The Insidious Failure Modes of Emerging Lighting Technologies

Bryan Winningham
Outline

• Why the Energy Independence and Security Act of 2007 has caused the push for alternative types of lighting
• Lighting basics, explaining the evolution of a simple product into a complicated device
• LED bulb failure and their impact on the installation and users
Why are incandescent bulbs going away?

- Signed by President George W. Bush to help the United States become more energy independent
- Sets energy efficiency standards for light bulbs
- First phase took effect in 2012
Benefits of adoption

• Reduce emissions from power plants by reducing power consumption
• Cost savings to consumers who adopt new lights
Affected Lights

- Screw based bulbs
- Technology neutral
- Increased efficiency
# Expected Efficiency

<table>
<thead>
<tr>
<th>Incandescent Bulb rating</th>
<th>Power rating after</th>
<th>Effective date</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 watt</td>
<td>≤72 watts</td>
<td>January 1, 2012</td>
</tr>
<tr>
<td>75 watt</td>
<td>≤53 watts</td>
<td>January 1, 2013</td>
</tr>
<tr>
<td>60 watt</td>
<td>≤43 watts</td>
<td>January 1, 2014</td>
</tr>
<tr>
<td>40 watt</td>
<td>≤29 watts</td>
<td>January 1, 2014</td>
</tr>
</tbody>
</table>
Lighting Basics
Temperature of light
Incandescent Bulbs

• Commonly “A”-type lamp
• Least energy efficient
• Produce visible light by heating a coil or filament of tungsten wire, that glows when heated by an electrical current
• Long life lamps have thicker, stronger filaments, last longer but are less energy efficient
• Bulb life 1000 hours
Incandescent Bulbs

Photo: Andreas Suetterlin
Energy Saving incandescent (or Halogen) Bulbs

- Similar design and color to incandescent bulb
- Capsule containing halogen gas surrounds heating element
- May have reflectors to reflect heat back into gas capsule increasing efficiency
- More costly to purchase then standard incandescent but more efficient
- Generally, last longer then incandescent bulbs
- Bulb life 1000 to 3000 hours
Energy Saving incandescent (or Halogen) Bulbs
Energy Saving incandescent (or Halogen) Bulbs
Compact Fluorescent Light (CFL) Bulbs

- Tubular shape, sometimes enclosed in globe with integral ballast and screw base
- Similar to linear fluorescent tube lamps
- Contain argon gas and a small amount of mercury
- Use about 75% less energy than incandescent bulbs
- Bulb life 10,000 hours
- Temperature limited, mostly for indoor use
Compact Fluorescent Light (CFL) Bulbs
Compact Fluorescent Light (CFL) Bulbs
Light Emitting Diode (LED) Bulbs

• Also known as Solid State Lighting (SSL) and is based on semiconductor materials

• Requires electronic LED driver circuit, thermal management, and color correction

• Low heat producer

• Uses 75% less energy than incandescent bulbs

• “Good Quality” Bulb Life 25,000 hours
Light Emitting Diode (LED) Bulbs
Energy Star Qualifications

- Suitability of Purpose
- Color quality
- Light output
- Lifetime
- Heat Management
LED Bulb Limitations

- Not to be hung upside down
- Enclosed
- Temperature usage constraints
- Dimmable
- Usage limited to 3 hours per day
Light Emitting Diode (LED) Bulbs

**Warranty**
Each bulb has a 5-year warranty. If a bulb is not satisfied with its performance, it can be returned for a replacement. Warranty is void if the bulb is mishandled and/or if the bulb is not used in its intended application.

**Guarantee**
Each bulb has an energy guarantee of 10 years. In case of failure, the bulb will be replaced for free. The guarantee is void if the bulb is mishandled and/or if the bulb is not used in its intended application.

**Warning**
This device complies with part 15 of the FCC Rules. Operation is subject to the following conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation. This device has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures: (a) Reorient or relocate the receiving antenna, (b) Increase the separation between the equipment and receiver, (c) Connect the equipment into an outlet on a circuit different from that to which the receiver is connected. Consult the dealer or an experienced radio/TV technician for help.

**Life**
Based on 3 hours/day, 4.57 years

**Light Appearance**
Warm

**Energy Used**
9 watts

**Brightness**
750 lumens

**Estimated Yearly Energy Cost**
$0.68
Based on 3 hours/day, 11.5c/kWh

**Distributed by**
L E Sourcing, Inc.
P.O. Box 1535
N. Wilkesboro, NC 28669
www.lesourcing.com

**Product Date Code**
04-16

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**Design**
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LED Bulb Limitations

Warning
This device complies with part 15 of the FCC Rules. Operation is subject to the following 2 conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation. Note: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures: Reorient or relocate the receiving antenna. Increase the separation between the equipment and receiver. Connect the equipment into an outlet on a circuit different from that to which the receiver is connected. Consult the dealer or an experienced radio/TV technician for help. NOT FOR USE WITH DIMMERS. THIS DEVICE IS NOT INTENDED FOR USE WITH EMERGENCY EXIT FIXTURES. NOT SUITABLE FOR ENCLOSED FIXTURES.
LED Bulb Limitations

GE LEDs offer outstanding energy efficiency, long-lasting performance and just-right brightness, all in one package. They’re dimmable and illuminate your home with a warm white light. Use this GE LED general purpose light in table lamps, sconces and open fixtures. It’s great for frequently used fixtures—GE LED’s long life and low energy use will help you save money on energy.

**Product Features:**
- Worry-free use and disposal
- Mercury Free
- Lasts 13 years*
- $82 in energy savings* per bulb
- 3000K - bright white

**General Purpose LED for general use fixtures**

Limited Warranty: Guaranteed to last 5 years based on rated life at 3 hours use per day at 120V. If this bulb does not last for 5 years (based on 3 hours per day / 7 days per week) return bulb, proof of purchase and your name and address to GE Lighting, Product Service Dept., 1975 Noble Road, Cleveland, Ohio 44112. GE will replace your bulb. BULB REPLACEMENT IS GE’S SOLE WARRANTY OblIGATION, AND INCIDENTAL AND CONSEQUENTIAL DAMAGES ARE EXCLUDED. Some states do not allow the exclusion or limitation of incidental or consequential damages, so the above exclusion may not apply to you. This warranty gives you specific legal rights and you may also have other rights which vary from location to location.

Minimum starting temperature -20 °C.

**Product Specifications:**
- general purpose
- indoor use
- standard bulb shape
- medium base

<table>
<thead>
<tr>
<th>Lighting Facts</th>
<th>Per Bulb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brightness</td>
<td>760 lumens</td>
</tr>
<tr>
<td>Estimated Yearly Energy Cost</td>
<td>$1.20</td>
</tr>
<tr>
<td>Based on 3 hrs/day, 11¢/kWh</td>
<td></td>
</tr>
<tr>
<td>Cost depends on rates and use</td>
<td></td>
</tr>
<tr>
<td>Life</td>
<td>13.7 years</td>
</tr>
<tr>
<td>Based on 3 hrs/day</td>
<td></td>
</tr>
<tr>
<td>Light Appearance</td>
<td>Cool</td>
</tr>
<tr>
<td>3000 K</td>
<td></td>
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<tr>
<td>Energy Used</td>
<td>10 watts</td>
</tr>
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**Manufactured for GE Lighting**

<table>
<thead>
<tr>
<th>Listed LED Lamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>60w de</td>
</tr>
<tr>
<td>760 lúmenes</td>
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</tbody>
</table>

PC 39111
Desc: LED10A1993K-3P/LT
Res. #1469663

Nela Park
Cleveland, OH 44112
Made in China
Fabricado en China
LED Bulb Failures and Effects on the Installation and Users
Consumer Products Safety Commission Recalls

**MAY 24, 2016**

**Philips Lighting Recalls Metal Halide Lamps Due to Burn and Laceration Hazards**

The outer bulbs can shatter, resulting in hot internal pieces of glass falling from the lamps, posing a burn and laceration hazard.

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**MARCH 16, 2016**

**GE Lighting Recalls High-Intensity LED Replacement Lamps Due to Impact Hazard**

The lamp can separate from its base and fall onto consumers below, posing an impact hazard.

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**JANUARY 27, 2016**

**Lunera Recalls LED Lamps Due to Fire, Burn and Electric Shock Hazards (Recall Alert)**

The Helen GX23 LED lamps can overheat, posing fire, burn and electric shock hazards.

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**DECEMBER 08, 2015**

**Technical Consumer Products Recalls LED Lamps Due to Electrical Shock Hazard**

Water can enter the lamp in wet location applications, posing an electric shock hazard to the user.
Consumer Products Safety Commission Recalls

**Philips Recalls Halogen Bulbs Due to Laceration and Burn Hazards**

The lens of the bulb can shatter in the lamp or the lens fall off and shatter, posing a laceration and burn hazard.

**Osram Sylvania Recalls T8 LED Tubes Due to Burn Hazard**

Lamps can overheat and melt, posing a burn hazard.

**LED Candelabra Lights Recalled by Infinity Green Products Due to Fire Hazard (Recall Alert)**

The LED light bulbs can overheat and catch fire.

**Philips Lighting Recalls Endura and Ambient LED Bulbs Due to Shock Hazard**

The dimmable LED bulbs have improper wiring. When used, they can electrify lamps and shock users.
Doctors Issue Warnings about LED Street Lighting

Radio Frequency Interference

CAUTION

Not intended for use with emergency exit fixtures, emergency exit lights, electronic timers, photocells or dimmers. This device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) this device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation. Any changes or modifications not expressly approved by the manufacturer could void the user’s authority to operate the equipment.

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures: reorient or relocate the receiving antenna, increase the separation between the equipment and receiver, connect the equipment into an outlet on a circuit different from that to which the receiver is connected; or consult the dealer or an experienced radio/TV technician for help.
Reliability of LED Lights Depends On

- Operating temperatures
- Heat management
- Power supply
- Materials
- Electrical and material interfaces
Failures Observed in Other Research

- LED Chip
  - Excessive junction temperature on LED
  - Humidity ingress
  - Unstable power supplies
  - Electro static discharge damage
Failures Observed in Other Research

- LED internal construction
  - Interface to substrate of chip
  - Encapsulation of chip not hermetically sealing
  - Aging of encapsulation materials
  - Different material expansion coefficients of components
Failures Observed in Other Research

• Power supply
  • IGBT/MOSFET
  • Film capacitor
  • Surface mount capacitor
  • Surface mount resistor
Differences in LED Bulb Design

- LEDs in series or parallel
- Power supply in potting compound or not
- Varying heat sink designs
Temperature and Humidity Stressors
## Testing Procedures

<table>
<thead>
<tr>
<th>Step</th>
<th>Activity</th>
<th>Time (Minutes)</th>
<th>Temperature (F)</th>
<th>Humidity</th>
<th>Humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ramp</td>
<td>10</td>
<td>75</td>
<td>85</td>
<td>Off</td>
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<tr>
<td>2</td>
<td>Ramp</td>
<td>25</td>
<td>239</td>
<td>85</td>
<td>On</td>
</tr>
<tr>
<td>3</td>
<td>Soak</td>
<td>15</td>
<td>239</td>
<td>85</td>
<td>On</td>
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<tr>
<td>4</td>
<td>Ramp</td>
<td>75</td>
<td>14</td>
<td></td>
<td>Off</td>
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<tr>
<td>5</td>
<td>Soak</td>
<td>15</td>
<td>14</td>
<td></td>
<td>Off</td>
</tr>
<tr>
<td>6</td>
<td>Goto 1</td>
<td>10K cycles</td>
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<td></td>
<td></td>
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<tr>
<td>7</td>
<td>End</td>
<td></td>
<td></td>
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</tbody>
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Testing Data Sample
Failure Mechanisms Observed During Testing

- LED failures
- Power supply board failures
5 Bulbs in Parallel with degradation
LED Failures
LED Failures
LED Failures
LED Failures
Power supply failure
Power supply failure
Power supply failure
Power supply failure
Summary

- Why the Energy Independence and Security Act of 2007 has caused the push for alternative types of lighting
- Lighting basics, explaining the evolution of a simple product into a complicated device
- LED bulb failure and their impact on the installation and users
Consumers aren’t necessarily getting the savings that they were promised
Questions?