Strategies in Light
ADVANCING THE FUTURE OF LIGHT
THE LED SHOW

How long will it last?

Predicting LED system life based on the application

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Introduction

- How long does an LED lamp last?
  - Common claims: 5 to 25 years, based on 3 hours per day use
- Why lamp life?
  - Payback analysis
- Does frequent on/off switching of LED bulbs shorten their life?
  - Common claim:
    - The operating life of an LED is unaffected by turning it on and off, while lifetime is reduced for fluorescent lamps.

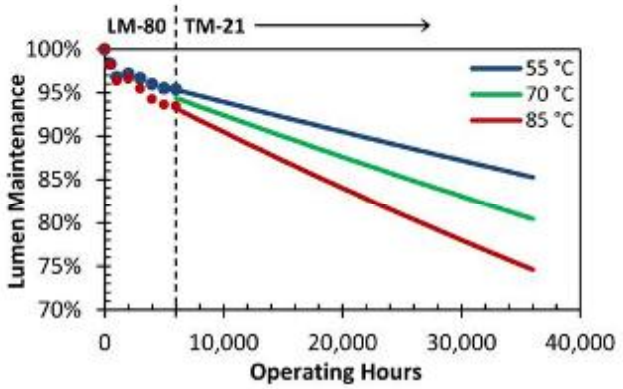
User expectation

- Users may assume the LED lamp will last 22 years as stated in the label, in any application.
- However, they may find the product failing much faster in some applications than the life values claimed on the label.

How is LED bulb life measured?

- Industry practice:
  - Determining L_{70} (lumen maintenance)
    - Continuous testing for at least 6000 (hrs)
    - Data extrapolation
      - IESNA LM80 / TM21
  - LED bulb life is estimated
    - Estimate Tj of the LED within the bulb during operation
    - Determine the L_{70} value at that Tj

Low power | High power | COB | Mid power | CSP



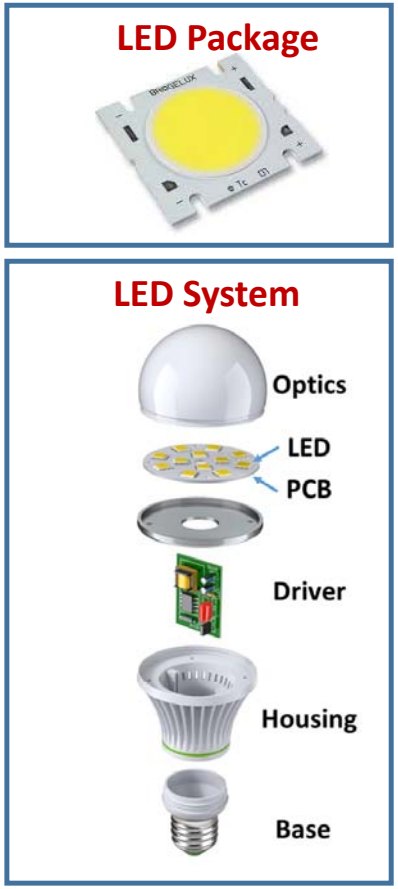
What is the problem?

LED Lighting System

- The problem with product lifetime rating method
  - Tests only one component
  - Considers only one failure type
  - Continuous-on testing

- An LED system has many components
  - Failure of any one component can cause system failure
  - Failure can be catastrophic or parametric
  - In practice products are turned on and off

- Therefore, the claimed lifetime numbers may not represent what consumers experience.



Study Objective

- The study objective was to develop a short duration test method that can predict LED system life in an application.
  - Environment temperature
    - Resulting Tj of LED
  - ON-OFF switching pattern
- and
  - Considers both catastrophic and parametric failure times

Background

- Since 2009, LRC's researchers have been investigating LED system life testing under ASSIST program sponsorship

  References:

  - Accelerated Life-testing Study to Predict LED System Failure, Strategies in Light 2014, Feb 25-27, Santa Clara, CA.
  - Narendran, N., and Y. Liu. 2015. LED life versus LED system life. In: SID '15 Digest of Technical Papers, paper 62-2, SID Display Week 2015: International Symposium, Seminar and Exhibition, May 31-June 5, 2015, San Jose, CA.
  - 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).

- To accurately capture system failure and estimate life:
  - The whole lighting system must be tested
  - The test procedure must include ON-OFF switching
  - All failure types must be considered
    - Catastrophic and Parametric

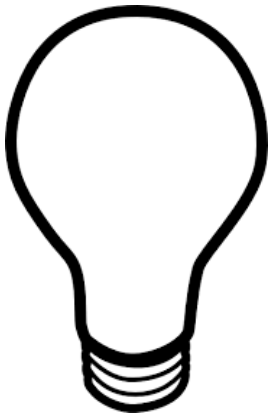
Experiment

- Step 1: Determining LED Tj in application
  - LED A-lamp, 75W incandescent equivalent, in a 3-lamp surface mount fixture
    - T_j of LEDs = 146°C
    - T_{room} = 30°C
  - When swiched on and off
    - Delta Temperature = 116°C

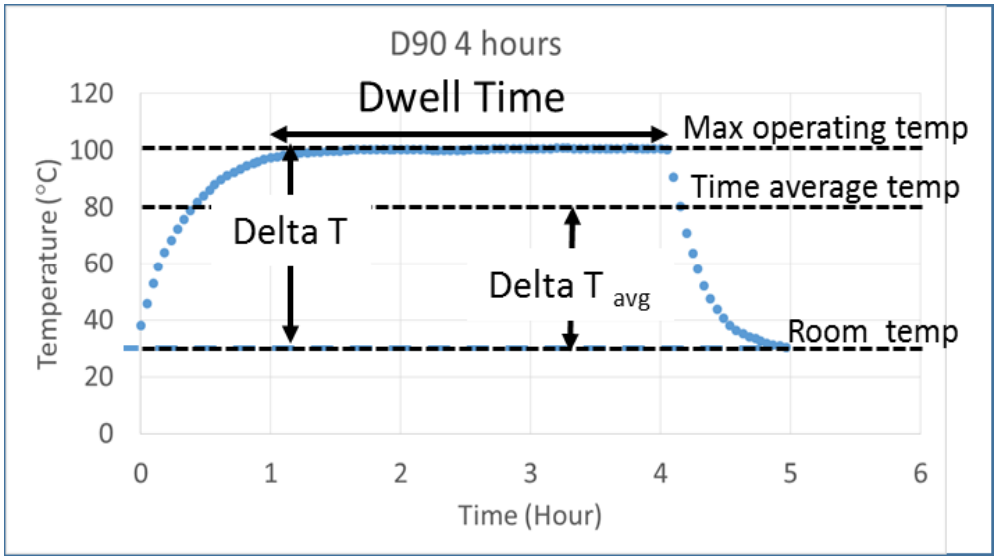
LED lamp used in the study: 75W Equivalent Dimmable Warm White A19 LED Light Fixture Light Bulb

Experiment setup and test procedure

- Type of product
  - LED A-lamp
  - 30 samples each



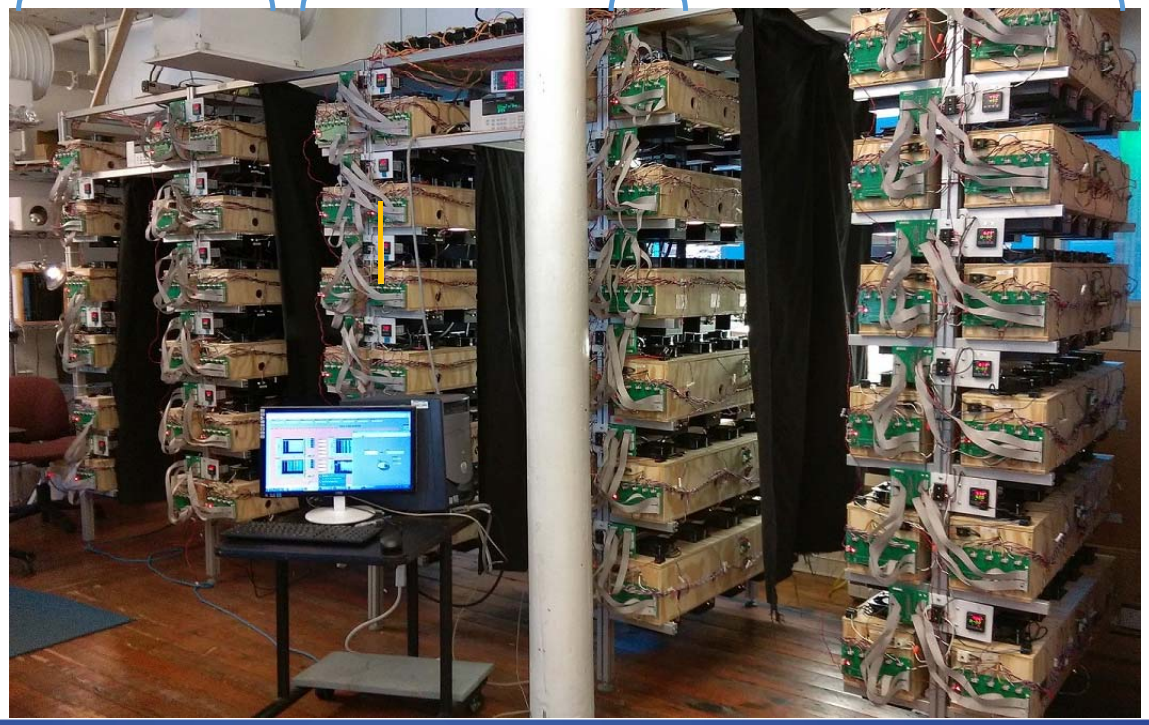
- Test variables
  - Delta Temperature (DT)
    - D80/D90/D100 °C
  - Dwell Time
    - 2-hrs/4-hrs/Continuous



Test Setup

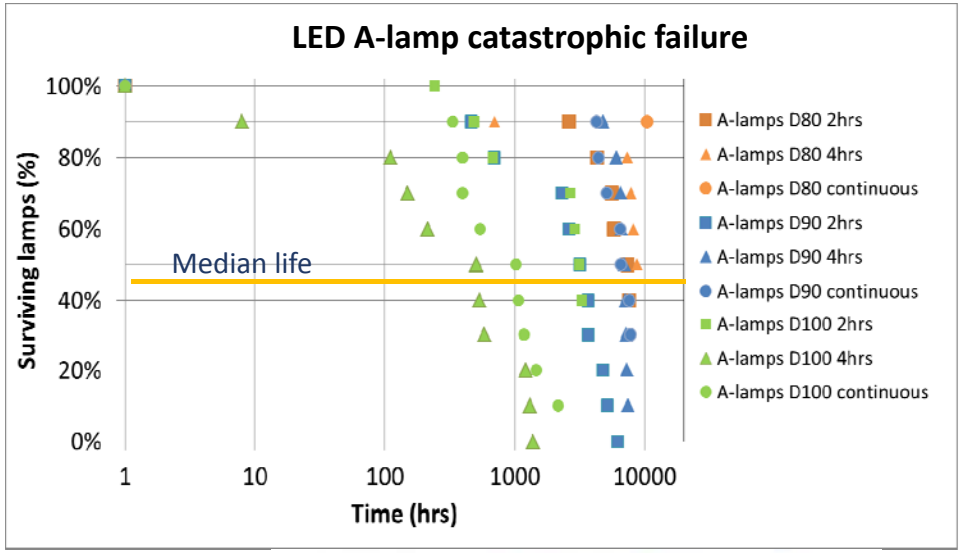
Energy Star Rated Products (270 samples)

A-lamps **MR16 lamps** **Downlights**



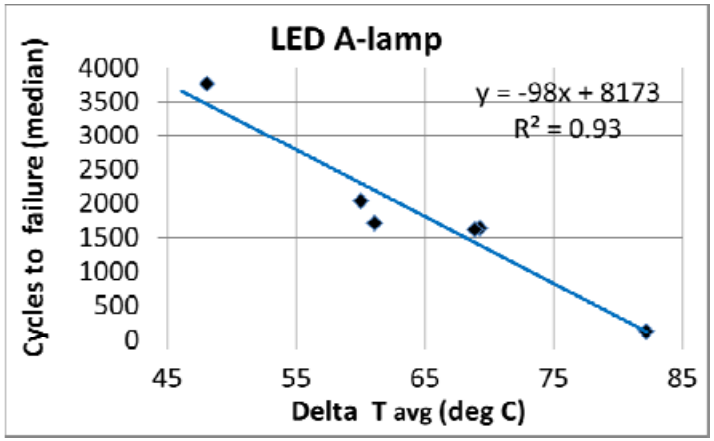
Data: LED A-lamp catastrophic failures

- Catastrophic failure:
  - Median life depends on DT and dwell time
- Failure modes
  - LED failure = 84%
    - PCB solder failure
  - Driver failure = 16%



Data: LED A-lamp catastrophic failures

- Higher Delta T results in shorter time to failure
- Shorter dwell time results in shorter time to failure
  - Frequent switching shortens life
- Cycles to failure (median life) and delta temperature are related linearly (inverse)



Delta T avg (°C)

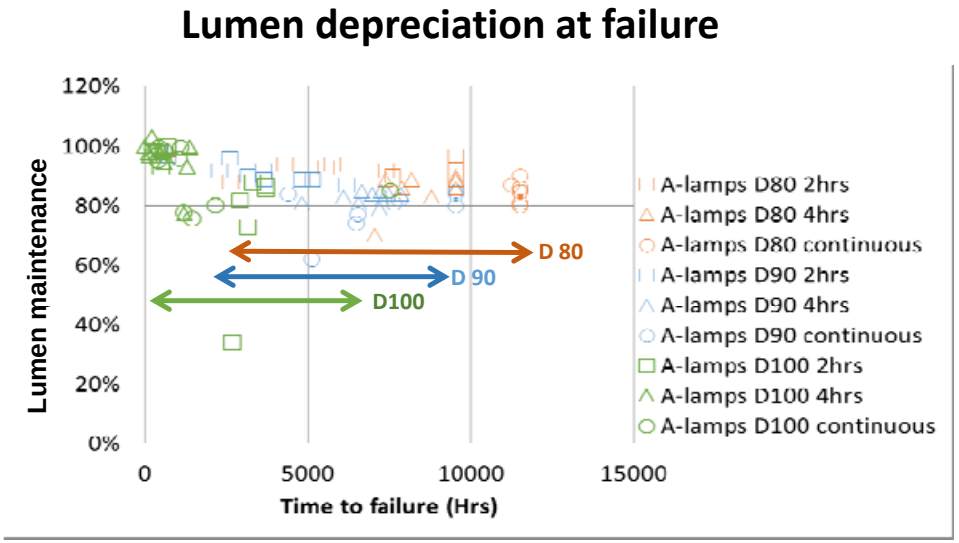
Delta T/Dwell Conditions	2 hrs	4 hrs
80°C	48	60
90 °C	61	69
100°C	69	82

Time to failure (median life in hours)

Delta T/Dwell Conditions	2 hrs	4 hrs
80°C	7,516	8,801
90°C	3,411	7,091
100°C	3,225	521

Data: LED A-lamp lumen depreciation

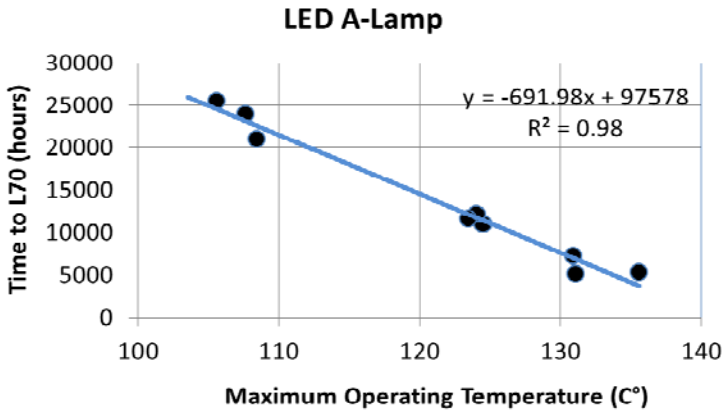
- Majority of the tested LED A-lamps failed catastrophically before lumen maintenance reached the 70% value.
  - That is the reason why catastrophic failure must be considered as well



Results: A-lamp lumen depreciation

For the product tested:

- L70 and maximum operating temperature have linear relationship
- The projected L70 values are similar for each DT condition
  - Cycling - minimum effect



Maximum operating temperature (°C)

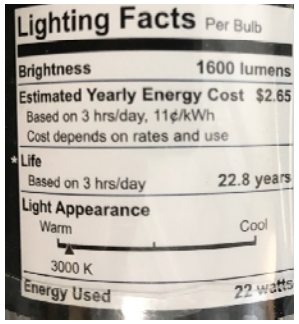
Delta Temp/Dwell Conditions	**2 hrs**	**4 hrs**	**Continuous on**
80°C	106	108	108
90°C	125	124	124
100°C	131	136	131

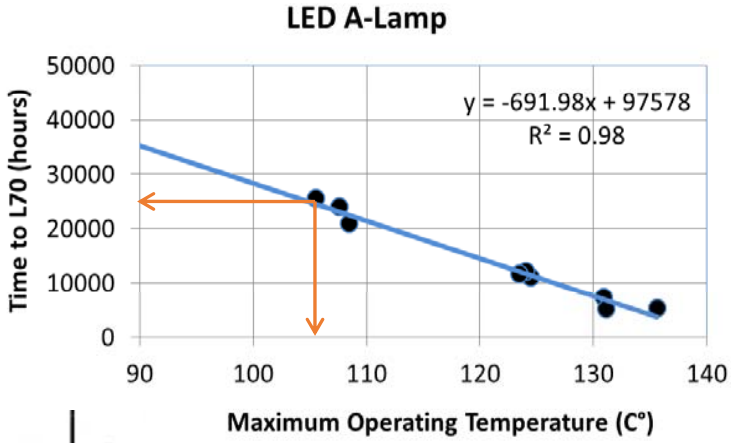
Time to failure (L_{70} in hours)

Delta T/Dwell Conditions	**2 hrs**	**4 hrs**	**Continuous on**
80°C	25,528	20,998	23,979
90°C	11,019	12,185	11,657
100°C	7,289	5,308	5,171

Life of an LED lighting system

- Based on current industry standards, the lamp life claim (L70) of 25,000 hours is reasonable.
- **Question**: Will the consumer see the lamp operate for the claimed hours?





Life of an LED lighting system

- Study results show for the LED A-lamps tested both failure types exist
  - Catastrophic (Cease to produce light)
  - Parametric (Lumen depreciation)

- Shorter of the two times to failure determines the system lifetime

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

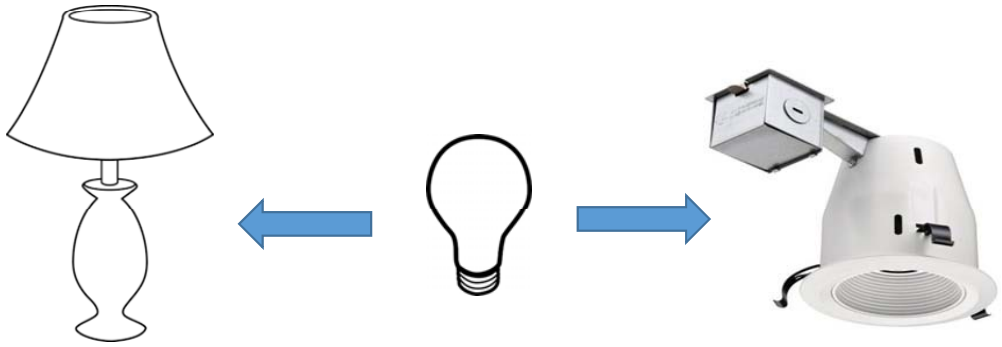


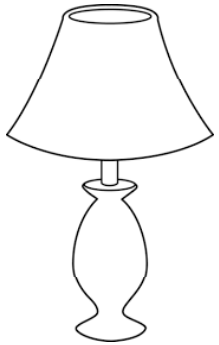
Table lamp

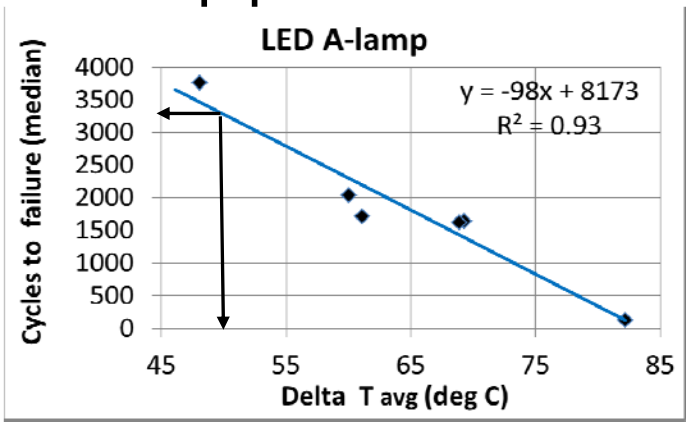
Recessed downlight

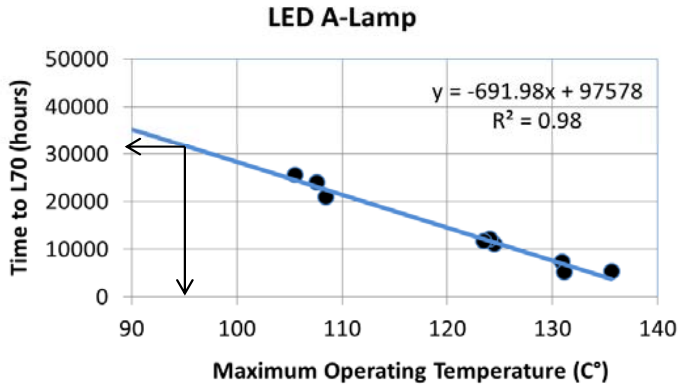
LED A-lamp life estimation in an application

- Example 1: LED Table lamp
  - Used 3 hours per day, 1 cycle
    - Maximum Tj = 95°C at T_{room} 30°C
    - Delta T_{avg} = Tavg – T_{room} = 50°C
    - Estimated median lamp life
      - Catastrophic : 3250 cycles = 8.9 yrs
      - L70: 32,000 hrs = 29 yrs

- Lamp life = 8.9 years; 9746 hours





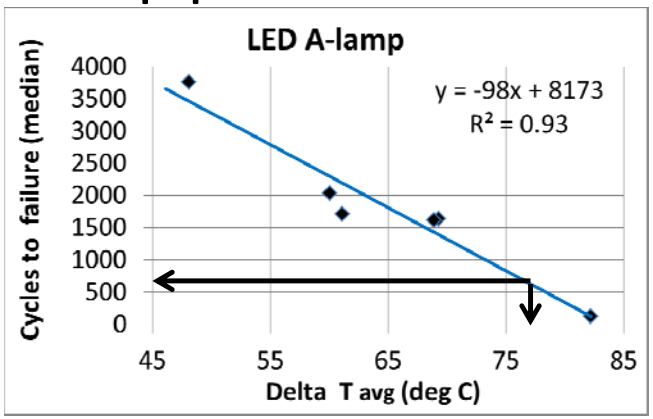


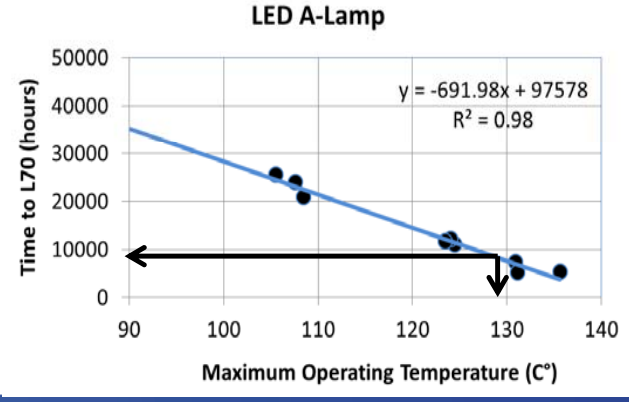
LED A-lamp life estimation in an application

- Example 2: Downlight (Non-IC)
- Used 2 hours per day; 1 cycle.
  - Maximum Tj = 129°C at Troom 30°C
  - Delta Tavg = 77°C
  - ~ 600 days = ~ 1.9 years

  - Estimated median lamp life
  - Catastrophic : 700 cycles = 1.9 yrs
  - L70: 9,000 hrs = 12.3 yrs

- Lamp life = 1.9 years; 1387 hours





Summary

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);

- For the LED A-lamps tested, failure includes both catastrophic and parametric.
  - Switching LED systems ON and OFF can shorten lamp life.
    - Therefore, the LED system life test procedure must include ON-OFF switching.
- Higher percentage (84%) of lamp failures was catastrophic and was due to solder joint failure. The balance (16%) was due to driver failure.
- Cycles to failure has a high correlation to delta time-averaged temperature.
- Time to L70 (parametric failure) has a high correlation to maximum operating temperature.
- The proposed test method
  - Can predict LED system life in application
    - If Tj and switching pattern (ON-OFF cycling) are known.

Lessons learned

- Contrary to common belief
  - Switching LED systems ON and OFF can shorten lamp life similar to other traditional light sources
- Current industry practice for testing LED lighting products and rating lifetime needs revision

  LED product Life testing method:
  - Whole system must be tested
  - Must include On-Off switching
  - Must consider catastrophic and parametric failures
    - Use the shorter time to failure
    - Parametric shift must include light output and power demand over time

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www.lrc.rpi.edu/programs/solidstate/index.asp