LED Lifetime
Importance of LED Lifetime

• Cost benefit calculation requires:
  − Asset price
  − Energy savings per hour
  − Lifetime - hours of operation
  − Labour charge ($0 ?)

• Need an indication of product lifetime
• Important factor in purchasing choice
Verification for cost benefit

Energy savings per hour

• Measurement of:
  − Electrical power
  − Luminous flux

Product Life (hours of operation)

• Need to determine end of life
  − Time to failure
End of Life: Modes of Failure

• Catastrophic (failure to produce light)
  – Failure to produce light

• Parametric (reduced functionality)
  – Lumen maintenance - Lack of a useful amount of light output
  – Colour maintenance - change in the colour appearance
  – Flicker - Perceptible intermittent light output
Prevalence of LED Failure Modes

• Systematic field data is of very limited availability

• Survey results: Next Generation Lighting Industry Alliance (NGLIA) in the USA
  - Higher incidence of catastrophic failure modes reported by members


Key Initiators of Catastrophic Failure Modes

- High operating current
- High inrush current
- High ambient temperature
- High operating temperature
- Rapid and large temperature changes
Product Endurance

• Dependent on:
  − Electrical component quality
  − Integrity of electrical interfaces/connections
  − Ability of product to dissipate heat

Source: lightingmatters.com.au
Verification of Product Endurance

• Verifying the lifetime by operating LED products until actual end of life is not practical

• But the ability of a product to endure certain operating conditions can provide some indication of the model’s likelihood to reach its intended (claimed median) lifetime
Evidence of Failures in the Market

EEPLIANT 2014 Report – LED lamp test results

• After 6,000h of operation
  − 15 lamps (17%) failed lumen maintenance requirements
  − 19 lamps (22%) failed lamp survival requirements

• Note: Models selected were biased to those identified as potentially non-compliant lamps
IEC 62612, IEC 62717 Endurance Tests

1. Accelerated operational life (i.e. Extreme conditions)
   - 10°C above maximum rated operating temperature
   - ON continuously
   - 1000 hours

2. Ambient temperature cycling (i.e. Max rated)
   - -10°C (1h hold) transition for 1h to 40°C (1h hold)
   - ON (34 min): OFF (34 min)
   - 250 thermal cycles (1000 hours)

3. Supply switching (i.e. Typical)
   - 25°C ambient temperature
   - ON (30s): OFF (30s)
   - # cycle equals half the hours of rated life (eg 125 hours for 15k hour product)
Effectiveness of IEC Endurance Tests

Supply Switching Test

EEPLIANT 2014 Report (Dec 2017)

- Findings for LED lamp testing (pages 22, 23)
  - Some screening tests supported the view that the switching of lamps at high frequency does not have a significant impact on lamp life.
  - Indications that switching combined with typical warming and cooling cycles may have a significant impact.

- Policy recommendations (pages 22, 23)
  - Shorten the period for lifetime testing to a maximum of 3000 hours
  - Combine with the use of enforced temperature stress regimes or similar approaches that accelerate the aging of lamps
Options for Improve Endurance Test Conditions

• Modify power supply switching cycle to:
  − Increase temperature range of operation
  − Increase temperature gradient between components within product

• Research evidence (Lighting Research Center, USA)
  − Suggested increased ON and OFF times achieve stabilised chip temperatures at much higher and lower temperatures.
Effects of Switching Cycle on Temperature

• In-house test results indicate significant difference in LED package/pcb TMP temperature due to different power supply switching cycles.

• Supply Switching cycles
  − 2.5h ON : 0.5h OFF
  − 1m ON : 1m OFF (equipment was not capable of 30s intervals)

• Ambient temperature
  − Uncontrolled. Approximately 16°C - 23°C
## Effects of Switching Cycle on Temperature

<table>
<thead>
<tr>
<th>Non-directional GSL lamp</th>
<th>Directional PAR38 lamp</th>
<th>Downlight with remote driver</th>
</tr>
</thead>
<tbody>
<tr>
<td>12W (65g)</td>
<td>18W (465g)</td>
<td>18W (module = 285g)</td>
</tr>
</tbody>
</table>

TMP = Temperature Measurement Point
Example 1: Non-directional lamp

- No stabilised temperature
- Average TMP around 45°C
Example 1: Non-directional lamp

- Stabilised TMP temperature: ~63°C
- Cools to near ambient: 20°C
Example 1: Non-directional lamp

- Fast switching: No thermal stress nor thermal differential

**Switch Cycles Summary**

\[ \Delta T_{\text{max}} \approx 16^\circ C \]

\[ \Delta T_{\text{min}} \approx 24^\circ C \]

- Power: 12W
- Weight: 65g
Example 2: Directional PAR38 lamp

- No stabilised temperature
- Average TMP around 45°C

Power: 18W
Weight: 465g

\[ \Delta T = 12^\circ C \]
Example 2: Directional PAR38 lamp

- Stabilised TMP temperature: ~70°C
- Cools to ~10°C above ambient
Example 2: Directional PAR38 lamp

- Fast switching: No thermal stress

Switch Cycle Summary

ΔTmax ≈ 21°C

ΔTmin ≈ 13°C

Power: 18W
Weight: 465g
Example 3: Downlight

- No stabilised temperature
- Average TMP around 37°C

**Switch Cycle:**
1 min ON - 1 min OFF

ΔT ≈ 6°C

Power: 18W
Weight: 285g
Example 3: Downlight

- Stabilised TMP temperature: ~50°C
- Cools to ~10 °C above ambient
Example 3: Downlight

- Fast switching: No thermal stress

Switch Cycle Summary

\[ \Delta T_{\text{max}} = 13^\circ \text{C} \]
\[ \Delta T_{\text{min}} \approx 13^\circ \text{C} \]

Power: 18W
Weight: 285g
Impact on Product of Slower Switch Cycle

- Higher max TMP temperature
- Lower min TMP temperature
- Larger temperature difference (max-min)
- Temperature gradients between adjacent materials within a product will also be greater, due to differences in thermal resistance and mass.
- Sheer forces between materials will increase (due to different coefficients of thermal expansion) and their bonding integrity tested.

- Example: Electrical components will have increased thermal stress

![Diagram showing thermal expansion coefficients of GaN/Si and GaN/sapphire. (Source: [S. Leng 17])](image-url)
Comparison with IEC Endurance Switching Test

**Australian LED Lamp Laboratory Test (2018) Findings**

- **30s ON : 30s OFF (life/2 cycles)**
  - 20 LED lamp models, 5 samples of each created zero failures

- **2.5h ON : 0.5h OFF (1200 cycles)**
  - Subset of 11 models
  - 5 samples of each

<table>
<thead>
<tr>
<th>Model</th>
<th>Failures Total</th>
<th>Average Lumen Maintenance</th>
<th>Required Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5/5</td>
<td>na</td>
<td>95.8%</td>
</tr>
<tr>
<td>B</td>
<td>0/5</td>
<td>103.0%</td>
<td>93.1%</td>
</tr>
<tr>
<td>C</td>
<td>0/5</td>
<td>89.1%</td>
<td>93.1%</td>
</tr>
<tr>
<td>D</td>
<td>0/5</td>
<td>89.4%</td>
<td>95.8%</td>
</tr>
<tr>
<td>E</td>
<td>0/5</td>
<td>114.7%</td>
<td>93.1%</td>
</tr>
<tr>
<td>F</td>
<td>0/5</td>
<td>98.7%</td>
<td>94.8%</td>
</tr>
<tr>
<td>G</td>
<td>3/4</td>
<td>107.2%</td>
<td>95.8%</td>
</tr>
<tr>
<td>H</td>
<td>0/4</td>
<td>65.8%</td>
<td>no claim</td>
</tr>
<tr>
<td>I</td>
<td>0/4</td>
<td>95.9%</td>
<td>96.5%</td>
</tr>
<tr>
<td>J (linear)</td>
<td>0/5</td>
<td>93.9%</td>
<td>no claim</td>
</tr>
<tr>
<td>K (linear)</td>
<td>0/5</td>
<td>93.2%</td>
<td>no claim</td>
</tr>
</tbody>
</table>
Teardown Analysis of Failures

• Investigation of lamps which failed endurance testing for 2.5h ON : 0.5h OFF

• Results
  − Socket has come off the lamp disconnecting one wire. No other defect.
  − Connection between LEDs broken (thermal stress?) All LED chips and driver still functional.
  − Phosphor peeled off the LED filaments. One filament defective. Driver still o.k.
  − Resistor burned (overloaded). LED filaments are still o.k.
  − One lamp flashes some seconds when powered. Another lamp fails to operate. Both lamps, all LEDs still o.k. Driver defects could not be analysed because it is glued into heat sink using cast resin.
Summary: Improved Endurance Test & Criteria

Compromise between extensive testing and sufficient testing to identify significant product endurance issues.

Test Conditions

• Power supply switching cycle:
  − ON 2.5 h and OFF 0.5 h
  − 1200 cycles (3000 h of operation)
  − Uncontrolled ambient temperature (or normal air-conditioning)

Criteria

• Catastrophic Failure
  − Maximum of 1 of 10 samples fail to operate at end of test

• Parametric
  − Minimum lumen maintenance level (based on claimed life)
Thank you

Questions?

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