Long-Term Photometric Performance of Airfield Luminaires

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Background

- LED-based solutions offer many potential benefits for airfield applications
  - Energy savings
  - Long life
    - More reliable operation
    - Reduced maintenance costs
- However, LED systems are relatively new and there are not sufficient data about long-term performance.

Background: Economic viability

- The initial cost of LED-based luminaires can be significantly higher than that of traditional luminaires
  - Life-cycle cost effectiveness is determined by potential energy and maintenance savings, and
  - the life cycle cost can only be determined if a realistic useful life value is known.
- Knowing the useful life of a luminaire allows planning and execution of preventive maintenance without disruption of airport operations.

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Background: Photometric performance

- A functional definition of life is needed for LED airfield luminaires
  - Life of existing luminaires is well understood due to the predictable nature of incandescent lamps
    - Light output depreciation relatively small before lamp fails
  - LED-based solutions will have differing performance depending on the system integration and the application environmental conditions
  - Safe airport operations depend on the adequate photometric performance of luminaires at all times

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Useful life: A definition

- Luminaires are expected to provide the required photometric characteristics for the length of their useful life, thus:
  - Useful life is the time until a given luminaire falls out of photometric specifications in terms of intensity distribution or color.
  - Luminaire life should not be based on L_{70} values for LEDs alone.

Goal of the study

- The goal of this study is to gather data on light output depreciation, color shift, and intensity distribution changes from different types of luminaires under different temperatures of operations
- This study
  - does not consider catastrophic failure
  - does not consider the effect of power quality on driver performance

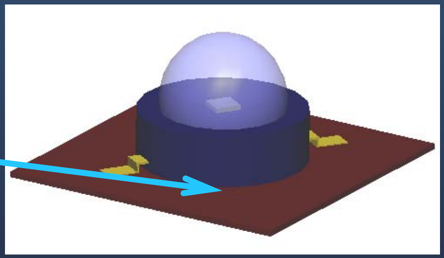
Protocol for testing

- Photometric characterization of luminaires
  - Measured intensity distribution using bar photometer
- Operation of luminaires at constant 6.6 A
  - At three pre-selected LED board temperatures
  - ~ 55°C, 80°C, 100°C (similar to IES LM-80-08)
- Gathered relative light output and spectral power distribution (SPD) every ~1000 h for 10,000 h
- Final intensity distribution measured at the end of test period
- Determined percent light output depreciation, and color and intensity distribution shift over test period

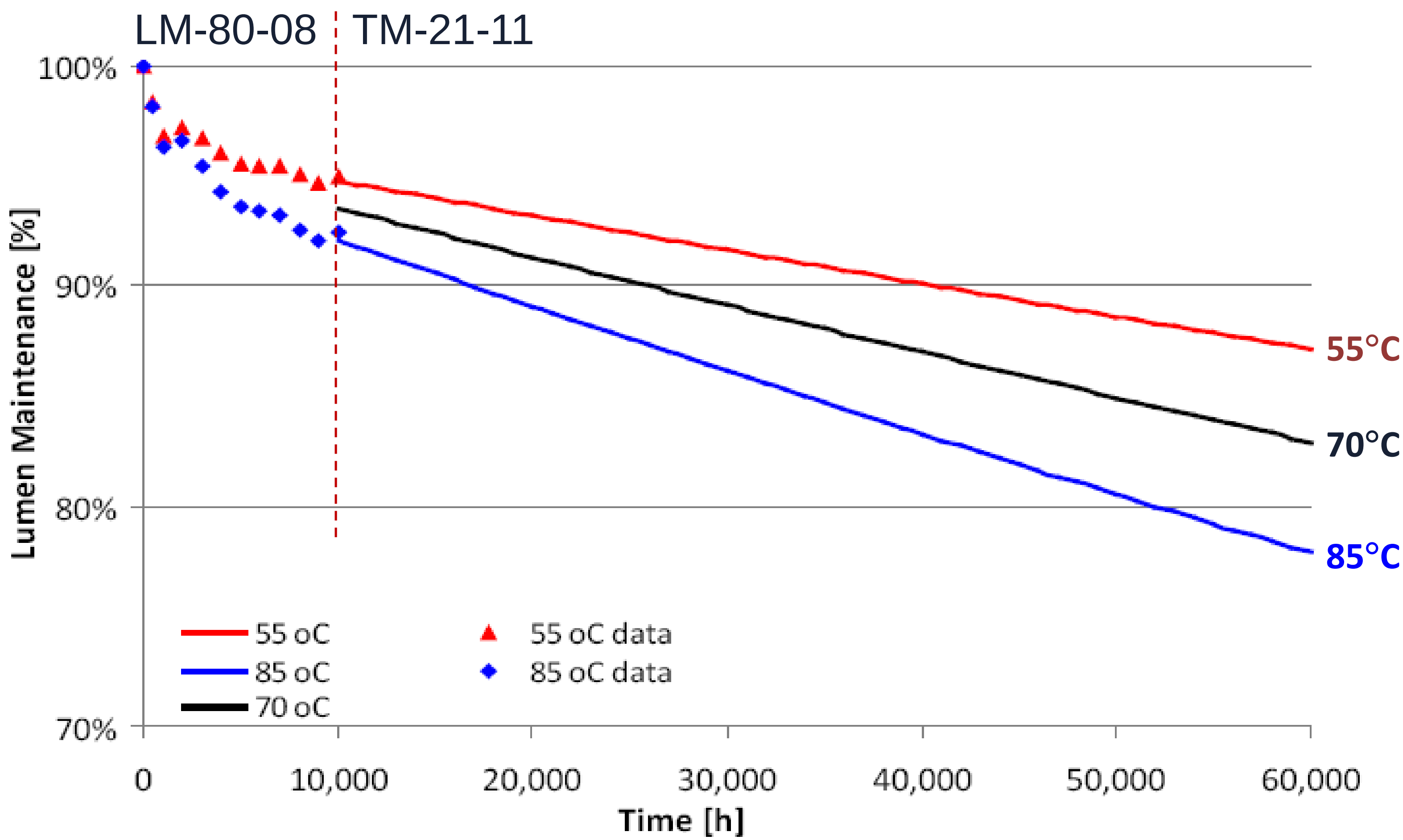
IES LM-80-08

- Operation at three case temperatures: 55°C, 85°C, and a 3rd value specified by the manufacturer, all at the same drive current.
  - Case temperature: X (-2°C)
  - The temperature of the surrounding air: X (-5°C)
  - Relative humidity should be less than 65%

Ts, thermocouple at the test point specified by LED manufacturer



Example IES LM-80 + TM-21 Interpolation at 70°C



Tuttle, R. et al., 2011. TM-21 Update: Method for Projecting Lumen Maintenance of LEDs. CORM 2011 Technical Conference.

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IES TM-21: Interpolation

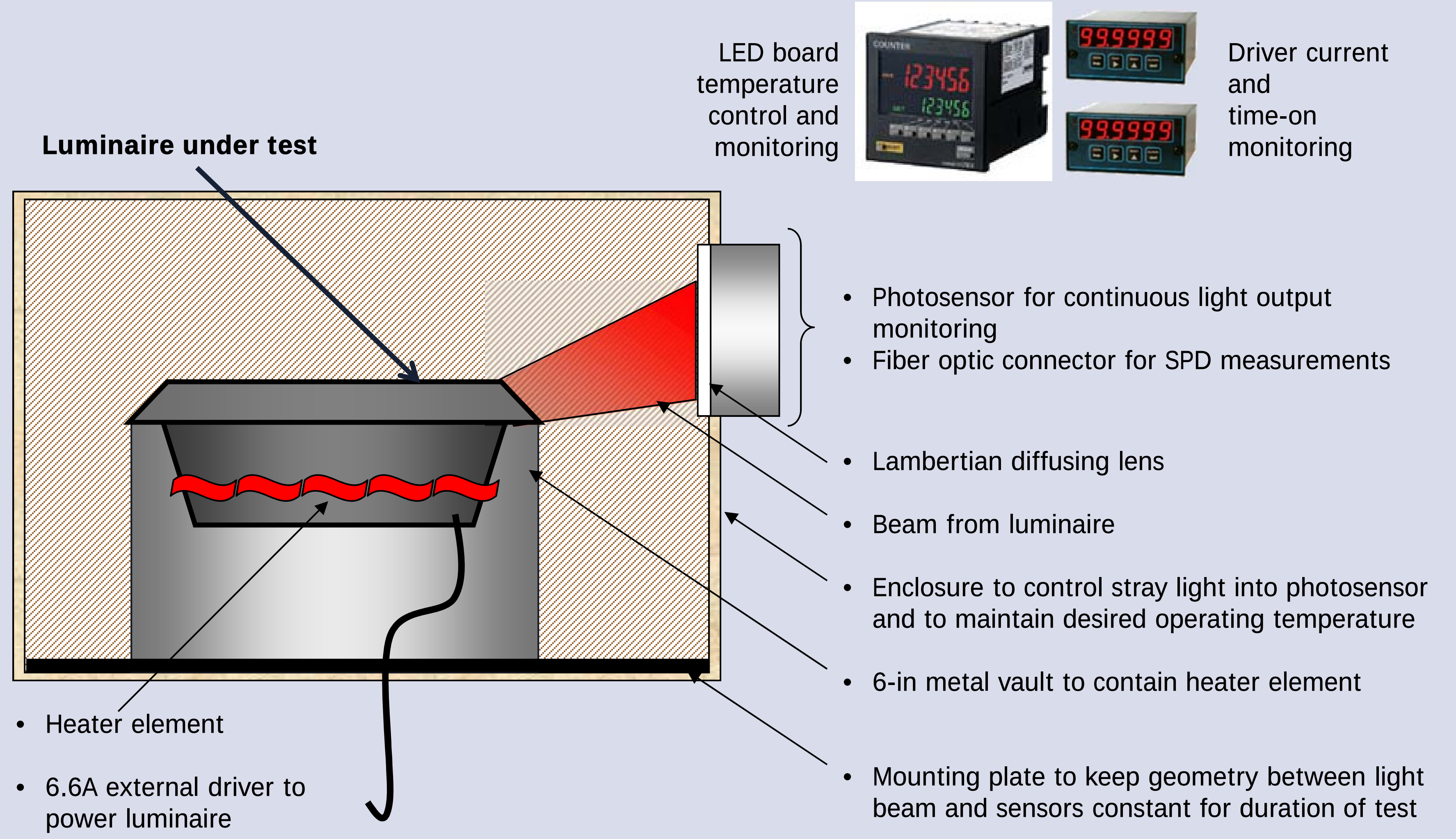
- Temperature interpolation
  - Arrhenius equation to calculate in-situ decay rate constant:

$$\alpha_i = A\exp\left(\frac{-E_a}{k_B T_{s,i}}\right)$$

A = pre-exponential factor;
E_a = activation energy (in eV);
$T_{s,i}$ = in-situ absolute temperature (in K);
k_B= Boltzmann's constant (8.6173×10^{-5} eV/K)

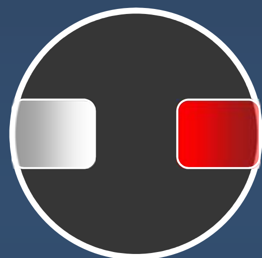
Tuttle, R. et al., 2011. TM-21 Update: Method for Projecting Lumen Maintenance of LEDs. CORM 2011 Technical Conference.

Schematic of test setup



Samples tested

- Three red/white directional Runway Centerline luminaires



- Three white Touchdown Zone luminaires

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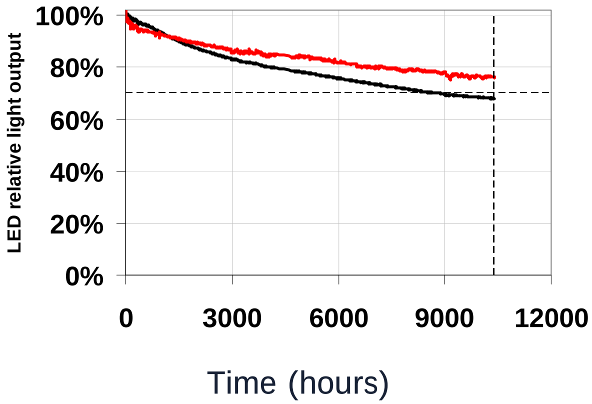
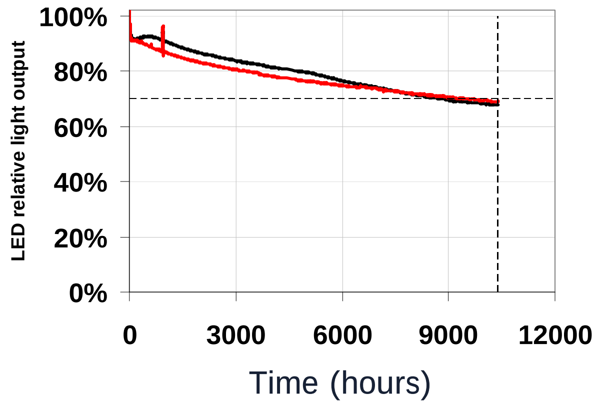
Runway Centerline luminaires
Light output depreciation

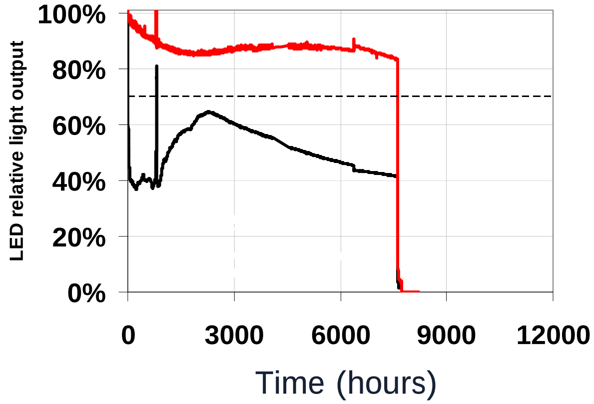
A0 (59 °C)



A2 (80 °C)



A3 (100 °C)

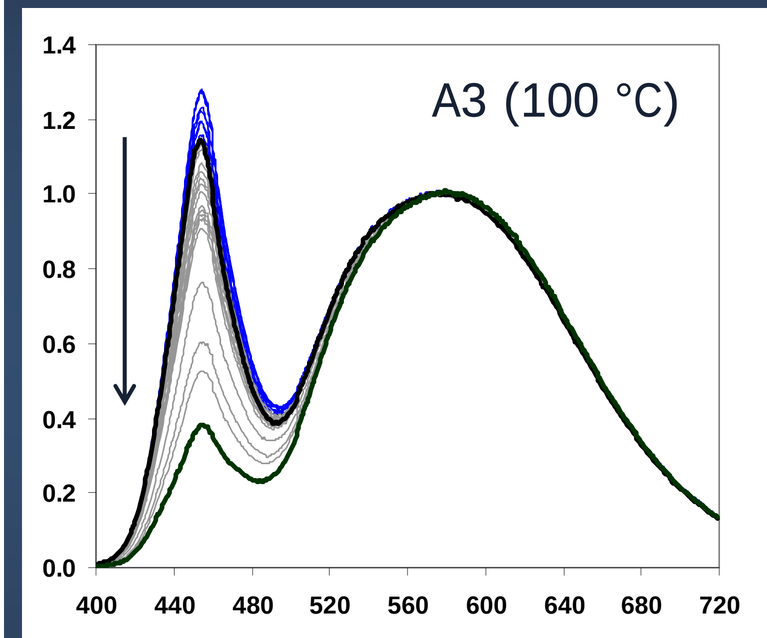


Driver temperature:
A0 (90 °C)

A2 (100 °C)

A3 (130 °C)

Runway Centerline luminaires
Color shift – White



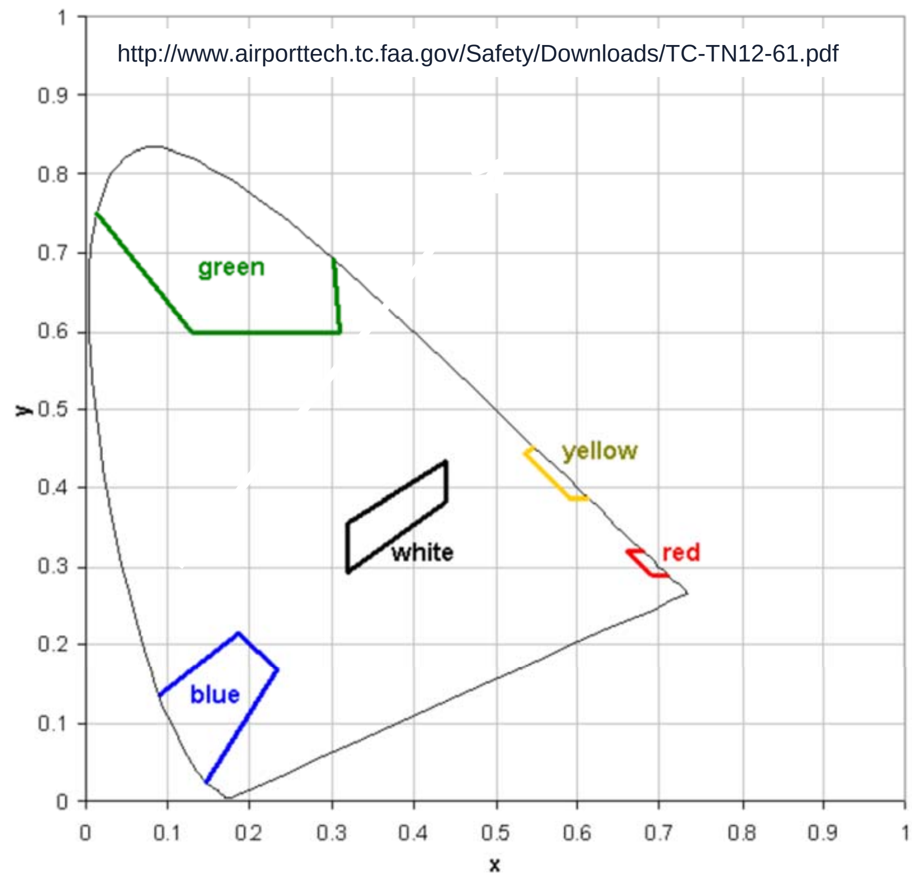
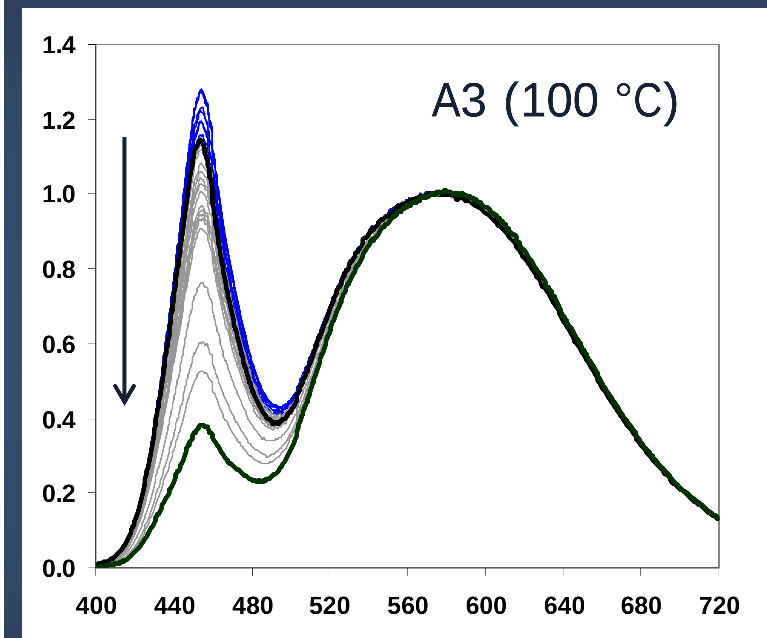
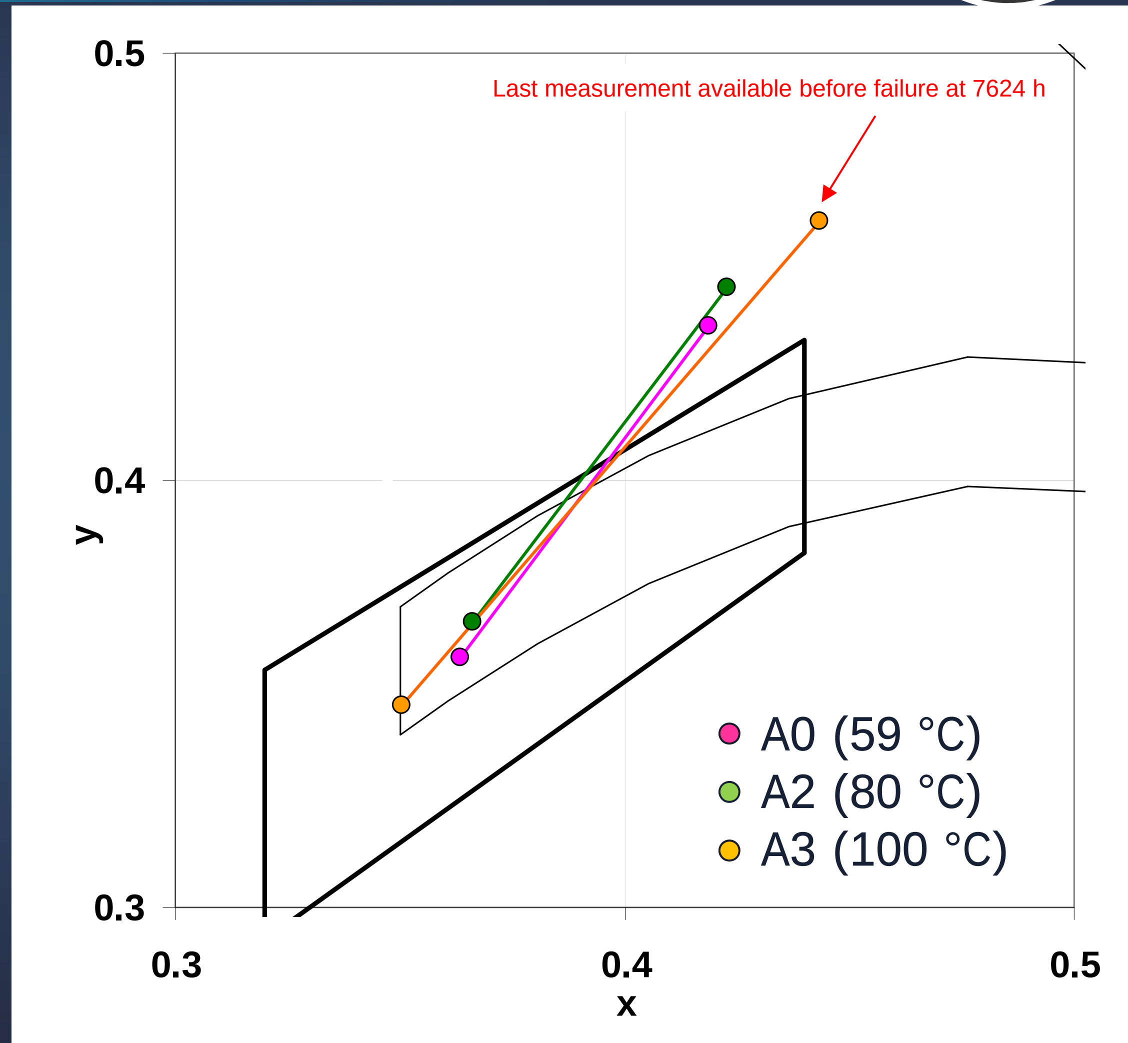


Figure 42. Proposed Chromaticity Boundaries, Plotted in the CIE 1931 (x,y) Chromaticity Diagram

Runway Centerline luminaires
Color shift – White





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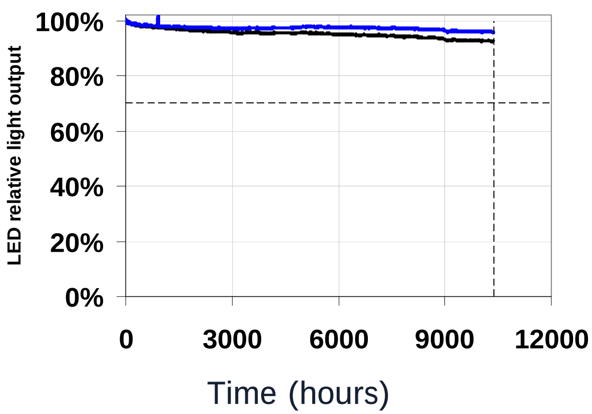
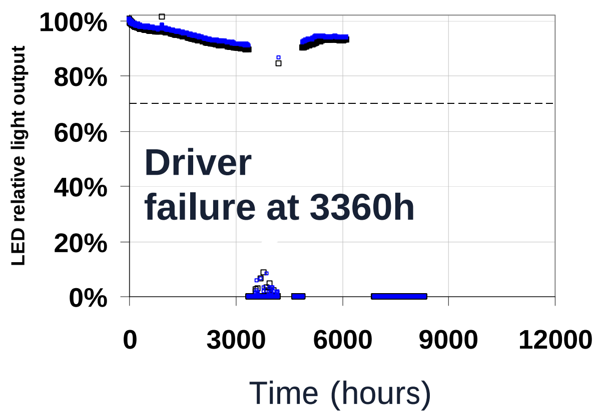
Touchdown Zone luminaires
Light output depreciation

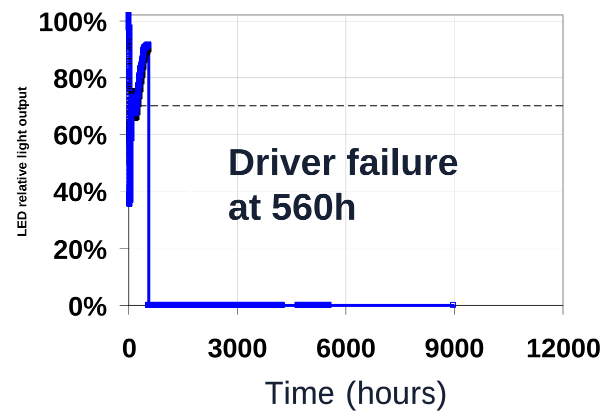
B1 (55 °C)



B2 (80 °C)



B3 (100 °C)

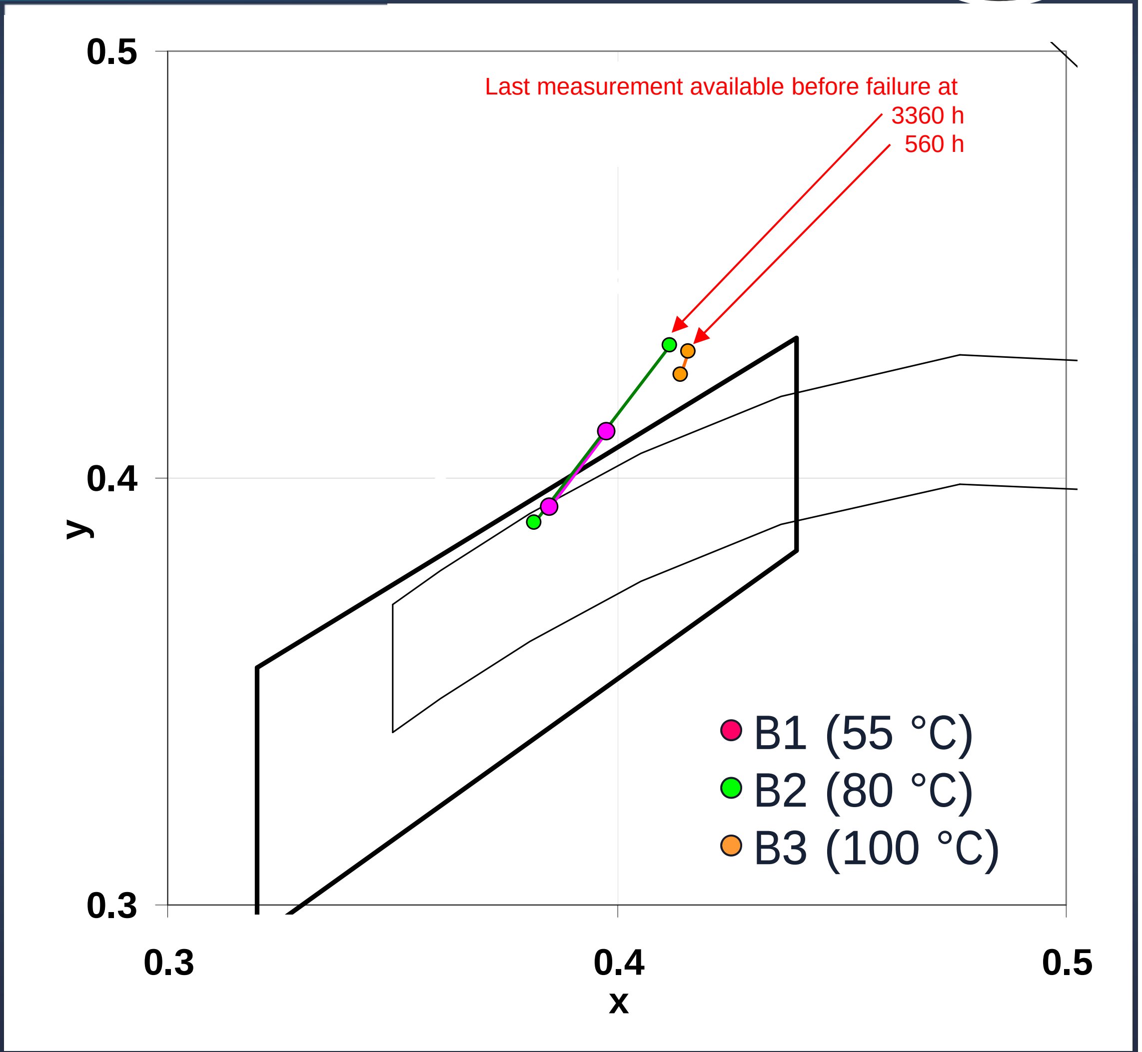


Driver temperature:
B1 (58 °C)

B2 (82 °C)

B3 (104 °C)

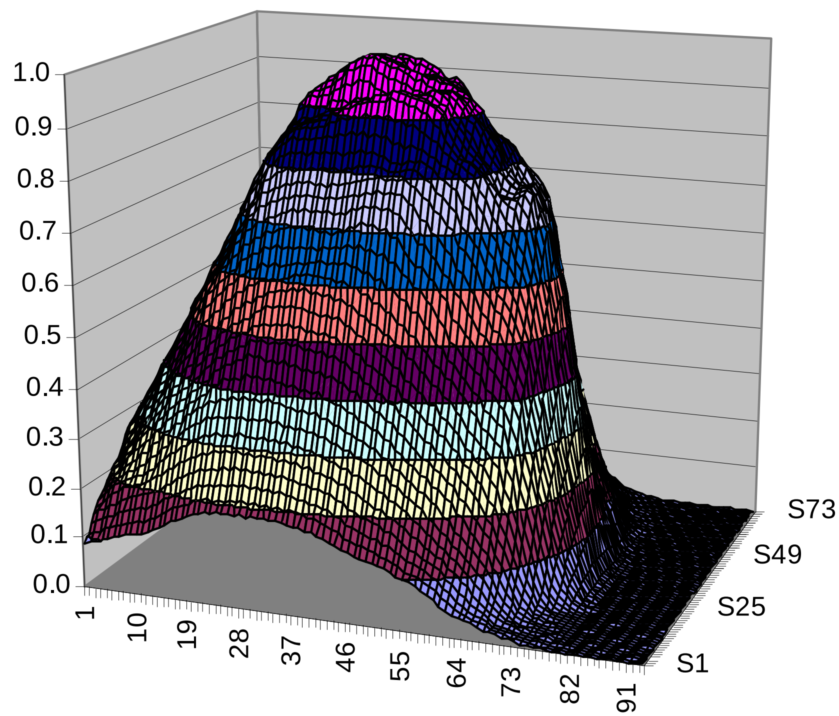
Touchdown Zone luminaires
Color shift – White



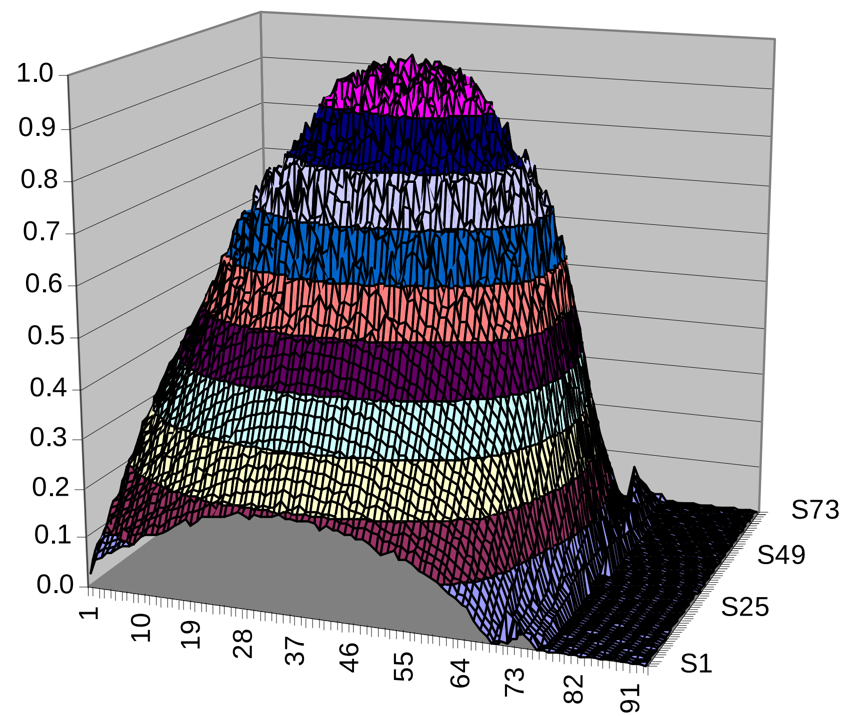
Runway Centerline luminaires Intensity distribution – Red

A3 (100 °C)

Initial measurement, t= 0 h



Measurement after failure at 7624 h



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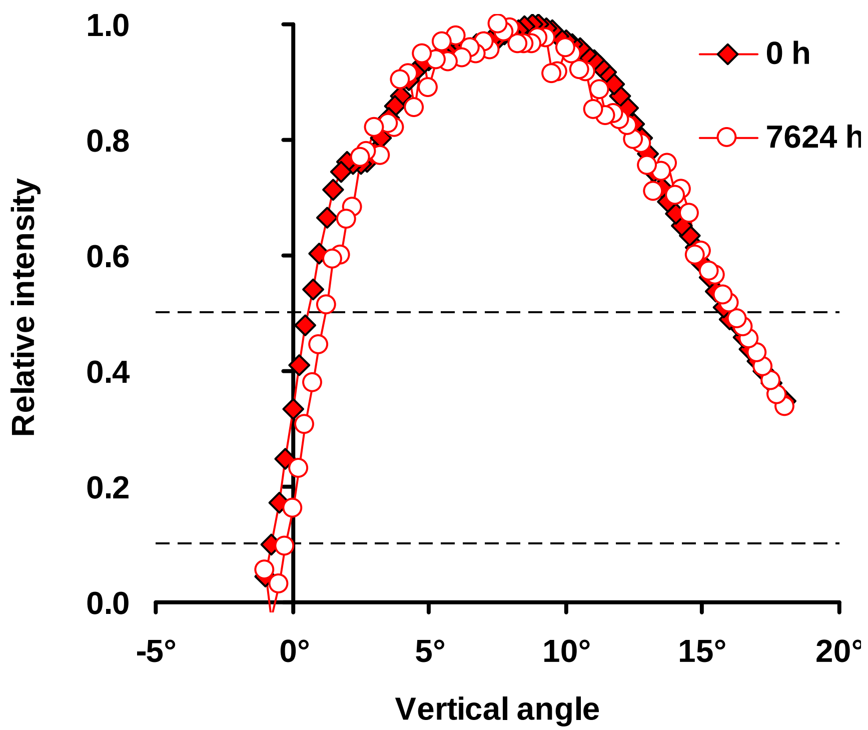
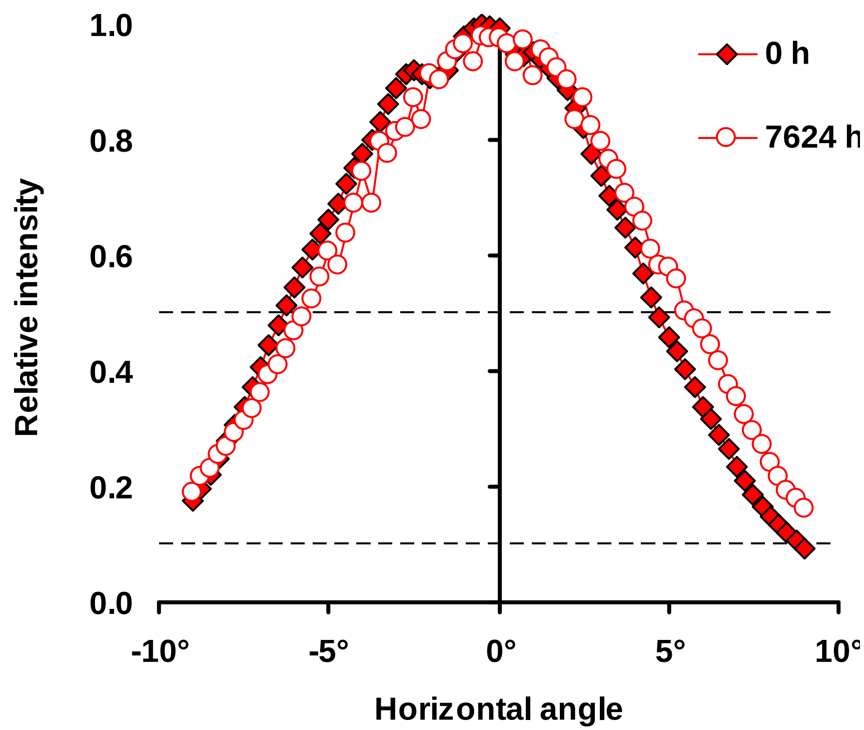
Runway Centerline luminaires
Intensity distribution – Red

A3 (100 °C)

Initial measurement, t= 0 h

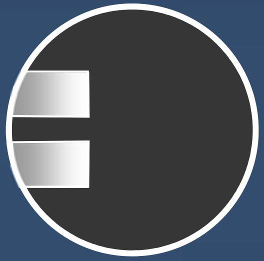


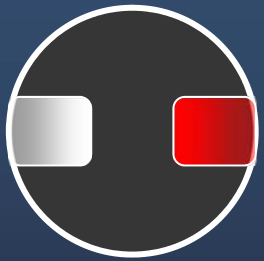
Measurement after failure at 7624 h



Summary (1)

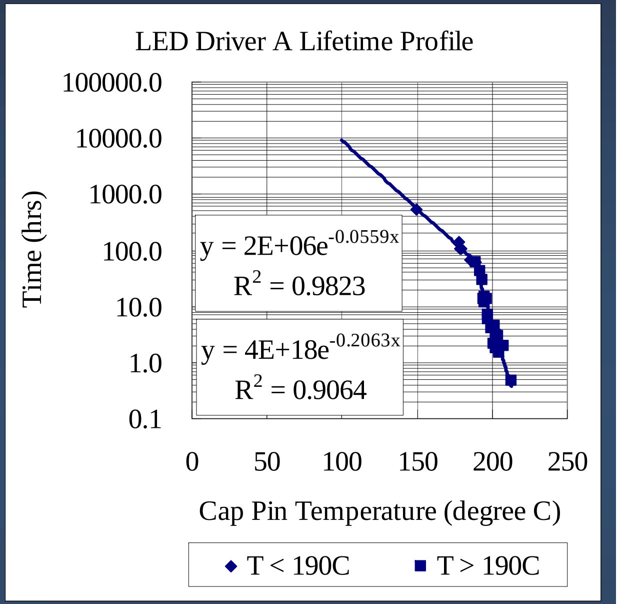
- Overall test duration 10,404 hours
- Complete system failures due to driver loss:
  - Two touchdown zone luminaires
    - at 560 h of operation (100 °C condition)
    - at 3360 h of operation (80 °C condition)
  - One runway centerline luminaire
    - at 7630 h of operation (100 °C condition)





LED driver reliability

- Output electrolytic capacitor is one of the weakest components in an LED driver.
- Heat affects electrolytic capacitors.
  - ESR increase and capacitance decrease are indicators of capacitor degradation.
  - The LED driver output current ripple increases when ESR increases and capacitance decreases.
- Therefore, driver output current ripple can be used to predict LED driver life.
- Driver lifetime decreases exponentially with temperature.



LRC 2011 study sponsors ASSIST and NY State CAT

Han, L., and N. Narendran. 2012. An accelerated test method for predicting the useful life of an LED driver. *IEEE Transactions on Power Electronics*.

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Summary (2)

- Light output and chromaticity maintenance
  - Runway centerline luminaires (A0-A3 samples)
    - Relative light output loss of 30-37%
    - Color shift between 32-step and 52-step MacAdam ellipses
  - Touchdown zone luminaires (B1-B3 samples)
    - Relative light output loss of 5-11%
    - Color shift between 7-step and 16-step MacAdam ellipses

Summary (3)

- Intensity distribution maintenance
  - Runway centerline luminaires (A2 sample at 80 °C)
    - White: 0.5° to 1° change at full-width half-max intensity
  - Runway centerline luminaires (A3 sample at 100 °C)
    - Red: 0.5° to 0.75° change at full-width half-max intensity
  - Touchdown zone luminaires (B2 sample, 80 °C)
    - White: <0.5° change at full-width half-max intensity

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Conclusion

- LED systems have many components; failure of any of the components will lead to system failure
  - LED/LED Array, optics, heat sink/thermal management components/TIM, mechanical housing, driver/ control, etc.
- LM-80 data not a good life metric for LED system.
  - Need an industry accepted definition of system life
    - and accelerated test methods that can predict system parametric/catastrophic failure under realistic operating conditions
- Future studies to include on/off cycling

Acknowledgements

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  - Funding through Cooperative Agreement 10-G-013
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