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Solid-State Lighting Program:

Lighting Application Efficiency R&D Meeting

August 2022

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Disclaimer

DOE Solid-State Lighting Program, "Lighting Application Efficiency R&D Meeting," August 2022.

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Comments

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R&D Meeting Participants

Kyung Lee	Guidehouse
Wendy Davis	University of Sydney
Wouter Soer	Lumileds
Bob Karlicek	Rensselaer Polytechnic Institute (RPI)
Alp Durmus	Pennsylvania State University
Belal Abboushi	Pacific Northwest National Laboratory
Siobhan Rockcastle	University of Oregon
Bruce Cherniak	Intel
David Demarle	Intel
Timothy Logan	HKS

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1 Introduction

On August 31, 2022, ten subject matter experts from industry, national laboratories, and universities gathered at the invitation of the Department of Energy (DOE) Solid-State Lighting (SSL) Program to help identify critical research and development (R&D) topic areas in lighting application efficiency (LAE). The guidance provided by stakeholders in these various forums helps identify critical R&D areas that may be incorporated into DOE's technical roadmaps and R&D funding opportunities.

This year the meeting was held virtually. The meeting commenced with "soapbox" presentations, in which each participant gave a short presentation describing what they believed to be the key R&D challenges for LAE over the next three to five years. This was followed by a general discussion of the critical challenges hindering LAE advances today. This report summarizes the outcome of the discussions on critical challenges and identifies corresponding R&D tasks within the existing task structure. Outlines of the participants' soapbox presentations and related remarks are included in Appendix A: Participant Presentations of the report.

2 Key Findings

The meeting format encouraged each of the attendees to present their perspectives on critical R&D challenges for LAE. In the discussions that followed the soapbox presentations, several topics arose that could lead to significant breakthroughs in technology development and implementation:

- LAE implications for human perception of lighting
- Daylight/Electric light integration
- Modeling, guidance, and simplification
- Pilot and Case studies to understand real world effects

2.1 LAE Implications for Human Perception of Lighting

The lighting application efficiency framework requires that lighting is targeted, spectrally optimized, and has appropriate light levels, all with respect to the needs at a specific time. Following this guidance will result in changes to the perceived lighting conditions because there is more light on the target but less away from the target, light colors will be shifted, and there will be dynamism in the lighting system overall. However, these subsequent changes to perception of the lighting system raise concerns about how fast lighting scenes should adapt as occupancy, activities, locations, postures change within a space. In natural lighting circumstances, there is a diel pattern in lighting conditions and more rapid changes due to weather or as a result of human movement. The variability of natural lighting conditions introduces fundamental questions about how quickly lighting should change in indoor settings for LAE and for occupant wellbeing. In addition to longer scale temporal effects, there are questions about the perception of more irregular lighting conditions with uneven light levels and what the acceptability thresholds will be in these situations.

2.2 Daylight/Electric Light Integration

Daylight is a predictable contributor to the lighting setting. However, glare and light level contributions need to be managed and will change throughout the day and year and with weather conditions. Electric lighting can be controlled to be responsive to daylight contributions not just with basic light levels but also with glare-light level trade-offs. While models have shown that daylighting is cost effective for providing light levels that support well-being compared to basic electric lighting, building designs need to be optimized to deliver the daylight with minimized glare and some level of electric light will always be required. In most buildings, daylight only reaches a portion of the occupants and daylight is typically considered to be a high value factor for the location within a building.

2.3 Modeling, Guidance, and Simplification

The framework of lighting application efficiency is enabled by lighting technology advancements, requires guidance for lighting deployers, and maintains the opportunity for lighting design. Lighting modeling tools provide a means to predict the lighting conditions but with the lighting dynamism suggested with LAE, existing models quickly become intractable since each lighting setting effectively requires an additional luminaire within the lighting model. The almost infinite potential lighting configurations and controllability of luminaires needs to be simplified and managed so that clear lighting deployment guidance can be provided to achieve the benefits of LAE. This could conceivably be achieved by using predictive models to provide optimal configurations for a space to achieve desired LAE outcomes, but this inverts the typical predictive lighting model where lighting functions are predetermined to achieve a static and uniform lighting condition. With LAE, more granular lighting targets are based on occupancy, room conditions, gaze, posture, and other factors that can drive the optimal lighting layout, optical distribution, spectral power distribution, and light output from luminaires; and LED technology has the flexibility to provide more precise performance levels. However, models with optimized lighting product performances and layouts as outputs require lighting targets, room conditions, room layouts, expected occupancy levels, and expected activities as inputs. All of these factors can be known and anticipated, but a more advanced lighting design process is necessary. In general, the lighting modeling tools and processes lag in capturing the precision and dynamism offered by LED lighting technology and simplified, practical guidance needs to be provided for those who would like to achieve the benefits of LAE.

2.4 Pilot and Case Studies

LAE has the clear potential to save energy, but this needs to be clearly demonstrated with case studies. Case studies can document the energy savings and serve to identify unanticipated downsides or complications with the framework and inform guidance. Case studies can also assist in determining benefits beyond energy savings, such as lighting conditions that promote health and wellbeing, safer lighting with reduced glare and improved visibility, reduced excess light and light trespass, and streamlined lighting product supply chains as luminaires can be configured to the specific setting. The LAE framework is cross-disciplinary, requiring lighting technology development, predictive modeling of light levels and layouts, research to determine and quantify the benefits and minimize side effects, and development of guidance to deploy LAE concepts at scale. These disciplines will benefit from real world feedback from LAE focused installations.

Appendix A: Participant Presentations

Kyung Lee, Guidehouse: LAE Potential Energy Savings

Kyung Lee, consultant at Guidehouse Inc., discussed recent DOE analyses that aimed to look at the potential energy savings from viewing lighting application efficiency. Most of the focus of energy savings in lighting have been traditionally focused on light source efficiency, measured in lumens per watt. To calculate how the LAE framework can provide additional savings, three representative lighting product markets were analyzed: linear fixtures, high/low bays, and outdoor area lighting. These three markets consume an estimated energy consumption of 324 TWh per year. Within these three markets, if all installed lighting in the U.S. were converted to "state-of-the-art" LEDs (95th percentile light source efficacy), the energy consumption would be reduced by 50% to 162 TWh per year. Primary studies have indicated that energy savings of 30-60% in optical deliver efficiency, 2-15% in spectral efficiency, and 35-49% in intensity effectiveness are theoretically possible. Lee calculated that a conservative use of these possible energy savings from LAE could yield an additional 85 TWh of energy savings beyond just source efficacy, indicating that a large opportunity for energy savings exists within the LAE framework that warrants further research and development to maximize energy savings while improving the quality of light delivered to end users.

Wendy Davis, University of Sydney: Spatial Efficiency: Static vs Dynamic Lighting

Wendy Davis, former professor at the University of Sydney, began the presentations by outlining what she sees as the major components of LAE: luminaire efficiency, spatial efficiency, and visual sensitivity. Luminaire efficiency denotes the efficiency of the fixture, or the ratio of power emitted by the fixture as light to the total electric power supplied to the fixture. Spatial efficiency refers to the ratio of the amount of light that enters occupants' eyes to the total light emitted. Finally, visual sensitivity has to do with the eye of the observer and the useful portion of the spectrum. After defining these concepts, Davis moved on to describe some key research questions in each component in the short-, medium-, and long-term. She argued that breaking LAE into components makes it easier to identify and understand the complexity of key research areas. Next, Davis described research done by her and Alp Durmus, which showed that increasing the density of light in a room could raise spatial efficiency. The goal of the research is to identify key aspects of a lighting design plan and develop methods for designers to calculate them. Finally, Davis also specifically suggested "understanding the perceptual consequences of temporal changes in lighting" as a topic for research.

Belal Abboushi, PNNL: Daylight and Electric Lighting Integration (DELI)

Belal Abboushi, researcher at PNNL, described his work aimed at developing a commercially available software tool for accurate simulation of electric light and daylight. The tool would also enable consideration of light source spectrum in simulations. The project was broken up into four main tasks: development of software for daylight and electric light simulations, validation of the software through real world testing, commercialization of the software, and market education. The project began in January of 2022, and some of the programming and laboratory validation is already complete. Abboushi moved on to discussing the findings of a paper recently published by his colleagues at PNNL. They found that designing lighting to meet circadian lighting metrics requires 15-100% more lighting energy consumption. Finally, Abboushi proposed future research topics in lighting. He suggested research into view dependent lighting distribution, using zoning and controls to balance energy use with occupant needs, and field research into the energy impact of meeting health recommendations for lighting. He also pointed out the need to recommend lighting retrofits that will both meet occupants' health needs and save energy.

Bob Karlicek, RPI: Opportunities in Lighting Science and Lighting Application Efficiency

Bob Karlicek, professor at RPI, discussed the goals of LAE measures and provided an update on his ongoing digital lighting project with Lumileds and HKS. Karlicek argued that the ultimate goal of digital lighting is to provide "the right light where and when you need it." He said that the industry and science is rapidly approaching the point at which they can fully deliver on that promise. His work with Lumileds and HKS aims to create a lighting system that can fully adapt to occupants' needs using autonomous control. Achieving this goal would mean that the system could perform the job of a lighting designer by itself, on the fly. However, there are many challenges and technical hurdles that hinder the implementation of this lighting system. It requires steerable beams, advanced sensing, and complex VR rendered simulations. Based on his work thus far using a steerable lighting fixture and motion sensors for occupants, Karlicek projects energy savings of about 74% using beam steering. He mentioned that the biggest challenge is in sensing and control. Karlicek believes the path to progress in LAE is through integration of building information modeling, VR, and precision occupancy sensing.

Tim Logan, HKS: Sculpt

Tim Logan of HKS described the modeling efforts as part of the DOE funded R&D led by Rensselaer Polytechnic Institute. The subject of the R&D project aims to improve the functionality capabilities of luminaires to enable improved lighting application efficiency. The new functionality is beam steering and spectral power distribution control in fixtures. Compared to static light sources, these functionalities require much more advanced lighting design and modeling capabilities to enable prediction of light levels from the wide range of possible beam positions as well as consideration of spectral power distribution.

Wouter Soer, Lumileds: Application Efficiency Benefits of Digital Light Sources

Wouter Soer, product development director at Lumileds, presented on the benefits of digital light sources from an LAE perspective. Soer began by defining a digital light source, describing it as an array of digitally addressable pixels. This allows the system to send light only where it's needed, creating the "ultimate delivery efficiency" according to Soer. The technology has many applications, from automotives to retail displays to adaptive lighting. Adaptive lighting is the focus of the project Bob Karlicek had previously mentioned, which he works on in conjunction with Lumileds and HKS. As part of that project, Lumileds has developed a working prototype of a digital troffer fixture. Each "LED" in the troffer is actually a 7x7 grid of segmented LEDs, each of which can be individually controlled. This allows one light source to create many different lighting patterns. Soer says that prior research indicates that this configuration can achieve energy savings of 67%. He also noted that the technology has many additional benefits outside of energy savings, including reduced glare, reduced light pollution, and better dosage of circadian stimuli. Soer stated that further research must be done to address sensor integration, source efficiency penalties from digital light sources, and digital and dynamic lighting design. He concluded by saying that pilot studies that demonstrate the technology to users and lighting designers can help educate the market and corroborate benefits.

Siobhan Rockcastle, University of Oregon: Energy Efficient Lighting and Window Shading Controls to Support Occupant Health

Siobhan Rockcastle, professor at the University of Oregon, presented results from her study comparing the health impacts of daylight versus electric lighting. Rockcastle first outlined the difference between visual comfort and the non-visual benefits of light, which include entraining circadian rhythms. She then pointed out that while shading systems can benefit building occupants by reducing the cooling load and minimizing glare, they can also negatively impact circadian health. Rockcastle designed a simulation to compare the health impacts of daylight to those of electric lighting. She set up a 3D rendered model of a computer lab with windows on one wall and used weather data to determine the daylight reaching occupants during the test period. Radiance, a lighting simulation toolkit, was used to determine how much shading would be needed to prevent glare and how much lighting energy would be needed to supplement daylight due to shading. Rockcastle then determined what portion of timestamps had light levels that achieved the WELL health standard for Equivalent Melanopic Lux in both the shaded and unshaded scenarios. She found that a system without shading met the standard more often and used less energy for electric lighting than one with shading. She also concluded that ceiling-mounted electric lighting systems are not energy-optimal for achieving circadian health benefits, and that simulations like the ones she ran can elucidate complex relationships. Rockcastle suggested simulating electric lighting and automated shading by zone in future studies.

David Demarle, Intel: Powering Scientific Visualization and Photorealistic 3D Design

David Demarle, software engineer at Intel, informed the group about the Intel oneAPI Rendering Toolkit, which can be used for photorealistic lighting simulations. The Toolkit is a family of libraries for rendering that is open source, highly optimized, and includes low level libraries. It has been used to create animations and scenes for movies, scientific visualization, design and architecture, and game development. Included in the Toolkit is Intel's Embree, which is designed to perform ray tracing calculations in space using geometric queries. Also included is OpenVKL, which is similar to Embree but is used for volume sampling and intersection. Finally, OSPRay Studio excels at playing with how an object is rendered. Demarle concluded by showing two case studies of a room with photometric lights rendered in OSPRay Studio. One case study was created without measured lights, while the other included photometric distribution profiles from IES. Demarle said that Intel is moving to include measured light sources in the program, as they did with the second example.

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