Dim-to-Warm LED Lighting Reliability

LSRC
LED Systems Reliability Consortium

NGLIA
NEXT GENERATION LIGHTING INDUSTRY ALLIANCE

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Introduction

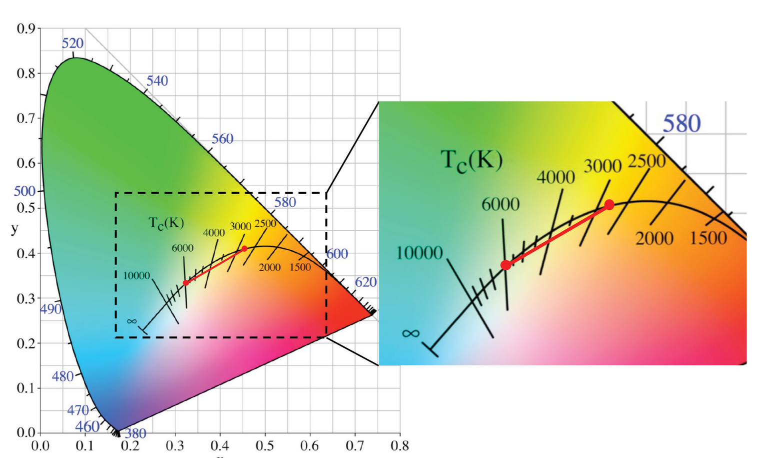
The U.S. Department of Energy, together with the Next Generation Lighting Industry Alliance (NGLIA), formed an industry consortium, the LED Systems Reliability Consortium (LSRC), a group of industry experts working collaboratively to coordinate activities, foster improved understanding of light-emitting diode (LED) lighting reliability, and develop an advanced luminaire reliability model for lighting manufacturers and end users.

The objective of this study is to understand testing and reliability concerns associated with dim-to-warm (D2W) LED lighting products. To address theses challenges, the work includes the following:

- Developing a methodology to characterize performance and make assessments of common D2W architectures
- Analysis of common D2W architectures and performance metrics
- Accelerated Stress Test (AST) for D2W LED lamps

Tunable Lighting Architectures

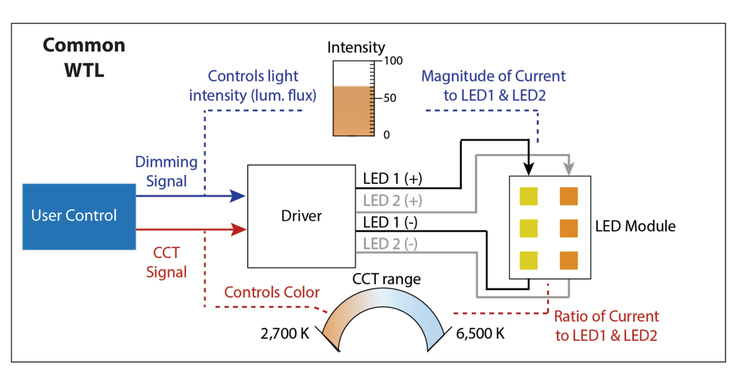
White tunable LED lighting systems combine warm white LEDs (usually around 2700 K) and cool white LEDs (usually around 6000 K) to provide a lighting system that enables tuning of chromaticity values along the line between each of the two LEDs' correlated color temperature (CCT) values. Adjusting the amount of current delivered to each of the two color channels, or primaries, will tune the overall luminaire CCT.

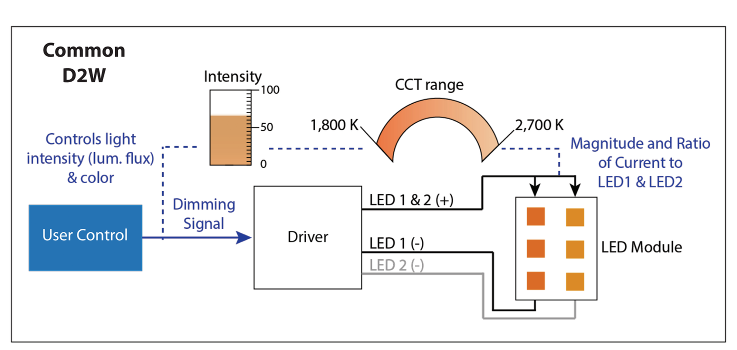


D2W lighting is a subset of white tunable LED lamps and luminaires that was developed to mimic the spectral behavior of incandescent lamps when dimmed. D2W products differ from white tunable LED (WTL) luminaires by incorporating an architecture to automatically change the CCT to a warmer value as the intensity of the light is dimmed. D2W 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.

Typically, a two-channel driver is used for both products, with differences lying in method of control:

- D2W has a single control input for both LED primaries (power).
- WTL uses separate control signals for each LED primary.



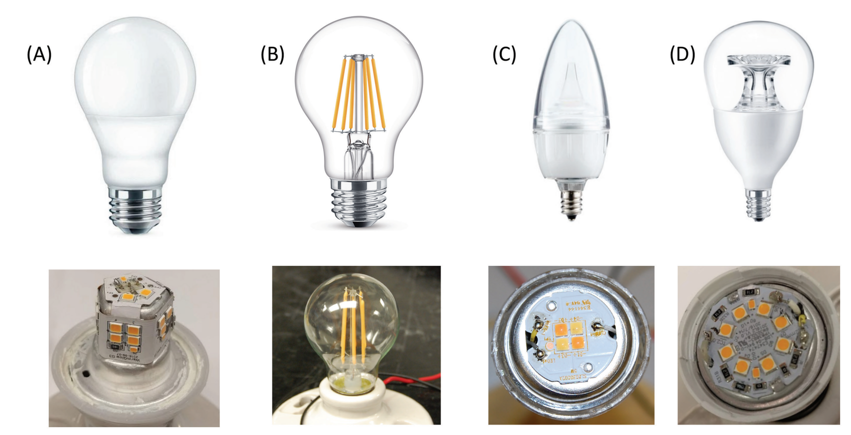


Characterizing Tunable LED Systems

Characterization Objectives

Devise a methodology for D2W 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 versus light output be evaluated at the fully powered state versus dimmed state consistently for the different dimming control architectures in the products studied?
- How should the impact of varying dimmer technologies on the performance of the D2W LED lighting products be evaluated?
- How should reliability be determined on these products with multiple power settings?



Testing Procedure

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

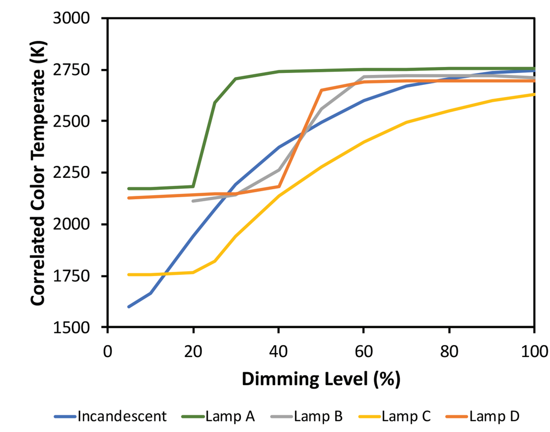
- High current (highest CCT value, no dimming)
- Low current (lowest CCT value, deep dimming)
- Medium current (CCT value variable, moderate dimming)

At the highest current setting, either one or two LED primaries switch on; at the medium current setting, both LED primaries turn on, but usually at different current levels; at the lowest current setting, only one LED primary operates.

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

* color rendering index

Dimming Behavior of Dim-to-Warm LED Lamps



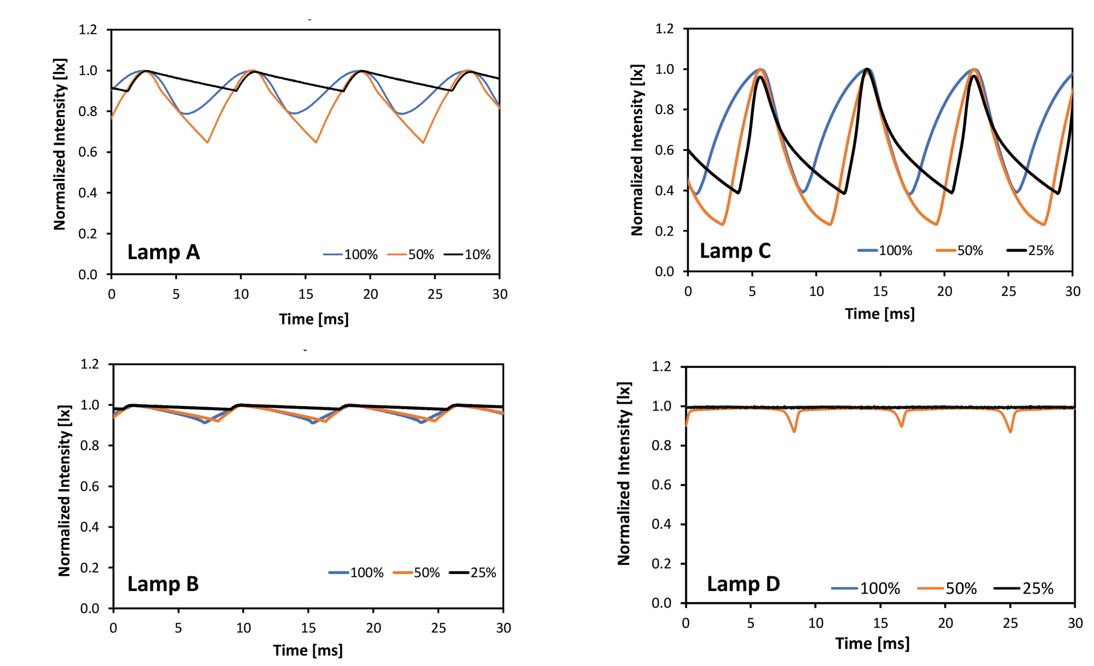
Dimming Characteristics

- D2W LED lamps are intended to emulate the warm dimming spectral characteristics of incandescent lamps, while also delivering the energy efficiency of solid-state lighting (SSL).
- 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

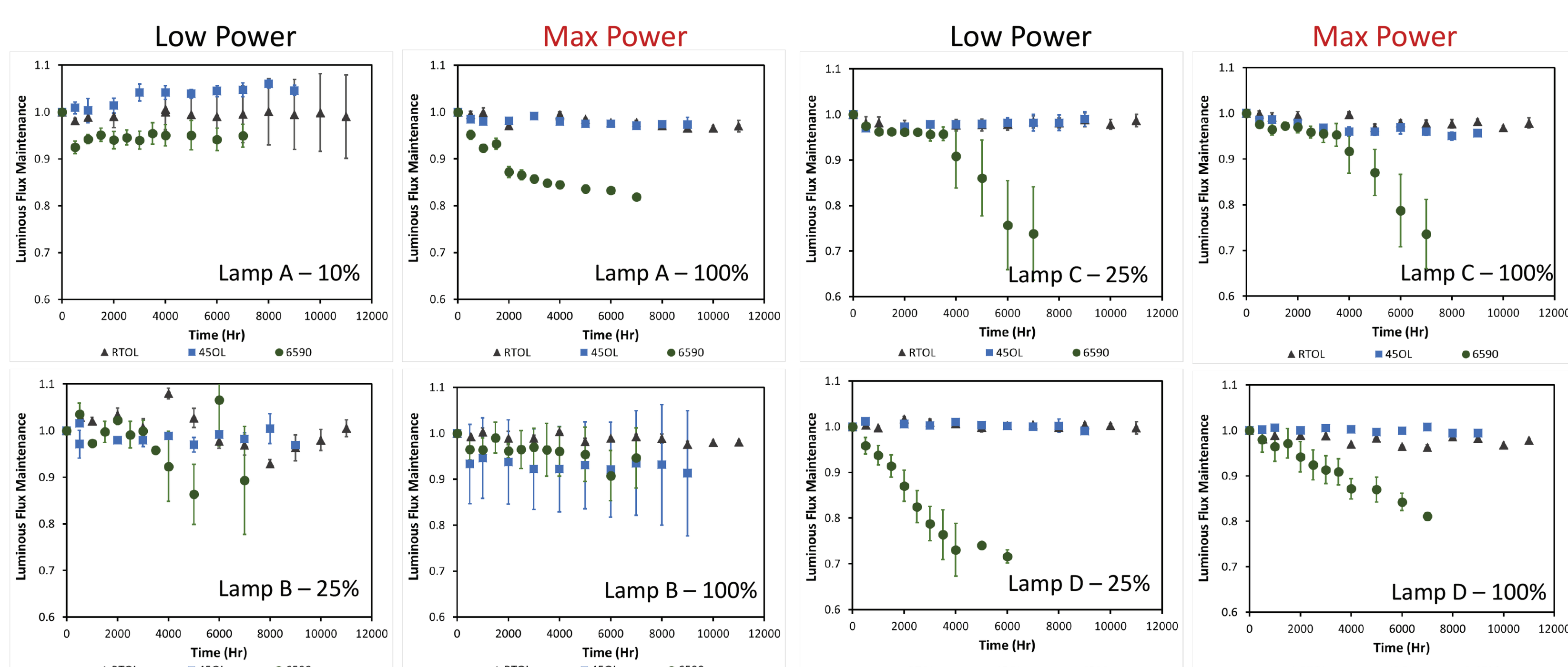
Temporal Light Artifacts (TLA)

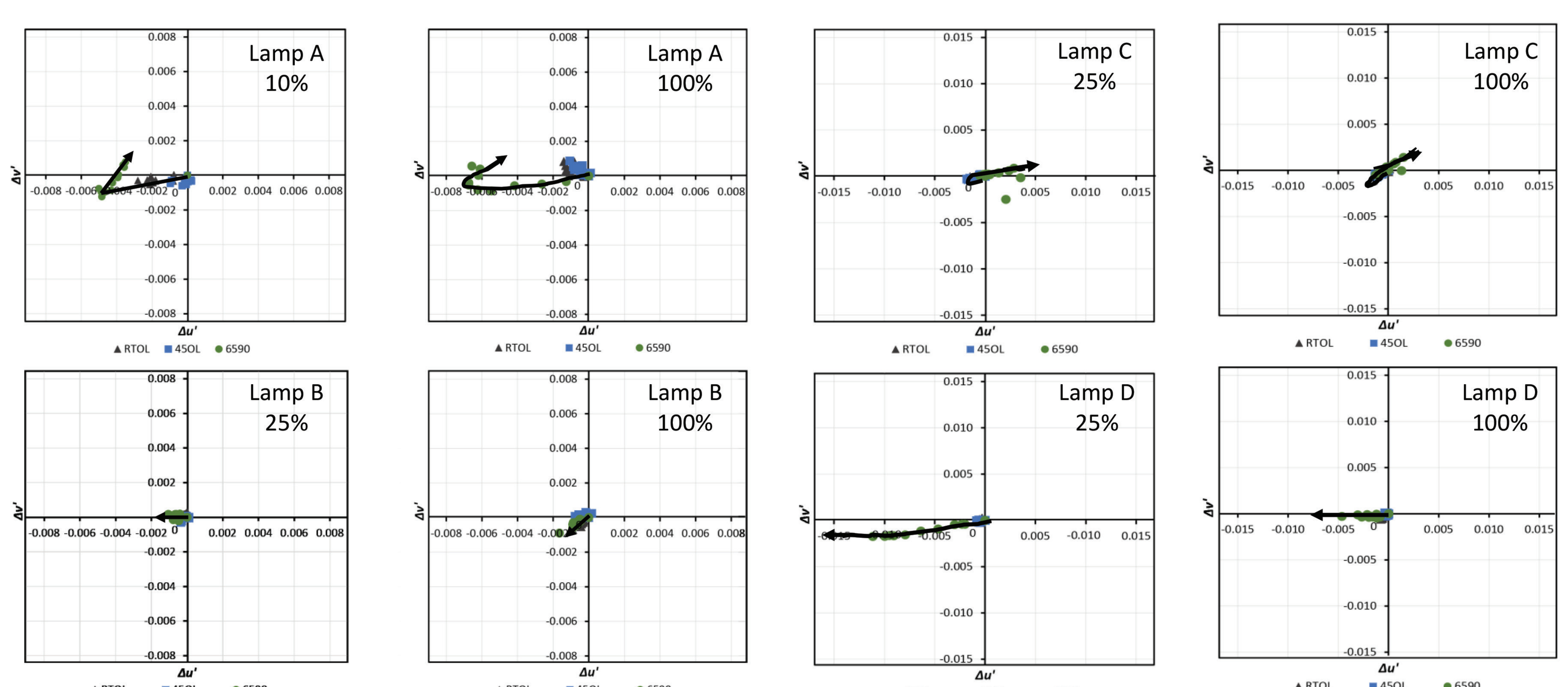
- Dimming an LED lamp can increase or induce the fluctuation of luminance with time and can cause visible effects to the observer, such as flicker or stroboscopic effects.
- The stroboscopic visibility measure (SVM) and short-term flicker indicator (P_{ST}) show the detectability threshold (PST = 1, or SVM = 1 according to NEMA 77-2017) that an average human observer in a population has a 50% probability of detecting the artifact.
- The behavior of the A-lamps varied at different dimming levels, though all values were below the recommended thresholds of 1 for SVM and P_{ST}.
- The candelabra lamps had a much larger performance difference. Lamp C had more TLA than the A-lamp models, whereas Lamp D was significantly better than Lamp C at all dimming levels.
- The TLA behavior of the lamps did not undergo significant performance differences after AST.

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 Results



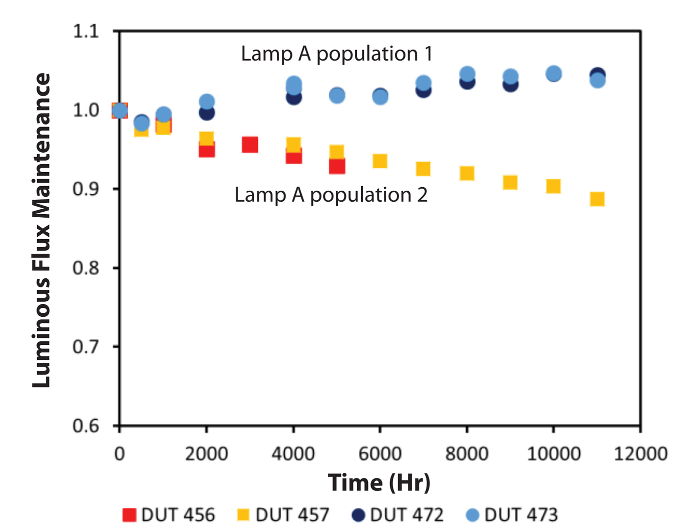


Accelerated Stress Testing Measurements

- RTOL: Room temperature operating life test
- 45OL: Operational life test conducted at 45ºC
- 6590: Life test conducted at 65ºC and 90% relative humidity

Luminous Flux Maintenance (LFM)

- A-lamps (Lamps A and B) had generally high LFM (> L80) at both low and maximum power at all AST test protocols.
- Candelabra lamps had lower LFM (< L80) at the most aggressive AST test protocol (6590).
- Differences in LFM were observed in Lamp A, depending on the test population's purchase date. This LFM difference between the two test populations could be a manufacturing flaw, a consequence of slight variations in components used, or a deliberate change in design by the lamp manufacturer.



Chromaticity Shift

- Chromaticity shift was stronger under the 6590 test conditions for all four lamps tested.
- Lamp A shifted to the green direction before later shifting in the red-yellow direction at both low and max power. Green shifts are typically from oxidation of the nitride red phosphors, which shifts the red spectral peak position to shorter wavelengths.
- Lamp B chromaticity remained relatively stable for the entire test duration.
- The likely difference in chromaticity shift between Lamp A and Lamp B was caused by the difference in lamp design. Lamp A used a traditional design consisting of a central LED module, while Lamp B used a filament-style design.
- Lamp C shifted in the green and green-blue direction at low and max power, respectively, then turned toward the red direction over time. This is typically seen with a loss in green phosphor peak emission intensity relative to the red peak.
- Lamp D chromaticity shift proceeded in the green direction for the entire test period at both low and max power settings, indicating red phosphor oxidation was occurring. The lower CCT LED primaries (on at low power level) were more affected by oxidation than the higher CCT LED primaries.

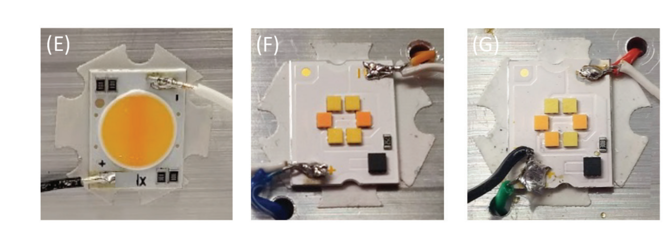
Summary and Future Work

Summary

- D2W 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 D2W light, including the algorithms on when to engage the different primaries in illumination during the dimming cycle.
- The results in this study show that testing only at full power (100%) does not provide full performance information. Efficacy, flicker, and TLA all change at different dimming levels, and these parameters can fall out of range of some performance standards or specifications upon dimming. At least three levels should be tested to ensure that all circuits and 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 D2W behavior for LED primaries integrated into one light source are being evaluated.



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