From the Laboratory to the California Marketplace: A New Generation of LED Lighting Systems

Key Research Outcomes

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State of California Energy Commission

Today's Agenda

- **10:00 am – Introduction (Cori Jackson, CLTC)**
  - Project team
  - Project goals & objectives
- **10:10 am – Key Research Outcomes (CLTC Team)**
  - Consumer Preference Study Results
  - Product Evaluation Results
  - Technology Transfer Activities
  - Industry Engagement
- **11:40 am – Questions & Answers (All)**

CEC's Project Manager:	Adel Suleiman
Principal Investigator:	Michael Siminovitch
Engineering Director:	Keith Graeber
Project Manager:	Cori Jackson
Project Engineers:	Nicole Hathaway
	Philip von Erberich
	Manuel Lopez
	Drew Harper

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Project Goals & Objectives

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The Problem

Today's lighting products should be designed to:

- Meet consumer expectations
- Provide value
- While saving energy

We don't know what consumers expect or value!

The Solution

Vanity mock-up

Home office mock up

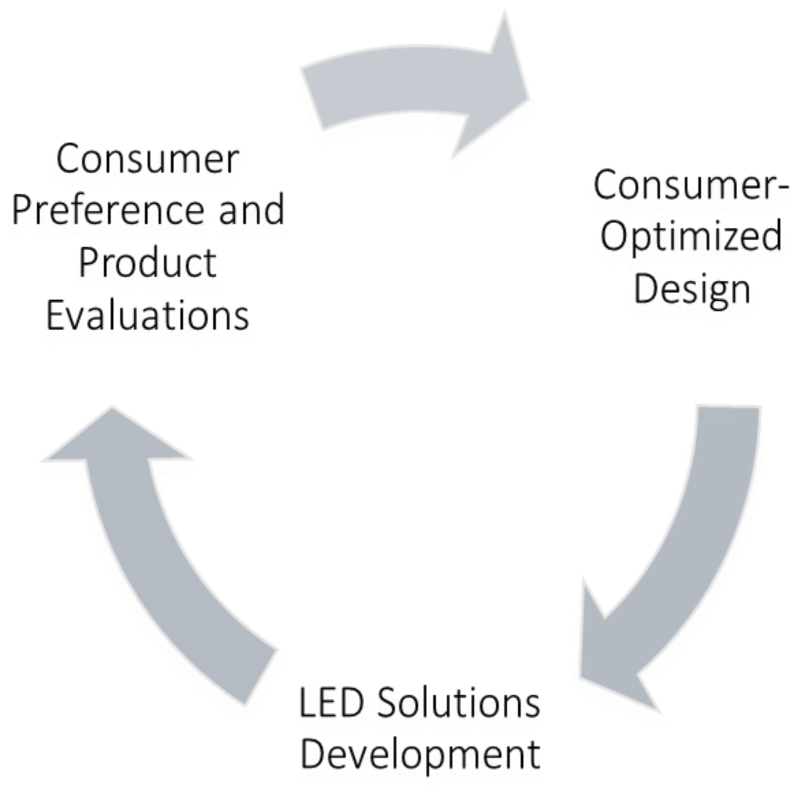
Color sorting task

1. Determine consumer preferences for major lighting performance features in common applications
2. Apply outcomes in development of lighting system specifications & prototypes
3. Increase LED lighting system adoption across California through engagement with industry
4. Decrease energy use and carbon emissions

Project Objectives

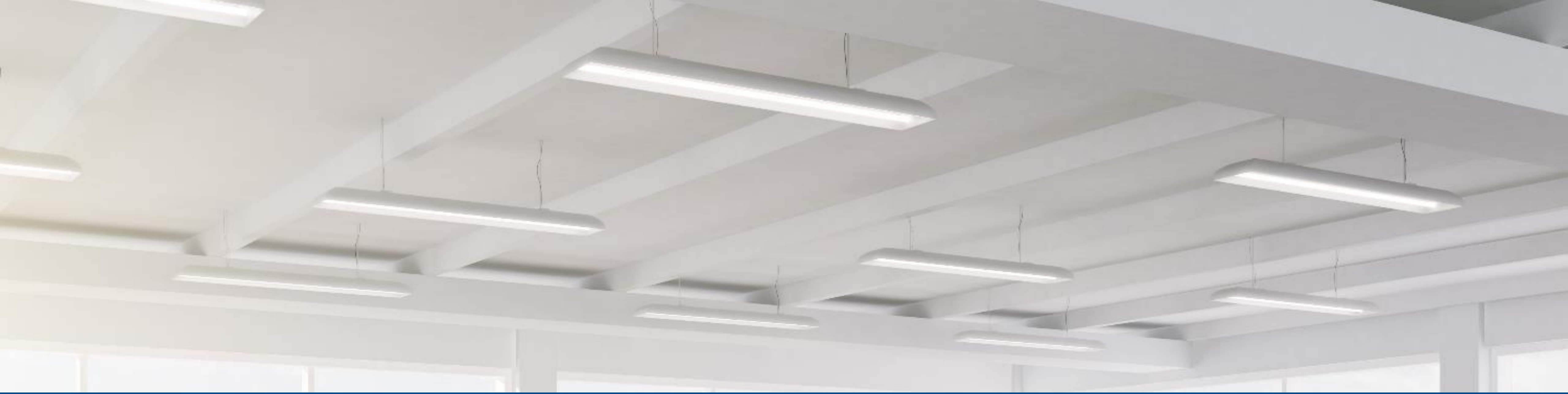
Consumer Preference Studies

- Color
- Control
- Packaging
- Longevity



Targeted Products

- Sources
- Retrofit kits
- Luminaires



Key Research Outcomes

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Key Research Outcomes

1. Consumer Preference Study Results
2. Product Evaluation Results
3. Technology Transfer Activities
4. Industry Engagement

Key Research Outcomes

1. **Consumer Preference Study Results**
   - **Melanopic Threshold Study**
   - **Lighting Service Delivered & Color Fidelity**
2. Product Evaluation Results
3. Technology Transfer Activities
4. Industry Engagement

Melanopic Threshold Study

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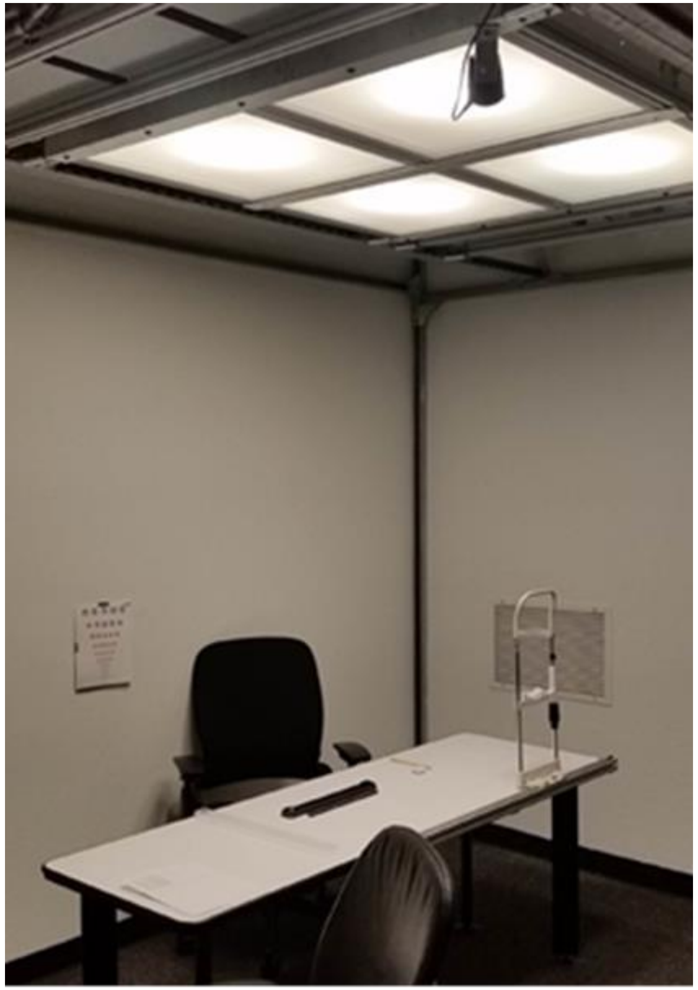
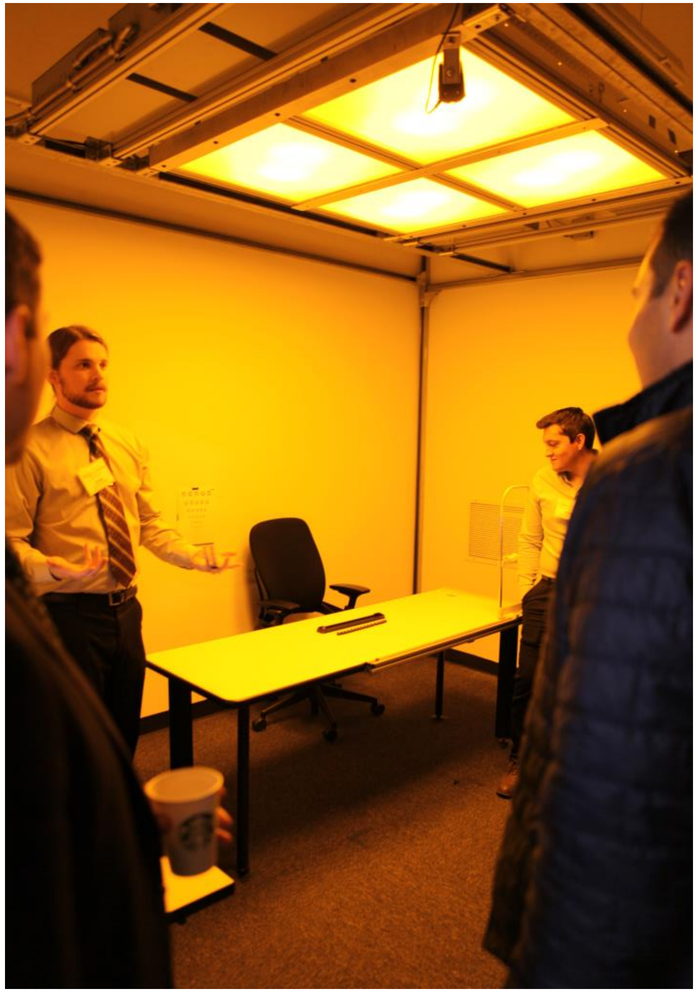
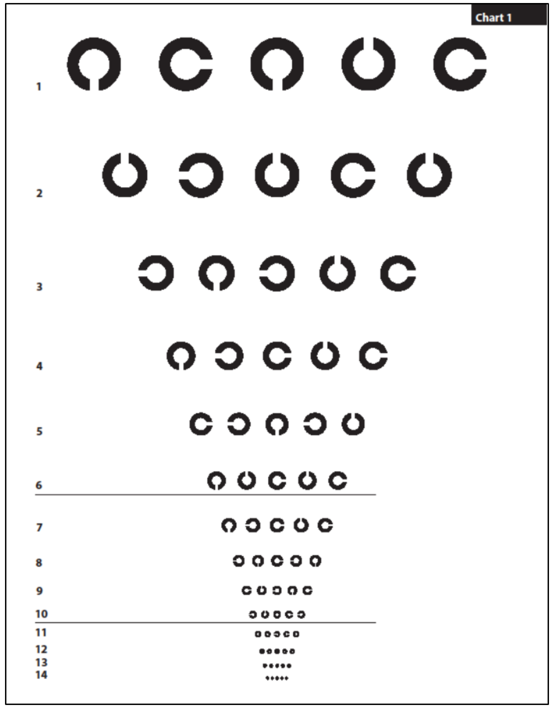
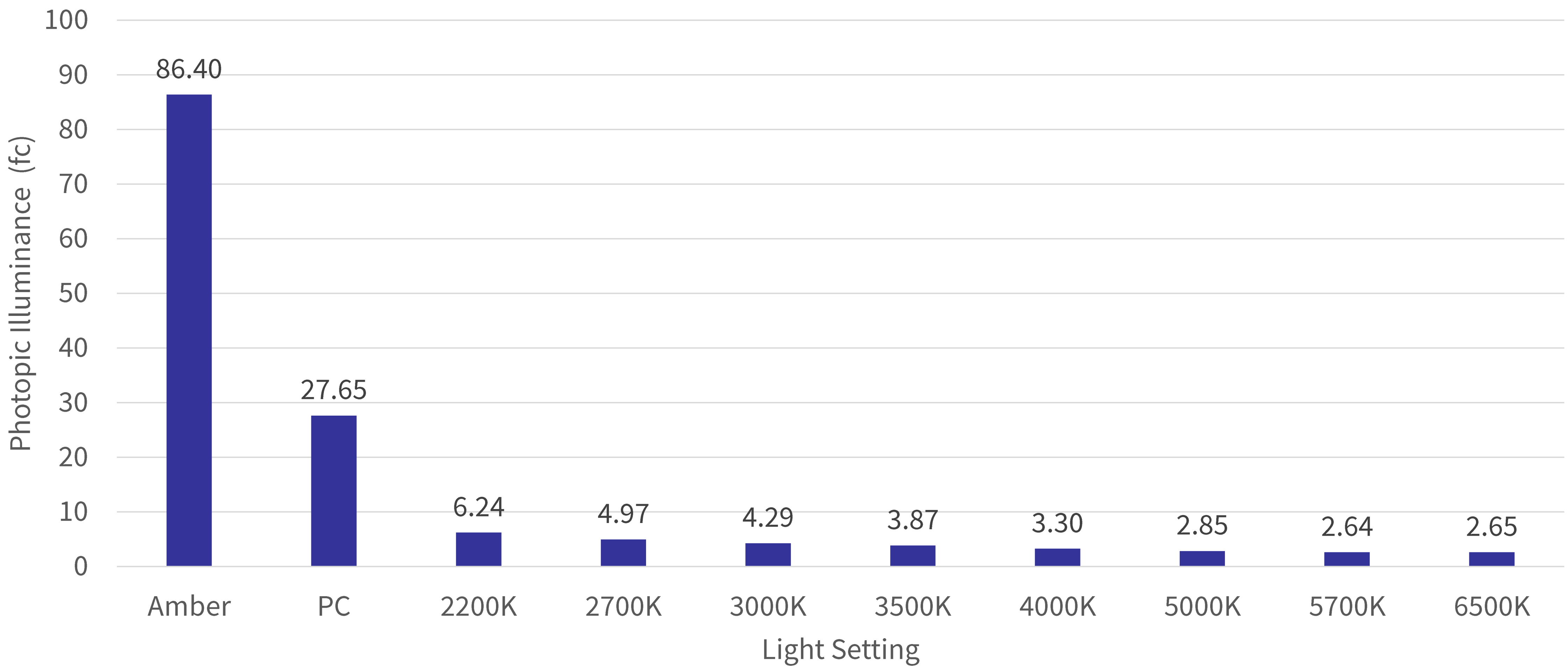
Melanopic Threshold Study





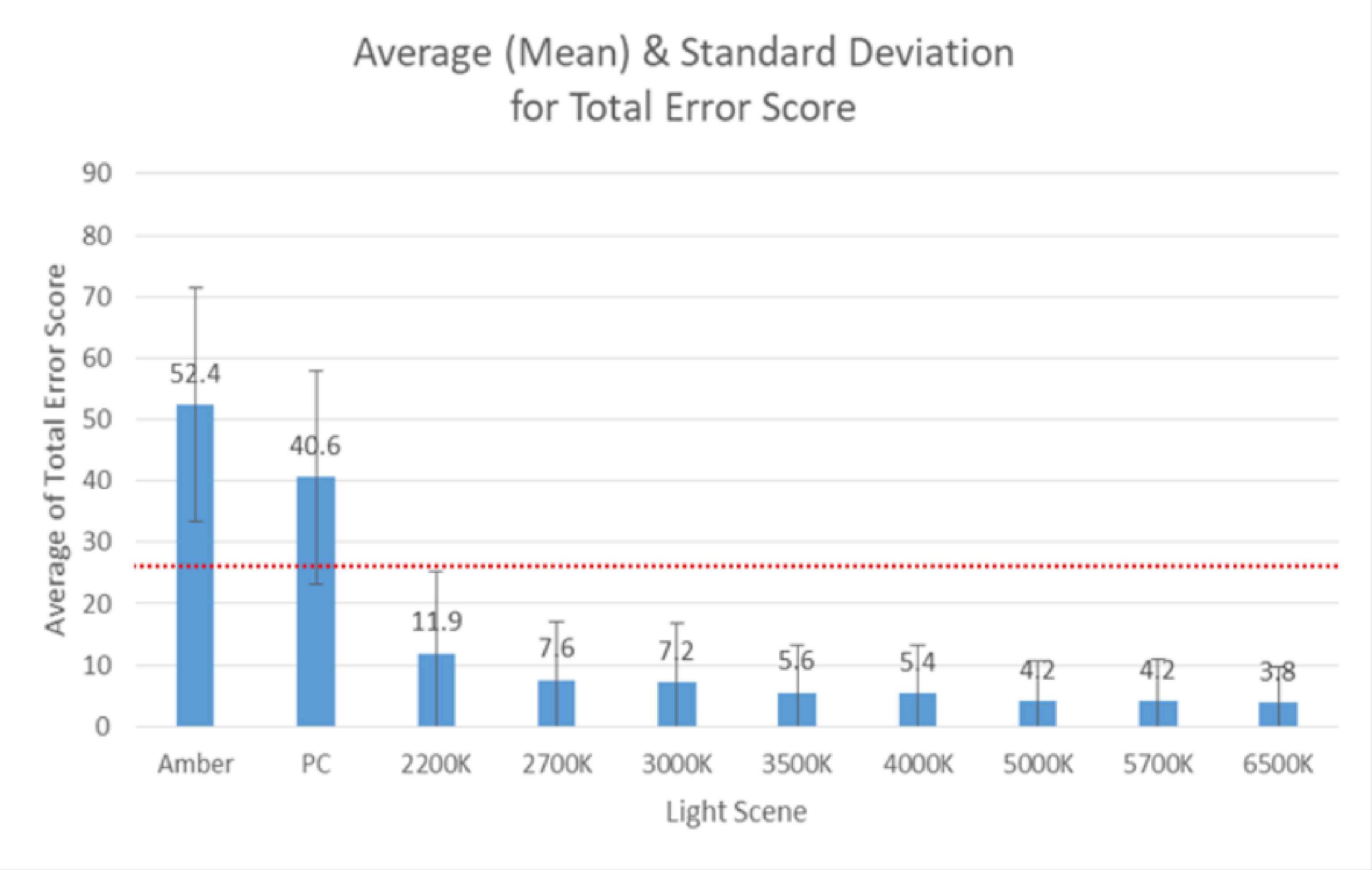


Photopic Light Levels at Melanopic Threshold



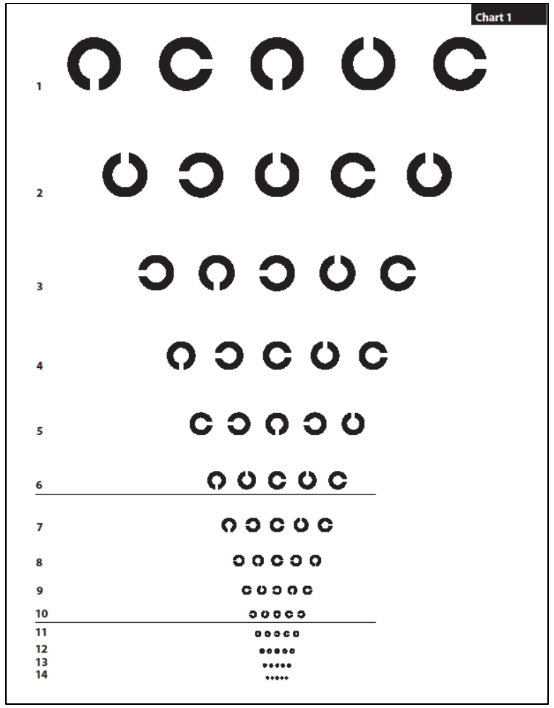
Color Sorting Results

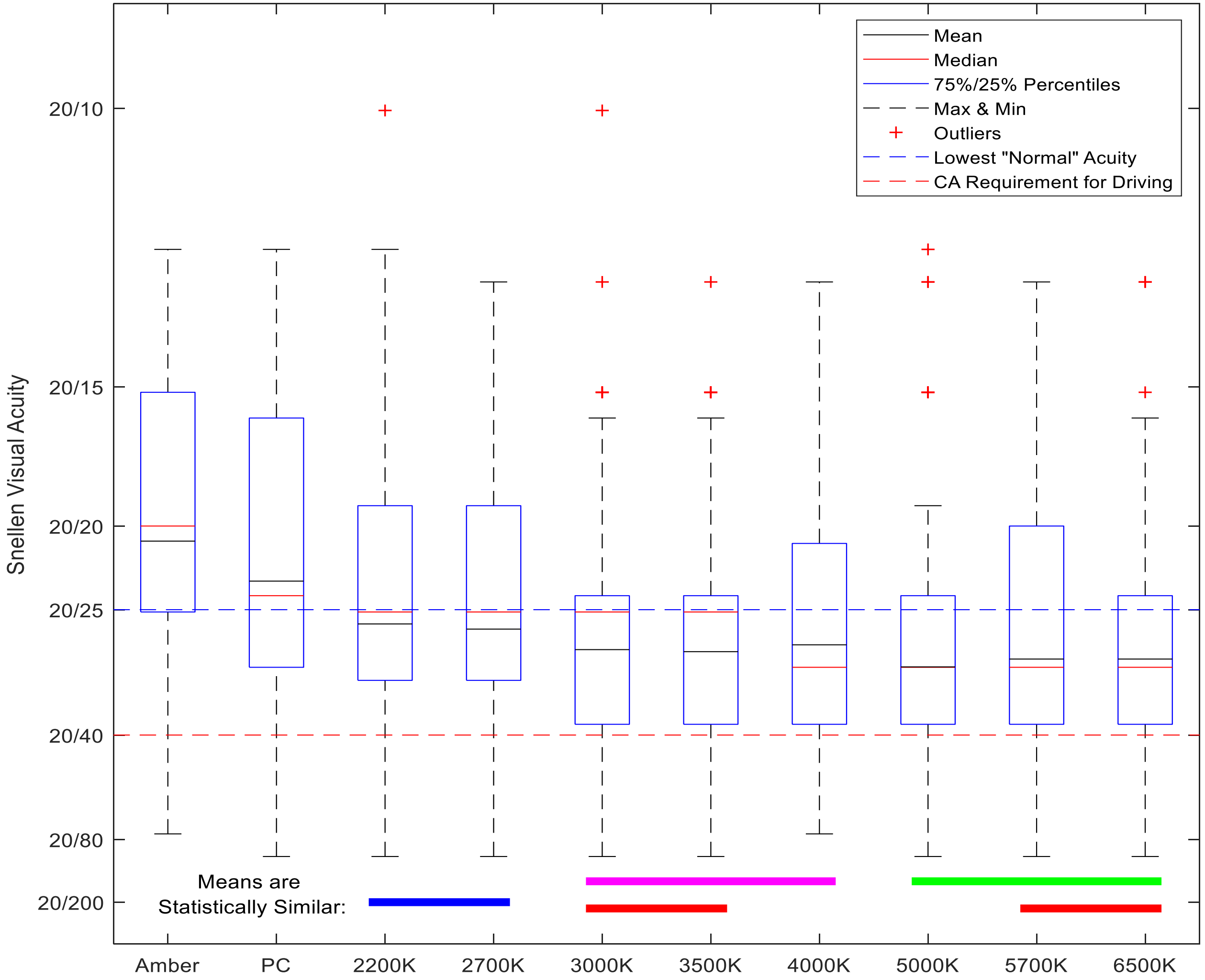
Farnsworth-Munsell D-15 Test



Visual Acuity Results

Landolt-C Test





Transitioning Research to Residential Applications

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Field Study in Residential Corridor

Lighting Service Delivered & Color Fidelity

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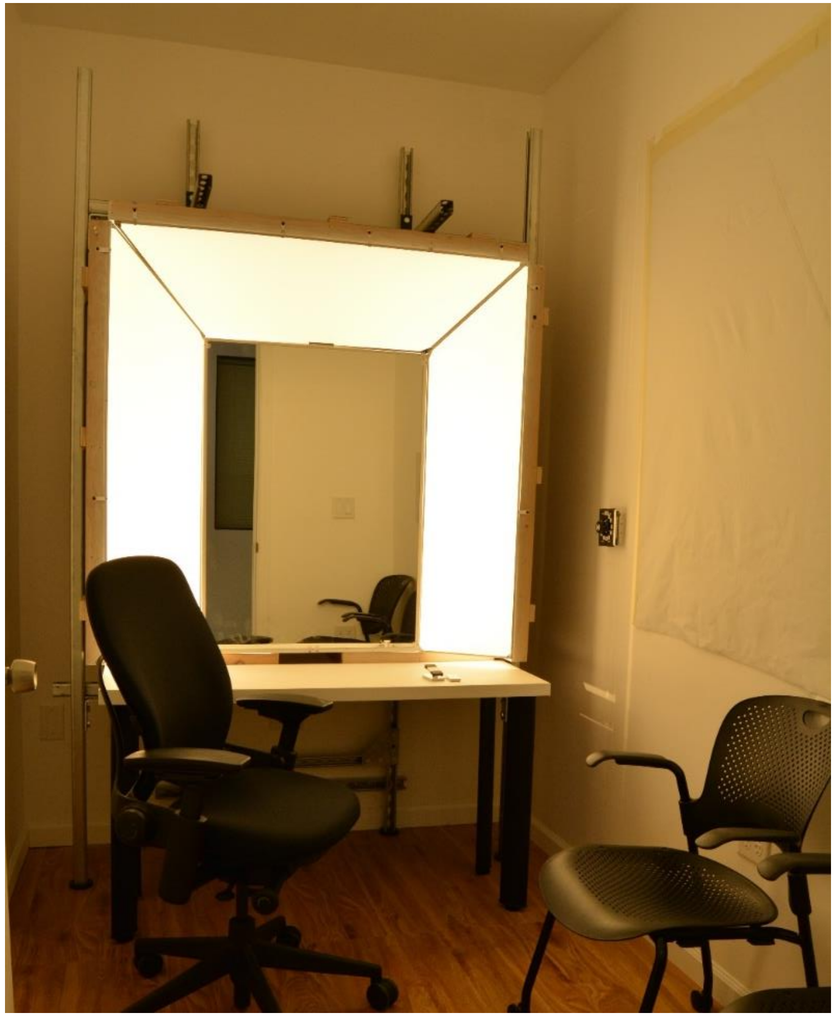
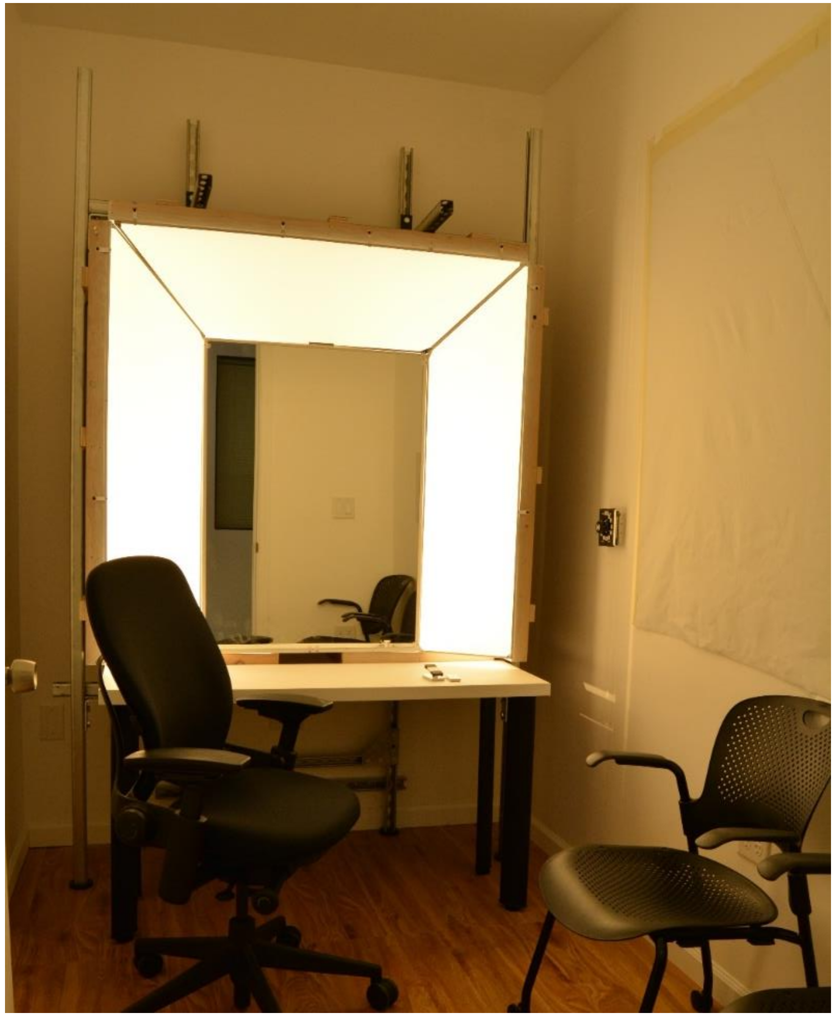
Lighting Service Delivered & Color Fidelity

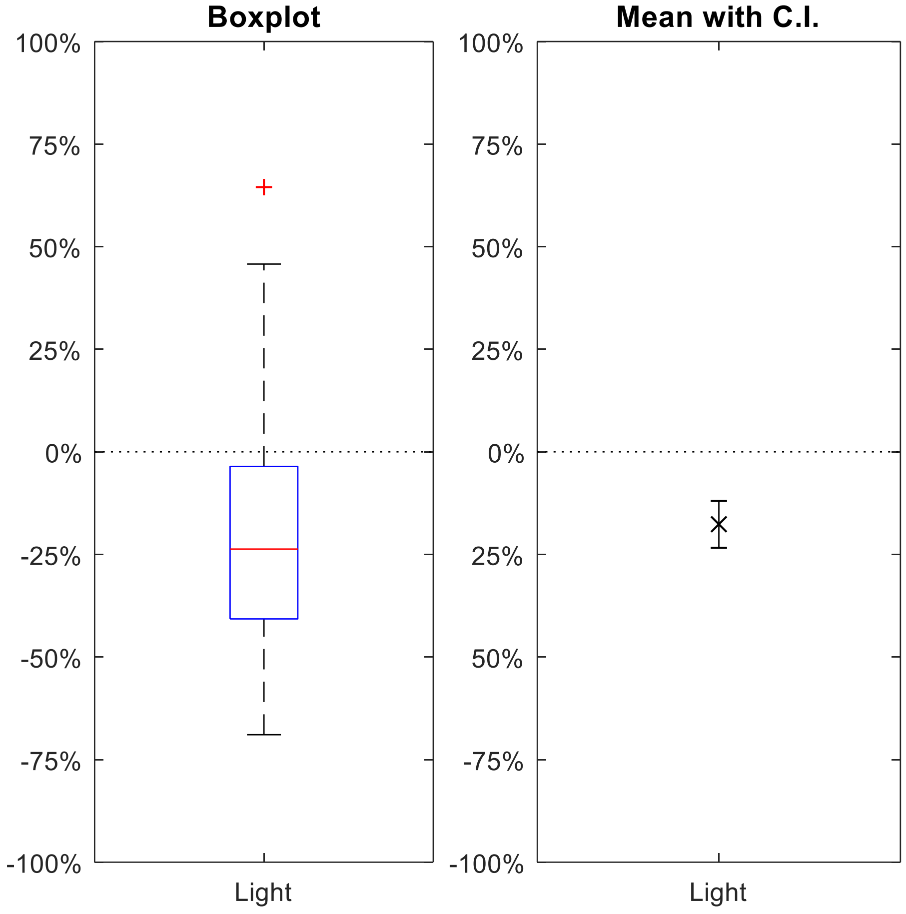


	Color Fidelity (CRI - R_a)	R_9	CCT (K)	D_{uv}
High Color Fidelity	95	76	2679	0.0004
Low Color Fidelity	82	9	2666	0.0005

Lighting Service Delivered & Color Fidelity



Percent Difference in Light Chosen From Low to High CRI



Transitioning Research to Healthcare Applications

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Background

- Analysis of face and hands photos indicate color quality improvements between 82, 97 and 95 Red CRI lights sources

- Self examination tests at CLTC using mirror setup indicated that high CRI is more effective for skin evaluation than 82 CRI light

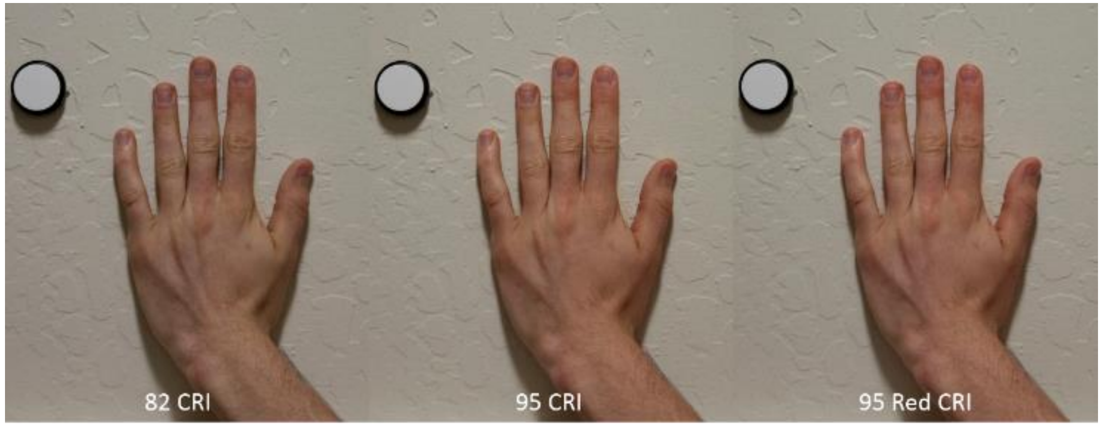
Project Partners

- **UC Irvine Dermatology Department**
  - Christopher B. Zachary, MD – *Chair of Dermatology at UCI*
  - Natasha Atanaskova Mesinkovska, MD PhD – *Chief Scientific Officer*
  - Margit Juhasz, MD – *Dermatology Clinical Research Fellow*
- **California Lighting Technology Center (CLTC)**
- **California Energy Commission**

Study Objectives

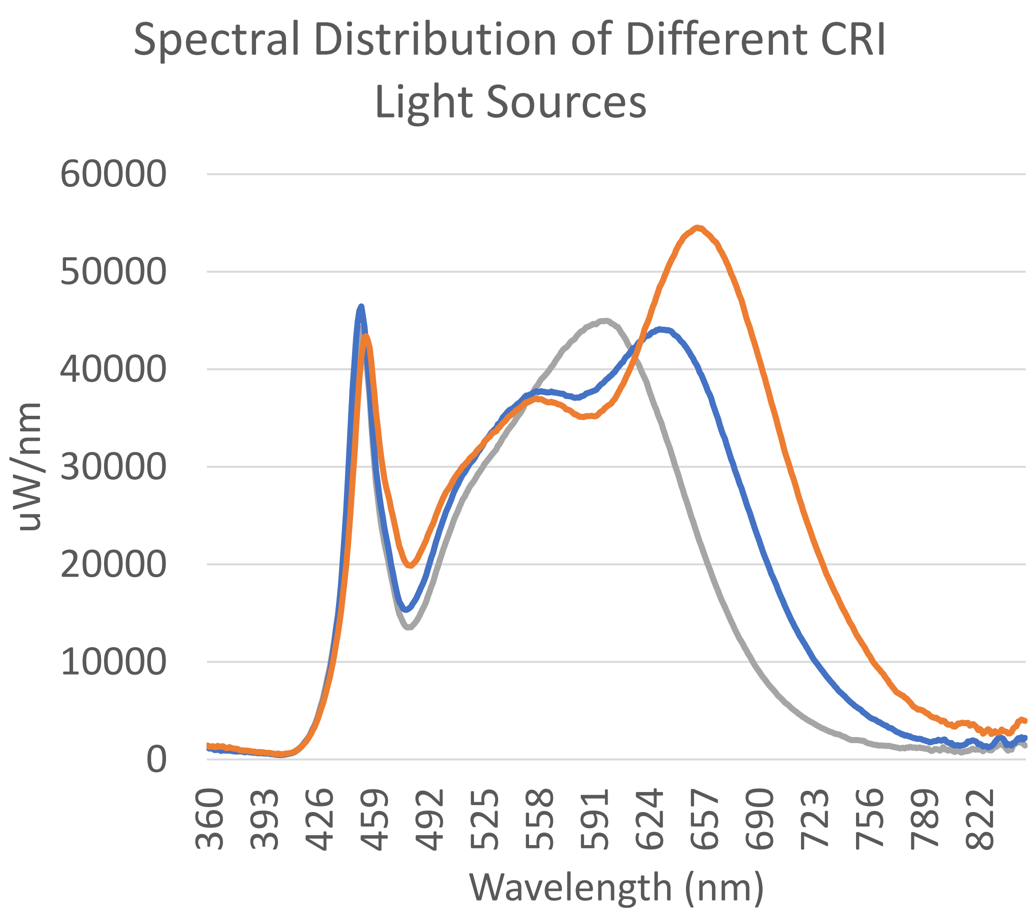
1. Improve assessment of skin disorders in dermatology clinics

2. Improve patient comfort



Lighting System Specification

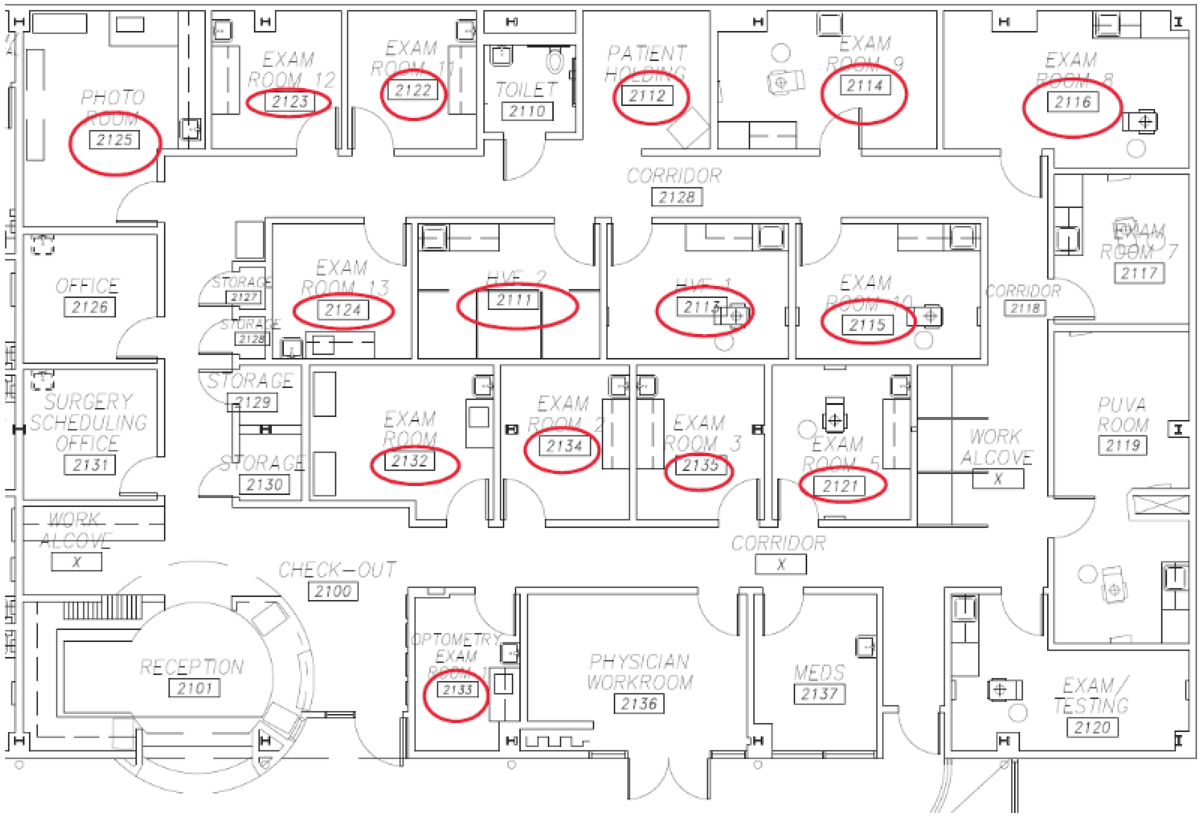
- CLTC and industry partners developed a variable CRI LED luminaire with three normalized channels:
  - 82 CRI
  - 97 CRI
  - 95 + (red enhanced) CRI
    - Red enhanced channel has a higher red-light spectral content than 97 CRI channel
- Luminaire power and switching is controlled through a PoE system with custom control software



Field Study at UC Irvine

- Adjustable color quality LED light fixtures in 15 rooms for clinical use

- For each setting, clinicians evaluate the following:
    - Different skin conditions
    - Naturalness of the patient's skin
    - Effectiveness of the lighting for skin evaluation
    - Room comfort
    - Preference for use in their dermatology practice



Key Research Outcomes

1. Consumer Preference Study Results
2. **Product Evaluation Results**
    - **Product Life Testing**
    - **Linear LED Lamps – Interoperability Testing**
3. Technology Transfer Activities
4. Industry Engagement

LED Product Life Testing

Product Evaluations – Life Testing

- Third-party verification of 138 LED lamp performance for 12,000 hours of runtime
  - **Medium Screw Base LED Lamps (14 Products)**
    - *7 omni-directional (2 are filament-style)*
    - *7 directional*
  - **Linear LED Lamps (7 products)**
    - *UL Type A (3)*
    - *UL Type B (2)*
    - *UL Type A/B (1)*
    - *UL Type C (1)*
  - **Candelabra Lamps (2 Products)**

- Three early failures (within 1,000 hours of run time)
  - 2 samples of one filament-style LED medium screw base product
  - 1 linear LED lamp sample

Product Evaluations – Life Testing

- **Projected Rated Life vs. Manufacturer Claimed Rated Life**
  - Used industry standard measurement and calculation methods
    - Lifetime standard, IES LM-84-14 & TM-28-14
    - Photometric Measurements, IES LM-79-08
  - 26% of tested products failed to meet manufacturer claimed rated life (6 of 23)

- **Product Safety and Reliability**
  - No safety concerns encountered over the course of the evaluation
  - All samples of two ‘filament-style’ products failed

Linear LED Lamp Product Evaluations

- 3 of the 7 linear LED lamp products experienced failures due to three main modes:
  - Connections between lamp and driver (6 of 6)
  - Driver (1 of 6)
  - Resistor (4 of 6)

	Manufacturer Claimed Rated Life (hours)	Projected Rated Life (L_{70}) Based on In-Situ Performance (hours)
TLED-1	50,000	**N/A (6 failures)**
TLED-2	50,000	>60,000
TLED-3	50,000	>60,000
TLED-4	50,000	>60,000
TLED-5	50,000	>60,000 (1 failure)
TLED-6	50,000	>60,000
TLED-7	50,000	**N/A (4 failures)**

Linear LED Lamp – Interoperability Testing

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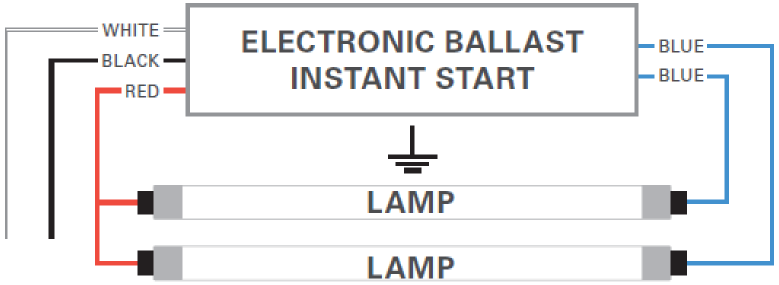
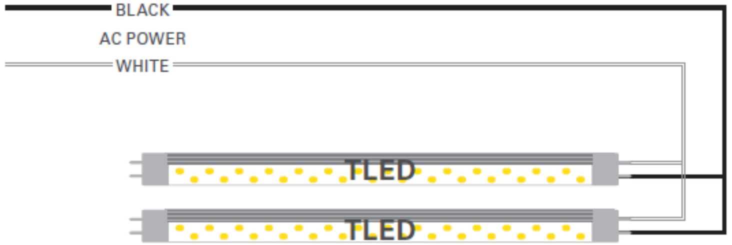
Linear LED Lamp – Electrical Architectures

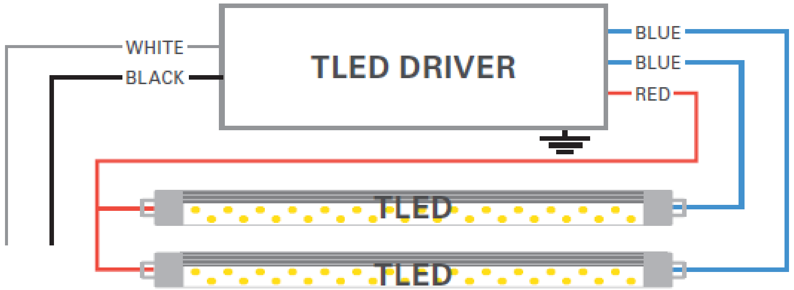
- **UL Type A:** Internal driver that is designed to operate on a linear fluorescent lamp ballast.



- **UL Type B:** Internal driver that must be connected directly to line voltage for power.



- **UL Type C:** External driver that is designed to replace both the linear fluorescent lamp and fluorescent lamp ballast.



- **Hybrids:** Linear LED lamps with two Type A, B or C options in one product. Also referred to as 'dual-mode' by select manufacturers

Linear LED Lamps with Ballasts

CLTC conducted interoperability testing to evaluate placing lamps currently found on the market into incorrect fixture types, i.e. Type A lamps in Type B wiring harness.

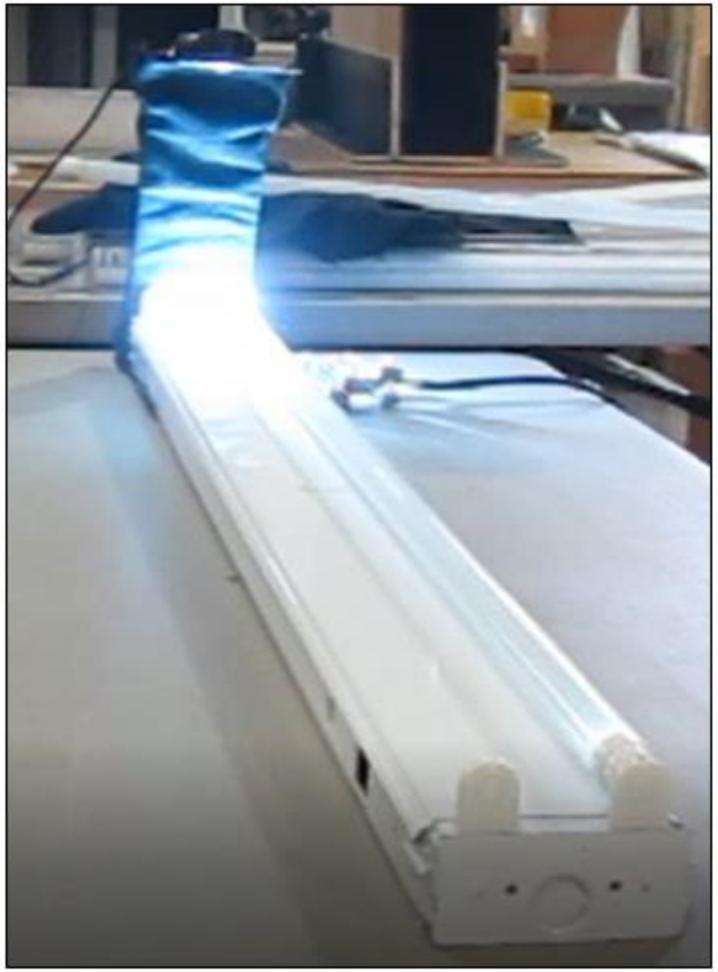
		Ballast			
Product ID	UL Type	Ballast 1	Ballast 2	Ballast 3	Ballast 4
Product A	Type A	-1.96% @ 83°F	2.04% @ 90°F	-8.64 @ 83°F	Baseline
Product B	Type A	Baseline	DNF	9.06% @ 82°F	16.37% @ 92°F
Product C	Type B	DNF	DNF	DNF	DNF
Product D	Type B	DNF	DNF	DNF	DNF
Product E	Type C	-53.42% @ 81°F	DNF	-57.62% @ 86°F	-52.77% @ 88°F
Product F	Type C	DNF	DNF	DNF	DNF
Product G	Type AC	7.4% @ 83°F	Baseline	12.18% @ 82°F	18.07% @ 94°F
Product H	Type AC	-7.58% @ 82°F	DNF	-3.56% @ 84°F	Baseline
Product I	Type AB	-18.49 @ 81°F	DNF	Baseline	15.18% @ 87°F
Product J	Type AB	-28.8% @ 81°F	DNF	Baseline	DNF
Product K	Type B	DNF	DNF	DNF	DNF
Product L	Type B	DNF	DNF	DNF	DNF

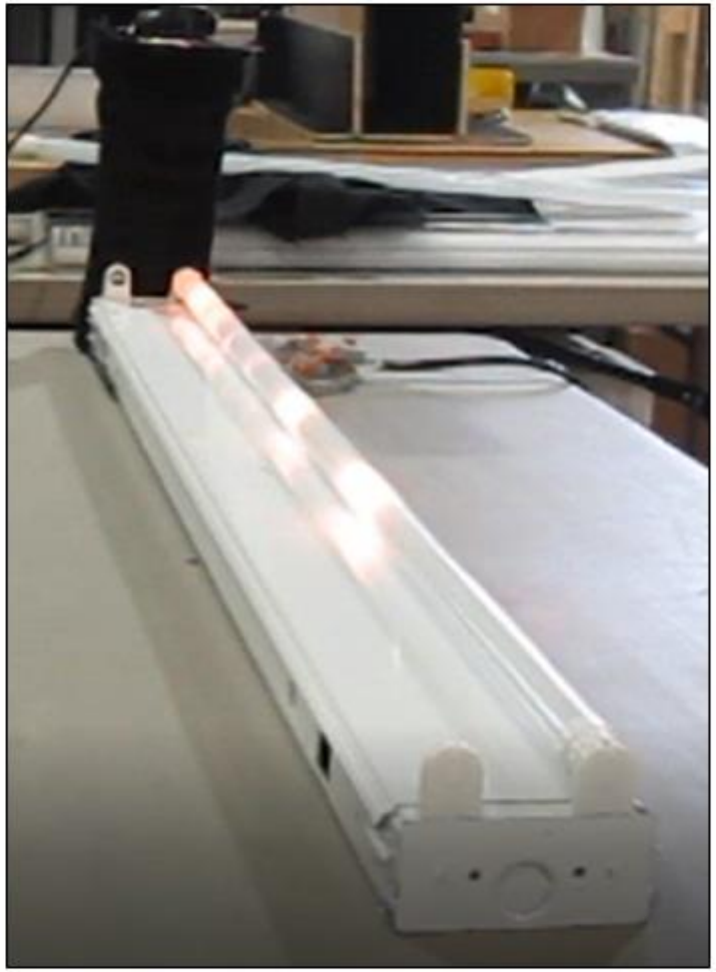
Linear LED Lamp with Drivers

		Drivers			
Product ID	UL Type	Driver 1	Driver 2	Driver 3	Driver 4
Product A	Type A	DNF	-19.06% @ 83°F	0.34% @ 82°F	DNF
Product B	Type A	DNF	-6.53 @ 82°F	22.09% @ 87°F	DNF
Product C	Type B	DNF	DNF	DNF	DNF
Product D	Type B	DNF	DNF	DNF	DNF
Product E	Type C	Baseline	-64.93% @ 81°F	-97.69% @ 81°F	-12.28% @ 79°F
Product F	Type C	DNF	DNF	DNF	Baseline
Product G	Type AC	DNF	Baseline	27.03% @ 87°F	DNF
Product H	Type AC	DNF	-13.18% @ 81°F	Baseline	DNF
Product I	Type AB	DNF	-16.15% @ 81°F	-31.16% @ 87°F	DNF
Product J	Type AB	DNF	1.69% @ 81°F	-0.39% @84°F	DNF
Product K	Type B	DNF	DNF	DNF	DNF
Product L	Type B	DNF	DNF	DNF	DNF

Linear LED Lamp – Interoperability Testing

		Line Voltage	
Product ID	UL Type	Single-Ended	Double-Ended
Product A	Type A	DNF	DNF
Product B	Type A	DNF	DNF
Product C	Type B	Baseline	DNF
Product D	Type B	DNF	Baseline
Product E	Type C	DNF, Sparks	DNF
Product F	Type C	N/A	N/A
Product G	Type AC	DNF	DNF
Product H	Type AC	DNF @ 158°F	DNF
Product I	Type AB	Baseline	DNF
Product J	Type AB	Baseline	DNF
Product K	Type B	Baseline	DNF
Product L	Type B	Baseline	DNF





Linear LED Lamp Performance Specification

- **Electrical Architecture,** UL Type C
- **Color fidelity**, Rf value greater than 92 +/- 2 measured by TM-30-18
- **Light Output**, single lamp output of 2,250 lumens
- **System Efficacy**, at least 120 lm/W
- **Controllability**, minimum dimming level of at least 10% full power
- **Distribution**, beam angle of at least 220 degrees with no less than 20% of total flux emitted in the 100-180 degree zone
- **Rated life**, 50,000 hours or greater (aligned with DLC)

Key Research Outcomes

1. Consumer Preference Study Results
2. Product Evaluation Results
3. **Technology Transfer Activities**
   - **Transitioning Linear LED Lamp Specification into the Million LED Challenge**
   - **Investigating Areas Currently Governed by Standards**
4. Industry Engagement

Technology Transfer Activities

Transitioning Linear LED Lamp Specification into the Million LED Challenge

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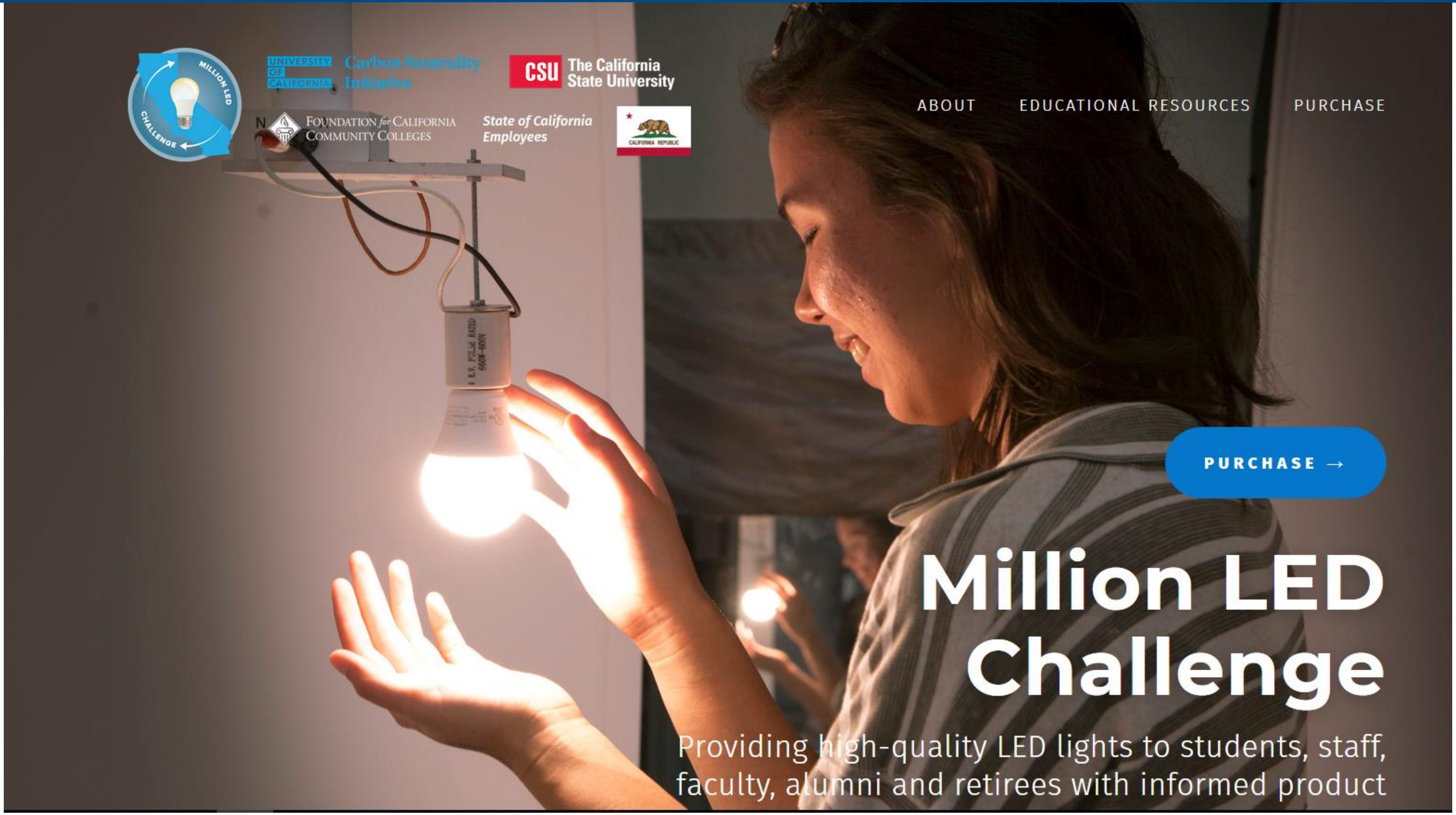
Million LED Challenge



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Million LED Challenge

- **Two-phase approach**
  - Phase 1: Screw base lamps and downlights (Available Now)
  - Phase 2: Retrofit solutions for recessed troffers, i.e. linear fluorescent replacements (Coming Soon)
- **Develop performance specification**
  - CLTC lighting quality & consumer preference research
  - California Energy Commission Voluntary Specification for MLC Phase 1
- **Establish MLC program**
  - UC Office of the President partners with California State University, California Community Colleges and the California Department of General Services
  - Establishes purchasing process
    - Assured product quality (RFP process)
    - Reduced price (collective purchasing)
    - Ease of purchase

Linear LED Lamps (TLEDs)

- Electrical architecture, UL Type C
- Light output, bare single lamp light output of 2,250 lumens
- Efficacy, at least 120 lumens per Watt
- Dimming, minimum dimming level to at least 10 percent of full light output
- Controllability, be able to pair with lighting control devices **(control-ready)**
- Color, R_f value greater than 90 measured by IES TM-30-18
- Distribution, beam angle of at least 220 degrees with no less than 20 percent of total flux emitted in the 100–180 degree zone
- All else, meet **DLC minimum criteria**

LED Retrofit Kits & Fixtures

- Efficacy, at least 120 lumens per Watt
- Dimming, minimum dimming level to at least 10 percent of full light output
- Controllability, be able to pair with lighting control devices **(control-ready)**
- Color, R_f value greater than 90 measured by IES TM-30-18
- Distribution, provide photometric distribution file in IES LM-63 format
- All else, meet **DLC minimum criteria**

What is control-ready?

All LED retrofit solutions should be pairable with lighting controls that will allow for control strategies including personal tuning, occupancy sensing, daylight harvesting and automated demand response, where appropriate.

Light Source Color Binning

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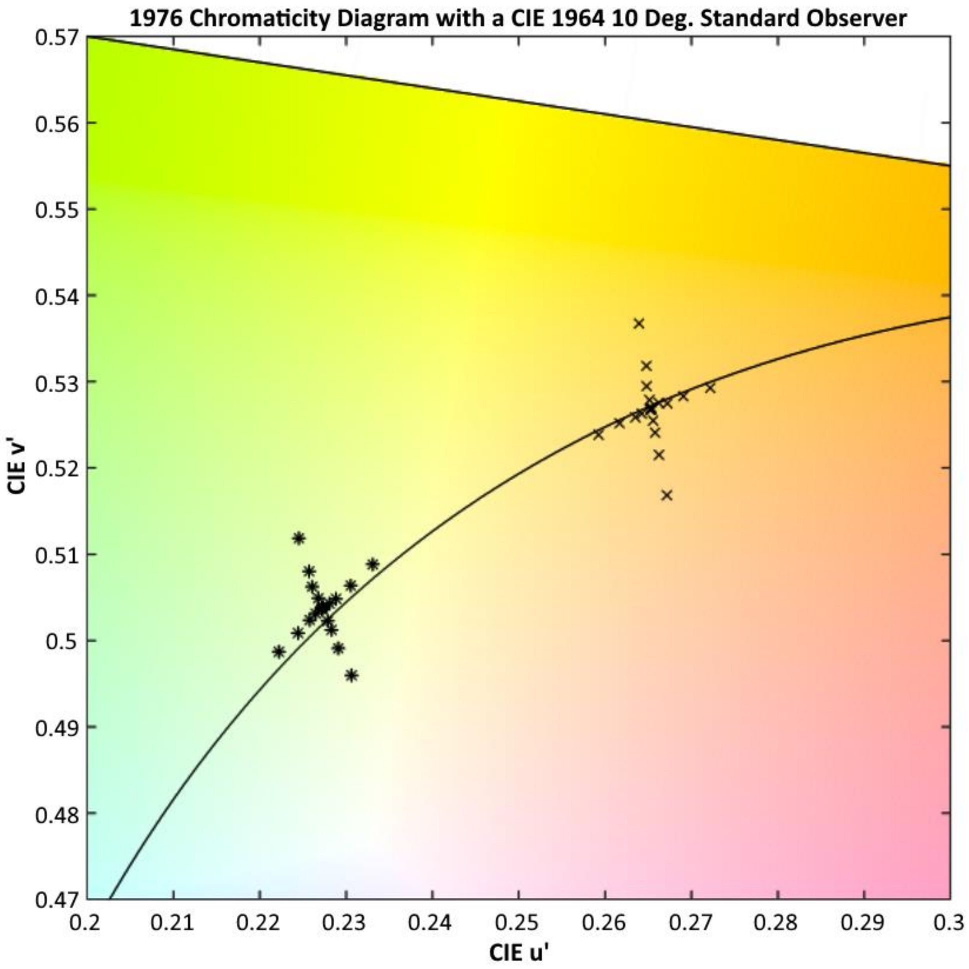
Light Source Binning Methodology

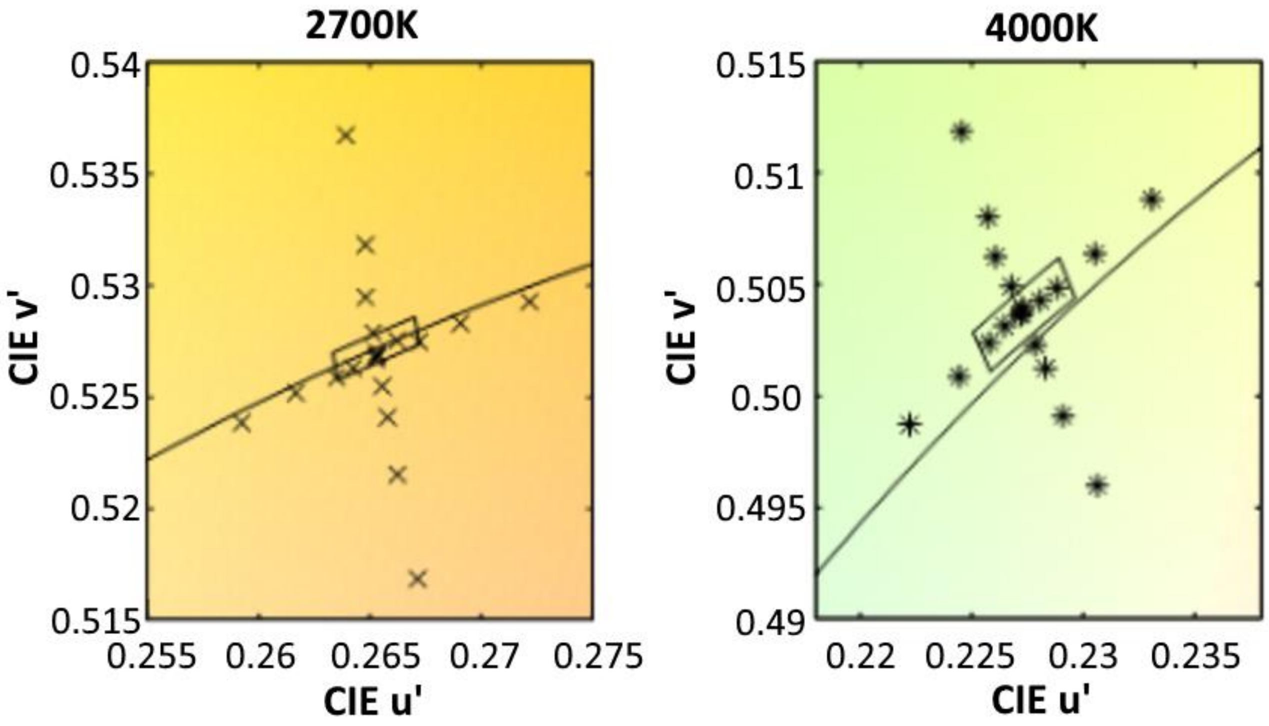


Consumer preference testing conducted for two directions to plot quadrangles to determine 'just noticeable difference'.

Light Source Binning Results

2700 K Bins		
Size	*Edge*	*% Perceived*
1 Step	+CCT	4%
	-CCT	13%
	+duv	31%
	-duv	53%
2 Step	+CCT	17%
	-CCT	9%
	+duv	93%
	-duv	84%
4 Step	+CCT	65%
	-CCT	72%
	+duv	98%
	-duv	100%
7 Step	+CCT	98%
	-CCT	98%
	+duv	100%
	-duv	98%

4000 K Bins		
Size	*Edge*	*% Perceived*
1 Step	+CCT	22%
	-CCT	2%
	+duv	22%
	-duv	28%
2 Step	+CCT	9%
	-CCT	4%
	+duv	72%
	-duv	63%
4 Step	+CCT	63%
	-CCT	70%
	+duv	91%
	-duv	93%
7 Step	+CCT	91%
	-CCT	93%
	+duv	98%
	-duv	98%



Bins are plotted in u', v' chromaticity diagram using the CIE 2006 standard 10-degree observer.

Just Noticeable Flicker

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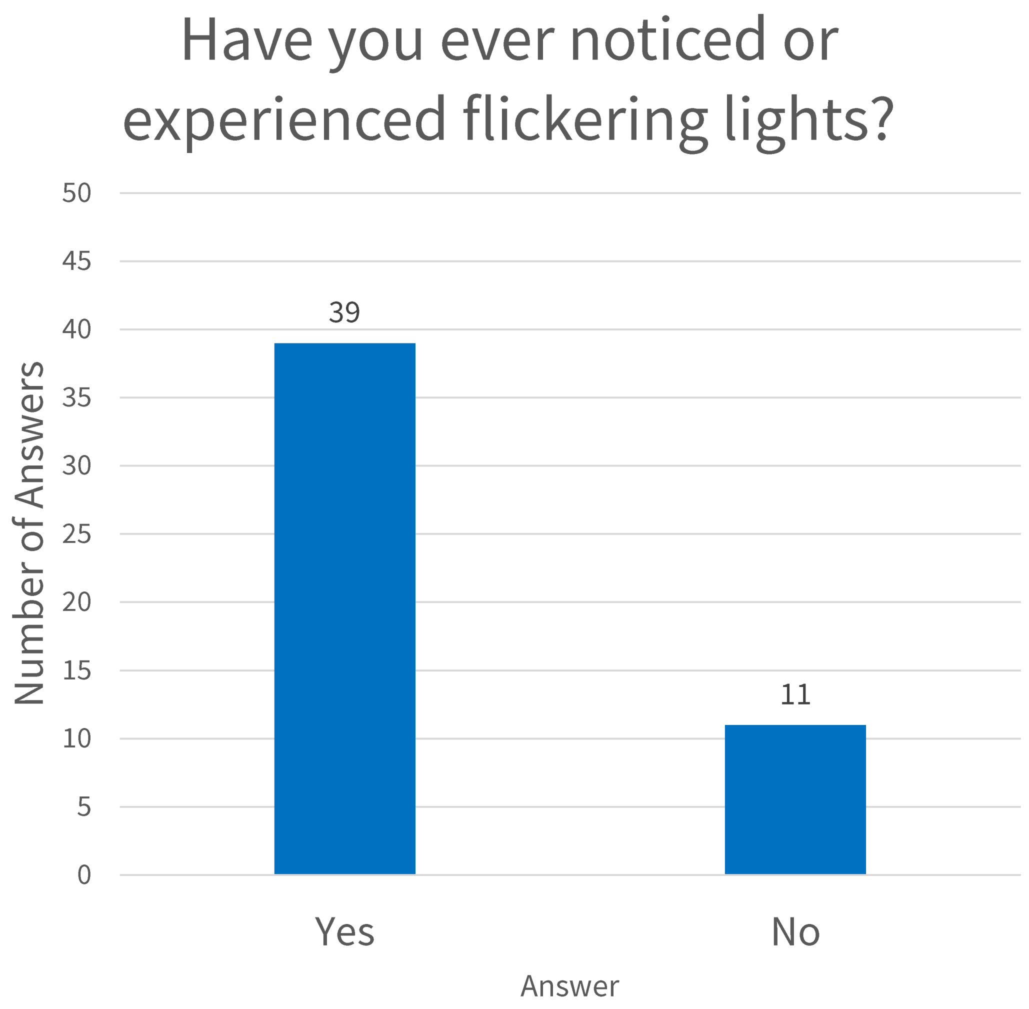
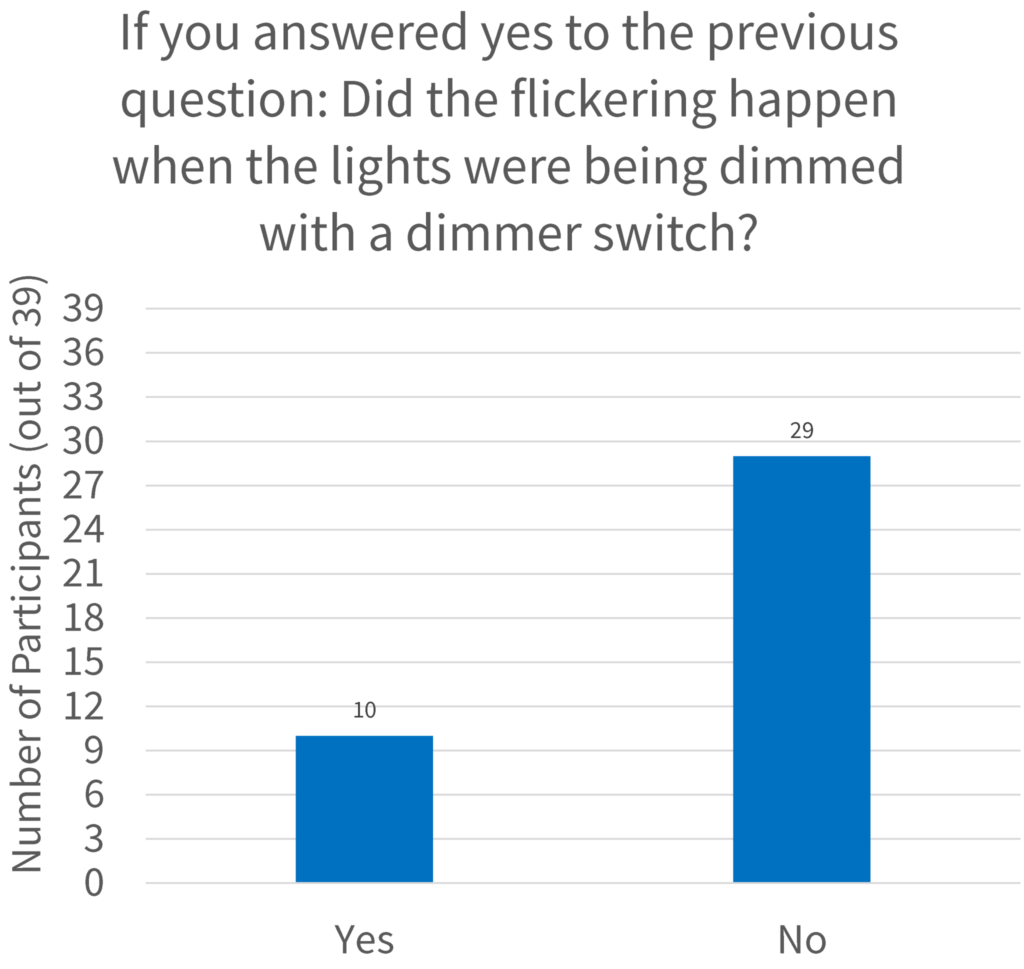
Flicker Study Results

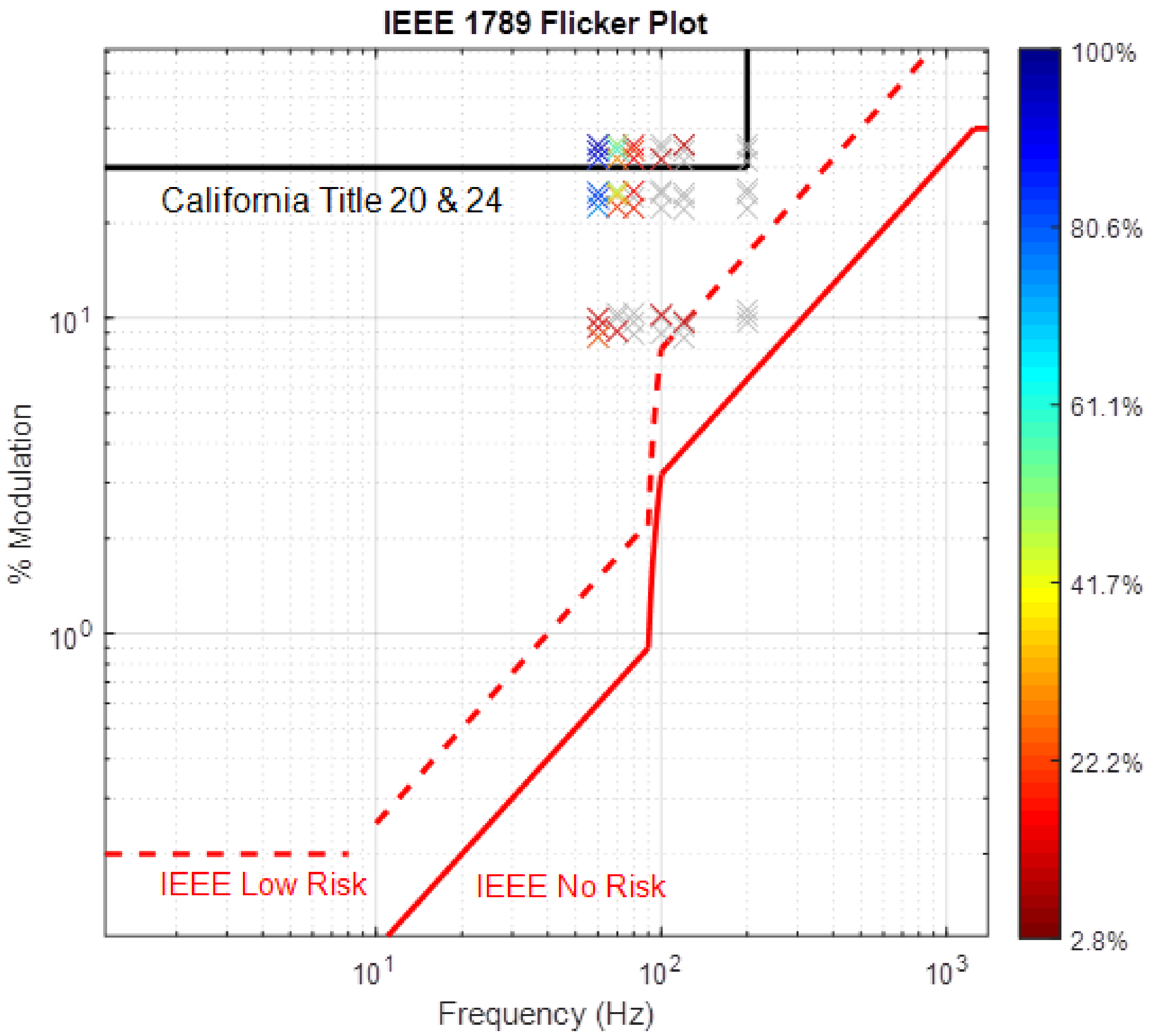




Flicker Study Background

- Study Goal
  - Determine if study participants can detect visible flicker as compared to industry standards
- Setup
  - Phosphor converted white lights uniformly illuminated 0.5-meter sphere
  - Lights programmed to flicker with 54 combinations:
    - 3 different waveforms
    - 3 different percent modulations
    - 6 different frequencies
- Procedure
  - Study participant shown 54 combinations in random and asked if they saw flicker:
    - If yes, they were instructed to press a button that logged their response
    - If no, the next combination was shown

Flicker Study Results



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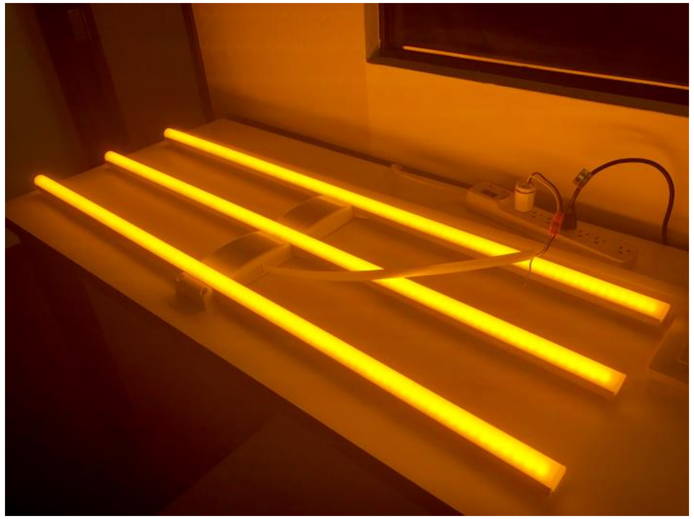
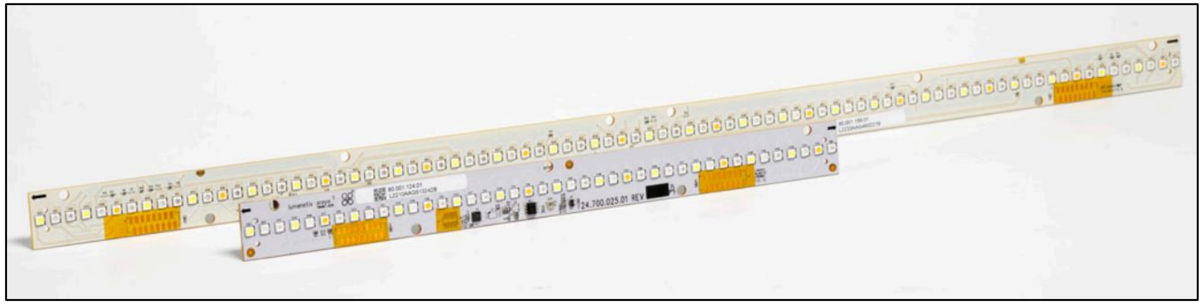


Industry Engagement



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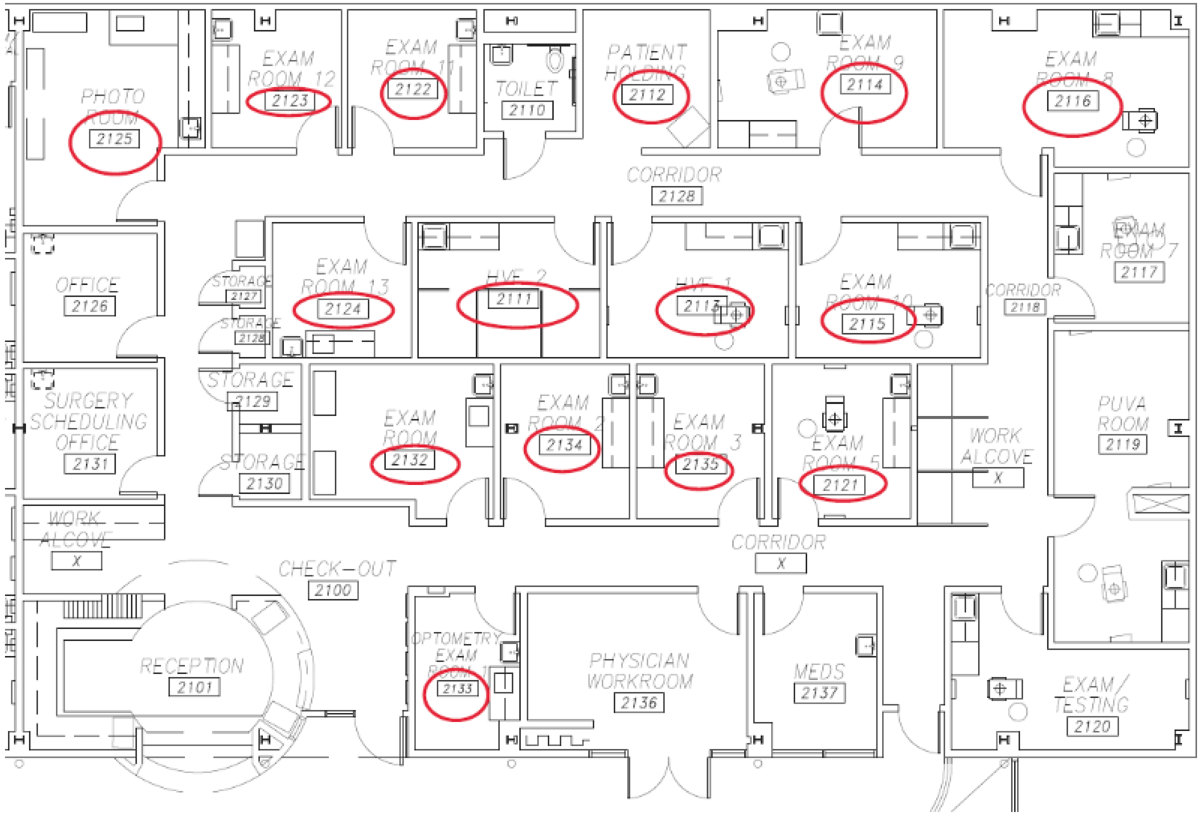
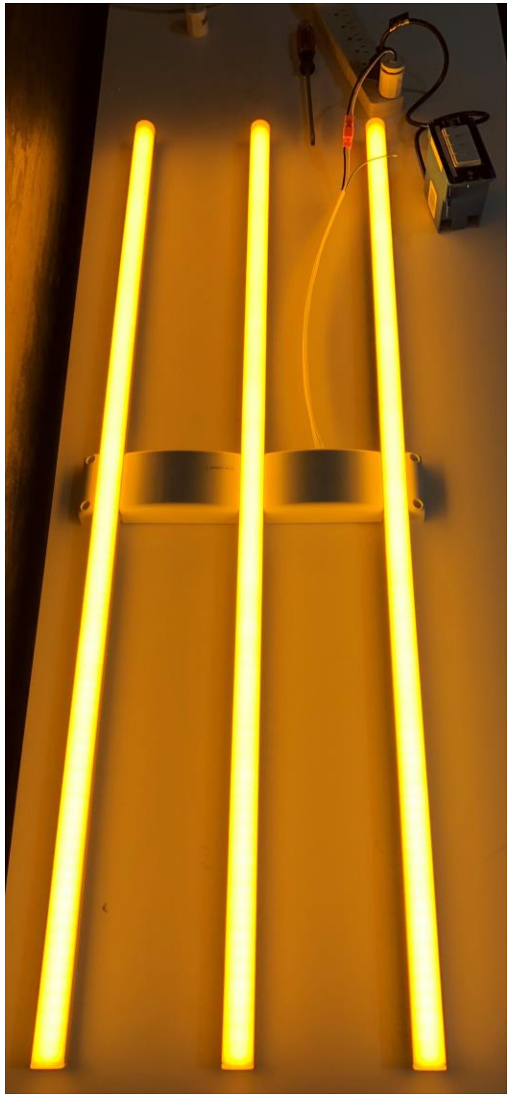
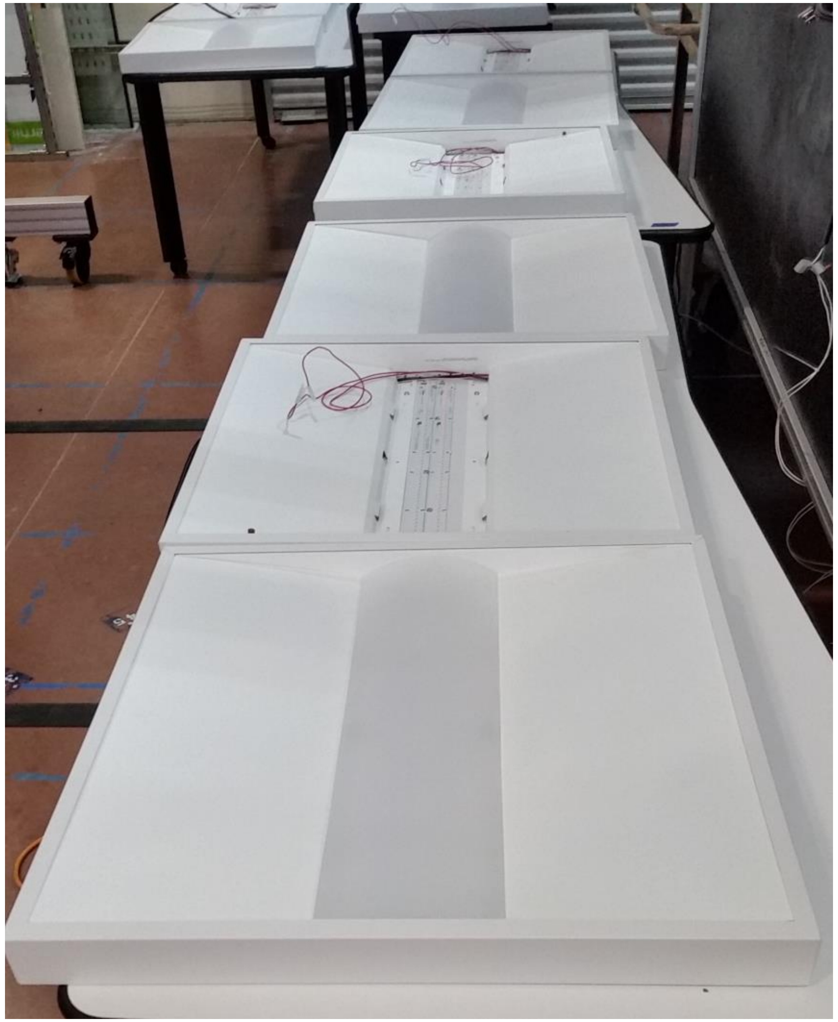
Field Study at UC Irvine

Field Study at UC Irvine



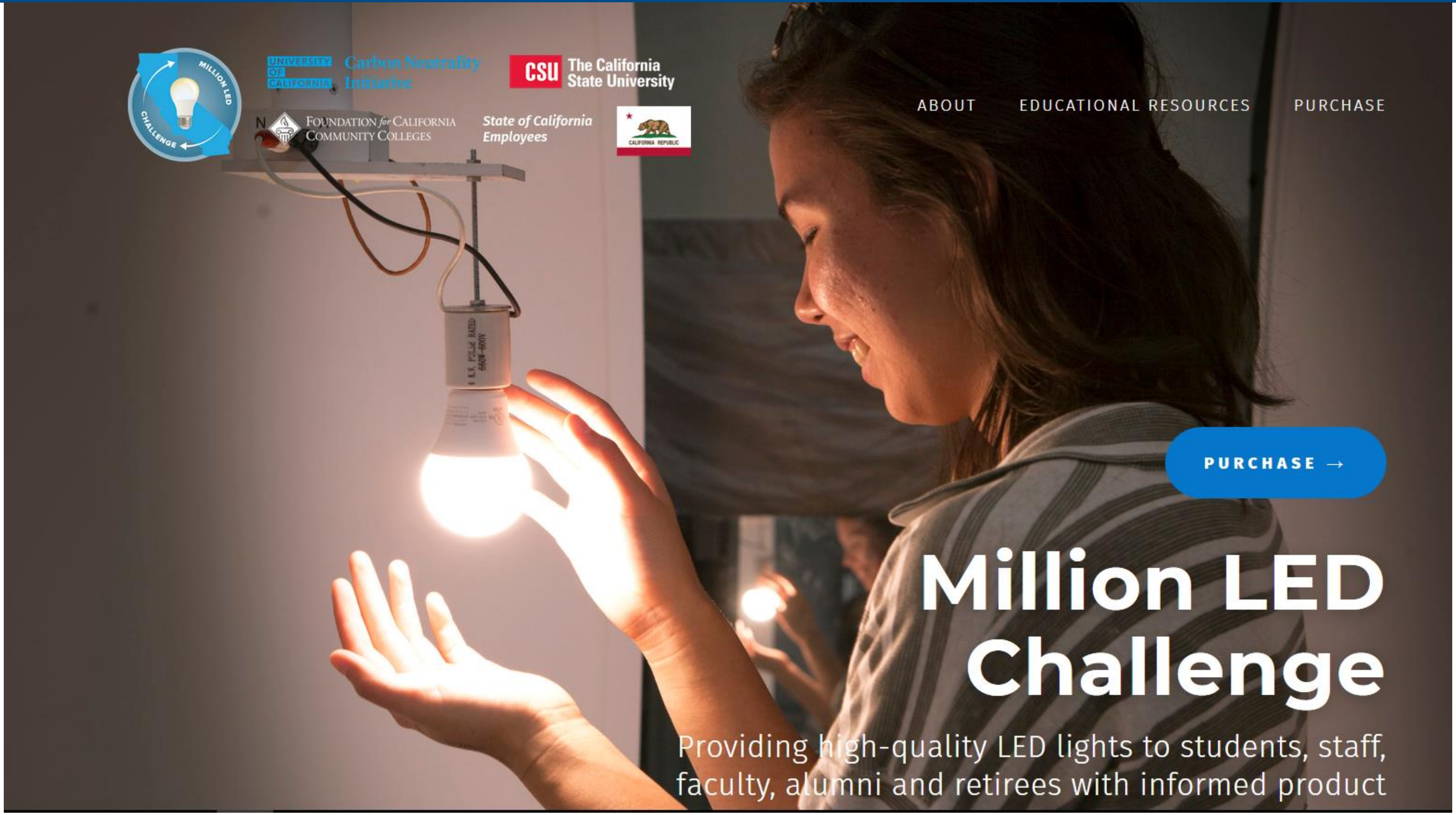
Amber/White Corridor Lighting





Amber/White Corridor Lighting

Million LED Challenge



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From the Laboratory to the California Marketplace: A New Generation of LED Lighting Systems

Questions?

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