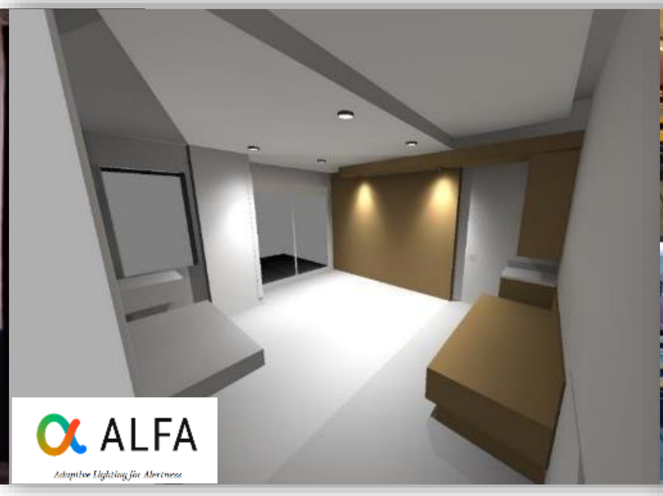
U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Emerging Lighting Science



Pacific Northwest National Laboratory

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PNNL-SA-142459

Project Summary

Timeline:

Start date: 10/1/2018 (new scope for ongoing work)

Planned end date: 9/30/2021

Deliverables expected for FY19

1. Six journal papers (submitted)
2. Six technical reports (incl. energy impacts study)
3. LightFair, EDRA, IALD, CIE, IES, other conference presentations and webinars

Budget:

Total Project $ to Date:

- DOE: $5069k
- Cost Share: $0

Total Project $:

- DOE: $10069k
- Cost Share: $0

Key Partners:

GA Tech/SimTigrate	Emory Univ. Hospital
Univ. of KY Hospital	Univ. of Oregon
Renton WA Schools	Penn State Univ.
Folsom Cordova Schools	Harvard Medical School
Boulder Community Health	Univ. of Colorado

Project Goals & Outcomes:

This project seeks to answer key questions about the energy implications of emerging science on how light affects human needs; the ways in which lighting can be designed to support these needs while minimizing energy use; and how future SSL systems can be optimized to minimize energy use while maximizing the desired human benefits in these applications. This project supports the Building Technologies Office goal to reduce lighting energy use intensity by 30% by 2030.

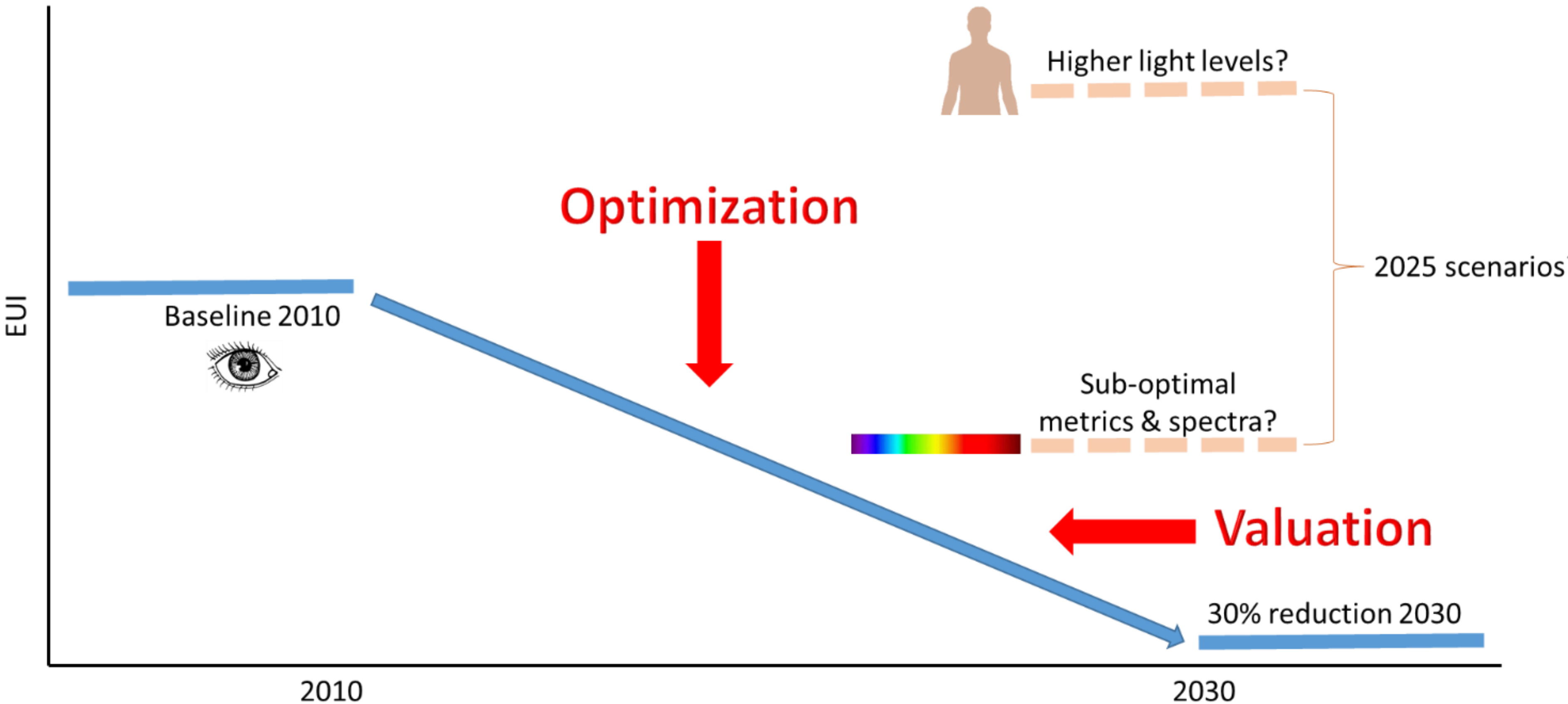
Challenge

Problem Definition:

- Traditional approaches to lighting energy efficiency have focused exclusively on optimizing lighting systems for ***human visual performance***
  - Basis for the related design metrics and DOE targets for SSL technology
- Emerging research indicates that future lighting technologies and applications will need to serve ***holistic needs*** that go beyond visual performance
  - Improved color quality, control of glare, avoidance of flicker, consideration of circadian rhythms, and provision of acute alerting effects
  - Economic valuation of these non-energy impacts may affect lighting energy use
- Design metrics and lighting technologies that are optimized for visual performance are ***not optimal for these holistic needs***, which could threaten the ability to meet DOE's energy use reduction goals for buildings

PROJECT GOAL: Support energy use intensity reduction goals for buildings with research that helps ensure that future generations of lighting technologies and future lighting design metrics are optimized to support new demands for lighting while minimizing the energy used

Approach



A transition from human visual needs to more holistic goals may mean:

- increased energy use intensity (EUI) due to higher light levels and /or
- slower EUI reductions due to sub-optimal metrics and technologies

Research that ***optimizes*** the metrics and technology, and that increases perceived ***value*** of the benefits of future technology improvements, directly supports BTO goals.

Approach: Four Task Areas and Purposes

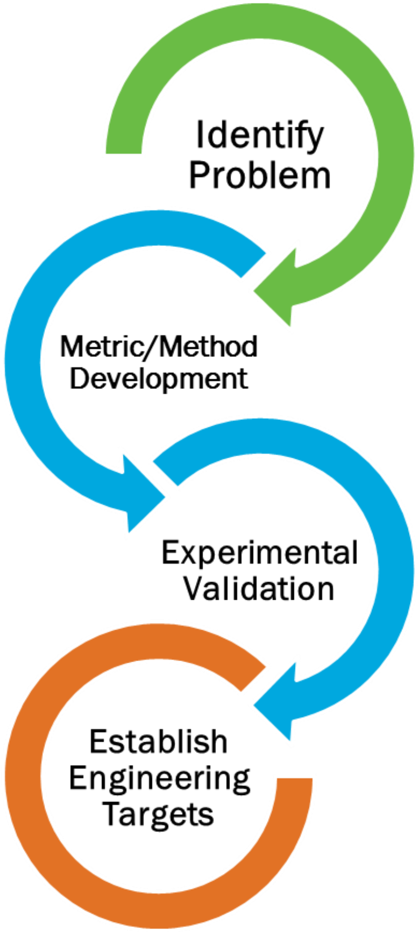
1. ***ENERGY:*** How will the emerging science of human effects of light affect U.S. building energy use?
    - optimization & valuation of future SSL technology

2. ***VISUAL:*** What knowledge is needed to optimize future generations of SSL systems for minimizing energy use while providing the appropriate light for human visual needs?
    - color, flicker, glare, optical materials

3. ***NON-VISUAL:*** What knowledge is needed to optimize future generations of SSL systems for minimizing energy use while providing the appropriate light for human non-visual needs?
    - metrics, simulations

4. ***REALISTIC SETTINGS:*** How valid are research results found in controlled laboratory studies when applied to realistic, complex environments
    - healthcare, education, offices

PROCESS

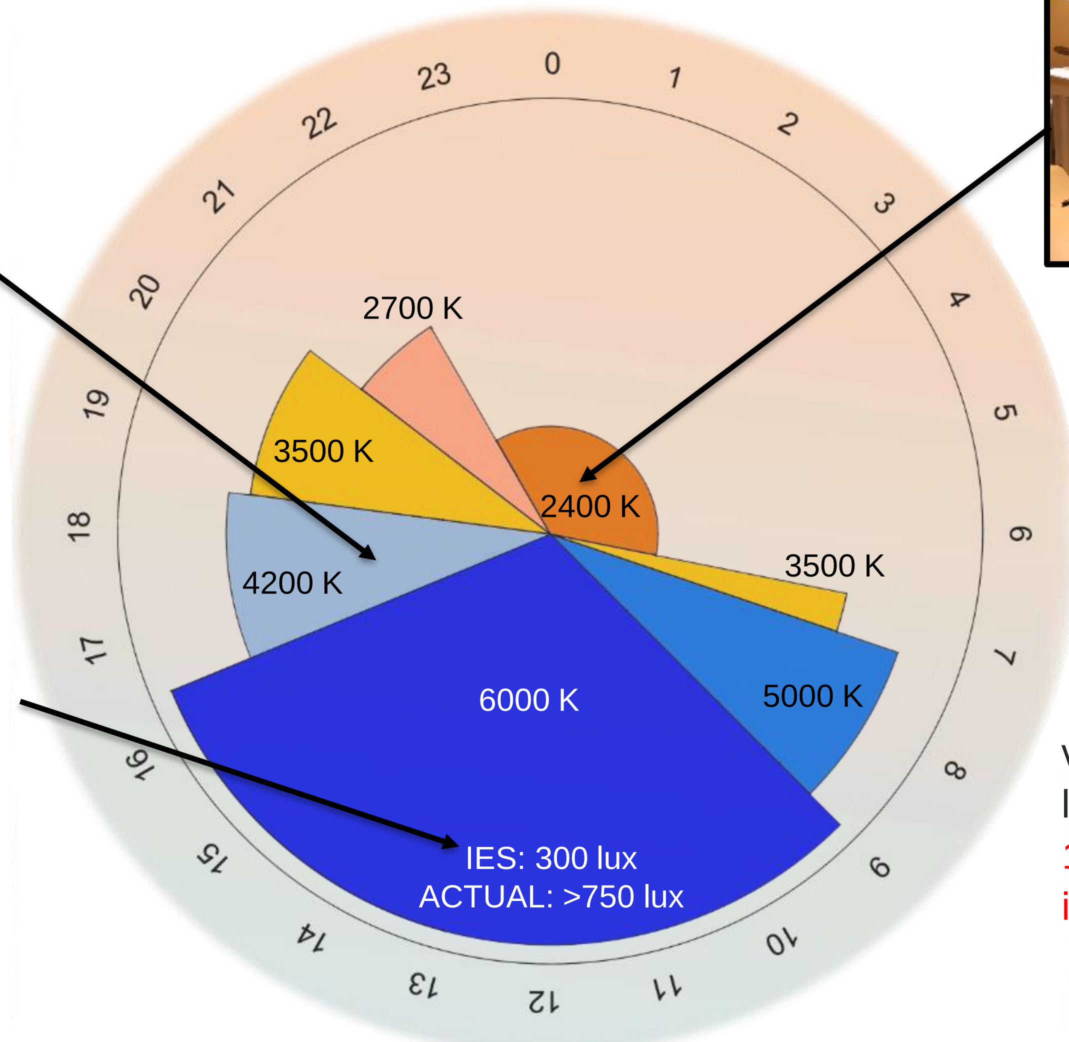


PROGRESS for Task 1: Energy

Higher light levels?

Swedish Medical Behavioral Health Unit

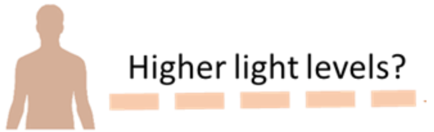
Light level and spectrum varies over 24 hour cycle



Light levels are more than double the recommendations for visual task needs due to circadian stimulus design goals

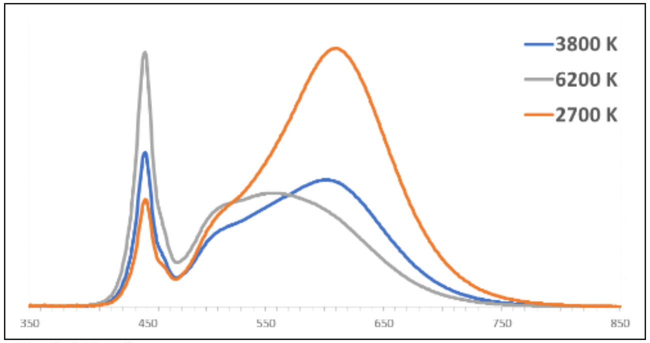
vs. recommended light level base case: 19-42% energy increase

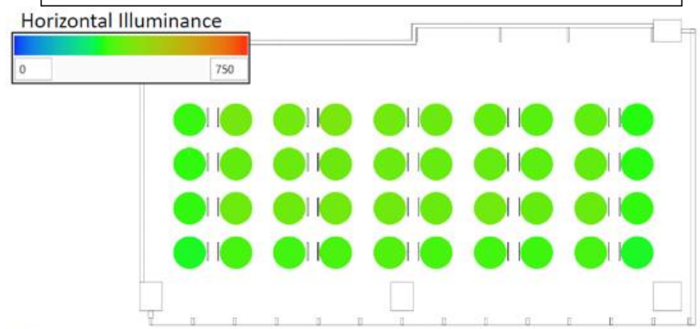
PROGRESS for Task 1: Energy

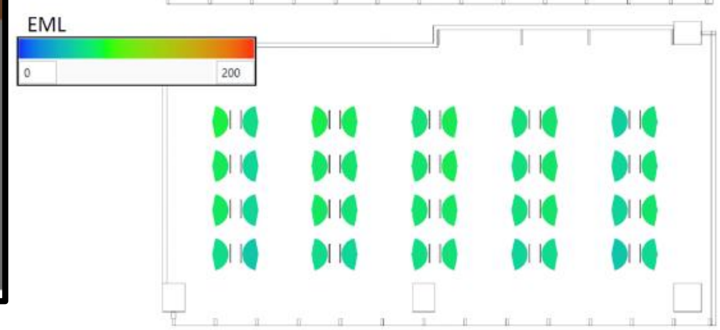


Simulation Studies: Open office with neutral finishes and wood furniture

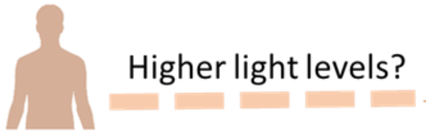
- 5000 ft^2; 40 workstations; 40 tunable 2x2 luminaires; baseline condition meets IES visual reqts.
- Comparisons to evaluate Equivalent Melanopic Lux (EML) as specified in WELL Building Certifications, using the Adaptive Lighting for Alertness (ALFA) software







PROGRESS for Task 1: Energy



SPD	% output	Ave Lux$_v$	Ave EML$_v$	WELL v2 1a	Annual kWh1	Annual kWh2
3800K	40	160	90	NO	1910	--
3800K	100	390	250	NO	8080	--
2700K	100	390	160	NO	8080	--
6200K	100	390	330	YES	8080	3710

Analysis 1: Tunable System (Current Technology)

- IES requires 150 lx vertical
- WELL v2 1a requires 240 EML electric light at all workstations for maximum points
- kWh1 assumes 5000 hrs./year
- kWh2 assumes high intensity for 4 hrs./day per WELL
- WELL requires at least a 94% increase in annual energy use

Analysis 2: Spectral Optimization (Future Technology)

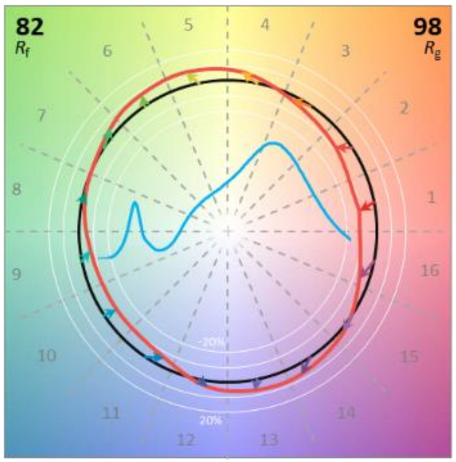
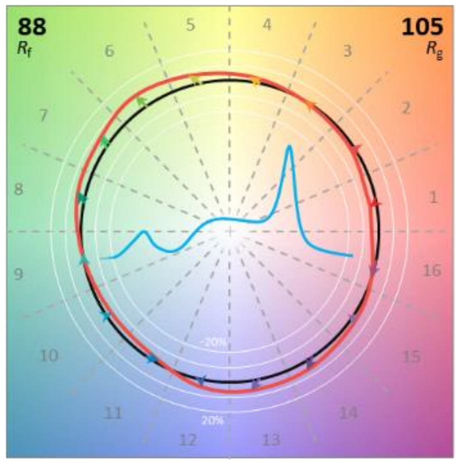
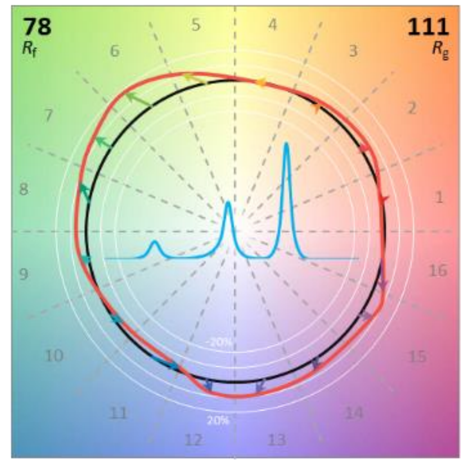
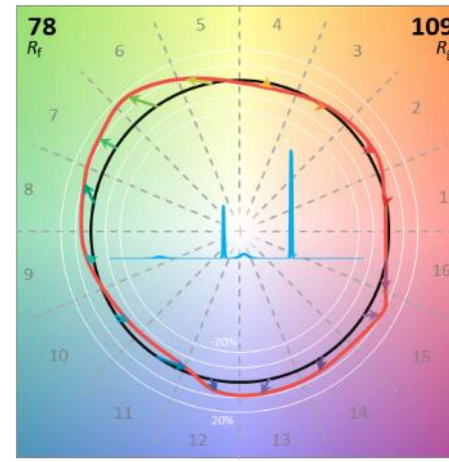
- Luminous efficacy of radiation (LER) analyses show what can be achieved by future technology with optimized spectral power distribution (SPD)
- Optimal SPD has 5.2% higher LER than 6200K for similar EML, at lower CCT
- Direct energy analyses not possible until incorporated into commercial luminaires

SPD	% output	Ave Lux$_v$	Ave EML$_v$	WELL v2 1a	LER
3800K	40	160	90	NO	316
6200K	40	160	130	NO	310
Lo M/P	40	160	75	NO	332
Hi M/P	40	160	125	NO	260
Optimized	40	160	130	NO	326

PROGRESS for Task 1: Energy

Sub-optimal metrics & spectra?

High quality color rendition has traditionally required sacrifices in efficiency – but new metrics coupled with future technology optimizations can enable high efficiency and high color quality

Typical	Available	Near Future?	Far Future?
			
Preference = Low	*Preference = Medium*	*Preference = High*	*Preference = High*
LER = 330	**LER = 351**	**LER = 398**	**LER = 416**

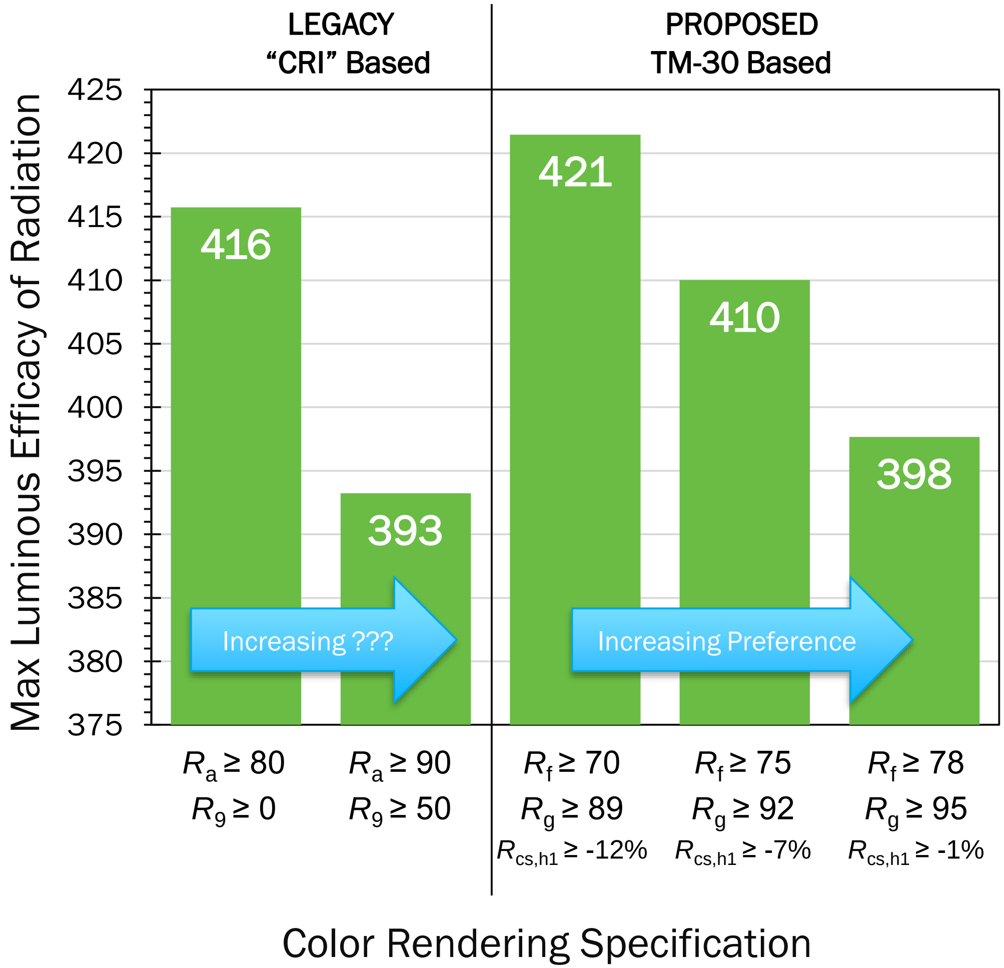
+6% Spectral Efficiency

+21% Spectral Efficiency

+26% Spectral Efficiency

PROGRESS for Task 1: Energy

Sub-optimal metrics & spectra?



Royer, Michael. 2019. Evaluating tradeoffs between energy efficiency and color rendition. Under review at *Optics Express.*

Legacy CRI metric

- Increasing from 80 to 90 reduces LER_{max} by 6.0%
- No basis in preference

IES TM-30 metrics

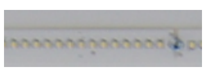
- Increasing from C to B reduces LER_{max} by 2.6%
- Increasing from C to A reduces LER_{max} by 5.5%
- LER_{max} for TM-30 A is higher than for CRI = 90
- Grounded in emerging science on preference
- "Green gap" and red remain key aspects for color rendition & energy efficiency

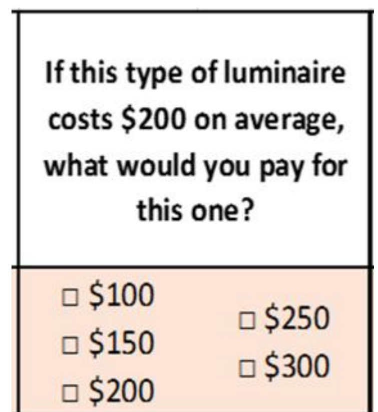
PROGRESS for Task 1: Energy

Valuation

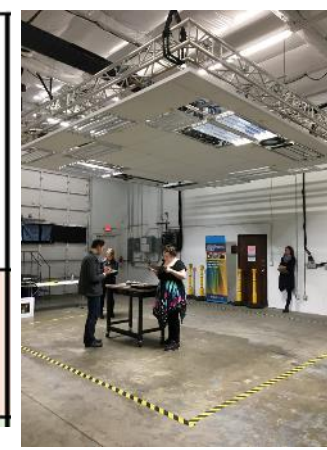
Valuation of lighting quality: 23 experts evaluated 7 hi-bay LED luminaires

- Assessed mock-up installation for visual comfort, distribution of light, color quality, appearance
- Rankings derived from written comments
- Value assigned by experts based on average price

	# LEDs	Rank	$ Value	lm/W
	Diffuser	1	$230	136
	1080	2	$196	165
	2862	3	$192	158
	576	4	$191	177
	672	5	$174	162
	756	6	$173	200
	536	7	$168	167


If this type of luminaire costs $200 on average, what would you pay for this one?

☐ $100
☐ $150
☐ $200
☐ $250
☐ $300



Miller, NM, T Beeson, J McIntosh, S Safranek. *Top Efficacy Performers: An investigation into high-achieving LED luminaires.* PNNL-27648, 2018.

Task 1: Energy

Valuation

Developed a three-stage project to formally address the valuation of non-energy impacts and the expected effects that those valuations will have on lighting energy use:

1. **Develop *descriptions* of baseline, near- and far-term future advanced luminaire scenarios for use in economic valuation**
   - Future scenarios incorporate results of PNNL research in optimization of metrics and technology
   - Streetlights/glare; Streetlights/environmental
   - Office/flicker; Office/non-visual effects (tunable); LED lamps/color rendition
   - *Completed*
2. **Estimate the *value* of advanced luminaires expected to result from PNNL research, using methodologies developed to help quantify "non-energy impacts (NEI)" of energy efficiency programs for electric utilities**
   - Subcontract with Skumatz Economic Research Associates, SERA
   - completion 6/10/19
3. **Estimate future potential *energy savings* that are expected to result from the research planned by PNNL using valuation inputs from SERA to an established lighting cost/market model**
   - Subcontract with Navigant
   - completion 8/30/19

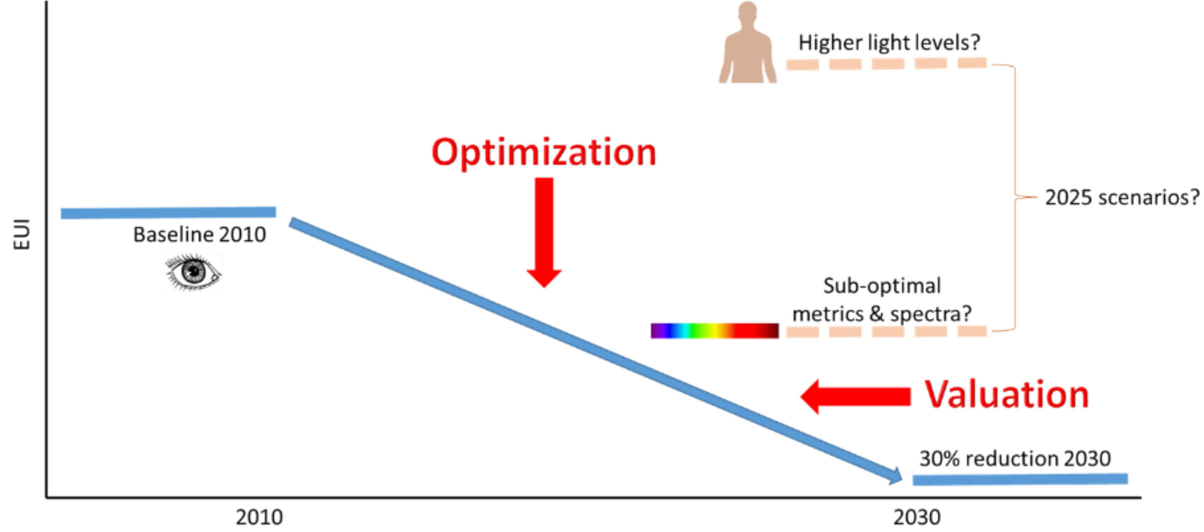
PROGRESS for Task 1: Energy

Valuation

Example information for valuation exercise – home LED lamps; color rendering

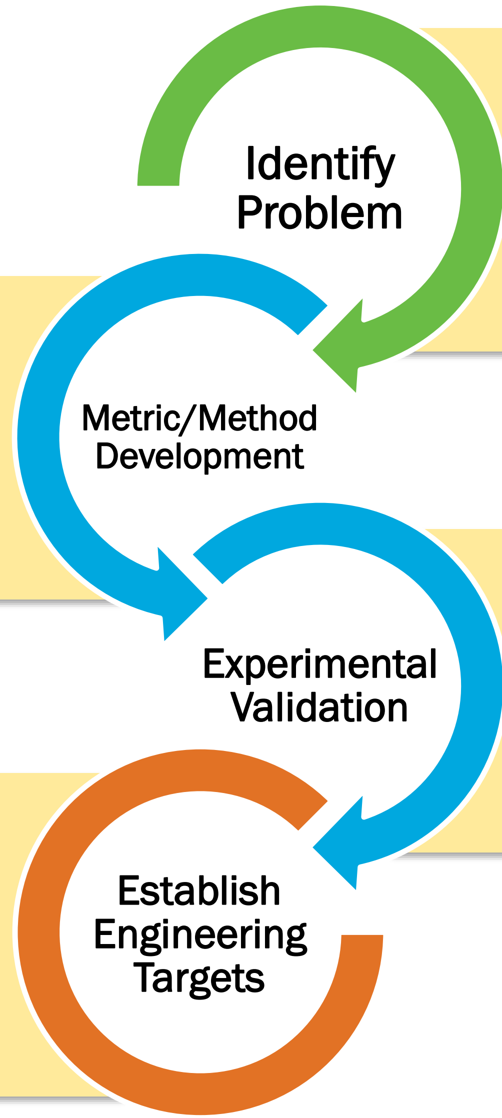
COLLOQUIAL DESCRIPTION	TECHNICAL DESCRIPTION
Color rendering similar to that provided by good quality fluorescent luminaires. The lighting makes colors look somewhat dull and unnatural and whites may have a slight yellowish tint; the light itself may have a slight greenish tint.	CIE R_a 80-84 and CIE R_9 0-20. LER 330
Near-term Performance: The lighting makes colors look natural, but some colors are a little bit dull. Whites are untinted. Energy efficiency increases by approximately 10% versus baseline. No change in price.	IES TM-30-18 $R_f \geq 75$, $R_g \geq 95$, $R_{cs,h1} \geq -7\%$, $R_{cs,h1} \leq 15\%$ Future whiteness index. Future updates to chromaticity. LER 365
Long-term Performance: The lighting makes colors look vibrant and pleasing. Whites are crisp and clean. The light is an untinted neutral white. Energy efficiency increases by approximately 20% versus baseline. No change in cost.	IES TM-30-18 $R_f \geq 78$, $R_g \geq 95$, $R_{cs,h1} \geq -1\%$, $R_{cs,h1} \leq 15\%$ Future whiteness index. Future updates to chromaticity. LER 400

REMAINING WORK – Task 1: Energy



- Complete energy estimates based on valuation of non-energy impacts
- Continue with simulations for energy estimates based on WELL Standard
  - Testing effects of different variables: finishes, directions, etc.
  - Expand to other applications: healthcare, education, etc.
  - Document and publish results in peer-reviewed building energy journals
- Translate optimization targets into estimated electrical energy implications
- Final summary report completed by 9/30/2019

Task 2 Visual :: Approach



Stakeholders
- Users
- Specifiers
- Manufacturers
- Researchers

Lighting Standards Orgs

IES	ANSI
CIE	ISO
NEMA	
IEEE	

Key Research Partners
- Penn State University
- University of Oregon
- University of Sheffield
- University of British Columbia
- National Research Council Canada
- Hong Kong Polytech

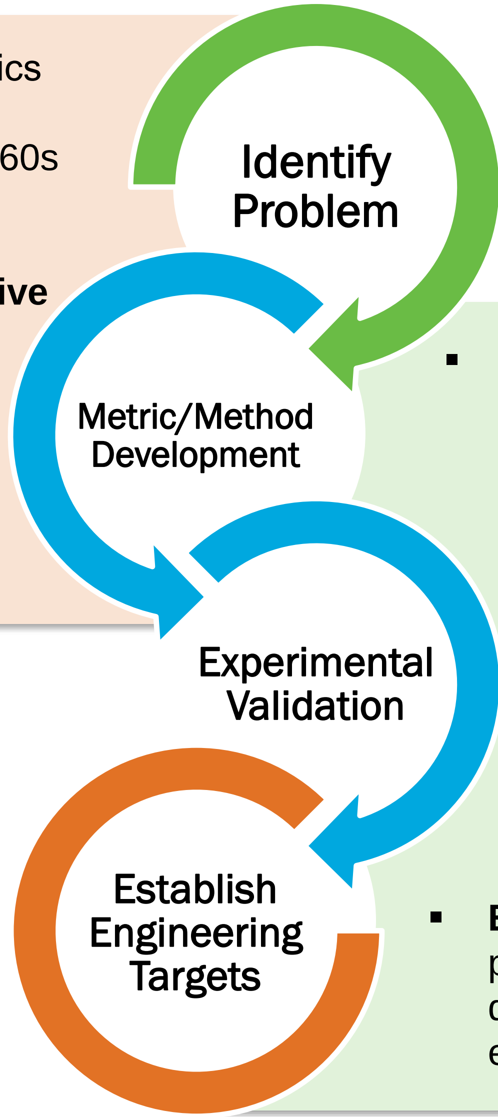
Specification Agencies
- DesignLights Consortium
- ENERGY STAR
- WELL Building Institute

Lighting Stakeholders

Task 2 Visual :: Approach

- Many of today's methods and metrics related to visual perception are **outdated**, dating from the 1930-1960s
- Deficiencies prevent optimization, leading to **quality issues, ineffective R&D investments, and wasted energy**
- SSL has **exposed** limitations, but also offers vastly greater flexibility to maximize performance

PROBLEMS



SOLUTIONS

- **Improve methods** for characterizing and communicating applied lighting performance attributes related to color, flicker, glare, and optics
  - Deepen fundamental knowledge of human perceptions of light via psychophysical and physiological **human factors experiments**
  - Use **theoretical models** to optimize SPDs and understand tradeoffs between varying qualities
- **Ensure appropriate balance** of performance and efficiency, improving quality to ensure widespread use and energy savings

Task 2 Visual :: Color

GOALS

- Establish psychophysically-relevant color **metrics**
- Generate **structure and guidance** to enable technology transformation
- Ensure SSL is chosen for quality and efficiency, with simultaneous improvement vs. current

PROGRESS

- ANSI/IES TM-30-18; Annexes E & F pending
- "Analysis of color rendition specification criteria." SPIE 2019.
- “Experimental validation of color rendition specification criteria based on ANSI/IES TM-30-18.” LR&T. Submitted for publication.
- “Evaluating Tradeoffs between energy efficiency and color rendition.” Optics Express. Submitted for Publication.
- “A vector field color rendition model for characterizing color shifts and metameric mismatch.” Leukos 2019.

More: https://www.energy.gov/eere/ssl/color-rendition

FUTURE

- Outfit new laboratory facility to continue psychophysical experiments; investigate **refinements of and additions** to newly-developed metrics
- Conduct experiments using **physiological outcome measures** to validate subjective responses
- Develop methods for optimizing SPDs for **reduced absorption** by colored objects
- Investigate updates to definitions of **CCT and D_{uv}** to align with perception

Task 2 Visual :: Color

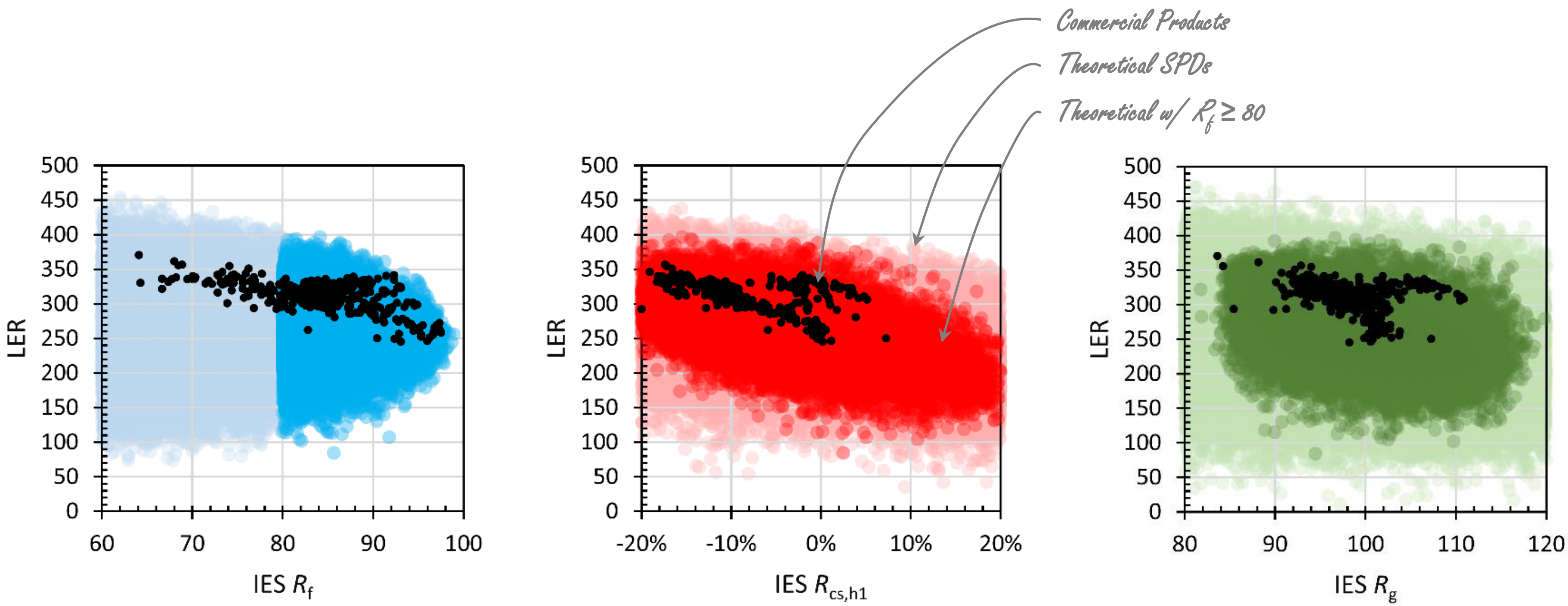
Royer, Michael P. "**Analysis of color rendition specification criteria**." *Light-Emitting Devices, Materials, and Applications*. Vol. 10940. International Society for Optics and Photonics, 2019.

1 Recommended specifications pending inclusion in ANSI / IES TM-30-18 as Annex E
Pending implementation by DesignLights Consortium and WELL Building Standard
Color Preference 1: $R_f \geq 78$, $R_g \geq 95$, $-1\% \leq R_{cs,h1} \leq 15\%$
Color Preference 2: $R_f \geq 74$, $R_g \geq 92$, $-7\% \leq R_{cs,h1} \leq 15\%$
Color Preference 3: $R_f \geq 70$, $R_g \geq 89$, $-12\% \leq R_{cs,h1} \leq 15\%$

KEY IMPACT:
New specs clearly outperform old and will better guide product development and specification.

Task 2 Visual :: Color

Royer, Michael P. “**Evaluating Tradeoffs between energy efficiency and color rendition**." *Optics Express*. Submitted for peer review.



LER (lumens/Watt$_{optical}$) represents potential if electrical efficiency fully addressed.

KEY IMPACT:

- Established relationships between LER and new measures of color rendition
- Using new Color Preference specs enables higher LER$_{max}$ by avoiding strong tradeoff with high fidelity

Task 2 Visual :: Glare

GOALS

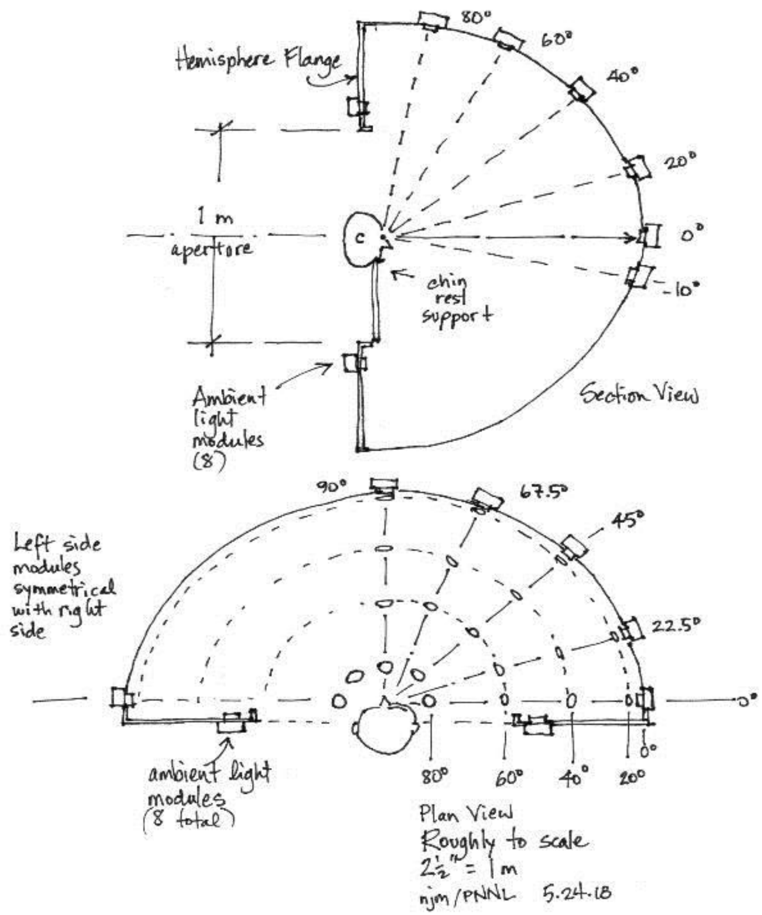
- Contribute **updates** to *Unified Glare Rating* (UGR)
- Establish tool and guidance to enable lighting stakeholders to **mitigate glare** when necessary
- Help to improve quality of SSL luminaires while **limiting unnecessary energy efficiency tradeoffs**

PROGRESS

- "HDRI for luminance measurement: A review of sources of error." Leukos. Submitted for publication.
- Designed apparatus for evaluating glare perception over field of view

FUTURE

- Human factors experiment to **extend and validate the position index**, an important component of UGR
- Human factors experiment on **contribution of spectral power distribution** to glare perception



Task 2 Visual :: Optical Materials

GOALS

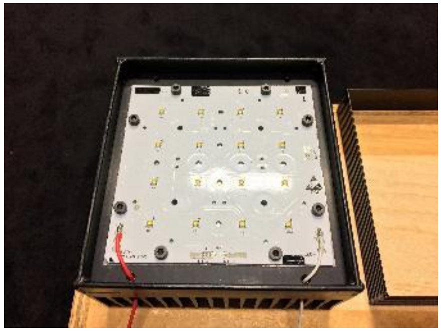
- Develop measure of luminance uniformity for diffusing materials to **improve luminaire design**
- Document tradeoffs between transmission and obscuration to **enable selection of most efficient materials**

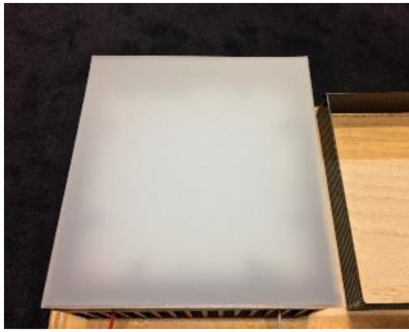
PROGRESS

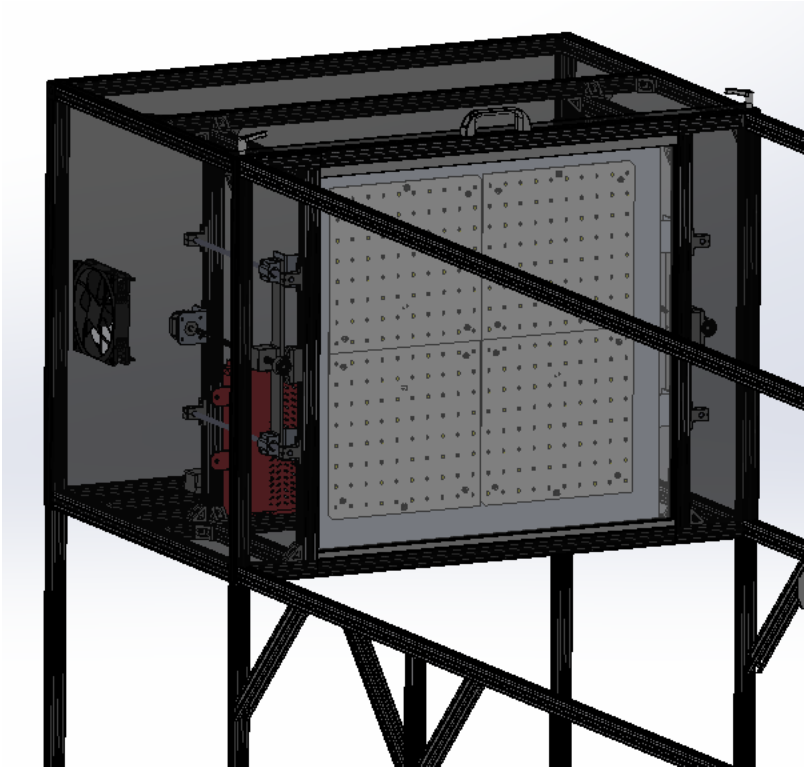
- Conducted outreach to optical materials companies to establish research priorities
- Designed new apparatus for evaluating visual uniformity of diffusing elements
- Created taxonomy of materials, obtained samples

FUTURE

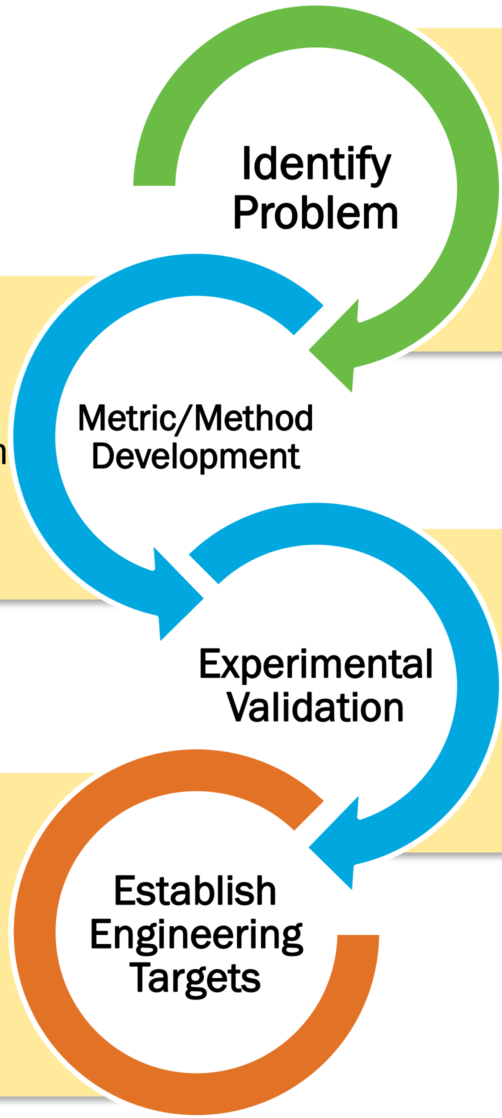
- **Comparison of HDR and luminance meter** measurements of spatial luminance patterns
- **Human factors study** of uniformity perception
- Evaluation of **long-term stability** for LED luminaire optical components







Task 4 Realistic Settings :: Approach



Stakeholders

Architectural Design firms: HGA, Boulder Associates, ZGF, Pivotal

Technical & Design Orgs

IES – CIE – NEMA – IEEE - ANSI

Enviro. Design Research Association
Center for Health Design
Practice Green Health

Key Research Partners

Oregon Health & Sciences University
Harvard Medical School
SimTigrate Design Lab / Georgia Tech
Emory University Hospital
University of Kentucky Medical School
Boulder Community Health

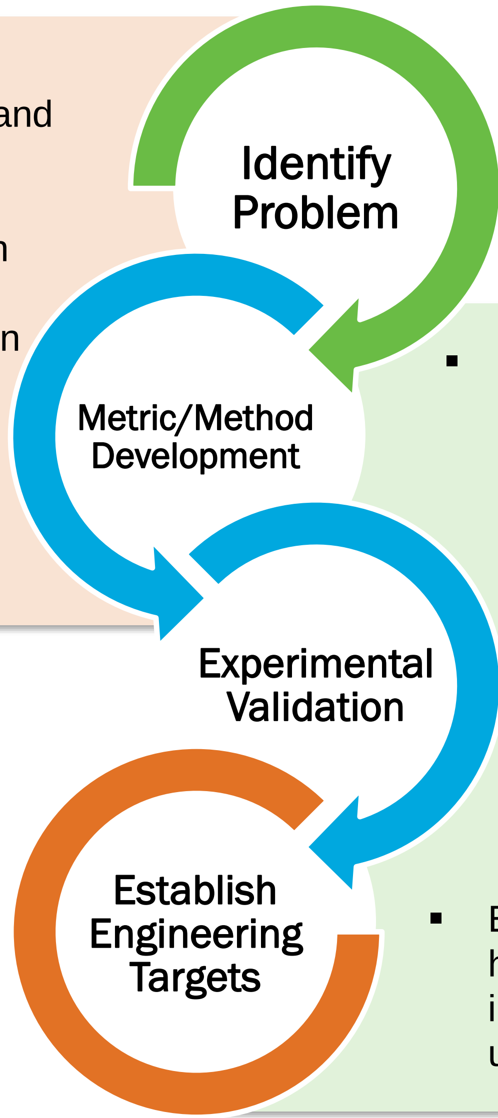
Design Standards

WELL Building Institute
Collab. High Performance Schools
Facility Guidelines Institute
USGBC
GSA , DoD

Task 4 Realistic Settings :: Approach

- As basic science on the holistic effects of light advances, metrics and design standards are in transition
- These transitions create confusion for technology developers and pressure to overdesign, resulting in wasted energy
- SSL research can contribute to optimizing the metrics, standards, and technology solutions

PROBLEMS



SOLUTIONS

- Improve methods for characterizing and communicating applied lighting performance attributes related to the holistic effects of light
  - Explore and document the extent of these holistic effects of light in realistic settings in buildings
  - Engage with new stakeholders who influence design metrics and standards for different applications
- Ensure appropriate balance of meeting human needs and energy efficiency, improving quality to ensure widespread use and energy savings

Task 4 Realistic Settings :: Patient Rooms

GOALS

- Optimize patient room lighting for reduced EUI while meeting needs of caregivers, patients, guests
- Build on results from “DOE-inside” R&D effort
- Establish accepted evidence base for new healthcare design standards that can inform future technology solutions

PROGRESS

- Commissioned mock-up room at SimTigrate GA Tech
- Completed journal paper on nurse survey results
- Completed 1st experiment at SimTigrate (nurses)
- Designed 2nd experiment at SimTigrate (patients +)
- Identified “simulation” room in Emory Midtown

FUTURE

- Publish series of peer-reviewed journal papers to build the evidence base for new metrics
- Coordinate design and installation of research-oriented lighting system in sim room at Emory
- Seek similar opportunities at other hospitals

Georgia Tech SimTigrate Design Lab

EMORY HEALTHCARE

Task 4 Realistic Settings :: Classrooms

GOALS

- Optimize classroom lighting for reduced EUI while meeting needs of students and teachers
- Build on results from “DOE-inside” R&D effort
- Establish accepted evidence base for new classroom design standards that can inform future technology solutions

PROGRESS

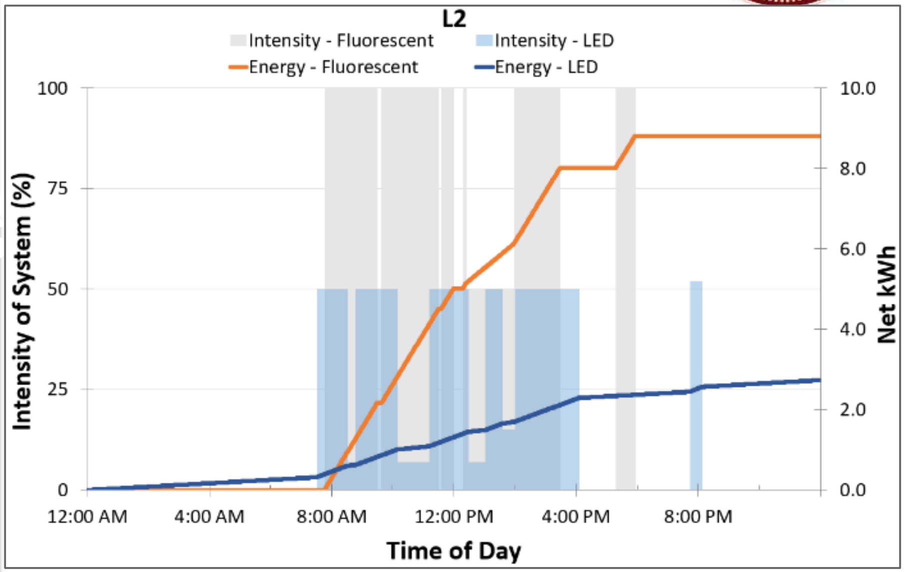
- Completed CFB and FCU Phase 1 (FY18)
- Prepared and delivered webinar for BBA members
- Completed FCUSD Phase 2 Report (March 2019)
- Completed article for LD+A magazine
- Established relationship with Renton WA district

FUTURE

- Presentation on FCUSD project at LightFair 2019
- Develop technical paper for peer-reviewed journal on CFB and FCUSD
- Develop project plans for Renton Schools, possible collaboration with Harvard Medical School

SMUD SACRAMENTO MUNICIPAL UTILITY DISTRICT

FOLSOM CORDOVA UNIFIED SCHOOL DISTRICT



Task 4 Realistic Settings :: Work in progress

GOALS

- Focus on high EUI and/or high energy use applications, especially those where design metrics are in transition
- Contribute to optimization of metrics and technology and valuation of NEI to support EUI goals
- Leverage DOE funding through collaborations

PROGRESS

- Delivered IES webinar on health metrics
- Completed initial data analysis for U of KY NICU; several conference presentations completed
- Completed Phase 1 of Boulder Community Health (BCH) research project; collaboration with Harvard Medical School for data
- Engaged on design and research team for Emory MCI facility and research program
- Supported DOE-funded research project at Suburban Hospital with Uniformed Services Univ.
- Established collaboration with Brown Univ. for Phase 2 research at ACC Care Center
- Collaborations on HDRI and virtual reality (VR) research with U of CO and U of OR

FUTURE

- Workshop and seminars at LightFair, EDRA, IES
- Complete analyses, reports, papers on UK, BCH, other current projects
- Initiate new collaborative efforts to address gaps in evidence base for optimization and valuation

UK University of Kentucky College of Medicine

Boulder Community Health

EMORY HEALTHCARE

BROWN

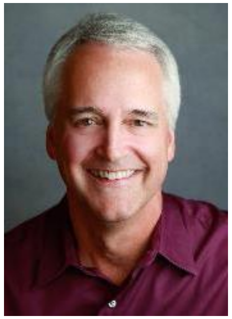
HARVARD MEDICAL SCHOOL

USU Uniformed Services University

acc SENIOR SERVICES

SUBURBAN HOSPITAL JOHNS HOPKINS MEDICINE

Team



Bob Davis

Technical Director

MS, Arch Eng
PhD, Psychology

30+ yrs lighting

6 yrs PNNL

Fellow IES

Michael Royer

Task Leader, Visual

MAE & PhD, Arch Eng

Human Factors

Color science

8 yrs PNNL

Andrea Wilkerson

Task Leader, Nonvisual & Realistic Settings

MS & PhD, Arch Eng

Human factors

6 yrs PNNL

Jessica Collier

MFA, Lighting Design

Human factors

PNNL associate 2019

Alp Durmus

MS, Arch Lighting

PhD, Architecture

Human factors

Color science

PNNL post-doc 2019

Kelly Gordon

Program Manager

MPP, Public Policy

Team Leader, Advanced Lighting

19 yrs PNNL

Marc Ledbetter

Economics, Energy

30+ yrs energy efficiency

25+ yrs PNNL

Naomi Miller

MS, Lighting

Flicker, Glare expert

30+ yrs lighting

10 yrs PNNL

Fellow IES, IALD

Sarah Safranek

MS, Arch Eng

HDRI, Simulations

2 yrs PNNL

Impact: Project deliverables from 10/1/18-present

Journal and conference papers

- Perceived colour fidelity under LEDs with similar R_f but different R_a, published in LR&T, Jan 2019
- A vector field color rendition model for characterizing color shifts and metameric mismatch, published in LEUKOS, Jan 2019
- Analysis of color rendition specification criteria, published in Proc of Light-Emitting Devices, Materials, and Applications, SPIE, Mar 2019
- Lighting research today (guest editor editorial), accepted by LEUKOS, Mar 2019
- HDRI for luminance measurement, submitted to LEUKOS, Dec 2018
- Nurse satisfaction with patient room lighting, draft submitted to DOE, Mar 2019
- Evaluating tradeoffs between energy efficiency and color rendition, submitted to Optics Express, Mar 2019
- Experimental validation of color rendition specification criteria based on ANSI/IES TM-30-18, submitted to LR&T, Mar 2019

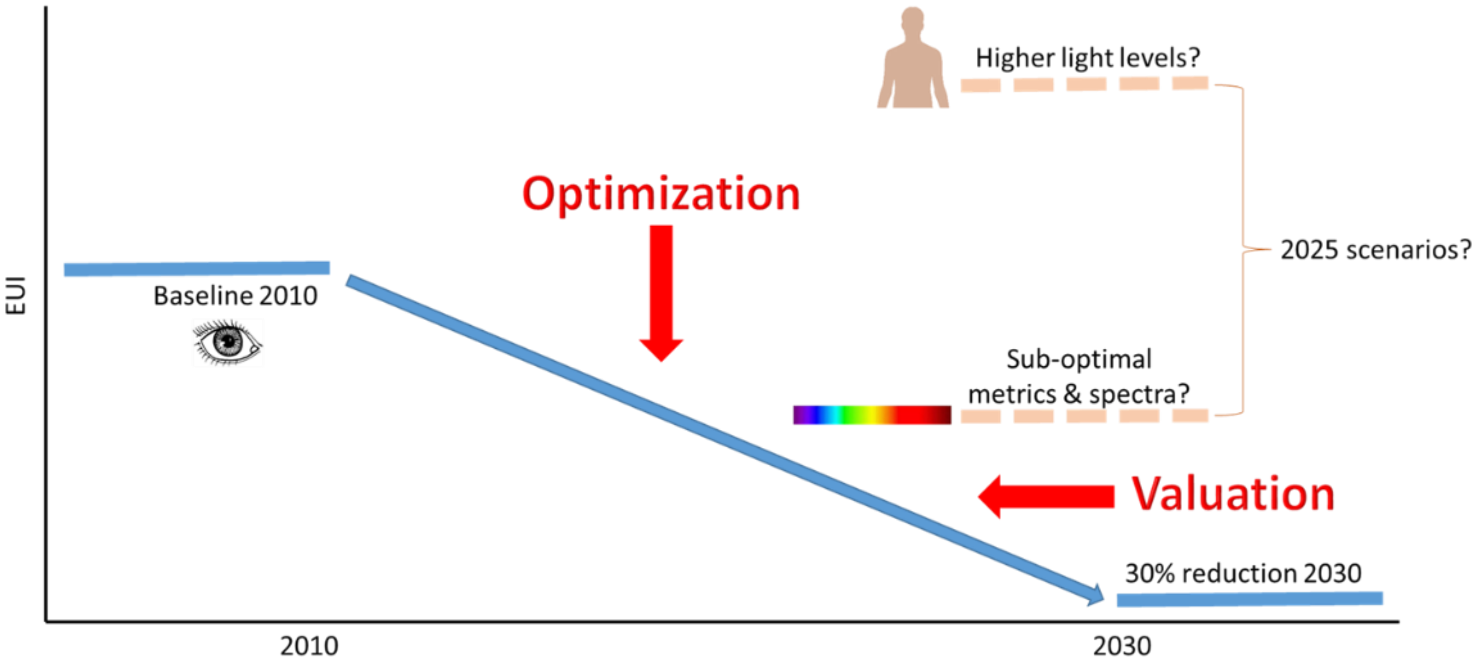
Technical reports

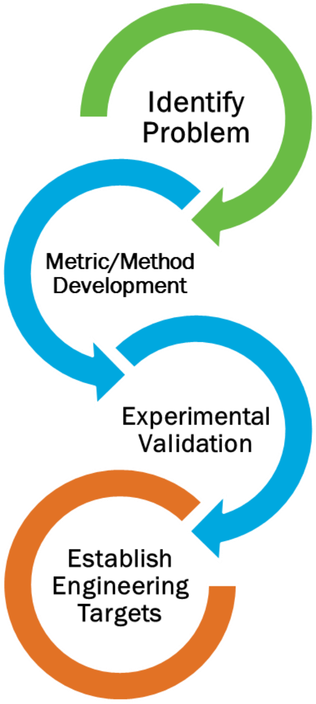
- Characterizing photometric flicker. Nov 2018
- Evaluating tunable lighting in classrooms - Supplemental Report. Feb 2019

Presentations

- Top performers high-bay project, DOE webinar, Oct 2018
- Light and health seminar, LightShow West, Los Angeles CA, Oct 2018
- Spectral and energy simulations, Solemma Symposium, Ithaca NY, Oct 2018
- Tunable lighting studies, DOE R&D Workshop, Dallas TX, Jan 2019
- Circadian metrics, IES Metrics in Motion Series, IES webinar, Feb 2019
- Color rendition specifications, SPIE Photonics West, Feb 2019
- UK NICU tunable lighting, Gravens Conference, Orlando FL, March 2019

Impact





- Research on emerging lighting science in visual and non-visual effects, with confirmation in realistic settings, supports optimized metrics and design targets for future lighting technology, and contributes to proper valuation of the non-energy benefits of lighting
- Without this research, lighting may not fully contribute to the 30% EUI reduction goals of BTO by 2030

Acronyms

ALFA	Adaptive Lighting for Alertness (software)
ANSI	American National Standards Institute
BTO	Building Technologies Office
CCT	Correlated Color Temperature
CFB	Carrolton - Farmers Branch school district
CIE	International Lighting Commission (French initials)
CRI	Color Rendering Index
EDRA	Environmental Design Research Association
EML	Equivalent Melanopic Lux
EUI	Energy Use Intensity
FCUSD	Folsom Cordova Unified School District
HDRI	High Dynamic Range Imaging
IALD	International Association of Lighting Designers
IEEE	Institute of Electrical and Electronics Engineers
IES	Illuminating Engineering Society
ISO	International Organization for Standardization
LER	Luminous Efficacy of Radiation (lumens produced per optical watt of radiation)
NEI	Non-Energy Impacts
NEMA	National Electrical Manufacturers Association
TM-30	Technical Memorandum 30 (a color metrics document published by the IES)
USGBC	United States Green Building Council

Thank You

Pacific Northwest National Laboratory
Dr. Robert Davis, Technical Director
503-417-7572 robert.davis@pnnl.gov

REFERENCE SLIDES

Project Budget

Project Budget
Variances: Original planned budget was $2500k per year for 3 years. In year 1, budget was increased due to:

- Increased volume of research opportunities within scope
  - Visual phenomena research
  - Realistic settings research
- Decreased scope in Application Specific Lighting project allowed for budget shift to Emerging Lighting Science project

Cost to Date: as of March 2019 month end, $1399k cumulative cost to date
Additional Funding: None

Budget History					
FY 2018 (past)		FY 2019* (current)		FY 2020 – FY 2021 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
n/a		$5069k		$5000k	

*Note: Includes FY2018 carry-over funds

Project Plan and Schedule

Project Schedule												
Project Start: 10/1/2018	Completed Work											
Projected End: 9/30/2021	Active Task (in progress work)											
	◆ Milestone/Deliverable (Originally planned) use for mis											
	◆ Milestone/Deliverable (Actual) use when met on time											
	FY19				FY20				FY21			
Emerging Lighting Science	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Journal paper related to SSL and human physiological effects of light	◆											
Journal paper related to SSL and human visual responses		◆										
Current/Future Work												
Report on energy impacts of human physiological applications				◆								
Go/no-go decision based on projected energy impact				◆								
Status report on current laboratory and field evaluation projects					◆							
Journal paper submitted on a topic related to human visual response						◆						
Report on a completed laboratory or field evaluation project							◆					
Journal paper submitted on a topic related to human non-visual responses							◆					
Evaluation report comparing modeled to measured data from a field site								◆				
Journal paper submitted on a topic related to human visual response									◆			
Journal paper submitted on a topic related to human non-visual responses										◆		
Report on a completed laboratory or field evaluation project											◆	
Recommendations for future SSL technology developments related to human visual and non-visual effects												◆