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
LIGHTING BASICS

- Efficient Lighting Design
- Effective Lighting Maintenance

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
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

QUANTITY OF ILLUMINATION

Inverse Square Law

\[ E = \frac{I}{d^2} \]

where \( d \) = distance from light source to surface of interest
TYPES OF LIGHT SOURCES

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

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
**Light Source Efficacy**

Note: Source efficacy values include ballast losses

### Light Source Efficacy

<table>
<thead>
<tr>
<th>Category</th>
<th>Type</th>
<th>Overall Luminous Efficacy (lm/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion</td>
<td>candle</td>
<td>0.3 [F]</td>
</tr>
<tr>
<td></td>
<td>gas mantle</td>
<td>2 [G]</td>
</tr>
<tr>
<td>Incandescent</td>
<td>5 W tungsten incandescent (120 V)</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>40 W tungsten incandescent (120 V)</td>
<td>12.6 [H]</td>
</tr>
<tr>
<td></td>
<td>100 W tungsten incandescent (220 V)</td>
<td>13.8 [I]</td>
</tr>
<tr>
<td></td>
<td>100 W tungsten glass incandescent (220 V)</td>
<td>16.7 [J]</td>
</tr>
<tr>
<td></td>
<td>100 W tungsten incandescent (120 V)</td>
<td>17.5 [K]</td>
</tr>
<tr>
<td></td>
<td>2.6 W tungsten glass incandescent (5.2 V)</td>
<td>19.2 [L]</td>
</tr>
<tr>
<td></td>
<td>quartz halogen (12–24 V)</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>photographic and projection lamps</td>
<td>35 [M]</td>
</tr>
<tr>
<td>Fluorescent</td>
<td>9–26 W compact fluorescent</td>
<td>60–72 [N]</td>
</tr>
<tr>
<td></td>
<td>T12 tube with magnetic ballast</td>
<td>60 [O]</td>
</tr>
<tr>
<td></td>
<td>T5 tube</td>
<td>70–100 [P]</td>
</tr>
<tr>
<td></td>
<td>T8 tube with electronic ballast</td>
<td>80–100 [Q]</td>
</tr>
<tr>
<td>Light-emitting diode</td>
<td>white LED</td>
<td>10–161 [R]</td>
</tr>
<tr>
<td>Arc lamp</td>
<td>xenon arc lamp</td>
<td>30–50 [S]</td>
</tr>
<tr>
<td></td>
<td>mercury-xenon arc lamp</td>
<td>50–55 [T]</td>
</tr>
<tr>
<td>Gas discharge</td>
<td>1400 W sulfur lamp</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>metal halide lamp</td>
<td>65–115 [U]</td>
</tr>
<tr>
<td></td>
<td>high pressure sodium lamp</td>
<td>150 [V]</td>
</tr>
<tr>
<td></td>
<td>low pressure sodium lamp</td>
<td>183–200 [W]</td>
</tr>
</tbody>
</table>

Section L - 10
COLOR RENDERING INDEX (CRI)

EXHIBIT 3
TYPICAL CRI VALUES FOR SELECTED LIGHT SOURCES

<table>
<thead>
<tr>
<th>Source</th>
<th>Typical CRI Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent/Halogen</td>
<td>100</td>
</tr>
<tr>
<td>Fluorescent</td>
<td></td>
</tr>
<tr>
<td>Cool White T12</td>
<td>62</td>
</tr>
<tr>
<td>Warm White T12</td>
<td>53</td>
</tr>
<tr>
<td>High Lumen T12</td>
<td>75-95</td>
</tr>
<tr>
<td>T9</td>
<td>75-95</td>
</tr>
<tr>
<td>T10</td>
<td>50-95</td>
</tr>
<tr>
<td>Compact</td>
<td>80-95</td>
</tr>
<tr>
<td>Mercury Vapor (clear/coated)</td>
<td>15/50</td>
</tr>
<tr>
<td>Mercury Vapor (clear/coated)</td>
<td>60/70</td>
</tr>
<tr>
<td>High-Pressure Sodium</td>
<td></td>
</tr>
<tr>
<td>Standard</td>
<td>22</td>
</tr>
<tr>
<td>Deluxe</td>
<td>65</td>
</tr>
<tr>
<td>White HPS</td>
<td>85</td>
</tr>
<tr>
<td>Low-Pressure Sodium</td>
<td>0</td>
</tr>
</tbody>
</table>

COLOR TEMPERATURE

[Diagram showing color temperature range with various light sources indicated]
**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.
    
    \[
    \text{Lux} = \frac{\text{lumens}}{\text{m}^2} \\
    \text{FC} = \frac{\text{lumens}}{\text{ft}^2}
    \]
    
    Consensus standards for light levels are set by the Illuminating Engineering Society of North America (IESNA.org).
### RECOMMENDED LIGHT LEVELS
Source: IESNA

<table>
<thead>
<tr>
<th>TYPE OF ACTIVITY</th>
<th>RANGE OF ILLUMINANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public spaces with dark surroundings</td>
<td>2-3.5 fc</td>
</tr>
<tr>
<td>Simple orientation for short temporary visits (typical hallway)</td>
<td>5-7 fc-19 fc</td>
</tr>
<tr>
<td>Working spaces where visual tasks are only occasionally performed</td>
<td>10-15-23 fc</td>
</tr>
<tr>
<td>Ambient lighting for computer use</td>
<td>20-25-30 fc</td>
</tr>
<tr>
<td>Performance of visual tasks</td>
<td></td>
</tr>
<tr>
<td>High contrast or large size (typical office)</td>
<td>20-30-50 fc</td>
</tr>
<tr>
<td>Medium contrast or small size</td>
<td>50-75-100 fc</td>
</tr>
<tr>
<td>Low contrast or very small size</td>
<td>100-150-200 fc</td>
</tr>
<tr>
<td>Low contrast and very small size over a prolonged period</td>
<td>200-300-500 fc</td>
</tr>
<tr>
<td>Performance of very prolonged and exacting visual tasks</td>
<td>500-750-1000 fc</td>
</tr>
<tr>
<td>Performance of very special visual tasks of extremely low contrast and small size</td>
<td>1000-1500-2000 fc</td>
</tr>
</tbody>
</table>

### 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
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

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
LAMP LUMEN DEPRECIATION (LLD)

Lighting L - 19

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.
**Lumen Method Formula**

\[
N = \frac{F_1 \times A}{Lu \times LLF \times Cu}
\]

where

- \(N\) = the number of lamps required
- \(F_1\) = 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.

\[ h = 3.0 - 0.6 \]
\[ = 2.4 \text{ metres} \]

\[ \text{RCR} = 2.5 \times h \times \frac{(2L+2W)}{(LxW)} \]
\[ = 5 \times 2.4 \times \frac{(10 + 15)}{(10 \times 15)} \]
\[ = 12 \times \frac{25/150}{2} \]
\[ = 2 \]

PHOTOMETRIC CHART
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
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
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

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.
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!

<table>
<thead>
<tr>
<th>Item</th>
<th>HPS</th>
<th>LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total System Wattage</td>
<td>300 W</td>
<td>141 W</td>
</tr>
<tr>
<td>Average Delivered Lumens per fixture</td>
<td>19,000</td>
<td>8,040</td>
</tr>
<tr>
<td>(photopic)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Footcandles (photopic)</td>
<td>1.96</td>
<td>1.01</td>
</tr>
<tr>
<td>Average Delivered Lumens (scotopic)</td>
<td>11,780</td>
<td>17,206</td>
</tr>
<tr>
<td>Average Footcandles (scotopic)</td>
<td>1.22</td>
<td>2.16</td>
</tr>
</tbody>
</table>

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:

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

<table>
<thead>
<tr>
<th>Lamp</th>
<th>Maintained Light</th>
<th>Wattage</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 - T5/ HO Lamps</td>
<td>19,000 Lumens</td>
<td>242 watts</td>
</tr>
<tr>
<td>1 - MVR250/ U</td>
<td>13,500</td>
<td>293</td>
</tr>
<tr>
<td>1 - MVR250/ Pulse</td>
<td>17,000</td>
<td>288</td>
</tr>
<tr>
<td>6 - T5/ HO Lamps</td>
<td>28,500 Lumens</td>
<td>363 watts</td>
</tr>
<tr>
<td>1 - MVR400/ U</td>
<td>23,500</td>
<td>458</td>
</tr>
<tr>
<td>1 - MVR400/ Pulse</td>
<td>33,000</td>
<td>456</td>
</tr>
</tbody>
</table>

* (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](image1)

![6 Lamp T-8 High Bay](image2)

Source: Orion Lighting

### Compare Lighting Power Density to ASHRAE/IES 90.1 Values

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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Offices</td>
<td>1.63</td>
<td>1.30</td>
<td>1.00</td>
<td>0.90</td>
</tr>
<tr>
<td>Education</td>
<td>1.79</td>
<td>1.50</td>
<td>1.20</td>
<td>0.99</td>
</tr>
<tr>
<td>Retail</td>
<td>2.36</td>
<td>1.90</td>
<td>1.50</td>
<td>1.40</td>
</tr>
<tr>
<td>Warehouse</td>
<td>0.53</td>
<td>1.20</td>
<td>0.80</td>
<td>0.66</td>
</tr>
</tbody>
</table>
Typical Lighting Operation

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Annual Hours of Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembly</td>
<td>2760</td>
</tr>
<tr>
<td>Avg. Non-Residential</td>
<td>3500</td>
</tr>
<tr>
<td>Education</td>
<td>2605</td>
</tr>
<tr>
<td>Food Sales</td>
<td>5200</td>
</tr>
<tr>
<td>Food Service</td>
<td>4580</td>
</tr>
<tr>
<td>Health Care</td>
<td>7630</td>
</tr>
<tr>
<td>Lodging</td>
<td>8025</td>
</tr>
<tr>
<td>Mercantile</td>
<td>3325</td>
</tr>
<tr>
<td>Office</td>
<td>2730</td>
</tr>
<tr>
<td>Warehouse</td>
<td>3295</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Application</th>
<th>Energy Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offices (Private)</td>
<td>25-50%</td>
</tr>
<tr>
<td>Offices (Open Spaces)</td>
<td>20-25%</td>
</tr>
<tr>
<td>Rest Rooms</td>
<td>30-75%</td>
</tr>
<tr>
<td>Corridors</td>
<td>30-40%</td>
</tr>
<tr>
<td>Storage Areas</td>
<td>45-65%</td>
</tr>
<tr>
<td>Meeting Rooms</td>
<td>45-65%</td>
</tr>
<tr>
<td>Conference Rooms</td>
<td>45-65%</td>
</tr>
<tr>
<td>Warehouses</td>
<td>50-75%</td>
</tr>
</tbody>
</table>

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**

\[
\Delta kW = (800 \text{ fixtures})(0.455 \text{ kW/lamp})(2 \text{ lamps}) - (800 \text{ fixtures})(0.465 \text{ kW/fixture}) = 356 \text{ kW}
\]

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

Energy $ savings = (356 \text{ kW})(8000 \text{ hrs/yr })(0.05/\text{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

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
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

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
LED EXAMPLES:

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. (LFI). The conversion dramatically reduced energy consumption while improving the customer experience with high-quality, warm-white LED lighting.

LFI’s 13-watt LED fixture replaced a 65-watt BR30 incandescent lamp. Electricity requirements for lighting fell from 3,135 W down to 484 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
**FUNDAMENTAL LAW OF ILLUMINATION OR INVERSE SQUARE LAW**

\[ E = \frac{I}{d^2} \]

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.

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?

\[ \text{Lux} = 500 \times \left(\frac{13^2}{7^2}\right) = 1725 \text{ Lux} \]
COMPACT FLUORESCENT EXAMPLE

**Example: Compact Fluorescent Lamps**

**Old System:** Screw-in fluorescent lamps (230-V, 40-W) with saturated magnetic ballasts, downgrading reflector, plastic or wood housing, inexperienced installation, and facility maintenance.

**New System:** Screw-in fluorescent lamps (230-V, 40-W) with integrated electronic ballasts, a downgrading reflector, metal housing, experienced installation, and better facility maintenance.

**Results:**
- 0.0% energy savings, virtually no change in lamp efficiency.

**Savings:**
- Demand savings: 0.0 kW
- Energy savings: 24,804 kWh/yr
- Cost savings: $1,984.32/yr
- Total Savings: $1,984.32

**Total Project Cost:** $2,656
**Payback:** 1.40 yr

**Kilowatt Savings:**

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

**Kilowatt-hour Savings:**

\[ (5.3 \text{ kW})(4680 \text{ hrs/yr}) = 24,804 \text{ kWh} \]

**Demand $ Savings:**

\[ (5.3 \text{ kW})(4\text{$/kW-mo})(12 \text{ mo/yr}) = \$254.40/yr \]

**Energy $ Savings:**

\[ (24,804 \text{ kWh/yr})(\$0.08/\text{kWh}) = \$1,984.32/yr \]

**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 2x4' 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; 50% less lamp life using instant-start mode ballasts.

Savings: Demand savings: 27.4 kW; energy savings: 0.660 kWh/yr; dollar savings $4/kW-mo and $0.08/kWh.

$9,280/yr; relamping savings: materials <$.61/yr; labor <$43/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 = 27.4 kW

Total $ savings

(27.4 kW)[($4/kW-mo)(12 mo/yr) + (3640 hrs/yr x $0.08/kWh)] = $9,290/yr
## FLUORESCENT LAMP LIFE AT VARIOUS BURN CYCLES

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

Source: NALMCO

## OCCUPANCY SENSOR EXAMPLE

Uncontrolled System: Six conference rooms, each with four 4-lamp fluorescent fixtures (88 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

Energy savings

\[
\text{Energy savings} = (24 \text{ fixture})(0.188 \text{ kW/fixture})(2600 \text{ hrs/yr})(0.30)(\$0.08/\text{kWh}) = \$282/\text{yr}
\]
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?

\[
\text{Lighting-Related HVAC Energy (kWh)} = \frac{\text{Direct Lighting Energy (kWh)}}{\text{COP of HVAC system}} \times \text{% of year HVAC System Operates} \times \text{% of light heat impacting HVAC load}
\]
LIGHTING-RELATED ENERGY SAVINGS

- COP = Energy Units Delivered to (Removed from) Space
  Energy Units Into System

LIGHTING-RELATED HVAC ENERGY EXAMPLE

- 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

1000 x (0.5 x 0.9 / 3.0) = 1000 x 0.15 = 150 kWh
**Example Lighting / HVAC Interaction**

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

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

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**NEGLECTED LIGHTING SYSTEMS LOSE EFFICIENCY OVER TIME**

[Chart: Lost Efficiency Over Time]  
Source: EPA Green Lights
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)

TOTAL LIGHT LOSS FACTOR (LLF) EXAMPLES

<table>
<thead>
<tr>
<th></th>
<th>T12 Spot</th>
<th>T12 Group</th>
<th>T8 Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>LLD</td>
<td>0.82</td>
<td>0.78</td>
<td>0.93</td>
</tr>
<tr>
<td>LBO</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>LDD</td>
<td>0.65</td>
<td>0.80</td>
<td>0.80</td>
</tr>
<tr>
<td>Total LLF*</td>
<td>0.53</td>
<td>0.62</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Source: EPA Green Lights
LIGHTING SYSTEM LIFE CYCLE COSTS

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

Source: IES ED-150.9
Lighting System
Life Cycle Costs

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

Direct Lighting Energy Costs

- Energy Use (kWh) =
  Lighting Power (kW)
  x Operating Time (hrs)

- Energy Cost Savings =
  Actual Avoided Costs
  (based on rate schedule)
CALCULATING ANNUAL LAMP REPLACEMENTS

• Given:
  - 1000 each 3-lamp fixtures
  - Annual fixture operation = 4000 hrs
  - Average rated lamp life = 25,000 hrs

• Calculate average annual lamp replacements:

\[
ALR = \frac{(1000 \times 3) \times 4000}{25000} = 3000 \times 0.16 = 480
\]

BENEFITS OF GROUP RELAMPING

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

Source: GE Lighting
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:
  \[ GRI = \frac{25,000 \times 0.7}{4000} \]
  \[ = \frac{17,500}{4000} \]
  \[ = 4.375 \text{ years} \]
  \[ = 52.5 \text{ months} \]

Group Relamping Example

<table>
<thead>
<tr>
<th></th>
<th>Spot Relamping (on burn-out)</th>
<th>Group Relamping (@ 70% of rated life)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relamp cycle</td>
<td>20,000 hours</td>
<td>14,000 hours</td>
</tr>
<tr>
<td>Average relamps</td>
<td>525 relamps/yr</td>
<td>750 relamps/yr</td>
</tr>
<tr>
<td>Average material cost</td>
<td>$1,391 /year</td>
<td>$1,988 /year</td>
</tr>
<tr>
<td>Average labor cost</td>
<td>$3,150 /year</td>
<td>$1,125 /year</td>
</tr>
<tr>
<td>Average disposal cost</td>
<td>$263 /year</td>
<td>$375 /year</td>
</tr>
<tr>
<td>AVG. MAINT. BUDGET</td>
<td>$4,804 /year</td>
<td>$3,488 /year</td>
</tr>
</tbody>
</table>

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 fixture
- 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

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 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
EXAMPLE 2 – LIFE CYCLE COST

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

Find: Life Cycle Cost (LCC)

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
Example 2

LIFE CYCLE COST (LCC)

Example 3A

Example 3B

END OF SECTION L