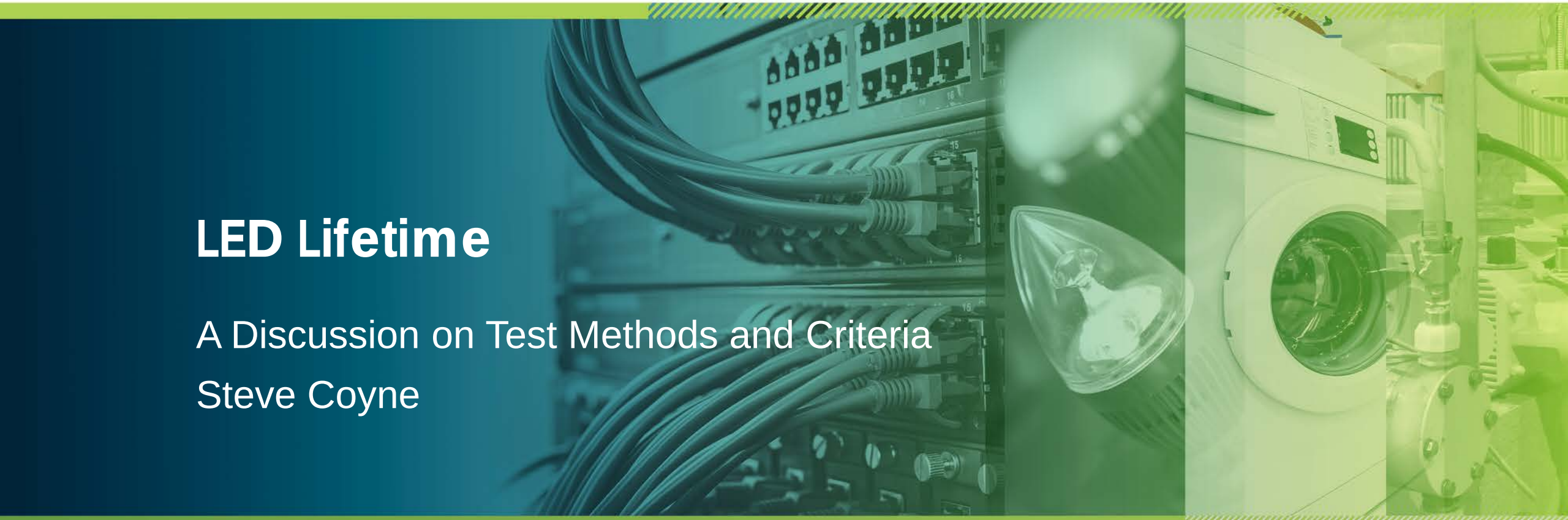
IEA Technology Collaboration Programme
on Energy Efficient End-Use Equipment



LED Lifetime

A Discussion on Test Methods and Criteria

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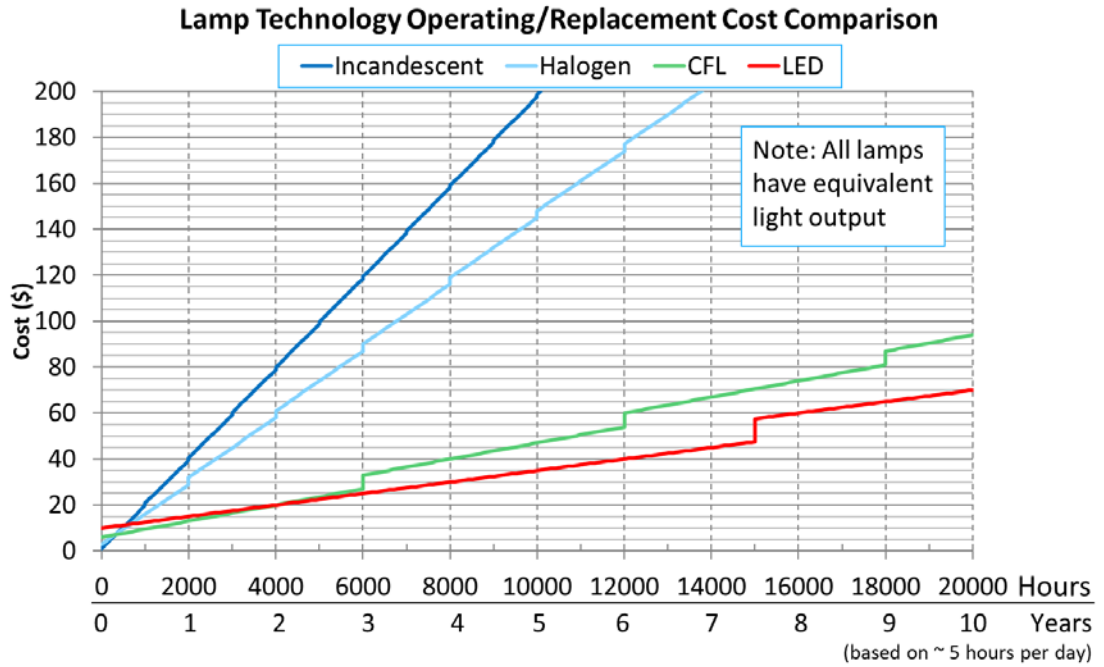
iea-4e.org

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)

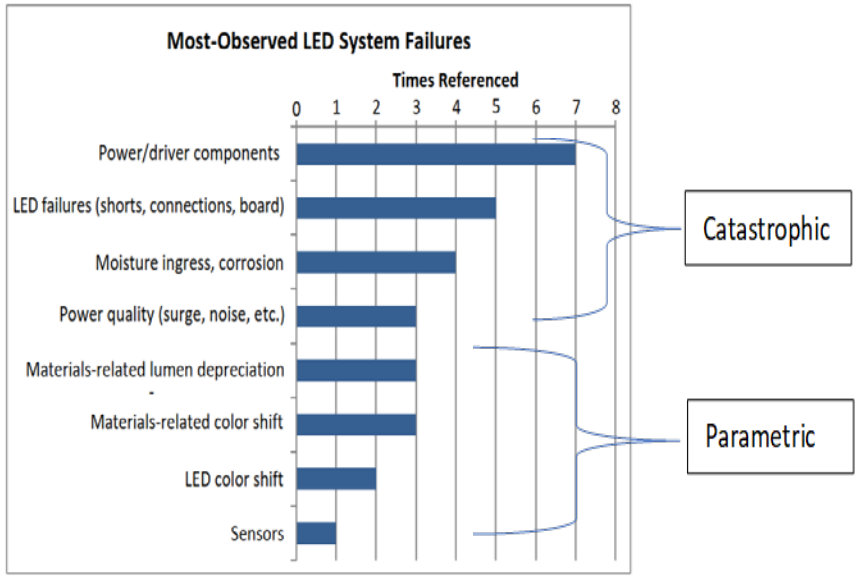
- Need to determine end of life
  - Time to failure

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

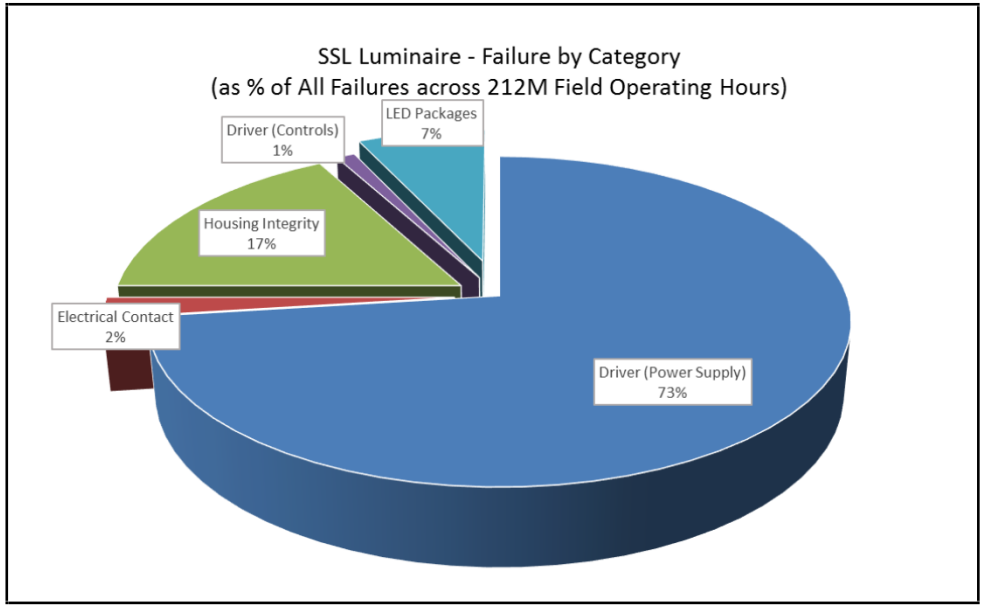
Prevalence of LED Failure Modes

- 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



U.S. Department of Energy, *LED Luminaire Lifetime: Recommendations for Testing and Reporting (3rd Ed, 2014)*

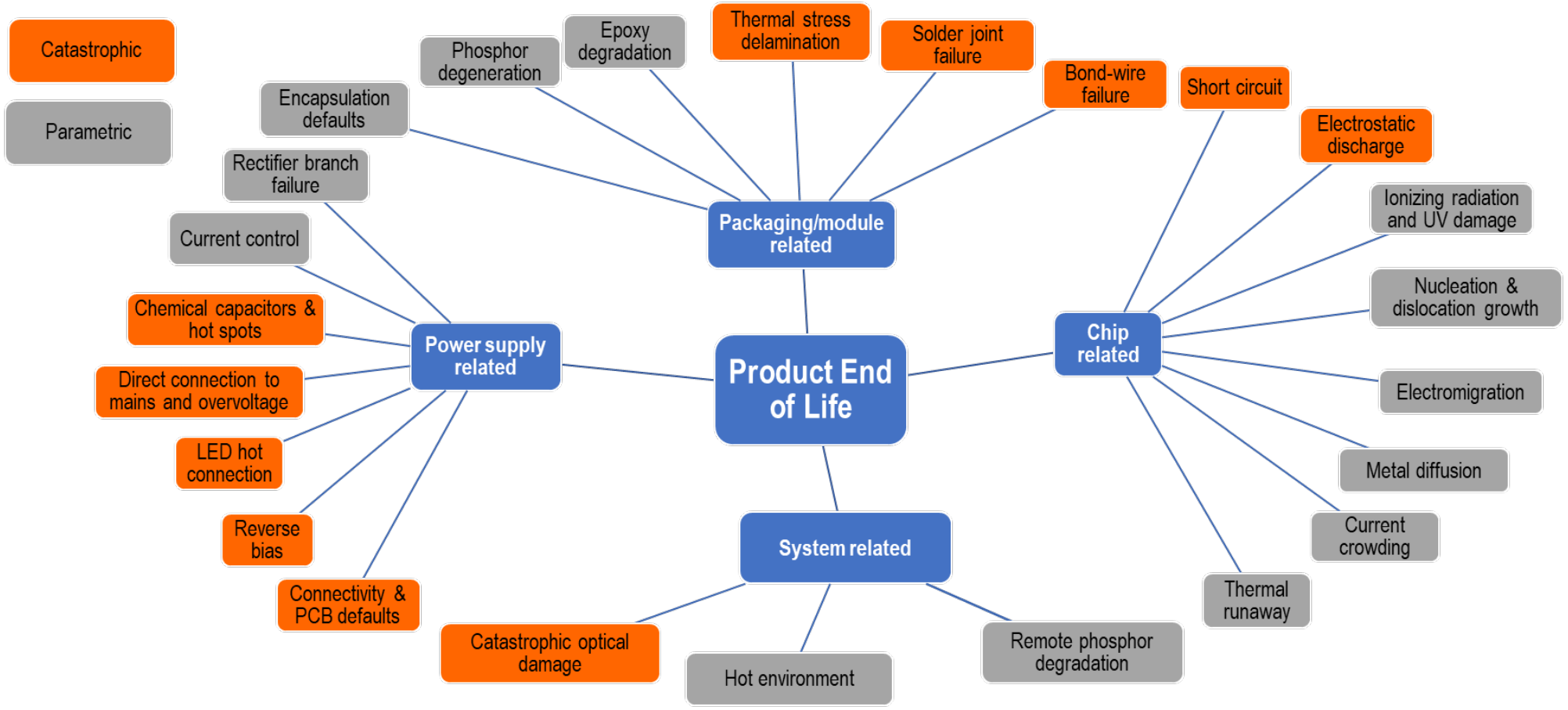
Figure 4D-59. Locations of Catastrophic Failure in SSL Luminaires



NOTE: Information is based on 212 million operating hours for luminaires and was provided to the LSRC by Appalachian Lighting Systems, Inc. Source: Reference [97].

RTI International for U.S. Department of Energy, *System Reliability Model for Solid State Lighting (SSL) Luminaires (2017)*

Causes of Product Failure

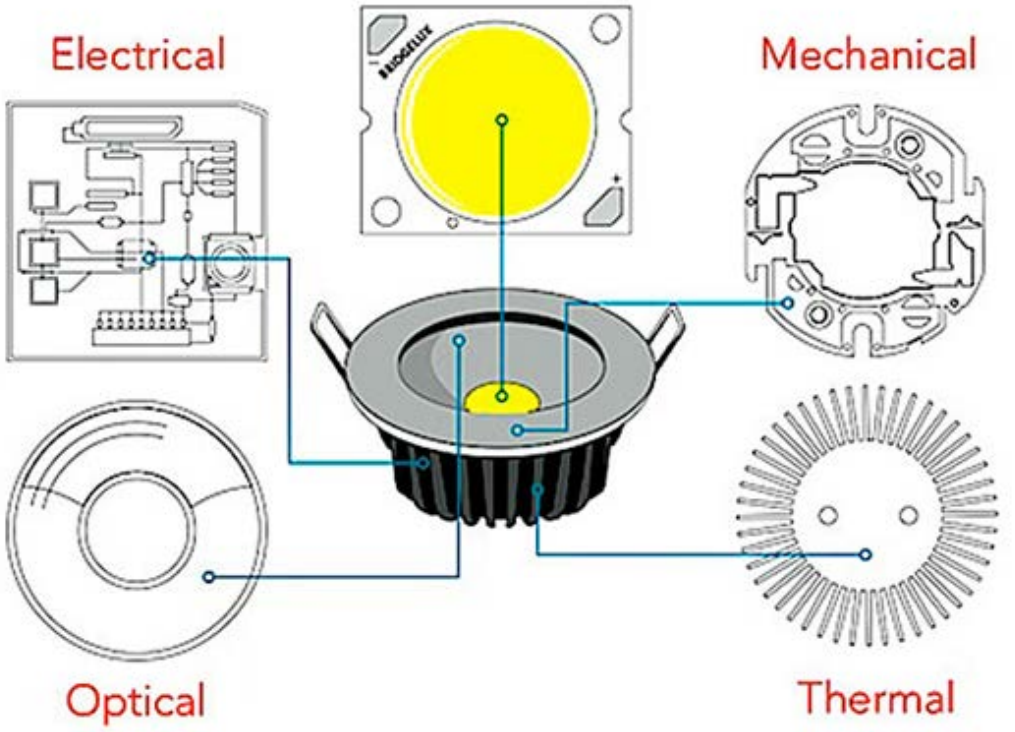


Key Initiators of Catastrophic Failure Modes

- 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 for1h 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)

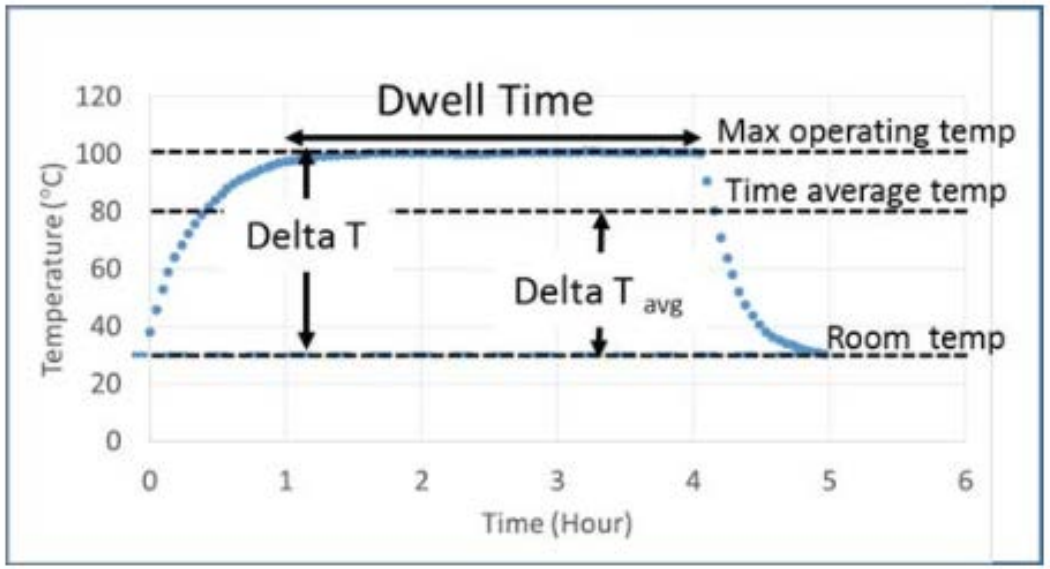
- Findings for LED lamp testing (pages 22, 23)
  - Some screening tests supported the view that the switching of lamps at high frequency does not have a significant impact on lamp life.
  - Indications that switching combined with typical warming and cooling cycles may have a significant impact.

- 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.



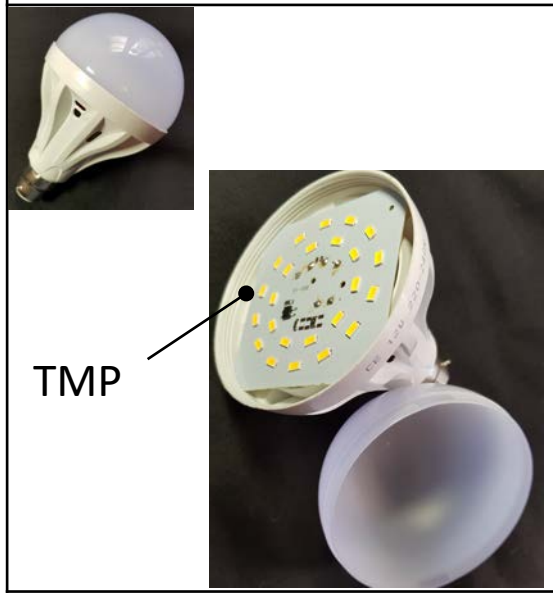
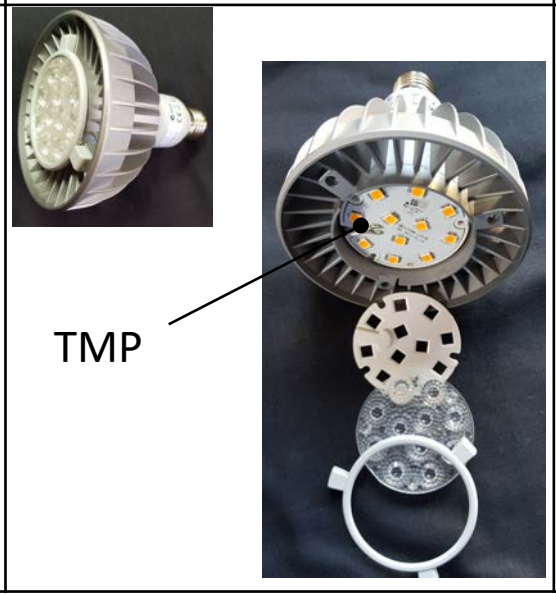
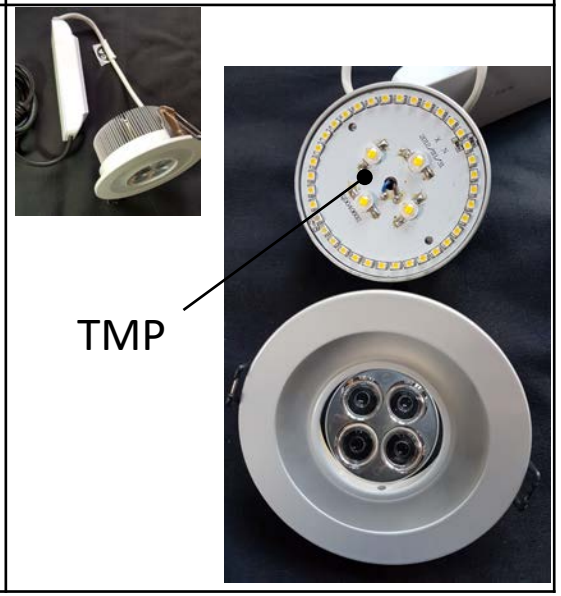
Effects of Switching Cycle on Temperature

- 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

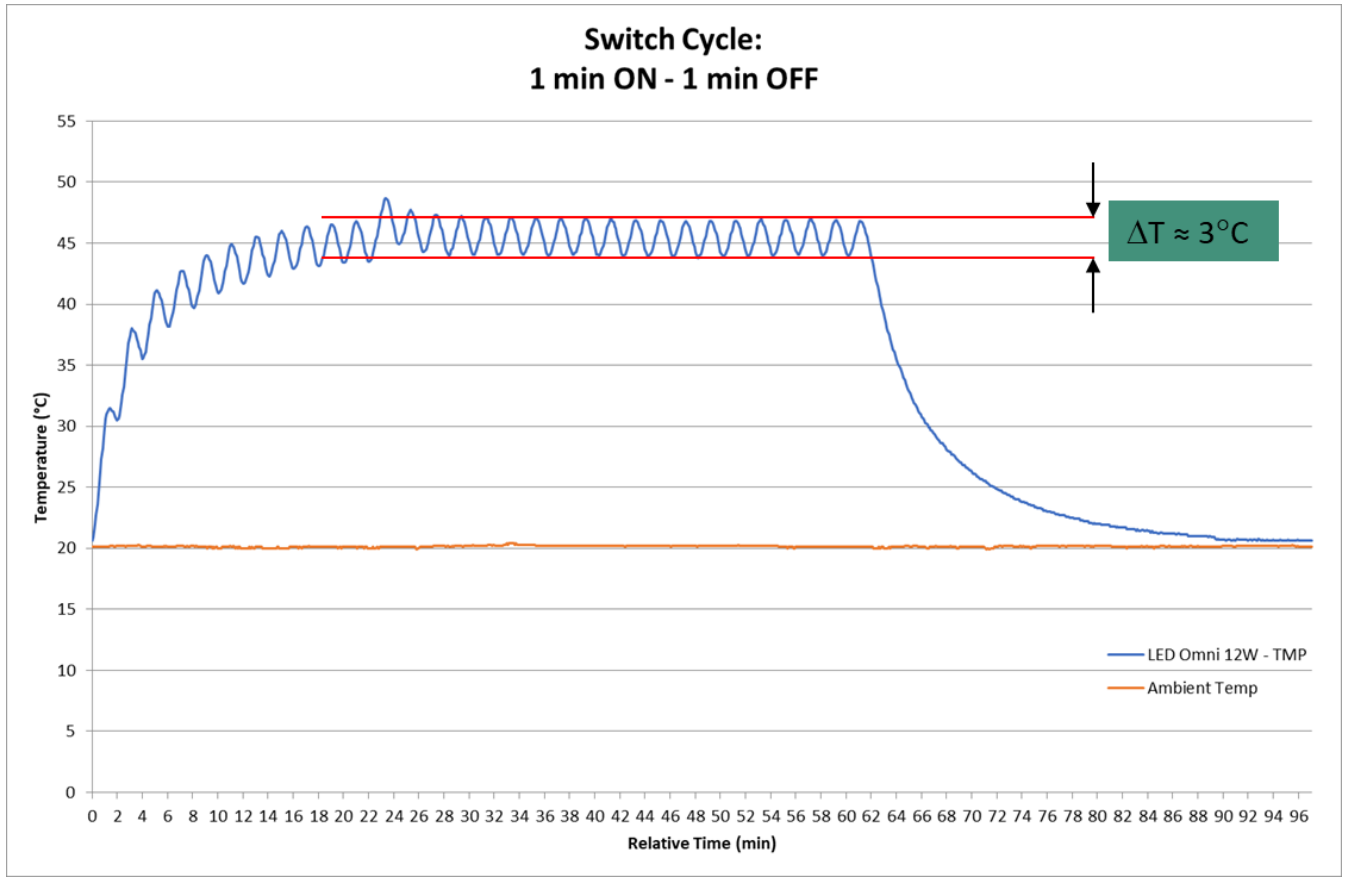
Effects of Switching Cycle on Temperature

Non-directional GSL lamp 12W (65g)	Directional PAR38 lamp 18W (465g)	Downlight with remote driver 18W (module = 285g)
		

TMP = Temperature Measurement Point

Example 1: Non-directional lamp

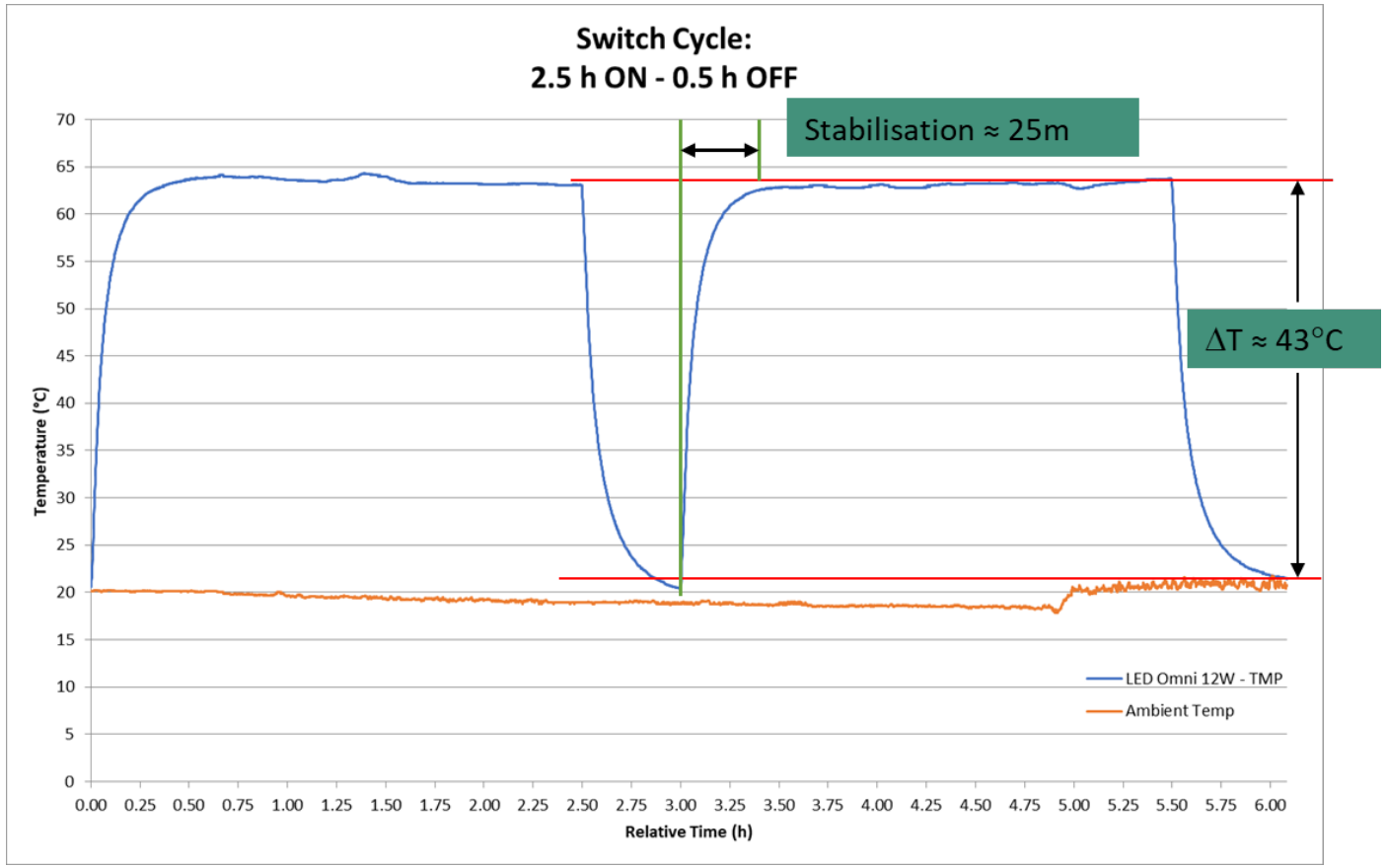
- No stabilised temperature
- Average TMP around 45°C



Power: 12W
Weight: 65g

Example 1: Non-directional lamp

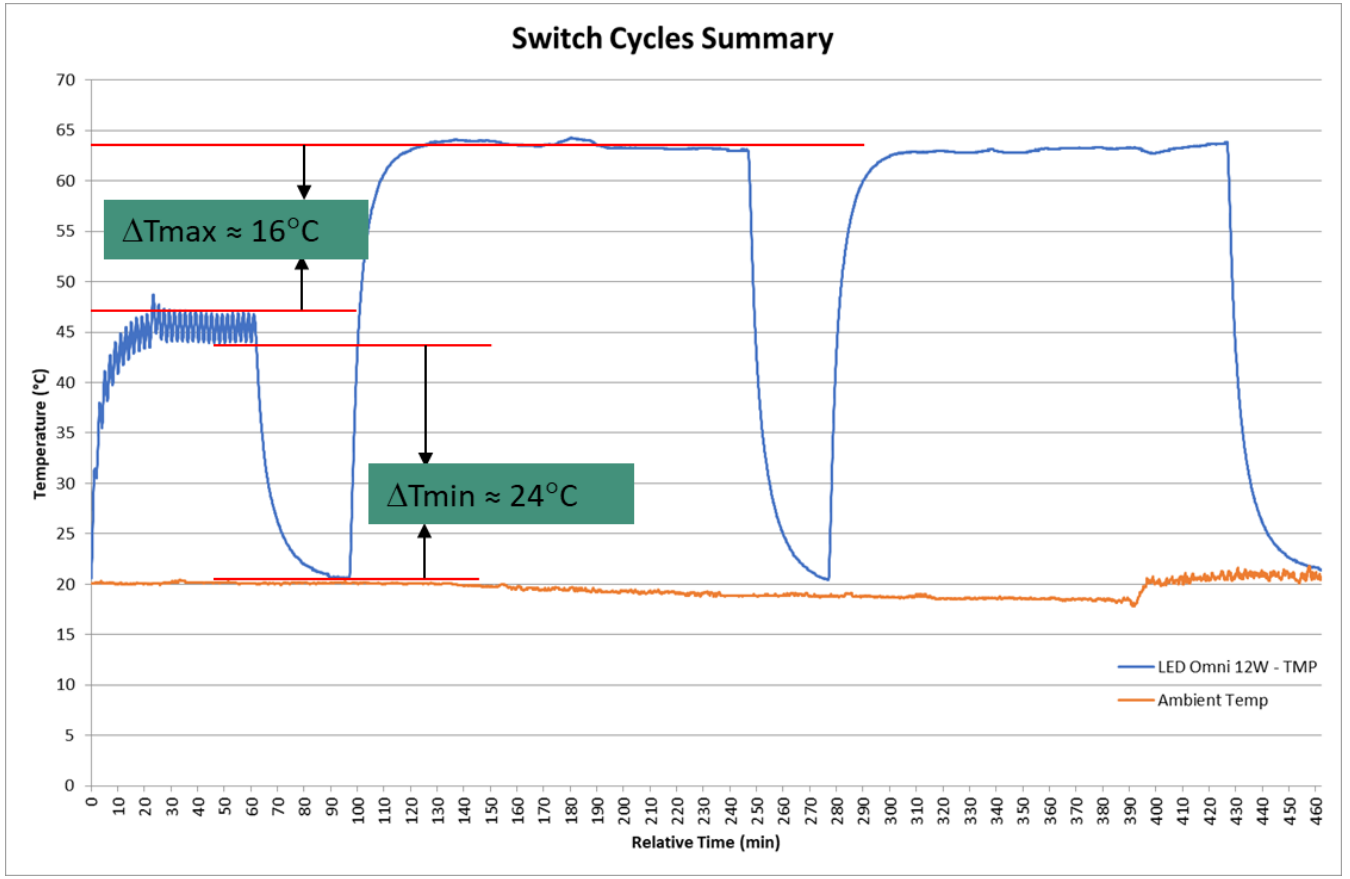
- Stabilised TMP temperature: ~63°C
- Cools to near ambient: 20°C



Power: 12W
Weight: 65g

Example 1: Non-directional lamp

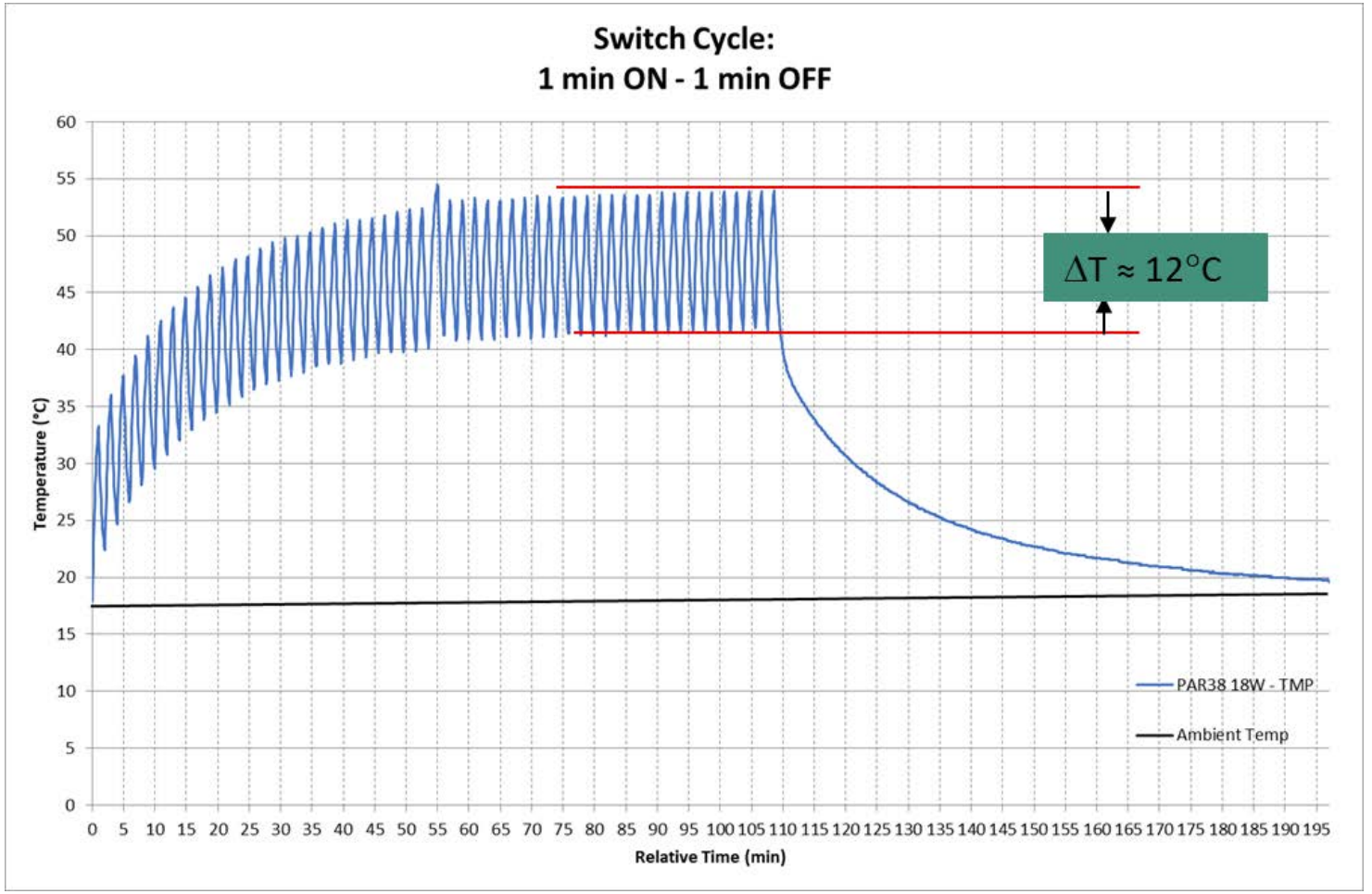
- Fast switching: No thermal stress nor thermal differential



Power: 12W
Weight: 65g

Example 2: Directional PAR38 lamp

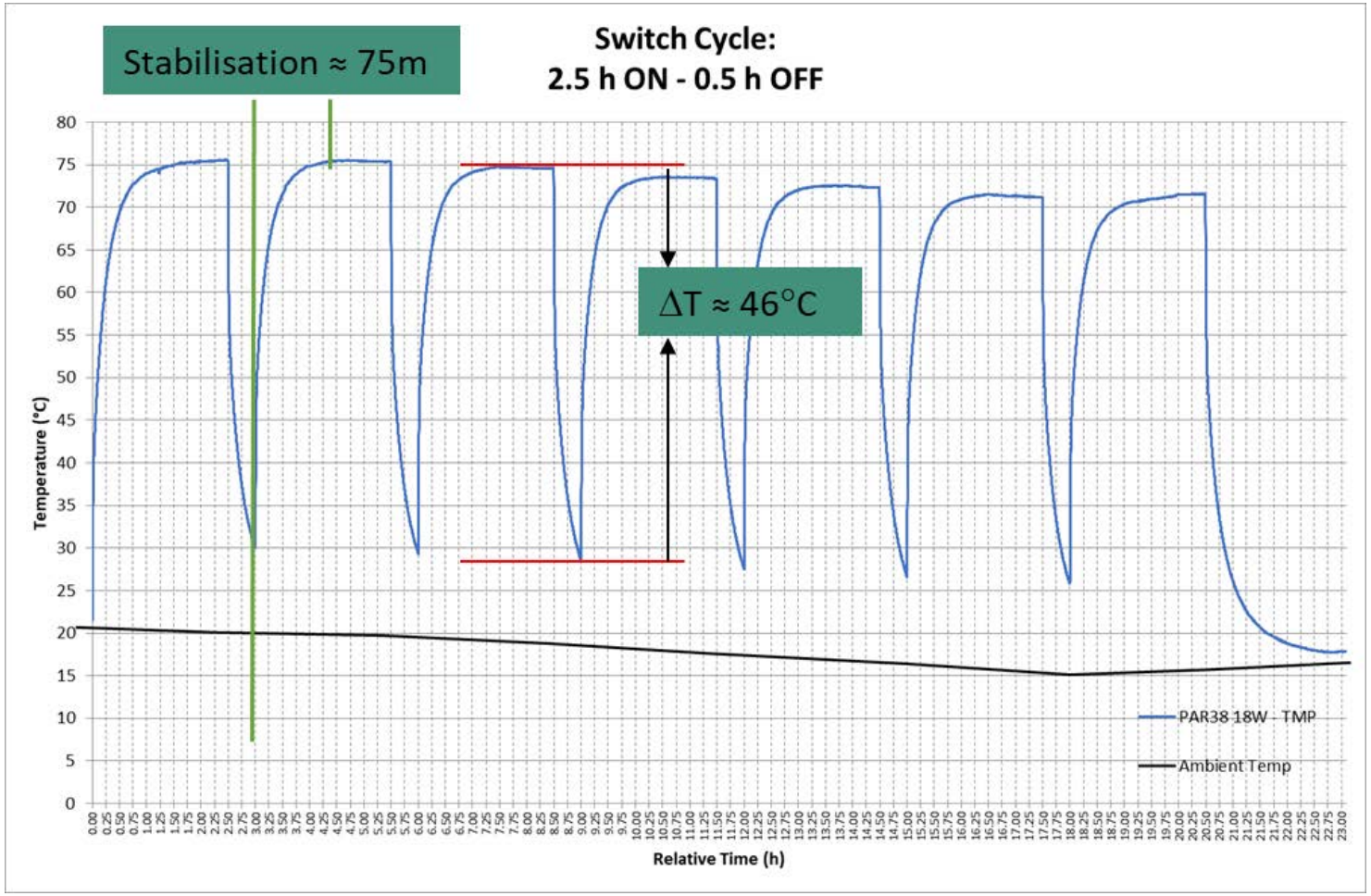
- No stabilised temperature
- Average TMP around 45°C



Power: 18W
Weight: 465g

Example 2: Directional PAR38 lamp

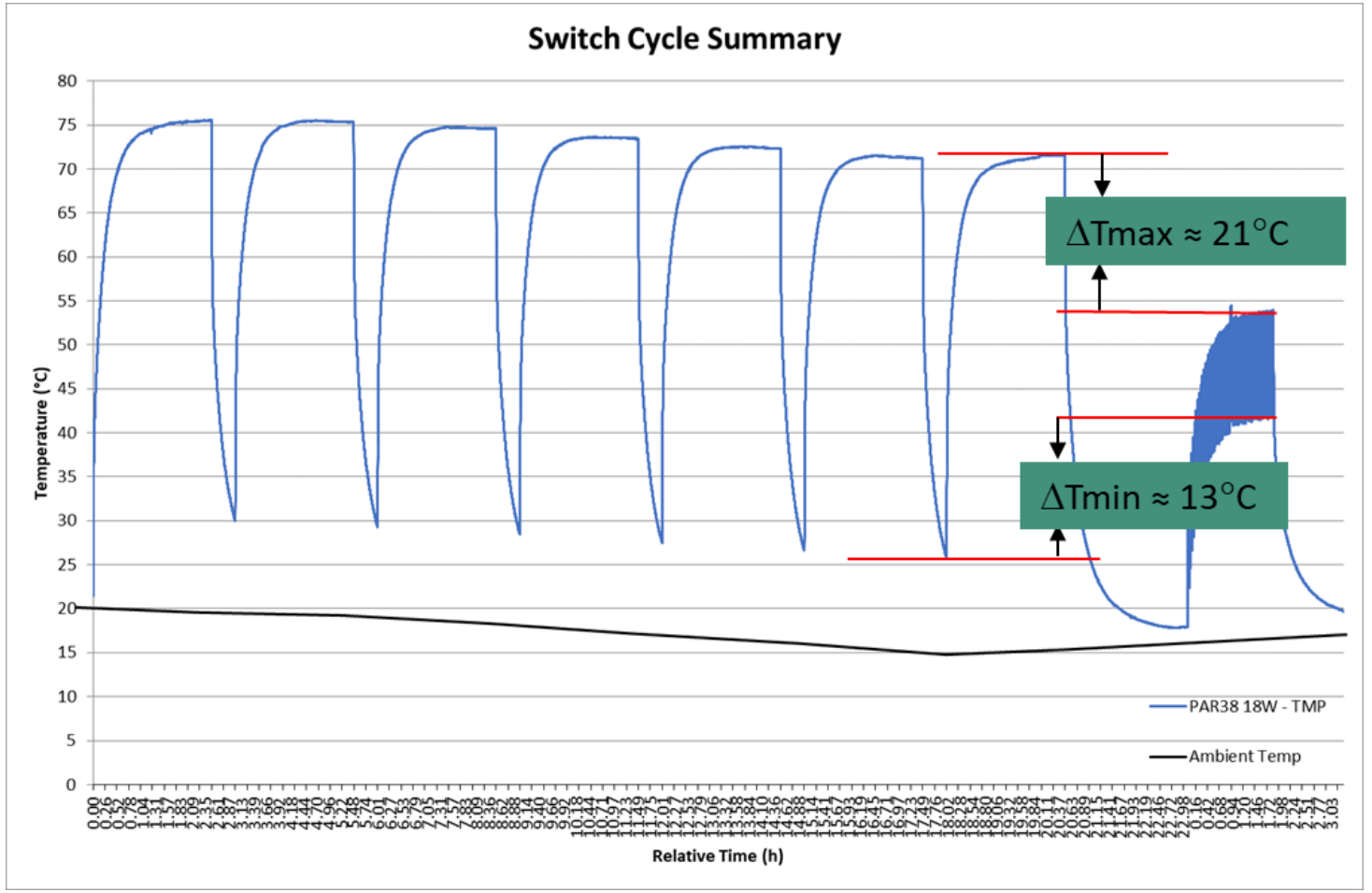
- Stabilised TMP temperature: ~70°C
- Cools to ~10 °C above ambient



Power: 18W
Weight: 465g

Example 2: Directional PAR38 lamp

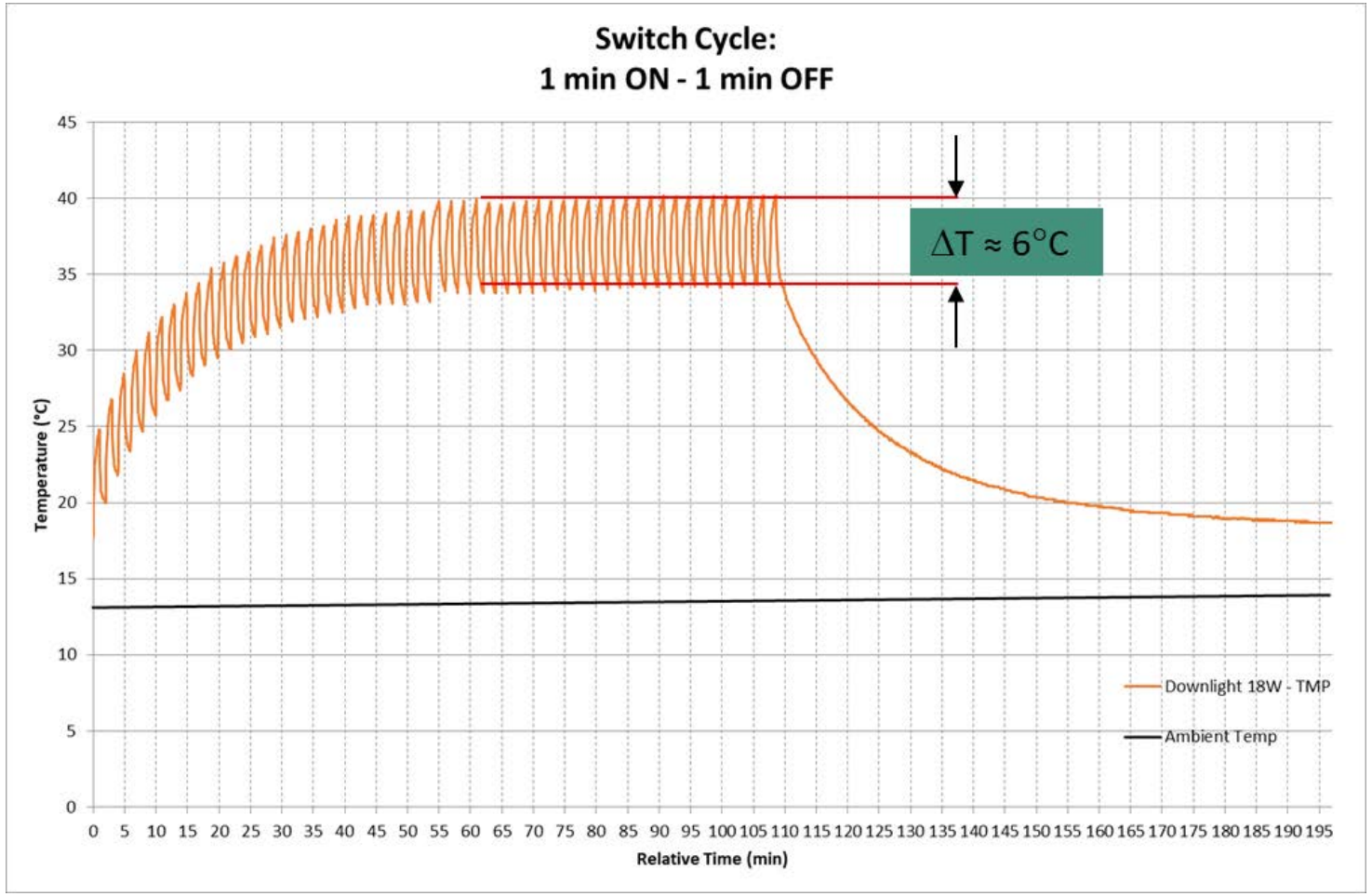
- Fast switching: No thermal stress



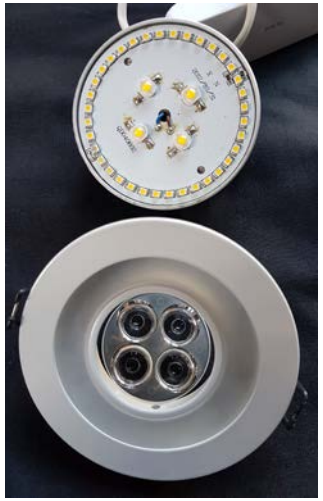
Power: 18W
Weight: 465g

Example 3: Downlight

- No stabilised temperature
- Average TMP around 37°C

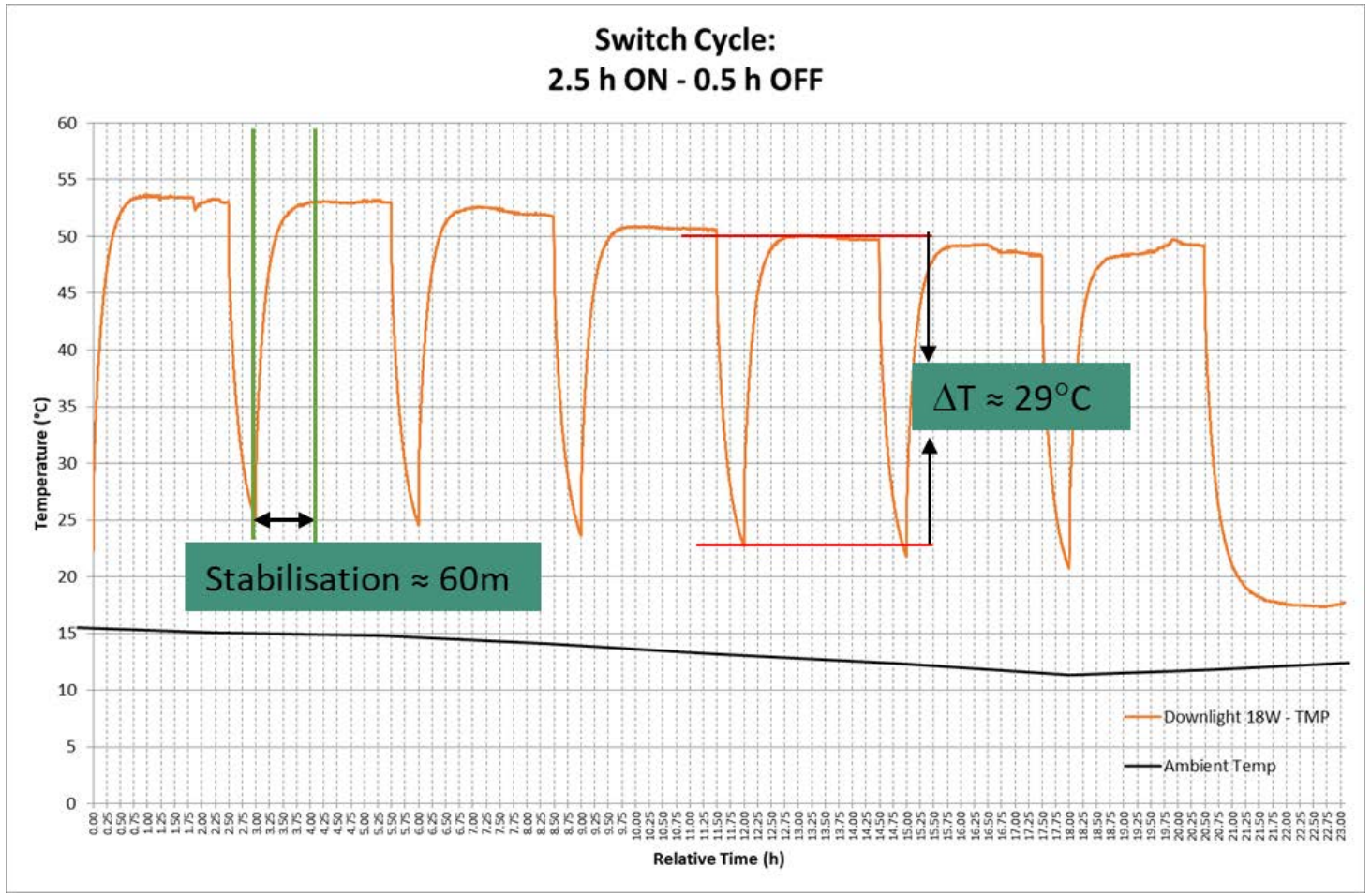


Power: 18W
Weight: 285g



Example 3: Downlight

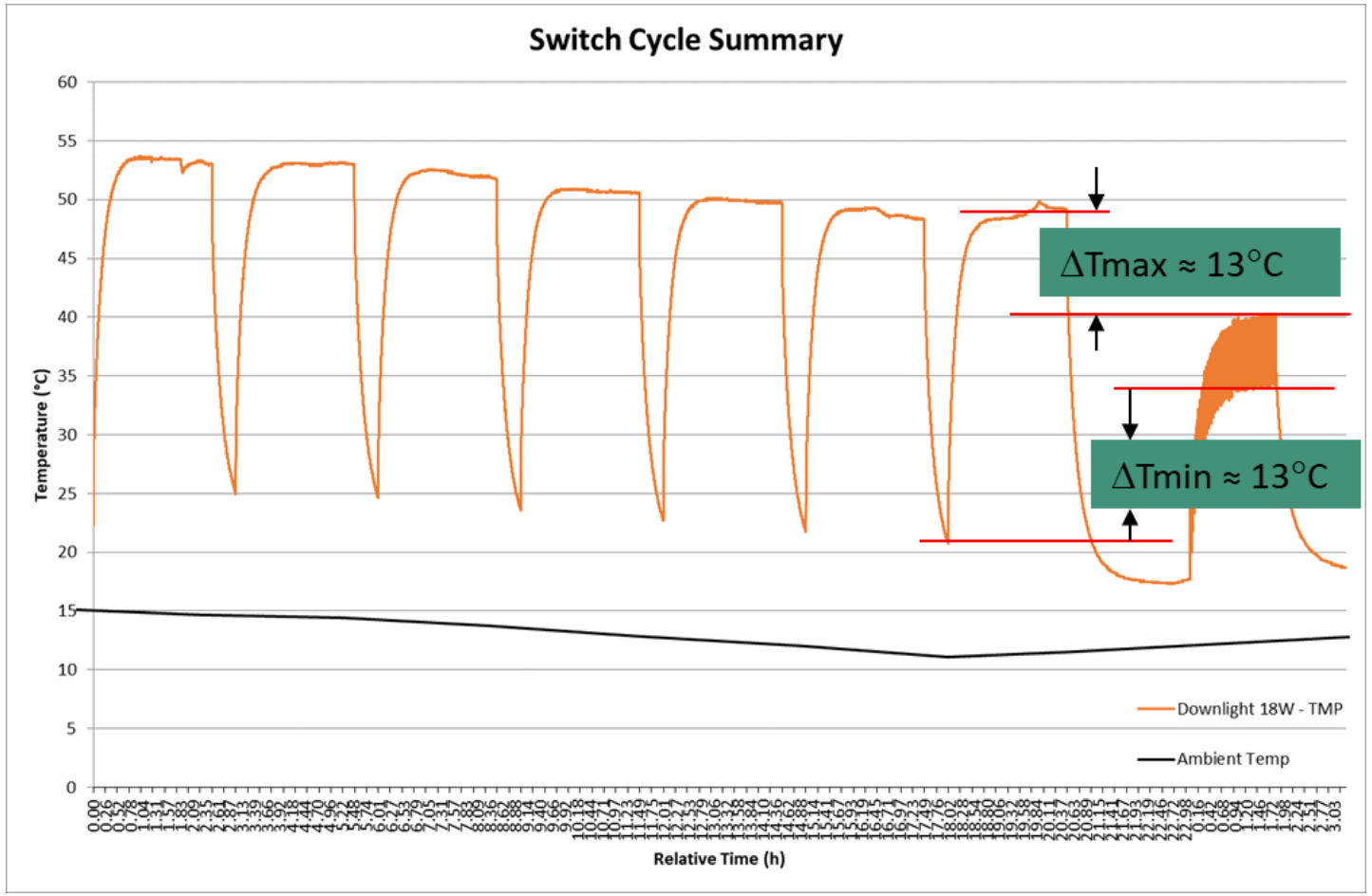
- Stabilised TMP temperature: ~50°C
- Cools to ~10 °C above ambient



Power: 18W
Weight: 285g

Example 3: Downlight

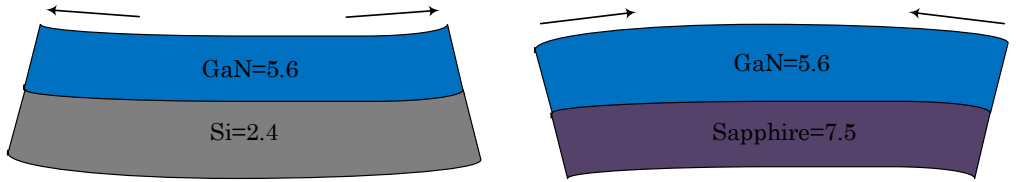
- Fast switching: No thermal stress



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



Thermal expansion coefficients of GaN/Si and GaN/sapphire. (Source: [S.Leng 17])

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

Based on claimed life

Model	2.5h ON / 0.5 OFF (3000hr)		
	Failures Total	Average Lumen Maintenance	Required Minimum
A	5/5	na	95.8%
B	0/5	103.0%	93.1%
C	0/5	89.1%	93.1%
D	0/5	89.4%	95.8%
E	0/5	114.7%	93.1%
F	0/5	98.7%	94.8%
G	3/4	107.2%	95.8%
H	0/4	65.8%	no claim
I	0/4	95.9%	96.5%
J (linear)	0/5	93.9%	no claim
K (linear)	0/5	93.2%	no claim

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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