Introduction to Lighting Systems and Controls

Course No. ENRG 54

Outline

A. Introduction to fundamentals of lighting

- Lighting terminology
- Physics and principles of lighting
- Units of measurement
- Vision and colors
- Ambient, directional and task lighting
- Over- and under-illuminance

B. Lighting systems

- Components
- Types of lamps
- Ballasts
- Lamp comparison matrix
- Types of lighting luminaires and intensities
- Energy efficiency measures (EEMs)

C. Lighting controls

- Basic concepts of effectiveness of lighting control
- Types and appropriate applications of lighting controls
- Lighting control equations
- Energy efficiency measures (EEMs)

D. Additional EEMs

- De-lamping
- Scotopic lighting
- Task and ambient light levels
- Circadian rhythms

E. Lighting measurements

- Tools
- Data loggers and applications

F. Lighting calculations

- Equation and method of calculating lumens (zonal cavity formula)
- Equation and method of calculating energy savings
- Method of calculating skylight energy savings

G. Lighting standards, codes and regulations

- Underwriters' Laboratory (UL)
- Uniform Building Code (UBC)
- Americans with Disabilities Act (ADA)
- Title 24 applications

H. O&M measures to assure optimal performance

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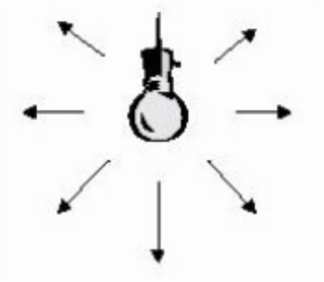
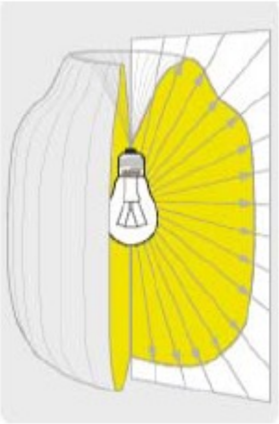
1. Lighting terminology
   - Luminous flux
   - Illuminance
   - Reflectance
   - Power
   - Efficacy
   - Lighting power density
   - Lamp life
   - Lumen depreciation
   - Correlated color temperature
   - Color rendering index (CRI)
   - Ballast factor

Luminous flux

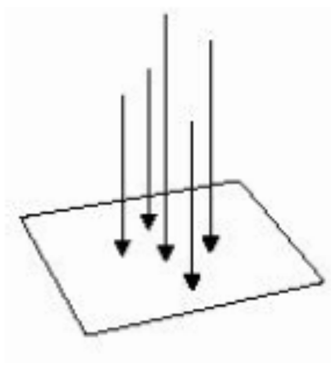
- Total amount of light emitted by a source in all directions
- Measured in lumens
- Used to rate the output of lamps

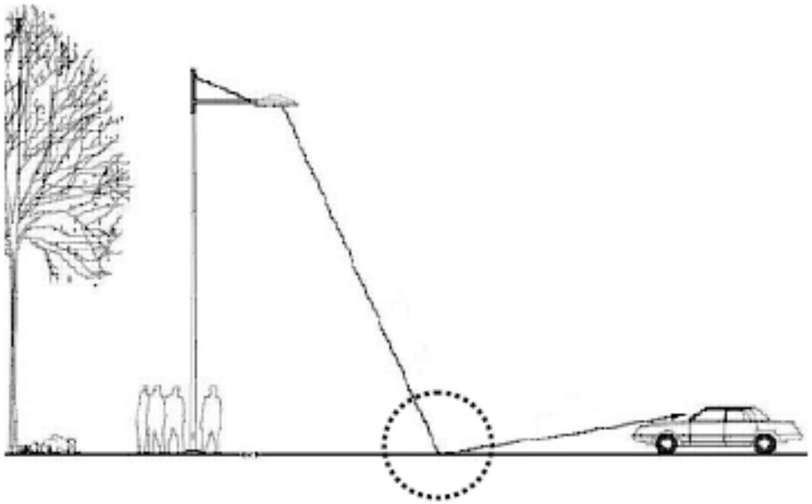




Illuminance

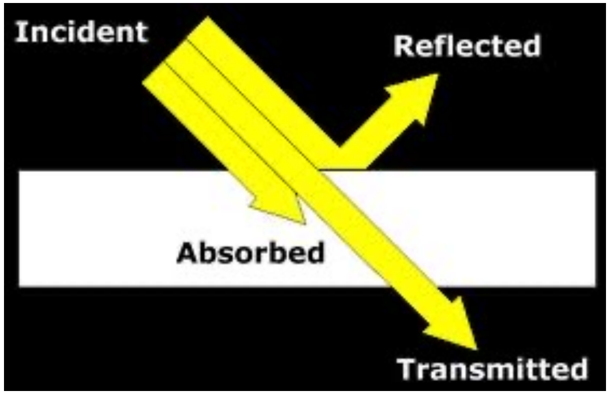
- The density of light (total luminous flux) falling on a surface
- Requires an area unit
- Measured in lumens per ft^2 (*footcandles* or fcd)
- Also measured in SI: lux (lumens per meter2)

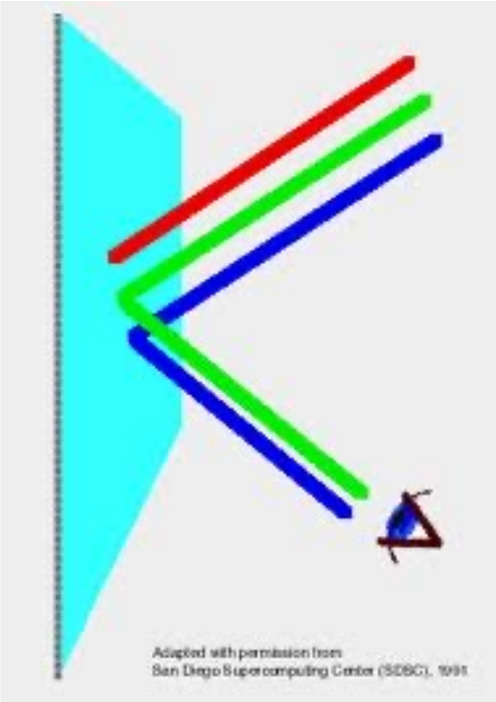




Reflectance

- the fraction of incident light that is reflected at an interface





Power

- The rate at which energy is transferred, used, or transformed.
- Measured in joule per second (J/s), known as the watt.
- The rate at which a light bulb transforms electrical energy

into heat and light is measured in watts.

$$P = I \cdot V$$

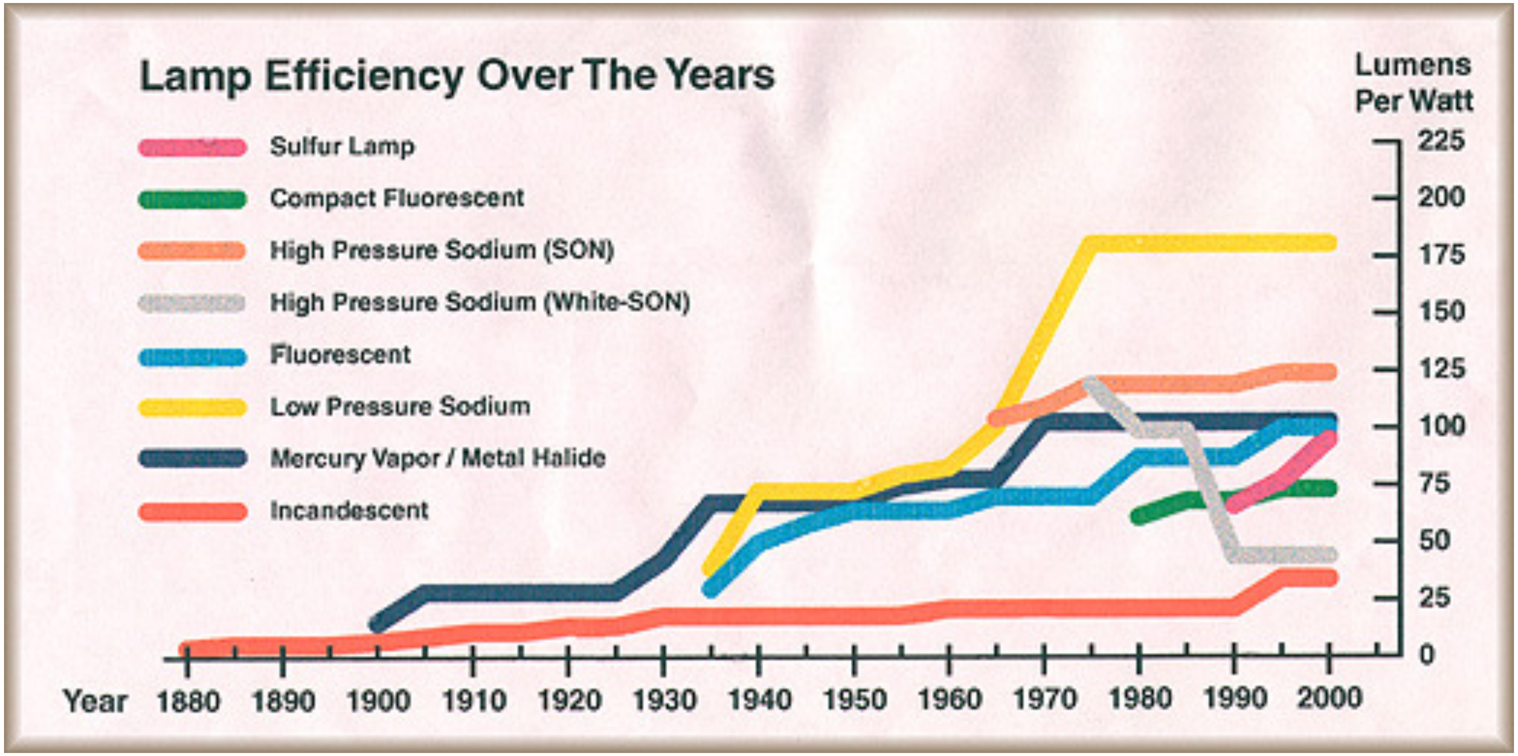
P : the power (watts)
V : the voltage drop (volts)
I : the current through (amperes)

Efficacy

- A measure of lamp (and ballast) performance, or called the efficiency of light bulbs:
- unit lumens/watt
- A measure of how well a light source produces visible light
- Varies by lamp (and ballast) type

$$\frac{\text{Light output}}{\text{Power input}}$$

Efficacy



http://americanhistory.si.edu/lighting/tech/chart.htm

Lighting power density (LPD)

- A measure of the power intensity of lighting systems
- $\dfrac{\text{lighting power}}{\text{the area of a room}}$
- Measured in watts/sf^2
- Energy code provides limits by space use or building type

Exercise: a 34 ft X 50 ft classroom installed 20 lighting fixtures, each with 85 input watts. Calculate LPD in this room.

Lighting power density (LPD)

Exercise: a 34 ft X 50 ft classroom installed 20 lighting fixtures, each with 85 input watts. Calculate LPD in this room.

Answer:

$$\frac{\text{lighting power}}{\text{the area of a room}} = \frac{85 \text{ X } 20}{34 \text{ X } 50} = \frac{1700}{1700} = 1 \text{ watt/sf}^2$$

Lamp life

- Total operating time that ½ of test set remains burning
- Tested under consistent temperatures and time/start

  - 77°F

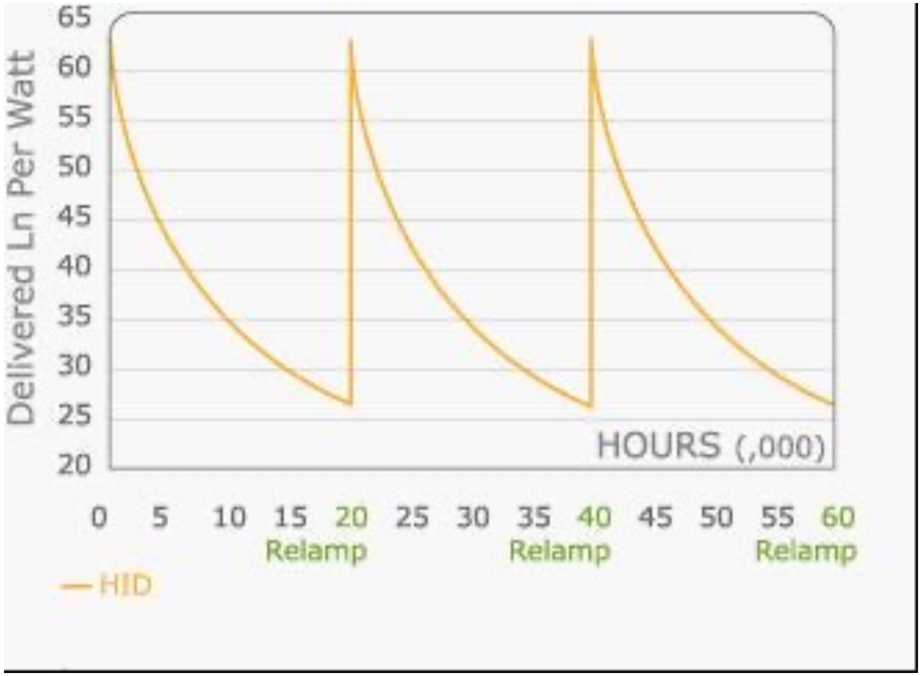
  - 3 hrs/start for fluorescents

  - 10 hrs/start for HID sources

  - 12 hrs/start data available from some manufacturers
- Measured in hours

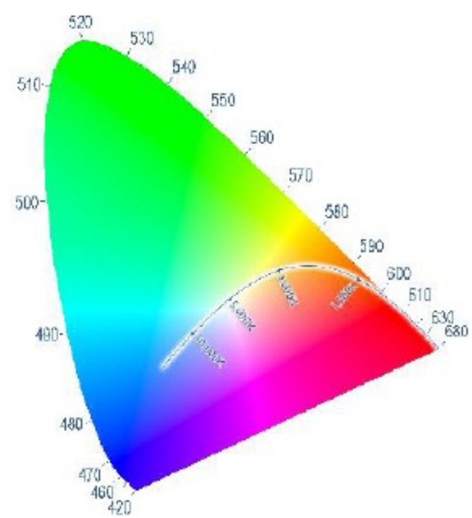
Lamp Lumen depreciation (LLD)

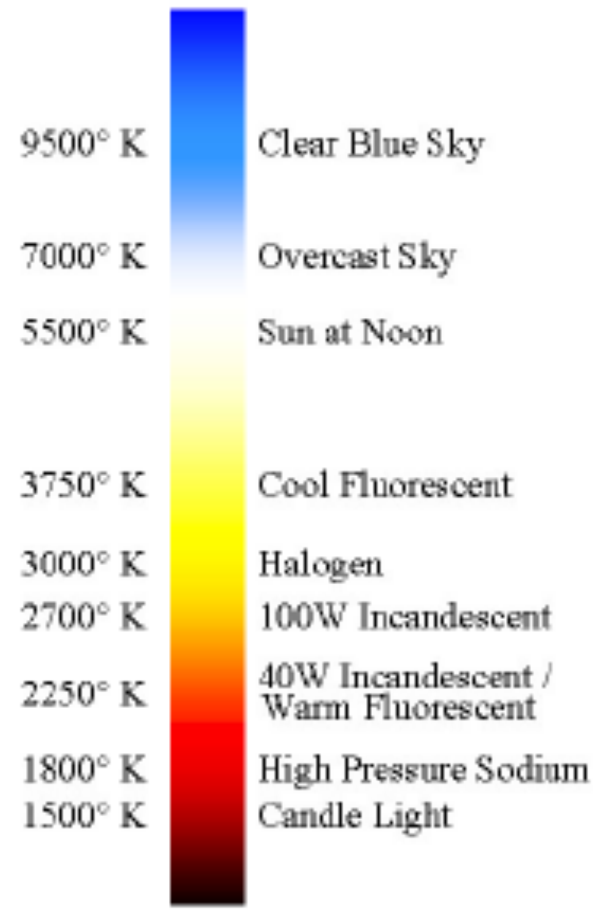
- Given as a percentage of initial lumens
- Describes the decrease in output of a lamp during its operable life
- Factors include lamp aging and dirt accumulation



Correlated color temperature (CCT)

- Used to describe the color appearance of white light source
- Measurement of coolness or warmness of a light source
- Unit in degrees Kelvin (° K)





Color rendering index (CRI)

- A measure of how well a light source renders colors when compared to a reference source of the same CCT
- reference source depends on CCT
- 0-100 point scale
- reference website: http://en.wikipedia.org/wiki/Color_rendering_index

80 – 100 CRI

60 - 75 CRI

0 - 20 CRI

Ballast factor

- Lamp lumen ratings are determined under controlled test conditions on a reference ballast with a default ballast factor of 1.0
- used to describe ballast that under- or over-drives lamps

Energy Star Key Efficiency Criteria:

Characteristics	Minimum Requirement
Light Output	Non-directional luminaires : ≥ 800 lumens, or ≥ 450 lumens for fixtures with three sources or mores. Directional fixtures: ≥ 125 lumens/foot for undercabinet, 200 lumens/foot for cove mount, 345 or 575 for downlights, 200 lumens/head for accent lights, 300 lumens for outdoor post-mounted luminaires.
Source Efficacy (non-directional luminaires)	≥ 65 lm/W; ≥ 70 lm/W after September 2013
Luminaire Efficacy (directional luminaires)	Dependent on fixture type/application starting at ≥ 29 lm/W
Power Factor	Residential: ≥ 0.5; Commercial: ≥ 0.9; Solid state residential with input power; greater than 5 watts: ≥ 0.7
Correlated Color Temp.	Lamps shipped with luminaires shall have one of the following nominal correlated color temperatures (CCT): 2700K, 3000K, 3500K, 4000/4100K, 5000K (commercial only)
Color Rendering Index	Ra>=80
Light Source Life	Fluorescent and HID: ≥ 10,000 hours; Halogen incandescent: ≥ 2,500 hours; Solid state (LED): ≥ 25,000 residential or ≥ 35,000 commercial

Useful resource:

Energy star product list:
http://downloads.energystar.gov/bi/qplist/Light%20Fixtures%20Product%20List.pdf?b207-e461

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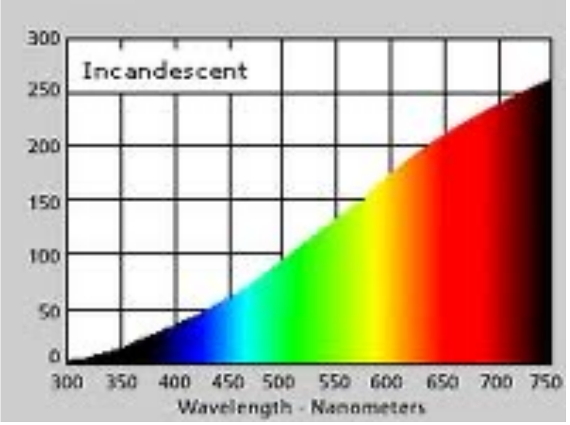
2. Physics and principles of lighting

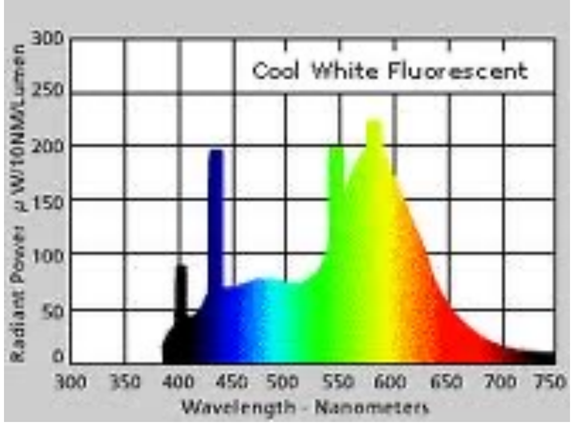
Spectral power distribution

Inverse square law

Spectral power distribution

- Describes the power per unit area per unit wavelength of an illumination
- Can be measured by a spectrophotometer

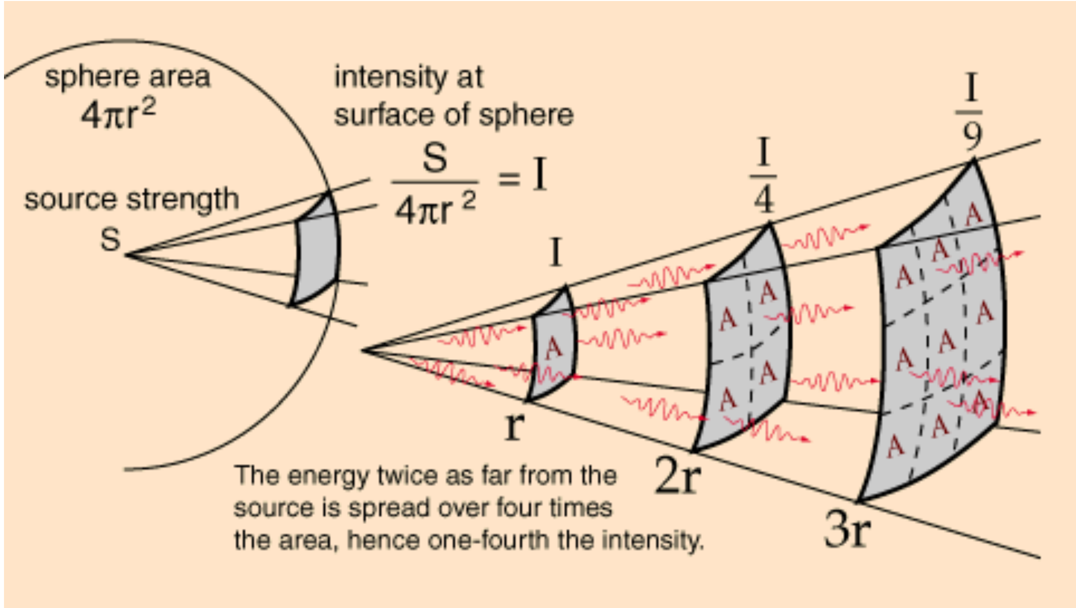




Inverse square law

- Light intensity is inversely proportional to the square of the distance from the source.

$$Intensity \propto \frac{1}{distance^2}$$



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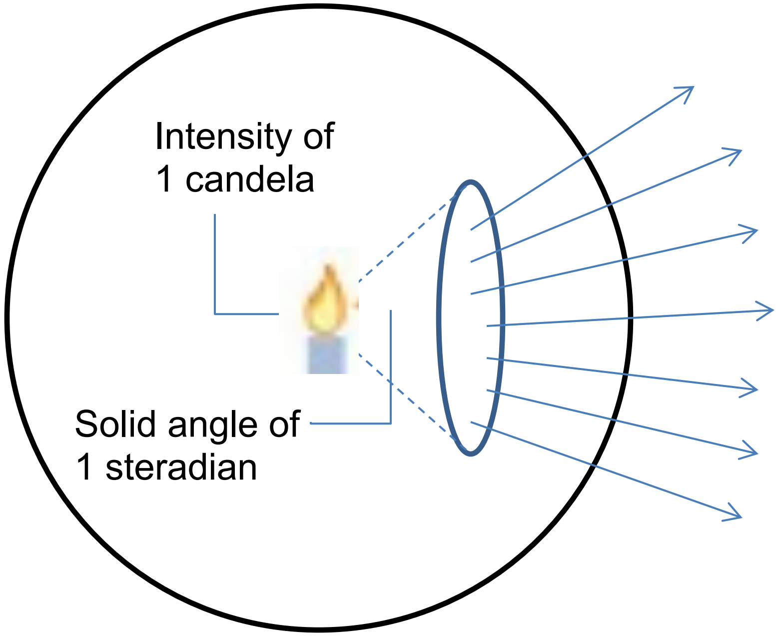
3. Units of measurement
    a. Lumen
    b. Foot-candle
    c. Power (wattage)
    d. kWh

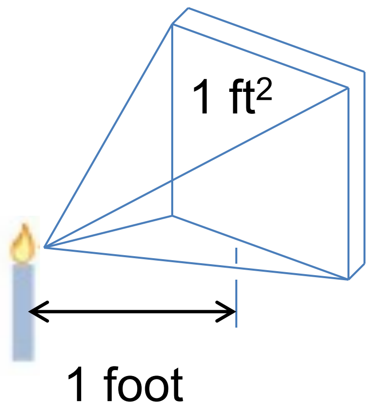
Lumen (symbol: lm)

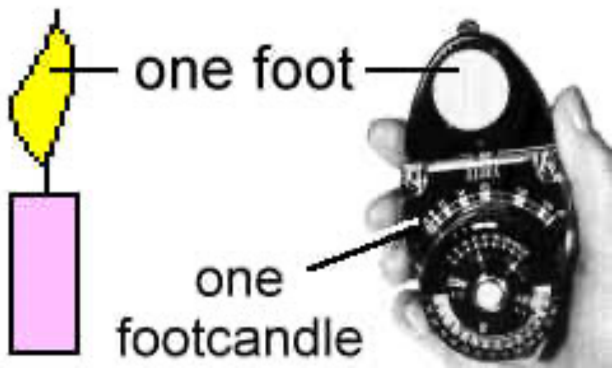
- SI unit of luminous flux
- total light output from a light source
- 1 lm = 1 cd· sr



Footcandle (fc)

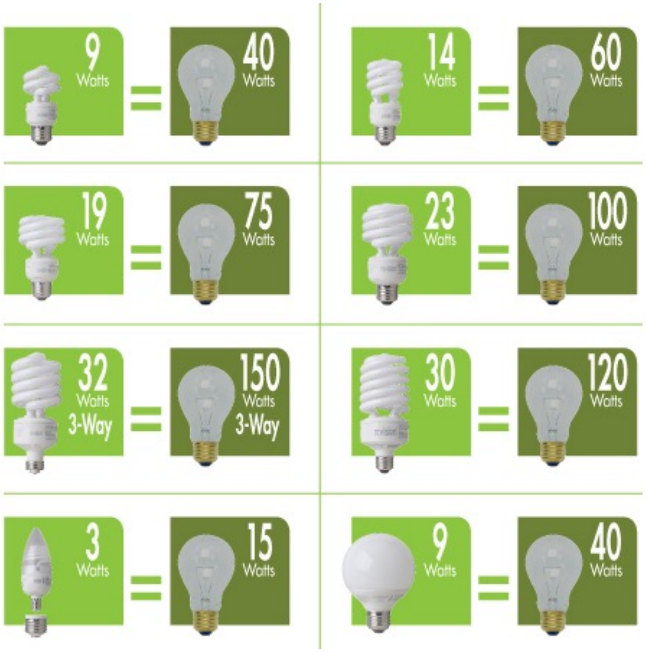
- Density of light incident on a surface
- Surface can be real or imaginary
- US Unit is *footcandle (fc)*– Lumen per square foot
- SI Unit is *lux (lx)* – Lumen per square meter





Power (wattage)

- The rate at which a light source transforms electrical energy into heat
- Measured in watts



http://www.nvisioncfl.com/watt-equivalent.aspx

Kilowatt hour (kWh)

- A unit of energy
- one kilowatt (1 kW) of power expended for 1 hr of time
- *kWh = Watts * Time (hrs)* / 1000

Exercise:
A parking lot has 10 street lamps which are turned on 12 hours per day everyday. Each streetlamp uses 250 W HPS. Calculate the current annual total kWh. Calculate the energy saving if each lamp was changed to a 53 W LED.

Kilowatt hour (kWh)

Exercise:
A parking lot has 10 street lamps which are turned on 12 hours per day everyday. Each streetlamp uses 250 W HPS. Calculate the current annual total kWh. Calculate the energy saving if each lamp was changed to a 53 W LED.

Answer:

1. kWh of 1 HPS per day = 250 W * 12 hr / 1000 = 3 kWh
   kWh of 10 HPS per year = 3 kWh * 10 * 365 = 10960 kWh

2. kWh of 1 LED per day = 53 W * 12 hr / 1000 = 0.636 kWh
   kWh of 10 LED per year = 0.636 kWh * 10 * 365 = 2321.4 kWh
   energy saving = 10960 – 2321.4 = 8628.6 kWh

Or energy saving = watts saved per lamp * 12 hr * 10 * 365/1000
= (250-53) *12 * 10 * 365/1000 = 8628.6 kWh

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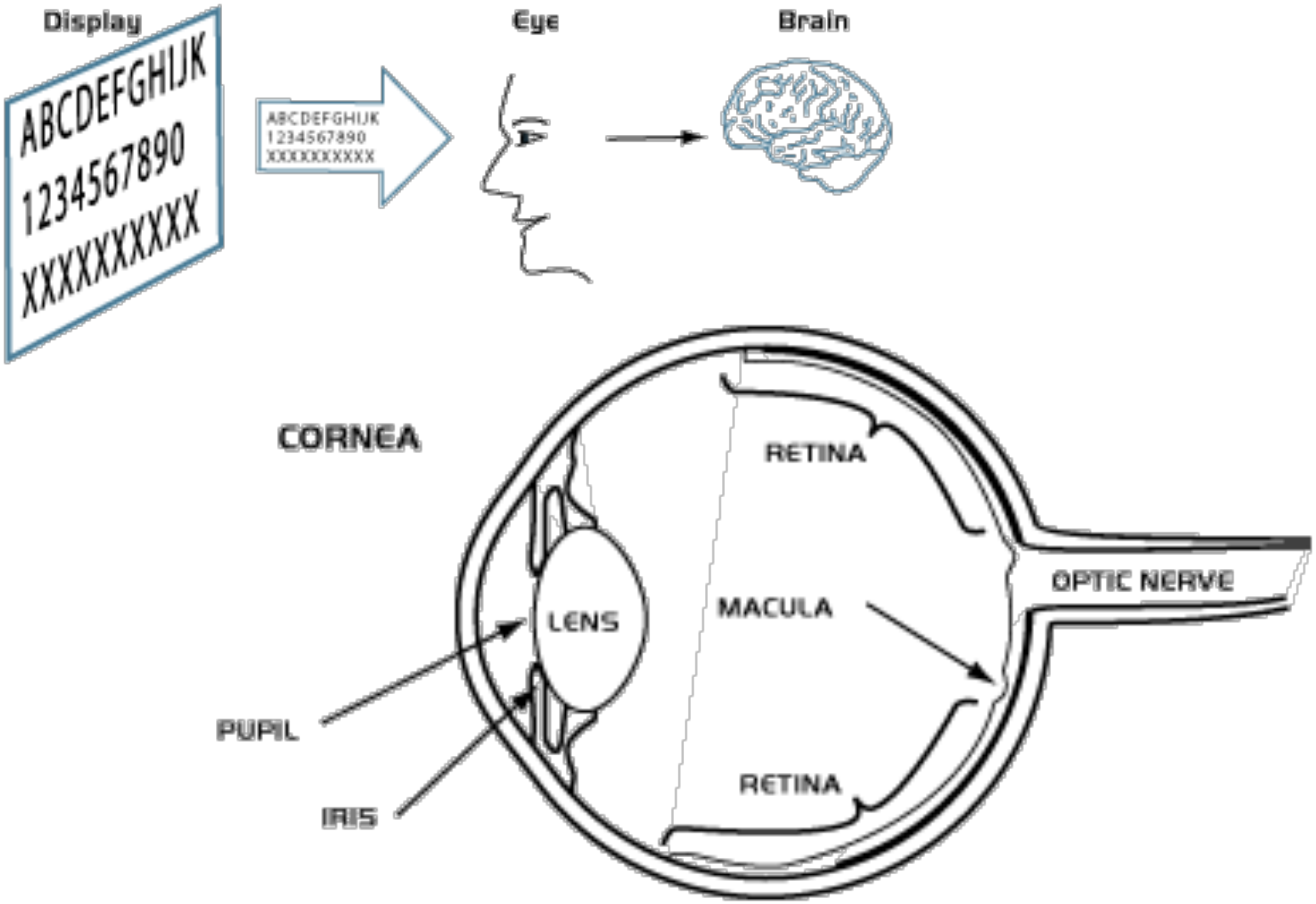
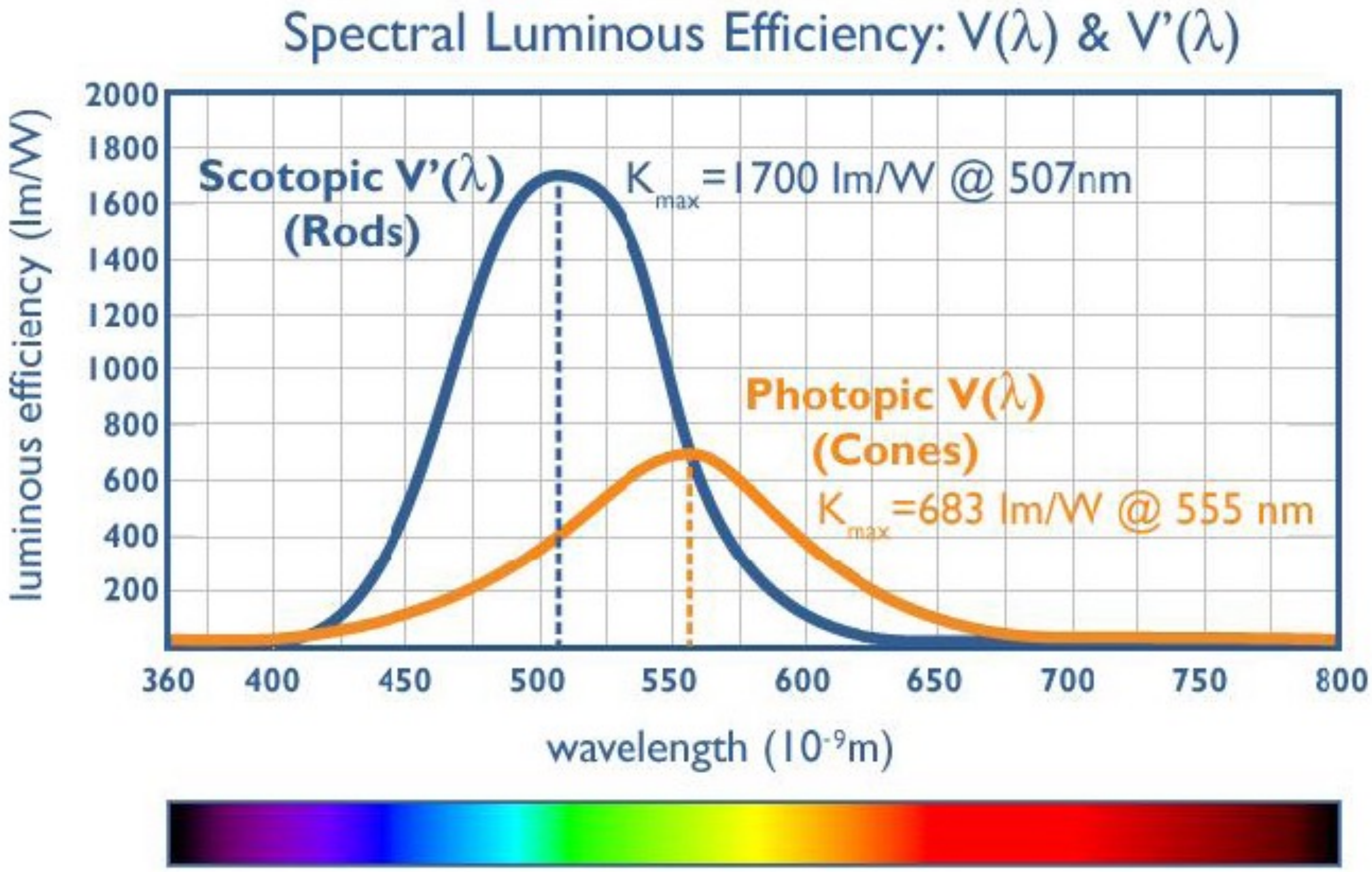
Structure of eye



Spectral Luminous Efficiency

Luminous Efficiency



Structure of eye

- “Seeing” is the perception of light that reaches the photoreceptors in retina.

- Two sets of photoreceptors:
  - rods, active at low light levels
    100 million per eye
    sensitive to motion

  - cones, active at high light levels
    8 million per eye
    3 types provide color vision:
    short, middle, long

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Scotopic/Photopic Spectrally enhanced

“ The theory behind spectrally enhanced lighting is that, for the same amount of light output (measured with a standard luminance meter), lamps with a higher correlated color temperature (CCT) will appear brighter than those with lower CCT. Thus, energy can be saved because the actual light output of the higher CCT lamps can be decreased, while maintaining perceived brightness and visual acuity relative to lower CCT lamps.”

From “ Spectrally Enhanced Lighting Program Implementation for Energy Savings: Field Evaluation”, prepared by Pacific Northwest National Laboratory, funded by DOE

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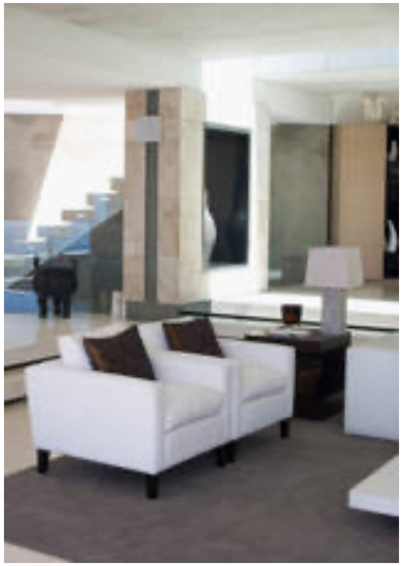
Ambient lighting

- sources of light already available naturally
- illumination generally comes from all directions that has no visible source
- contrast to directional lighting



Directional lighting

- Lighting travels in a specific direction
- Provides illumination on a work plane or an object.

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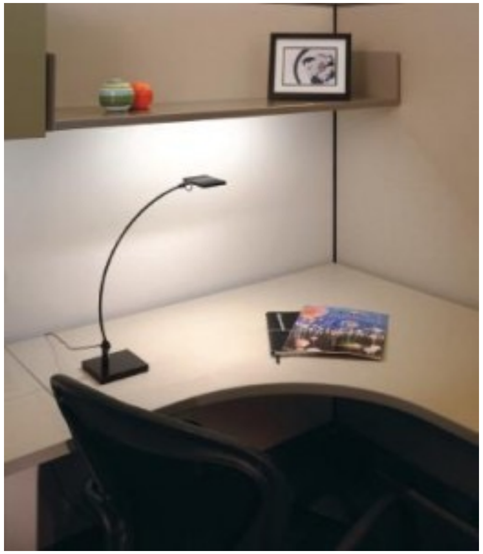
Task lighting

- Often refers to office lighting
- Used to increase illuminance on the reading or working area



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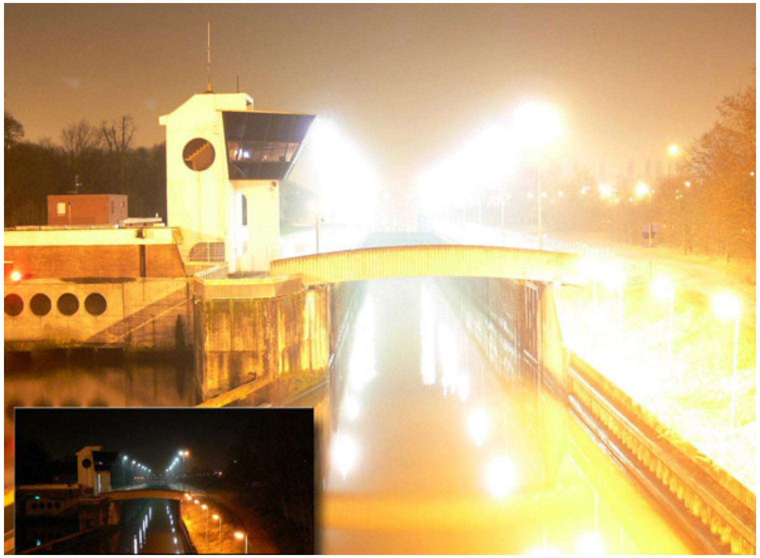
Over-illuminance

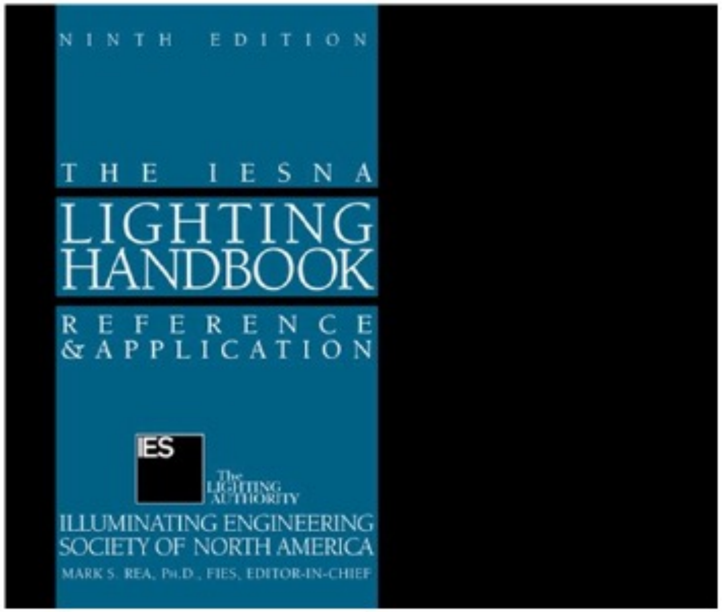
- Light intensity beyond what is required for a specified activity
- Glare is an indication of over-illumination
- Is a significant waste of energy



Under-illuminance

- Light intensity too low to get job done efficiently

Lighting design guide



Orientation and simple visual tasks. Visual performance is largely unimportant. These tasks are found in public spaces where reading and visual inspection are only occasionally performed. Higher levels are recommended for tasks where visual performance is occasionally important.

A	Public spaces	30 lx (3 fc)
B	Simple orientation for short visits	50 lx (5 fc)
C	Working spaces where simple visual tasks are performed	100 lx (10 fc)

Common visual tasks. Visual performance is important. These tasks are found in commercial, industrial and residential applications. Recommended illuminance levels differ because of the characteristics of the visual task being illuminated. Higher levels are recommended for visual tasks with critical elements of low contrast or small size.

D	Performance of visual tasks of high contrast and large size	300 lx (30 fc)
E	Performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size	500 lx (50 fc)
F	Performance of visual tasks of low contrast and small size	1000 lx (100 fc)

Special visual tasks. Visual performance is of critical importance. These tasks are very specialized, including those with very small or very low contrast critical elements. Recommended illuminance levels should be achieved with supplementary task lighting. Higher recommended levels are often achieved by moving the light source closer to the task.

G	Performance of visual tasks near threshold	3000 to 10,000 lx (300 to 1000 fc)

BEST Center Curricula, Resources & Recordings

Academic Programs
Georgia Piedmont Technical College - Building Automation Systems
Milwaukee Area Technical College - Sustainable Facilities Operations
Laney College - Commercial HVAC Systems
City College San Francisco - Commercial Building Energy Analysis & Audits

Professional Development Materials, Presentations & Videos
National Institutes
Building Automation Systems Instructor Workshops
Webinars (e.g., BEST Talks)

Faculty Profile Videos
Reports & Case Studies
Marketing Resources

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