CEM/CEA | Session No. 3

LIGHTING SYSTEMS

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Overview

- All type of facilities have lighting.
- Lighting accounts about 30-70% of the total energy cost in commercial buildings while ranging around 5-25% in the industrial facility.
- Lighting has an impact on productivity & comfort.
- Lighting system significantly impact a buildings HVAC system.
- Typically, lighting has a high potential for energy savings.

Learning Objectives

- Explain the importance of effective lighting in various contexts.
- Familiarize with fundamentals of lighting (quality & quantity).
- Describe energy-efficient lighting options & explore integration with building automation.
- Recognize the requirement with the lighting standards and regulations.
- Distinguish lighting retrofit savings and opportunities.

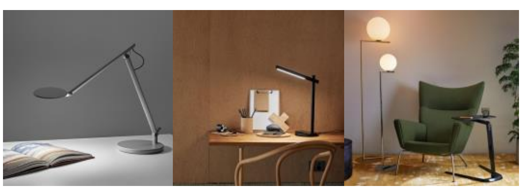
Lighting System

The first step in lighting design is to determine the visual needs of the space and identify what type of lighting to use. Lighting types are divided into four (4) categories:

1. Ambient lighting – typically used for circulation and general lighting to give a "sense of space." Design ambient lighting systems before designing systems to accommodate the other lighting types.

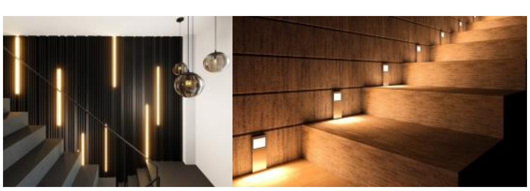
Lighting System

2. Task lighting – used where clearly defined lighting levels are required to complete detailed work, such as paperwork, reading, or bench-top experiments.



Lighting System

3. Accent lighting – used for architectural purposes to add emphasis or focus to a space or to highlight a display.



Lighting System

4. Emergency or egress lighting – use to provide a pathway for exiting a building if an emergency arises.

Lighting System Components

A lighting system consist of **light sources** (lamps), **luminaires** (or fixtures) and **ballasts**. Each component will affect the performance, energy use and annual operating cost of the lighting system.

Lamp Types:
- Incandescent Lamps
- Fluorescent Lamps
- High Intensity Discharge (HID) Lamps
- Low Pressure Sodium Lamps
- LED Lamps

Ballasts Types:
- Magnetic
- Electronic

Types of Light Fixture (Luminaire)
- Recessed Lighting Fixture
- Indirect & Direct Pendant Lighting Fixture
- Track Lighting Fixture
- Linear LED Light Fixture
- Wall Surface Mounted/Scone
- Floor and Table Lighting Fixture
- Outdoor Lighting Fixture

Lighting System Components

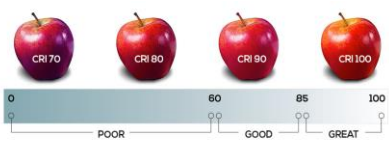
Lighting Fundamentals

Quality
- Color Rendering Index (CRI)
- Correlated Color Temperature (CCT)
- Glare and Uniformity

Quantity
- Watts (input power)
- Lumens (light produced by a lamp)
- Lux (actual light reaching the work plane)

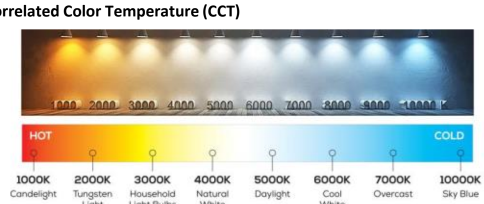
Quality

Color Rendering Index (CRI) refers to how a light source renders the colors of other objects and surfaces. This is measured on a scale of 1-100 and the closer to 100 the more accurate object colors appear.



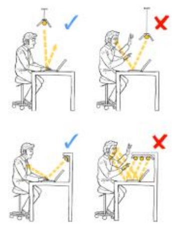
Quality

Correlated Color Temperature (CCT)



Quality

Glare is a visual sensation caused by excessive and uncontrolled brightness in the field of view.



Quality

Uniformity describes how evenly light spreads over an area. It is expressed as the ratio between the minimum to average lux or the minimum to maximum lux. With **light uniformity standard of 0.4 – 0.6** for general office area and warehousing.

$$U_1 = E_{(minimum)} / E_{(average)}$$

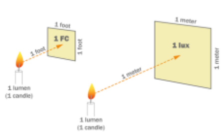
$$U_2 = E_{(minimum)} / E_{(maximum)}$$

U stands for uniformity and E stands for lux level.

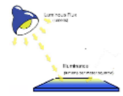
Quantity

Lighting quantity is primarily expressed in three types of units:

- **Watts** - represents the electrical input to the lighting system
- **Lumens** - is the unit of measure to the output of the lamp
- **Foot-Candles/Lux** – unit of measure (result) on the actual light reaching the work plane



Quantity



Electrical power equivalents for different lamps

Minimum light output (lumens)	Electrical power consumption (watts)			
	Incandescent		Compact fluorescent	LED
	Non-halogen	Halogen		
90	15	6	2–3	1–2
200	25		3–5	3
450	40	29	9–11	5–8
800	60		13–15	8–12
1,100	75	53	18–20	10–16
1,600	100	72	24–28	14–17
2,400	150		30–52	24–30[10]

SI photometry quantities

Quantity		Unit		Dimension [nb 1]	Notes
Name	Symbol[nb 2]	Name	Symbol		
Illuminance	E_v	lux (= lumen per square metre)	lx (= lm/m^2)	$L^{-2} \cdot J$	Luminous flux *incident* on a surface
Luminous flux, luminous power	Φ_v[nb 3]	**lumen** (= candela steradian)	lm (= cd⋅sr)	J	Luminous energy per unit time
Luminous efficacy (of a source)	η[nb 3]	lumen per watt	lm/W	$M^{-1} \cdot L^{-2} \cdot T^3 \cdot J$	Ratio of luminous flux to power consumption

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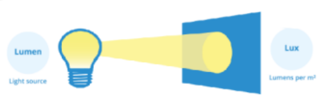
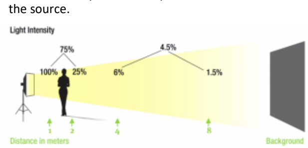
Quantity



Quantity

Inverse Square Law - states that the cross-sectional area increases with the square of the distance from the source. Therefore, the illuminance on this surface varies inversely with the square of the distance from the source.



The Inverse Square Law of Light

Inverse Square Law

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

Where:

E = Illuminance on the surface, (lux)

I = Luminous intensity of the source in the direction of the surface, (cd)

d = Distance from the source to the surface

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Quantity – Inverse Square Law

Sample problem:

The high bay lamps in a factory are mounted 45 feet above the floor. The lighting level at the floor is 10 footcandles. One area of the warehouse needs to increase the lighting level to 50 footcandles, so it is proposed that the lamps in this area be lowered. What is the greatest lamp height that would provide the required lighting level?

A. 20 feet
B. 24 feet
C. 27 feet
D. 31 feet

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

$$10 = \frac{I}{45^2} \text{ and } 50 = \frac{I}{d^2}$$

$$\text{Therefore}, d^2 = \frac{10 \times 45^2}{50}$$

$$\text{so } d = \sqrt{\frac{20,250}{50}} = 20 \text{ feet}$$

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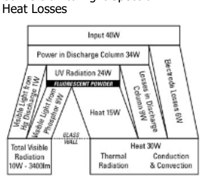
Quantity

Energy Balance Diagram for Discharge Lamp - when electrical energy is given to any discharge lamp, the electrical energy mainly gets distributed in three parts:
- Losses within Lamp
- Conversion to Light Spectrum
- Heat Losses



Energy Balance Diagram for Conventional Fluorescent Lamp:

Input Energy: 100 %

Output Energy Distribution

Power Losses at Tube – 34.0 %

Electrode Losses – 16.5 %

Non Electrode Losses – 17.5 %

Power Losses in Phosphor Layer – 0.5 %

UV radiation (escaping from tube) – 37.5%

Visible Radiation – 28 %

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Quantity

Heat Load Generated by 4 x 14 W T5 Luminaires:

Considering the above, the Heat generated by 4 x 14 W T5 Luminaire would be:
Wattage of Lamp – 14 W   No of Lamps – 4 Nos
Total Wattage of all four lamp – 56 W
Lamp Wattage converted into heat – 36W (9W per Tube)
4x14 W T5 Electronic Ballast Watt Loss converted into heat – 8 W
Total Input Wattage converted into heat in case of 4 x 14 W T5 Luminaire – 44 W

BTU/Hr Conversion due to Electrical wattage converted into heat
Wattage to BTU/Hr conversion formula is as under: 1 W = 3.4144 BTU/Hr

Hence, 44 W of wattage which gets converted into heat in case of 4 x 14 W T5 Luminaire will translate into 150.26 BTU/Hr

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Quantity

Total Electrical Wattage consumption in 25 W LED Luminaire:

No of LEDs in Module: 25 Nos.
Nominal Forward voltage of each LED: 3.2 V
Nominal Forward Current of each LED: 350 mA
Total Wattage of each LED : 3.2x0.350 = 1.12W
Total Wattage of 25 LED Cluster Module: 1.12 W x 25 = 28 W
Power Consumption in LED Drivers: Approx. 6 W

Total Power Consumption for 25 LED Module including Driver = 34 W

Assuming entire 34 W of LED power is leading to heat generation, total heat generated by 25 LED Luminaire will be 116.01 BTU/Hr

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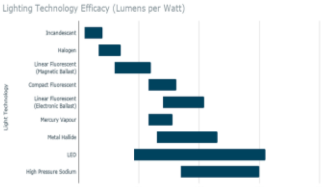
Quantity

The **luminous efficacy** of a lamp is an estimate of the light output (lumens) divided by the electrical power input (watts) under test conditions, the higher the output while input is kept constant, the greater the efficacy.



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IES Recommended Light Levels

Application and Task	Maintained Horizontal		Maintained Vertical		Comments
	Average (fc)[1]	Range (fc)[2]	Average (fc)[1]	Range (fc)[2]	
COMMON AREAS					
ATM or Service Kiosk	20	10-40	10	5 - 20	Vertical at face of ATM
Circulation/Corridor	5	2.5 - 10	3	1.5 - 6	Independent Passageway
Conference Room	See Commercial Office				
Filing (Intermittent)	15	7.5 - 30	10	5 - 20	
Restroom (General)	5	2.5 - 10	3	1.5 - 6	
Restroom (Vanities)	15	7.5 - 30	20	10 - 40	See also Fixtures/Lockers/Showers
Lunch & Break Room	10	5 - 20	3	1.5 - 6	
Stairs	5	2.5 - 10	3	1.5 - 6	Not High Activity or Surveillance
COMMERCIAL OFFICE					
Open Office (Desk)	40	30 - 50	-	-	Measured at desk height
Private Office (Desk)	40	30 - 50	-	-	Measured at desk height
Conference Room (Table)	30	15 - 60	-	-	
Whiteboard (Reading)	-	-	15	7.5 - 30	
Whiteboard (Presenting)	-	-	30	15 - 60	
Presentation Screen (Projector)	-	-	1.5	1.5 - 6	
Lunch & Break Room	15	5 - 20	-	-	

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IES Recommended Light Levels

Application and Task	Maintained Horizontal Average (fc)[1]	Maintained Horizontal Range (fc)[2]	Maintained Vertical Average (fc)[1]	Maintained Vertical Range (fc)[2]	Comments
EXTERIOR					
Parking (Covered)	5	-	-	-	1 Min; 10:1 Max-Min Uniformity
Parking (Uncovered) Zone 3 (Urban)	1.5	0.75 - 3	0.8	0.4 - 1.6	
Parking (Uncovered) Zone 2 (Suburban)	1	0.5 - 2	0.6	0.3 - 1.2	
Gas Station Canopy	12.5	10 - 15	-	-	
Safety (Building Exterior)	1	0.5 - 2	-	-	For security issues, raise Avg to 3
INDUSTRIAL/MANUFACTURING					
Assembly & Inspection (Simple) Component Manufacture (Large Part)	30	15 - 60	30	15 - 60	
Component Manufacture (Med. Part)	50	25 - 100	50	25 - 100	
Assembly & Inspection (Difficult) Component Manufacture (Fine Part)	100	50 - 200	100	50 - 200	
Assembly & Inspection (Exacting)	300	150 – 600	-	-	

https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926.56
DOLE, OSH Standard, Rule 1075: Illumination

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IES Recommended Light Levels

Recommended Light Levels by Space: The table provides recommended light levels from the IES Lighting Handbook and LPD *(lighting power density)* levels from the IECC 2021. Check your local jurisdiction for other or more stringent requirements.

ROOM TYPE	LIGHT LEVEL (FOOT CANDLES)	LIGHT LEVEL (LUX)	IECC 2021 LIGHTING POWER DENSITY (WATTS PER SF)
Lobby - Office/General	20-30 FC	200-300 lux	0.84
Locker Room	10-30 FC	100-300 lux	0.52
Lounge / Breakroom	10-30 FC	100-300 lux	0.59
Mechanical / Electrical Room	20-50 FC	200-500 lux	0.43
Office - Open	30-50 FC	300-500 lux	0.61
Office - Private / Closed	30-50 FC	300-500 lux	0.74
Parking - Interior	5-10 FC	50-100 lux	0.15
Restroom / Toilet	10-30 FC	100-300 lux	0.63
Retail Sales	20-50 FC	200-500 lux	1.05
Stairway	5-10 FC	50-100 lux	0.49
Storage Room - General	5-20 FC	50-200 lux	0.38
Workshop	30-75 FC	300-750 lux	1.26

International Energy Conservation Code (IECC)

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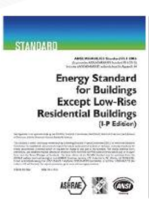
Lighting Standards & Codes



Whole Building Lighting Power Densities W/m2	
Offices	8.83
Retail	13.56
Warehouse	7.10
Education	9.36

Building type	90.1-2016	90.1-2019	90.1-2022
Office	0.79W/sq.ft.	0.64W/sq.ft.	0.62W/sq.ft.
Retail	1.06W/sq.ft.	0.84W/sq.ft.	0.78W/sq.ft.
School/University	0.81W/sq.ft.	0.72W/sq.ft.	0.70W/sq.ft.
Hospital	1.05W/sq.ft.	0.96W/sq.ft.	0.92W/sq.ft.
Manufacturing	0.90W/sq.ft.	0.82W/sq.ft.	0.82W/sq/ft.
Warehouse	0.48W/sq.ft.	0.45W/sq.ft.	0.45W/sq.ft.

Allowable Lighting Power Densities (LPD) for a space
LPD = Total Lighting Power / Space Area (W/m2)

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Basics of Lighting Design

The first step of lighting design is to **establish the general requirements for the artificial lighting** in terms of the main visual tasks to be carried out in the building. The next step is to **determine the lighting requirements** in terms of revealing the form of the building and helping to create the right character of the interior, referred to as the 'Building lighting'.

1. The Zonal Cavity (Lumen) method - used to calculate the average illuminance and assumes an equal foot-candle/lux level throughout the area.
2. Point by Point method - makes use of the inverse-square law, which states that the Illuminance at a point on a surface perpendicular to the light ray is equal to the luminous intensity of the source at that point divided by the square of the distance between the source and the point of calculation/surface.
3. Watt Per Square Feet (W/SF) method - A measure of the amount of power used by lighting per unit of building area (divide the wattage consumed in the room by its area).

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Basics of Lighting Design

The following equation is used in the **lumen method** of design:

E = (F x N x U x M) / A

Where:
E = average horizontal illumination at the working plane in Lux
F = lamp lighting design Lumens
N = number of lamps
U = utilization factor
M = maintenance factor
A = area of the working plane in square meters (m^2)

UTILISATION FACTOR (U)
This is the ratio of the lumens received on the working plane to the total flux output of lamps.

MAINTENANCE FACTOR (M)
This is a ratio which takes into account the light lost due to an average expectation of dirtiness of light fittings and the room surfaces.

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Basics of Lighting Design

EXAMPLE:
An office of 8m long by 7m long requires an illumination level of 400 lux on the working plane. It is proposed to use 80 W fluorescent light fittings having a rated output of 7,375 lumen each. Assuming a utilization factor of 0.5 and a maintenance factor of 0.8, calculate the number of light fittings required.

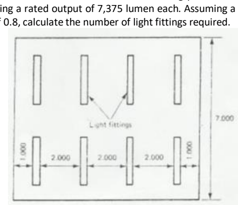
E = 400 lux — A = 8m x 7m
F = 7375 lumens — N = ?
U = 0.5 — M = 0.8

E = (F x N x U x M) / A

N = (E x A) / (F x U x M)

N = (400 x 8 x 7) / (7375 x 0.5 x 0.8)

N = 7.59 fittings ~ use 8 fittings



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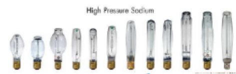
Light Sources Overview

Technology	CRI	CCT (K)	Life (hours)
Incandescent	100	2700	1,000
Fluorescent	70-85	3000-6000	20,000
Induction	80	4000	85,000-100,000
HPS	22-50	2000	24,000
LPS	0-10	1700	18,000
Metal Halide	80	4000	15,000-20,000
LEDs	70-100	3000-6000	*40,000-60,000



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Light Sources Overview

LED Lighting Technology

Suitable for practically all applications (indoor & outdoor)

- Retrofit for new fixtures A, C, T, R, G type bulbs
- LED tubes to replace FL's
- LEDs are more flexible in light direction targeting
- Retrofit options for low or high ceiling spaces

Energy efficient

- Use at least 75% less energy than incandescent bulb
- Use at least 50% less energy than CFL's
- Longer lifespan compared to that of FL's or CFL's

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Light Sources Overview

TrueForce LED Industrial and Retail Mains (Highbay – HPI/SON/HPL)

The best LED solution for High Intensity Discharge (HID) lamp replacement

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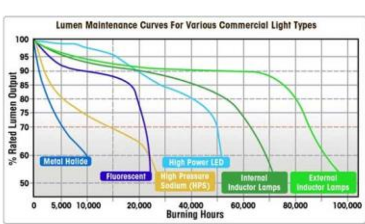
Light Sources Overview

Light Sources Overview

Depreciation of Lamp Lumen Output Over Time

Lumen Depreciation is simply stated as the loss of lumen output over a period of time in any given lamp. Most lamps naturally reduce the lumen output over time but to varying degrees depending on type. It is important to note that lumen depreciation isn't the same thing as burning out a lamp.



Energy Savings Lighting Controls

- Occupancy/Motion Sensors
  - Infrared and/or ultrasonic
  - Percentage savings depends on site occupancy
- Programmable timers (mechanical or digital)
- Others, admin control using signage/s




Natural Lighting - Daylighting

Daylighting is the use of windows and skylights to bring sunlight into your space. Today's highly energy-efficient windows, as well as advances in lighting design, reduce the need for artificial lighting during daylight hours without causing heating or cooling problems.


Sample LED Lighting Retrofit Project

No.	Location	Wattage FL	Quantity	Est. Operation (Hour)	# of Days Operation	Consumption (kWh)
1	First Floor	28	1466	24	365	359,580.48
2	Second Floor	28	1686	24	365	413,542.08
3	Third Floor	28	704	24	365	172,677.12
				Total Energy Consumption (kWh) per Year:		945,799.68

No.	Location	Wattage LED	Quantity	Est. Operation (Hour)	# of Days Operation	Consumption (kWh)
1	First Floor	16	1466	24	365	205,474.56
2	Second Floor	16	1686	24	365	236,309.76
3	Third Floor	16	704	24	365	98,672.64
				Total Energy Consumption (kWh) per Year:		540,456.96
				Annual Energy Saving (ES) kWh:		405,342.72
				Cost of Energy (Php/kWh):		6.60
				Annual Energy Cost Savings - ECS (Php):		2,675,261.95
				Total Investment Cost (Php):		2,845,728.0
				Annual Energy Cost Savings - ECS (Php):		2,675,262.0
				Annual Demand kW Cost Savings (Php):		300,309.0
				Simple Payback Period (Years):		0.96
				Return of Investment (ROI):		5%


Sample LED Lighting Retrofit Project

Energy Savings (ES) = (total # of lamps) x ($wattage_{FL}$ – $wattage_{LED}$) x (operating hours/year)
= (3,856 lamps) x (28W – 16W) x (8,760 hours/year)
= (405,342,720 Wh/year) / (1,000 kWh/Wh)
= **405,342.72 kWh/year**

Energy Cost Savings (ECS) = ES x Cost of Energy
= 405,342.72 kWh/year x Php9.18/kWh
= **Php 2,675,261.95/year**

Sample LED Lighting Retrofit Project

Annual Demand Cost Savings (ADCS) = (kW reduction) x (kW charge)
= [(12W x 3,856 lamps)/1000] x (P540.84/mo) x (12 mo/year)
= **Php 300,309.00 / year**

Simple Payback Period (years) = Investment Cost / (ECS + ADCS)
= Php 2,845,728 / (Php 2,675261.95 + Php 300,309.00)
= **0.96 years**

Return of Investment (ROI) = [(ECS + ADCS) – Investment Cost] / Investment Cost
= [Php2,975,570.95 – Php2,845,728.00] / (Php2,845,728.00)
= **5%**

Lighting System Audit

As Lighting is the easiest system to measure, examine and implement in the auditing. Energy can be saved in a lighting system by reducing the illumination levels, improving lighting system efficiency, trimming operating hours and by taking advantage of available daylighting.

Benefits of Lighting Improvements:
In addition to saving on energy and subsequent cost savings. Improving a facility's lighting system efficiency comes with the following benefits;

- **Lower maintenance** – Replacement of lighting sources with longer lasting alternatives (for example fluorescent lasts 10 to 20 times longer than incandescent). This means that fewer bulb replacements would be made, saving labor and costs.

Lighting System Audit

- **Lower cooling costs**– Each kW of lighting energy reduced, results in a heat load reduction of 3,142 Btu/Hr. Thus, if the lighting efficiency improvement reduces the demand by 3.5kW, the air conditioning load drops by one ton, or 12,000 Btu/Hr.
- **Better productivity** – Improving your lighting can help people see their work better, reduce eye strains and fatigue. Better lighting increases productivity.
- **Increased sales and image** – in commercial retail shops, better lighting systems help to sell merchandise better. And also used to accent the image the store wishes to project.
- **Increased safety** – Proper lighting systems and levels help illuminate dark or hazardous areas etc.

Basic Lighting Audit Tips

Lighting Audit Tip #1: Know Your Objective
Determine and meet the required light levels (foot-candle or lux)

Lighting Audit Tip #2: Know Your Tools
Basically, camera, tape measure/digital laser, lux meter and audit form

Lighting Audit Tip #3: Know Your Numbers
Measure light levels, total wattage, operating hours, energy bills

Lighting Audit Tip #4: Know Your Plan
Account tips 1, 2 & 3 so you'll have a high-level information for you EE&C project and compute ROI

Key Points

✓ The lighting system in a facility is an important area and easy to examine and to improve in terms of quality, energy efficiency and conservation.

✓ Energy-efficient lighting control systems not only reduce energy consumption (kWh) and demand (kW) but also offer significant energy cost savings in the long run.

✓ Energy audits help in developing an energy-saving strategies by identifying areas of energy waste and inefficiency.

KNOWLEDGE REVIEW
(Select the best answer)

1. What lighting type typically used for circulation and general lighting to give a "sense of space?
   a. Ambient Lighting
   b. Task Lighting
   c. Accent Lighting

2. What type of lighting is used for architectural purposes to add emphasis or focus to a space or to highlight a display?
   a. Task Lighting
   b. Accent Lighting
   c. Emergency Lighting

KNOWLEDGE REVIEW
(Select the best answer)

3. What does task lighting focus on in illumination design?
   a. Overall ambient lighting
   b. Highlighting specific activities
   c. Light source recognition

4. Which of the following is considered a traditional light source?
   a. LEDs
   b. Fluorescents
   c. Halogens

KNOWLEDGE REVIEW
(Select the best answer)

5. What lighting quality refers to to how a light source renders the colors of other objects and surfaces?
   a. CRI
   b. CCT
   c. Glare

6. What lighting quality describes a visual sensation caused by excessive and uncontrolled brightness in the field of view?
   a. CCT
   b. Uniformity
   c. Glare

KNOWLEDGE REVIEW

(Select the best answer)

7. What lighting quantity represents the electrical input to the lighting system or lamps?
   a. Watts
   b. Uniformity
   c. Lumens

8. What lighting quantity is the unit of measure to the actual output of the lamp?
   a. Foot-Candle
   b. Lux
   c. Lumens

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(Select the best answer)

9. _________ is the amount of lumens per watt from a particular energy source. A common misconception in lighting terminology is that lamps with greater wattage provide more light.
   a. Efficiency
   b. Efficacy
   c. Effectively

10. What method of lighting design is used to calculate the average illuminance and assumes an equal foot-candle/lux level throughout the area?
   a. Lumen method
   b. Point by point method
   c. Watt per square feet method

THANK YOU!