U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Solid-State Lighting Program:

Building Integration R&D Meeting

August 2022

(This page intentionally left blank)

Disclaimer

DOE Solid-State Lighting Program, "Building Integration R&D Meeting," August 2022.

This report was prepared for:
Solid-State Lighting Program
Building Technologies Office
Energy Efficiency and Renewable Energy
U.S. Department of Energy

Authors:
Gregory D. Thomson, PlanArchology LLC
Sean Donnelly, Guidehouse, Inc.
Kyung Lee, Guidehouse, Inc.

Comments

The Energy Department is interested in feedback or comments on the materials presented in this document. Please write to Wyatt Merrill, Technology Manager for Solid-State Lighting and Building Electric Appliances, Devices, and Systems (BEADS)

Wyatt Merrill, PhD
Solid-State Lighting Technology Manager
BEADS Technology Manager
U.S. Department of Energy
1000 Independence Avenue SW
Washington, D.C. 20585-0121

Acknowledgements

The Department of Energy would like to acknowledge and thank all the participants for their valuable input and guidance provided during the solid-state lighting R&D discussions. This report is the product of their efforts:

SSL R&D Meeting Participants

Conveners

Wyatt Merrill	Solid-State Lighting Technology Manager
Gregory D. Thomson	PlanArchology, LLC

Stakeholder Presenters

Dorene Maniccia	DesignLights Consortium
Gayathri Unnikrishnan	WELL Buildings
Michael Myer	Pacific Northwest National Laboratory
Jennifer Li	Slipstream, Inc.
Kevin van den Wymelenberg	University of Oregon
Lincoln Xue	Oak Ridge National Laboratory
Gabe Fierro	Colorado School of Mines/National Renewable Energy Laboratory

Observers

Morgan Pattison	Solid State Lighting Services, Inc.
Norman Bardsley	Bardsley Consulting
Kyung Lee	Guidehouse, Inc.
Sean Donnelly	Guidehouse, Inc.

Table of Contents

1 Introduction

On August 16, 2022, seven 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 identify critical research and development (R&D) topic areas for building systems integration. This small-group meeting is a forum for experts to directly provide technical input to the DOE SSL Program. The Program also collects inputs from stakeholders through R&D workshops and ongoing stakeholder engagement. This stakeholder guidance helps the DOE SSL Program identify critical R&D topics which may be suitable for R&D funding.

This year, the building integration meeting was held virtually. The meeting commenced with "soapbox" presentations where each participant gave a short presentation describing what they believed to be the key lighting and building integration technology challenges for SSL over the next three to five years. This was followed by a general discussion of the most critical technology challenges facing the industry today.

The meeting format provided an opportunity for lighting experts across the research spectrum to exchange ideas and explore collaborative research concepts. Participants included researchers funded by the DOE SSL Program.

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

2 Key Findings

The meeting format encouraged attendees to present their 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. This small group meeting emphasized the hardware, software, and human behavior-based impacts on the integration of LED-based lighting systems with other buildings systems. These systems include daylighting, solar controls, heating, ventilation, and air conditioning (HVAC) systems, and other systems that impact the operations of the building lighting system. There were some recurring themes that arose during these discussions regarding research areas that could lead to significant breakthroughs in SSL performance:

- Identifying suitable technology integration schemes by building use type, geography, and desired outcomes,
- Overcoming market barriers to adoption of integration technologies – identifying, measuring, and communicating value proposition including and beyond basic return on investment
- Engaging building occupants, users, and operators in the operation of integrated systems
- System complexity, resilience, and ease of use

2.1 Tailoring Technology Integration Schemes for Various Applications

Throughout the meeting there were several points of discussion that emphasized the need for the architecture, engineering, and construction (AEC) industry to better understand the non-technological barriers to system integration.

One such barrier to integration is the organizational structure of AEC teams, which need better mapping of the team structure and working processes necessary for successful integration. Electrical teams and HVAC teams are usually separate and self-contained. This often means that neither are willing to take responsibility for systems integration or sensor installation. Having a separate sensor and integration team was raised as a possible solution to this problem, but participants ultimately agreed that it was best for sensors to remain associated with the lighting system. One benefit of this setup is that lighting professionals are responsible for the sensors and sensors are integrated with the lighting system. If sensors were installed independent of lighting, building systems designers will have to manage sensor integration with multiple systems, making installation and commissioning more difficult. Furthermore, placing sensors at light fixtures gives them easy access to the building electrical systems.

A second barrier is the lack of information in matching building use cases and system types to best practices for maximizing energy savings from systems integration. There is considerable interest from the AEC professions regarding the acquisition and dissemination of better information about this. For example, participants noted that for retrofit projects, wireless technology is often much cheaper than wired technology since it does not require running new wiring above the ceiling. However, contractors do not always recognize that this will save costs, leading to inflated bids. One proposed solution was the development of a simple checklist or matrix to match best practices and technologies for the chosen baseline conditions. This could prevent bid inflation and lead contractors to better understand the benefits and challenges associated with different systems. Participants also remarked that development of semantic protocols is ongoing and that in the next 5-10 years, stakeholders can expect to see better clarification about which protocols are better for certain building types or systems integrations.

2.2 Value Proposition Beyond Energy Savings

There continues to be substantial interest in understanding the value justification for increased costs associated with more complex and interconnected systems. This is especially true as the absolute value of energy savings is decreasing due to increasing adoption of LED lighting. As energy savings from lighting systems alone begin to level off, it is necessary to examine the value proposition of integrating lighting systems with other mechanical, electrical, and plumbing (MEP) systems. The participants showed that advanced lighting control systems (ALCS) can achieve considerable HVAC savings in buildings where there has been little attention paid to measurement and verification of performance, and the general absence of continued verification beyond initial commissioning.

This contrasts with the continued difficulty in demonstrating high levels of savings for the integration of plug loads. Consequently, participants stated that HVAC systems should be prioritized for integration over plug loads. Although HVAC systems are complex, they are easier to centralize than plug loads, which are distributed. In addition, plug loads make up a comparatively smaller part of the building energy consumption when compared with HVAC, so the impact of increasing plug load efficiency is relatively minor.

Participants also discussed how vertically-integrated companies, which control all the necessary systems technologies, can discern and overcome the non-trivial integration barriers in the marketplace. Participants agreed that more pilot studies would be helpful in demonstrating the value of integration. Incentives were also suggested as a useful tool for increasing adoption.

2.3 Occupant and User Engagement

Multiple participants raised the issue of engaging building occupants and operators in the proper functioning of integrated building systems. The discussion identified human behavioral issues linked to the increased level of technology in building systems and how user interfaces and systems design are impacted. In particular, human behavior impacts the function of complex building systems (and their interactions) when the connections and operation are not explained well to occupants. Participants observed that training needs to happen on a continual basis as the pool of building occupants is dynamic – including personnel tasked with building operations and maintenance. Additionally, participants discussed how to ensure that occupant experience was used in the development of retro-commissioning strategies that are persistent yet responsive to changing occupant needs. One participant noted that International Well Building Institute (IWBI) includes occupant surveys in its post-integration evaluation.

2.4 System Complexity, Resilience, and Ease of Use

The final aspect of the discussion addressed the connection between a system’s complexity and its ease of use over the long term, both as a matter of persistence and resilience. At the 2021 Building Integration R&D meeting, the group discussed critical concerns related to increased levels of 1-way communication and 2-way communication between systems that are both in front of and behind the meter. Specifically, participants and industry stakeholders were concerned about software and firmware resilience essential for cybersecurity. In the 2022 discussion on the other hand, resilience and persistence were addressed as they pertain to the capacity of integrated systems to remain functional despite changes to operations by occupants. While participants discussed this topic only briefly, it is still a topic of interest that requires more research.

Appendix A: Participant Presentations

Dorene Maniccia, DesignLights Consortium (DLC): Lighting Systems Building Integration, The Holy Grail for Market Transformation

Dorene Maniccia, of the DLC, discussed the interoperability of lighting systems through the networked lighting controls lens, and the larger lighting ecosystem. She described three primary categories of interoperability as being Device-to-device (D2Di), Device-to-system, and System-to-system. The DLC is engaged in new initiatives addressing these types of interoperability. The D2Di initiative is identifying key issues related to intra- and inter- luminaire component interoperability.

A second initiative, in the Device-to-system area, addresses the heterogeneous and proprietary nature of reporting from energy management systems. The DLC is working on the development of a common energy reporting file format using common .csv/.xls formats for data storage, which would replace the proprietary file formats these systems currently use for reporting. This includes determining whether using standard formats can simplify and reduce data storage requirements.

A third initiative focuses on the lighting controls solution gap between the large commercial building versus the small and medium commercial building markets. Solutions for small and medium commercial buildings need to be simple and deployable at the room scale.

The final initiative addresses cyber security. Maniccia discussed the changes in meaning for common terminology resulting from transitioning from mechanical to digital controls. Historically lighting systems infrastructure was made up of wires and conduit. Contemporary infrastructure includes routers, servers, and networking cables. In this context, Maniccia ended her presentation discussing the need for a digital buildings framework where all systems can function in an interoperable fashion, especially in light of the 2030 Target for decarbonized buildings. A digital buildings technology framework would help with standardized protocols for enabling the fully digital building. She asked what the best option for establishing this framework would be - existing BIM, IFC, or other standards, or a new framework. Maniccia stated that DLC recommendations for R&D investment in integration were not always focused on technology. Significant workforce development is needed. One potential effort in this area could be in the form of a connected building consortium.

Gayathri Unnikrishnan, International Well Building Institute (IWBI): Building Performance

Gayathri Unnikrishnan, from the IWBI, discussed updates to the WELL Buildings standard. Unnikrishnan described multiple means for WELL clients to demonstrate progress in improving their building stock. She cited three different ways that this was possible: certifications, ratings, and organization wide programs. The certifications and ratings are location-based achievements, while the organization wide programs are not restricted to one specific location or building site. This is because assets in a portfolio can be spread across wide geographical areas. Specifically, she addressed the WELL Performance Rating, which is intended to use data on building performance, as well as insights from occupant experience, to transform organizational culture and business decision-making surrounding the physical infrastructure of buildings. The data used for the WELL Performance Rating relies on continuous monitoring of a variety of performance metrics, using on-site testing for direct measurements or samples for lab testing of quantitative metrics of indoor air, water, lighting, thermal, and acoustic quality. In addition, there is a qualitative assessment measuring occupant experience through surveys. This can be applied to other spaces and buildings that are not being used, and for reasons other than COVID shutdowns. With the data collection systems in place, the next task is matching the collected data with the survey results. This creates a human-in-the-loop situation where surveys are also part of the continuous monitoring of the building.

At this point in the discussion, Unnikrishnan pointed out that there is great technology available, but there is not a standardized way for reporting the data on a continuous level. The interior air quality (IAQ) and thermal conditions are much more straightforward regarding health and well-being, while there is not an equally straight-line linking lighting to health and well-being. Next, she turned to the barriers to wide adoption of continuous monitoring of building operation. Those barriers include installation costs (especially for existing buildings), technology knowledge (operator concerns about how new technology operates), and the lack of interoperability between manufacturers. Reducing the steep cost barriers for existing buildings is critical for making headway toward energy savings for these buildings. The IWBI noted that research topics that are important in its work include balancing energy efficiency (EE) with occupant comfort and well-being and using wearables to communicate securely to improve individual comfort and satisfaction. The IWBI is also engaged in guaranteeing user personalization and privacy are maintained. This is particularly important to ensure that the personalization includes the ability to impact thermal, acoustic, and visual environments. When it comes to occupant experience surveys being used to reinforce and improve other quantitative performance metrics, the IWBI is hoping to achieve 60% occupant participation, and it is using the ongoing rating of buildings to encourage continuous participation at this level.

Michael Myer, Pacific Northwest National Laboratory (PNNL): 2022 US DOE LED R&D

Michael Myer, of PNNL, discussed integrating lighting systems with HVAC systems. Myer noted that there are difficulties and benefits of integrating between systems, and that among DOE supported lighting integration using occupancy sensing there were mixed results. In some cases, buildings achieved savings of up to 70%, but only if the HVAC systems were running continuously (essentially 24 hours a day, 7 days a week). In other cases, it was determined that integration did not make sense because of the building type, method of operations, or current systems. One of the benefits of integrating lighting and HVAC systems is the ability to use the resulting data to dictate operational changes. This can help curb performance drift. Myer noted that recent integration work revealed the need for an easily accessible database of HVAC systems suitable for integration. This could be as simple as a matrix of system types and effective integration options, including distinctions between detailed integration types and how controls are operated (e.g., occupancy-based vs. time schedule).

Myer then moved on to discuss codifying the integration of building systems. He noted that typical construction projects have multiple pathways to compliance within building codes and codifying the integration of systems raised several questions. What does lighting integration look like when an HVAC system is in an occupied, standby, or demand response mode? Would certain systems be required to be integrated, as opposed to being operated in a parallel fashion? How does this work when the sensors are integrated with one system, but the data is needed to operate multiple systems? Having answers to these questions is important to establishing the most efficient way through the multiple pathways of systems integration code compliance. One example of the difficulties associated with codifying integration is establishing which of multiple network existing protocols for building systems is the right one. Another codification sticking point is in the trades and practices divisions of specifications and construction contracts, where there is significant confusion regarding responsibility for individual systems.

Next, Myer turned to the various benefits of building integration. One benefit he described was the capacity of integrated systems approaches to buy down installation costs through operational savings. Myer believes that the measurement and verification (M&V) of building systems has a critical problem with the verification element. This is because the standard building automation system (BAS) is not smart or intelligent, it is simply a data storage device. To move from measurement to measurement and verification, third-party software is needed to analyze the data that the BAS collects. Having active and continuous verification ensures that efficiency measures and systems performance are persistent. This would be another area for a simple database to clarify potential savings by building and systems typology. Part of the development of a matrix of this type is understanding more about how effective different controls protocols are. Myer described a PNNL project for rating control systems from 1-10 based on how those control systems perform relative to historic setpoints.

Jennifer Li, Slipstream, Inc.: DOE Integrated Controls Pilot & DOE Public Sector: City County Building, Madison, WI

Jennifer Li, of Slipstream, Inc, discussed the results of a DOE integrated controls retrofit pilot study. The emphasis was on the replacement of linear fluorescent lighting (LF) with wireless luminaire level lighting controlled (LLLC) LED fixtures. Li emphasized that in the examples from this pilot study controlling plug loads represented a high installation cost with not as much operational savings. She also pointed out that 1-for-1 fixture replacement (LF to LED) is often the least expensive because there is no extensive rewiring for a different number of fixtures, nor is there a need to reconfigure any existing ceiling conditions. However, doing this 1-for-1 replacement typically results in a much higher maximum light output from the new fixtures. This type of installation requires controls for high end trim and dimming to control lighting levels within code requirements. These measures can help avoid overlighting spaces and causing excessive glare or other uncomfortable conditions.

Li also discussed an ongoing project with a county owned, and city leased, property. The project included upgraded systems and new glazing to reduce energy use and improve occupant comfort and satisfaction. This project was similar to many other tenant improvement or building retrofit projects, in that it involved primarily contractors rather than design professionals. To ensure that the project reached its savings potential, the project contract had to establish a clear scope that required controls design, not just fixture layout. While this type of contract would require a higher level of effort from the contracting process, it does not include any of the in-depth analysis that would come with professional architectural lighting design and daylighting analysis.

This type of project highlights the hurdles that interrupt savings potential of energy efficiency (EE) projects with multiple energy conservation measures (ECMs). To effectively integrate the various systems (in this case lighting and HVAC) the multiple lighting, plug load, and HVAC zones need to be thoroughly mapped to understand where overlaps or gaps in the zones may lead to integration difficulties. This is just one area where there is a demonstrable need for an integration lead for different aspects of the project. From the operational perspective, integration can be short circuited by improper management of the system design by operations and maintenance (O&M) staff, or lack of understanding by the building occupants. If the occupants don't understand how to participate in achieving their own comfort and satisfaction with lighting levels and temperature within system design, they will not be good partners in having actual energy consumption match predicted energy consumption. Li indicated that part of this pilot project was to create a standard contract process for county owned assets to achieve EE savings as predicted. She did note that this did not include language specific to the creation of a retrofit team with the inclusion of an integration lead. Lessons learned from the project included the need for basic information about nomenclature for BAS space names, where meaningful space names make it easier to integrate later. Li ended by noting that payback rates for different integration efforts are a challenge, but HVAC integration can help with this because often the HVAC systems are running very inefficiently. It is also important to capture non-energy benefits and demonstrate how their dollar value helps with return on investment and payback to get projects implemented.

Kevin van den Wymelenberg, University of Oregon: Importance of Integrating Daylighting with Electric Lighting Systems

Kevin van den Wymelenberg, from the University of Oregon, discussed daylight integration with electric lighting systems. His presentation emphasized the connection between well designed lighting systems and occupant well-being. He started his discussion by highlighting that the SARS-COV2 pandemic resulted in buildings being deemed unsafe for occupation. If this unsafe condition is, in part, a result of the overall building design, it means that design professions are an equally vital part of the solution to ensuring that buildings can be safe during different types of disruptive events (e.g., pandemic, climate change, weather emergency). In this context it is necessary to weave together indoor environmental quality (IEQ), building operational energy, peak energy demand, and other systems operations to address the role of design and energy. van den Wymelenberg stated that design professionals can inspire optimism if they think about design as a way out of the crises affecting us now.

When it comes to integrating daylighting with other building systems, van den Wymelenberg indicated that daylight should be viewed as the cornerstone of integration. Buildings designed for proper daylighting provide connection to nature and views, which is proven to decreases stress and improve healing. He said that daylight is, by a factor of 10, the biggest impact for circadian stimulus. Additionally, full spectrum daylight can improve indoor air quality as it can deactivate virus (even through UV filtered glazing). When daylight is integrated with the lighting and HVAC systems, it has a role to play in viral deactivation. Electric lighting systems are distributed infrastructure, at the human scale, which can include onboard distributed data collection and a digital backbone to support smart buildings. Network lighting controls (NLC) can support a variety of other information streams beyond just more efficient operation of lighting systems. This can include asset tracking, plug load management, safety and security, and space utilization. If designed effectively with a user interface, lighting can also guide people to better daylit areas for circadian stimulus.

Integrating lighting systems with HVAC systems can also improve how fresh air is delivered to a space. This can be thought of as demand driven ventilation (which has faster controls), whereas demand control ventilation uses CO_2 detection, which is a lagging indicator. Using this demand driven ventilation could make ventilation more responsive to occupants. Daylight is also key element of user experience in buildings, as it impacts all occupants with its presence or absence. It is a universally desirable element in buildings and has many positive health impacts – especially mental health and circadian rhythms.

Lincoln Xue, Oak Ridge National Laboratory (ORNL): Power Electronics and Control Integration for Lighting

Lincoln Xue, of ORNL, discussed lighting controls from the perspective of changes to how power electronics are designed and installed in typical buildings. He described how control integration for lighting could be reframed in the context of understanding how power is distributed from the grid. This description continued with a discussion about how devices and appliances in a home or office typically use a power supply to transform grid energy into energy at the right voltage for that device. Virtually every plug load and device in a building (including LED lights) has a power supply, which means these plug loads usually cannot receive power direct from the grid. Another negative aspect of these power supplies is that they are often low quality and low efficiency. Because users don't see or interact with these power supplies, they don't care about how they perform.

Xue then asked whether devices can be attached to the grid directly to eliminate the power supply. He stated that to achieve this vision of devices without power supplies, it is necessary to have something like an electric resources manager. This type of interface infrastructure can make device specific power supplies part of the building rather than part of the devices. This in turn can make devices smaller and more efficient and avoid unnecessary heat generation. The interface needs to be adaptable to multiple load types and multiple grid types and be capable of behind the meter (BTM) grid services. To achieve this new interface typology, there is a need for the development of a smart panel and a centralized grid interface portal. This in turn calls for the creation of an integrated building energy management (BEM) center. With direct connection between plug load devices and the grid, it is necessary to use power electronics as fast protection rather than a breaker or switch.

Xue walked the group through the positive aspects of this new type of electrical power distribution infrastructure. This infrastructure typology offers improved power quality to and from the grid, which enables both better performance of devices BTM and adding power back into the grid from distributed energy resources (DERs). Cyber security questions will need to be answered, as well as what this new infrastructure would look like deployed in a building across the design, construction, and operations lifecycles. The change in the underlying electrical power distribution in a building means that traditional grounded outlets in buildings could be replaced with USB outlets. Other questions that need to be answered include whether the existing electrical infrastructure components in buildings can be reused in the development of a new main panel or new outlets.

Gabe Fierro, Colorado School of Mines/National Renewable Energy Laboratory (NREL): Network Interoperability & Semantic Protocols

Gabe Fierro, from the Colorado School of Mines and NREL, discussed semantic protocols. His presentation covered the basics of network interoperability and semantic protocols. He began by describing the different layers in a communications protocol. Fierro described why the internet having a single protocol (IP) makes it easy to interact with it. From the baseline he described, the choice of different protocols is sometimes based on their extensibility, which is the ability of a protocol to allow individual users to add their own objects and properties.

BACnet is one open protocol that is well understood and can be implemented by individuals without a need for a special license. The problem with BACnet is that the descriptions and names of points for objects and devices are not governed by any standard. This lack of standard methods for nomenclature is an impediment to discoverability and interpretability. In addition, BACnet is designed for small devices with low computing power on a local area network (LAN). However, it is a good choice because it is independently certified, so it is interoperable. It also has critical adoption mass.

There are other protocols used around the world, each of which have different pros and cons. Some of these protocols were invented in the early years of connected computing and are still in use today. The absence of semantic protocols means that descriptions and/or names of points and devices are mostly free texts, making them hard to interpret.

Fierro moved on to discuss the larger AEC industry, development of digital models, and the use of those digital models to describe everything from the design, construction, and operation of buildings. He pointed out that most AEC descriptions of spatial organization and building systems are irrelevant to controls and communications development. Pain points in creating digital mapping of building systems include the manual discovery of points, which is time consuming and expensive. Because most semantic naming comes after the fact, there is a question about whose job it is to curate the naming (e.g. an integrator) and ensure everyone is on the same page when it comes to naming standards. Once a building's systems have been integrated, there is a question about ownership over the data from those different systems. Fierro named several semantic protocols for formalizing naming conventions. They include: Project Haystack, Brick, ASHRAE 223P, RealEstateCore, and Azure digital twin.

(This page intentionally left blank)

U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

For more information, visit:
energy.gov/eere/ssl

DOE/EE-2664 ▪ August 2022