Luminaires for Advanced Lighting in Education

2017 Building Technologies Office Peer Review

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Lynn Davis, ldavis@rti.org
RTI International

Project Summary

Timeline:

Start date: **July 1, 2015**

Planned end date: **March 31, 2017**

Key Milestones

1. **Luminous efficacy > 120 lumen/watt at all white colors (> 125 lumen/watt demonstrated on November 2016)**
2. **L85 > 75,000 hours and B50 > 60,000 hours (June 2016).**
3. **White tuning range from 2700 K to 5500 K (2700 K to 6500 K demonstrated on March 2016).**
4. **Technology demonstration site completed (March 2016).**

Budget (January 2017):

Total Project $ to Date:

- DOE: **$401,223**
- Cost Share: **$156,833**

Total Project $:

- DOE: **$450,000**
- Cost Share: **$156,833**

Key Partner: Finelite, Inc.

RTI INTERNATIONAL

FINELITE Better Lighting

Project Outcome:

The Next Generation Integrated Classroom Lighting System (NICLS) is a high efficacy (> 120 LPW), fully dimmable tunable white lighting system for use in the cost-conscious educational market. The system user interface (UI) was custom designed with inputs from teachers and educational professionals. The product is certified as "Qualified Made in USA" per FTC guidelines.

Problem Statement

- Energy costs are the second largest operational expense for school districts – after teachers' salaries. First costs and operational costs are key drivers for infrastructure decisions. Proper management of lifetime costs can provide more $$ for instruction.
- Current classroom lighting systems must be flexible and easy to use to accommodate different teaching methods, how students of all ages learn, and visitors/substitute teachers.
- Lighting can provide teachers an added tool for the classroom
  - Gain attention of students
  - Promote relaxation/cool down after recess
  - Provide the right lighting levels for different tasks
    - Direct instruction with white boards or smart boards
    - Note taking during audiovisual presentations
    - Computer work
- However, the vast majority of classrooms only have on/off control. Even simple dimming is rarely available in classrooms (< 2%).

Target Audience

- The interests of the target audience is variable
  - School district administration: costs & student performance
  - Facilities staff: reliability and low maintenance
  - Principles: accommodates multiple users of the building
  - Teachers: simple to use & enhances the learning environment
  - Architects and Designers: installation meets performance specs
  - Contractors: simple, straight forward installation
- K-12 schools account for roughly 10% of the total commercial building floor area and account for roughly 8% of total commercial build energy use. (*DOE Advanced Energy Retrofit Guide: K-12 Schools).*
- K-12 Schools use >$8 billion annually in energy with ~$1.5 billion directly attributable to lighting. ASHRAE guidelines for classrooms call for lighting power density of <1.4 Watts/ft^2 in the classroom.

Impact of the Project

- The primary output from this project is the NICLS technology: U.S.-made commercially available lighting products that provide the benefits of high efficacy, tunable white lighting (TWL) to the educational lighting market.
  - Near- and intermediate-term impact can be measured by product sales volume and energy savings; other long-term metrics such as domestic job creation in manufacturing & installation of these products may be positively impacted.
- A secondary output is the development of a mock classroom test bed and demonstration site to research the benefits to students and teachers of TWL technology.
  - Impact can measured by new research that creates market demand for energy efficient TWL technologies in classrooms by demonstrating benefits to teachers and students.

Approach – Light Engine Design Goals

- Leverage one LED package that is highly efficient (economies of scale).
- Distributed light source to minimize glare and simplify luminaire design.
- Two-chip solution: white color tuning range 2700 K to 6500 K.
- Board-level luminous efficacy >150 LPW.

2323 Package

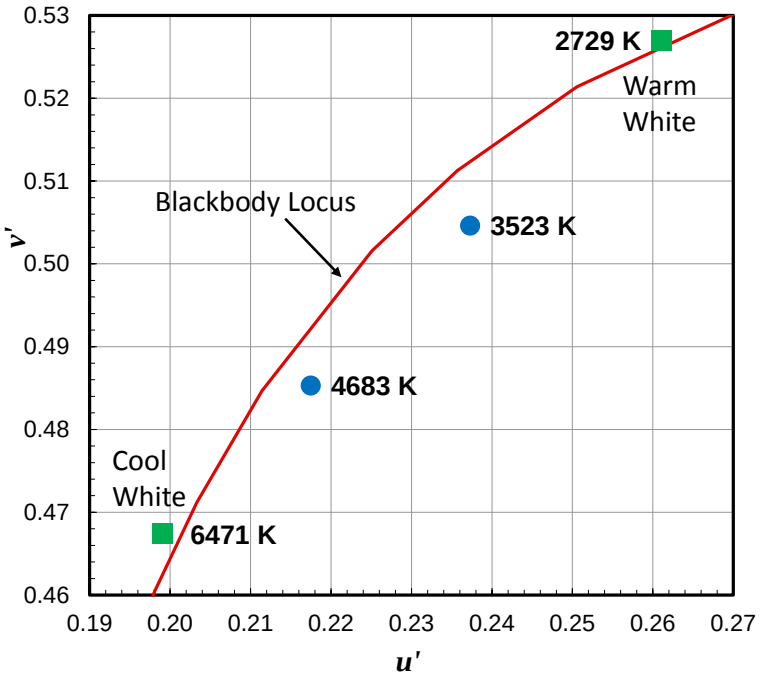
6500 K: 127 LPW (ITL)
2700 K: 109 LPW (ITL)

X

√√

6500 K: 168 LPW (ITL)
2700 K: 153 LPW (ITL)

5630 Package



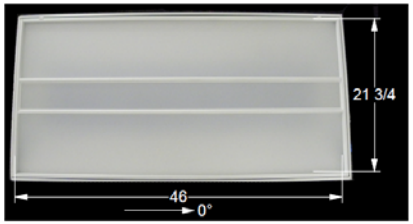
ITL = Independent Testing Laboratories, Inc.
LPW = Lumen per Watt

Approach – Luminaire Designs

- 9 different luminaire designs were investigated.
- For each design, various optical, LED, and material combinations were investigated (111 variations total across the designs).
- Designs that would not meet DOE requirements due to glare or luminous efficacy (either today or with near-term upgrades) were eliminated.
- Performance of final targets validated by third-party testing.

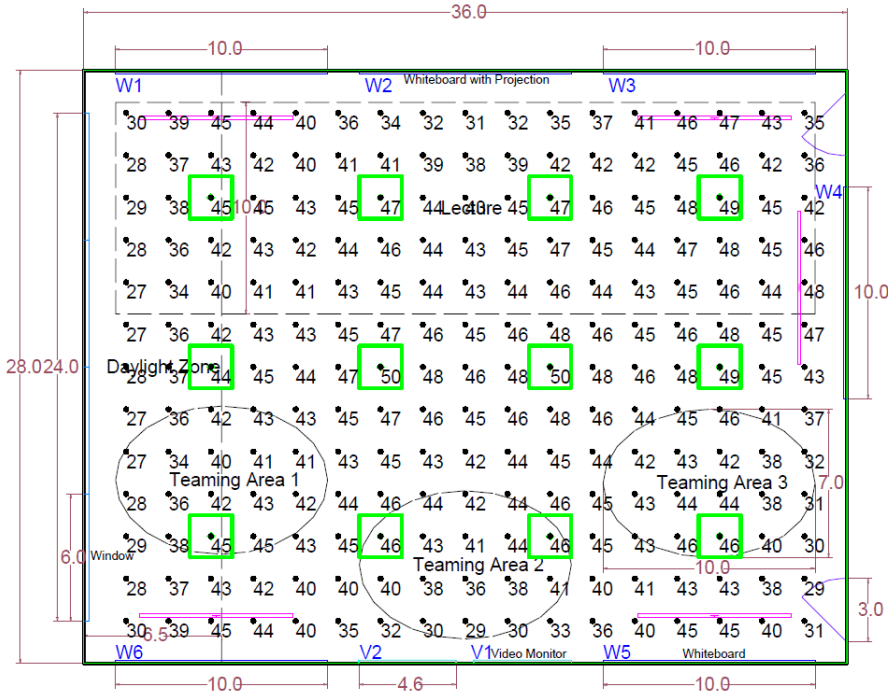
itl boulder
THE LIGHT CENTER OF THE INDUSTRY SINCE 1955
NVLAP TESTING
NVLAP LAB CODE: 200925-0
INDEPENDENT TESTING LABORATORIES, INC.
4066 CAMELOT CIRCLE, LONGMONT, CO 80504 USA
PHONE: (303) 442-1255 • FAX: (970) 535-3114 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

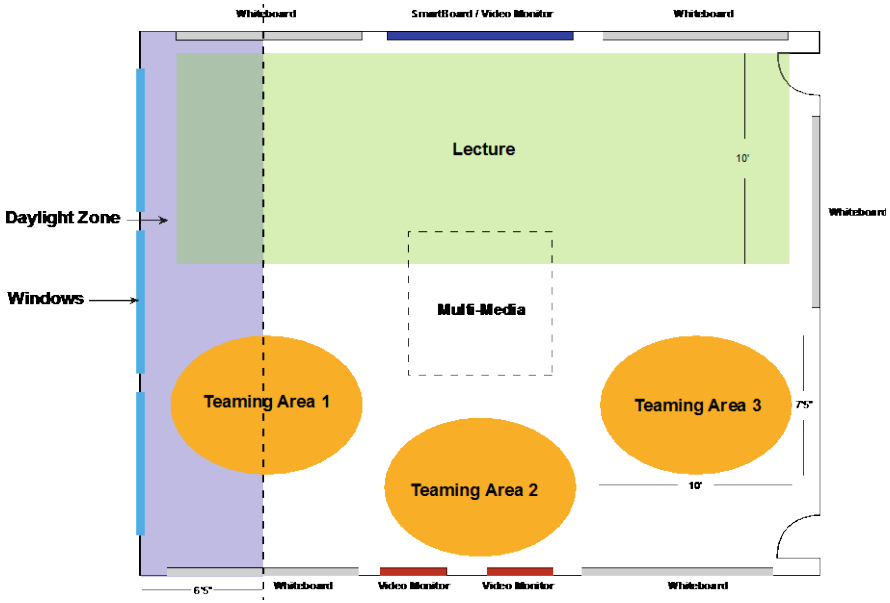
REPORT NUMBER: ITL88654-GONIOPHOTOMETRY PAGE: 1 OF 6
ISSUE DATE: 12/05/16
PREPARED FOR: FINELITE, INC.
CATALOG NUMBER: HPR-F-2X4-DCO-LED-V-8-TW (2700K)
LUMINAIRE: FABRICATED METAL HOUSING WITH WHITE PAINTED INTERIOR FINISH, FORMED WHITE PAINTED METAL REFLECTOR AND LED DRIVER COVER, 4 WHITE CIRCUIT BOARDS EACH WITH 160 LEDS, THREE-PIECE FROSTED HOLOGRAPHIC PLASTIC LENS IN FABRICATED WHITE PAINTED FRAME. LENS FROSTED BOTH SIDES. DIMMER CONTROL ADJUSTED TO HIGHEST OUTPUT SETTING "MAX" AND COLOR CONTROL ADJUSTED TO "2700" FOR THIS TEST. ONLY 320 WARM WHITE LEDS ON FOR THIS TEST.
LAMPS: THREE HUNDRED TWENTY WARM WHITE LIGHT EMITTING DIODES (LEDS), VERTICAL BASE-UP POSITION.
INPUT ELECTRICAL: 120.0 VOLTS, 50.3 WATTS, 0.422 AMPS
MOUNTING: RECESSED
LED DRIVER: ELDOLED POWERDRIVE 561/M, DRIVER HAS MULTIPLE LEADS, LINE INPUT AND LED OUTPUT LEADS CONNECTED FOR THIS TEST, CLIENT STATES DRIVER PROGRAMMED FOR 1000mA OUTPUT.
FINELITE 89704 POWER CENTER,
FINELITE 89703 CONTROLLER.
NOTE: DATA SHOWN IS ABSOLUTE FOR THE SAMPLE PROVIDED AT RATED INPUT VOLTAGE (120VAC, 60Hz) TO THE DRIVER. POWER CENTER AND CONTROLLER POWER NOT INCLUDED IN ELECTRICAL MEASUREMENTS.
TEST PROCEDURE: IESNA LM-79-08
TEST DISTANCE = 35.0 FEET



Approach – Layout of Demonstration Classroom

- Photopia simulations run on all luminaire types that meet DOE project goals.
- Final layout used 2x2 troffer troffers and wall wash luminaires for white boards. This troffer present a good technology challenge.
- Leverage inputs from teachers, principals, and school facilities engineers to fine-tune layout, especially the user interface.





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Key Issues

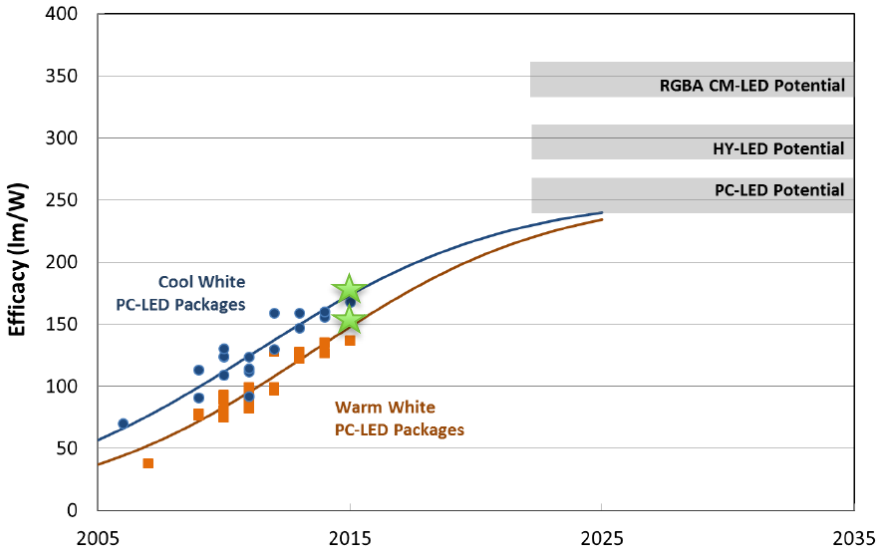
- The initial design of the luminaire and room layout meet most DOE goals right away. The one exception was achieving good luminous efficacy target at low correlated color temperatures (CCT).
  - Mitigation: Leveraged improved chip architectures (available in Fall 2016) to exceed DOE luminous efficacy goals at all CCTs.
- Efficiency of commercially available multi-channel drivers is in the mid-80s range. Represents the largest impact on overall system efficiency.
  - Mitigation: Utilize the most efficient driver technology. Additional research is needed to improve driver efficiency.
- There was an overwhelming response from our focus groups that teachers want more research on how to effectively use lighting as a new tool in the classroom.

Distinctive Characteristics – Luminous Efficacy

- Utilize a dispersed light source comprised of cost effective, high efficiency mid-power LEDs operated in region of minimal droop.
- Utilize exclusive supply agreements with Best-in-Class suppliers to provide LED module performance that exceeds DOE goals for LED packages!
- LED module design simplifies Bill-Of-Material from troffers by reducing heat sink requirements and simplifying optical designs.
- Utilize high efficiency, low loss optical materials in luminaire design so most of the LED module-level performance translates to the luminaire.

LED Module Performance

Current	2700 K	6500 K
350 mA	166.3 LPW	182.2 LPW
700 mA	152.8 LPW	167.7 LPW



LED Package Performance

From 2016 DOE SSL R&D Plan

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Distinctive Characteristics – System Architecture

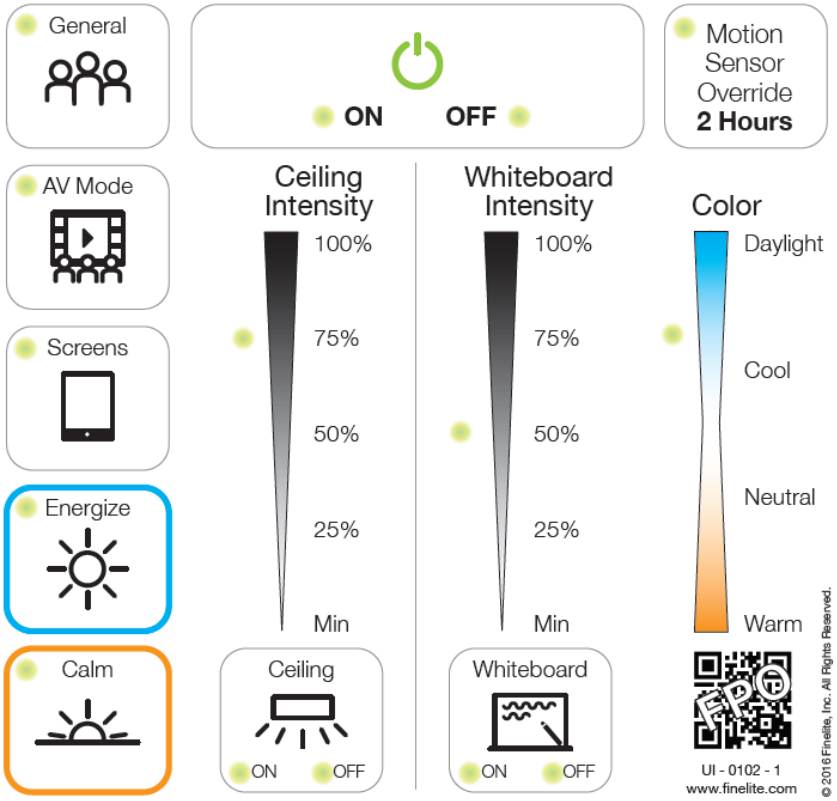
- Luminaire designs
  - 2x2 and 2x4 troffers
  - Direct-Indirect Pendants
- Volumetric lighting throughout.
- Luminaires available for highlighting white boards and presenters.
- Two-zone daylight harvesting for energy consumption reduction.
- Occupancy sensor that can be overridden when needed.
- Plug-and-play architecture that is easy to assemble and service in the field.
- Entire assembly available from one source

Area/Zone	Metric	Mode	DOE Requirements	Photopia Layout D2095-11/17/2015
Lecture Area	Horizontal Illuminance	Lecture	400 lux (37.2 fc) @ 30" AFF	41.41 fc
	Ave:Min	Lecture	< 2:1	1.53
	Horizontal Illuminance	AV	50 lux (4.65 fc) @ 30" AFF	5.94 fc
	Ave:Min	AV	< 2:1	1.98
	Vertical Illuminance	Lecture	150 lux (13.9 fc) @ 48" AFF	21.9 fc
	Vertical Illuminance	AV	30 lux (2.79 fc) @ 48" AFF	3.31 fc
	CCT	All	2700 - 5000 in ANSI bins	2700 - 6500
Projection Areas and Video Monitors	Vertical Illuminance	AV	< 50 lux (4.65 fc) at all points on screen	
Whiteboard	Vertical Illuminance	Lecture	300 lux (27.9 fc) average	29.04 fc
	Ave:Min	Lecture	< 3:1	1.31
Teaming	Horizontal Illuminance	Lecture	300 lux (27.9 fc) @ 30" AFF	41.41 fc
	Ave:Min	Lecture	< 3:1	1.53
	Horizontal Illuminance	AV	30 lux (2.79 fc) @ 30" AFF	5.94 fc
	Ave:Min	AV	< 3:1	1.98
	Vertical Illuminance	Lecture	75 lux (6.97 fc) @ 48" AFF	22.21 fc
	CCT	All	2700 - 5000 in ANSI bins	2700 - 6500

- The NICLS technology exceeds all of DOE design goals.
- Offers >25% improvement in energy efficiency over fixed CCT fluorescents and > 22% improvement over the average fixed CCT LED luminaires in Lighting Facts.

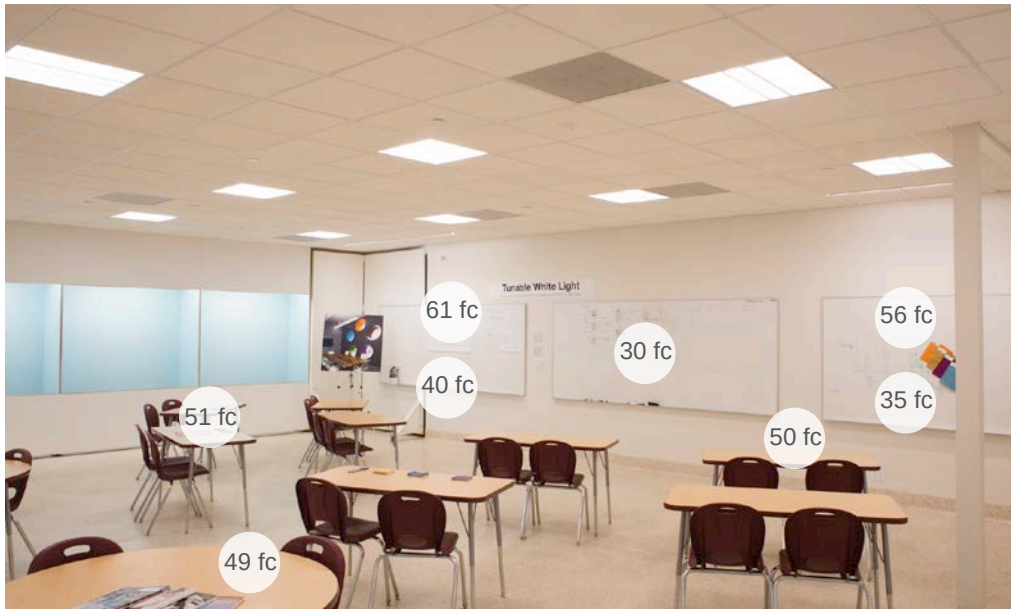
Distinctive Characteristics – User Interface Design

- More than 85 teachers, principals, and other educational professional participated in focus groups to design the user interface (UI).
- Overwhelming agreement that the UI should consist of a touch pad at the front of the classroom and web-based app to allow teacher movement.
- Colors, icons, terminology, and layout of the UI were important to quickly and intuitively convey system use
  - Moved away from numbers-based UIs designed for building managers
- Strong preference among focus group participants for preset lighting configurations. Some preference for freedom to chose CCT and dimming levels.

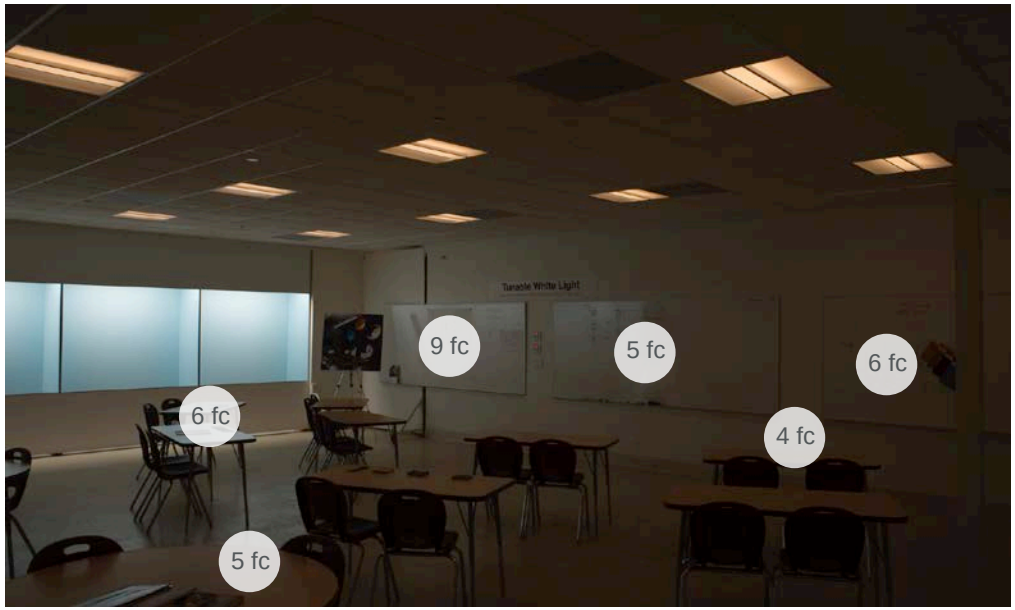


Accomplishments – Demonstration Site

CCT 4250K / Ceiling .27 W/sq ft at 75% / Whiteboard .19 W/sq ft at 100% / Total: .46 W/sq ft



CCT 2700K / Ceiling .005 W/sq ft at 10% / Whiteboard .002 at 10% / Total: .007 W/sq ft



CCT (K)	Ceiling Dimming	White-board Dimming	Total LPD (W/ft²)
6500 K	100%	100%	0.67
4250 K	80%	100%	0.50
4250 K	75%	100%	0.46
3750 K	60%	50%	0.22
3750 K	30%	Off	0.04
2700 K	10%	10%	0.007

MARKET IMPACT

Exceeds ASHRAE 90.1 & California Title 24 requirements by 50% or more.

Tunable white lighting is an added benefit.

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Awards/Recognition and Lessons Learned

- This project was featured in a DOE Success Story - https://energy.gov/eere/ssl/rti-international-and-finelite-develop-luminaires-advanced-lighting-classroom
- Lessons Learned
  - White tunable LED lighting provides a valuable tool to enhance the learning environment in classrooms and teachers want/need more research on how use this tool effectively.
  - Improving the efficiency of two-stage multi-channel drivers offers additional opportunity to improve overall system efficiency.

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RTI INTERNATIONAL AND FINELITE DEVELOP LUMINAIRES FOR ADVANCED LIGHTING IN THE CLASSROOM

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Lighting layout in an educational space.

Energy costs for lighting are a large operational expense for schools and universities, where – despite clear evidence that adjusting lighting levels and chromaticity to the task at hand improves student performance – lighting has been underutilized as a classroom tool. With the help of DOE funding, RTI International and Finelite are developing and testing an LED-based next-generation integrated classroom lighting system that makes it easy to control light levels and chromaticity (the color of the light) in three classroom zones. The lighting system also incorporates daylight harvesting to further reduce energy consumption. One of the objectives of this project is to spur demand for energy efficient lighting in schools by demonstrating the potential benefits of color-tunable lighting on the effectiveness of the educational process.

Together with sensors and a controller, the fixtures form a made-in-USA system operated from a user interface that's either mounted in the front of a classroom or accessed through a wireless handheld device. The design of the user interface for the controller was based on the input from more than 80 teachers and school administrators. The targeted performance metrics include a CCT that varies between 2700K and 6500K, a luminous efficacy > 120 lm/W and a CRI > 83 at all CCTs, full dimming, and a rated lifetime > 60,000 hours. The technology already meets or exceeds all of the initial-performance goals, and accelerated stress testing is underway to demonstrate the long-term performance of the system. Results to date have been outstanding, with no electrical failures and luminous flux maintenance projections of

Project Integration and Collaboration

- Partners, Subcontractors, & Collaborators
  - Finelite, Inc. is our key partner on this work. They are actively working to commercialize white tunable lighting built specifically to address the needs of teachers & students based on findings of this research.
  - Pacific Northwest National Laboratory has provided valuable inputs on key performance metrics such as flicker and color quality.
- Communications (Averaging 1 public presentation/quarter)
  - 2016 DOE Solid-State Lighting Research & Development Workshop
  - 2016 Illuminating Engineering Society Research Symposium III – Light & Color
  - 2016 LightFair International
  - 2016 DOE Solid-State Lighting LED Product Development and Manufacturing R&D Roundtable
  - 2016 Illuminating Engineering Society Annual Conference
  - 2016 DOE SSL Market Introduction Workshop
  - 2017 DOE Solid-State Lighting Research & Development Workshop
  - 2017 IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (May 2017)

Next Steps and Future Plans

- The NICLS technology is currently available on a limited basis. Broadly available later in ‘17.
- Clear requests from teachers and administrators that more research is needed to catalyze the change-over to energy efficient, white tunable lighting. Research should examine the benefits to students and teachers of white tunable lighting.
  - Better focus on tasks at hand
  - Promote relaxation and calming environment
  - Accommodate use of new technology in the classroom

REFERENCE SLIDES

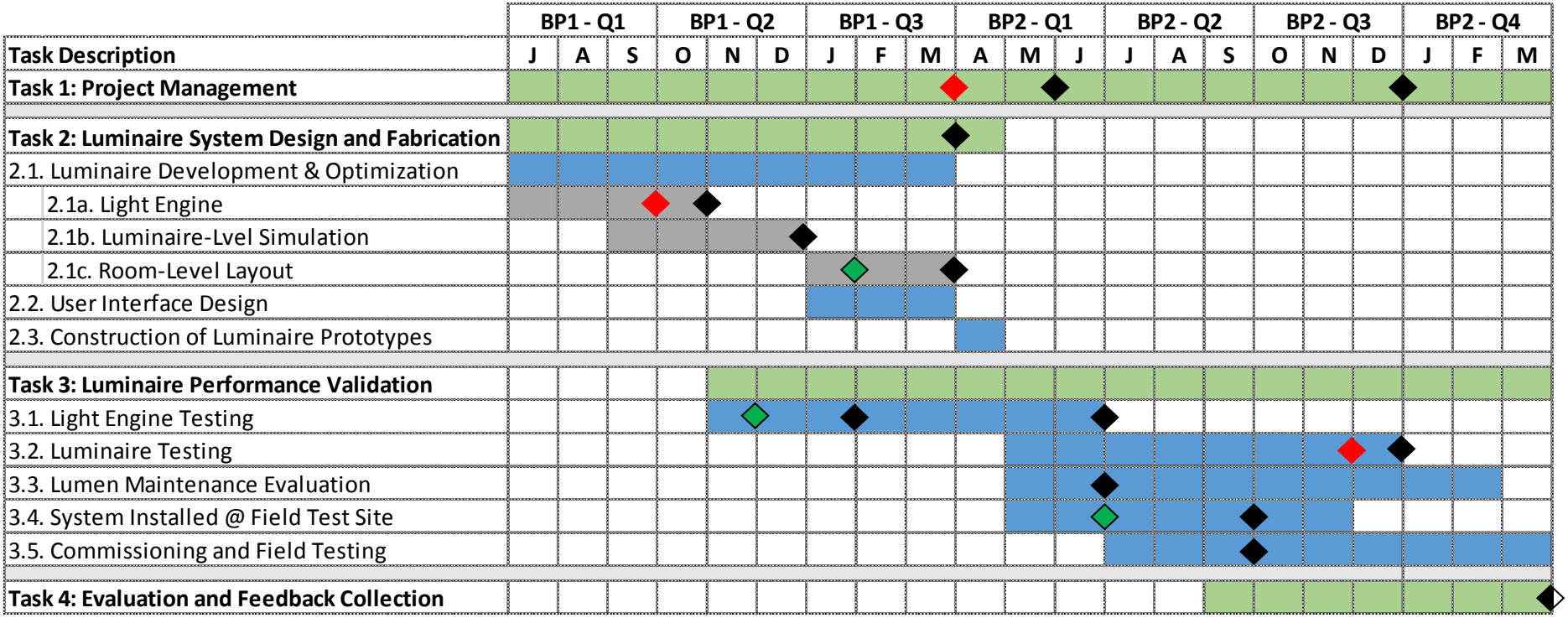
Project Budget

Project Budget: July 2015 – March 2017
Variances: None
Cost to Date: On schedule at $401,223 (Federal) and $156,833 in cost share
Additional Funding: No other funding sources

Budget History					
July 2015 – FY 2016 (past)		FY 2017 (current)		FY 2017 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$288,335	$144,381	$112,888	$12,452	$161,665	$12,452

Project Plan and Schedule

- Initiation date: July 2015, Planned completion date: March 2017
- Go/no-go after BP1 was based on calculated luminaire performance
- The team is currently completing evaluations on luminaires and demonstration layout, summarizing user feedback on the UI and the lighting system, and drafting the final project report.



- Changes in completion date:
  - 2016 DOE Peer Review was scheduled later than anticipated
  - Additional iterations were conducted to achieve the final light engine design
  - An additional round of LM-79 testing was conducted on completed luminaires