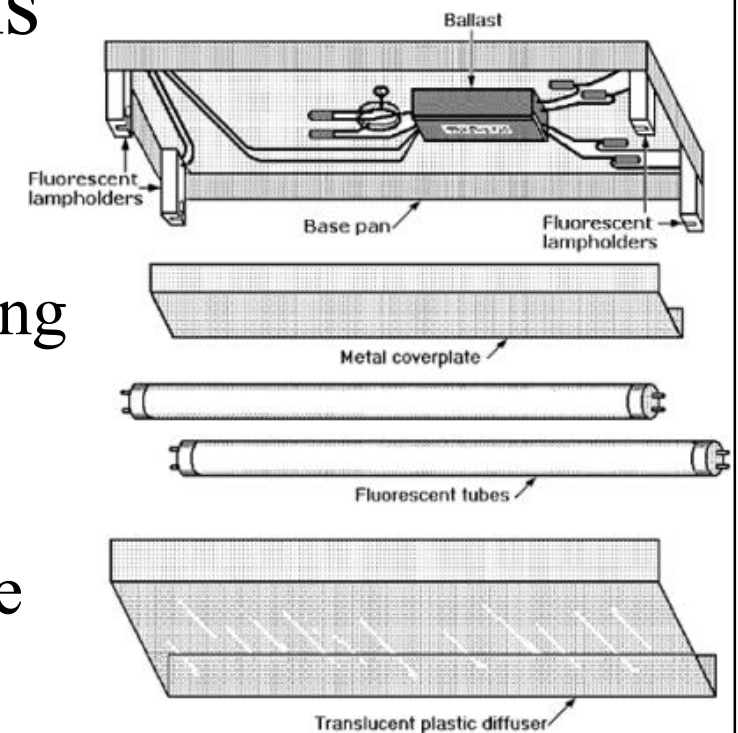
- Components of lighting systems

- Lighting components

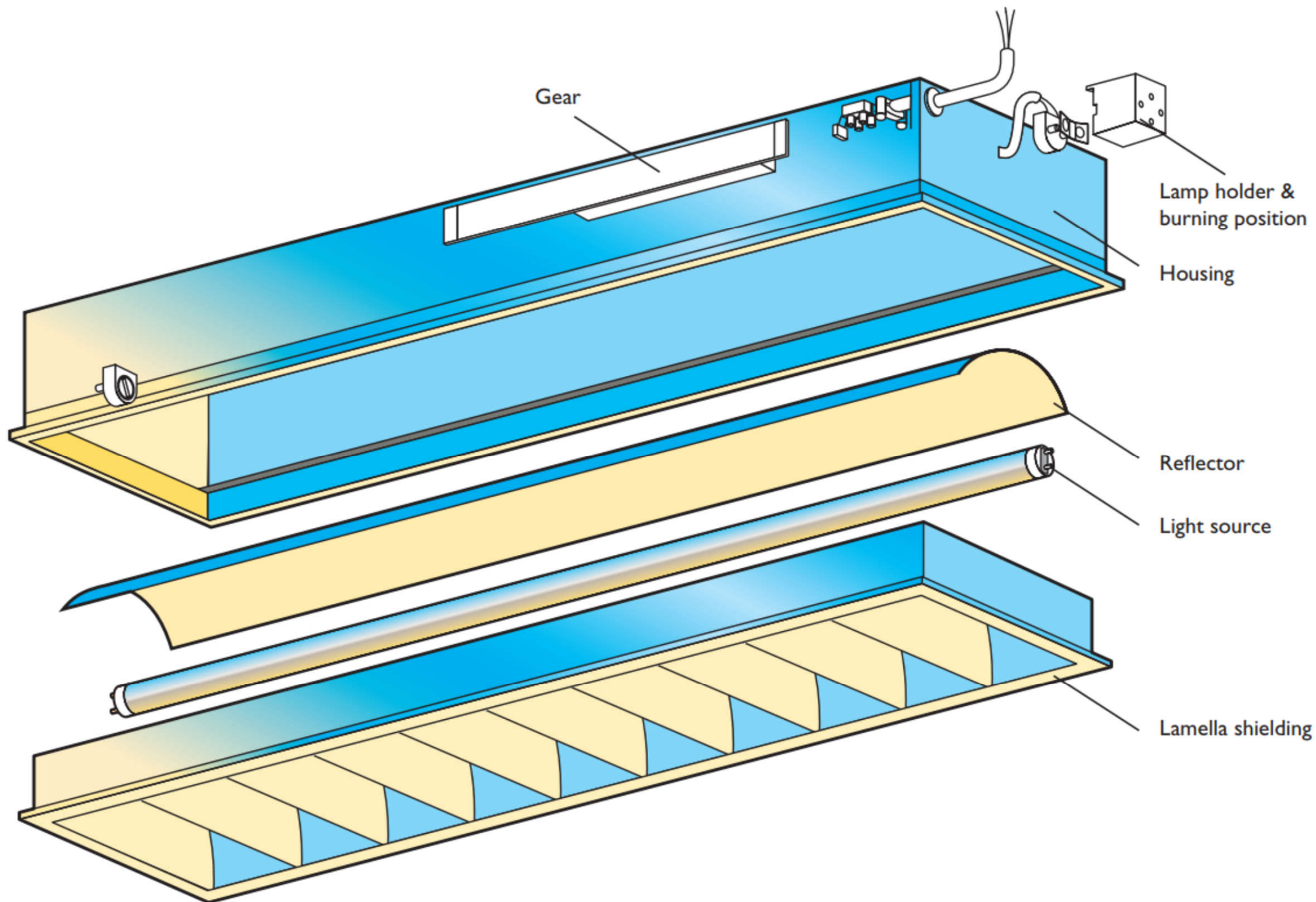
- Power source
    - Power controller: switching/dimming
    - Power regulators: ballasts
    - Light source: lamp
    - Optical control: luminaire or fixture

- 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



# Applications & luminaires



- Luminaire (light fixture)

- A complete lighting system:

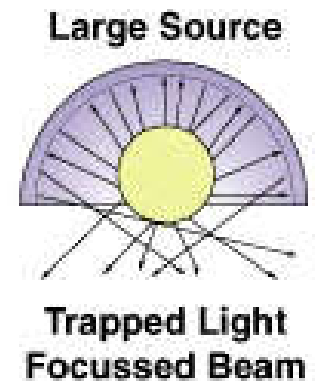
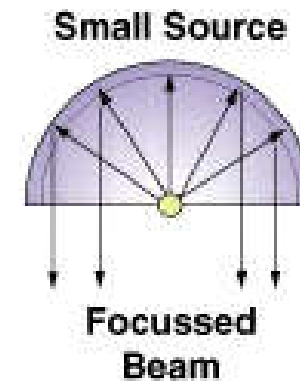
- A housing and lampholders
- Lamps (w/ a ballast/transformer)
- Optical system

- 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

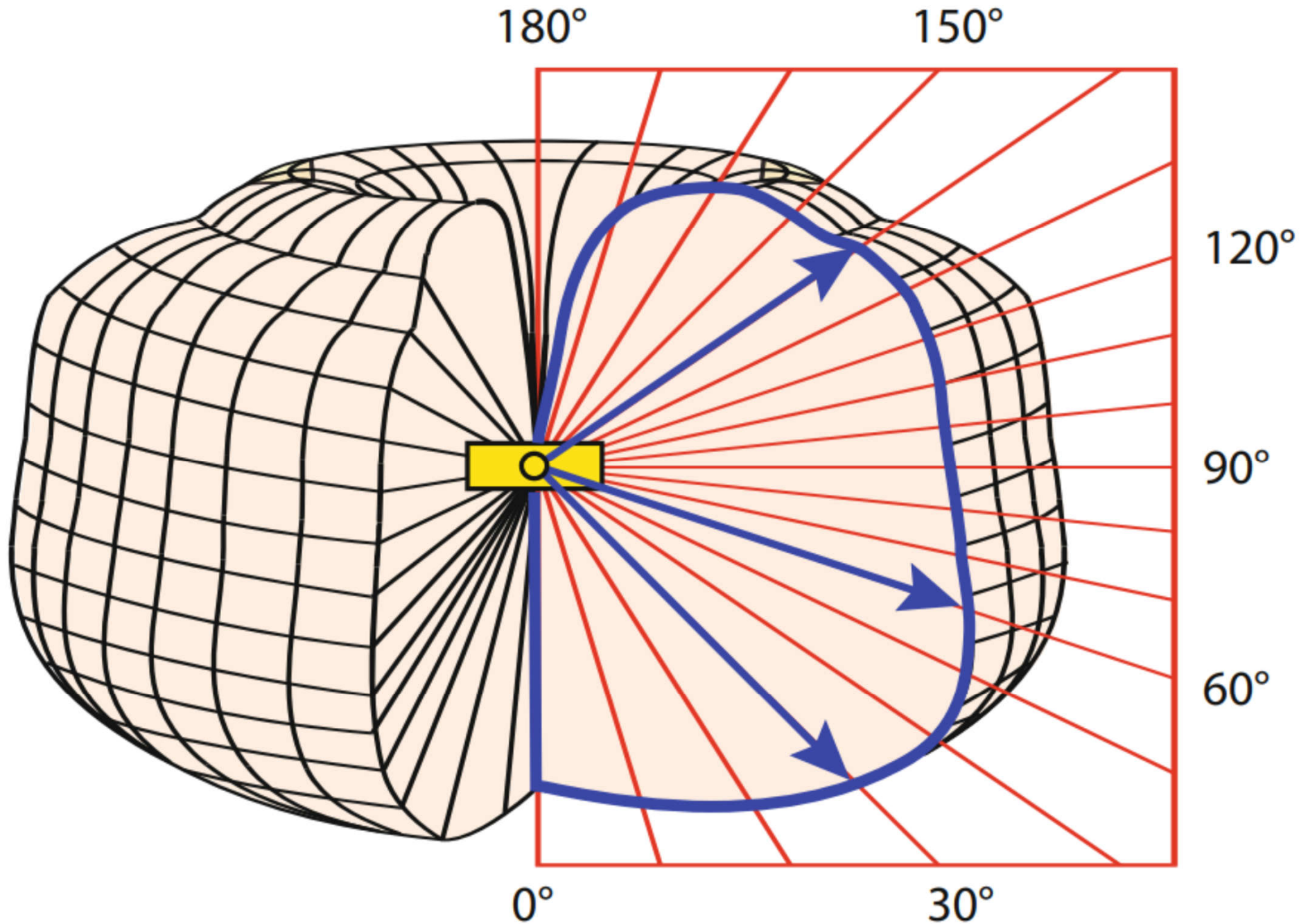
## IDENTICAL REFLECTORS





# Light distribution of a luminaire

(The lengths of the arrows represent the luminous intensities)



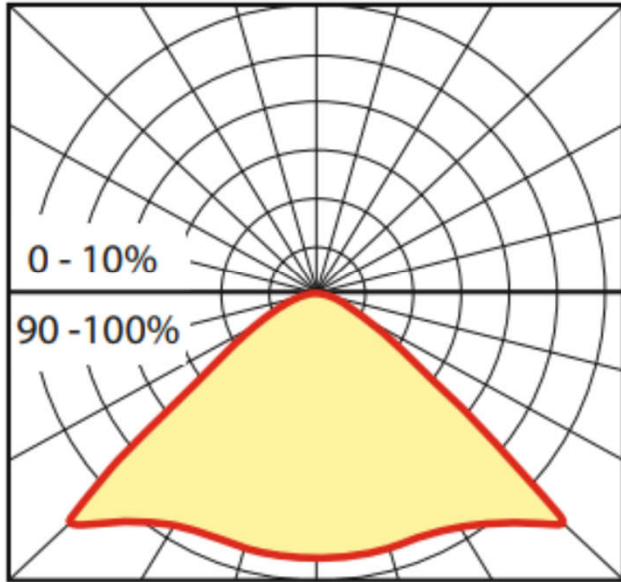
# Applications & luminaires



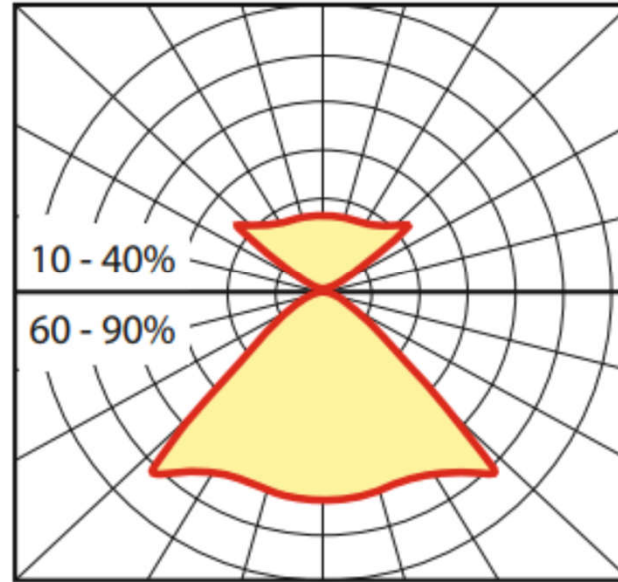
- Six basic classifications of luminaires:
  - Direct luminaire where all the light is directed down
  - Semi-direct luminaire where the majority of the light is directed down
  - General diffuse luminaire where light is distributed in all directions
  - Direct-indirect luminaire where light is distributed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

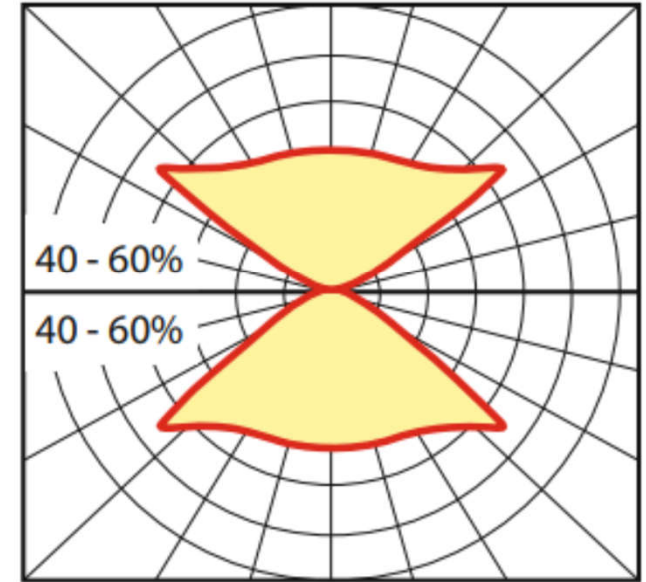
Direct



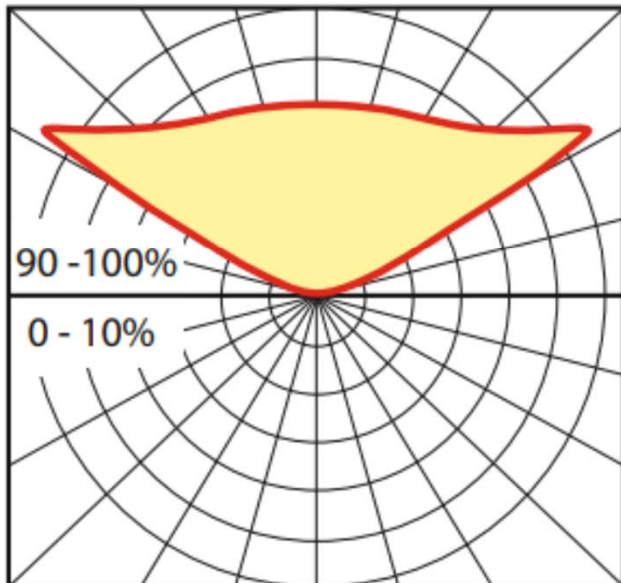
Semi-direct



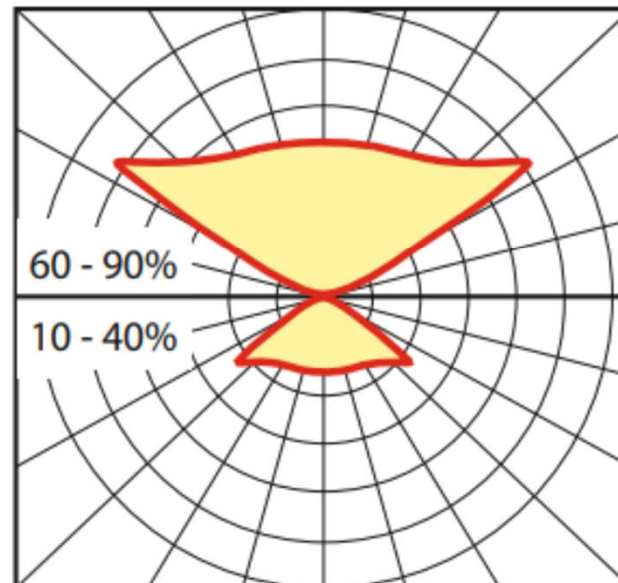
Direct-indirect



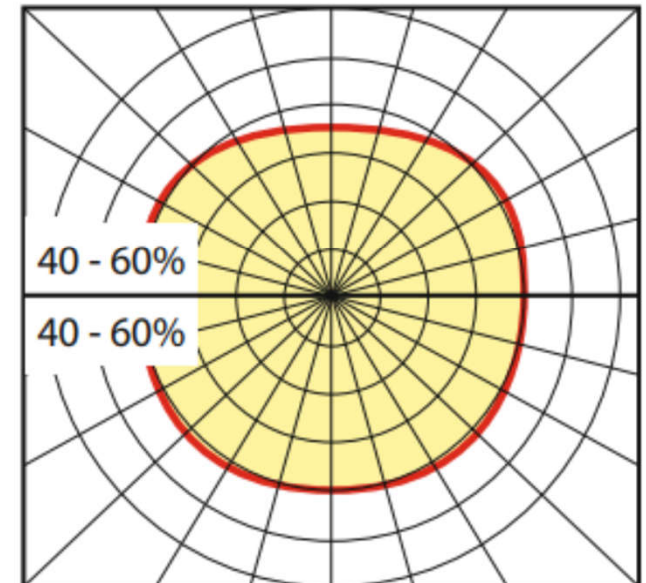
Indirect



Semi-indirect



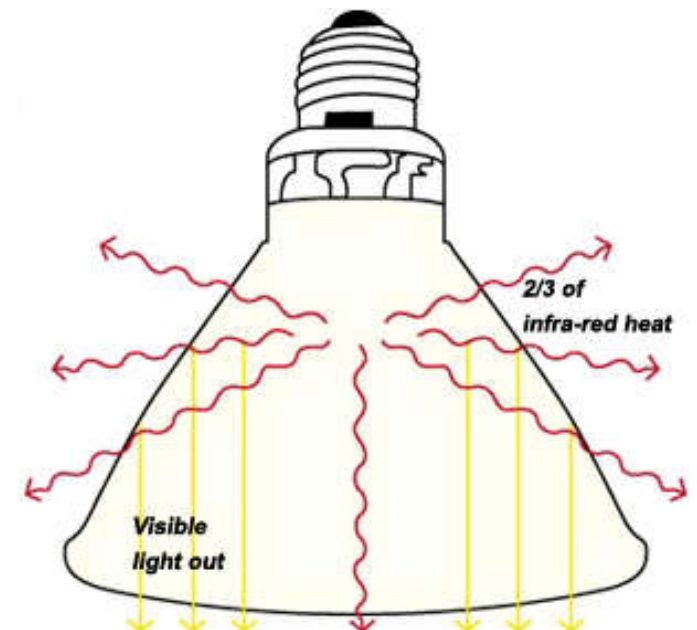
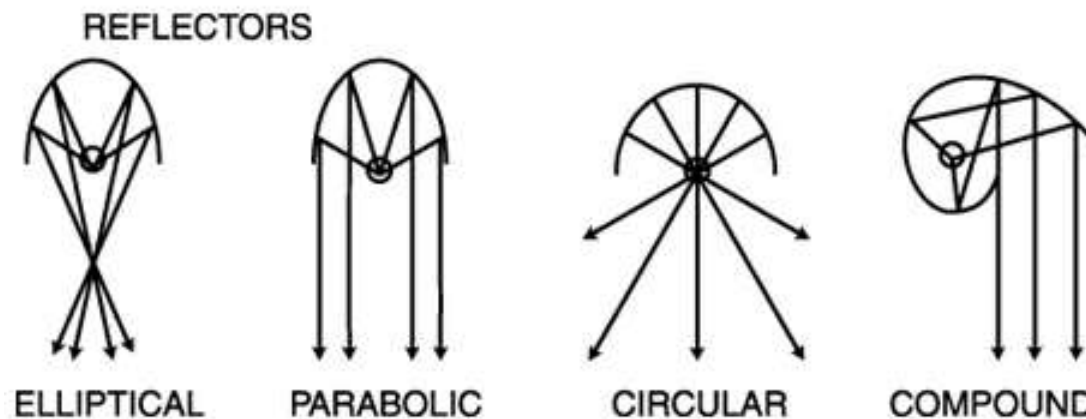
General-diffuse



# Applications & luminaires



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



# Methods of controlling light

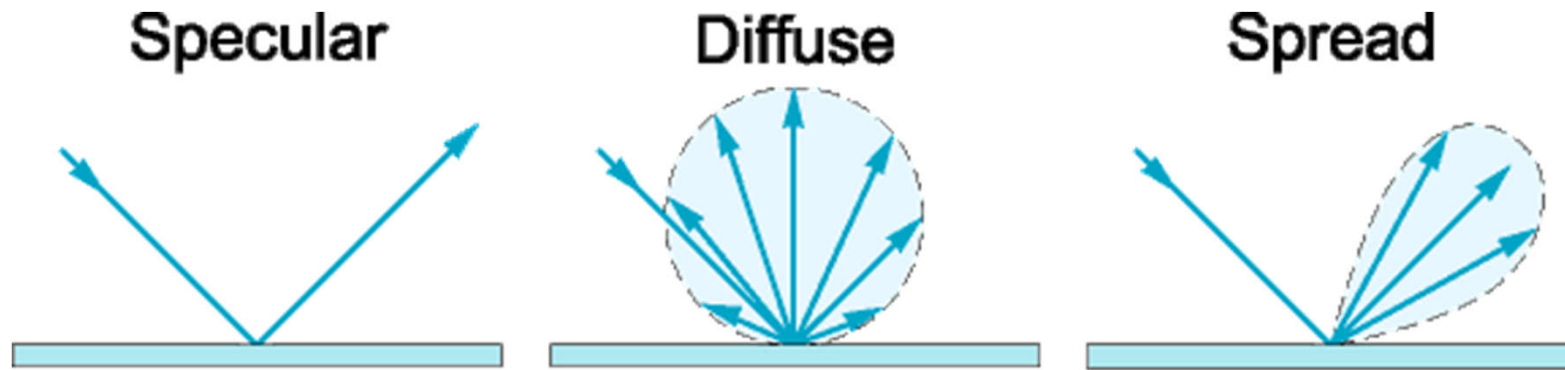


Fig. 3.2 Specular, diffuse, and spread reflection from a surface.

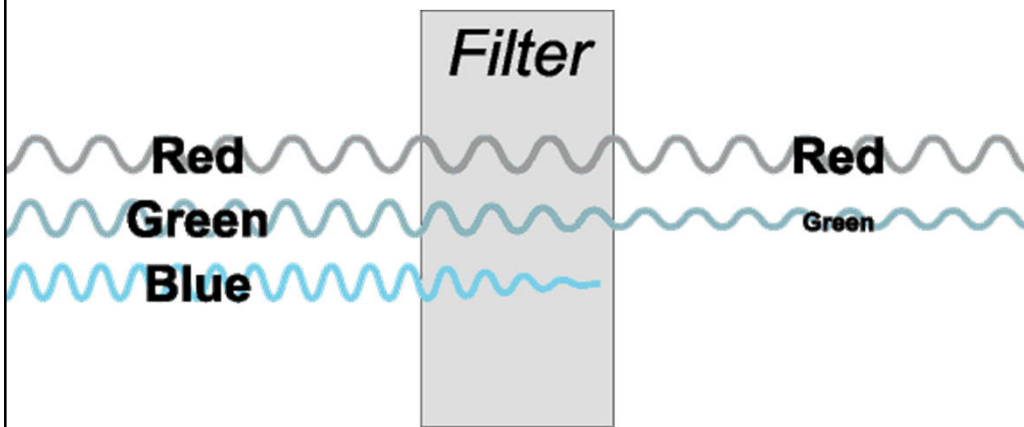


Fig. 3.3 Transmission through an optical filter.

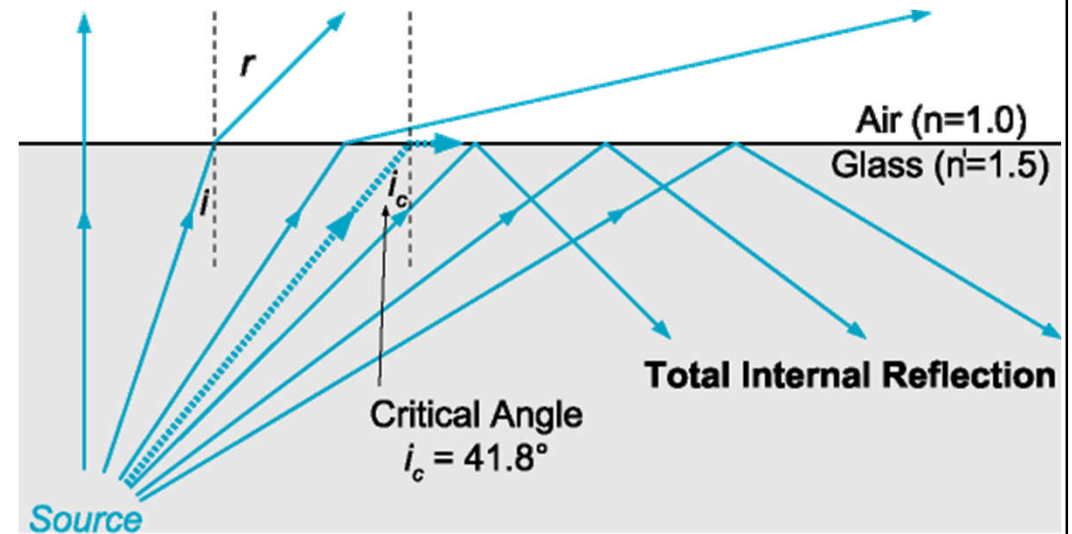
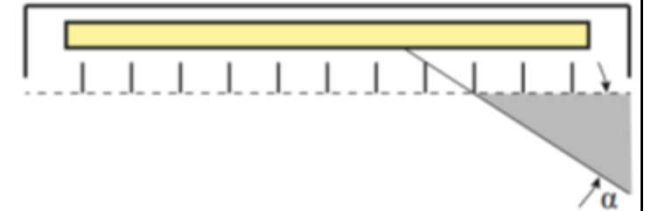
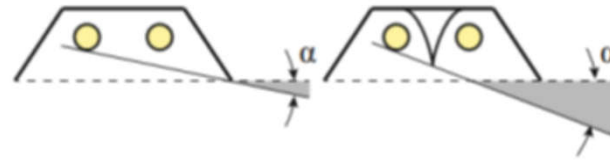


Fig. 3.5 Refraction and total internal reflection.

# Applications & luminaires



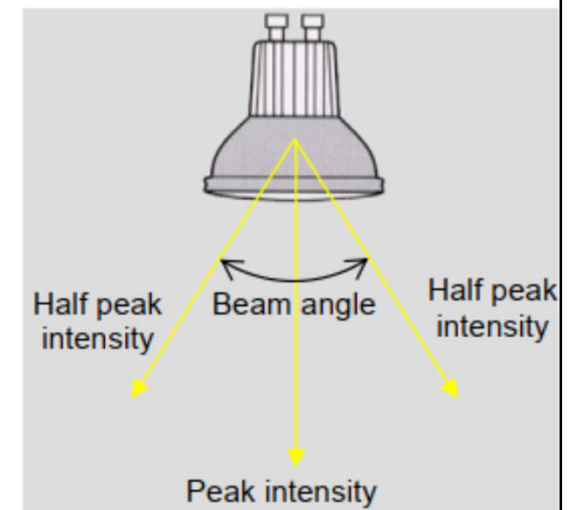
- Shielding angle



- 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



- Luminaires Efficacy Rating (LER)
  - $LER = (\text{Photometric Efficiency} \times \text{Total Lamp Lumens} \times \text{Ballast factor}) / \text{Luminaire Input Watts}$
- 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

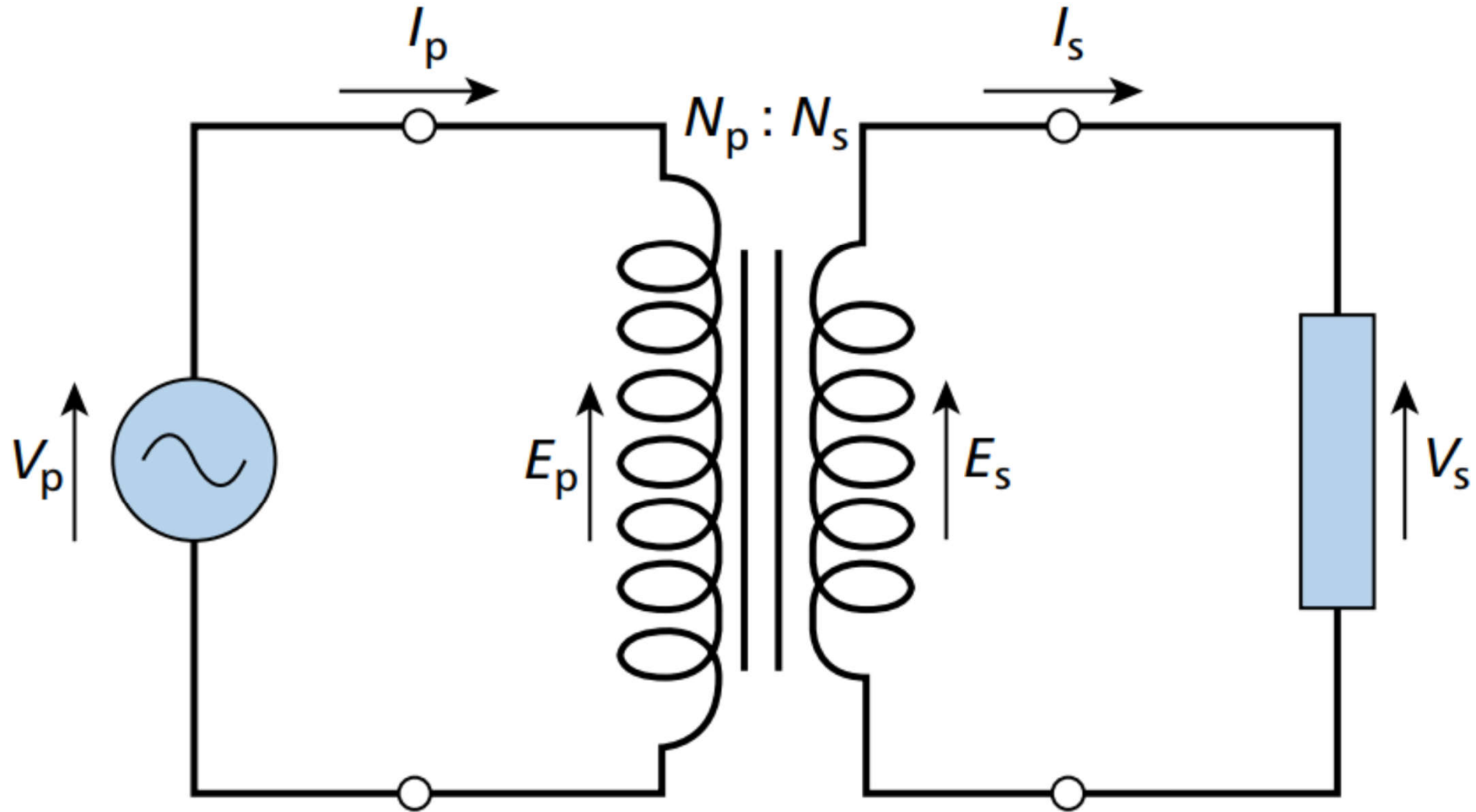


- Lamps & light sources requiring control gear:
  - Incandescent lamps (other than mains electricity rated)
  - Fluorescent lamps
  - High intensity discharge lamps
  - Other discharge lamps
  - LED/OLED light sources
  - Emergency luminaires
- Incorporated within the luminaire, separate or remote; may also supply multiple luminaires



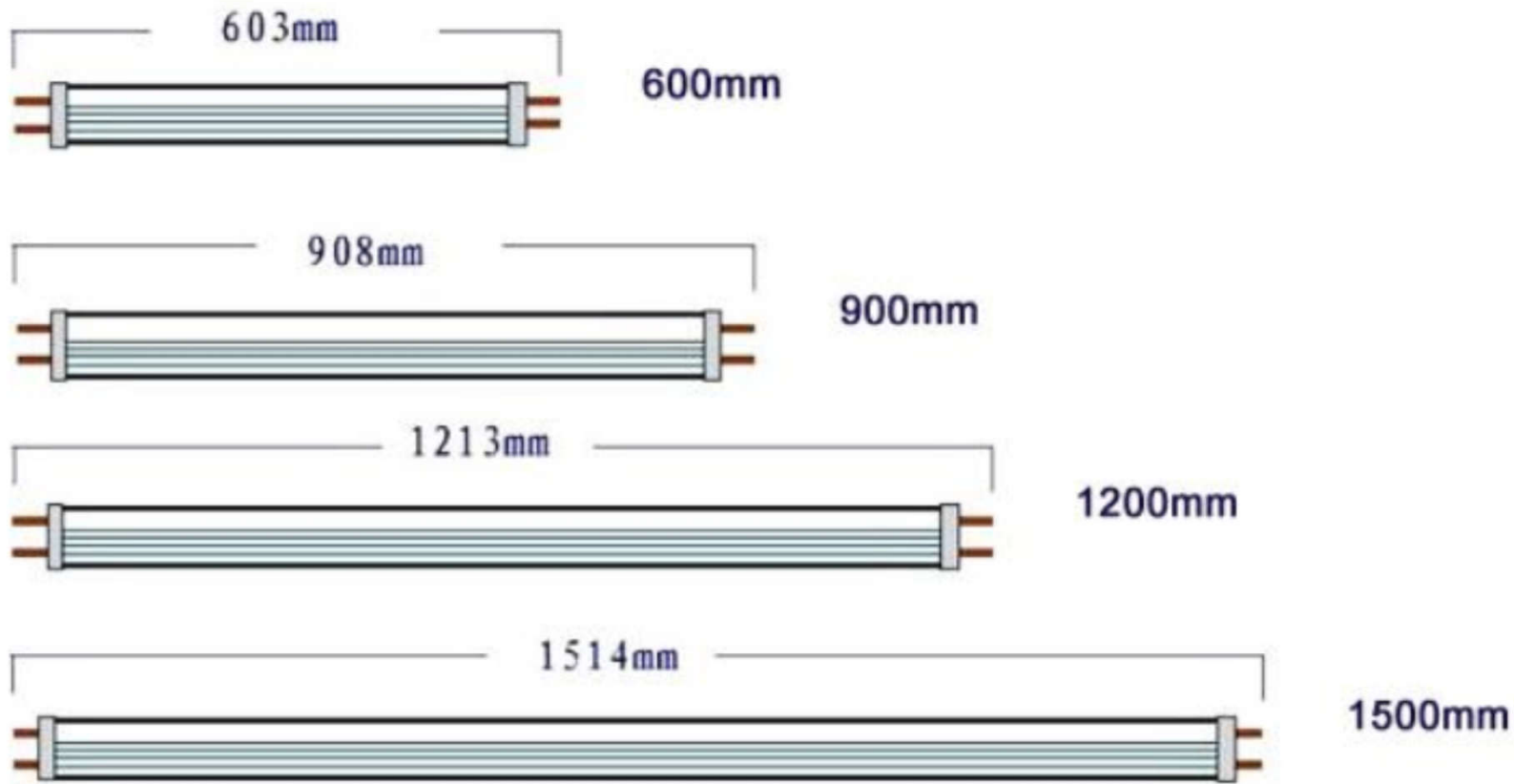


# Transformer for low voltage incandescent lamps

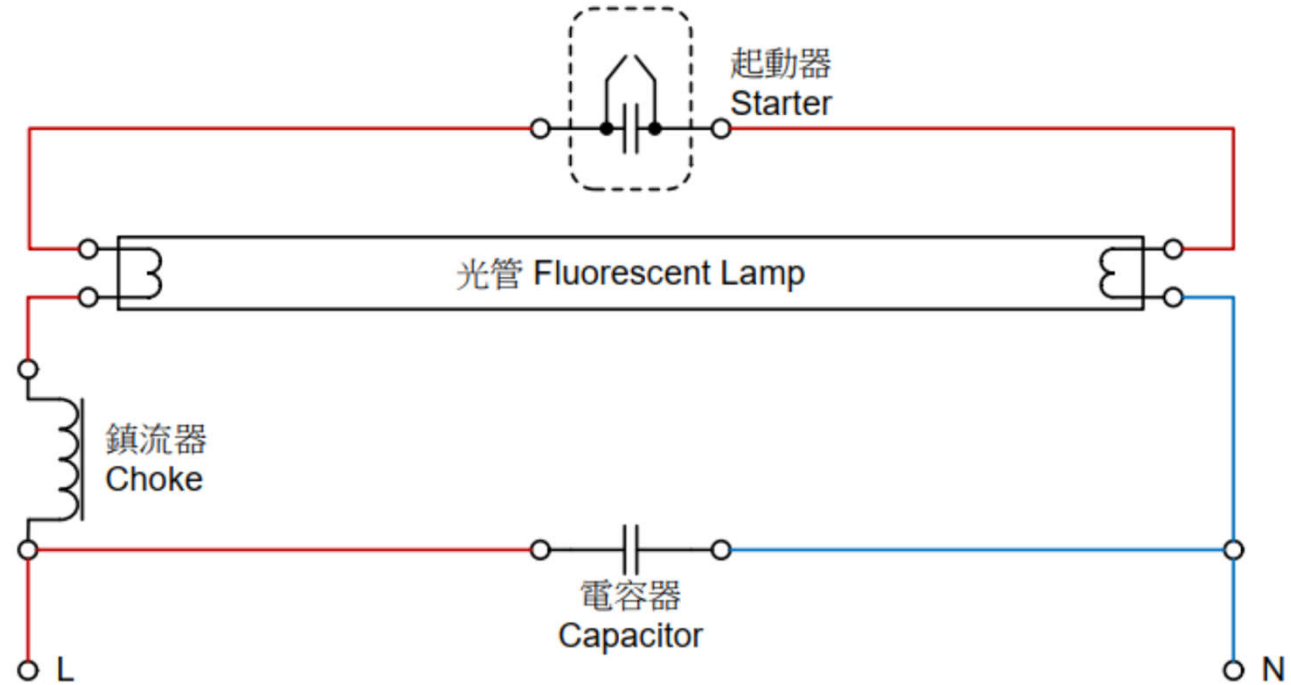


$$\frac{V_p}{V_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s}$$

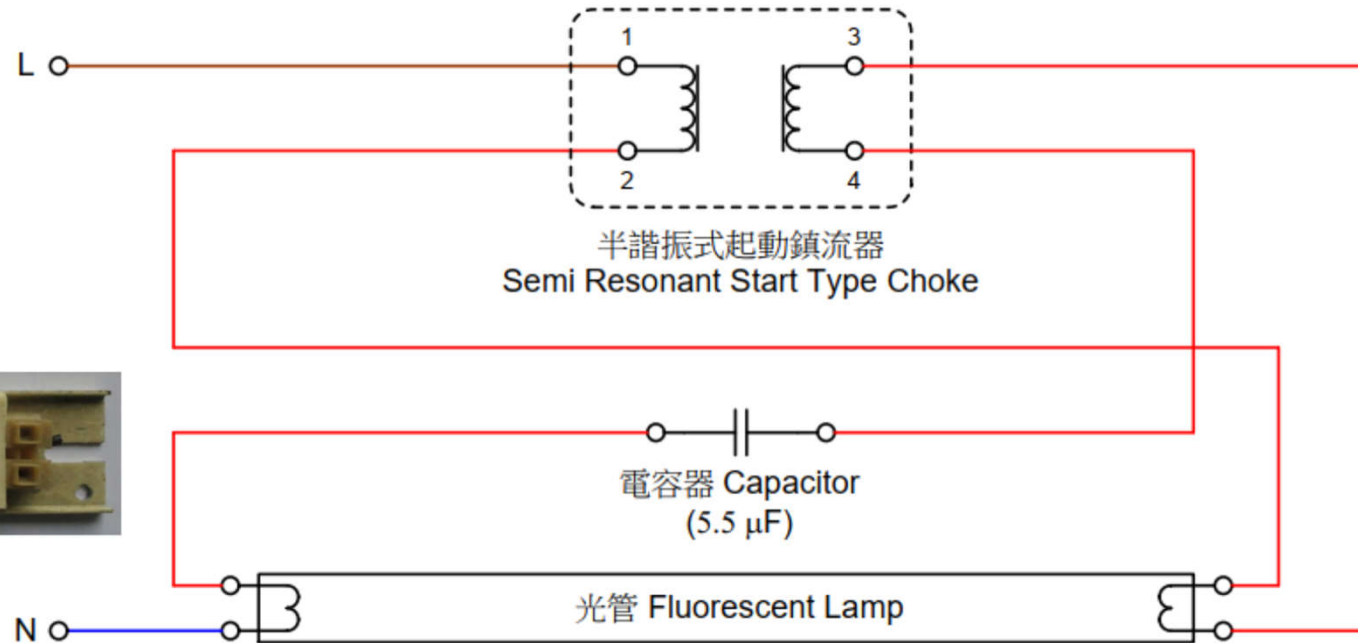
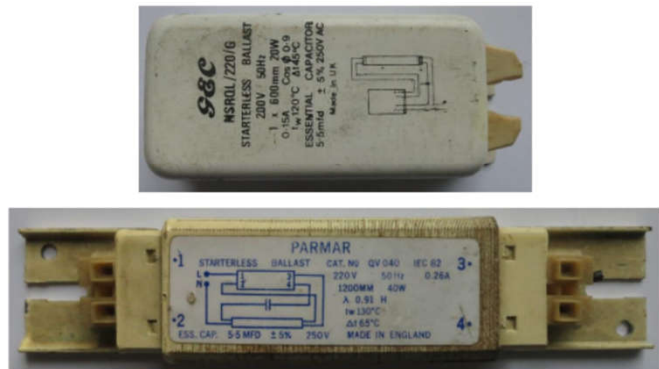
# Fluorescent lamps & starters 螢光管和起動器



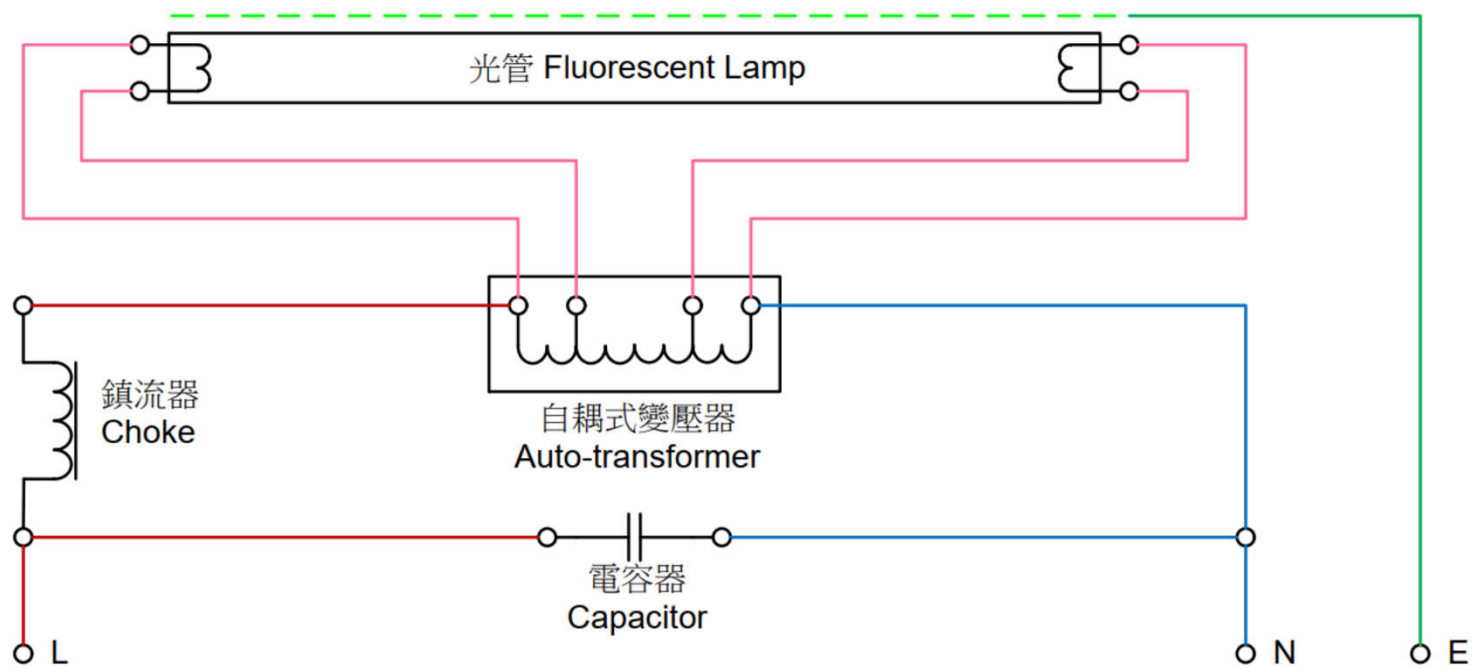
## Glow Type Fluorescent Lamp Circuit (啟輝式光管電路):



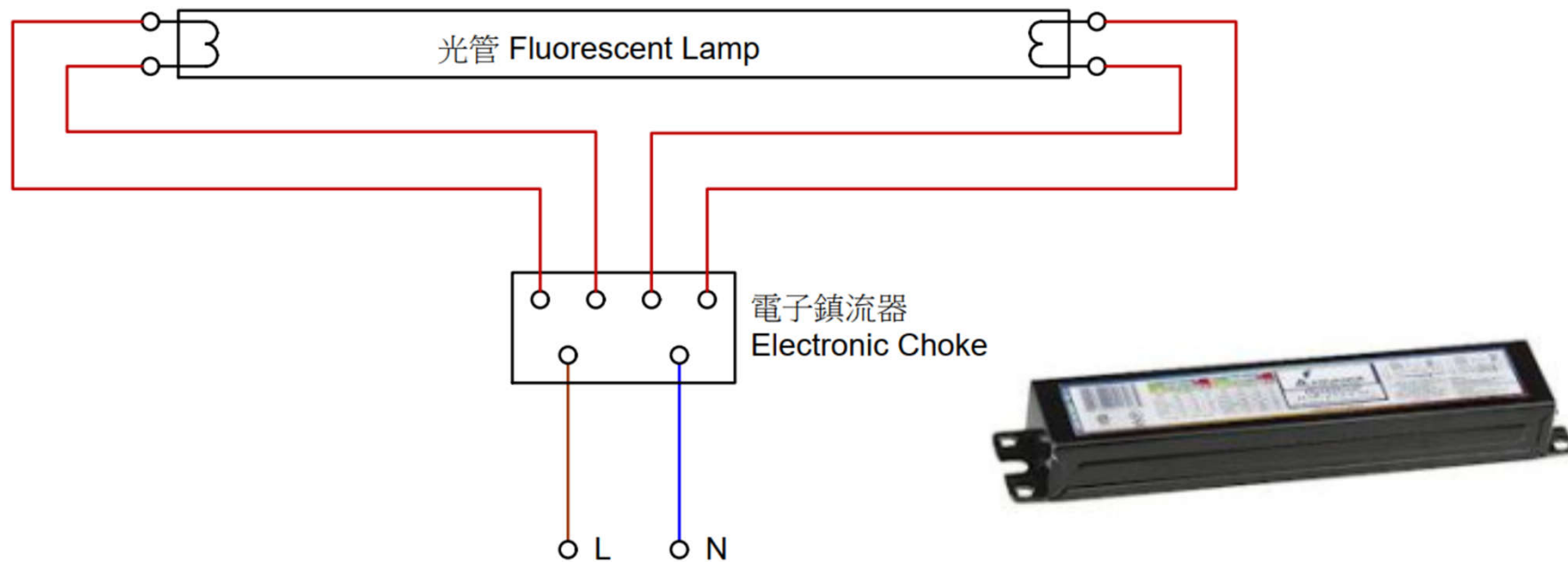
## Semi Resonant Start Type Fluorescent Lamp Circuit (半諧振式起動光管電路):



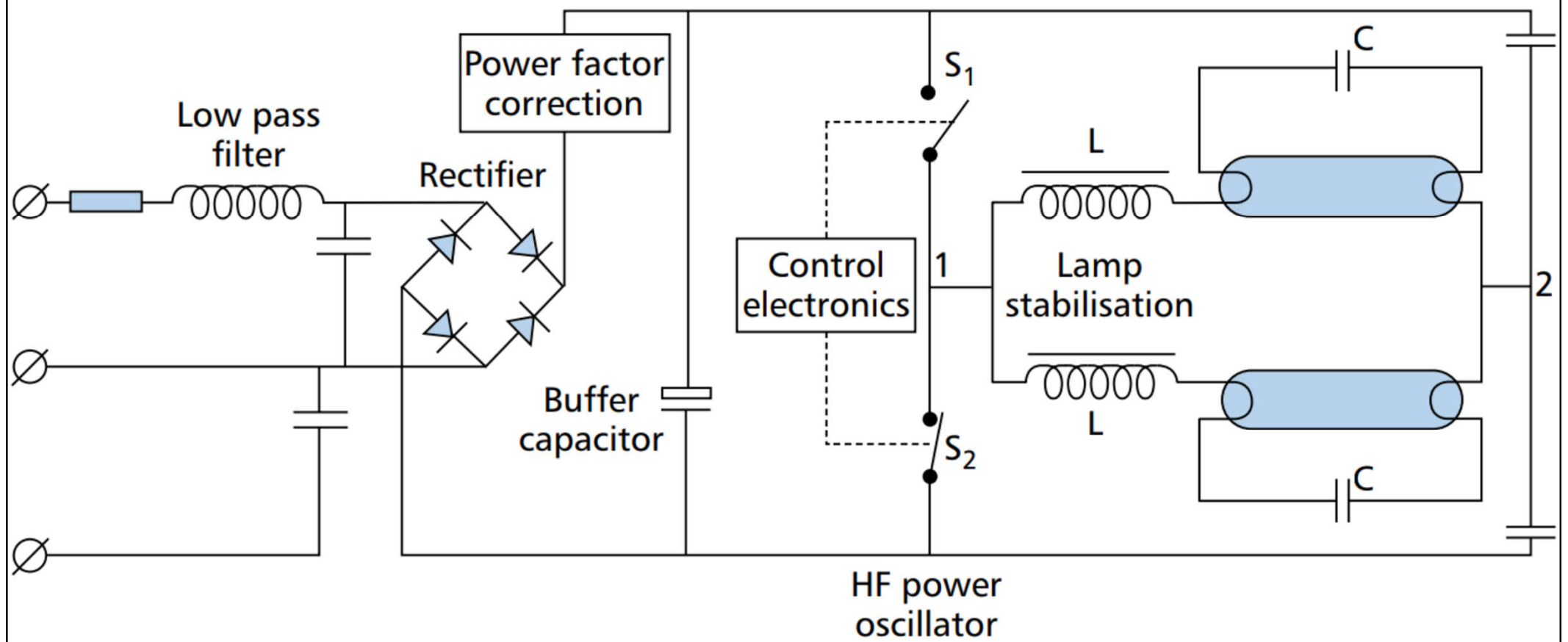
## Quick Start Fluorescent Lamp Circuit (快速起動光管電路):



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

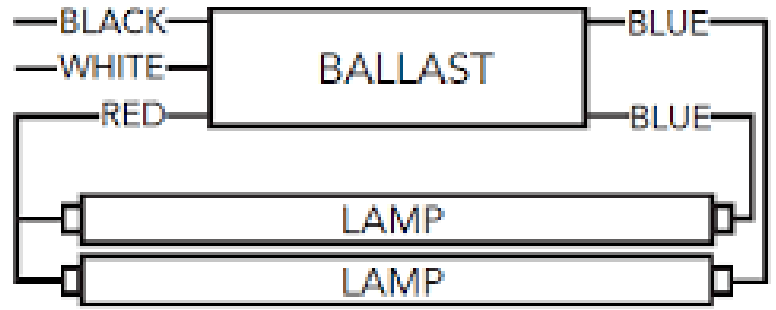


# Circuit diagram of an electronic ballast for two fluorescent lamps



HF power oscillator

## Wiring Diagram



For 1-lamp operation cap one blue lead



(Source: The SLL Lighting Handbook 2018)



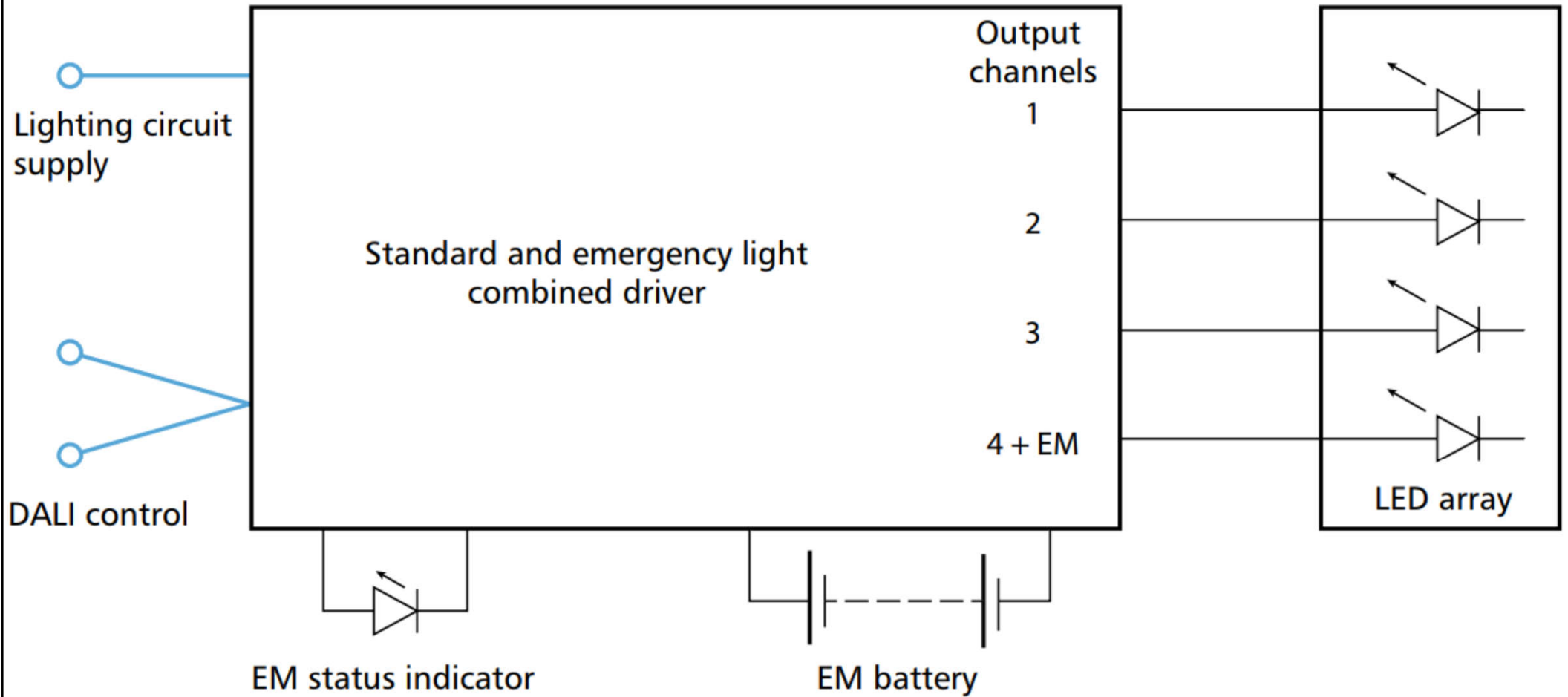
# Control gear



- 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

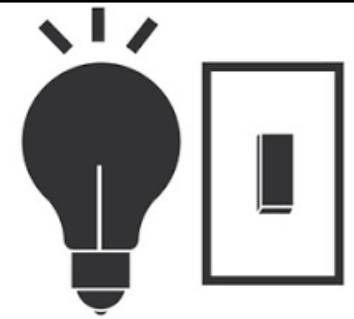


Control gear for emergency lighting applications:  
Single driver with automatic control & remote monitoring;  
only channel 4 remains in operation during emergency conditions





# 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

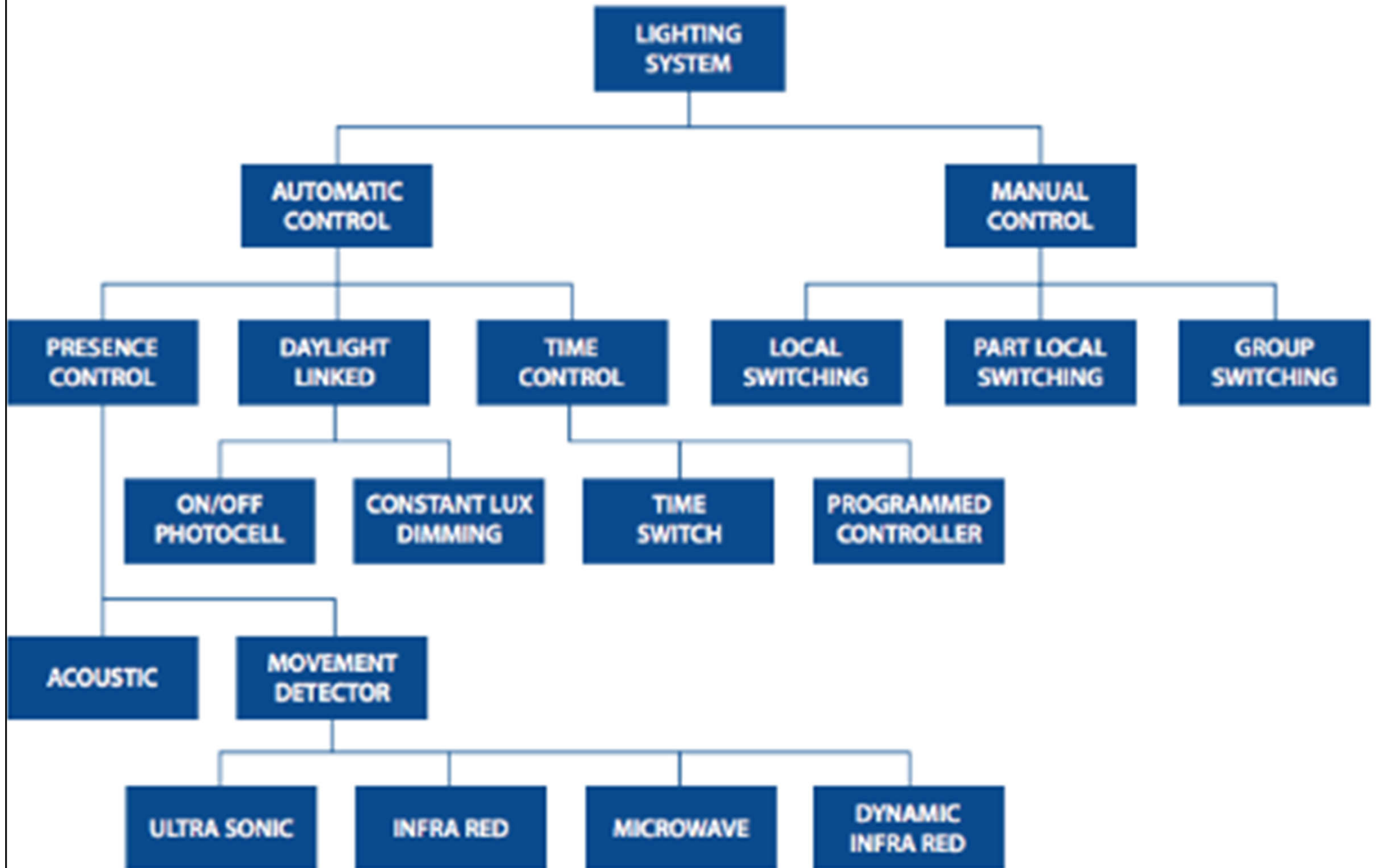


- Benefits for the owner:
  - Flexibility to satisfy user visual needs
  - Automation to reduce energy costs & improve sustainability

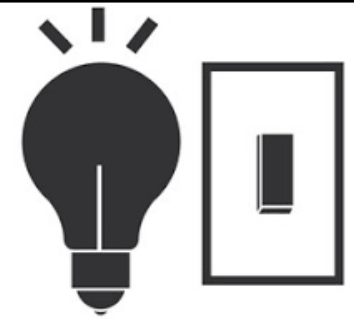
## Benefits of good lighting controls

| <b>Visual Needs</b>                                                                                                                                                                                                                                                                                                           | <b>Energy Management &amp; Sustainability</b>                                                                                                                                                                                                                                                                                           |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"><li>• Change space appearance</li><li>• Facilitate different functions of the space</li><li>• Alter atmosphere &amp; mood</li><li>• Reduce glare &amp; visual discomfort conditions</li><li>• Increase user satisfaction by providing users the ability to control their lighting</li></ul> | <ul style="list-style-type: none"><li>• Reduce both energy demand &amp; energy consumption</li><li>• Reduces building operating costs</li><li>• Comply with building energy codes</li><li>• Facilitate more efficient building operation &amp; maintenance</li><li>• Provide data &amp; information for building optimization</li></ul> |

# Overview of lighting control methods



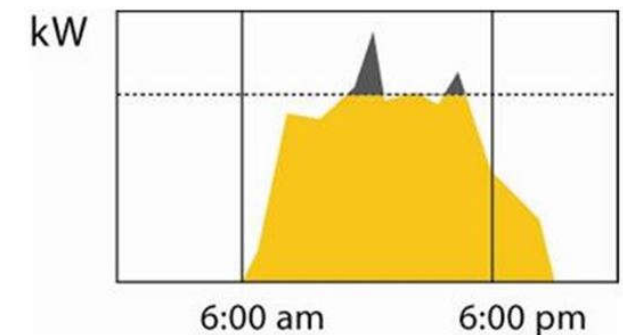
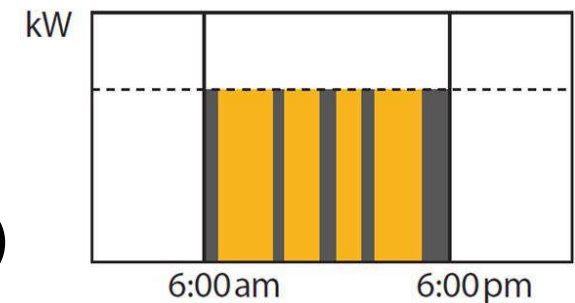
# Lighting controls



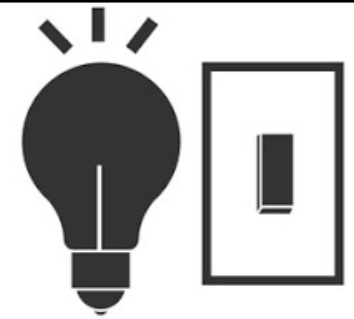
- Control strategies



- 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 ( $\downarrow$  demand costs)

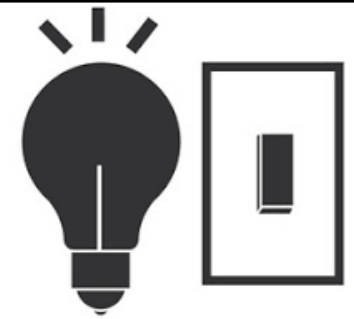


# Lighting controls



- 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

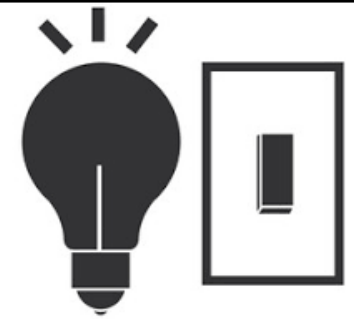
# Lighting controls



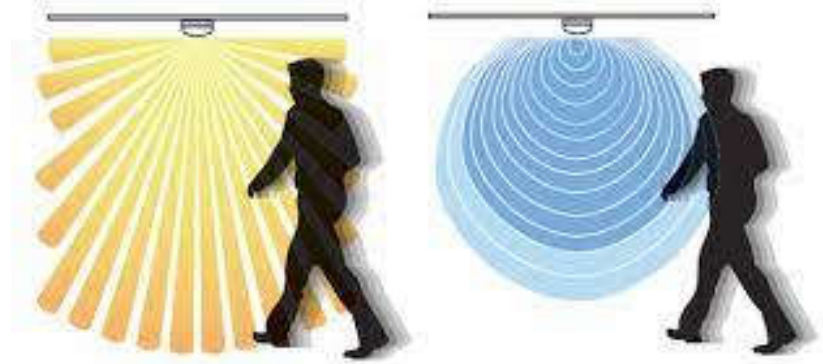
- Lighting control techniques & tools
  - Manual control (switches)
  - Timed control (timeclocks)
  - Presence detection
  - Absence detection
  - Photocells
  - Daylight linking
  - Constant illuminance adjustment
  - Dimming & regulation



# 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



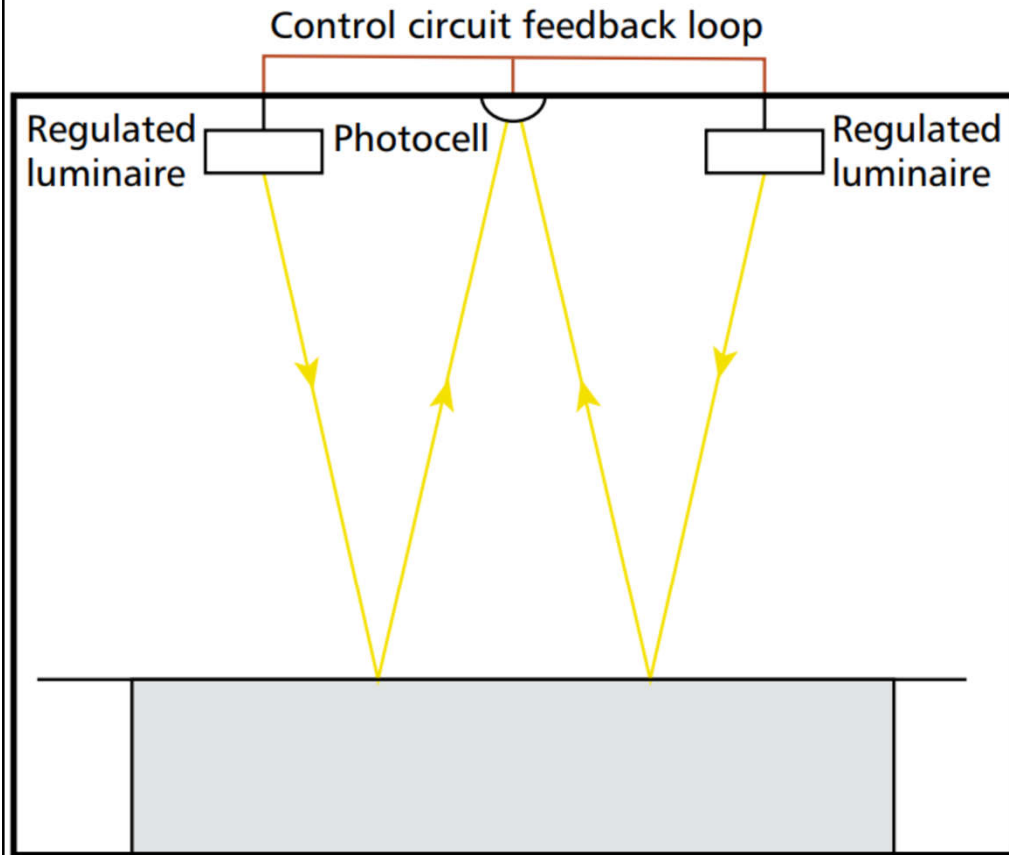
# Daylight linking of luminaires from left to right



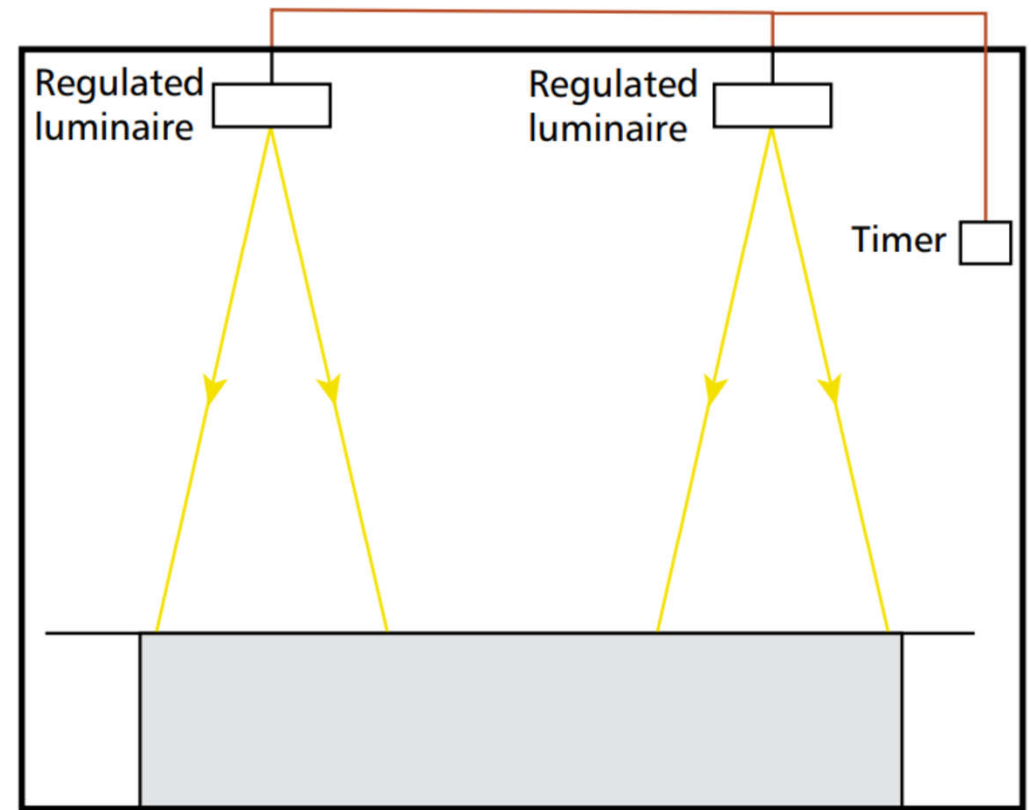
(Source: SLL, 2016. *Control of Electric Lighting*, Lighting Guide 14, Society of Light and Lighting (SLL), London.)



# Lighting control for constant illuminance adjustment

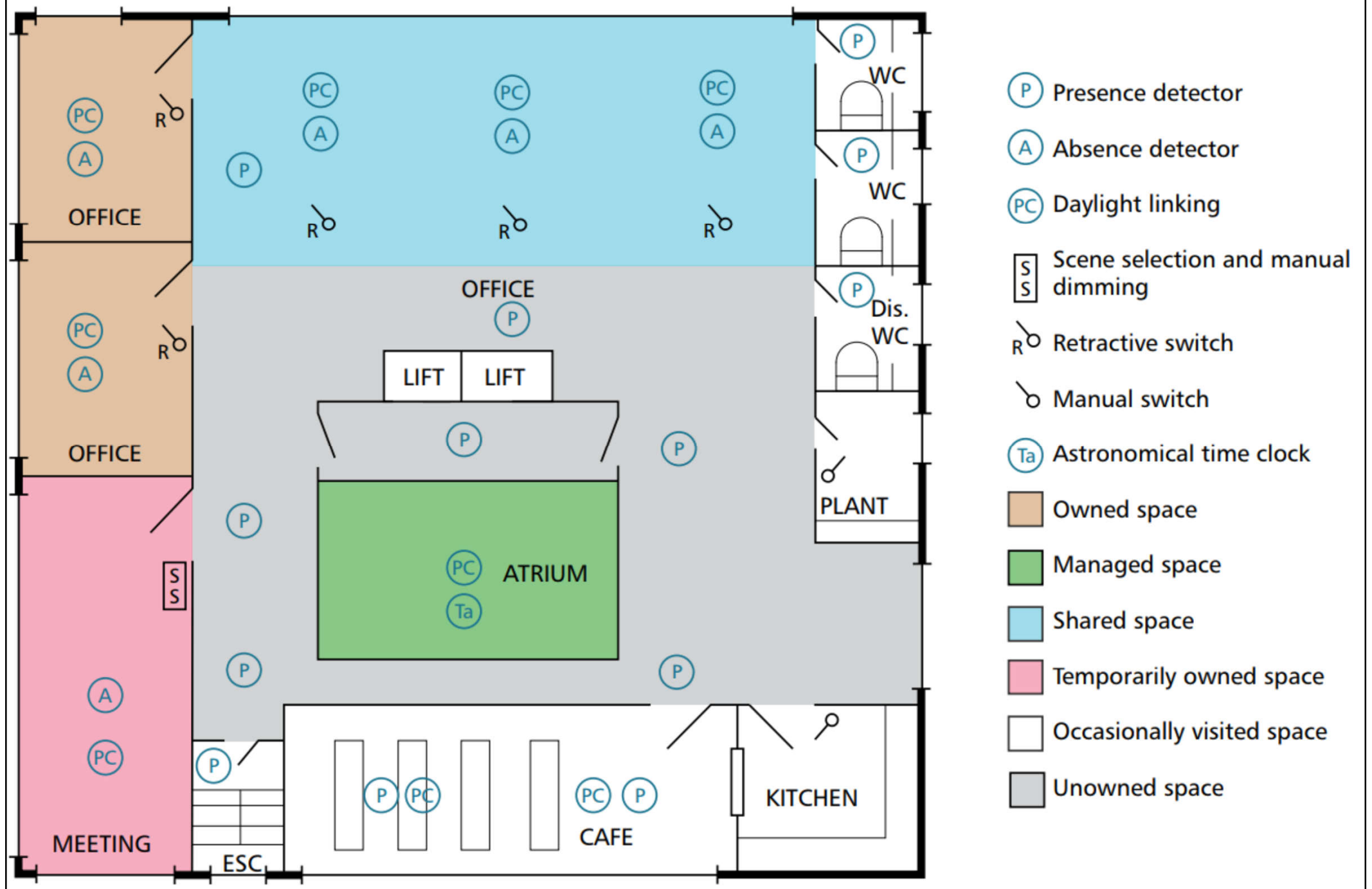


(a) A photocell is used to measure the reflected light from the working plane to adjust the light output to the required output



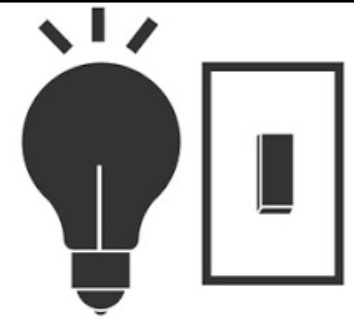
(b) a timer/data connection is used to regulate the luminaire output at a pre-set level based on 'hours run/maintenance offsets' feedback from the luminaires and manufacturer's data on lamp degradation

# Example of lighting control arrangement for a typical office area



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

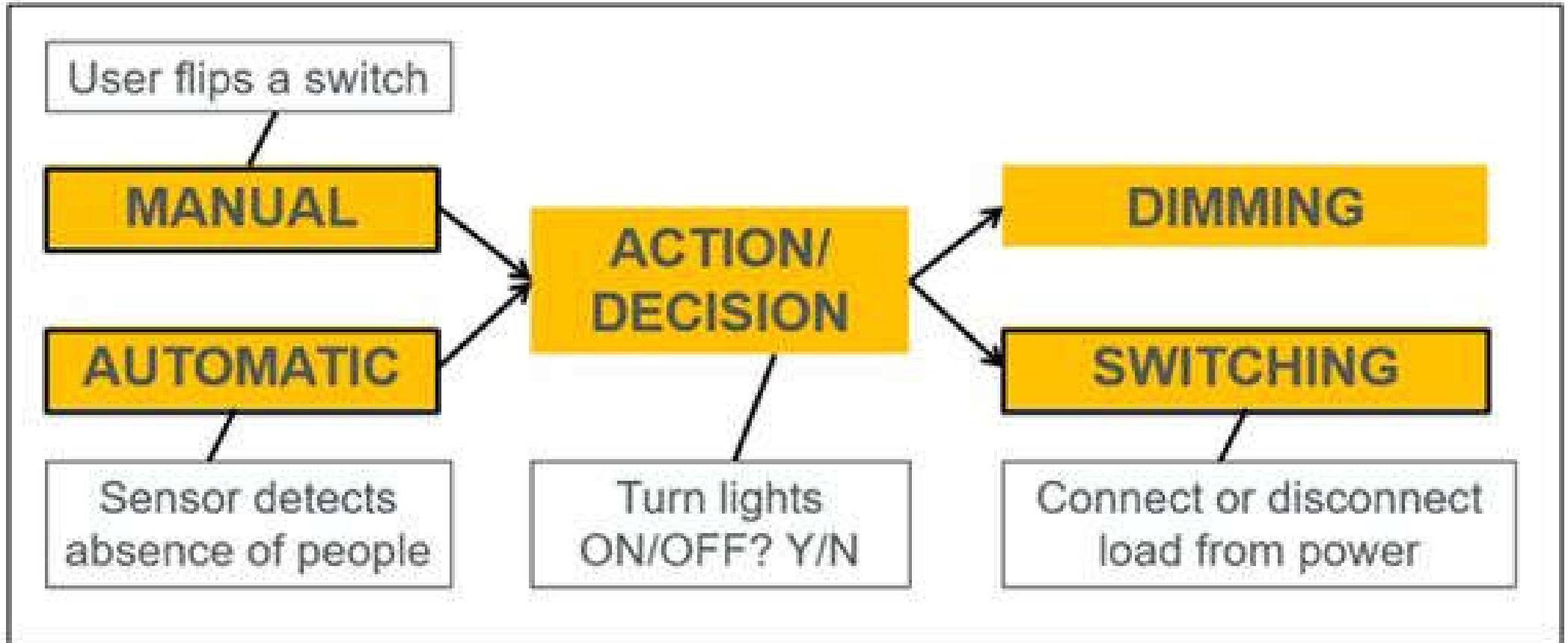
# Lighting controls



- 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

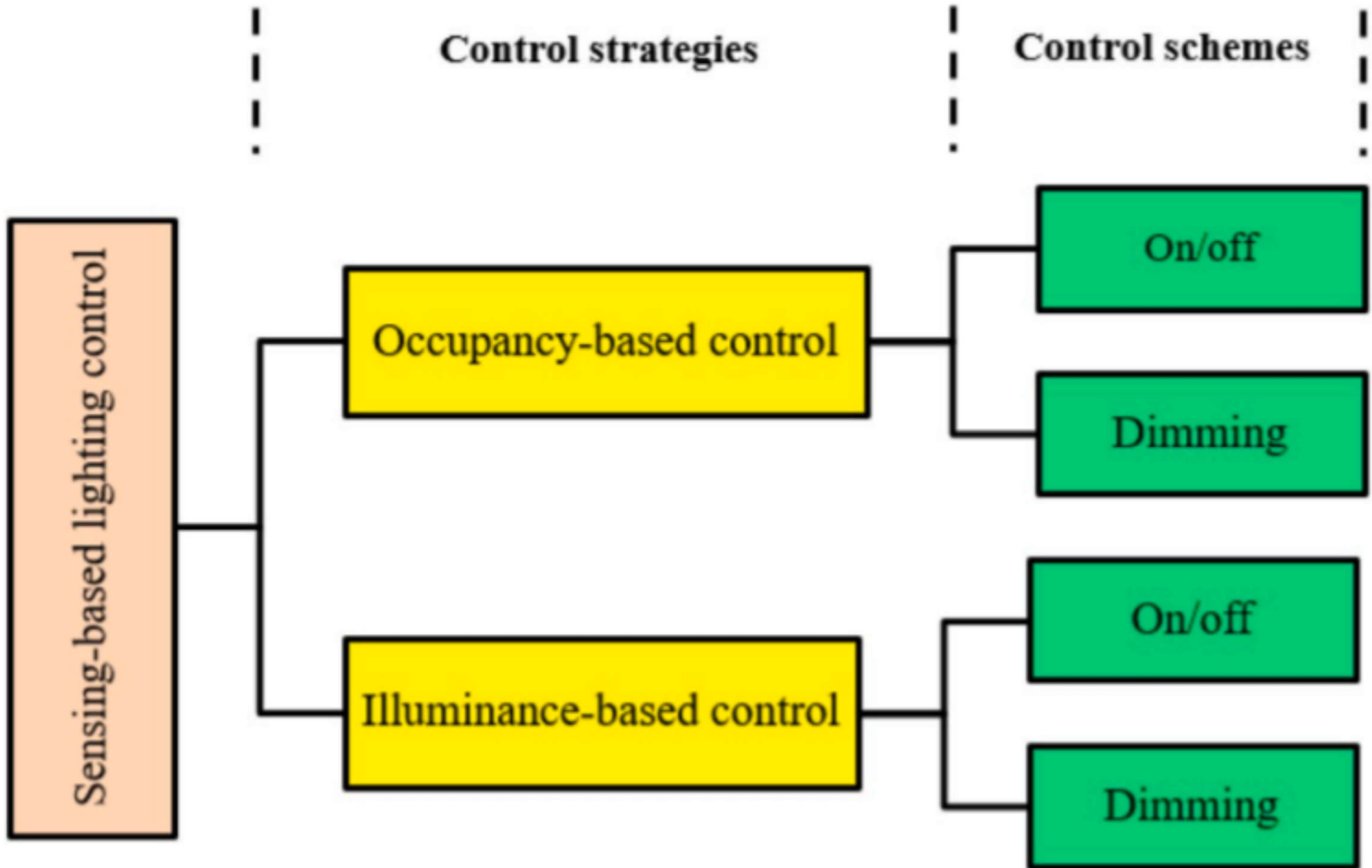


# Manual & automatic lighting control strategies (manual-ON wallbox occupancy sensor)

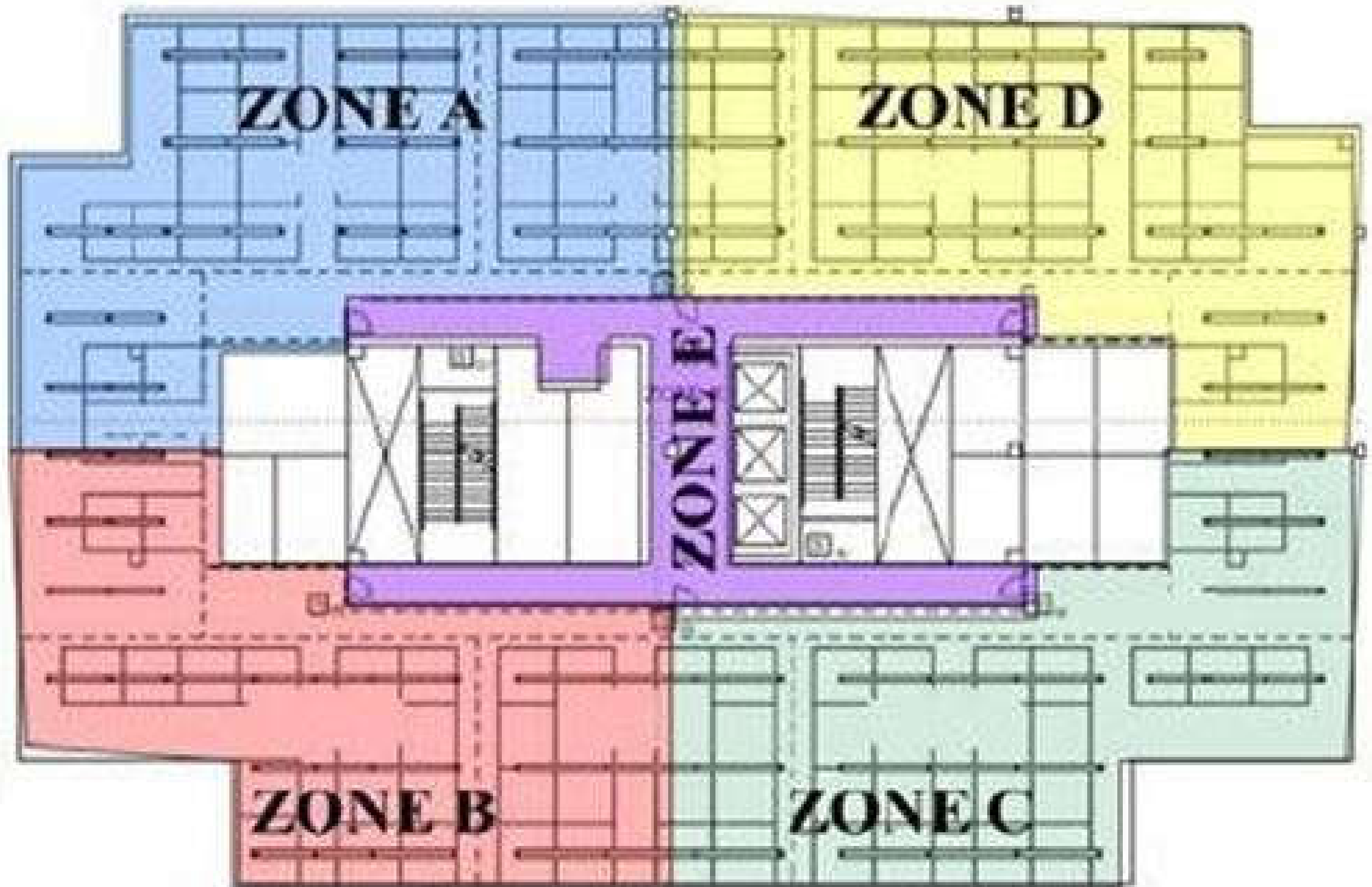


## MANUAL-ON OCCUPANCY (VACANCY) SENSOR

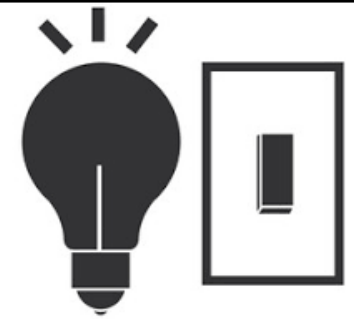
# Categories of control strategies and schemes of lighting systems



# An example of control zoning for lighting control system



# 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:

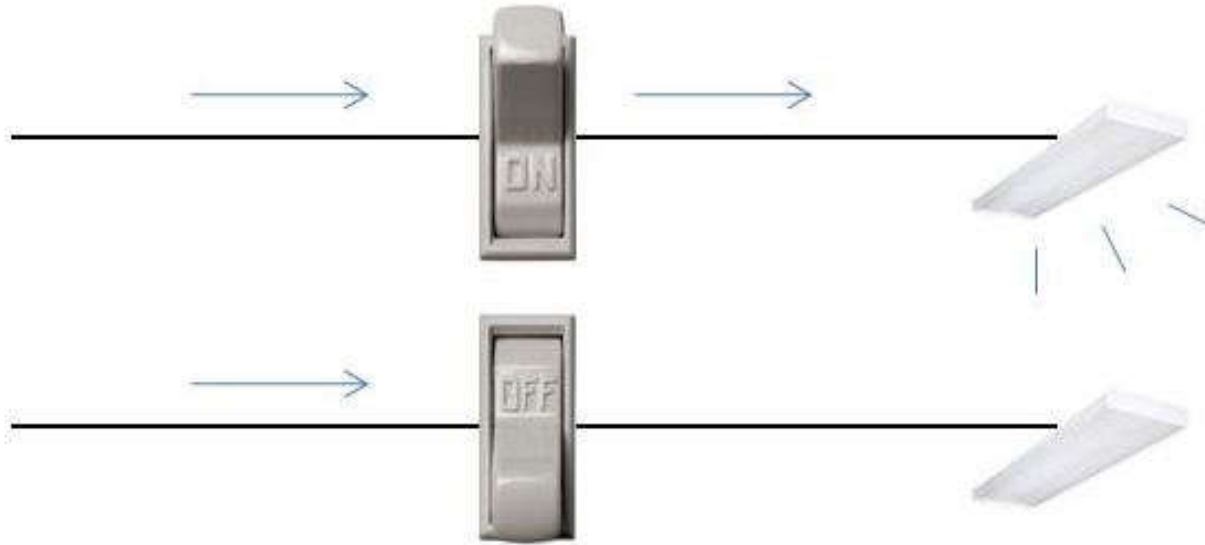
| WHAT                                 | HOW                                                        |
|--------------------------------------|------------------------------------------------------------|
| Produce the right amount of light... | Light output (intensity) dimming                           |
| ...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:

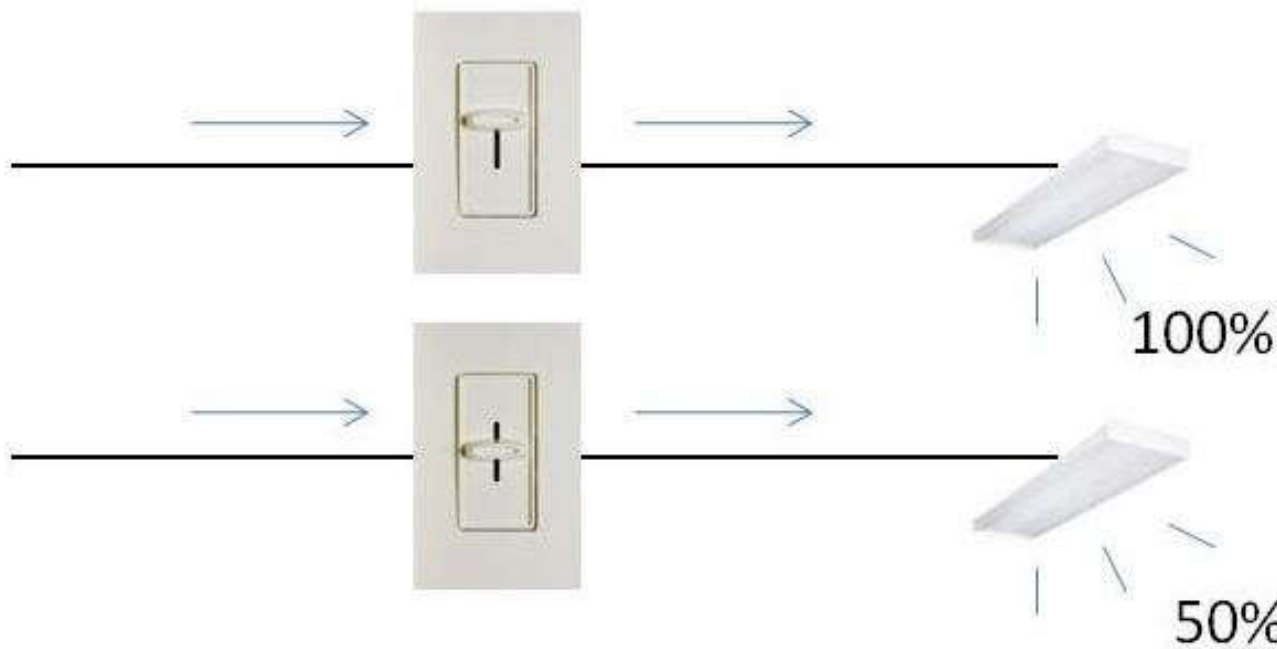
| WHAT                                                         | HOW                                                                                                           |
|--------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|
| 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                     |



# Switching & dimming lighting controls



(a) Switching (ON/OFF)



(b) Dimming

# Lighting control of correlated colour temperature (CCT)



5500K, Full on 100%

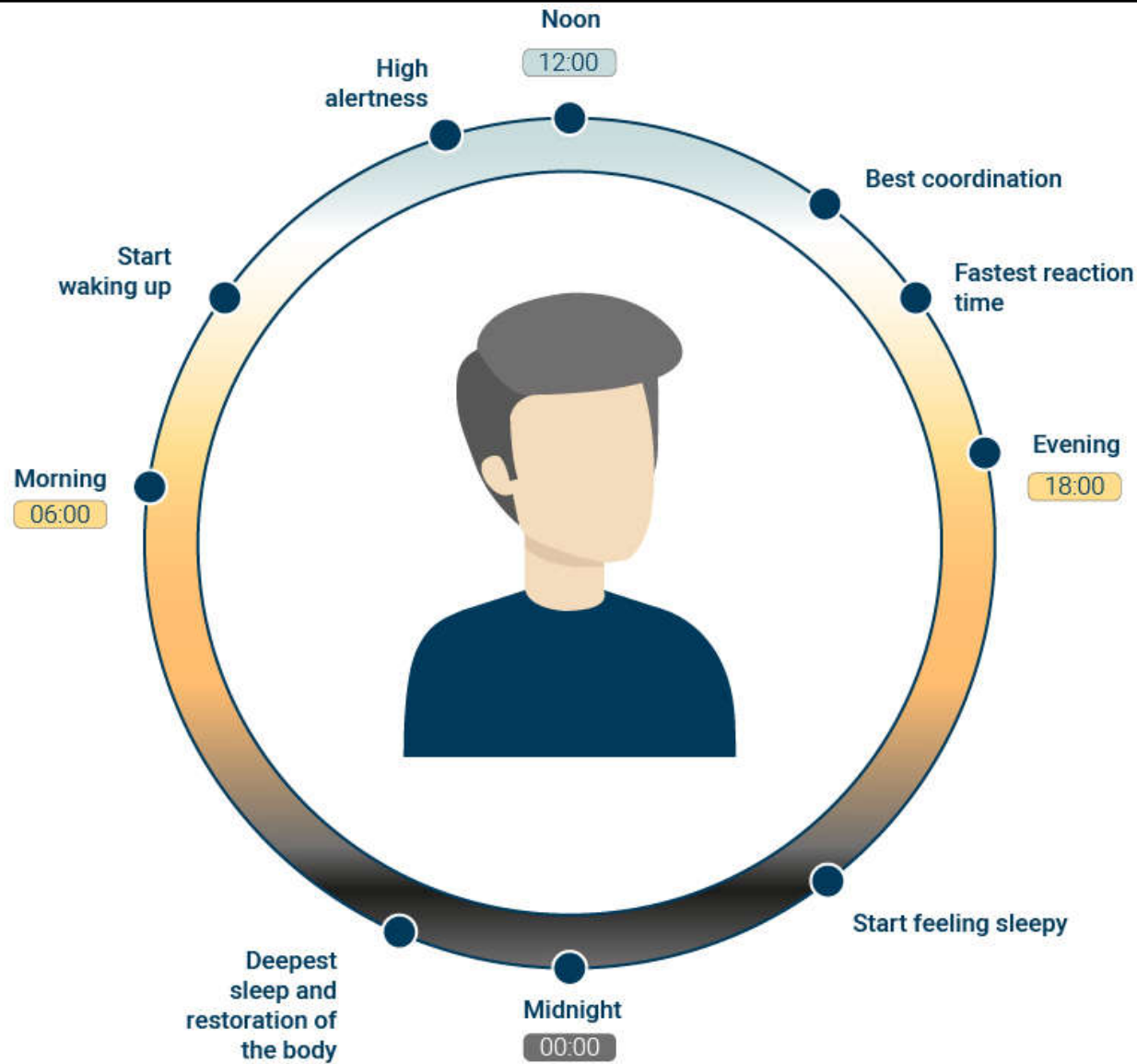


3800K, Dimmed to 75%



2400K, Dimmed to 50%

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



## Physiological and psychological benefits of human centric lighting (HCL)

**Morning**



Cool light.  
High intensity.

**Afternoon**



White light.  
High intensity.

**Evening**



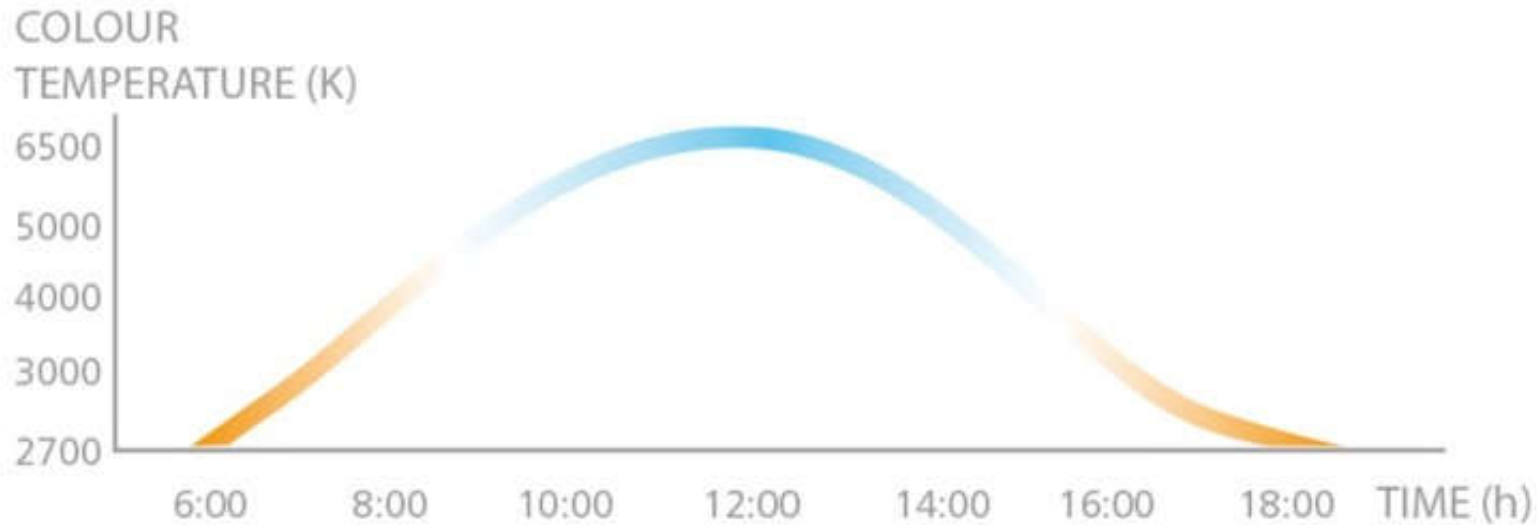
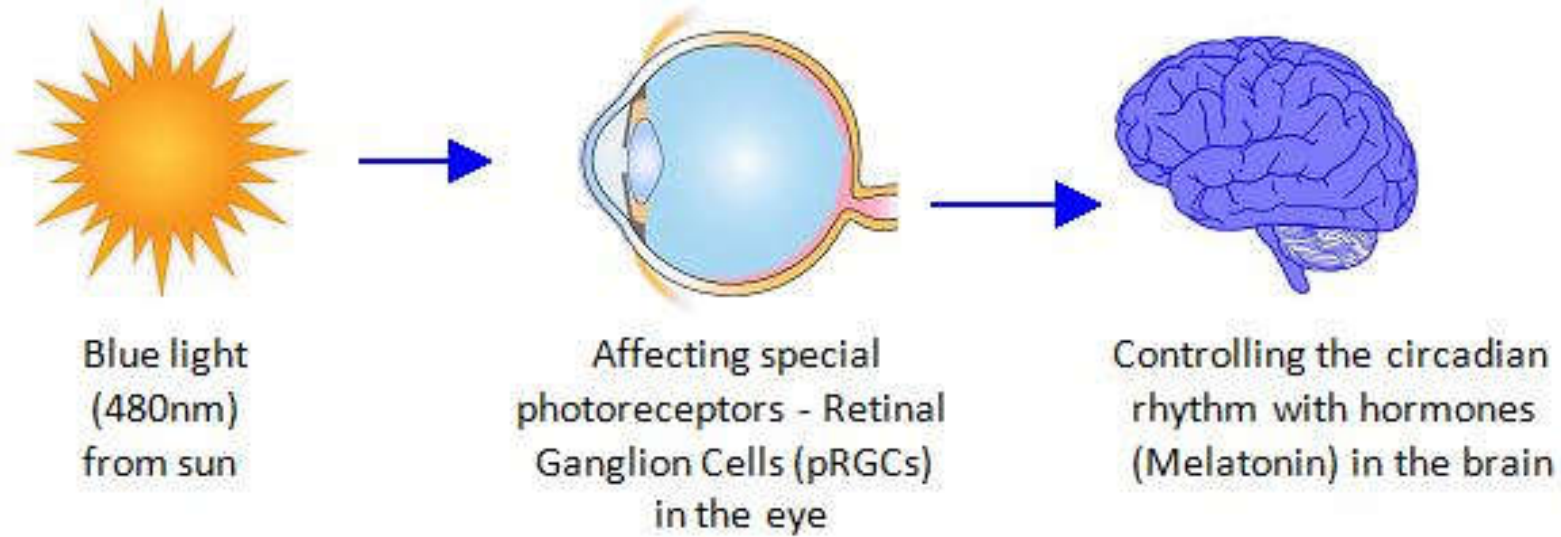
Warm light.  
Low intensity.

**Night**

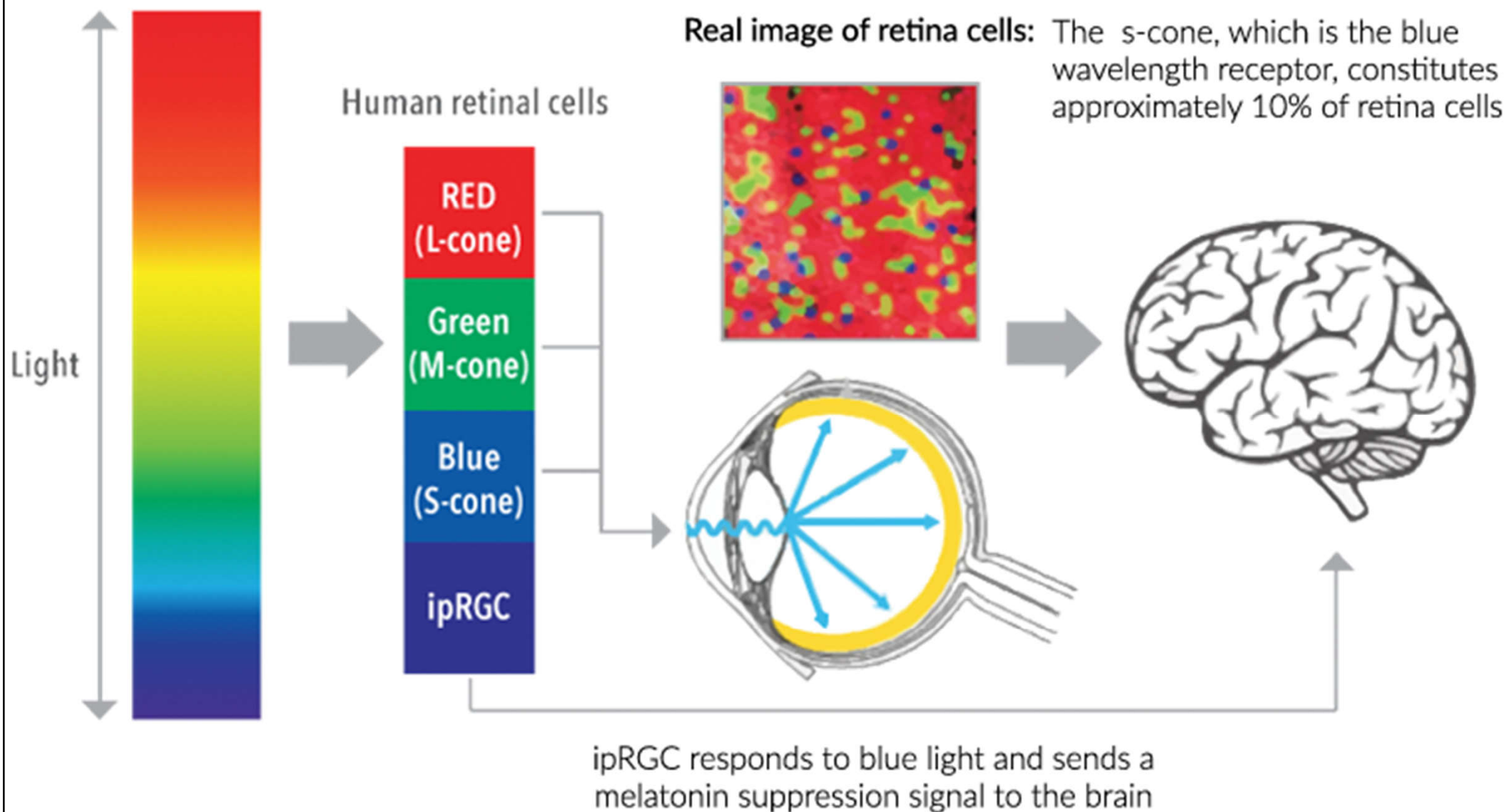


No light.

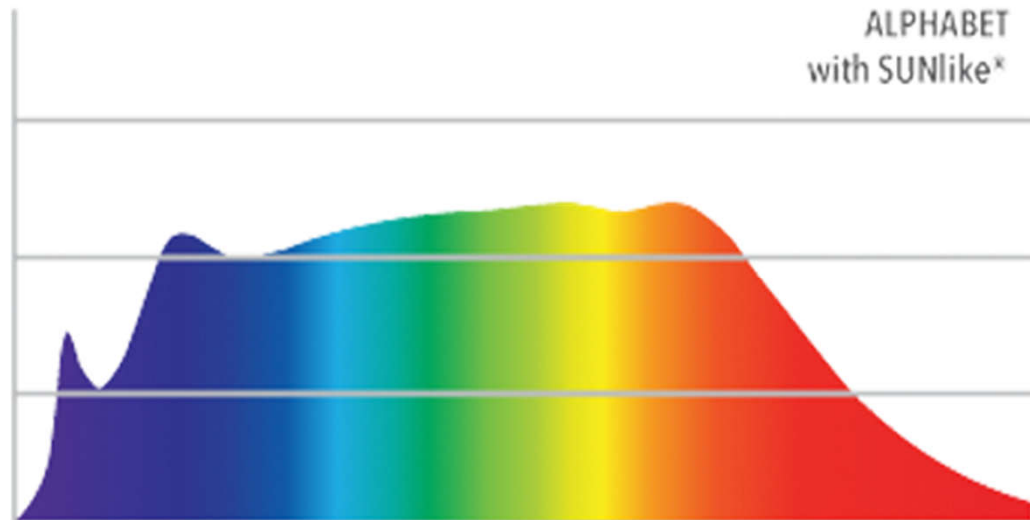
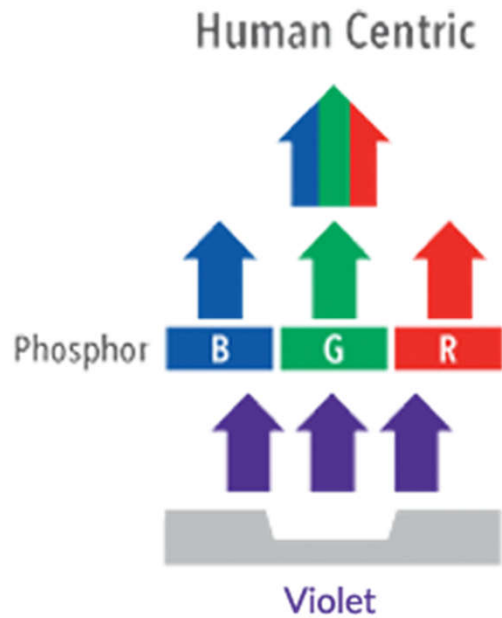
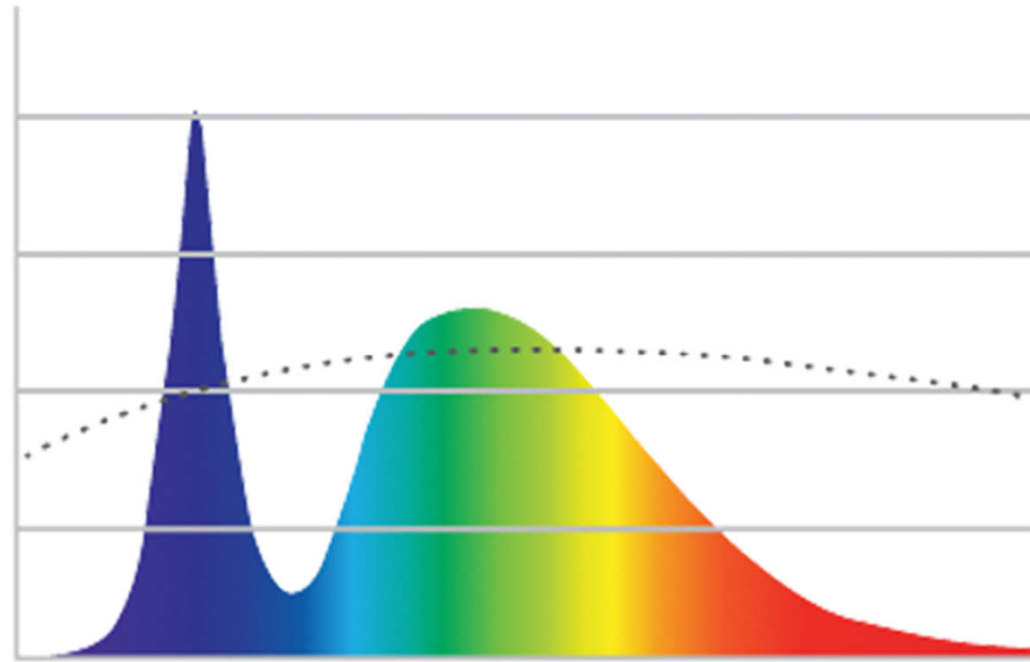
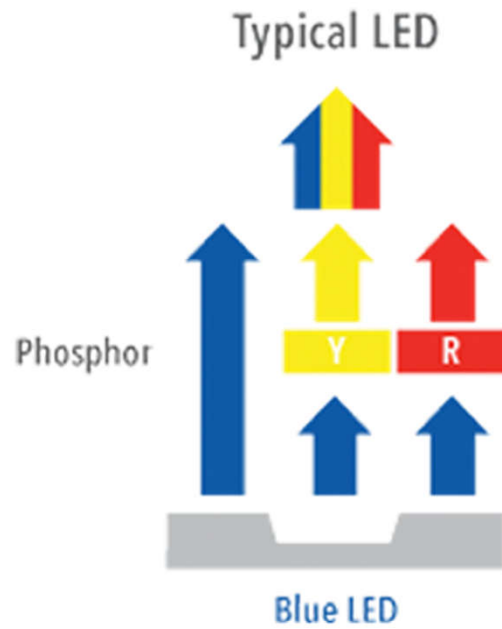
# Control of colour temperature for human centric lighting (HCL) & circadian cycles



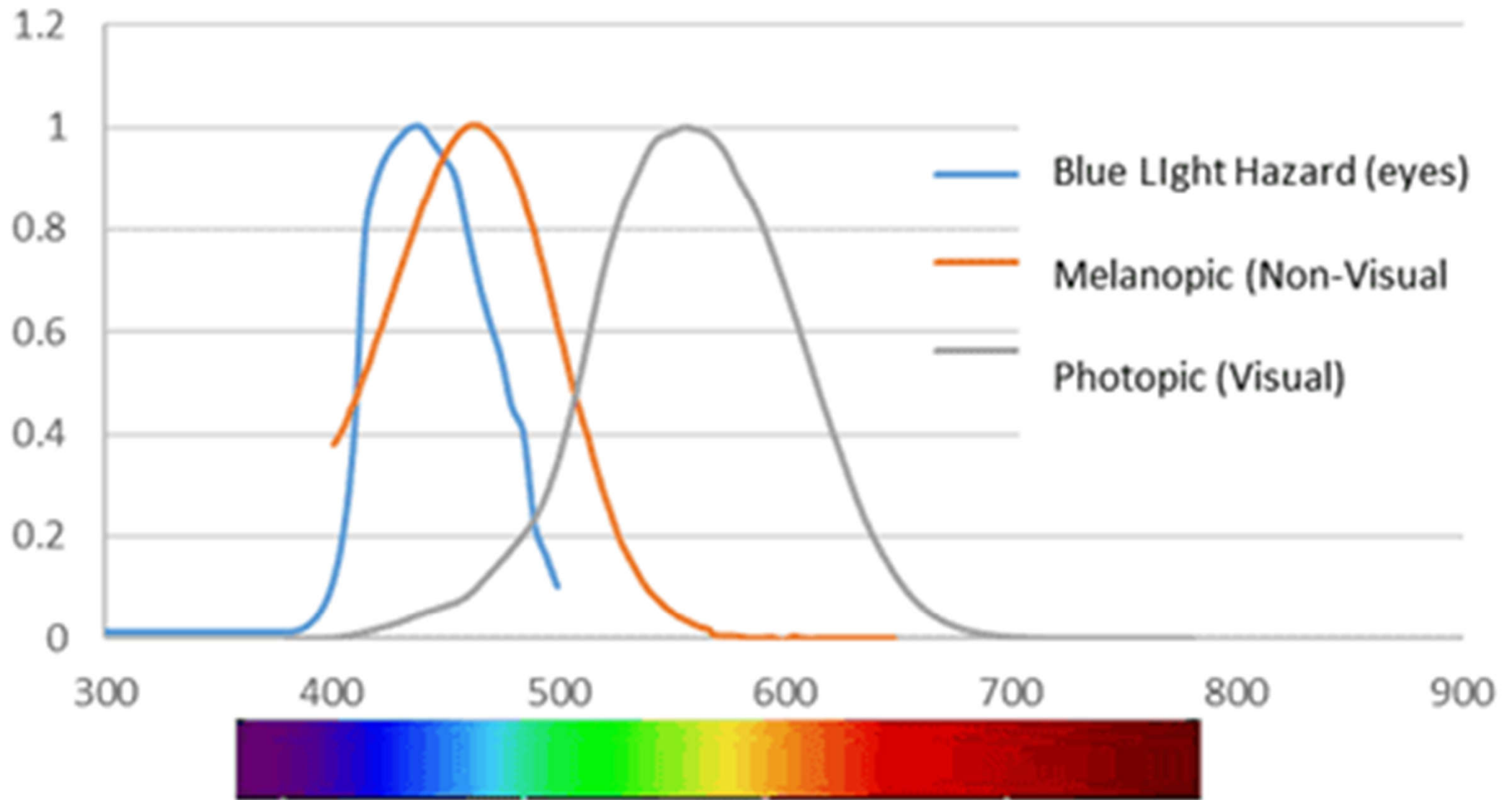
# Considerations of lighting colour for non-visual effects



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



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





# Further Reading

---

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