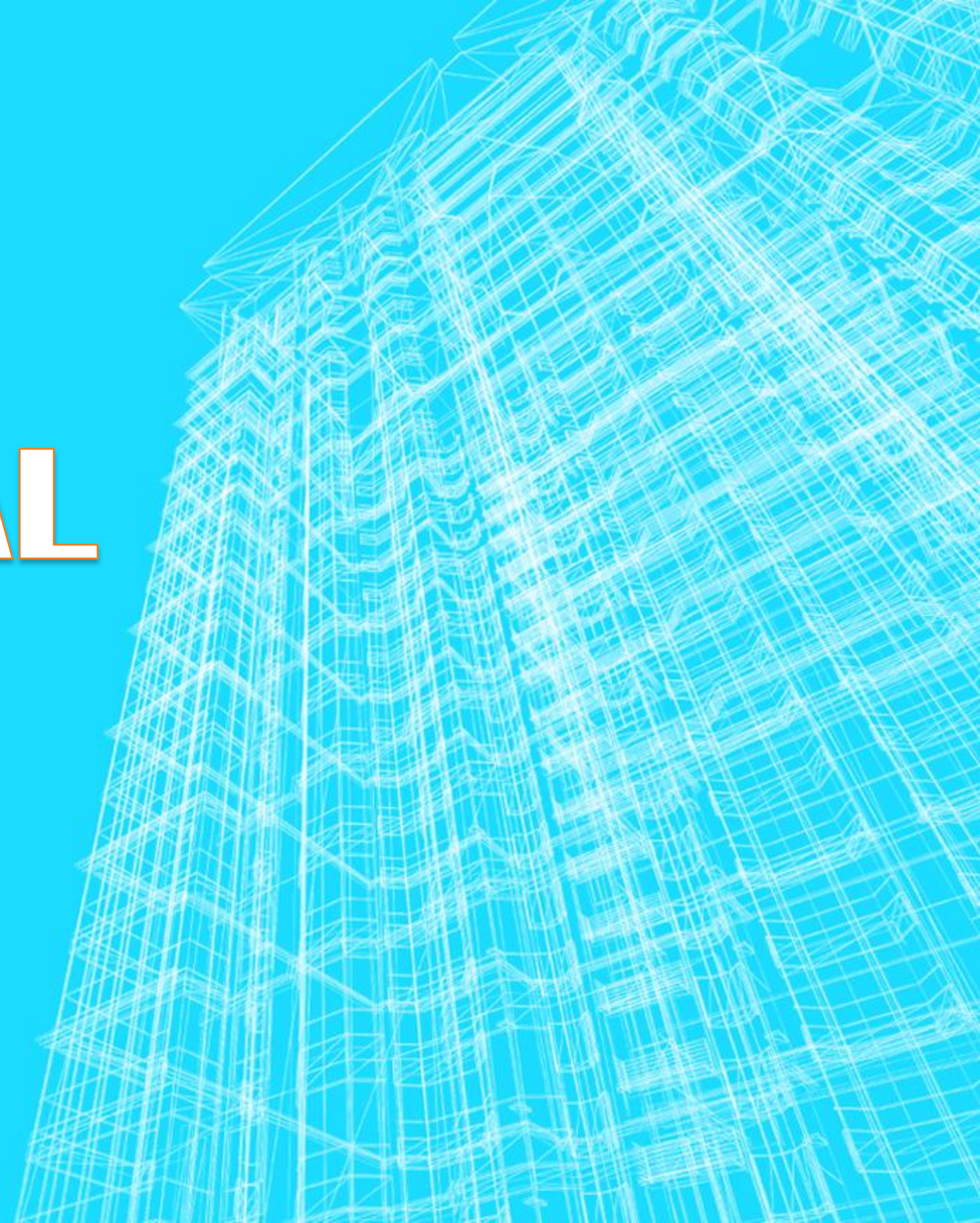
LIGHT AND ARCHITECTURAL LIGHTING SYSTEMS

Chapter 4



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EE 30 – Electrical Engineering Utilities

BSCE2B – Group 2

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INTRODUCTION

- Lighting accounts for 20 to 25% of the electricity consumed in the United States and Canada and almost 20% of total global electricity consumption.
- The fundamental reasons for providing light in a space are to make the objects in the space visible and to conduct activities that must take place in the space.
- Good architectural lighting provides the right quantity of light, with excellent color rendition and minimal glare. Quality lighting has been shown to improve productivity and enhance worker satisfaction.
- This chapter introduces basic lighting terminology and the procedures of simple lighting design. This presentation highlights material that acquaints the technician with basic design principles.

4.1 A CHRONICLE OF ARTIFICIAL LIGHTING

HISTORICAL PERSPECTIVE

– Light has played an important role in human activity throughout history. Up until the early part of the 20th century, people have relied on natural lighting and flame sources such as wood, candle wax, whale oil, coal oil, coal gas and kerosene but with the advent of electricity and incandescent lamps communities started switching to the safer, cost-effective electricity powered lighting.

- **Foot-candle** - the earliest known unit of lumination still used today
- **Herman Sprengel** - a German chemist invented a more efficient vacuum pump in 1865 which was critical to the development of incandescent light bulb.
- **Joseph Swan** - first developed a working incandescent light bulb using carbon-filament lamp in February 5, 1879.

- **Thomas Alva Edison**

  – first announced the successful development of an incandescent lamp with a baked carbonized cotton thread filament in December 21, 1879.
  – first to develop a commercially feasible electric light, a low-cost lamp that could remain lit for a long period of time.
  – 1882 - Edison Electric Light Company later known as Consolidated Edison Company powered incandescent streetlights and lamps in parts of London and later in New York which served as a model for future utilities.
  – On August 26, 1895, the Niagara Falls Power Company became the first commercial utility to produce and transmit hydroelectric power.
  – In 1939, General Electric introduced fluorescent lighting, an electric light source that is more efficient than the incandescent lamp.

PROFESSIONAL ORGANIZATION

– developed technical standards, specifications and design techniques that govern the design and construction of building lighting and electrical systems.

Some of the organizations related to building lighting and electrical systems are:

- Illuminating Engineering Society of North America (IESNA),
- International Association of Lighting Designers (LALD),
- National Electrical Manufacturers Association (NEMA), and
- the American Lighting Association (ALA).

STANDARDS AND CODES

- **National Electrical Code (NEC)**

- model code that specifies the minimum provisions necessary for protecting people and property from the use of electricity and electrical equipment.
- applies to both the manufacture and installation of electrical equipment.
- most municipalities and counties require that residential and commercial electrical wiring conform to the NEC. In some jurisdictions, certain NEC requirements are superseded by local requirements.
- lighting installations powered by electricity must comply with this code.

- **ASHRAE/IESNA 90.1 (American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc./Illuminating Engineering Society of North America, Inc., Standard 90.1)**

- addresses energy consumption in commercial and high-rise residential buildings.
- sets minimum performance standards for building systems and components that have an impact on building energy consumption, including the building envelope, heating, ventilation and air-conditioning (HVAC) systems, and lighting.

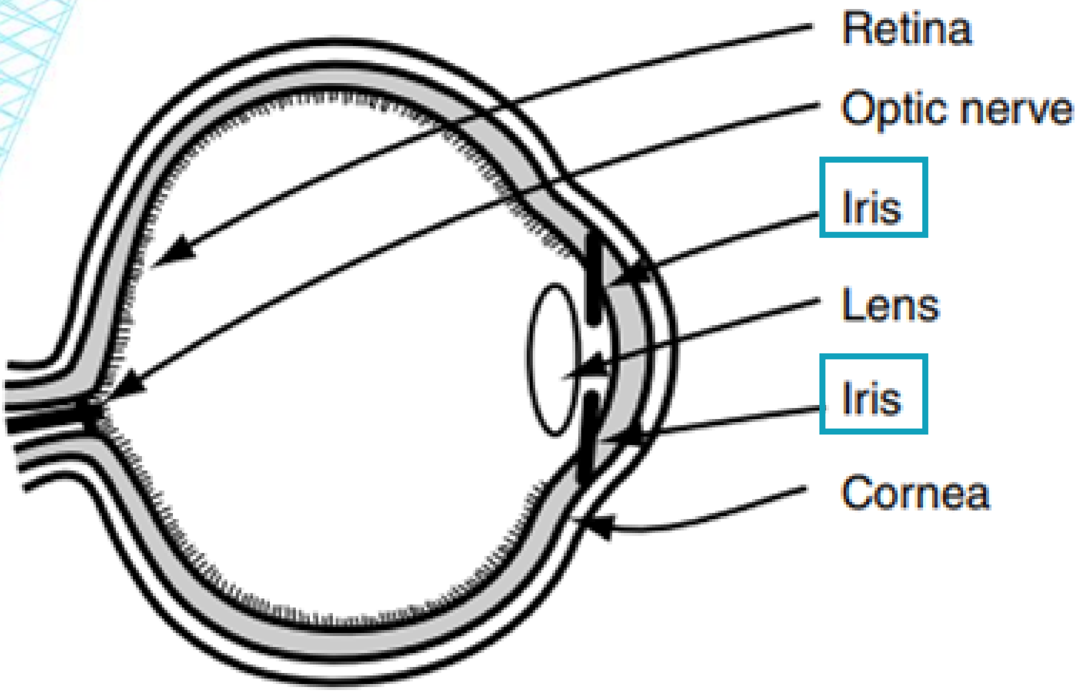
4.2 ELEMENTS OF SEEING

- Design of a good lighting system involves application of a blend between scientific principles, artistic skill, and design experience.
- ***Optics*** is that branch of physics that relates to the properties of light and the function of vision. It involves a study of the human visual system and how it interacts with light. The basic principles of vision and light as related to building lighting systems will be introduced.

THE VISUAL SYSTEM

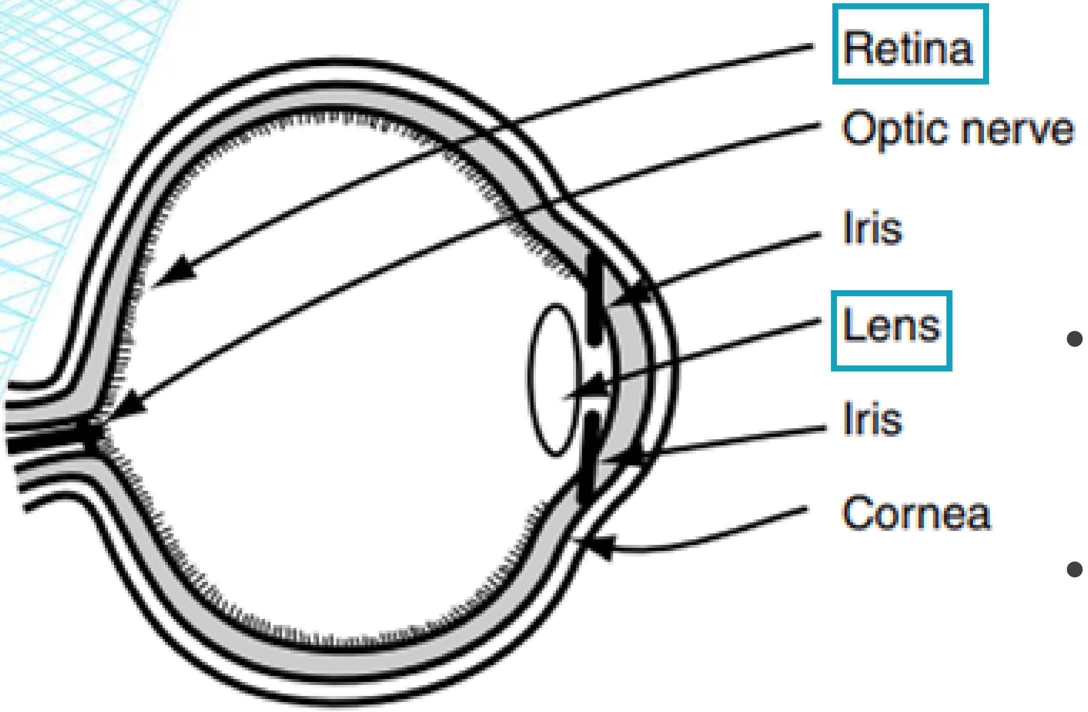
- The visual system of a human is composed of the eye, optic nerve, and certain parts of the brain.
- The eye is the organ that allows a human to sense light and produce electrical impulses that will be sent through the optic nerve to the brain.
- The brain is that part of the visual system where the impulses are processed.

THE EYE



- The eye functions much like a simple, very crude camera. Rays of light pass through the transparent *cornea* of the eye and through an opening called the *pupil*.

- The **iris** surrounds the *pupil* and adjusts for the amount of light available. It opens and closes to control the quantity of light the interior of the eye receives, much like the aperture on a camera opens and closes to limit the light to which the film is exposed.



- The **lens** is a transparent ellipsoidal medium that changes thickness, allowing it to bend and focus the rays of light entering the interior of the eye. The **lens** thickens to focus rays of light from objects nearby and narrows to focus light from distant objects. The **lens** concentrates the rays of light on the retina, a membrane on the back of the eye.
- The **retina** is composed of nerve cells with photoreceptors that are shaped like rods and cones.
- These photoreceptors do not discern color well, so dimly lit objects are perceived as being uncolored—that is, seen in shades of gray. The photoreceptors that are shaped like cones provide color vision and respond best to bright light.

- There are three different types of cone-shaped photoreceptors in the retina. Each type responds to one of the primary colors of light: red, green, and blue. In individuals with normal vision, the electrical impulses from each cone blend together to create the sensation of other colors. However, about 5% of the population, mostly males, has defective color vision.

- **Color blindness** is the inability to distinguish colors. The most common form of color blindness is found in those individuals who have difficulty distinguishing red from green. Individuals who are completely red–green color-blind see yellows and blues normally, but have trouble differentiating reds and greens. They tend to see reds and greens as yellow. Individuals who are totally color-blind see only black, white, and shades of gray.

4.3 LIGHT

- form of energy known as electromagnetic radiation.
- travels as an electromagnetic wave.
- Light travels through the vacuum of space – unlike sound.
- It travels at 300 000 km/s

ELECTROMAGNETIC RADIATION

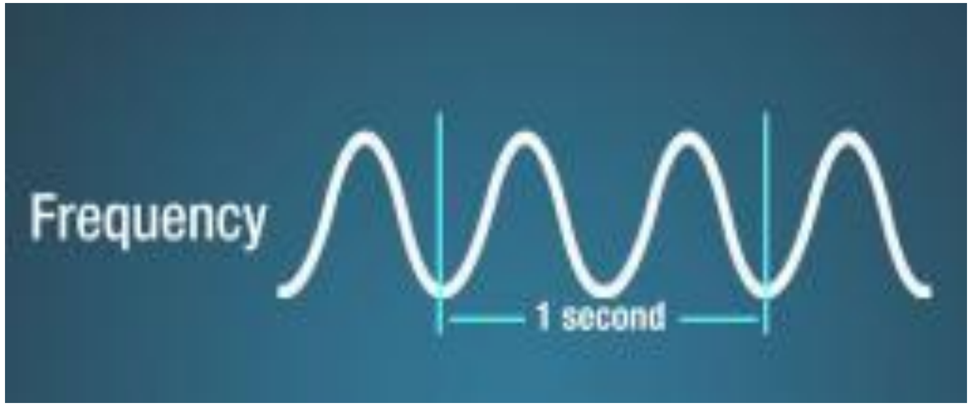
- energy radiated in the form of a wave caused by an electric field interacting with a magnetic field.
- result of the acceleration of charged particles.
- categorized by wavelength and frequency.

Wavelength (λ)

- measured as the distance from one peak of one wave to the next wave.
- expressed in meters or nanometers (1 nm 000 001 meter or one billionth of a meter).

Frequency

- number of wave cycles per second.
- expressed in units of hertz (Hz).
- TV and radio waves are several meters long with frequencies ranging from 10 kilohertz to 300 000 Megahertz.



- Most light sources emit electromagnetic radiation composed of different wavelengths of light.
- Sunlight striking the earth’s outer atmosphere is made up of ultraviolet (about 5%), visible light (about 45%), and infrared (about 50%) radiation.

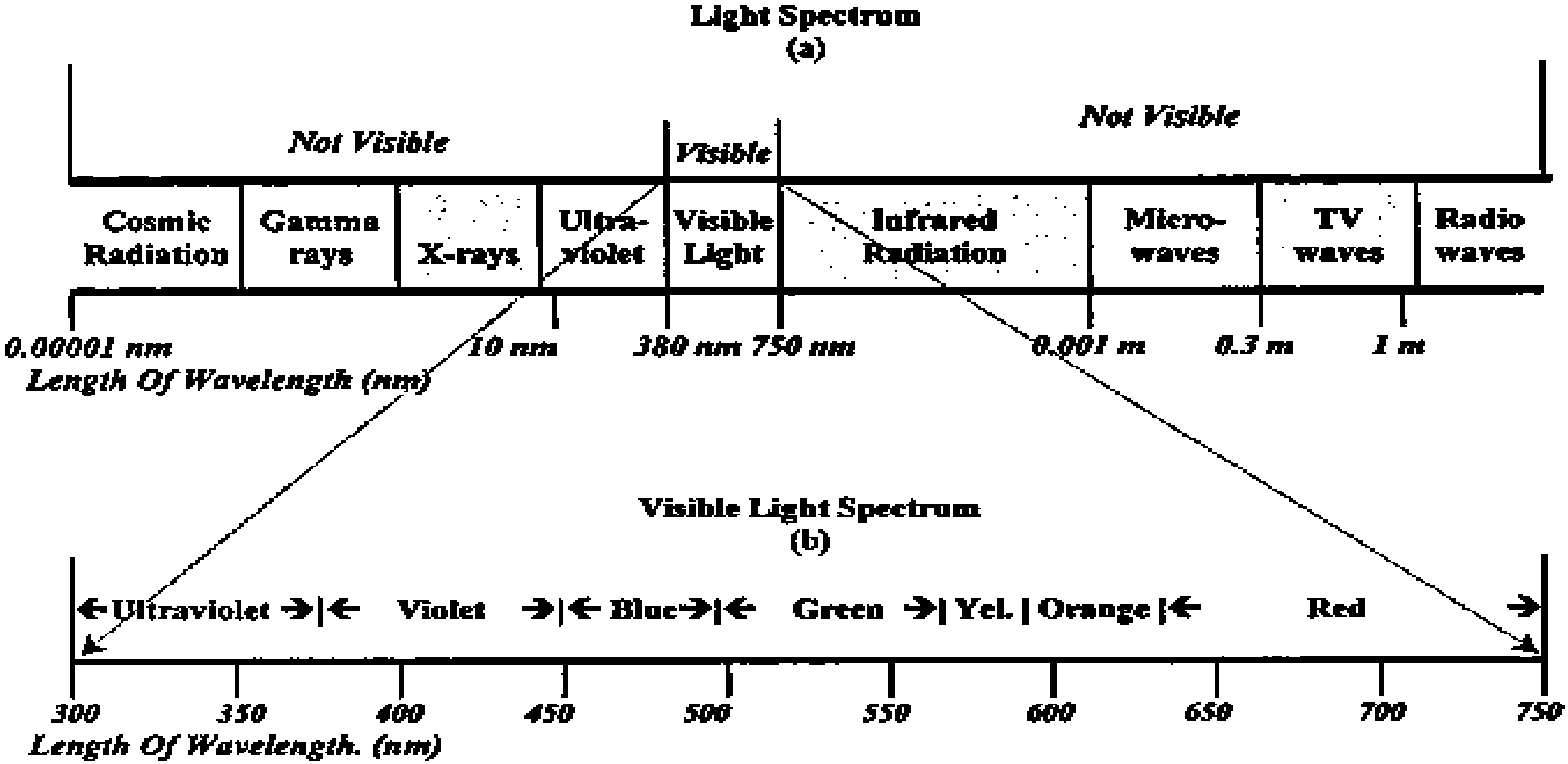
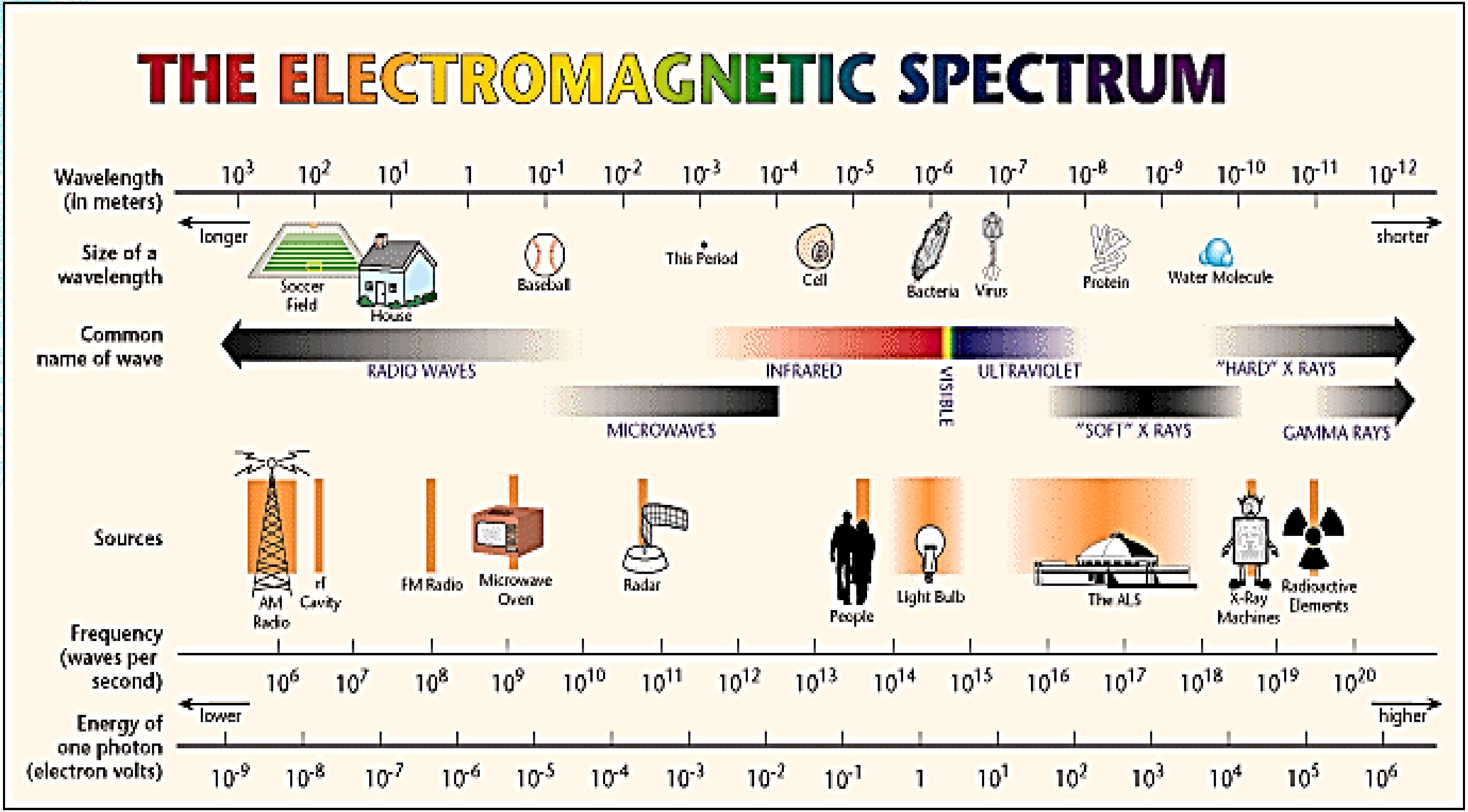


FIGURE 4. Classifications of electromagnetic radiation spectrum are grouped by wavelength. Shown are the (a) full light spectrum and the (b) visible light spectrum that is part of the light spectrum. One nanometer (nm) is 1/1 000 000 000 meter (m).

Color	Wavelength
violet	380–450 nm
blue	450–495 nm
green	495–570 nm
yellow	570–590 nm
orange	590–620 nm
red	620–750 nm

Table 1. Wavelength ranges of visible light by color. Visible light is the wavelengths of electromagnetic radiation spectrum to which the human eye is sensitive.



THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
10^3 10^2 10^1 1 10^-1 10^-2 10^-3 10^-4 10^-5 10^-6 10^-7 10^-8 10^-9 10^-10 10^-11 10^-12
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Sources
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10^6 10^7 10^8 10^9 10^10 10^11 10^12 10^13 10^14 10^15 10^16 10^17 10^18 10^19 10^20
lower
higher
Energy of one photon (electron volts)
10^-9 10^-8 10^-7 10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 1 10^1 10^2 10^3 10^4 10^5 10^6

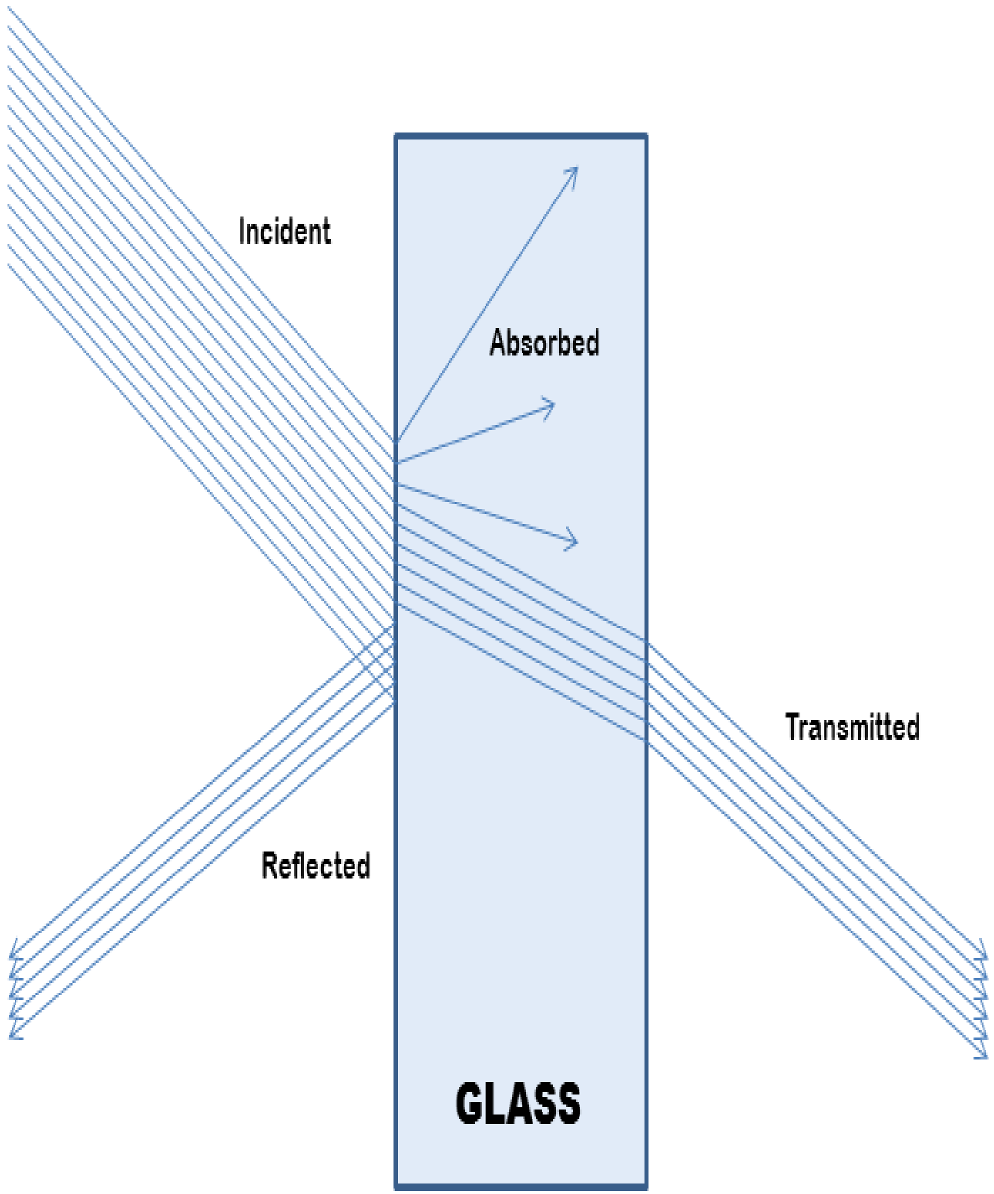
VISIBLE LIGHT

- part of electromagnetic radiation spectrum
- capable of exciting the retina and ultimately producing a visual sensation;
- it is the wavelengths of electromagnetic radiation to which the human eye is sensitive

BEHAVIOR OF LIGHT

- When light strikes a surface, the surface is illuminated. Illuminance is the amount of light incident on (striking) a surface. Luminance is how bright an object appears. The eye sees luminance as the light leaving an object, but the eye cannot see it without visible light reflecting off the object in the direction of the viewer.

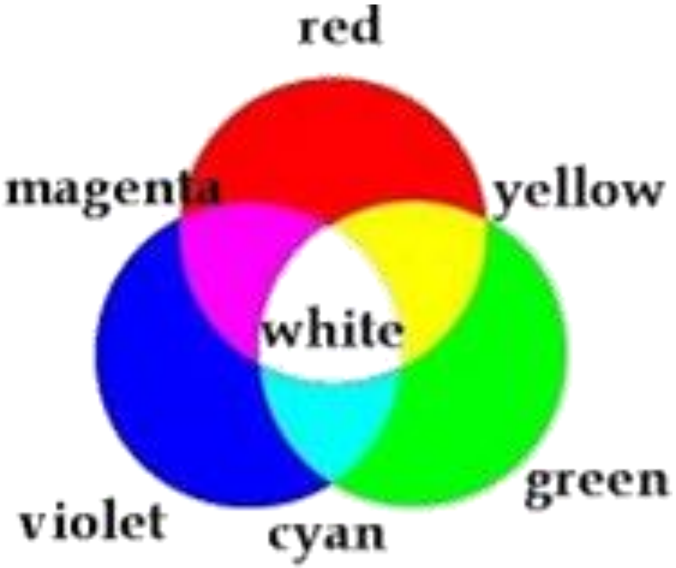
- **Reflectance** is the ratio of reflected light versus the light striking the surface. Specular reflection occurs when light is reflected off a polished or mirror-like surface. For example, the reflectance of a dull black surface may be about 0.10.
- **Transmittance** is ratio of light transmitted through body to light illuminating surface. A transparent body transmits light without distorting the image. Frosted glass is a type of translucent medium. Ordinary window glass is an example of a transparent medium.
- **Absorptance** is the ratio of the light absorbed versus the light striking the surface. For example, the absorptance of a dark black surface may be about 0.90 (90% is absorbed).



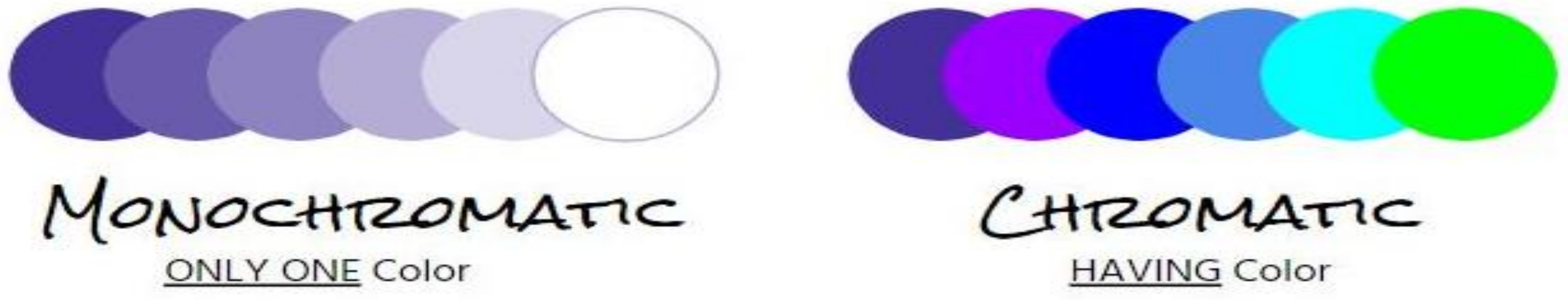
4.4 THE COLOR OF LIGHT

COLOR PERCEPTION

- **Color perception** is the ability to distinguish and interpret different wavelengths of visible light. Artificial and natural (daylight) light sources are composed of many wavelengths having varying magnitudes. An opaque object will selectively absorb different proportions of each of these wavelengths and reflect the remainder toward the viewer. So, an object that absorbs all of the longer wavelengths and reflects the shorter wavelengths will be perceived as violet or blue.



- A light source producing a blend of wavelengths that are evenly distributed across the light spectrum is perceived by the human eye as white or normal light. This light is actually made up of all wavelengths of visible light. It contains the individual red, green, and blue wavelengths that make up the primary colors of light.
- The primary colors of light are additive; they can be used in various combinations to produce any other color by adding color. When they are combined together, primary colors of light produce white. The colors of pigments are magenta (purplish red), cyan (greenish blue), and yellow. They are opposite of the colors of light.



- A chromatic light source emits a fairly even distribution of all wavelengths of light. Most light sources are not fully chromatic. A monochromatic light source produces visible light in a very small range of wavelengths: a red light emits predominantly red wavelengths; a green light gives off predominantly green wavelengths; and so on. Type of wavelengths emitted by a light source will influence color

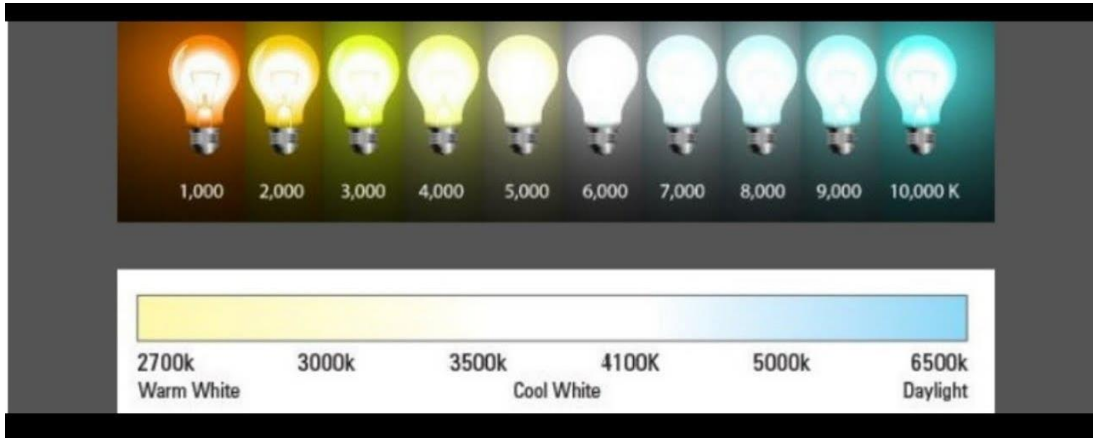
COLOR QUALITY

- A light source that produces a blend of wavelengths evenly distributed across the light spectrum is perceived as white light. White light renders all colors—that is, a multicolored surface illuminated by a white light will render all colors evenly. Generally, a good quality light source renders all colors uniformly. A light source of poor color quality renders the different colors unevenly.

Two methods are used to rate the quality of color emitted by a light source:

The Color Temperature

Color Rendering Index



VISUAL ACUITY

- **Visual acuity** is the ability to distinguish fine details. It is the “keenness” of vision that is necessary to perform tasks such as reading, writing, drafting, sewing, or surgery. Technically, visual acuity is measured as the ability to identify black symbols (letters) on a white background at a specific distance as the size of the symbols is varied. A person’s visual acuity depends on the function of the eye (the retina) and the interpretative ability of the brain.

- Black text on a white background is easy to see because black (ρ 0.10) and white (ρ 0.80) have vastly different reflectance. On the other hand, light gray text (ρ 0.60) on a dark gray background (ρ 0.40) have similar reflectance so the object is harder to see.

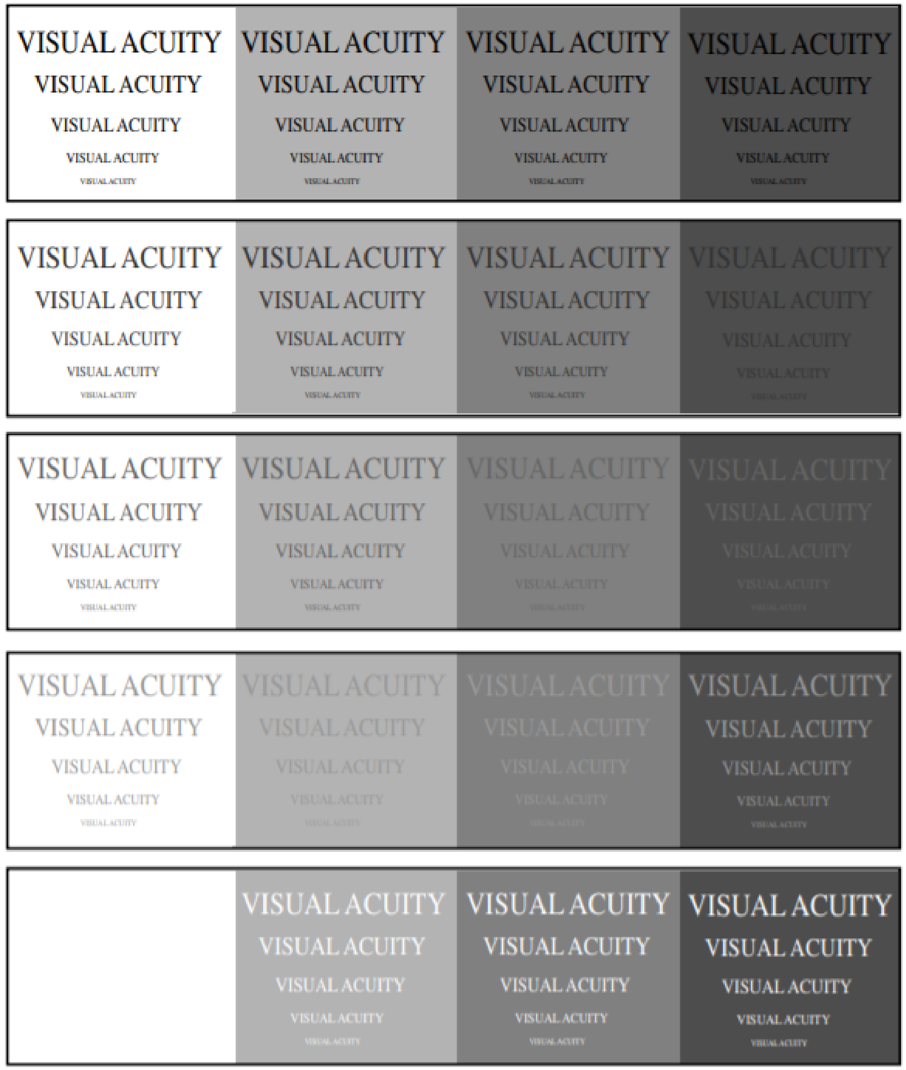


FIGURE 20.5 Contrast between an object and its background and size of the object influence visual acuity.

4.5 CHARACTERISTIC OF ARTIFICIAL LIGHTING

LAMPS, LUMINAIRES AND LIGHT FIXTURES

What is a lamp? 

- A lamp is a device that generates light.
- Common misconception of a lamp and a light bulb is that the light bulb is simply the glass portion of a lamp that encloses and protects the working parts of the light source, while the lamp itself is the source of light.

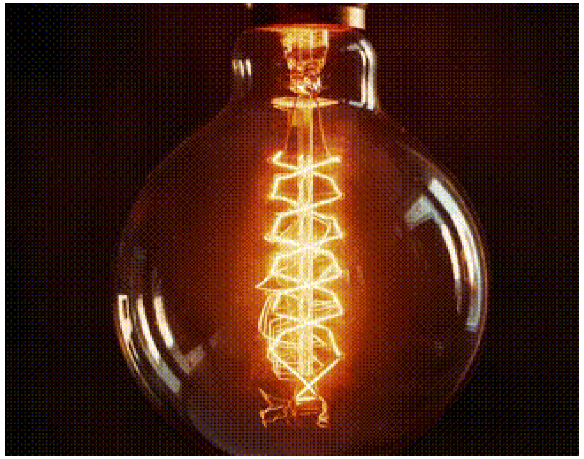
Categories of Lamps

Incandescent Lamps

Gaseous Discharge Lamps

Incandescent Lamps

- This kind of lamps provide light source by incandescence, which is the emission of light caused by heating the filament.



Gaseous Discharge Lamps

- This category can be divided into 2 more sub-category: low-pressure lamps, and high-intensity discharge (HID).

Low-pressure discharge

- Fluorescent lamps
- Low-pressure sodium lamps

High-intensity Discharge

- Mercury Vapor Lamps
- Metal Halide Lamps
- High-pressure sodium lamps

What is a Luminaire? 

- A **luminaire** is a complete lighting unit which consists of lamps, lamp sockets, any lenses, refractors, or louvers, any ballasts, and the housing.
- A light fixture is a luminaire that does not have lamps.
- The term ‘lantern’ is generally used to describe a luminaire.

LIGHT OUTPUT

- Luminous flux is the measure of the perceived power of light expressed in *lumens* (*lm*).
- A lumen is defined as the quantity of light given out through a steradian by a source of one candela of intensity radiating equally in all directions.
- Candela (*cd*) is the SI unit of luminous intensity --- that is, the power emitted by a light source in a particular direction.
- A candela is the luminous intensity, in a given direction.

LUMINOUS EFFICACY

- Luminous efficacy is the ratio of the light output of a light source (a specific lamp) to the electrical energy consumed to produce the light source.
- It is expressed in units of lumens per watt of electric power (lm/W) and thus typically referred to as LPW.

LPW= light output (lm)/power input (W)

Example: Determine the luminous efficacy of:

Q: A 40 W incandescent lamp that emits 505 lm of light.

A: LPW= 505lm/40 W = 12.6 lm/W

CORRELATED COLOR TEMPERATURE

- The color of light emitted by a light source correlates to the temperature of the emitting source. In physics, a black body is a theoretically ideal body that perfectly radiates energy.

- Technically, color temperature only applies directly to light sources that incandesce (emit light from heating) such as the ordinary incandescent lamp. Gaseous discharge lamps such as fluorescent, mercury vapor, metal halide, and high- and low-pressure sodium lamps do not incandesce. They are, however, rated by their apparent or correlated color temperature.

Light Source	Temperature (K)
Dull red glow (black body)	800
Low-pressure sodium lamp*	1750
Candle flame/sunlight at sunrise	1800
High-pressure sodium lamp*	2100
Tungsten filament incandescent lamp	2600 to 3000
Bright yellow glow (black body)	3000
Fluorescent, mercury vapor, metal halide lamps*	3000 to 5000
"Warm white" fluorescent	3000
"White" fluorescent	3500
"Cool white" fluorescent	4100
"Daylight" incandescent lamp	4700
White glow (black body)	5000
Noon sunlight	5500
LED (light-emitting diode)	6000
"Daylight" fluorescent	7000
Overcast sky	7000
Light blue glow (black body)	8000
Clear blue sky	10 000
Brilliant blue glow (black body)	60 000

COLOR RENDERING INDEX

- The color rendering index (CRI) is a method of numerically comparing the color distribution of a light source to a reference lamp. The reference lamp emits light over the full visible light spectrum at the same color temperature as the light source being tested.
- Approximate CRI values for different commercially available lamps are provided in Table 20.4. In theory; a lamp with a higher CRI more closely emulates the reference lamp and provides a better color rendition.

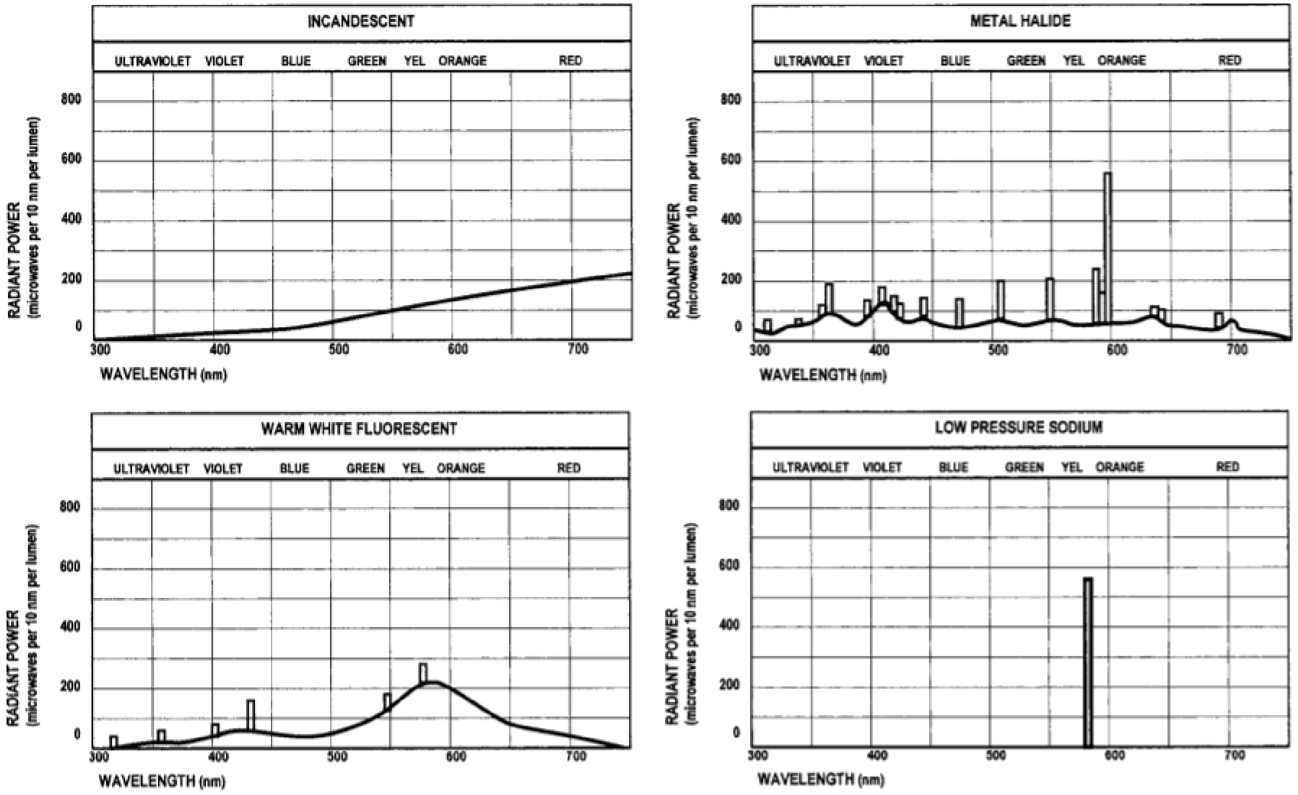
TABLE 20.4 APPROXIMATE COLOR RENDERING INDEX (CRI) FOR DIFFERENT COMMERCIALLY AVAILABLE LAMPS.

Lamp Type	Approximate CRI
Natural light	100
Incandescent	95 to 99
Fluorescent	22 to 92
Mercury vapor	15 to 50
Metal halide	65 to 75
High-pressure sodium	20 to 25*
Low-pressure sodium	0

*One color-enhancing type has achieved a CRI of 70.

SPECTRAL POWER DISTRIBUTION DATA

- A **spectral power distribution** curve is a graphic presentation of the quantities of light emitted by a lamp by wavelength component. These curves are a plot of radiant power versus specific wavelength across the light spectrum. They provide a visual fingerprint of the color characteristics of the light emitted by the source over the visible part of the spectrum. Spectral power distribution curves for specific lamps are available from the manufacturer.



LAMP LIFE

- The rated life of a lamp is its median life expectancy, expressed in hours. It is the cumulative time that lapses before 50% of a representative group of lamps has failed and the other lamps in the group continue operating. For example, a 60 W soft white incandescent lamp can be expected, on average, to burn for 1000 hr. Based on continuous testing of lamps in laboratories, the 1000-hr rating is the point in time when 50% of the test samples have burned out and 50% are still burning.

Example 20.2

A lamp manufacturer's specifications for a 40 W fluorescent lamp indicates an output of 2680 lm, a rated life of 20 000 hr and a cost of $6.00 per lamp. Data for a 150 W incandescent lamp indicates an output of 2850 lm, a rated life of 750 hr, and a cost of $2.00 per lamp. When in use, it is anticipated that these lamps will be operated 10 hr per day, 220 days per year.

a. For each lamp, approximate the time period that elapses before replacement is necessary.

150 W incandescent lamp:

750 hr/(220 days/year · 10 hr/day)
= 0.34 years (4.1 months)

40 W fluorescent lamp:

20 000 hr/(220 days/year · 10 hr/day)
= 9.1 years (110 months)

b. Approximate the cost of each type of lamp over a 10-year period, assuming use and lamp costs remain constant.

150 W incandescent lamp:

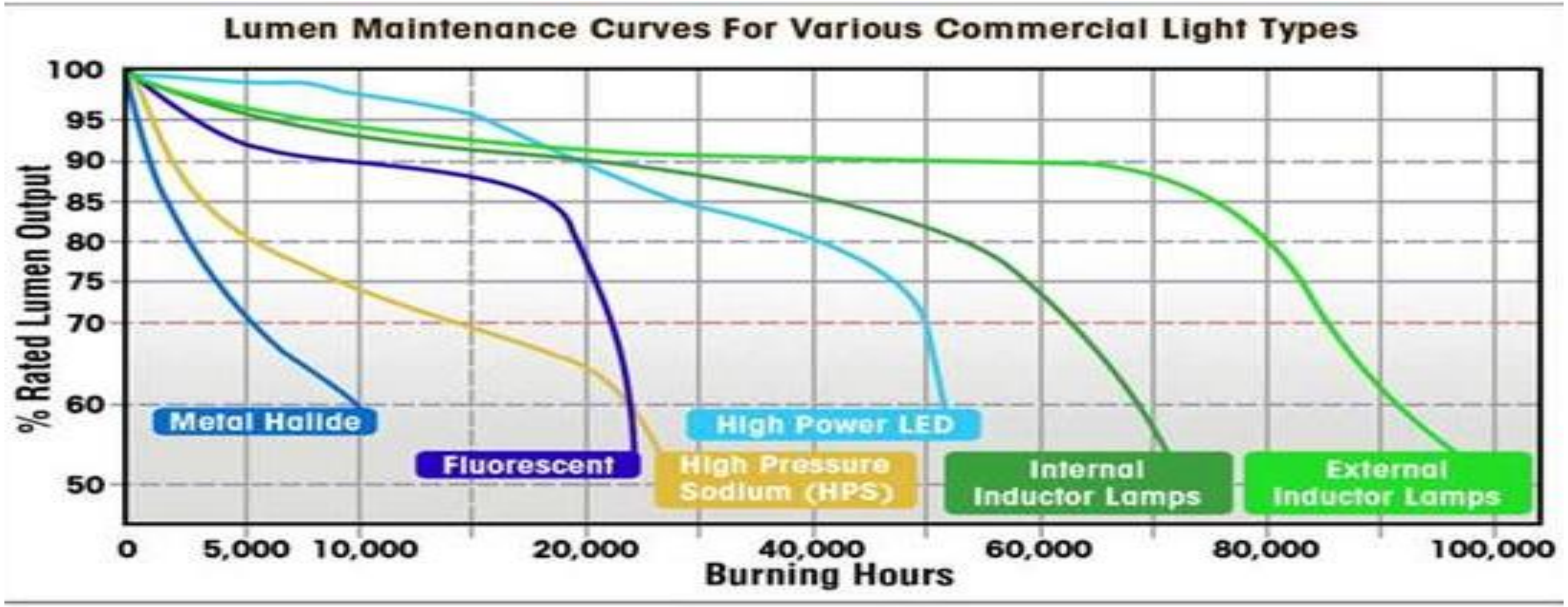
10 years/0.34 years per lamp = 29.4 lamps
29.4 lamps over 10 years @ $2.00 per lamp = $58.80

40 W fluorescent lamp:

10 years/9.1 years per lamp = 1.1 lamps
1.1 lamps over 10 years @ $6.00 per lamp = $6.60

DEPRECIATION OF LAMP OUTPUT

- As lamps operate the luminous flux (lumen output) will decrease. As incandescent lamps operate their light output degrade to about 85% of lamp's initial lumen output. With fluorescent and HID lamps, lumen depreciation will vary by lamp type, size, and use. Degradation to 60 to 80% of the lamp's initial lumen output is common at the end of a fluorescent lamp's rated life. Degradation to 50 to 70% of the initial lumen output is typical at the end of an HID lamp's rated life



4.6 TYPES OF ARTIFICIAL LIGHT SOURCES

INCANDESCENT LAMPS

- Emit visible light as a result of heating; *they incandesce.*
- Also known as "**Light Bulb**" by the lay consumer.
- In 1890s, Thomas Edison introduced a commercially successful lamp and the basic design of incandescent lamp remained unchanged.

Advantages	**Disadvantages**
- low lamp cost	- short rated life
- reliability	- poor efficacy (LPW)
- familiarity	
- good color rendition	

- It is design to balance between efficacy and lamp life
  - the hotter the filament, the more efficient the lamp is in converting electricity into light and the whiter the light
  - hotter operation, reduce lamp life, as a result incandescent lamp of the same wattage can have different output and rated lives

- Incandescent Filaments can reach temperatures of between 4600 and 6000°F (2300 to 3000 K)
  - electromagnetic radiation from filament includes a significant amount of visible light, mainly in red, orange, and yellow wavelengths
- As an incandescent lamp burns, the filament evaporates and deposits on the inner surface of the glass bulb.
  - about 85% of lamp’s initial output reduce the light output
  - the filament can be operated at higher temperatures with chemically inert fill gases such as argon, krypton, or xenon
- Standard incandescent lamps come in an assortment of *wattages*, *voltages*, *shapes*, and *types of bases*.
  - Incandescent lamps have wattages of between 3 to 1000 W and Voltages of 6 to 277 V; the 120, 125, and 130 V lamps are the most common

TABLE 20.5 LAMP DESIGNATIONS OF SELECTED BULBS.

Lamp Designation	Description of Bulb Shape
A	Standard light bulb shape
ER	Ellipsoidal reflector
IR	Infrared reflecting
MR	Multifaceted reflector
PAR	Parabolic aluminized reflector
PS	Pear-shaped bulb
R	Reflector
T	Slender, tube-shaped bulb

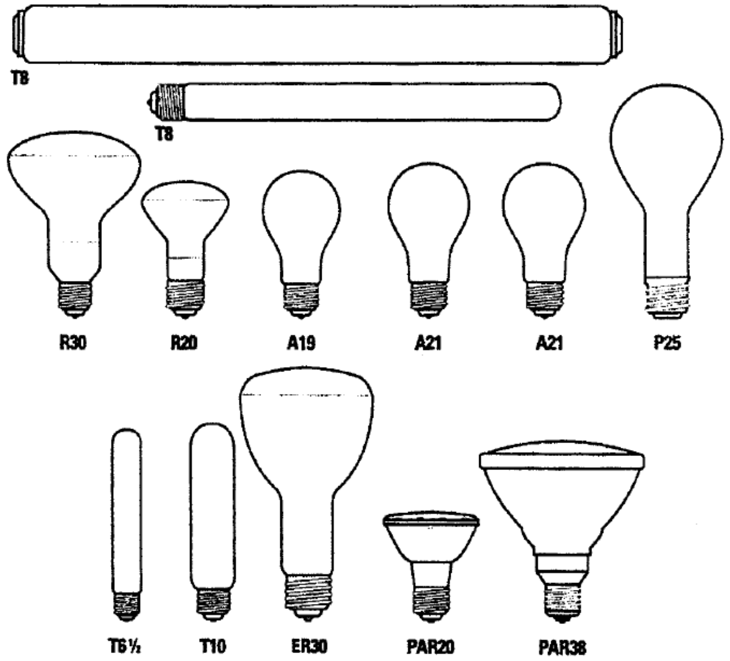


FIGURE 20.8 Selected incandescent lamp shapes.

Threaded or pinned bases hold the lamp in the socket and attach the lamp to the electrical circuit:

- Medium Base
  - – familiar threaded base found with ordinary lamp up to 300 W.
- Candelabra Base
  - – smaller threaded base used in ornamental lighting such as chandeliers.
- Mogul Base
  - – larger threaded base found on lamps that are 300 W or greater.

Special use incandescent lamps are also available.

- Long-life lamps
  - used in applications where the difficulty or cost of changing lamps is prohibitive.
- Rough service lamps
  - special version of standard lamps that are helpful for rough or vibration service.
- Plastic-coated lamps
  - not unbreakable but they break less frequently and when they break, the shattered glass contained within the plastic coating.
- Low-voltage lamps
  - used in decorative and accent lighting applications that require good control or highlighting.

TABLE 20.6 LAMP CHARACTERISTICS FOR SELECTED INCANDESCENT LAMPS. COMPILED FROM VARIOUS INDUSTRY SOURCES.

Input	Bulb Shape	Base	Description	Rated Life	Output	Efficacy (LPW)	Color Rendition
W				hr	lm	lm/W	CRI
7.5	S11	Medium	White	1400	39	5.2	95+
10	S14	Medium	Clear	1500	77	7.7	95+
15	S15	Medium	Clear	3000	110	7.3	95+
25	A19	Medium	Clear	2500	215	8.6	95+
40	A19	Medium	Standard	1000	505	12.6	95+
	A19	Medium	Clear	1500	480	12.0	95+
50	A21	Medium	Inside frost	1000	875	17.5	95+
60	A19	Medium	Standard	1000	865	14.4	95+
	A19	Medium	Clear	1000	870	14.5	95+
	A19	Medium	Long life	1500	820	13.7	95+
75	A19	Medium	Standard	750	1190	15.9	95+
	A19	Medium	Clear	750	1220	16.3	95+
	A19	Medium	Long life	1125	1125	15.0	95+
100	A19	Medium	Standard	750	1730	17.3	95+
	A19	Medium	Clear	750	1750	17.5	95+
	A19	Medium	Long life	1125	1600	16.0	95+
150	A21	Medium	Standard	750	2850	19.0	95+
	A21	Medium	Clear	750	2850	19.0	95+
200	A21	Medium	Standard	750	3910	19.6	95+
	A21	Medium	Clear	750	4010	20.1	95+
300	PS25	Medium	Clear	750	6360	21.2	95+
500	PS35	Mogul	Clear	1000	10 850	21.7	95+
750	PS52	Mogul	Clear	1000	17 040	22.7	95+
1000	PS52	Mogul	Clear	1000	23 740	23.7	95+

TUNGSTEN-HALOGEN LAMPS

- Frequently called *halogen lamps*, a smaller, brighter, and more expensive version of incandescent lamp.
- Contain high-pressure halogen gases such as *iodine* or *bromine*
  - allow the tungsten filaments to be operated at higher temperatures and higher efficacies;
    - advantages of better color rendition, more light output, and a longer life.
- Generate intense heat and require adequate clearance and good ventilation for heat dissipation.
- It cannot be touched by hand without depositing residual skin oils that substantially reduce the life of the quartz glass bulb.

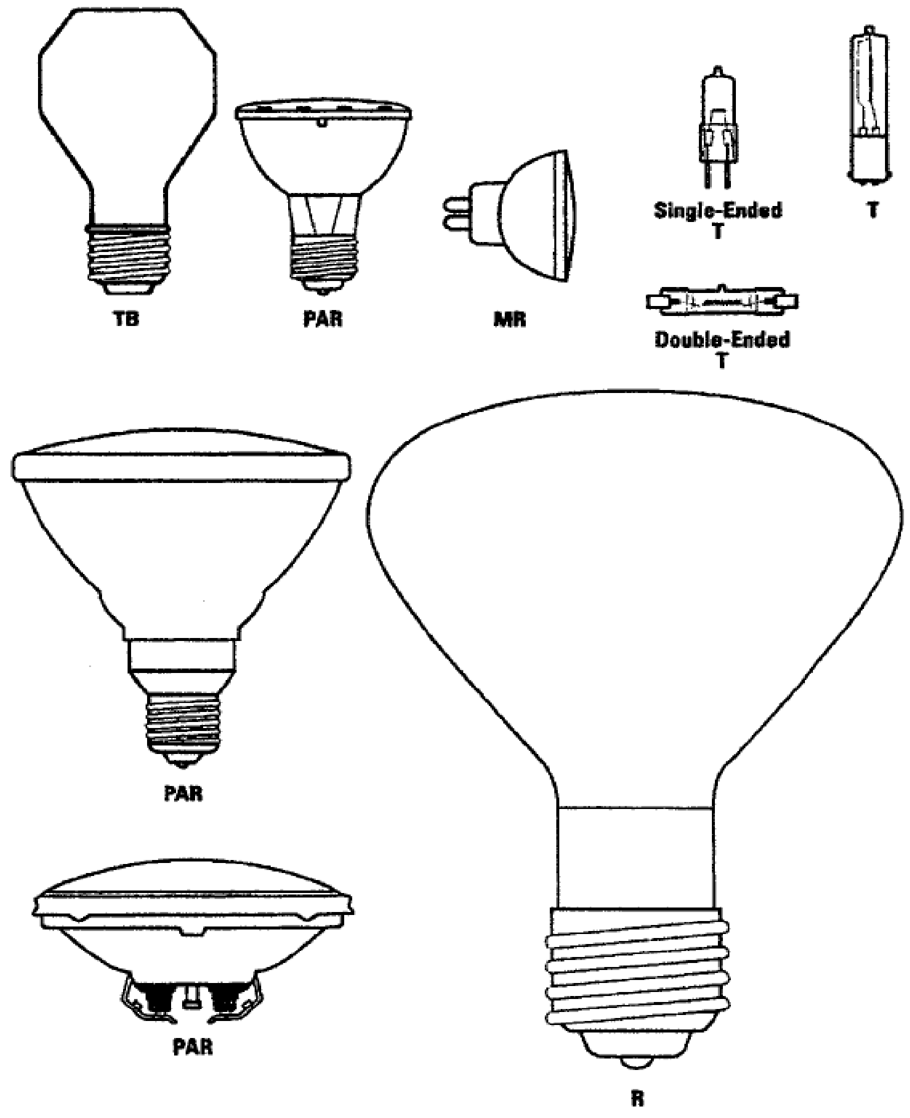


FIGURE 20.9 Selected tungsten-halogen lamp shapes.

GASEOUS DISCHARGE LAMPS

- Electricity passing through a gas such that it causes the gas to arc.
- It produces *continuous* light by passing electricity through a gas contained within the lamp.
  - producing ultraviolet radiation that causes a phosphor coating on the inside of the lamp to glow.
  - unlike incandescent lamps that produce light by getting a filament hot.
- Gaseous discharge classification;
  - fluorescent, mercury vapor, metal halide and low-and-high pressure sodium lamps

- **What is Ballast?**
  - An additional device that is required in all *gaseous discharge lamps.*
  - A voltage transformer and current-limiting device designed to start properly control the flow of power to discharge light sources such as *fluorescent* and *HID lamps.*
  - It can consume up to 20% of the electricity used to power a luminaire.

Types of Ballasts

- Magnetic or Iron Ballasts
  - increase and control voltage, heavy noise.
- Electronic Ballasts
  - use solid-state electronic components, less noise and capable of dimming lamp (lumen) output.
  - letter ratings: A is extremely quiet; B is slightly noisy; C is moderately noisy; and so on.
- Ballast noise
  - extremely annoying in quite spaces.

- **Ballast factor (BF)**
  - Is calculated by dividing the lumen output of a lamp ballast combination by the lumen output of the same lamp on a reference ballast.
- Ballasts and lamps should be matched so the luminaire can produce the largest light output.

FLUORESCENT LAMPS

- Is composed of a tubular glass bulb that is covered with a thin phosphor coating on its inside surface.
  - glass bulb is filled with a low-pressure gas containing mercury vapor.
- *Cathodes* are filament-like coils at the end(s) of the bulb that act as terminals for the electric acr.

- **Linear fluorescent lamps (LFL)**
  - are commercially available in straight, U-shaped of circular tubes in a variety of sizes, wattages, voltages, colors, and types of base.

T12 lamp that measures 12/8's or 1½ inches in diameter

T10 lamp that measures 10/8's or 1¼ inches in diameter

T8 lamp that measures 8/8's or 1 inch in diameter

T6 lamp that measures 6/8's or ¾ inch in diameter

T5 lamp that measures 5/8's or ⅝ inch in diameter

T9 lamp that measures 9/8's or 1⅛ inches in diameter (circular lamps).

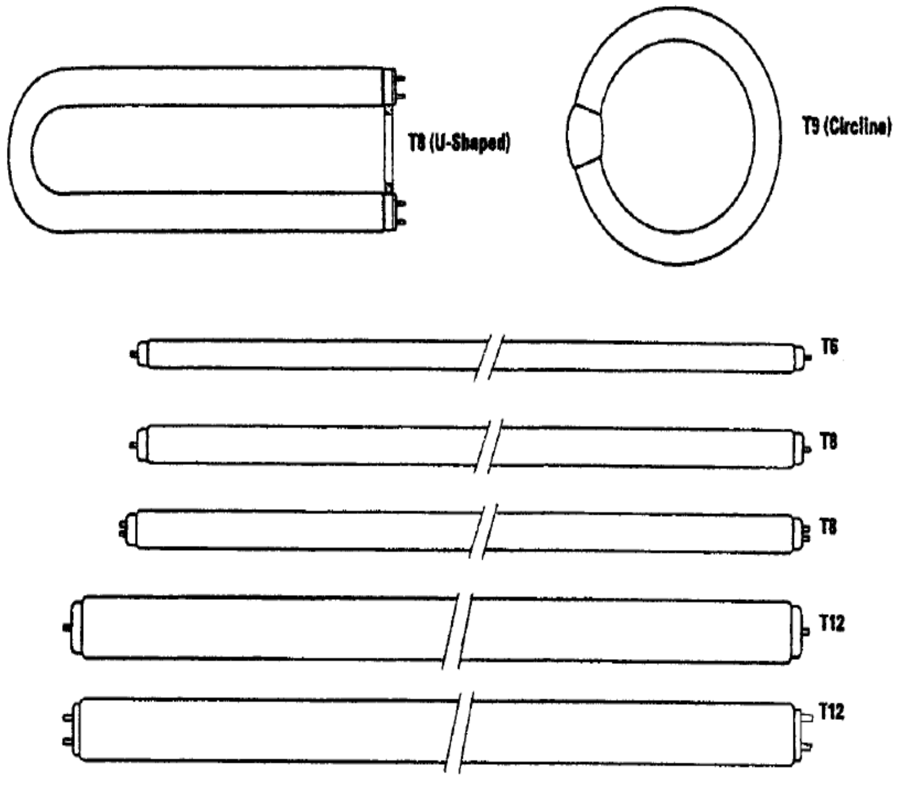


FIGURE 20.10 Selected linear fluorescent lamp shapes.

- ***High Output (HO) and Very High Output (VHO)*** **Fluorescent Lamp**
  - offer higher light (lumen) output in comparison to standard output fluorescent lamp.
  - it consume more power and have significantly lower efficacies.
  - used in re-lamping applications where improved light levels are required such as *warehouse*, *factories*, and *school gymnasiums*.
- **Compact Fluorescent Lamps (CFL)**
  - are miniaturized fluorescent lamps.
  - manufactured with integral ballast and a standard screw base that can be installed in a standard light fixture in place of incandescent lamps.
  - designed as a substitute for standard size incandescent lamp:

7 W CFLs replace 25 W incandescent lamps

11 W CFLs replace 40 W incandescent lamps

13 W CFLs replace 60 W incandescent lamps

19 W CFLs replace 75 W incandescent lamps

23 W CFLs replace 100 W incandescent lamps

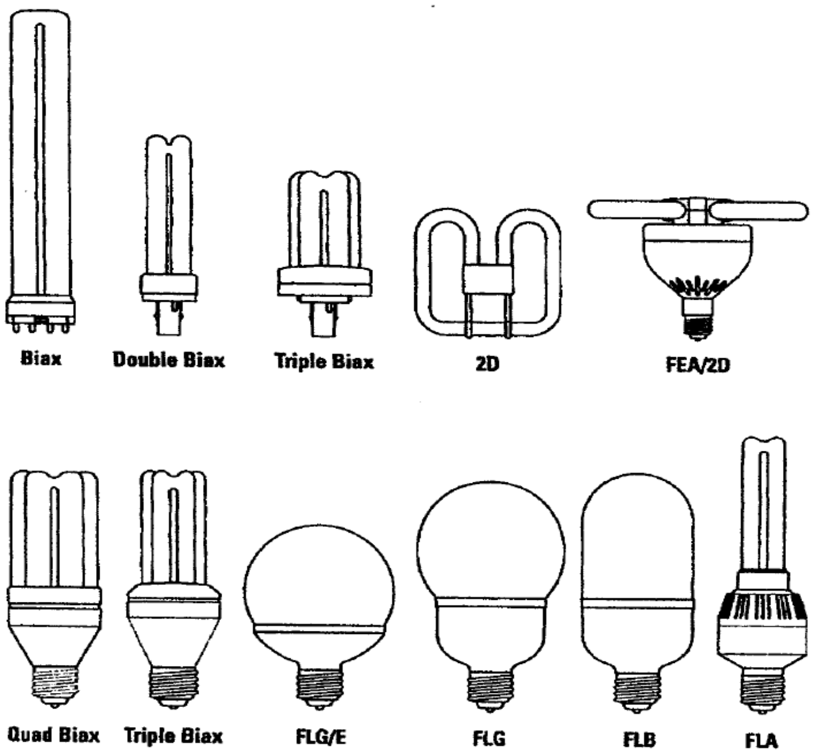


FIGURE 20.11 Selected compact fluorescent lamp shapes.

- Fluorescent light fixture comes in a variety of shapes, wattages, and Voltages.
- Straight-, circular-, and U-shaped tubes are available, with the 48-in straight tube the most common.
- Fluorescent lamps are available in wattages of between 20 to 125 W and lengths of 6 to 96 inches.

TABLE 20.7 LAMP CHARACTERISTICS FOR SELECTED COMPACT FLUORESCENT LAMPS. COMPILED FROM VARIOUS INDUSTRY SOURCES.

Input	Description or Lamp Designation	Rated Life	Output		Efficacy (LPW)		Color	
			Initial	*Mean*	Initial	*Mean*	Temperature	Rendition
W		hr	lm	*lm*	lm/W	*lm/W*	K	CRI
Rapid-Start, Four-Pin, Plug-In (Biax T5) Lamps								
18	F18BX/SPX30/RS	20 000	1250	*1130*	69.4	*62.8*	3000	82
18	F27BX/SPX41/RS	20 000	1250	*1130*	69.4	*62.8*	4100	82
27	F27BX/SPX30/RS	12 000	1800	*1620*	66.7	*60.0*	3000	82
27	F27BX/SPX41/RS	12 000	1800	*1620*	66.7	*60.0*	4100	82
39	F39BX/SPX30/RS	12 000	2850	*2510*	73.1	*64.4*	3000	82
39	F40/30BX/SPX41/RS	20 000	3150	*2840*	80.8	*72.8*	4100	82
50	F50BX/SPX30/RS	14 000	4000	*3400*	80.0	*68.0*	3000	82
50	F50BX/SPX41/RS	14 000	4000	*3400*	80.0	*68.0*	4100	82
Compact Fluorescent Ballasted, One-Piece, Screw-In, Lamps for Medium-Base Incandescent Sockets								
15	FLE15TBZ/SPX27EC	10 000	825	*700*	55.0	*46.7*	2700	82
20	FLE20TBZ/SPX27EC	10 000	1200	*1020*	60.0	*51.0*	2700	82
23	FLE23TBZ/SPX27EC	10 000	1520	*1290*	66.1	*56.1*	2700	82
28	FLE28TBZ/SPX27EC	10 000	1750	*1485*	62.5	*53.0*	2700	82
Compact Fluoescent Twin-Tube Lamps								
7	CFT7W	10 000	400	—	57.1	—	2700	82
9	CFT9W	10 000	580	—	64.4	—	2700	82
13	CFT13W	10 000	800	—	61.5	—	2700	82
Compact Fluorescent Twin-Tube Lamps								
18	FT18W	20 000	1250	—	69.4	—	3000	82
24	FT24W	12 000	1800	—	75.0	—	3000	82
36	FT36W	12 000	2900	—	80.6	—	3000	82
40	FT40W	20 000	3150	—	78.8	—	3000	82
55	FT55W	12 000	4800	—	87.3	—	3000	82

- Has a variety of colors or temperatures such as *Daylight, Cool White, Soft White, Warm White*, and *Deluxe Warm White* that cover the color temperature range from 3000 to 6500 K. Color or temperature varies with the type of phosphor coating.
- The **phosphor** blend in a fluorescent lamp determines the color temperature and color rendering of the light emitted by the lamp.
- **Halo phosphors** are the most popular, least expensive, and lowest quality phosphors.
- All fluorescent lamps are designed to operate at a specific air temperature, usually a surrounding air temperature of 77°F (25°C).

TABLE 20.8 LAMP CHARACTERISTICS FOR SELECTED T12 (1½ INCH DIAMETER), 48 INCH NOMINAL LENGTH, FLUORESCENT LAMPS. COMPILED FROM VARIOUS INDUSTRY SOURCES.

	Description or	Rated	Output		Efficacy (LPW)		Color	
Input	Lamp Designation	Life	Initial	*Mean*	Initial	*Mean*	Temperature	Rendition
W		hr	Lumens	*Lumens*	lm/W	*lm/W*	K	CRI
Rapid-Start Lamps								
40	F40CW—Cool White	20 000	3050	*2680*	76.3	*67.0*	4150	62
40	F40WW—Warm White	20 000	3150	*2770*	78.8	*69.3*	3000	52
40	F40D—Daylight	20 000	2550	*2240*	63.8	*56.0*	6250	75
40	F40N—Natural	20 000	2100	*1740*	52.5	*43.5*	3700	90
40	F40C50—Chroma 50	20 000	2250	*1870*	56.3	*46.8*	5000	90
40	F40C75—Chroma 75	20 000	1950	*1680*	48.8	*42.0*	7500	92
Energy-Saving Rapid-Start Lamps								
34	F40CW—Cool White	20 000	2650	*2280*	77.9	*67.1*	4150	62
34	F40WW—Warm White	20 000	2750	*2370*	80.8	*69.7*	3000	52
34	F40D—Daylight	20 000	2225	*1910*	65.4	*56.2*	6250	75
34	F40C50—Chroma 50	20 000	2000	*1720*	58.8	*50.6*	5000	90
Color-Enhancing, Rapid-Start Lamps								
40	F40SPX30	20 000	3250	*2960*	81.3	*74.0*	3000	82
40	F40SPX35	20 000	3250	*2960*	81.3	*74.0*	3500	82
40	F40SPX41	20 000	3250	*2960*	81.3	*74.0*	4100	82
40	F40SPX50	20 000	3250	*2820*	81.3	*70.5*	5000	82
Energy-saving, Color-Enhancing, Rapid-Start Lamps								
34	F40SPX30	20 000	2850	*2570*	83.8	*75.6*	3000	82
34	F40SPX35	20 000	2850	*2570*	83.8	*75.6*	3500	82
34	F40SPX41	20 000	2850	*2570*	83.8	*75.6*	4100	82
34	F40SPX50	20 000	2700	*2430*	79.4	*71.5*	5000	82
High Output Lamps								
60	F48T12/CW/HO—Cool White	12 000	4050	*3520*	67.5	*58.7*	4150	62
60	F48T12/D/HO—Daylight	12 000	3400	*2960*	56.7	*49.3*	6250	75
60	F48T12/WW/HO—Warm White	12 000	4130	*3590*	68.8	*59.8*	3000	62
Energy Saving, Color-Enhancing, High-Output Lamps								
60	F48T12/SPX30/HO	12 000	4350	*3920*	72.5	*65.3*	3000	82
60	F48T12/SPX35/HO	12 000	4350	*3920*	72.5	*65.3*	3500	82
60	F48T12/SP30/HO	12 000	4250	*3830*	70.8	*63.8*	3000	70
60	F48T12/SP35/HO	12 000	4250	*3830*	70.8	*63.8*	3500	73
60	F48T12/SP41/HO	12 000	4250	*3830*	70.8	*63.8*	4100	70
Very High Output Lamps								
110	F48T12/CW/1500—Cool White	10 000	6200	*4030*	56.4	*36.6*	4150	62
110	F48T12/WW/HO—Warm White	10 000	6280	*4080*	57.1	*37.1*	3000	62

FLUORESCENT LUMINAIRE EFFICACY

- **Luminaire Efficacy Rating (LER)**
  - is the ratio of light (the luminous flux, in lumens) emitted by a *fluorescent* luminaire to the electrical energy consumed, including the ballast.
  - it rates the effectiveness of like luminaires in a manner similar to the EPA miles/gallon rating for automobiles. It is a good measure of the efficiency of *similar* fluorescent luminaires.

TABLE 20.9 LAMP CHARACTERISTICS FOR SELECTED T8 (1 INCH DIAMETER), 48 INCH NOMINAL LENGTH, TRAMLINE FLUORESCENT LAMPS. COMPILED FROM VARIOUS INDUSTRY SOURCES.

Input	Description or Lamp Designation	Rated Life	Output		Efficacy (LPW)		Color	
			Initial	*Mean*	Initial	*Mean*	Temperature	Rendition
W		hr	Lumens	*Lumens*	lm/W	*lm/W*	K	CRI
32	F32T8/SPX30	20 000	2950	*2650*	92.2	*82.8*	3000	84
32	F32T8/SPX35	20 000	2950	*2650*	92.2	*82.8*	3500	84
32	F32T8/SPX41	20 000	2950	*2650*	92.2	*82.8*	4100	80
32	F32T8/SPX50	20 000	2800	*2520*	87.5	*78.8*	5000	80
32	F32T8/SP30	20 000	2850	*2570*	89.1	*80.3*	3000	75
32	F32T8/SP35	20 000	2850	*2570*	89.1	*80.3*	3500	75
32	F32T8/SP41	20 000	2850	*2570*	89.1	*80.3*	4100	75
32	F32T8/SP65	20 000	2700	*2565*	84.4	*80.2*	6500	75
32	F32T8/SP50	20 000	2750	*2610*	85.9	*81.6*	5000	78
32	F32T8/SP30	20 000	2850	*2710*	89.1	*84.7*	3000	78
32	F32T8/SP35	20 000	2850	*2710*	89.1	*84.7*	3500	78
32	F32T8/SPX35	20 000	2950	*2800*	92.2	*87.7*	3500	86
32	F32T8/SPX41	20 000	2950	*2800*	92.2	*87.7*	4100	86
32	F32T8/SP41/C	20 000	2850	*2710*	89.1	*84.7*	4100	78
32	F32T8/SPX50	20 000	2800	*2660*	87.5	*83.1*	5000	86
Extra-Life								
32	F32T8/XL/SP30ECO	24 000	2850	*2710*	89.1	*84.7*	3000	78
32	F32T8/XL/SP35ECO	24 000	2850	*2710*	89.1	*84.7*	3500	78
32	F32T8/XL/SP41ECO	24 000	2850	*2710*	89.1	*84.7*	4100	78
32	F32T8XL/SPX30ECO	24 000	2950	*2800*	92.2	*87.5*	3000	86
32	F32T8XL/SPX35ECO	24 000	2950	*2800*	92.2	*87.5*	3500	86
32	F32T8XL/SPX41ECO	24 000	2950	*2800*	92.2	*87.5*	4100	86
32	F32T8SXL/SP30ECO	30 000	2850	*2675*	89.1	*83.6*	3000	82
32	F32T8SXL/SP35ECO	30 000	2850	*2675*	89.1	*83.6*	3500	82
32	F32T8SXL/SP41ECO	30 000	2850	*2675*	89.1	*83.6*	4100	81

- Comparing the LER of two luminaires is not quite as simple as comparing the EPA mileage ratings of two different automobiles.
- Each rating contains a two-letter code indicating source and product category, such as FL, FP, FW, and so on. F stands for fluorescent, L stands for lensed, parabolic louvered (P), wraparound (W), strip (S), and industrial (I) luminaire categories.
- Only luminaires within a specific product category should be compared.

The LER is found by the following equation, where the luminaire efficiency (EFF), luminaire power input (watts), and ballast factor (BF) are from the fixture manufacturer's data and the total rated lamp lumens (TLL) is from the lamp manufacturer's data:

$$\text{LER} = (\text{EFF} \cdot \text{TLL} \cdot \text{BF})/\text{W}$$

Example 20.3

Fixture manufacturer's data for a two-lamp fluorescent luminaire provides a luminaire efficiency of 0.60, a luminaire power input (watts) of 85 W, and ballast factor of 0.87. Data from the lamp manufacturer indicates that the fluorescent lamps under consideration will output 3050 lumens. Compute the LER.

$$\text{LER} = (\text{EFF} \cdot \text{TLL} \cdot \text{BF})/\text{W}$$

$$\text{LER} = (0.6 \cdot 2 \cdot 3050\ \text{lm} \cdot 0.87)/85\ \text{W} = 37.5\ \text{lm/W}$$

HIGH INTENSITY DISCHARGE LAMPS

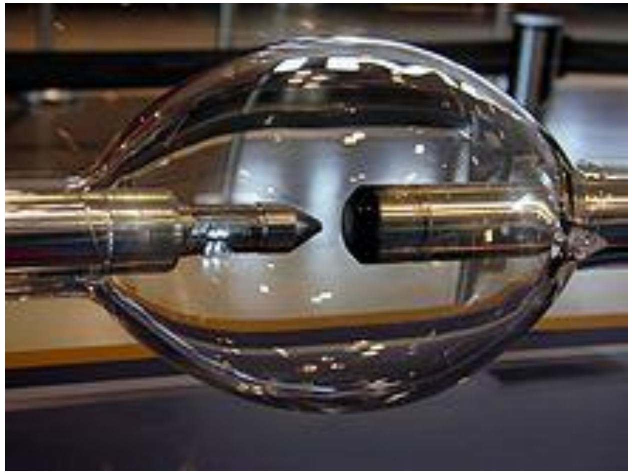
- also called as HID lamps
- produce a very bright light by discharging an arc
  - *when electrical current passes through a metal gas contained under high pressure in a glass bulb.*
- include ***mercury vapor, metal halide, and high-pressure sodium lamps.***

How do these differ from fluorescent lamps?

- HID lamps' gas is under higher pressure compared to fluorescent lamps.
- The lamp is physically smaller compared than that of the fluorescent lamp.
- The light emitted from HID lamps are more concentrated.

Components:

1. Internal arc tube – *contains the fill gas.*
2. Large outer glass bulb – *surrounds the arc tube to avoid shattering that could result from direct contact with water and other fluids.*



Common Types of HID Lamps:

1. **Mercury Vapor (*MV)* Lamps**
2. **Metal Halide (*MH*) Lamps**
3. **High-Pressure Sodium (*HPS*) Lamps**
4. **Low-Pressure Sodium (*LPS*) Lamps**

- **Mercury Vapor Lamps**
  - MV lamps are the first commercially available HID lamps.
  - High pressure MV lamps without color correction produce a blue-white light directly from their discharge arc.
  - These lamps are constructed of an internal quartz tube enclosed in an outer glass envelope.
  - A small amount of liquid mercury is sealed in an argon gas fill inside the quartz tube.
  - After the warm-up period, the arc emits both visible and ultraviolet (UV) light.
  - Phosphor coatings can be added to improve color rendition.

  - MV lamps are available in wattages ranging from 50 to 1000 W.

- **Metal Halide Lamps**
  - MH lamps are constructed similar to MV lamps except that it has various metal halides added to mercury and argon in the glass fill
  - It offers much better efficacy and color rendition compared to MV lamps
  - It is available in wattages ranging from 32 to 1000 W.
  - These produce high levels of UV radiation that must be shielded by glass in the lamp or fixture.
  - Use of metal halides increases luminous efficiency and improves color rendition.
  - No phosphor is needed to produce a cool white color, but some may be added to improve rendering of oranges and reds.

- **High-Pressure Sodium Lamps**
  - HPS lamps contain an internal arc tube made of a translucent ceramic material rather than quartz glass because of the high temperature (2350 deg.F/1300 deg.C)
  - These are available in wattages ranging from 18 to 1000 W and vary more widely than other HID lamps in their efficacy and color quality.
  - The arc tube is enclosed in an outer glass envelope like other HID lamps.
  - A small amount of solid metallic sodium and mercury is sealed in a xenon gas fill inside the ceramic arc tube.

- **Low-Pressure Sodium Lamps**
  - are a blend between HID and fluorescent technologies
  - produces a monochromatic yellow light consisting almost entirely of orange-yellow wavelengths.
  - colors are dramatically changed.
  - These lamps are constructed of a large sodium-resistant glass tube containing sodium and a neon-argon gas mixture.
  - Excess sodium is contained in the arc tube because the glass may absorb or react with some of the sodium.
  - As the tube is rather large, it is bent into a tight U-shape and enclosed in an outer bulb.
  - The inner surface of the outer bulb is coated with a material that reflects infrared radiation but passes visible light.

- Full light output does not occur immediately when power is applied
- There is a start-up time delay called *strike time* before the lamp reaches it peak output.
- A restart delay called the *restrike time* of one to several minutes is needed before the lamp reaches its peak output.
- It should not be operated if the outer glass envelope is cracked or broken.
- Unlike fluorescent lamps, these generate full light output at low air temperatures, although a special ballast may be needed.

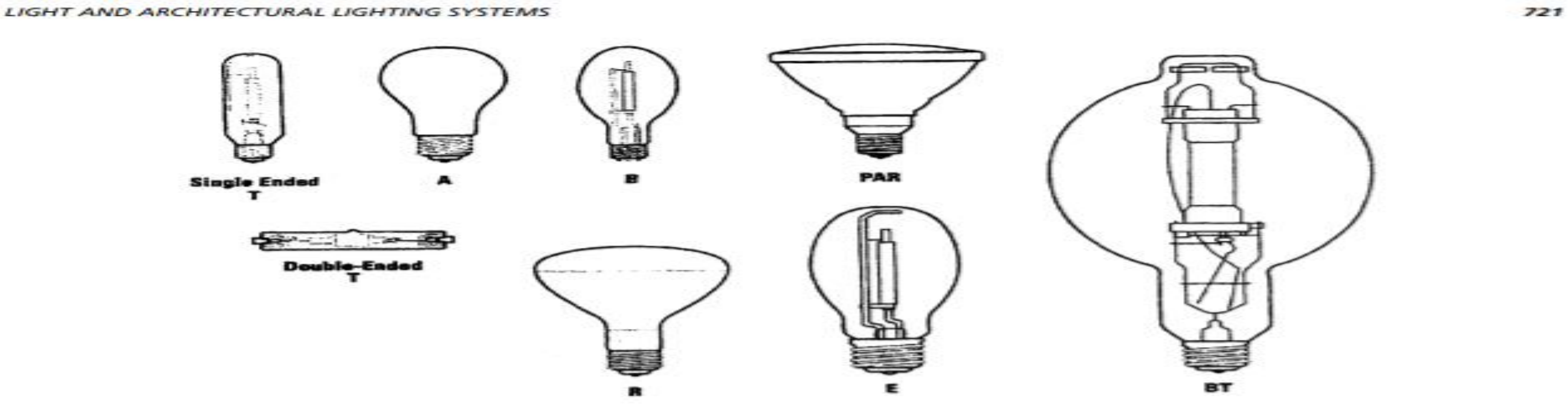
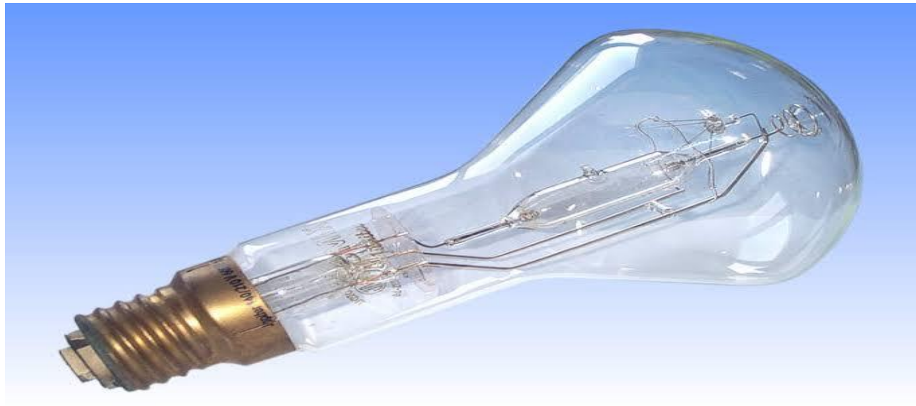


FIGURE 20.12 Selected high-intensity discharge (HID) lamp shapes.

BLENDED LAMPS

- combine the luminous efficiency of an HID lamp with the good color rendering capability of an incandescent lamp.
- No start time and thus total luminous flux is available immediately.
- Color rendition is fair to good.



- **Mercury-Tungsten Blended Lamps**

  Advantage: They are directly interchangeable with incandescent lamps and have a longer lamp life.

  Disadvantage: They cannot be dimmed.

TABLE 20.10 LAMP CHARACTERISTICS OF SELECTED HIGH0 INTENSITY DISCHARGE (HID) AND BLENDED LAMPS. COMPILED FROM VARIOUS INDUSTRY SOURCES.

Input	Description or Lamp Designation	Rated Life	Output		Efficacy (LPW)		Color	
			Initial	*Mean*	Initial	*Mean*	Temperature	Rendition
W		hours	Lumens	*Lumens*	lm/W	*lm/W*	K	CRI
Mercury Vapor Lamps								
100	HR100DX38 Deluxe White	24 000	4200	*3200*	42.0	*32.0*	3900	50
175	HR175DX39 Deluxe White	24 000	8600	*7200*	49.1	*41.1*	3900	50
250	HR250DX37 Deluxe White	24 000	12 100	*9800*	48.4	*39.2*	3900	50
400	HR400DX33 Deluxe White	24 000	22 500	*17 500*	56.3	*43.8*	3900	50
1000	HR1000DX34 Deluxe White	16 000	62 000	*47 700*	62.0	*47.7*	3900	50
Metal Halide								
100	MVR100/U/MED Clear	15 000	8100	*5750*	81.0	*57.5*	4000	75
	MVR100/C/U/MED Coated	15 000	7600	*4850*	76.0	*48.5*	4000	75
175	MVR175/U Clear	10 000	14 000	*10 350*	80.0	*59.1*	4000	65
	MVR175/C/U Diffuse	10 000	13 200	*9750*	75.4	*55.7*	3900	70
250	MVR250/U Clear	10 000	21 000	*17 000*	84.0	*68.0*	4200	65
	MVR250/C/U Diffuse	10 000	19 800	*16 000*	79.2	*64.0*	3900	70
400	MVR400/U Clear	20 000	36 000	*28 800*	90.0	*72.0*	4000	65
	MVR400/C/U Clear	20 000	33 900	*27 100*	84.8	*67.8*	3700	70
1000	MVR1000/U Clear	12 000	110 000	*88 000*	110.0	*88.0*	4000	65
	MVR1000/C/U Clear	12 000	105 000	*79 800*	105.0	*79.8*	3400	70
High-Pressure Sodium								
100	LU100 Clear	24 000	9500	*8550*	95.0	*85.5*	2000	22
150	LU150/MED Clear	24 000	16 000	*14 400*	106.7	*96.0*	2000	22
200	LU200 Clear	24 000	22 000	*19 800*	110.0	*99.0*	2100	22
250	LU250 Clear	24 000	28 000	*27 000*	112.0	*108.0*	2100	22
310	LU310 Clear	24 000	37 000	*33 300*	119.4	*107.4*	2100	22
400	LU400 Clear	24 000	51 000	*45 000*	127.5	*112.5*	2100	22
1000	LU1000 Clear	24 000	140 000	*126 000*	140.0	*126.0*	2100	22
Mercury–Tungsten Blended Lamps								
160	MVT 160	6000	2400	*1920*	15.0	*12.0*	3500+/−	63
160	MVT 160	6000	2500	*2000*	16.0	*12.8*	3500+/−	63
160	MVT 160	6000	2900	*3625*	18.0	*14.4*	3500+/−	63
160	MVT 160	6000	3000	*2400*	18.75	*15.0*	3500+/−	63
160	MVT 160	6000	3100	*2480*	19.5	*15.6*	3500+/−	63
250	MVT 250	6000	5600	*4480*	22.5	*18.0*	3500+/−	62
250	MVT 250	6000	5800	*4640*	23.2	*18.6*	3500+/−	62
500	MVT 500	6000	14 000	*11 200*	28.0	*22.4*	3500+/−	50
500	MVT 500	6000	14 200	*11 360*	28.5	*22.8*	3500+/−	50

SOLID-STATE LIGHTING

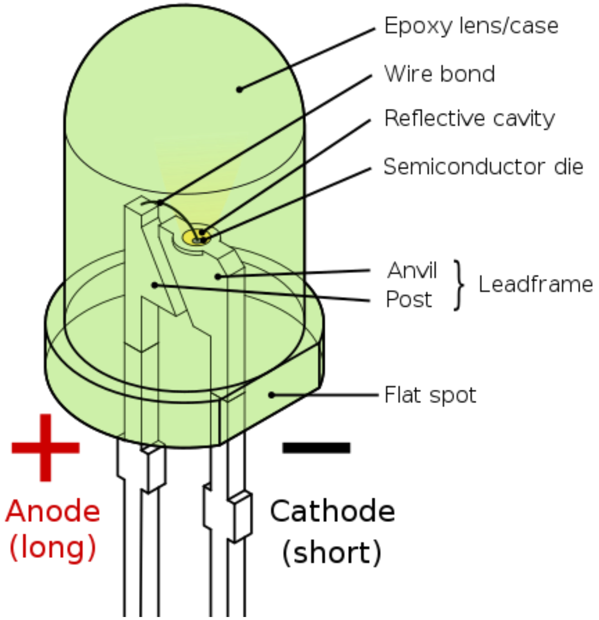
– refers to a type of lighting that uses *light-emitting diodes (LEDs), organic light-emitting diode lights (OLEDs), or polymer light-emitting diodes (PLEDs)*

- **Light-Emitting Diodes**

– semiconductor that consists of a chip of semiconducting material treated to create a structure with two electron-charged electrons.

– an individual chip emits light in a specific wavelength, so the light source is near monochromatic.

– The specific wavelength or color emitted by an LED depends on the materials used to make the diode.



- Red LED's are based on aluminum gallium arsenide (AlGaAs);
- Blue LED's are from indium gallium phosphide (InGan); and
- Green LED's are from aluminum gallium phosphide (AlGaP)

- The specific wavelength or color emitted by an LED depends on the materials used to make the diode.
  - White light can be achieved with LEDs in two main ways :
    1. Phosphor conversion, in which a blue or near-UV chip is coated with phosphor(s) to emit white light: and
    2. RGB systems, in which light from multiple monochromatic LEDs (red, green, and blue) is mixed, resulting in white light.
- are vibration and shock resistant
- have no moving parts, no fragile glass, no mercury, no toxic gasses, and no filament
- not subject to sudden failure or burnout and have an exceptionally long life (50 000+ to 100 000 hours)
- gradually degrade in performance over time
- low voltage and cool to touch
- emit light in a specific focused direction, reducing the need for reflectors and diffusers that can trap light
- well suited for decorative and accent lighting such as that found in retail stores, theaters, and restaurants.

MERCURY CONTENT OF LAMPS

- Fluorescent and HID lamps have some mercury content.
- These may need to be recycled or disposed of in hazardous waste landfills instead of municipal solid waste landfills under the U.S. Resource Conservation and Recovery Act.

4.7 FORMS OF ARCHITECTURAL LIGHTING

ARCHITECTURAL LIGHTING

– Good architectural lighting is crucial to the performance of everyday activities and to the appreciation of the built environment.

Basic functions of light in interior building spaces:

- Ambient Lighting
- Local Lighting
- Accent Lighting
- Decorative Lighting

Ambient Lighting

- Sometimes called "**general lighting**"
- Provides uniform illumination throughout the space
- Illumination for color and texture.

Local Lighting

- Sometimes called "**task lighting**"
- Illumination provided for specific visual function
- Can influence the effectiveness of the individual performing the task

Accent Lighting

- Is directional lighting used to emphasize a particular object or area
- Emphasizing a particular architectural feature, piece of artwork, photograph, or plant

Decorative Lighting

- Light source that adds a quality of interest to the space
- Combines with other types of lighting to give an overall "feel" to a room that serves little purpose other than to look attractive

EMERGENCY & SAFETY LIGHTING

– Is a secondary lighting system that provides **backup illumination** when the power supply to the normal lighting system is interrupted.

These includes:

- Emergency Lighting
- Stand-by Lighting
- Safety Lighting
- Escape Lighting
- Exit Lighting

Emergency Lighting

- Required in the critical care and emergency spaces found in hospitals, police, fire protections and crisis management areas.

Stand-by Lighting

- Enables normal activities to continue substantially unchanged.
- Powered by an emergency generator or battery backup system

Safety Lighting

- Ensures the safety of people involved in a potentially hazardous process

Escape Lighting

- To ensure that an escape route can be effectively identified and used in case of failure of normal lighting system

Exit Lighting

- Illuminated signage used to provide clear directions for an emergency exit of building occupants

4.8 LIGHTING INSTALLATION

TRADITIONAL LIGHTING INSTALLATION

- There are many types of luminaires and lighting installations that can illuminate a building space or highlight a centerpiece.

TABLE 20.14 COMMON TYPES OF LUMINAIRES.

Indoor

Adjustable accent
Bath/vanity
Cabinet
Cable/rail
Chandelier
Cornice
Cove
Decorative
Demanding environment
Desk
Downlight
Exit/emergency
Floodlight
Floor Lamps
Fluorescent linear
Fluorescent troffer
Track
Wallwasher
Valance
Workstation panel mount
Uplight
Undercabinet
Fluorescent wraparound
High bay
Industrial fluorescent
Inspection/task
Low bay
Pendent
Recessed
Sconce
Showcase/display
Sports
Spotlight
Table lamps

Outdoor

Area post mount
Area wall mount
Canopy mount
Floodlighting
High mast
Landscape low mount
Landscape specialty
Pathway
Parking garage
Parking lot
Road work
Sign lighting
Sports
Street

Specialty

Entertainment/stage
Fiber optics
Light pipe
Linear (rope, tube, string)

Common Types of Luminaire

- **Pendent**
  - a luminaire that is hang with a cord, chain, or tube that enables it to be suspended from a ceiling or other support. It broadcasts light over the entire space.

- **Uplight**
  - is a luminaire where a shielded light source directs its light to the ceiling, where it is reflected back to the space.

- **Downlight**
  - a luminaire that is usually attached to or recessed in the ceiling and emits a concentrated light downward.

PHOTO 20.8 A decorative pendent light suspended from a ceiling, which provides ambient lighting. (Used with permission of ABC)

PHOTO 20.10 An HID uplight luminaire. (Used with permission of ABC)

PHOTO 20.11 An HID uplight installation providing ambient lighting in a gymnasium. (Used with permission of ABC)

- **High Hat**
  - a type of downlight that is a recessed, canister-shaped luminaire with a shielded lamp that emits light downward.

- **Recessed Luminaires**
  - are mounted above the ceiling or behind a wall or other surface so that any visible projection of light is insignificant.

PHOTO 20.13 A recessed light fixture during construction. After it is secured to the joists, placement of the fixture can be adjusted (left to right). (Used with permission of ABC)

- **Scones**
  - a decorative, wall-mounted luminaires that provide ambient illumination. They can direct light upward, downward, or in all directions.

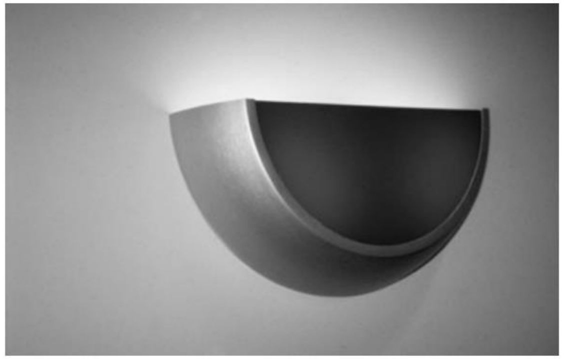
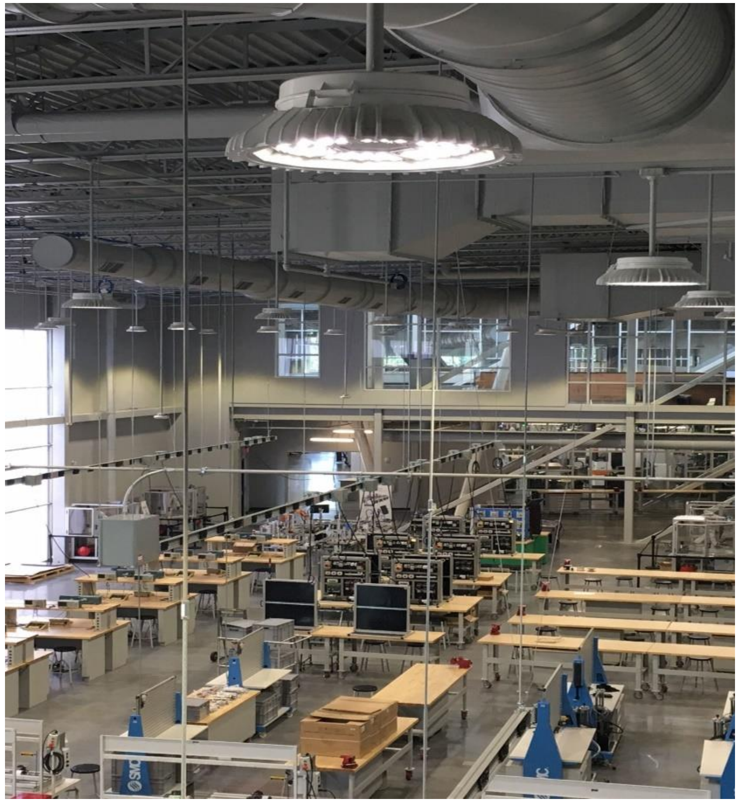


PHOTO 20.15 A decorative wall sconce. (Used with permission of ABC)

- **High Bay Luminaires**
  - are used in high-ceiling areas, 20 ft (6 m) or higher, that require uniform illumination. High bay fixtures installed in a grid pattern are typically used to provide ambient illumination in warehouses, gymnasiums, and retail superstores. These luminaires are high wattage (200 W or more) so they can deliver light over long distances. The fixture size is fairly large, about 2 ft (0.6 m) for a typical fixture.



- **Low Bay Luminaires**
  - are more compact. They are designed for use in low- to medium-ceiling areas, 12 to 20 ft (3 to 6 m). They are typically used for general illumination in offices, retail spaces, and loading dock areas. Both high bay and low bay luminaires can be used in up lighting and downlighting applications.

PHOTO 20.16 A low-bay HID luminaire. (Used with permission of ABC)

- **Spotlight**
  - is a luminaire that is designed to emit an intense, concentrated beam of light with usually no more than a 20° divergence (spread) from where it is directed.

- **Floodlight**
  - a luminaire that emits an intense light that is broader than a spotlight and that is capable of being pointed in any direction.

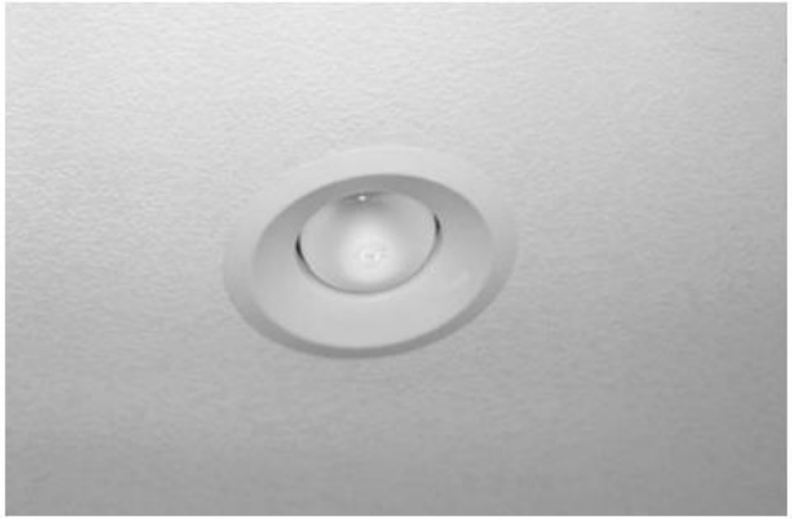
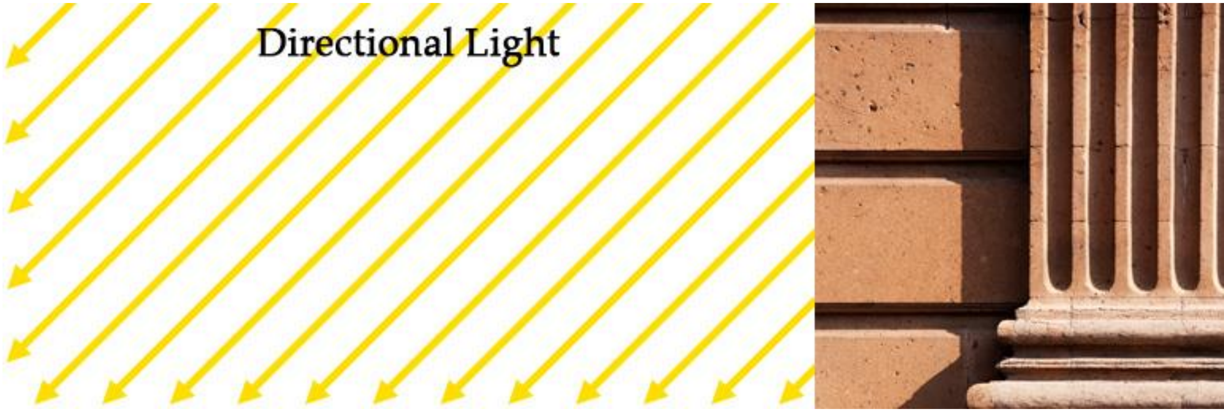


PHOTO 20.17 A surface-mounted floodlight luminaire. (Used with permission of ABC)

Common Lighting Installation

- **Directional Lighting**
  - is illumination where light received at the work plane or light illuminating an object is incident predominantly from a particular direction. The only light that is important is the light that falls where it is needed. Spot, flood, and track lighting are common types of directional lighting.

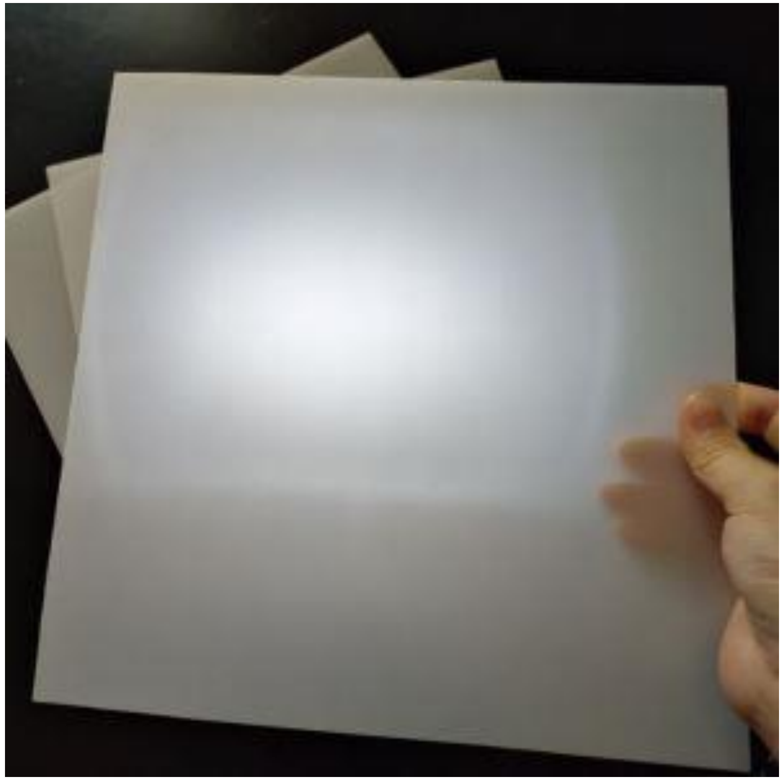


- **Track Lighting**
  - a directional lighting installation where luminaires are attached to and are moveable along a metal track. A more subtle method of directional lighting involves the use of one of the many different recessed downlights.

PHOTO 20.18 A track lighting installation. (Used with permission of ABC)

- **Diffused Lighting**
  - is a lighting installation in which the light on the working plane or on an object is not incident predominantly from a particular direction. Diffused light is cast and disbursed over a large area.

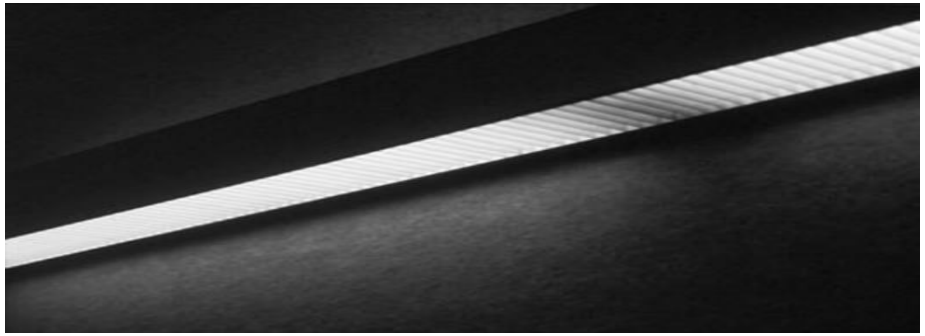
- **Diffuser**
  - is a lighting component such as a translucent glass refractor that redirects or scatters the light from a source. This type of lighting can be produced by a variety of *indirect lighting* techniques, where much of the light reaches the work plane after it has reflected off another surface such as a wall or ceiling. Diffused lighting is frequently used to provide soft, background lighting.



- **Cornice Lighting**
  - a lighting installation where the light source is shielded by a panel that is parallel to the wall and attached to the ceiling; it distributes light over the wall.

- **Cove Lighting**
  - an uplighting installation where the light source is shielded by a ledge or recess with light dispersed over the ceiling and upper wall.

- **Valance Lighting**
  - a lighting installation where the light source is shielded by a panel that is parallel to the wall at the top of a window



- **Fluorescent Lighting**
  - widely used for general lighting installations in buildings.

- **Fluorescent Luminaires**
  - Fluorescent luminaires are available in recessed, surface-mounted, or pendent style fixture designs. Unlike the concentrated light emitted by other commercially available light sources, fluorescent lamps produce a diffuse light that is relatively glare free and visually comfortable. As a result, they have been and continue to be the standard for ambient illumination for classroom and office lighting installations.

PHOTO 20.9 A linear fluorescent uplight used to provide ambient lighting in a library. (Used with permission of ABC)

Fluorescent luminaires can be…

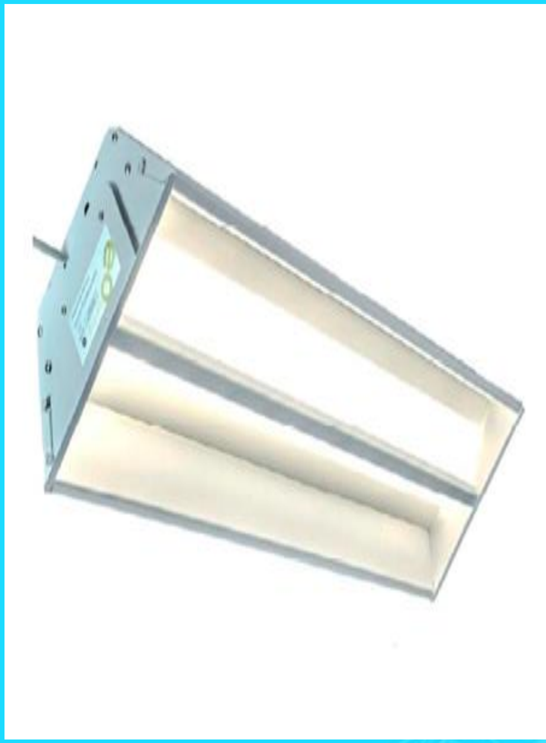
- **Lensed**
  - have a flat lens to diffuse the light.
- **Parabolic Louvered**
  - have parabolic-shaped reflectors and open louvers to direct the light downward.

PHOTO 20.22 Recessed linear fluorescent luminaries with deep-cell parabolic louvers. Louvers create openings for emitting light and reflect light from the fixture, which reduces glare. (Used with permission of ABC)

- **Wraparound**
  - have a lens that wraps around the lamps to diffuse and direct the light outward.

PHOTO 20.20 A linear fluorescent luminaire with prismatic wraparound lens that diffuses light. (Used with permission of ABC)

- A ***troffer*** is a linear luminaire constructed of an inverted metal trough that serves as a fixture for fluorescent lighting lamps. It is usually installed with the opening flush with the ceiling.



Fluorescent luminaires can be incorporated in a luminous ceiling that is constructed of open fluorescent luminaires mounted above a translucent suspended ceiling. They can also be used in a strip installation consisting of rows of bare-bone fixtures with exposed lamps.

- **New Lamp and Luminaire designs** – Offer excellent lighting and solutions to specific lighting problems.

- **Halogen and Compact fluorescent lamps** – small, offer low maintenance, and have excellent light and color qualities.

- **Metal Halide Lamp** – good color rendering qualities and work well in spaces with high ceiling.

- **High Pressure Sodium (HPS) Lamps** – used when color rendition is not important such as factories and warehouse.

- **Low Pressure Sodium (LPS) Lamps** – are rarely used in building interiors because they produce a monochromatic yellow light that renders even the most vibrant colors in the shade of yellow.

Incandescent, Halogen, and ***High-intensity Discharge (HID) lamps*** produce a very intense light, a direct view of the lamp can be extremely irritating. Even with diffusion globes or lenses, the light can be very intense.

Hazardous Areas

Hazardous Location such as paint spray booths, flammable chemical areas, refinement plants and corrosive area has a specific type of luminaries approve for this area. The agency such as Underwriters Laboratory, Inc. (UL), tests and lists the approve fixtures for a specific types of use. Special fixtures and lamps are also required when a luminaire will be used in installations involving extreme temperatures.

REFLECTOR LAMPS

– Are incandescent, compact fluorescent or HID lamps with a built-in reflecting surface. HID and Incandescent versions are made from a single piece of bowl-molded soft or hard glass. Compact fluorescent versions may be one piece or designed so that the inner lamp can be replace.

Two types of Reflector Lamp:

- **Elliptical Reflector (ER) Lamp** – Incandescent lamp with an elliptically shaped reflector. Particularly effective at increasing efficiency of baffled-down lights.

- **Parabolic Aluminized Reflector (PAR) Lamp** – That may use an incandescent filament, halogen filament tube, or HID arc tube, is a pressed-glass reflector lamp. Relay on both internal reflector and prisms in the lens for the control of the light beam.

REMOTE-SOURCE LIGHTING INSTALLATIONS

– Is an advance lighting technology that transports light from a single source over a distance to one or more light outlets emits light evenly along the way. It is more costly than traditional lighting installations. Use in decorations and gives healthy and safety benefits it releases less ultraviolet energy and infrared. However, RSL is less energy efficient than conventional systems.

Two Systems of RSL:

- **Fiber optic RSL systems**- is a set of reflectors, filters, and lenses to fed the light of fiber optic cables and a fixture to distribute the light at the point of illumination. The number of fixtures depends on the intensity of the light source.

- **Light pipe RSL systems**- a hollow tube with a reflective inner surface that directs light through the tube. The most common linings are prismatic films and mirrored surface.

4.9 LIGHT DISTRIBUTION AND GLARE

DISTRIBUTION OF LIGHT

Candlepower (Candela) Distribution Curve

- is a graphical representation that illustrates the luminous intensity around the cross- section of a lamp or luminaire.
- It is a curve on a polar graph that shows the relative luminous intensity, in candela, around the lamp or luminaire
- A cross-sectional map of intensity (candelas) measured at many different angles. It is a two-dimensional representation and therefore shows data for one plane only.
- The heavy, dark line in the curve represents luminous intensity at various positions beneath the luminaire opening.
- If the distribution of the unit is symmetric:
  - the curve in one plane is sufficient for all calculations.
- If the distribution of the unit is asymmetric:
  - such as with street lighting and fluorescent units, three or more planes are required.

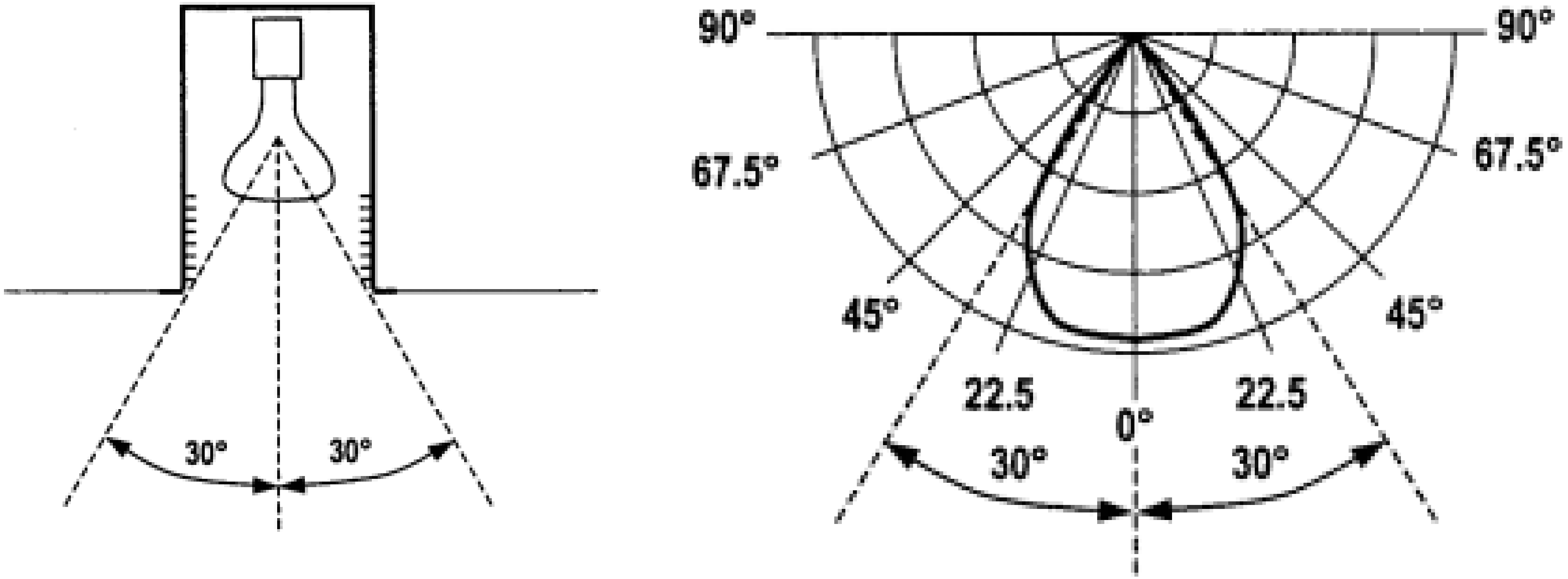


FIGURE 20.13 A candela (candlepower) distribution curve is a polar graph that represents the luminous intensity of a lamp or luminaire at measured horizontal distances and vertical angles. The heavy, dark line in the curve represents luminous intensity at various positions beneath the luminaire opening.

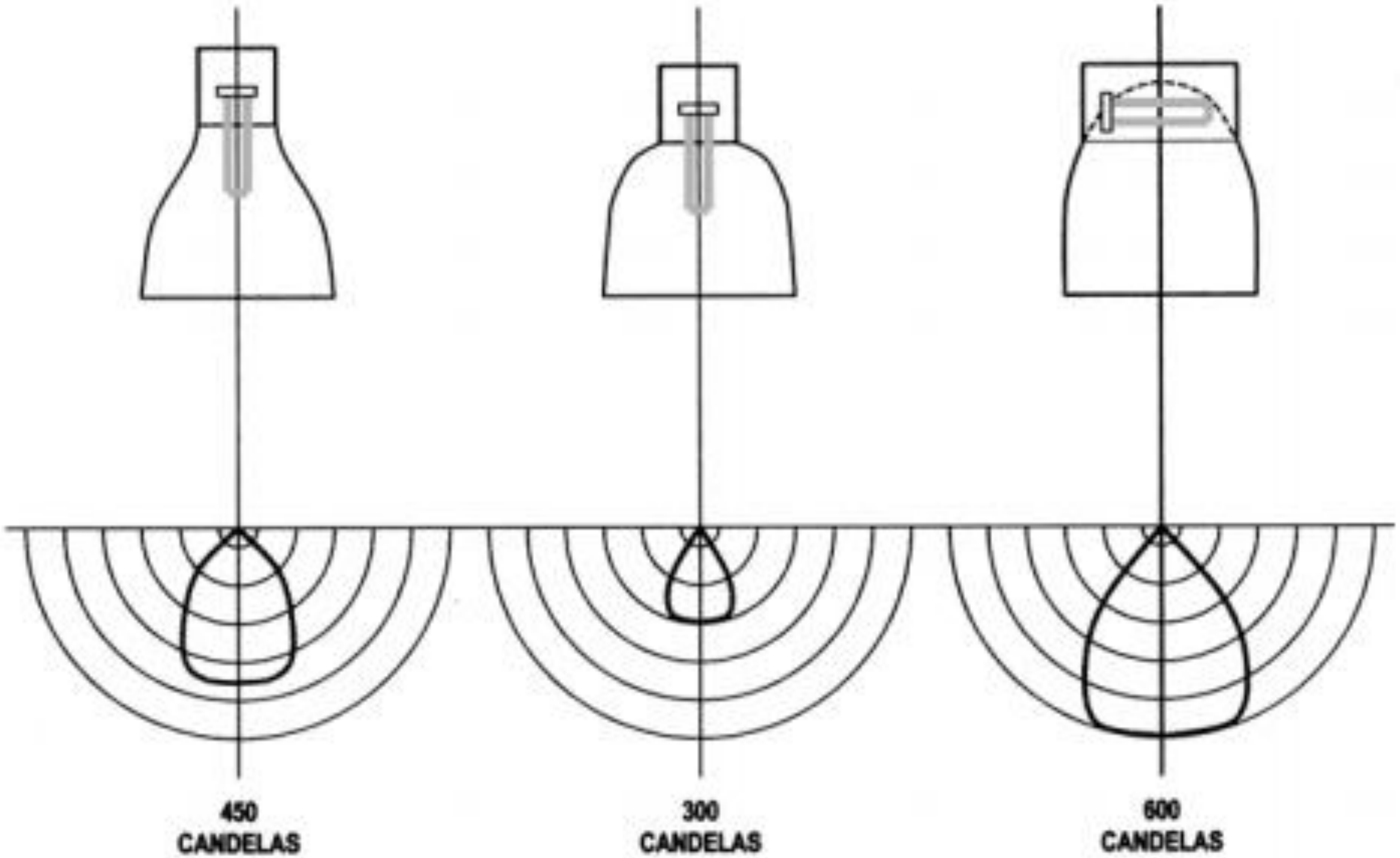


FIGURE 20.14 Shown are candlepower (candela) distribution curves for three different compact fluorescent luminaires. Candlepower distributions are one of the basic ways of comparing lighting system performance.

Categories of Light Distribution Produced By Luminaires:

- **Direct**
  – 90 to 100% of the light is directed downward for maximum use
- **Indirect**
  – 90 to 100% of the light is directed to the ceilings and upper walls and is reflected to all parts of a room or 90 to 100% of the light is directed downward for maximum use.
- **Semidirect**
  – 60 to 90% of the light is directed downward with the remainder directed upward
- **General diffuse/ direct-indirect**
  – Equal portions of the light are directed upward and downward
- **Highlighting**
  – Beam projection distance and focusing ability characterize this luminaire

GLARE

- Is excessive brightness in the field of vision that causes discomfort or, in extreme cases, produces a disability from a temporary loss of vision.
- It is a visual sensation caused by luminance that is sufficiently greater than the luminance to which the eyes are adapted.
- Glare can be an irritant of or impediment to vision. To prevent the design of lighting installations that produce discomfort, the visual comfort probability is calculated.

Visual Comfort Probability (VCP)

- is a rating of a lighting installation expressed as a percentage of individuals who, when viewing from a specified location and in a specified direction, will be expected to find it acceptable in terms of discomfort glare.
- In most spaces, the VCP should exceed %; that is, at least 70% of a statistical group of individuals will rate glare levels acceptable in the space being illuminated.
- Guidelines from the Illuminating Engineering Society of North America (IESNA) are used to compute the VCP.

Types of Glare:

- **Discomfort glare**
  - causes visual discomfort without necessarily impairing vision.
- **Disability glare**
  - occurs when visibility is impaired from excessive brightness.
- **Direct glare**
  - occurs when excessive light enters the eye directly from a light source.
- **Reflected glare**
  - the result of light entering the eye after reflecting off a glossy surface. A common type is called a veiling reflection: the reflection on a glossy surface that impedes seeing such as the reflection on a computer screen or on a glossy sheet in a magazine.

GLARE CONTROL

- Preventing glare requires special attention to fixture design, selection, and position to prevent light from entering the glare zone.
- Glare Zone - a zone above a 45° angle from the fixture’s vertical axis.
- When light is emitted into the glare zone, direct glare and reflected glare are likely, so light emitted in the glare zone can cause visual discomfort.
- Positioning and selecting light fixtures that do not throw light in the glare zone is a good way to reduce problems with glare.
- In small spaces, indirect lighting techniques consisting of cornice, cove, and valance lighting installations diffuse light well and prevent glare.
- As a shielded light source, an uplight directs its light to the ceiling, where it is reflected back to the space

GLARE CONTROL

- Uplights also prevent glare and work well in larger spaces such as gymnasiums and conference spaces.
- Properly designed downlights use baffles to prevent light from being thrown into the glare zone.
- Most linear fluorescent fixtures use either a lens or a louver to prevent direct viewing of the lamps so direct glare is prevented.

Lenses

- typically made from clear UV-stabilized plastics.
- Clear lens types include prismatic, batwing, linear batwing, and polarized lenses
- White translucent diffusers are much less efficient than clear lenses, and they result in relatively low visual comfort probability.
- New low-glare lens materials are available for retrofit and provide high visual comfort (a VCP of 80 or more) and high efficiency.
- Lenses are usually much less expensive but they provide less glare control than louvered fixtures.

Louvers

- slats in a light fixture that create openings for emitting light
- Louvers provide superior glare control and high visual comfort compared with lens-diffuser systems.
- The most common application of louvers is to eliminate the fixture glare reflected on computer screens.
- Deep-cell parabolic louvers (with 5 to 7 in cell apertures and depths of 2 to 4 in) provide a good balance between visual comfort and luminaire efficiency
- luminaire efficiency to about 40%. A disadvantage of the deep-cell louver is that it adds 2 to 4 in to the overall depth of a luminaire.

Baffles

- Opaque or translucent elements that shield a light source from direct view. They are typically part of the light fixture.
- Baffles prevent the light source from throwing light beyond a 30° angle from the fixture’s vertical axis.
- Keeps the light from being broadcast into the glare zone.

4.10 ILLUMINANCE AND LUMINANCE

- ***Illuminance*** is the amount of light incident on (striking) a surface.
- ***Luminance*** is the amount of light leaving an object, thus relating to how bright an object appears to the human eye.
- An object may be illuminated, but the eye cannot see it without visible light leaving (reflecting off) the object in the direction of the viewer.
- The luminance of a surface is equal to the reflected illuminance.

LUMINANCE

- a luminous intensity of a surface in a given direction per unit of projected area of the surface.

Luminance can be expressed in two ways:

- candelas per unit area
- lumens per unit area
- *Candela per square inch (cd/in2)*
- *foot lambert* (luminance of a surface emitting one lumen per square foot)
- *lambert* (luminance of a surface emitting one lumen per square cm)

The relationships behind these units of measurement are:

1 cd/in2 = 452 foot lamberts

1 lambert = 929 foot lamberts 2.054 cd/in2

ILLUMINANCE

- It is the density of luminous flux striking a surface.
- It describes how bright a surface *may* appear to the human eye depending upon the surface's reflectance.
- The appropriate units of measurement for illuminance are the foot-candle and lux.

❖***foot-candle (fc)*** - unit of measure of illuminance (E), the intensity of light falling on a surface. It is equal to one lumen of light uniformly illuminating a surface over an area of one square foot:

- 1 fc = 1 lm/ft2

- foot-candle, the oldest physical unit still in common use, was originally defined as the illuminance striking a surface held one foot away from a burning beeswax candle.
- Foot-candles incident on a surface are related to the lumens (lm) striking the surface and the area of the surface (A), in ft2:
  - E = lm/A

lux (lx)

- The SI (metric) unit for illuminance, which is one lumen of light uniformly illuminating a one square meter surface (lm/m2).
- Lux incident on a surface are related to the lumens (lm) striking the surface and the area of the surface (A), in m2: E lm/A.

- One foot-candle is roughly equal to 10 lux:

foot-candle (fc) = 10.764 lx

lux = 0.0929 fc

- By comparison, natural sunlight illuminates a surface 100 000 times more than light cast by a full moon on clear night.

TABLE 20.16 TYPICAL VALUES OF ILLUMINANCE FOR SELECTED CONDITIONS

Condition	Approximate Illuminance	
	Foot-Candles	Lux
Light cast by full moon on clear night	0.1	1
Street lighting	1	10
Work space lighting	10 to 100	100 to 1000
Lighting for surgery	1000	10 000
Natural sun light on clear day	6 000	60 000

RECOMMENDED ILLUMINANCE

- Large lighting installations that consumes lot of energy (electricity and cooling) or too much lighting that is not necessary in a building interior should be avoided.
  - it is wasteful because of higher investment (cost), maintenance, and energy.
- Cost that is enough to light is better.

LIGHT OUTPUT VS LIGHT INTENSITY

- **Light Intensity** (measured in foot-candles) or in terms of **lumens** per square meter **or** lux.
- **Light Output** is measured in lumens

- IESNA Divides The Level of Illuminance into 9 categories, each with 3 ranges of illuminance.

For example, the three ranges for a conference room are cited as 20-30-50 fc (200-300-500 lx). The three ranges of illuminance are based on occupant age, room surface reflectance (greater 70%) or younger occupants (age under 40) require less lighting , so the lower value of the three ranges is used.

Illuminance Categories are ranked in alphabetical order (A through I):

- ***Categories A through C*** have ranges of illuminance from 2-3-5 to 10-15-20 fc (20-30-50 to 100-150-200 lx). For ambient lighting in public and working spaces.
  - *Ex. Corridors, lobbies, stairs, and conversation areas (e.g restaurants and exhinition areas)*

- ***Categories D through F*** have ranges of illuminance from 20-30-50 to 100-150-200 fc (200-300-500 to 1000-1500-2000 lx). For common visual task requiring more difficulty.
  - *Ex. Classrooms, office and drafting areas, laboratories, and kitchen areas*

- ***Categories G through I*** have ranges of illuminance from 200-300-500 to 1000-1500-2000 fc (2000-3000-5000 to 10000-15,000-20,000 lx). For prolonged, visually demanding task.
  - *Ex. Sewing, precision machining, surgery.*

In General, recommended lighting levels increase as the size and contrast of the visual task decrease.

Thus, the recommended lighting level will be near the lower level of the range when the size and/or contrast of the visual task is large and will be near the upper level of the range when the size and/or contrast of the visual task is small

TABLE 20.17 RECOMMENDATIONS FOR LEVELS OF LIGHTING IN VARIOUS SPACES.

Space or Area	Foot-Candles	Lux
Schools		
Corridors	20	200
Auditoriums	20 to 30	200 to 300
Study halls	70 to 80	700 to 800
Classrooms	70	700
Whiteboard area	150	1500
Drafting rooms	80 to 100	800 to 1000
Laboratories	80	800
Art rooms	100	1000
Sewing rooms	120 to 150	1200 to 1500
Shop areas	100	1000
Gymnasium	50	500
Stores		
Circulation areas	30	300
Merchandise areas	100 to 150	1000 to 1500
Showcases	150 to 200	1500 to 2000
Industrial		
General lighting	30 to 50	300 to 500
Laundries	30 to 50	300 to 500
Locker rooms	30	300
Machines, rough	40 to 50	400 to 500
Machines, fine	80 to 100	800 to 1000
Intricate work	150 to 400	1500 to 4000
Assembly areas	50 to 100	500 to 1000
Theaters		
Entrance, lobby	30 to 40	300 to 400
Foyer	30 to 40	300 to 400
Auditorium	10	100
Post Office		
Lobby	30	300
Mail sorting area	100	1000
Corridors and storage	30	300

4.11 PRINCIPLES OF LIGHTING DESIGNS

BASIC DESIGN APPROACH

- Proper design of a lighting installation requires use of two calculating procedures:
  - Computing illuminance from a point source
  - Computing average illuminance levels
- Calculation of illuminance at specific points in a lighting installation is done to evaluate lighting uniformity, especially when using luminaires where maximum spacing recommendations are not supplied or where task lighting levels must be confirmed.

Symbols Used in Lighting and Electrical System Design

Electrical Design

- **E** is commonly used for Voltage
- **I** for amperage

Lighting design

- **E** is used as a symbol for illuminance
- **I** is the symbol for luminous intensity

COMPUTATIONS FOR ILLUMINANCE FROM A SINGLE POINT SOURCE

- Computing illuminance from a point is complex and generally involves computer analysis.
- The intensity of light traveling away from a source decreases as it gets farther from the source.
- A beam of light spreads over a larger area as the plane (surface) being illuminated is held farther away from the light source.
- Illuminance (E) is the density of luminous flux, the intensity of light on a surface.
- The illuminance of a surface decreases as the surface gets farther from the light source.

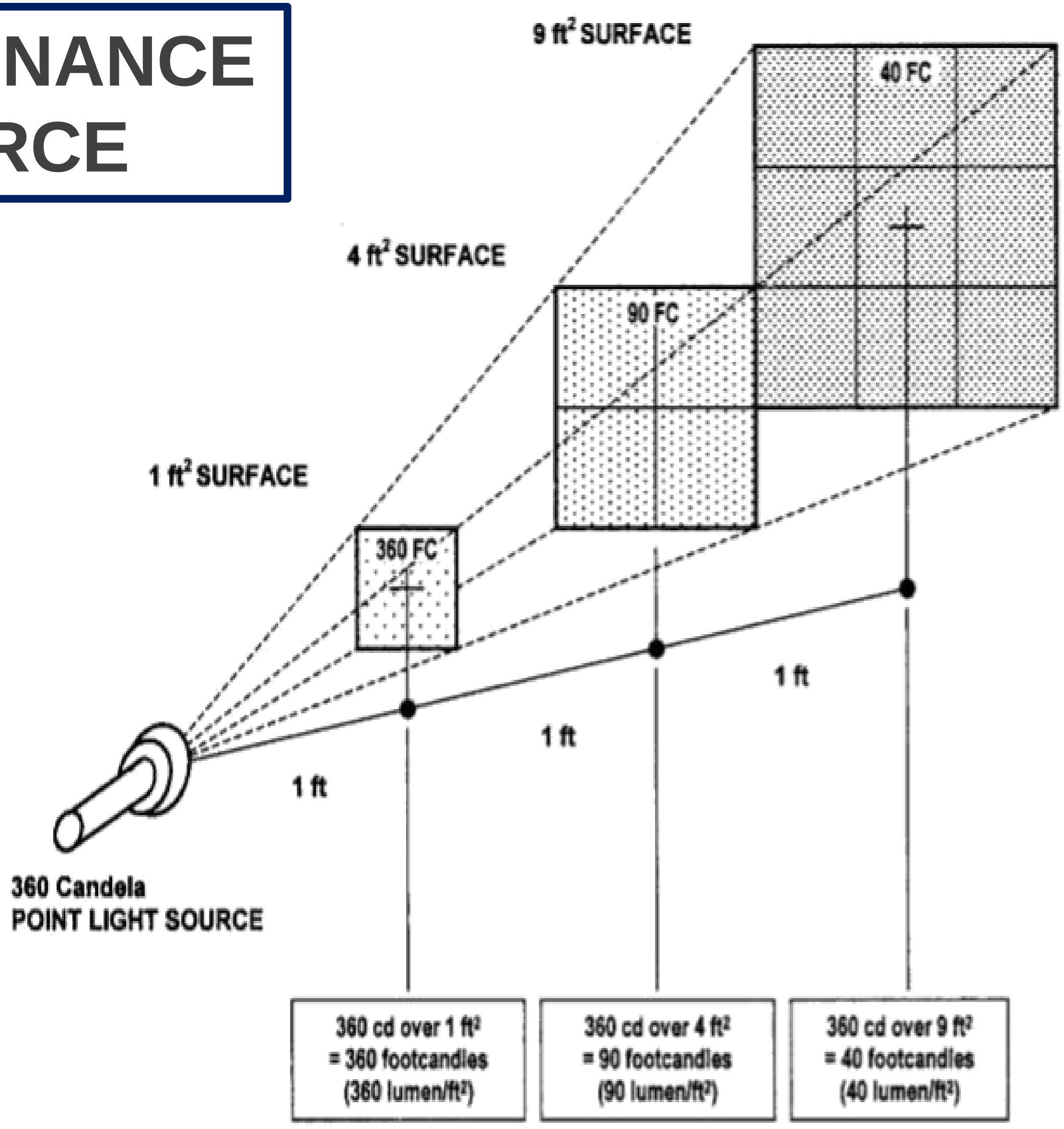


FIGURE 20.15

- **Inverse square law –** states that the illuminance at a point on a plane perpendicular to the line joining the point and a source is inversely proportional to the square of the distance between the source and the plane.

$$\mathbf{E = I/d^2}$$

- **Cosine law of incidence – states** that illuminance (E) at a point on a plane is proportional to the cosine of the angle of light incidence, where the angle of light incidence is measured between the direction of the incident light and the normal to the plane of the surface.

$$\mathbf{E = (I/\boldsymbol{d}^2)\cos\boldsymbol{\theta}}$$

Average Illuminance Level at the Work Plane

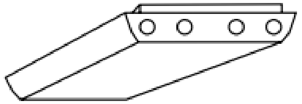
- **Target illumination –** average illuminance at a reference work plane.
- **Work plane –** usually horizontally positioned, at which work is performed and on which the illuminance is specified and measured.
  - 15 fc may be acceptable on the floor of a lobby
  - 30 fc on a table in a conference room
  - 75 fc on tables in a drafting production area

CALCULATING AVERAGE ILLUMINANCE LEVELS

- The ***zonal cavity method*** is the currently accepted method for calculating average illuminance levels for indoor areas unless the light distribution is extremely asymmetric. The basic principle behind this method is that foot-candles at the work plane are equal to flux over the work plane.

There are four basic steps in any calculation of illuminance level:

1. Determine cavity ratio (CR)
2. Determine effective cavity reflectance's
3. Select coefficient of utilization
4. Compute average illuminance level

Surface Prismatic Wraparound Fluorescent Luminaire (Four Lamps)														
		Reflectance	Coefficient of Utilization (CU)											
	Spacing Criteria (CS)	Ceiling cavity (ρ_{cc})	80			50			30			10		
		Wall Surfaces (ρ_w)	50	30	10	50	30	10	50	30	10	50	30	10
4 Linear Fluorescent Lamps		Cavity Ratio (CR)												
	1.5⊥ 1.2‖	10	.26	.21	.17	.24	.19	.16	.22	.18	.15	.21	.17	.17
		9	.29	.23	.19	.26	.22	.18	.25	.21	.18	.23	.20	.17
		8	.31	.27	.23	.29	.25	.21	.28	.24	.21	.26	.23	.20
		7	.35	.29	.26	.32	.28	.25	.30	.27	.24	.29	.26	.23
		6	.39	.33	.29	.36	.31	.29	.33	.29	.25	.31	.29	.26
		5	.44	.38	.34	.39	.35	.32	.37	.33	.30	.35	.31	.29
		4	.48	.44	.39	.44	.40	.37	.41	.38	.35	.39	.36	.33
		3	.54	.49	.46	.48	.46	.43	.46	.43	.40	.43	.40	.38
		2	.61	.56	.53	.54	.51	.48	.50	.58	.47	.47	.46	.44
		1	.67	.66	.63	.61	.59	.57	.56	.55	.53	.52	.51	.50
		0	.76	.76	.76	.67	.67	.67	.63	.63	.63	.57	.57	.57

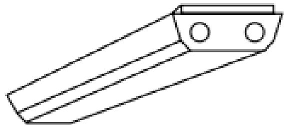
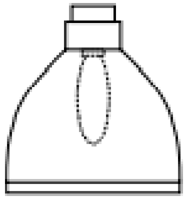
Surface Prismatic Wraparound Fluorescent Luminaire (Two Lamps)														
		Reflectance	Coefficient of Utilization (CU)											
	Spacing Criteria (CS)	Ceiling Cavity (ρ_{cc})	80			50			30			10		
		Wall surfaces (ρ_w)	50	30	10	50	30	10	50	30	10	50	30	10
2 Linear Fluorescent Lamps		Cavity Ratio (CR)												
	1.5⊥ 1.2‖	10	.27	.22	.18	.25	.20	.17	.23	.19	.16	.22	.18	.18
		9	.30	.24	.20	.27	.23	.19	.26	.22	.19	.24	.21	.18
		8	.33	.28	.24	.30	.26	.22	.29	.25	.22	.27	.24	.21
		7	.37	.31	.27	.34	.29	.26	.32	.28	.25	.30	.27	.24
		6	.41	.35	.31	.38	.33	.30	.35	.31	.26	.33	.30	.27
		5	.46	.40	.36	.41	.37	.34	.39	.35	.32	.37	.33	.31
		4	.51	.46	.41	.46	.42	.39	.43	.40	.37	.41	.38	.35
		3	.57	.52	.48	.51	.48	.45	.48	.45	.42	.45	.42	.40
		2	.64	.59	.56	.57	.54	.51	.53	.61	.49	.49	.48	.46
		1	.71	.69	.66	.64	.62	.60	.59	.58	.56	.55	.54	.53
		0	.80	.80	.80	.71	.71	.71	.66	.66	.66	.60	.60	.60

FIGURE 20.16 Coefficients of utilization for selected fixtures.

High Bay Intermediate-Distribution Reflector HID Luminaire														
	Spacing Criteria (CS)	Reflectance	Coefficient of Utilization (CU)											
		Ceiling Cavity (ρ_{cc})	80			50			30			10		
		Wall Surfaces (ρ_w)	50	30	10	50	30	10	50	30	10	50	30	10
1 HID Lamp		Cavity Ratio (CR)												
	1.0	10	.38	.33	.29	.37	.32	.29	.36	.32	.29	.35	.31	.28
		9	.41	.36	.31	.40	.35	.32	.39	.35	.32	.38	.35	.32
		8	.45	.40	.36	.44	.39	.36	.43	.39	.35	.46	.42	.39
		7	.50	.44	.45	.52	.48	.45	.51	.47	.44	.50	.47	.44
		6	.54	.49	.45	.52	.46	.45	.51	.47	.44	.50	.47	.44
		5	.59	.54	.50	.57	.53	.50	.56	.52	.49	.54	.51	.48
		4	.65	.60	.56	.62	.58	.55	.60	.57	.54	.59	.56	.54
		3	.71	.66	.63	.67	.64	.61	.65	.62	.60	.63	.61	.59
		2	.77	.73	.70	.73	.70	.68	.70	.68	.66	.68	.66	.65
		1	.84	.81	.79	.79	.77	.76	.76	.74	.73	.73	.72	.71
		0	.91	.91	.91	.84	.84	.84	.81	.81	.81	.77	.77	.77

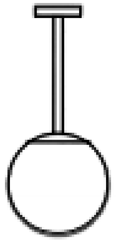
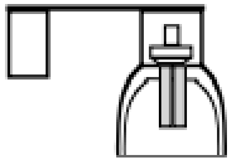
Sphere-Shaped Pendant Luminaire														
	Spacing Criteria (CS)	Reflectance	Coefficient of Utilization (CU)											
		Ceiling Cavity (ρ_{cc})	80			50			30			10		
1 Incandescent or Compact Fluorescent Lamp		Wall Surfaces (ρ_w)	50	30	10	50	30	10	50	30	10	50	30	10
		Cavity Ratio (CR)												
		10	.23	.17	.13	.19	.14	.10	.16	.12	.09	.13	.09	.07
		9	.26	.19	.15	.20	.15	.12	.17	.13	.10	.14	.11	.08
		8	.29	.22	.17	.23	.17	.14	.19	.15	.12	.15	.12	.09
		7	.32	.25	.20	.25	.20	.16	.21	.16	.13	.17	.13	.11
		6	.36	.28	.23	.28	.23	.19	.23	.19	.16	.19	.15	.13
		5	.40	.33	.27	.32	.26	.22	.26	.22	.19	.21	.18	.15
		4	.46	.38	.33	.36	.30	.26	.30	.26	.22	.24	.21	.18
		3	.52	.45	.39	.41	.36	.31	.34	.30	.28	.27	.24	.22
		2	.61	.54	.49	.47	.43	.39	.39	.36	.33	.32	.29	.27
		1	.71	.67	.63	.56	.53	.50	.47	.45	.43	.39	.37	.35
		0	.87	.87	.87	.69	.69	.69	.59	.59	.59	.49	.49	.49

FIGURE 20.16 *(Continued)*

Open Reflector Recessed Downlight Luminaire (Vertically Mounted Lamp)

1 Compact Fluorescent Lamp	Spacing Criteria (CS)	Reflectance	Coefficient of Utilization (CU)											
		Ceiling Cavity (ρ_{cc})	80			70			50			30		
		Wall Surfaces (ρ_w)	50	30	10	50	30	10	50	30	10	50	30	10
		Cavity Ratio (CR)												
	0.8	10	.42	.38	.36	.42	.38	.36	.41	.38	.36	.41	.38	.35
		9	.45	.41	.38	.45	.41	.38	.44	.41	.38	.44	.40	.38
		8	.48	.44	.42	.48	.44	.41	.47	.44	.41	.46	.43	.41
		7	.51	.48	.45	.51	.47	.45	.50	.47	.45	.49	.46	.44
		6	.55	.51	.49	.54	.51	.48	.53	.50	.48	.53	.50	.48
		5	.59	.55	.52	.58	.54	.52	.57	.54	.51	.56	.53	.51
		4	.62	.59	.56	.62	.59	.56	.60	.57	.55	.59	.57	.55
		3	.66	.63	.61	.65	.63	.60	.64	.61	.59	.62	.60	.58
		2	.71	.68	.66	.70	.67	.65	.67	.66	.64	.66	.64	.63
		1	.75	.74	.73	.74	.73	.71	.71	.70	.69	.69	.68	.67

Open Reflector Recessed Downlight Luminaire (Horizontally Mounted Lamp(s))

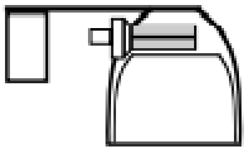
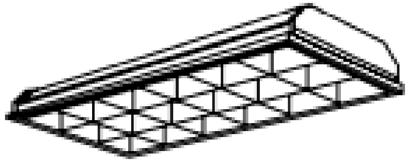
1 or 2 Compact Fluorescent Lamp(s)	Spacing Criteria (CS)	Reflectance	Coefficient of Utilization (CU)											
		Ceiling Cavity (ρ_{cc})	80			70			50			30		
		Wall Surfaces (ρ_w)	50	30	10	50	30	10	50	30	10	50	30	10
		Cavity Ratio (CR)												
	1.5	10	.31	.27	.24	.38	.27	.24	.30	.26	.24	.30	.26	.24
		9	.34	.30	.27	.41	.30	.27	.33	.29	.27	.33	.29	.27
		8	.38	.33	.30	.44	.33	.30	.37	.33	.30	.36	.32	.30
		7	.41	.37	.34	.47	.37	.34	.40	.36	.34	.39	.36	.33
		6	.45	.41	.38	.51	.41	.38	.44	.40	.38	.43	.40	.37
		5	.50	.45	.42	.54	.45	.42	.48	.44	.42	.47	.44	.41
		4	.54	.50	.47	.58	.50	.47	.52	.49	.46	.50	.48	.46
		3	.58	.55	.52	.61	.54	.52	.56	.53	.51	.54	.52	.50
		2	.63	.61	.58	.65	.60	.58	.60	.58	.56	.58	.57	.55
		1	.69	.67	.65	.69	.66	.64	.65	.63	.62	.62	.61	.60

FIGURE 20.16 *(Continued)*

Recessed Lay-in 2 ft × 4 ft Open Parabolic Troffer Luminaire (Two Fluorescent Lamp)

2 Linear Tube Fluorescent Lamps	Spacing Criteria (CS)	Reflectance	Coefficient of Utilization (CU)							
		Ceiling Cavity (ρ_{cc})	80			70			50	
		Wall Surfaces (ρ_w)	70	50	30	70	50	30	50	30
		Cavity Ratio (CR)								
	1.4⊥ 1.2‖	10	.41	.32	.26	.40	.30	.25	.29	.25
		9	.44	.34	.28	.42	.34	.28	.33	.28
		8	.47	.36	.30	.46	.36	.30	.35	.29
		7	.51	.40	.34	.50	.40	.34	.39	.34
		6	.55	.46	.39	.54	.45	.39	.42	.38
		5	.59	.51	.44	.58	.50	.44	.47	.42
		4	.65	.56	.50	.64	.56	.50	.54	.48
		3	.70	.64	.57	.69	.63	.56	.60	.56
		2	.78	.71	.66	.76	.70	.67	.68	.65
		1	.84	.81	.79	.82	.80	.78	.77	.75

Recessed Lay-in 2 ft × 4 ft Open Parabolic Troffer Luminaire (Three Fluorescent Lamp)

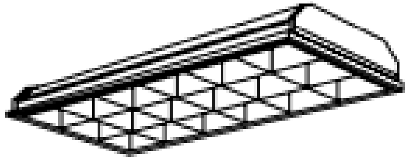
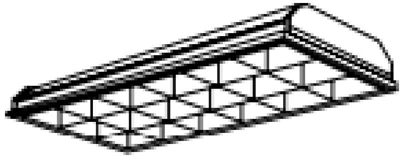
3 Linear Tube Fluorescent Lamps	Spacing Criteria (CS)	Reflectance	Coefficient of Utilization (CU)							
		Ceiling Cavity (ρ_{cc})	80			70			50	
		Wall Surfaces (ρ_w)	70	50	30	70	50	30	50	30
		Cavity Ratio (CR)								
	1.4⊥ 1.2‖	10	.39	.29	.25	.38	.28	.23	.28	.23
		9	.40	.32	.27	.40	.32	.27	.30	.26
		8	.44	.34	.29	.42	.34	.28	.34	.28
		7	.47	.39	.33	.46	.38	.33	.36	.32
		6	.51	.42	.36	.50	.41	.36	.40	.35
		5	.56	.46	.41	.54	.46	.40	.45	.40
		4	.59	.53	.46	.58	.52	.46	.50	.46
		3	.65	.58	.54	.64	.57	.53	.56	.52
		2	.70	.66	.61	.68	.65	.60	.63	.59
		1	.77	.75	.71	.75	.72	.70	.69	.68

FIGURE 20.16 *(Continued)*

Recessed Lay-in 2 ft × 4 ft Open Parabolic Troffer Luminaire (Four Fluorescent Lamp)										
4 Linear Tube Fluorescent Lamps	Spacing Criteria (CS)	Reflectance	Coefficient of Utilization (CU)							
		Ceiling Cavity (ρ_{cc})	80			70			50	
		Wall Surfaces (ρ_w)	70	50	30	70	50	30	50	30
		Cavity Ratio (CR)								
	1.4⊥ 1.2||	10	.35	.28	.23	.34	.28	.23	.27	.23
		9	.38	.29	.26	.36	.29	.25	.28	.25
		8	.40	.33	.28	.40	.32	.28	.32	.27
		7	.44	.35	.30	.42	.34	.30	.34	.29
		6	.46	.39	.34	.46	.39	.34	.38	.34
		5	.51	.42	.39	.48	.42	.38	.41	.38
		4	.55	.47	.42	.53	.46	.42	.46	.41
		3	.58	.54	.48	.57	.53	.48	.51	.47
		2	.64	.59	.56	.61	.58	.56	.56	.54
		1	.68	.67	.65	.67	.65	.64	.63	.60

Recessed Lay-in 2 ft × 4 ft Lensed Troffer Luminaire (Four Fluorescent Lamp)										
4 Linear Tube Fluorescent Lamps	Spacing Criteria (CS)	Reflectance	Coefficient of Utilization (CU)							
		Ceiling Cavity (ρ_{cc})	80			70			50	
		Wall Surfaces (ρ_w)	70	50	30	70	50	30	50	30
		Cavity Ratio (CR)								
	1.4⊥ 1.2||	10	.46	.35	.29	.44	.35	.29	.34	.28
		9	.49	.38	.31	.47	.37	.31	.36	.31
		8	.52	.41	.34	.51	.41	.34	.40	.34
		7	.56	.45	.38	.54	.44	.38	.43	.37
		6	.60	.49	.42	.58	.49	.42	.47	.41
		5	.65	.55	.48	.63	.54	.47	.52	.46
		4	.70	.61	.54	.68	.60	.53	.57	.52
		3	.76	.68	.61	.74	.66	.61	.64	.59
		2	.83	.76	.71	.81	.75	.70	.72	.68
		1	.90	.86	.83	.88	.85	.82	.81	.79

FIGURE 20.16 *(Continued)*

The CR is determined by either of the following formulas: $\mathbf{CR} = [5\,\mathbf{MH}(\mathbf{L} + \mathbf{W})]/\mathbf{LW}$ or $\mathbf{CR} = (2.5\,\mathbf{MHp})/\mathbf{A}$

where

MH: distance between the plane of the luminaires and reference work plane, in inches, feet, or meters.

L: length of the space, in feet or meters

W: width of the space, in feet or meters

p: perimeter of space, in feet or meters

A: area of the space to be illuminated, in square feet or square meters

- The first formula works well for rectangular-shaped rooms. The second formula applies to odd-shaped rooms.

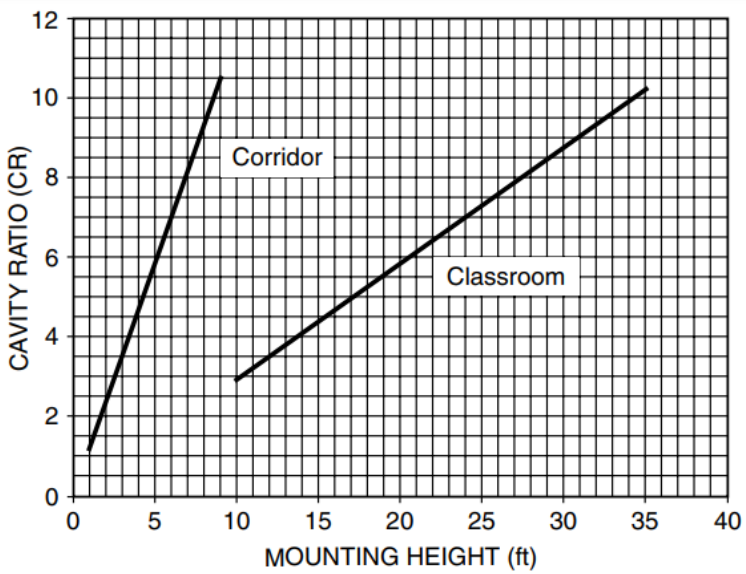


FIGURE 20.18 Relationship between cavity ratio (CR) and mounting height (MH) in a 30 ft by 40 ft classroom and a 30 ft by 5 ft corridor.

The basic formulas used in average illuminance computations are shown below. Typically formula number 1 is used in design of a lighting installation.

1. Number of luminaires (#) required in a space:

$$\# = (\mathbf{E} \cdot \mathbf{A})/(\mathbf{n} \cdot \mathbf{LM} \cdot \mathbf{CU} \cdot \mathbf{LLF})$$

2. Average illuminance in a space (foot-candles in service):

$$\mathbf{E} = (\# \cdot \mathbf{n} \cdot \mathbf{LM} \cdot \mathbf{CU} \cdot \mathbf{LLF})/\mathbf{A}$$

3. Minimum required area per luminaire to maintain the desired illuminance:

$$\mathbf{A} = (\mathbf{n} \cdot \mathbf{LM} \cdot \mathbf{CU} \cdot \mathbf{LLF})/\mathbf{E}$$

Where;

A: area of the space to be illuminated, in ft2 or m2

CU: coefficient of utilization of luminaire

E: illuminance, in foot-candles or lux

#: number of luminaires (light fixtures)

n: number of lamps in luminaire

LLF: light loss factor

LM: lamp output, in lumens

- A room is made up of three spaces called *cavities*. The space between the luminaires and the work plane is referred to as the *room cavity*; the space between the work plane and the floor is called the *floor cavity*; and the space between the ceiling and the luminaires (if they are suspended) is defined as the *ceiling cavity*.

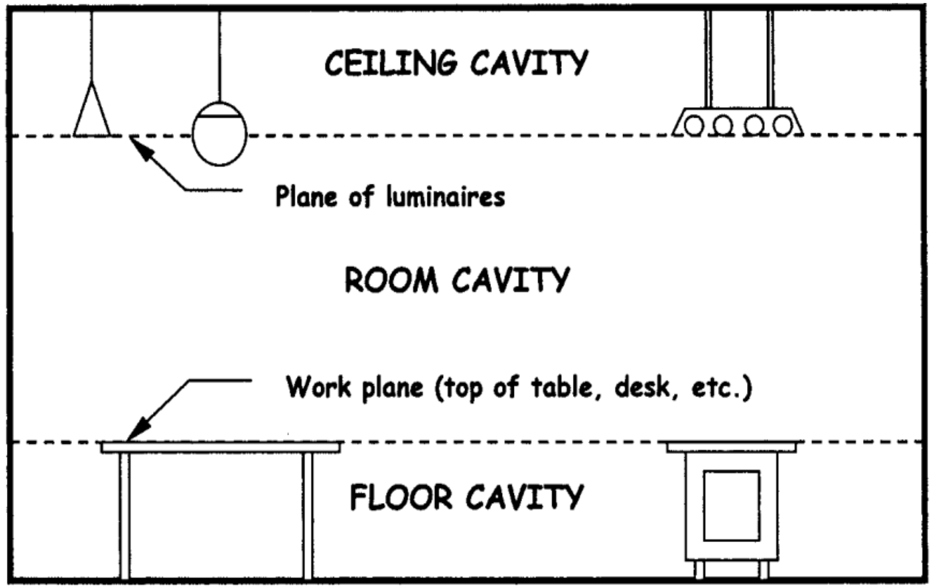


FIGURE 20.17

LUMINAIRE SPACING

- Once the number of luminaires (#) required for uniform illumination has been determined, the luminaires must be arranged. Incandescent and HID luminaires generally cast light evenly in all directions, which permits uniform spacing in even rows and columns, although even rows and offset columns may be used. Tubular fluorescent luminaires generally require spacing that is greater perpendicular to the axis of the lamps versus parallel with the lamps. To ensure uniform illumination of the work plane, luminaires cannot be spaced too far apart.

SPACING CRITERION

The spacing criterion (CS) ratio is an approximate maximum spacing-to-mounting height ratio required to ensure uniform illumination on the work plane. It is used as a conservative guide to determine maximum center-to-center luminaire spacing.

$$\mathbf{S} \leq (\mathbf{CS} \cdot \mathbf{MH})$$

where

S: luminaire spacing, in feet or meters

MH: mounting height, in feet or meters

CS: spacing criteria

- For most incandescent and HID luminaires, *spacing (S)* is the center-to-center luminaire spacing, in feet or meters, between two successive luminaires in a lighting installation.
- *Mounting height (MH)* is the distance between the plane of the luminaires and reference work plane, in feet or meters. Fluorescent luminaires and some others distribute light asymmetrically; that is, they throw light farther perpendicular to the length of the tube rather than parallel.

- With average illuminance and spacing requirements known, the number of the luminaires in a simple rectangular space can be approximated by the following expression:

$$\# \cdot \mathbf{A}/\boldsymbol{S}^{2}$$

Where;

A: area of the space to be illuminated, in square feet or meters

S: luminaire spacing, in feet or meters

#: number of luminaires (light fixtures)

Example 20.12

The 48-in fluorescent luminaires specified in Example 20.7 have spacing coefficients of 1.5/1.2. They are mounted 9 ft above the floor. The work plane is 30 in from the floor. Determine the maximum center-to-center spacing of the luminaires and arrange the 16 fixtures according to the spacing requirements.

$$\text{MH} = 9\text{ ft} - 2.5\text{ ft} = 6.5\text{ ft and } S \le (\text{CS} \cdot \text{MH})$$

Perpendicular (⊥) to the length of the tube:

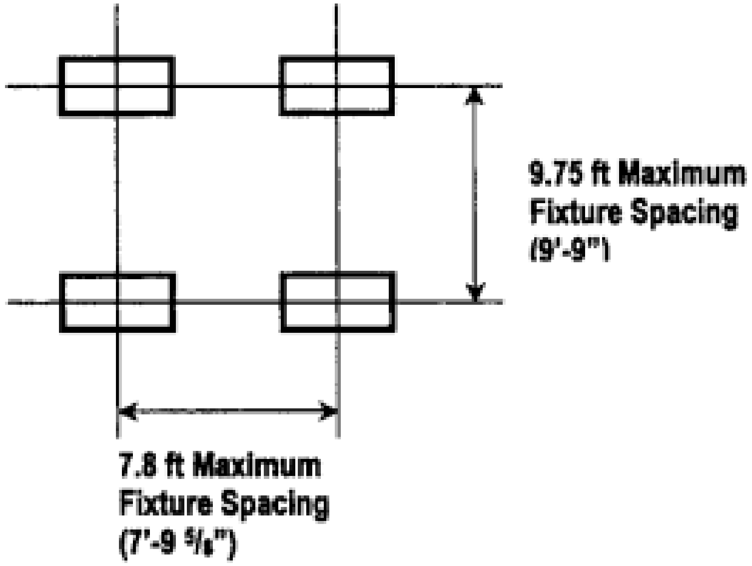
$$S_{\perp} = \text{CS} \cdot \text{MH} = 1.5 \cdot 6.5\text{ ft} = 9.75\text{ ft} = 9\text{ ft-}9\text{ in}$$

Parallel (||) to the length of the tube:

$$S_{\parallel} = \text{CS} \cdot \text{MH} = 1.2 \cdot 6.5\text{ ft} = 7.80\text{ ft} = 7\text{ ft-}9\tfrac{5}{8}\text{ in}$$

The arrangement of luminaires is shown in Figure 20.19.

Spacing Criterion



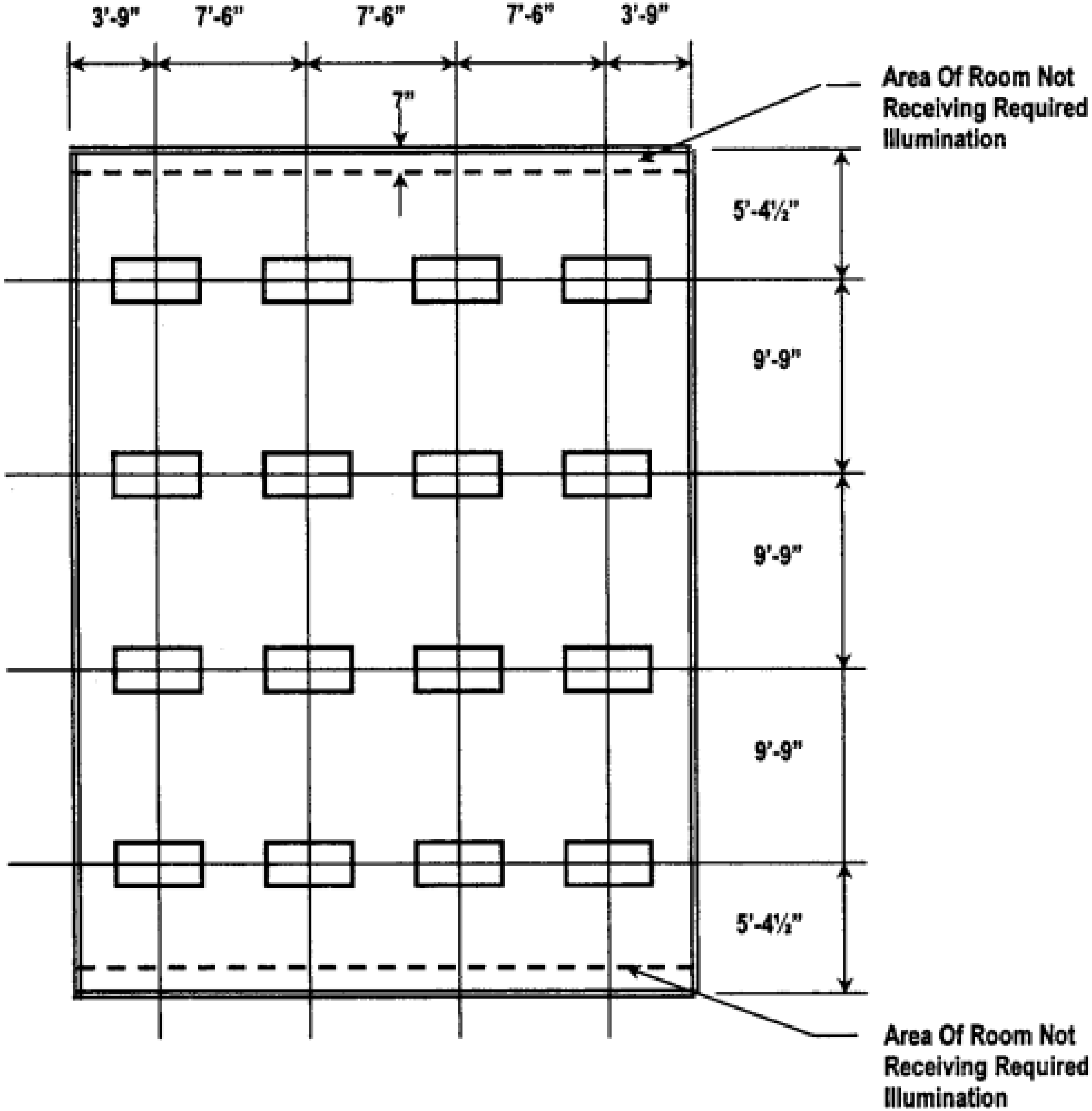


FIGURE 20.19

POWER DENSITY AND POWER ALLOWANCE

- ***Unit power density*** *(UPD)* of a lighting installation is the power consumed for illumination (W) divided by the area (ft^2 or m^2) served by the lighting installation. It is expressed in $\mathrm{W/ft}^2$ or $\mathrm{W/m}^2$. It is frequently used as a measure of installed building lighting efficiency; a lower UPD indicates a higher efficiency.
- Energy standards such as ASHRAE/IESNA 90.1 provide a *power allowance* ($\mathrm{W/ft}^2$ or $\mathrm{W/m}^2$) that limits the unit power density for lighting installations in various space and function types. Power allowances are adjusted for type and characteristics of lighting controls (e.g., occupancy sensors versus manual switching) and use of daylighting in a complex computation method.

Building Type and Space	Power Allowances $\mathrm{W/ft}^2$	Power Allowances $\mathrm{W/m}^2$
Building Type		
Offices, range depending on the floor area	1.50 to 1.90	0.14 to 0.18
Retail, range depending on the floor area	2.10 to 3.30	0.20 to 0.31
Schools, range depending on the floor area and type of school	1.50 to 2.40	0.14 to 0.22
Room/Space Type		
Corridors	0.8	0.01
Office, open	1.3	0.13
Office, enclosed	1.5	0.15
Restroom	1.0	0.10
Corridor	0.7	0.07
Fast food restaurants	1.3	0.12
Leisure dining restaurants	2.5	0.23
Hospital emergency room	2.3	0.21

TABLE 20.19

REDUCING THE COOLING LOAD

- The intent behind the power allowance standard is to stimulate use of more efficient lighting, but it also reduces a building's cooling load by reducing waste heat. All of the energy consumed by lighting is converted directly as heat into the space. Therefore, any improvement of lighting system efficiency reduces the amount of heat that must be removed by the air cooling system. This results in air cooling energy savings during the operation of the building.

BENEFITS OF ENERGY EFFICIENT LIGHTING

- The electricity required for lighting would be cut by at least 50%. Frequently, a blended lighting installation with a mix of efficient lighting (e.g., HID) can be used to provide efficient ambient lighting and combined with lamps for good color rendition (e.g., incandescent) to provide for a more efficient system.
- Reduce annual carbon dioxide emissions, sulfur dioxide emissions, nitrogen oxide emissions and other forms of pollution (ash, scrubber waste, acidic drainage and waste from coal mining, radioactive waste, and natural gas leakage).

4.12 LIGHTING DESIGN PRACTICES AND CONSIDERATIONS

HISTORICAL DESIGN PRACTICES

- Banks of light fixtures were routinely used to uniformly light classrooms, offices, manufacturing work spaces, and retail stores.
- Uniform ambient lightning is uninteresting to the occupant and very wasteful because of high investment in rows of light fixtures

ARCHITECTURAL LIGHTING DESIGN

- Both a science and an art, and there is no single correct lighting solution for all situations.
- The creative side of lighting design helps make the space aesthetically interesting and psychologically comfortable.

PHOTO 20.25 A conventionally lit classroom space. (Courtesy of NREL/DOE)

PHOTO 20.26 A classroom space lit with uplights, a more comfortable seeing environment because there is less glare. (Courtesy of NREL/DOE)

The main goals in designing aesthetically pleasing architectural lighting system are to:

- Provide a sufficient quantity of light to meet the seeing needs of the occupants that is not excessive
- Provide the appropriate quality (color rendition) of light
- Provide a balance and variety to add interest to the space being illuminated

Layered Light

- a non uniform, balanced use of all types of architectural lighting.
- tends to create a composition quality that best suits good atmosphere within most spaces by blending color rendering and other properties of the different light sources.

Ambient Lighting

- the most essential form of lighting because it is the basic background of light for almost every room. In many applications, it is desirable to have the major ambient light source dimmable.

PHOTO 20.28 Ambient lighting provided by decorative ceiling and wall-mounted fixtures. (Used with permission of ABC)

PHOTO 20.28 Ambient lighting provided by decorative ceiling and wall-mounted fixtures. (Used with permission of ABC)

Task/Local Lighting

- illuminates a specific visual function and can influence he effectiveness of the individual performing task.
- focus light in a particular direction or area, without casting any glare.
- good task lighting makes work easier.

PHOTO 20.29 Halogen accent lighting used as task lighting over a conference table. (Used with permission of ABC)

Accent Lighting

- used to add drama and emphasize a particular object or area.
- low voltage halogen are excellent applications of accent lighting.
- picture lights focus attention on wall paintings of interest, up-lights, or cans of light on the floor shining upward, illuminate plants and sculptures.

Decorative Lighting

- aesthetically adds interest to the space by blending with other types of lighting to give an overall “feel” to a space.
- decorative lighting may provide some ambient lighting, it serves principally as an eye-catching attraction. Use decorative lighting sparingly.

PHOTO 20.30 Decorative halogen accent lighting can add interest to a space but can also cause glare. These eye-level accent lights were intended to provide accent and task lighting, but they adversely affect visual comfort from glare at eye level. (Used with permission of ABC)

The following are some of the design considerations associated with lighting installations in common spaces:

Entrances

- The entrance or foyer is the transitional space from public to private and exterior to interior. It offers the first impression of a home or building. Lighting in homes and commercial establishments should draw attention to the building entry. Ambient illumination is also important to make guests/occupants feel welcome and comfortable.

Offices/Studies

- Reading and writing require quality lighting that limits eye fatigue caused from glare. Often, this space can take advantage of a beautiful vista out the window and good natural ambient light daylight. At night, an ambient light source should be provided to compensate for daylight. Computers require special attention. Soft indirect lighting is enough illumination and should be properly located so as not cause patterns on the screen

Restrooms/Bathrooms

- In restrooms and bathrooms, the best light washes the face from all directions, softening shadows. There should be sufficient light to see detail for grooming but not so much to cause glare and discomfort. Quality lighting can be accomplished within any design style because there is great variety in well engineered fixtures.

Dining Spaces

- Lighting should make the food, the table setting, and the people look attractive, so excellent color rendition is a must. Ambient lighting should be low to make the occupants sitting at the dining tables feel isolated. A center-pendent luminaire works well if not too obtrusive. A chandelier is very appropriate in formal dining, particularly in residences.
- The light level from the center-pendent luminaire or chandelier should be indirect so it does not draw attention from other, more important views. Ambient lighting should be low to draw attention away from the occupants sitting at dining tables. A balance of accent lighting showing off artwork, a special sideboard, and the table centerpiece is very effective and desirable.

Kitchen Spaces

- In the home, kitchen lighting has become very important because this space has become a central focal point. As a gathering point and a place of special work, lighting must be a well-conceived part of the overall design.
- Inappropriate lighting can make rich materials look dark and cause glare off shiny counters. Ambient and well-placed task lighting are the successful solution and the ability to control light levels is essential in the open-plan house.
- In commercial kitchens, adequate, diffused lighting with good color rendition is a must.

EXIT ILLUMINATION AND MARKING

– Building codes generally require that building exits be illuminated any time that the building is occupied, with light having an intensity of not less than one foot-candle at the floor/walking surface level.

PHOTO 20.31 Exit lighting. (Used with permission of ABC)

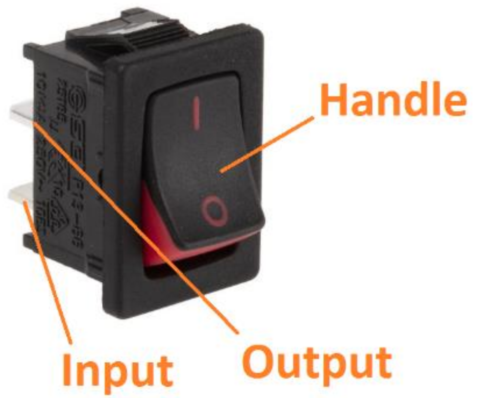
- Exit signage, like that shown in Photo 20.31, should safely mark exits or direct occupants to an exit where the route is not directly apparent. When two or more exits from a story are required by code (most commercial buildings), exit signs are required at stair enclosure doors, horizontal exits, and other required exits from the story.
- Each exit sign must have the word “EXIT” in plainly legible letters not less than 6 in high nor less than 3⁄4 in wide. Any door, passage, or stairway that is neither an exit nor a means of exit and that may be mistaken for an exit shall be identified by a sign reading, “NOT AN EXIT,” or a similar phrase.
- An exit sign shall be distinctive in color and must offer contrast with decorations, interior finish, or other signs in the space. Decorations, furnishings, protrusions, or equipment cannot impair visibility of an exit sign. Directional exit sign guide occupants to an exit where the route is not directly apparent.
- A sign reading “EXIT” or a similar phrase, with an arrow indicating the direction, must be located at locations where the route to the nearest exit is not apparent.

4.12 LIGHTING SYSTEM CONTROLS

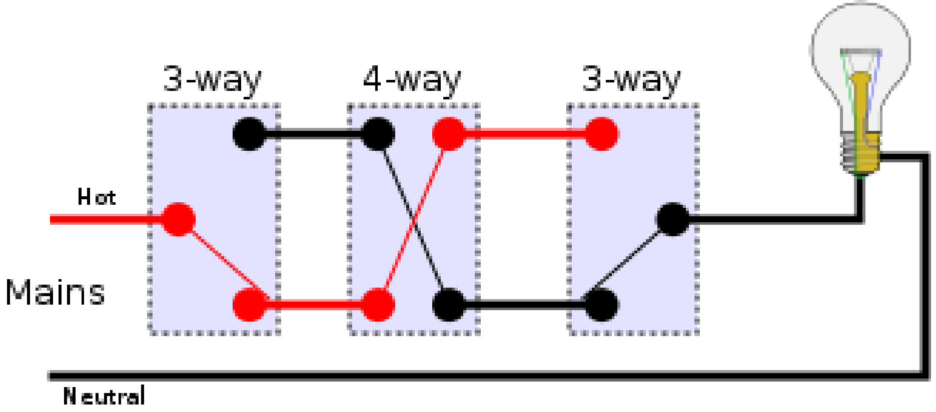
- **Lighting System Controls –** a variety of switches and controls are used to manage operation of lighting installations.
- A **switch** is an electrical device that opens an electrical circuit, thereby shutting the lights off or closing the circuit to energize the lighting installation.
- A **switch or group of switches** can control the lighting installation from one or multiple locations.

Common types of switches used in lighting installations:

- **Single-pole, single throw (SPST)** - switches are a simple on/off switch that controls a lighting installation from one location.



Common types of switches used in lighting installations:



- **Three-way switches (S3) and four-way switches (S4)** can be circuited to control a lighting installation from two or more locations.
  - **Two three-way switches** are required to control a lighting installation from two locations.
  - **Two three-way switches** and *one or more four-way switch* are required to control a lighting installation from three or more locations.
- **Automatic switches** - deactivate the lighting circuit after a preset time period has lapsed.
- **Dimmer switches** - can be used to vary the luminous flux (lumen output) from lamps in a lighting installation.

PHOTO 20.32 A wall-mounted dimmer switch used to control several banks of track lights.

Common types of switches used in lighting installations:

- **Keyed switches** - limit access to switches for lights and equipment to authorized personnel. They are available with SPST, and capabilities. Often used in lighting installations to provide better control of lighting

PHOTO 20.33 Ganged (multiple) key switched.

- **Door switches** - can activate a lighting circuit when a door is open or closed (e.g., similar to a refrigerator light).
- **Time clocks** - can be used to control the time period that a lighting installation operates.
- **Electronic timers**
  - automatically control operation of a lighting installation with electronic components that are wired into the circuitry.
  - They allow great flexibility as they can easily be set for daily and weekly cycles.
  - It requires relay switching on larger lighting loads.

Common types of switches used in lighting installations:

- **Photocell controls** - sense light and can be used to control night lighting in lieu of a time clock or timer.
- **Occupancy sensors** - control a lighting installation by sensing occupants in a space and usually mounted on the wall or ceiling. Works well in interior spaces such as classrooms and offices.

Central Lighting Control System

- A central *lighting control system* offers building operators full control of multiple lighting installations from a single location.
- It controls the lighting installations in a building along with controlling HVAC equipment, fire protection and security systems, and other devices.
- Advantage: Light circuits can be controlled in a remote location that, on some systems, can be controlled remotely off-site.

4.14 DAYLIGHTING PRINCIPLES

FUNDAMENTAL PRINCIPLES

Daylighting

- the efficient and effective use of direct, diffuse, or reflected sunlight to provide full or supplemental illumination for building interiors during hours of sunlight.

Sunlight

- excellent color rendition and brilliance.
- diminishes the need for artificial light in buildings and thus saves lighting costs up to 80% (in some buildings).

Effective use of daylighting

- Daylighting in buildings also typically decreases space heating and cooling costs.
- Generally improves occupant comfort by providing a more pleasant, naturally lit indoor environment.

LIGHT AND ARCHITECTURAL LIGHTING SYSTEMS

Advantages

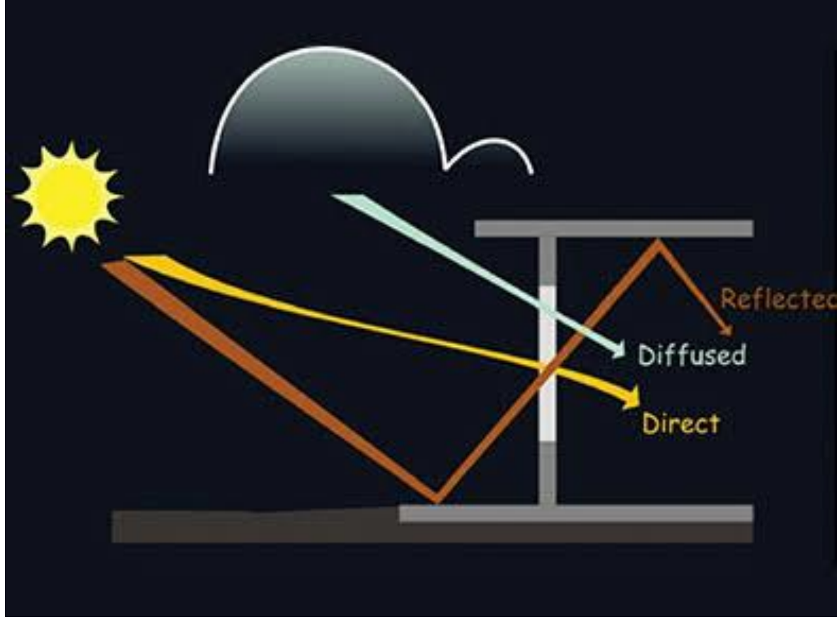
- good for human eye it tends to adapt more easily to daylight.
- the glazed surfaces needed for daylighting give the occupants a sense of contact with the outdoors.
- daylighting increases worker and student productivity, and reduces absenteeism.
- daylighting has also been shown to contribute to higher sales in retail stores.
- In factories, daylighting can reduce the loss of worker productivity during power failures.

Disadvantages

- the major disadvantage of daylighting is the unpredictable availability of sunlight.
- if not designed properly, oversized glazed areas that allow daylight into a building may contribute to higher building heat losses in the winter and undesirable heat gain in the summer.
- occupant comfort can also be adversely affected by uneven heating or cooling and glare from direct sunlight.
- additionally, sunlight can fade interior finishes and furnishings.

DAYLIGHT

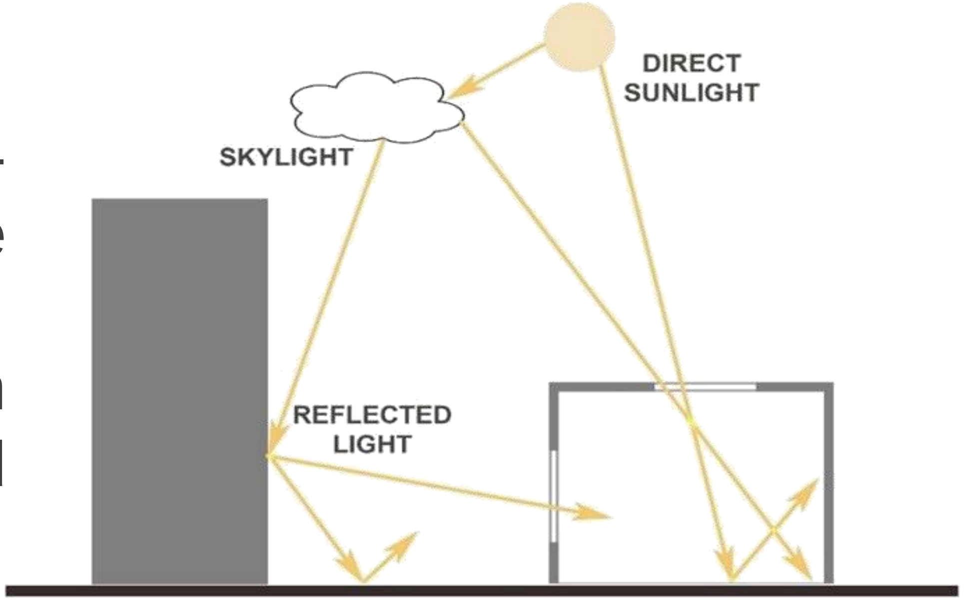
– A combination of direct, reflected, and diffuse sunlight.



1.) Direct light

– travels in a straight-line path from the sun

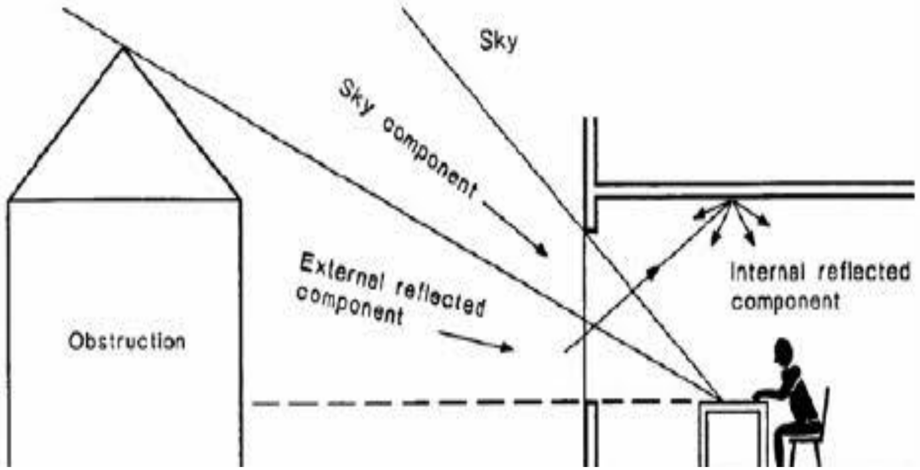
– more intense than diffuse and reflected sunlight.



2.) Reflected light

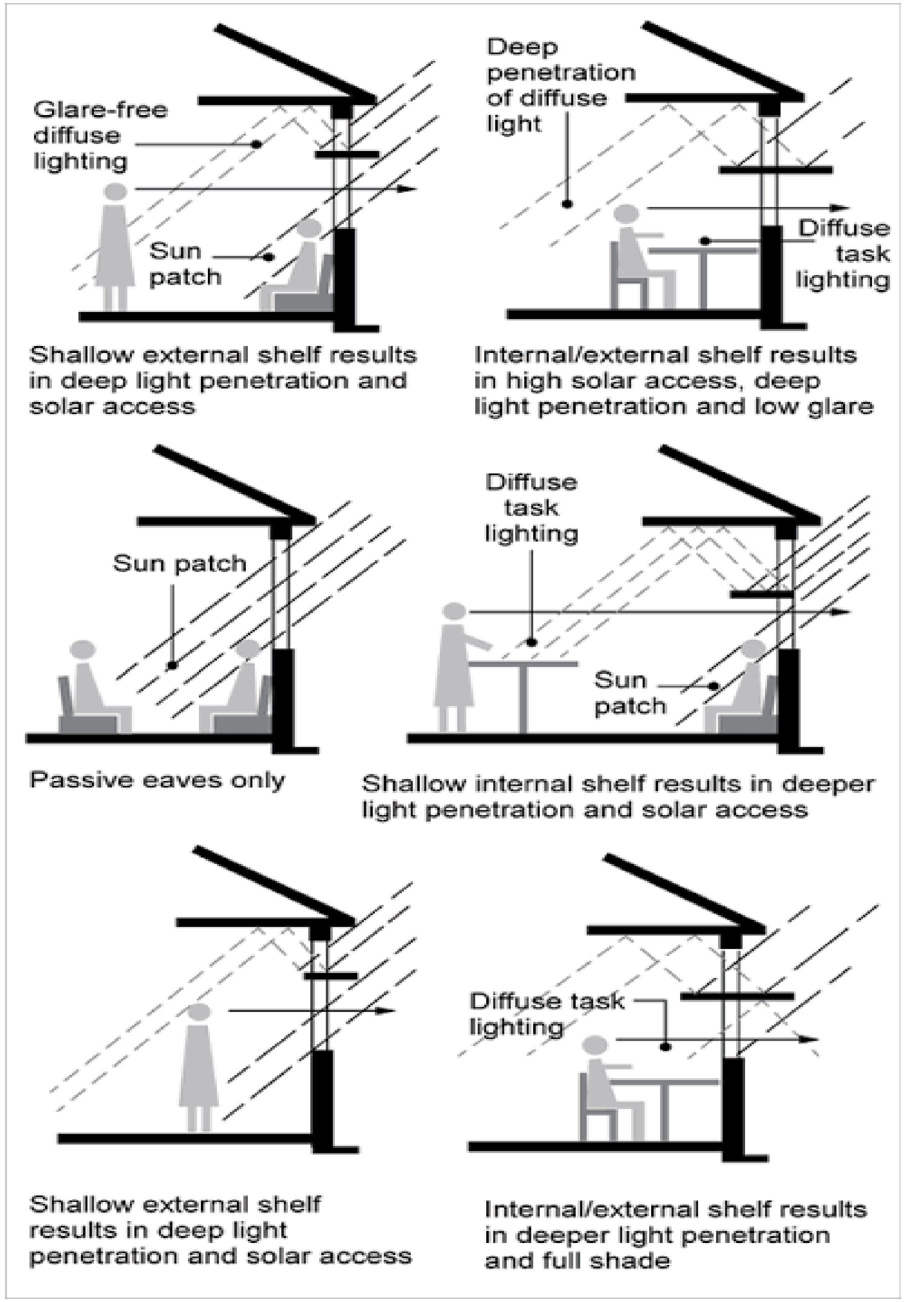
– strikes a surface and reflects off the surface in another direction.

– the receiving surface absorbs some sunlight before reflecting the light.



3.) Diffuse light

- is light that has been reflected or refracted by clouds, glazing, or other objects.
- Less intense than direct and reflected light and typically results in less glare.



GLAZINGS

– Typical performance measures for the center of glass for selected types of glazings are provided in Table 20.20. A description of these measures follows.

Overall Coefficient Of Heat Transfer (U)

- a measure of how easily heat travels through an assembly of materials
- The U factor has units of:

$$Btu/hr \cdot ft^2 \cdot {}^\circ\mathrm{F}(W/m \cdot {}^\circ\mathrm{C})$$

- Thermal insulating ability is also measured by the thermal resistance (R): a **higher R** factor indicates a **better** insulating performance.
- The R factor has units of:

$$hr \cdot ft^2 \cdot {}^\circ\mathrm{F}/Btu(m \cdot {}^\circ\mathrm{C}/W)$$

- The R factor is the **inverse** of the U factor.
- R factors for **common** glazing materials range from **0.9 to 3.0** (U factors from **1.1 to 0.3**)
- Experimental **super window** glazings have a center-of-glass R factor of **8 to 10** (U factor of about **0.1**), but have an overall window R factor of only **about 4 to 5** (U factor of about **0.25 to 0.2**), because of edge and frame losses.

Solar Heat Gain Coefficient (SHGC)

- the fraction of solar heat that is transmitted through the glazing and ultimately becomes heat.
- The **lower the SHGC**, the **less** solar heat is transmitted through the glazing and the **greater** its shading ability.
- In general, **south-facing windows** in buildings designed for passive solar heating **should have windows with a high SHGC** to allow in beneficial solar heat gain in the winter.
- **East- and west-facing windows** that receive undesirable direct sunlight in mornings and afternoons **should have lower SHGC assemblies**.

Visible Transmittance (VT)

- is the percentage of visible light (light in the **380 to 720 nm range**) that is transmitted through the glazing.
- **low VT glazing** such as bronze, gray, or reflective-film windows are more logical for office buildings or where reducing interior glare is **desirable**.
- A typical clear, single-pane window has a VT of about 0.88, meaning it transmits 88% of the visible light.

Light-to-solar Gain Ratio (LSG)

- is the ratio between SHGC and VT of a single glazing.
- It provides a gauge of the relative efficiency of different glazing types in transmitting daylight while blocking heat gains.
- The **higher** the LSG ratio the **brighter** the room is without adding unnecessary amounts of solar heat.

TABLE 20.20 TYPICAL CENTER-OF-GLASS PERFORMANCE MEASURES FOR SELECTED TYPES OF GLAZINGS. TOTAL WINDOW VALUES ARE SIGNIFICANTLY DIFFERENT. COMPILED FROM VARIOUS INDUSTRY SOURCES.

Glazing Types	Overall Coefficient of Heat Transfer (U Factor)	Solar Heat Gain Coefficient (SHGC)	Visible Transmittance (VT)	Light-to-Solar Gain Ratio (LSG)
Single glazed, clear	1.10	0.86	0.88	1.04
Double glazed, clear	0.49	0.76	0.81	1.07
Double glazed, bronze	0.49	0.62	0.61	0.98
Double glazed, spectrally selective	0.49	0.32	0.44	1.38
Double glazed, low-e (e = 0.10)	0.32	0.60	0.77	1.28
Triple glazed, low-e (e = 0.15)	0.27	0.49	0.68	1.39

TYPES OF GLAZING MATERIALS

Glass

- Historically, only glass was used as a glazing material.
- long life, high light transmission, hardness, and stiffness.

Plastic

- During the past two decades, plastic glazings have become an alternative to glass.
- much lighter in weight and are resistant to shattering, so they pose less of a safety hazard.
- The plastics commonly used for glazing are acrylics and polycarbonates.

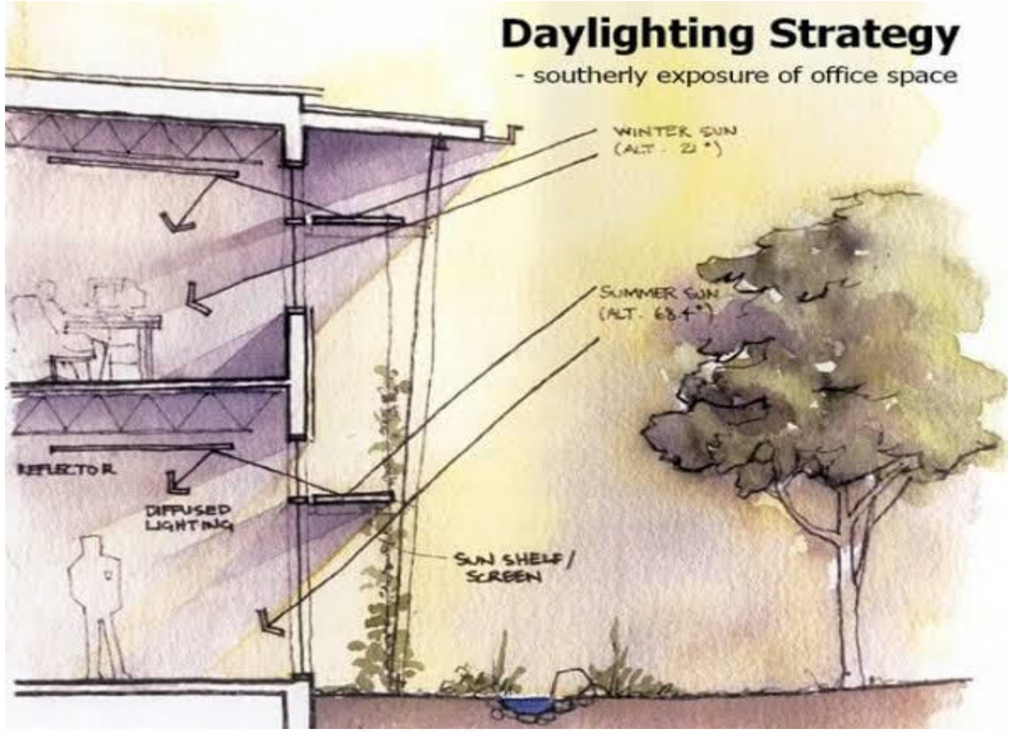
Glass and plastic Combined

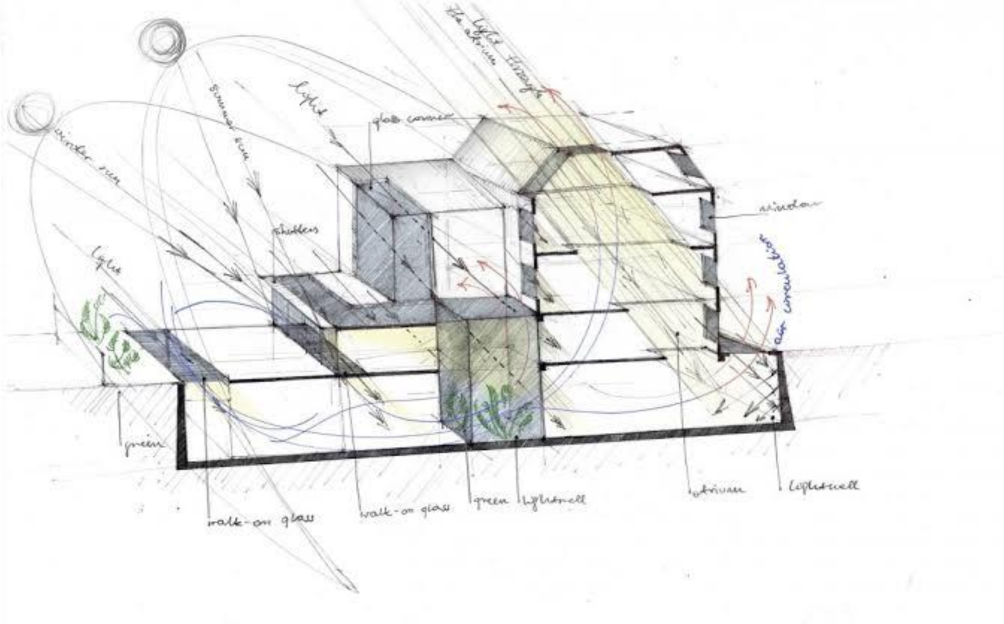
- combined in a composite to minimize the limitations of each.
- **glass is used for the outer sheet**, where it can provide considerable protection to the plastic, while the **inner plastic sheet** protects against glass breakage.
- Ordinary window glass strongly absorbs the damaging UV portion of sunlight, so a plastic material **will survive longer** if it is installed inside glass.

DAYLIGHTING STRATEGIES

- **Daylighting systems** must be designed to provide illumination in areas where it is most needed and to do so without adversely affecting occupant comfort.

- A **basic daylighting strategy** is to increase the number and size of glazed areas in the walls or ceilings of a building, but simply using large glazed openings does not ensure good daylighting.





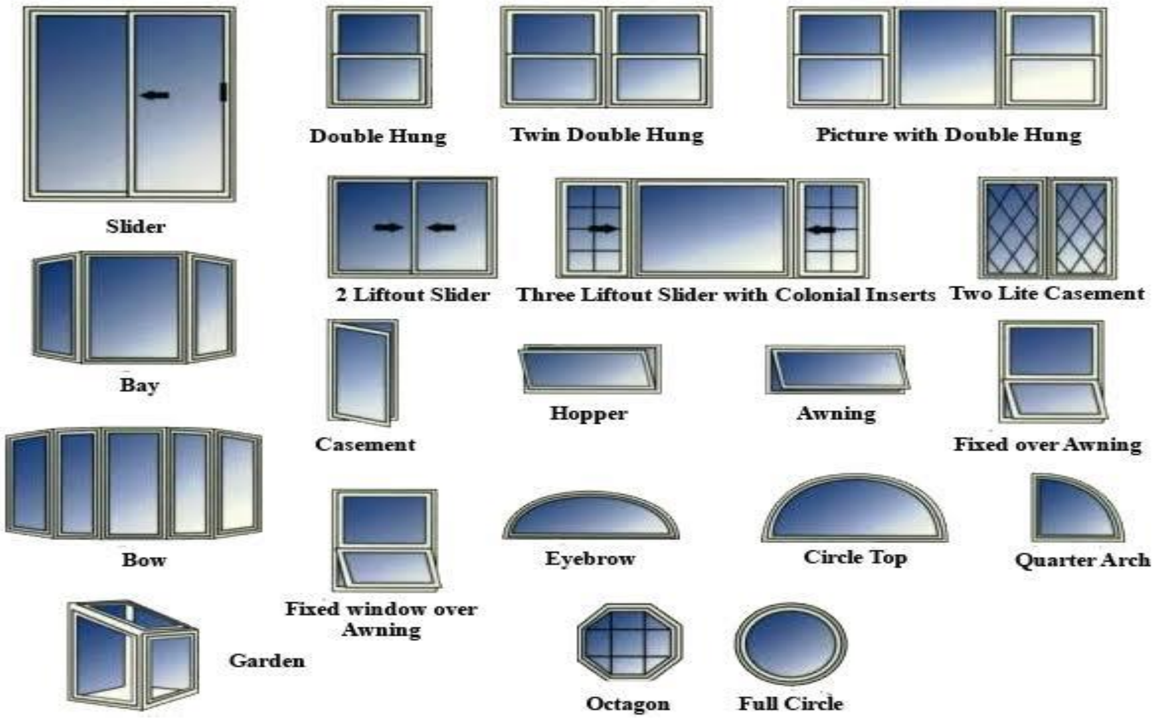
1.) Windows

– The main functions of windows are to bring in daylight and fresh air (if windows are operable) and introduce a view of the outdoors.

Fenestration

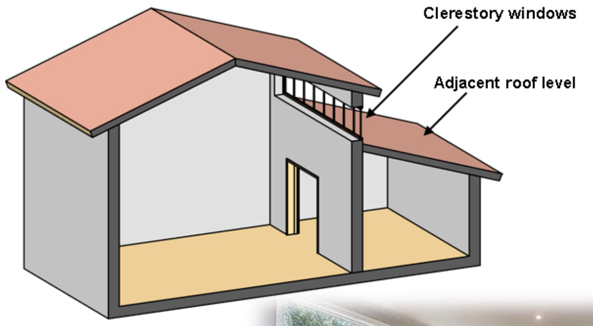
– is a design term that describes window size, arrangement, and glazing type (the glass and coatings used in the window).

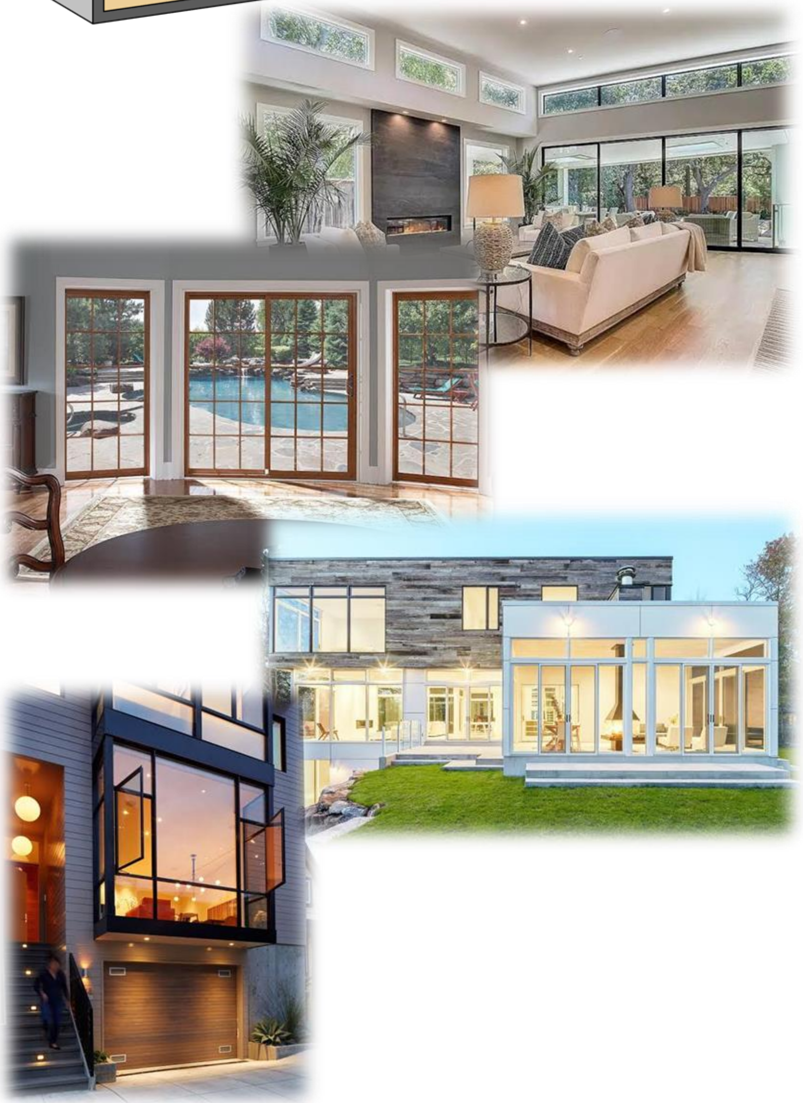
– it affects daylighting, passive solar heating, space cooling, and natural ventilation.



Clerestory Window System

- is a fenestration arrangement in an upper story wall that extends above one roof surface; it introduces daylight into the ceiling area of the space.
- An **atrium** is an interior courtyard covered with glazing. Rooms and spaces 8 adjoining the atrium receive daylight entering through the glazed roof.
- **Clerestories and atriums** are effective daylighting strategies because they introduce daylighting deep into a structure.
- A **fenestration arrangement** of several smaller windows can provide uniform daylight illumination if properly distributed in the space being illuminated.
- Good distribution is difficult to achieve in large deep rooms or in interior spaces without outside walls.





In **cold climates in the northern hemisphere**, the low position of the sun produces a shallow angle and a heat gain that contributes to space heating.

South-facing windows

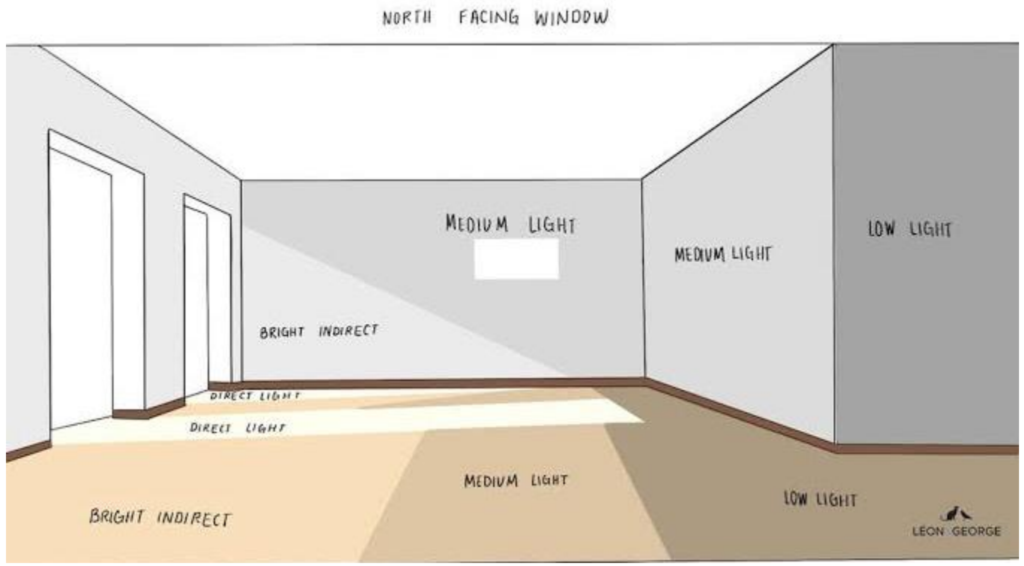
- limit solar gains in the summer because the steep angle of the summer sun with respect to the glass.
- generally results in a **net energy gain** over the winter season in all but severe climates.
- Additionally, a slanted south-facing window surface **should be avoided** because it gains heat all year long and is particularly poor at limiting solar heat gains in the summer.

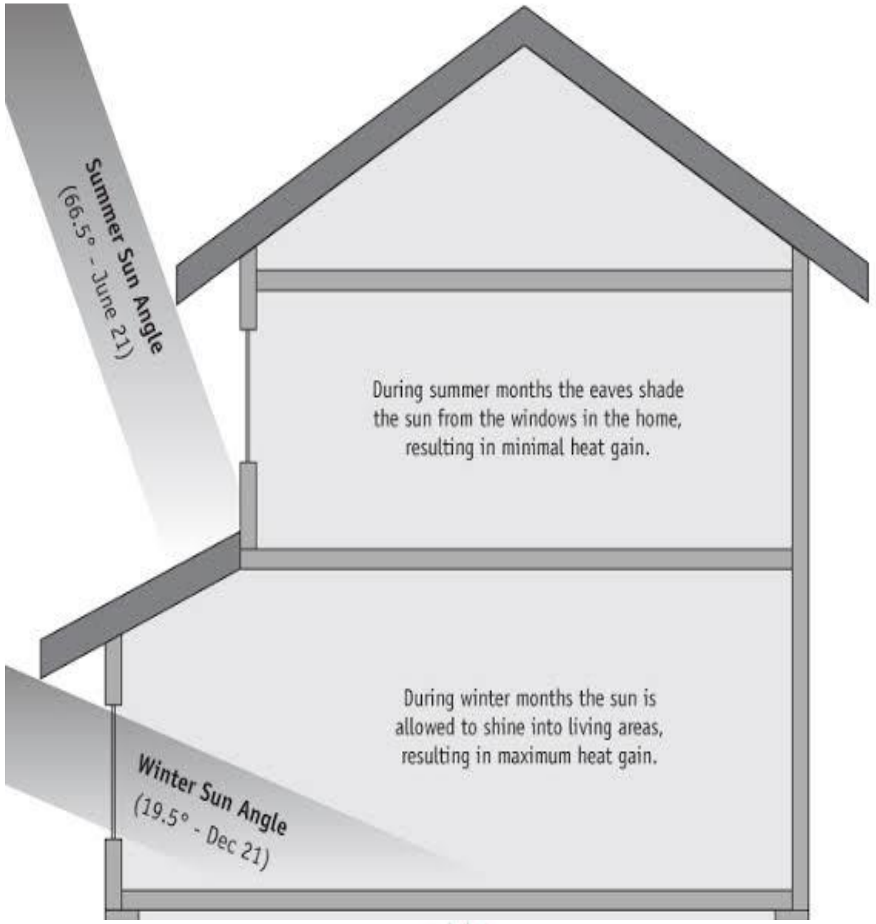
East- and west-facing windows

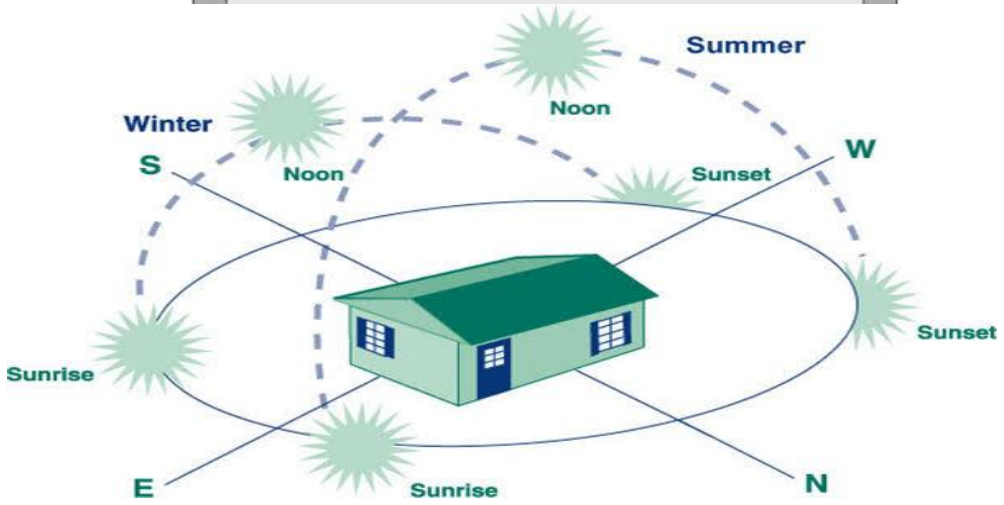
- exposed to considerable direct sunlight during these times of the day.
- Windows facing in these directions **should only be used when no other method of introducing daylight is possible** and where control of direct sunlight and glare is achievable.
- Although overhangs are impractical for east- and west-facing windows, vertical shading can be used.
- Additionally, vegetation (e.g., trees and shrubs) can be strategically located to shade window areas facing east and west.

North-facing windows

- Although in the northern hemisphere, north-facing windows do **provide good quality daylighting**, excessive heat loss and mean radiant temperature in the winter is a concern in cold climates.
- In hot climates, north-facing windows can provide good daylighting without heating the building.







2.) Skylights

- is a transparent panel located in a roof opening that allows direct and diffuse sunlight into the building.
- are commonly made from glass, glass composites, plastics, and plastic composites.

Roof Monitor

- is a type of skylight system that is a raised, typically triangular shaped, extension of a roof and that has at least one glazed surface.
- provide large quantities of reflected and diffuse light into the interior of the building.
- Installations with large skylights commonly suffer from excess brightness directly below the skylight, accompanied by gloomy dark areas surrounding the skylight.
- Repetitive layout of small skylights provides uniform illumination within the space.
- Additionally, less alteration of the roof structure is needed with smaller skylights.
- Skylight design should include gutters to capture condensation that flows off the interior surface of the glazing.

PHOTO 20.34 Skylights on a building roof. (Used with permission of ABC)

PHOTO 20.35 Exterior windows designed to introduce daylight in a gymnasium. (Used with permission of ABC)

PHOTO 20.36 Naturally lit high school corridor area. (Used with permission of ABC)

PHOTO 20.37 Naturally lit bank lobby area. (Used with permission of ABC)

PHOTO 20.38 Stepped windows provide soft, natural lighting to the open office area below. (Courtesy of NREL/DOE)

PHOTO 20.39 Stepped windows and light shelves throw natural light deep into the building. (Courtesy of NREL/DOE)

PHOTO 20.40 Side lights and a roof monitor in the center of the ceiling throws natural light evenly. (Courtesy of NREL/DOE)

Skylights

Advantages

- Skylights are effective for many industrialized and maintenance operations.
- Warehousing can be a favorable application.
- They can be used to provide a sense of natural ambience, which is valuable in applications such as restaurants, transportation centers, and other public areas.
- Skylights can also be effective for retailing because sunlight has excellent color rendition and brilliance.

Disadvantages

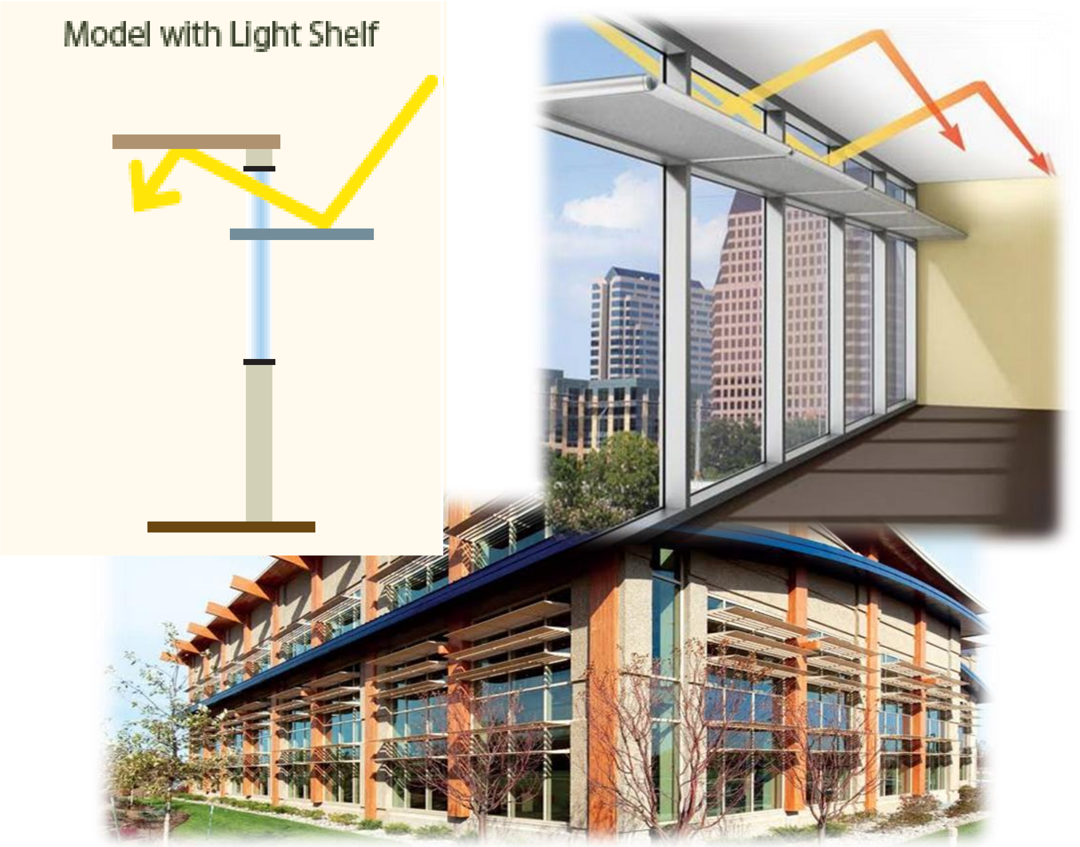
- The large fluctuations in illumination intensity caused by movement of clouds across the sun.
- In addition, daylighting makes it more difficult to avoid veiling reflections, which are a problem especially with reading tasks (e.g., reading paperwork and a computer screen).
- Skylights are not valuable in regions that regularly have heavy cloud cover for a large fraction of the time.
- Additionally, skylights do not produce a useful amount of daylight if it is shaded by adjacent structures or vegetation.

3.) Reflective Light Shelves

- is a passive (non-mechanical) architectural element or mechanism that allows sunlight to enter deep into a building.
- may be located on the interior or exterior of the building envelope.
- Exterior light shelves may also function as overhangs that shade the window from the high summer sun.
- Properly designed light shelves allow daylight to penetrate the interior of the space up to 21⁄2 times the distance between the floor and the top of the window.

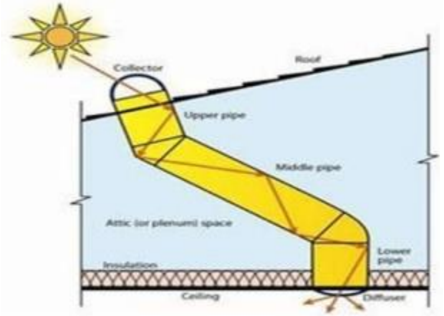
Examples include:

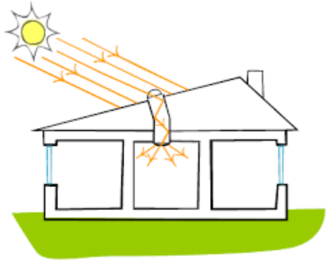
- light shelves suspended by stainless steel cables,
- fabric light shelves stretched over metal tubes, and ;
- assemblies of commercially available components created by ceiling manufacturers.



4.) Light Pipes

- Most commercially available ***light pipes*** consist of an exterior, roof-mounted transparent dome, a reflecting metal pipe, and a diffuser for installation at the ceiling level of the space.
- It can pass through attic spaces much more easily.
- *Flexible pipes* are easier to install, but they suffer more light loss from increased light absorption from reflection and scatter on the inside surface of the pipe wall.

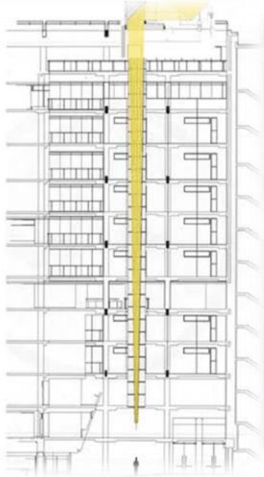


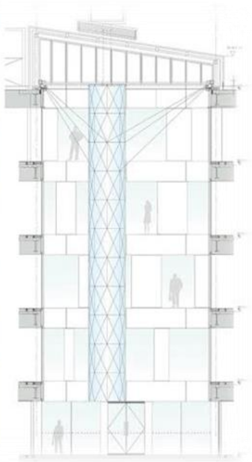


Sun tracking light pipe

- is a type of light pipe that has a movable mirror or light-refracting system and that can be used to align the incoming sunlight with the axis of the light pipe, thereby minimizing reflection losses.

- The light reflecting apparatus gets in the way of the whole sky when the sun is obscured. Another disadvantage is the need for occasional maintenance.





5.) Fabric Roof Membranes

- Translucent **fabric roof membranes** can be used to introduce daylight through the roof itself.
- The main use for fabric structures has been for sports stadiums, shopping malls, harbors, and airports (Denver International Airport).
- Fabric structures may be divided into **two categories**: *tension* and *air supported*.
  - **Air-supported structures** use a membrane, supported by air pressure, to act as the roof and walls of the structure.
  - **Tension** structures use a membrane, supported by a cable, to act as the roof of a structure.
- ***Polyvinyl chloride-polyester*** and ***Teflon-coated*** woven fiberglass fabrics are commercially available fabric roof membranes that have been used successfully.
- A second inner fabric liner is needed for insulation, sound control, and protection against condensation.

HOW MUCH AREA

- Illuminance of outdoor sunlight: 6000 fc
- Given an area of one hundred times greater will give an illuminance of 60 fc, an acceptable intensity for general lighting tasks. So, in theory, clear sky sunlight can be distributed to adequately light an area that is one hundred times greater than the area of captured sunlight. If one assumes that one-quarter of the sunlight entering a daylighting system can effectively be used for daylighting, then an aperture of sunlight of about 4% is required—roughly 4 of window or skylight area for every 100 of floor area.

TABLE 20.21 REPORTED OUTPUT OF A COMMERCIALLY AVAILABLE LIGHT PIPE. COMPILED FROM VARIOUS INDUSTRY SOURCES.

Size		Full Sun Summer Approx. 10500 fc		Overcast Summer Approx. 4500 fc		Clear Sky Winter Approx. 2000 fc		Approximate Area that Can Be Lit to Normal Daylight Level	
in	mm	fc	lx	fc	lx	fc	lx	ft^2	m^2
8	200	30	300	22	220	10	100	80	7.5
13	330	63	630	45	450	24	240	150	14
18	450	95	950	68	680	35	350	230	22
21	530	122	1220	87	870	43	430	320	30
24	600	154	1540	110	1100	54	540	430	40
30	750	215	2150	148	1480	62	620	530	50
36	900	258	2580	172	1720	70	700	650	60
40	1000	310	3100	211	2110	76	760	750	70
By Comparison									
100 W lamp		17	170	17	170	17	170	–	–