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Solid-State Lighting Program: Building Integration R&D Meeting

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Disclaimer

DOE Solid-State Lighting Program, "Building Integration R&D Meeting," October 2021.

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Comments

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1 Introduction

On October 19, 2021, five subject matter experts on lighting systems integration with other building systems gathered at the invitation of the Department of Energy (DOE) Solid-State Lighting (SSL) Program. The experts aimed to help identify critical research and development (R&D) topic areas for the integration of building lighting systems with other mechanical, electrical, and plumbing (MEP) systems in buildings, and to coordinate these various systems with sensing and control capabilities. This small group discussion meeting is one forum for experts to provide technical input to the DOE Solid-State Lighting Program. The Program also collects inputs from stakeholders at the annual Lighting R&D Workshop, via a Lighting R&D Request for Information (RFI), and other means. The guidance provided by stakeholders in these various forums helps identify critical R&D areas which DOE may incorporate into technical roadmaps and funding calls.

In 2021, the SSL Program held the meeting virtually due to travel difficulties and concerns related to the COVID-19 pandemic. The meeting commenced with "soapbox" presentations where each participant was invited to give a short presentation describing what they believed to be the key technology challenges for SSL building integration over the next three to five years. This was followed by a general discussion of the most critical technology challenges facing the industry today. As the meeting concluded, meeting hosts asked the participants to contribute ideas regarding program content for the upcoming R&D Workshop, which was held virtually from January 31–February 3, 2022.

The meeting format provided an opportunity for lighting experts across the research spectrum to exchange ideas and explore collaborative research concepts in lighting integration. Participants included invited experts in lighting-relevant science and technology disciplines drawn from academia, national laboratories, and industry. They included researchers funded by the SSL Program and non-DOE-funded researchers.

This report summarizes the outcome of the discussions on critical technology challenges and identifies corresponding R&D tasks within the existing task structure. Appendix A provides outlines of the participants' soapbox presentations and related remarks.

The meeting format encouraged each of the attendees to participate and present his/her perspectives on critical R&D challenges. The discussions that followed the soapbox presentations offered a variety of valuable insights into a range of research topics that could advance SSL technology. The theme of this small group meeting emphasized the hardware, software, and human behavior-based impacts of the integration of light-emitting diode (LED)-based lighting systems with other buildings systems, including daylighting and solar controls, heating, ventilation, and air conditioning (HVAC) systems, and more. The discussion included some recurring themes regarding research areas that could lead to significant breakthroughs in SSL performance. Section 2 outlines these themes in more detail.

2 Key Findings

Integration of building systems offers many potential advantages, including unified system controls, energy savings, and human health benefits. However, challenges remain that inhibit building managers and building systems professionals from fully realizing these benefits. Participants raised what they viewed as the key issues during their discussion.

2.1 Value justification

Building owners and operators have considerable interest in understanding the value-justification for more expensive, complex, and interconnected systems, especially as the absolute value of lighting energy savings diminishes. In this case, participants were focused on the value proposition of the non-energy benefits of advanced lighting control systems (ALCS). Due to recent shifts to hybrid work, building occupancy schedules have become more variable. This variability may necessitate more complex systems. Sensors included as part of these systems could collect data on lighting levels, daylight, light spectrum, or air quality, all of which impact occupant health. For example, studies suggest that access to daylight in the workspace is associated with better sleep and increased happiness.[2] [3] Data on the indoor environment can produce valuable insights into both energy use and occupant comfort and health. Furthermore, integrating lighting with other building systems can add value by allowing building managers to react to issues affecting parameters such as indoor air quality and building temperature in real time. Building managers can also adjust these parameters automatically according to their preferences.

If the aforementioned systems are to be effective, building managers must address system errors when they occur, rather than simply disabling the system's advanced or integrated features. However, they may lack the necessary training to do so. Furthermore, lighting professionals would need to determine how to implement advanced solutions in existing systems. Building managers are unlikely to completely redesign their lighting whenever an important new feature becomes available. Lighting designers should aim to create "plug and play" systems wherever possible. This ties into another theme of the value justification discussion: continued maintenance and improvement.

Participants discussed a need to shift away from the traditional view of building lighting as a system that can be ignored until it fails, at which point it is replaced. One alternative is lighting as a service (LaaS). This could be beneficial for organizations' accounting, as lighting costs could be distributed over regular intervals rather than cropping up randomly in response to system failures. One hurdle to this approach is that organizations generally aim to minimize maintenance costs. Additionally, many organizations contract out their facility maintenance and may be reluctant to alter these agreements. Organizations sometimes have multiple contracts governing different facilities, making changes more complicated and time consuming.

2.2 Cybersecurity

Cybersecurity is a central concern to building managers utilizing advanced building automation systems (BAS) and ALCS. These systems require 2-way communication between equipment and controls interfaces to be effective. Bad actors could exploit vulnerabilities in this communication or the system software or firmware. MEP systems and lighting are critical services for building occupants, and occupants would be subject to major inconveniences or danger in the event of failures in these systems. The potential for an unauthorized user to gain access to or control of these systems is perhaps even more concerning. Such a user could easily wreak havoc for building managers and occupants. There is even a risk that their actions could cause human health impacts. Federal building managers must be especially conscious of cybersecurity risks, as attacks could have ramifications for national security. Considering these issues, it is crucial that cybersecurity experts review

[2] C. Blume, C. Garbazza and M. Spitschan, "Effects of light on human circadian rhythms, sleep and mood," Somnologie, pp. 147-156, 2019.

[3] American Psychiatric Association, "Seasonal Affective Disorder (SAD)," American Psychiatric Association, October 2020. Available: https://www.psychiatry.org/patients-families/depression/seasonal-affective-disorder

ALCS and BAS software for vulnerabilities before use. Experts should likewise vet updates pushed to these systems.

2.3 User interface issues

Confusing and nonintuitive user interfaces also hinder adoption of advanced lighting systems. Although these systems have versatile, powerful capabilities, users often find their interfaces difficult to navigate and thus may be unwilling to use them. This issue also impacts system and building performance. Users may too easily make small mistakes that have cascading negative effects on the indoor space.

2.4 Risks of different component lifetimes

Manufacturers and researchers must also develop systems whose components are reparable and/or have similar lifetimes to prevent integrated luminaires and systems from being thrown out when one small piece fails. This issue is more pronounced as LEDs achieve greater market adoption, since LED fixtures are often made in a way that makes it difficult to access individual components of the system. This contrasts with previous technologies, such as fluorescent lamp fixtures, in which ballasts, lamps, and the fixture housing are usually separate components that can be changed out independently. Although retrofit kits allowing installation of LEDs in existing fixtures do exist, building managers and installers often find them difficult to use, making it cheaper and faster to completely replace these fixtures.

The addition of sensors into fixtures as part of ALCS adds to this issue, as sensors can sometimes fail before lamps. One solution to this problem might be manufacturer designed software included in fixtures that could diagnose issues in the fixture and notify building managers. This software could eliminate the need for some sensors, preventing disposal of fixtures due to sensor failure. These types of software solutions are common in mechanical systems.

When the presence of additional components cannot be avoided, manufacturers should strive to make these components "plug-and-play." Plug-and-play components require minimal commissioning and can work with different brands or types of fixtures, making installation simple. These components can save organizations time and money.

2.5 Standardization of communication protocols

A major theme of the discussion was the need for the lighting controls industry to unite around standard communication protocols with interoperable hardware. This will allow building managers to install and replace lighting components without having to worry about whether they will work with their existing systems.

Currently, the lighting systems industry predominantly uses proprietary communications platforms. As a result, there is no standard communication protocol for lighting controls systems and smart lighting fixtures. Although manufacturers agree that standardization is necessary, they are hesitant to agree on a specific communication protocol to use industry-wide. They worry that any move to standardize could force them to redesign their products to comply with the new standard, leading to increased costs. In addition, manufacturers are resistant to coming together to discuss this issue, because they do not want to share proprietary information with competitors. These factors combine to create a deadlock in the industry, in spite of the fact that almost all stakeholders agree that standardization is necessary. Participants were unsure about how to break the deadlock but noted that external intervention, either through regulation or through shifts in procurement requirements, is one potential solution.

Standardization has numerous benefits. Building managers could replace various components as needed without spending time determining whether new components will work with their current system. This type of plug-and-play scenario makes it much easier for users to work with ALCS, which could lead to increased adoption of these systems. Standardization could also improve cybersecurity. If the industry were to shift to a singular communication protocol, cybersecurity experts could screen communication systems for potential vulnerabilities and address security gaps much more easily. Users could rest assured that signals sent between fixtures and controls systems are secure, since the protocol would ideally be subject to rigorous auditing.

3 Suggestions for the DOE Lighting R&D Workshop

The 2022 Lighting R&D Workshop, which was held January 31–February 3, 2022, offered another opportunity to continue the discussion on critical R&D challenges. A goal of this R&D meeting was therefore to gather input about topical areas for a panel discussion on integrated lighting systems.

Based on the key findings from the discussion, the DOE SSL Program identified the following as potential discussion topics for the Lighting R&D Workshop:

- the benefits (and implications of) a significant increase in the sensors associated with integrated building systems and their potential to provide important data for improved performance;
- the return on investment of increased costs associated with integrated systems that are inherently more complex, particularly when the absolute value of energy savings is diminishing, but potential non-energy benefits are increasing;
- software and firmware resilience and persistence related to increased levels of communication, including 2-way communication, specifically effects on system operation during updates and the addition of other spaces and building systems to the core system controls;
- best practices for simulating and predicting energy demand and occupant health impacts based on new metrics for circadian stimulus and the integration of daylighting and electric lighting systems to best meet these new benchmarks.

Appendix A: Participant Presentations

Ruth Taylor, Pacific Northwest National Laboratory: Next Generation Lighting Systems

Ruth Taylor, of the Pacific Northwest National Laboratory, discussed the results of research efforts undertaken by the Next Generation Lighting Systems (NGLS) program. The NGLS is organized by the DOE and includes the Illuminating Engineering Society and the International Association of Lighting Designers as partners. The NGLS is part of DOE efforts to improve connected lighting systems and their controls. Taylor began her presentation by discussing how people are the messy, complicated part of the "equation" for optimizing lighting systems. Overall, the presentation emphasized that communication and vocabulary are fundamental to improved workflows and better integration, and that most of the problems with the integration and installation of controls are on the human side. The NGLS operates a few living labs, which grew out of relationships with designers and manufacturers. The living labs include an interior lab at Parsons School of Design at The New School in New York City as well as an exterior lab at the Virginia Tech Transportation Institute in Blacksburg, Virginia. The living labs were created to understand how advanced lighting controls performed in real world trials.

The NGLS program asked questions about the veracity of self-commissioning and out-of-the-box descriptions of lighting systems controls. The systems studied were very simple – set up to be easy to operate out of the box. The NGLS found many issues with these systems. There were many complications unrelated to the technology itself. Rather, complications involved users and installers and how they work together. The sense of the studies was that the industry is still stuck on this area of development. As a result, the NGLS felt that the focus should be on the people involved in the design, implementation, and operation of lighting systems. Taylor indicated that in light of this determination, observational research on the installation and commissioning process was warranted. There is a need to sit and watch real people in real time without intervention to see where the pitfalls and errors occur during the process. She noted that the way people do things in real life often cannot be predicted. Observational research is necessary to make headway on the development of actual out-of-the-box installations. Finally, Taylor noted that the NGLS is focusing on communication and vocabulary problems, design and workflow, and working on a tool or model specification to make the vocabulary and communication more consistent.

Gayathri Unnikrishnan, International Well Building Institute: Performance Certification and Defining High Performance Buildings.

Gayathri Unnikrishnan, of the International Well Building Institute (IWBI), discussed Performance Certification and Defining High Performance Buildings. Unnikrishnan began her discussion by noting that the IWBI has approximately 2.4 billion square feet of WELL Building certified space around the world. The certification of this space is aligned with the WHO definition of health, which consists not just of the absence of disease, but of making life better. Unnikrishnan pointed out that the physical and social environments that people occupy are key and that buildings are an important element of preventative care. In light of this consideration, building technologies need to be viewed not just in terms of energy savings technologies but also their impacts on human health. Because of how current buildings are typically designed, and how existing buildings are configured, there is a huge opportunity to improve people's health through lighting. Better lighting and daylighting exposure are in demand for building professionals, and healthy building features are not only good for health but have benefits in business too. These include longer lease terms, higher lease values, lease renewal, property value, etc.

She posited the following questions about lighting: How do we make lighting a feedback loop within a building? How do we identify and equip the people who make decisions within that building? Better lighting and daylight can be a gateway to better buildings through connection to other systems. This was highlighted by a graphic showing how occupants rated the importance of different elements of building systems. Unnikrishnan noted that the IWBI is putting people at the center of policy, design, and operations. In order to do this, we need to ask: "Who are the people that can make these decisions and what do they need?" and "How do we create a space and how do we make these decisions earlier?" Doing this leads to designing buildings for visual comfort, with light to see and light to promote sleep. It also leads to asking questions about what the impact of effective lighting is and how to design better spaces where daylight is not held as a perk. When we talk about electric lighting and daylighting, there is considerable variation based on the needs of the people and the space. Glare, flicker, color rendering, and control are all very important for electric lighting systems, as is addressing glare for daylight systems and ensuring that access to daylighting is equitable amongst the building occupants. But addressing these issues requires doing things differently. In part this is done through on-site testing- we need to start making measurement and analysis more common. Using both qualitative and quantitative features of buildings allows the coupling of occupant experience and building performance – quantifying the qualitative side of buildings. Unnikrishnan also raised questions about how to improve existing buildings when there are relatively few systems in place that can allow this type of measurement and documentation. This raises more questions, such as: What needs to be measured? What should facility managers act on? How are we coupling occupant experience within this measurement program? How can we make an accessible survey on comfort and people's experience? Unnikrishnan described the overall IWBI goal as seeking to define what high performance buildings and systems are and what the impact can be for the planet and people.

Michael Myer, Pacific Northwest National Laboratory: Codes & Standards

Michael Myer, from the Pacific Northwest National Laboratory, discussed building codes and standards and their impact on the integration of lighting systems with other building systems. He started his presentation by describing how PNNL supports federal agencies, sometimes related to policy. In these circumstances, he has found there are difficult hurdles for value and limited savings that can stymie penetration of advanced lighting controls systems. He cited the example of the Department of Defense, which requires a building automation system (BAS) with central monitoring for HVAC systems. However, adding lighting is more expensive because there are so many elements in a lighting system. Therefore, lighting is not included in this BAS requirement. In addition, because of the ubiquity of BACNET, a communication protocol for building automation that is designed for fewer objects, system sizes are often limited.

Myer noted that codes are approaching diminishing returns for individual systems, and that there needs to be a move beyond basic compliance tools. For example, he pointed to the need to move beyond kWh savings in the codes, and into discussions of power as issues of resilience or grid-interactive buildings are arising. More tools are needed for integration, measurement, and analysis to make code adoption easier and cheaper. Myer also pointed to the current problems with building integration of lighting systems and the challenges that are ahead, such as the increase in the number of sensors. This will lead to more commissioning and O&M problems, and more points of failure. At the GSA level, he sees the risks of getting stuck in communication protocols, resulting in stalled progress on integration. With these things in mind, Myer identified several areas of research that are critical, including research that supports commissioning of complex systems (Cx), basic Fault Detection and Diagnostics (FDD), and developing operational profiles that can detect when the system is not operating as expected.

Myer also pointed out for the need to find more ways of doing integration. He is seeing pushback on new technology in order to realize more energy savings, but he observed that we are near the limit of savings opportunities for individual technologies. Integration of systems will lead to more savings. However, moving to advanced systems will lead to increased IT burdens. Firmware updates are hugely challenging and expensive, especially on the federal side. This leaves the financial burden of these extra maintenance costs an open question. To minimize these impacts, Myer discussed the need to streamline digital technologies and not worry about the review costs. He also identified a need for more value options, faster IT scans, and better building protocols. He highlighted several important research and technology needs in this space including tools to determine if the integration is working as designed and installed so that when minor changes take place it can be assured that the system will automatically reset. Another need he pointed out was sample code or other third party tools to make sure that there is persistence in the integration. Myer also mentioned the need for standardized widgets for things like standardized control ports, deep dives on specific problems, and the need to move away from analog one-way signals and toward 2-way digital communications. Finally, Myer pointed to the Integrated Lighting Campaign, which is examining better ways of estimating integration efforts, as there are significant M&V expenses being incurred. One way to avoid this is to work towards standardized and repeatable solutions – avoiding each project being a custom development. One other finding from the Integrated Lighting Campaign is that building owners and operators often do not know their savings, and there are better ways of measuring energy savings in terms of overall project value.

Kevin Powell, Director - Center for Emerging Building Technologies, General Services Administration: Building Integration - Advanced Luminaires

Kevin Powell, the Director of the General Services Administration's (GSA) Center for Emerging Building Technologies presented the perspective of the facility owner on Building Integration - Advanced Luminaires. Powell started the presentation by stating why the GSA cares about advanced lighting controls and building integration. As a building owner, the GSA controls building HVAC, lighting, and shell. Being able to control lighting and mechanical/electrical/plumbing (MEP) based on occupancy is necessary to realize the utilization of lighting control as part of grid-interactive efficient buildings (GEB), demand side management, and flexible loads. Lighting would seem like a very flexible load for these purposes. In addition, daylighting and integration of daylighting with electric lighting controls is needed in order to use lighting to promote health and wellness in a space. Finally, sensors add value and provide the opportunity for spatial utilization and realizing non-energy benefits.

From there, Powell discussed the opportunities provided by lighting controls. Historically, lighting in commercial spaces has been the largest single base building load (although since LEDs have attained widespread use in buildings, lighting energy use has been greatly reduced). Of the building base loads, the easiest and potentially the lowest cost to control is lighting. Powell emphasized that when it comes to controls the idea is to be able to turn off lighting when people are not there. The more nuanced view of this control is to take advantage of natural light by dimming the electric lights during occupied times. Powell continued his presentation with a discussion of the GSA Green Proving Ground test beds. There are two demonstrations in process, as well as ongoing work on a technical guide document to roll out the studies and give guidance on what technologies and products the GSA should be buying.

Following the discussion of what the GSA is currently working on, Powell discussed the barriers to building integration of lighting systems. The single biggest barrier may be cybersecurity for controls. Controls must be 2-way in order to be effective, which presents an enormous security risk. For the GSA, this requires several layers of security clearance. Hardware needs to be remediated for each piece. With a multi-vendor system and multi-product system, this can be incredibly difficult, time consuming, and expensive, as any firmware pushing of updates needs to be in a trusted environment. Powell argued that research and funding is needed to determine if there a better remediation method, funding source, etc. for making this work easier. He asked whether this is better accomplished through the creation of a standard for systems controls software and firmware. GSA is evaluating Software as a Service (SaaS) solutions. These solutions are more complex in the federal world, as the service must be on the federal cloud. This poses numerous conflicts with proprietary systems and software.

Powell then began a discussion of the difficulties with systems integration that the GSA currently encounters. In general, systems are difficult to install and integrate, however low voltage systems are different. With lighting systems there is the potential for thousands of sensors in a space, and things go wrong. Continuous commissioning is a huge challenge especially with different types of controls systems. At the smaller scale of lamps and fixtures there is a discontinuity between technology life cycles. LED chips are good for a long time, but sensors and drivers have shorter lifetimes. These items can be difficult to replace when they fail. With this disconnect between the LED chips and the other technology in a LED fixture, how can GSA ensure there is an equal LCA / lifespan for all technologies in a fixture? From a cost perspective, it can be hard to determine the payback period. Payback period is how decisions about systems installations are made. Modeled controls show energy savings of 20%-50%, however the real-world application of these controls shows that they are not installed and commissioned cost effectively. Additionally, LEDs already save so much that the cost of upgrading to expensive controls doesn't make sense in most cases. Based on the previous discussion, Powell noted that there is a need to have a complete rethink of the problem. He detailed the possibility of a building-scale DC microgrid, with an open BAS protocol that would also operate the overall BAS for HVAC systems. This BAS would be powered over ethernet, resulting in one network and control system.

David Kaneda, IDeAs Consulting, Inc: Deep green, net zero energy, electrical systems

David Kaneda, from IDeAs Consulting, Inc, discussed Deep green, net zero energy, electrical systems. His presentation started with a discussion of the need to address the building envelope with respect to daylighting and electric lighting systems. Electric lighting and daylighting systems require tradeoffs between opaque, insulated walls and transparent or translucent windows. This involves energy and overall building performance tradeoffs too. Daylight harvesting and color tuning are becoming more possible, with finer grain controls over LEDs for both light quantity as well as quality. Kaneda emphasized that the standardization of component pieces is a critical path towards better integration. He also reiterated Kevin Powell's point regarding the change in the overall building electrical load from electric lighting systems. Historically the lighting load was large, whereas it is now much lower due to LEDs, and trending lower still. By this metric, lighting energy is not much of an issue anymore because buildings are saving so much. For example, in some buildings Kaneda has worked on, the lighting energy load is less than 10% of the total electrical load. The caveat here is that this type of performance is most likely for well daylit buildings.

Kaneda pointed to another element of lighting systems integration that is adding complexity to the problem: finding the best method to address the changing standards for color, quantity, and overall quality. Color rendering and space issues are huge, which demands the development of an easy to understand standard. In addition, recent research on light levels and adaptation, especially for emergency egress and outdoor spaces, needs to be included in the integration question. The first issue to address is the integration of electric light and daylight. This means starting with the basics, like trying to streamline systems design and integration so the lights are on only when the space is occupied. Integrating daylighting should involve taking the available daylight and making it the same in the winter and the summer on the interior of the building. This can be done through the use of electrochromic glass, skylights, window blinds. The WELL standard has a much bigger focus on health and physiology into building design which is welcome.

Another significant industry problem is what happens when a building is finished and handed over to the owner. Designers seldom revisit their past projects – so they miss out on what works well and what doesn't. Is there a research topic that can be developed to address this? This would allow designers to develop awareness of the issues surrounding design failures and success. In turn, this could prevent designing the same system with the same issues over and over. Kaneda views standardization as important so lighting designers have something to work with. However, standard writers need to ensure they are not changing standards frequently. Wrapping up his presentation, Kaneda expressed the need to make technical information accessible to designers so they can understand it without being an MD or PhD and ensure that all buildings are well designed to make spaces healthier and better for occupants.

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