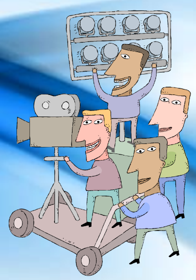


Lighting Basics and Lighting System Improvements

Session Objectives

- Discuss concepts and characteristics of energy-effective lighting design
- Outline principles and practices of good lighting maintenance
- Identify typical lighting energy conservation opportunities
- Demonstrate lighting economics calculations and relationships
- Work example lighting calculations

Section L - 2

Lighting Basics

- Efficient Lighting Design
- Effective Lighting Maintenance

Section L - 3

Principles of Efficient Lighting Design

- Meet target light levels
- Efficiently produce light
- Efficiently deliver light
  - Balance efficiency with aesthetics, lighting quality, visual comfort
- Automatically control lighting operation

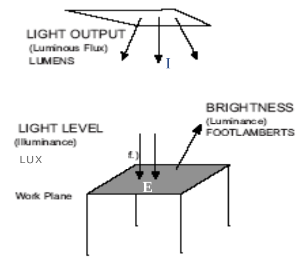
Section L - 4

Factors in Successful Lighting Applications

- Amount of light required in Lux
- Efficacy in Lumens/watt
- Lumen output of lamps and fixtures
- Color rendition, Color Rendering Index - CRI
- Color temperature in Kelvins
- Types of light sources
- Lighting quality

Section L - 5

Quantity of Illumination



Inverse Square Law

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

where d = distance from light source
to surface of interest

Section L - 6

Types of Light Sources

Incandescent	Low Pressure Sodium
Tungsten Halogen	Induction
Mercury Vapor	LED
Fluorescent	
Metal Halide	
High Pressure Sodium	

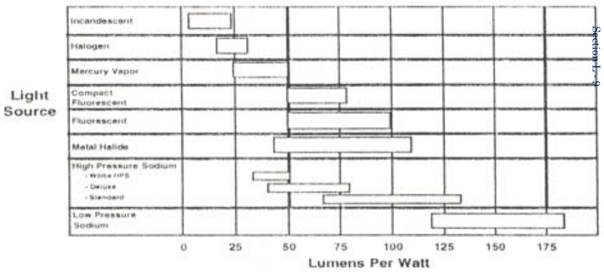
Section L - 7

What Does a Ballast Do?

- A ballast does three things:
  - Conditions the lamp to start
  - Applies a high voltage spike to start the gas discharge process
  - Applies a current limiter to reduce the lamp current to a safe operating level
- Ballast factor
  - Normal light output (0.85-0.95)
  - Can specify reduced or increased light output in electronic ballasts with proportional reduction or increase in power

Section L - 8

Light Source Efficacy



Note: Source efficacy values include ballast losses

Light Source Efficacy

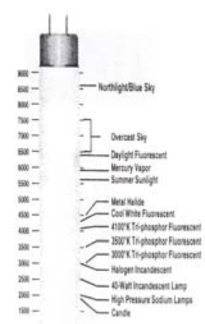
Category	Type	Overall luminous efficacy (lm/W)
Combustion	candle	0.3 [6]
	gas mantle	2 [7]
Incandescent	5 W tungsten incandescent (120 V)	5
	40 W tungsten incandescent (120 V)	12.6 [8]
	100 W tungsten incandescent (220 V)	13.8 [9]
	100 W tungsten glass halogen (220 V)	16.7 [10]
	100 W tungsten incandescent (120 V)	17.5 [8]
	2.6 W tungsten glass halogen (5.2 V)	19.2 [11]
	quartz halogen (12–24 V)	24
	photographic and projection lamps	35 [12]
Fluorescent	9–26 W compact fluorescent	60–72 [13][14]
	T12 tube with magnetic ballast	60 [15]
	T5 tube	70–100 [16]
	T8 tube with electronic ballast	80–100 [15]
Light-emitting diode	white LED	10–161 [17][18][19]
Arc lamp	xenon arc lamp	30–50 [20][21]
	mercury-xenon arc lamp	50–55 [20]
Gas discharge	1400 W sulfur lamp	100
	metal halide lamp	65–115 [22]
	high pressure sodium lamp	150 [23]
	low pressure sodium lamp	183–200 [23][24]

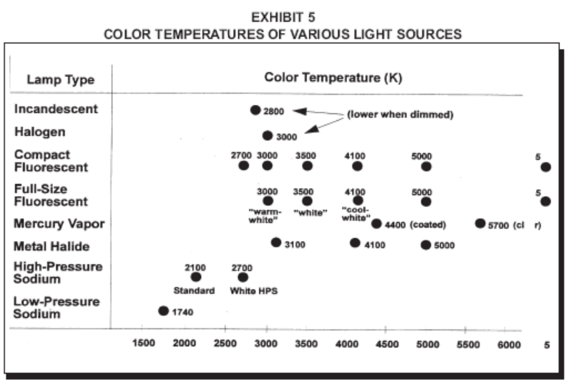
Color Rendering Index (CRI)

EXHIBIT 3
TYPICAL CRI VALUES FOR SELECTED LIGHT SOURCES

Source	Typical CRI Value
Incandescent/Halogen	100
Fluorescent	
Cool White T12	62
Warm White T12	53
High Lumen T12	73-85
T8	75-85
T10	80-85
Compact	80-85
Mercury Vapor (clear/coated)	15/50
Metal Halide (clear/coated)	65/70
High-Pressure Sodium	
Standard	22
Deluxe	65
White HPS	85
Low-Pressure Sodium	0

Color Temperature

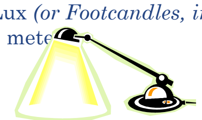




Section L - 13

AMOUNT OF LIGHT REQUIRED FOR SPECIFIC APPLICATIONS

- We often use more light than is needed for many applications and tasks.
  - Light levels are measured in Lux *(or Footcandles, in IP units)* using an illuminance meter.



Lux = lumens / m^2

FC = lumens / ft^2

Consensus standards for light levels are set by the Illuminating Engineering Society of North America (IESNA.org).

Section L - 14

RECOMMENDED LIGHT LEVELS
Source: IESNA

TYPE OF ACTIVITY	RANGE OF ILLUMINANCE
Public spaces with dark surroundings	2-3-5 fc
Simple orientation for short temporary visits (typical hallway)	5-7½-10 fc
Working spaces where visual tasks are only occasionally performed	10-15-20 fc
Ambient lighting for computer use	20-25-30 fc
Performance of visual tasks	
High contrast or large size (typical office)	20-30-50 fc
Medium contrast or small size	50-75-100 fc
Low contrast or very small size	100-150-200 fc
Low contrast and very small size over a prolonged period	200-300-500 fc
Performance of very prolonged and exacting visual tasks	500-750-1000 fc
Performance of very special visual tasks of extremely low contrast and small size	1000-1500-2000 fc

Section L - 15

SOME TYPICAL LIGHT LEVELS NEEDED ARE:

Parking lot	20 Lux
Hallways	100 Lux
Factory floor	300 Lux
Offices	500 Lux
Inspection	1000 Lux
Operating room	10000 Lux

Section L - 16

Average Rated Life

- Average rated life of a lamp is median value of life expectancy of a group of lamps
  - Time at which 50% have failed, 50% are surviving
  - Fluorescent lamps rated at 3 hours on, 20 minutes off per operating cycle
  - HID lamps rated at 10 hours on, one hour off per operating cycle
- Increased frequency of switching will decrease lamp life in hours, but typically increase useful calendar life
  - Energy savings more significant than lamp costs

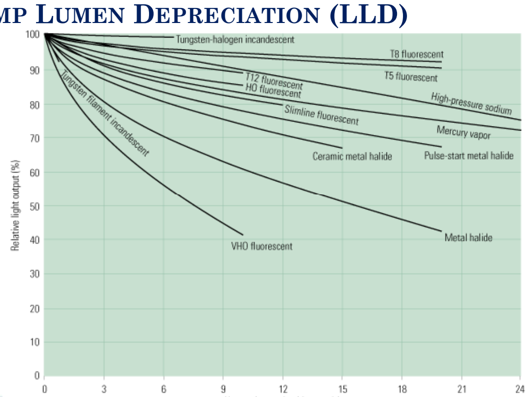
Section L - 17

Lighting Maintenance Principles

- Light output of all lighting systems decreases over time
- Lighting systems are over-designed to compensate for future light loss
- Improving maintenance practices can reduce light loss (depreciation) and can either:
  - allow reductions in energy consumption (redesign), or
  - improve light levels
- Group maintenance practices save money

Section L - 18

Lamp Lumen Depreciation (LLD)



Notes: HO = high output; VHO = very high output.

Section L - 19

Lighting System Design Methods

1. **Lumen Method**
   - Assumes an equal lux level throughout the area.
   - This method has been used frequently since it is simple.
2. **Point by Point Method**
   - The current method of design based on the Fundamental Law of Illumination.
   - Requires a computer program and extensive computation.

Section L - 20

Lumen Method Formula

$$N = \frac{F1 \times A}{Lu \times LLF \times Cu}$$

where

N = the number of lamps required
F1 = the required Lux level at the task
A = area of the room in square metres
Lu = the lumen output per lamp
Cu = the coefficient of utilization
LLF = the combined light loss factor

Example of Lumen Method

Find the number of lamps required to provide a uniform 500 Lux on the working surface in a 15 x 10 room. Assume two 3000 lumen lamps each per fixture, and assume that LLF is 0.65 and CU is 70%.

$$N = \frac{500 \times 150}{3000 \times 0.65 \times 0.7} = 55$$

The number of two-lamp fixtures needed is 28.

The Coefficient of Utilization (CU)

The coefficient of utilization is a measure of how well the light coming out of the lamps and the fixture contributes to the useful light level at the work surface.

It may be given, or you may need to find it:

- Use Room Cavity Ratio (RCR) to incorporate room geometry
- Use Photometric Chart for specific lamp and fixture

Room Cavity Ratio (RCR)

RCR = 2.5 x h x (Room Perimeter)/(Room Area)

Where

L = room length
W = room width
h = height from lamp to top of working surface

Example

Find the RCR for a 10 by 15 rectangular room with lamps mounted on the ceiling at a height of 3 metres, and the work surface is a 60 cm bench.

h = 3.0 – 0.6
= 2.4 metres

RCR = 2.5 x h x (2L+2W)/(LxW)
= 5 x 2.4 x (10 + 15)/(10 x 15)
= 12 x 25/150
= 2

Photometric Chart

Report LS1 1101 Lamp: 400 Watt Clear Lumens: 50,000 Mounting Surface/Pendant	COEFFICIENTS OF UTILIZATION Zonal Cavity Method Effective Floor Cavity Reflectance 0.20

RC	80			70			50		30	
RW	70	50	30	70	50	30	50	30	50	30
RCR 1	94	91	89	91	88	86	83	81	78	77
2	88	84	80	86	81	78	77	74	73	71
3	83	77	72	80	75	70	71	67	67	65
4	78	71	65	75	69	64	66	61	63	59
5	73	65	59	70	63	58	60	56	58	54
6	68	58	52	66	58	52	55	51	53	49
7	63	54	48	61	53	47	51	46	49	44
8	59	49	43	57	48	43	46	41	45	40
9	55	45	39	53	44	38	42	37	41	36
10	51	41	35	49	40	35	39	34	37	33

Example

Find the Coefficient of Utilization for a 10 by 15 rectangular room with a ceiling height of 3 metres, a ceiling reflectance of 70% and a wall reflectance of 50% using the photometric chart on the previous page.

The RCR from before was 2.0. Using RC = 70% and RW = 50%, the CU is found as CU = 0.81, or
81%

What to Look for in Lighting Audit

- Lighting Equipment Inventory
- Lighting Loads
- Room Dimensions
- Illumination Levels
- Hours of Use
- Lighting Circuit Voltage

Potential Lighting ECMs

- Fluorescent Upgrades
- Delamping
- Incandescent Upgrades
- HID Upgrades
- Controls Upgrades
- Daylight compensation

Three Major Areas for Lighting Improvement

Much of the cost savings from new retrofit lighting can be achieved in three major areas:

1. Replace incandescent lamps with fluorescent, or compact fluorescent lamps (CFLs)
2. Upgrade fluorescent fixtures with improved components
3. Install lighting controls to minimize energy costs

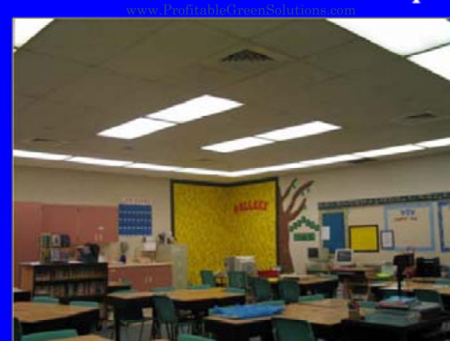
Applications of Compact Fluorescent Lights

- Task lights
- Downlights
- Wallwashers
- Outdoor fixtures – even in low temperatures
- Many kinds of fixtures available
- Exit lights
- Can be dimmed – so use in conference rooms
- Can be used in refrigerators and freezers

Heritage Oak Control Classroom

(New Construction at 1.75 watts / sq foot)

www.ProfitableGreenSolutions.com



Heritage Oak ICLS System
(0.8 watts / square foot)

NEW LIGHTING TECHNOLOGY

- **Induction lamps**
  - Long life -- 100,000 hours for lamp & ballast
  - Phillips QL lamps in 55W, 85W and 165W
  - New application with reflector to replace metal halides as sign lights for road and commercial signs. Last four times as long

Section L - 34

- OSRAM/Sylvania is the other maker of long life induction lamps
- Icetron in 70W, 100W and 150W sizes
- Also 100,000 hours
- Properties about same as QL lamp
  - Efficacy around 80 L/W (150 W ICE)
  - CRI 80
  - Instant start, and re-start
  - Operate in hot and cold environments

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NEW INDUCTION LAMPS 2009

- Smaller induction lamps are now available
- New sizes are 12, 23 and 40 W
- However, these smaller lamps are only rated at 30,000 hours life; and efficacies are 60 – 70 L/W.
- May be better choices than CFLs in some cases.
- Larger induction lamps 70 – 150 W are becoming quite a bit cheaper now.

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LED Lighting

- 80% of all new exit lights are LED lights
- But, there are some other interesting applications
  - **Traffic Signals**
    - Green 30 cm ball — 140 W to 13 W LED
    - Red 30 cm ball — 140 W to 11 W LED
    - Life — 1 year to 7 years for LED
    - Cost — $3 to $75 for LED
  - **Commercial Advertising Signs (Neon)**
    - Neon 15 mm tube — 9 W/metre
    - LED 15 mm replacement — 3.1 W/metre

LEDs for White Light

- Growth Area… *but beware of lamp life and lumen depreciation.*
- Performance is dependent on supplier/configuration.

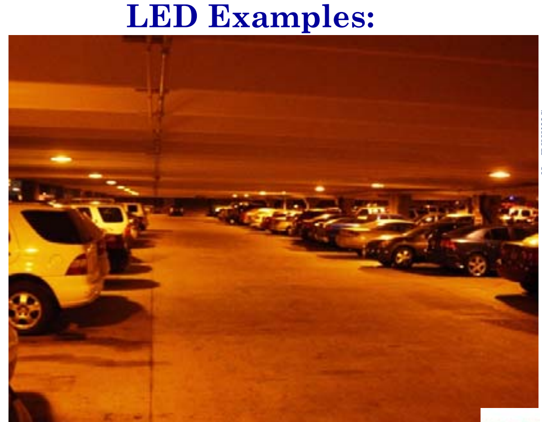
- Watch for this technology to become more accepted as development is rapid.

Parking Lot Example: "white" light appears brighter to eye!

Item	HPS	LED
Total System Wattage	300 W	141 W
Average Delivered Lumens per fixture (photopic)	19,000	8,040
Average Footcandles (photopic)	1.96	1.01
Average Delivered Lumens (scotopic)	11,780	17,206
Average Footcandles (scotopic)	1.22	2.16

Photopic vision is how the eye perceives objects and colors under bright light. Conversely, scotopic vision is how the eye perceives objects and colors under low-light conditions, such as a parking lot at night. The above measurements show that LED lights provide more perceived light at night while using much less energy.

LED Examples:



LED Examples:

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T5HO and High Bays

High Bay & Fluorescent T5/HO (it's not just for HID anymore!)

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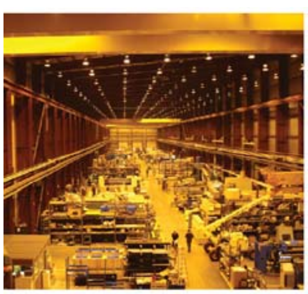
Lamp	Lamp and Ballast * Maintained Light	Wattage
4 - T5/HO Lamps	19,000 Lumens	242 watts
1 - MVR250/U	13,500	293
1 - MVR250/Pulse	17,000	288
6 - T5/HO Lamps	28,500 Lumens	363 watts
1 - MVR400/U	23,500	458
1 - MVR400/Pulse	33,000	456

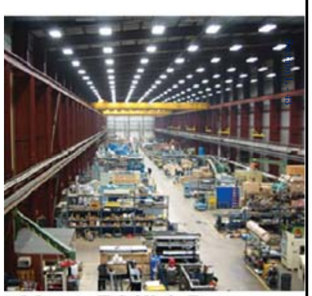
* (Impact of Fixture Design on Performance NOT included)

AND: Instant on, dimmable, choice of colors, no color shift…

T-8 High Bay Retrofit



High Pressure Sodium



6 Lamp T-8 High Bay

Source: Orion Lighting

Compare Lighting Power Density to ASHRAE/IES 90.1 Values

- **Example Whole Building Lighting Power Densities (W/ft2)**

	1989	1999/2001	2004/2007	2010
Offices	1.63	1.30	1.00	0.90
Education	1.79	1.50	1.20	0.99
Retail	2.36	1.90	1.50	1.40
Warehouse	0.53	1.20	0.80	0.66

Typical Lighting Operation

Building Type	Annual Hours of Operation
Assembly	2760
Avg. Non-Residential	3500
Education	2605
Food Sales	5200
Food Service	4580
Health Care	7630
Lodging	8025
Mercantile	3325
Office	2730
Warehouse	3295

Lighting Control Technologies

- On/off snap switch, timers and control systems
- Solid-state dimmers
- Dimming electronic ballasts
- Occupancy sensors
- Daylighting level sensors
- Daylight harvesting systems
- Window treatment controls and electrochromic glass
- Facility-wide lighting dimmers for demand response
- Digital lighting control systems with control busses
- Individual occupant lighting control

Energy Savings Potential With Occupancy Sensors

Application	Energy Savings
Offices (Private)	25-50%
Offices (Open Spaces)	20-25%
Rest Rooms	30-75%
Corridors	30-40%
Storage Areas	45-65%
Meeting Rooms	45-65%
Conference Rooms	45-65%
Warehouses	50-75%

CEM Exam Review Questions

1. The efficacy of a light source refers to the color rendering index of the lamp.
   A) True B) False

2. Increasing the coefficient of utilization of fixtures in a room will in many instances increase the number of lamps required.
   A) True B) False

3. Which HID lamp has the highest efficacy – for the same wattage?
   A) Mercury vapor
   B) Metal halide
   C) High pressure sodium

4. One disadvantage to metal halide lamps is a pronounced tendency to shift colors as the lamp ages.
   A) True B) False

5. A 25,000 square metre high bay facility is presently lit with 800 twin 400 watt mercury vapor fixtures (455 watts per lamp including ballast). What are the annual savings of replacing the existing lighting system with 800 single 400-watt high-pressure sodium fixtures (465 watts per lamp Including ballast)? Assume 8000 hours operation per year, an energy cost of \$0.05 per kWh, and a demand cost of \$6.00 per kW-month.

   Solution

SOLUTION

ΔkW = (800 fixtures)(.455 kW/lamp)(2 lamps) –
(800 fixtures)(.465 kW/fixture) = 356 kW

Demand \$ savings = (356 kW)(\$6/kW-mo)(12 mo/yr) = \$25,632/yr

Energy \$ savings = (356 kW)(8000 hrs/yr))(\$0.05/kWh)
= \$142,400/yr

Total \$ savings = (\$25,632 + \$142,400)/yr = \$168,032/yr

Cost = (800 fixtures)(\$400/fixture) = \$320,000 ??

LIGHTING APPENDIX

Upgrading Fluorescent Fixtures

- Improved fluorescent lamps
  - T-8, T-10, T-12 Tri-phosphor lamps
  - New third generation T-5 and T-8 lamps
  - New Super T- 8 lamps
  - New induction lamps
- Electronic ballasts
  - Standard non-dimmable ballasts
  - Consider dimming ballasts
  - New programmable ballasts for long-life lamps
- Reflectors and new reflector fixtures – up/down fixtures

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Fluorescent Retrofits

Existing System: T12 lamps with magnetic ballasts

Retrofit Alternatives:

1. T12 low wattage lamps (34W) – replace lamps only
   - Less light, less energy consumption
2. T8 (32W) – replace lamps and ballasts
   - Same light, less energy consumption, better color rendering, less lamp flicker, less ballast hum
   - Can operate 4 lamps per ballast
   - Can be tandem wired
   - Electronic ballasts can be parallel wired

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3. T10 (42W) – replace lamps only
   - More light, same energy consumption
4. T10 (42W) – replace lamps and ballasts
   - Much more light, same energy consumption, same benefits as T8's
5. T5 (28W) – replace lamps and ballasts
   - Same light, less energy consumption than T8's
6. New 28W and 30W T8's now available
   Super T8s with 3100 lumens (32W)
7. New 25,000 and 30,000 hour life lamps available, with use of programmable start ballasts matched to lamps

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Lighting Quality Measures

- **Visual comfort probability (VCP)** indicates the percent of people who are comfortable with the glare (brightness) from a fixture
- **Spacing criteria (SC)** refers to the maximum recommended distance between fixtures to ensure uniformity
- **Color rendering index (CRI)** indicates the color appearance of an object under a source as compared to a reference source

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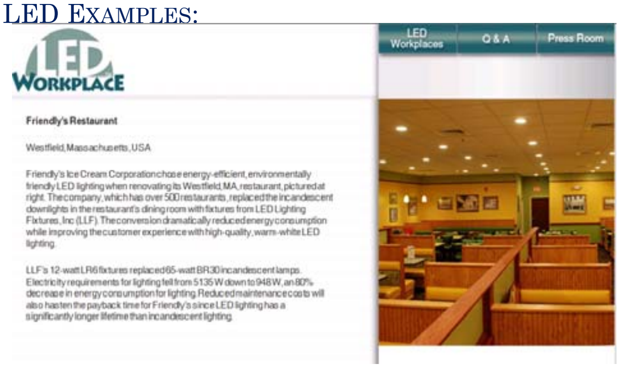
LED Examples:


LED Workplace

Friendly's Restaurant

Westfield, Massachusetts, USA

Friendly's Ice Cream Corporation chose energy-efficient, environmentally friendly LED lighting when renovating its Westfield, MA, restaurant, pictured at right. The company, which has over 500 restaurants, replaced the incandescent downlights in the restaurant's dining room with fixtures from LED Lighting Fixtures, Inc (LLF). The conversion dramatically reduced energy consumption while improving the customer experience with high-quality, warm-white LED lighting.

LLF's 12-watt LR6 fixtures replaced 65-watt BR30 incandescent lamps. Electricity requirements for lighting fell from 5135 W down to 948 W, an 80% decrease in energy consumption for lighting. Reduced maintenance costs will also hasten the payback time for Friendly's since LED lighting has a significantly longer lifetime than incandescent lighting.

LED Photos

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58

Fundamental Law of Illumination or Inverse Square Law

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

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where

- E = Illuminance in Lux
- I = Luminous intensity in lumens
- d = Distance from light source to surface area of interest in metres

One Lux is equal to one lumen per square metre)
(One footcandle is equal to one lumen per square foot)

Example

In a high bay facility, the lights are mounted on the ceiling which is 13 metres above the floor. The lighting level on the floor is 500 Lux. No use is made of the space between 7 metres and 13 metres above the floor.

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In a theoretical sense – that is, using the fundamental law of illumination – what would be the light level in Lux directly below a lamp if the lights were dropped to 7 metres?

$$\text{Lux} = 500 \times (13^2/7^2) = 1725 \text{ Lux}$$

Compact Fluorescent Example

COMPACT FLUORESCENT LAMPS

For retrofit applications in task lights, wall sconces, downlights, wallwashers, and outdoor fixtures, a wide variety of lamp shapes and types are available. These include globes, capsules, floods, and twin/quad-tube units. The most common retrofit applications are in open fixtures with mounting heights less than 12 feet. In some applications, users may prefer to hardwire the ballast in the fixture to prevent replacement with incandescent lamps. Lamps with excellent color rendering capabilities (80-85 CRI) are recommended for most indoor applications.

Wattages: 5-26W

Replaces: 25-100W incandescents

Energy Savings: 60-75%

Efficacy: 26-58 lm/W

Lamp Cost: $3-6

Ballast Cost: $9-24

Rated Lamp Life: 10,000 hrs

Color Quality: 60-85 CRI

Dimming: Not in retrofit applications

Qualifications: These lamps can have starting limitations in freezing temperatures, and operation in enclosed fixtures may shorten lamp and ballast life and reduce light output. Because compact fluorescents are not point sources; other technologies may be more suitable in applications—such as retail display lighting—where good beam control is required. Some conventional fixture types may not be large enough to accept the larger size of the fluorescent lamp/ballast package. Check manufacturer data to determine impacts of ballast use on power factor and power quality.

Example: Compact Fluorescent Lamps

Old System: Incandescent hallway recessed downlighting in 12' ceiling; 100 fixtures @ 75 watts (@ $3.50); operating hours: 15 hrs/day, 6 days/week (4,680 hrs/yr)

New System: Screw-in fluorescent lamps (82 CRI) with integrated magnetic ballasts; downlighting reflectors; 100 fixtures @ 22 watts (including ballast operation)

Results: 71% energy savings; virtually unchanged light level and appearance; 10 times longer lamp life

Savings: Demand savings: 5.3 kW; energy savings: 24,800 kWh/yr; dollar savings @ $4/kW/mo and $0.08/kWh: $2,238/yr; relamping savings: materials $796/yr; labor $2,106/yr

Net Savings: $5,140/yr

Cost: Material: 100 lamp/ballast capsules @ $18; 100 reflectors @ $4; Labor: 100 installations @ $3

Total Project Cost: $2,500

Payback: $2,500/$5,140/yr = 0.49 yr

Calculation for Compact Fluorescent Example

kW savings
100 fixtures (.075 kW/fixture - .022 kW/fixture) = 5.3 kW

kWh savings
(5.3 kW)(4680 hrs/yr) = 24,804 kWh

Demand $ savings
(5.3 kW)($4/kW-mo)(12 mo/yr) = $254.40/yr

Energy $ savings
(24,804 kWh/yr)($0.08/kWh) = $1,984.32/yr

Total dollar savings
($254.40 + $1,984.32)/yr = $2239/yr

T-8 Example

Example: T-8 Fluorescent System Retrofit

Old System: Office lighting consisting of 360 fluorescent 2'x4' fixtures; operating hours:14 hrs/day, 5 days/week (3640 hrs/yr); each fixture draws 188 watts with 4 standard cool white 40-watt fluorescent lamps (@ $2) and 2 standard magnetic ballasts

New System: Each fixture now draws 112 watts with 4 tri-phosphor F40T8 32-watt fluorescent lamps and 1 electronic T-8 instant-start mode ballast*

Results: 40% energy savings; 2% reduction in light level; improved color rendering; 50% fewer ballasts to replace; 25% less lamp life using instant-start mode ballasts

Savings: Demand savings: 27.4 kW; energy savings: 99,600 kWh/yr; dollar savings @ $4/kW/mo and $0.08/kWh: $9,280/yr; relamping savings: materials <$612/yr>; labor <$437/yr>

Net Savings: $8,231/yr

Cost: Material: 1440 F32T8 fluorescent lamps @ $3.25; 360 T-8 instant-start mode electronic ballasts @ $31; labor: 360 installations @ $20

Total Project Cost: $23,040

Payback: $23,040/$8,231/yr = 2.8 yrs (with 10% a/c factor, payback becomes 2.5 yrs)

*Building codes in some states do not allow all four lamps to be operated by a single ballast. In such cases, two adjacent fixtures can share two ballasts that are wired to leave the two-level switching intact. Assume an additional $15 wiring cost per fixture. The payback period increases to 3.5 years.

Calculation for T-8 Example

Demand savings

(360 fixtures)(.188 - .112) kW/fixture = 27.4kW

Total $ savings

(27.4 kW)[($4/kW-mo)(12 mo/yr) + (3640 hrs/yr x $0.08/kWh)] = $9290/yr

Fluorescent Lamp Life at Various Burn Cycles

Lamp	3	6	10	12	18	24
40-w T12 pre-heat	15,000	17,500	21,250	22,500	25,000	28,125
40-w T12 rapid start	20,000	24,420	27,750	28,860	31,600	37,700
32-w T8 instant start	15,000	17,500	21,250	22,500	25,000	28,125
32-w T8 rapid start	20,000	24,420	27,750	28,860	31,600	37,700

Source: NALMCO

Occupancy Sensor Example

Uncontrolled System: Six conference rooms, each with four 4-lamp fluorescent fixtures (188 watts) operating 10 hrs/day, 5 days/week (2,600 hrs/yr); lamps @ $2

Controlled System: When conference rooms are unoccupied for longer than five minutes, the fixtures are now automatically turned off; they now operate about 7 hrs/day, 5 days/week (1,820 hrs/yr)

Results: 30% energy savings; no change in fixture appearance or light level

Savings: Energy savings: 3,519 kWh/yr; dollar savings @ $0.08/kWh: $282/yr; relamping savings: materials $7/yr; labor $19/yr

Net Savings: $308/yr

Cost: Material: 6 switch-mount occupancy sensors @ $70; labor: 6 installations @ $10

Total Project Cost: $480

Payback: $480/$308/yr = 1.6 yrs (with 10% a/c factor, payback becomes 1.4 yrs)

Energy savings
(24 fixture)(.188 kW/fixture)(2600 hrs/yr)(0.30)($0.08/kWh)
= $282/yr

Lighting-Related HVAC Energy

- How much lighting energy becomes a load on the HVAC system?
  - How much heat is generated by lighting?
  - Where does lighting heat go?
  - How does it affect the energy consumption of the HVAC system?

Lighting-Related HVAC Energy

- Lighting-Related HVAC Energy (kWh) =
  Direct Lighting Energy (kWh)

  x % of year HVAC System Operates
  x % of light heat impacting HVAC load
  / COP of HVAC system

Lighting-Related Energy Savings

- COP = <u>Energy Units Delivered to (Removed from) Space</u>
  Energy Units Into System

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Lighting-Related HVAC Energy Example

	Lighting-Related HVAC Energy (kWh)	Example
=	Direct Lighting Energy (kWh)	1000 kWh
x	% of year HVAC System Operates	0.5
x	% of light heat impacting HVAC load	0.9
/	COP of HVAC system	3.0

1000 x (0.5 x 0.9 / 3.0) = 1000 x 0.15 = 150 kWh

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Example Lighting / HVAC Interaction

Location	Cooling Loads	Heating Loads Large Building	Heating Loads Small Building
Tampa, FL	-33%	0%	0%
Phoenix, AZ	-30%	0%	0%
New Orleans, LA	-29%	1%	2%
Los Angeles, CA	-23%	0%	0%
Knoxville, TN	-21%	4%	11%
Philadelphia, PA	-17%	6%	18%
Denver, CO	-16%	7%	22%
San Francisco, CA	-16%	1%	2%
Detroit, MI	-14%	8%	23%
Providence, RI	-13%	7%	22%
Seattle, WA	-7%	4%	13%

Source: Advanced Lighting Guidelines 2003
(based on methodology of Rundquist, et.al. 1993)

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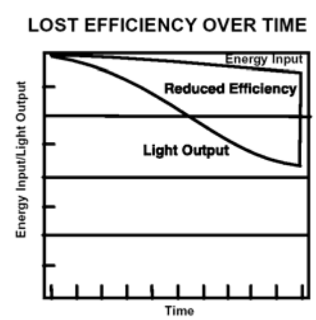
Neglected Lighting Systems Lose Efficiency Over Time



Source: EPA Green Lights

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Light Loss Factors (LLF)

- Non-recoverable
  - Luminaire Ambient Temperature
  - Voltage to Luminaire
  - Ballast Factor (BF)
  - Luminaire Surface Depreciation
- Recoverable
  - Lamp Burnout Factor (LBO)
  - Lamp Lumen Depreciation (LLD)
  - Luminaire Dirt Depreciation (LDD)
  - Room Surface Dirt Depreciation (RSDD)

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Total Light Loss Factor (LLF) Examples

	T12 Spot	T12 Group	T8 Group
LLD	0.82	0.78	0.93
LBO	1.00	1.00	1.00
LDD	0.65	0.80	0.80
Total LLF*	0.53	0.62	0.74

Source: EPA Green Lights

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Lighting System Life Cycle Costs

- Initial Costs
- Energy Costs
- Maintenance Costs
  - Relamping
  - Reballasting
  - Cleaning
  - Miscellaneous Maintenance
  - Insurance & Property Taxes
  - Depreciation

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Lighting System Life Cycle Costs

- Initial Costs
  - Equipment
  - Installation
  - Wiring
  - HVAC
- Energy Costs
- Maintenance Costs

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Lighting System Life Cycle Costs

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- Initial Costs
- Energy Costs
  - Direct Lighting Costs
  - Lighting-Related HVAC (Indirect) Costs
- Maintenance Costs

Direct Lighting Energy Costs

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- Energy Use (kWh) =
  Lighting Power (kW)
  x Operating Time (hrs)
- Energy Cost Savings =
  Actual Avoided Costs
  (based on rate schedule)

Calculating Annual Lamp Replacements

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- Given:
  - 1000 each 3-lamp fixtures
  - Annual fixture operation = 4000 hrs
  - Average rated lamp life = 25,000 hrs
- Calculate average annual lamp replacements:
  ALR = (1000 x 3) x 4,000 / 25,000
  = 3000 x 0.16
  = 480

Benefits of Group Relamping

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- Lower labor cost
- More light
- Fewer un-replaced burnouts
- Less lamp stocking
- Fewer work interruptions

CALCULATING GROUP RELAMPING INTERVAL

- Given:
  - 1000 each 3-lamp fixtures
  - Annual fixture operation = 4000 hrs
  - Average rated lamp life = 25,000 hrs
  - Group replace lamps at 70% of rated life
- Calculate group relamping interval:

  GRI = 25,000 x 0.7 / 4000
  = 17,500 / 4000
  = 4.375 years
  = 52.5 months

Group Relamping Example

	Spot Relamping (on burn-out)		Group Relamping (@ 70% of rated life)	
Relamp cycle	20,000	hours	14,000	hours
Average relamps	525	relamps/yr	750	relamps/yr
Average material cost	$1,391	/year	$1,988	/year
Average labor cost	$3,150	/year	$1,125	/year
Average disposal cost	$263	/year	$375	/year
AVG. MAINT. BUDGET	$4,804	/year	$3,488	/year
Assumptions:				
Material	$2.65	/lamp	$2.65	/lamp
Labor (relamp & clean)	$6.00	/lamp	$1.50	/lamp
Disposal (recycle)	$0.50	/lamp	$0.50	/lamp
Operation	3,500	hours/yr	3,500	hours/yr
Fixtures	1,000	lensed troffers	1,000	lensed troffers
Lamps/fixture	3	F32T8	3	F32T8

LIGHTING MAINTENANCE ACTION CHECKLIST

- Group relamp to reduce lumen depreciation and maintenance costs
- Clean fixtures at the time of relamping, more often in dirty locations
- Write a lighting maintenance policy
- Design your lighting projects to incorporate effective maintenance
- Get help when needed from lighting management companies, consultants, distributors, manufacturers, etc.

Source: EPA Energy Star / Greenlights

ASSUMPTIONS FOR EXAMPLES

- Average energy cost: $0.07/kWh
- Four lamps in a fixtue
- Annual fixture operation: 3500 hrs
- Lamp life: 28,860 hrs
- Labor to replace lamps: $6/lamp
- System life: 15 years
- No inflation or time value of money

EXAMPLE 1 – ANNUAL OPERATING COST

Given: Case A
Fixture Power: 144 W
Lamp Cost: $1.50 each

Case B
Fixture Power: 101 W
Lamp Cost: $3.00 each

EXAMPLE 1 – ANNUAL OPERATING COST

Given: Case A
Fixture Power: 144 W
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Case B
Fixture Power: 101 W
Lamp Cost: $3.00 each

EXAMPLE 1

Find: Annual Energy Cost (AEC)
Annual Material (lamps) Cost (AMC)
Annual Labor Cost (ALC)
Total Annual Operating Cost (AOC)

EXAMPLE 1A

Solution: AEC(A) = 0.144 kW x 3500 hrs/yr x $0.07/kWh
= $35.28/yr

AMC(A) = 4 lamps x 3500 hrs/yr / 28860 hrs/lamp x $1.50/lamp
= 0.485 lamps/yr x $1.50/lamp = $0.73/yr

ALC(A) = 0.485 lamps/yr x $6/lamp = $2.91/yr

AOC(A) = AEC(A) + AMC(A) + ALC(A)
= $35.28 + $0.73 + $2.91
= $38.92/yr

Example 1B

Solution: AEC(B) = 0.101 kW x 3500 hrs/yr x $0.07/kWh
= $24.74/yr

AMC(B) = 4 lamps x 3500 hrs/yr x
$3.00/lamp
28860 hrs/lamp
= 0.485 lamps/yr x $3.00/lamp = $1.46/yr

ALC(B) = 0.485 lamps/yr x $6/lamp = $2.91/yr

AOC(B) = AEC(A) + AMC(A) + ALC(A)
= $24.74 + $1.46 + $2.91
= $29.11/yr

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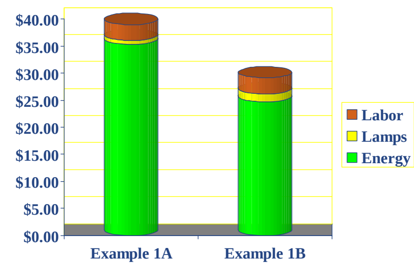
Example 1



Total Annual Operating Cost

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Example 2 – Life Cycle Cost

Given: Initial Cost(A): $50
Initial Cost(B): $100
Discount Rate: 5%

Find: Life Cycle Cost (LCC)

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Example 2

Solution: LCC = IC + [P/A,5%,15] (AEC + AMC + ALC)

LCC(A) = $50 + 10.380 ($35.28 + $0.73 + $2.91)
= $50 + $366.21 + $7.58 + $30.21
= $454.00

LCC(B) = $100 + 10.380 ($24.74 + $1.46 + $2.91)
= $100 + $256.80 + $15.16 + $30.21
= $402.17

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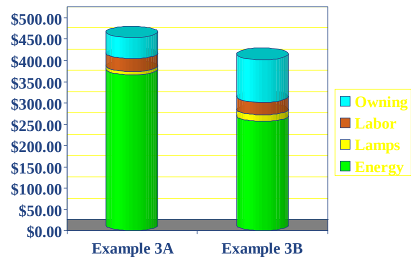
Example 2

LIFE CYCLE COST (LCC)



END OF SECTION L