LIGHTING
and
LIGHTING SYSTEMS
Introduction

• Lighting is an important area of opportunity for energy savings, since it is a large fraction of use of electricity in residential and commercial buildings.

• Lighting energy use is not a big percentage of overall electric energy used in a manufacturing or industrial plant, but it may still be a relatively large number of kilowatt-hours or dollars.
• Our oldest lamp is the incandescent lamp, and it is not much different from the first practical lamp that Thomas Edison made.
• The incandescent lamp contains a resistive filament that is connected directly to the supply voltage. The filament burns white hot, and produces a lot of heat and a little bit of light.
• Less than 10 percent of the input energy is converted to light.
• Eventually, even that light energy turns into heat in the space where the lighting is operating.
Lighting Terminology

• **Lumen** - The light output of a lamp is measured in a physical quantity called lumens, abbreviated Lu.
  - This value is provided to users as a catalog or product specification.
  - For example, a typical 100 watt incandescent lamp has a light output of about 1700 lumens. A typical 1200 mm fluorescent lamp has a light output of about 3000 lumens.

• **Input** - The lamp input is in terms of electrical power and has the units of watts.
Principles of Efficient Lighting Design

• Meet target light levels
• Produce light efficiently
• Deliver light efficiently
• Control lighting operation automatically
Factors in Successful Lighting Applications

- Amount of light required – in Lux (Lu/m²)
- Lumen output of lamps and fixtures - Lu
- Energy efficiency – Efficacy in Lumens/watt
- Color Rendering Index - CRI
- Color Temperature – in Kelvins
- Types of light sources
- Lighting quality
Amount of Light Required For Specific Applications

• Light levels are measured in Lux, using a lightmeter.

• Acceptable minimum standards of light levels are set by the Illuminating Engineers Society (IES).

• Typical requirements are:
  – School, commercial office \(500 \text{ Lux} \) at the task location
  – Factory floor \(300 \text{ Lux} \) at the task location
**Lux** - Lighting levels – or illuminances – are measured in Lux with a light meter.

- One Lux is one lumen per square metre.
- Lighting level standards are set by the Illuminating Engineering Society (IES), and are listed in detail in the IES Lighting Handbook.
- Lighting standards for watts/square metre for common buildings are listed in the ASHRAE 90.1 commercial building code, and the IES requirements are referenced.
- ASHRAE 90.1 is an IEC standard.
Efficacy - the performance measure for electric lamps

- Efficacy is measured in units of lumens per watt (Lu/W).
- This is not a measure of efficiency since it has units.
  
  • Efficiency has no units, and is either expressed as a decimal number like 0.90, or is stated in percent, like 90%.
– Efficacies vary with type and size of lamps.
  • A 100 watt incandescent lamp has about 17 lumens per watt
  • A modern T8 lamp with electronic ballast has about 100 lumens per watt.
– To calculate the efficacy for a lamp that requires a ballast, you must add the ballast power to the lamp power to get the correct total wattage input.
– The higher the lumen per watt rating of a lamp the better -- meaning greater light output for a fixed wattage input.
Example

A 60 watt incandescent lamp has an output of 1100 lumens. What is the efficacy?

The efficacy equals 1100 lumens divided by 60 watts

\[ = 18.3 \text{ Lu/W} \]
Example

A fluorescent fixture contains two 40 watt lamps and a ballast that draws 20 watts. If each lamp produces 3000 lumens, what is the efficacy of the lamps and the fixture?

Lumens total = 3000 + 3000 = 6000 lumens

Wattage total = 40 + 40 + 20 = 100 watts

Efficacy = 6000 lumens divided by 100 watts
= 60 Lu/W
Efficacy of Light Sources

**Light Source**
- Standard Incandescent
- Tungsten Halogen
- Halogen Infrared Reflecting
- LED
- Compact Fluorescent 5-26 Watts
- Compact Fluorescent 27-55 Watts
- Linear Fluorescent
- Mercury Vapor
- Compact Metal Halide
- Metal Halide
- High Pressure Sodium
- Low Pressure Sodium

**Lamp plus Ballast - Initial Lumens/Watt**

- 0  20  40  60  80  100  120  140  160  180
• **Color temperature** - another physical property of a lamp.
  
  – It is measured in Kelvins, not degrees.
  
  – The color temperature of a lamp varies from about 2600 to 2800 Kelvins for an incandescent lamp, to around 6500 K for a daylight lamp.
– The color temperature of a lamp tells us what the light from the lamp looks like.

• A low color temperature – like 2600 K – means that the light from the lamp appears warm in color – meaning it has a red, yellow or orange tint.
• A 4100 K lamp is called a cool white lamp, since it appears cool in color – meaning that it produces stronger green, blue or violet colors.
• **Color Rendering Index (CRI)** - Another property of lamps that is related to how we see different colors under its light.

  – The CRI is a number between 0 and 100.
    * The reference standard is a very special incandescent lamp at a lighting laboratory.
    * The light output of this lamp sets the standard for CRI as 100.

  – Users can find data on the CRI of lamps in catalog or product specifications.
– Most incandescent lamps have CRIs in the 95 – 100 range.
– The CRI is generally associated with the quality of lighting. The U.S. EPA Green Lights program rates CRI and lighting quality as follows:

<table>
<thead>
<tr>
<th>CRI Range</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>75 – 100</td>
<td>Excellent</td>
</tr>
<tr>
<td>65 – 75</td>
<td>Good</td>
</tr>
<tr>
<td>55 – 65</td>
<td>Fair</td>
</tr>
<tr>
<td>0 – 55</td>
<td>Poor</td>
</tr>
</tbody>
</table>

– CRI and the color temperature of a particular lamp determine how we see colors under that lamp.
– For any color temperature, the higher the CRI, the more closely we see colors correctly.
• **Types of Lamps** - Common types of lamps include:
  
  – incandescent
  – tungsten halogen (also incandescent)
  – compact fluorescent
  – full-size fluorescent
  – mercury vapor
  – metal halide
  – high-pressure sodium
  – low-pressure sodium
  – LED
• **Ballasts** - Except for incandescent lamps (including tungsten halogen lamps), all other lamps are discharge lamps that require a ballast to start and run the lamps.
  
  – Older ballasts were large, heavy parts called “coil and core” or magnetic ballasts, because they contained a coil of wire wrapped around a heavy iron core.
  
  – Newer ballasts are electronic, and are lighter, cooler, more efficient, and last longer.
A ballast usually does three things. It:

1. Conditions the lamp to start (usually meaning warming up the filaments)
2. Provides a big spike of high voltage to start the gas discharge process
3. Quickly inserts a current limiter into the circuit to reduce the lamp current down to a safe and sustainable value
LAMP LUMEN DEPRECIATION (LLD)

- 8' T12 Fluorescent (225 mA)
- 8' HO Fluorescent (800 mA)
- 8' VHO Fluorescent (1500 mA)
- 4' T8 Fluorescent (265 mA)
- High Pressure Sodium
- Metal Halide
- Mercury Vapor

Percent Relative Light Output

Hours of Operation in Thousands
Lumen Method Formula

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

where

- \( N \) = the number of lamps required
- \( F_1 \) = the required lux level at the task
- \( A \) = area of the room in square metre
- \( L_u \) = 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 12 x 10 metre room.

Assume two 3000 lumen lamps each per fixture, and assume that LLF is 0.65 and CU is 70%.

\[
N = \frac{500 \times 120}{3000 \times 0.65 \times 0.7} = 44
\]

The number of two-lamp fixtures needed is 22.
Four Areas for Lighting Improvements

Most of the cost savings from new retrofit lighting can be achieved in four areas:

1. Replace incandescent lamps with fluorescent, or compact fluorescent lamps
2. Upgrade fluorescent fixtures with improved components
   - New T8s and T5s
   - Electronic ballasts
3. Install lighting controls to minimize energy costs
4. Replace old exit lights with new LED models
Application of Compact Fluorescent Lights

- Task lights
- Downlights
- Wallwashers
- Outdoor fixtures
- Refrigerators and freezers
- Exit lights if you don’t want LEDs
- Can now be dimmable
CFL Savings Example

• Replace a 75 watt incandescent lamp with an 18 watt self-ballasted CFL. The lamps are used 3000 hours per year.
  – The CFL uses ¼ the energy of an incandescent
  – The savings is 75 – 18 = 57 watts
  – The kWh savings for the lamp is 57 watts × 3000 hours = 171 kWh
  – The life of the CFL is 7500 hours. The life of a standard incandescent lamp is 750 hours.
  – The CFL lasts ten times as long and saves additional $ on maintenance costs.
Upgrading Fluorescent Fixtures

• Improved fluorescent lamps
  – T8, T5 and T5 HO Tri-phosphor lamps
  – Higher efficacy and higher CRI
  – Long life T8s
• Electronic ballasts
  – All electronic vs. hybrid
  – No flicker, no hum
• Induction lamps and ballasts --100,00 hours!
Consider a room 7 by 25 metres with old 40 watt cool white T12 fluorescent lamps in four lamp fixtures – or troffers – and each troffer has two magnetic ballasts using 15 watts each.

Our lighting retrofit project is to replace the old systems with T8 lamps and electronic ballasts. The room was very overlighted with the original design, and our retrofit will be to put three 32 watt T8’s in each fixture, together with two ballasts, having a total power requirement of 90 watts.

Find the lighting energy savings if the lights are on 4000 hours each year.
Solution

Old system

Fixture $W = \frac{4 \text{ lamps}}{\text{lamp}} \times 40 \text{ W} + \frac{2 \text{ ballasts}}{\text{ballast}} \times 15 \text{ W} = 190 \text{ W}$

New system

Fixture $W = 90 \text{ W}$ (given)

Wattage savings $= \frac{190 \text{ W} - 90 \text{ W}}{\text{fixture}} = \frac{100 \text{ W}}{\text{fixture}}$

Energy savings

$\frac{\text{KWh/yr}}{\text{fixture}} = \frac{100 \text{ W}}{\text{fixture}} \times \frac{16 \text{ fixtures}}{\text{yr}} \times \frac{4000 \text{ h}}{\text{yr}} = \frac{6,400 \text{ KWh}}{\text{yr}}$
Lighting Power Density

- Lighting power density is another performance measure that is used in design and in Building Codes.
- Find the lighting power density for the example just given for the new system:
  - $kW = (16 \text{ fixtures}) \times (90W/\text{fixture}) = 1440$ watts
  - The area of the space is $7 \times 25 = 175$ square metres
  - The LPD = $(1440 \text{ watts})/(175 \text{ square metres})$
  - $= 8.23 \text{ watts/square metre}$
Lighting Retrofits

• Replacing older lights with newer, more efficient lights often offers a very attractive energy and cost saving project.

• Many older buildings and facilities still use 40-watt T12 cool-white fluorescent lamps, or 34-watt T12, low-wattage lamps, and magnetic ballasts.

• New T8 lamps with electronic ballasts are probably still the most popular choice for office and commercial retrofits.

• In new construction, T8 or T5 lamps with electronic ballasts may be used.
Fluorescent Upgrades From T12s with Magnetic Ballasts

• T8 (32 W) electronic ballasts
  – Same light but less energy
  – Multiple lamps per ballast option
  – Tandem wiring option
  – T8 (30 W) available now
  – Very little lumen depreciation (95%)

• T5 (28 W) electronic ballasts
  – Same light but least energy
  – HID type retrofit option popular
  -- May need to use indirect lighting
Lighting Savings Calculations

- DS in kW = \((kW_{\text{old}} - kW_{\text{new}})\)
- ES in kWh = \((kW_{\text{old}} - kW_{\text{new}}) \times \text{(hours of use)}\)
- kW_{\text{old}} = (\text{wattage of old lamp + wattage of old ballast}) \times \text{(number of lamps)/1000}
- kW_{\text{new}} = (\text{wattage of new lamp + wattage of new ballast}) \times \text{(number of lamps)/1000}
- Cost savings = Demand cost savings + Energy cost savings
Lighting Savings Example

A 244,000 square foot 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

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

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

**Energy $ savings** = ((356 kW) \times (8000 \text{ hrs/yr})) \times ($0.05/kWh) = $142,400/yr

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

**Cost** = (800 fixtures) \times ($400/fixture)
= $320,000
Lighting Controls

• On/off switch
• Timers and control systems (DDC)
• Solid-state dimmers
• Dimming electronic ballasts or bi-level ballasts
• Occupancy sensors
• Day lighting level sensors
  – Daylight harvesting
  – 40 - 60% savings compared to full artificial lighting
  – Better productivity and attendance
• **Lighting controls** – Timers, dimmers and occupancy sensors can provide large savings by turning lights down when they are not needed at full light output levels, and turning them off when they are not needed at all.

  – Occupancy sensors can detect heat using PIR (passive infrared radiation) technology, or detect sound using ultrasonic technology.

  – Newer occupancy sensors are dual mode with both PIR and ultrasonic technology.
• **Daylight harvesting** – This used to be called “daylighting;” it is the use of sunlight to augment our artificial lighting system.
Occupancy Sensor Savings
(From Energy Star)

- Offices 25-50%
- Rest rooms 30-75%
- Corridors 30-40%
- Storage areas 45-65%
- Meeting/ 45-65%
  conference rooms
- Warehouses 50-75%,
Comparison of exit sign alternatives

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Wattage</th>
<th>Life</th>
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<tbody>
<tr>
<td>Incandescent lamp</td>
<td>24-40</td>
<td>2 to 8 months</td>
</tr>
<tr>
<td>LEDs</td>
<td>1-5</td>
<td>10+ years</td>
</tr>
<tr>
<td>CFLs</td>
<td>10-24</td>
<td>1 to 2 years</td>
</tr>
<tr>
<td>Electroluminescent panels</td>
<td>1</td>
<td>10+ years</td>
</tr>
<tr>
<td>Photoluminescent materials</td>
<td>0</td>
<td>10+ years</td>
</tr>
<tr>
<td>Cold cathode</td>
<td>5</td>
<td>10 years</td>
</tr>
</tbody>
</table>

Source: E SOURCE
Lighting Audits

Conduct a room-by-room lighting inventory

- Light fixtures
- Lamp types, size and numbers
- Levels of illumination
- Uses of task lighting
- Hours of operation
- Ballasts
- Use of occupancy sensors
# Lighting Audit Checklist Data Form

<table>
<thead>
<tr>
<th>Area</th>
<th>Lamp Type</th>
<th>Lamp Wattage</th>
<th>Light Level (lux)</th>
<th>No. of fixtures</th>
<th>Lamps per fixture</th>
<th>Reflector use (Y/N)</th>
<th>Usage Time</th>
<th>Ballast info</th>
<th>A/C (Y/N)</th>
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</tbody>
</table>
Lighting ECMs

- T12 Lamps
- Magnetic Ballasts
- Incandescent lamps
- Lighting Controls

- T8 Lamps
- Electronic Ballasts
- CFL
- Check That They are Operating Properly
- Add If Not Present

- Color rendition
- Productivity & Safety

- Lamp Change out
- Improve to Meet Facility Requirements
Exit Sign ECMs

- 2 - 40 Watt lamp style
  ➔ LED retrofit kit
  ➔ Cold cathode kit
  ➔ LED exit signs
# Exit Sign Upgrades

<table>
<thead>
<tr>
<th>Source</th>
<th>Wattage</th>
<th>Life</th>
<th>Replacement</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent</td>
<td>40</td>
<td>8 months</td>
<td>lamp(s)</td>
<td>NA</td>
</tr>
<tr>
<td>Low wattage incandescent</td>
<td>8</td>
<td>10 years</td>
<td>light tube</td>
<td>$30 (retrofit)</td>
</tr>
<tr>
<td>Compact Fluorescent</td>
<td>10+</td>
<td>1.7 years</td>
<td>lamp(s)</td>
<td>$30 (retrofit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$120 (new)</td>
</tr>
<tr>
<td>Light Emitting Diode</td>
<td>4</td>
<td>20+ years</td>
<td>circuit board</td>
<td>$45 (retrofit)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$120 (new)</td>
</tr>
<tr>
<td>Electro-luminescent</td>
<td>1</td>
<td>8+ years</td>
<td>light panel</td>
<td>$190 (new)</td>
</tr>
<tr>
<td>Self-luminous (tritium)</td>
<td>0</td>
<td>10-20 years</td>
<td>luminous tube</td>
<td>$250 (new)</td>
</tr>
</tbody>
</table>