SSL System Reliability Prediction Method

February 11, 2013

ASSIST
Alliance for Solid-State Illumination Systems and Technologies

Lighting Research Center

Projects August 2012-July 2013

	Funds allocated
Project A. Color rendering metrics	$75,000
Project B. Secondary optics reliability and LED lens temp measurement	$50,000
Project C. Color shift research, contribution from other components in the system	$50,000
Project D. Expand dimming definition and add metric for dimmer compatibility (funds allocated here will include standards support for flicker as well)	$35,000
Project E. Accelerated and improved photometric testing	$50,000
Project F. SSL summer research internship	$75,000
Project G. System reliability: expand current program to include vibration	$40,000
Project H. Annotated bibliography of selected topics	$0*
ASSIST Operations (administration, website, meeting costs, etc.)	$75,000
Total	**$450,000**

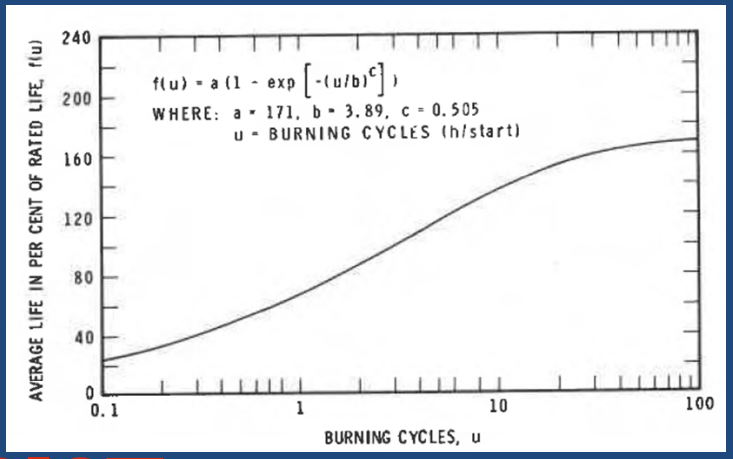
* Project H will be completed within the administrative budget for 2012-2013.

Study Objective

- To develop an accelerated test method that can predict the failure of LED luminaires under realistic operating conditions (catastrophic failure).
  - To predict lifetime based on factors such as:
    - application temperature, on-off cycling, and others if applicable.

- Similar to linear fluorescent lamp

Effect of burning cycles on average lamp life for fluorescent lamps



1. F.J. Vorlander and E. H. Raddin, "The effect of operating cycles on fluorescent lamp performance," ***Illuminating Eng.,*** pp. 21-27, Jan. 1950.
2. "Fluorescents-on/off," *Lighting Design Appl.* vol. 3, pp. 38-39,Jan. 1973.
3. L.A. Carriere. M.S. Rea "Economics of Switching Fluorescent Lamps," *IEEE Trans. on Industry Applications* Vol. 24, No. 3, May/June 1988, p. 370-379.

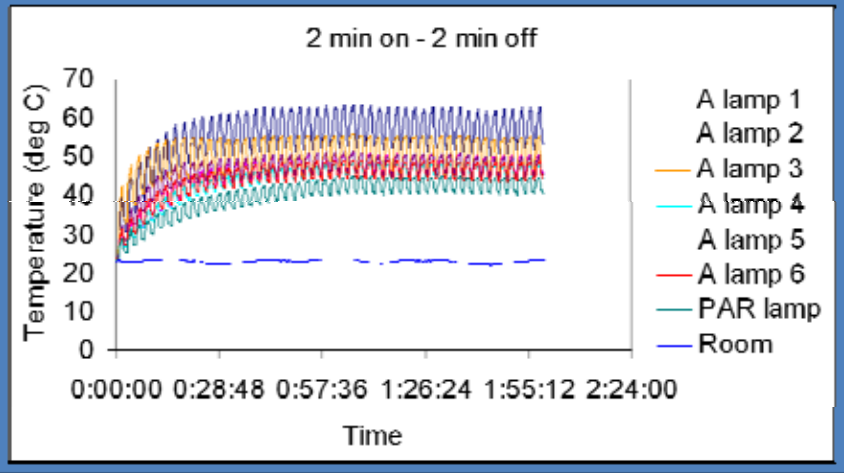
Background

- ENERGY STAR Program
  - Rapid-cycle stress test
    - 2 min ON / 2 min OFF
- 2009 LRC study:
  - Showed that 2 min ON / 2 min OFF introduces only a small DT, and therefore the damage that leads to failure may be small.

Rapid-Cycle Stress Test	Cycle times must be 2 minutes on, 2 minutes off. Lamp will be cycled once for every two hours of L_{70} life.

Rapid Cycle Stress Test: All Lamps

Lamp Type	ENERGY STAR Requirements	Methods of Measurement and/or Reference Documents	Supplemental Testing Guidance
All Lamps	Lamp shall survive cycling once for every hour of rated life (minimum of 10,000 cycles). Each cycle shall be 5 minutes on, 5 minutes off.	Measurement: IES LM-65-10 (clauses 2,3,5,6) ANSI C78.5-2003	For dimmable/2-way/3-way products, measurements shall be made at the highest wattage setting listed for the model. **Sample Size**: 10 lamps per model: 5 units tested base-up and 5 units tested base-down unless the manufacturer restricts specific use or position. If position is restricted, all units shall be tested in restricted position. The sample shall be a unique sample for this test. **Passing Test**: ≥ 9 units shall survive the minimum number of cycles.



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Background

- Real-life light fixture cycling pattern:
  - Office:
    - 6am to 6pm (12 hrs on, 12 hrs off)
  - Home:
    - 6am to 10am, 6pm to 10pm (4 hrs on, 4 hrs off)

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

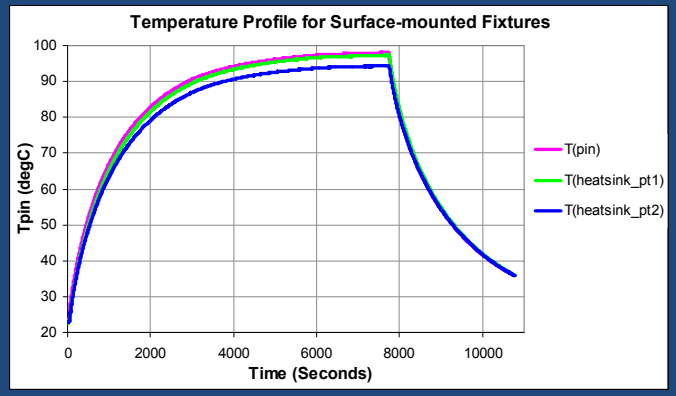
http://www.ledsource.com/products/residential

- LRC pilot studies identified the following acceleration parameters:
  - ΔT, Max. Tj, Ramp rate, Dwell time

- Final study started October 2010

Pilot study

- Objective
  - To identify the pin temperature of the LEDs when the lamps are placed inside a surface-mounted luminaire
- Test set-up
  - 3 LED integral lamps in a surface-mounted fixture
- Results:
  - Max T pin = 98°C
  - Min T pin = 23°C
  - Delta T pin= 75°C



Study #1

- Selected system – LED Integral lamp (G25)

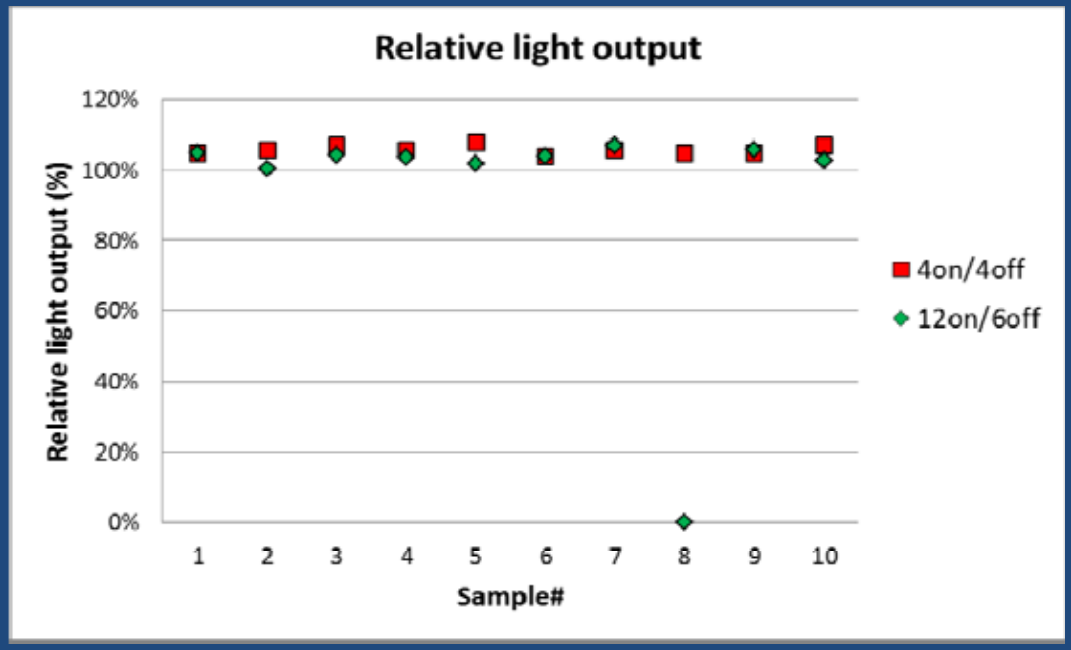
- Test conditions:
  - Realistic
    - (12hrs on/6hrs off, 4hrs on/4hrs off)
  - Delta T
  - T max
  - Ramp rate
  - Dwell time

Results: Realistic Conditions

Status
As of Jan-24-2013, only 1 catastrophic failure

Test item	# of samples
4 hrs on-4 hrs off	10
12 hrs on- 6 hrs off	10

Min. T	25°C
Max. T	95°C
ΔT	70°C
Dwell time*	1 hr (4 hrs on); 9 hr (12 hrs on)
Ramp rate*	0.6°C/min



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Results: Dwell Time

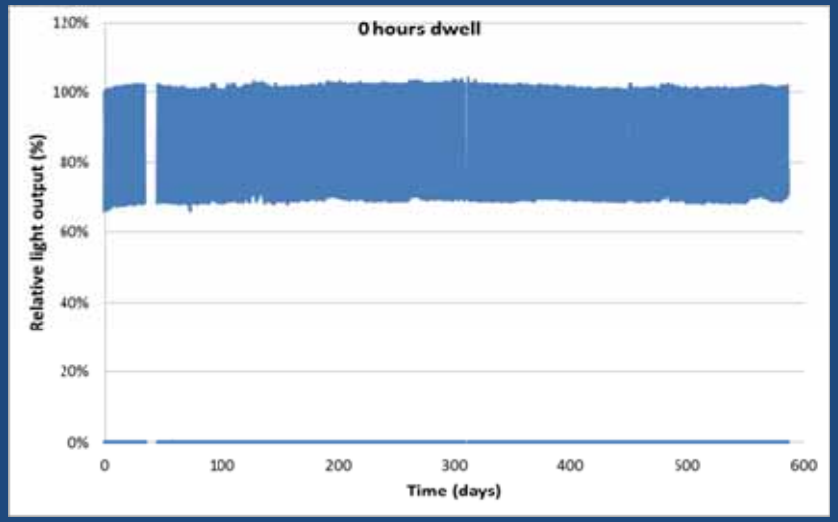
Status

As of Jan-24-2013

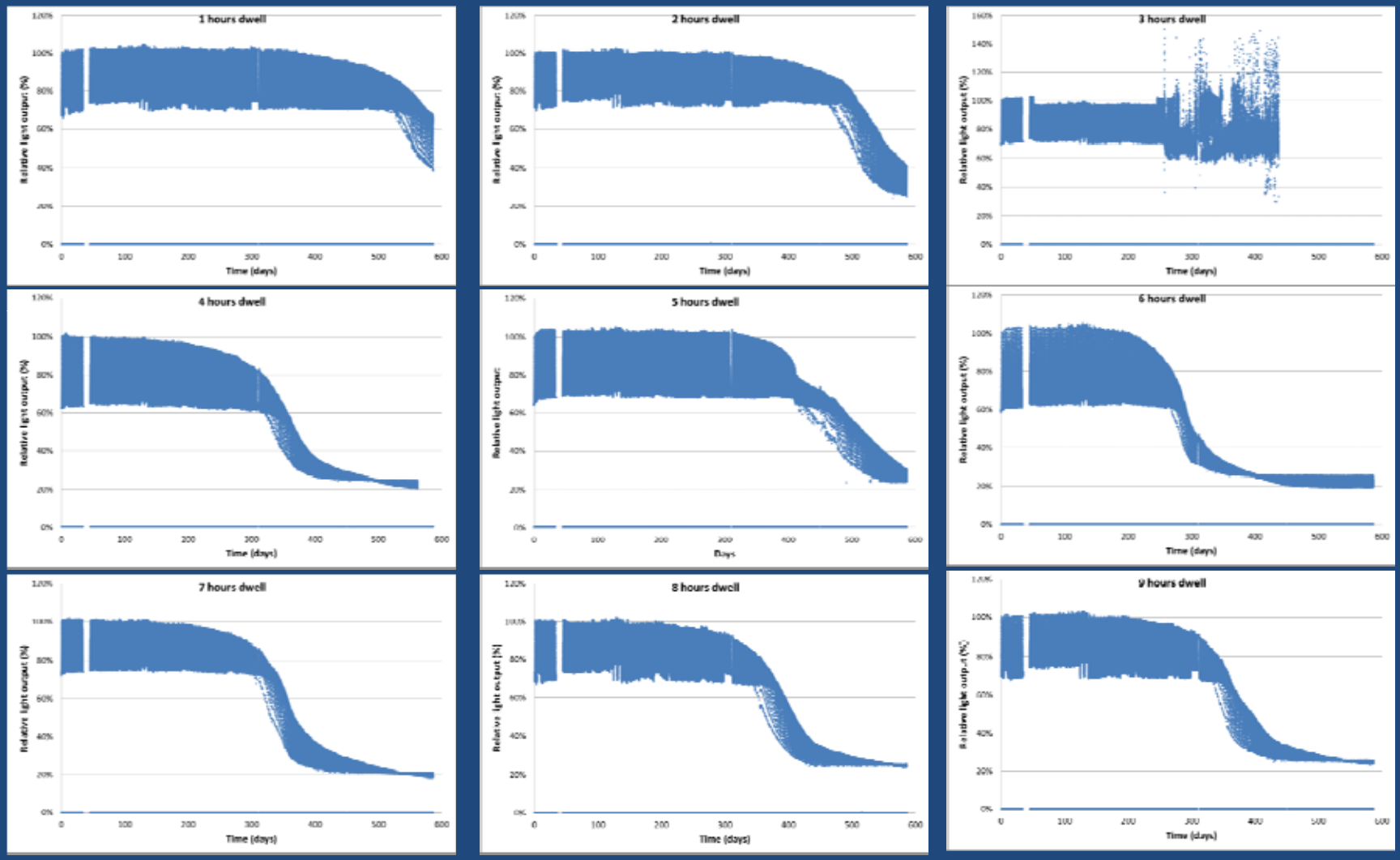
- Δ70°C group: 1 catastrophic failure / all others no failure or lumen depreciation
- Δ95°C group: 1 catastrophic failure / all others significant lumen depreciation

Conditions	# of test samples
Dwell time (Profile 1, Profile 2)	**10 * 2**

Thermal Condition	#1	#2
Min. T	25°C	25°C
Max. T	95°C	120°C
ΔT	70°C	95°C
Dwell time* hrs	0,1,2,3,4,5,6,7,8,9	0,1,2,3,4,5,6,7,8,9
Ramp rate*	0.6°C/min	1.2°C/min



Results: Delta 95°C – Dwell time study



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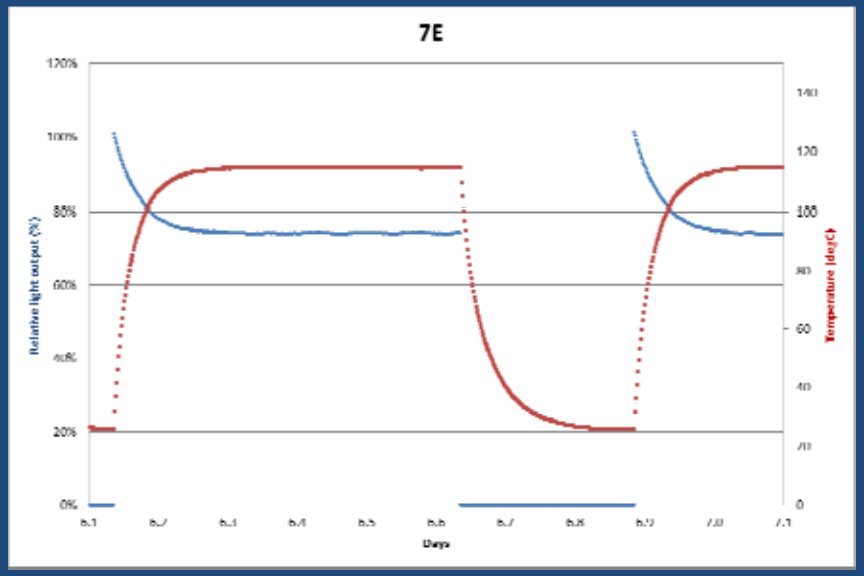
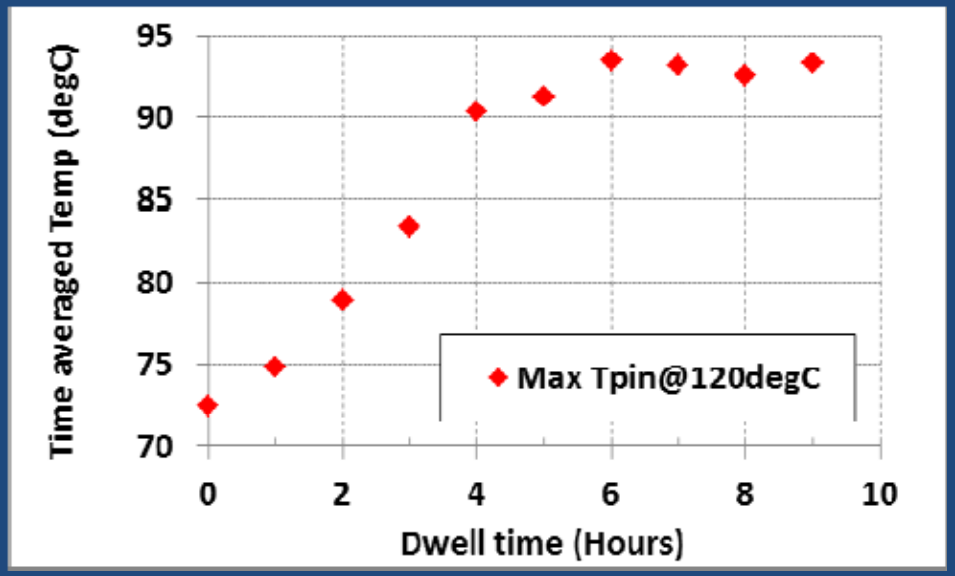
Time-averaged temperature

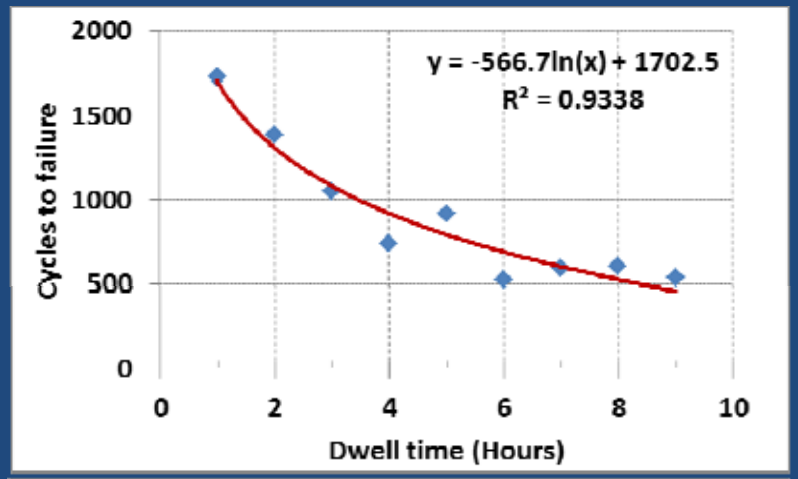
- Failure should correspond to time-averaged temperature of the cycles
  - Higher time-averaged temperature at larger dwell times
    - Greater damage to the system components at higher temperatures

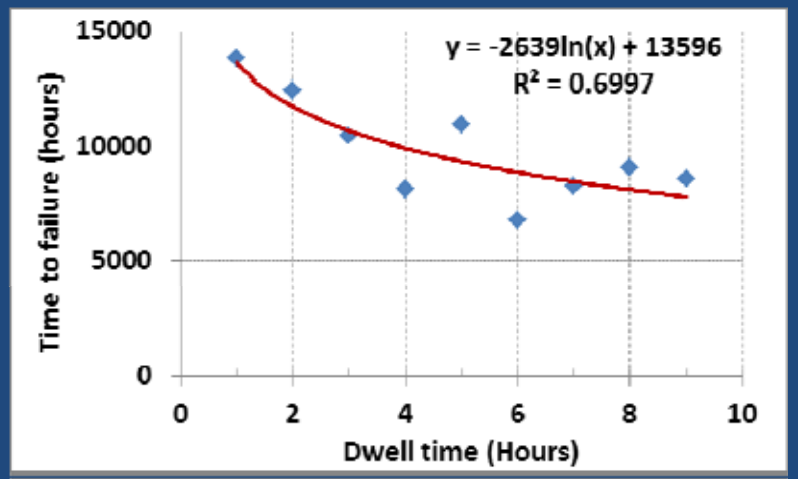


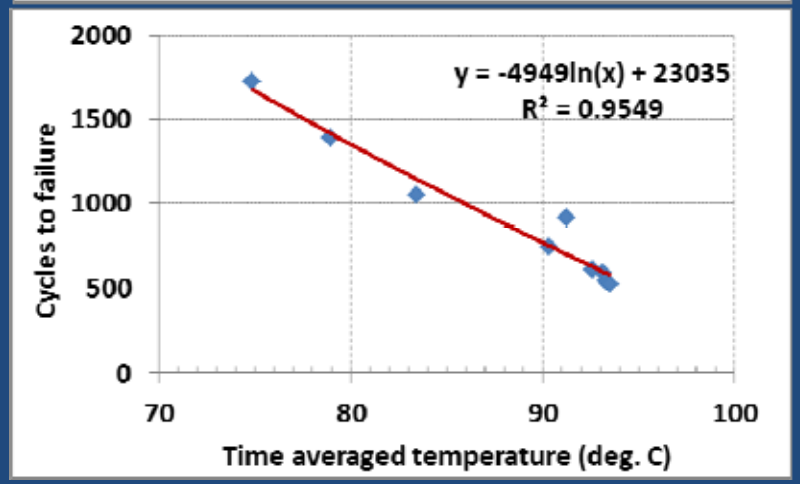


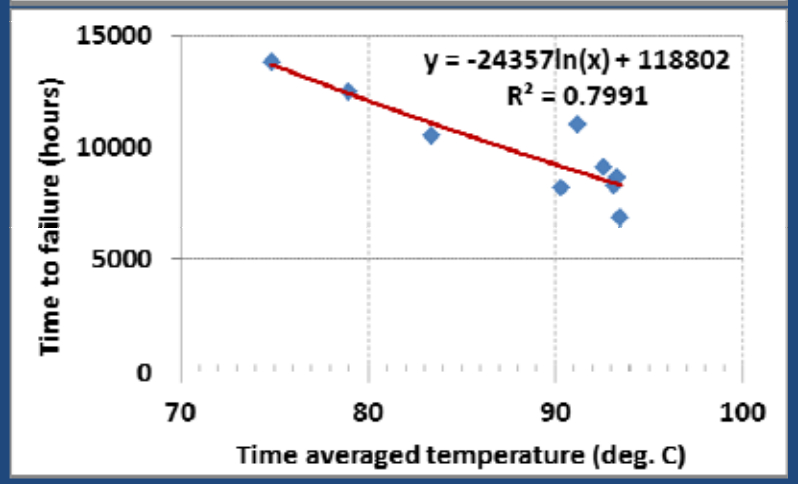
Results

- Failure assumption: 70% light level



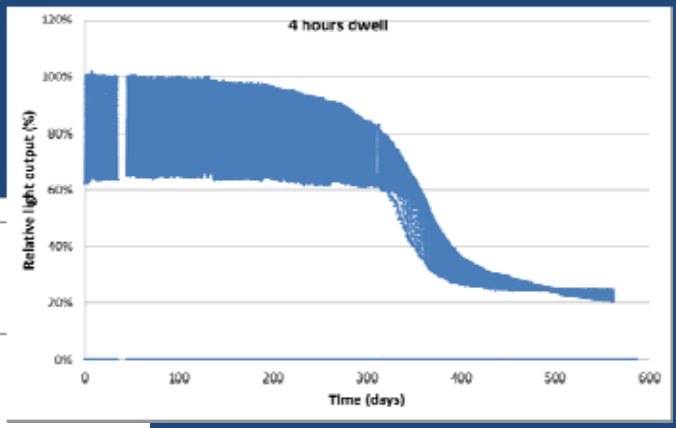


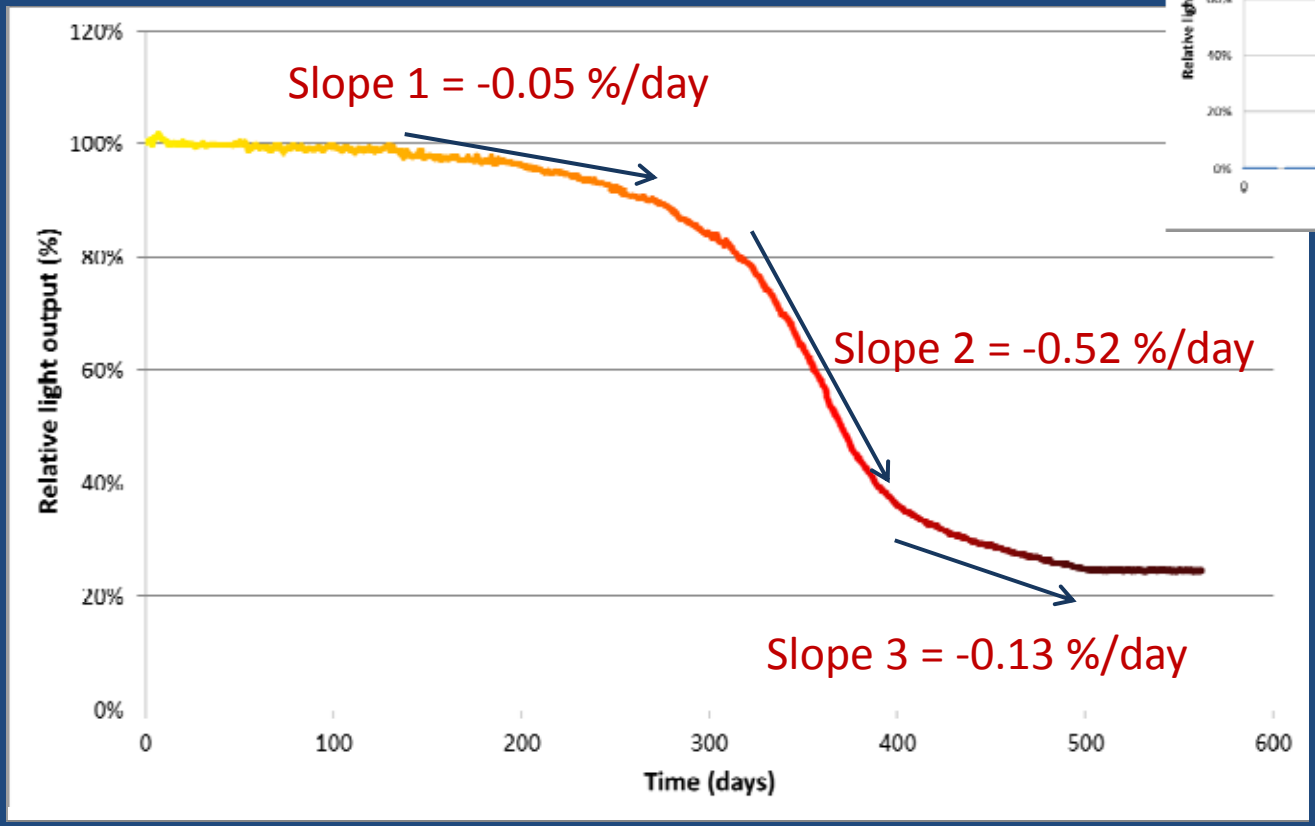




General depreciation pattern

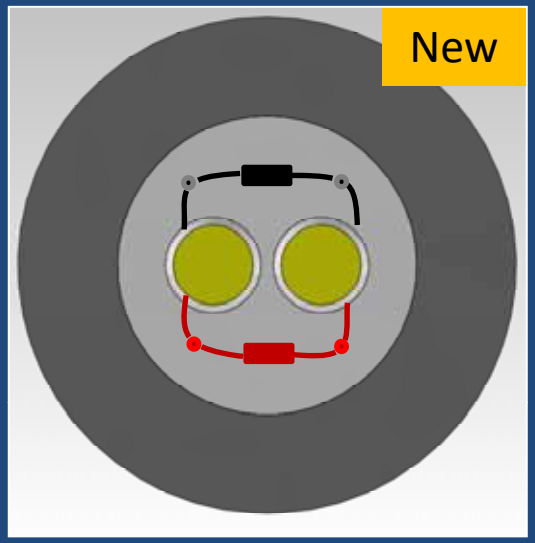
- Multiple degradation factors:
  - Loss - 1 % every 18.8 / 1.9 / 7.5 days

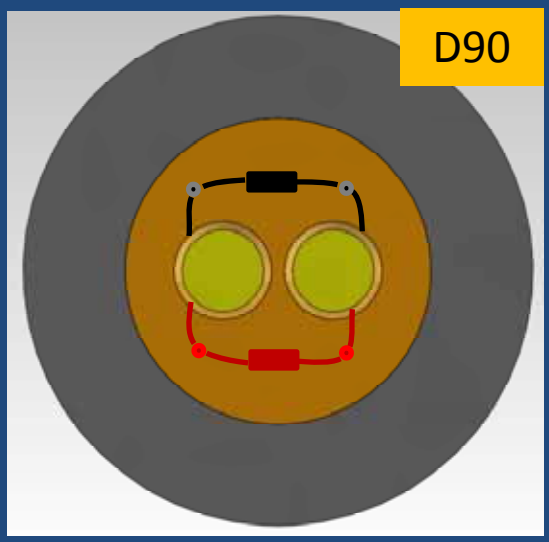




*4 hours dwell sample

Failure analysis





Measured Terminals

Lamp A	Series Resistance LED 1 (Ω)	Series Resistance LED 2 (Ω)	Equivalent resistance (Ω)	Current through LED package (mA)
New Lamp A	35.5	36.6	18.0	96
Lamp at delta 70°C	46.2	37.4	20.7	82
Lamp at delta 95°C	46.0	42.7	22.1	66

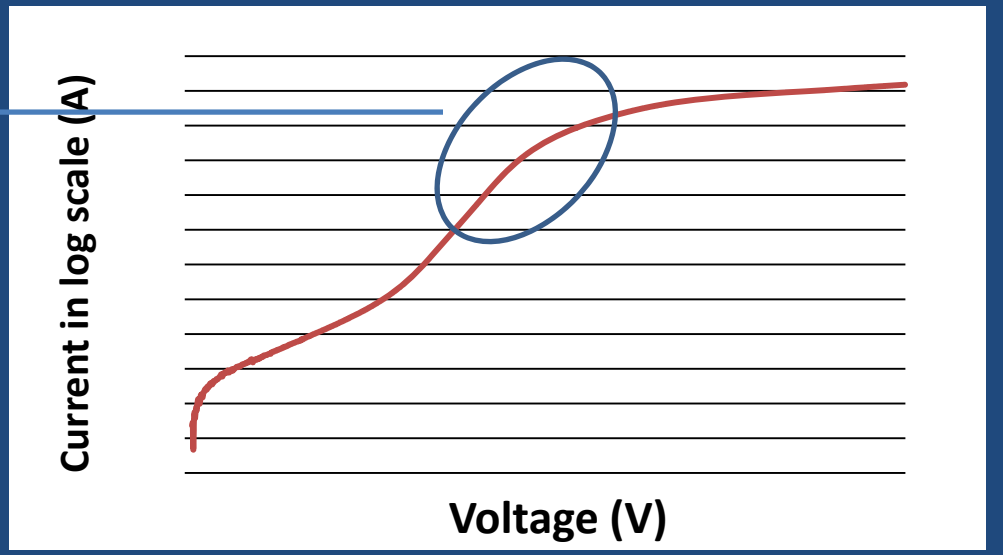
Package Series Resistance

- The LED package was disconnected from the driver of the integral lamp.
- The two terminals of the package are connected to a source measure unit, and an IV trace of the package is obtained.
- The series resistance is extracted from the IV trace.

$$\frac{I}{g_d} = \frac{nKT}{q} + Ir_s$$

$$g_d = \frac{dI}{dV}$$

n: Ideality factor
q: absolute value of electron charge
K: Boltzmann's constant
T: absolute temperature
r_s: Series resistance
I: Current



References: D.K. Schroder, 2006; M.Shur, 1996, W.R. Runyan, 1975

Summary

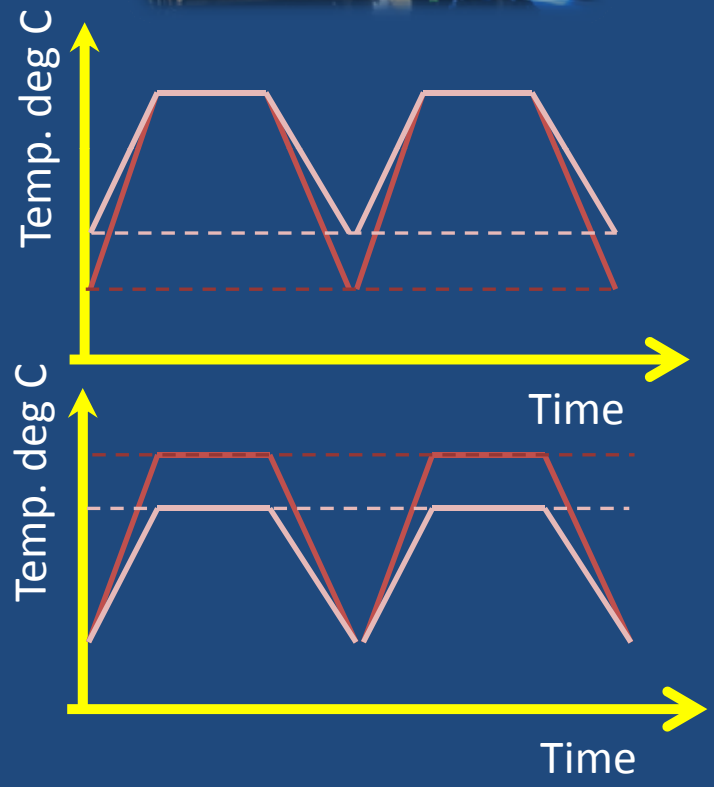
- For the selected product
  - Cycling without dwell time did not show any degradation or failure
  - Cycling with dwell time showed no catastrophic failure, but showed gradual light output decrease due to multiple failure modes
    - Electrical parameter changes
      - Driver; LED; Circuit
    - Optical changes
      - Age-related color changes within package (reflectivity)
  - Cycles to failure has better correlation than time to failure with dwell time (and time-averaged temperature) at 95°C delta temperature cycling

Study #2

- Selected system – LED Integral A-Lamp
  - Varying delta T and dwell time
    - Same T max
    - Same T min

$T_{Ambient}$=25°C, Dwell Time=2 hours, Ramp rate=5°C/min				
Sample	Lamp 4	Lamp 4	Lamp 4	Lamp 4
Min. T	60°C	50°C	40°C	30°C
Max. T	120°C	120°C	120°C	120°C
ΔT	**60°C**	**70°C**	**80°C**	**90°C**
Ramp rate	**5°C/min**	**5°C/min**	**5°C/min**	**5°C/min**

$T_{Ambient}$=25°C, Dwell Time=2 hours, Ramp rate=5°C/min				
Sample	Lamp 4	Lamp 4	Lamp 4	Lamp 4
Min. T	30°C	30°C	30°C	30°C
Max. T	90°C	100°C	110°C	120°C
ΔT	**60°C**	**70°C**	**80°C**	**90°C**
Ramp rate	**5°C/min**	**5°C/min**	**5°C/min**	**5°C/min**



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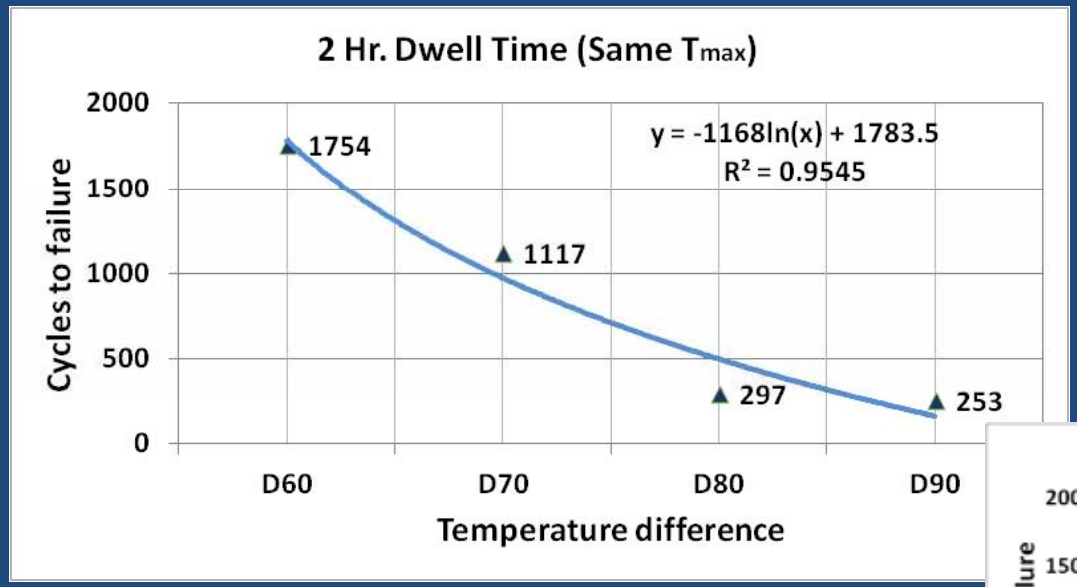
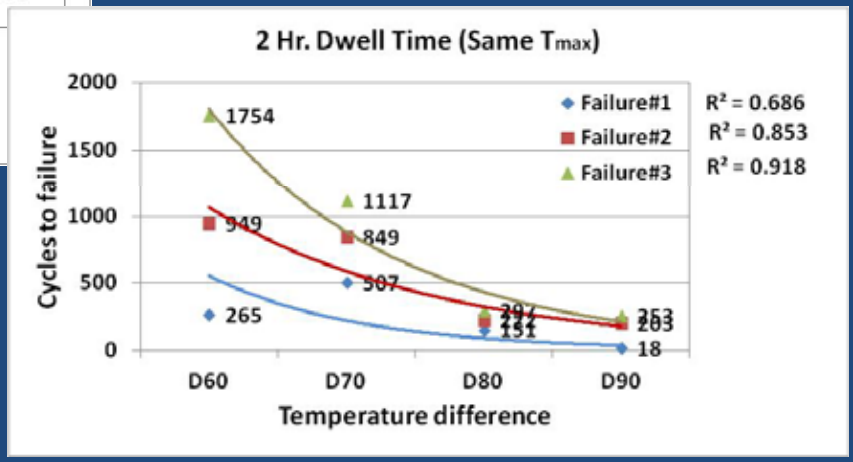
Results: 2 hr dwell time (Same T_{max})

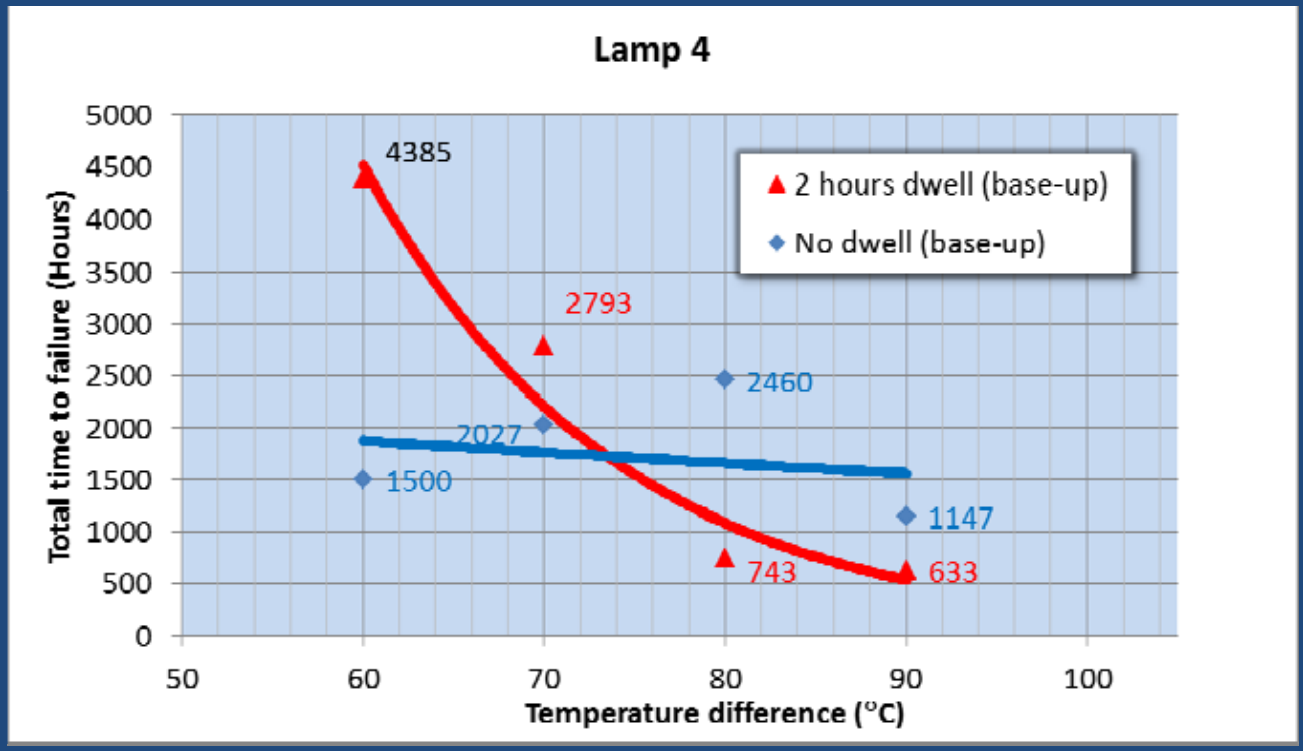
- Cycles to failure shows good relationship with delta T
  - Possible failure reason: Solder joint disintegration





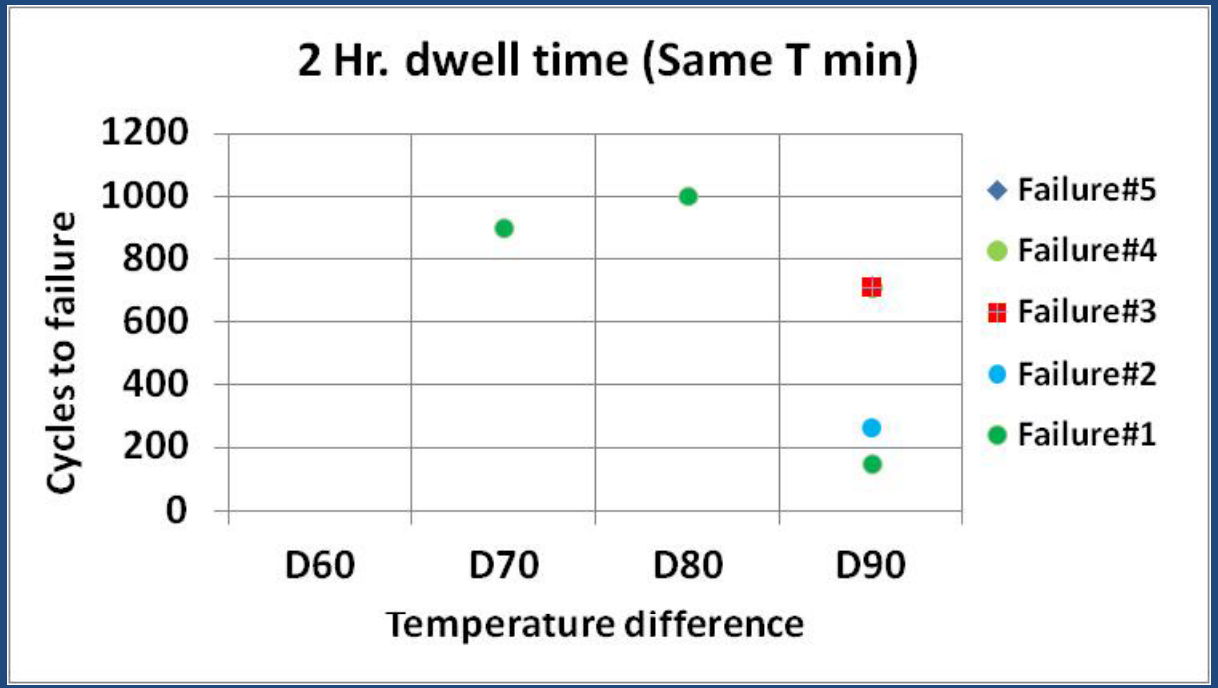
Results: No dwell time (Same T max)

- No dwell time case did not show any relationship as a function of delta T



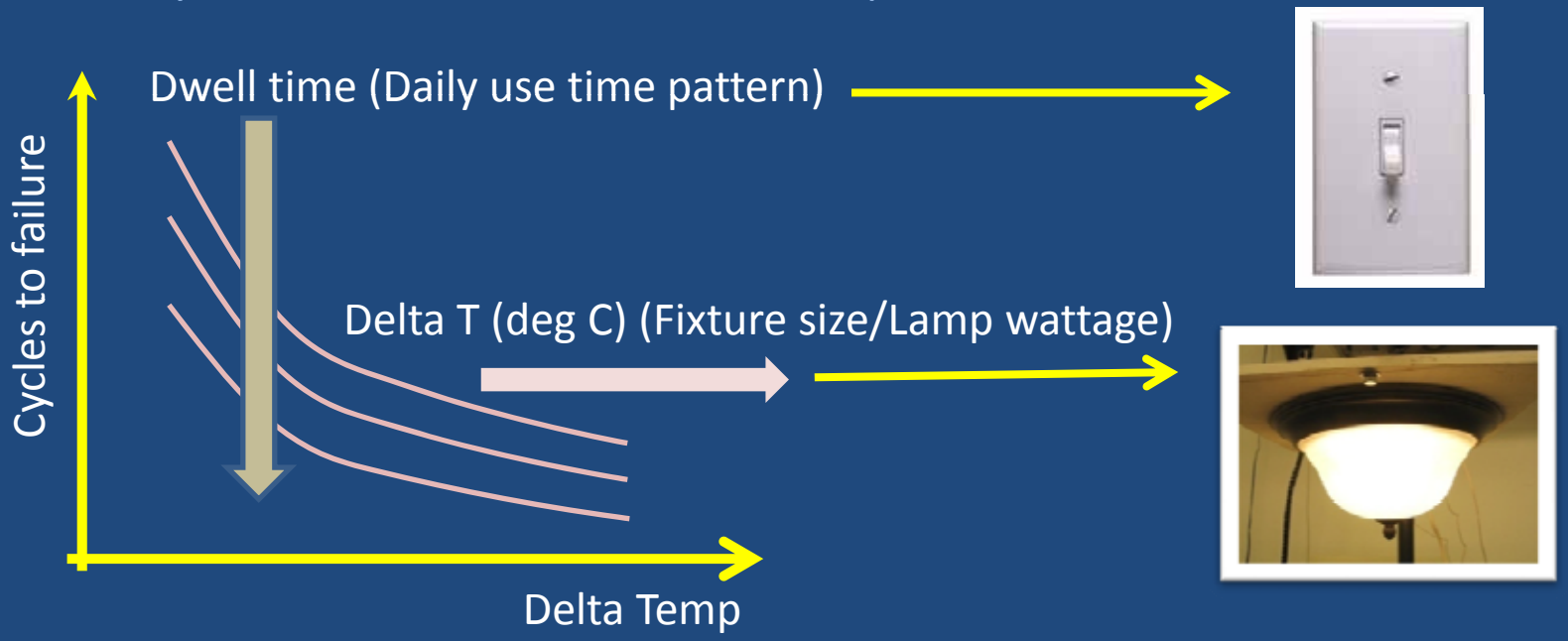
Results: 2 hr dwell time (Same T min)

- With same T min the maximum and time averaged temperature will be lowest for D60 and highest for D90.
  - This a is more likely scenario in real life rather than same T max.
  - Time to gather data may be longer than same T max case



Summary

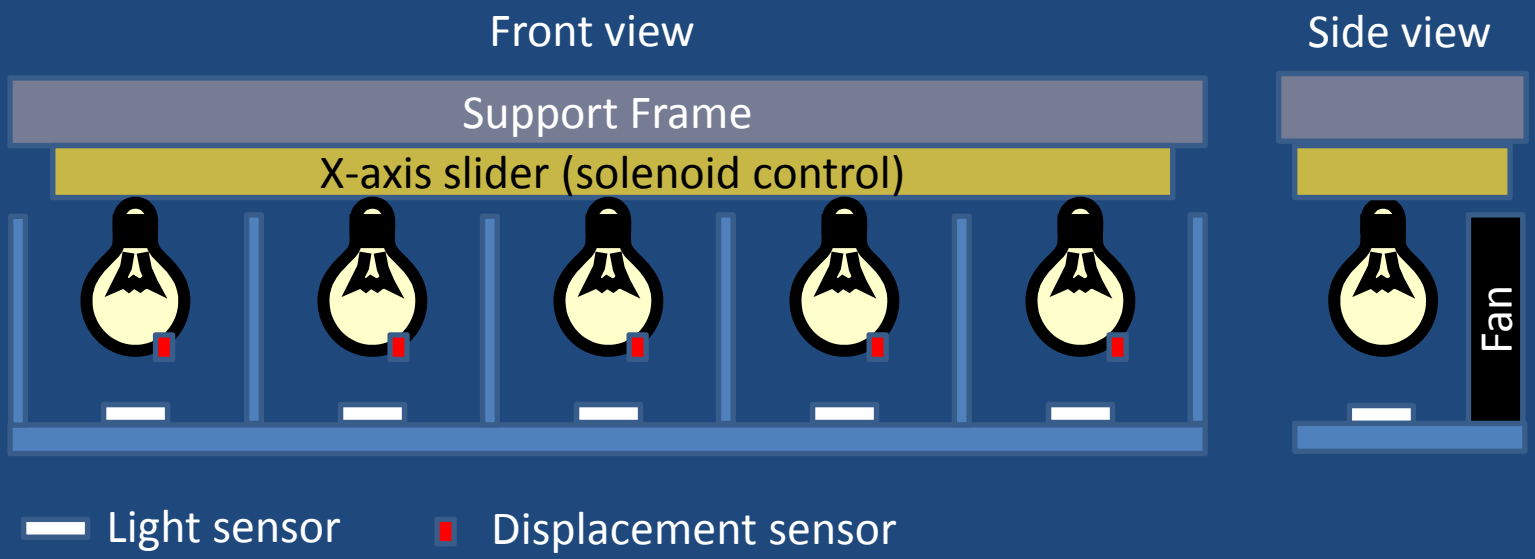
- Failure acceleration to predict system life
  - Looking for relationships between
    - cycle or time to failure and dwell time
    - cycle or time to failure and delta temperature



- Additional experiment: Added vibration to the test setup

Vibration test setup

- IEC/MIL standard were referenced
  - X axis movement
  - Lamp resonance frequency



*IEC 60068-2-6 standard , Environmental testing –Part 2,Vibration (sinusoidal)
*MIL-STD-202G, Electronic and electrical component parts

Discussion

- Presently used industry standards for rapid cycle testing (2 min On / 2 min Off) has very little value for reliability testing
  - Faster cycles cause small temperature swings on system components.
    - Thus very little damage to system components

- Failure modes will differ significantly between products/brands
  - However, delta T and dwell time at maximum temperature may show good relationship with cycles/or time to failure
    - Thus, allowing for system lifetime prediction in applications