Development of Lighting Application Efficacy Measurement Framework

Performing Organizations: Pennsylvania State University, University of Sydney
PI Name and Title: Alp Durmus, Assistant Professor
PI Email: alp@psu.edu
Project #: DE-EE0009690

Project Summary

Objective and outcome

To holistically capture the total efficiency of lighting in architectural spaces.

A quantified framework and tools for lighting application efficacy (LAE)

This is a first-year project.

Team and Partners

Pennsylvania State University

University of Sydney

Stats

Performance Period: 10/2021 – 09/2024

DOE budget: $361,2k, Cost Share: $90,3k

Milestone 1: Spatial efficiency spreadsheets

Milestone 2: Weighting factor calculations

Milestone 3: LAE toolbox and user manuals

Problem

Lighting consumes significant electricity in residential and commercial sectors in the U.S.

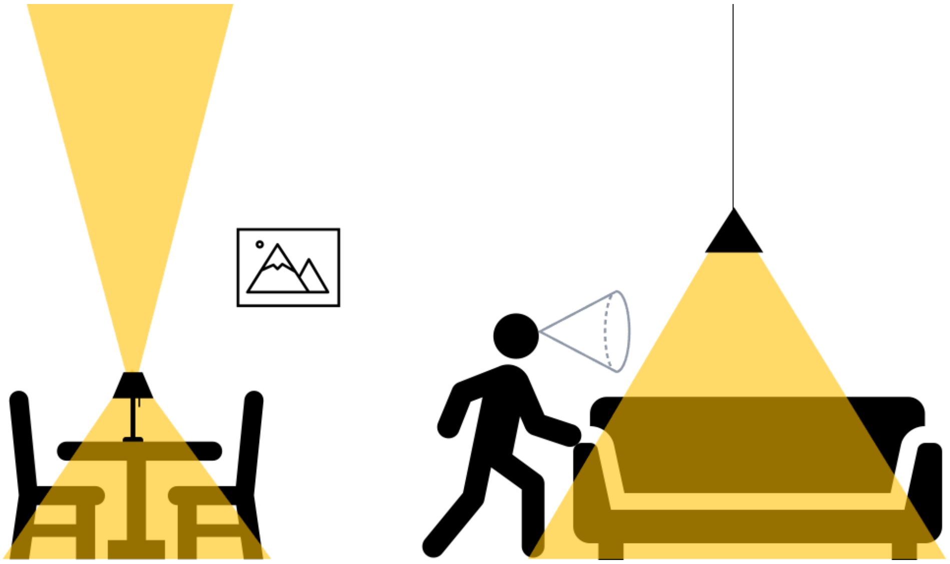
Current approaches to the energy efficiency of lighting systems are rather piecemeal, addressing individual components, such as maximized use of daylight, lighting control strategies, and optimization of the efficacy of individual light sources.

The efficiency of lighting use (e.g., light observed by occupants) is currently not characterized.

Alignment and Impact

The project focuses on developing a framework to holistically quantify the effectiveness of lighting in buildings.

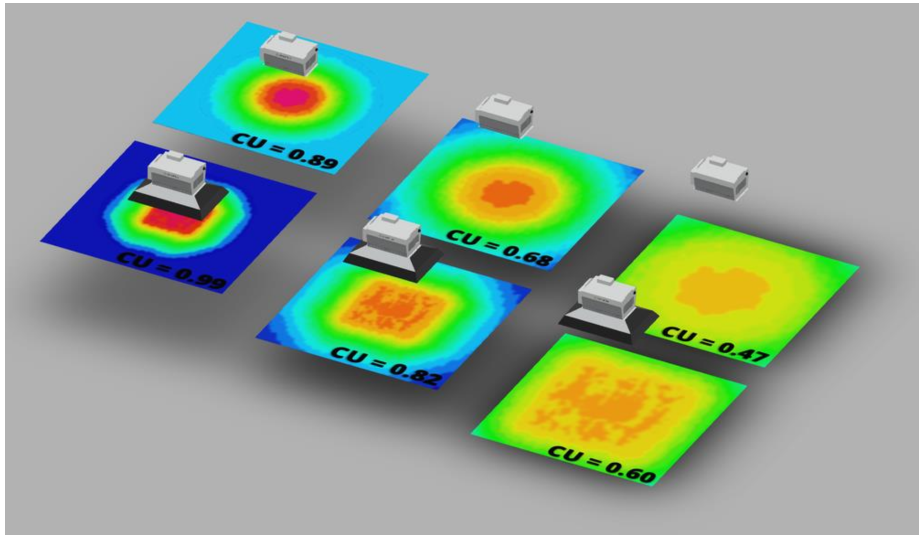
Lighting application efficacy (LAE) can capture the total efficiency of lighting in architectural spaces by considering the primary pathway of light: starting with the generation of light by the source and ending with the perception of light by the observer(s).



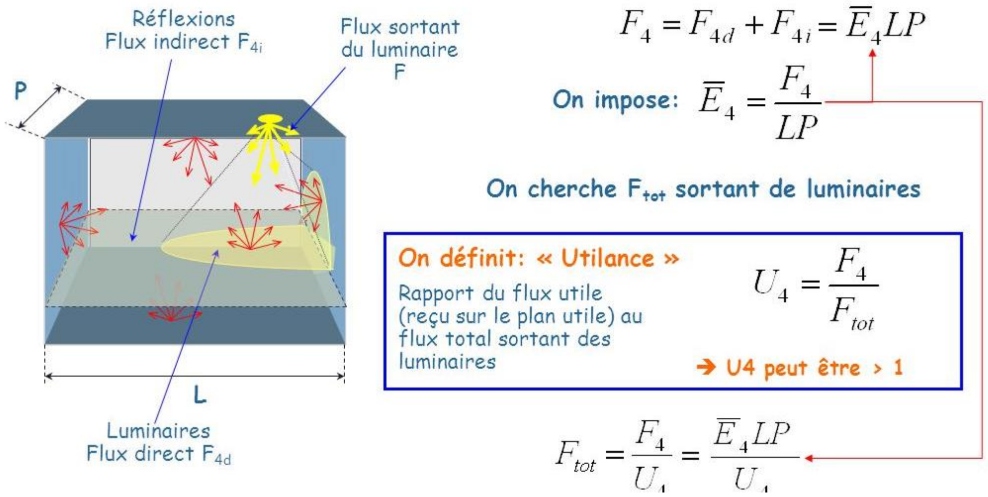
Approach

Current approach is quantifying luminous efficacy (unit: lm/W) for individual light sources.

For task plane lighting efficiency, there are luminous flux based methods, such as coefficient of utilization (CU) or utiliance (U).



https://growflux.com/blogs/posts/coefficient-of-utilization-cu-explained

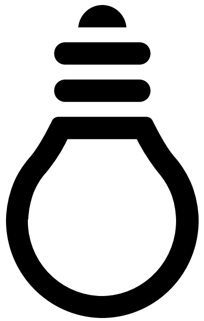


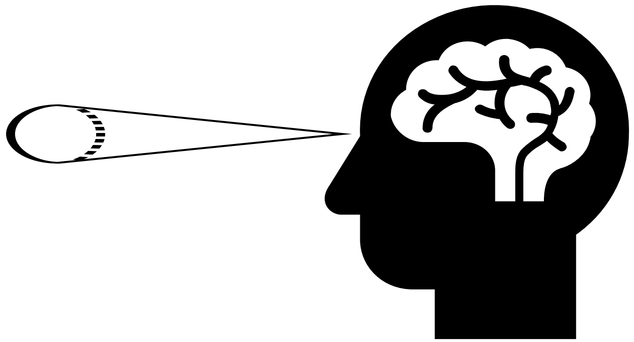
https://slideplayer.fr/slide/2580562/

Approach

Limitations of current approaches:

- Luminous efficacy only applies to individual light sources.
- Not all light emitted to a space is useful (reaches the eye).
- Photopic luminous efficiency function is based on the 2-degree visual field of view.
- Photopic luminous efficiency function is based L and M cones only (S-cone, rod, ipRGC contributions are ignored).





Approach

$$\text{LAE} = \sum_{t} \eta_{\text{luminaire}} \times \eta_{\text{spatial}} \times S_{\text{visual}}$$

Temporal | Electrical | Spatial | Spectral

Approach

$$\text{LAE} = \eta_{\text{luminaire}} \times \eta_{\text{spatial}} \times S_{\text{visual}}$$

Luminaire efficiency

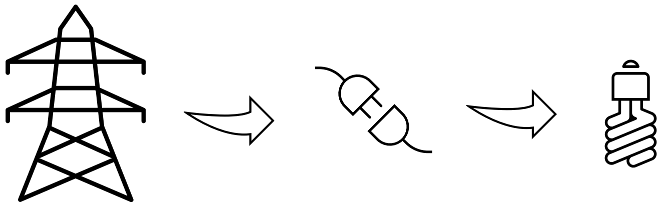
$\Phi_{\text{e,total}} / P_{\text{e}}$

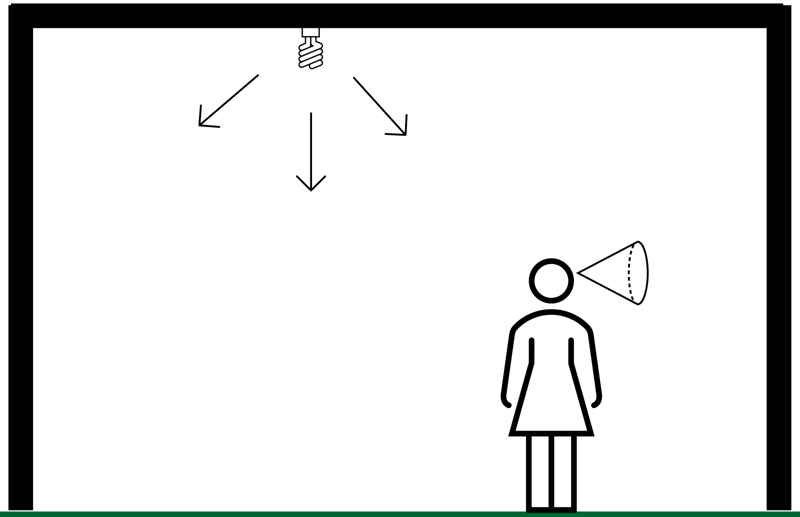
Spatial efficiency

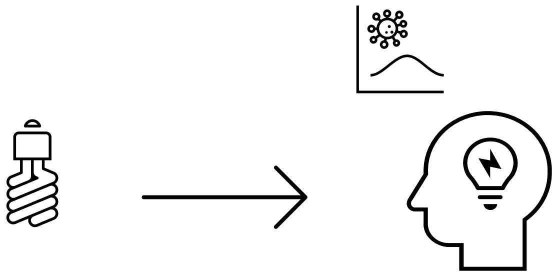
$\Phi_{\text{e,target}} / \Phi_{\text{e,total}}$

Visual sensitivity

$V_{\text{x}}(\lambda)$







Approach

	Luminaire efficiency $\eta_{luminaire}$	Spatial efficiency $\eta_{spatial}$	Visual sensitivity S_{visual}
Version 1: Near-term Low complexity	• Radiant efficiency • Light output ratio	• Proportion of emitted light directed to areas within occupants' visual fields • Proportion of emitted light directed to task area(s)	• Spectral luminous efficiency (V_λ)
Version 2: Medium-term Moderate complexity	All of the above +		
	• Efficiency changes as a function of operating time		• Effect of contrast on perceived brightness
Version 3: Long-term High complexity	All of the above +		
	• Control system efficiency • Efficiency changes from altered conditions (e.g., temperature)	• Spatially dynamic lighting (e.g., gaze-dependent lighting)	• State of visual adaptation • Occupant age • Sensitivity as a function of location within visual field

Year 1 scope

Existing knowledge
Proposed research
Future and other research

Approach

Challenges:

- Designers could negatively react to overprescribed methods of efficiency.
- Computational methods may require coding skills.
- The LAE may need to capture even finer details.

Mitigation:

- Constant communication with stakeholders
- A user-friendly calculator for early use
- Other researchers hopefully joining the effort to improve the framework.

Progress and Future Work

Accomplishments

Spatial efficiency

Work plane

Precise: Manuals Radiance ALFA

Approximate: Toolbox

Visual field angles

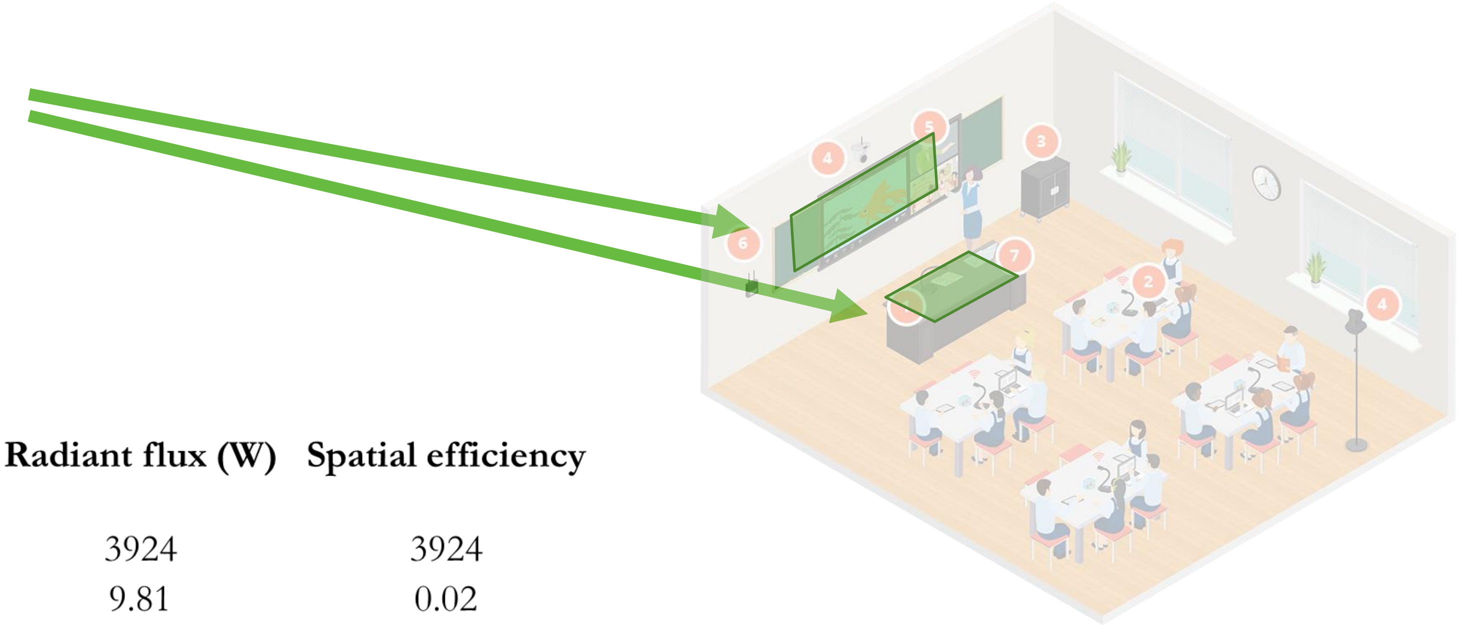
Precise: Manuals Radiance ALFA

Approximate: Toolbox

Progress and Future Work

Accomplishments: spatial efficiency for work plane

$$\eta_{\text{spatial}} = \frac{\phi_{e,target}}{\phi_{e,total}}$$



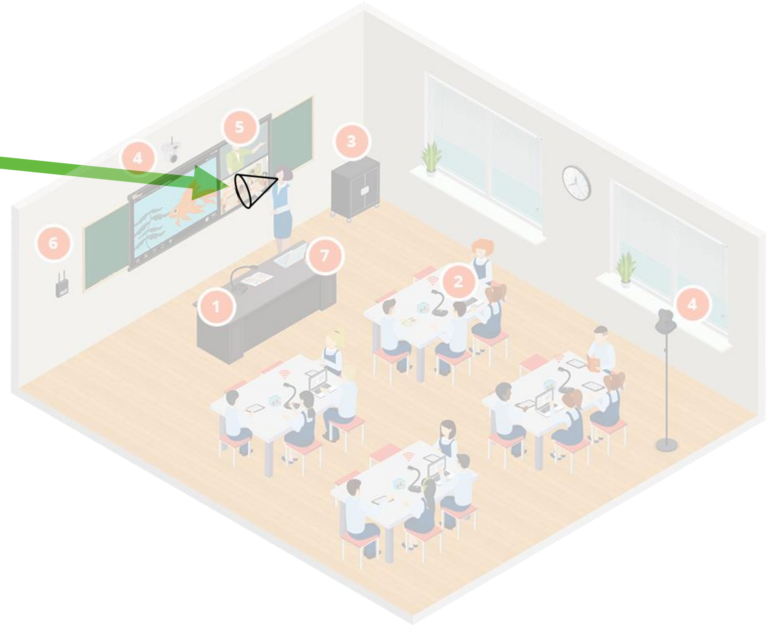
https://www.aver.com/solution/classroom-technology

	Room area (m^2)	Area per luminaire (m^2)	Radiant flux (W)	Spatial efficiency
N	3924	3924	3924	3924
Mean	326.25	4.50	9.81	0.02
SD	137.75	1.86	5.48	0.04
Median	400.00	4.35	8.56	0.01
Min	12.25	2.51	0.80	0.00
Max	400.00	12.25	26.20	0.42
Range	387.75	9.74	25.40	0.41
SE	2.20	0.03	0.09	0.00

Progress and Future Work

Accomplishments: spatial efficiency for field of view

$$\eta_{\text{spatial}} = \frac{\phi_{e,target}}{\phi_{e,total}}$$



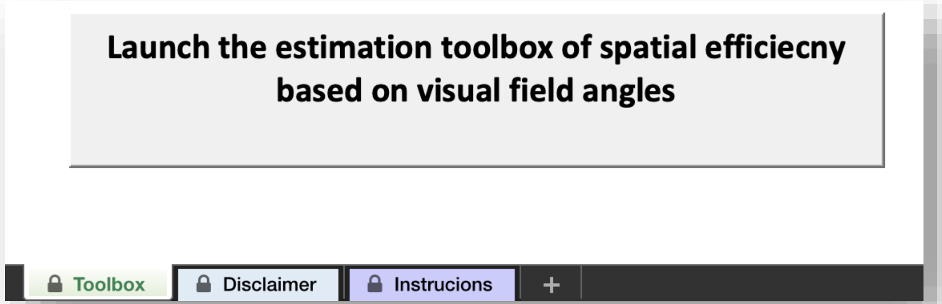
https://www.aver.com/solution/classroom-technology

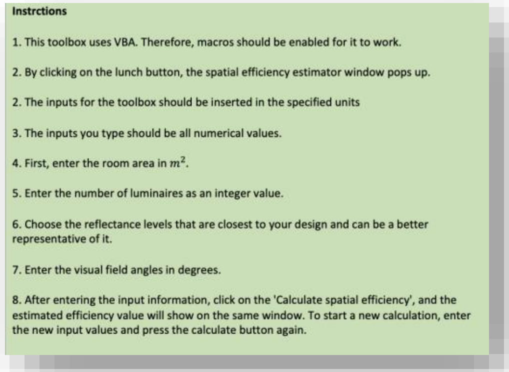
	Room area (m^2)	Area per luminaire (m^2)	Visual field angle (degrees)	Radiant flux (W)	Spatial efficiency
N	1944	1944	1944	1944	1944
Mean	67.08	4.57	93.33	3.17	0.03
SD	32.95	2.42	53.14	4.12	0.05
Median	9.25	4.35	90.00	1.49	0.01
Min	12.25	2.51	30.00	0.01	0.00
Max	90.25	12.25	160.00	22.67	0.51
Range	78.00	9.74	130.00	22.66	0.51
SE	0.75	0.05	1.21	0.09	0.00

Progress and Future Work

Milestones:

- Technical report summarizing the first-year work and finances
- User manuals for Radiance and ALFA
- Spreadsheet toolbox for spatial efficiency in work plane and field of view





Instrctions

1. This toolbox uses VBA. Therefore, macros should be enabled for it to work.

2. By clicking on the lunch button, the spatial efficiency estimator window pops up.

2. The inputs for the toolbox should be inserted in the specified units

3. The inputs you type should be all numerical values.

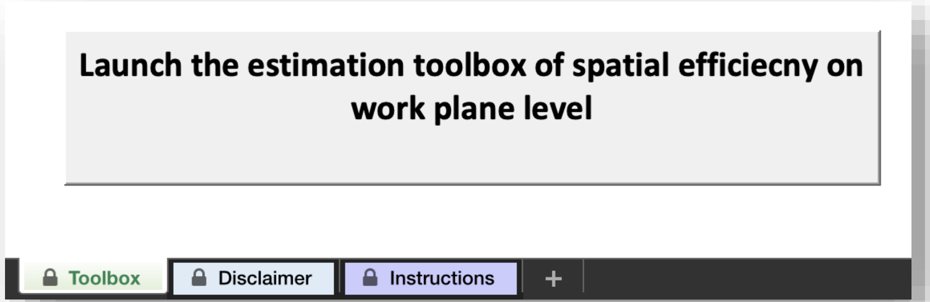
4. First, enter the room area in m^2.

5. Enter the number of luminaires as an integer value.

6. Choose the reflectance levels that are closest to your design and can be a better representative of it.

7. Enter the visual field angles in degrees.

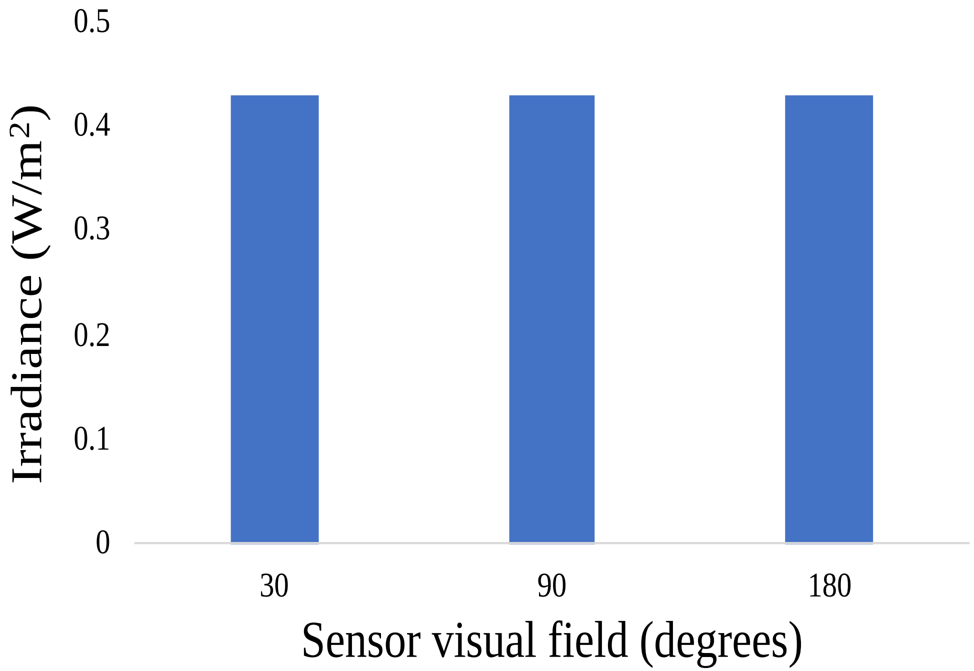
8. After entering the input information, click on the 'Calculate spatial efficiency', and the estimated efficiency value will show on the same window. To start a new calculation, enter the new input values and press the calculate button again.

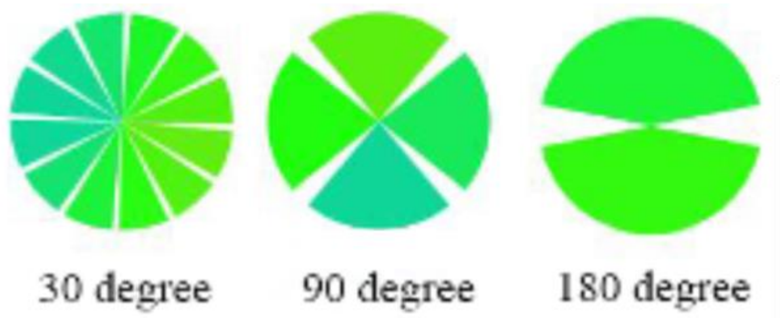


Progress and Future Work

Challenges and lessons learned:

- Direct lighting can and should be quantified to account for negative effects (e.g., glare).
- Sensor field of view in ALFA is not adjustable.





Progress and Future Work

Future plans:

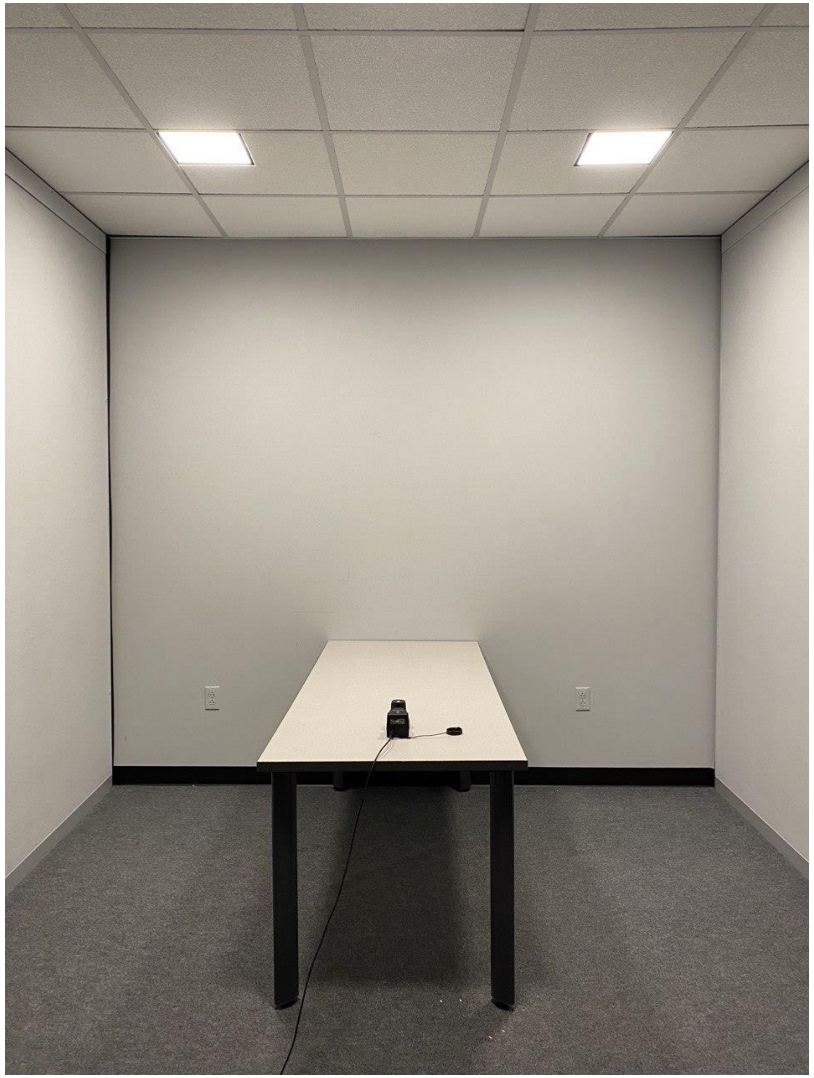
- Disseminate the outcomes of the project and collect feedback from the lighting community
- Year 2 will look into the effect of contrast on visual sensitivity.
- Beyond the end of this project: incorporate other considerations into LAE, improve user friendliness, software adoption by developers.

IES Illuminating ENGINEERING SOCIETY

INTERNATIONAL ASSOCIATION OF LIGHTING DESIGNERS | IALD

LEDucation

cie International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission



Thank You

Pennsylvania State University, University of Sydney

Alp Durmus, Assistant Professor

alp@psu.edu

DE-EE0009690

REFERENCE SLIDES

Project Execution

	Year 1				Year 2				Year 3			
Activity	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Task 1.0	■				■				■			
Task 2.0	■	■	■	■								
Subtask 2.1	■	■										
Subtask 2.2	■	■										
Subtask 2.3			■									
Subtask 2.4			■	■								
Subtask 2.5				■								
Subtask 2.6			■									
Subtask 2.7				■								
Milestone 1				■								
Go/No-Go Decision 1				■								
Task 3.0					■	■	■	■				
Subtask 3.1					■	■						
Subtask 3.2					■	■						
Subtask 3.3							■	■				
Subtask 3.4							■	■				
Subtask 3.5								■				
Milestone 2								■				
Go/No-Go Decision 2								■				
Task 4.0									■	■	■	■
Subtask 4.1									■	■		
Subtask 4.2									■	■		
Subtask 4.3											■	■
Subtask 4.4											■	■
Milestone 3												■
Outreach				■	■	■	■	■	■	■	■	■

3-month no cost extension

- Delays: due to background clearance, staff job change, complexities of Radiance FOV calculations.

Team

PI: Dr. Alp Durmus
Assistant Professor, Penn State University

Co-PI: Dr. Wendy Davis
Honorary Associate Professor, University of Sydney, Australia

Co-PI: Dr. Wenye Hu
Associate Lecturer, University of Sydney, Australia

Graduate students: Wangyang Song, Yuwei Wang

Undergraduate student: George Zhu