Consumer Preference Informs the Next Generation of LED Lighting Solutions

Michael Siminovitch, Keith Graeber, Philip von Erberich, Ryan Allen

CLTC is working to improve adoption of LED light sources by developing optimized performance and product designs. Design criteria are being determined through a series of targeted studies aimed at identifying the features and performance attributes most valued by today's consumers.

A cross-section of the general public were asked to conduct a number of tasks under varying lighting conditions. These studies evaluated the qualitative and quantitative experiences of the participants to identify consumer preferences for color related metrics. Three of the tasks are shown here:

- Identifying subtle variation in light color for informing lamp color binning (Figure 1).
- Sorting color chips under equal power high and low fidelity lights to determine if the loss in efficacy is compensated for by the increased visual performance (Figure 2).
- Raising the light level of a vanity fixture to a preferred light level under low and high fidelity lights to quantitatively determine the value of increased color fidelity (Figure 3).

CLTC is conducting Phase 2 of a two-phase study to further understand consumer preference for light sources and lighting control behavior.

Figure 1a. Color binning test setup at CLTC laboratory

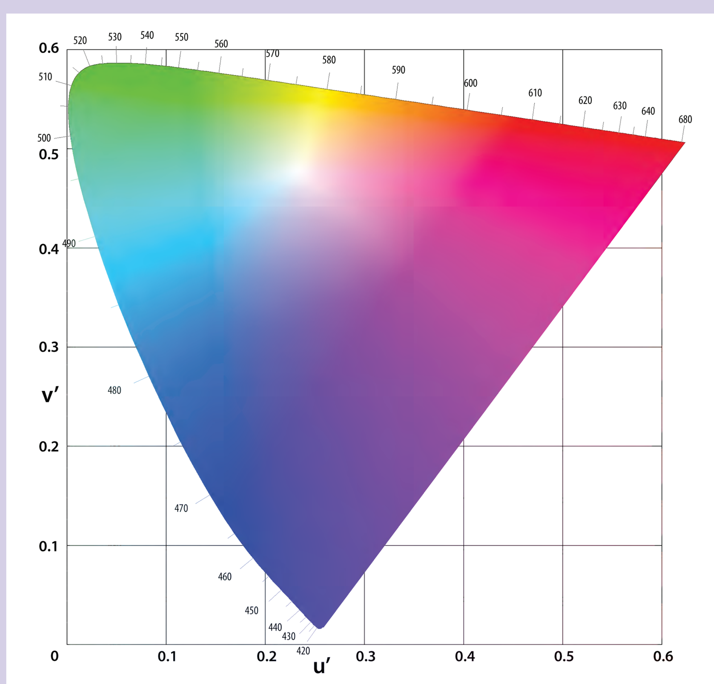

Figure 1b. 7-step binning for 1976 color space (ANSI C78.377-2015)

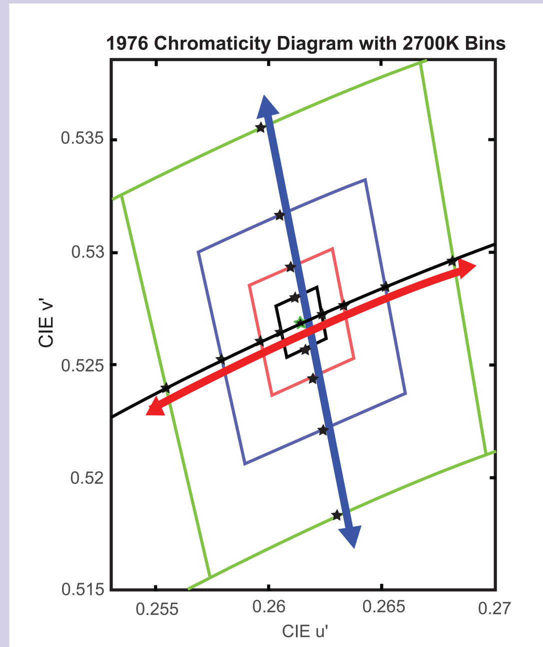

Figure 1c. Each star represents the lamp color point randomly selected for one of the four lamps.

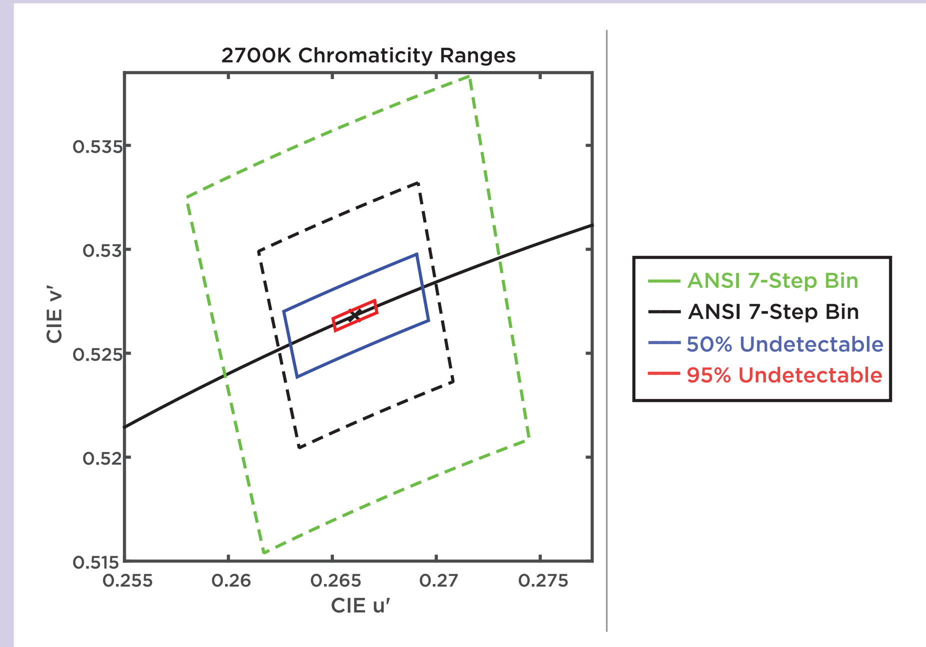

Figure 1d. The results of the participants observations were used to create two new bins for acceptable variance in color of light sources.

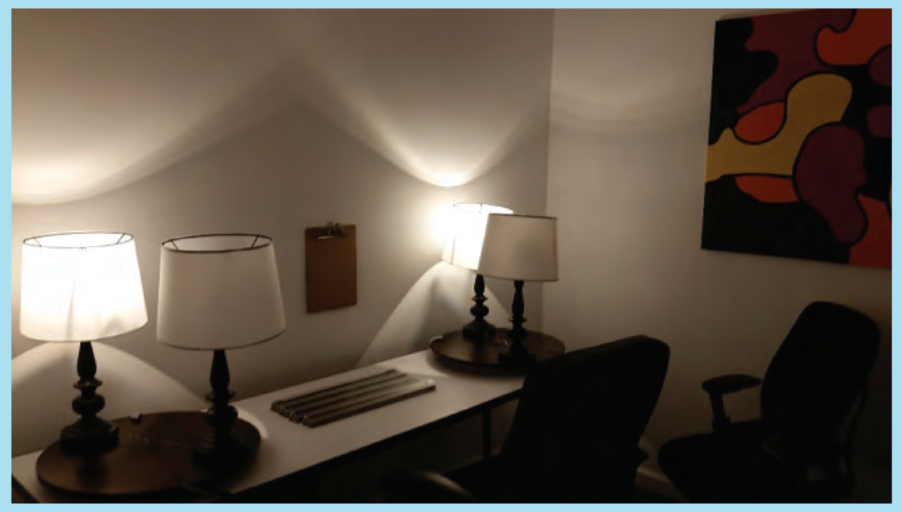

Figure 2a. This home office environment was used to quantify discrimination ability under two lighting conditions: high color fidelity and low color fidelity.

Figure 2b. The calculated error score of the Red-Green and Blue-Red Farnsworth-Munsell color tiles was used to quantify the improvement in color sorting performance under the two light sources.

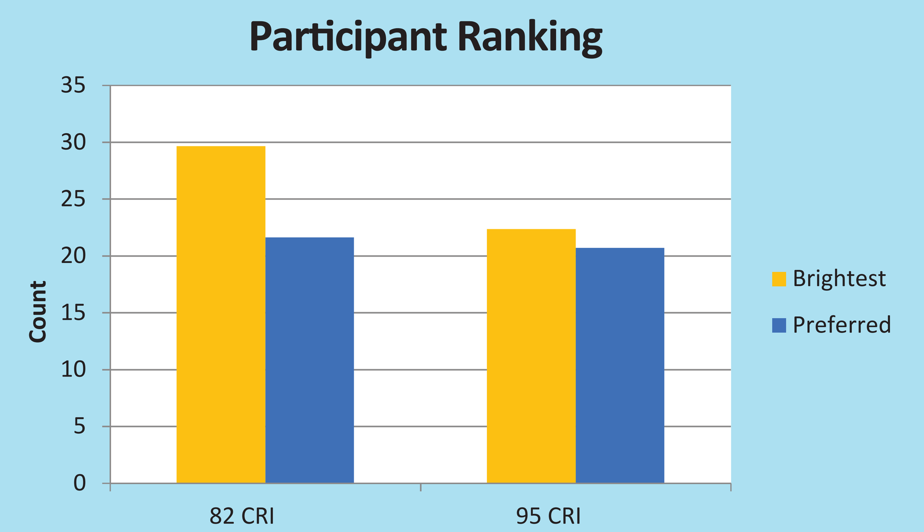

Figure 2c. The low fidelity scene had 25% more light, but was perceived as brighter only 50% of the time. Even with 25% less light, the high fidelity scene was preferred for color sorting 58% of the time.

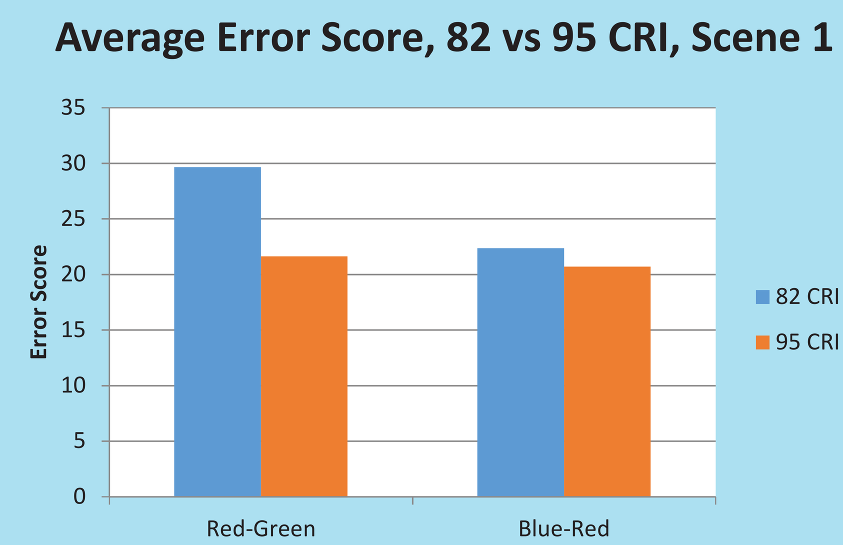

Figure 2d. The colored chips were sorted more accurately in the 95 CRI light than the 82 CRI light.

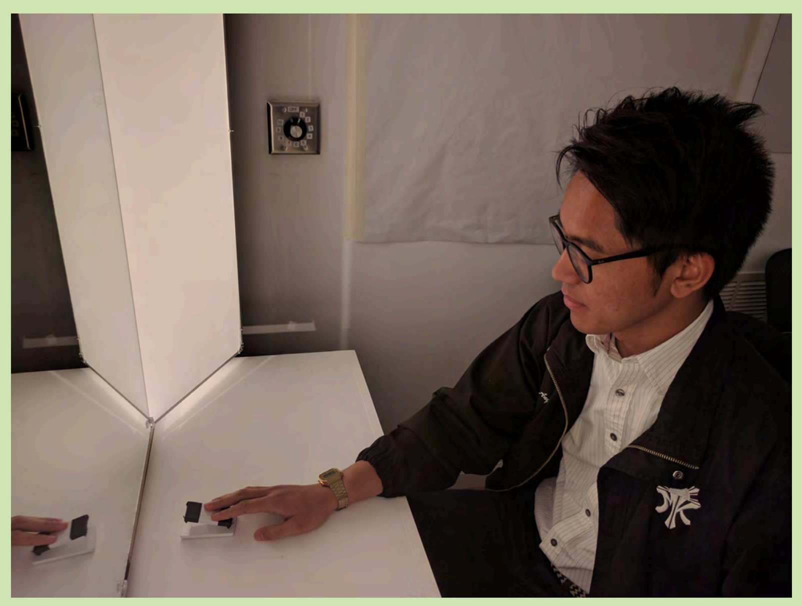

Figure 3a. This vanity test setup was used to understand the amount of light reduction that is acceptable with increased color fidelity.

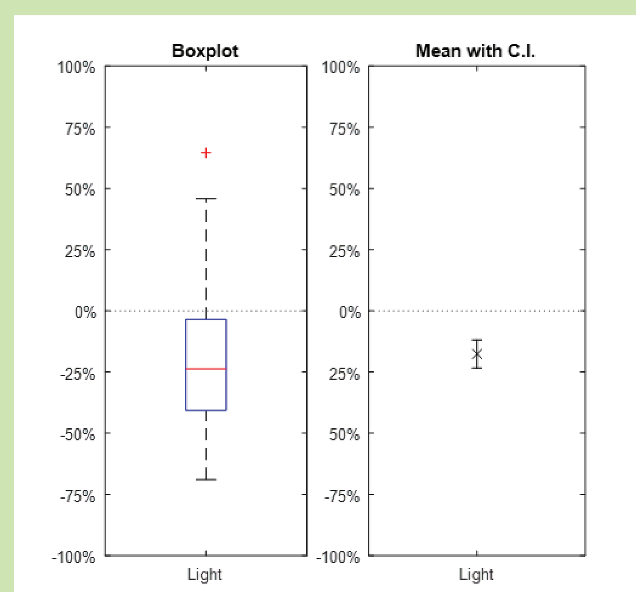

Figure 3b. Results from participants' interactions with the vanity test setup indicated that on average people choose 18% less light for the vanity visual task in the high fidelity scene than the low fidelity scene.

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Integrated Building Control Retrofit Packages for Existing Buildings

Konstantinos Papamichael, Keith Graeber, Philip von Erberich, Manuel Lopez, Andrew Harper

The California Lighting Technology Center, in collaboration with California Energy Commission, is conducting research to develop and evaluate technology that integrates the control of heating, ventilating, air conditioning (HVAC), lighting, and fenestration systems. This integrated approach will increase building-wide energy efficiency, reduce peak demand and improve occupant comfort. The goal of this effort is the demonstration and evaluation of an Integrated Building Control Retrofit Package (IBCRP) in the laboratory and an existing building. A diagram of an example IBCRP is shown in Figure 1.

The laboratory testing is underway at CLTC (Figure 2) to verify the communication and performance abilities of commercially available products to be specified as the IBCRP. Refinement activities are in progress to optimize the performance of the products in preparation for the field demonstration in The Barn on the UC Davis campus.

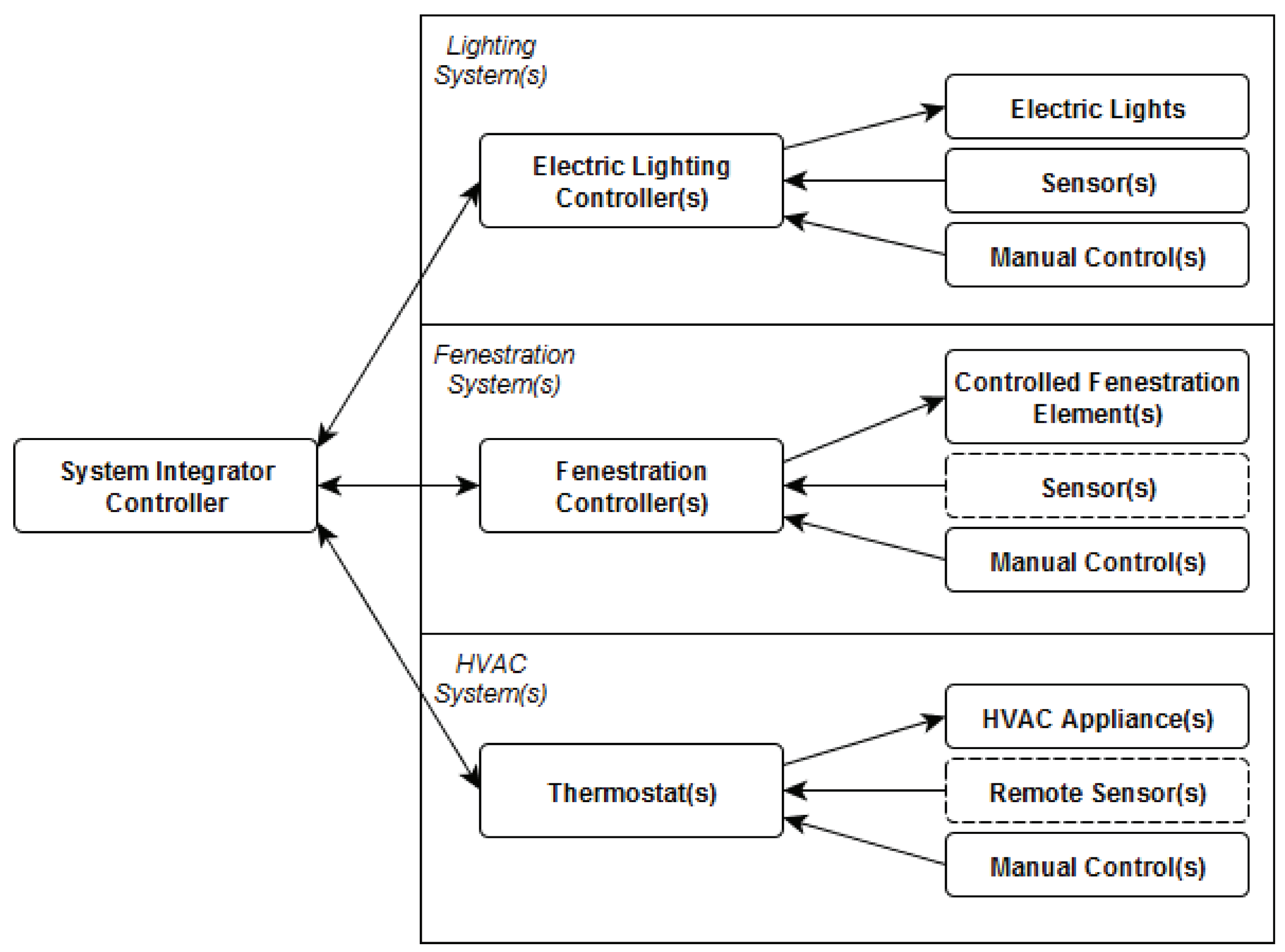

Figure 1. Integrated Building Control Retrofit Package - Overview

Figure 2. Integrated Building Controls Laboratory at CLTC

Figure 3. The Barn facility, UC Davis by Pete Scully

Figure 4. Electric lighting system in CLTC laboratory

Figure 5. Venting skylight with solar shade and photo sensor looking outdoors.

Figure 6. Venting window with adjustable rolling solar film

Figure 7. HVAC unit used in laboratory testing to confirm communication with integrated system components

Figure 8. Automated Controls: Central controller and system controllers for IBCRP

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The Million Lamp Challenge

Michael Siminovitch, Nicole Graeber, Adrian Ang, Manuel Lopez

High quality LED light sources are an effective way for Californians to reduce their carbon foot print, reduce energy use and save money! The Million Lamp Challenge is set up to generate rapid transformation from CFL and incandescent lighting technologies to high-performance, high-quality LED technology in California.

The Million Lamp Challenge was formed to make high-quality, high-efficiency light bulbs available at a great price. The lamps will be available for purchase to current students, staff, faculty and alumni of the UC, CSU, CCC and DGS systems by August 2018.

The challenge is a two-phase effort, with the first phase focused on screw-base lamps and the second phase focused on luminaire retrofit solutions.

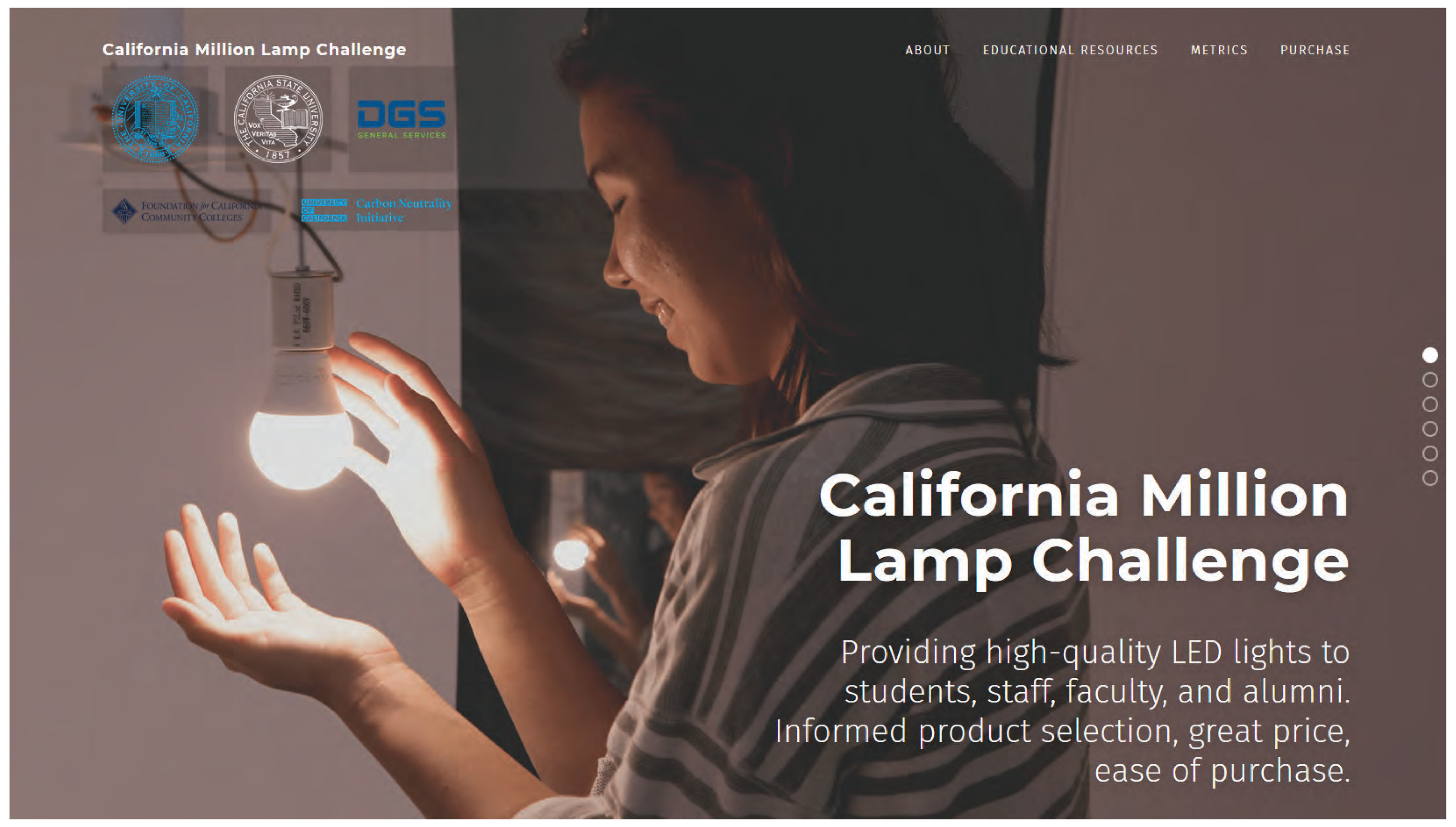
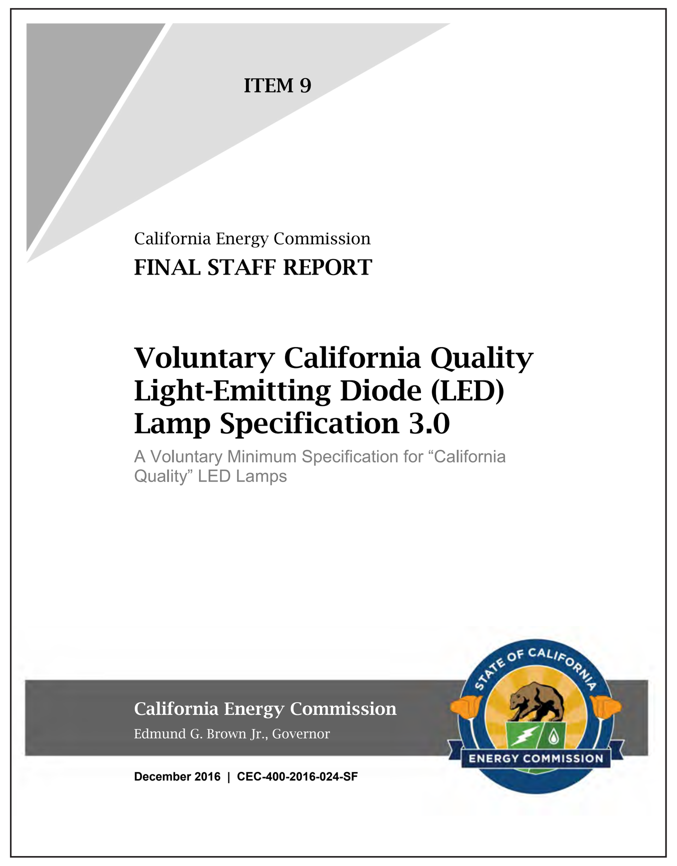


Figure 1. Million Lamp Challenge Website (www.millionlampchallenge.org)



ITEM 9

California Energy Commission
FINAL STAFF REPORT

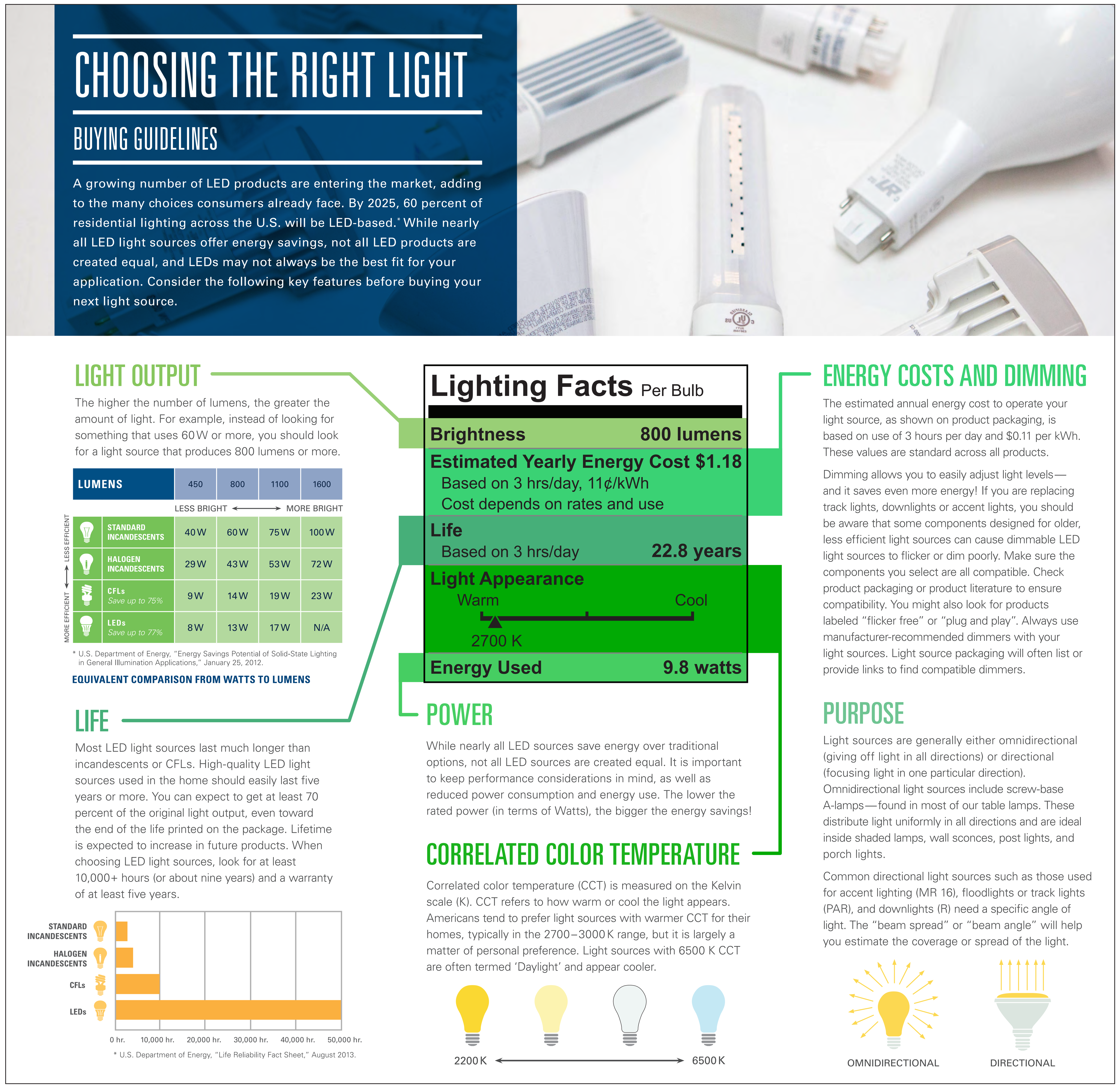
Voluntary California Quality Light-Emitting Diode (LED) Lamp Specification 3.0

A Voluntary Minimum Specification for "California Quality" LED Lamps

California Energy Commission
Edmund G. Brown Jr., Governor

December 2016 | CEC-400-2016-024-SF

Figure 2. California Energy Commission's Voluntary Quality LED Lamp Specification



CHOOSING THE RIGHT LIGHT

BUYING GUIDELINES

A growing number of LED products are entering the market, adding to the many choices consumers already face. By 2025, 60 percent of residential lighting across the U.S. will be LED-based.* While nearly all LED light sources offer energy savings, not all LED products are created equal, and LEDs may not always be the best fit for your application. Consider the following key features before buying your next light source.

LIGHT OUTPUT

The higher the number of lumens, the greater the amount of light. For example, instead of looking for something that uses 60 W or more, you should look for a light source that produces 800 lumens or more.

LUMENS	450	800	1100	1600
	LESS BRIGHT ⟷ MORE BRIGHT			
STANDARD INCANDESCENTS	40 W	60 W	75 W	100 W
HALOGEN INCANDESCENTS	29 W	43 W	53 W	72 W
CFLs *Save up to 75%*	9 W	14 W	19 W	23 W
LEDs *Save up to 77%*	8 W	13 W	17 W	N/A

LESS EFFICIENT ⟷ MORE EFFICIENT

* U.S. Department of Energy, "Energy Savings Potential of Solid-State Lighting in General Illumination Applications," January 25, 2012.

EQUIVALENT COMPARISON FROM WATTS TO LUMENS

LIFE

Most LED light sources last much longer than incandescents or CFLs. High-quality LED light sources used in the home should easily last five years or more. You can expect to get at least 70 percent of the original light output, even toward the end of the life printed on the package. Lifetime is expected to increase in future products. When choosing LED light sources, look for at least 10,000+ hours (or about nine years) and a warranty of at least five years.

* U.S. Department of Energy, "Life Reliability Fact Sheet," August 2013.

Lighting Facts Per Bulb

Brightness	**800 lumens**
Estimated Yearly Energy Cost Based on 3 hrs/day, 11¢/kWh. Cost depends on rates and use	**$1.18**
Life Based on 3 hrs/day	**22.8 years**
Light Appearance Warm – Cool	2700 K
Energy Used	**9.8 watts**

POWER

While nearly all LED sources save energy over traditional options, not all LED sources are created equal. It is important to keep performance considerations in mind, as well as reduced power consumption and energy use. The lower the rated power (in terms of Watts), the bigger the energy savings!

CORRELATED COLOR TEMPERATURE

Correlated color temperature (CCT) is measured on the Kelvin scale (K). CCT refers to how warm or cool the light appears. Americans tend to prefer light sources with warmer CCT for their homes, typically in the 2700–3000 K range, but it is largely a matter of personal preference. Light sources with 6500 K CCT are often termed 'Daylight' and appear cooler.

ENERGY COSTS AND DIMMING

The estimated annual energy cost to operate your light source, as shown on product packaging, is based on use of 3 hours per day and $0.11 per kWh. These values are standard across all products.

Dimming allows you to easily adjust light levels—and it saves even more energy! If you are replacing track lights, downlights or accent lights, you should be aware that some components designed for older, less efficient light sources can cause dimmable LED light sources to flicker or dim poorly. Make sure the components you select are all compatible. Check product packaging or product literature to ensure compatibility. You might also look for products labeled "flicker free" or "plug and play". Always use manufacturer-recommended dimmers with your light sources. Light source packaging will often list or provide links to find compatible dimmers.

PURPOSE

Light sources are generally either omnidirectional (giving off light in all directions) or directional (focusing light in one particular direction). Omnidirectional light sources include screw-base A-lamps—found in most of our table lamps. These distribute light uniformly in all directions and are ideal inside shaded lamps, wall sconces, post lights, and porch lights.

Common directional light sources such as those used for accent lighting (MR 16), floodlights or track lights (PAR), and downlights (R) need a specific angle of light. The "beam spread" or "beam angle" will help you estimate the coverage or spread of the light.

Figure 3. How to Choose the Right Light Infographic, Developed in Partnership with California Energy Commission

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Outdoor Occupancy Sensing

Konstantinos Papamichael, Keith Graeber, Manuel Lopez

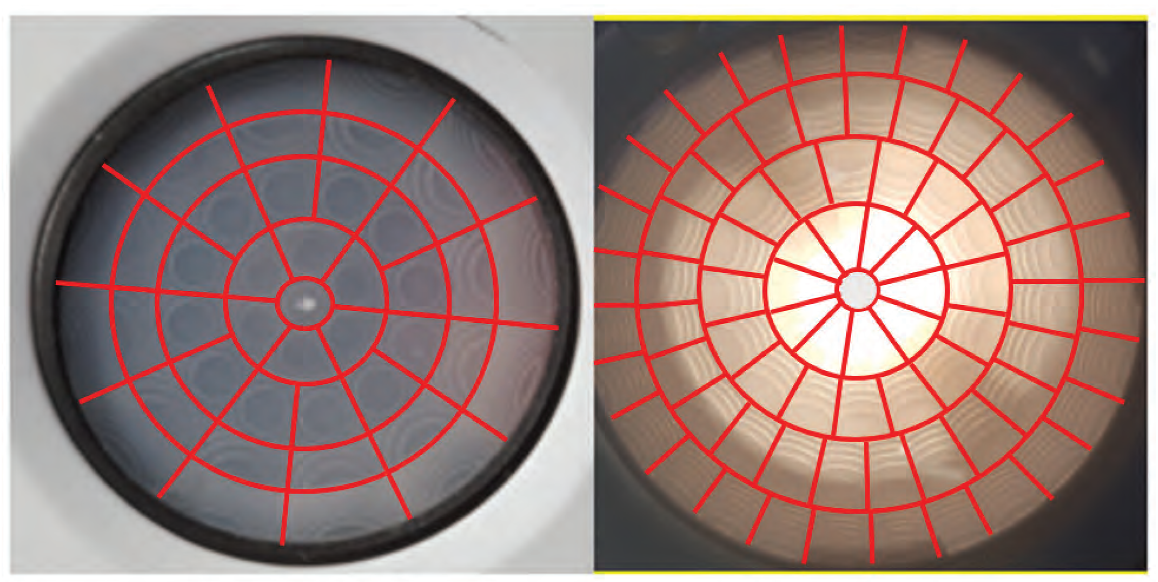
Occupancy-based lighting control is a very effective energy saving strategy in both indoor and outdoor applications. In the outdoor environment, occupancy controls are most often employed as part of a multi-level control strategy. Under a multi-level strategy, the controls are used to reduce lighting to a low level when an area is vacant. When movement is detected, lighting is automatically returned to full output.

Existing outdoor occupancy sensors are limited in terms of detection area and in some cases, cannot provide the necessary coverage to detect occupants within a desired outdoor area. CLTC, with support from the Office of Naval Research, examined these existing sensing strategies and developed one potential new approach to overcome the shortcomings of traditional outdoor occupancy controls.

Table 1 shows the occupancy controls examined as part of this research. Evaluation results led CLTC to propose a dual technology sensing approach composed of LiDAR and PIR devices.

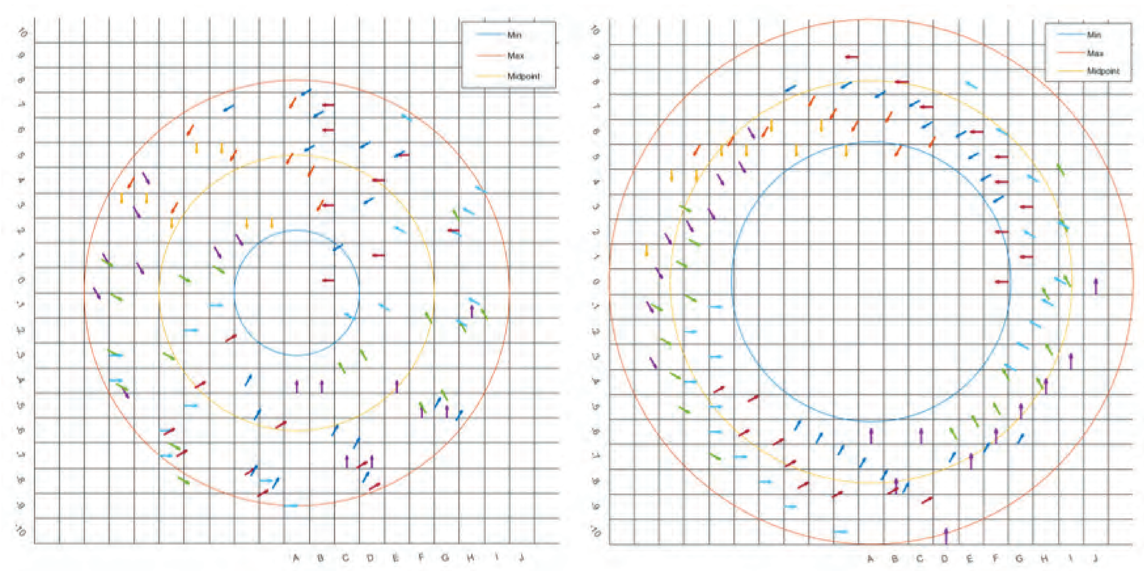
Sensor ID	Technology	Key Characteristics
Test sensor 1	Passive infrared	Flat sensor optic
Test sensor 2	Passive infrared	Enhanced domed sensor optic
Test sensor 3	LiDAR	Mechanically scanning sensor
Test sensor 4	Microwave	Single array sensor
Test sensor 5	LiDAR	Solid state sensor

Table 1. Types of sensors evaluated during the project.



(a) (b)

Figure 1a. PIR Technology evaluated during the project. The research for this project included development of an outdoor testing procedure.



(a) (b)

Figure 1b. Composition of perimeter characterization data from all rotations for (a) Test Sensor 1 and (b) Test Sensor 2. The maximum, minimum, and midpoint trigger distances can be seen in the corresponding orange, blue, and yellow circles. Detection distances are shown with arrows, grouped in different colors for each direction of movement.

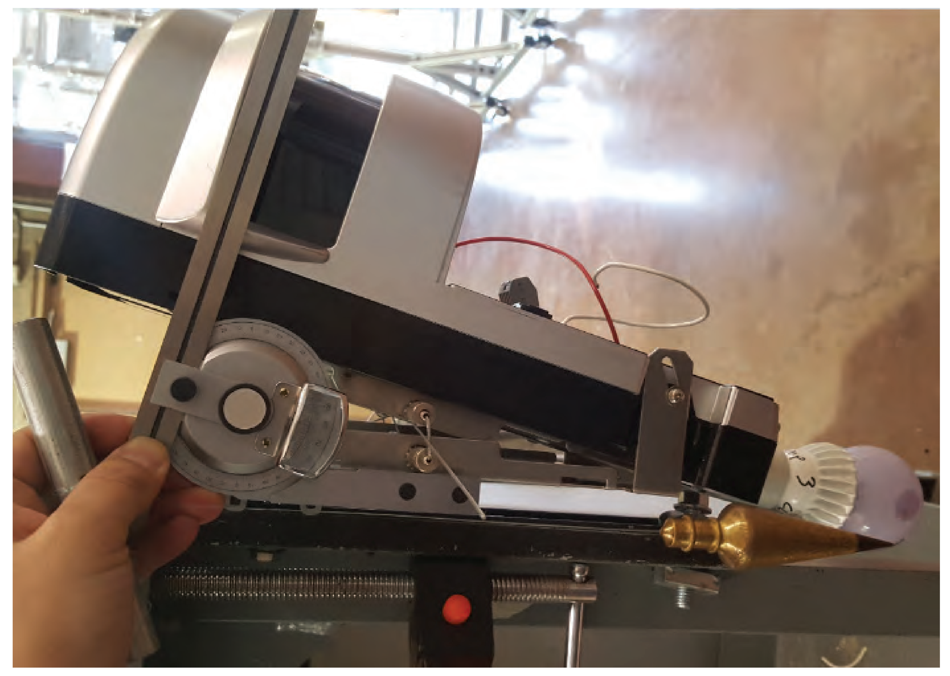


Figure 2a. LiDAR Technology (Test Sensor 3) evaluated for stand-alone use and in dual-technology approach.

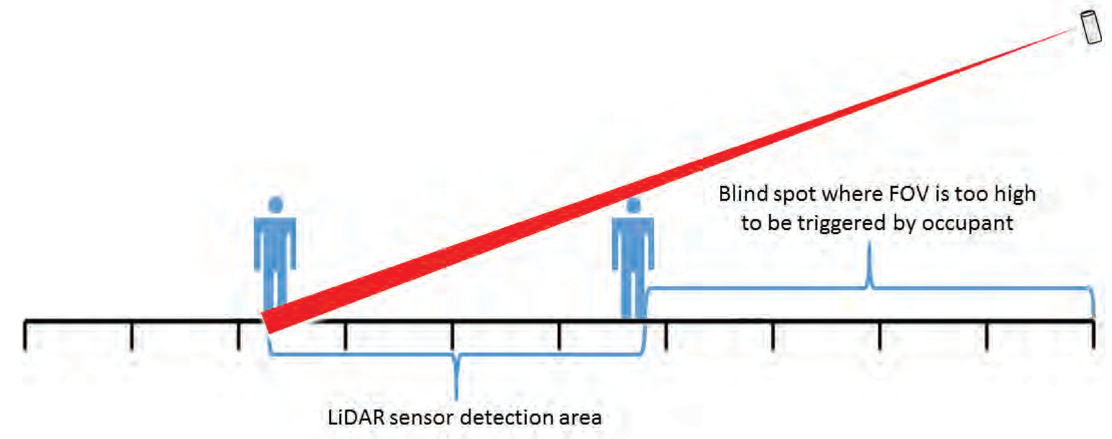


Figure 2c. Example of the FOV limitation of the LiDAR technology when mounted higher than the average human height, where a person can pass under the planar detection coverage. Differences in various angles can be seen as FOV becomes more vertical, coverage distance of the device becomes shorter.

Figure 3a. Microwave Technology — Test Sensor 4 connected to mounting bracket with a trigger-able lighting load.

Figure 3c. Remote-controlled toy car used to simulate small animals.

SENSOR:	Test Sensor 2 (PIR)	Test Sensor 4 (Microwave)
Min	5.0 ft	30.0 ft
25th Percentile	8.5 ft	37.8 ft
Median	10.0 ft	39.5 ft
75th Percentile	11.0 ft	43.0 ft
Max	12.0 ft	50.0 ft
Mean	9.7 ft	39.9 ft

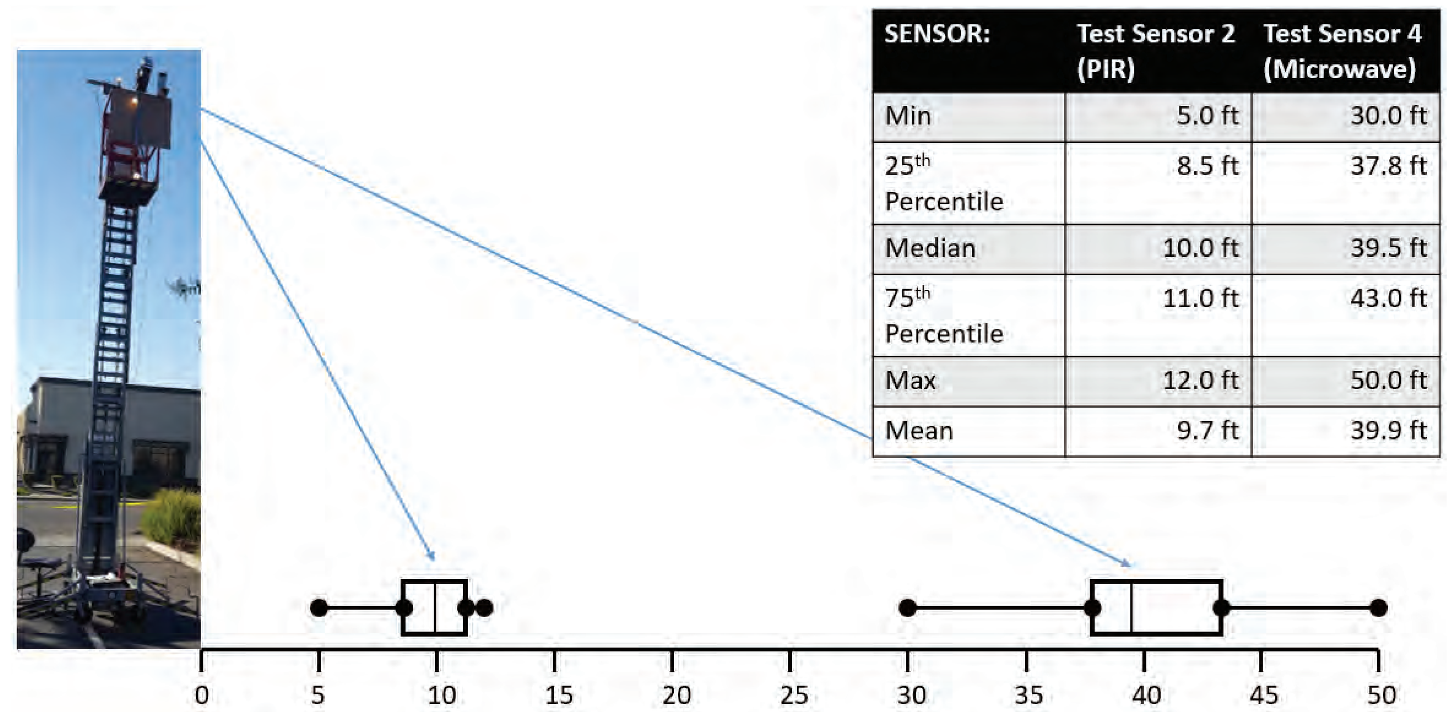


Figure 3b. Results of small animal testing for Test Sensor 2 & 4.

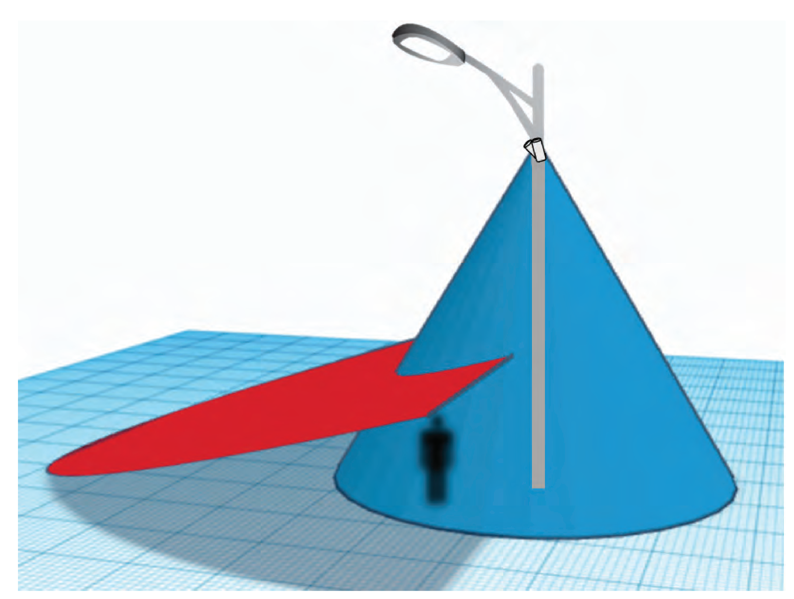


Figure 4. 3D view of sensors detection areas in the dual-technology approach.

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Linear LED Lamp Evaluation

Michael Siminovitch, Cori Jackson, Keith Graeber, Thomas Rubio

LED lamps marketed to replace linear fluorescent products are an emerging product category with the potential to deliver significant energy and maintenance cost savings. While customers gravitate towards these products due to their potential benefits, information on product performance under real-world conditions and in less than ideal configurations is sparse. In particular, data on linear LED product performance in fixtures other than recessed troffers is very limited.

To help fill these gaps and provide data to support development of targeted programs, CLTC assessed a cross-section of typical linear LED products operating in non-troffer fixtures and under specific scenarios expected of commercial building retrofits.

CLTC completed photometric and electrical evaluation of 13 commercially available linear LED lamps and one standard, 700 series linear fluorescent, which was used as the baseline for compliance. Linear LED products fall into the following categories:

- **Type A:** Linear LED lamp with internal driver that is designed to operate on a linear fluorescent lamp ballast.
- **Type B:** Linear LED lamp with internal driver that must be connected directly to line voltage for power.
- **Type C:** Linear LED lamp with external driver that is designed to replace both the linear fluorescent lamp and fluorescent lamp ballast.
- **Hybrid:** Products that operate under multiple scenarios such as with a fluorescent ballast and also when the ballast is replaced with a compatible LED driver. These hybrid products, also called dual-mode products, are currently available in Types AB and AC.

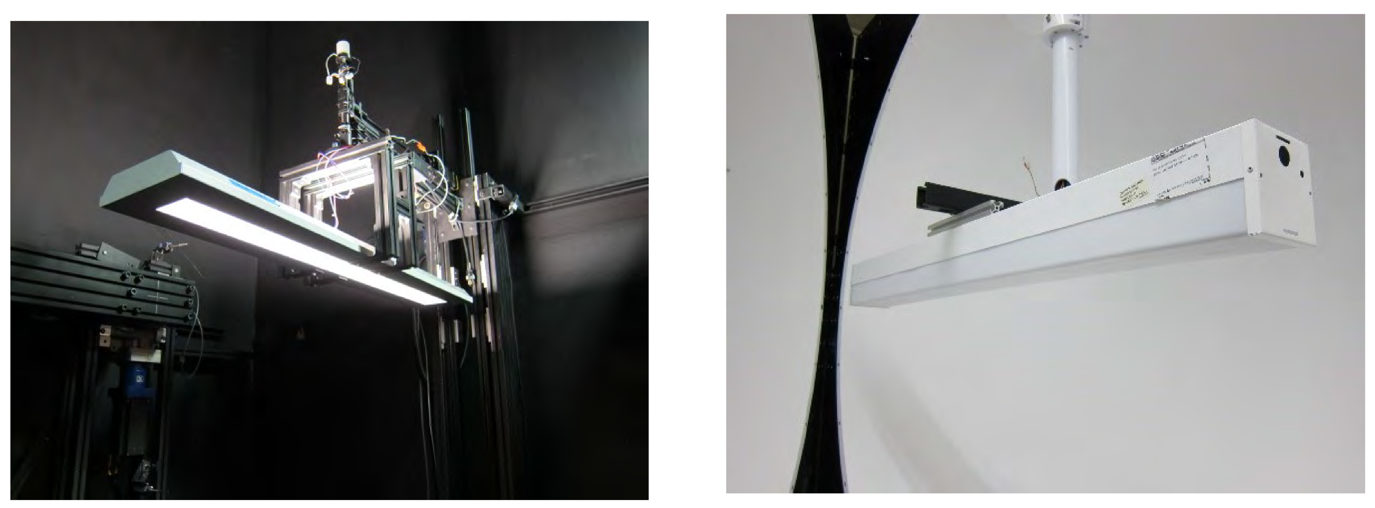

Figure 1. Linear Suspended Pendant (Left) and Linear Wrap Fixture (Wrap)

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Linear LED Type C products performed best of all products tested. Linear LED Type C products performed best of all products tested. On average, Type C LED products delivered about 10 percent more light in the wrap as compared to the fluorescent, 10 percent less in the pendant and about the same in the bare-lamp fixture. Test results are shown in Table 1 and Figure 2.

Product ID	Operating Mode (Type A, B or C)	Bare-Lamp Strip			Wrap			Pendant		
		Power (W)	Light Output (lm)	System Efficacy (lm/W)	Power (W)	Light Output (lm)*	System Efficacy (lm/W)	Power (W)	Light Output (lm)	System Efficacy (lm/W)
Fluorescent	-	57.1	4,675	81.9	52.4	3,092	59	56.8	4,196	73.9
LED B	A	32.6	3,251	99.7	32.2	2,295	71.3	32.4	2,235	69
LED B	B	29.3	3,302	112.7	28.9	2,325	80.4	29.2	2,299	78.7
LED C	A	34.9	4,017	115.1	34.6	3,032	87.6	34.9	3,466	99.3
LED C	B	29.5	4,087	138.5	29.2	3,045	104.3	29.4	3,476	118.2
LED D	A	33.6	3,974	118.3	33.3	2,840	85.3	33.9	2,679	79
LED D	B	28.6	3,612	126.3	28.1	2,550	90.7	28.5	2,446	85.8
LED J	A	29.6	3,792	128.1	29.5	2,926	99.2	29.6	2,955	99.8
LED J	C	34.9	4,716	135.1	34.1	3,453	101.3	34.9	3,483	99.8
LED L	A	36.3	4,404	121.3	36	3,229	89.7	36.2	3,748	103.5
LED L	C	35.7	4,315	120.9	35.4	3,178	89.8	35.6	3,693	103.7

Table 1. Linear LED Lamps – Hybrids: Input Power, Light Output, and System Efficacy for Two-Lamp Configuration

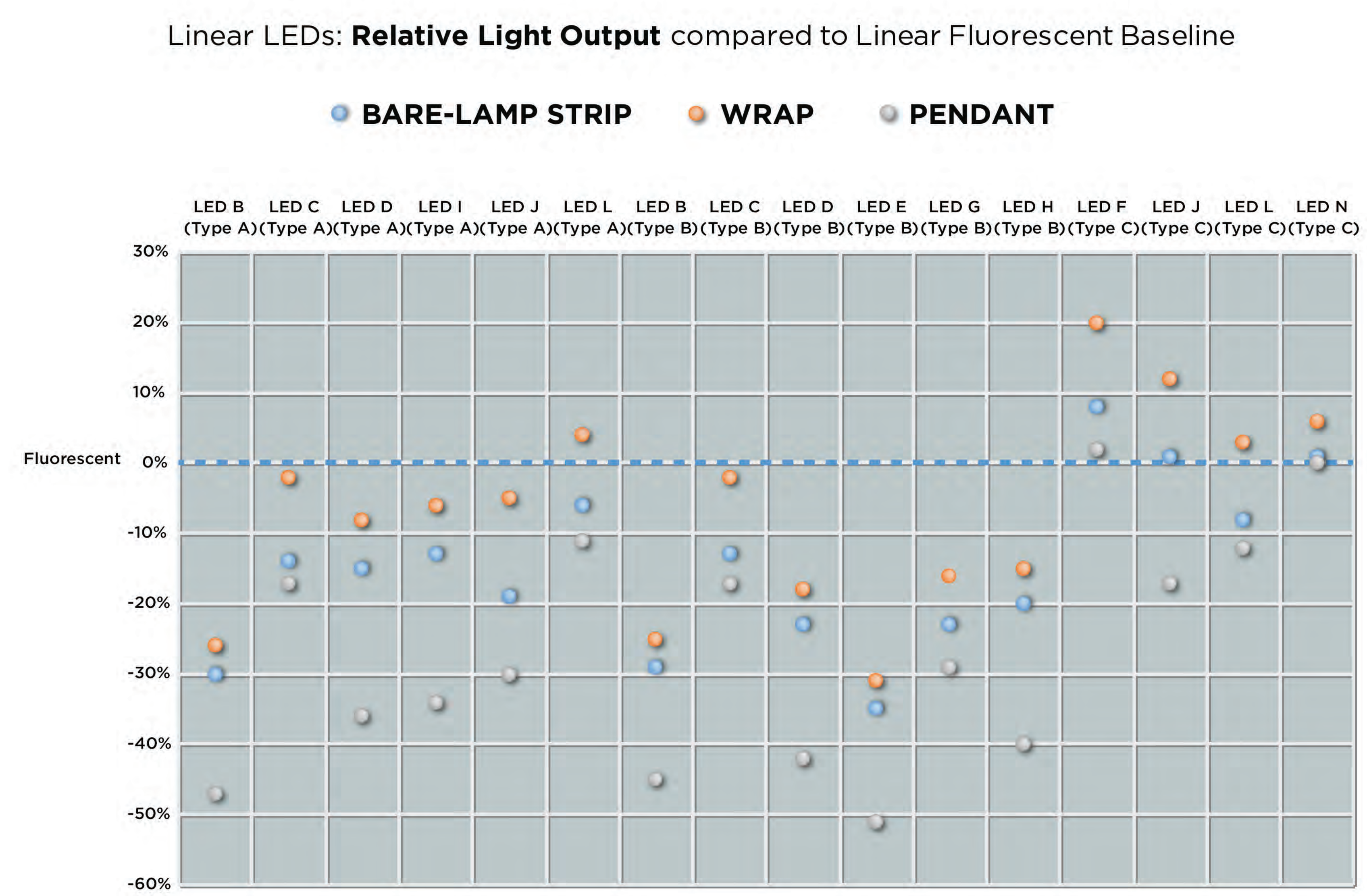

Figure 2. Light Output, System Efficacy, and Energy Use Compared to Linear Fluorescent Baseline

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Lighting Foundations:
Training Kit Development for California Community Colleges

Michael Siminovitch, Cori Jackson, Andrew Chapman, Bryn Cloud

Staff and students at the California Lighting and Technology Center developed lighting education kits to support basic lighting education at California's community colleges. These kits were developed specifically to provide support to ongoing and future classes in lighting design, building technology and controls.

The lighting kits consist of lighting products, necessary hardware packages, a user manual and educational slides for classroom use. In total, 12 kits were distributed to community college instructors to be used throughout California.

Key subject areas include:

- ❖ Light spectrum, vision and color
- ❖ Light sources including LED technology
- ❖ Fixtures and source integration
- ❖ Distribution, optics and beam angle
- ❖ Sensors and controls
- ❖ Energy use and environmental impacts

Figure 1. Photos of the Lighting Education Kit (Left) and UC Davis student working with lighting materials from the Lighting Education Kit.

Figure 2. Professor Michael Siminovitch presenting at Train-the-Trainer Event. Presenting Lighting Kits to California Community College educators

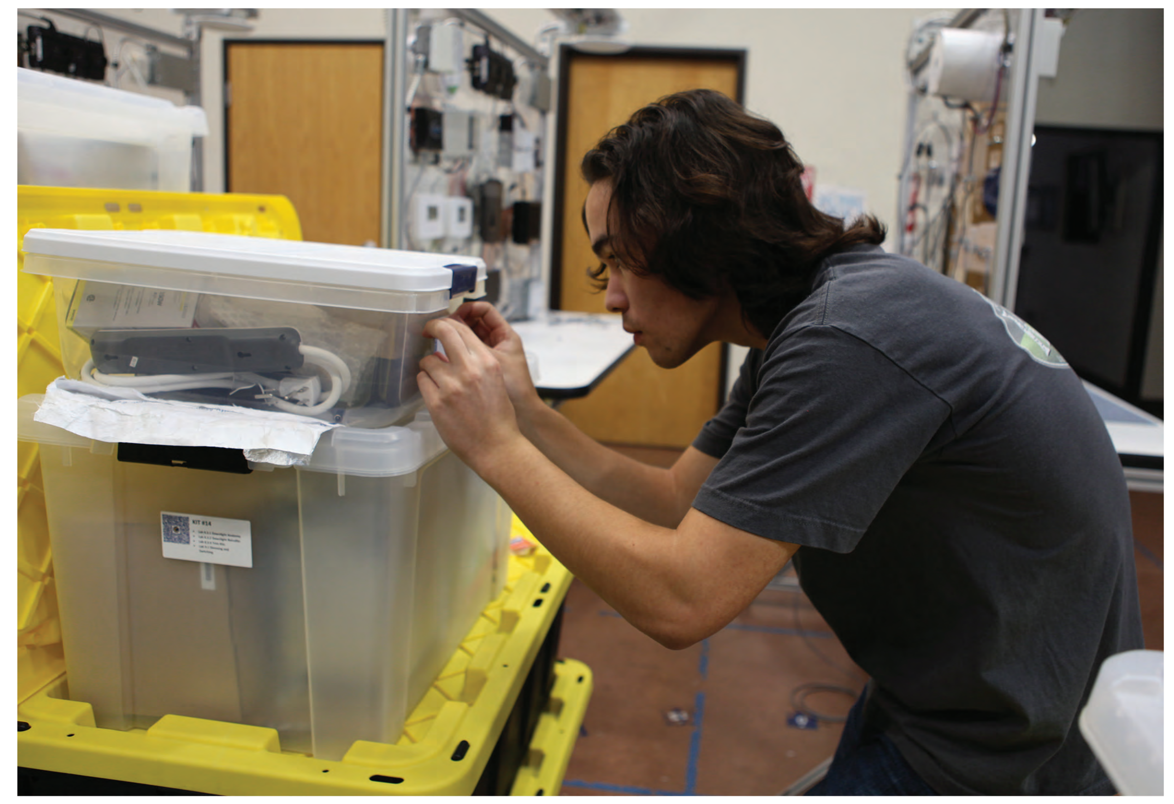

Figure 3. Lighting Foundation Kits being constructed by UC Davis students

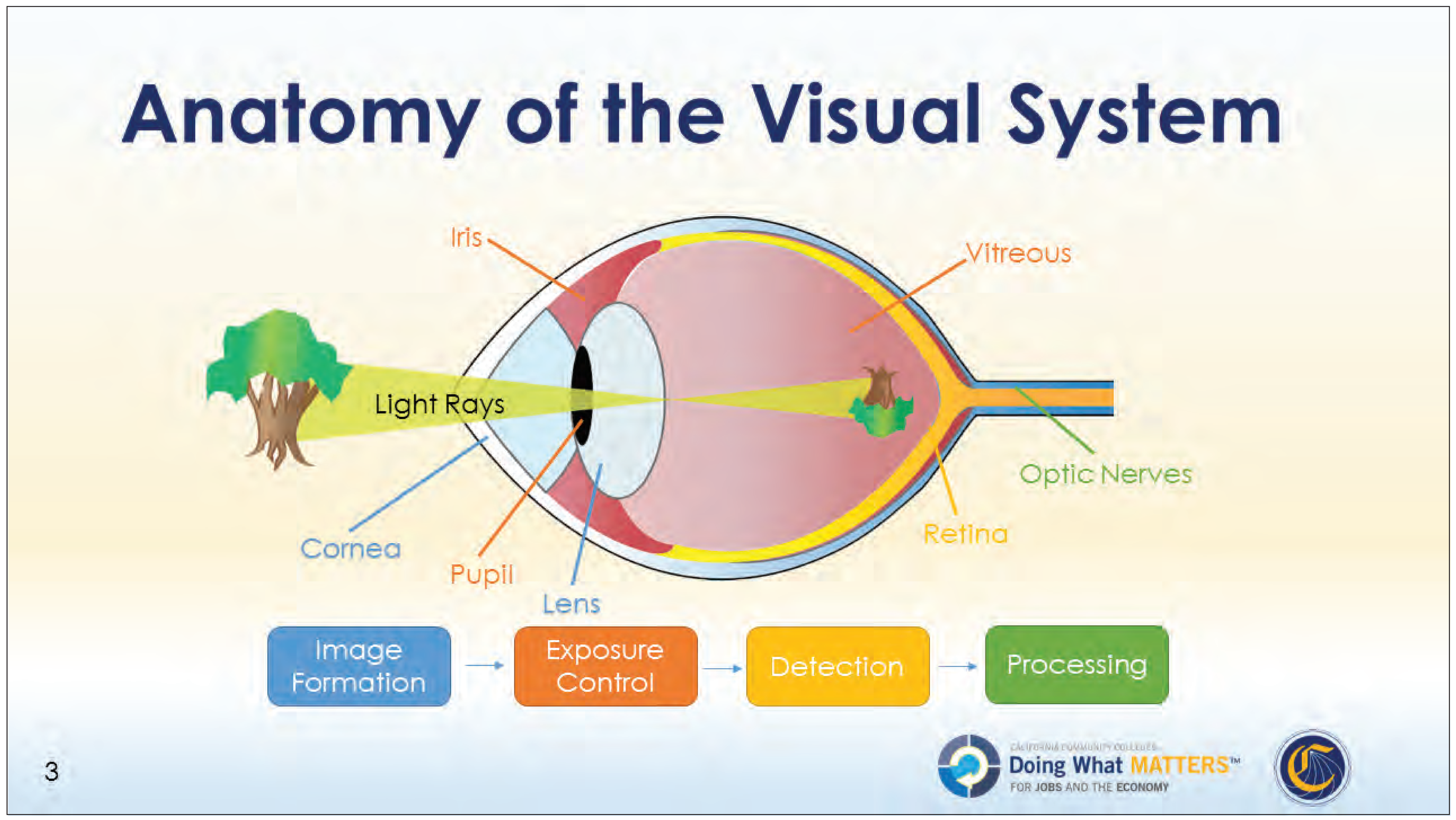

Figure 4. Graphic Used to Educate Students on Human Vision

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