How to Change a Lightbulb

LED Lighting for Museums

Scott Rosenfeld
srosenfe@si.edu
LIGHTING SOURCES:

1. Sunlight
2. Incandescent (includes Halogen)
3. Fluorescent
4. HID
5. LED
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2. Incandescent (includes Halogen)
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Controllable Qualities of Light

1. Quantity
2. Distribution
3. Spectrum
4. Movement
5. Angle
Controllable Qualities of Light

1. Quantity: How Much Light?
2. Distribution: What is the composition of the light?
4. Movement: Does the light move? Do the people move?
5. Angle: Where does the light come from?
## Typical Museum Lighting Requirements

<table>
<thead>
<tr>
<th>Light Sensitivity of the Material</th>
<th>Illuminance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highly &amp; Moderately Light Sensitive</td>
<td>50-75 Lux</td>
</tr>
<tr>
<td>Low Light-Sensitivity</td>
<td>150-350 Lux</td>
</tr>
<tr>
<td>Not Light Sensitive</td>
<td>No Limit</td>
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</table>

10.76 Lux = 1 Foot-candle
<table>
<thead>
<tr>
<th>METRIC</th>
<th>UNIT</th>
<th>USE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminous Flux</td>
<td>• Lumen</td>
<td>Quantity of potential light spread in all directions from source</td>
</tr>
<tr>
<td>Illuminance</td>
<td>• Lux = lumens/ meter(^2)</td>
<td>Quantity of light striking a surface</td>
</tr>
<tr>
<td></td>
<td>• Footcandles= lumens/foot(^2)</td>
<td></td>
</tr>
<tr>
<td>Luminance</td>
<td>• Lumen/ Steradian</td>
<td>Quantity of light directed in a direction</td>
</tr>
<tr>
<td></td>
<td>• Candela</td>
<td></td>
</tr>
<tr>
<td>METRIC</td>
<td>UNIT</td>
<td>USE</td>
</tr>
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<td>--------------</td>
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<td></td>
<td>• Footcandles = lumens/foot^2</td>
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<tr>
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<td>• Lumen/Steradian</td>
<td>Quantity of light directed in a direction</td>
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<tr>
<td></td>
<td>• Candela</td>
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<tr>
<td>METRIC</td>
<td>UNIT</td>
<td>USE</td>
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</tr>
<tr>
<td></td>
<td>• Candela</td>
<td></td>
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</table>
### Lamp Comparison

<table>
<thead>
<tr>
<th>Item Number</th>
<th>Ordering Abbreviation</th>
<th>Lumens</th>
<th>Incandescent</th>
<th>Watt</th>
<th>Beam Angle</th>
<th>Average Rated Life (hours)</th>
<th>CBCP (cd)</th>
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</thead>
<tbody>
<tr>
<td>59017</td>
<td>50AR70/70</td>
<td>2600</td>
<td>150 W</td>
<td>25-28 W</td>
<td></td>
<td>15,000</td>
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<tr>
<td>59018</td>
<td>50AR111/111</td>
<td>1600</td>
<td>100 W</td>
<td>16-20 W</td>
<td></td>
<td>12,000</td>
<td></td>
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<tr>
<td>59019</td>
<td>50AR111/111</td>
<td>1100</td>
<td>75 W</td>
<td>9-13 W</td>
<td></td>
<td>6000</td>
<td></td>
</tr>
<tr>
<td>59020</td>
<td>50AR111/111</td>
<td>800</td>
<td>60 W</td>
<td>8-12 W</td>
<td></td>
<td>30000</td>
<td>23,000</td>
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<tr>
<td>59021</td>
<td>50AR111/111</td>
<td>450</td>
<td>40 W</td>
<td>6-9 W</td>
<td></td>
<td>30,000</td>
<td></td>
</tr>
</tbody>
</table>

**Specs:**

- **3000K**
  - Vivid
  - 18.5W
  - CRI 95
  - R9 95
  - Indoor/Outdoor

- **CBCP (cd):**
  - 15,000
  - 12,000
  - 6000
  - 23,000
  - 30,000
### OPTION #1 - INCANDESCENT

<table>
<thead>
<tr>
<th>Item Number</th>
<th>Ordering Abbreviation</th>
<th>Watts</th>
<th>Beam Angle</th>
<th>Average Rated Life (hours)</th>
<th>CBCP (cd)</th>
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<tbody>
<tr>
<td>59017</td>
<td>50AR70/SP8</td>
<td>50</td>
<td>8°</td>
<td>3000</td>
<td>15,000</td>
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<tr>
<td>Brand X</td>
<td>50ALR18/SP10</td>
<td>50</td>
<td>10°</td>
<td>2000</td>
<td>12,000</td>
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<tr>
<td>Brand X</td>
<td>50PAR20/HAL/SP10</td>
<td>50</td>
<td>10°</td>
<td>2500</td>
<td>6000</td>
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<tr>
<td>55104</td>
<td>50AR111/SP8</td>
<td>50</td>
<td>8°</td>
<td>3000</td>
<td>23,000</td>
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<tr>
<td>Brand X</td>
<td>50PAR36/H/NSP8</td>
<td>50</td>
<td>8°</td>
<td>4000</td>
<td>30,000</td>
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</table>

### OPTION #2 – LED

<table>
<thead>
<tr>
<th>3000K</th>
<th>Halogen Equivalent</th>
<th>Watts</th>
<th>Beam</th>
<th>Lumens</th>
<th>CBCP</th>
<th>Model #</th>
<th>Code</th>
<th>Snap</th>
<th>Spec</th>
<th>Sheet</th>
<th>LM79</th>
<th>IES</th>
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<tr>
<td></td>
<td>Vivid</td>
<td>75W</td>
<td>18.5</td>
<td>9</td>
<td>1000</td>
<td>24100</td>
<td>SR111-18-09D-930-03</td>
<td>00885</td>
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<tr>
<td>18.5W</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>CRI 95</td>
<td>75W</td>
<td>18.5</td>
<td>25</td>
<td>1000</td>
<td>5400</td>
<td>SR111-18-25D-930-03</td>
<td>00887</td>
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<tr>
<td>R9 95</td>
<td></td>
<td>75W</td>
<td>18.5</td>
<td>36</td>
<td>1000</td>
<td>2500</td>
<td>SR111-18-36D-930-03</td>
<td>00889</td>
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<tr>
<td></td>
<td>Indoor/Outdoor</td>
<td>75W</td>
<td>18.5</td>
<td></td>
<td>1000</td>
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</table>
Lumens/ Watt = Efficacy

- 1000 lumens / 18.5 watts = 54 lumens/watt
- 64% savings over 50 watt incandescent
Today's best LED’s = 125-160 lumens/watt
Target best efficacy = 200 lumens/watt
Theoretical limit = 255 lumens/watt

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Theoretical limit = 255 lumens/watt
Controllable Qualities of Light

1. Quantity
2. Distribution
3. Spectrum
4. Movement
5. Angle
Distribution
Types of LED Track Lighting Fixture Types

1. Retrofit LED – replaceable LED screw-in lightbulb

2. Integral LED – (may be repaired)
Retrofit LED System
Integral LED System
Integral LED System
Integral LED System
Integral LED System

LENSED OPTIC
Step 1:
WALL WASHING

LENS
BLACK CUT-OFF
OPTIONAL KICKER REFLECTOR
LIGHT REDUCTION SCREEN
OBJECT LIGHT

CUT-OFF AND CROSS BAFFLE

ON/ OFF SWITCH
Controllable Qualities of Light

1. Quantity
2. Distribution
3. Spectrum
4. Movement
5. Angle
EXAMPLE OF DISTRIBUTION OF PAR LAMPS

**LED15PAR30LN/DIM/830/NFL25**

- Wattage: 15
- Lumens: 770
- CBCP (cd): 2000
- Beam Angle: 25°

**LED10PAR30/DIM/SG/830/SP10**

- Wattage: 10
- Lumens: 550
- CBCP (cd): 17,000
- Beam Angle: 10°

**Beam Spreads**
- 4°
- 8°
- 15°
- 25°
- 40°
Retrofit LED System
Integral LED System
Integral LED System
4-Degree Spot

19mm Light Source with 20 Degree Lensed Optic
Controllable Qualities of Light

1. Quantity
2. Distribution
3. Spectrum
4. Movement
5. Angle
Two Methods that LED’s Create White Light

1. Phosphor converted
   • Blue LED
   • Violet LED
   • Ultraviolet LED

2. Multi-color LEDs
Two Methods that LED’s Create White Light

1. Phosphor converted
   • Blue LED
   • Violet LED
   • Ultraviolet LED

2. Multi-color LEDs
Phosphor
BLUE LEDS
Assessing Light, UV and IR
Two Methods that LED’s Create White Light

1. Phosphor converted
   - Blue LED
   - Violet LED

2. Multi-color LEDs
   - Red, Blue, Green
   - Red, Blue Green, “White”
   - Red, Blue Green, Amber
   - Red, Blue, Green, Lime
   - Red, Blue, Green, Lime, Deep Blue, Amber, Cyan
RETROFIT
Multi-color LED

SPECTRAL POWER DISTRIBUTION COMPARISON

- Reference Source
How to assess Spectrum

1. Chromaticity

2. Color Rendering
Chromaticity: CIE Color Space

**Color Temperature**
- Red to blue shifts along locus
- Kelvin scale

**Duv**
- Pink to blue shifts along isotherm
**Chromaticity: CIE Color Space**

**Color Temperature**
- Red to blue shifts along locus
- Kelvin scale

**Duv**
- Pink to blue shifts along isotherm
What is the right color of light for artworks?
“He who claims to see colors independent of their illusionary changes fools only himself and no one else”

Joseph Albers
a few useful chromatic tips.....
Color Stability (over time)
Delta u’v’ = 0.0064
How to assess Spectrum

1. Chromaticity

2. Color Rendering
   a) Color Fidelity
   b) Saturation
Metamarism: Different SPDs produce the same color

Incandescent @ 2850K

Tri-color Florescent @ 2950K

LED @ 2950K

Metamarism: Different SPDs produce the same color
Metamarism

- CREE 3000K
- MSI 3000K
- SORAA 3000K
- GE STANDARD 3000K
COLOR RENDERING: CRI SHOULD BE GREATER THAN 80

<table>
<thead>
<tr>
<th></th>
<th>TCS01</th>
<th>TCS02</th>
<th>TCS03</th>
<th>TCS04</th>
<th>TCS05</th>
<th>TCS06</th>
<th>TCS07</th>
<th>TCS08</th>
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<tr>
<td>DE*ab</td>
<td>3.4</td>
<td>1.7</td>
<td>1.7</td>
<td>4.3</td>
<td>3.9</td>
<td>2.3</td>
<td>2.2</td>
<td>4.8</td>
</tr>
</tbody>
</table>

8 COLOR SAMPLES
IES: TM-30 Measures color fidelity, gamut and hue shift

<table>
<thead>
<tr>
<th>A. NATURE</th>
<th>B. SKIN</th>
<th>C. TEXTILES</th>
<th>D. PAINTS</th>
<th>E. PLASTIC</th>
<th>F. PRINTED</th>
</tr>
</thead>
</table>

99 COLOR SAMPLES
HIGH FIDELITY
Fidelity \( \text{Rf} = 91 \)
Gamut \( \text{Rg} = 106 \)
\( \text{CRI} = 92 \)
\( \text{LUX} = 350 \)

HIGH GAMUT
Fidelity \( \text{Rf} = 46 \)
Gamut \( \text{Rg} = 115 \)
\( \text{CRI} = 18 \)
\( \text{LUX} = 350 \)

2987 K
\( Duv = 0.002 \)
3000K
\( Duv = 0.004 \)
Controllable Qualities of Light

1. Quantity
2. Distribution
3. Spectrum
4. Movement
5. Angle
FLICKER IS EVIL
FLICKER CHECKER
Set camera to Slo Motion video (240 frames per second).
This slows down the flicker rate by a factor of 8. Film for 5 seconds.
Play back the video on the phone. Flashing, stripes, or other artifacts may indicate flicker
or strobe or phantom array effect.

NO GUARANTEE, BUT IT'S A GOOD INDICATOR, AND IT'S FUN.

Thanks Naomi
“Dominant flicker frequency shall always be $\geq 100$ Hz for any static dim level.”
As defined in the IEEE 1789-2015 standard, must remain in the ‘No Effect’ zone to at least 2% dim level, and in the ‘Low Risk’ zone to at least 0.5% dim level.”
Occupyancy Sensors Are Awesome
Lighting Controls

1. Window Screens and color filters
Lighting Controls

1. Window Screens and color filters
Lighting Controls

1. Window Screens (retrofit lamps)
2. Dimmers
   - Centrally located
   - On board of fixture
1. Window Screens (retrofit lamps)
2. Dimmers
   - Centrally located (beware of flicker!)
   - On board of fixture
3. Computer Control of Each Fixture (Dimming and/or color)
   - Wireless (Zigbee or BLE)
   - Data track
How to Change a Lightbulb

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