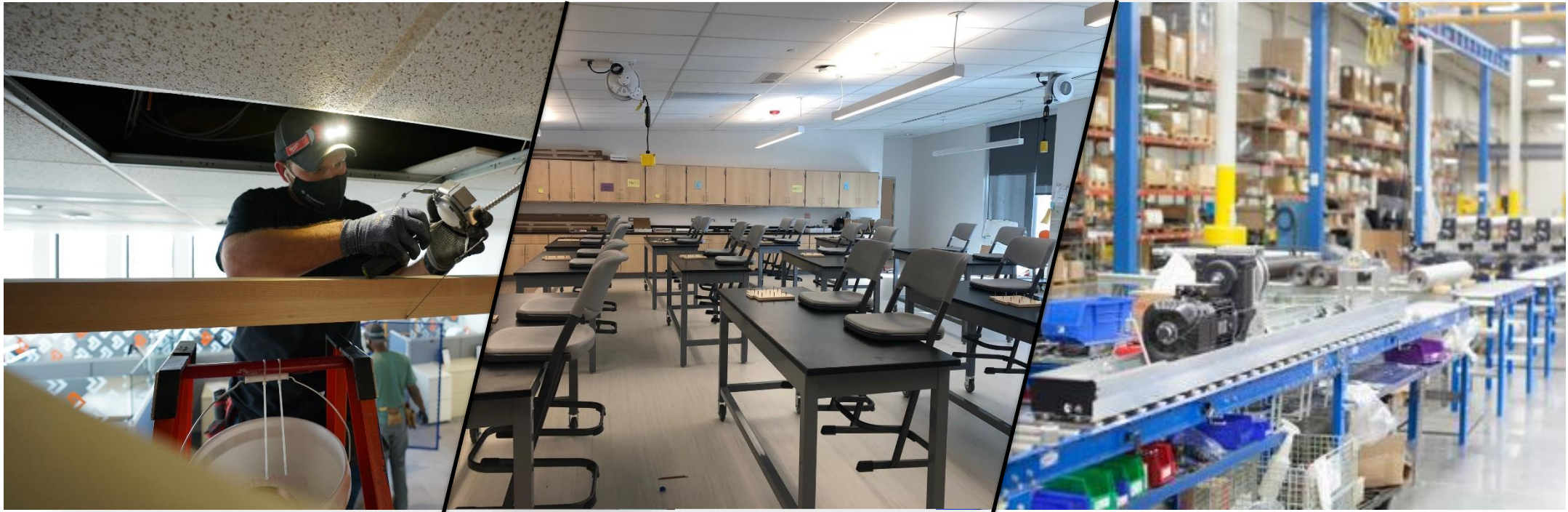


Lighting System Field Research + Training Resources



Pacific Northwest National Laboratory

Andrea Wilkerson, PhD | Lighting Researcher | andrea.wilkerson@pnnl.gov

Ruth Taylor | Project Manager | ruth.taylor@pnnl.gov

3.2.1.02: PNNL - CBI: Optimizing Lighting Systems for Decarbonization, Life Cycle Sustainability, and Occupant Benefits

Project Summary | Field Research

Objective and outcome

Increase deployment of advanced lighting systems to support building decarbonization through direct energy savings, while improving the wellbeing and comfort of occupants. Advanced lighting systems have the potential to deliver much higher application efficiency, with lighting control key.

Team and Partners

PNNL: Andrea Wilkerson, Ruth Taylor, Robert Davis, Naomi Miller, Sarah Safranek, Jessica Collier, Corey Strachan

Partners: GA Tech, Emory Univ., Parsons, NEEA, VTTI, Penn State, Indian Comm. School, Brigham and Women's Hospital, Boulder Comm. Health, HFMH Architects, Boulder Associates, ETC Inc.



Stats

Performance Period: FY23 (Ongoing FY22-24)

DOE budget: \$1188k, Cost Share: \$0

Milestone 1: Emory University Case Study

Milestone 2: NEEA Office Case Study

Milestone 3: ETC Office + Factory Case Study

Milestone 4: Indian Community Schools Case Study

Project Summary | Training Resources

Objective and outcome

Inform lighting industry about barriers to successful use of advanced lighting control systems, providing tools to help practitioners effectively document projects and produce workforce training resources to better equip electrical contractors and facility managers face new challenges with the installation, configuration, and maintenance of advanced lighting control systems.

Team and Partners

PNNL: Ruth Taylor, Jessica Collier

Partners: Dan Blitzler, IES, NEMA



Stats

Performance Period: FY23

DOE budget: \$480k, Cost Share: \$0

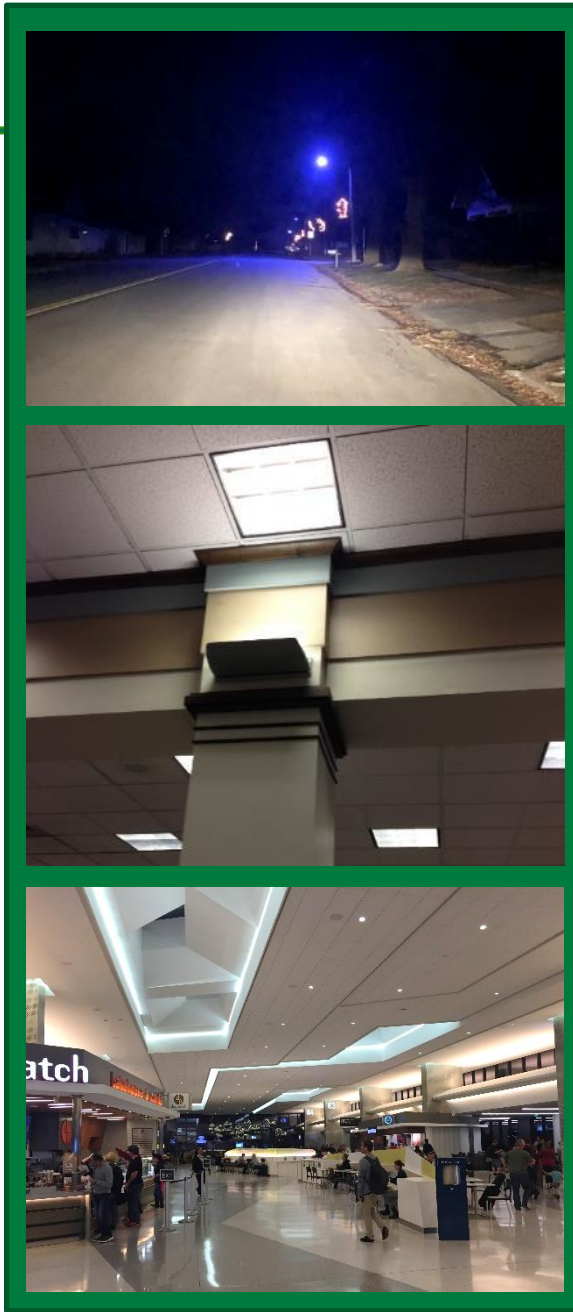
Milestone 1: Draft system selection training resources ready for internal review

Milestone 2: Final training resources deployed

Problem | Current State of Lighting Systems

Lighting system potential for ALL people and energy efficiency not yet fully realized

- Efficiency supports decarbonization goals, a critical step for many buildings.
- Lighting controls remain underutilized, with about two-thirds of commercial buildings having no lighting controls beyond a light switch. Installed penetration projections remain low under the current rate of adoption.
- Challenges continue to plague lighting control systems, including poor sensor performance, compatibility and interoperability issues, configuration complexity, and unpredictable performance. There is a gap between the stated potential of systems and the reality experienced in actual installations.
- Traditional approaches to lighting energy efficiency have focused on optimizing lighting systems for human visual performance; however, research indicates lighting systems need to serve holistic needs.



Problem | System Complexity

- Connected systems that are overly complicated and time-consuming to install/configure often do not perform to expectations and eventually get disabled.
- Reducing configuration complexity will increase the likelihood of energy savings. Systems that don't get used don't save energy.
- For connected systems to be broadly deployed, installation and configuration must be simplified to match owner/occupant needs.



Alignment and Impact | Realizing Lighting System Potential

For ALL People

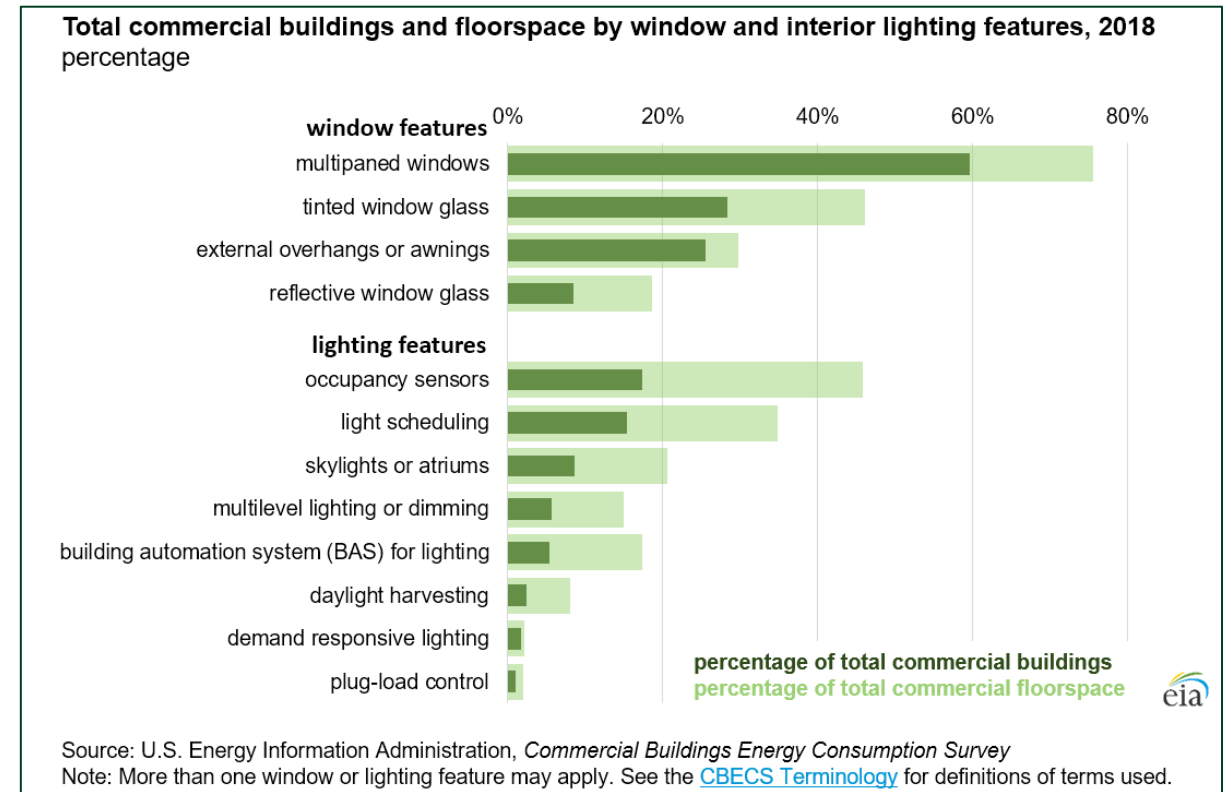
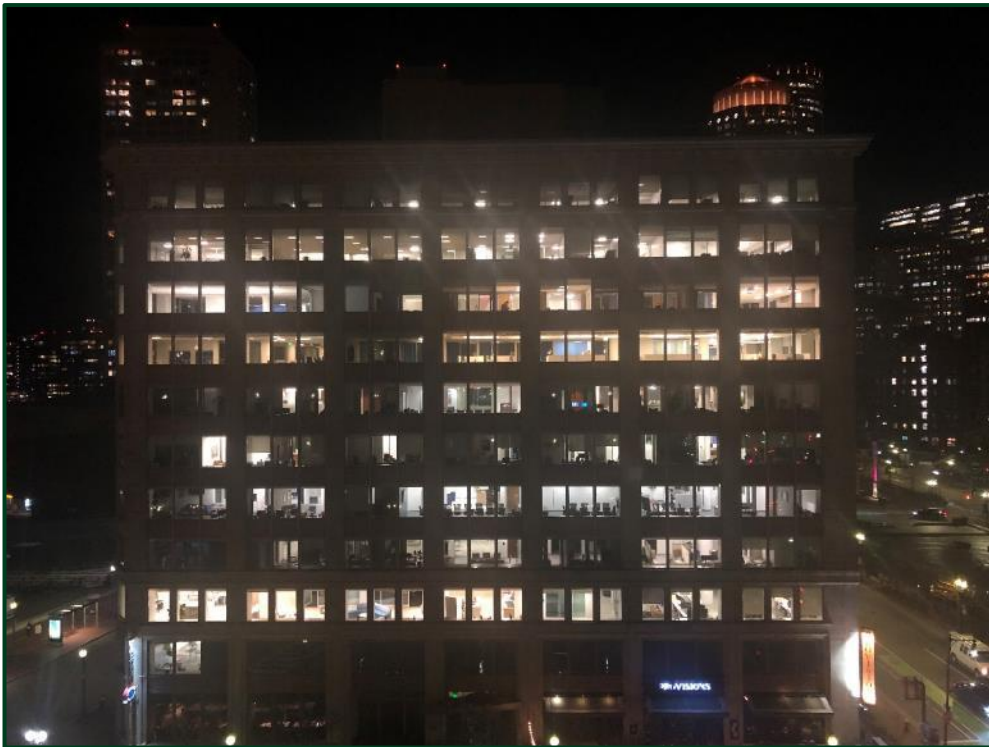
- Achieving the benefits of advanced lighting systems for the diverse occupants who work, live, learn, heal, and play in environments lighted by these systems. For benefits to be realized for ALL, technologies need to perform well in ALL buildings.
- Research indicates that future lighting technologies and applications will need to serve holistic needs beyond visual system performance, including color quality, control of glare, avoidance of flicker, consideration of circadian rhythms and other physiological effects.



Alignment and Impact | Realizing Lighting System Potential

For Efficiency

According to DOE forecasts, installed penetration of connected lighting systems by 2035 is estimated to yield an additional source energy savings of 156 tBTU.



Connected lighting system energy savings goals will never be realized if systems are disabled because they do not meet user performance expectations.

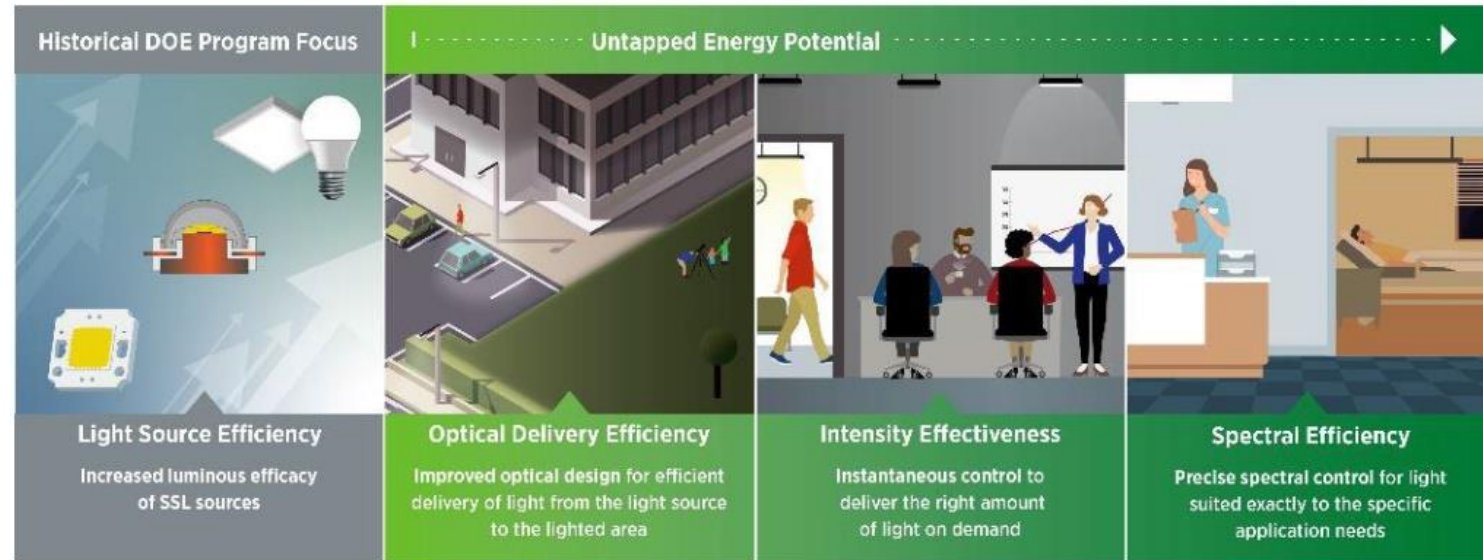
Approach | Capabilities and Potential

Improving Lighting Application Efficiency, Realizing the Full Potential of LEDs

Lighting application efficiency (LAE) - the effective generation and delivery of optimized light to the user in the right place at the right time.

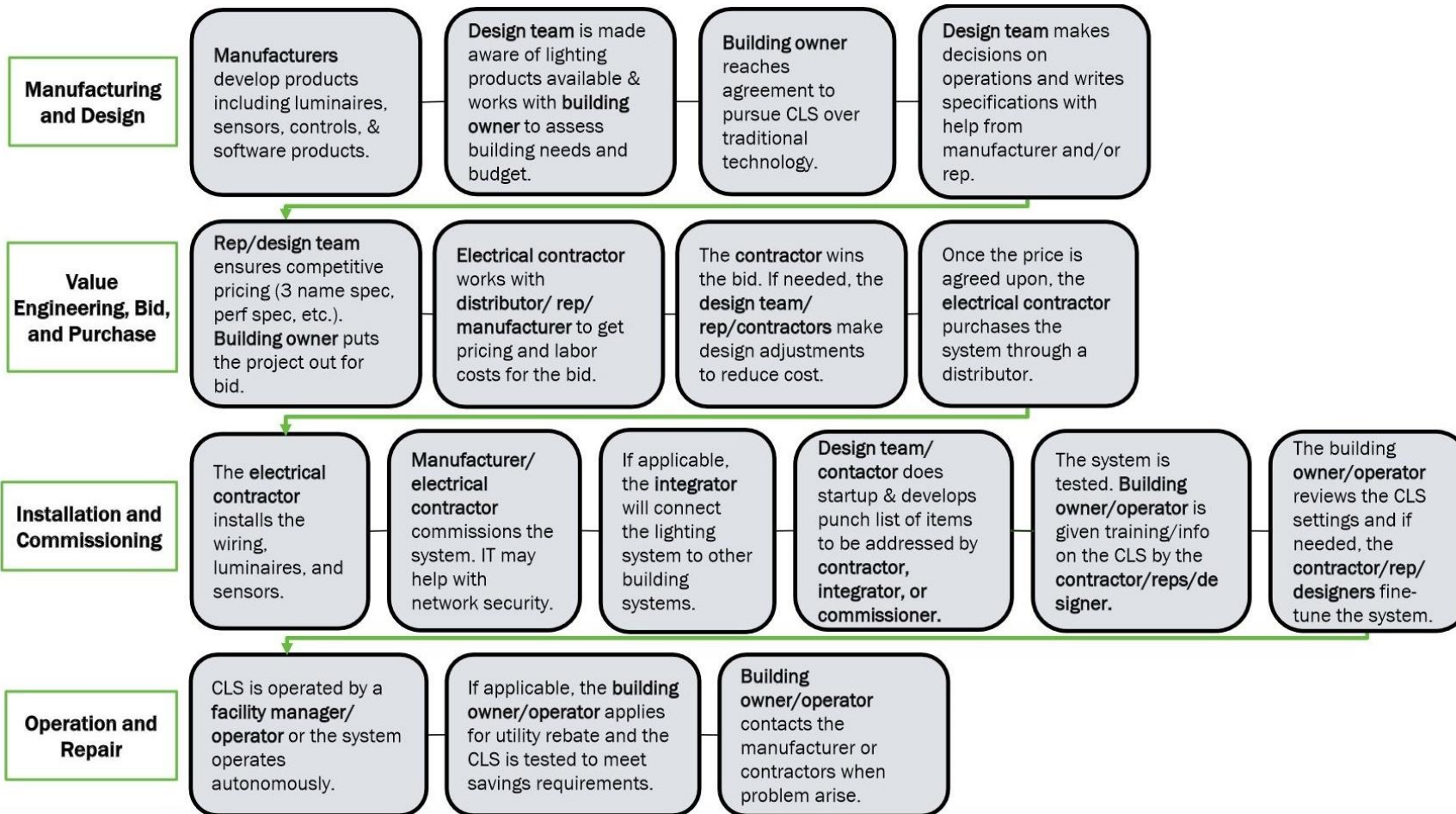
Core Capabilities:

- Collaborative approach, real projects
- Observational research
- Understand design intent, challenges
- Document long-term performance
- Partnerships with external SMEs
- Lighting and spectral measurements
- Occupant subjective and objective data
- Outcome data relevant to end user
- Control system data



Approach | Stakeholder Engagement

Realizing the Full Potential Requires Engagement with Lighting Stakeholders



Connected Lighting Supply Chain Diagram – From page 14 of Connected Lighting Systems Stakeholders Research Study September 2021

Approach | Field Research

Realizing the Full Potential Requires Time in Real Buildings

- Advanced lighting systems can deliver much **higher application efficiency**; right amount and spectrum at the right place and time. These flexible systems can adapt to the dynamic nature of occupancy, tasks, daylight availability, and other needs, and give people the control they want over their environments.
- Field demonstrations **gather and share relevant, actionable insights** related to the installation, commissioning and maintenance of advanced lighting systems. Successes and shortcomings are carefully detailed for others to learn from.
- Sites are chosen because of the **lighting energy use** they represent nationwide, the potential to document **occupant benefits** that can broadly apply, the opportunity to learn from lighting **system integration** with other building systems, and strong **collaborations**.



Approach | Field Research

Realizing the Full Potential Requires Time with People

- Understanding field performance and occupant outcomes in real environments is critical for **maximizing benefit** of lighting systems while **minimizing energy** use.
- Primary stakeholders for this work are building **occupants** affected by lighting systems, building **owners** and **operators** who procure and maintain these systems, and the **designers** and **specifiers** who directly influence architectural spaces and equipment selection. **Stakeholder experience** with lighting systems **impacts adoption**.
- Traditionally, lighting needs have been solely focused on visual tasks; however, research has shown **circadian**, **neuroendocrine**, and **neurobehavioural responses to light**. The visual and non-visual implications of architectural lighting should be carefully considered.
- **Occupant satisfaction, productivity, health** outcomes and overall **well-being** are all important considerations for realizing the value advanced lighting systems can deliver for people and efficiency.



Approach | Observational Research

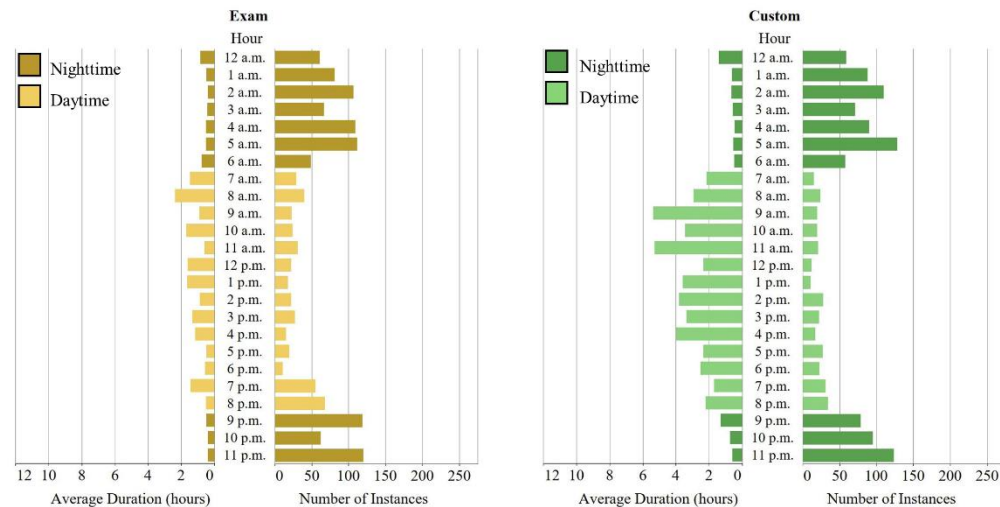
To find the real ‘pressure points’ in real installations, *people* need to observe and evaluate the *people* installing, configuring, and using the systems in real time, without assistance - it just can’t be done in a demonstration, mock-up, or testing lab.



Progress and Future Work | Getting to Actionable Results

Actionable Results from Papers Published 2020 to 2023

1. Occupants favor multiple lighting zones and individual control
2. Occupants find tunable CCT lighting acceptable, but use of saturated color can produce negative reactions
3. High CCT can result in negative reactions
4. Nighttime lighting needs attention



Bob Davis and Andrea Wilkerson

The Lunch Version Imagine learning about these research results over a quick bite

Understanding how research fits together takes time and can be challenging, including for researchers. PNNL lighting research results from the field are spread over multiple reports and journal articles, each focused on the outcomes from a specific study. This article aims to distill recent results from PNNL projects in healthcare environments into actionable insights that can help improve healthcare environments.

These healthcare projects range from a survey of nurses working in medical-surgical units in traditional hospitals with fluo-

ferent zones. Studies of tunable lighting in a mock-up patient room in Georgia also showed a preference for multiple zones of light, especially compared to traditional patient room lighting with the primary lighting over the bed. Interestingly, preference was not affected when the luminaires in the different lighting zones had different correlated color temperatures (CCTs), indicating that patients and visitors can be empowered to tailor their own lighting without necessarily affecting overall room perceptions. The inclination to control multiple lighting zones was also supported by occupant use

able lighting has been able to occupants, an instances preferred, re traditional static-white systems. While most y lize tunable technology white and warm white converted (PC) LEDs, color-tunable linear lut was used in the mock room to graze the wal foot of the patient bed and several lighting conditions experienced by the participants used saturated red or blue. Those conditions were not well received by the adult participants, perhaps in part because the lighting was introduced with-

33

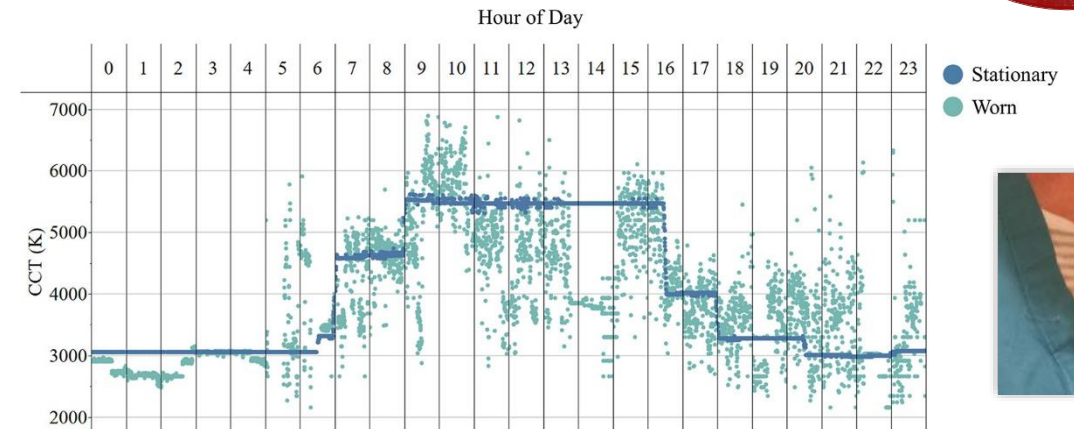
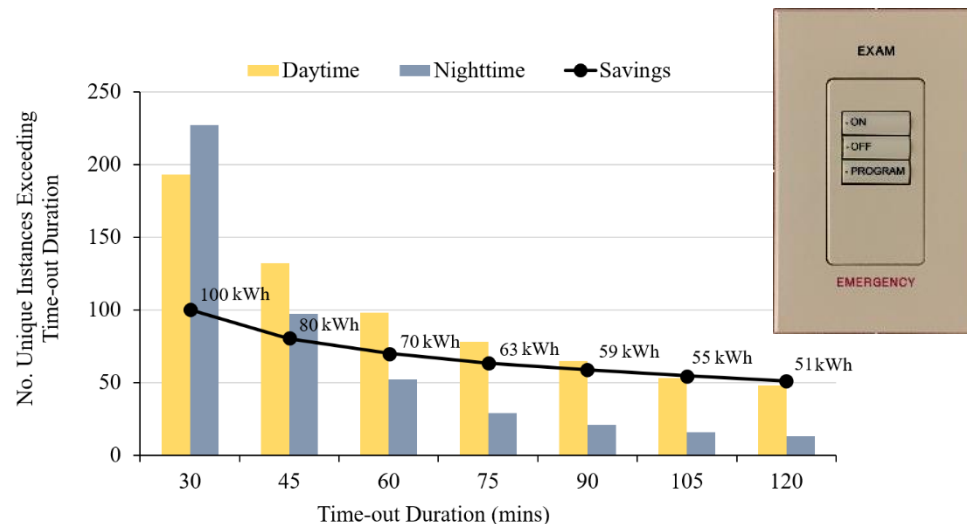
Nighttime lighting requires a Goldilocks scenario



Progress and Future Work | People + Efficiency in Healthcare

Learning Lessons in Healthcare Environments

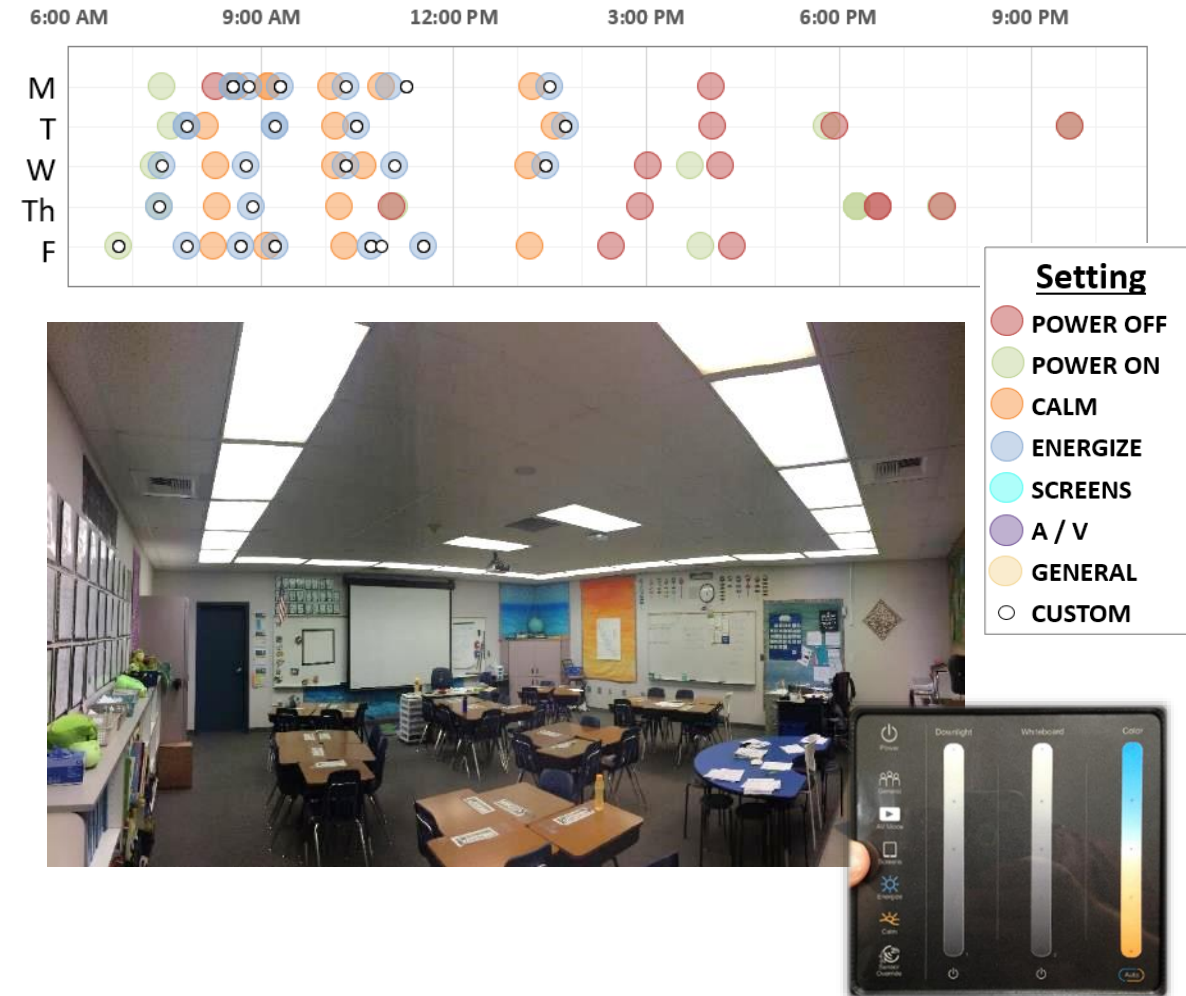
- Translations of light and health recommendations in real environments vary considerably
- A singular focus on light and health metrics can have negative consequences, and should be balanced with other lighting quality considerations
- Occupant light exposure throughout a day is dynamic
- Advanced lighting systems add operational complexity, necessitating education for staff and occupants



Progress and Future Work | People + Efficiency in Education

Learning Lessons in Educational Environments

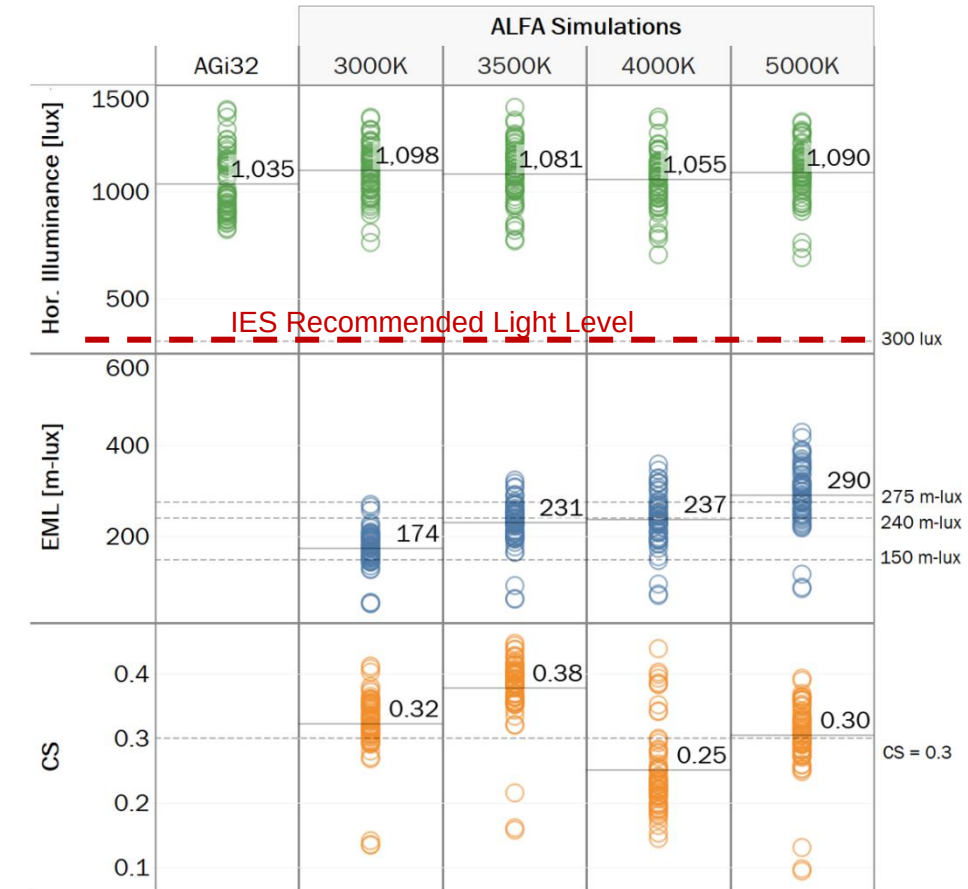
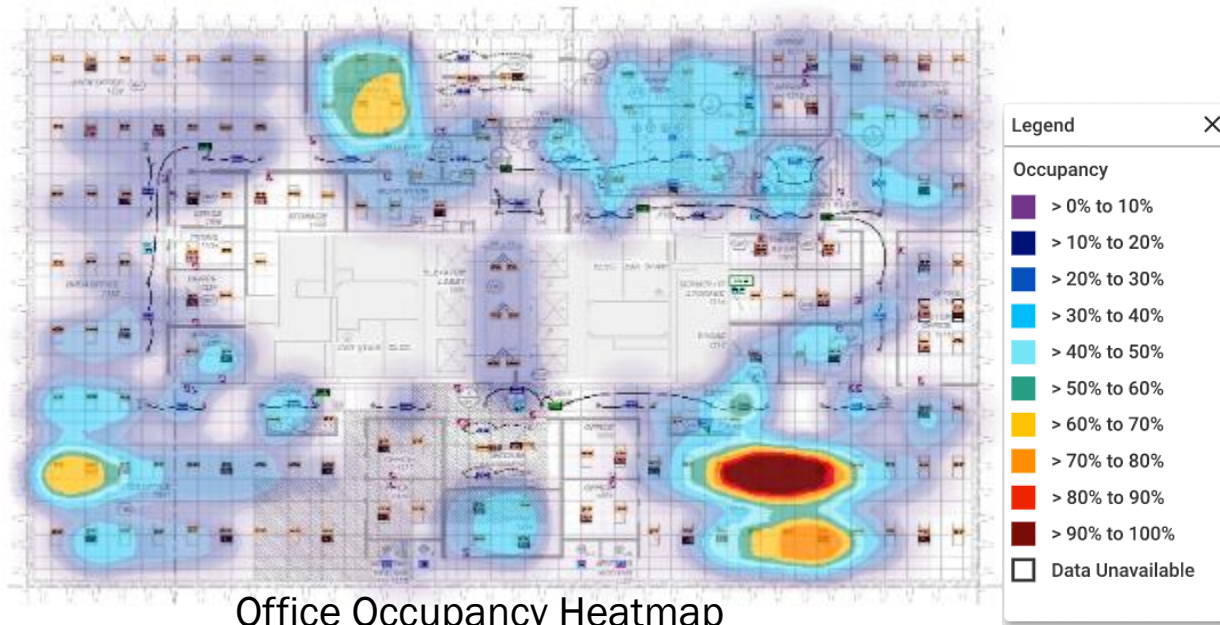
- Observing and recording human-technology interaction with lighting controls
- Initial data shows how lighting is used by special education teachers to support students
- Reasons for installing tunable lighting vary, including providing culturally important connections to nature
- Many opportunities to further value of lighting controls systems for energy savings, occupant outcomes, benefits, and integration with HVAC systems



Progress and Future Work | People + Efficiency in Workplaces

Learning Lessons in Workplaces

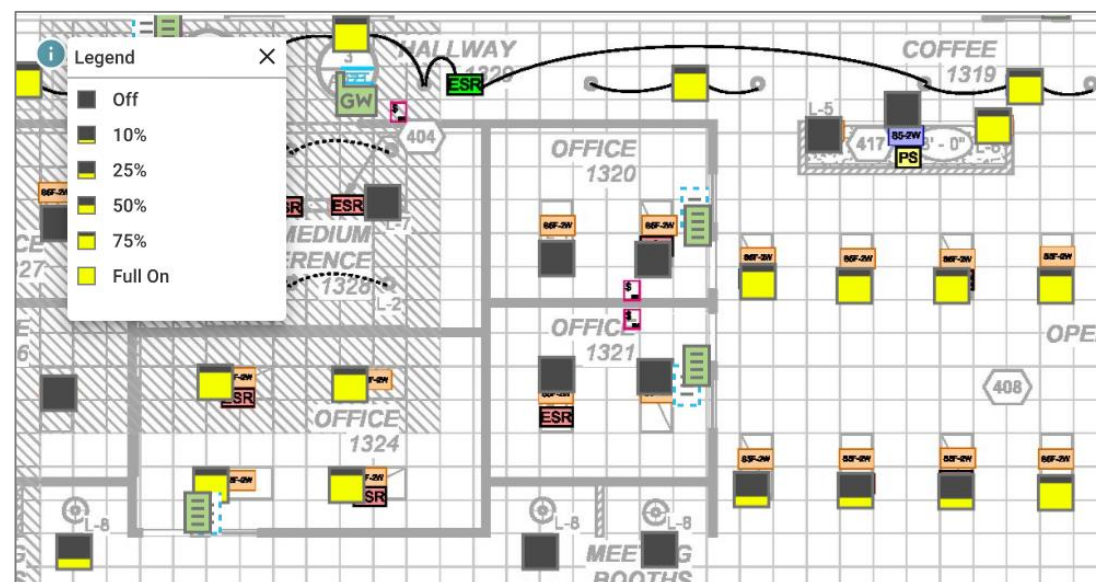
- Delivering vertical light level at the eye of occupants while minimizing glare is difficult with currently available luminaires
- Meeting circadian metric thresholds (EML and CS) can result in horizontal illuminance levels three times IES recommendations for visual tasks
- Advanced control and integration features remain challenging to commission, limiting the potential of these systems



Progress and Future Work | People + Efficiency

Research Questions

- How do lighting and health research and recommendations get translated into real projects?
- What are the energy efficiency implications of advanced lighting systems in these applications, designed for light and health recommendations?
- Do tunable lighting systems provide measurable health and well-being benefits to building occupants?
- Do occupants prefer tunable or static lighting in their environments?
- Does tunable lighting provide teachers with a greater sense of control and satisfaction?
- Do systems need regular servicing or commissioning in order to maintain performance?
- Are control system updates needed, and if so, how are these accomplished?



Progress and Future Work | Field Publications

Sharing and Learning, October to April 2023

- FY23 Site Visits: Electronic Theatre Controls (ETC), Benchmark Senior Living, Arlington Public Schools, Indian Community School, Northwest Energy Efficiency Alliance (NEEA), University of Wisconsin
- Presentations: Energy Exchange, Environments for Aging, Center for Healthcare Design Workshop, Council for Optical Radiation Measurements (Light and Health session chair), IES NYC section, IES NC section, Lytei (podcast)
- Case Studies: Emory University Cognitive Empowerment Center, NEEA Office
- Papers Published: IMEG Office Study published in Buildings (Feb), Boulder Community Health – Design and Measurement published in Health Environments Research & Design (Mar)
- Reports Published: Cook County Offices (Jan), Boulder Community Health – Occupant Outcomes (~Apr/May)



Training Resources

Alignment and Impact – Energy Savings from Controls are Significant

- Basic lighting controls savings range from 24% to 38% of lighting energy use
- Two-thirds of commercial buildings still have no lighting controls beyond a light switch
- DLC found average portfolio-level energy savings of 49% for networked lighting controls across 194 projects in commercial and industrial buildings
- DOE estimated installed stock penetration of connected lighting controls in commercial buildings of 22% by 2035 under the current (slow) pace of adoption
 - DOE forecast with more aggressive research, development, and deployment support was 79% installed penetration in commercial buildings in 2035, yielding additional site energy savings of 15 TWh per year (~10m metric tons of CO₂e)

2018 ENERGY SAVINGS FORECAST OF SOLID-STATE LIGHTING IN GENERAL ILLUMINATION APPLICATIONS

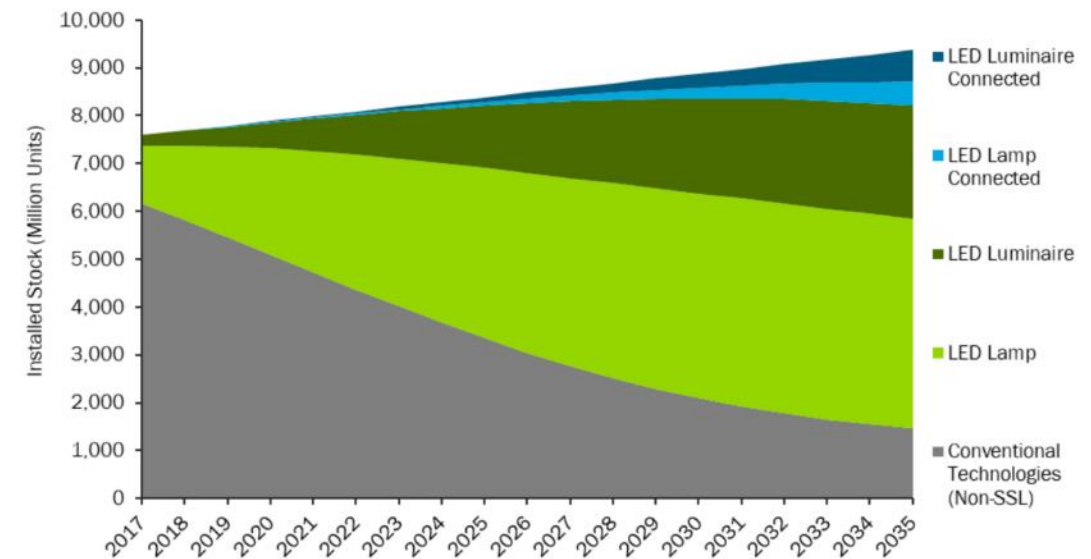


Figure 4.1 Total U.S. Installed Stock Projections for the Current SSL Path Scenario. In 2017, LED lighting makes up about 19% of the overall installed stock, and it is projected that the installed penetration of LED lamps and luminaires will increase dramatically through 2035 to reach about 84%.

Alignment and Impact – DOE's Vision

THE WAY ELECTRICITY IS GENERATED AND CONSUMED IN THE U.S. IS QUICKLY CHANGING



Urgency to decarbonize buildings and electricity grid (Economy Carbon Neutral by 2050)



Increasing: deployment of variable energy resources, and efficiency (By 2030 consumption should be carbon-free & locally generated)



Increasing electrification of vehicles and buildings (100% zero-emission vehicles by 2035)



Need to modernize fragile electricity system infrastructure (Decarbonization of the electricity grid by 2035)



Need to expand access, meet customer needs, and save money

Problem – Energy Savings Depends on Use and Performance

Energy savings cannot be realized if systems are not installed and used correctly.

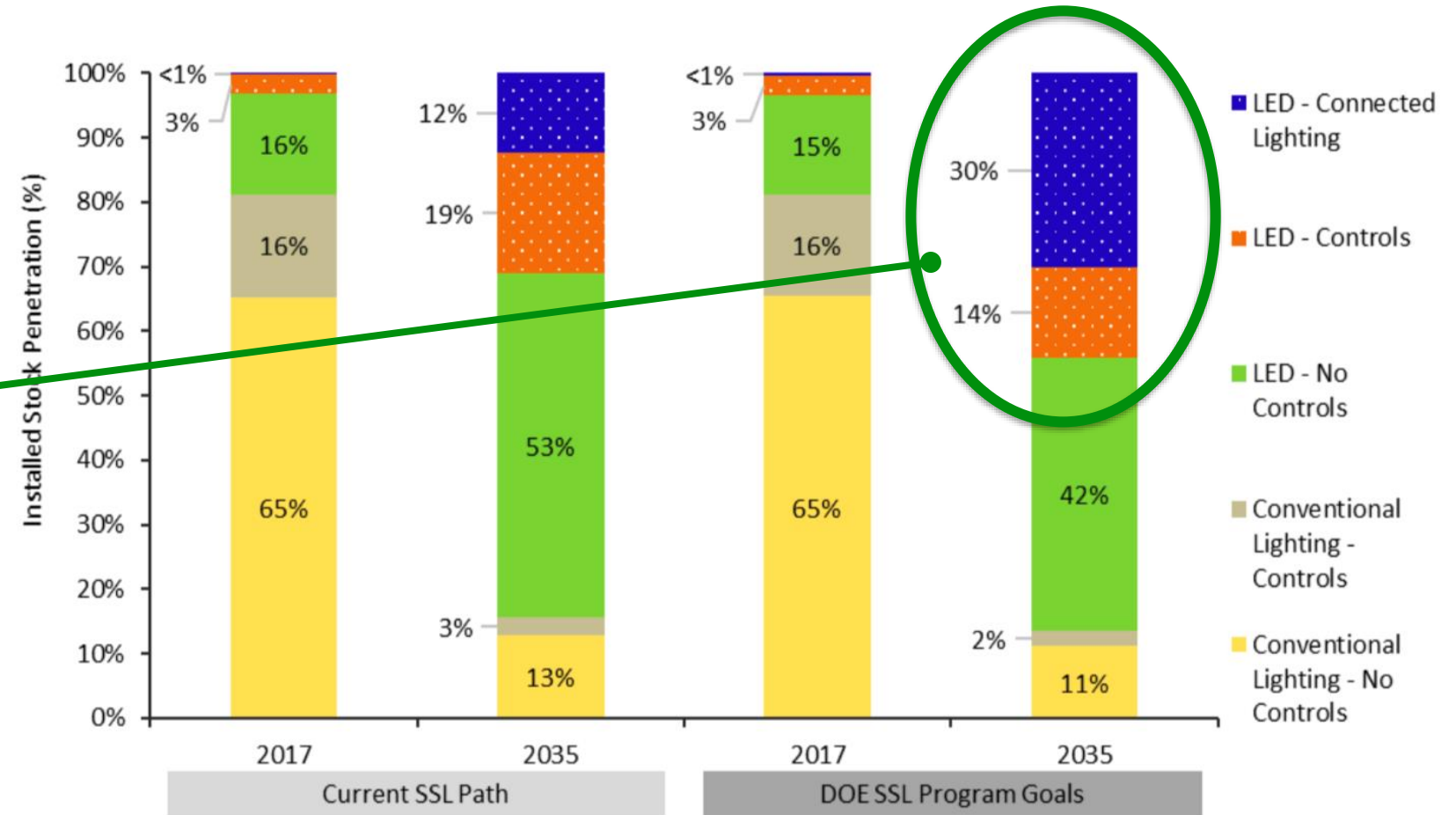
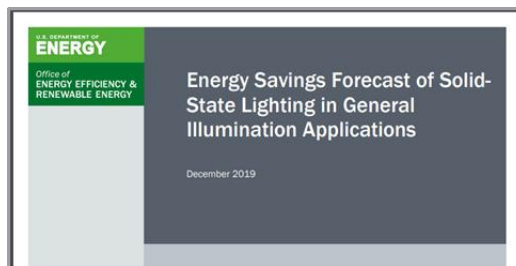


Figure 4.7 Lighting Controls Installed Penetration for LED Lighting vs. Conventional Lighting

Energy Savings Forecast of SSL in General Illumination Applications. DOE. 2019.



Problem – Finding Qualified and Trained People

- **Designers**
 - Focused on lighting or power
 - Limited in-depth knowledge of controls
 - Older professionals can be out-of-date
- **On-site supervisors**
 - Most are very good
 - Scarce resource, get moved around
 - Don't receive information from HQ
- **Field service techs**
 - May not understand specific system
 - Difficult to schedule

Finding qualified and trained installers and field service technicians is a major challenge today.



Problem – Communication and Documentation

Documentation

- Incomplete sequence of operations (S00)
- Conflicts between S00 and controls intent narrative (CIN)
- Inconsistent drawings and symbols
- S00 arrives late (after wiring has begun)
- Installers don't get the information they need to complete the installation and configuration
- Vocabulary is confusing

Documentation is consistently a significant problem.

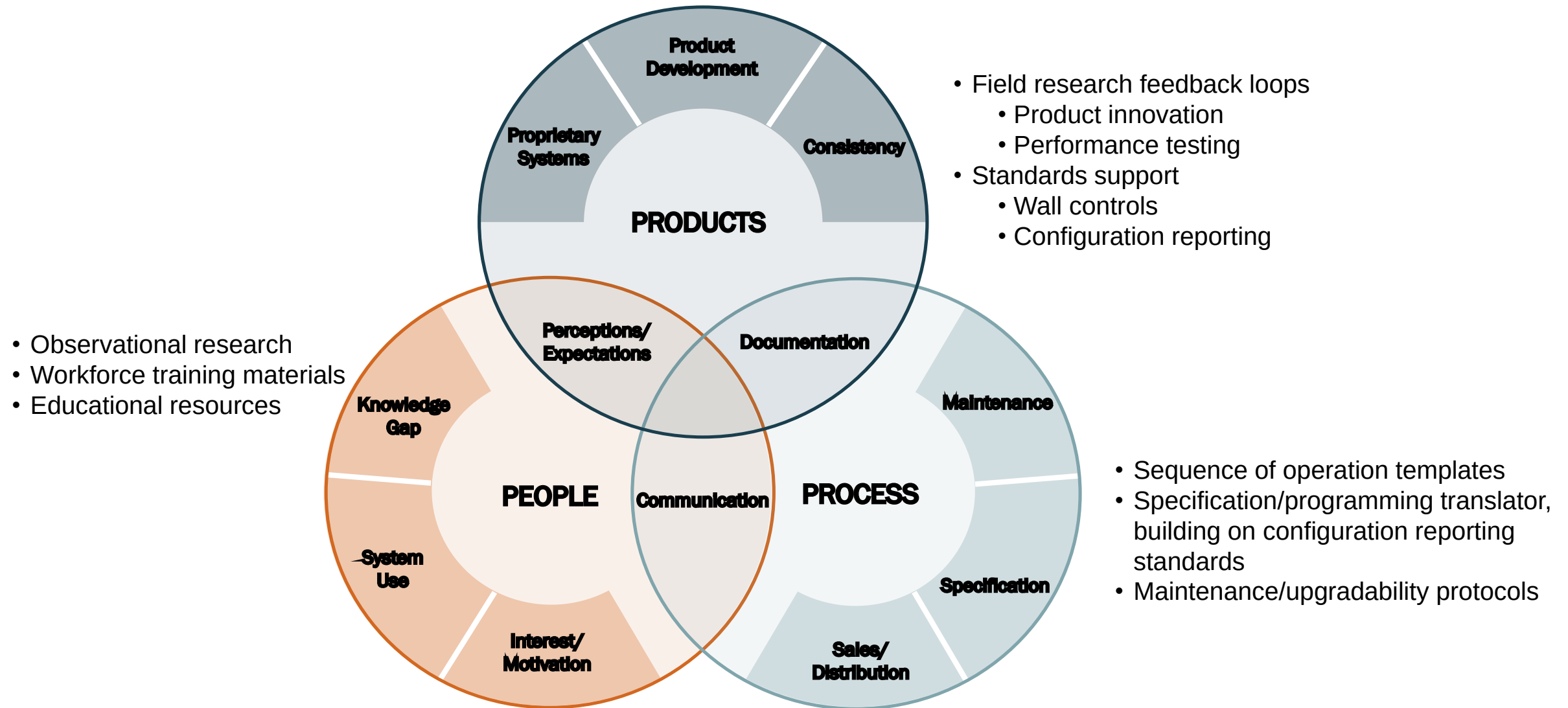


Approach – Understanding the Market

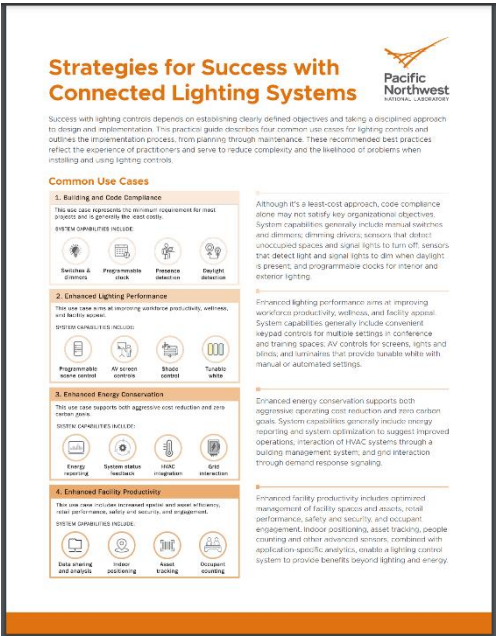
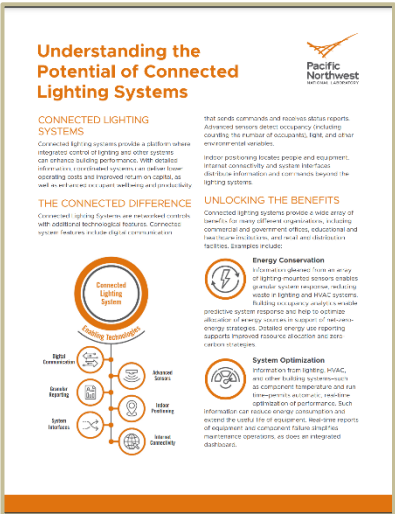
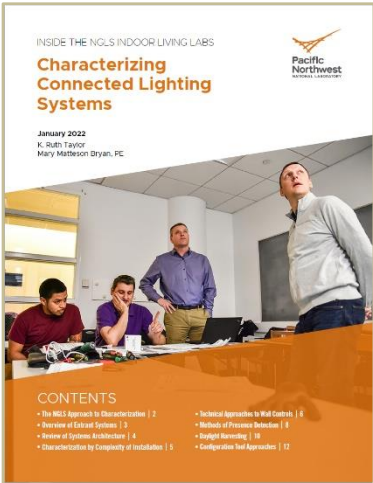
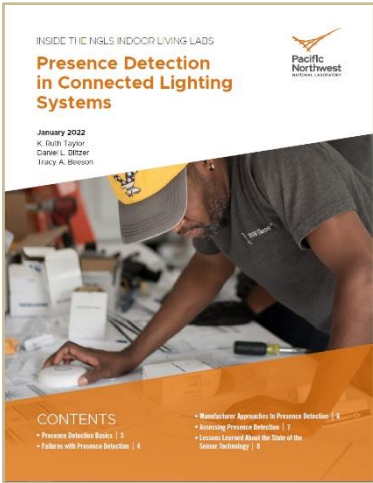
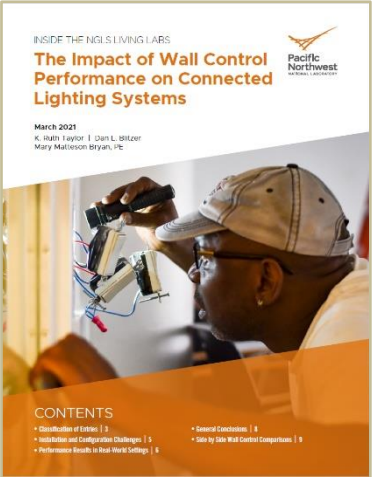
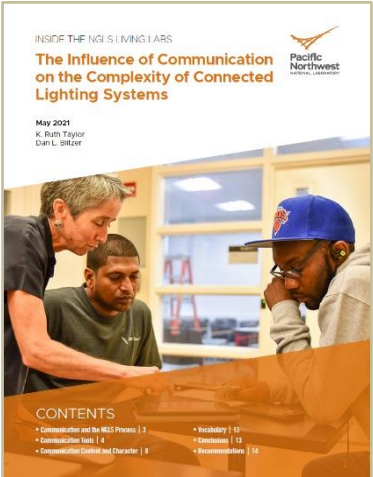
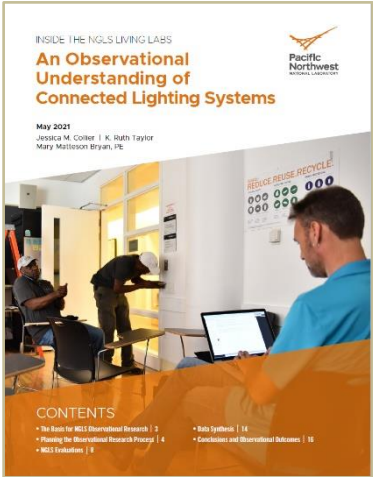
- Controls market is quite immature
- Analog 0-10V systems predominate
- Wireless systems are growing
- Luminaire-integrated controls are gaining momentum
- Energy code requirements can be a mixed blessing for controls
- Sales agencies are building stronger controls capabilities
- Controls-capable personnel are hard to find
- New systems are typically released with issues
- Problems don't stay fixed



Approach – Boiling Down the Issues to Facilitate Solutions



Progress and Future Work – Building on Living Lab Resources



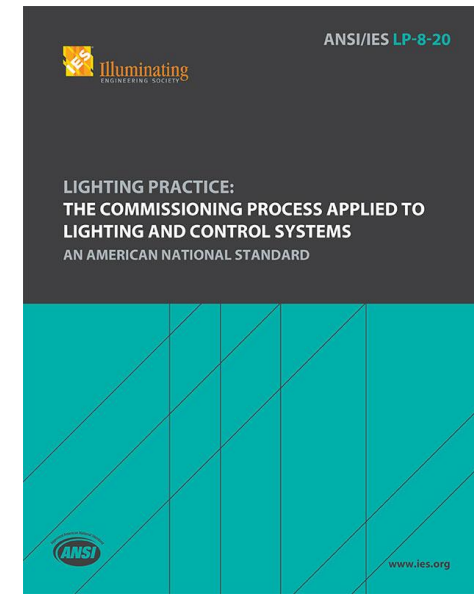
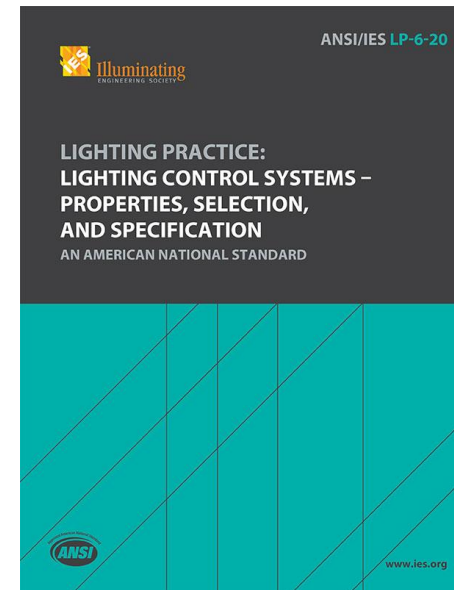
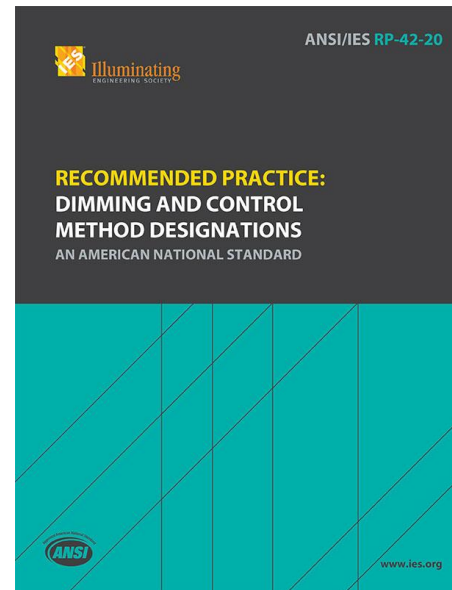
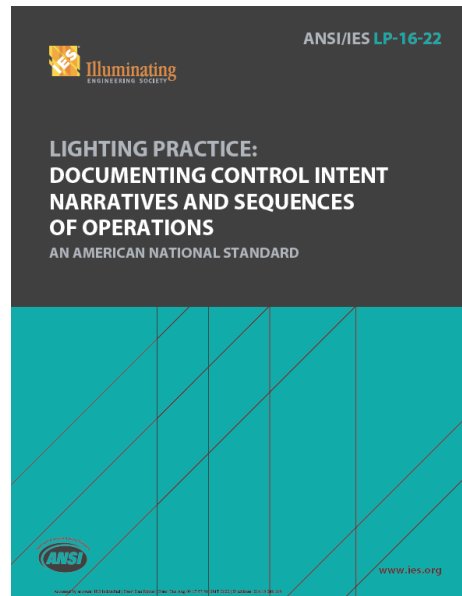
Progress and Future Work - Workforce Training Materials

- Technical schools, vocational training
- Continuing education – Trade associations, unions
- Existing lighting and controls resources
 - CALCTP California Advanced Lighting Controls Training Program (<https://www.calctp.org/>)
 - LDL Lighting Design Lab (<https://www.lightingdesignlab.com/>)
 - DLC Design Lights Consortium – Advanced Lighting Control Systems Training Program (<https://www.designlights.org/our-work/networked-lighting-controls/lighting-controls-training-programs/>)
 - LCA Lighting Controls Association (<https://lightingcontrolsassociation.org/>)



Progress and Future Work - Working with Standards Groups

- ANSI/IES LP-16-22 released
- ANSI 137.8 (user interface) working group
- ANSI 137.9 (system configuration report) working group
- LP-6 update



Thank You

Pacific Northwest National Laboratory

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3.2.1.02 PNNL - CBI: Optimizing Lighting Systems for Decarbonization, Life Cycle Sustainability, and Occupant Benefits

REFERENCE SLIDES

Project Execution | Field Research

	FY2022				FY2023				FY2024			
Planned budget	\$ 1,541,889				\$ 1,187,704							
Spent budget	\$ 1,022,116				\$ 499,122							
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Milestone: Cook County Office Report	◆											
Q2 Milestone: Boulder Comm. Health Light Exposure Journal Paper		◆										
Q3 Milestone: IMEG Office Literature Review and Pilot Study Paper			◆									
Q4 Milestone: Boulder Comm. Health Staff and Patient Outcomes Paper				◆			◆					
Current/Future Work												
Q1 Milestone: Emory University Case Study					◆							
Q2 Milestone: NEEA Office Case Study						◆						
Q3 Milestone: ETC Office + Factory Case Study							◆					
Q4 Milestone: Indian Community Schools Case Study								◆				

- Go/no-go decision points, June 30: Decision on highest impact sectors (education, healthcare, workplace) and technology features (tunable, simple controls) for energy and non-energy benefits
- FY22 Q4 Milestone: Delays due to collaborator schedule

Team | Field Research + Training Resources



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10 yrs PNNL



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BA Architecture &
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4 yrs PNNL



Corey Strachan

BA, Arch Eng
Joined PNNL 2022



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