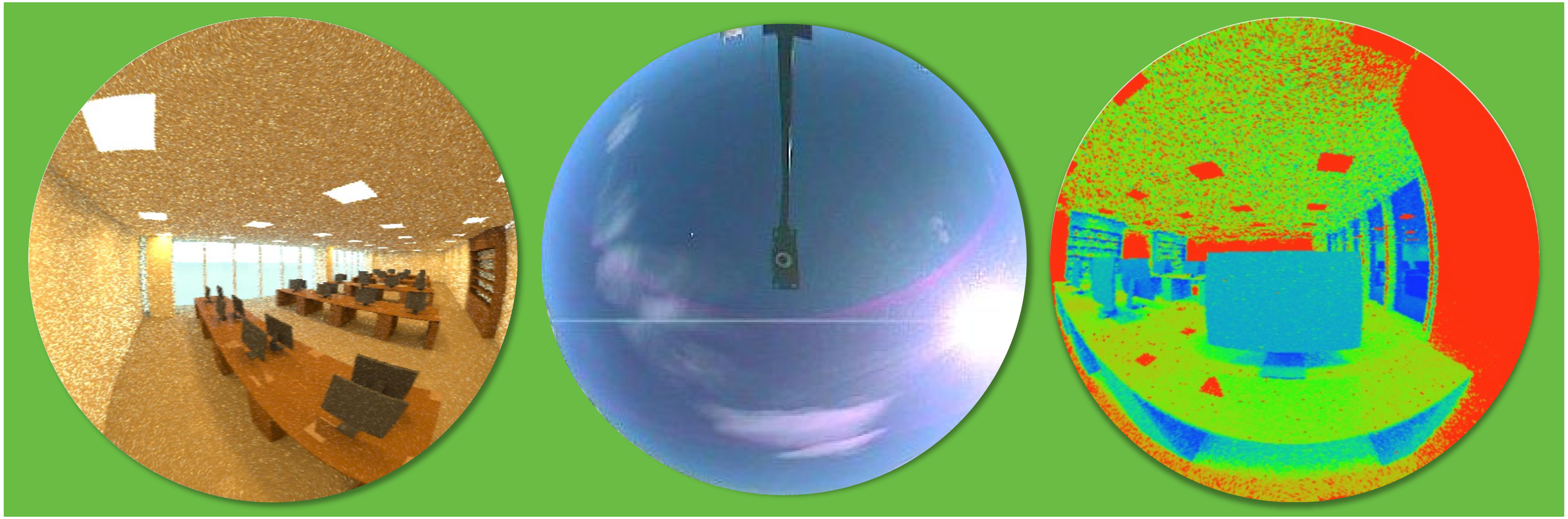
Daylight + Electric Light Integration (DELI)



Pacific Northwest National Laboratory
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Project Summary

Timeline:

Start date: Oct 2019

Planned end date: Sep 2022

Key Milestones (expected through FY21)

1. Technical report on spectral simulation sensitivity analysis.
2. Technical report on energy impacts of daylight + electric light integration.

Budget:

Total Project $ to Date:

- DOE: $710K
- Cost Share: $0

Total Project $:

- DOE: $997K
- Cost Share: $0

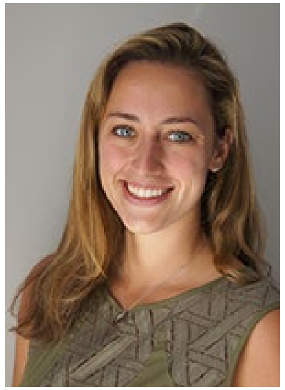
Key Partners:

Lawrence Berkeley National Laboratory
University of Washington
University of Oregon

Project Outcome:

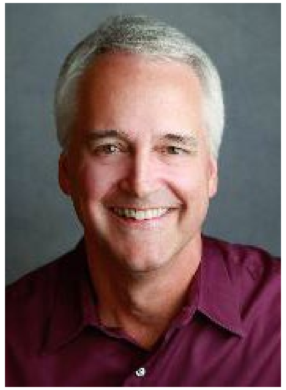
- Transform the way that daylighting and electric lighting systems are designed and implemented in buildings.
- Inform the development of spectral simulation software tools for daylight and electric lighting systems.
- Provide new lighting system design guidelines that balance circadian lighting metric recommendations with building energy savings.

Team



Sarah Safranek
Principle Investigator
PNNL – 4 yrs
MS, Arch Eng

Belal Abboushi
Technical Support
PNNL – 2 yrs
PhD, Arch



Bob Davis
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PNNL – 8 yrs
MS, Arch Eng
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30+ yrs lighting
Fellow IES

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Program Manager
MPP, Public Policy
Team Leader, Advanced Lighting
PNNL - 20 yrs

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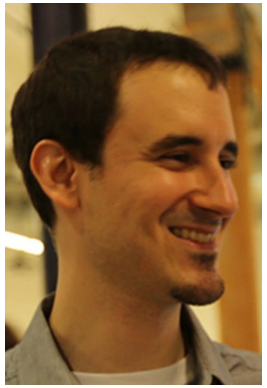
PhD, Arch

Siobhan Rockcastle
Univ. Oregon
MS, Building Technology
PhD, Arch



Alen Mahic
Univ. Oregon
MS, Arch

Challenge

Solid-State Lighting R&D Opportunities (2019); Lighting Application Efficiency topic:

- Priority: "Develop a general framework, mathematical model, and ***computer simulation approach*** to characterize lighting application efficiency for any lighting application."
- "A key pillar to Lighting Application Efficiency framework will be ability to predict light levels, light directionality, and ***spectral power distribution*** for any area in a lighted space…"
- Continued advancements and adoption of LED lighting has the potential to save 500 TWh per year by 2035 compared to conventional lighting technologies. Lighting Application Efficiency research, including tools and outcomes from this project, will help to realize these savings.

Metrics	2019 Status	Interim 2025 Targets	2035 Targets
Lighting Application Efficiency framework and model	No comprehensive framework or model	Application agnostic model that can be used to optimize total *Lighting Application Efficiency*	Ubiquitous use of *Lighting Application Efficiency* modeling for building, room, lighting layout, and product design

Challenge: Problem Definition

- Meeting existing recommendations for circadian lighting metrics (equivalent melanopic lux, circadian stimulus, melanopic equivalent daylight illuminance) will require higher light levels than what is currently recommended by Illuminating Engineering Society for visual tasks.

- **PNNL study estimates that designing to meet circadian lighting metrics with electric lighting alone may increase light levels and energy use by 10-100%.**
  - See Safranek et al., 2020, Energy Impact of Human Health and Wellness Lighting Recommendations for Office and Classroom Applications, *Energy & Buildings*

- Daylight and tunable electric lighting systems are expected to help counter this increase in energy but their impact on total building energy use needs further investigation.

- **“Research during [the last thirty years] estimated that electric lighting controls that are responsive to daylight will have the potential to save 50-80% of electric lighting systems energy.”**
  - See Thomson et al., 2021, Achieving Integrated Daylighting and Electric Lighting Systems: Current State of the Art and Needed Research, *Energies.*

Challenge

Building standards with circadian lighting recommendations:

INTERNATIONAL WELL BUILDING INSTITUTE™

COLLABORATIVE FOR HIGH PERFORMANCE CHPS SCHOOLS

UL

Lighting software tools:

Radiance

ALFA Adaptive Lighting for Alertness

AGi32 lighting software by Lighting Analysts

LARK SPECTRAL LIGHTING

Honeybee

Circadian lighting metrics:

- Equivalent melanopic lux (EML)
- Circadian stimulus (CS)
- Melanopic equivalent daylight illuminance (mEDI)

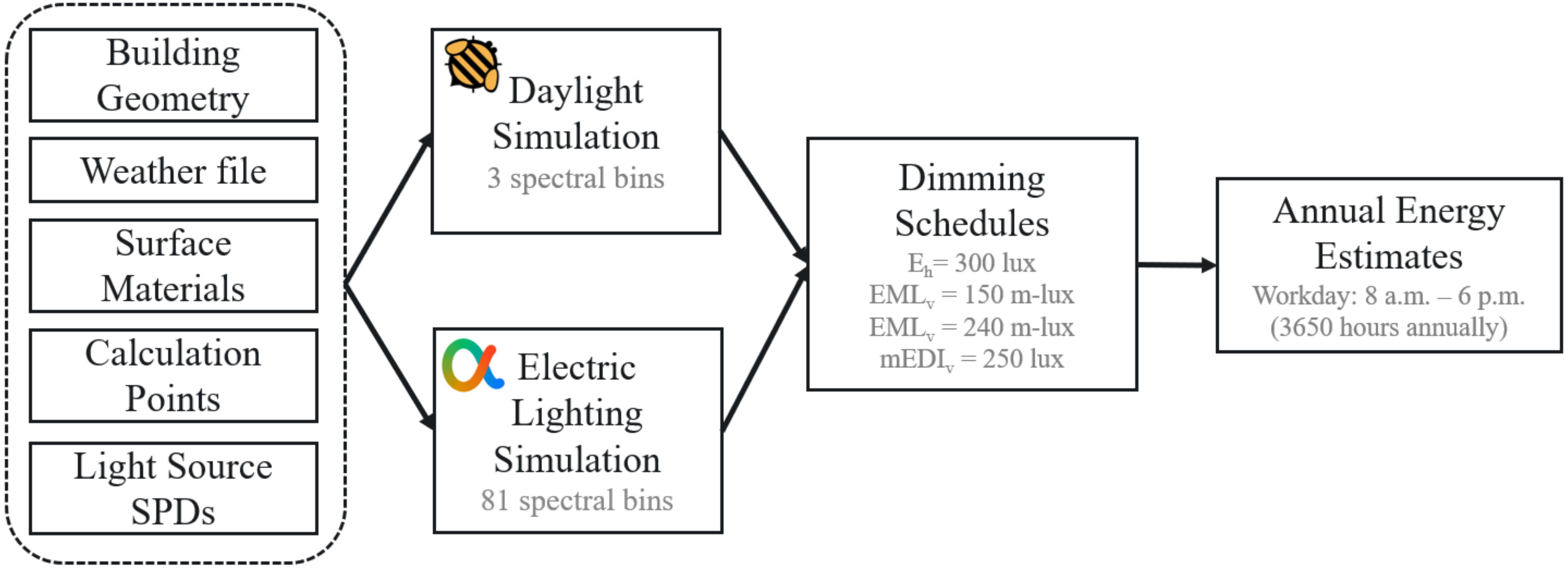
Circadian lighting metrics, recommendations, and software tools are still developing.

Availability of software tools for calculating circadian lighting metrics for daylight + electric light are currently limited and most have not been formally validated.

Approach

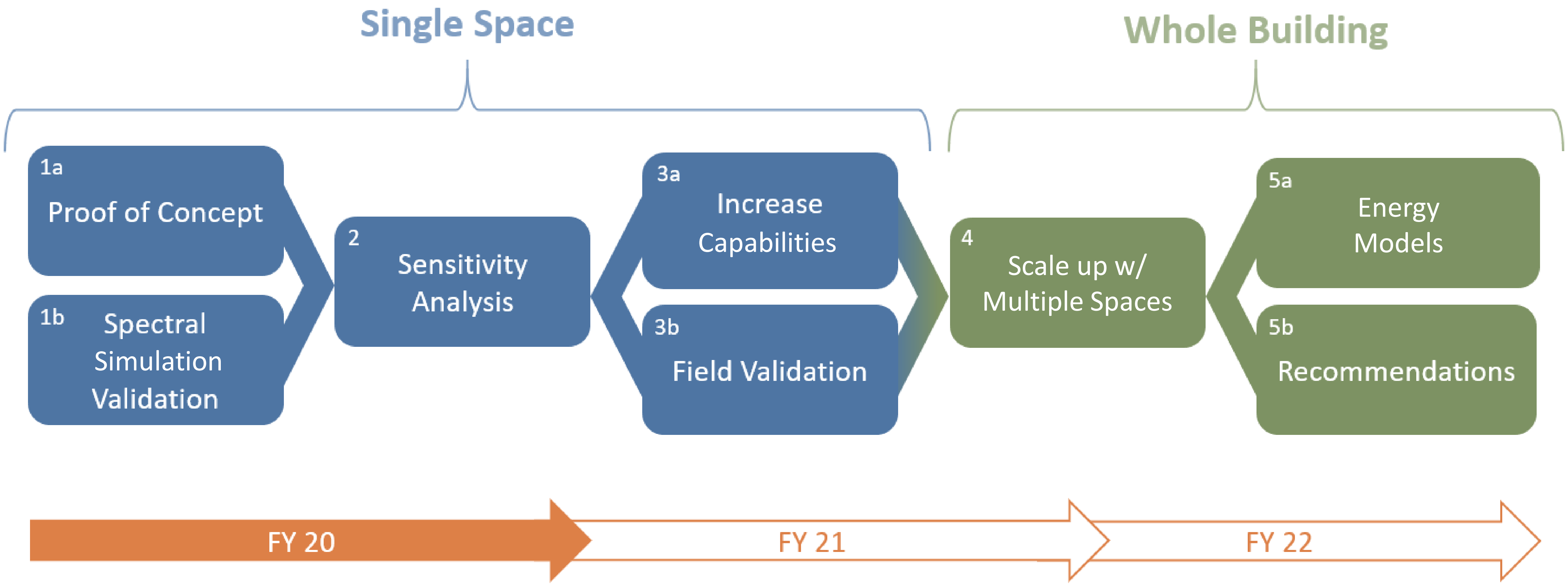
Integrating Simulations of Daylight + Electric Light

- Evaluate existing software tools for spectral simulations of daylight and electric light.
- Using existing software tools, create a workflow to simulate daylight and electric light annually.
- Generate energy estimates for designing to meet circadian lighting recommendations.



Approach

Integrating Simulations of Daylight + Electric Light



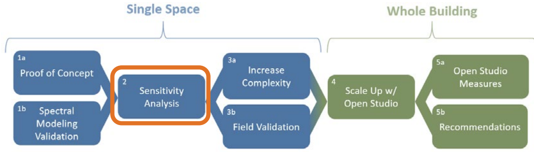
Impact

- **Quantified potential error in using existing 3-channel spectral simulation tools to represent LED spectra (19% error). Showed improved accuracy in simulating LED spectra by using 9- or 81-channels (<10% error).**
  - See Abboushi et al., "The Effect of Spectral Resolution of Light Sources on Photopic and a-opic Quantities" published in Photonics West Digital Forum Conference Proceedings Feb 2021

- **Identified deficiencies in existing sky model used in spectral simulations of daylight. Developed framework for increasing the accuracy in modeling the spectral variability of daylight.**
  - See Inanici et al., "Evaluation of Sky Spectra and Sky Models in Daylighting Simulations," submitted to Lighting Research & Technology Jul 2021

- **Created simulation workflow to integrate daylight and electric light for estimating circadian lighting metrics. Daylight dimming estimated to provide up to 44% in energy savings compared to electric lighting only scenarios.**
  - See Safranek et al., "Energy Impacts of Human Health and Wellness Recommendations with Daylight and Electric Light Integration" DOE technical report, Mar 2021, PNNL-31171

Progress : Number of Spectral Channels



GOALS:

- How do available spectral simulation tools for daylight or electric light compare for predicting circadian lighting metrics?
- How do different simulation parameters impact predicted metrics in two office models?

KEY IMPACT:

- Identified deficiencies in standard 3-channel simulation tools.
- Showed improved accuracy in simulating LED spectra by going from 3-channels (19% error) to 9- or 81-channels (<10% error).

COLLABORATORS:

BERKELEY LAB

UNIVERSITY of WASHINGTON

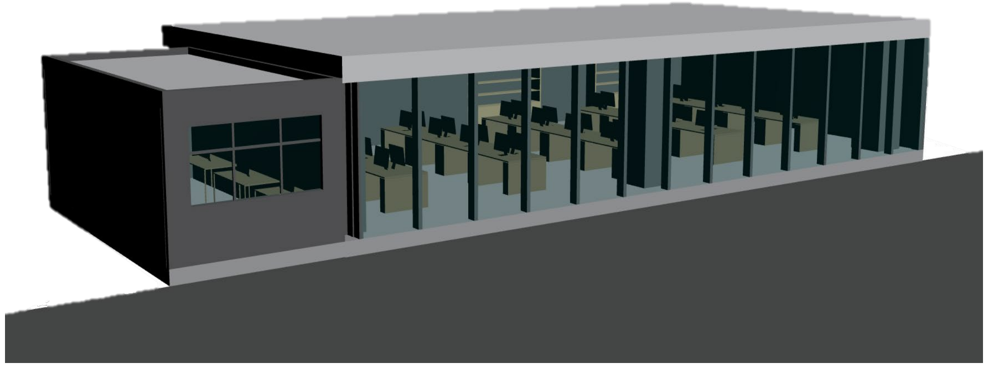
APPROACH:

Radiance

ALFA
Adaptive Lighting for Alertness

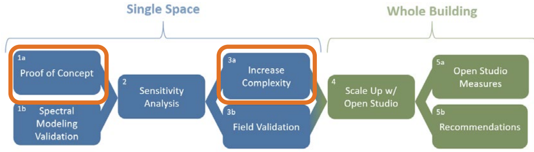
AGi32 lighting software by Lighting Analysts

LARK SPECTRAL LIGHTING



Small Office Model	**Large Office Model**
320 ft^2	2060 ft^2
6 desks	40 desks
3 luminaires	24 luminaires
45% WWR	90% WWR

Progress : DELI Simulation & Energy Estimates



GOALS:

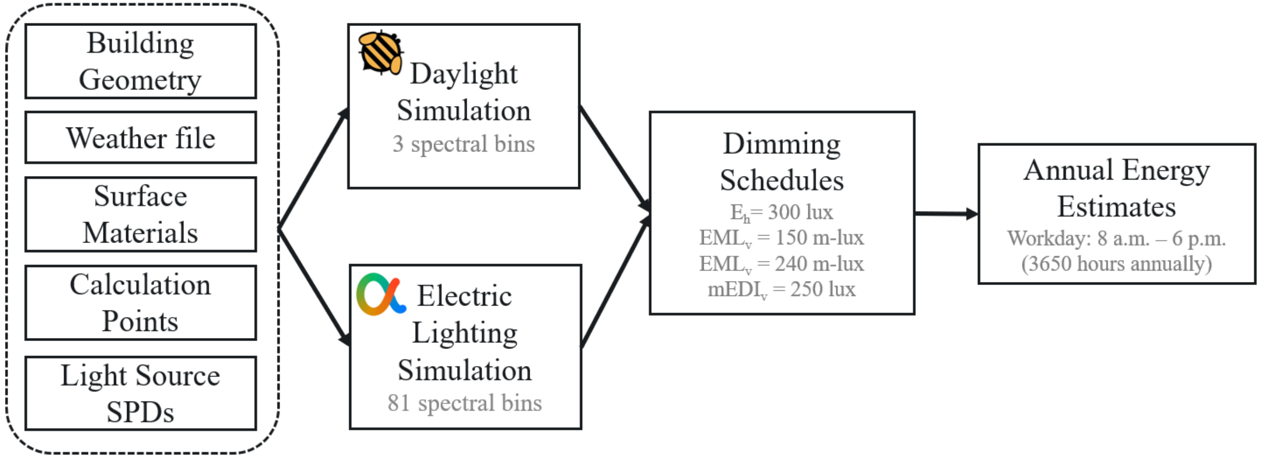
- Create workflow using existing software tools for spectral simulations of daylight and electric light to estimate the energy impacts of designing to meet circadian lighting recommendations.

KEY IMPACT:

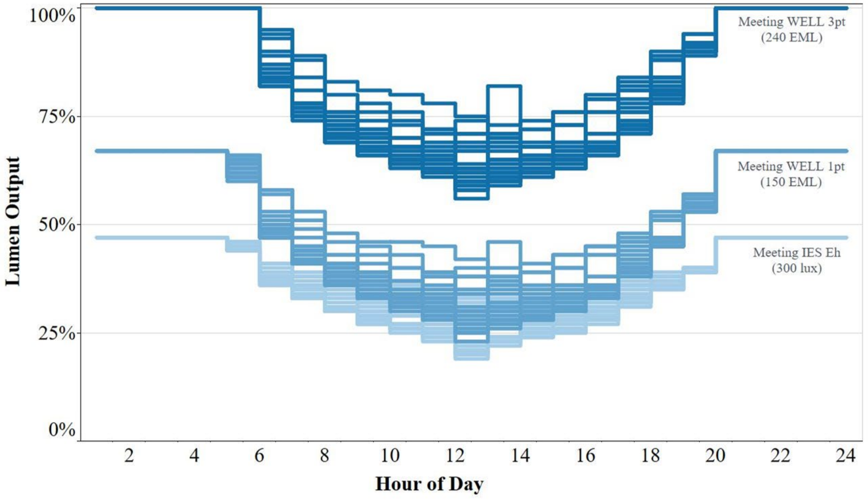
- Simulations with daylight dimming had an estimated energy savings of 44% compared to those with electric lighting only.
- Output of annual dimming schedules to be used in whole-building energy modeling software tools.

APPROACH:

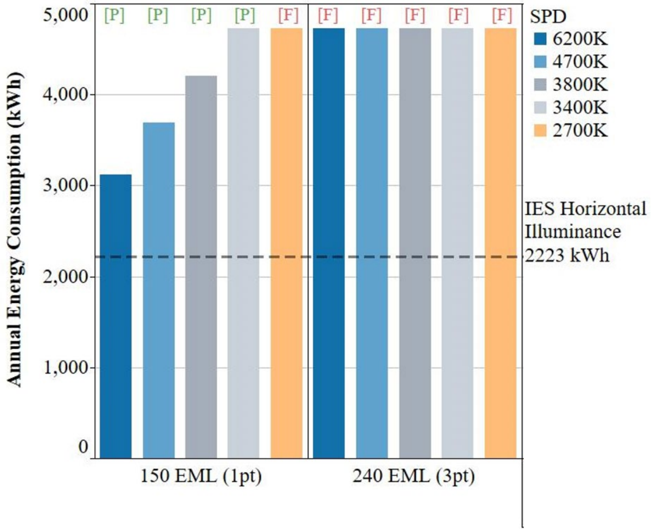
Workflow



Dimming Schedules



Annual Energy Estimates



Stakeholder Engagement

- Building systems researchers,
- Lighting designers,
- Architects,
- Building owners

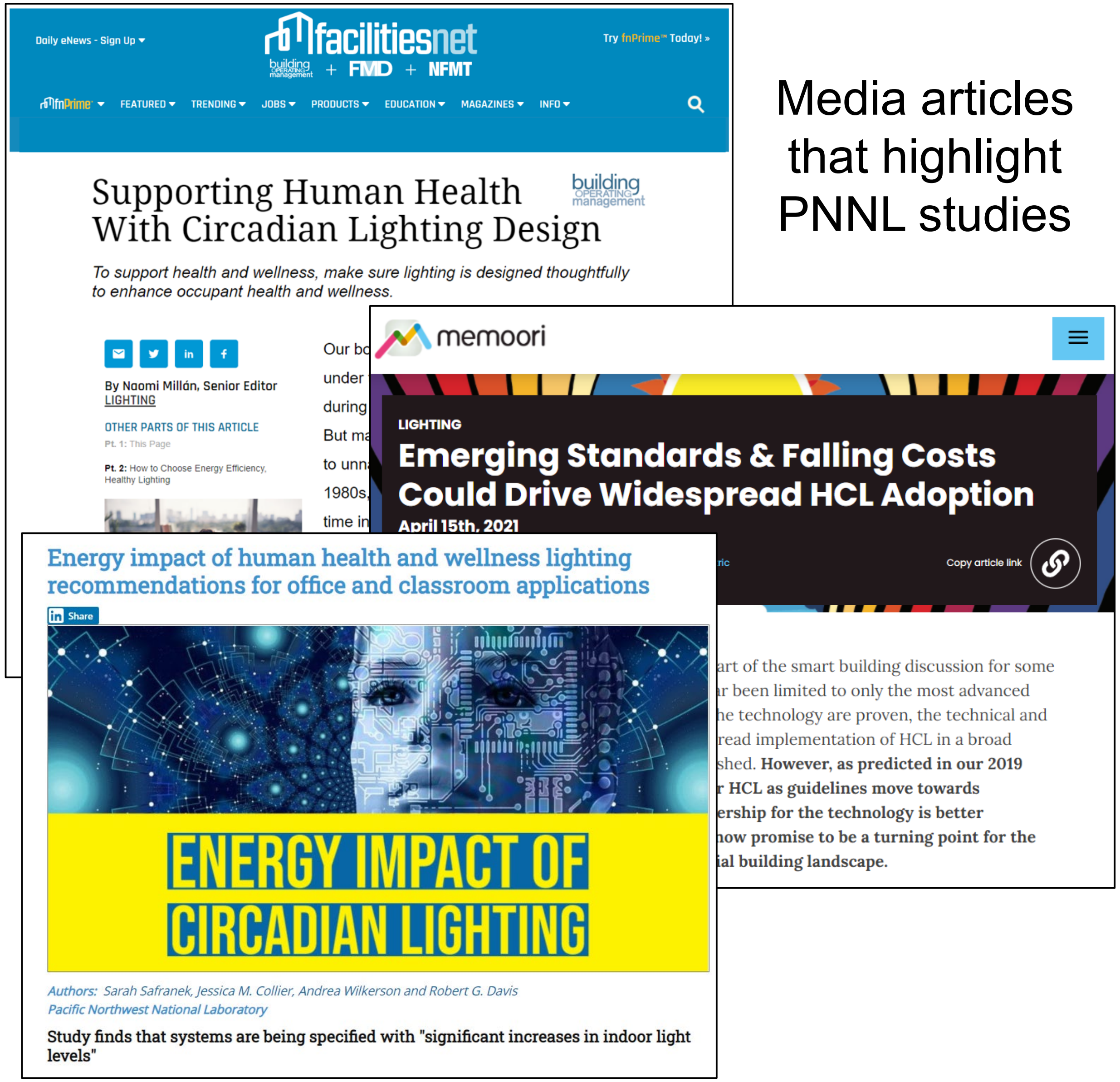
DOE Lighting R&D Workshop: Daylight + Electric Light Integration (DELI) Poster, Jan 2021

IES Webinar Series: "Meeting the Moment: Lighting and WELLNESS," Jun 2021 | 300+ attendees

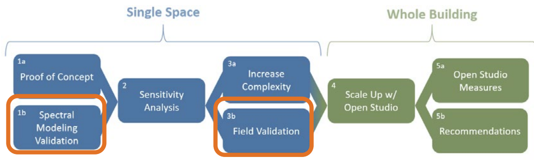
Conference presentation: "Spectral Simulations of Daylight and Electric Light in Offices," Mar 2021

Conference presentation: "From Static to Dynamic," Oct 2019 | 150+ attendees

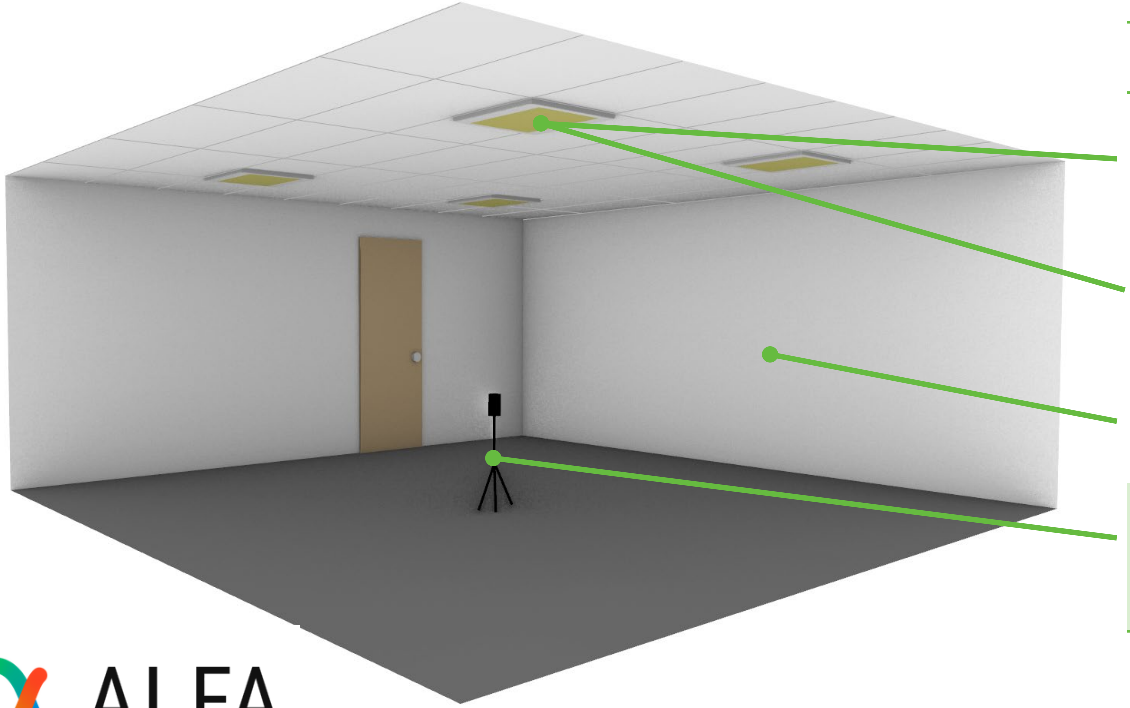
Media articles that highlight PNNL studies



Remaining Project Work



Validation studies – How do ALFA estimates of spectral irradiance compare to measurements in laboratory and field environments with LED luminaires?



Measurement	Typical	Preferred
Intensity distribution	None – Manufacturer provided	Goniophotometer
Luminaire SPD	Illum. Spectrophotometer (CL500A)	Integrating sphere
Surface SRD	None	Spectrophotometer (CM600d)
Spectral irradiance	None	Illum. spectrophotometer (CL500A)

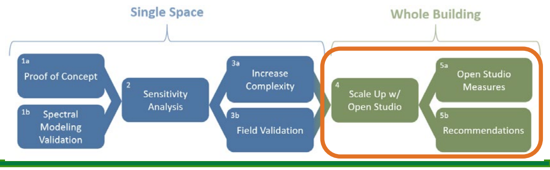
ALFA

Adaptive Lighting for Alertness

EXPECTED IMPACT:

Increased use and acceptability of spectral simulation software tools

Remaining Project Work



Include additional lighting parameters to increase accuracy of whole building energy models

In progress through FY 21

Increase capabilities of simulation workflow for a single space to include:

- Glare
- Shading
- Zonal control of electric lighting

Planned for FY 22:

- Scale-up to allow for **whole building energy simulations**
- Estimate **thermal loads** from daylight
- Provide new lighting system **design recommendations** for meeting circadian lighting metrics with consideration of energy impacts

Collaborators: UNIVERSITY OF OREGON

Thank You

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REFERENCE SLIDES

Project Budget

Project Budget: $997K
Variances: No variances; on track to original planned budget.
Cost to Date: $523K
Additional Funding: $0

Budget History					
FY 2020 (past)		FY 2021 (current)		FY 2022 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$302K	-	$400K	-	$287K	-

Project Plan and Schedule

Project Schedule
Project Start: Oct 2019
Project End: Sep 2022