DIM-TO-WARM LIGHTING

LED SYSTEMS RELIABILITY CONSORTIUM

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LED Systems Reliability Consortium

- To address the challenge of understanding product lifetimes for new advances in lighting technologies, the DOE and NGLIA formed an industry consortium, the LED Systems Reliability Consortium (LSRC).

- The LSRC is a group of industry experts working collaboratively to coordinate activities, foster improved understanding of LED lighting reliability, and develop an advanced luminaire reliability model for lighting manufacturers and end users.

- Work by the LSRC and other research funded by DOE is focused on understanding the various degradation mechanisms in LED lighting systems to enable the development of new models for system reliability that can be confidently understood, predicted, and communicated.

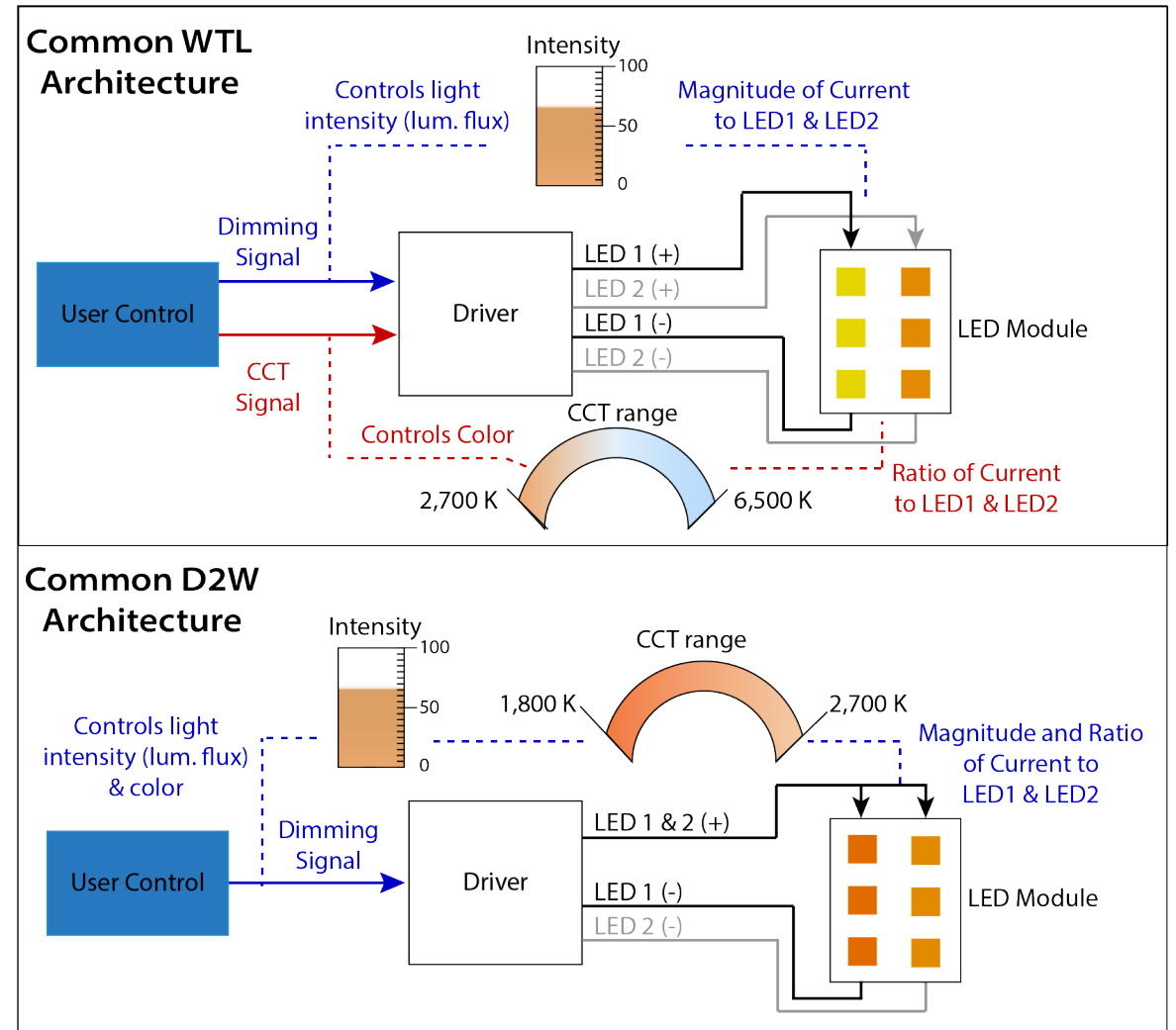www.energy.gov/eere/ssl/led-systems-reliability-consortium

White Tunable Luminaires

- Two LED primaries: warm white & cool white.

- Adjusting the amount of current delivered to each of the two primaries will tune the overall luminaire CCT along the tie line.

- Three LED primaries are required follow the blackbody curve.
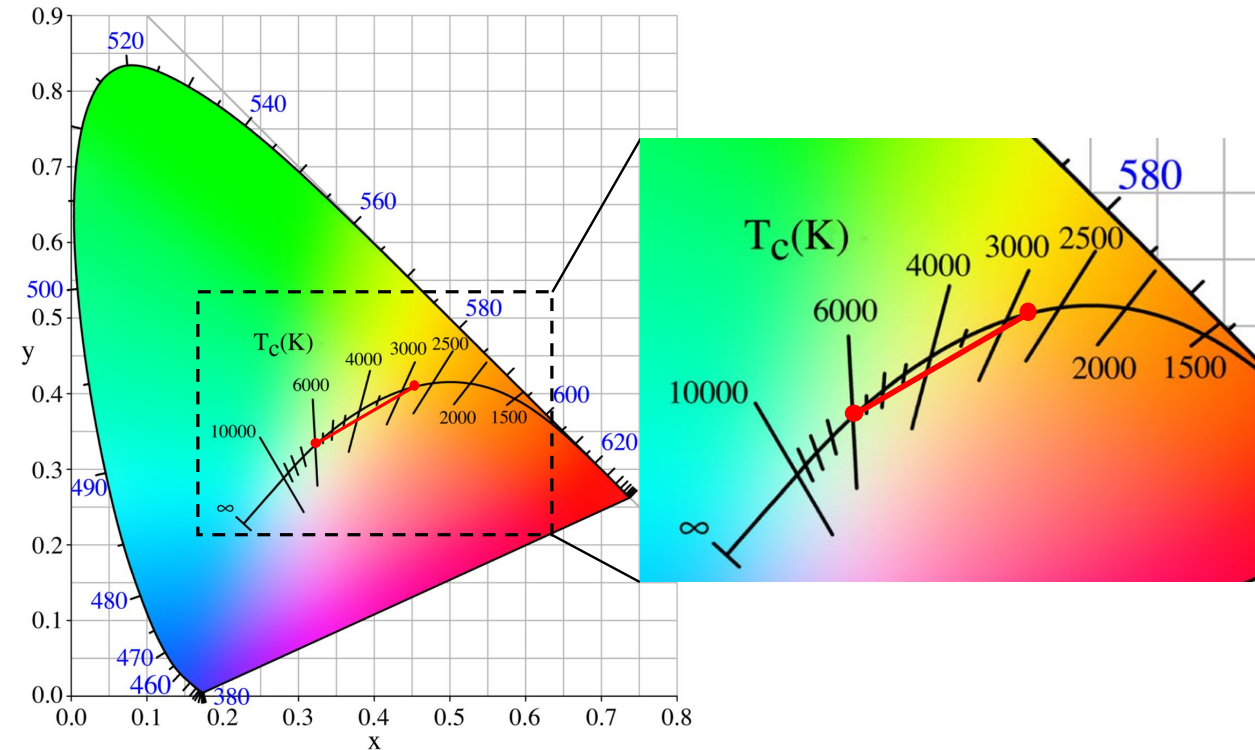
Dim to Warm Lighting

- Dim-to-warm LED lighting requires at least two different LED primaries, but usually only one control signal (single channel) that adjusts both chromaticity and intensity simultaneously according to the preprogrammed logic set by the manufacturer.

Common WTL Architecture

Intensity

Controls light intensity (lum. flux)

Magnitude of Current to LED1 & LED2

Dimming Signal

User Control

Driver

LED 1 (+)
LED 2 (+)
LED 1 (-)
LED 2 (-)

LED Module

CCT Signal

Controls Color

CCT range

2,700 K — 6,500 K

Ratio of Current to LED1 & LED2

Common D2W Architecture

Intensity

CCT range

1,800 K — 2,700 K

Controls light intensity (lum. flux) & color

Magnitude and Ratio of Current to LED1 & LED2

Dimming Signal

User Control

Driver

LED 1 & 2 (+)
LED 1 (-)
LED 2 (-)

LED Module

Characterizing Tunable LED Systems

- LSRC Study: Devise a methodology for dim-to-warm products and later expand it to a broader range of product types including scene switching and full color tunability.

  ➢ How many power levels should be measured?

  ➢ How can CCT vs. light output be evaluated at the fully powered state and dimmed state consistently for the different dimming control architectures in the products?

  ➢ How should the impact of varying dimmer technologies on the performance of the dim-to-warm LED lighting products be evaluated?

  ➢ How should reliability be determined on these products with multiple power settings?

Dim-to-Warm Lamp Evaluations

- Initial evaluation: lamp form factors were selected with different LED source types

Lamp ID	Lamp Type	Light Output (lm)	Input Power (Watts)	CCT (K)	CRI
A	A-lamp (standard)	800	9.5	2200 – 2700	80
B	A-lamp (filament)	800	8.5	2200 – 2700	80
C	Candelabra	345	5.0	1800 – 2700	90
D	Candelabra	450	5.5	2200 – 2700	80

- The initial testing protocol was to operate the LED lamps at three settings:

  ➢ High current (highest CCT value, no dimming)

  ➢ Low current (lowest CCT value, deep dimming)

  ➢ Medium current (CCT value variable, moderate dimming)

# Dim-to-Warm Lighting Study
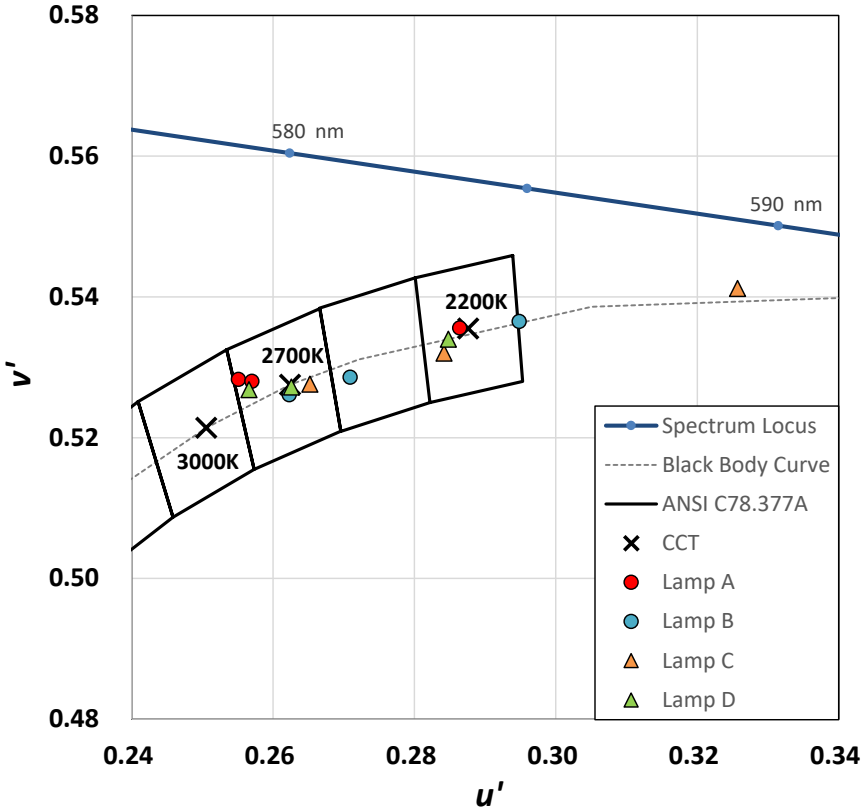
Dimming Behavior
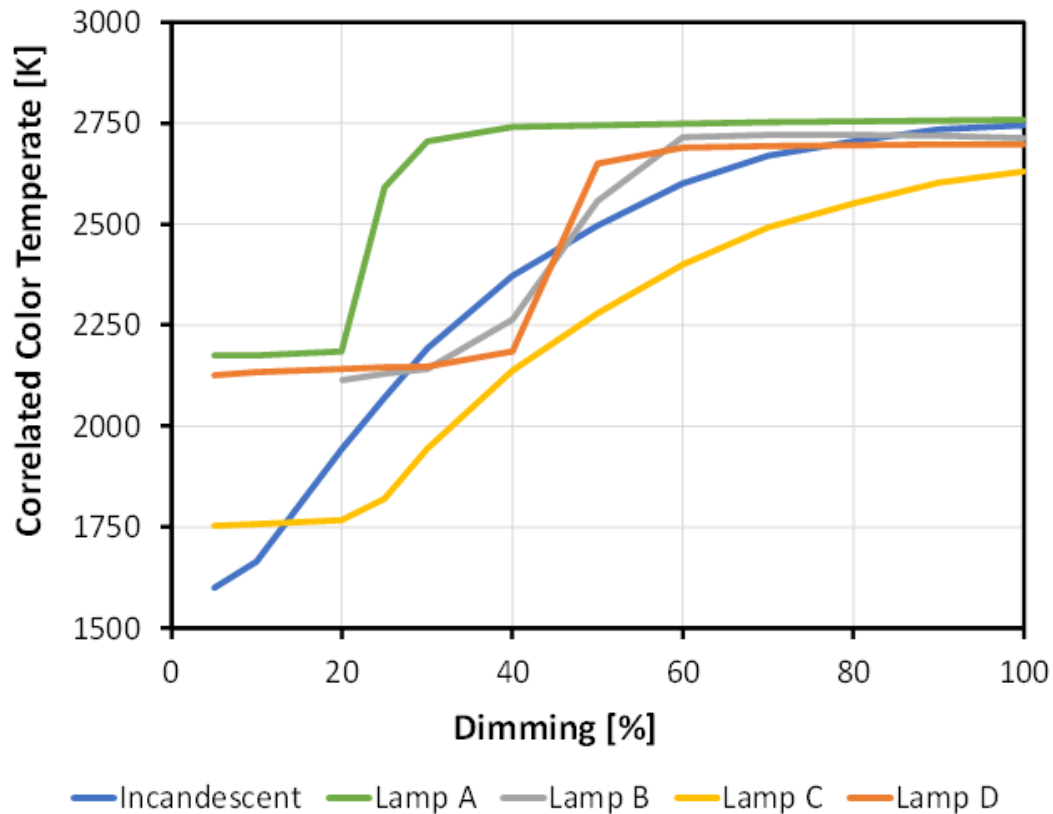
- Dimming a typical incandescent lamp produces a smooth change in the CCT value, from 2744 K at 100% power to 1600 K at 5% dimming

- Only Lamp C was able to emulate the general shape of the incandescent dimming curve, albeit at lower CCT values.

- Greater differences were found for Lamps A, B, and D, where the CCT value for these lamps remained near the same CCT value for a significant portion of the dimming range

Temporal Light Artifacts (TLA)

- Dimming an LED lamp can increase or induce the fluctuation of luminance with time and can cause visible effects to the observer, such as flicker or stroboscopic effects.

- The stroboscopic visibility measure (SVM) and short-term flicker indicator (PST) show the detectability threshold (PST = 1 or SVM = 1) that an average human observer in a population has a 50% probability of detecting the artifact.
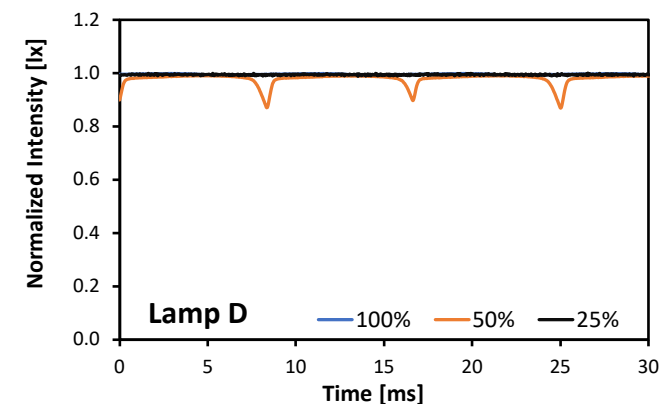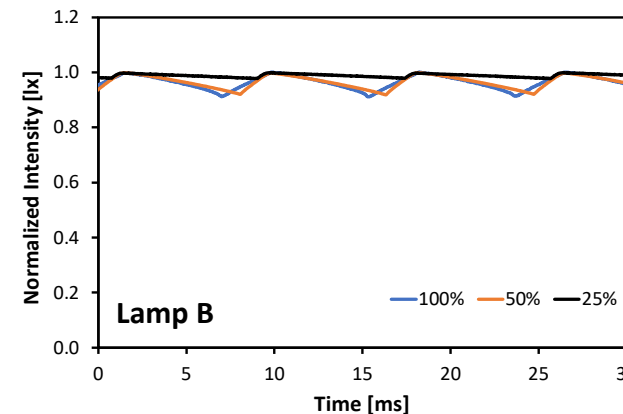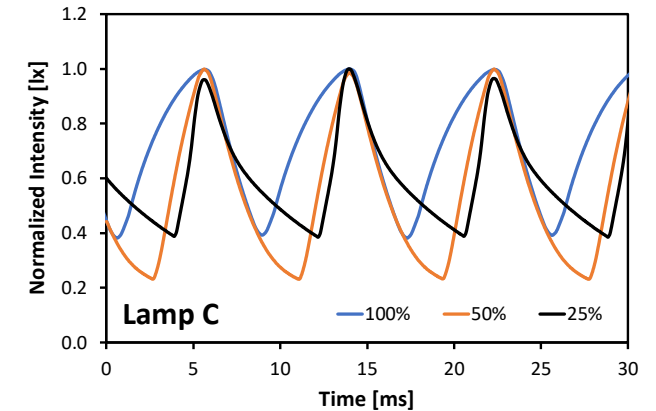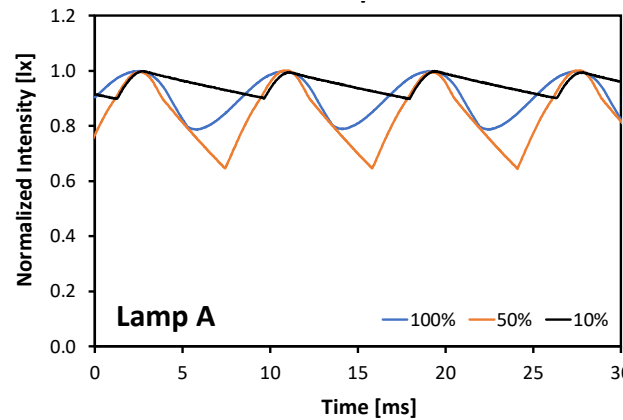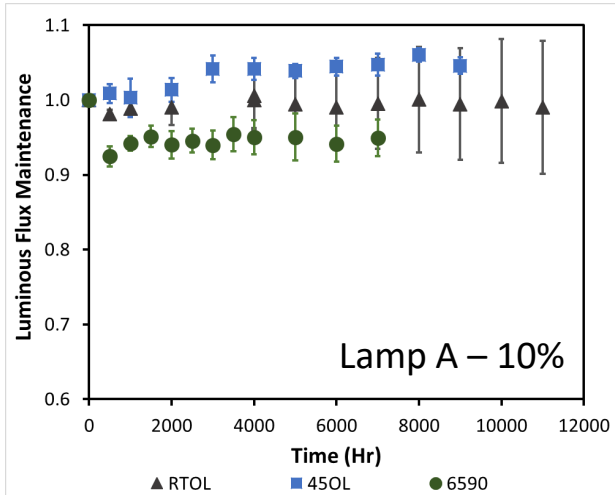
Lamp ID	SVM/P_{ST}	Low Power	Moderate Power	Max Power
Lamp A	SVM	0.134	0.783	0.374
	P_{ST}	0.291	0.282	0.067
Lamp B	SVM	0.028	0.102	0.114
	P_{ST}	0.121	0.148	0.267
Lamp C	SVM	1.305	2.107	1.300
	P_{ST}	0.785	0.421	0.496
Lamp D	SVM	ND*	0.068	0.007
	P_{ST}	ND*	0.290	0.062

Reliability Testing
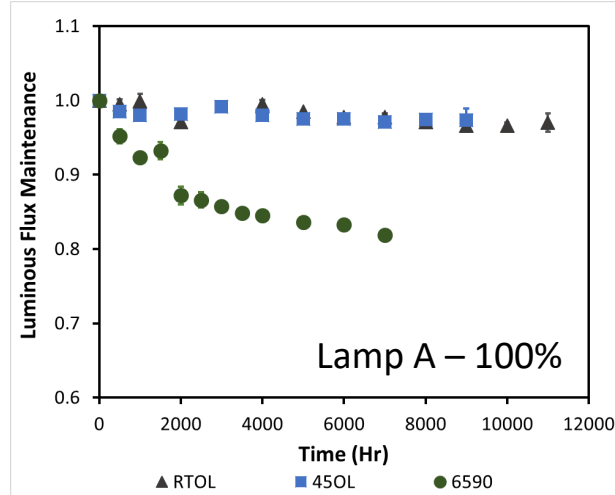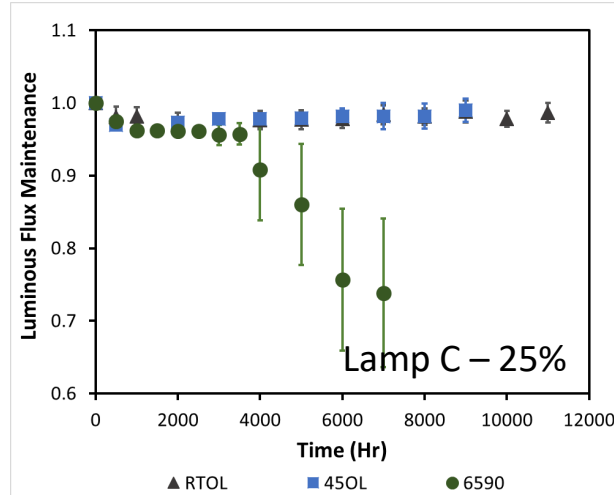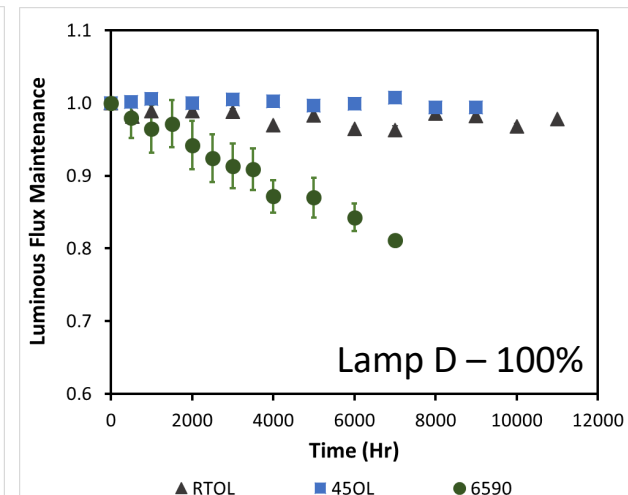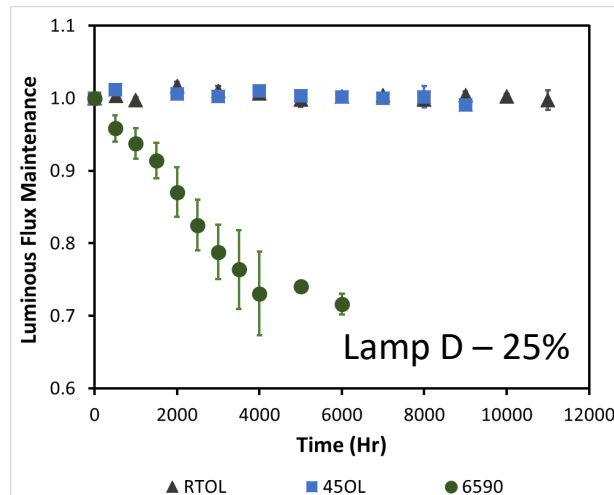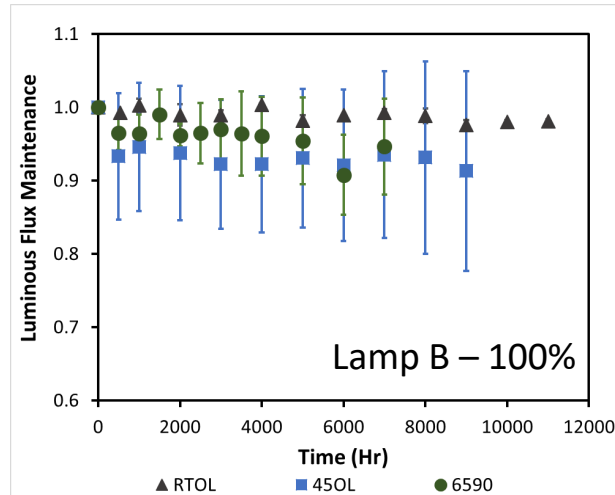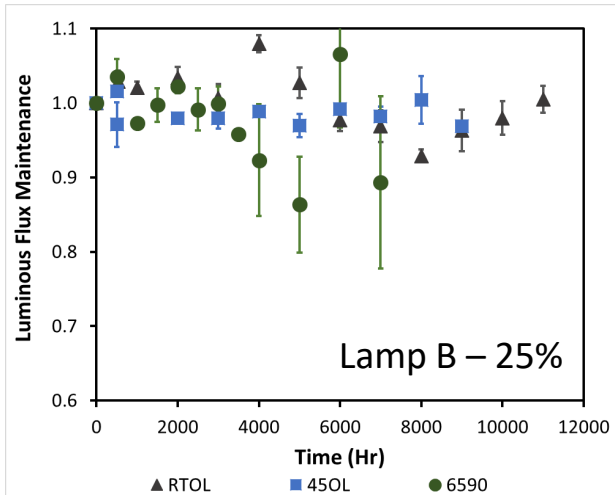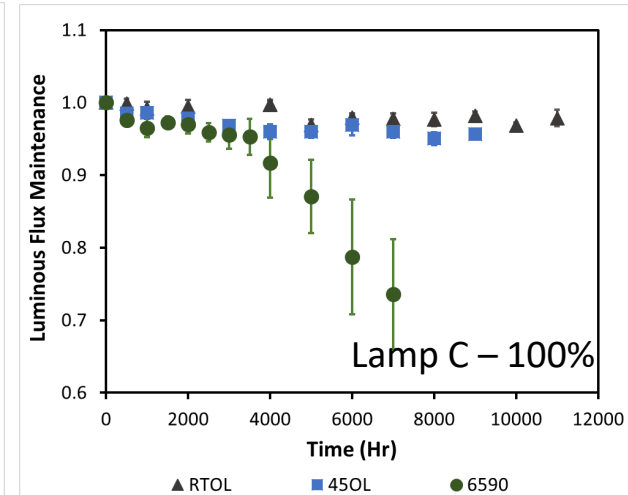
Chromaticity Shift

Manufacturing Variability

- Differences were observed in some lamps depending on the test population's purchase date.
- Variation between test populations of the same product model could be a manufacturing flaw, a consequence of slight variations in components used, or a deliberate change in design by the lamp manufacturer.
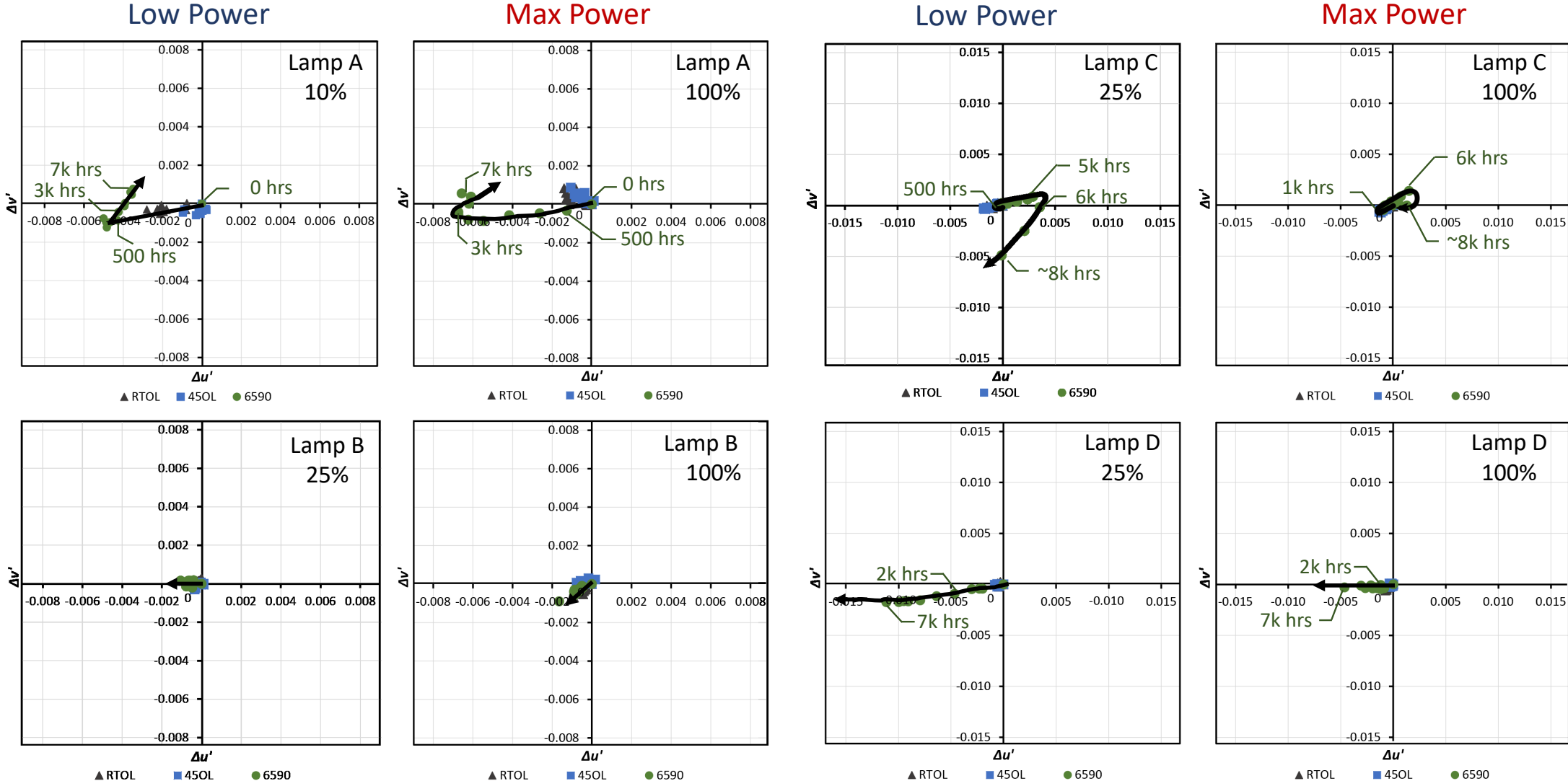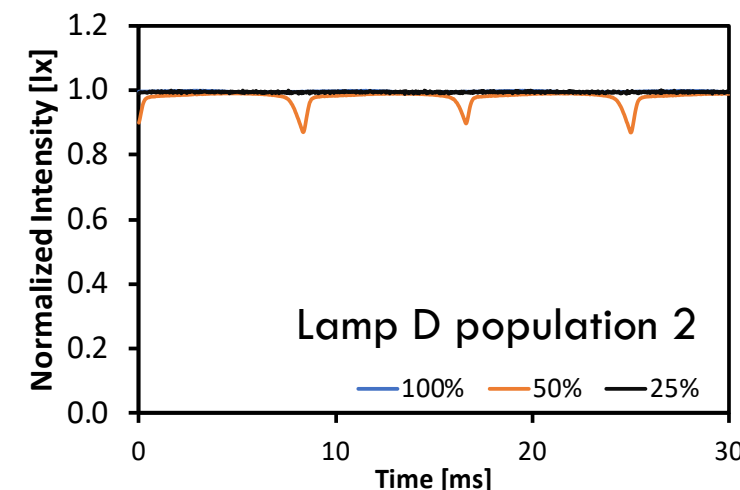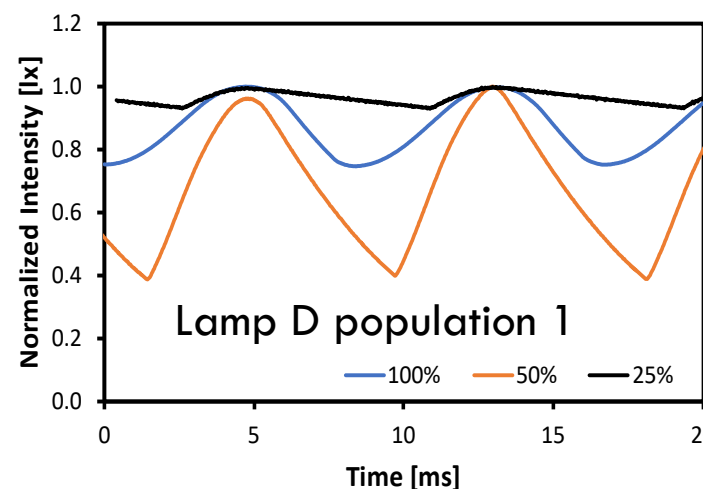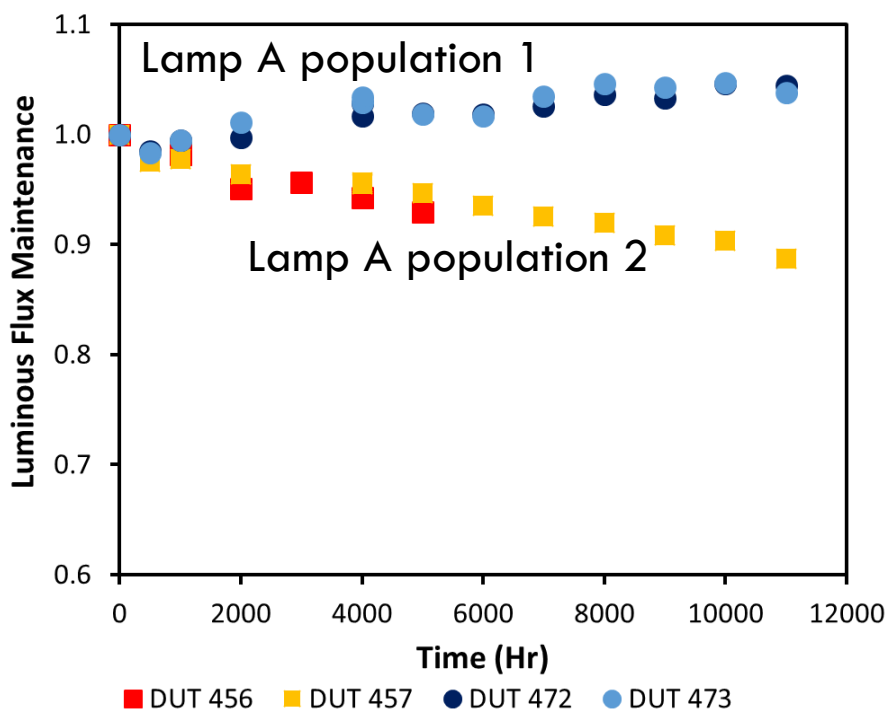

Lamp ID	SVM/P$_{ST}$	Low Power	Moderate Power	Max Power
Lamp D Population 1	SVM	0.094	1.312	0.486
	P$_{ST}$	0.082	0.923	0.193
Lamp D Population 2	SVM	ND*	0.068	0.007
	P$_{ST}$	ND*	0.290	0.062

ND* = not detected

Summary

- Dim-to-warm lamps were generally found to have two separate LED primaries with different phosphor mixes to create the color tuning range upon dimming.
  - There are differences in how the LED arrays function to produce dim-to-warm light, including the algorithms on when to engage the different primaries in illumination during the dimming cycle.

- Testing only at maximum power (100%) does not provide full performance information.
  - Efficacy, flicker, and TLA all change at different dimming levels.
  - These parameters can fall out of range of some performance standards or specifications upon dimming.
  - At least three levels should be measured to ensure that all LED primaries are encompassed.

- TLA was induced or increased for all products tested during the dimming cycle, some worse than others.
  - Electrical efficiency and power factor also tended to decrease with dimming.

Future Work

- New LED module architectures that can provide dim-to-warm behavior for LED primaries integrated into one light source are being evaluated.