EPA ENERGY STAR®

Lighting Webinar Series

The Quest for a Short Term Reliability Test

September 29, 2016

A short-duration LED system life test

Nadarajah Narendran, Ph.D.

Lighting Research Center
Rensselaer Polytechnic Institute

Troy, NY 12180

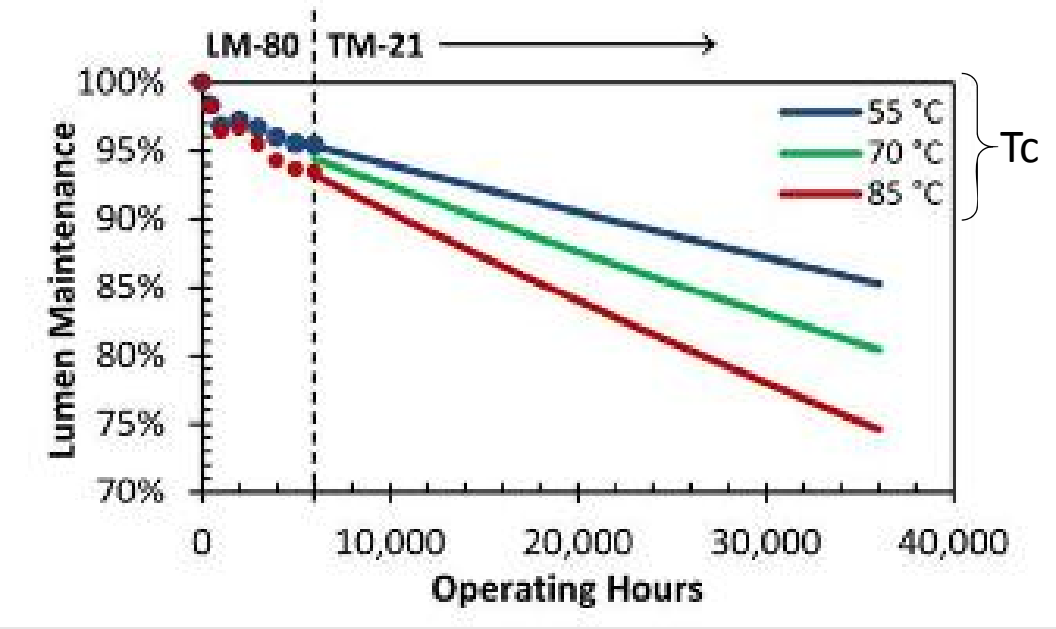
Background

- One of the claimed benefits for LED lighting is long life.
  - Lifetime claims for commercially available products are typically in the 25,000-hour range.
- User expectation:
  - The lamp will last 25,000 hours in all applications.

http://www.ledflatpanelslighting.com/sale-767795-15w-black-house-surface-mounted-led-ceiling-lights-for-jewelry-lighting.html

Background

- How is LED system life estimated today?
  - The LED in the system is tested according to IESNA LM-80 and the L70 value is estimated according to IESNA TM-21.



Background

- An LED system has many components
  - LED(s), circuit board, driver, optics, heat sink, and others
- Failure of any one component can cause system failure
- Failure can be catastrophic or parametric

Background

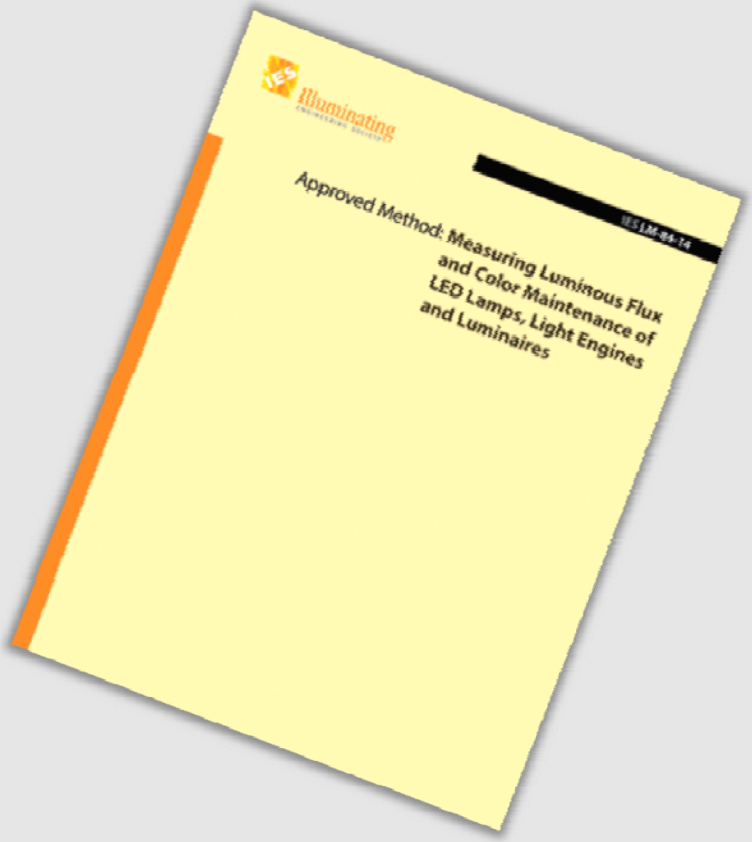
- Lighting system use pattern in applications:
  - Office:
    - 7 am to 7 pm
      (12 hrs on, 12 hrs off)
  - Home:
    - 5 am to 9 am and
    - 6 pm to 10 pm
      (4 hrs on, 4 hrs off)

https://community.lighting.philips.com/

http://www.ledsource.com/products/residential

Background

- For testing LED systems, the IESNA published a method, LM-84-14.
  - This is an improvement over LM-80 because it tests the whole system rather than just the LED.
- However, the drawbacks are:
  - Continuous-on testing
  - Considers only parametric failure of system light output (lumen depreciation) and color maintenance



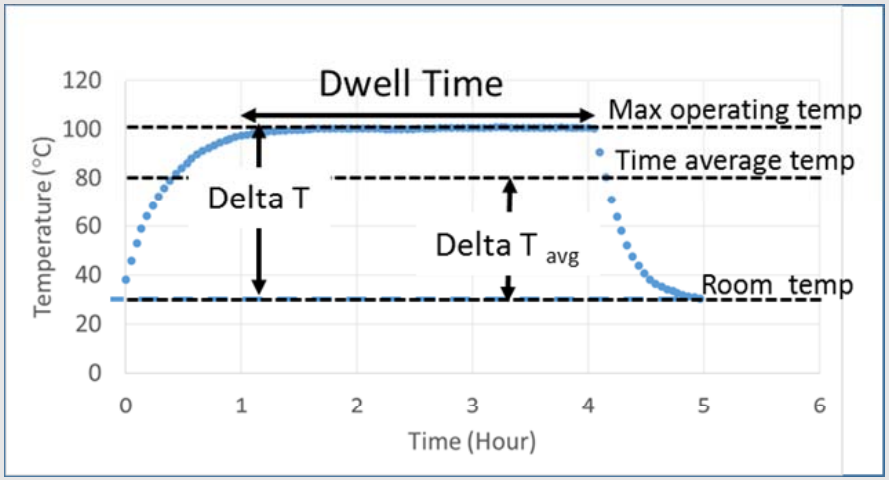
Background

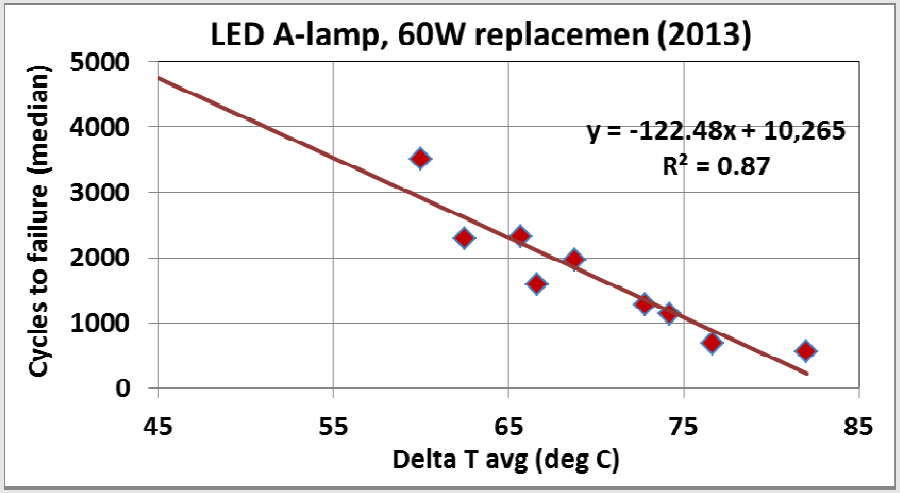
- Since 2009, LRC researchers have been investigating LED system life testing
  - Sponsored by the ASSIST program
- **Study objective**: To develop a short-duration test method that can be useful for estimating LED system life when used in applications.

ASSIST program sponsors

Background

- LRC initial study findings: To accurately capture system failure and estimate life,
  - The whole lighting system must be tested
  - The test procedure must include on-off cycling
    - Suitable delta T and dwell time
- Results: Catastrophic failure
  - A good linear relationship between cycles to failure and delta temperature





Background – Public presentations

- The test procedure and the results of this initial LRC study were presented at several venues to gather feedback
  - 2014
    - Accelerated Life-testing Study to Predict LED System Failure
      - Strategies in Light, Feb 25-27, 2014, Santa Clara, CA
    - An Accelerated Test Method for Estimating LED System Life
      - The 14th International Symposium on the Science and Technology of Lighting (LS14), June 22-27, 2014, Como, Italy
    - LED System Life
      - 9th SSL Annex, Expert Meeting, October 2014, Portland, OR
  - 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

Expanded study

- With additional funding from BPA, NYSERDA and ASSIST the LRC expanded the study
  - Larger sample size and more systems

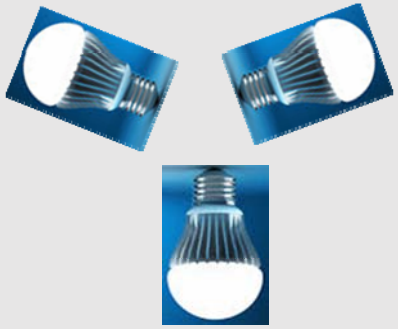
- Study objective: To develop a test method that can help estimate LED system life based on factors such as
  - environment temperature (resulting T_j)
  - use pattern (On-Off cycling)

and

  - considers both catastrophic and parametric failure times
    - Uses the shorter of the two

Pilot study: Identify LED Tj in application

- An LED A-lamp, 75W incandescent equivalent, in a 3-lamp surface mount fixture
  - Tj of LEDs = 146°C
  - Troom = 30°C
  - DT = 116°C
    - DT = Tj - Troom
- Two other LED A-lamps, 60W incandescent equivalent, in a 3-lamp surface mount fixture
    - Delta Temperature = 90°C
    - Delta Temperature = 85°C

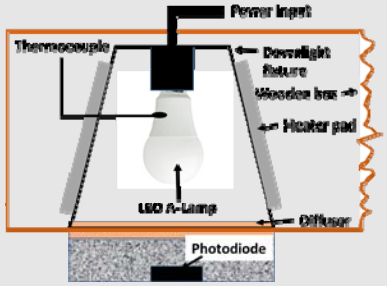


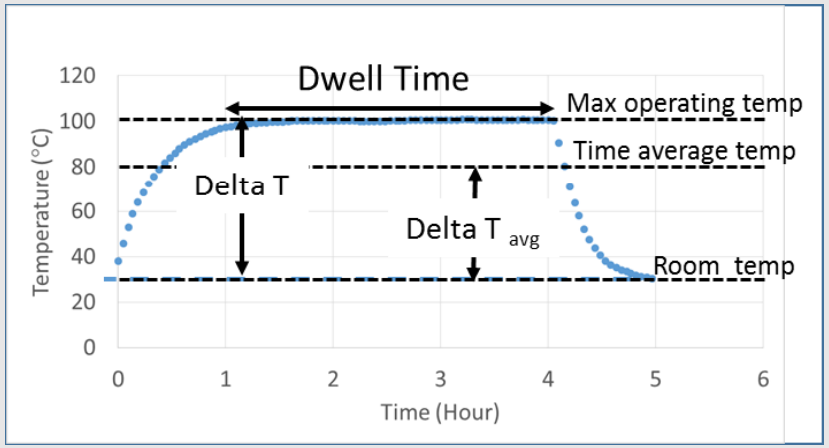
Experiment setup and test procedure

- Type of product tested
  - LED A-lamps
  - 90 samples

- Independent variables
  - Delta Temperature (ΔT)
    - D80/D90/D100 °C
      - Based on pilot study results
  - Dwell Time
    - 2-hrs/4-hrs/Continuous

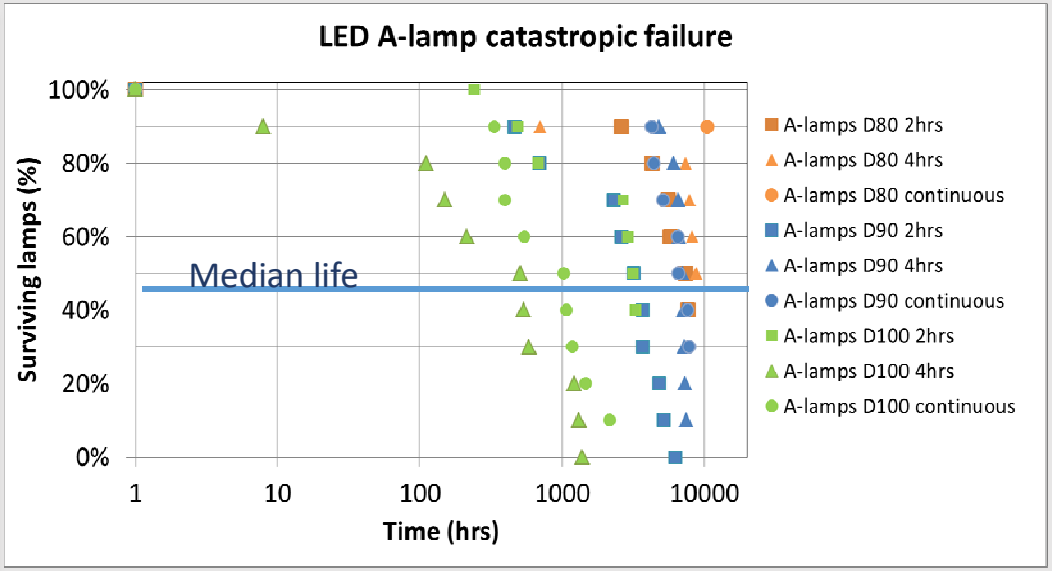
- Dependent variables
  - Light output
  - Chromaticity
  - Power Input
  - Current Input
  - Lamp temperature

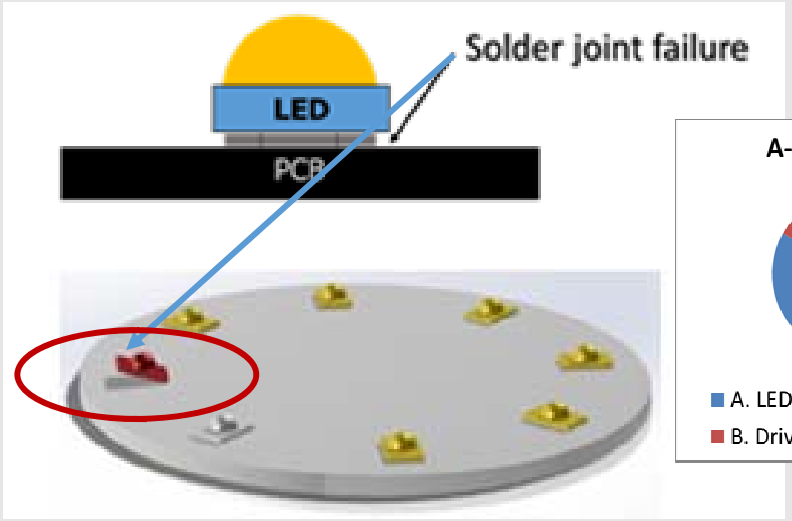


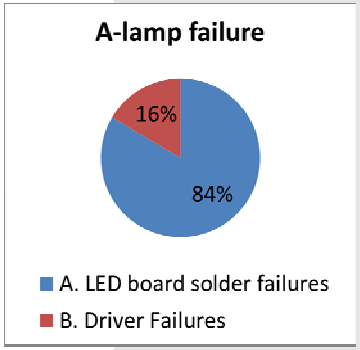


Data: LED A-lamp catastrophic failures

- Median life due to catastrophic failure is affected by delta T and dwell time
- Failure modes
  - LED failure = 84%
    - PCB solder failure
  - Driver failure = 16%

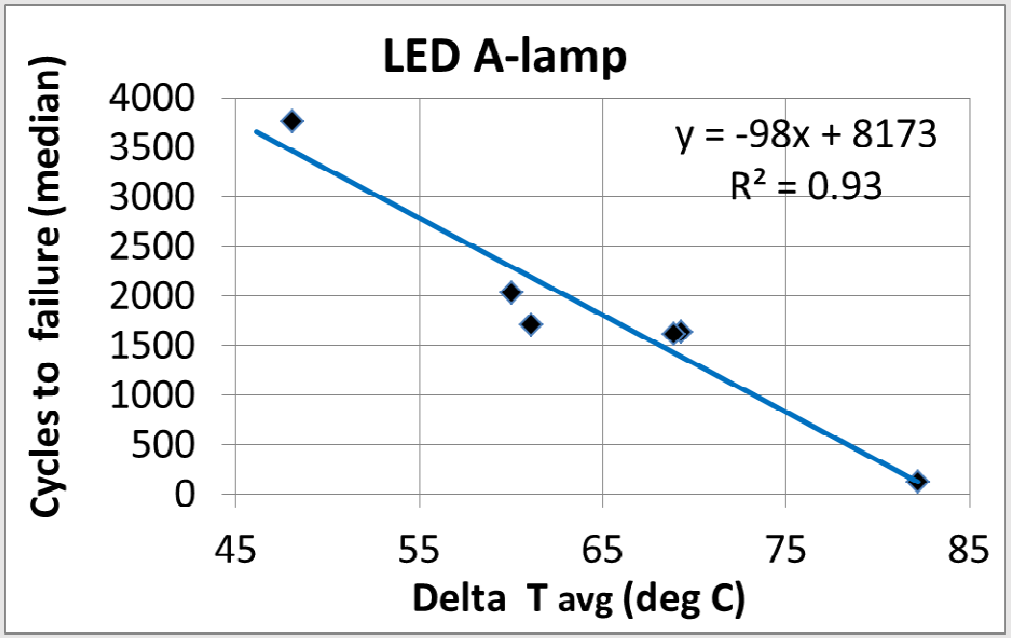






Data: LED A-lamp catastrophic failures

- Delta temperature:
  - Higher delta T results in shorter time to failure
- Dwell time:
  - Shorter dwell time results in shorter time to failure
    - For 80°C and 90°C
    - The trend is not clear at 100°C
      - Possible other failure mechanisms
- Cycles to failure as a function of delta temperature shows an inverse linear relationship
  - Goodness-of-fit (R^2) > 0.9



Delta T average (°C)

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

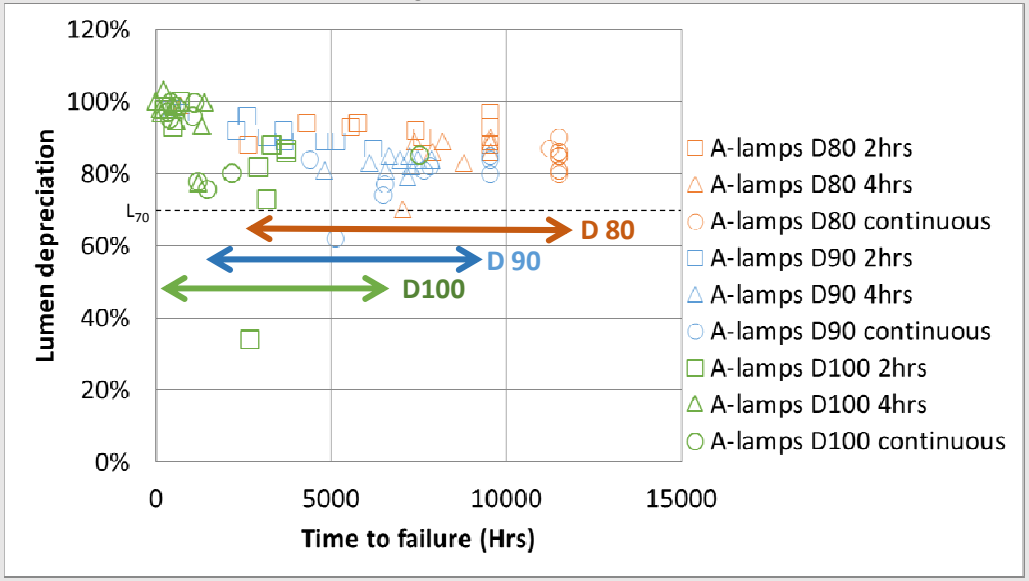
Time to failure (median life in hours)

Delta T	Dwell time 2 hrs	Dwell time 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

- The majority of the LED A-lamps tested failed catastrophically before the lumen depreciation reached the 70% value.

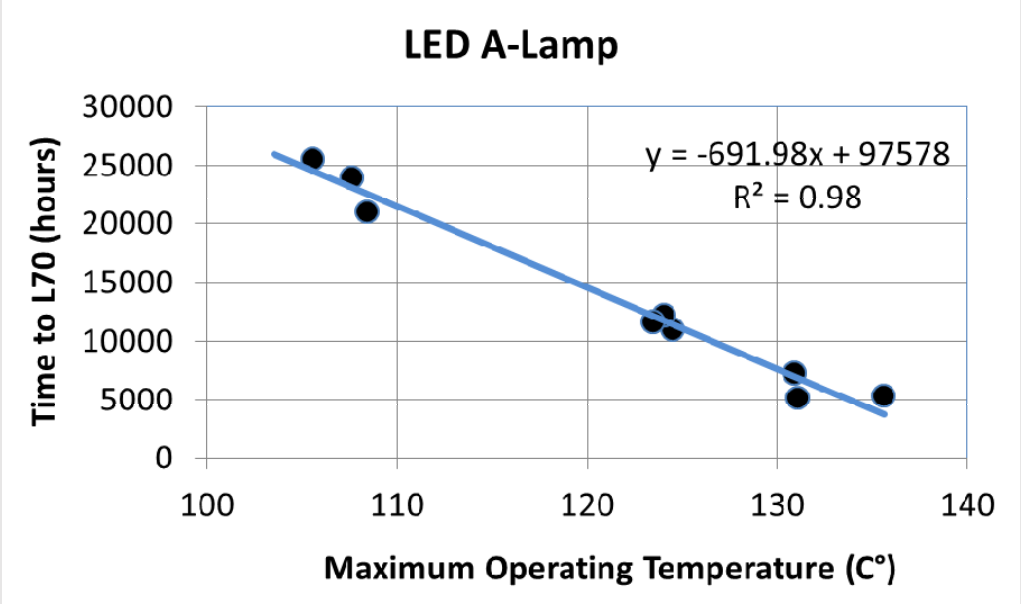
Lumen depreciation at failure



Results: A-lamp lumen depreciation

For the product tested:

- Time to failure, projected L70 as a function of maximum operating temperature, shows an inverse linear relationship
  - Goodness-of-fit (R^2) > 0.9
- The projected L70 values are similar for each delta T condition
  - Cycling has minimum effect



Maximum operating temperature (°C)

Delta T	Dwell time		
	2 hrs	4 hrs	Continuous on
80°C	106°C	108°C	108°C
90 °C	125°C	124°C	124°C
100°C	131°C	136°C	131°C

Time to failure (L70 in hours)

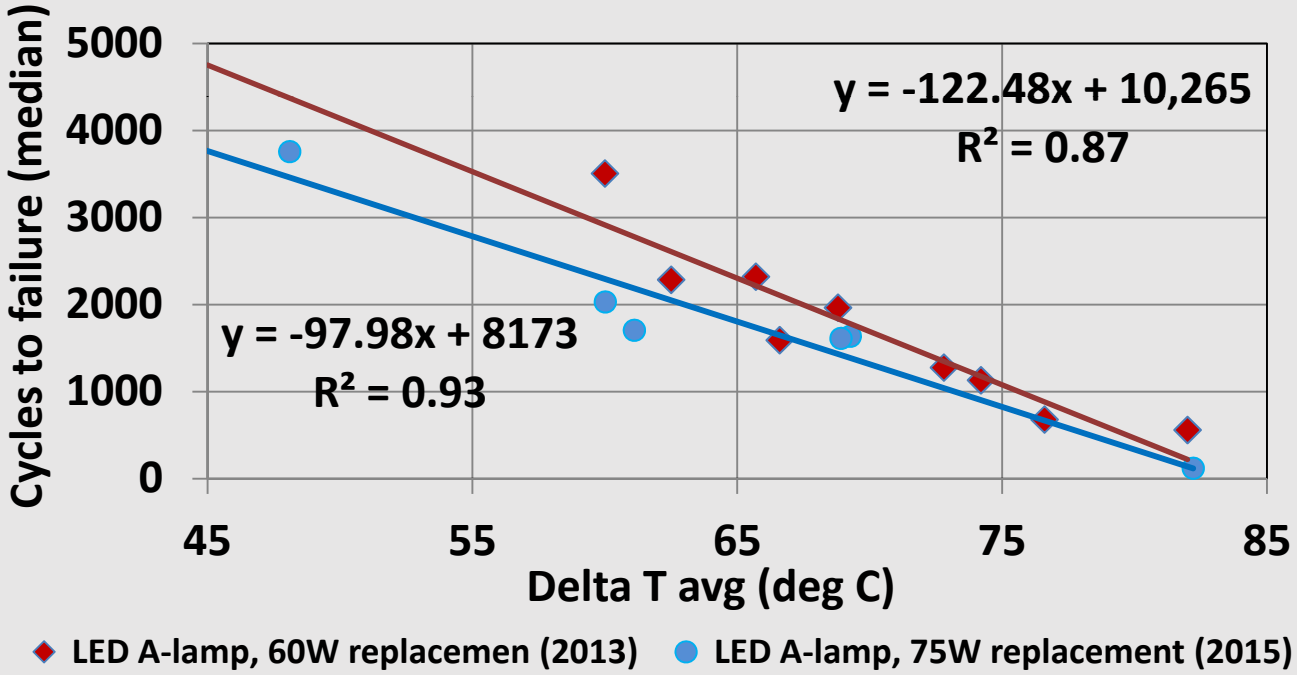
Delta T	Dwell time		
	2 hrs	4 hrs	Continuous on
80°C	25,528	20,998	23,979
90 °C	11,019	12,185	11,657
100°C	7,289	5,308	5,171

Results: A-lamp

- Study results show for the LED A-lamps tested
  - Both failure types exist
    - Catastrophic
      - ON-OFF cycling (dynamic stress) influenced catastrophic failure
    - Parametric
      - Maximum operating temperature influenced lumen depreciation
- Shorter of the two determines the lifetime of the system in a given application
  - Catastrophic failure time is shorter than lumen depreciation, L70
    - Strong case for including switching ON and OFF into test methods
- Contrary to conventional wisdom, switching LED systems on and off can shorten lamp life.

Results: A-lamp

- Results from two LED A-lamp life tests
  - The 60W equivalent product was procured in 2013
  - The 75W equivalent product was procured in 2015



Usefulness of test method

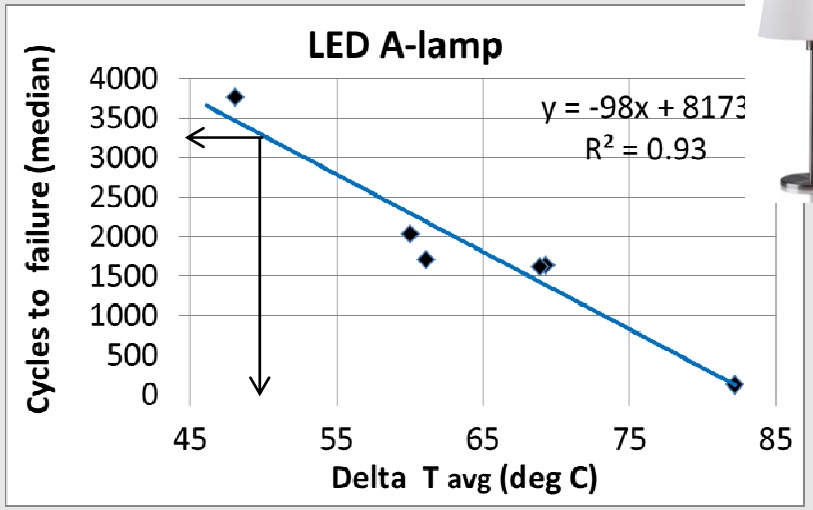
LED A-lamp life estimation in an application

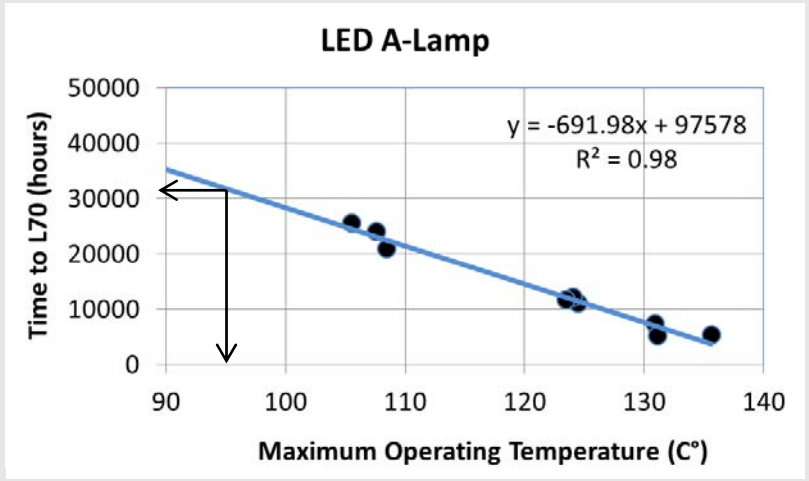
- To illustrate the usefulness of this test method and results, two applications where the same lamp can be used were selected and their lamp life in each application was estimated.

Example 1: LED Table lamp

- Used 3 hours per day
  - Maximum Tj = 95°C at Troom 30°C
  - Delta $T_{avg} = T_{avg} - T_{room} = 50°C$

  Estimated median lamp life
  - Catastrophic : 3250 cycles = 8.9 yrs
  - L70: 32,000 hrs = 29 yrs
- Lamp life = 8.9 years





LED A-lamp life estimation in applications

- The tested LED A-lamp
  - In a table lamp will last 8.9 years
  - In a non-IC downlight will last 1.9 years

Table lamp

Non-IC downlight

Summary

- Failure types include both catastrophic and parametric.
- Contrary to conventional wisdom, switching LED systems on and off can shorten lamp life.
- Cycles-to-failure (catastrophic) has a high correlation to time-averaged delta temperature.
- Time-to-L70 (parametric failure) has a high correlation to maximum operating temperature.
- The proposed test method can help predict LED system life in any application if Tj and use pattern (ON-OFF cycling) are known.
- For more information:

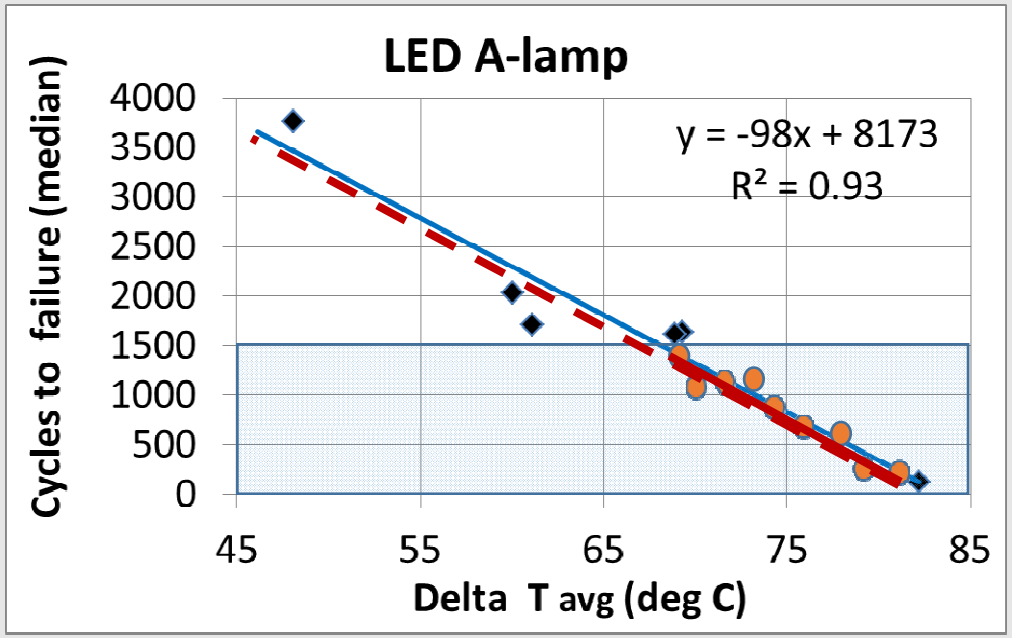
Narendran, N., Y. Liu, X. Mou, D.R. Thotagamuwa, and O.V. Madihe Eshwarage. 2016. Projecting LED product life based on application. *Proceedings of SPIE* 9954, Fifteenth International Conference on Solid State Lighting and LED-based Illumination Systems, 99540G (September 14, 2016); doi: 10.1117/12.2240464.

http://www.lrc.rpi.edu/programs/solidstate/pdf/Narendran-SPIE2016-99540G.pdf

Final thought

Duration of life testing

- By selecting suitable DT and dwell time, the cycles to failure can be restricted to within 1500.
  - Time to failure within 3000 hours
  - Data extrapolation can be used to determine cycles to failure at lower temperatures
- Test time can be 3000 hours or less



Acknowledgments

- Bonneville Power Administration (BPA Technology Innovation Project # 322), New York State Energy Research & Development Authority (NYSERDA contract # 46905), and Alliance for Solid-State Illumination Systems and Technologies (ASSIST) for their financial support for this study
  - Levin Nock - BPA, Janice Peterson - BPA, and Marsha Walton - NYSERDA

- Jennifer Taylor, Martin Overington, Jean Paul Freyssinier, Indika Perera, Howard Ohlhous, Dexter Taylor, Antonio Capó, and Abhinay Sandupatla of Rensselaer's Lighting Research Center for their valuable contributions to the project.

- US Environmental Protection Agency

Thank you

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