ENERGY EFFICIENT LIGHTING

Prof. Suryanarayana Doolla
Content

- Basics of Illumination
- Types of light source, lighting
- Comparison of commercial lamps
- Energy efficient lighting
  - More light from less power
  - Selection of LED
  - Lighting controls
  - Energy efficiency in street lights
    - Centralize and Decentralized control
- Conclusion
Why study Light?

- Light is an extremely efficient way of altering perception.
- Improve weight gain in premature infants.
- Increase the length and quality of sleep.
- “Some researchers believe that even very low levels of blue light during sleep might weaken the immune system and have serious negative implications for health.”
- Bad lighting can ruin perfectly good design.
- Light can alleviate seasonal depression.
Consumption in India

- One-fifth of electricity consumption in India is through lighting.
- Lighting contributes significantly to peak load.
- A large portion of total lighting is used in inefficient technologies.
- About 400 million light points in India today are lighted by incandescent bulbs; their replacement by CFLs would lead to a reduction of over 10,000 MW in electricity demand.
- Bachat Lamp Yojana – CFL @ Rs. 15 per piece – rest of money is claimed through CDM.
Why Energy Efficiency in Lighting?

- High and rising energy prices
- Change in Global Climate
- Exhaustion of Non Renewable Sources for electricity generation
- Leads to reduction of investment for expansion of electric power sector
Physics of Light

- Light is a member of a large family called electromagnetic radiation (EMR)
- Heat, light, x-rays, microwaves, U.V. are all examples of EMR
- EMR travels with speed of light and has a wide spectrum of wavelength
- The visible spectrum includes radiation from 380 Nm to 750 Nm in wavelength
- Visible light consist of violet, indigo, blue, green, yellow, orange
Spectrum of EMR-Light

**COMPLETE ELECTRO-MAGNETIC RADIATION SPECTRUM**

- **WAVELENGTH (IN METERS)**
  - $10^{-1}$: GAMMA RAYS
  - $10^{-8}$: X-RAYS
  - $10^{-6}$: ULTRA-VIOLET
  - $10^{-3}$: INFRA-RED
  - $10^{-1}$: MICROWAVES
  - $10^{-1}$: RADIO WAVES
  - $10^5$: POWERLINE EMISSIONS

**THE VISIBLE SPECTRUM**

- **WAVELENGTH (IN METERS)**
  - $4 \times 10^{-7}$: 400 nm (VIOLET)
  - $5 \times 10^{-7}$: 500 nm (BLUE)
  - $6 \times 10^{-7}$: 600 nm (GREEN)
  - $7 \times 10^{-7}$: 700 nm (YELLOW)
  - $770$ nm (ORANGE)

Source: www.thelightingtextbook.com
Terminology in Lighting

3 INTERACTIONS OF LIGHT

LUMENS "OFF OF" A LIGHT SOURCE
= LUMINANCE OR EXITANCE

LIGHT SOURCE

LUMENS "ONTO" A SURFACE
= ILLUMINANCE

REFLECTIVE SURFACE

LUMENS "OFF OF" A SURFACE
= LUMINANCE OR EXITANCE

VIEWER

Source: www.thelightingtextbook.com
Lumens, Efficacy

- Luminous flux: It is measure of perceived power of light. Lumen is standard unit for luminous flux.
- Luminous flux incident on a surface per unit area is called Illuminance and lux is the SI unit. 1 lux = 1 lm/m²
- How well a source provides a visible light for a given amount of power is generally termed as Efficacy.
- Luminous efficacy of a source (LES) is the ratio of lumens per unit input power (lm/W). Input power is generally assumed to be electricity.
“Effect of an illuminant on the color appearance of objects by conscious or subconscious comparison with their color appearance under a reference illuminant”, International Commission on Illumination (CIE)

- Ability of a light source to accurately reproduce colors of objects in comparison with an ideal source

- Good - Day light, incandescent, metal halide, good LED’s (80-100)
- Bad - Low pressure sodium lamp has poor color rendering (0-10)
- Average - High pressure sodium has average color rendering (20-60)
Color Temperature

- The temperature at which a heated black body radiator matches the color of light source
- Usually measured in kelvin (K)
- Higher color temperatures (5000 K or more) are "cool" (green–blue) colors, and lower color temperatures (2700–3000 K) "warm" (yellow–red) colors.
- Correlated color temperature in case of CFL as there is no physical heating of a black body
Process involved in Artificial lighting

- Incandescence
- Luminescence
- Fluorescence
- Phosphorescence

- **Good efficient lighting is obtained by combining Luminescence and Fluorescence.**
Types of Lighting

- Incandescent lamp
- Gas Discharge lamp
  - Low pressure discharge (Fluorescent, CFL, LPSV)
  - High pressure discharge (*metal halide*, *HPSV*, *high pressure mercury vapor*), HID family
- Solid State Lighting
  - Light Emitting Diode (LED)
  - Organic Light emitting diode (OLED)

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Incandescent Lamp

- It is oldest and common type of lamp
- Light up instantly and provide warm light
- Do not need a ballast and cheaper
- Light is produced when coil of Tungsten is heated by passing electric current
- Most of the power is lost in heat
- Less Efficacy (15-20lm/watt) and lowest average life of (1000-3000 hours)
- Very good Color Rendering Index (~100)
- Standard incandescent, tungsten halogen and reflector are three common types
High Intensity Discharge

- An electric arc between two electrodes is used to produce intensely bright light
- Mercury, sodium or metal halide act as the conductor
- HID have highest efficacy and longest life (60-150 lm/watt, 8000-40000 hrs)
- They are used generally for outdoor purpose and large indoor arena
- Ballast needs time to establish arc and hence they take 10 minutes (max) when first turned on

Source: http://www.energysavers.gov
## Comparing Commercial Lamps

<table>
<thead>
<tr>
<th></th>
<th>Incandescent</th>
<th>Fluorescent</th>
<th>HID</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard</td>
<td>Halogen</td>
<td>Full-Size or U-bent</td>
</tr>
<tr>
<td>Wattage</td>
<td>3-1,500</td>
<td>10-1,500</td>
<td>4-215</td>
</tr>
<tr>
<td>Lamp Efficacy</td>
<td>6-24</td>
<td>8-35</td>
<td>26-105</td>
</tr>
<tr>
<td>Average Rated Life (hours)</td>
<td>1000-3,000</td>
<td>2,000-4,000</td>
<td>7,500-24,000</td>
</tr>
<tr>
<td>CRI (%)</td>
<td>99</td>
<td>99</td>
<td>49-96</td>
</tr>
<tr>
<td>Start-to-Full Brightness</td>
<td>immediate</td>
<td>immediate</td>
<td>0-5 seconds</td>
</tr>
<tr>
<td>Re-Strike Time</td>
<td>immediate</td>
<td>immediate</td>
<td>immediate</td>
</tr>
<tr>
<td>Lumen Maintenance</td>
<td>very good</td>
<td>excellent</td>
<td>very good</td>
</tr>
</tbody>
</table>

Source: American Council for Energy Efficient Economy
Energy Efficiency Techniques

- Use of Day light, turn off the lights when not required
- Proper maintenance of lamps
- Replacement with energy efficient lamps
- Incorporate proper lighting controls
- **Use of electronic chokes instead of conventional electromagnetic ballasts**
- Use of dimming controls
- Use of 28 watt T5 instead of 40 watt standard FTL
From Magnetic to Electronic Ballast

- **Magnetic Ballast**
  - 230V/50Hz
  - Ignitor
  - Lamp
  - Simple, low cost, high reliability
  - Large and heavy
  - External ignitor
  - Re-ignition causes line frequency flickering
  - No lamp power regulation

- **HF Electronic Ballast**
  - $f_s > 20\text{kHz}$
  - Lamp
  - Higher cost
  - Small and light
  - Integrated ignitor
  - No flickering and audible noise
  - With lamp power regulation (more intelligent)
HID Ballast Block Diagram

- EMI Filter
- Rectifier
- PFC
- Buck
- Full-Bridge
- Output Stage

- Line
- 400V/450V
- Aux Power Supply
- LS Driver
- HS Driver
- HB Driver
- PFC controller
- Analog HID-Lamp Controller

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Three Stage HID Electronic Ballast

Achieve high PF, low I_{THD}
Provide constant lamp power regulation
Provide high ignition voltage
Avoid Acoustic resonance (10K~500kHz)
More Light from Less Power - CFL

Compact Fluorescent Lamp

- Electric current is passed through a tube containing Argon (inert gas) and Mercury Vapor
- This emits UV light which strikes the fluorescent coating (phosphor) inside of the tube and finally emits visible light
- CFL needs more energy during start and consumes less energy later

Source: Energy Star
# How to choose in CFL?

<table>
<thead>
<tr>
<th>Incandescent bulb (W)</th>
<th>Minimum Light Output (lumens)</th>
<th>CFL (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>450</td>
<td>9 – 13</td>
</tr>
<tr>
<td>60</td>
<td>800</td>
<td>13 – 15</td>
</tr>
<tr>
<td>75</td>
<td>1100</td>
<td>18 – 25</td>
</tr>
<tr>
<td>100</td>
<td>1600</td>
<td>23 – 30</td>
</tr>
<tr>
<td>150</td>
<td>2600</td>
<td>30 – 52</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type</th>
<th>Purpose</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm White and Soft White</td>
<td>Standard replacement of Incandescent Bulb</td>
<td>2700 – 3000 K</td>
</tr>
<tr>
<td>Cool White and Bright White</td>
<td>Good for Kitchen and Work Spaces</td>
<td>3500 – 4100 K</td>
</tr>
<tr>
<td>Natural or Day light</td>
<td>Reading</td>
<td>5000 – 6500 K</td>
</tr>
</tbody>
</table>

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## How to choose in CFL?

<table>
<thead>
<tr>
<th></th>
<th>Table/Floor Lamp</th>
<th>Pendant Fixture</th>
<th>Ceiling Fixture</th>
<th>Ceiling Fan</th>
<th>Wall Sconces</th>
<th>Track Lighting</th>
<th>Outdoor Covered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spiral</td>
<td>☺</td>
<td>☺</td>
<td>☺</td>
<td>☺</td>
<td>☺</td>
<td>☺</td>
<td>☺</td>
</tr>
<tr>
<td>Covered</td>
<td>☺</td>
<td>☺</td>
<td></td>
<td>☺</td>
<td></td>
<td></td>
<td>☺</td>
</tr>
<tr>
<td>A shape</td>
<td>☺</td>
<td></td>
<td></td>
<td>☺</td>
<td></td>
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<td>☺</td>
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<tr>
<td>Globe</td>
<td></td>
<td>☺</td>
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<td></td>
<td></td>
<td></td>
<td>☺</td>
</tr>
<tr>
<td>Tube</td>
<td>☺</td>
<td></td>
<td>☺</td>
<td>☺</td>
<td></td>
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<td>☺</td>
</tr>
<tr>
<td>Globe</td>
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<td>☺</td>
<td></td>
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<td></td>
<td></td>
<td>☺</td>
</tr>
<tr>
<td>Indoor Reflector</td>
<td></td>
<td></td>
<td></td>
<td>☺</td>
<td></td>
<td>☺</td>
<td>☺</td>
</tr>
<tr>
<td>Outdoor Reflector</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>☺</td>
</tr>
</tbody>
</table>

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More Light from Less Power - LED

- It is essentially a semiconductor diode
- It consists of a chip of semiconducting material treated to create a structure called a p-n (positive-negative) junction
- When an electron meets a hole, it falls into a lower energy level, and releases energy in the form of a photon (light).
- The specific wavelength or color emitted by the LED depends on the materials used to make the diode.
More Light from Less Power - LED

- Red LEDs are based on aluminum gallium arsenide (AlGaAs).
- Blue LEDs are made from indium gallium nitride (InGaN).
- Green from aluminum gallium phosphide (AlGaP).
- "White" light is created by combining the light from red, green, and blue (RGB) LEDs.
- White - by coating a blue LED with yellow phosphor.

Source: Energy Star
More Light from Less Power - LED

- No Mercury
- CRI of 92, some LED lights are dimmable
- Long Life (> 50000 hrs), high efficacy (160 lm/W@350mA)
- They generally consume 80% less power than incandescent lamp and 50% of CFL.
- 12W LED can replace 65W Incandescent??
**How to choose an LED? Step 1**

<table>
<thead>
<tr>
<th>LED</th>
<th>lux</th>
<th>Drive Current</th>
<th>Test temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFR 1</td>
<td>91 lm</td>
<td>350 mA</td>
<td>$T_A$ 25</td>
</tr>
<tr>
<td>MFR 2</td>
<td>107 lm</td>
<td>350 mA</td>
<td>$T_J$ 25</td>
</tr>
<tr>
<td>MFR 3</td>
<td>130 lm</td>
<td>700 mA</td>
<td>$T_A$ 25</td>
</tr>
<tr>
<td>MFR 4</td>
<td>100 lm</td>
<td>350 mA</td>
<td>$T_{pad}$ 25</td>
</tr>
</tbody>
</table>

- Purchase decision shall not be made on top line numbers
- Light output, light efficacy, lumen maintenance, operating temperature

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How to choose an LED?  Step 2

- 70% output after 50000 hours
- Maximum output at any instant

![Graph: Forward Current vs. Normalized Relative Luminous Flux, $T_A = 25^\circ C$]
## How to choose an LED?  Step 2

<table>
<thead>
<tr>
<th>LED</th>
<th>lux</th>
<th>Normalized lux</th>
<th>Test temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFR 1</td>
<td>91 lm</td>
<td>164 lm</td>
<td>$T_A$ 25</td>
</tr>
<tr>
<td>MFR 2</td>
<td>107 lm</td>
<td>182 lm</td>
<td>$T_J$ 25</td>
</tr>
<tr>
<td>MFR 3</td>
<td>130 lm</td>
<td>130 lm</td>
<td>$T_A$ 25</td>
</tr>
<tr>
<td>MFR 4</td>
<td>100 lm</td>
<td>165 lm</td>
<td>$T_{pad}$ 25</td>
</tr>
</tbody>
</table>

- LED from MFR 3 is the giving least lumen output at 700 mA
- We are not comparing all the LEDs at common temperature, use temperature derating graphs
# How to choose an LED? Step 3

<table>
<thead>
<tr>
<th>LED</th>
<th>Normalized lux</th>
<th>Data sheet $T_J$ max</th>
<th>Operating $T_J$ for $T_A$ of 25°C</th>
<th>Flux derating factor</th>
<th>Actual Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFR 1</td>
<td>164 lm</td>
<td>145</td>
<td>135</td>
<td>72%</td>
<td>118 lm</td>
</tr>
<tr>
<td>MFR 2</td>
<td>182 lm</td>
<td>150</td>
<td>128</td>
<td>78%</td>
<td>142 lm</td>
</tr>
<tr>
<td>MFR 3</td>
<td>130 lm</td>
<td>125</td>
<td>141</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>MFR 4</td>
<td>165 lm</td>
<td>150</td>
<td>130</td>
<td>81%</td>
<td>133 lm</td>
</tr>
</tbody>
</table>

- MFR 3 Exceeds maximum junction temperature at this operating condition
- Check for output lumen after 50,000 hours

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How to choose an LED?  Step 4

<table>
<thead>
<tr>
<th>LED</th>
<th>Actual Flux</th>
<th>Data sheet T&lt;sub&gt;J max&lt;/sub&gt;</th>
<th>Operating T&lt;sub&gt;J&lt;/sub&gt; for T&lt;sub&gt;A&lt;/sub&gt; of 25°C</th>
<th>L70/50kh conditions</th>
<th>Current to achieve lumen maint.</th>
<th>Actual Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFR 2</td>
<td>142 lm</td>
<td>150</td>
<td>128</td>
<td>T&lt;sub&gt;J&lt;/sub&gt;&lt;85°C</td>
<td>407 mA</td>
<td>107 lm</td>
</tr>
<tr>
<td>MFR 4</td>
<td>133 lm</td>
<td>150</td>
<td>130</td>
<td>T&lt;sub&gt;J&lt;/sub&gt;&lt;135°C</td>
<td>700 mA</td>
<td>133 lm</td>
</tr>
</tbody>
</table>

- MFR 2 – To achieve 50k hrs, the LED shall be operated at 407 mA at T<sub>J</sub> at 85°C and it delivers a 107 lm at the end of 50000 hrs
- Off the shelf drivers are available for 350 mA and 700 mA

Source: http://www.philipslumiled.scom
Lighting Controls

- Types
  - Infrared sensors
  - Motion sensors
  - Automatic timers
  - Dimmers

- SCADA, GSM/GPRS based centralized control system for street light

- Save energy by on/off and dimming

- Up to 40% energy saving in street lights without replacing existing fixtures
Energy Efficiency in Street Light

- Street light contribute to peak power consumption
- Replacement with high efficient bulbs and fixtures
- Electronic Timer
- Nature Switch
- Dimmable ballast or Magic Box
- Voltage regulator
- Centralized control using GSM/SCADA
- Regular maintenance of fixtures
- Power factor improvement techniques
Street light control system - Architecture

Source: M2M Brochure
Centralized control of street lights

- Load balancing information (voltage, current & pf)
- Exact identification of failure (Fuse, CB, Power failure status)
- Lamps glowing and non glowing information
- Theft and functioning of switch gear
- Twilight based
- Alternate lighting pattern is possible
- Dimming can be incorporated
- Communication via SMS/GPRS/EDGE/Radio/CDMA
- Number of hours of glowing, complete MIS

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Energy Efficiency/Saving projects

- Does street light required such complex architecture? What will be the implementation cost?
- Energy Saving Company (ESCO) – BEE listed
- Investment is done by ESCO and financial risk to the municipal corporation or government is low
- Return on Investment is obtained to ESCO based on savings
- Sharing of profits on public private partnership (PPP) mode
- CDM benefits

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Conclusions

- Energy efficiency is a really smart way to reduce demand on power system and reduce CO$_2$ emissions quickly
- Use day light where ever possible
- Reduce the excess light level to the required level
- Common lamps especially incandescent and CFL loose their output over time and hence needs replacement
- Consider group re-lamping to save labor

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Conclusions

- Re-lamping - Use high efficiency ballast and lamps
- Perform simple maintenance which will improves illumination
- New buildings should be designed in such a way that maximum day light is utilized
- Use better luminaries and improved controls
Thank You

STOP CLIMATE CHANGE
BAN THE BULB!
GREENPEACE

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