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LED Lighting Product Life and Failure: Why We Need New Test Methods for Accurate Life Reporting in Applications

L18S20

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May 10, 2018

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Course Description

Laboratory testing of consumer LED lighting products is showing that manufacturer-reported life estimates are missing the mark when it comes to residential applications. The results show that LED systems are not living up to life claims because industry test methods do not consider common operating parameters in applications, such as on-off switching and high temperature. This course will: describe the research showing the causes of LED system failure; show how to accurately predict LED system life by knowing the system's operating temperature and use patterns; and explain current industry test methods and strategies for revising standards.

Learning Objectives

At the end of the this course, participants will be able to:

1. Learn what research tells us about the causes of LED lighting product failure in residential lighting applications

2. Learn how to accurately calculate and predict the lifetime of LED lighting systems in applications

3. Learn about current industry life-testing methods and standards for LED systems and how they may lead to erroneous life claims by manufacturers

4. Learn how research is used to inform test procedure writing and revision by standards-setting bodies

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LED Lighting Product Life and Failure: Why We Need New Test Methods for Accurate Life Reporting in Applications

May 10, 2018 – 10:30 am

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May 6 – 10, 2018

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Course Description and Learning Objectives

- This course describes laboratory research on LED system life when on-off switching and temperature are considered, and describes how industry-adopted life-testing methods need to change in order for manufacturers to provide accurate life estimates.

Four Specific Learning Objectives

1. Learn what research tells us about the causes of LED lighting product failure in residential lighting applications
2. Learn how to accurately calculate and predict the lifetime of LED lighting systems in applications
3. Learn about current industry life-testing methods and standards for LED systems and how they may lead to erroneous life claims by manufacturers
4. Learn how research is used to inform test procedure writing and revision by standards-setting bodies

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Laboratory Study for LED System Life-Test Method Development

Lighting Research Center
Rensselaer

CHICAGO, IL USA
McCormick Place
May 6 – 10, 2018

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Background

- A claimed benefit for LED lighting is long life.
  - Over 20,000 hours
- User expectation:
  - The lamp will last 20,000 hours when used in all applications
- However, application conditions vary.
  - Environment: Ventilated / Enclosed
  - Use pattern: Switching pattern (ON-OFF cycling)

Lighting Facts Per Bulb

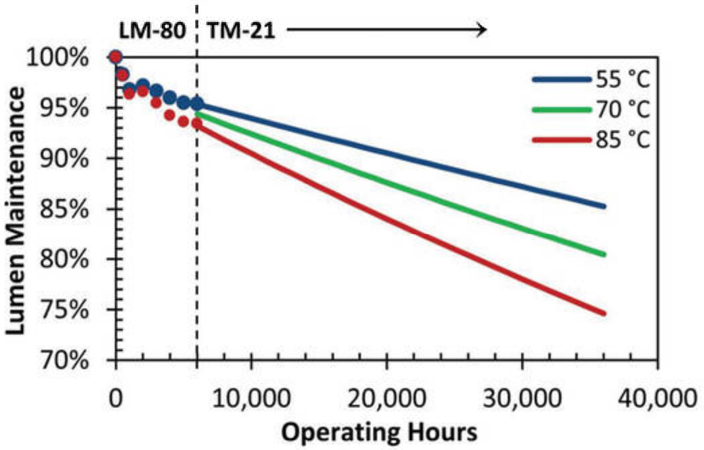
Brightness	**800 lumens**
Estimated Yearly Energy Cost Based on 3 hrs/day. 11¢/kWh Cost depends on rates and use	**$1.02**
Life Based on 3 hrs/day	**22.8 years**
Light Appearance Warm — Cool 2700 K	
Energy Used	**8.5 watts**

https://www.topbulb.com/blog/step-step-buy-led-bulb-home/

http://www.ledflatpanelslighting.com/sale-7670795-15w-black-house-surface-mounted-led-ceiling-lights-for-jewelry-lighting.html

Background

- How is LED product lifetime measured and reported?
  - The LED within the system is tested according to LM-80
  - Continuous-on testing for at least 6000 hours
  - Data extrapolation according to TM-21 to estimate time to L70
  - Estimated L70 at in-situ board temperature



www.csemag.com/single-article/led-specifications/517310ca50064c25c4d247d86f23cf3a.html

www.bridgelux.com/

Background

- An LED system has many components.
  - Light Emitting Diode (LED), Printed Circuit Board (PCB), driver, optics, heat sink, etc.
  - Failure: catastrophic or parametric

- Lighting systems are usually turned on and off in applications.

- The drawbacks of current life test method:
  - Tests only one component (LED)
  - Continuous-on testing for 6000 hours
  - Considers only one failure type (Parametric)

Background

- Testing LED systems:
  - IESNA LM-84-14
  - An improvement over LM-80
    - Tests the whole system
- However, the drawbacks are:
  - Continuous-on testing
  - Considers only parametric failure
    - lumen depreciation
- Manufacturers are still using the LM-80/TM-21 method to rate LED system (product) life.

https://www.ies.org/store/measurement-testing/measuring-luminous-flux-and-color-maintenance-of-led-lamps-light-engines-and-luminaires/

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Study objective

- To develop a test method to estimate LED system life based on
  - environment temperature (resulting Tj)
  - use pattern (On-Off cycling)

  and

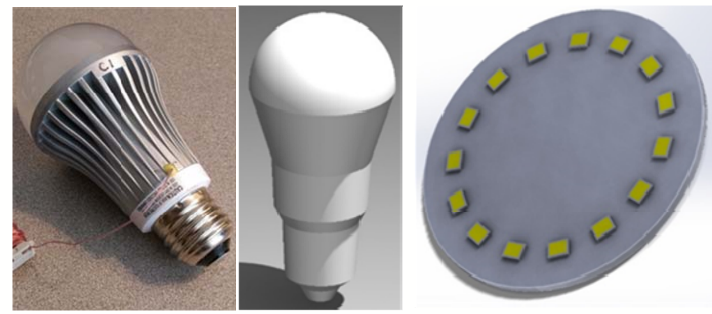
  - for lifetime values consider both catastrophic and parametric failure times

Credit: Lighting Research Center

http://www.electrical-online.com/lightsandswitches/

Test method – Initial test

- To identify LED Tj in application
  - LED A-lamps, 75W incandescent equivalent, in a 3-lamp surface mount fixture
    - Tj of LEDs = 146°C (max. operating temperature)
    - Troom = 30°C
  - When switched on and off
    - DT = 116°C

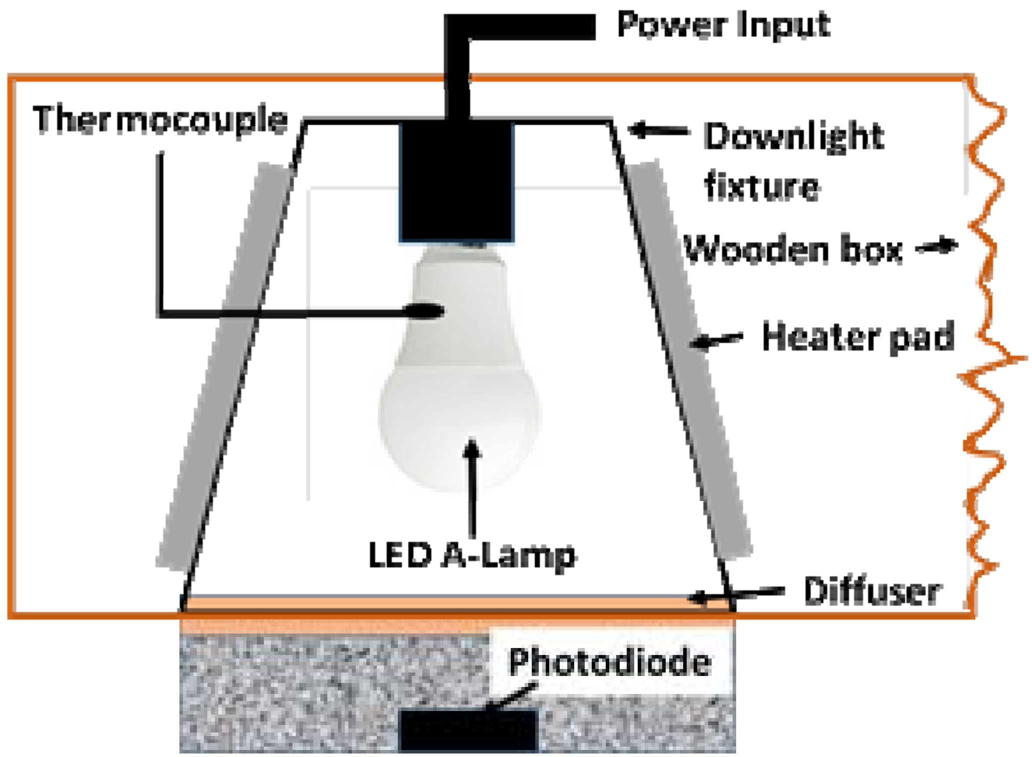


Credit: Lighting Research Center

https://www.homedepot.com/b/Lighting-Flushmount-Lights/N-5yc1vZc7nk

Experiment setup

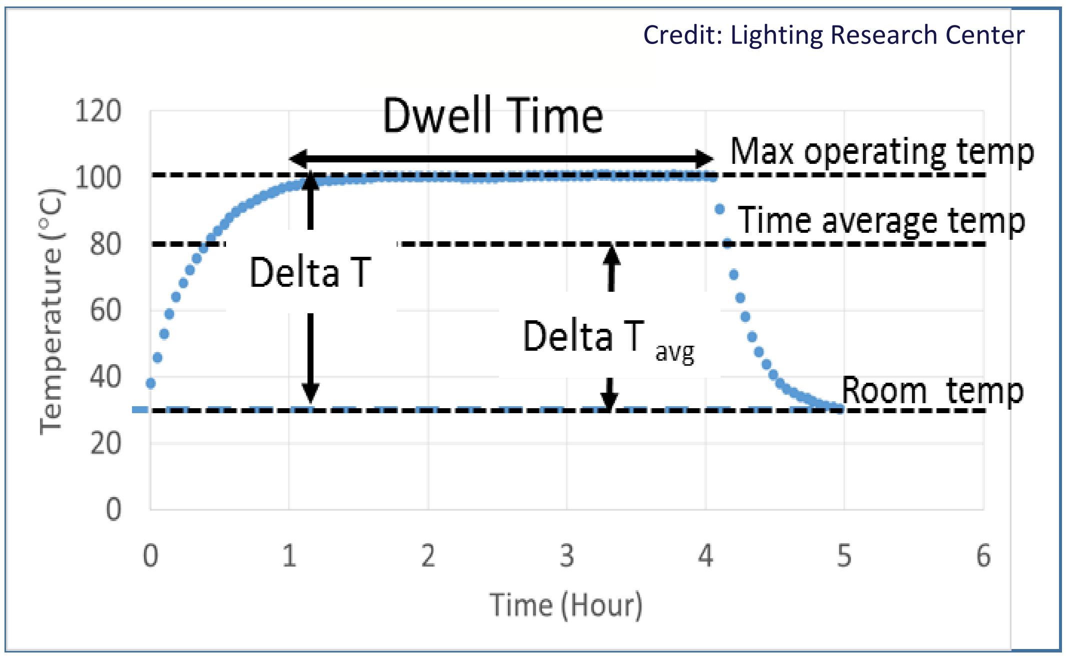
- Type of product tested
  - LED A-lamps (15 W: 75W incandescent equivalent)
  - 90 samples



Credit: Lighting Research Center

Experiment setup

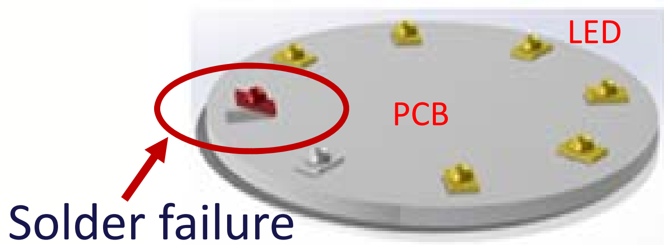
- Independent variables
  - Delta Temperature (DT) [D80/D90/D100 °C]
  - Dwell Time [2-hrs/4-hrs/Cont.-on]
- Dependent variables
  - Light output & Color; Power and current Input
  - Lamp temperature



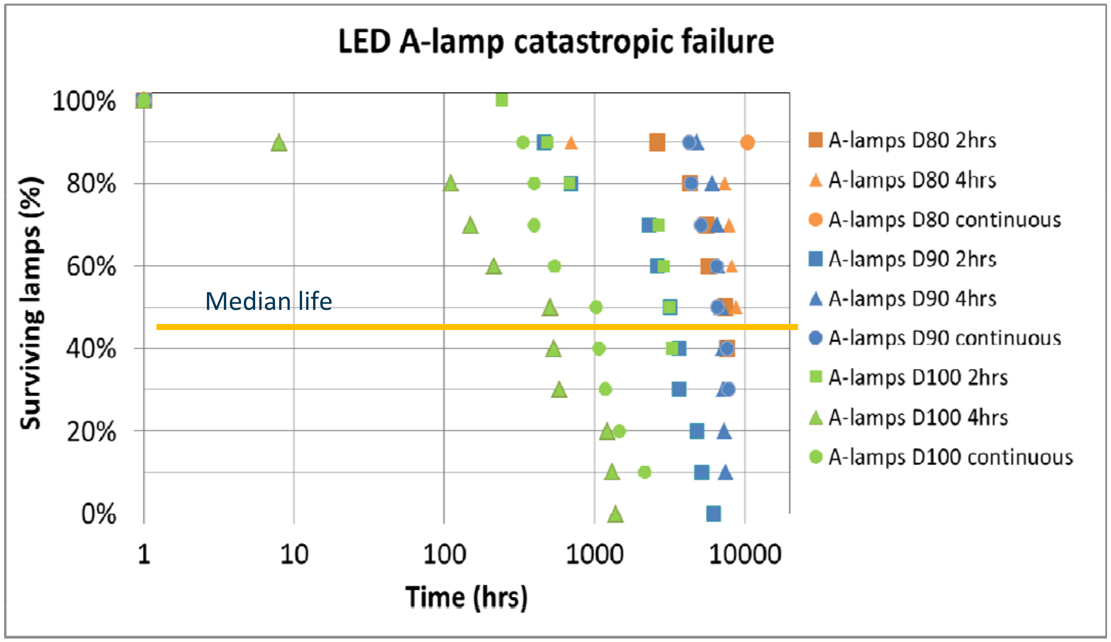
Results

- Tested LED A-lamps experienced both types of failures
  - Catastrophic and Parametric

Observed failure modes
PCB solder failure = 84%
Driver failure = 16%



Credit: Lighting Research Center



Reference: Narendran, N., Y. Liu, X. Mou, D.R. Thotagamuwa, and O.V. Madihe Eshwarage. 2016. Projecting LED product life based on application. Proceedings of SPIE 9954, Fifteenth International Conference on Solid State Lighting and LED-based Illumination Systems, 99540G (September 14, 2016).

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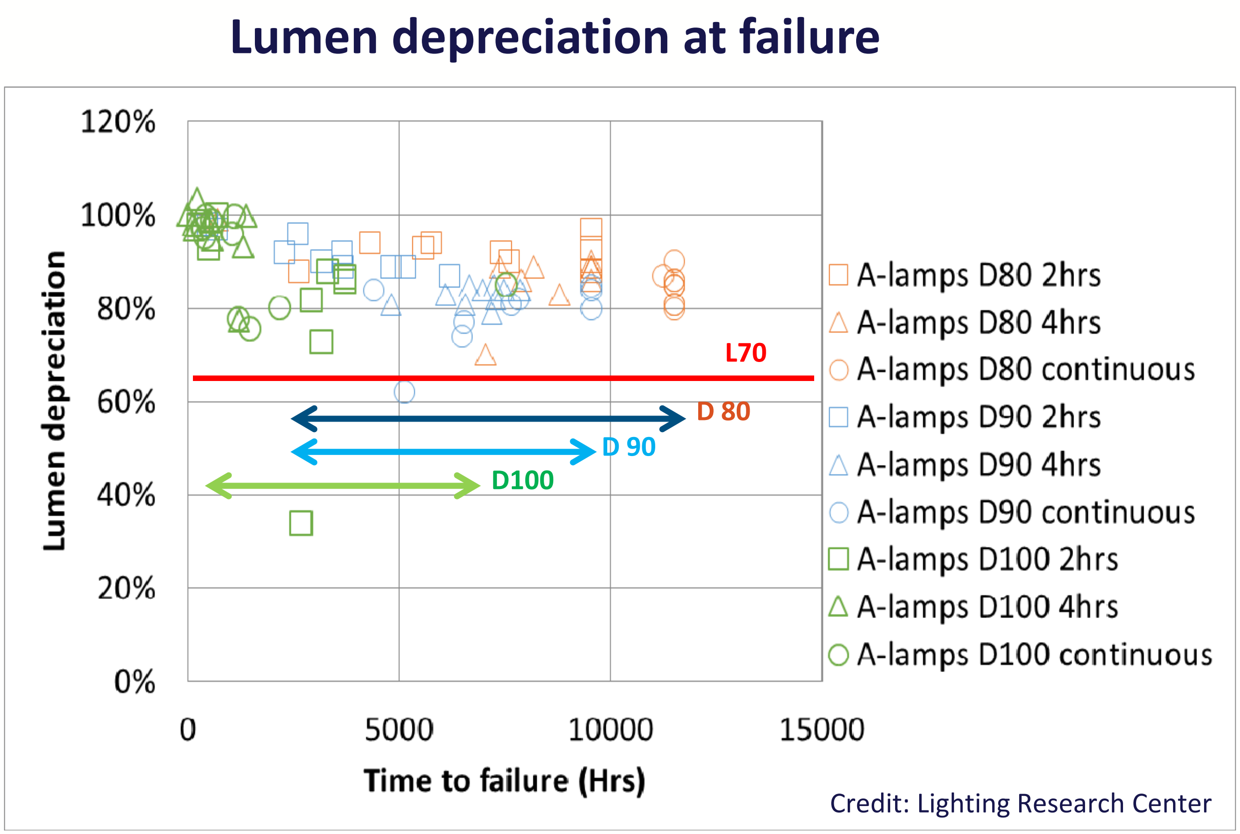
Data: LED A-lamp lumen depreciation

- In this experiment, majority of the LED A-lamps failed catastrophically before the lumen depreciation reached the 70% value



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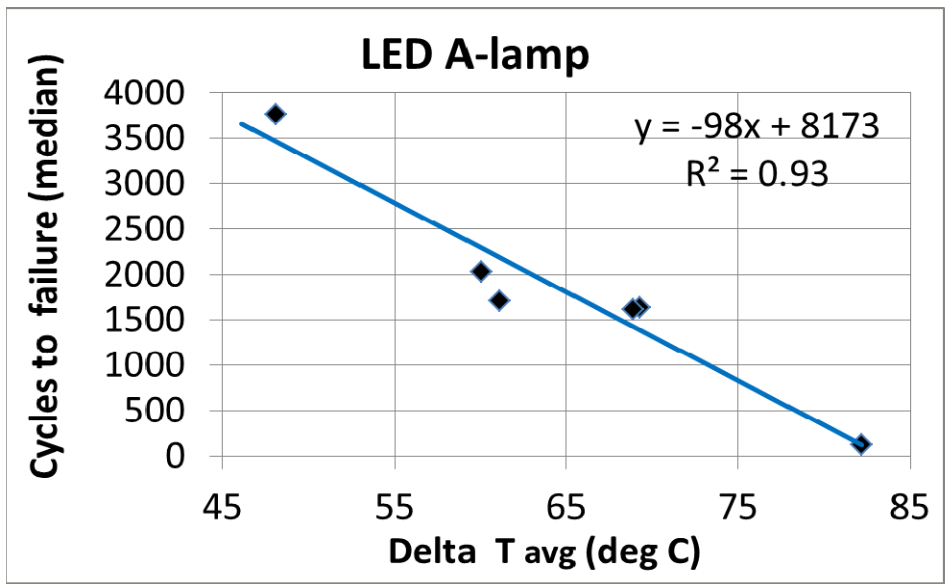
Results

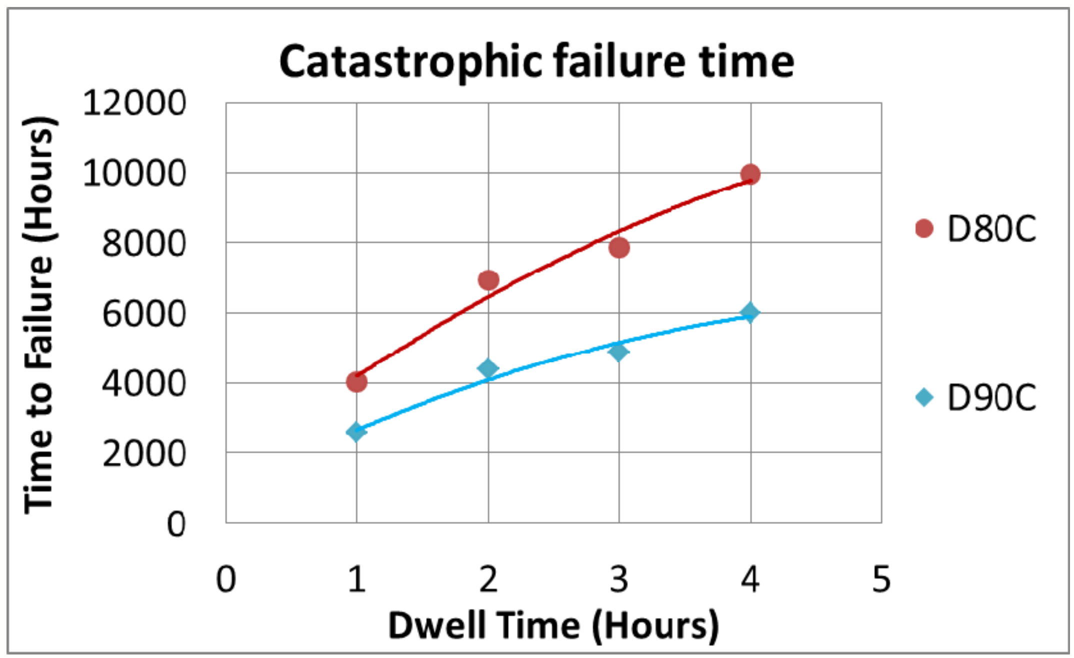
- Catastrophic failures
  - Frequent switching shortened LED lamp life
  - Higher Delta T shortened life
  - Cycles to failure (median life) and delta time-averaged temperature have an inverse linear relationship



Reference: Narendran, N., Y. Liu, X. Mou, D.R. Thotagamuwa, and O.V. Madihe Eshwarage. 2016. Projecting LED product life based on application. Proceedings of SPIE 9954, Fifteenth International Conference on Solid State Lighting and LED-based Illumination Systems, 99540G (September 14, 2016).

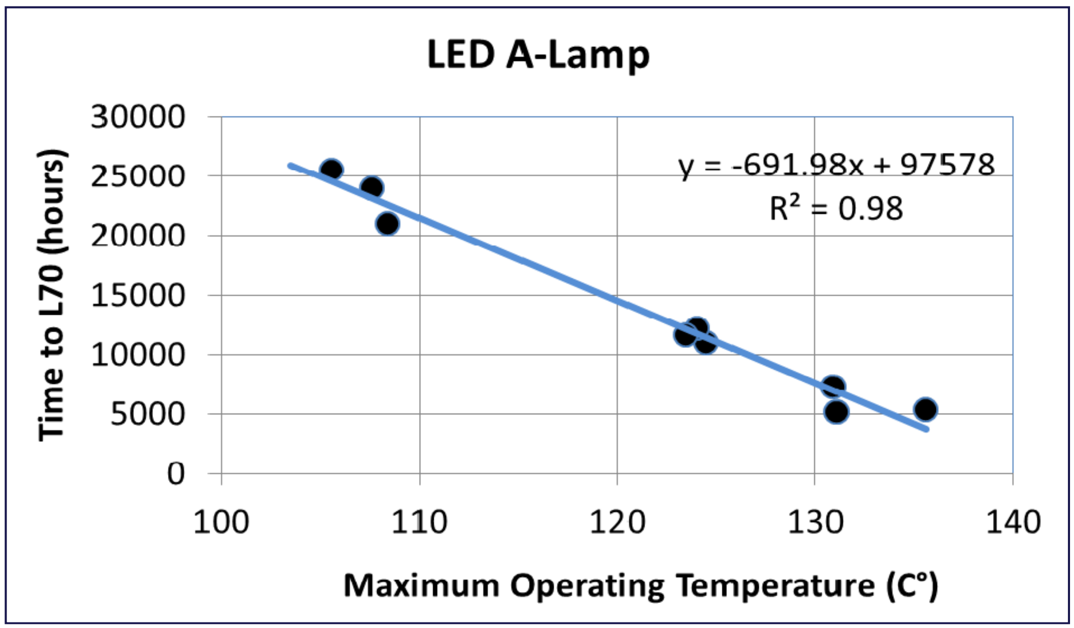
Results

- Catastrophic failures
  - – Frequent switching shortens lamp life
  - – Time to catastrophic failure depends on
    - Delta T
    - Dwell time



Results

- Parametric failures
  - Lumen depreciation:
    - L70, time to failure (median life), and maximum operating temperature have an inverse linear relationship



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Predicting lifetime in applications

- To illustrate the usefulness of the method, two sample applications where the same lamp can be used were selected to estimate lamp life.

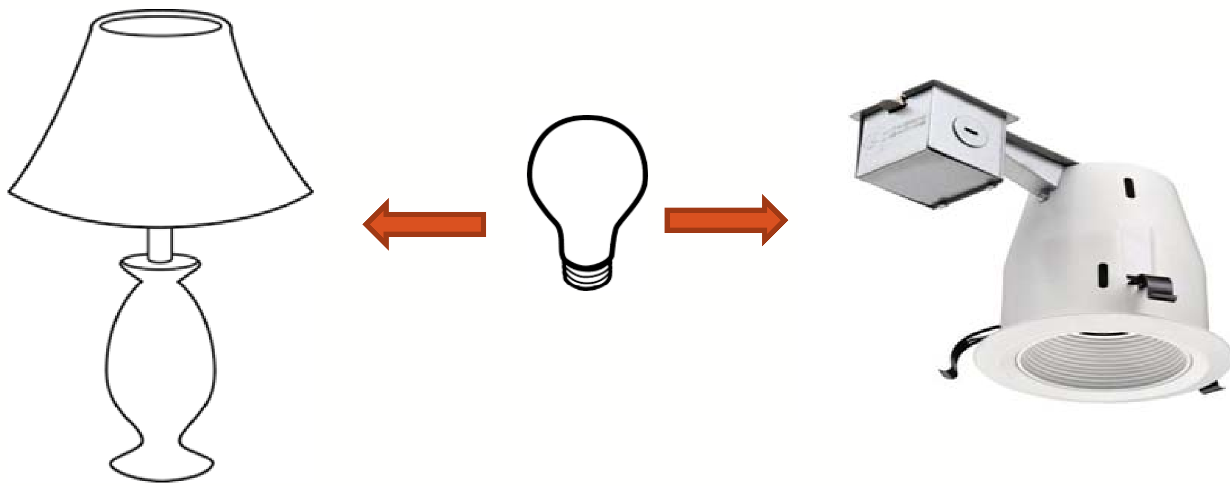


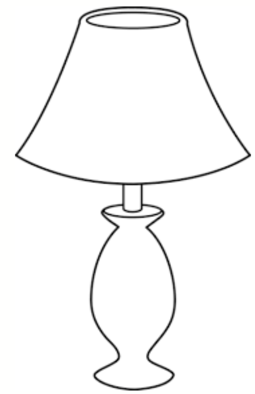
Table lamp

Recessed downlight

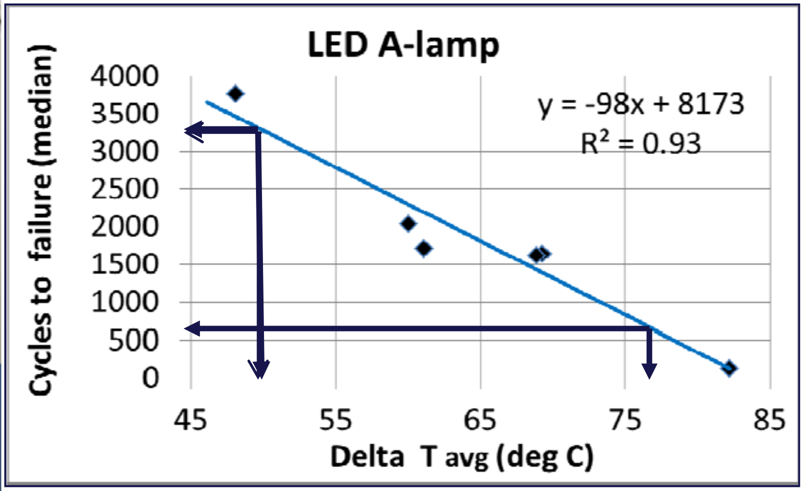
LED A-lamp life estimation in applications

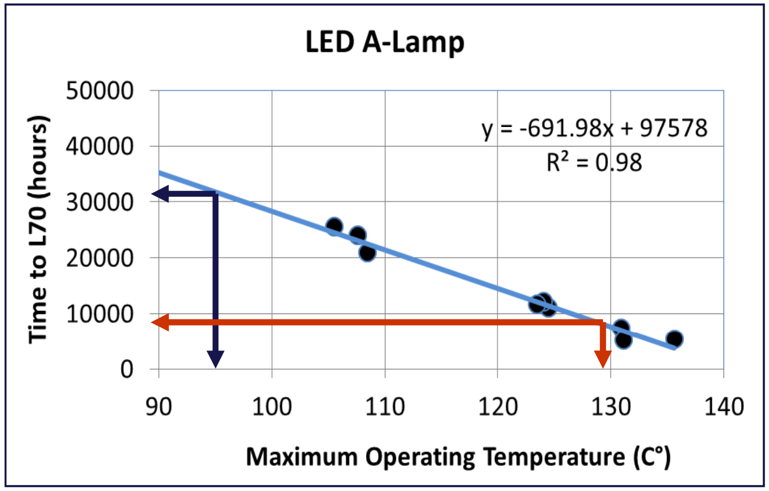
Example 1: LED Table lamp

- Used 3 hours per day, 1 cycle
  - Maximum Tj = 95°C
  - Delta T avg = 50°C
- Estimated median lamp life
  - Catastrophic:
    - 3250 cycles = 8.9 yrs
  - Parametric
    - L70: 32,000 hrs = 29 yrs



Lamp life = 8.9 years
= 9746 hrs





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LED A-lamp life estimation in applications

Example 2: Downlight

- Used 2 hours per day, 1 cycle
  - Maximum Tj = 129°C
  - Delta T avg = 77°C

Estimated median lamp life

Catastrophic:

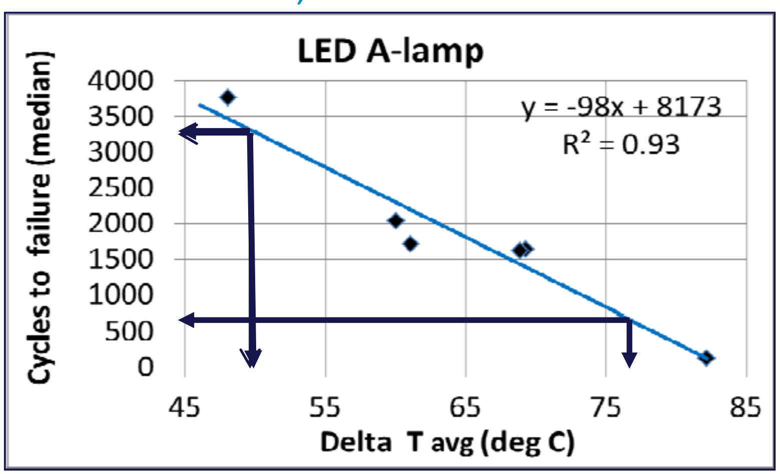
700 cycles = 1.9 yrs

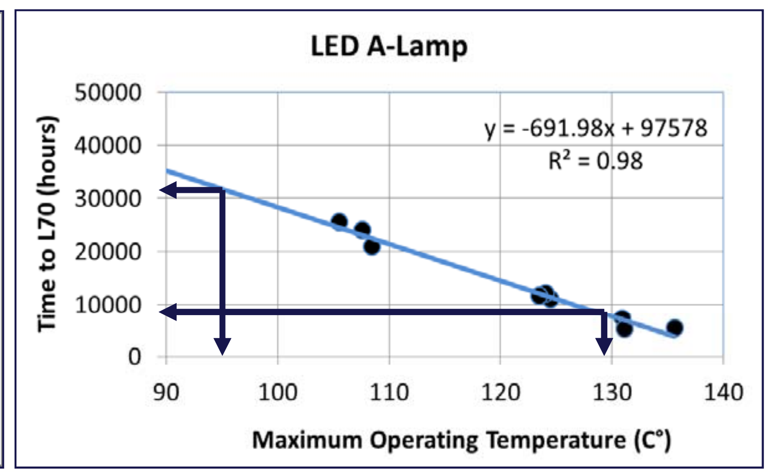
Parametric

L70: 9,000 hrs = 12.3 yrs

– L70: 32,000 hrs

Lamp life = 1.9 years
= 1387 hrs





Lessons learned

- Contrary to common belief
  - Switching LED systems ON and OFF can shorten lamp life

- Current industry practice for testing LED lighting products and rating lifetime needs revision
  - LED product life-testing method:
    - Whole system must be tested
    - On-Off switching must be included
    - Catastrophic and parametric failures must be considered
      - Time to failure is the shorter of the two

Short Duration Low Cost Test Procedure

- Objectives:
  - To develop and verify a low cost life-test setup to test LED A-lamps
  - To determine the time required to complete the test

Narendran, N., Y. Liu, X. Mou, and D.R. Thotagamuwa. 2017. Predicting LED system life: A long-term study of the factors that determine performance and failure. *Proceedings of the IES 2017 Annual Conference*, August 10-12, Portland, Oregon.

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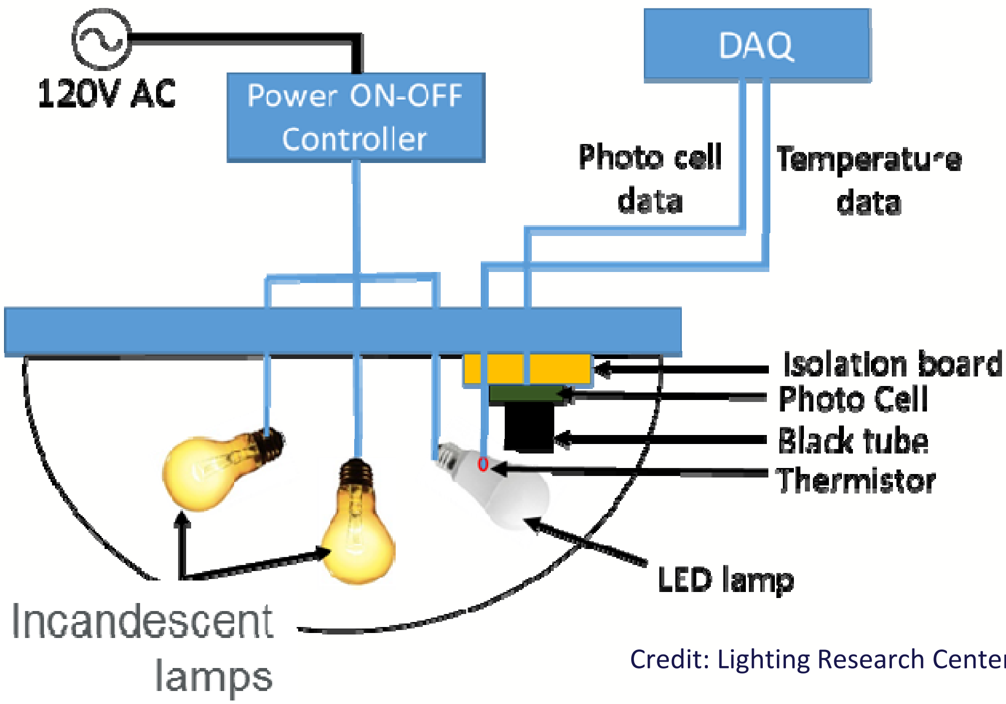
Low cost life-test setup

- LED test lamp inside a 3-lamp surface mount fixture with 2 incandescent A-lamps



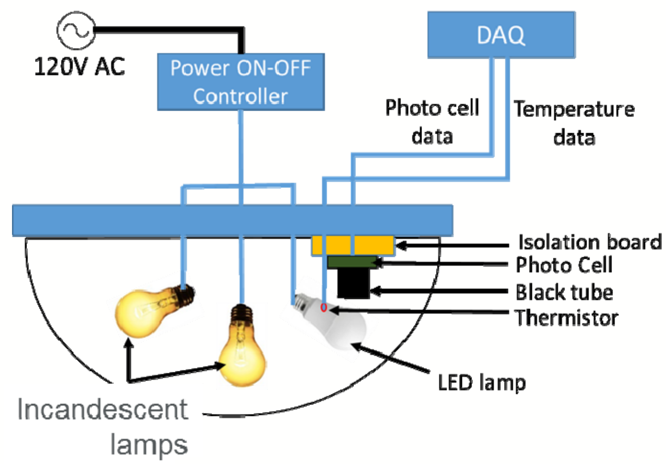
Credit: Lighting Research Center

Test rack

Credit: Lighting Research Center

Low cost life-test setup

- Delta T: Achieved by using 2 incandescent lamps
  - 25W/40W/60W
- Dwell time: Achieved using a power ON-OFF controller
  - 3 hours on/1 hour off



Credit: Lighting Research Center

- $T_{body:}$ measured by a thermistor attached to the lamp
- Light output: measured using a photo cell with a black tube aimed at the LED lamp

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Initial test

- Estimated LED Tj values and delta T values

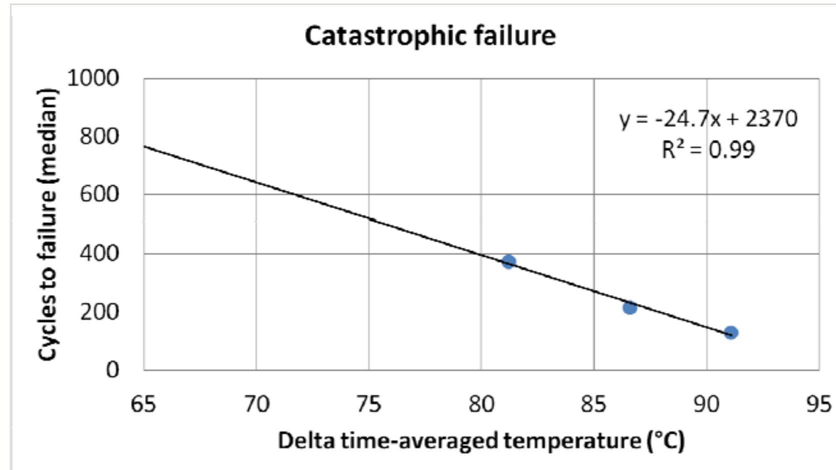
Heater lamps	2*25W	2*40W	2*60W
On-Off Cycle	3 hr/1 hr	3 hr/1 hr	3 hr/1 hr
T ref max	100 C	110 C	116 C
Tj max operating	125 C	135 C	141 C
T ref min	26 C	30 C	30 C
Delta TAT	81 C	87 C	91 C
Delta T	99 C	105 C	111C

Total ON time = 3 hrs

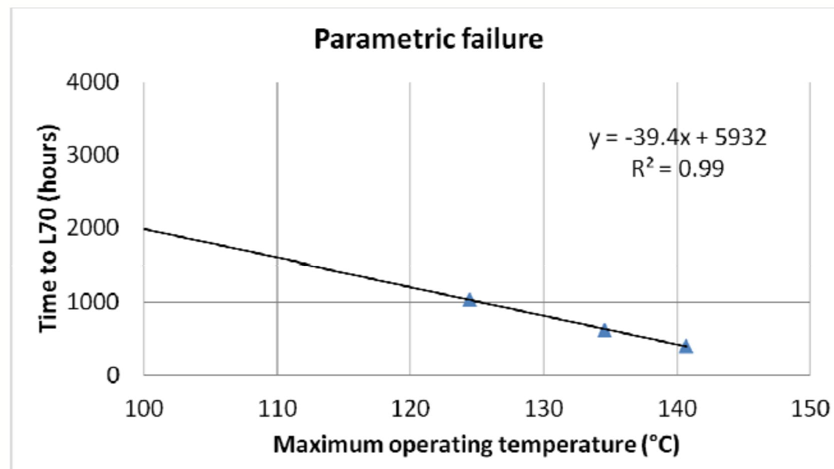
- Dwell time = 2.2 hrs
- Warm up time = 0.8 hrs
- Cool down time = 1 hr

Results

- Times to catastrophic and parametric (L70) failures showed results similar to the previous studies



- Total test time less than 1500 hours



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Results

- The low cost life-test setup results are similar to the results from the more elaborate test setup.
  - Both failure types, catastrophic and parametric, were observed.
    - Cycles to failure (median life) and delta time-averaged temperature have an inverse linear relationship with goodness-of-fit, R2 = 0.99.
    - L70, time to failure (median life), and maximum operating temperature have an inverse linear relationship with goodness-of-fit, R2 = 0.99.
- Time to complete the tests was within 1500 hrs.

Summary

- In applications, LED systems will encounter:
  - Both failure types catastrophic and parametric
  - Switching LED systems ON-OFF can shorten life
- Current industry practice needs revision.
    - Whole system must be tested including On-Off switching
    - Catastrophic and parametric failures must be considered
      - Time to failure is shorter of the two times
- A low cost test setup can be created.
  - Using surface mount fixtures
  - Testing time less than 1500 hours
- LED lamp life can be predicted in any application by knowing the Tj and use pattern.

Acknowledgments

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  - Jennifer Taylor

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This project was supported by the above-mentioned organizations and such support does not constitute an endorsement by these organizations of the views expressed herein.

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A Large-Scale LED Lamp Life Test

CHICAGO, IL USA
McCormick Place
May 6 – 10, 2018

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Erik Page and Associates
Energy Efficient Lighting Consultants

1. Background
2. Experimental Design
3. Results - Photometrics
4. Results – Life Testing
5. Results – Post Mortem Analysis
6. Conclusions

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Lighting Opinions Per Bulb

Brightness	**VERY!**
Yearly Energy Cost	**NOT MUCH!**
Life	**A LONG TIME!**

Light Appearance

Warm-ish — Way Cool

2700 K

Energy Used	**NOT MUCH!**

CPUC LED Lab Test

Background

- California Public Utilities Commission (CPUC) supported a large, multiyear lab test of LED lamps:
  - California utilities spend big $$$ on LED programs
  - Large unknowns about LED performance – particularly life
  - Stakeholders urged a focus on thermal factors

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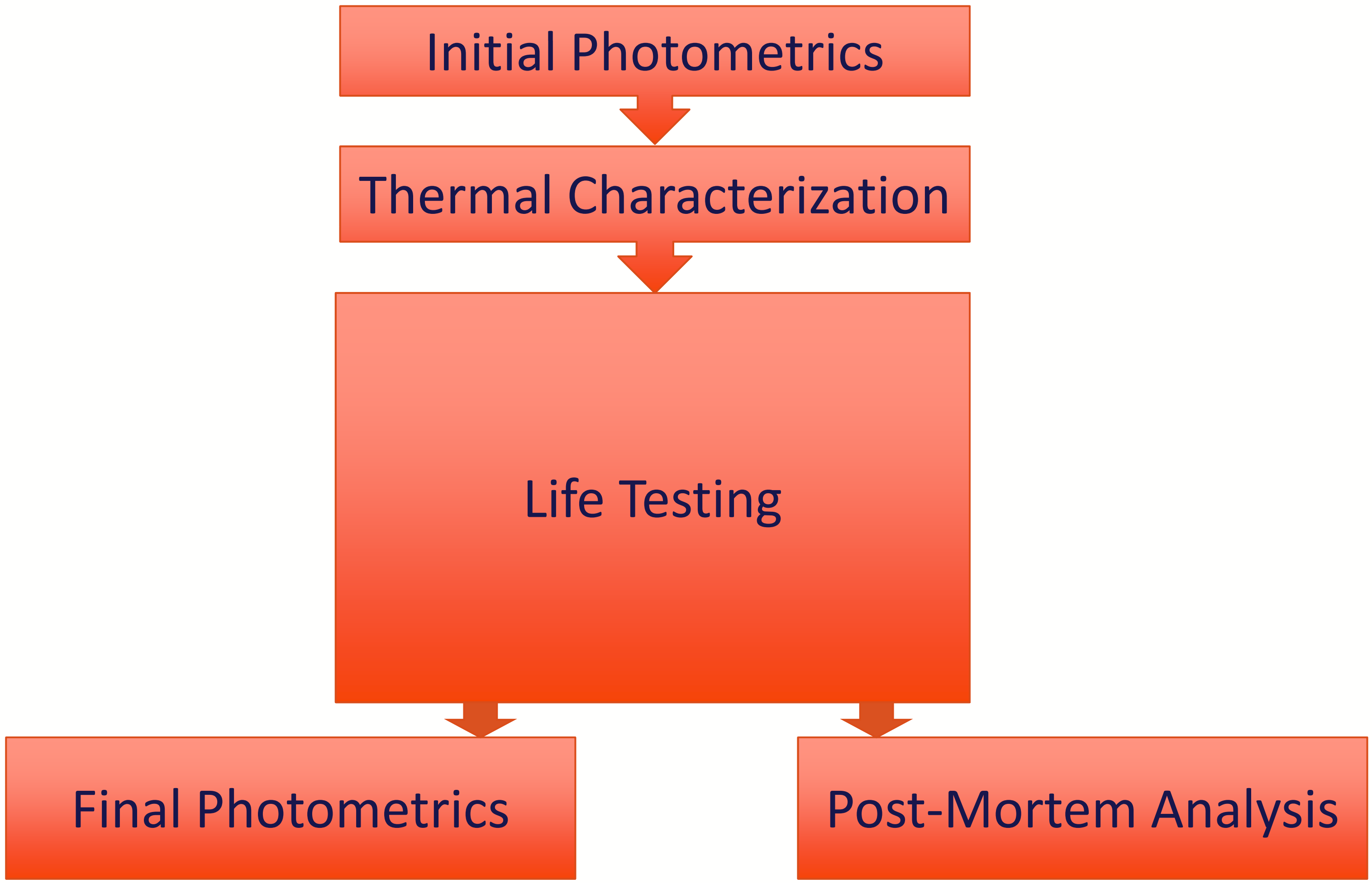
Experimental Design

Experiment Overview



Experimental Design

Test Sample

Type	Models	Samples
A-Lamp	38	342
Globe, Torpedo, Bullet	23	99
Reflector	31	186
Trim-kit	13	39
Total	**105**	**666**

- Representative of CA market based on prior shelf surveys
- “Off the shelf” procurement

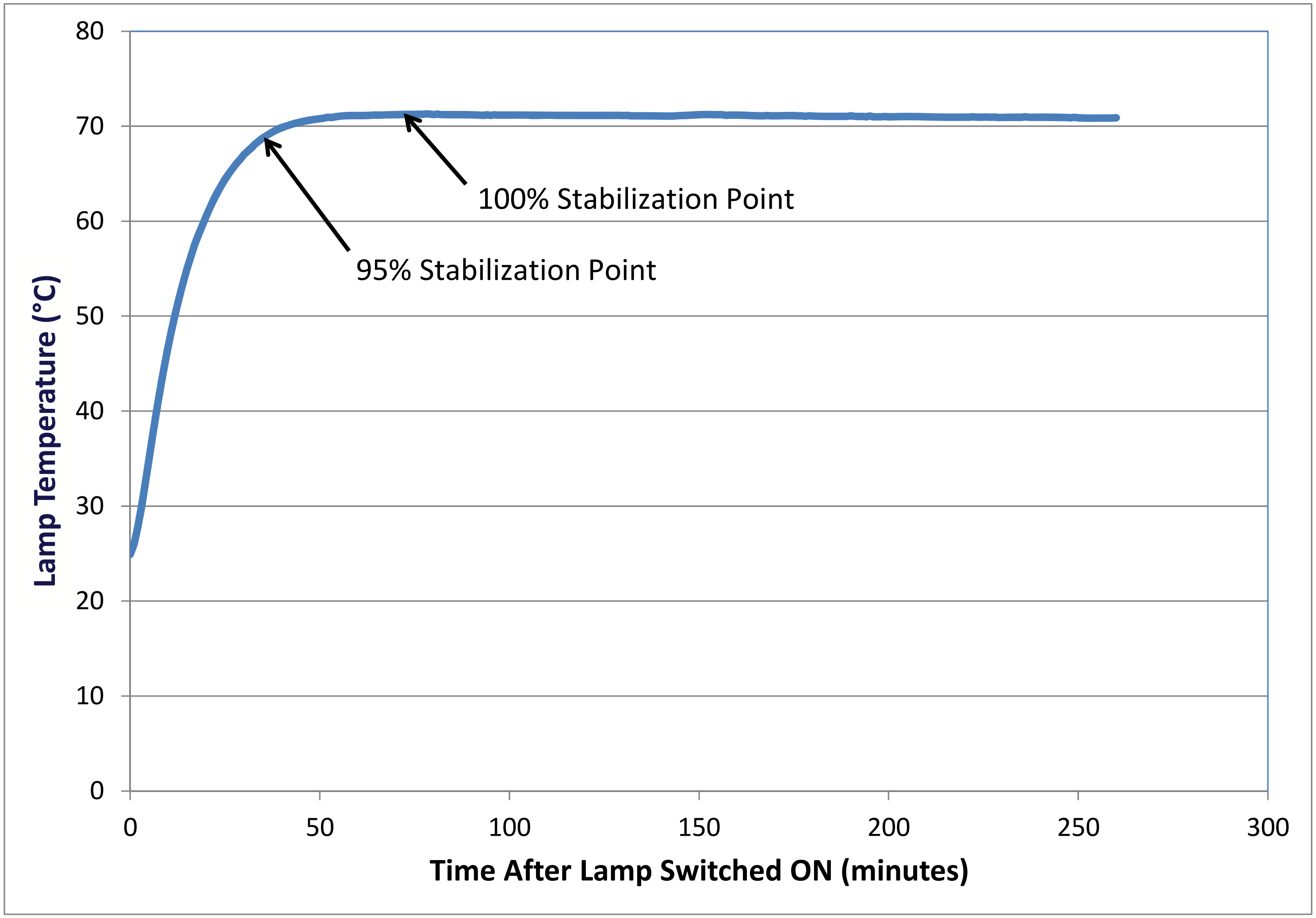
Experimental Design

Test Fixtures

Fixture	Lamps
Recessed Downlights	• 114 A-Lamps • 93 Reflectors • 39 Trim Kits *Subtotal = 246*
Enclosed Ceiling Fixtures	• 114 A-Lamps • 30 Globe, Torpedo, Bullet *Subtotal = 144*
Bare Sockets	•114 A-Lamps • 69 Globe, Torpedo, Bullet • 93 Reflectors *Subtotal = 276*

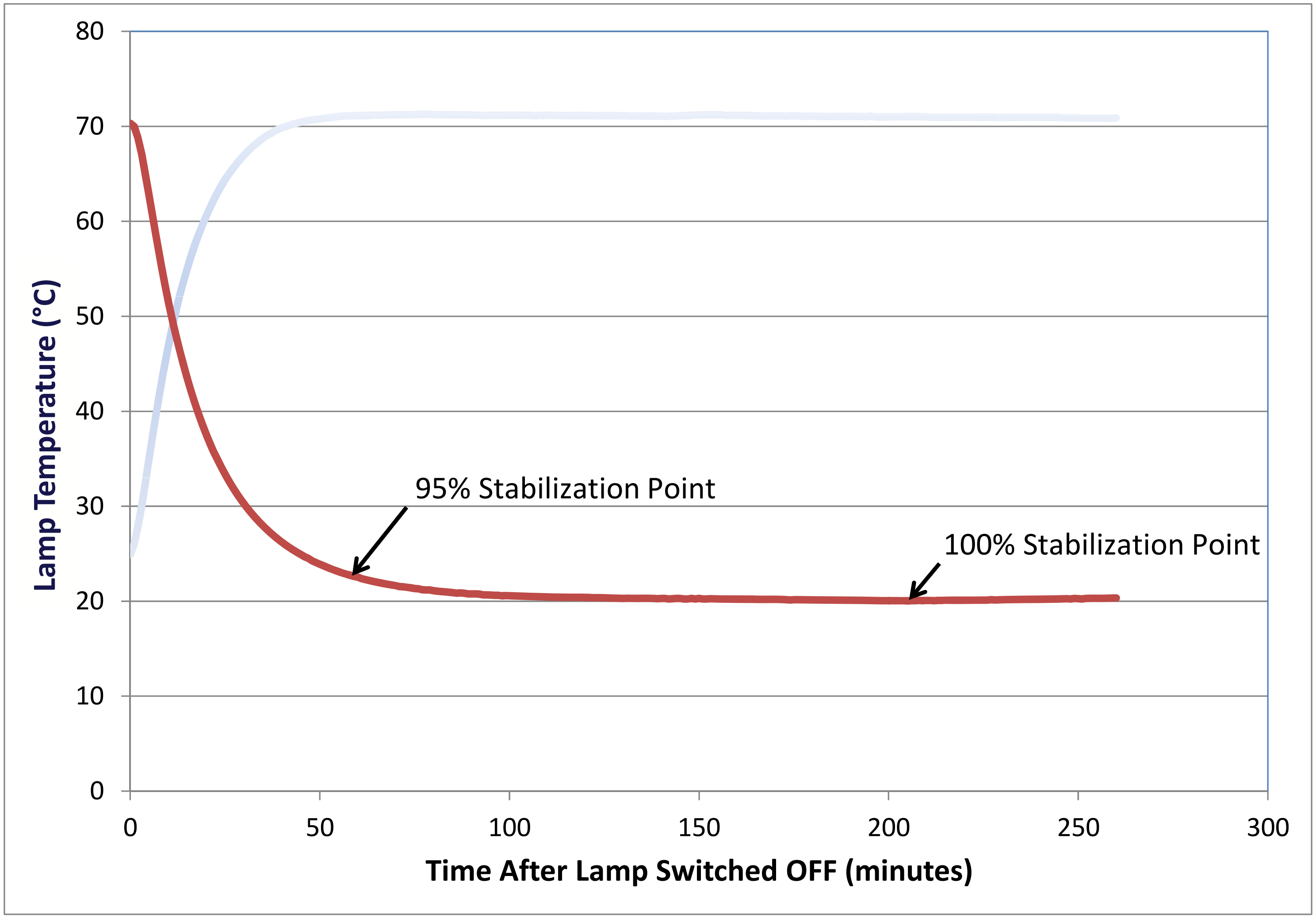
Experimental Design

Thermal Testing



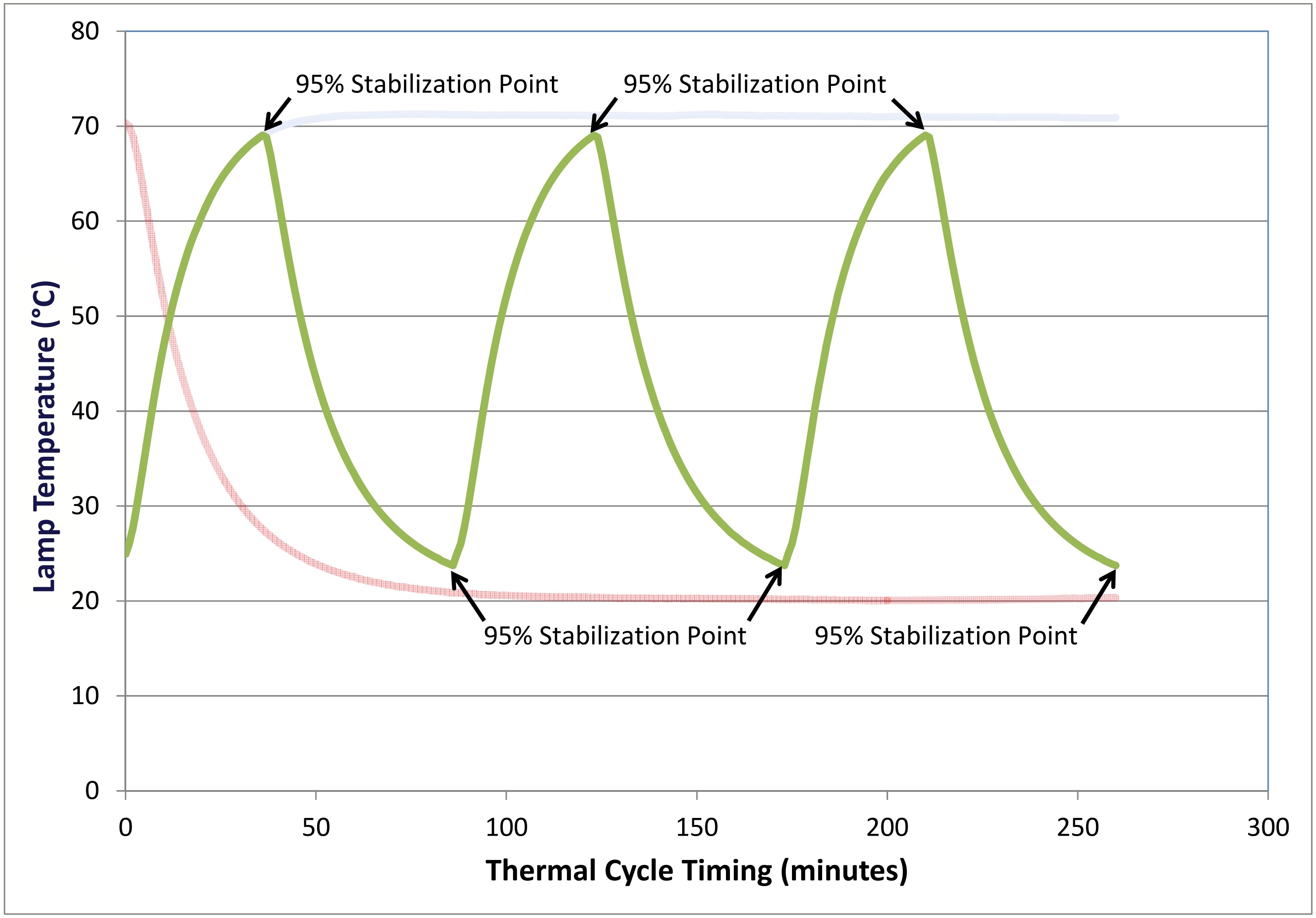
Experimental Design

Thermal Testing



Experimental Design

Thermal Testing



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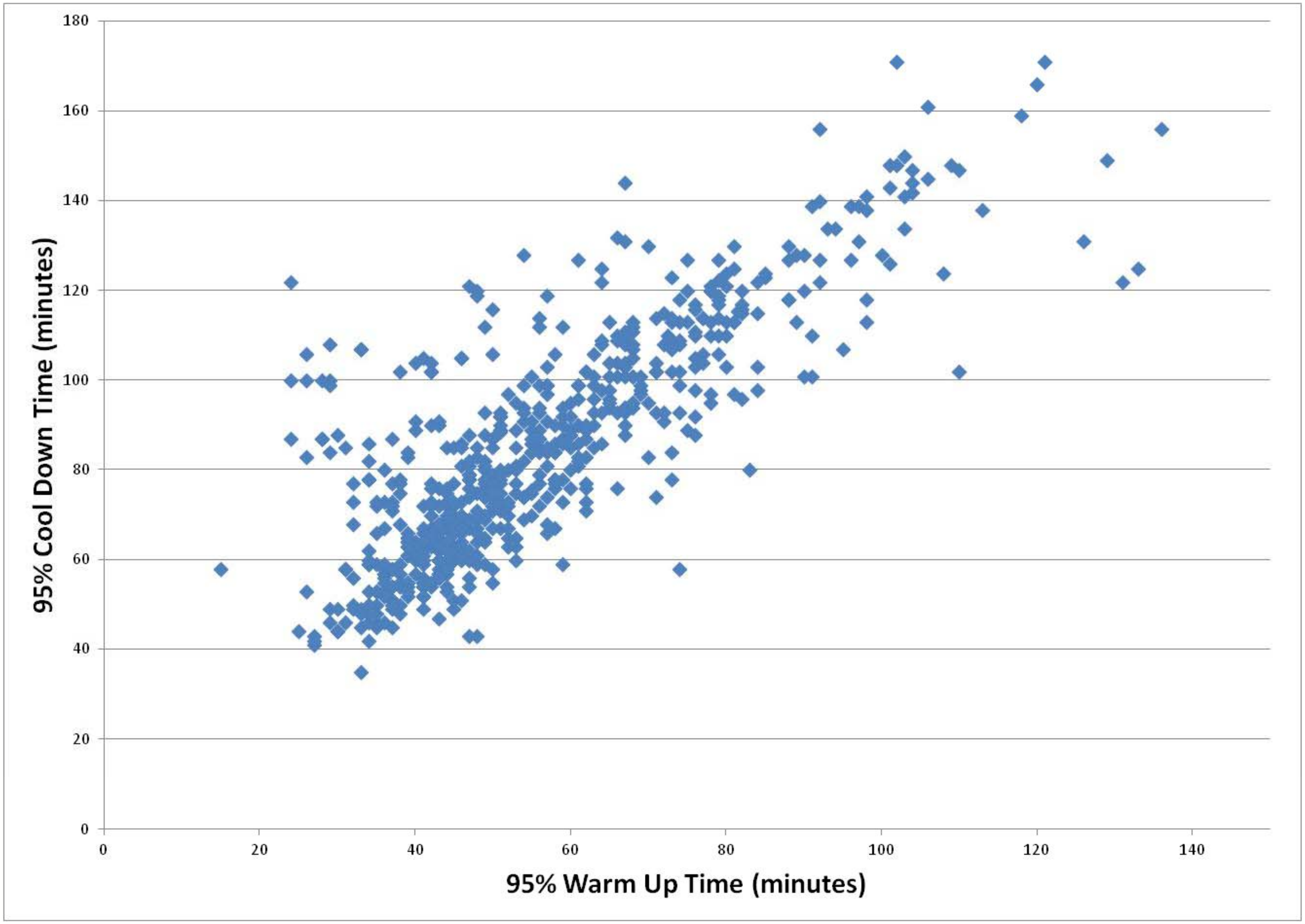
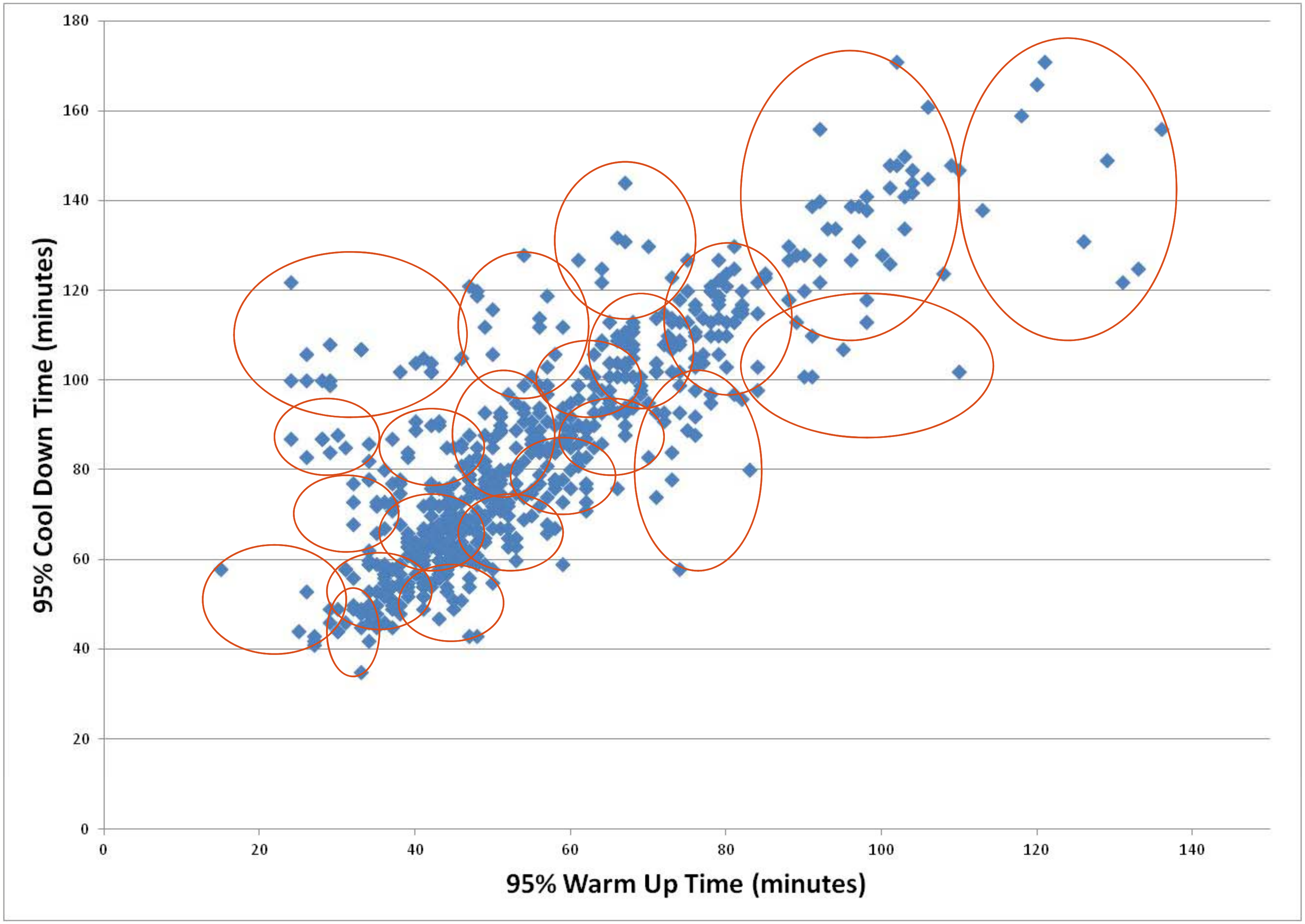
Experimental Design

Thermal Test Results => Life Testing Inputs



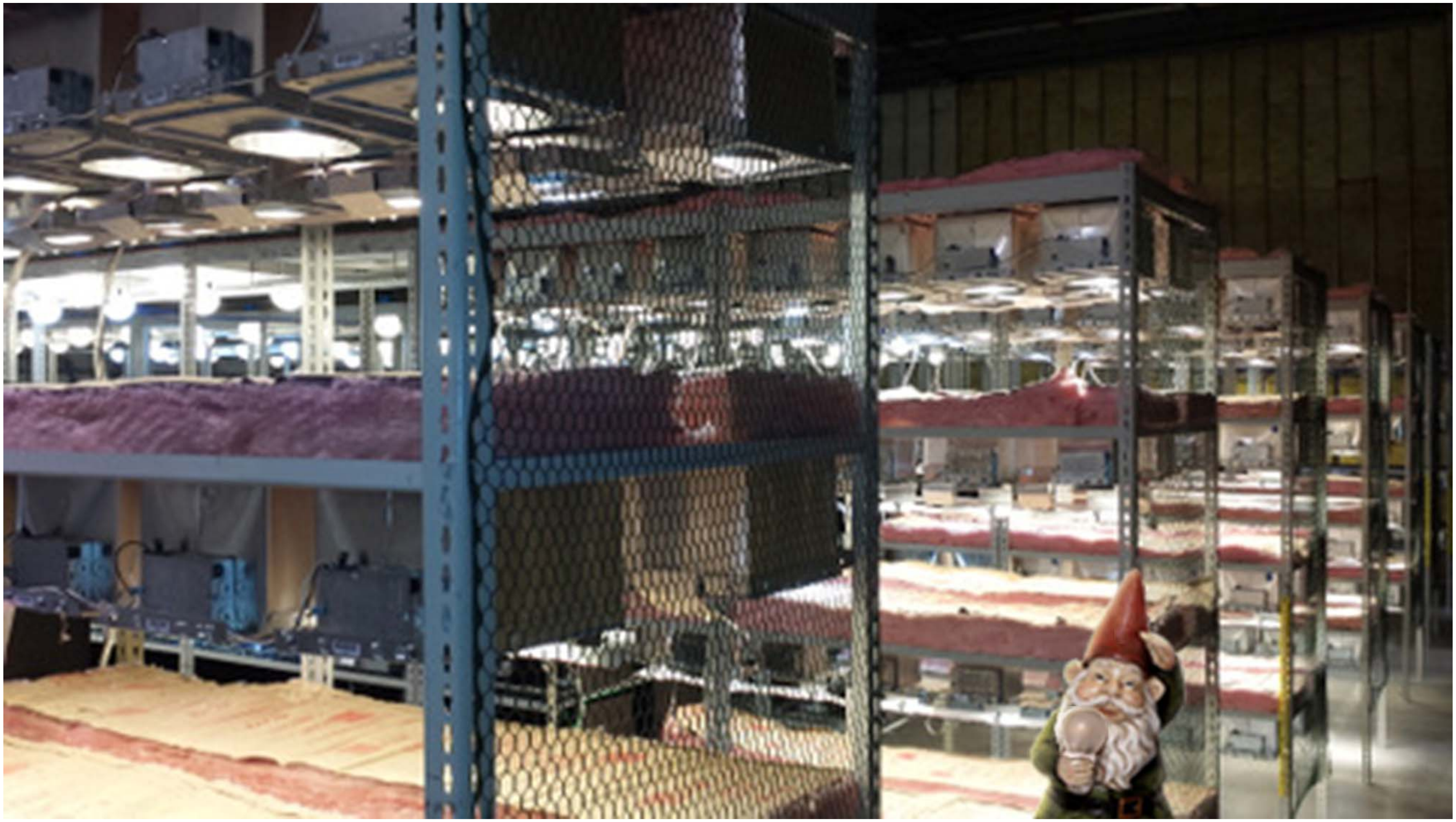
Experimental Design

Thermal Test Results => Life Testing Inputs



Experimental Design

Recessed Downlight Test Racks



Experimental Design

Enclosed Ceiling Fixture and Bare Socket Test Racks

1. Background

2. Experimental Design

3. Results - Photometrics

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5. Results – Post Mortem Analysis

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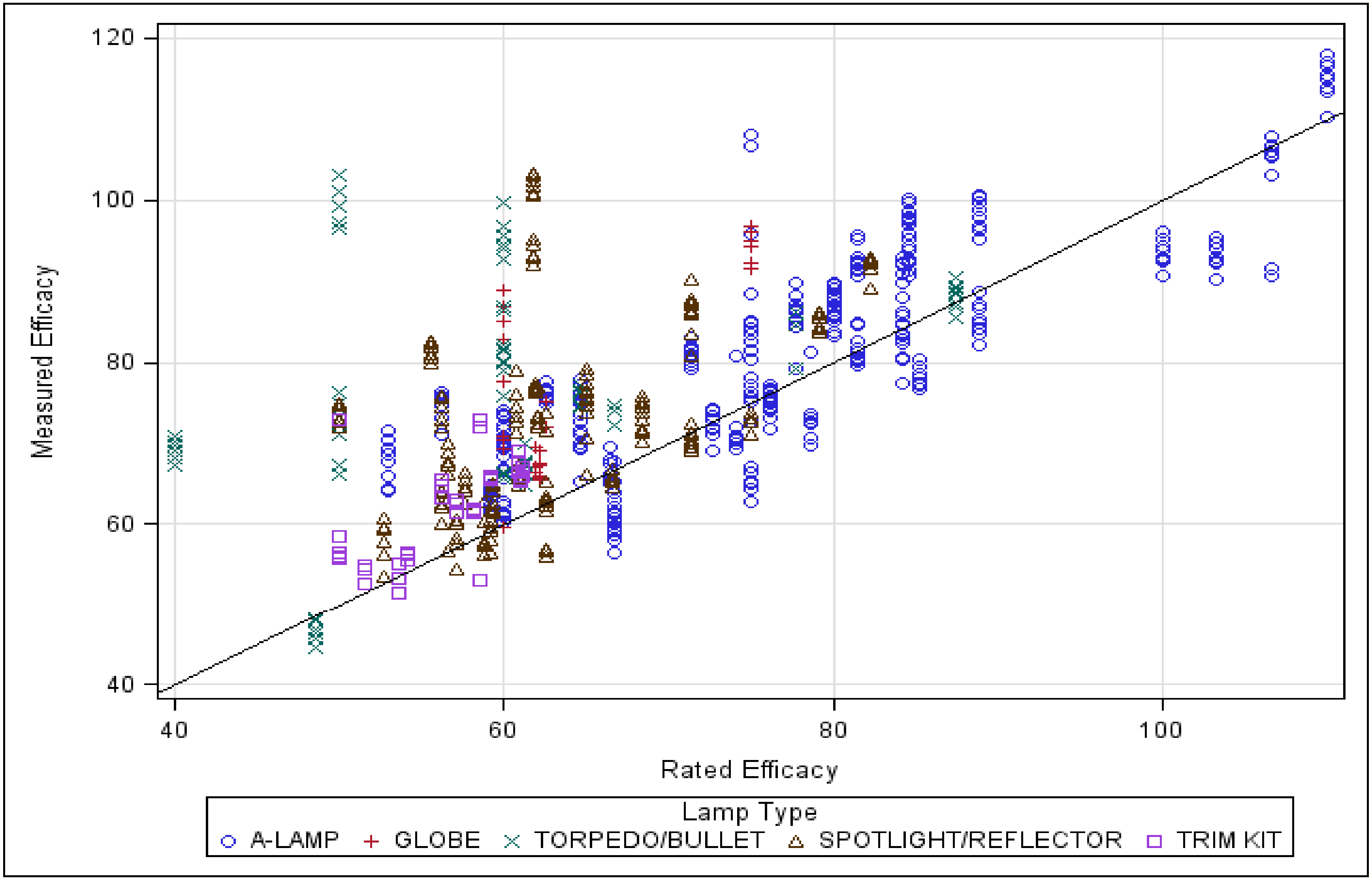
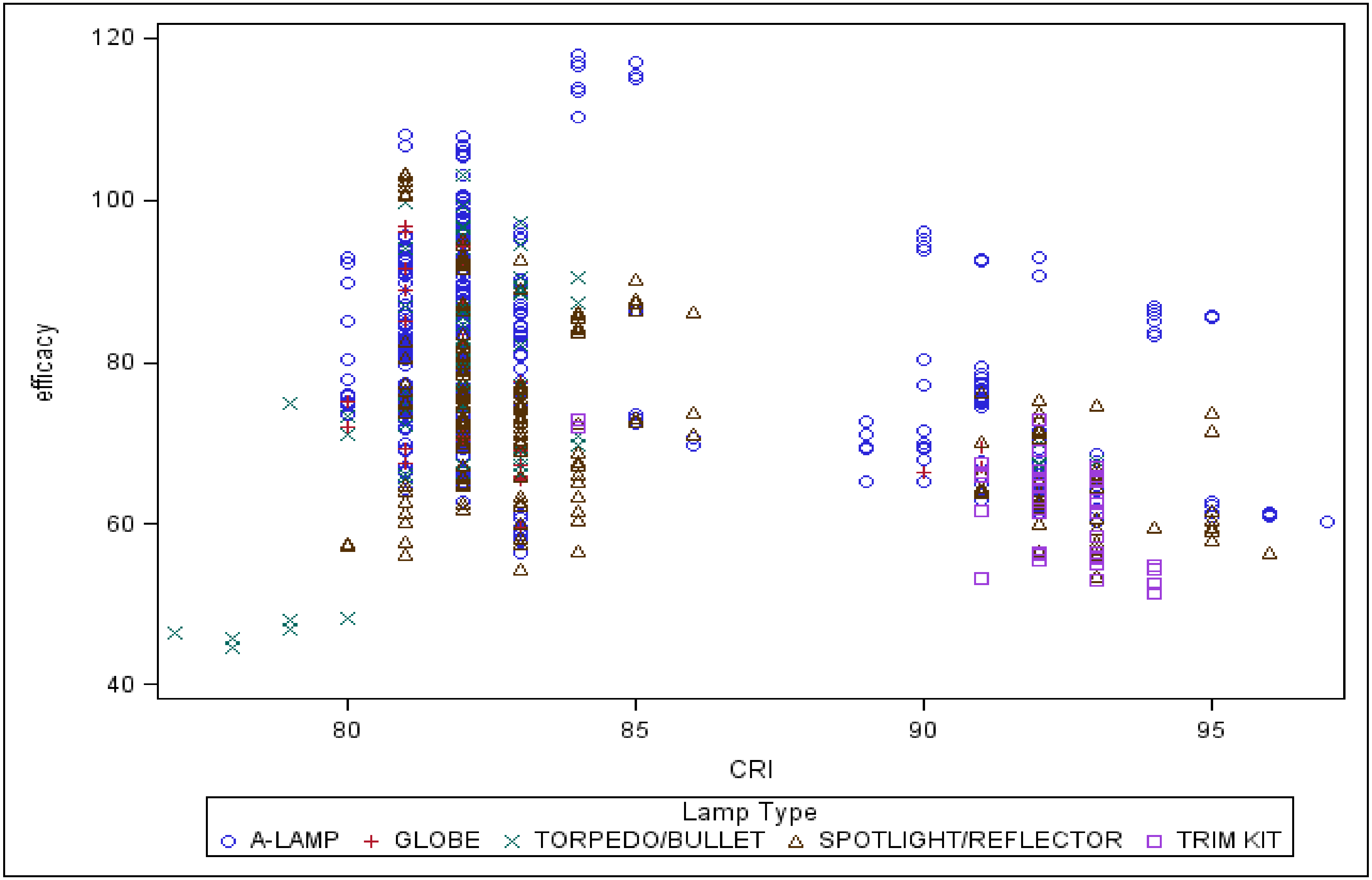
Experimental Results

Photometrics



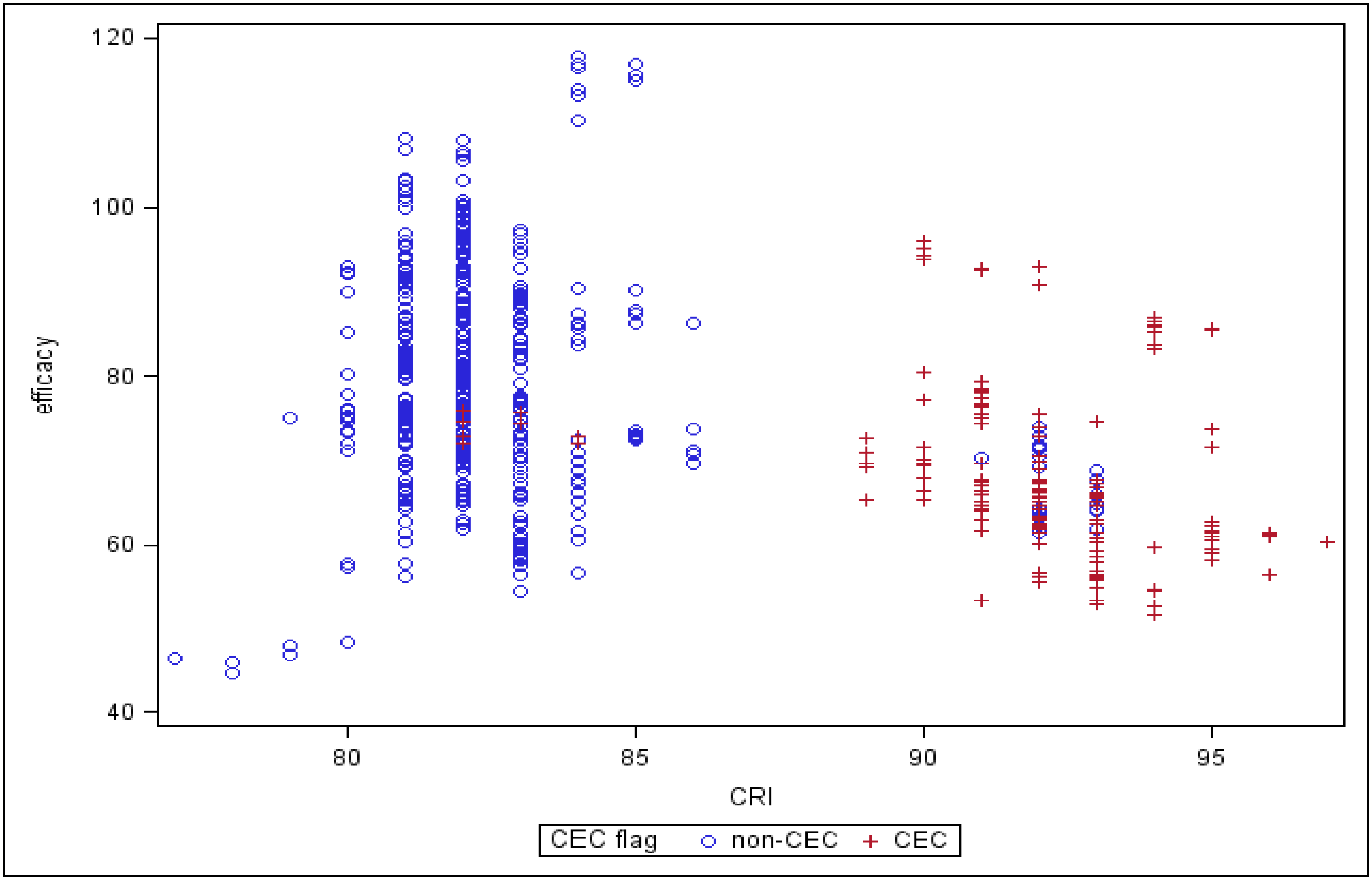
Experimental Results

Photometrics



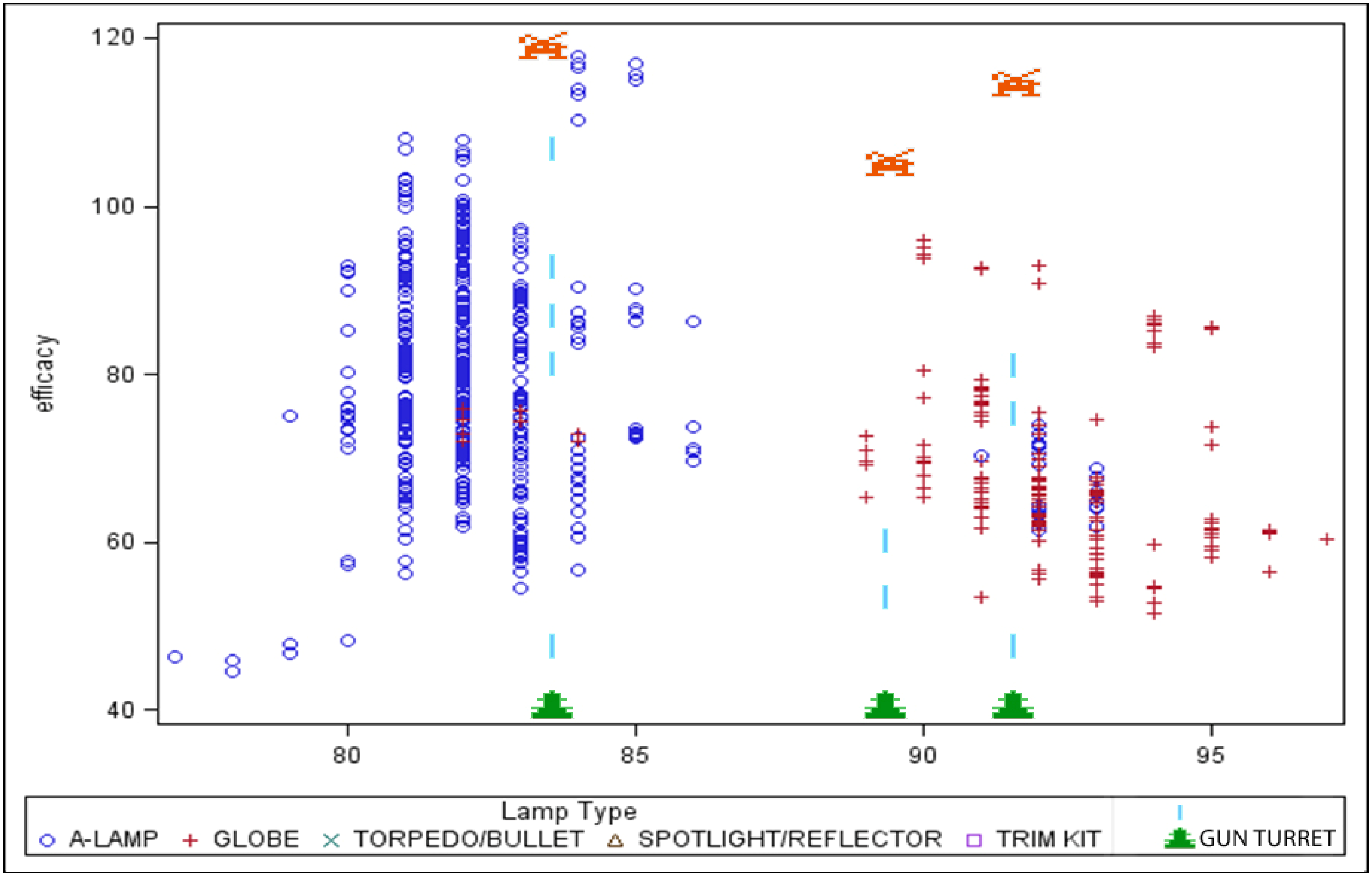
Experimental Results

Photometrics



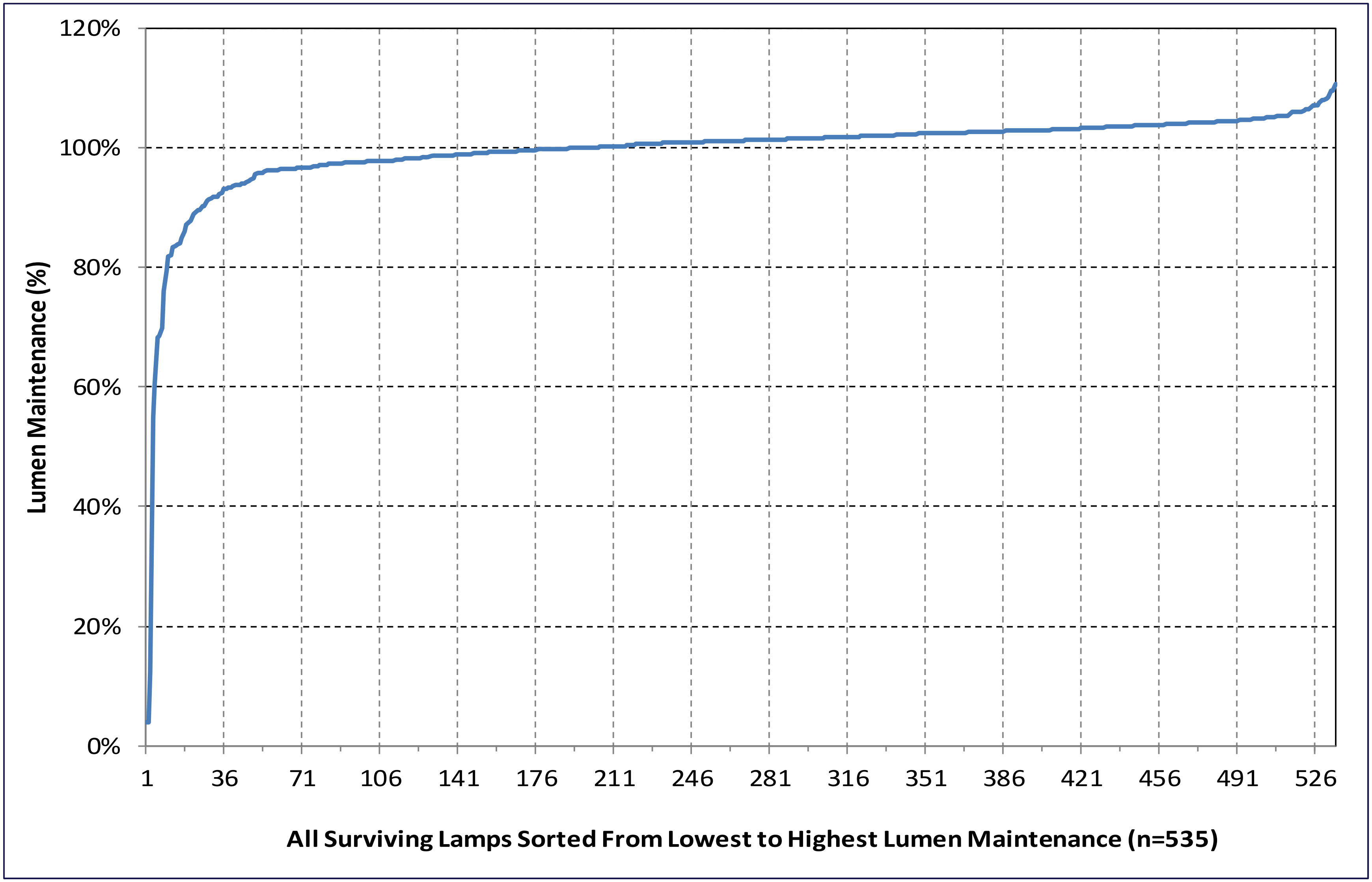
Experimental Results

Photometrics



Results

Photometrics



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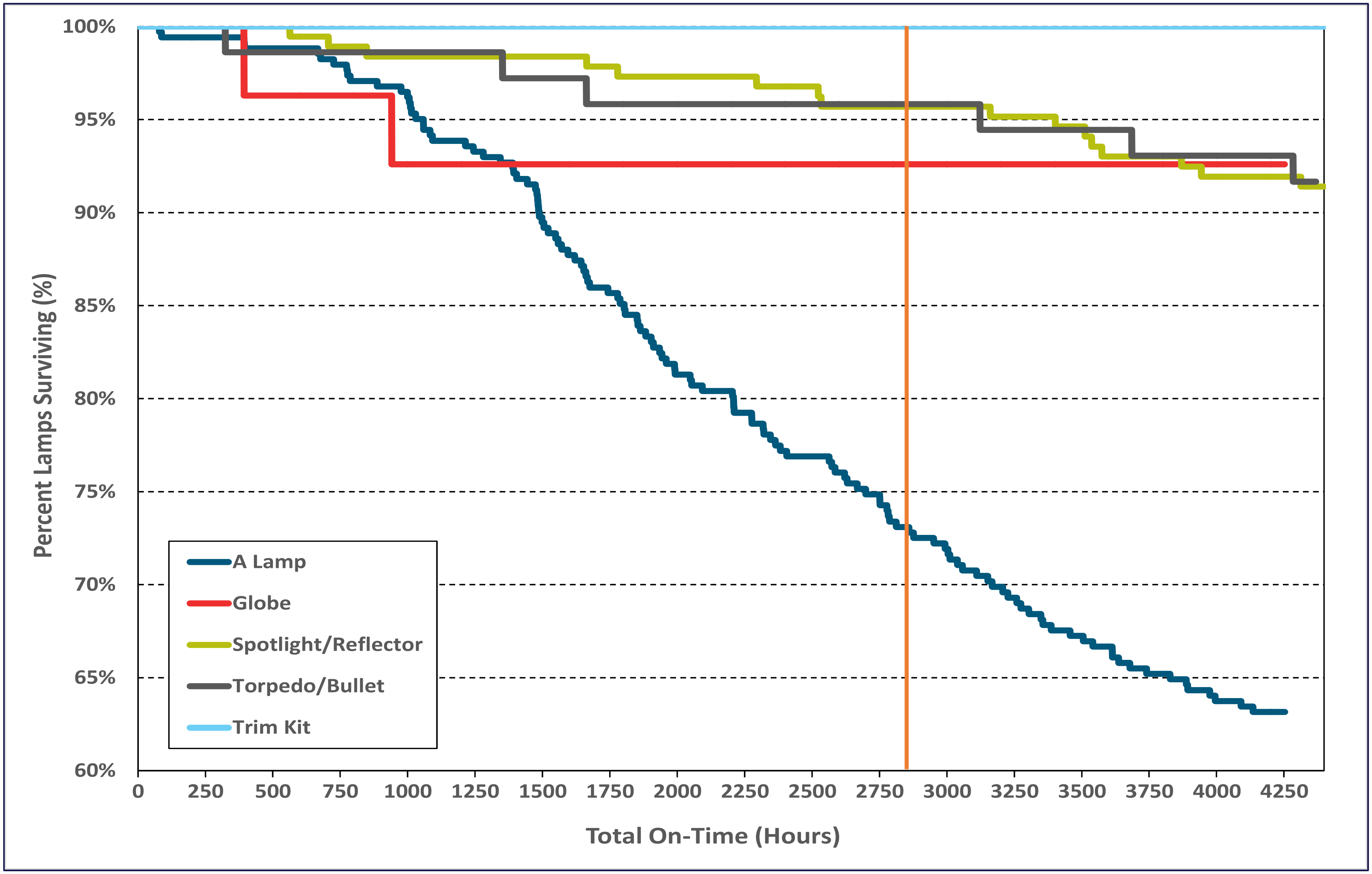
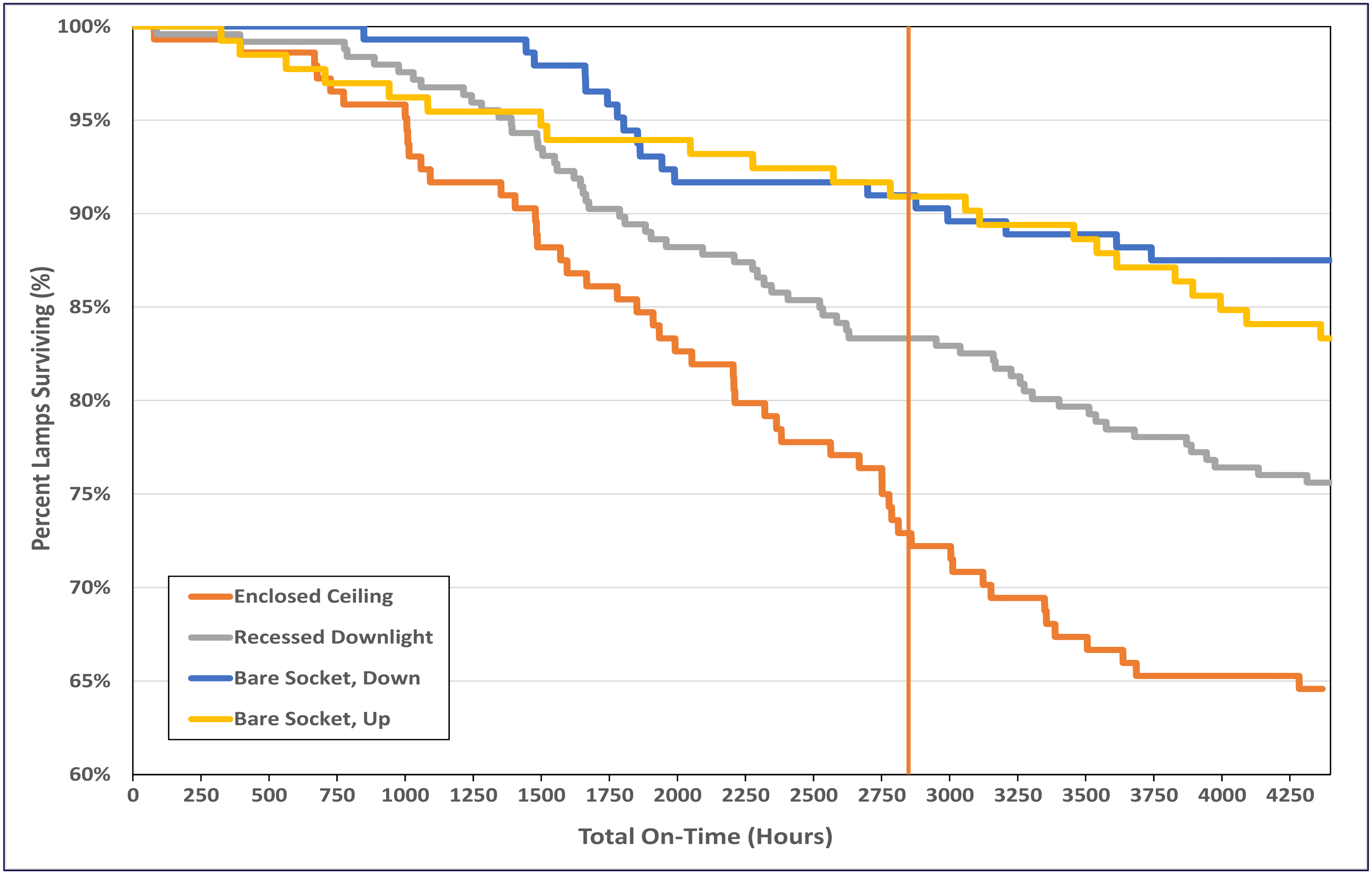
Results

Life Testing



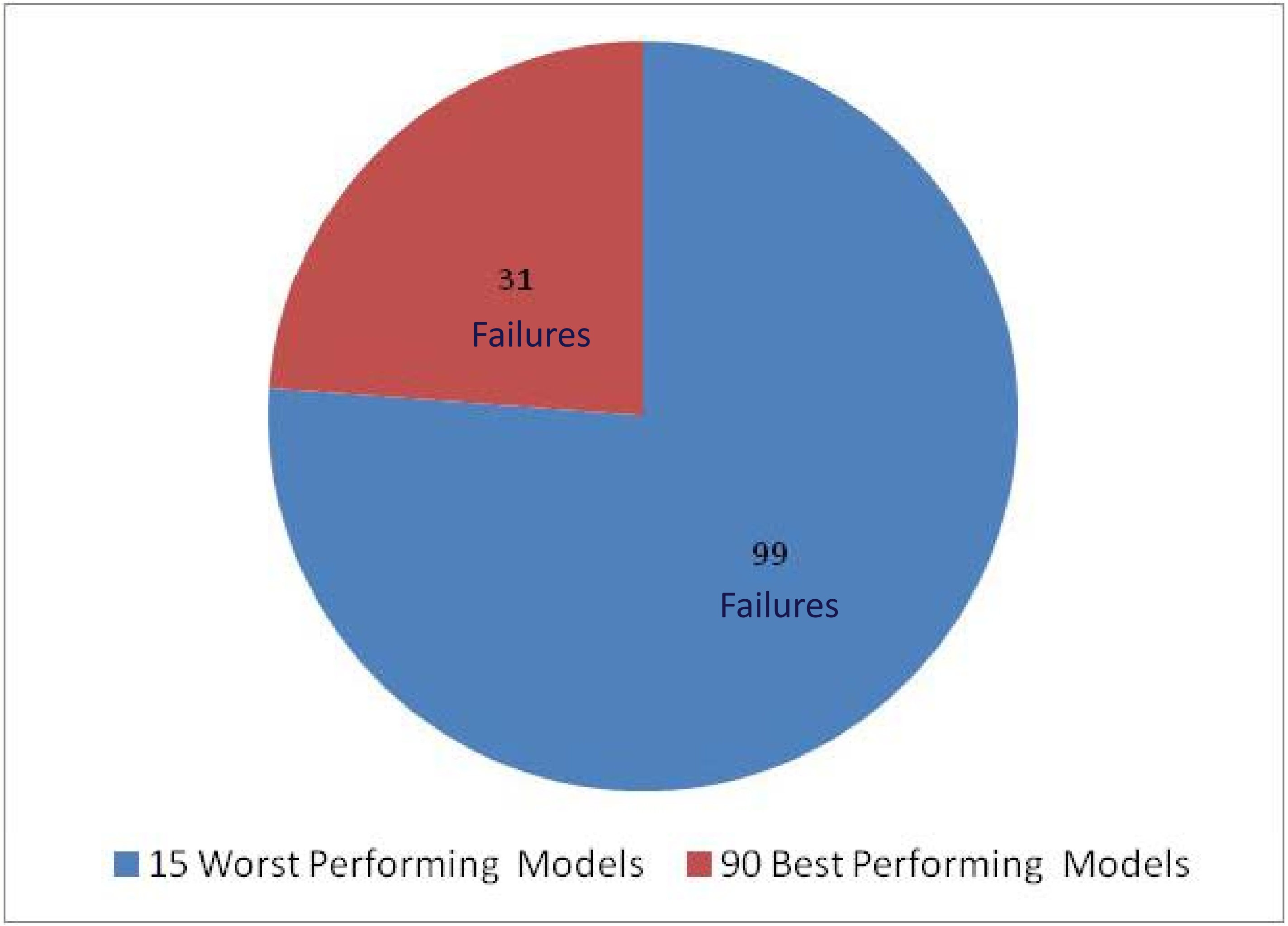
Results

Life Testing



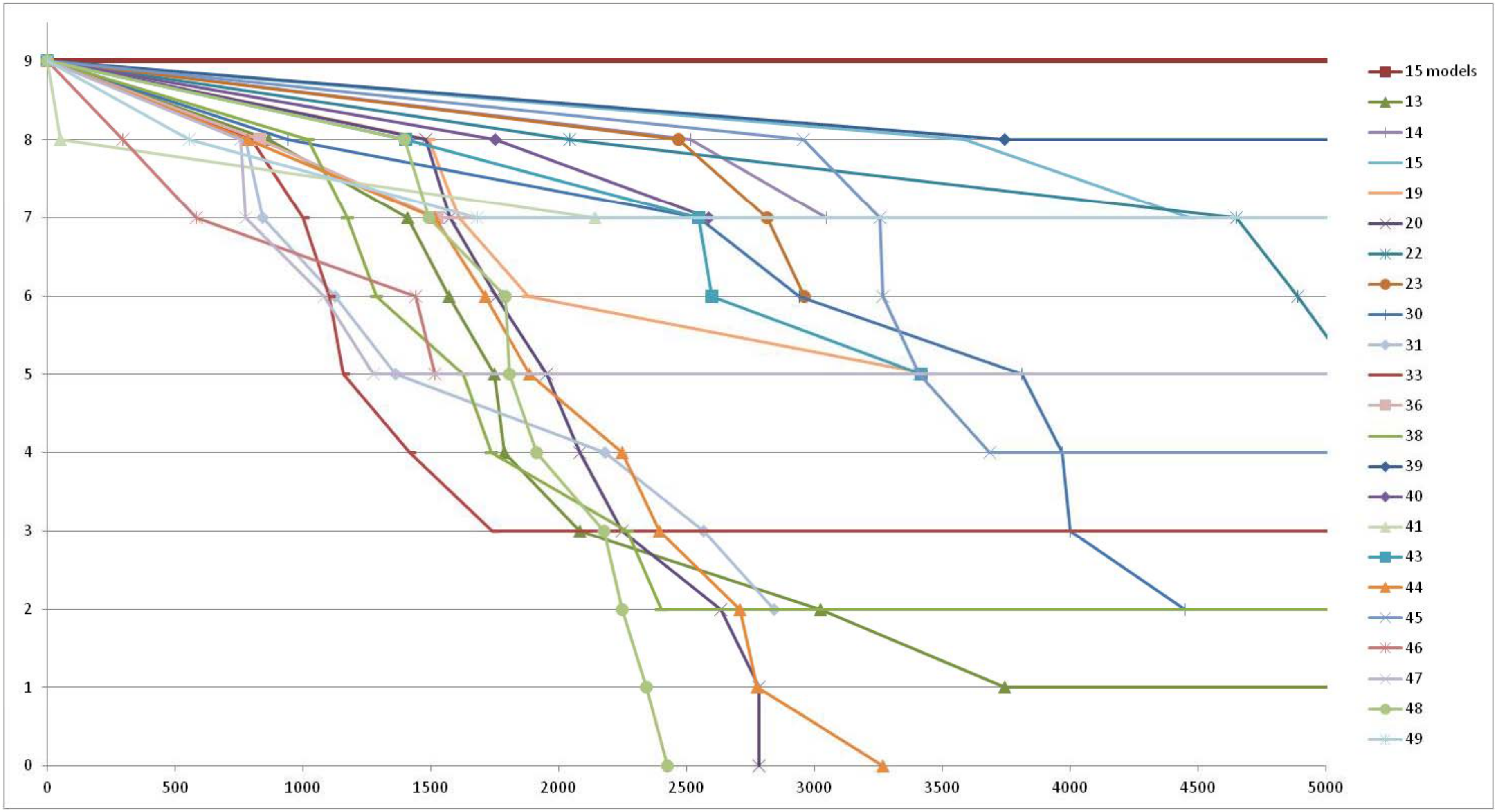
Results

Life Testing – Failures by Model



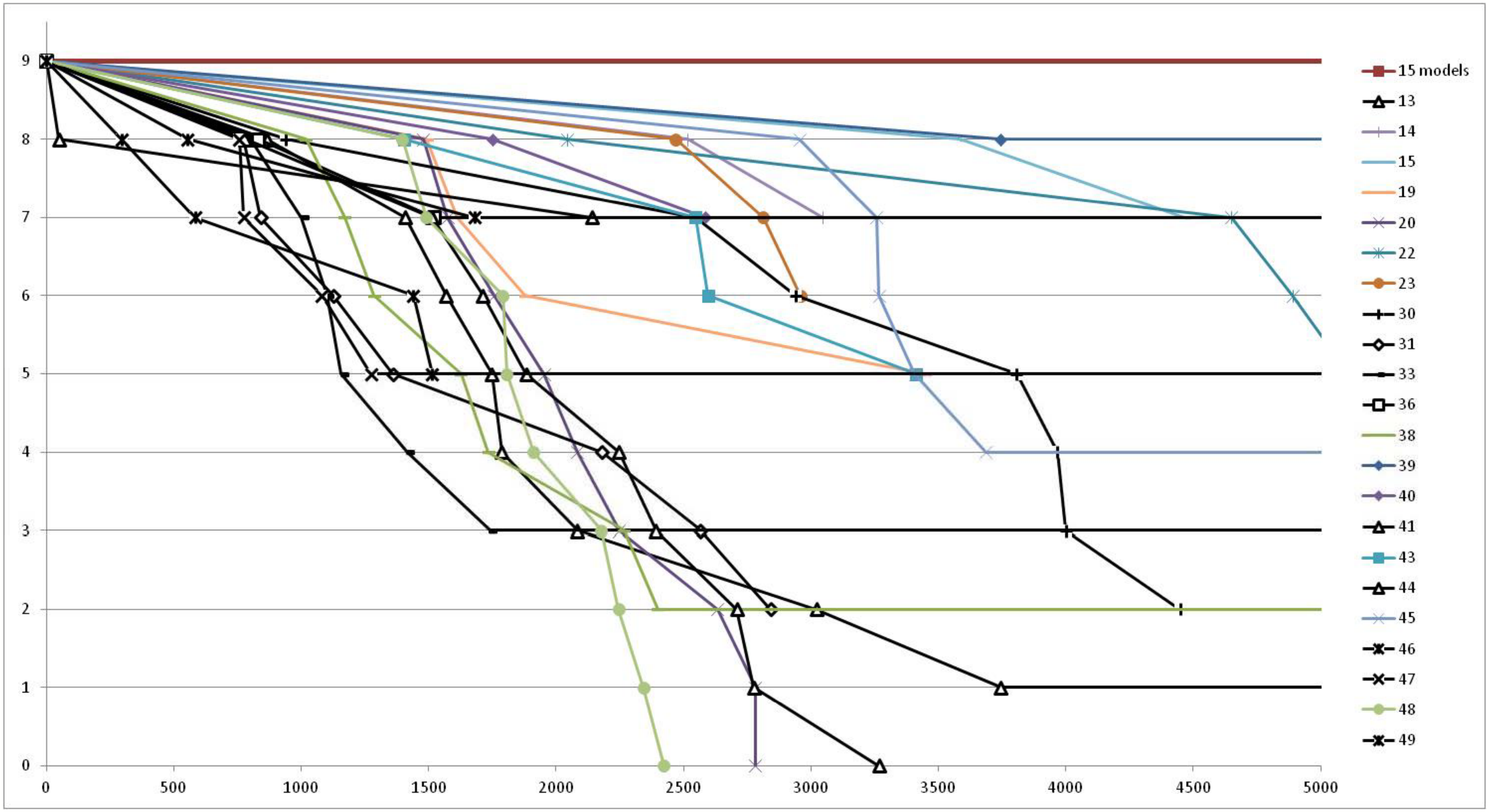
Results

Life Testing – All A-Lamps



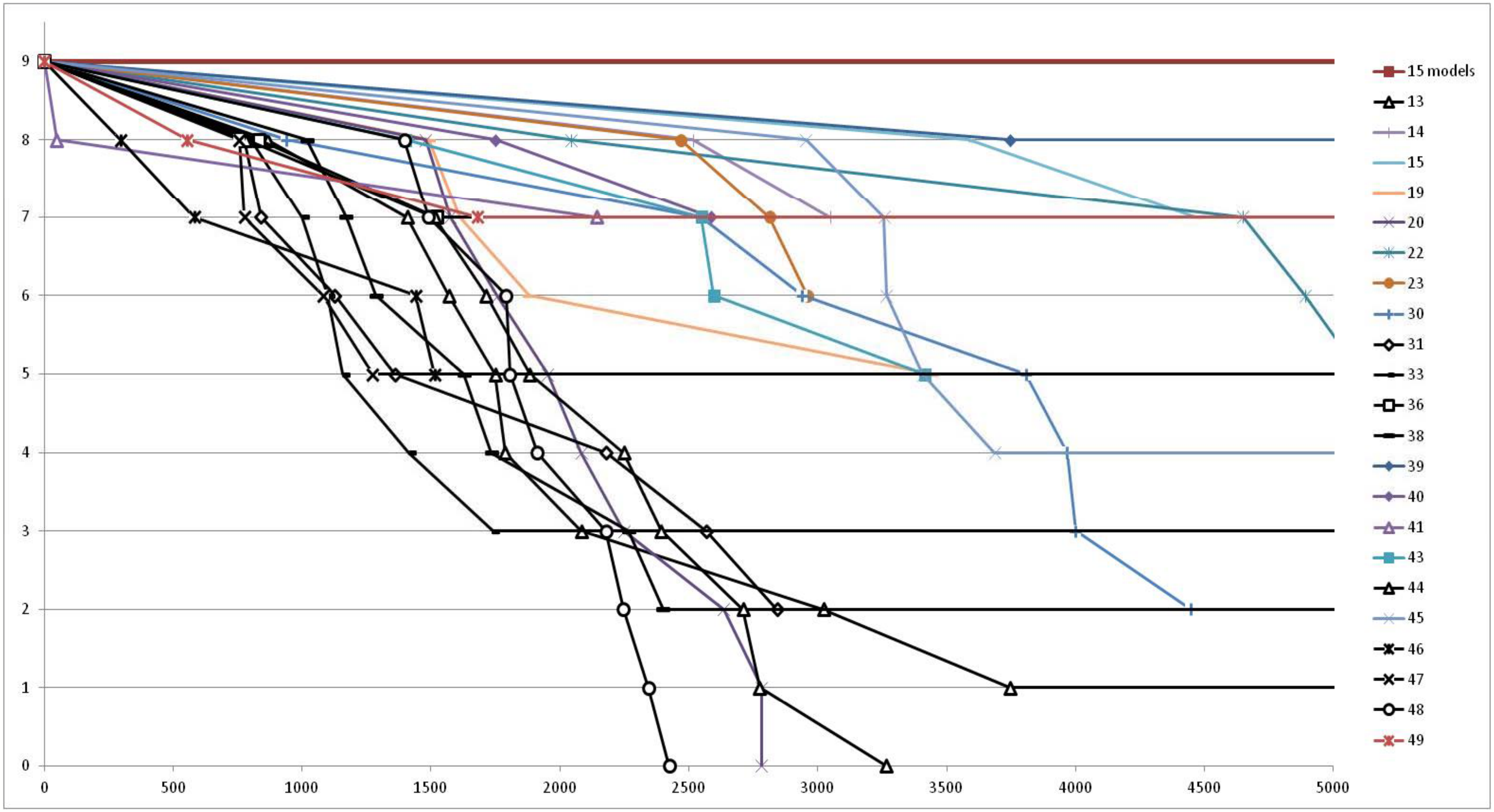
Results

Life Testing - **1 or more failures before 1000 cycles**



Results

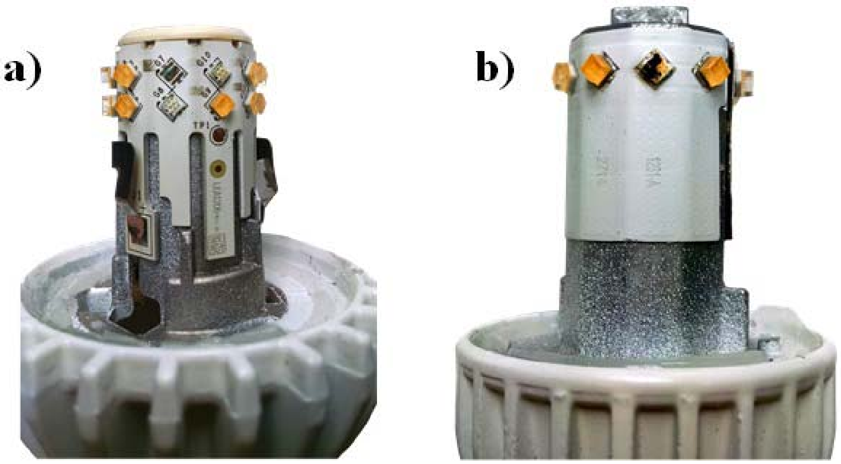
Life Testing **- 2 or more failures before 1500 cycles**

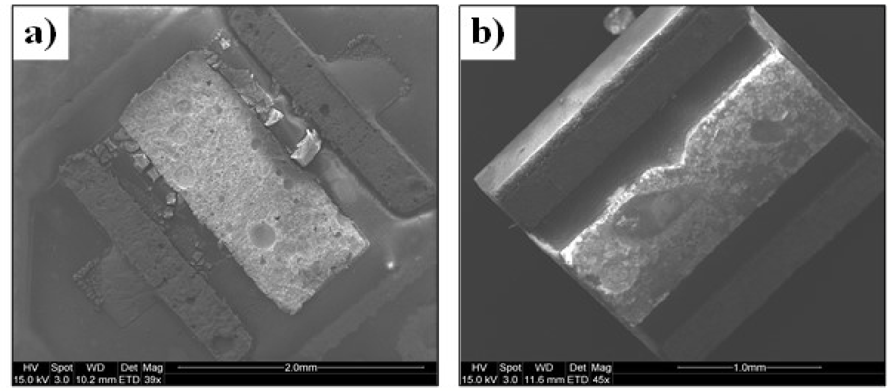


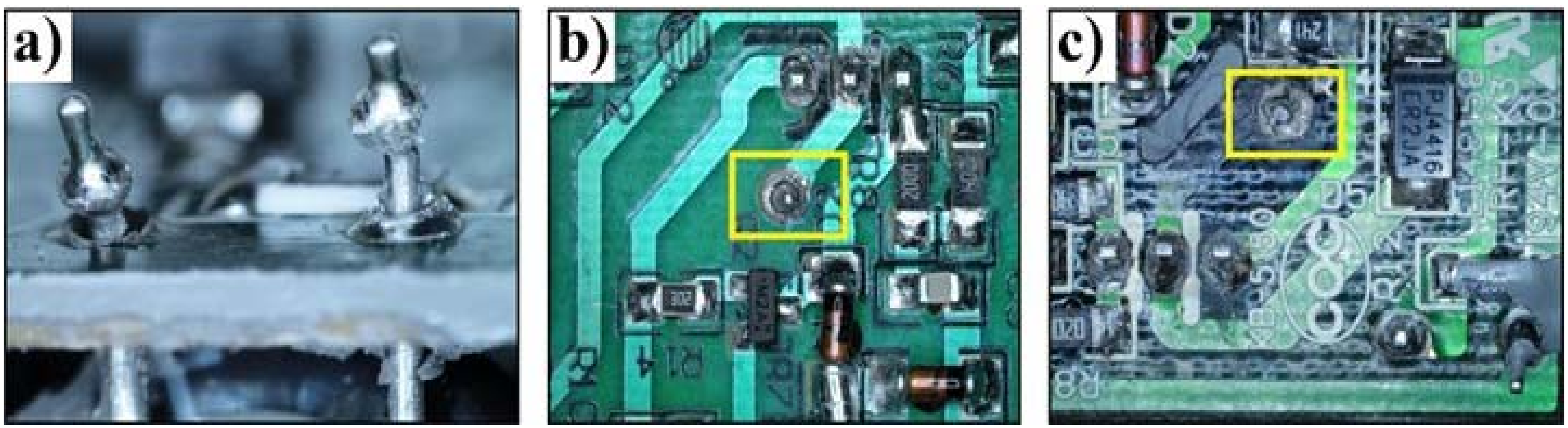
1. Background
2. Experimental Design
3. Results - Photometrics
4. Results – Life Testing
5. **Results – Post Mortem Analysis**
6. Conclusions


Post-Mortem
Forensics
ENE
RIME SCENE DO NOT

Post-mortem forensics

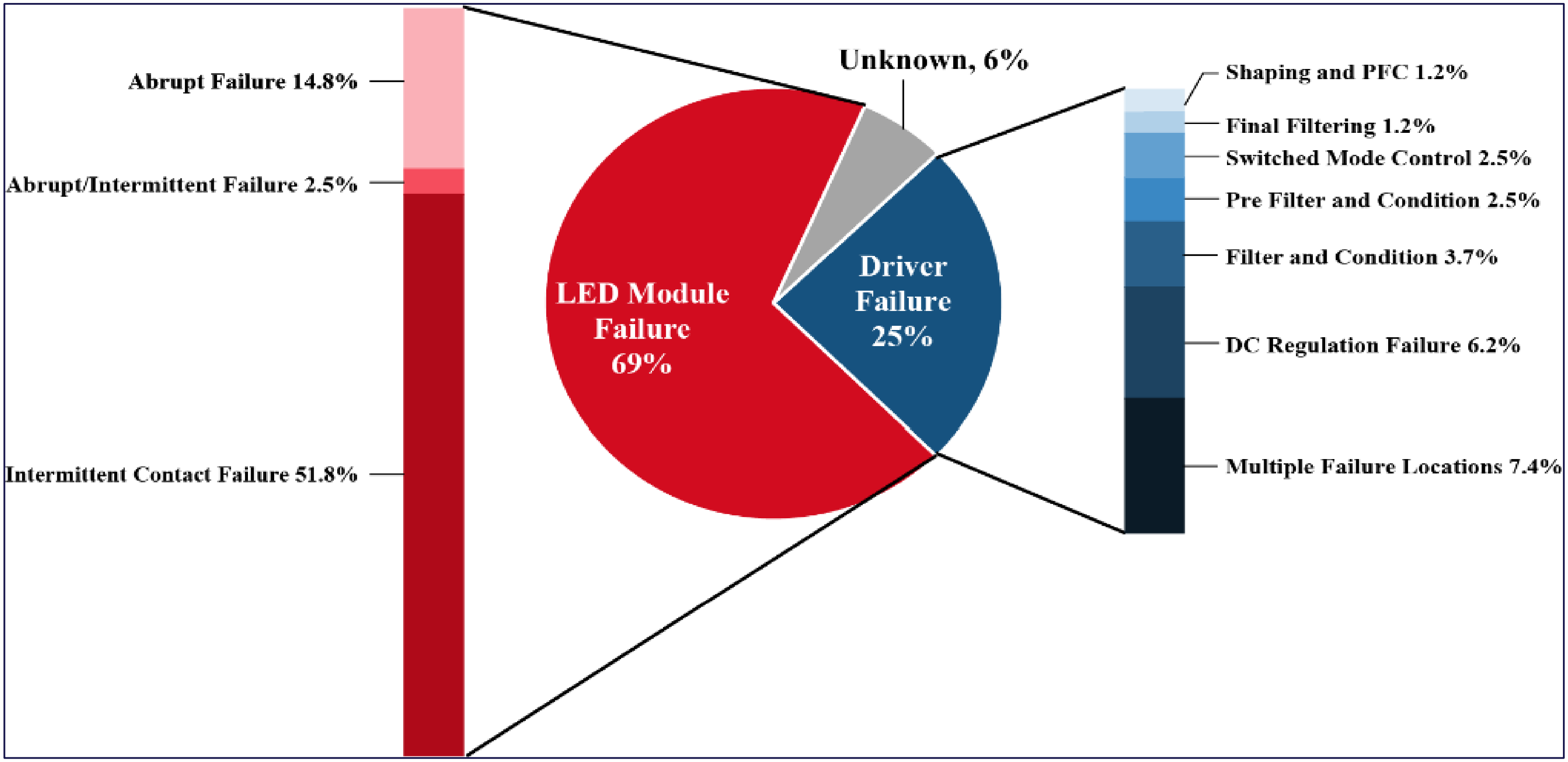






Post-mortem forensics

Failure location for all failed LED test lamps



Mainly solder or contact failures consistent with high heat conditions

1. Background

2. Experimental Design

3. Results - Photometrics

4. Results – Life Testing

5. Results – Post Mortem Analysis

6. Conclusions

Conclusions

- Thermal Cycling Matters
  - Operating temperature and thermal cycling have significant impact on LED lamp Life
  - 75% failed lamps 15% of the models
  - A 1,500 cycle (4 month) screening test can separate the good from the bad
- Rated values for photometric performance largely accurate
- Lumen Maintenance less of a concern that lamp failure

Acknowledgments

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  - Mike Ting, michael.ting@itron.com, (510) 844-2883
  - Erik Page, erik@erikpage.com, (415) 448-6575
- Labs: *ITL Boulder and RTI International*
  - Robert Berger, rberger@itlboulder.com, (303) 442-1255
  - Lynn Davis, ldavis@rti.org, (919) 316-3325

- Full report at : https://pda.energydataweb.com/api/view/1950/LED_Lab_Test_Report.pdf

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Current & Developing Industry Standards: Reliability and Robustness Components vs Luminaires

CHICAGO, IL USA
McCormick Place
May 6 – 10, 2018

LIGHTFAIR.COM

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Reliability and Robustness

- Reliability - the probability that a product will perform its intended function under stated conditions for a given period of time
  - Probability, product, failure, function, conditions, and time
  - Empirical model & physics-of-failure based model
  - Initiated during the research & development
  - Provides data for warranty policy and implementing improvements to product design and/or manufacturing processes

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Reliability and Robustness

- Robustness: the degree to which a system or component can function correctly in the presence of invalid inputs or stressful environmental conditions
  - Typically at elevated stress levels with no requirement for testing to failure
  - Survival of a certain minimum threshold duration
  - Typically be completed quickly
  - Typically performed using production samples

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Published Standards

- IES LM-80 & TM-21
- IES LM-84 & TM-28
- IES TM-26
- IES LM-86

https://www.ies.org/store/

Published Standards

- IEC 62612 - Self-ballasted LED lamps for general lighting services with supply voltages > 50 V – Performance requirements
- IEC 62717 - LED modules for general lighting – Performance requirements
- IEC 62722-2-1 - Luminaire performance - Part 2-1: Particular requirements for LED luminaires


IEC 62612
Edition 1.0 2013-06

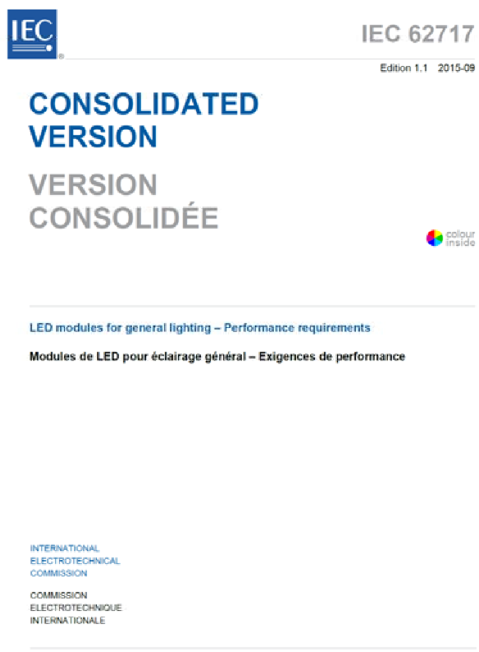
INTERNATIONAL STANDARD
NORME INTERNATIONALE

Self-ballasted LED lamps for general lighting services with supply voltages > 50 V – Performance requirements

Lampes à LED autoballastées pour l'éclairage général avec des tensions d'alimentation > 50 V – Exigences de performances

INTERNATIONAL ELECTROTECHNICAL COMMISSION
COMMISSION ELECTROTECHNIQUE INTERNATIONALE

ICS 29.140.01 ISBN 978-2-83220-872-4


IEC 62717
Edition 1.1 2015-09

CONSOLIDATED VERSION
VERSION CONSOLIDÉE

LED modules for general lighting – Performance requirements

Modules de LED pour éclairage général – Exigences de performance

INTERNATIONAL ELECTROTECHNICAL COMMISSION
COMMISSION ELECTROTECHNIQUE INTERNATIONALE

ICS 29.140.99 ISBN 978-2-8322-2940-8


IEC 62722-2-1
Edition 1.0 2014-11

INTERNATIONAL STANDARD
NORME INTERNATIONALE

Luminaire performance –
Part 2-1: Particular requirements for LED luminaires

Performance des luminaires –
Partie 2-1: Exigences particulières relatives aux luminaires à LED

INTERNATIONAL ELECTROTECHNICAL COMMISSION
COMMISSION ELECTROTECHNIQUE INTERNATIONALE

ICS 29.140.40 ISBN 978-2-8322-1942-3

https://webstore.ansi.org/default.aspx

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Published Standards

- IEC TS 62861 - Guidelines for principal component reliability testing for LED light sources and LED luminaires


IEC

IEC TS 62861

Edition 1.0 2017-03

TECHNICAL SPECIFICATION

https://webstore.ansi.org/default.aspx

IEC TS 62861

- Two types of qualification tests
  - Accelerate stress test (AST) – reliability model exists
  - Initial qualification test (IQT) – basic level of robustness (no model exists)
- Component tests
  - LED package and interconnects
  - Optical materials
  - Electronic subassemblies
  - Active and passive cooling systems
  - Construction materials

IEC TS 62861 – LED package and interconnects

- Sampling 30 devices and mount on test boards
- JESD51-51 – Solder point temp, junction temp, or thermal resistance
- Pre- and post-stress electrical and photometrics
  - Luminous flux or radiant flux (± 20 %)
  - Forward voltage (± 15 %)
  - Color coordinates or dominant/peak wavelength (0.006)
- Solderability – IEC 60068-2-58 (IEC 60068-2-20 w/leads)
- Resistance to soldering heat – reflow – J-STD-020E

IEC TS 62861 – LED package and interconnects

- Temperature and operation stress
  - Low temperature operating life (LTOL) JESD22-A108D; 1000 h; -40°C ambient
  - High temperature operating life (HTOL) 78 LEDs; 1000 h; max I at allowed t_{amb}
  - Pulsed operating life (PLT) 1000 h; t_{amb}=55 °C; pulse width 100µs, duty cycle 3%
- Thermo-mechanical stress
  - Temperature cycling (TMCL) JESD22-A104D; 78 LEDs; 500 cycles;15 min -40°C – 15 min t_{amb}= max (min 85 °C)
  - Vibrations variable frequency (VVF) JESD22-B103B

IEC TS 62861 – LED package and interconnects

- Temperature and humidity stress
  - Wet high temperature operating life (WHTOL) JESD22-A101C; 78 LEDs; 1000 h; t_{amb}=85 °C; 85 % RH; 1 h on/ 1 h off
  - Damp heat cycling (DHC) IEC 60068-2-30; -10°C/25°C dry; 25°C/65°C 90% RH; 10 cycles; 24 h/cycle
- Electrical stress – ESD-HBM
  - ANSI/ESDA/JEDEC JS-001, the human body model
- Environmental stress
  - Hydrogen sulfide; IEC 60068-2-43
  - Flowing mixed gas corrosion (FMGC); IEC 60068-2-60
  - Sulfur dioxide; IEC 60068-2-42

IEC TS 62861 – Final Product Testing

- Section 10 – Component reliability data - final product testing
- Endurance tests - IEC 62612, IEC 62717 & IEC 62722-2-1
- IEC 62612 - Self-ballasted LED lamps – Performance requirements
  - Temperature cycling test: -10°C/40°C over 4 h; 250 periods; 34 min on/34 min off;
  - Supply switch test: on/off 30 s; number of cycles half of rated hours of use
  - Accelerated operation life test: 1000 h; 10 K above max temp; 50°C not specified

IEC TS 62861 – Final Product Testing

- IEC 62717 - LED modules – Performance requirements
  - Temperature cycling test: 50°C change; 250 periods; 10 s on/50 s off (10 cycles); or like lamp
  - Supply switch test: on/off 30 s; number of cycles half of rated hours of use
  - Accelerated operation life test: 1000 h; 10 K above max temp; 50°C not specified
- IEC 62722-2-1 - Luminaire performance - Part 2-1: Particular requirements for LED luminaires
  - Perform IEC 62717 on Luminaire if LED module was not tested

IES TM - LED Lamp/Luminaire Robustness Testing

Scope - This document provides a series of robustness tests for LED lamps, light engines, and luminaires in over-stress conditions that relate to specific applications or potential failure mechanisms in specific operating environments. LED lamp/light engine/ luminaire-specific test conditions focusing on system-level test methodologies, procedures, and conditions are included.

Because these tests are intended for end-users to help provide an assessment of product quality, manufacturers are neither required, nor expected, to conduct these tests. This document is not intended for design phase product evaluation and shall not be used for regulatory compliance.

This document does not cover the topic of reliability and; therefore, does not make any recommendations regarding predictive estimates or extrapolation.

IES TM - LED Lamp/Luminaire Robustness Testing

- Thermal/Humidity
  - Thermal Cycling
  - Low temp operation
  - Internal Heat
  - High Temp/High Humidity
  - Thermal Shock
- Electrical
  - Power Cycling
  - Transient Test
  - ESD
- Mechanical
  - Vibration
  - Impact Test?
- Corrosion/Contaminants

Final Summary

1. Current methods predict a ‘best case’ scenario for the lifetime of an LED system.
2. Research demonstrates that application-specific testing is required to accurately represent the expected lifetime of an LED system.
   - Cycling concerns
   - Material interactions
3. Accelerated methodologies would be ideal but research is required to ensure that new failure mechanisms are not created that would never be seen under normal operating conditions.
4. The development of robustness testing where testing is within the limits of product specifications is a positive next step in the process.

Please remember to complete the course evaluations.

Thank you.